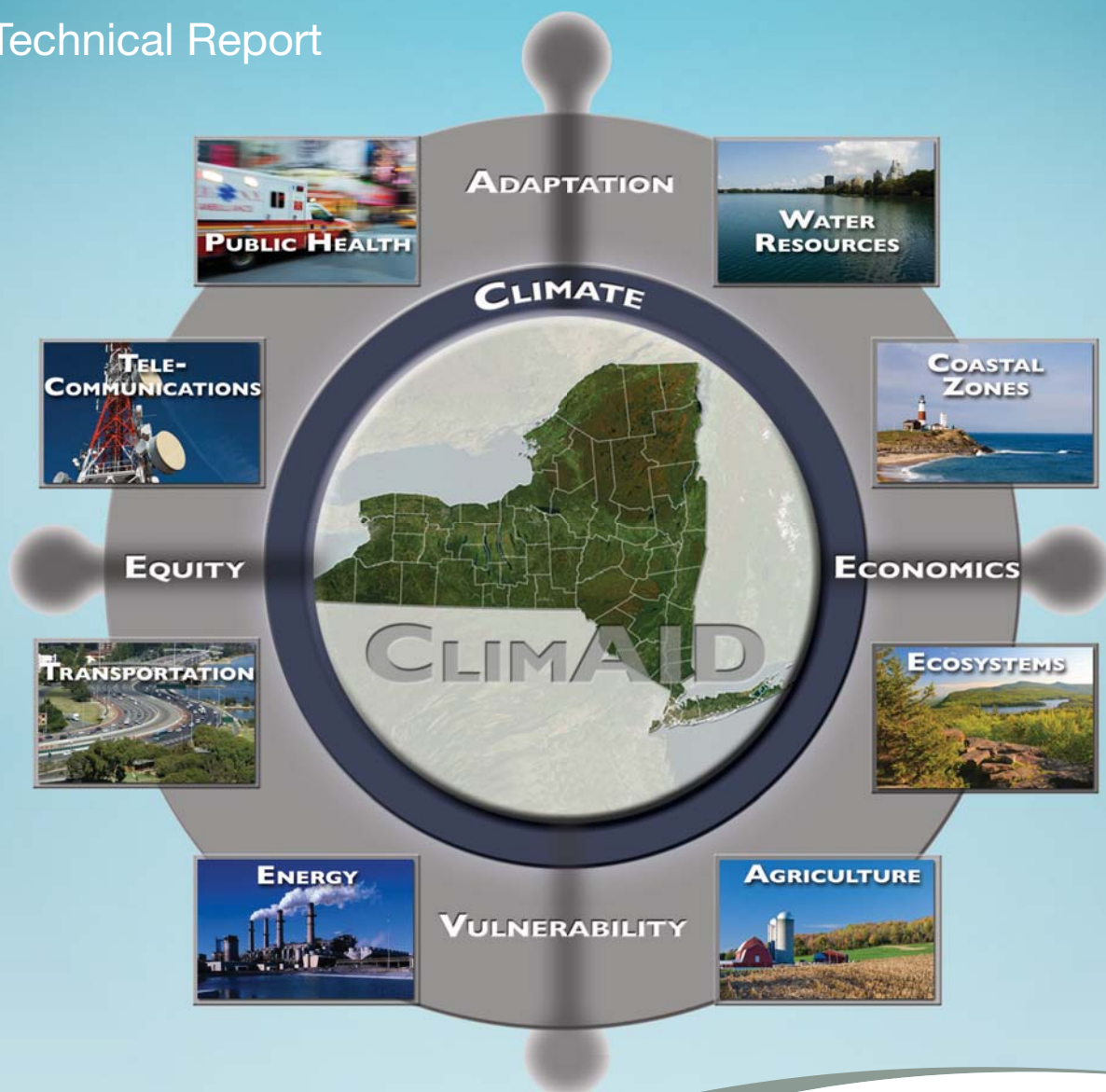


New York State Energy Research and Development Authority

Responding to Climate Change in New York State

Technical Report



Final Report
No. 11-18

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RESPONDING TO CLIMATE CHANGE IN NEW YORK STATE: THE CLIMAID INTEGRATED ASSESSMENT FOR EFFECTIVE CLIMATE CHANGE ADAPTATION IN NEW YORK STATE

Final Report

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NOTICE

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ABSTRACT

Climate change is already beginning to affect New York State, and these impacts are projected to grow. At the same time, the state has the ability to develop adaptation strategies to prepare for and respond to climate risks now and in the future. The ClimAID assessment provides information on climate change impacts and adaptation for eight sectors in New York State: water resources, coastal zones, ecosystems, agriculture, energy, transportation, telecommunications, and public health. Observed climate trends and future climate projections were developed for seven regions across the state. Within each of the sectors, climate risks, vulnerabilities, and adaptation strategies are identified. Integrating themes across all of the sectors are equity and environmental justice and economics. Case studies are used to examine specific vulnerabilities and potential adaptation strategies in each of the eight sectors. These case studies also illustrate the linkages among climate vulnerabilities, risks, and adaptation, and demonstrate specific monitoring needs. Stakeholder participation was critical to the ClimAID assessment process to ensure relevance to decision makers across the state.

KEYWORDS

Climate change; adaptation; impacts; vulnerability; climate risk; sector impacts

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Cynthia Rosenzweig, NASA GISS and Columbia University
William Solecki, Hunter College at City University of New York
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Integrated Assessment for Effective Climate Change Adaptation in New York State

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ClimAID: Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State

Authors: Cynthia Rosenzweig, William Solecki, and Arthur DeGaetano

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Introduction

New York State is already experiencing impacts as a result of climate change, and impacts are projected to increase with further warming. At the same time, the state has great adaptive capacity to address them. From the Great Lakes to Long Island Sound, from the Adirondacks to the Susquehanna Valley, climate change will affect the people and resources of New York State. Risks associated with climate change include greater incidence of heat stress caused by more frequent and intense heat waves; greater incidence of heavy rainfall events affecting food production, natural ecosystems, and water resources; and sea level rise leading to increased flooding in coastal areas. Climate change may exacerbate existing stresses on the people and activities of New York State and, in some cases, might provide opportunities such as enhancement of its water resources and agricultural potential. The goals of the Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State (ClimAID) are to provide New York State decision-makers with cutting-edge information on its vulnerability to, as well as its ability to derive benefits from, climate change and to facilitate the development of adaptation strategies informed by both local experience and scientific knowledge. Further aims of ClimAID are to highlight areas related to climate change and New York State that warrant additional research and to identify data gaps and monitoring needs in order to help guide future efforts.

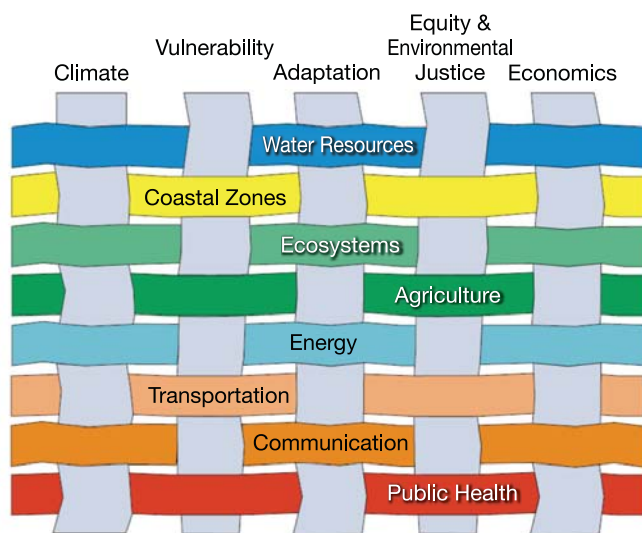


Figure 1 ClimAID integrating themes and sectors, illustrating the interwoven fabric of climate change assessment

Initiated in 2008, ClimAID is funded by the New York State Energy Research and Development Authority (NYSERDA) as part of its Environmental Monitoring, Evaluation, and Protection Program (EMEP). The assessment proceeds from the acknowledgement that the unique combination of natural resources, ecosystems, economic activities, and human population of New York State will not be immune to the impacts of climate change, and that local communities and the State as a whole, therefore, need to plan for and adapt to these effects. Climate change poses special challenges for New York State decision-makers related to the uncertainties inherent in future climate projections and the complex linkages among climate change, physical and biological systems, and socioeconomic sectors.

Working interactively with stakeholders, the ClimAID team focused on five integrating themes across a broad range of key sectors (**Figure 1**). The five integrating themes are climate, vulnerability, adaptation, equity and environmental justice, and economic costs associated with climate change impacts and adaptive measures, as well as the benefits of avoiding impacts. The five integrating themes were selected based on discussions with NYSERDA and sector stakeholders about factors of key relevance for responding to a changing climate in the state. The eight sectors are Water Resources, Coastal Zones, Ecosystems, Agriculture, Energy, Transportation, Telecommunications, and Public Health.

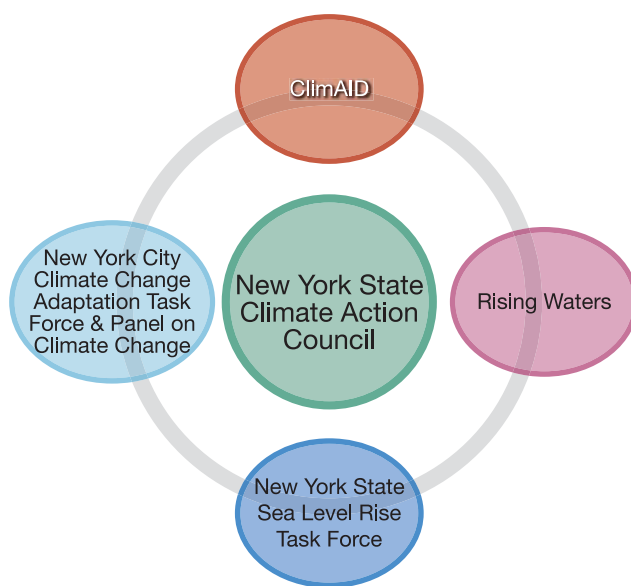


Figure 2 Interactions of ClimAID assessment with other climate change adaptation initiatives in New York State

Progress in reducing vulnerability and building adaptive capacity to respond to climate change depends on integrating the best available local and scientific knowledge with lessons learned from previous and current efforts. To that end, ClimAID built on key findings from prior assessments, and coordinated with concurrent research and policy initiatives on climate change adaptation, such as the Rising Waters project (a regional planning effort for the Hudson Valley convened by The Nature Conservancy and partners),¹ the New York State Sea Level Rise Task Force convened by the New York State Legislature,² the New York City Climate Change Adaptation Task Force led by the Mayor's Office of Long-Term Planning and Sustainability of New York City,³ and the New York City Panel on Climate Change (NPCC) convened by Mayor Bloomberg of New York City⁴ (Figure 2). The New York State Climate Action Council is preparing mitigation and adaptation policy recommendations for the Governor's Office.⁵

Climate Change in New York State

Climate change is already affecting and will continue to affect a broad set of activities across New York State. Its geographical and socioeconomic diversity means that New York State will experience a wide range of effects. There will be opportunities to explore new varieties, new crops, and new markets associated with higher temperatures and longer growing seasons. New York's relative wealth of water resources, if properly managed, can contribute to resilience and new economic opportunities. On the other hand, higher temperatures and increased heat waves have the potential to increase fatigue of materials in the water, energy, transportation, and telecommunications sectors; affect drinking water supply; cause a greater frequency of summer heat stress on plants and animals; alter pest populations and habits; affect the distribution of key crops such as apples, grapes, cabbage, and potatoes; cause reductions in dairy milk production; increase energy demand; and lead to more heat-related deaths and declines in air quality. Projected higher average annual precipitation and frequency of heavy precipitation events could also potentially increase the risks of several problems, including flash floods in urban areas and hilly regions; higher pollutant levels in water supplies; inundation of wastewater treatment plants and other vulnerable development in floodplains;

saturated coastal lands and wetland habitats; flooded key rail lines, roadways, and transportation hubs; and travel delays. Sea level rise will increase risk of storm surge-related flooding, enhance vulnerability of energy facilities located in coastal areas, and threaten transportation and telecommunications facilities.

Across the varied geography of New York State, many individuals, households, communities, and firms are at risk of experiencing climate change impacts. Some will be especially vulnerable to specific impacts due to their location and lack of resources.

ClimAID Team, Meetings, and Reviews

Because New York is large and diverse, special emphasis in ClimAID was placed on integration and coordination so that climate change impacts and potential responses could be addressed coherently across the geographic regions and the multidimensional sectors of the state.

The ClimAID team was made up of university and research scientists who are specialists in climate change science, impacts, and adaptation. Researchers came primarily, but not exclusively, from Columbia University, Cornell University, and Hunter College of the City University of New York (See front matter for list of ClimAID team members). The team was organized into groups that addressed the five integrating themes and the eight sectors.

Approximately every six months over the period November 2008 to June 2010, ClimAID team members gathered from around the state for face-to-face meetings. The kickoff meeting was held in Albany in the fall of 2008 to present the scope of work, identify sectors and stakeholders, and set priorities. The second meeting was held early in 2009 at Cornell University and focused on initial findings, overall emerging messaging, and identifying common themes. The third meeting was again held in Albany in the fall of 2009 and provided a further update of the findings. The final ClimAID meeting was held at Hunter College CUNY to discuss the major conclusions. The team also held regular teleconferences, approximately every two weeks in the beginning and then once a month. The integrating theme groups interacted directly with each of the sector groups throughout the process.

A Project Advisory Committee, convened by NYSERDA, was made up of experts from the sectors covered by ClimAID (Appendix A). The committee met approximately every six months to review draft materials and to advise on the overall scope and direction of the assessment.

Besides the Project Advisory Committee reviews, external reviews were conducted for the sector chapters in the early summer 2009 and early in 2010. Each chapter was reviewed by multiple outside experts in relevant fields (see Annex I).

Stakeholder Interactions

To ensure that the information provided by ClimAID was relevant to the climate-related decisions made by practitioners, stakeholder interactions were a key part of the process (**Figure 3**). Working with NYSERDA and the Project Advisory Committee, the sector leaders identified relevant stakeholders from the public sphere (e.g., state and local agencies), nonprofit organizations (e.g., non-governmental community and environmental groups), private-sector entities (e.g., businesses), and academic institutions for each of the sectors, and organized the stakeholder interactions. (For a list of stakeholder organizations by sector, see Appendix B and the sector chapters).

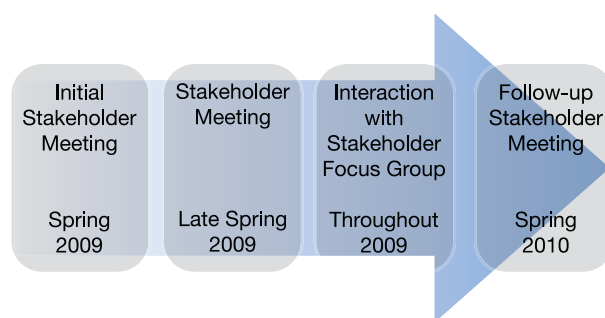


Figure 3 ClimAID sector stakeholder process

While each sector developed its own stakeholder process, sectors generally convened sector-specific stakeholder meetings in the first four-month period of ClimAID; developed, administered, and analyzed a survey to a wider group of sector stakeholders; formed a focus group of key stakeholders for ongoing discussion and advice throughout the assessment; and held a final stakeholder meeting in the third four-month period to present preliminary results and get feedback on draft conclusions and recommendations. See sector chapters for fuller descriptions of stakeholder interactions.

Integrating Themes

ClimAID developed five key themes to integrate across the eight sectors: climate, vulnerability, adaptation, equity and environmental justice, and economics.

Sector	Case Study Title
Water Resources	Susquehanna River Flooding, June 2006* Orange County Water Supply Planning
Coastal Zones	1-in-100-Year Flood and Environmental Justice* Modeling Climate Change Impacts in the Hudson River Estuary Salt Marsh Change at New York City Parks and Implications of Accelerated Sea Level Rise
Ecosystems	Hemlock—Cascading Effects of Climate Change on Wildlife and Habitat Creative Approaches to Monitoring and Adaptive Management—New York's Invasive Species Program as a Model Maple Syrup Industry—Adaptation to Climate Change Impacts Brook Trout—Reduction in Habitat Due to Warming Summers*
Agriculture	Frost Damage on Grapes Potato Late Blight Drought Dairy Heat Stress*
Energy	Impact of Climate Change on New York State Hydropower Climate Change-Induced Heat Wave in New York City*
Transportation	Future Coastal Storm Impacts on Transportation in the New York Metropolitan Region*
Telecommunications	Winter Storm in Central, Western, and Northern New York*
Public Health	Heat-related Mortality Among People Age 65 and Older* Ozone and Respiratory Diseases Extreme Storm and Precipitation Events West Nile Virus

*In-depth case study including economic and environmental justice analysis

Table 1 Case studies by sector

A group of ClimAID scientists focused on each of these themes, working with the sectors to ensure broad coordination across the assessment. Case studies of specific impacts and/or locations were selected for each of the sectors that provided special analysis of the five themes (**Table 1**). See chapters 1, 2, and 3 for detailed descriptions of the concepts and methods used in the integrating themes.

Climate

The Climate group analyzed both past and future climate in New York State (see “Climate,” Chapter 1). Climate observations from across New York State obtained from the NOAA Northeast Regional Climate Center were used to analyze trends in key variables and thus to answer the question, “Is climate changing in New York State?” The Climate group also developed a set of climate change scenarios for New York State to

facilitate the assessment of potential impacts under future conditions. The group assessed the degree to which current-generation climate models are able to replicate observed climate and climate trends over the past several decades in New York State and analyzed the relevant results for New York State of regional climate models and statistical downscaling. As part of this effort, results were analyzed from the North American Regional Climate Change Assessment Program (NARCCAP), which is conducting a coordinated set of current and future regional climate model simulations. The Climate group assessed global and regional climate model simulations on the basis of the availability of climate change simulations, spatial and temporal resolution, selection of climate variables, and accuracy in representing New York State climate.

The Climate group developed a set of climate change projections for New York State as a whole and for seven climate regions within the state based on 16 global

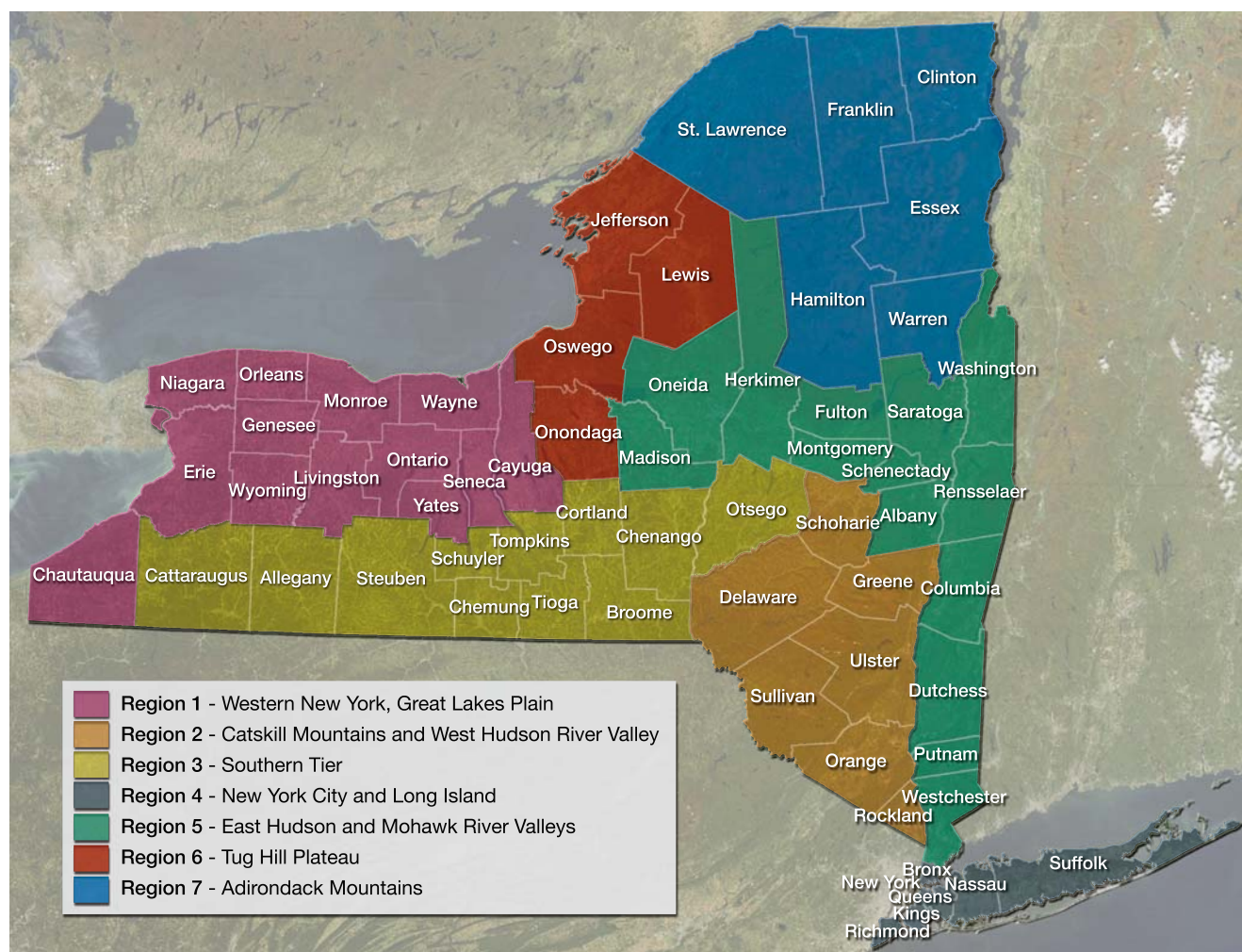


Figure 4 Climate regions of New York State

climate models and three emission scenarios (**Figure 4**). The outcomes are presented as model-based probabilities or “uncertainty envelopes”⁶ around the projections. Because extreme climate events are associated with the greatest risks, the Climate group also developed model-based probabilities of the future occurrence of extreme events (e.g., heat waves, droughts, and floods) in New York State. The Climate group associated confidence levels with the projections, using a rating based on that employed by the Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4) (IPCC, 2007). These ratings (e.g., “extremely likely,” “very likely”) are based on the correspondence between observations and climate model projections, agreement among climate models, and expert judgment.

For sea level rise, the Climate group developed a set of projections for the coastal area of New York State and conducted a historical analysis of current and historical storm damage on its infrastructure systems. The sea level rise projections were based on global climate models and methods with the addition of a “rapid ice-melt scenario” that takes into account current accelerated rates of ice melt in Greenland and Antarctica and documented rates of melting in paleoclimate records. The Climate group also analyzed tide gauge records, historical storms, future climate model simulations, and storm surge model simulations to assess the potential for changes in the spatial and temporal distribution of coastal storms (hurricanes and nor’easters) for the state.

Working with each of the sectors, the Climate group defined specific climate hazards as identified by stakeholders and produced tailored products for use in the sector assessments. Based on the vulnerabilities identified for each sector, the Climate group identified and developed a set of climate hazard indicators that could be monitored to track current climate trends and variability, and enable comparisons to historical data and future scenarios. These climate hazard indicators will help inform the development of appropriate adaptation programs and policies.

Throughout the assessment, the Climate group presented uncertainties surrounding climate modeling in general and in downscaling to regional levels within the state in particular, highlighting data gaps and monitoring needs, and indicating areas that require further research related to climate hazard and risk

analysis, modeling uncertainty, and downscaling in New York State.

Vulnerability

The ClimAID Vulnerability group identified both near-term and longer-term climate vulnerabilities for New York State (see “Vulnerability and Adaptation,” Chapter 2). To ensure that the assessment was aimed at the most pressing near-term climate impacts, the sectors worked with stakeholders to target vulnerabilities that currently affect the state, such as heat waves, floods, droughts, and coastal and inland flooding. The assessment also identified future climate vulnerabilities in order to provide information that will enable the state to take early action to reduce the possibility of catastrophic or large-scale climate impacts and/or to take full advantage of climate change opportunities.

Based on published literature and salience for New York State stakeholders, the Vulnerability group brought forward a range of criteria for identifying the climate change vulnerabilities in each sector. Key vulnerability criteria related to climate impacts in New York State include the following:

- magnitude
- timing (e.g., seasonality)
- persistence and reversibility
- likelihood (based on estimates of uncertainty)
- distributional aspects within a region or among socioeconomic groups
- importance of the at-risk systems
- thresholds or trigger points that could exacerbate the change

Through stakeholder interactions, analysis of previous studies, and case studies, the ClimAID assessment then evaluated how these and related criteria affect potential vulnerabilities in each sector. In communication with stakeholders, ClimAID then compiled a set of potential vulnerabilities related to climate change, highlighting those with higher impacts for New York State.

Adaptation

The ClimAID Adaptation group identified, developed, and assessed adaptation strategies for the eight sectors included in the assessment (see Chapter 2,

“Vulnerability and Adaptation”). Developing climate change adaptation strategies requires input from a breadth of academic disciplines as well as stakeholder experience to ensure that recommendations are both scientifically valid and practically sound. For each sector and in direct response to the climate hazards, key vulnerabilities, and stakeholder priorities identified in the assessment, the Adaptation group worked with the sector teams and stakeholders first to catalog existing adaptation practices already in place and then to develop and assess potential adaptation strategies to the expected climate impacts. The Adaptation group used empirical, quantitative, and qualitative methods, taking into account the relevant issues in each sector. To further expand the range of options, the group also conducted a benchmark study examining adaptation strategies such as health-alert systems already being implemented in other regions of the United States and the world.

The Adaptation group categorized existing and potential adaptations with respect to various mechanisms (see **Table 2**).

The potential for synergistic or unintended consequences of adaptation strategies was considered as part of the assessment process.

The Adaptation group also identified research gaps, data requirements, and monitoring needs in the area of climate change adaptation to help guide future research efforts in New York State. Of particular interest was the identification of existing linkages between climate science and existing and potential policy adjustments, as well as opportunities to enhance these science-policy linkages through the identification of co-benefits and other conditions. Co-benefits are positive effects that adaptation actions can have on mitigating climate change (e.g., reduction of greenhouse gas emissions) or

on improving other aspects of the lives of New York State citizens. An example of a mitigation co-benefit is the establishment of green roofs that keep residents cooler while reducing the use of air conditioners, thereby reducing fossil fuel emissions at power plants. An example of a co-benefit with other aspects is the upgrading of combined sewer and stormwater systems to reduce current pollution, while helping to prepare for future climate change impacts.

Equity and Environmental Justice

The equity and environmental justice component of ClimAID involves three types of parallel efforts: 1) development of equity and environmental justice assessments for each sector, based on a review of background literature in these areas, 2) participation in sector case studies, and 3) attention to participation of a broad range of groups or representatives in the sector meetings with stakeholders (see “Equity and Economics,” Chapter 3).

For the selected case studies, the Equity and Environmental Justice group explored critical environmental justice issues with respect to intensity and extent of impacts and vulnerability and the potential for unintended consequences of adaptation. Both distributional and procedural aspects of equity and environmental justice were included in the assessment. In terms of distribution of climate hazards, there is an emphasis on identification of situations where particular groups may be systematically disadvantaged, either in terms of differences in vulnerability or capacity to adapt to climate change or in terms of the impacts of policies surrounding adaptation. Concerning distributional issues, the analysis is focused on inequalities in vulnerability to climate change, capacity to adapt to climate change, and effects of adaptation policies.

In terms of procedural elements, key considerations include incorporation of equity issues in adaptation discussions and policies, mechanisms for participation among a broad range of societal groups in future adaptation planning and policy efforts, and incorporation of equity and environmental justice stakeholders (such as associations of elderly, disabled, and health-compromised—for example, those suffering from asthma—people; low-income groups; farm workers; and small business owners) in climate vulnerability and adaptation assessments.

Adaptation Mechanism	Definitions
Type	Behavior, management/operations, infrastructure/physical component, risk-sharing, and policy (including institutional and legal)
Administrative group	Private vs. public; governance scale – local/municipal, county, state, national
Level of effort	Incremental action, paradigm shift
Timing	Years to implementation, speed of implementation (near-term/long-term)
Scale	Widespread, clustered, isolated/unique

Table 2 Adaptation mechanisms and definitions

These distributional and procedural definitions of equity and environmental justice are used throughout ClimAID. The broader aims include consideration of potential inequalities associated with climate change along both traditional lines that have been identified within the environmental justice literature (e.g., underprivileged, minority groups), as well as along new lines that may emerge under an altered climatic regime (e.g., different-sized firms) or may result from the implementation of adaptation policies and plans.

Economics

The Economics group broadly surveyed the economic value of each of the eight ClimAID sectors as well as the potential damages and adaptation costs associated with climate change impacts. They also carried out a detailed economic assessment for a selected case study in each of the sectors regarding the monetary costs of climate change impacts and adaptation (see Chapter 3, “Equity and Economics”). The goal was to evaluate the economic costs associated with the impacts of and adaptations to climate change that are likely to affect the different sectors of the New York State economy. Where possible, variations in costs were calculated across time and space. Measures of economic impact reviewed in the analysis included human welfare losses incurred due to healthcare costs, lost income and wage differentials, and productivity and consumer losses.

The economic analysis builds on the impacts and adaptation information in each of the sectors as well as economic data from New York State and analyses of the costs of impacts and adaptation strategies elsewhere. Methods included interviews, risk-based assessment of key impacts of climate change on sectors, and the framework of cost-benefit analysis (recognizing its significant limitations in evaluating adaptation to climate change) to provide an overview of the costs of impacts and adaptation strategies.

For a selected case study in each sector, the Economics group worked with the sector groups and stakeholders to create a “short list” of potential impacts and adaptation strategies. The Economics group then ranked these impacts and strategies based on the potential costs and benefits (as avoided impacts from the vulnerability assessment) associated with each. Cost and benefit estimates were derived from standard

pricing protocols and discount rate measures. For the selected case studies, the Economics group conducted economic analyses for different time horizons depending on the sector adaptations under consideration: short-term (i.e., actions within the next five years), medium-term (i.e., actions within the next five to 15 years), and long-term (i.e., actions to be taken beyond 15 years) responses. The Economics group, when possible, included the expected lifetimes (e.g., for capital-intensive infrastructure), amortization times (often linked to bonds that public entities use to finance public projects), and discount rates.

Sectors

ClimAID assessed how Water Resources, Coastal Zones, Ecosystems, Agriculture, Energy, Transportation, Telecommunications, and Public Health in New York State are currently affected by climate, how they may be affected by future climate change, and how they may adapt. Stakeholders provided key information about climate-related decisions for each sector. Each sector chapter begins with a description of the sector followed by sections that present the five integrating themes of climate hazards, vulnerabilities, adaptation, equity and environmental justice, and economics specific to the sector. A key focus of each sector chapter is a highlighted case study with in-depth analysis of potential adaptation strategies for a major climate hazard related to the sector. Case studies of other key climate vulnerabilities and adaptation methods are included in the sector chapters as well. An Appendix to each sector chapter describes how stakeholders were engaged in the assessment.

Water Resources

Water resources are dependent on multiple interacting climate factors, including air temperature and the timing and quantity of snow, rainfall, and evaporation. The Water Resources sector emphasizes in Chapter 4 that water resources in New York State are already subject to numerous human-induced stresses and these pressures are likely to increase over the coming decades.

Potential vulnerabilities for water resources and related infrastructure described in Chapter 4 include flooding, increase in duration and/or frequency of dry periods

affecting drinking water supplies in systems with low storage relative to demand, changes in demand for commercial and agricultural water related in part to climate-related factors, and declines in water quality due to higher water temperatures and decreased stream flows in summer. There may be enhanced opportunities for New York State as a potentially water-rich area in future climate conditions.

Examples of adaptation strategies for water resources detailed by the Water Resources sector for floods include 1) development of cost-effective stormwater-management infrastructure that enhances natural hydrologic processes (infiltration into soils, recharging groundwater, evaporation) and slows the movement of stormwater instead of rapidly conveying it to waterbodies, and 2) consideration of phased withdrawal of infrastructure from high-risk, flood-prone areas. For water supplies, adaptation strategies include establishment of guidelines for systematic management of water supplies under drought and implementation of an automatic gauging and reporting network to provide improved early-warning systems for supply shortages. For non-potable water supplies, the chapter suggests mechanisms for better coordination of water use in shared water bodies, the development of a public online system for tracing water usage across the state, establishment of minimum flow requirements for water withdrawals, and the preparation of a statewide water plan.

In regard to water quality, adaptation strategies evaluated in the chapter include design modifications to insure that regulatory requirements are met under current and future climate conditions; research and monitoring are needed to understand impacts of low-flows and higher temperatures on water quality, and potential changes to nutrient, sediment, and pathogen pollution in a changing climate.

Coastal Zones

The Coastal Zones sector in the ClimAID assessment focused on the regions close to the ocean, rather than on the coastal areas of the Great Lakes. Climate change vulnerabilities related to the Great Lakes are discussed in Climate Risks (Chapter 1), Water Resources (Chapter 4), Ecosystems (Chapter 6), Energy (Chapter 8), Transportation (Chapter 9), and Telecommunications (Chapter 10). Climate hazards related to coastal zones

encompass the distinct but related factors of sea level rise, coastal storms, increasing coastal water temperatures, and changes in precipitation patterns. These hazards are likely to occur in combination. As highlighted in Chapter 5, coastal zones in New York State are already stressed by high levels of development, which tend to reduce groundwater recharge and degrade water quality in the region.

Potential vulnerabilities for coastal zones described in the Coastal Zones sector in Chapter 5 include more frequent coastal flooding over larger areas during storms, increased shoreline erosion leading to alteration of the coastline, changes in the location of the salt front in the Hudson River estuary, loss of coastal wetlands, and changes in fish and shellfish populations.

Examples of adaptation strategies for coastal zones detailed in Chapter 5 include incorporating climate change and sea level rise information into land-use planning (for instance, setback zones requiring that new coastal development be a minimum distance from the shore). Other adaptation strategies include preparation of a detailed inventory of shoreline assets located in at-risk areas; acquiring of open coastal land for storm protection, recreation, and ecosystems; development of design criteria for new infrastructure; design of retrofit and/or relocation options for existing infrastructure that are more flexible to changing conditions and periodic reassessment; creation of a dynamic framework for updating policy guidelines given the “moving target” of climate change; and establishment of a network of stakeholders and volunteers to assist in monitoring for sea level rise response and coordinating outreach and education efforts. Key tasks for climate change adaptation in the coastal zones are to monitor coastal hazard zones over time in order to determine optimal timing of adaptation measures and to coordinate efforts across the state.

Ecosystems

Climate hazards of particular relevance as detailed by the Ecosystems sector are warmer winter temperatures, increased frequency of summer heat stress, increased frequency of heavy rainfall events, and increased frequency of late summer droughts.

Chapter 6 characterizes the potential vulnerabilities of natural ecosystems to climate changes as the loss of

spruce/fir forests in the Adirondacks and major shifts in tree species composition across the state, the loss of hemlock stands as a result of the woolly adelgid insect pest expanding its range northward, the effects on coldwater fish with repercussions for sport fishing, and the impacts on ski and snowmobile businesses.

Examples of adaptation strategies presented in Chapter 6 for ecosystem management include creation of migration corridors, reduction of human impacts in particularly vulnerable areas, and creation of more protected areas.

Agriculture

The Agriculture sector describes the climate change hazards of particular relevance in Chapter 7. These include warmer summer temperatures and longer growing seasons, increased frequency of summer heat stress and warmer winters, reduced snow cover, increased frequency of late-summer droughts, and increased frequency of heavy rainfall events.

Chapter 7 characterizes the potential vulnerabilities for agriculture as increased insects and diseases, heightened weed pressure, and the effects of excess water and drought. Key agricultural industries in the state that may be affected include dairy and livestock (via heat stress effects on productivity and changes in feed availability and prices), and poor spring bloom and yields of apples and other temperate fruit crops because of inadequate winter chill hours.

Examples of on-farm adaptation strategies described in the chapter for dairy and livestock industries include diet and feeding management; use of fans, sprinklers, and other cooling systems; and enhancement of cooling capacity in housing facilities. For crops, on-farm adaptations include shifting planting dates; diversification of crop varieties and crops; chemical and non-chemical control of insects, disease, and weeds; expanded irrigation capacity and other capital investments; and freeze and frost protection for perennial fruit crops. Chapter 7 explores adaptation strategies beyond the farm through such mechanisms as information delivery/extension systems, locally available design and planning assistance, disaster-risk management and insurance, financial assistance, and policy and regulatory decisions.

Energy

Climate hazards of particular relevance described by the Energy sector in Chapter 8 include anticipated changes in heating and cooling degree days; changes in hydrology affecting hydropower potential, including increased flooding along the coasts and in rivers and declines in streamflow; higher water temperatures; ice and snow storms; and wind. Based on the climate change projections, the Energy chapter evaluated the implications of changing loads on energy system operations in different parts of the state.

The energy sector explored climate vulnerabilities for electricity generation, transmission, and distribution. Potential vulnerabilities for energy supply include impacts on thermoelectric power generation and power distribution, impacts on natural gas distribution infrastructure, and impacts on renewable power generation. Potential vulnerabilities for energy demand include changes in total demand, seasonal variability, and peak demand.

Examples of adaptation strategies for the Energy sector described in Chapter 8 include changes in power dispatch rules to de-emphasize the use of vulnerable system assets; establishment of larger incentives to promote energy efficiency in order to reduce energy demand during extreme heat events and associated peak load demands; strategies to promote the more rapid deployment of distributed generation technologies (including solar, on-site combined heat and power technology, etc.) to both reduce demand on the grid and reduce site-specific system vulnerabilities; construction of additional power generation capacity to offset anticipated periodic losses in hydropower availability; changes in flood protection land-use practices to site power generation capacity in areas less vulnerable to flooding or extreme weather events; and requirements that utilities begin upgrading their transmission and distribution systems to prepare for demand growth associated with changing temperature levels around the state.

Transportation

Climate hazards of particular relevance to transportation include warmer summer and winter temperatures, increased precipitation, decreased snowfall, sea level rise, increased likelihood of heat

waves, increased likelihood of coastal and inland floods, changes in extreme events including hurricanes and nor'easters, and potential changes in wind speed and patterns and associated changes in wave climate.

Examples of potential vulnerabilities for transportation from Chapter 9 include increased stress on materials from increased temperatures and precipitation, increased coastal flooding risks due to sea level rise and storm surges, increased inland flooding from more intense precipitation events (especially in urban and hilly areas), and potential impacts of saltwater intrusion on coastal infrastructure.

Examples of adaptation strategies for the Transportation sector described in Chapter 9 relate to coastal hazards, heat hazards, precipitation hazards, and winter storms including snow and ice. Strategies explored include raising the level of new critical infrastructure and essential service sites; including climate change adaptation knowledge when retrofitting older infrastructure; switching to more durable materials; changing land-use planning mechanisms; and creating increased resilience through flexible adaptation pathways in operations, management, and policy decisions.

Telecommunications

Climate hazards related to telecommunications described in Chapter 10 are extreme temperatures, heat waves, and intense precipitation; sea level rise, coastal floods, and storms; and ice storms. The primary vulnerability brought forward is communications outages caused by these climate hazards.

Adaptation strategies presented by the Telecommunications sector in Chapter 10 include tree trimming to avoid damage to existing wires, switching from aboveground to belowground infrastructure, the use of fiber optics rather than wires, and wireless systems instead of land lines. A general adaptive principle in the sector is to increase redundancy via the use of generators and backup solar-powered battery banks. Other useful adaptation strategies include relocation of central offices away from floodplains and diversification of telecommunications media, e.g., the continued development of high-speed broadband and wireless services throughout the state.

Public Health

Climate hazards described by the Public Health sector in Chapter 11 include increasing temperature (especially heatwaves), extreme precipitation and flooding events, and changing patterns of monthly temperatures and precipitation.

Vulnerabilities for public health detailed in Chapter 11 include illness and death associated with more frequent and severe heat waves. Cold-related death is projected to decrease, although increases in heat-related death are projected to outweigh reductions in cold-related death. Vulnerabilities related to climate change also include illness and death associated with ozone and fine-particle air pollution, asthma and other respiratory diseases including allergies associated with altered pollen and mold seasons, cardiovascular disease, and infectious diseases. Climate plays a strong role in the emergence and/or changing distributions of vector-borne diseases, such as those spread by mosquitoes and ticks.

Examples of adaptation strategies for public health from Chapter 11 include integrating specific information about climate-related vulnerabilities into ongoing programs of public health surveillance, prevention, and response, rather than developing new programs to deal with unique challenges; developing scenarios that integrate climate forecasts into planning around heat emergencies and heat-warning systems; and integrating climate forecasts into ongoing planning for air quality.

Case Studies

Case studies were done for each of the ClimAID sectors (**Table 1**) and are found at the ends of the chapters. Some of these served in particular as a crosscutting element across the sectors and as a way to highlight concrete climate change adaptation challenges and opportunities across the state. For these in-depth case studies, the ClimAID sectors identified, with input from stakeholders, high-priority vulnerabilities in each sector. The in-depth case studies targeted those areas, communities, subpopulations, or sub-sectors that experience frequent climate impacts under current climate conditions. The aim was to identify useful climate adaptation strategies, taking into account uncertainties in future climate projections. Through the case studies, the ClimAID team identified and

illustrated the linkages connecting climate hazards, vulnerabilities, adaptation strategies, equity and environmental justice, and economics. Specific monitoring needs were identified as well.

Assessment Outcomes

The ClimAID assessment identified key climate change vulnerabilities and presented potential adaptation strategies for eight sectors in New York State. The assessment developed a coordinated set of climate change scenarios for the state as a whole and for seven regions within the state. This information contributed to the New York State Climate Action Council (CAC) process through the creation of a generalized set of adaptation guidelines and sector templates (see **Table 3** and Annexes I and II for a description of the CAC adaptation process and the ClimAID Climate Change Adaptation Guidebook and sector templates). Further ClimAID economic analyses that contributed to the CAC process are included in Annex III of this report.

The generalized set of guidelines described in the guidebook could be used by practitioners around the state to develop flexible yet prioritized responses to the risks of climate change. The guidebook provides a stakeholder guide to climate change adaptation, including a series of steps that can help to guide the process of considering how to assess vulnerabilities and establish adaptation plans within an organization. These were developed and tested as part of the activities of the Climate Action Council Adaptation Technical Working Group. Such decision-support tools aid development of science-based adaptation strategies and describe a coordinated approach to the development of effective adaptations among and across sectors. In some cases, climate change might provide opportunities to the state; these were brought forward as well.

Another ClimAID outcome is the identification of information gaps and research needs developed in conjunction with stakeholders and decision-makers. The ClimAID data, climate change projections, reports, and findings are publicly available on the Internet.

A key lesson of the ClimAID assessment is that such a coordinated approach is useful in dealing with the challenges and opportunities inherent in climate change and the complexities of integrating adaptation into the myriad of New York State activities.

Appendix A. Project Advisory Committee Members

Name	Affiliation
Jim Austin	NYS Department of Public Service
Alan Belenz	NYS Department of Environmental Conservation
Adam Freed	New York City Office of Long-Term Planning and Sustainability
John Kahabka	New York Power Authority
Naresh Kumar	Electric Power Research Institute
Jason Lynch	U.S. Environmental Protection Agency, Clean Air Markets
Lisa Moore	Environmental Defense Fund
Christina Palmero	NYS Department of Public Service
Barry Pendergrass	NYS Department of State
Ron Rausch	NYS Department of Agriculture and Markets
Patricia Reixinger	NYS Department of Environmental Conservation
Victoria Simon	New York Power Authority
James Wolf	Consultant
John Zamurs	NYS Department of Transportation

Review and assess existing climate stress conditions. Clarify goals and identify intersections of climate trends and changes with respect to achieving goals.
Compare with climate trends and change projections for New York State. How will these affect particular sectors?
Characterize adaptation strategies for operations and management, infrastructure, and policies for thresholds and ranges of key climate variables (e.g., temperature, sea level, storm surge, and precipitation) needed to maintain resilience.
Evaluate potential adaptation strategies (cost/benefit, environmental impacts) for management, infrastructure, and policy in the short, medium, and long terms; assess effectiveness and costs relative to benefits accrued; evaluate human capacity to respond or implement the strategies.
Prioritize flexible adaptation pathways (over decades).
Review climate trends and scenarios (at regular intervals).

Table 3 Climate change adaptation assessment guidelines (see ClimAID Climate Change Adaptation Guidebook, Annex II, for full description)

Appendix B. Stakeholder Organizations Engaged in ClimAID Assessment (see Sector Chapters for complete lists)

Water Resources

NYS Department of Environmental Conservation, NYS Department of Health, NYC Department of Environmental Protection, county and local water and sewer departments, U.S. Geological Survey, U.S. Army Corps of Engineers, Delaware River Basin Commission, NYS Soil and Water Conservation Committee, Cornell Cooperative Extension, Susquehanna River Basin Commission, Directors of Lake Associations, American Wildlife Conservation Foundation, American Public Works Association, Federation of NYS Solid Waste Association, NY Forest Owners Association, Ontario Dune Coalition, Director of State Wetland Managers and State Floodplain, municipal engineers, town planners, watershed council program managers, private engineering consultants.

Coastal Zones

NY District of U.S. Army Corps of Engineers, NYS Department of State, NYS Department of Transportation, NYS Emergency Management Office, NYC Department of Environmental Protection, Metropolitan Transportation Authority, The Nature Conservancy, the Port Authority of New York and New Jersey, NYC Office of Emergency Management, FEMA Region II, National Park Service, Stony Brook University, Suffolk and Nassau Counties, NYC Department of Parks and Recreation, DEC Hudson River Estuary Program and NYS Climate Change Office, New York Sea Grant Extension, NYC Climate Change Adaptation Task Force, NYC Panel on Climate Change, NYS Sea Level Rise Task Force.

Ecosystems

NYS Department of Environmental Conservation; U.S. Geological Survey; U.S. Fish and Wildlife Service; Cornell Cooperative Extension; The Nature Conservancy; National Wildlife Federation; Audubon New York; Wildlife Conservation Society; Adirondack Mountain Club; NY Forest Landowners Association;

Empire State Forest Products Association; Olympic Regional Development Authority; land, fish, and wildlife managers; maple growers.

Agriculture

Cornell Cooperative Extension, Cornell Integrated Pest Management Program, NYS Department of Agriculture and Markets, U.S. Department of Agriculture, Finger Lakes Grape Growers Association, Sweet Corn Grower Association, crop consultants, individual farmer collaborators.

Energy

Electric Power Research Institute, New York State Energy Research and Development Authority, New York State Department of Public Service, New York State Independent System Operator, Alliance for Clean Energy New York, Cogentrix, Con Edison, Dynegy, FirstLight Power, Suez GDF, National Grid, NRG Energy, NY Power Authority, TransCanada, Ravenswood, USPowerGen, Environmental Energy Alliance of NY, AES, Long Island Power Authority, NYS Department of Environmental Conservation, New York City Mayor's Office of Long-Term Planning and Sustainability.

Transportation

NYS Department of Transportation, Metropolitan Transportation Authority, Port Authority of New York and New Jersey, Amtrak, U. S. Army Corps of Engineers, CSX Corporation, NYS Emergency Management Office, NJ TRANSIT.

Telecommunications

Verizon, AT&T, Sprint Nextel, T-Mobile, UPS, FedEx, Time-Warner Cable, Federal Communications Commission, Cablevision, CTANY, National Grid, New York City Mayor's Office, Department of Homeland Security, NYS Emergency Management Office, NYC Office of Emergency Management, NYS Department of Environmental Conservation, Sea Level Rise Task Force, NYS Department of Public Service, NYS Energy Research and Development Authority.

Public Health

NYS Department of Health; NYS Department of Environmental Conservation; NYC Department of Health and Mental Hygiene; U.S. Environmental Protection Agency Region II; U.S. Centers of Disease Control; National Oceanic and Atmospheric Administration; city, State, and federal governmental agencies in the areas of environment, health, planning, and emergency management; non-governmental environmental organizations; academic institutions with research interests in public health and climate change; environmental justice organizations; clinical health sector organizations.

¹ <http://www.nature.org/wherewework/northamerica/states/newyork/science/art23583.html>

² <http://www.dec.ny.gov/energy/45202.html>

³ http://www.nyc.gov/html/planyc2030/html/plan/climate_task-force.shtml

⁴ <http://www.nyas.org/Publications/Annals/Default.aspx>

⁵ <http://nyclimatechange.us/InterimReport.cfm>

⁶ The model-based probabilities do not encompass the full range of potential climate changes, since future greenhouse gas emissions may be higher than the emissions scenarios used in their construction.

Chapter 1

Climate Risks

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Introduction

This chapter describes New York State's climate and the climate changes the state is likely to face during this century. The chapter contains: 1) an overview; 2) observed climate trends in means and extremes; 3) global climate model (GCM) validation, methods, and projections (based on long-term average changes, extreme events, and qualitative descriptions); and 4) conclusions and recommended areas for further research. To facilitate the linking of climate information to impacts in the eight ClimAID sectors, the state is divided into seven regions. Three appendices describe the projection methods, outline a proposed program for monitoring and indicators, and summarize the possible role of further downscaling climate model simulations for future assessments.

The climate hazards described in this chapter should be monitored and assessed on a regular basis. For planning purposes, the ClimAID projections focus on the 21st century. Although projections for the following centuries are characterized by even larger uncertainties and are beyond most current infrastructure planning horizons, they are briefly discussed in Appendix A because climate change is a multi-century concern.

Observed Climate Trends

- Annual temperatures have been rising throughout the state since the start of the 20th century. State-average temperatures have increased by approximately 0.6°F per decade since 1970, with winter warming exceeding 1.1°F per decade.
- Since 1900, there has been no discernable trend in annual precipitation, which is characterized by large interannual and interdecadal variability.
- Sea level along New York's coastline has risen by approximately 1 foot since 1900.
- Intense precipitation events (heavy downpours) have increased in recent decades.

Climate Projections

These are the key climate projections for mean changes and changes in extreme events.

Mean Changes

- Mean temperature increase is extremely likely this century. Climate models with a range of greenhouse gas emissions scenarios indicate that temperatures across New York State¹ may increase 1.5–3.0°F by the 2020s,² 3.0–5.5°F by the 2050s and 4.0–9.0°F by the 2080s.
- While most climate models project a small increase in annual precipitation, interannual and interdecadal variability are expected to continue to be larger than the trends associated with human activities. Projected precipitation increases are largest in winter, and small decreases may occur in late summer/early fall.
- Rising sea levels are extremely likely this century. Sea level rise projections for the coast and tidal Hudson River based on GCM methods are 1–5 inches by the 2020s, 5–12 inches by the 2050s, and 8–23 inches by the 2080s.
- There is a possibility that sea level rise may exceed projections based on GCM methods, if the melting of the Greenland and West Antarctic Ice Sheets continues to accelerate. A rapid ice melt scenario, based on observed rates of melting and paleoclimate records, yields sea level rise of 37–55 inches by the 2080s.

Changes in Extreme Events³

- Extreme heat events are very likely to increase and extreme cold events are very likely to decrease throughout New York State.
- Intense precipitation events are likely to increase. Short-duration warm season droughts will more likely than not become more common.
- Coastal flooding associated with sea level rise is very likely to increase.

A Note on Potential Changes in Climate Variability

Climate variability refers to temporal fluctuations about the mean at daily, seasonal, annual, and decadal timescales. The quantitative projection methods in ClimAID generally assume climate variability will remain unchanged as long-term average conditions shift. As a result of changing long-term averages alone, some types of extreme events are projected to become more frequent, longer, and intense (e.g., heat events), while events at the other extreme (e.g., cold events) are projected to decrease.

In the case of brief intense rain events (for which only qualitative projections can be provided), both the mean and variability are projected to increase, based on a combination of climate model simulations, theoretical understanding, and observed trends. Both heavy precipitation events and warm season droughts (which depend on several climate variables) are projected to become more frequent and intense during this century. Whether extreme multi-year droughts will become more frequent and intense than at present is a question that is not fully answerable today. Historical observations of large interannual precipitation variability suggest that extreme drought at a variety of timescales will continue to be a risk for the region during the 21st century.

1.1 Climate Change in New York State

Global average temperatures and sea levels have been increasing for the last century and have been accompanied by other changes in the Earth's climate. As these trends continue, climate change is increasingly being recognized as a major global concern. An international panel of leading climate scientists, the Intergovernmental Panel on Climate Change (IPCC), was formed in 1988 by the World Meteorological Organization and the United Nations Environment Programme to provide objective and up-to-date information regarding the changing climate. In its 2007 Fourth Assessment Report, the IPCC states that there is a greater than 90 percent chance that rising global average temperatures, observed since 1750, are primarily due to human activities. As had been predicted in the 1800s (Ramanathan and Vogelmann, 1997; Charlson, 1998), the principal driver of climate change over the past century has been increasing levels of atmospheric greenhouse gases associated with fossil-fuel combustion, changing land-use practices, and other human activities. Atmospheric concentrations of the greenhouse gas carbon dioxide are now more than one-third higher than in pre-industrial times. Concentrations of other important greenhouse gases, including methane and nitrous oxide, have increased as well (Trenberth et al., 2007). Largely as a result of work done by the IPCC and the United Nations Framework Convention on Climate Change (UNFCCC), efforts to mitigate the severity of climate change by limiting levels of greenhouse gas emissions are under way globally.

Some impacts from climate change are inevitable, because warming attributed to greenhouse gas forcing mechanisms is already influencing other climate processes, some of which occur over a long period of time. Responses to climate change have grown beyond a focus on mitigation to include adaptation measures in an effort to minimize the current impacts of climate change and to prepare for unavoidable future impacts. Each ClimAID sector used the climate-hazard information described in this chapter to advance understanding of climate change impacts within the state, with the goal of helping to minimize the harmful consequences of climate change and leverage the benefits.

New York State was divided into seven regions for this assessment (**Figure 1.1**). The geographic regions are grouped together based on a variety of factors, including type of climate and ecosystems, watersheds, and dominant types of agricultural and economic activities. The broad geographical regions are: Western New York and the Great Lakes Plain, Catskill Mountains and the West Hudson River Valley, the Southern Tier, the coastal plain composed of the New York City metropolitan area and Long Island, the East Hudson and Mohawk River Valleys, the Tug Hill Plateau, and the Adirondack Mountains.

Climate analysis was conducted on data from 22 meteorological observing stations (**Figure 1.1**; **Table 1.1a**). These stations were selected based on a combination of factors, including length of record, relative absence of missing data and consistency of station observing procedure, and the need for an even

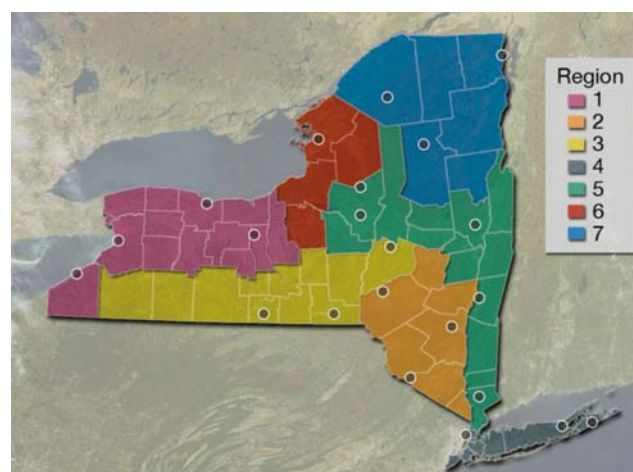


Figure 1.1 ClimAID climate regions. Circles represent meteorological stations used for the climate analysis

spatial distribution of stations throughout the regions and state.

Global climate model-based quantitative projections are provided within each region for:

- temperature,
- precipitation,
- sea level rise (coastal and Hudson Valley regions only), and
- extreme events.

The potential for changes in other variables is also described, although in a more qualitative manner because quantitative information for them is either unavailable or considered less reliable. These variables include:

- heat indices,
- frozen precipitation,

Station	Location	NYSERDA region	Data source	Length of coverage	Time-scale
Buffalo/Niagara International Airport	Buffalo	Region 1	COOP	1970–2008	Daily
Rochester International Airport	Rochester	Region 1	COOP	1970–2008	Daily
Geneva Research Farm	Geneva	Region 1	COOP	1970–2008	Daily
Fredonia	Fredonia	Region 1	COOP	1970–2008	Daily
Mohonk Lake	Mohonk Lake	Region 2	COOP	1970–2008	Daily
Port Jervis	Port Jervis	Region 2	COOP	1970–2008	Daily
Walton	Walton	Region 2	COOP	1970–2008	Daily
Binghamton Link Field	Binghamton	Region 3	COOP	1970–2008	Daily
Cooperstown	Cooperstown	Region 3	COOP	1970–2008	Daily
Elmira	Elmira	Region 3	COOP	1970–2008	Daily
Bridgehampton	Bridgehampton	Region 4	COOP	1970–2008	Daily
Central Park	New York	Region 4	COOP	1970–2008	Daily
Riverhead Research Farm	Riverhead	Region 4	COOP	1970–2008	Daily
Saratoga Springs 4 S	Saratoga Springs	Region 5	COOP	1970–2008	Daily
Yorktown Heights 1 W	Yorktown Heights	Region 5	COOP	1970–2008	Daily
Utica - Oneida Country Airport	Utica	Region 5	COOP	1970–2008	Daily
Hudson Correctional	Hudson	Region 5	COOP	1970–2008	Daily
Boonville 4 SSW	Boonville	Region 6	COOP	1970–2008	Daily
Watertown	Watertown	Region 6	COOP	1970–2008	Daily
Indian Lake 2 SW	Indian Lake	Region 7	COOP	1970–2008	Daily
Peru 2 WSW	Peru	Region 7	COOP	1970–2008	Daily
Wanakena Ranger School	Wanakena	Region 7	COOP	1970–2008	Daily

Table 1.1a The 22 New York State stations used in regional baseline averages and extreme events

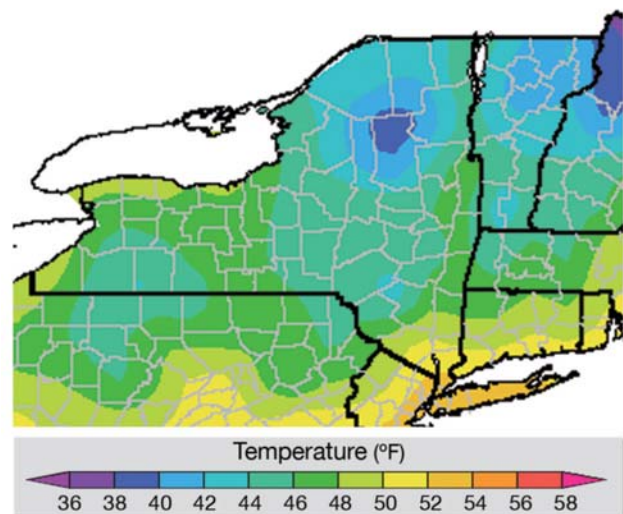
- lightning,
- intense precipitation of short duration, and
- storms (hurricanes, nor'easters, and associated wind events).

1.2 Observed Climate

This section describes New York State's mean climate, trends, and key extreme events since 1900. The climate and weather that New York State has experienced historically provides a context for assessing the climate changes for the rest of this century (Section 1.3.3 and Section 1.3.4).

1.2.1 Average Temperature and Precipitation

New York State's climate can be described as humid continental. The average annual temperature varies from about 40°F in the Adirondacks to about 55°F in the New York City metropolitan area (**Figure 1.2**). The wettest parts of the state—including parts of the Adirondacks and Catskills, the Tug Hill Plateau, and portions of the New York City metropolitan area—average approximately 50 inches of precipitation per year (**Figure 1.3**). Parts of western New York are relatively dry, averaging about 30 inches of precipitation per year. In all regions, precipitation is relatively consistent in all seasons, although droughts and floods are nevertheless not uncommon.



Source: Northeast Regional Climate Center

Figure 1.2 Normal average temperature in New York State

1.2.2 Sea Level Rise

Prior to the Industrial Revolution, sea level had been rising along the East Coast of the United States at rates of 0.34 to 0.43 inches per decade (Gehrels, et al., 2005; Donnelly et al., 2004), primarily because of regional subsidence (sinking) as the Earth's crust continues to slowly re-adjust to the melting of the ice sheets since the end of the last ice age. Since the Industrial Revolution, regional sea level has been rising more rapidly than over the last thousand years (Holgate and Woodworth, 2004). Currently, rates of sea level rise on New York State's coastlines have ranged across the region from 0.86 to 1.5 inches per decade, averaging 1.2 inches per decade since 1900. Sea level rise rates over this time period, measured by tide gauges, include both the effects of global warming since the onset of the Industrial Revolution and the residual crustal adjustments to the removal of the ice sheets. Most of the observed current climate-related rise in sea level over the past century can be attributed to expansion of the oceans as they warm, although melting of glaciers and ice sheets may become the dominant contributor to sea level rise during this century (Church et al., 2008).

1.2.3 Snowfall

New York State averages more than 40 inches per year of snow. Snowfall varies regionally, based on topography and the proximity to large lakes and the Atlantic Ocean (Figure 1.4). Maximum seasonal

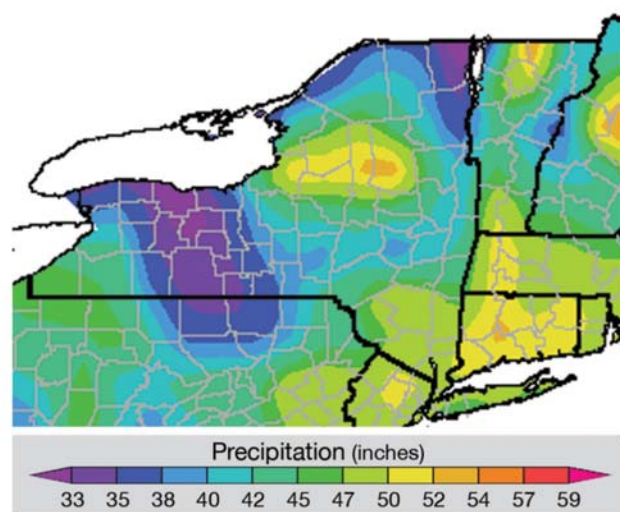
snowfall is more than 175 inches in parts of the Adirondacks and Tug Hill Plateau, as well as in the westernmost parts of the state. The warming influence of the Atlantic keeps snow in the New York metropolitan region and Long Island below 36 inches per year. Heavy snow squalls frequently occur near the Great Lakes, generating as much as 48 inches of snow in a single storm. In southern parts of the state, snowfall amounts occasionally exceed 20 inches during nor'easters. New York City, for example, experiences snow storms that exceed 20 inches about once every 30 years (New York State Climate Office, 2003).

1.2.4 Extreme Events

New York State is affected by extremes of heat and cold, intense rainfall and snow, and coastal flooding caused by tropical storms and nor'easters. Due to the large regional variations in the state's climate, no single extreme event metric is appropriate for the entire state. For example, in the northern parts of the state 0°F may be an appropriate metric for some stakeholder applications, whereas 32°F is more appropriate in the southern coastal plain, where maritime air from the Atlantic Ocean moderates temperatures.

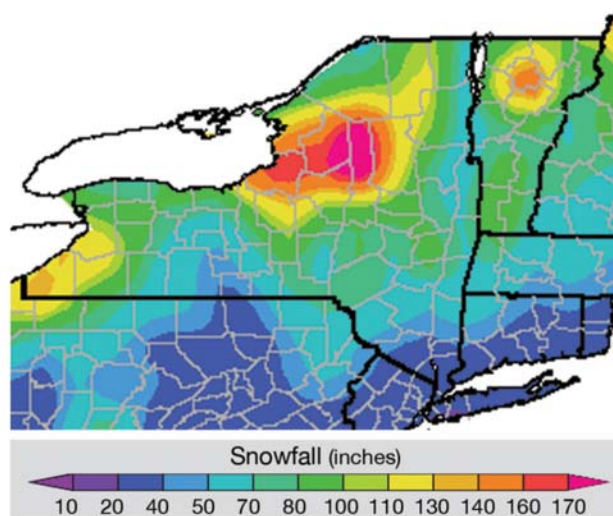
Extreme Temperature and Heat Waves

Extreme hot days and heat waves are thus defined in several ways to reflect the diversity of conditions experienced across New York State:



Source: Northeast Regional Climate Center

Figure 1.3 Normal average precipitation in New York State



Source: Northeast Regional Climate Center

Figure 1.4 Normal average snowfall in New York State

- Individual days with maximum temperatures at or above 90°F
- Individual days with maximum temperatures at or above 95°F
- Heat waves, defined as three consecutive days with maximum temperatures above 90°F

Extreme cold days are also defined to reflect the state's regional climate variations:

- Individual days with minimum temperatures at or below 32°F
- Individual days with minimum temperatures at or below 0°F

In all locations, the number of extreme events from year to year is highly variable. For example, in 2002, Port Jervis experienced temperatures of 90°F or higher on 31 different days; in 2004 days with temperatures of 90°F or higher only occurred four times.

Extreme Precipitation and Flooding

Throughout New York State, heavy rainfall can lead to flooding in all seasons. Urban areas (due to impermeable surfaces, including roads and buildings), steep slopes, and low-lying areas are particularly vulnerable. In much of central and northern New York State, flooding is most frequent in spring, when rains and rapid snowmelt lead to runoff. Ice jams sometimes contribute to serious flooding in very localized areas during spring and winter as well. Farther south, inland floods are more frequent during the summer.

Across the state, mechanisms responsible for producing heavy rainfall vary and are generally more common near the coasts. Intense precipitation can be associated with small-scale thunderstorms, most common in the warmer months. Large-scale coastal storms (see Coastal Storms), including cold/cool-season nor'easters (which can produce snow and ice in addition to rain) and warm-season tropical cyclones, can also produce intense precipitation.

Another extreme precipitation event experienced in regions of New York State is lake-enhanced snow events. These snowfall events, which can last anywhere from an hour to a few days, affect places downwind of the Great Lakes (and, to a lesser extent, the Finger Lakes) in western New York. Parts of Western New York

(including Buffalo) receive snowfall from Lake Erie, while the Tug Hill region (including Watertown and Oswego) experiences snowfall from Lake Ontario. Lake-enhanced snowfall is localized; areas within miles of each other can experience large differences in snowfall totals. For example, an October 2006 lake-effect snow event produced as much as 2 feet of snow in parts of the Buffalo metropolitan area, while just 20 miles away, Niagara Falls received approximately an inch of snow (Hamilton, 2007).

Destructive winds, lightning strikes, and hail are common during severe thunderstorms, but tend to affect small areas. Freezing rain events are more rare, but can affect larger areas.

Coastal Storms

The two types of storms with the largest impact on the coastal areas of the state are tropical cyclones and nor'easters. Tropical cyclones strike New York State very infrequently (generally between July and October), can produce large storm surges along the coast, and can cause wind damage and intense precipitation throughout the entire state. Nor'easters are far more frequent and of longer duration; they generally do not occur during the warmest months. Nor'easters are generally associated with smaller surges and weaker winds along the coast than tropical cyclones. Nevertheless, nor'easter flood effects can be large, since their long duration can extend the period of high winds, high water, and wave action over multiple tidal cycles.

A large fraction of New York City and coastal Long Island, especially the south shore, is less than 10 feet above average sea level and is vulnerable to coastal flooding during major storm events, both from inland flooding and from coastal storm surges. The current

Station	NYSDERDA region	Data source	Length of coverage	Timescale
Rochester	Region 1	USHCN	1900–2008	Monthly
Port Jervis	Region 2	USHCN	1910–2008	Monthly
Elmira	Region 3	USHCN	1900–2008	Monthly
New York City (Central Park)	Region 4	USHCN	1900–2008	Monthly
Albany	Region 5	USHCN	1900–2008	Monthly
Watertown	Region 6	USHCN	1900–2008	Monthly
Indian Lake	Region 7	USHCN	1900–2008	Monthly

Table 1.1b Seven New York State stations used for temperature and precipitation analysis, including drought

100-year flood event (see Appendix A for a description of how return periods are defined and calculated) can produce an 8.6-foot storm surge across much of New York City.

1.2.5 Historical Analysis

An analysis of historical trends in seasonal and annual average temperature and precipitation was conducted at one station with a long data record in each of the seven regions (**Table 1.1b**).⁴ The observed monthly data source is Version 2 of the United States Historical Climatology Network (USHCN) product (<http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html>). The data are corrected for time of observation and change in observation practice through time. Missing data are filled in using optimized spatial interpolation; these interpolations have been shown not to affect trends (Menne et al., 2009). This data product is not specifically adjusted for urbanization (Menne et al., 2009).

For extreme event projections, daily data came from the NOAA Cooperative Observer Program (COOP) data set (<http://www7.ncdc.noaa.gov/IPS/coop/coop.html>), with missing data filled in using spatial interpolation (Menne et al., 2009).⁵

	Annual (°F/decade)	Spring (°F/decade)	Summer (°F/decade)	Fall (°F/decade)	Winter (°F/decade)
Albany	0.18**	0.25**	0.13*	0.06	0.29**
Elmira	0.01	-0.02	-0.09	0.00	0.17
Indian Lake	0.15**	0.13	0.05	0.14*	0.29*
NYC	0.39**	0.45**	0.33**	0.28**	0.53**
Port Jervis	0.06	0.09	0.02	-0.08	0.20*
Rochester	0.20**	0.26**	0.19**	0.10	0.25*
Watertown	0.17**	0.17*	0.15**	0.08	0.31**

Temperature in °F per decade

* Significant at the 95% level. ** Significant at the 99% level.

	Annual (in/decade)	Spring (in/decade)	Summer (in/decade)	Fall (in/decade)	Winter (in/decade)
Albany	1.13**	0.33	0.34	0.36**	0.10
Elmira	0.30	0.01	-0.08	0.26	0.11
Indian Lake	-0.06	-0.01	-0.04	0.08	-0.10
NYC	0.47	0.24	-0.05	0.25	0.04
Port Jervis	0.11	0.15	-0.21	0.12	0.04
Rochester	0.29	0.01	0.15	0.20*	-0.07
Watertown	0.35	-0.01	0.05	0.23*	0.09

Precipitation in inches per decade

* Significant at the 95% level. ** Significant at the 99% level.

Source: Columbia University Center for Climate Systems Research. Data are from NOAA NCDC USHCN

Table 1.2a Observed climate trends in New York State (1901–2000)

Average annual and seasonal temperature and precipitation trends were calculated for three time periods: 1901–2000 (**Table 1.2a**), 1970–2008 (**Table 1.2b**) and 1970–1999 (**Table 1.2c**). The 1900s and 30-year time periods are frequently used for analysis (see Trenberth et al., 2007 and Hayhoe, 2007 for local application). By analyzing a full century, the role of unpredictable decade-to-decade variability can be reduced. The 30-year timeslice is referred to as the “climate normal” and has wide application in the meteorological and climate communities (for example, Guttman, 1989; WMO, 1989). The 30-year trend has strong appeal to stakeholders since it is deemed more representative of the experienced climate than is the 100-year trend; the 30-year trend also better reflects the global carbon dioxide forcing associated with warming at the end of the 20th century. However, at such short timescales, regional trends can be dominated by climate variability. The analysis is extended through 2008 to reduce this problem.

Temperature

The well-documented warming trend in New York State (Hayhoe, 2007 and 2008) from 1970 through 1999 is even more robust when extended through 2008

	Annual (°F/decade)	Spring (°F/decade)	Summer (°F/decade)	Fall (°F/decade)	Winter (°F/decade)
Albany	0.64**	0.23	0.69**	0.47	1.23**
Elmira	0.61**	0.31	0.71**	0.44	1.04*
Indian Lake	0.70**	0.36	0.38	0.73**	1.39**
NYC	0.60**	0.43	0.31	0.47*	1.23**
Port Jervis	0.43**	0.05	0.51**	0.45*	0.78
Rochester	0.49**	0.27	0.23	0.36	1.18**
Watertown	0.57**	0.21	0.39	0.60*	1.15*

Temperature in °F per decade

* Significant at the 95% level. ** Significant at the 99% level.

	Annual (in/decade)	Spring (in/decade)	Summer (in/decade)	Fall (in/decade)	Winter (in/decade)
Albany	1.33	0.16	0.50	0.62	-0.15
Elmira	1.68	0.52	0.77	0.36	-0.08
Indian Lake	0.43	0.26	0.06	-0.10	0.06
NYC	-0.16	-0.48	0.41	0.31	-0.62
Port Jervis	0.47	-0.53	0.07	0.91	-0.22
Rochester	0.30	0.08	0.11	0.20	-0.15
Watertown	0.73	0.30	-0.03	0.42	-0.04

Precipitation in inches per decade

* Significant at the 95% level. ** Significant at the 99% level.

Source: Columbia University Center for Climate Systems Research. Data are from NOAA NCDC USHCN

Table 1.2b Observed climate trends in New York State (1970–2008)

(Table 1.2). The annual temperature trends for all seven stations are significant at the 99 percent level over the 1970–2008 period, whereas only three of seven are significant at that level for the 1970–1999 period. The seven-station average warming trend has decreased slightly from 0.63°F per decade over the 30-year period to 0.58°F per decade from 1970 through 2008. The seven-station, 100-year warming trend can be attributed almost entirely to the warming in recent decades.

Winter warming (the average over December, January, and February) contributes most strongly to the trends. Winter warming trends for 1970–2008 from four of the seven stations are significant at the 99 percent level as compared to three of the 1970–1999 trends. However, the seven-station average winter warming trends decrease from 1.63°F per decade to 1.14°F per decade, indicating that the winters of the past decade have not been particularly warm. When the 1970–2008 record is used in place of the 1970–1999 record, summer and to a lesser extent fall warming trends become more evident; three of the seven stations show summer warming that is significant at the 99 percent level for the 1970–2008 period. Averaged across the seven stations over the 1970–2008 period, summer warming trends are 0.46°F and fall warming trends are 0.50°F per decade.

	Annual (°F/decade)	Spring (°F/decade)	Summer (°F/decade)	Fall (°F/decade)	Winter (°F/decade)
Albany	0.58*	0.23	0.52	-0.02	1.64**
Elmira	0.76**	0.52	0.88*	0.21	1.51*
Indian Lake	0.87**	0.70	0.33	0.48	2.02**
NYC	0.67**	0.47	0.33	0.22	1.69**
Port Jervis	0.53*	0.25	0.38	0.19	1.35*
Rochester	0.43	0.30	0.07	-0.14	1.54
Watertown	0.59	0.24	0.35	0.18	1.65*

Temperature in °F per decade

* Significant at the 95% level.

** Significant at the 99% level.

	Annual (in/decade)	Spring (in/decade)	Summer (in/decade)	Fall (in/decade)	Winter (in/decade)
Albany	-0.59	-0.01	-0.73	0.55	-0.56
Elmira	0.03	0.72	-0.23	-0.08	-0.53
Indian Lake	-1.76	-0.24	-0.56	-0.36	-0.6
NYC	-2.27	-0.47	-0.73	-0.68	-0.55
Port Jervis	-0.61	-0.17	-0.62	0.46	-0.37
Rochester	0.15	0.16	0.21	0.34	-0.56
Watertown	-1.36	-0.01	-1.04	0.15	-0.35

Precipitation in inches per decade

* Significant at the 95% level. ** Significant at the 99% level. Source: Columbia University Center for Climate Systems Research. Data are from NOAA NCDC USHCN

Table 1.2c Observed climate trends in New York State (1970–1999)

Precipitation

Few precipitation trends at these seven stations are significant at even the 95 percent confidence level for any of the three time periods analyzed. Over the entire 1900s, annual precipitation (averaged across the seven stations) increased by 0.37 inches per decade, with weak increasing trends during each of the four seasons. The well-documented decreasing annual precipitation trend from 1970 through 1999 (-0.92 inches per decade in the seven-station average) reverses and increases (0.68 inches per decade in the seven-station average) when the 2000–2008 period is included. For the 1970–2008 period, only the winter trend decreases, at a negligible -0.17 inches per decade for the seven-station average. These results point to the dominant influence of natural variability at decade-to-decade timescales on precipitation, and suggest that average precipitation changes over the region's observed historical record cannot be attributed to climate change.

Extreme Events

For each of the seven stations, extreme event trends for the 1970–1999 and 1970–2007 periods were also calculated based on daily data. Due to large year-to-year variability in extreme events, the available temporal coverage of the daily data is lower than optimal for trend analysis. As a result, shifting of the years analyzed can produce a large change in the trends shown here. The trends analyzed were: number of days per year with maximum temperatures above 85°F;⁶ numbers of days per year with minimum temperatures below 32°F; heating and cooling degree days;⁷ length of growing season (defined as duration of period with temperatures above 32°F); number of days with precipitation exceeding 1 inch; and annual snowfall and snow depth.

Four of the seven stations showed a statistically significant (95 percent) decreasing trend in the number of days with minimum temperatures at or below 32°F over the 1970–2007 period (Table 1.3, top). At Saratoga Springs, there were 7.1 fewer days per decade. Consistent with this trend, all seven stations showed a decrease in heating degree days, although the trend was only significant at the 99 percent level at two of the seven stations (Table 1.3, middle). Most of the stations showed decreased annual snowfall and snow depth between 1970 and 2007; however, given the large year-to-year variability, none

Station	Number of days below 32°F (days/decade)***
Rochester	-2.32
Port Jervis	-1.21
Elmira	-3.21*
New York City (Central Park)	-2.73
Saratoga Springs	-7.10**
Watertown	-3.90**
Indian Lake	-5.14**

Station	Heating degree days (degree days/decade)***
Rochester	-109.9
Port Jervis	-46.3
Elmira	-137.4*
New York City (Central Park)	-91.5
Saratoga Springs	-278.4**
Watertown	-163.2*
Indian Lake	-204.0**

Station	Annual snowfall (inches/decade)***
Rochester	0.94
Port Jervis	-0.43
Elmira	0.7
New York City (Central Park)	2.37
Saratoga Springs	-1.63
Watertown	0.13
Peru	-5.38

* Significant at the 95% level. ** Significant at the 99% level.

*** Negative values indicate that these events have been occurring less frequently over approximately the last 40 years. Source: Columbia University Center for Climate Systems Research. Data are from NOAA NCDC USHCN

Table 1.3 Trends in extreme events (1970–2007)

of the snow trends is statistically significant (Table 1.3, bottom).

1.3 Climate Projections

Global climate models are mathematical representations of the behavior of the Earth's climate system through time. Each model couples the ocean, atmosphere, and land and ice surfaces. Climate models have increased in complexity as computational power has increased. Recent integrated climate model simulations, done for the IPCC 2007 report, were run at higher spatial resolution than earlier models and, due to improved physical understanding, incorporated complex physical processes more accurately such as cloud physics. Current climate models are generally able to reproduce the warming that occurred over the

last century at global and continental scales (Hegerl et al., 2007) but not regional scales (Christensen et al., 2007) when they run in a hindcast mode, which uses accurate historical greenhouse gas concentrations. These models are also able to reproduce some of the key climate characteristics of paleoclimates that were far different than today's climate, which lends additional confidence that global climate models' future simulations are generally realistic. Of the IPCC simulations, the 16 state-of-the-art global climate models that had available output for each of three emissions scenarios (only seven global climate models are available for sea level rise) were selected to develop the projections for the New York State ClimAID assessment. A full description of these emissions scenarios can be found in section 1.3.3.

The large number of available global climate models allows future climate projections to be made using model-based probabilistic assessment across a range of climate sensitivities (the average equilibrium temperature response of a global climate model to doubling the atmospheric carbon dioxide concentration relative to preindustrial levels). The global climate model results used here were calculated from outputs from the World Climate Research Program and the Program for Climate Model Diagnosis and Intercomparison. The outputs of recent simulations of these models are collected by these programs (http://www.pcmdi.llnl.gov/ipcc/about_ipcc.php) at the Lawrence Livermore Laboratory in Berkeley, California.

Although global climate models are the primary tool used for long-range climate prediction, they do have limitations. For example, they simplify some complex physical processes, such as convective rainfall (rain events accompanied by instability often associated with thunderstorms and heavy rain). In addition, the spatial and temporal scales of some climate variables, such as thunderstorms, are finer than the resolutions of global climate models. Furthermore, they do not fully include all relevant local climate forcings, including some aerosols, black carbon (which increases warming by absorbing heat in the atmosphere and reducing snow and ice's ability to reflect sunlight), land-cover changes, urban heat island effects, and changes in the amount of solar radiation.⁸ For these and other reasons, local climate may change in ways not captured by the models, leading to temperature, precipitation, and sea level rise changes outside the ranges presented here.

1.3.1 Climate Model Validation

Because the 16 coupled climate models (IPCC AR4) were run with observed time-varying 20th century carbon dioxide concentrations and other forcings, results can be compared to the observed data for the same period. Evaluation of climatology/averages and long-term trends are standard metrics used in many studies (for example, Randall et al., 2007; Hegerl et al., 2007; Brekke et al., 2008) of global climate model historical performance. While validation can be conducted on a range of climate variables, this analysis focuses on the two long-term average surface variables from global climate models that are of most interest to stakeholders: temperature and precipitation. Because long-term temperature and precipitation trends have minimal spatial variation in the Northeast in current-generation global climate models (Horton et al., 2010), this analysis focuses exclusively on single gridbox (see Section 1.3.2, Regional Projections for more information) results from the three geographical extremes of the state: the Adirondack region, Western New York, and the coastal

Station	Observed 100-year temperature (°F)	Global climate model ensemble 100-year temperature (°F)
Rochester	47.51	42.57
New York City	54.18	49.78
Indian Lake	40.40	40.82

Station	Observed 100-year precipitation (in)	Global climate model ensemble 100-year precipitation (in)
Rochester	29.83	40.06
New York City	45.25	46.62
Indian Lake	39.84	44.46

Source: Columbia University Center for Climate Systems Research. Data are from USHCN and PCMDI

Table 1.4a Observed and modeled temperature and precipitation for the 1900s

Station	Observed 30-year temperature (°F)	Global climate model ensemble 30-year temperature (°F)
Rochester	47.89	42.83
New York City	55.06	50.35
Indian Lake	40.18	41.17

Station	Observed 30-year precipitation (in)	Global climate model ensemble 30-year precipitation (in)
Rochester	33.25	40.26
New York City	50.76	46.79
Indian Lake	39.97	44.93

Source: Columbia University Center for Climate Systems Research. Data are from USHCN and PCMDI

Table 1.4b Observed and modeled temperature and precipitation 1970–1999

plain. The assessment was conducted on 1900s (**Table 1.4a**) and 1970–1999 periods (**Table 1.4b**) of the hindcast global climate model simulations conducted for the IPCC Fourth Assessment Report. These hindcasts closely approximate the greenhouse gas concentrations that were present in the atmosphere over the time period represented by the simulation.

Mean Climate

For the New York City region, the average temperature for the 1970–1999 period, according to the models, is 50.3°F. The observed temperature at Central Park was 55.0°F. While observations exceed the global climate models in all months, the departure is largest in July at 6.8°F degrees, and smallest in January at 2.3°F, indicating that the annual temperature cycle is damped in the global climate models. Both observed temperatures and modeled average temperatures are lowest in January and highest in July. The discrepancy between the observed and modeled temperatures is due, in part, to the urban heat island, which is not simulated by global climate models, and to a tendency for the selected grid boxes to be centered in the cooler zone north of the coastal plain (since ocean-dominated grid boxes were not included in the analysis).

The global climate models' average annual precipitation from 1970 through 1999 for the Coastal Plain also falls below observations for Central Park by 8 percent. However, the modeled average is comparable to New York City as a whole (La Guardia airport's average, for example, is only 3 inches lower than the modeled mean). Most of the global climate models are able to capture the relatively even distribution of precipitation throughout the year.

For the Western New York region, the average temperature for the 1970–1999 period, according to the models, is 42.9°F. This is approximately 5°F colder than the corresponding observed temperature at Rochester. The hindcast average precipitation is approximately 7 inches higher than the observed value of 33 inches at Rochester.

In the Adirondack region, the average temperature for the 1970–1999 period, according to the models, is 41.2°F. The observed temperature at Indian Lake was 40.2°F. The hindcast average precipitation is approximately 5 inches (12 percent) higher than the

observed values at Indian Lake, but is representative of the region as a whole, which includes areas that receive more than 50 inches of precipitation per year.

Trends

Historical trend analysis is challenging for multiple reasons. First, over the historical period, the climate change signal from greenhouse gases was not as strong as it is expected to be during this century. Additionally, because the ocean and atmosphere in the climate models interact, the oceans in the models evolve independently from the real ocean through time. As a result, the global climate model historical simulations do not feature the same ocean temperatures and forcing that actually occurred at multi-year to decadal timescales. Thus, the role of natural variability relative to climate change in generating a trend in the models—or in the models relative to observations—cannot be easily assessed. Trends and statistical significance are therefore calculated independently for observations and models.

In Western New York, annual observed temperatures increased 0.2°F per decade over the 20th century. Only the fall trends were not significant at the 95 percent level. Modeled temperatures have warmed by 0.13°F per decade since 1900. The annual and seasonal model trends are all significant at the 99 percent level, with the greatest seasonal warming (0.17°F) present in winter. For the 1970–1999 period, the observed warming increased to 0.43°F per decade. No trends for the 1970–1999 observed period were significant. Over the same period, modeled annual warming was 0.34°F; both the modeled annual trend and the fall trend of 0.53°F per decade are significant at the 99 percent level.

The only significant trend in Rochester's observed average precipitation was for the fall season over the 20th century, at 0.20 inch per decade. The global climate models ensemble precipitation for the 20th century was significant annually and for all seasons but the summer. While the observed trends were not significant for the 1970–1999 period, the global climate model ensemble showed a significant increase in annual average precipitation.

For the Adirondack region (Table 1.5, Indian Lake station), the observed warming trend of 0.15°F per decade for the 1900s is well simulated by the global climate model hindcast of 0.14°F per decade. In the

observations, approximately half of the warming is due to winter warming; in the global climate models, winter warming exceeds warming in other seasons, but each of the four modeled seasonal trends is similar and significant at the 99 percent level. Over the 1970–1999 period, the global climate model ensemble underestimates the observed annual temperature trend (0.34°F modeled versus 0.87°F observed per decade), although both trends are significant at the 99 percent level. While the observed warming during that time period is primarily in the winter, the global climate model ensemble warming is only significant at the 99 percent level in the summer and fall, when the warming trend in the model is also the largest.

1900–1999 Annual and Seasonal Temperature Trends (°F/decade) Region 7 – Indian Lake***				
100-year average temperature	17%	83%	ENS	Observed
December–February	0.05	0.29	0.16**	0.29*
March–May	0.00	0.26	0.12**	0.13
June–August	0.05	0.24	0.12**	0.05
September–November	0.07	0.21	0.15**	0.14*
Annual	0.04	0.27	0.14**	0.15**

1970–1999 Annual and Seasonal Temperature Trends (°F/decade) Region 7 – Indian Lake				
30-year average temperature	17%	83%	ENS	Observed
December–February	-0.48	0.84	0.16	2.02**
March–May	-0.36	0.67	0.22	0.70
June–August	0.17	0.56	0.40**	0.33
September–November	0.19	0.96	0.55**	0.48
Annual	0.1	0.59	0.34**	0.87**

1900–1999 Annual and Seasonal Precipitation Trends (inches/decade) Region 7 – Indian Lake***				
100-year average precipitation	17%	83%	ENS	Observed
December–February	-0.05	0.16	0.40*	-0.10
March–May	0.02	0.15	0.01	-0.01
June–August	-0.16	0.07	0.03**	-0.04
September–November	-0.02	0.12	0.06*	0.08
Annual	-0.01	0.41	0.14**	-0.06

1970–1999 Annual and Seasonal Precipitation Trends (inches/decade) Region 7 – Indian Lake				
30-year average precipitation	17%	83%	ENS	Observed
December–February	-0.15	0.42	0.15	-0.60
March–May	-0.35	0.29	-0.08	-0.24
June–August	-0.45	0.28	-0.02	-0.56
September–November	-0.22	0.40	0.13	-0.36
Annual	-0.44	0.80	0.10	-1.76

* Significant at the 95% level. ** Significant at the 99% level.

*** Observed data set came from Indian Lake, New York, 1901–2000.

Shown are the observed values for Indian Lake, the GCM ensemble average (ENS), and two points on the GCM distribution (17th and 83rd percentiles) representing the central range. Source: Columbia University Center for Climate Systems Research. Data are from WCRP and PCMDI

Table 1.5 Indian Lake validation

Indian Lake's observed average precipitation trends are not significant in any seasons for both the 1900s and 1970–1999 periods (Table 1.5). The same is true of the global climate ensemble for the 1970–1999 period; however for the 1900–1999 period, the ensemble shows statistically significant (99 percent) increases in precipitation both annually and during the summer.

In the coastal plain, the modeled annual temperature increases by 0.13°F per decade during the 1900s. This can be attributed to the 0.32°F per decade trend from 1970 through 1999. The observed 1970–1999 trend is greater at 0.67°F per decade. Observed per-decade temperature increases over the entire 1900s, however, are nearly triple that of the models, at 0.39°F. The 1900s model ensemble trend is similar in each season, while the 1970–1999 model ensemble shows the most temperature increase in the fall and summer. Observed temperature increases during the 1900s, by contrast, were largest in the winter and the smallest during the fall, though all seasons showed significant warming in all seasons. The entire observed warming trend during the past three decades can be attributed to winter warming.

The ensemble average model precipitation trend for the coastal plain is negligible over the 100-year record. The 1970–1999 30-year record shows a small increase of 0.18 inch per decade, due almost entirely to a small increase in winter precipitation. Nevertheless, in all four seasons, the central range of global climate models span from decreasing to increasing values. Over the 1970–

1999 period, observed precipitation patterns show a small decrease in precipitation, which is due to decreases in summer and fall precipitation that outweigh increases in spring precipitation. This trend, however, is highly dependent on the selection of years, suggesting that 100-year trends for precipitation are more appropriate, given precipitation's high year-to-year and decade-to-decade variability in the region.

Validation Summary

While the global climate models are able to reproduce the state's climatology with limited biases, departures from observations over the hindcast period (due largely to spatial scale discontinuities between point data and GCM gridboxes)—are large enough to necessitate the use of climate change factors—future global climate model departures from global climate model baseline values—rather than direct model output. This finding provides a rationale for bias-correction such as the change factors or delta-method approach used for the ClimAID assessment (see section 1.3.3 for a description of this method).

The picture regarding trend validation is more complex. Ideally the global climate change factors from each model could be trained using historical trends, but this is not advisable for several reasons. While the 30-year modeled trends deviate from observations, these deviations do not necessarily indicate that global climate model sensitivity and regional response to

Climate Model Acronym	Institution	Atmospheric Resolution (latitude x longitude)	Oceanic Resolution (latitude x longitude)	References
BCCR	Bjerknes Center for Climate Research, Norway	1.9 x 1.9	0.5 to 1.5 x 1.5	Furevik et al., 2003
CCSM	National Center for Atmospheric Research, USA	1.4 x 1.4	0.3 to 1.0 x 1.0	Collins et al., 2006
CGCM	Canadian Center for Climate Modeling and Analysis, Canada	2.8 x 2.8	1.9 x 1.9	Flato 2005
CNRM	National Weather Research Center, METEO-FRANCE, France	2.8 x 2.8	0.5 to 2.0 x 2.0	Terray et al., 1998
CSIRO	CSIRO Atmospheric Research, Australia	1.9 x 1.9	0.8 x 1.9	Gordon et al., 2002
ECHAM5	Max Planck Institute for Meteorology, Germany	1.9 x 1.9	1.5 x 1.5	Jungclaus et al., 2005
ECHO-G	Meteorological Institute of the University of Bonn, Germany	3.75 x 3.75	0.5 to 2.8 x 2.8	Min et al., 2005
GFDL-CM2.0	Geophysical Fluid Dynamics Laboratory, USA	2.0 x 2.5	0.3 to 1.0 x 1.0	Delworth et al., 2006
GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory, USA	2.0 x 2.5	0.3 to 1.0 x 1.0	Delworth et al., 2006
GISS	NASA Goddard Institute for Space Studies	4.0 x 5.0	4.0 x 5.0	Schmidt et al., 2006
INMCM	Institute for Numerical Mathematics, Russia	4.0 x 5.0	2.0 x 2.5	Volodin and Diansky, 2004
IPSL	Pierre Simon Laplace Institute, France	2.5 x 3.75	2.0 x 2.0	Marti, 2005
MIROC	Frontier Research Center for Global Change, Japan	2.8 x 2.8	0.5 to 1.4 x 1.4	K-1 Developers, 2004
MRI	Meteorological Research Institute, Japan	2.8 x 2.8	0.5 to 2.0 x 2.5	Yuikimoto and Noda, 2003
PCM	National Center for Atmospheric Research, USA	2.8 x 2.8	0.5 to 0.7 x 1.1	Washington et al., 2000
UKMO-HadCM3	Hadley Center for Climate Prediction, Met Office, UK	2.5 x 3.75	1.25 x 1.25	Johns et al., 2006

Table 1.6 Global climate models used in the ClimAID assessment

greenhouse gas forcing is incorrect in the models. For example, observed trends, especially for precipitation, also vary substantially based on the time period selected due to high year-to-year and decade-to-decade variability, which the models are not expected to experience concurrently with their freely evolving climate system. The fact that some important, regionally varying external forcings, including some aerosols, are not included in all the global climate models would be expected to further lead to departures from observations over the historical period. Finally, the models are missing local features that may have influenced the trends, including the urban heat island and precipitation island in those stations that are urban centers. In the New York metropolitan region, the heat island effect has been substantial (Rosenzweig et al., 2009; Gaffin et al., 2008). While these missing forcings may contribute to errors in the future, these errors are expected to become relatively less important as the warming role of increasing greenhouse gas concentrations becomes more and more dominant.

1.3.2 Projection Methods

For the ClimAID assessment, global climate models were used to develop a set of climate projections for New York State. Projections were made for changes in mean annual climate (Section 1.3.3) and extreme events (Section 1.3.4). Model-based probabilities for temperature, precipitation, sea level rise, and extreme events are created based on global climate model simulations (see **Table 1.6** for more information about the global climate models) and greenhouse gas emissions scenarios (IPCC, 2000) used in the IPCC Fourth Assessment Report (IPCC, 2007). This approach has been applied to many regions, including locally for New York City as part of the New York City Panel on Climate Change activities in support of New York City's Climate Change Adaptation Task Force (New York City Panel on Climate Change, 2010; Horton et al., 2010).

Emissions Scenarios

To produce future climate scenarios, global climate model simulations are driven with projected greenhouse gas emissions scenarios (**Figure 1.5**). Each emissions scenario represents a unique blend of demographic, social, economic, technological, and environmental

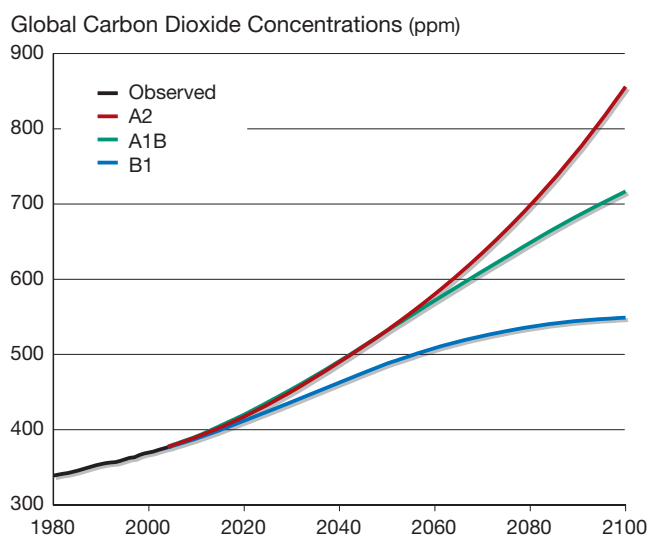
assumptions (IPCC, 2000). The following three scenarios are used for this analysis:

A2: Relatively rapid population growth and limited sharing of technological change combine to produce high greenhouse gas levels by the end of this century, with emissions growing throughout the entire century.

A1B: Effects of economic growth are partially offset by introduction of new technologies and decreases in global population after 2050. This trajectory is associated with relatively rapid increases in greenhouse gas emissions and the highest overall carbon dioxide levels for the first half of this century, followed by a gradual decrease in emissions after 2050.

B1: This scenario combines the A1 population trajectory with societal changes tending to reduce greenhouse gas emissions growth. The net result is the lowest greenhouse gas emissions of the three scenarios, with emissions beginning to decrease by 2040.

Additional IPCC-based scenarios, such as the high-end A1FI scenario, yield moderately higher greenhouse gas concentrations (and therefore climate response) by the end of this century than the three scenarios indicated



Based on IPCC emissions scenarios. Observed carbon dioxide concentrations through 2003 and future carbon dioxide concentrations in the A1B, A2, and B1 scenarios (2004 to 2100). Source: Columbia University Center for Climate Systems Research. Data are from WCRP and PCMDI

Figure 1.5 Future carbon dioxide concentrations used in the ClimAID assessment

above. High-end climate change scenarios along the lines of A1FI are discussed qualitatively, especially with regard to the rapid ice melt scenario. Such trajectories should continue to be monitored and reassessed over time. The A1FI scenario was not included in the model-based approach described here due to few available corresponding global climate model simulations.

Model-based Probability

The combination of 16 global climate models and three emissions scenarios produces a matrix with 48 scenarios for temperature and precipitation;⁹ for each scenario time period and variable, the results constitute a model-based probability function. The results for the future time periods are compared to the model results for the 1970–1999 baseline period. Average temperature change projections for each month are calculated as the difference between each model's future simulation and the same model's baseline simulation, whereas average monthly precipitation is based on the ratio of a given model's future precipitation to the same model's baseline precipitation (expressed as a percentage change).¹⁰ Sea level rise methods are more complex since sea level rise is not a direct output of most global climate models.

Sea Level Rise

The GCM-based methods used to project sea level rise for the coastal plain and Hudson River include both global components (global thermal expansion, or sea level rising as a result of increases in water temperature, and meltwater from glaciers, ice caps, and ice sheets) and local components (local land subsidence, i.e., sinking, and local water surface elevation).

Within the scientific community, there has been extensive discussion of the possibility that the GCM approach to sea level rise may substantially underestimate the range of possible increases. For this reason, an alternative rapid ice melt approach has been developed based on paleoclimate studies. Starting around 20,000 years ago, global sea level rose 394 feet; present-day sea level was reached about 8,000 to 7,000 years ago. The average rate of sea level rise during this 10,000 to 12,000-year period was 0.39–0.47 inch per year. This information is incorporated into the rapid ice melt scenario projections. More information on this

method, including how it is integrated with the global climate model-based methods, can be found in Appendix A, “Rapid Ice Melt Sea Level Rise Scenario.”

Extreme Events

Extremes of temperature and precipitation (with the exception of drought) tend to have their largest impacts at daily rather than monthly timescales. However, monthly output from climate models has more observational fidelity than daily output (Grotch and MacCracken, 1991), so a hybrid projection technique was employed for these events. The modeled mean changes in monthly temperature and precipitation for each of the 16 global climate models and three emissions scenarios were applied to each region's observed daily data from 1971 to 2000 to generate 48 time series of daily data.¹¹

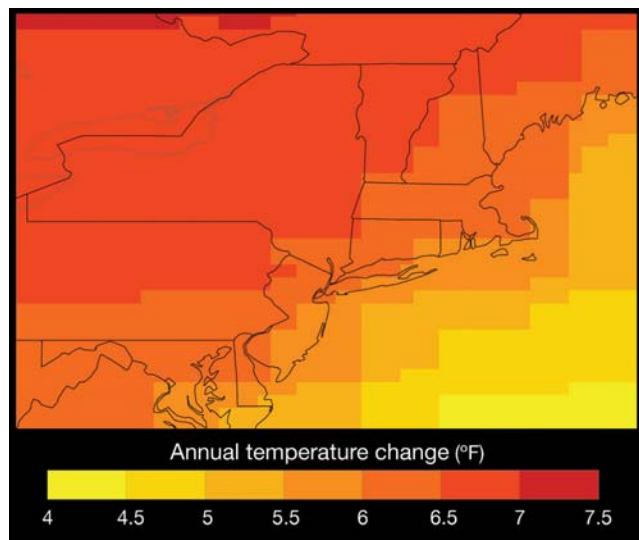
This is a simplified approach to projections of extreme events, since it does not allow for possible changes in variability through time. While changes in variability are generally highly uncertain (rendering the precise changes in extreme event frequency highly uncertain as well), changes in frequency associated with average monthly shifts alone are of sufficient magnitude to merit consideration by long-term planners as they develop adaptation strategies that prepare for extreme events.

Regional Projections

The projections for the seven regions of New York State are based on global climate model output from each model's single land-based model gridbox covering the center of each region. The precise coordinates of each model's gridboxes differ since each global climate model has a different spatial resolution. These resolutions range from as fine as about 75 by 100 miles to as coarse as about 250 by 275 miles, with an average resolution of approximately 160 by 190 miles. Changes in temperature (**Figure 1.6a**) and precipitation (**Figure 1.6b**) through time are region-specific (for example, 3°F degrees of warming by a given timeframe for a particular region). Neighboring regions, however, exhibit similar average changes in climate. This spatial similarity indicates that the average change results shown here are not very sensitive to how the region was defined geographically.

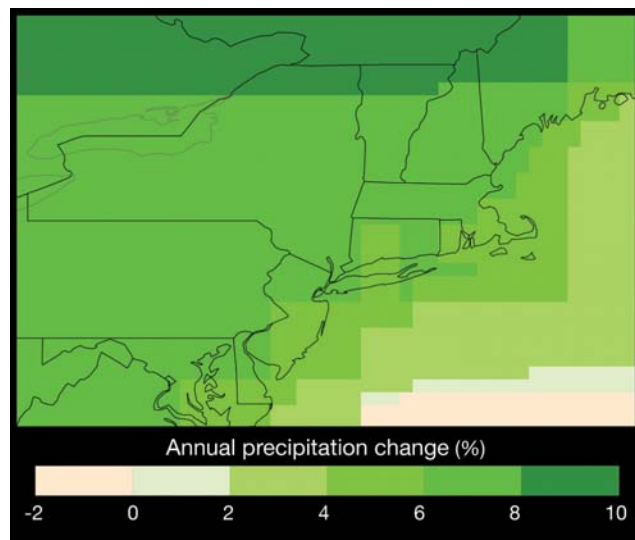
By applying the projected changes from the relevant gridbox to observed data, the projections become specific to the region. For example, although Rochester's projected change in temperature through time is similar to New York City's, the number of current and projected

days per year with temperatures below 32°F differs between the two locations because they have different baseline temperatures. Thus, the spatial variation in baseline climate is much larger than the spatial variation of projected climate changes.



Source: Columbia University Center for Climate Systems Research. Data are from WCRP and PCMDI

Figure 1.6a Projected change in annual temperature for the 2080s in the Northeast relative to the 1980s baseline period



Source: Columbia University Center for Climate Systems Research. Data are from WCRP and PCMDI

Figure 1.6b Projected change in annual precipitation for the 2080s in the Northeast relative to the 1980s baseline period

		Baseline ¹ 1971–2000	2020s	2050s	2080s
Region 1					
Stations used for Region 1 are Buffalo, Rochester, Geneva and Fredonia.	Air temperature ²	48°F	+1.5 to 3.0°F	+3.0 to 5.5°F	+4.5 to 8.5°F
	Precipitation	37 in	0 to +5%	0 to +10%	0 to 15%
Region 2					
Stations used for Region 2 are Mohonk Lake, Port Jervis, and Walton.	Air temperature ²	48°F	+1.5 to 3.0°F	+3.0 to 5.0°F	+4.0 to 8.0°F
	Precipitation	48 in	0 to +5%	0 to +10%	+5 to 10%
Region 3					
Stations used for Region 3 are Elmira, Cooperstown, and Binghamton.	Air temperature ²	46°F	2.0 to 3.0°F	+3.5 to 5.5°F	+4.5 to 8.5°F
	Precipitation	38 in	0 to +5%	0 to +10%	+5 to 10%
Region 4					
Stations used for Region 4 are New York City (Central Park and LaGuardia Airport), Riverhead, and Bridgehampton.	Air temperature ²	53°F	+1.5 to 3.0°F	+3.0 to 5.0°F	+4.0 to 7.5°F
	Precipitation	47 in	0 to +5%	0 to +10%	+5 to 10%
Region 5					
Stations used for Region 5 are Utica, Yorktown Heights, Saratoga Springs, and the Hudson Correctional Facility.	Air temperature ²	50°F	+1.5 to 3.0°F	+3.0 to 5.5°F	+4.0 to 8.0°F
	Precipitation	51 in	0 to +5%	0 to +5%	+5 to 10%
Region 6					
Stations used for Region 6 are Boonville and Watertown.	Air temperature ²	44°F	+1.5 to 3.0°F	+3.5 to 5.5°F	+4.5 to 9.0°F
	Precipitation	51 in	0 to +5%	0 to +10%	+5 to 15%
Region 7					
Stations used for Region 7 are Wanakena, Indian Lake, and Peru.	Air temperature ²	42°F	+1.5 to 3.0°F	+3.0 to 5.5°F	+4.0 to 9.0°F
	Precipitation	39 in	0 to +5%	0 to +5%	+5 to 15%

¹ The baselines for each region are the average of the values across all the stations in the region.

² Shown is the central range (middle 67%) of values from model-based probabilities; temperature ranges are rounded to the nearest half-degree and precipitation to the nearest 5%.

Source: Columbia University Center for Climate Systems Research. Data are from USHCN and PCMDI

Table 1.7 Baseline climate and mean annual changes for the 7 ClimAID regions

Projections for extreme events use baseline climate and projected changes in temperature, precipitation, and sea level rise relative to the given baseline for the timeslices, which are defined by averaging all 22 stations within a given region (**Table 1.7**).

Timeslices

Although it is not possible to predict the temperature, precipitation, or sea level for a particular day, month, or even specific year due to fundamental uncertainties in the climate system, global climate models can project the likely range of changes over decadal to multi-decadal time periods. These projections, known as timeslices, are expressed relative to the given baseline period, 1970–1999 (2000–2004 for sea level rise). The timeslices are centered around a given decade. For example, the 2050s timeslice refers to the period from 2040–2069.¹² Thirty-year timeslices (10 years for sea level rise) are used to provide an indication of the climate normals for those decades. By averaging over this period, much of the random year-to-year variability—or noise—is cancelled out,¹³ while the long-term influence of increasing greenhouse gases—or signal—remains (Guttman, 1989; WMO, 1989).

1.3.3 Average Annual Changes

Higher temperatures and sea level rise are extremely likely for New York State. For temperature and sea level rise, all simulations project continued increases over the century, with the entire central range of the projections indicating more rapid temperature and sea level rise than occurred during the last century. Although most projections indicate small increases in precipitation, some do not. Natural precipitation variability is large; thus, precipitation projections are less certain than temperature projections. There is a distinct possibility that precipitation will decrease over both 10-year and 30-year timescales. For all variables, the numerical projections for later in this century are less certain than those for earlier in the century (i.e., the ranges of outcomes become larger through time), due to uncertainties in the climate system and the differing possible pathways of the greenhouse gas emission scenarios.

Comparing observed data with projected changes for temperature and precipitation provides context with

regard to how projected changes in the region compare to historical trends and long-term variability (**Figure 1.7**). To emphasize the climate signal and deemphasize the unpredictable year-to-year variability, a 10-year filter has been applied to the observed data and model output.

Temperature

Average annual temperatures are projected to increase across New York State by 1.5–3.0°F in the 2020s, 3.0–5.5°F in the 2050s, and 4.0–9.0°F in the 2080s (**Table 1.7**; **Figure 1.6a**). By the end of the century, the greatest warming may be in the northern parts of the state. The state's growing season could lengthen by about a month, with summers becoming more intense and winters milder. The climate models suggest that each season will experience a similar amount of warming relative to the baseline period.

Beginning in the 2030s, the emissions scenarios diverge, producing temperature patterns that are distinguishable from each other (**Figure 1.7**). This is because it takes several decades for the climate system to respond to changes in greenhouse gas concentrations. It also takes several decades for different emissions scenarios to produce large differences in greenhouse gas concentrations.

Precipitation

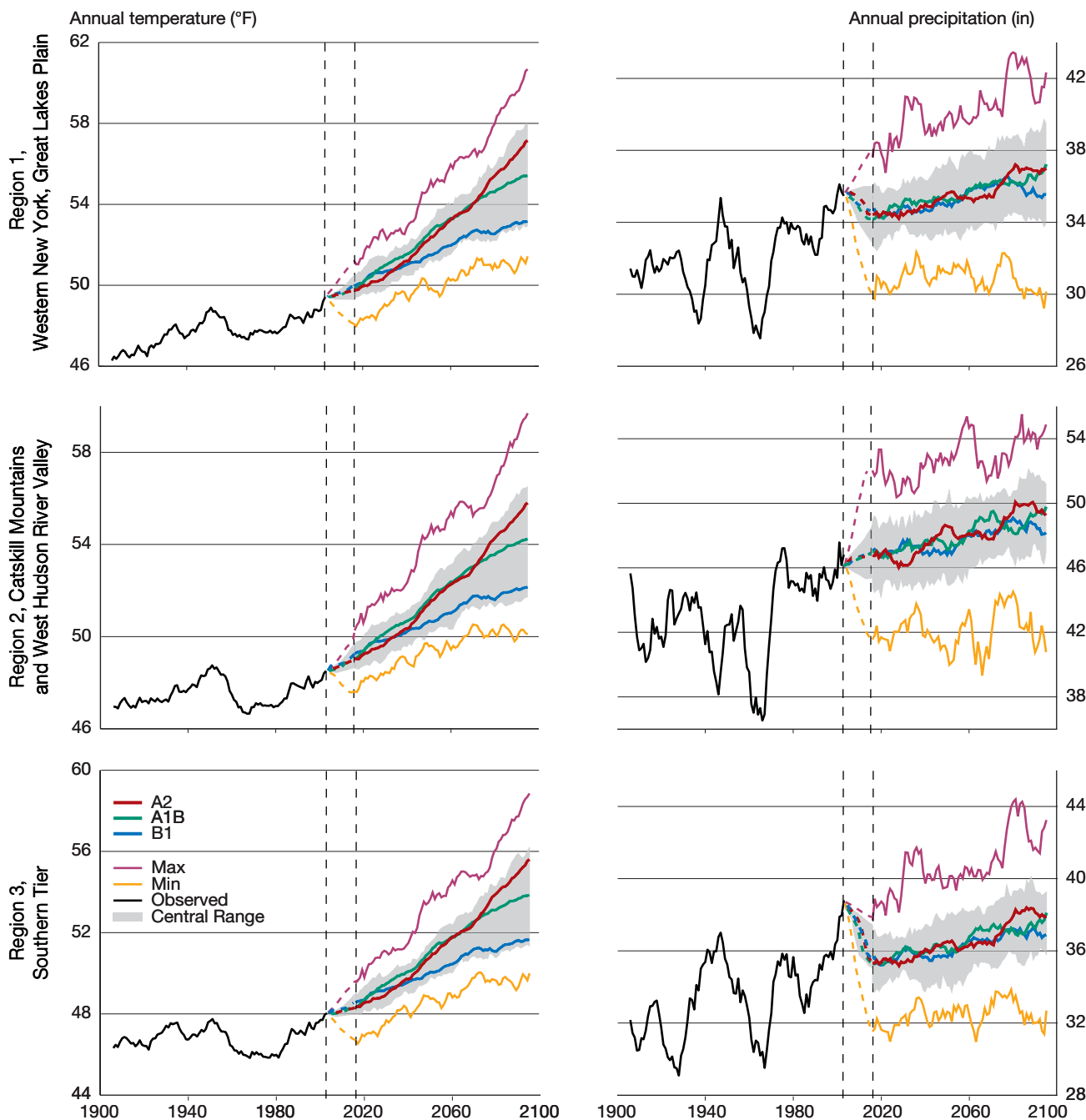
Regional precipitation across New York State may increase by approximately 0–5 percent by the 2020s, 0–10 percent by the 2050s, and 5–15 percent by the 2080s (**Table 1.7**; **Figure 1.6b**). By the end of the century, the greatest increases in precipitation may be in the northern parts of the state. While seasonal projections are less certain than annual results, much of this additional precipitation may occur during the winter months. During September and October, in contrast, total precipitation is slightly reduced in many climate models.

Precipitation is characterized by large historical variability, even with 10-year smoothing (**Figure 1.7**). Beginning in the 2040s, the climate models diverge, with the lower-emission B1 scenario producing smaller increases in precipitation than the high-emission A1B and the mid-emission A2 scenarios. However, even

after the 2040s there are occasional periods where the B1 scenario projects more precipitation than that of A2. At no point in the century are the A2 and A1B scenario-based precipitation projections consistently distinguishable.

Sea Level Rise

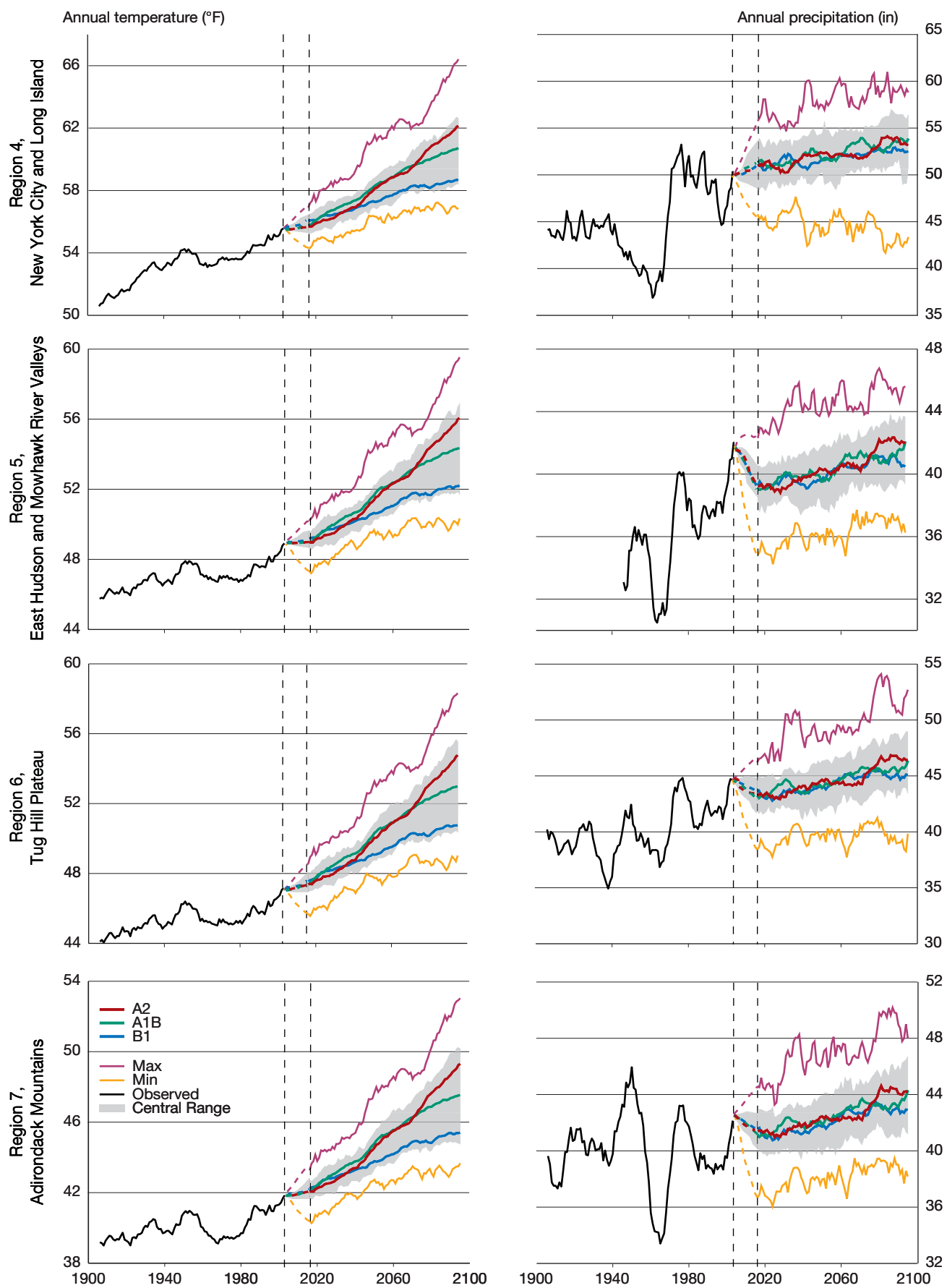
Sea level is projected to rise along the coast and in the tidal Hudson by 1–5 inches in the 2020s, 5–12 inches in the 2050s, and 8–23 inches in the 2080s, using the



Observed (black line) and projected temperature (left) and precipitation (right). Projected model changes through time are applied to the observed historical data. The green, red, and blue lines show the average for each emissions scenario across the 16 global climate models. The shaded area indicates the central range. The bottom shows the minimum projection across the suite of simulations, and the top line shows the maximum projections. A 10-year filter has been applied to the observed data and model output. The dotted area between 2004 and 2015 represents the period that is not covered as a result of 10-year filter. Note different scales for temperature and precipitation.

Source: Columbia University Center for Climate Systems Research. Data are from USHCN, WCRP and PCMDI

Figure 1.7 Observed and projected temperature (left) and precipitation (right) for the ClimAID regions of New York State. Note that the y-axis is specific to each graph (continues on next page)



GCM-based model projections (**Table 1.8**). Beginning in the 2050s, the low-emissions B1 scenario produces smaller increases in sea level than the higher-emissions A1B and A2 scenarios, and in the 2080s, the A2 scenario projects more sea level rise than A1B. The A2 scenario diverges from A1B approximately 10 years earlier for temperature than it does for sea level rise, in part reflecting the large response time of the ocean and ice sheets relative to the atmosphere.

The model-based sea level rise projections are characterized by greater uncertainty than the temperature projections, largely due to the possibility that future changes in polar ice sheets may accelerate melting beyond currently projected levels; this possible change is not captured by global climate models. This uncertainty is weighted toward the upper bound; that is, the probability that sea level rise will be lower than the GCM-based projection is very low, but the probability that sea level rise will exceed the GCM-based projection is higher.

The rapid ice melt sea level rise scenario addresses the possibility of the ice sheets melting more rapidly. This scenario is based on extrapolating the recent accelerating rates of ice melt from the Greenland and West Antarctic ice sheets and on paleoclimate studies that suggest sea level rise on the order of 0.39–0.47 inch per year may be possible. This scenario projects a sea level rise of 37 to 55 inches by the 2080s. The potential for rapid ice melt should be considered, in part, because of its potential for large consequences. It is also uncertain how rapid ice melt might indirectly influence sea level in the New York region through second-order effects, including gravitational, glacial isostatic adjustments, and rotational terms (e.g., Mitrovica et al., 2001, 2009).

Region 4: New York City and Long Island	2020s (inches)	2050s (inches)	2080s (inches)
GCM-based ¹	+2 to +5	+7 to +12	+12 to +23
Rapid ice-melt scenario ²	~5 to +10	~19 to +29	~41 to +55
Region 5: East Hudson and Mohawk River Valleys	2020s (inches)	2050s (inches)	2080s (inches)
GCM-based ¹	+1 to +4	+5 to +9	+8 to +18
Rapid ice-melt scenario ²	~4 to +9	~17 to +26	~37 to +50

¹ Shown is the central range (middle 67%) of values from global climate model-based probabilities rounded to the nearest inch.

² The rapid-ice melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies.

Table 1.8 ClimAID Assessment sea level rise projections

To assess the risk of accelerated sea level rise over the coming years, scientific understanding as well as many key indicators should be monitored and reassessed on an ongoing basis (Appendix B).

1.3.4 Changes in Extreme Events

Despite their brief duration, extreme climate events can have large impacts, so they are a critical component of this climate change impact assessment. The frequencies of heat waves, cold events, intense precipitation, drought, and coastal flooding in the seven regions are projected to change in the coming decades, based on average global climate model shifts (**Table 1.9**). The average number of extreme events per year for the baseline period is shown, along with the middle 67 percent and full range of the model-based projections. Because the model-based probability does not represent the actual probability distribution, and shifts in extreme event distributions are not constrained to the types of average shifts described above, the relative magnitude of projected changes, rather than the actual projected number of events, should be emphasized.

Heat Waves and Cold Events

The total number of hot days in New York State is expected to increase as this century progresses. The frequency and duration of heat waves, defined as three or more consecutive days with maximum temperatures at or above 90°F, are also expected to increase (**Table 1.9**). In contrast, extreme cold events, defined both as the number of days per year with minimum temperature at or below 32°F, and those at or below 0°F, are expected to decrease. Some parts of each region, such as cold high-altitude zones, are likely to experience fewer heat events and more cold events in the future than regional averaging would suggest, because of the cold tendency in their baseline climates.

Intense Precipitation and Droughts

Although the increase in total annual precipitation is projected to be relatively small, larger increases are projected in the frequency, intensity, and duration of extreme precipitation events (defined as events with more than 1, 2, or 4 inches of rainfall) at daily timescales. The projection for New York State is

Table 1.9 Extreme events projections

Rochester (Region 1): Full range of changes in extreme events: minimum, (central range*), and maximum					
Extreme event		Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	8	8 (10 to 17) 23	12 (17 to 30) 44	16 (22 to 52) 68
	95°F	0.8	0.9 (2 to 4) 6	2 (3 to 9) 17	3 (6 to 22) 38
	Number of heat waves per year ²	0.8	0.9 (1 to 2) 3	2 (2 to 4) 6	2 (3 to 7) 8
	average duration	4	4 (4 to 4) 5	4 (4 to 5) 5	4 (4 to 5) 7
Intense Precipitation	Number of days per year with min. temp. at or below 32°F	133	99 (104 to 116) 126	76 (90 to 103) 108	53 (75 to 97) 106
	Number of days per year with rainfall exceeding:				
	1 inch	5	3 (4 to 5) 6	3 (4 to 6) 7	3 (4 to 6) 7
	2 inches	0.6	0.4 (0.5 to 0.7) 0.9	0.3 (0.5 to 0.8) 1	0.2 (0.5 to 1) 1
Port Jervis (Region 2): Full range of changes in extreme events: minimum, (central range*), and maximum					
Extreme event		Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	12	13 (14 to 24) 34	16 (22 to 40) 53	21 (28 to 65) 75
	95°F	2	2 (2 to 5) 10	3 (5 to 12) 20	4 (7 to 28) 39
	Number of heat waves per year ²	2	2 (2 to 3) 5	2 (3 to 5) 7	3 (4 to 9) 10
	average duration	4	4 (4 to 5) 5	5 (5 to 5) 6	5 (5 to 6) 8
Intense Precipitation	Number of days per year with min. temp. at or below 32°F	138	101 (111 to 121) 128	70 (91 to 111) 115	57 (70 to 101) 112
	Number of days per year with rainfall exceeding:				
	1 inch	12	10 (11 to 13) 14	10 (12 to 14) 14	10 (12 to 14) 15
	2 inches	2	1 (2 to 2) 3	1 (2 to 3) 3	1 (2 to 3) 3
Elmira (Region 3): Full range of changes in extreme events: minimum, (central range*), and maximum					
Extreme event		Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	10	11 (14 to 19) 25	15 (21 to 33) 45	19 (26 to 56) 70
	95°F	1	2 (2 to 4) 7	2 (4 to 10) 18	4 (7 to 24) 38
	Number of heat waves per year ²	1	1 (2 to 3) 3	2 (3 to 4) 6	2 (3 to 8) 9
	average duration	4	4 (4 to 5) 5	4 (4 to 5) 5	4 (5 to 5) 7
Intense Precipitation	Number of days per year with min. temp. at or below 32°F	152	116 (122 to 124) 145	86 (106 to 122) 168	68 (87 to 114) 124
	Number of days per year with rainfall exceeding:				
	1 inch	6	5 (6 to 7) 8	5 (6 to 7) 8	5 (6 to 8) 10
	2 inches	0.6	0.5 (0.6 to 0.9) 1	0.5 (0.6 to 1) 1	0.4 (0.7 to 1) 2
New York City (Region 4): Full range of changes in extreme events: minimum, (central range*), and maximum					
Extreme event		Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	19	20 (23 to 31) 42	24 (31 to 47) 58	31 (38 to 66) 80
	95°F	4	4 (6 to 9) 15	6 (9 to 18) 28	9 (12 to 32) 47
	Number of heat waves per year ²	2	3 (3 to 4) 6	3 (4 to 6) 7	4 (5 to 8) 9
	average duration	4	4 (5 to 5) 5	5 (5 to 5) 6	5 (5 to 7) 8
Intense Precipitation	Number of days per year with min. temp. at or below 32°F	72	48 (53 to 62) 66	31 (45 to 54) 56	22 (36 to 49) 56
	Number of days per year with rainfall exceeding:				
	1 inch	14	11 (13 to 15) 16	11 (14 to 16) 16	11 (14 to 16) 17
	2 inches	3	2 (3 to 4) 5	3 (3 to 4) 5	2 (4 to 5) 5
Saratoga Springs (Region 5): Full range of changes in extreme events: minimum, (central range*), and maximum					
Extreme event		Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	10	11 (14 to 20) 28	17 (20 to 35) 49	18 (26 to 60) 75
	95°F	1	1 (2 to 4) 7	3 (3 to 10) 18	3 (6 to 25) 42
	Number of heat waves per year ²	2	2 (2 to 3) 4	3 (3 to 5) 7	3 (4 to 8) 9
	average duration	4	4 (4 to 5) 5	4 (4 to 5) 6	4 (5 to 6) 9
Intense Precipitation	Number of days per year with min. temp. at or below 32°F	134	121 (128 to 139) 147	92 (111 to 127) 135	78 (90 to 120) 131
	Number of days per year with rainfall exceeding:				
	1 inch	10	8 (10 to 11) 12	9 (10 to 11) 12	10 (10 to 12) 14
	2 inches	1	1 (1 to 2) 2	1 (1 to 2) 2	1 (1 to 2) 2

Watertown (Region 6): Full range of changes in extreme events: minimum, (central range*), and maximum					
Extreme event		Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	3	2 (4 to 7) 11	5 (8 to 17) 27	8 (12 to 36) 52
	95°F	0	0 (0.1 to 0.9) 2	0.2 (0.6 to 3) 7	0.8 (2 to 11) 23
	Number of heat waves per year ²	0.2	0.2 (0.4 to 0.9) 1	0.6 (0.8 to 2) 4	0.6 (1 to 4) 6
	average duration	4	3 (4 to 4) 5	3 (4 to 4) 5	4 (4 to 5) 7
Intense Precipitation	Number of days per year with min. temp. at or below 32°F	147	114 (120 to 130) 140	93 (108 to 121) 126	78 (91 to 114) 122
	Number of days per year with rainfall exceeding:				
	1 inch	5	5 (6 to 8) 9	6 (6 to 8) 9	5 (7 to 10) 11
	2 inches	0.8	0.4 (0.6 to 0.9) 1	0.5 (0.6 to 1) 1	0.3 (0.6 to 1) 2
Indian Lake (Region 7): Full range of changes in extreme events: minimum, (central range*), and maximum					
Extreme event		Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	0.3	0.3 (0.5 to 1) 2	0.5 (1 to 5) 7	1 (2 to 13) 23
	95°F	0	0 (0 to 0.1) 0.2	0.1 (0.1 to 0.3) 0.6	0.1 (0.2 to 2) 6
	Number of heat waves per year ²	0	0 (0 to 0.1) 0.2	0 (0.1 to 0.6) 0.7	0.1 (0.2 to 2) 3
	average duration	3	3 (3 to 3) 4	3 (3 to 4) 4	3 (4 to 4) 5
Intense Precipitation	Number of days per year with min. temp. at or below 32°F	193	155 (166 to 177) 184	125 (146 to 163) 173	108 (124 to 156) 166
	Number of days per year with rainfall exceeding:				
	1 inch	7	6 (7 to 8) 10	6 (7 to 9) 10	6 (7 to 10) 11
	2 inches	0.8	0.4 (0.7 to 1) 1	0.6 (0.7 to 1) 2	0.6 (0.8 to 1) 2

The values in parentheses in rows two through four indicate the central 67% range of the projected model-based changes to highlight where the various global climate model and emissions scenario projections agree. The minimum values of the projections are the first number in each cell and maximum values of the projections are last numbers in each cell.

* The central range refers to the middle 67% of values from model-based probabilities across the global climate models and greenhouse gas emissions scenarios.

¹ Decimal places shown for values less than 1, although this does not indicate higher precision/certainty. The high precision and narrow range shown here are due to the fact that these results are model-based. Due to multiple uncertainties, actual values and ranges are not known to the level of precision shown in this table.

² Defined as three or more consecutive days with maximum temperature exceeding 90°F.

³ NA indicates no occurrences per 100 years.

Source: Columbia University Center for Climate Systems Research. Data are from USHCN and PCMDI

consistent with global projections (Meehl et al., 2007) and with trends observed nationally (Karl and Knight, 1998; Kunkel et al., 2008).

Drought projections for this century reflect the competing influences of more total precipitation and more evaporation due to higher temperatures. By the end of this century, the number of droughts is likely to increase, as the effect of higher temperatures on evaporation is likely to outweigh the increase in precipitation, especially during the warm months. Drought projections, however, are marked by relatively large uncertainty. Drought in the Northeast has been associated with local and remote modes of multi-year ocean-atmosphere variability, including sea surface temperature anomalies in the North Atlantic (e.g., Namias, 1966; Bradbury et al., 2002) that are currently unpredictable and may change with climate change. Changes in the distribution of precipitation throughout the year and the timing of snowmelt could potentially make drought more frequent as well. The length of the snow season is very likely to decrease throughout North America (IPCC, 2007).

Coastal Floods and Storms

As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. The changes in coastal flood intensity shown here are solely due to gradual changes in sea level through time. Any increase in the frequency or intensity of storms themselves would result in even more frequent large flood events. By the end of this century, sea level rise alone may contribute to a significant increase in large coastal floods; coastal flood levels that currently occur once per decade on average may occur once every one to three years.

Due to sea level rise alone, flooding at the level currently associated with the 100-year flood may occur about four times as often by the end of the century, based on the more conservative IPCC-based sea level rise scenario. The rapid ice melt scenario, should it occur, would lead to more frequent flood events. It should be noted that the more severe, current 100-year flood event is less well characterized than the less severe, current 10-year flood, due to the limited length of the historical record.

The relative flood vulnerability between locations is likely to remain similar in the future. Thus, portions of the state that currently experience lower flood heights than those described here (for reasons including coastal bathymetry and orientation of the coastline relative to storm trajectories) are likely to experience lower flood heights in the future than these projections indicate.

Uncertainties Related to Extreme Events

Because extreme events are by definition rare, they are characterized by higher uncertainty than the annual averages described previously. The climate risks described in each sector chapter in the ClimAID assessment reflect the combination of the climate hazard probability and the related impacts. The method used with GCM projections assumes that the distribution of the extreme events described quantitatively will remain the same, while average temperature, precipitation, and sea level rise change (Table 1.9). A change in the distribution of extreme events could have a large effect on these results.

The occurrence of extreme events in a given year will continue to be characterized by high variability; in some cases, the pattern of changes will only become evident after many years, or even decades, are averaged. For example, much of New York State's record of significant drought was a multiyear event that occurred four decades ago in the 1960s; no drought since that time in the state has approached it in severity. Generally speaking, changes in variability in future climate are considered very uncertain, although there are exceptions. For example, precipitation at daily timescales is likely to increase in variability since the warming atmosphere can hold more moisture (Emori and Brown, 2005; Cubasch et al., 2001; Meehl et al., 2005).

Other Extreme Events

Some of the extreme events that have a large impact throughout the state cannot be quantitatively projected into the future at local scales due to the high degree of uncertainty. Qualitative information for some of these factors is provided, including:

- heat indices, which combine temperature and humidity,

- frozen precipitation (snow, ice, and freezing rain),
- large-scale storms (tropical storms/hurricanes and nor'easters) and associated extreme wind,
- intense precipitation of short duration (less than one day), and
- lightning.

By the end of the century, heat indices (which combine temperature and humidity) are very likely to increase, both directly due to higher temperatures and because warmer air can hold more moisture. The combination of high temperatures and high moisture content in the air can produce severe effects by restricting the human body's ability to cool itself. The National Weather Service heat index definition is based on the combination of these two climate factors.

Seasonal ice cover has decreased on the Great Lakes at a rate of 8 percent per decade over the past 35 years; models suggest this will lead to increased lake-effect snow in the next couple of decades through greater moisture availability (Burnett et al., 2003). By mid-century, lake-effect snow will generally decrease as temperatures below freezing become less frequent (Kunkel et al., 2002).

Intense mid-latitude, cold-season storms, including nor'easters, are projected to become more frequent and take a more northerly track (Kunkel et al., 2008).

Intense hurricanes and associated extreme wind events may become more frequent (Bender et al., 2010) as sea surface temperatures rise in the areas where such storms form and strengthen (Meehl et al., 2007; Emanuel, 2008). However, other critical factors in the formation and intensity of these storms are not well known, including changes in wind shear, the vertical temperature gradient in the atmosphere, and patterns of variability such as the El Niño Southern Oscillation climate pattern and large-scale ocean circulation (for example, the meridional overturning circulation). As a result, there is the possibility that intense hurricanes and their extreme winds will not become more frequent or intense. It is also unknown whether the tracks or trajectories of hurricanes and intense hurricanes will change in the future. Thus, the impacts of future changes in hurricane behavior in the New York State coastal region are difficult to assess given current understanding.

Downpours, with intense precipitation occurring over a period of minutes or hours, are likely to increase in frequency and intensity as the state's climate warms. Thunderstorm and lightning projections are currently too uncertain to support even qualitative statements.¹⁴

1.4 Conclusions and Recommendations for Future Research

Climate change is extremely likely to bring higher temperatures to New York State, with slightly larger increases in the north of the state than along the coastal plain. Heat waves are very likely to become more frequent, intense, and longer in duration. Total annual precipitation will more likely than not increase; brief, intense rainstorms are likely to increase as well. Additionally, rising sea levels are extremely likely and are very likely to lead to more frequent and damaging flooding along the coastal plain and Hudson River related to coastal storm events in the future.

Climate hazards are likely to produce a range of impacts on the rural and urban fabric of New York State in the coming decades. The risk-management adaptation strategies described in this report will be useful in reducing these impacts in the future, but are also likely to produce benefits today, since they will help to lessen impacts of climate extremes that currently cause damages. However, given the scientific uncertainties in projecting future climate change, monitoring of climate and impacts indicators is critical so that flexible adaptation pathways for the region can be achieved.

Region-specific climate projections are only a starting point for impact and adaptation assessments. For some sectors, climate changes and their impacts in regions outside New York may rival the importance of local climate changes, by influencing, for example, migration, trade, ecosystems, and human health. Furthermore, some of the hazards described here (such as drought), are often regional phenomena with policy implications (such as water-sharing) that extend beyond state boundaries. Finally, since climate vulnerability depends on many factors in addition to climate (such as poverty and health), some adaptation strategies can be initiated in the absence of region-specific climate change projections.

Given the existing uncertainties regarding the timing and magnitude of climate change, monitoring and reassessment are critical components of any climate change adaptation plan. A dense network of sustained observations with resolutions that allow more accurate projections on a decade-to-decade basis will improve understanding of regional climate, extreme events, and long-term trends. Monitoring climate indicators can also play a critical role in refining future projections and reducing uncertainties. In order to successfully monitor future climate and climate impacts, specific indicators must be identified in advance. For example, to assess the significant risk of accelerated sea level rise and climate change for the coastal regions over the coming years, polar ice sheets and global sea level should be monitored. These uncertainties of timing and magnitude point to the need for flexible adaptation strategies that optimize outcomes by repeatedly revisiting climate, impacts, and adaptation science rather than committing to static adaptations. Frequent science updates will help to reduce these uncertainties.

Future projections can also be refined with greater use of regional climate models (see Appendix C for a description of regional climate models), which can capture changes in local processes as climate changes, such as the difference in magnitude of temperature increases on land versus that of the ocean. Advanced statistical downscaling techniques (see Appendix D) that allow projections at more localized levels than those described here may be of use as well; such techniques tend to be more effective when they use predictor variables that are well simulated by global climate models and that are policy relevant.

There is also a need for improved simulation of future climate variability at year-to-year and decade-to-decade scales, a need that may be met by future generations of climate models. Even the background rates of climate variation and extremes such as the 100-year drought and coastal flood will be better understood as a wide range of approaches, such as long-term tree-ring and sediment records, are increasingly used.

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Appendix A. Uncertainty, Likelihoods, and Projection of Extreme Events

Uncertainty and Likelihoods

Climate projections are characterized by large uncertainties. At the global scale these uncertainties can be divided into two main categories:

- *Uncertainties in future greenhouse gas concentrations* and other climate drivers, which alter the global energy balance, such as aerosols and land-use changes; and
- *Uncertainties in how sensitive the climate system will be to greenhouse gas concentrations* and other climate drivers.

When planning adaptations for local and regional scales, uncertainties are further increased for two additional reasons:

- *Climate variability* (which is mostly unpredictable) can be especially large over small regions, partially masking more uniform effects of climate change; and
- *Changes in local physical processes* that operate at fine scales, such as land/sea breezes, are not captured by the global climate models used to make projections.

By providing projections that span a range of global climate models and greenhouse gas emissions scenarios, the global uncertainties may be reduced, but they cannot be fully eliminated. Averaging projections over 30-year timeslices and showing changes in climate through time, rather than absolute climate values, reduces the local- and regional-scale uncertainties, although it does not address the possibility that local processes may change with time.

The treatment of likelihood is similar to that developed and used by the IPCC. The six likelihood categories used here are as defined in the IPCC WG I Technical Summary (2007). The assignment of climate hazards to these categories is based on global climate simulations, published literature, and expert judgment.

Droughts

Droughts reflect a complex blend of climate and non-climate factors that operate at a number of timescales and are fundamentally different from other extreme events in that they are of longer duration. The drought timescale can last from a few months to multiple years. For this analysis, an intermediate timescale of 24 consecutive months was selected. In addition to precipitation, the other critical drought component is potential evaporation, which has a more complex relationship to drought. High temperatures, strong winds, clear skies, and low relative humidity all increase evaporative potential. Actual evaporation will generally be less than potential evaporation, however, since water is not always present for evaporation. For example, there will be little evaporation from dry soils, and as plants become water stressed under drought conditions, they become more effective at restricting their water loss to the atmosphere. Drought is also driven by water demand, so water-management decisions and policies can influence the frequency, intensity, and duration of droughts.

The Palmer Drought Severity Index (PDSI) uses temperature and precipitation to generate region-specific measures of drought and soil water excess. Because the calculation is strongly influenced by conditions in prior months, the PDSI is a good indicator of long-term phenomena like droughts. Potential limitations of the PDSI as used in this analysis include, but are not limited to, the exclusion of the water-demand component and the challenge of accurately capturing how potential evaporation changes with time. This analysis also does not consider water supplies stored on the ground as snow and ice.

The drought analysis conducted included two phases. First, the monthly PDSI was calculated for each observed data station from 1901 to 2000. Based on this calculation, the lowest consecutive 24 month-averaged PDSI value was defined as the 100-year drought. It should be noted that: 1) the drought record over the last 100 years can only provide a very rough estimate of the true 100-year drought; and 2) drought over a 24-month interval is only one possible definition.

In the second phase, the monthly changes in temperature and percentage changes in precipitation through time for each global climate model and

emissions scenario were applied to the observed station data. The number of times that the 100-year, 24-month drought threshold (as defined in the paragraph above) was exceeded was then recalculated. Only events that did not overlap in time were counted.

Coastal Flood and Storm-related Extreme Events

The quantitative analyses of changes in coastal flooding are based on changes in sea level only, not in storm behavior. Projections were made by superimposing future changes in average sea level onto the historical dataset. The sea level rise projections are for the decade-to-decade averages of the 2020s, 2050s, and 2080s relative to the average sea level of the 2000–2004 base period. For coastal flooding, the critical thresholds were the 10-year, 100-year and 500-year flood events.

The 10-year event was defined using historical hourly tide data from the Battery. Forty years' worth of hourly sea level data were available from a period spanning 1960 to 2006 (nearest-neighbor interpolation was used to fill in missing data points for those years with little missing data). The Battery tide gauge was used to assess the frequency and duration of extreme coastal flood events. The raw tidal data are accessible from the NOAA website (<http://tidesandcurrents.noaa.gov>).

Average sea level was used as the reference datum. For the purposes of the storm analysis, additional calculations were made. First, data were de-trended (to remove the linear sea level trend) and normalized by dividing the data by the long-term average. This procedure gives water levels that include the influence of astronomical tides. To calculate surge levels, which more directly reflect the strength of the storm itself than do water levels, the difference between the actual flood level and the predicted level (the astronomical tide) was calculated. This approach allows assessment of the frequency and duration of extreme flood events. The ClimAID assessment defines the 10-year event as the storm surge thresholds corresponding to the fourth-largest surge over the 40-year period of tide data. Once the 10-year threshold was identified, the final procedure involved adding sea level rise projections for this century to the historical storm data as modified above to assess how frequently these flood levels would occur during this century.

Inasmuch as hourly data are unavailable from tide gauges prior to 1960, different methods were applied for estimating the 100-year and 500-year floods. The 100- and 500-year storms were analyzed using flood return interval curves (stage-frequency relationships) that provide a correlation between the water elevation by coastal storms versus the likelihood of occurrence. These curves include both surge and tidal components. An increase in sea level results in a higher flood height for a storm of a given return interval. The alternative approach taken here is to calculate the decrease in the return period for a given flood height with sea level rise (e.g., what will be the change in return period for the current 100-year flood if sea level rises 2 feet by 2080?). The 500-year estimate especially must be considered highly uncertain.

The surge data for the 100-year and 500-year storm calculations are based on data provided by the U.S. Army Corps of Engineers for the Metro East Coast Regional Assessment (MEC, 2001). In that study, the Army Corps used the USACE Waterways Experiment Station (WES) Implicit Flood Model (WIFM) developed in the 1980s as the hydrodynamic storm surge model. This time-dependent model includes sub-grid barriers and allows grid cells to become flooded during a simulation. The surge data were calculated relative to the National Geodetic Vertical Datum of 1929 (NGVD29) at high tide (thus a storm-flood level), excluding the effects of waves, for combined nor'easters and hurricanes. The flood height data were converted to the North American Vertical Datum of 1988 (NAVD88) by subtracting 0.338 meters (1.11 feet) from the flood heights given by the Army Corps. The conversion factors can be obtained from the National Geodetic Survey.

As research continues to advance, it may become possible to better estimate the surges associated with the 100-year and especially the 500-year historical storms, which are currently not well known.

High-end Scenarios and Longer-term Projections

This section describes 1) the possibility that climate changes in this century may deviate beyond the ranges projected by global climate models, 2) the rapid ice melt sea level rise scenario, and 3) potential climate change beyond this century.

There are several reasons why future climate changes may not fall within the model-based range projected for the ClimAID assessment. Actual greenhouse gas emissions may not fall within the envelope encompassed by the three emissions scenarios used here (A2, A1B, B1). This could be due either to changes in greenhouse gas concentrations directly related to changes in human activities or indirectly due to changes in the Earth's carbon and methane cycles brought on by a changing climate. The simulations used here all have known deficiencies regarding carbon cycle feedbacks, and some global climate models do not include volcanic forcings, for example.

Additionally, the climate's sensitivity to increasing greenhouse gases during this century may fall outside the range of the 16 climate models used. Possible types of climate changes exceeding model-based estimates that could have large impacts on the region include shifts in the average latitudes or tracks of moisture-laden storms traversing eastern North America and/or changes in ocean circulation in the North Atlantic.

Rapid Ice Melt Sea Level Rise Scenario

The rapid ice melt scenario addresses the possibility of more rapid sea level rise than the IPCC-based approach yields. The motivation to consider sea level rise exceeding IPCC-based estimates is based on several factors, including:

- recent accelerated ice melt in Greenland and West Antarctica, which may indicate the potential for high levels of sea level rise over multiple centuries if ice melt rates continue to accelerate;¹⁵
- paleoclimatic evidence of rapid sea level rise;
- the fact that not all sea level rise components are properly simulated by global climate models, increasing uncertainty about global climate model-based sea level rise projections; and
- the potentially large implications for a coastal city of more rapid sea level rise.

While not a significant direct cause of sea level rise, recent well-documented decreases in summer and fall Arctic sea-ice area and volume are also raising concern, since the decreases point to polar climate sensitivity higher than predicted by models. This could potentially modify atmospheric and oceanic conditions over a broader region, with implications for Greenland's ice

sheet. For example, if warmer air were transported out of the Arctic to Greenland, Greenland's coastal and low-elevation glaciers might receive more moisture in the form of rain and less as snow.

Around 21,000 to 20,000 years ago, sea level began to rise from its low of about 394 feet below current levels. It approached present-day levels about 8,000 to 7,000 years ago (Peltier and Fairbanks, 2006; Fairbanks, 1989). Most of the rise was accomplished within a 12,000–10,000 year period; thus, the average rate of sea level rise over this period ranged between 0.39 and 0.47 inch per year. During shorter periods of more rapid rise, known as meltwater pulses, lasting several centuries, maximum rates of sea level rise ranged between 1.6 and 2.4 inches per year. These meltwater pulse sea level rise rates are considered too high to be matched during this century, since they occurred 1) after the ice sheets had already been undermined by thousands of years of forcing and 2) as abrupt intervals associated with singular events (e.g., ice dams breaking) at a time when total ice extent was much greater than today.

The rapid ice melt scenario assumes that glaciers and ice sheets melt at an average rate comparable to that of the last deglaciation (i.e., total ice melt increases linearly at 0.39 to 0.47 inch per year until 2100). However, the ice melt rate is more likely to be exponential. Thus, the average present-day ice melt rate of 0.04 inch per year (sum of observed mountain glacier melt [Bindoff et al., 2007] and ice sheets [Shepherd and Wingham, 2007]) during the 2000–2004 base period is assumed to increase to 0.39 to 0.47 inch per year (all ice melt) by 2100. An exponential curve is then fitted to three points: 2000, 2002 (midpoint of the 2000–2004 base period), and 2100. The other components—thermal expansion, local ocean dynamics, and subsidence—are added from the global climate model-based simulations and local information to this exponential meltwater estimates for the three timeslices. The rapid ice melt values combine the central range of the global climate model components and the range of estimates of rapid ice melt from the paleoclimate literature for multi-millennia timescales.

Longer-term Projections

Projections for the 22nd century are beyond most current infrastructure planning horizons. However,

planning for some long-lived infrastructure, which hypothetically could include, for example, new aqueducts and subway lines, would justify considering the climate during the next century. Furthermore, many pieces of infrastructure intended only to have a useful lifespan within this century may remain operational beyond their planned lifetime. It is also possible that future projects aimed specifically at climate change adaptation might benefit during their planning stages from long-term climate guidance.

Because next century's climate is characterized by very high uncertainty, only qualitative projections are possible, especially at a local scale. Despite uncertainties, the large inertia of the climate system suggests that the current directional trends in two key climate variables, sea level rise and temperature, will probably continue into the next century (Solomon et al., 2009). Given the large inertia of the ice sheets on Greenland and West Antarctica, continued evidence during the next decade of acceleration of dynamically induced melting would greatly increase the probability that these ice sheets would contribute significantly to sea level rise in the next century, even if greenhouse gas concentrations, and perhaps even global temperatures, were to stabilize at some point during this century.

Appendix B. Indicators and Monitoring

Monitoring and reassessment are critical components of any climate change adaptation plan. Adaptation plans should account for changes in climate science, impacts, technological advancements, and adaptation strategies.

In order to successfully monitor future climate and climate impacts, specific indicators to be tracked must be identified in advance. These indicators are of two types. First, climate indicators, such as extreme precipitation, can provide an early indication of whether climate changes are occurring outside the projected range.¹⁶ Given the large uncertainties in climate projections, monitoring of climate indicators can play a critical role in refining future projections and reducing uncertainties. Second, climate-related impact indicators provide a way to identify consequences of climate change as they emerge. For example, lower water quality may be a climate-related impact of extreme precipitation.

Regional climate indicators to monitor include, but are not limited to the following:¹⁷

Temperature-related

- average annual temperatures
- degree days in the hot and cold seasons
- temperature extremes
- coastal and inland water temperatures

Precipitation-related

- average annual precipitation
- extreme precipitation events
- droughts

Sea level rise and coastal flood-related

- average sea level
- high water levels
- extreme wind events

Additional larger-scale climate indicators should include:

- nor'easter frequency and intensity,
- tropical storms over the entire North Atlantic basin, as well as climatic conditions (including upper-ocean temperatures) that support tropical cyclones,
- variability patterns that influence the region, such as the North Atlantic Oscillation (large-scale ocean circulation patterns) and the El Niño Southern Oscillation climate pattern, and
- evidence of changes in the Earth's carbon cycle.

The possibility of rapid climate change in general and sea level rise in particular are two areas where the importance of monitoring and reassessment is well documented. Indicators of rapid ice melt to monitor could include, but should not be limited to:

- status of ice sheets,
- changes in sea-ice area and volume,
- global and regional sea level, and
- polar upper-ocean temperatures.

Climate variables cause certain climate-related impacts, which will also need to be monitored. These impacts include, but are not limited to:

- shoreline erosion,
- localized inland flooding,
- biological and chemical composition of waters, and
- changes in vegetation.

In addition to monitoring climate changes and their impacts, advances in scientific understanding, technology, and adaptation strategies should also be monitored. Technological advances, such as those in material science and engineering, could influence design and planning, and potentially result in cost savings. Monitoring adaptation plans in the region should be done both to determine if they are meeting their intended objectives and to discern any unforeseen consequences of the adaptation strategies. Some adaptation strategies will also have to be reassessed in the context of non-climate factors that are based on uncertain projections. For example, by monitoring trends in population, economic growth, and material costs, managers can tailor future climate change adaptation strategies to ensure they remain consistent with broader statewide objectives. Monitoring and reassessment of climate science, technology, and adaptation strategies will no doubt reveal additional indicators to track in the future.

Appendix C. Regional Climate Models

Additional downscaling methods have been employed in the ClimAID case studies including all or portions of New York State. These downscaling initiatives include both regional climate modeling and statistical downscaling (see Appendix D).

Regional climate models (RCMs) are similar to the models used for global modeling, except they run at higher spatial resolution and use different physics parameters for some processes such as convective precipitation (rain events accompanied by instability often associated with lightning, thunder, and heavy rain). Higher resolution improves the depiction of land and water surfaces as well as elevation. Because the domain is not global, information from outside the domain must be provided by a global climate model. Regional climate model simulations depend on high-quality global climate model boundary conditions; global climate model biases may thus be inherited by regional climate models. Additionally, regional climate models cannot provide feedbacks to the global climate models, so important observed local factors that impact the global scale may be missing from these experiments. Because regional climate model resolutions are generally no finer than three to four times the lateral resolution of the driving global

climate models, more complex double-nesting (essentially running a high-resolution RCM inside a lower-resolution RCM) computations may also be needed to achieve policy-relevant resolutions, which leads to further uncertainty in the regional climate models. Even at such fine scales, there are uncertainties regarding how the parameters of subgrid-scale processes (such as convective rainfall) are defined. Furthermore, even the most high-resolution regional climate model simulations generally require some corrections for bias.

Because regional climate modeling is computationally demanding, historically only a limited number of short-duration simulations have been performed, potentially limiting their value for climate change assessment. For example, in New York State, the New York City Department of Environmental Protection and Columbia University funded short-duration regional climate model simulations using both the Pennsylvania State University/National Center for Atmospheric Research mesoscale model (MM5) and the International Center for Theoretical Physics Regional Climate Model (ReGCM3) (Taylor et al., 2008). While validation of these proof-of-concept studies demonstrated that regional climate models can simulate historical average climate, the applicability of these results was limited by the fact that the experiments were limited to single-year runs. To be useful for climate change assessment, simulations over multiple decades driven by a number of climate models are needed.

An advantage of regional climate modeling relative to statistical downscaling techniques is that regional climate models do not depend on the assumption that historical relationships between predictors (the information provided by the global climate models) and predictands (the local information needed for impact analysis, e.g., daily precipitation) will continue in the future. Because regional climate models are physics-based, they do not need to rely on the assumption that relationships will remain the same, which may not be valid as the climate moves further from its present state. For example, regional climate models may be able to provide reliable information about how changes in land/sea temperature gradients may modify coastal breezes in the future.

The North American Regional Climate Change Assessment Program (NARCCAP) is an ongoing

project designed to address stakeholders' need for high-resolution climate projections. The program is a repository for multi-decade simulations, based on pairings of six regional climate models and four global climate models (**Table 1.10**). For validation purposes, all six regional climate models were also driven by a global climate model from 1980–2004 (the National Centers for Environmental Prediction/Department of Energy Atmospheric Model Intercomparison Project II (NCEP/DOE AMIP-II) Reanalysis) (**Table 1.10**). These reanalysis simulations represent the best estimate of observed conditions as simulated by a combination of observations and short-term global model simulation. Long-term climate change simulations over the northeastern United States are currently available from NARCCAP (<http://www.narccap.ucar.edu/>) for 2041 to 2070 for the A2 emissions scenario from two regional-climate-model/global-climate-model combinations, at an approximately 50-kilometer resolution. These combinations are the Canadian Centre for Climate Modeling and Analysis (CCCma) Coupled Global Climate Model (CGCM3) with the Canadian Regional Climate Model (CRCM) and the Geophysical Fluid Dynamics Laboratory (GFDL) 2.1 global climate model with the International Centre for Theoretical Physics regional climate model (RegCM3). These same two regional-climate-model/global-climate-model pairings have been hindcast for the 1970–1999 period based on coupled global climate model simulations.

Climate Model	Full Name	Modeling group
CRCM	Canadian Regional Climate Model	OURANOS / UQAM
ECPC	Experimental Climate Prediction Center Regional Spectral Model	University of California, San Diego / Scripps
HRM3	Hadley Regional Model 3 / Providing Regional Climates for Impact Studies	Hadley Centre
MM5I	MM5 – PSU/NCAR mesoscale model	Iowa State University
RCM3	Regional Climate Model version 3	University of California, Santa Cruz
WRFP	Weather Research and Forecast Model	Pacific Northwest National Lab

Driver GCM	Full Name
CCSM	Community Climate System Model
CGCM3	Third Generation Coupled Global Climate Model
GFDL	Geophysical Fluid Dynamics Laboratory GCM
HadCM3	Hadley Centre Coupled Model, version 3
NCEP	NCEP/DOE AMIP-II Reanalysis

Table 1.10 North American Regional Climate Change Assessment Program (NARCCAP) models

Regional Climate Model Validation

Because the Reanalysis product is the best estimate of the actual chronological order of the boundary conditions for the 1980–2004 period, the Reanalysis-driven simulations are used to estimate regional climate model biases and strengths. The RegCM3 and CRCM NCEP-driven simulations are compared here to the observed data for the Northeast from the University of Delaware (also available from NARCCAP/not shown here). Temperature and precipitation are evaluated for the winter and summer seasons.

The National Centers for Environmental Prediction (NCEP) Reanalysis simulation with RegCM3 has a cold bias in both winter and summer over New York State, indicating lower temperatures than the historical observations. The RegCM3 does not capture the observed pattern of increasing temperatures from west to east of the Great Lakes (Figure 1.8). This cold bias east of the Great Lakes is also present in the CRCM regional climate model in winter, but not in summer (not shown). In both winter and summer, cool biases are more prevalent than warm biases across the six regional climate models.

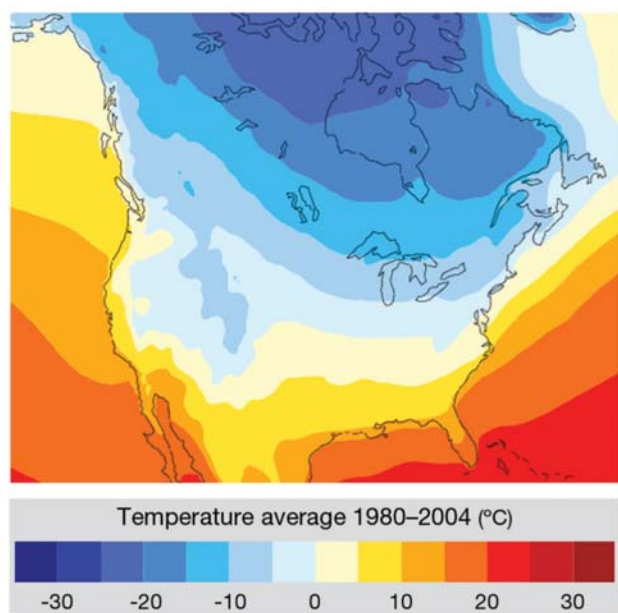
The NCEP-RegCM3 pairing captures eastern New York's tendency to receive more winter precipitation than the western part of the state. It also captures the

precipitation maximum (the state's highest precipitation area) downwind of Lakes Ontario and Erie (Figure 1.9). However, winter precipitation is overestimated by approximately 1 millimeter per day in the RegCM3 model. The summer precipitation minimum in western New York is also simulated; like the winter, summer precipitation is also overestimated by approximately 1 millimeter per day. The NCEP/CRCM pairing does not produce the overestimated precipitation bias seen with RegCM3 over New York State (not shown). Across the entire six regional climate models, winter precipitation biases span from strongly underestimating to strongly overestimating precipitation, while summer precipitation biases tend towards overestimates.

In general, the RCM results vary significantly among models. The majority of models show cool biases over the region, and there is a tendency for summer precipitation to be overestimated.

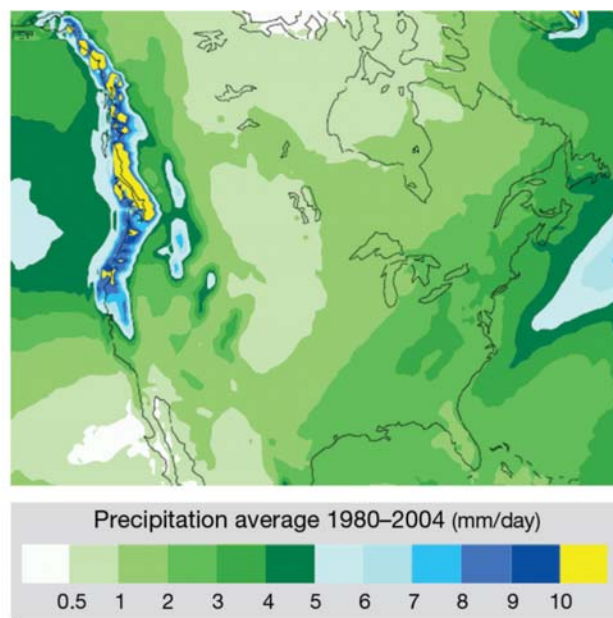
Regional Climate Model Projections

By comparing projected climate change from a global climate model only to projected changes from a regional climate model forced by the same global climate model, the effects of higher resolution can be emphasized. Discussed here are winter and summer temperature and precipitation results from the two



Source: NARCCAP

Figure 1.8 NCEP/RegCM3 winter (December, January, February) temperatures for 1980–2004



Source: NARCCAP

Figure 1.9 NCEP/RegCM3 winter (December, January, February) precipitation for 1980–2004

available global-climate-model/regional-climate-model pairings described above.

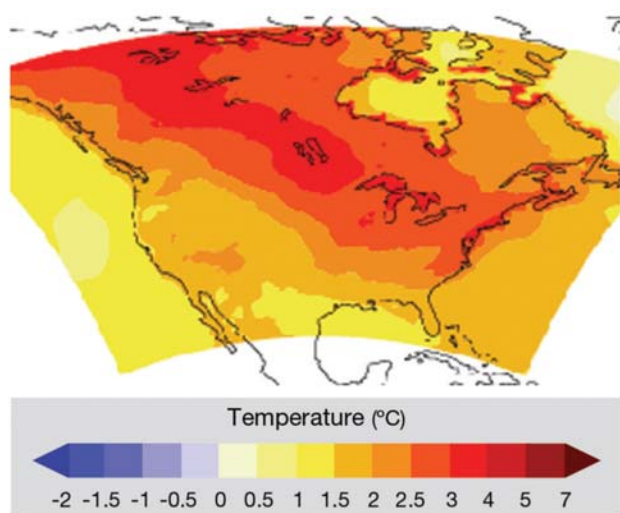
Over northeast North America, the winter spatial pattern of warming in RegCM3 driven by the GFDL global climate model is quite different than the GFDL model warming pattern alone (**Figure 1.10**). Whereas GFDL features the characteristic pattern of greater warming moving north (not shown), the GFDL-RegCM3 pairing features a local minimum east of Hudson Bay. As a consequence, while both models indicate that southeastern New York will warm by approximately 5.4°F, the GFDL/RegCM3 produces less warming to the north than the GFDL global climate model. The CRCM regional climate model driven by CGCM3 over New York State produces a warming trend of 4.5–5.4°F by the 2050s relative to the base period and is also less than the CGCM3 global climate model's results (not shown).

In summer, GFDL global climate model warming over much of the central United States is 1.8–3.6°F higher than the paired GFDL/RegCM3 regional climate model warming over the same region. Both the GFDL global climate model and the GFDL/RegCM3 regional climate model simulations produce the greatest New York warming in the western portions of the state that are farthest from the coast, with the global climate model indicating slightly higher temperatures than the regional climate model in western New York (**Figure**

1.11). By contrast, for most of the United States including New York State, the CRCM regional climate model driven by the CGCM3 global climate model produces approximately 1.8°F more warming than the CGCM3 global climate model alone (**Figure 1.12**). The CRCM regional climate model indicates that summer temperatures over the state will increase by 5.4–7.2°F.

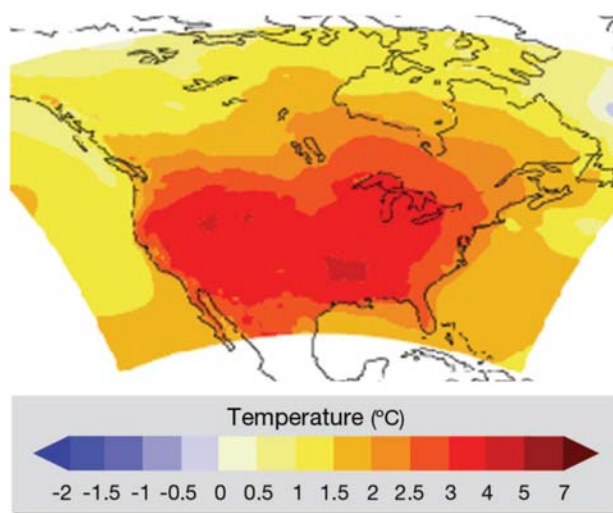
The GFDL global climate model produces large increases in winter precipitation—greater than 20 percent—in New York State, whereas the RegCM3 regional climate model driven by GFDL indicates a precipitation increase between 10 and 20 percent. Both the CGCM3 global climate model alone and the CGCM3/CRCM pairing indicate a 10–20 percent precipitation increase (not shown).

In summer the GFDL global climate model produces precipitation patterns that range from no change (0 percent) in southeastern New York to a greater than 10 percent decrease in precipitation in southwestern New York. Regional climate model precipitation changes have a fine spatial scale; precipitation increases by approximately 10 percent in much of the southern part of the state. The far west of the state shows precipitation decreases of approximately 10 percent. The CGCM3 global climate model produces slight decreases in precipitation ranging from 0 to 5 percent across the entire state (**Figure 1.13**). The CRCM regional climate model simulation driven by CGCM3



Source: NARCCAP

Figure 1.10 GFDL/RegCM3 modeled winter (December, January, February) temperature change for the A2 scenario in the 2050s



Source: NARCCAP

Figure 1.11 GFDL/RegCM3 modeled summer (June, July, August) temperature change for the A2 scenario in the 2050s

indicates even more drying throughout New York State, with precipitation decreases approaching 20 percent in New York's northern and western regions.

These two global climate model-regional climate model pairings demonstrate that a range of uncertainties persist in regional climate projections. Over New York State, the largest discrepancy is in summer precipitation.

Downscaling Extreme Events

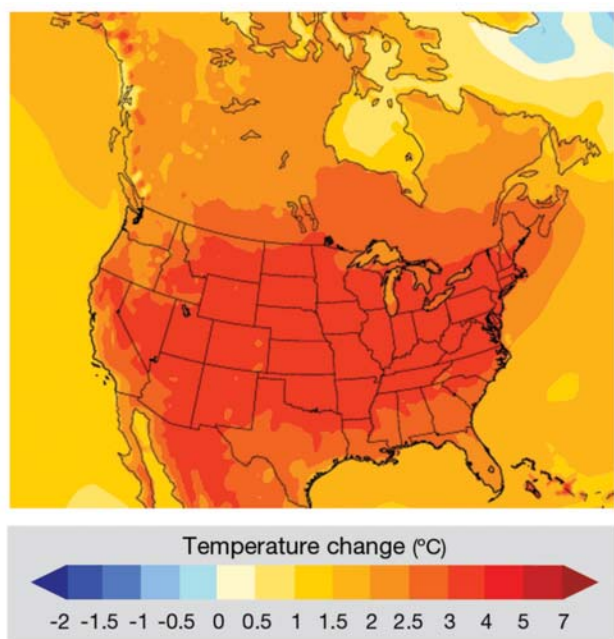
Regional climate model simulations hold promise for the simulation of changes in climate extremes, since many extreme events occur at smaller spatial scales than global climate model gridboxes.

Regional climate model simulations have also been conducted for the ecosystems sector. Specifically, Weather Research and Forecasting (WRF) regional climate model sensitivity experiments were conducted at Cornell University on the effects of changing Great Lake and atmospheric temperatures on lake-effect snow (see Chapter 6, "Ecosystems").

Future work by the climate team will evaluate 3-hour outputs from NARCCAP, to assess how the climate model projections of extremes such as intense precipitation, heat waves, and cold events described in this chapter could be augmented by regional climate model output.

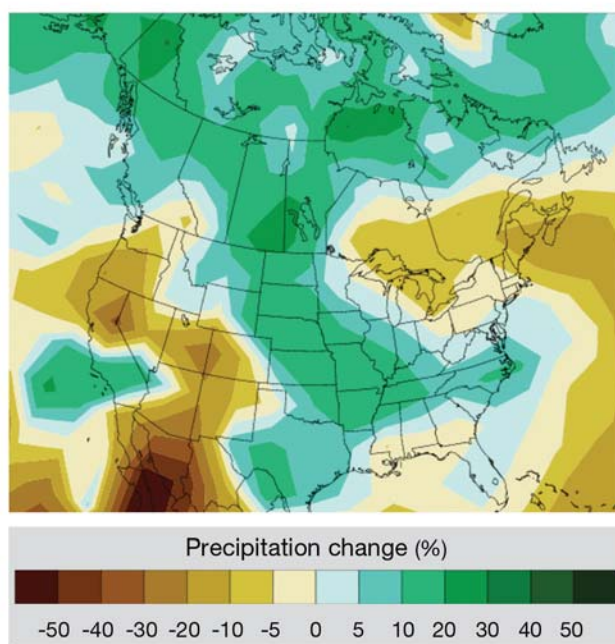
Appendix D. Statistical Downscaling in the ClimAID Assessment

An additional downscaling approach used in the ClimAID report to show potential changes in extremes to the end of the century is to utilize The Statistical DownScaling Model¹⁸ (SDSM) Version 4.2 of Wilby et al. (2002, 1999). SDSM is described as a hybrid of a stochastic weather generator and regression-based methods. Large-scale circulation patterns and atmospheric moisture variables are used to linearly condition local-scale weather generator parameters (e.g., precipitation occurrence and intensity) for the predictand series. This approach is potentially better for estimating extremes, as it attempts to bridge the gap between dynamical and statistical downscaling.



Source: NARCCAP

Figure 1.12 CGCM3/CRCM modeled summer (June, July, August) temperature change for the A2 scenario in the 2050s



Source: NARCCAP

Figure 1.13 Summer precipitation change (June, July, August), from the CGCM3 model for the A2 scenario in the 2050s

Downscaling using SDSM in the ClimAID report was completed for extreme precipitation events (see Chapter 4, “Water Resources” and Chapter 7, “Agriculture”) and winter snow cover (see Chapter 6, “Ecosystems”). In both cases, observed climate data were linked to large-scale predictor variables derived from the National Centers for Environmental Prediction (NCEP) reanalysis data set (Kalnay et al., 1996). For both projections in rainfall and snow cover, a dataset with an ensemble of 20 daily simulations was created using model output from the United Kingdom Meteorological Office Hadley Centre Climate Model version 3 (HadCM3; Pope et al., 2000).

For the precipitation events, the simulated daily data were used to construct extreme value series consisting of the annual maximum rainfall event for 30-year periods beginning in 1961. The first of these series included data from 1961–1990 and the last of these encompassed the 2071–2100 period. Additional statistical analysis was then conducted on these daily series (see Tryhorn and DeGaetano, 2011a). For snowfall, the two datasets were then combined by adding up the increases and decreases over time to give an estimate of the snow cover over the winter (Tryhorn and DeGaetano, 2011b).

¹ The range of temperature projections is the lowest and highest of values across the middle 67% of projections for all regions of New York State.

² The temperature and precipitation timeslices reflect a 30-year average centered around the given decade, i.e., the time period for the 2020s is from 2010–2039. For sea level rise, the timeslice represents a 10-year average.

³ Probability of occurrence is defined as follows: Very likely (>90% probability of occurrence), Likely (>66% probability of occurrence), and More likely than not (>50% probability of occurrence).

⁴ Preliminary analysis of those stations with lengthy records indicated that one station per region was generally sufficient to characterize each region's overall trends.

⁵ The USHCN data are a selected group of stations that come from the COOP data set.

⁶ Lower thresholds were used for the historical analysis than the projections, since warming is expected.

⁷ A degree day is defined as the difference between the daily mean temperature and 65°F. Heating degree days occur when the daily mean temperature is below 65°F, while cooling degree days occur when the daily mean temperature is above 65°F.

⁸ Changes in these additional factors are expected to have a smaller influence on climate change than increases in greenhouse gases during this century.

⁹ Due to limited availability of model outputs, sea level rise projections are based on seven GCMs.

¹⁰ The ratio approach is used for precipitation because it minimizes the impact of model biases in average baseline precipitation, which can be large for some models/months.

¹¹ Because they are rare, the drought and coastal storm projections were based on longer time periods.

¹² For sea level rise, the multidecadal approach is not necessary due to lower inter-annual variability; the 2050s timeslice for sea level (for example) therefore refers to the period from 2050–2059.

¹³ The influence of interdecadal variability cannot be eliminated with 30-year timeslices, however. While longer timeslices would reduce the influence of interdecadal variability, it would be at the expense of information about the evolution of the climate change signal through time.

¹⁴ Some research does suggest that lightning may become more frequent with warmer temperatures and more moisture in the atmosphere (Price and Rind, 1994, for example).

¹⁵ Neither the Greenland nor West Antarctic ice sheet has yet to significantly contribute to global and regional sea level rise, but because potential sea level rise is large, should current melt patterns continue to accelerate, their status should be monitored.

¹⁶ One potential pitfall of monitoring over short timescales, especially for small regions, is that it is easy to mistake natural variability for a long-term trend.

¹⁷ Many of these indicators are already tracked to some degree by agencies within New York State.

¹⁸ Available for download at <http://www.sdsm.org.uk>

Chapter 2

Vulnerability and Adaptation

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Introduction

The objective of this chapter is to introduce the issues of vulnerability and adaptation as a framework for analysis of the potential impacts and adaptation responses to climate change in New York State. Within the ClimAID assessment, vulnerability and adaptation are key integrating themes and are examined directly by each of the sectors.

New York State is increasingly faced with a changing climate that is beyond the range of past experiences (See Chapter 1, “Climate Risks”). Determining the potential consequences of climate change and possible responses is a complex task, as the effects of changes in climate will vary over space, through time, and across social groups.

This chapter outlines definitions and concepts associated with climate change vulnerability and adaptation (**Box 2.1**; Schneider et al., 2007). It also provides background on approaches to vulnerability and adaptation assessments and the different factors that contribute to both in the context of New York State. Details of the approaches used in the ClimAID assessment, as well as a description of the stakeholder engagement undertaken, are provided. Toward the end of the chapter, guidelines for evaluation and prioritization of vulnerability and adaptation actions are introduced.

It is reasonable to expect that adaptation to climate change will not always be a smooth process nor will it always be optimal or ideal. Adaptation will be ongoing, with mid-course corrections in response to the evolving context. The goal of the ClimAID assessment is to

provide information that will help the people of New York to better understand climate change in their own context and to decide on effective policies.

The objective of the ClimAID process was to define the vulnerability and adaptation potential within each of the eight sectors. Critical to the process was identifying the opportunities and challenges within each sector now and in the future. Because of the widely varying impact levels and adaptation possibilities, study of comparative vulnerability and adaptive capacity was not explicitly included in this assessment. Connections between the sectors (e.g., communication and energy, and ecosystems and agriculture) were made as part of the analytical process, but large-scale comparisons were deemed outside the scope of the study.

Vulnerability plays an essential role in determining the severity of climate change impacts. In ClimAID, *vulnerability* is defined as the degree to which systems are susceptible to, and unable to cope with, adverse impacts of climate change (Schneider et al., 2007).

A variety of approaches can help to reduce vulnerability to climate variability and extremes, including participatory planning processes, private initiatives, and specific government policies. Thus, there is an urgent need to understand the factors that affect the climate vulnerability of the state’s residents, ecosystems, and economy. It is recognized, however, that efforts to reduce current vulnerability will not be sufficient to prevent all damages associated with climate change in the long term, and that the reduction of atmospheric greenhouse gas concentrations will be necessary as well.

Box 2.1 Definitions

Vulnerability

Vulnerability to climate change is the degree to which systems are susceptible to, and unable to cope with, adverse impacts of climate change.

Adaptation

Actions that reduce the level of physical, social, or economic impact of climate change and variability, or take advantage of new opportunities emerging from climate change.

Exposure

The degree to which elements of a climate-sensitive system are in direct contact with climate variables and/or may be affected by long-term changes in climate conditions or by changes in climate variability, including the magnitude and frequency of extreme events.

Sensitivity

The degree to which a system will respond to a change in climate, either beneficially or detrimentally.

Adaptive Capacity

The ability of a system to adjust to actual or expected climate stresses or to cope with the consequences.

Connected to the concept of vulnerability is the capacity and capability of a society to adjust its functioning to better respond to actual and projected climate changes. This condition is broadly defined as climate change *adaptation*. Adaptation, in this context, includes those strategies and policies that can make both human and natural systems better able to withstand the detrimental impacts of climatic changes, and also potentially take advantage of opportunities emerging with climate change. Adaptations can take place at the individual, household, community, organization, and institutional level, and are defined broadly in ClimAID as actions of stakeholders.

2.1 Stakeholder Interactions

Addressing vulnerability requires merging expert and decision-makers' knowledge to capture the complexity of the vulnerabilities that influence priorities, preferences, opportunities, and constraints (NRC 1996, 2005). Accordingly, a key component of this assessment was early and continuous participation from stakeholders in the identified sectors. Stakeholders were defined broadly as individuals or groups that have anything of value that may be affected by climate change or by the actions taken to manage climate vulnerability. Examples include owners as well as practitioners, such as policy-makers, communities, and natural resource managers.

The assessment began with stakeholder-driven identification of climate change vulnerabilities through both past experience and visualized (anticipated or predicted) damage. ClimAID took this approach because the stakeholders themselves are in the best position to understand their own challenges, to decide their own course of action, and to take responsibility for those decisions (Lynch and Brunner, 2007). This type of ongoing stakeholder engagement avoids the pitfall of researchers assigning their own values to an assessment. The many specific values that figure in the interests of stakeholders vary greatly across each scale and are subject to change. But typically the values include community, property, other tangible and intangible cultural artifacts, and the animate (living) and inanimate (nonliving) natural environment, in addition to minimizing the costs of protecting such things. Issues of equity—winners and losers—and more specific environmental justice questions were also

critical to understanding the full character of the sector-specific vulnerabilities (see Chapter 3, "Equity and Economics").

Given this spatial and sector-specific variability, the format and scope of stakeholder interaction varied among the ClimAID sectors. Nonetheless, a general framework was followed by all sector teams that included the following:

- 1) An initial stakeholder meeting with presentations that described the ClimAID project, climate change, and likely types of impacts. At this meeting the researchers solicited input on the types of impacts and vulnerabilities likely to be faced by each stakeholder. This meeting focused on the identification of key climate vulnerabilities and associated climate variables for each sector.
- 2) Each sector developed a survey instrument and administered it either formally or semi-formally to elicit key sector vulnerabilities and potential adaptation strategies from a broader group of stakeholders across the state.
- 3) Focus groups were convened with key stakeholders for ongoing discussion and advice throughout the assessment. This entailed follow-up meetings and discussions to get feedback on the progress of the assessment and refine the analysis of sector-specific climate variables and vulnerabilities. These addressed vulnerabilities and climate variables and began a dialogue on adaptation alternatives and opportunities.
- 4) A final stakeholder meeting was conducted by each sector team to present the results of the assessment and to identify the steps required to act upon the findings.

Within individual sectors the form of this stakeholder process varied; these differences reflected the makeup of the stakeholder base for each sector. In the Energy sector, for instance, private industry comprised the majority of stakeholders, so stakeholder meetings tended to be one-on-one interviews with individual power generators. However, the Agriculture and Ecosystems sectors were a mix of government organizations, non-government organizations, citizens, and grower associations; broad workshops were followed by targeted focus-group sessions. Additional details on the sector-specific stakeholder engagements can be found in each sector chapter.

The stakeholders added vital insight about the range of risks and uncertainties they face and how they currently manage these challenges. Local experience was integrated with scientific knowledge from a variety of disciplines and used to identify key climate variables that were particularly relevant to each sector. The ClimAID Climate team then developed sector-specific “climate products” to guide scientific inquiry, such as the detailed analysis of flooding criteria in Chapter 4, “Water Resources.” This decision-focused science led the assessment of vulnerability and the development of adaptation strategies to expand the range of informed choices for stakeholders.

2.2 Vulnerability

The concept of vulnerability is useful for organizing an investigation into the impacts of climate change on the human–environment system. This perspective is particularly pertinent because it is inclusive, and human and natural systems are viewed as intimately coupled.

2.2.1 Vulnerability Concepts

Any system’s vulnerability to climate change is fundamentally determined by its exposure to shocks and stresses and its baseline sensitivity to those stresses (**Box 2.1**; Smit et al., 2001), concepts that are related to each other (see **Figure 2.1**). *Exposure* is the degree to which elements of a climate-sensitive system are in contact with climate and may be related to long-term changes in climate conditions or by changes in climate variability, including the magnitude and frequency of extreme events (Easterling et al., 2004). For example, as the population of New York State moves toward coastal areas, the state’s exposure to sea level rise and coastal storms increases. *Sensitivity* refers to the degree to which a system will respond to a change in climate, either beneficially or detrimentally. For example, corn is more sensitive to hot and dry conditions and is less able to take advantage of higher carbon dioxide levels than wheat, making it more physiologically sensitive to climate change (Easterling et al., 2004).

Furthermore, any system’s ability to cope with exposure and/or sensitivity depends on its level of *adaptive capacity*. Adaptive capacity describes the ability of a system to adjust to actual or expected climate stresses

or to cope with the consequences. Capacity, however, does not ensure positive action or any action at all. Although New York State has considerable adaptive capacity, people and property have not always been protected from adverse impacts of climate variability and extreme weather events, such as winter ice storms and extended heat waves.

Exposure and sensitivity give information about the potential impacts of climate change, while adaptive capacity is a measure of the extent to which a sector or group can respond to those impacts. The significance of climate impact depends on both the climate change itself and the characteristics of the system exposed to it (Ausubel, 1991; Rayner and Malone, 1998). The characteristics of any system—both the physical properties of its environment as well as the socioeconomic context (Smit et al., 2001; Tol and Yohe, 2007)—determine its vulnerability. These elements are place- and system-specific and are similar to those that influence a system’s adaptive capacity.

Human systems are distinguished from natural systems by their capacity to anticipate environmental changes and respond accordingly so as to best prepare for expected future conditions. The vulnerability of the people in New York State is largely determined by several key factors: behavioral norms that have been institutionalized through building codes, crop insurance, flood-management infrastructure, water systems, and a variety of other

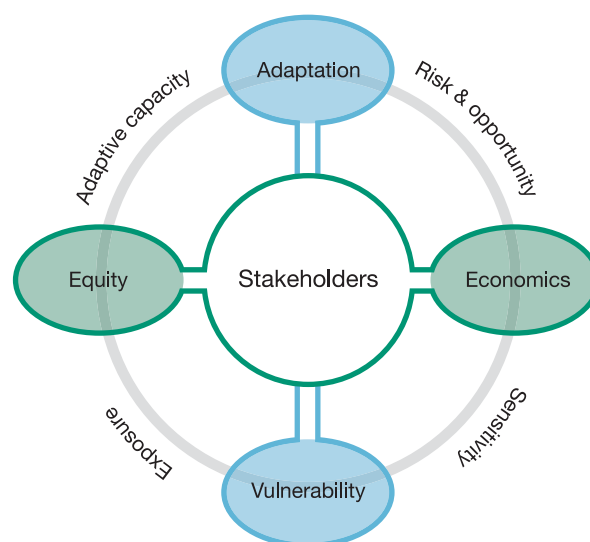


Figure 2.1 Vulnerability and adaptation

programs; socio-economic factors that affect access to technology, information, and institutions; geographic climate-sensitive health risks due to the proximity of natural resources, dependence on private wells for drinking water, and vulnerability to coastal surges or river flooding (Balbus and Malina, 2009); and biological sensitivity related to pre-existing medical conditions, such as the sensitivity of people with chronic heart conditions to heat-related illness (Balbus and Malina, 2009).

Natural systems are potentially more vulnerable to climate change than human systems because of their limited ability to adapt. Although biological systems have an inherent capacity to adapt to changes in environmental conditions, given the rapid rate of projected change, adaptive capacity is likely to be exceeded for many species (Easterling et al., 2004). Moreover, the vulnerability of ecosystems is increased by the effects of urbanization, pollution, invasion by exotic species, and fragmentation (or isolation) of habitats, all of which have already critically stressed ecosystems independent of climate change itself. An understanding of these components is essential for the formulation of effective climate policy.

2.2.2 Vulnerability Assessment Approaches

There are many different approaches to vulnerability assessment (Carter et al., 2007; Fussel, 2007; Polsky et al., 2007; Hahn, 2009). The main approaches are a risk-hazard approach (visualize future damages), a policy approach (visualize desired future), an adaptive capacity or resilience approach (assess current and future response capacity), and an integrated approach that combines aspects of these different approaches (e.g., the Center for Clean Air Policy Urban Leaders Adaptation Initiative). The risk approach is used for assessing the risk to a particular system that arises from exposure to hazards of a particular type and magnitude (e.g., Yohe, 1989; Preston et al., 2009). The policy approach is a goal- or problem-oriented approach in which analysis focuses on stakeholder-determined desired outcomes or solutions and analyzes the effectiveness of policies under climate change (e.g., Lynch et al., 2008; Tryhorn and Lynch, 2010). The adaptive capacity approach concentrates on the resources available, either actually or potentially, to cope with changes in the system (e.g., Vásquez-León et al., 2003; Brooks et al., 2005).

The ClimAID assessment uses an integrated approach that combines aspects of a risk-hazard approach and a policy approach. This approach aims to investigate vulnerability across a broad range of sectors and scales with a specific focus on the regions of New York State. Key interactions and feedbacks are represented through the use of climate scenarios (see Chapter 1, “Climate Risks”) in combination with the assessment of the effects of biophysical and socio-economic stresses on society and ecosystems. The incorporation of climate change scenarios into these types of assessments is still relatively new, and few protocols (e.g., building codes and standards, flood-protection guidelines) have yet been established by practitioners and their governing bodies (e.g., engineering associations, insurance providers).

2.2.3 Vulnerability Measures and Metrics

There is a great diversity of methods and approaches for measuring vulnerability (Adger, 2006; Polsky et al., 2009). Because vulnerability reflects both social and physical aspects of systems, it is not easy to reduce to a single metric and is not easily quantifiable.

Specific variables do not measure vulnerability directly, so many assessments attempt to quantify vulnerability by using indicators as proxies. This is because focusing on purely physical or social variables may not capture the issues that make individuals or localities vulnerable to multiple stresses. Many assessments combine indicators to create a single numeric index (e.g., vulnerability to flooding and the Livelihood Vulnerability Index) (Speakman, 2008; Hahn et al., 2009). For example, the Human Development Index uses life expectancy, health, education, and standard of living as a measure of national well-being (UNDP, 2007). If this approach is used, variable and causal linkages between indicators (e.g., between standard of living and health) must be well established to ensure that the relationship is valid. The indicators that are chosen to represent vulnerability need to be sensitive to redistribution of risk within a vulnerable population or system (Adger, 2006).

While composite indices can provide valuable insight into current patterns of physical and socioeconomic vulnerability, they can also lead to a loss of information about how the different indicators contribute to vulnerability and are unable to incorporate changes in

the larger national and global context. Patterns of vulnerability have become increasingly dynamic as the result of rapid, ongoing economic and institutional changes. The dynamic character of vulnerability means that it is particularly difficult to assess, as the factors that shape vulnerability—both the physical properties of a system and the socioeconomic context—are in a constant state of flux (Adger and Kelly, 1999; Thomas and Twyman, 2005). Under these circumstances, a flexible approach based on place-specific local variability within the broader state/federal policy guidelines and frameworks is suggested (Cutter and Finch, 2008). This requires replacing traditional indicators (e.g., share of drought-resistant crops, rainfall, per-capita staple food production, population density, infant mortality index) with dynamic indicators (e.g., change in access to credit, change in crop subsidy policies, change in national trade or investment policy stance, change in soil fertility, change in climate variability). (For more examples and explanation of the differences between traditional and dynamic indicators, see Leichenko and O'Brien, 2002.)

2.2.4 Evaluating Vulnerability in ClimAID

Throughout New York State, climate impacts and vulnerabilities vary widely by region and sector, as do the resources available to respond to climate change, necessitating regional solutions to adaptation rather than the proverbial one-size-fits-all approach. The ClimAID approach to assessment attempts to simplify the complex issues associated with climate change by dividing problems geographically and sectorally bringing into focus realities that are often discounted or overlooked in the development of the national- or state-level frameworks. Although detailed quantitative vulnerability studies were beyond the scope of this assessment, specific case studies for key vulnerabilities within each sector used a qualitative approach. A focus on key vulnerabilities is necessary to help policy-makers and stakeholders assess the level of risk, evaluate, and design pertinent response strategies.

The ClimAID assessment categorizes vulnerability through an evaluation framework and associated mapping activities (see Chapter 3, “Equity and Economics”) across eight sectors and seven regions of the state. General conclusions and recommendations regarding vulnerability and potential vulnerability-

reduction and adaptation strategies were then developed for each sector.

Within each sector chapter, vulnerabilities have been evaluated depending upon those systems or regions whose failure or alteration is likely to carry the most significant consequences. More details can be found in the sector chapters. In most instances, evaluation was qualitative, based on stakeholder input and the degree to which the relevant climate parameters were shown to change in the downscaled projections. A common set of criteria for evaluating vulnerabilities was used within each sector. The factors that were considered characterized anticipated impacts based on the “reasons of concern” developed by the IPCC Fourth Assessment Report (Schneider et al., 2007) (see **Box 2.2**).

The ClimAID assessment has not specifically identified vulnerability indices for New York State as a whole. Instead, each sector has worked individually to identify stakeholder characteristics that could potentially lead to climate vulnerability. The assessment uses different physical, socio-economic,

Box 2.2 Factors used to evaluate vulnerability in New York State

Magnitude (e.g., the area or number of people affected) and the intensity (e.g., the degree of damage caused)

Timing (is this impact expected to happen in the near term or in the distant future?)

Persistence (e.g., are previously rare events becoming more frequent?)

Reversibility (over the time scale of generations)

Likelihood (estimates of uncertainty)

Confidence in likelihood estimates

Distributional aspects within a region or among socio-economic groups

Importance of the at-risk systems—If the livelihoods of many people depend on the functioning of a system, this system may be regarded as more important than a similar system in an isolated area (e.g., a mountain snowpack system with large downstream use of the meltwater versus an equally large snowpack system with only a small population downstream using the meltwater)

Potential for adaptation (the ability of individuals, groups, societies, and nature to adapt to or ameliorate adverse impacts)

Thresholds or tipping/trigger points that could exacerbate change or initiate policy

Source: Schneider et al., 2007

and ecological indicators to measure vulnerability for different systems within the sectors. For example, the Coastal Zones sector uses coastal vulnerability index maps (Thieler and Hammer-Close, 2000; Gornitz et al., 2004) to illustrate the vulnerability of the New York State shoreline to sea level rise by considering a number of contributing geomorphological, geological, and oceanographic factors. The Water Resources sector has demonstrated that vulnerability to flooding in parts of New York State has often been related to socioeconomic factors. Similarly, the Public Health sector shows that those at higher risk for heat-related mortality are among the most vulnerable urban residents: elderly, the low-income populations, those with limited mobility and little social contact, those with pre-existing health conditions and belonging to certain racial/ethnic groups, and those lacking access to public facilities and public transportation or otherwise lacking air conditioning.

2.3 Adaptation

Adaptation to climate change focuses on actions that take place in response to a changing climate. Adaptation strategies do not directly include actions to reduce the magnitude of climate change, generally referred to as climate change mitigation, but instead present actions to lessen the impact of climate change or take advantage of changes caused by a shifting climate. In the context of the ClimAID project, two categories of adaptation strategies were examined, those that 1) reduce the level of physical, social, or economic impact of climate change and variability; or 2) take advantage of new opportunities emerging from climate change.

2.3.1 Adaptation Concepts

Adaptation strategies and actions have a direct connection to the risk and hazards management tradition. Individuals and organizations attempt to reduce their vulnerability and exposure to threats. Stakeholders and decision-makers within each ClimAID sector have developed extensive protocols to avert and manage hazards and to promote greater disaster-risk reduction. In many ways, adaptation to climate change fits into this tradition. How adaptation strategies are now being developed reflects, in turn,

both historical risk management and the emerging understanding of the magnitude and significance of ongoing climate change. In this way, climate change represents either an increased manifestation of established hazards (e.g., possibly longer and more intense droughts) and/or new hazards (e.g., emergence of a new type of pathogen moving northward with climate change).

Potential adaptation strategies can be further defined within a range of elements, including economics, timing, and institutional organization. Economic issues include the costs and benefits of adaptation and the relative distribution of both (see Economics section in Chapter 3, “Equity and Economics” and additional economic analysis in Annex III). A critical issue is the overall cost-to-benefit ratio and how much economic advantage there is to taking a specified action. There are difficulties in calculating these costs due to the issues in determining the “social rate of time discount,” that is, the rate used to compare the well-being of future generations to the well-being of those alive today. Potential opportunity costs also are important to determine, given what is understood about the rate of climate change and the sensitivities of the system in question. A primary question is whether the adaptation strategies take place in the short-term (less than 5 years), medium-term (5 to 15 years) or long-term (more than 15 years).

Crucial to the issue of timing is whether there are tipping points associated with dramatic shifts in the level of impacts and/or vulnerabilities and whether these tipping points become triggers for new policies and regulations. A tipping point can be defined as a moment in time when the operation of a system would move to a new phase as a result of changes in internal dynamics or a perceived need by associated managers. An example of a tipping point could be the occurrence of a major heat-mortality event such as occurred in Europe in 2003. Over 25,000 people, many of them elderly, died due to a heat wave that was five standard deviations away from normal (IPCC, 2007). This event triggered a massive public health adaptation response to heat waves in European countries that is in place today.

Another primary category of adaptation is the institutional organization of the entity responding to climate change. A key issue here is whether the stakeholder is administratively organized to collect and

monitor climate change conditions and to incorporate this information into decision-making analysis on a regular and ongoing basis. These conditions are necessary for the development of adaptation strategies that enable flexible responses to evolving scientific understanding and uncertainty; that is, putting in place adaptations that can be adjusted or shifted over time (i.e., years or decades) as new information and evidence indicate the need for shifts in strategies and policies to better respond to emerging climate threats and opportunities.

2.3.2 Adaptation Assessment Approaches

Adaptation to climate change includes a wide diversity of issues and considerations that are important for assessing the context and need for adaptation strategies and their potential success. Broadly speaking, two primary sets of considerations for adaptation strategies can be defined during an assessment: 1) those associated with the entity implementing, proposing, and/or planning the adaptation; and 2) those associated with the character of the adaptation strategy itself, and its (potential) impact.

Within the scholarly literature on adaptation assessment, these two sets are further refined into several elements of the adaptation development, planning, and implementation process. These elements include focus on the type of entity from which the adaptation emerges, the character of the strategy (e.g., timing, extent, impact), and adaptation financing.

Public and Private Sectors as Agents of Change

In the first category, a key element focuses on whether the adaptation emerged from the private sector or from the public sector. A related consideration is whether the stakeholder is traditionally proactive or reactive with respect to decision-making, in general, and issues of risk and vulnerability, specifically. Some ClimAID sectors—especially public health and water resources—spend extensive time and resources preparing for crises and, in turn, could be seen as having heightened capacity to plan and respond to climate change. Additional adaptation strategies can be implemented during times of crisis, because these moments open a policy window during which an opportunity for administrative reform and change can occur.

Gradual vs. Transformative Change

Some stakeholders have pre-existing trigger points for regulatory and administrative action, such as those that are embedded in heat and drought advisories and alerts. These trigger points can become the administrative structure within which adaptation to climate change can be developed. Related to this point is the question of whether climate change adaptation can be implemented simply as an extension or adjustment of existing rules, guidelines, or regulation, or if it must be implemented as a more significant transition within the stakeholder organization or operation. For example, stakeholders in all of the sectors have climate- or weather-risk policies, some of which are more developed than others. (In the Transportation sector, this could vary from New York City Transit's flood-mitigation policies to rural municipalities' road salting and plowing schedules to deal with snowfall.) Another related consideration is the possibility that the adaptation can be derived as an extension of existing codes, standards, or practices, or it can require a more significant reorganization of the entities' management structure and agenda.

Technical vs. Non-technical Adaptations

Another key element is whether the adaptation is technical in nature (e.g., engineering modification, hard option) or non-technical in nature (e.g., non-structural, soft option), such as policy and/or regulatory change. A connected issue is whether the strategy involves a simple adjustment to how the climate hazard is managed or involves a larger, system-wide change. An example could include increased efforts to provide shoreline protection from increased flood frequency (structural) as opposed to a more dramatic staged retreat from the coast (non-structural). Other elements associated with the character of the adaptation strategies include the timing of adaptation and its consequence. For example, is there a trigger point for action when the likelihood of a negative impact becomes sufficiently great such that a stakeholder response becomes necessary? Critical related questions are: How is the trigger point defined, and who determines that the trigger has been reached? Underpinning these considerations are questions of uncertainty and system complexity that result from the fact that, at the sector level, the organization and structure of a system, in

many situations, are not fully understood and the potential response to climate change remains only partially known.

Financial Elements

In regard to the character of the adaptation strategy itself, funding and expected benefit-cost ratio are two of the most important elements. The issue of liability is important as well because it directly relates the climate-hazard information to action. As information about climate change and its impacts becomes available, decision-makers are increasingly faced with the question of when and with what caveats to present this knowledge to the public. Will withholding information make them liable for potential future damages? Or will actively responding to the information result in liability issues if certain parties are more adversely affected as a result of the actions taken? For example, who will pay the costs of increased air conditioning? And who will pay for the costs associated with the loss of property use if sea level rise projections place additional property within the 100-year flood zone?

2.3.3 Assessing Adaptation in ClimAID

Within the ClimAID project, the investigators assessed adaptation strategies within New York State in a way that reflected the specific interests and information requirements of climate change stakeholders and decision-makers within the state. The assessment frame was distilled from the considerations and elements defined in Section 2.4.2 and translated into particular categories relevant to each ClimAID sector. The categorization procedure set the stage for the adaptation strategy evaluation process that followed.

To perform the adaptation assessment, ClimAID sector investigators inventoried a set of the sector stakeholders' present and planned adaptation strategies (the set does not include every possible adaptation strategy but highlights representative ones). As part of the analysis, each ClimAID sector team defined potential adaptation strategies that were identified by engaging in discussions and holding meetings with the stakeholders. The sector analyses focus both on those adaptations designed to limit exposure to increased climate risk as well as those that enhance the

stakeholder's ability to take advantage of opportunities presented by climate change, such as a switch in crop choice or shifts in water availability (e.g., water shortages may occur in other parts of the country while water supplies may increase overall in New York; see "Agriculture" and "Water Resources" chapters).

Adaptation Categories

The adaptation strategies developed through the stakeholder process were first divided into categories: type, administrative group, level of effort, timing, and scale (**Box 2.3**). "Type" includes whether the strategies were focused on management and operations, infrastructural change, or policy adjustments. "Administrative Group" defines the strategies as either emerging from the public or private sectors and the level of government (e.g., local/municipal, county, state, national) to which they pertain. "Level of Effort" indicates whether the strategy represents an incremental action or a larger-scale paradigm shift. "Timing" highlights the period during which the adaptation strategy will be implemented—short-term (less than 5 years), medium-term (5 to 15 years), or long-term (more than 15 years)—as well as the speed of implementation and the presence of established or known tipping points and policy triggers. "Scale"

Box 2.3 Categories of adaptation strategies

Type

- Behavior
- Management/operations
- Infrastructural/physical component
- Risk-sharing
- Policy (including institutional and legal)

Administrative Group

- Public or private
- Local/municipal, county, state, national government

Level of Effort

- Incremental action
- Paradigm shift

Timing

- a) Period
 - Short-term (less than five years)
 - Medium-term (five to 15 years)
 - Long-term (more than 15 years)
- b) Abrupt Changes
 - Tipping points
 - Policy triggers

Scale

- Widespread
- Clustered
- Isolated/unique

includes the overall spatiality of the adaptation impacts, specifically cataloging if the adaptation strategy impact is widespread, clustered, or isolated/unique (e.g., impact associated with a specific site or location) throughout the state.

Adaptation Strategy Evaluation

Once adaptation strategies have been categorized, evaluating them is a critical yet complex task. Strategy evaluation can help stakeholders to determine an order to implement strategies and aid in developing a broader agency- or organization-wide adaptation plan. Criteria that can be used to help evaluate strategies include cost, feasibility, efficacy, timing, resiliency, impacts on environmental justice communities, robustness, and co-benefits/unintended consequences (Major and O'Grady, 2010). These are briefly described below:

- **Cost**—What will be the economic impact of the strategies, including an estimate of short-, medium-, and long-term benefits and costs?
- **Feasibility**—How feasible is the strategy for implementation both within an organization and from perspectives such as engineering, policy, legal, and insurance? Are there expected technological changes that would impact future feasibility?
- **Efficacy**—To what extent will the strategy, if successfully implemented, reduce the risk?
- **Timing**—When is the strategy to be implemented? What factors affect the implementation schedule?
- **Resiliency**—To what extent is the strategy, when implemented, able to withstand shocks or stresses—either physical or social (e.g., policy) in character?
- **Impacts on environmental justice communities**—Will strategy impacts be negative or positive for communities already stressed by environmental risk exposures?
- **Robustness**—Is there the potential to install equipment or upgrade infrastructure that is designed to withstand a range of climate hazards? Are there opportunities for flexible adaptation pathways, i.e., incremental management adjustments associated with the pre-determined objective of updating adaptation based on emerging science and management needs?
- **Co-benefits/unintended consequences**—Will any strategies have positive or negative impacts on another stakeholder or sector? Is there potential for

cost sharing? Are there impacts on mitigation of greenhouse gases? Are there impacts on the environment or a vulnerable population?

Through meetings and discussions, sector leaders and stakeholders evaluated adaptation strategies via the criteria defined above. However, the quantification of benefits and costs was often confounded, particularly when sectors were represented by multiple stakeholders with diverse interests and values. This was particularly true in the Ecosystems sector, where the values of factors such as diversity of species and the preservation of natural areas are extremely difficult, if not impossible, to quantify. In many cases, net benefits to one group may be viewed as losses by a different stakeholder group; for example, warmer winters may benefit homeowners due to reduced heating costs and, at the same time, cause losses for the winter recreation industry. Finding the common interest under these circumstances is a complex task. Other topics to emphasize are the spatial and temporal character of the adaptation strategies and how easily modified they may be in response to a changing climate through time, i.e., do they contribute to the development of flexible adaptation pathways.

2.4 Outcomes

A major aim of the ClimAID assessment is to help New York State manage, rather than eliminate, uncertainties related to a changing climate. Drawing

Box 2.4 ClimAID vulnerability and adaptation assessment approach with links to the five integrating themes

- 1) Identify current and future climate hazards C
- 2) Conduct risk assessment inventory.....C, V, EEJ, E
- 3) Characterize risk of climate change.....C, V, EEJ, E
- 4) Develop initial adaptation strategies A
- 5) Identify opportunities for coordination.....A
- 6) Link strategies to capital and rehabilitation cycles.....A, E
- 7) Prepare and implement adaptation plans C, V, A, EEJ, E
- 8) Monitor and reassess vulnerability and adaptation ...C, V, A, EEJ,

C = Climate (Chapter 1);
V = Vulnerability (Chapter 2);
A = Adaptation (Chapter 2);
EEJ = Equity and Environmental Justice (Chapter 3);
E = Economics (Chapter 3)

on the work done as part of other state- and local-level adaptation assessments, especially the New York City Panel on Climate Change (Rosenzweig and Solecki, 2001; Rosenzweig et al., 2007; Rosenzweig et al. 2007b; NYCDEP, 2008; Major and O'Grady, 2010; NPCC, 2010), the ClimAID assessment developed an approach (see Annex II) that together can help stakeholders to evaluate adaptation strategies and to develop adaptation plans through a series of steps (**Box 2.4**). This basic approach is broadly applicable to each of the sectors. The framework allows knowledge about climate, vulnerability, adaptation, equity and environmental justice, and economics to be closely integrated with the needs of stakeholder decision-making as climate adaptation policy is developed by the State.

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Equity and Economics

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Introduction

The ClimAID assessment evaluates a number of critical issues that transcend all of the sectors. These integrating themes include vulnerability, adaptation, equity, and economics. Each merits special attention because they are vital to the development of meaningful and effective policy and regulatory responses to climate change. This chapter focuses on two of these themes, namely equity and economics, and describes how they are used within the assessment. The chapter also presents some of the key overarching findings of these two themes.

The equity theme, which emphasizes both equity and environmental justice, focuses on distributional and procedural inequalities that may be associated with climate change vulnerability and adaptation. Within New York State, vulnerabilities to the impacts of climate change and the capacity to adapt to these changes are highly uneven across urban and rural regions, sectors, and demographic groups. Heat waves, for example, typically have a disproportionately negative effect on low-income, elderly populations living in urban areas. These populations may have limited ability to afford air conditioning and may be unable or reluctant to seek relief from the heat outside due to lack of mobility or fear of crime. The equity and environmental justice element provides a means to identify inequalities associated with both climate impacts and adaptation strategies and also helps to ensure that underprivileged or underrepresented constituencies have a voice in climate policy at the local and state levels.

The economics theme, which concentrates on cost-benefit analysis of selected climate change impacts and adaptation options, presents critical information about the potential financial expenditures associated with different adaptation strategies. The economics theme explores the costs and benefits of adaptation strategies via case studies from each sector. Concerning heat waves in New York City, for example, some types of adaptation strategies, such as provision of subsidization of air conditioning for low-income urban residents across the state, will entail new financial outlays. Such outlays may be offset by health-related cost savings due to the reductions in heat-related morbidity (illness) and mortality (death). The economic costs of climate change in New York State are described in more detail in a related study titled “An Economic Analysis of Climate Change Impacts and Adaptations in New York

State.” This study, which is presented in full in Annex III, assesses of the costs associated with the impacts of climate change and evaluates the costs and benefits of various adaptation options for each of the ClimAID sectors.

Although both of the themes employ distinct methods and perspectives, both entail a common set of tasks, including:

- 1) *Development of general assessment statements for each sector.* These statements, which are grounded in the existing social science and policy literatures, describe the general characteristics of each sector and highlight key equity and economic issues within them.
- 2) *Execution of case studies.* In concert with the sector teams, analyses of equity and economic implications for a select set of in-depth case studies were also conducted.
- 3) *Development of synthesis statements.* Drawing from the general assessments and case studies, these statements identify vital policy issues that are common across the sectors.

Taken together, the themes present multi-faceted evaluations of the equity challenges and economic costs of impacts and adaptations presented by each sector. The themes not only permit analyses of distinct aspects of the vulnerabilities, climate risks, and adaptation options of each sector, but also help integrate the assessment by contributing to a common framework of analysis.

3.1 Equity and Environmental Justice

In recent years environmental change issues have been increasingly framed in relation to equity, drawing on some of the debates originating in the environmental justice movement (Cutter, 1985; Cutter and Solecki, 1986). Among equity-based analyses of climate change, the focus is typically on issues including responsibility for the mitigation of greenhouse gas emissions, vulnerability and capacity to adapt to climate change, and inter-generational equity (Müller, 2002; Kemfert and Tol, 2002; Tonn, 2003; Brown, 2003; Gardiner, 2004; Adger et al., 2006; Farber, 2007; Roberts and Parks, 2007; Beckman and Page, 2008; Paavola, 2008). A growing awareness of the equity issues surrounding

climate change is not surprising, given widespread recognition that the effects are likely to be highly uneven. Some individuals, households, farmers, or communities will experience significant negative effects, such as the loss of life and property due to climate extremes, loss of agricultural productivity, increased water stress, and so on. Others may experience only minor negative effects, and still others may experience net benefits, such as lower winter heating costs due to warmer temperatures, a longer agricultural growing season, increased forest productivity, or an expansion of tourism due to land-use changes (O'Brien and Leichenko, 2006 and 2010). Within New York State, climate change impacts are likely to be highly uneven across regions, sectors, and households, and already-disadvantaged populations may be particularly vulnerable to climate change. These issues are incorporated into the ClimAID assessment via an emphasis on equity and environmental justice.

3.1.1 Concepts and Definitions

Differences in climate change vulnerability are partly the result of differences in physical exposure to climate extremes or shifts in temperature and precipitation patterns across regions. They also emerge as the result of differences in ability to respond and adapt (IPCC, 2007). Vulnerability to extreme heat, for example, is influenced by differences in age, income, and health status. The ability to withstand business interruption as the result of a lengthy power outage following a storm is affected by differences in capital resources and the availability of climate-risk insurance among different firms and industries. Adaptation to sea level rise among coastal cities is affected by differences in financial resources for relocation or hardening (i.e., the construction of structures such as seawalls, bulkheads, storm surge barriers, and dikes) of vulnerable transportation infrastructure (Leichenko et al., 2010).

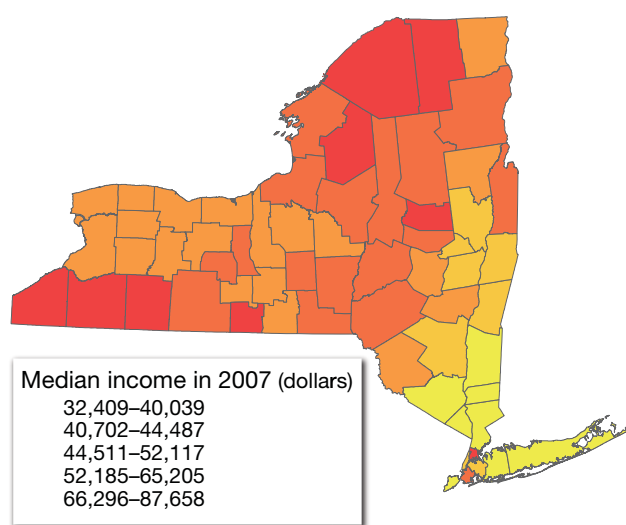
Although environmental justice efforts have historically focused on the inequitable distribution or concentration of environmental burdens such as brownfields and/or industrial facilities, these efforts have broadened in recent years to include consideration of equity and justice issues surrounding global pollution issues, particularly climate change (Ikeme, 2003; Agyeman et al., 2003). Connecting environmental justice with climate change raises questions such as whether adaptation policies have disproportionate impacts on

low-income communities, whether such communities will have to bear a disproportionate share of adaptation costs, and whether low-income communities will be subject to a disproportionate share of the negative impacts of climate change.

Mapping Spatial Inequalities in New York State

Inequalities surrounding climate change often play out in terms of differences in the ability to engage in adaptation planning. Over the past several years, a number of large U.S. states and major cities have developed plans for climate change adaptation (Thomas, 2009). Yet, even within a relatively wealthy country such as the United States, there are dramatic differences in household income between urban and rural portions of the country, where median household incomes in typical urban counties may be double, triple, or even quadruple those of rural places. Some of the poorest counties in the United States are located in rural areas of states such as Mississippi, Alabama, and West Virginia and in areas that are home to Native American Indian reservations (U.S. Census, 2009).

Within the state of New York, the median household income in 2007 was \$52,944. However, the variation across counties is noteworthy, with higher-income counties concentrated in the southeastern portion of the state and lower-income counties concentrated in the northern and western parts of the state (**Figure 3.1**).

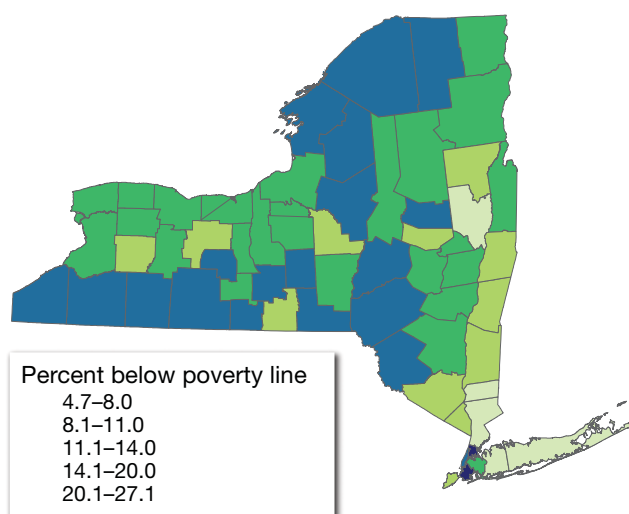


Source: American Community Survey (2007), U.S. Census

Figure 3.1 New York State income disparities reveal spatial differences in a region's ability to adapt to climate change

Although income levels are generally higher in the New York City metropolitan area, this is also the region of the state with the greatest income disparities. County incomes in the New York metropolitan area range from Nassau County with a median household income of more than \$87,000—among the richest in the United States—to Bronx County with a median income of just over than \$32,000 (U.S. Census, 2009). Such differences in income are indicative of differences in relative wealth within regions of New York State, which influences factors such as property values and local tax revenue and may translate into differences in the adaptive capacity of particular locations. In sector chapters, the equity and environmental justice analysis considers differences in vulnerabilities and adaptive capacities at finer levels of spatial resolution, including census block groups and tax parcels.

The success of adaptation strategies frequently hinges on the ability to change behavior, to access new capital inputs, and to manage new technology and knowledge. The interrelated problems of persistent poverty and low rates of educational attainment critically limit the intellectual and financial resource base that a household can draw on to adapt successfully. Furthermore, at a collective level, these problems can segregate communities and regions from access to social networks and cultural assets (i.e., social capital) that could expand their adaptation efforts through innovation and partnerships with outside industries and government.

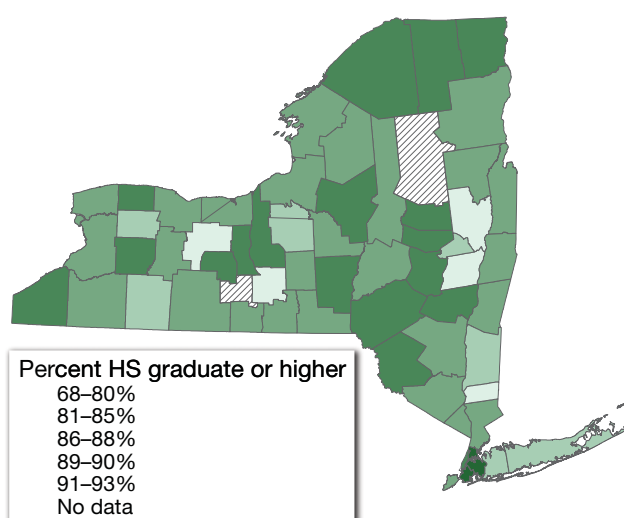


Source: U.S. Census, Small Area Income & Poverty Estimates, State and County Estimates for 2007

Figure 3.2 Poverty rates by county as an indicator of a region's ability to adapt to climate change

In New York State, regional inequalities in wealth, education, and poverty tend to overlap (**Figures 3.2 and 3.3**). Estimates of county poverty levels are based on household poverty thresholds, as defined by the U.S. Census. In 2007, the poverty threshold for a family of four with two dependent children was \$21,027 (U.S. Census, 2010). The highest rates of poverty and lowest rates of education are concentrated in urban counties such as the Bronx and Brooklyn. These extremes are all the more notable given that residents of neighboring counties, such as Nassau and Westchester, enjoy some of the highest average rates of educational attainment and lowest poverty in the state. Poverty also is endemic in rural counties in other regions, such as those north of the Adirondacks and in the Southern Tier.

Vulnerability and adaptation are also related to spatial differences in economic structure. Although New York State's economy is highly diversified, there are important differences in natural-resource dependency. In particular, the socioeconomic base of a number of rural counties is tied to employment in climate-sensitive industries (**Figure 3.4**). For example, in both Lewis County and Yates County, more than 10 percent of employment is based in agriculture and natural resources. The density of these jobs in the local economies underscores how certain regions may face disproportionate need for adaptation planning, raising critical questions about who is responsible for adaptation and how to equitably distribute adaptation-related resources.

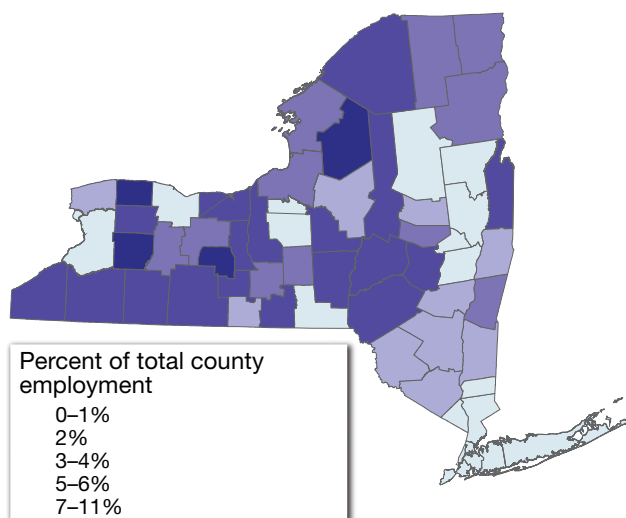


Source: U.S. Census American Community Survey, 2007

Figure 3.3 Educational attainment as a potential indicator of a region's ability to adapt to climate change

Defining Equity and Environmental Justice within ClimAID

The maps below draw attention to spatial differences across New York State in the ability of communities to adapt to climate change. These differences, which are likely to influence climate change vulnerability and adaptation, emphasize issues of distributional equity. Within the climate change literature, distributional equity may be defined as the fair distribution of outcomes or impacts associated with climate change (Kasperson and Dow, 1991). However, an emphasis on environmental justice requires attention to and recognition of both distributional and procedural equity. Within the broader literature on environmental justice, distributional equity emphasizes securing benefits and amenities such as access to parks and greenspace to offset environmental burdens that specific communities face. Procedural or process equity entails an equitable approach to environmental decision-making (Lake, 1996). In the context of climate change, procedural equity may be defined as inclusion of representatives of all affected communities and groups in decisions about climate change adaptation, including emergency preparedness and emergency response. Efforts to achieve procedural equity include mechanisms to ensure participation of affected actors in policy decisions (O'Brien and Leichenko, 2010).



Source: U.S. Department of Commerce, Bureau of Economic Analysis: REIS Table CA25N

Figure 3.4 Employment in agriculture and forestry, fishing, and other related activities as a percentage of total county employment

In defining the equity and environmental justice element within the ClimAID assessment, the study draws insights from both distributional and procedural approaches used within the environmental justice and climate change literatures. In terms of distribution, there is an emphasis on identification of situations where particular groups may be systematically disadvantaged either in terms of differences in vulnerability or capacity to adapt to climate change or in terms of the impacts of policies surrounding adaptation. While the equity and environmental justice analysis for some sectors emphasizes commonly recognized groups within the environmental justice literature (including lower-income, minority, and Native American populations), there is also consideration of equity effects across other units of analysis, such as rural regions versus urban areas, small versus large firms, or small versus large cities, as appropriate for the type of analysis conducted for each of the sectors.

For all of the sectors, the analysis of distributional equity issues includes consideration of:

- Inequalities in vulnerability to climate change;
- Inequalities in the capacity to adapt to climate change;
- Inequalities in adaptation policy benefits; and
- Inequalities in the effects of the adaptation policies.

In terms of procedural equity elements, key considerations include the incorporation of equity issues in adaptation discussions and policies, the mechanisms for broad and meaningful participation in future adaptation planning and policy efforts, and the incorporation of input from the equity and environmental justice stakeholders in the ClimAID assessment.

These distributional and procedural definitions of equity and environmental justice are used in various components of the assessment. The broader aims include consideration of potential inequalities associated with climate change along traditional lines that have been identified within the environmental justice literature (e.g., underprivileged, minority groups), as well as along new lines that may emerge under an altered climatic regime (e.g., different-sized firms) or may result from the implementation of adaptation policies and plans.

3.1.2 Approach for Equity and Environmental Justice Assessment

The equity and environmental justice component of ClimAID involves three types of parallel efforts: 1) development of equity and environmental justice assessments for each sector, based on review of background literature in these areas; 2) development of integrated case studies; and 3) attention to input from environmental justice groups or representatives in the sector meetings with stakeholders. Descriptions of each of these elements are presented below.

General Assessment for Each Sector

The first task for the equity and environmental justice element entails the creation of assessments for each sector that identify the key, relevant equity and environmental justice issues based on review of past studies. (Elements of these sector-specific assessments, including references to the studies reviewed, are presented in the sector chapters.) Each of the sector assessments addresses the same general questions. The questions, which emphasize equity and environmental justice issues surrounding both vulnerability and adaptation within each sector, are as follows:

- 1) Are there preexisting socioeconomic or spatial inequalities that make certain regions, communities, or groups of individuals systematically more vulnerable to the impacts of climate change on the sector? What groups or areas are likely to shoulder a disproportionate share of the burden from these impacts? Potential differentiations by group include socioeconomic status, education, health/disability, race, age, gender, culture, or citizenship. Community differentiations include the extent of segregation, access to health care, unemployment, and poverty/wealth/assets.
- 2) Are there groups, communities, or regions that are less able to adapt to the impacts of climate change and, therefore, merit special attention during adaptation planning?
- 3) Within the range of adaptation strategies in each sector, which strategies are more likely than others to exacerbate underlying socioeconomic disparities? Could some strategies change social and environmental dynamics so as to create emergent or unintended disparities? Are there situations in which strengthening adaptive

capacity in one area or for one group may, in turn, create, reinforce, or exacerbate maladaptation or vulnerability (either in an absolute or relative sense) in other groups or areas?

Each of the above questions was considered in a broad review of prior work on environmental justice and climate change. The questions also guided work on the integrated case studies, as discussed below. The sectoral assessments also touched on two additional questions related to the equity and environmental justice consequences of adaptation planning:

- 1) Are there certain groups, communities, or regions that may be systematically underrepresented during adaptation planning, unable to access or influence the process and procedures of decision-making, or otherwise disempowered, unable, or disinclined to consider adaptation when it is likely to be in their interest to do so?
- 2) When designing adaptation strategies, are there ways to insert mechanisms that encourage or ensure fair outcomes, whether preventive (e.g., avoiding and adjudicating disputes), corrective and compensatory (e.g., payments to an affected party to compensate for loss of access to a resource), or retributive (e.g., sanctions and penalties)?

Although a full assessment of these latter two questions was beyond the scope of the present study, raising these questions nonetheless represents an important starting point for incorporation of equity and environmental justice issues into future adaptation planning and policies in New York State.

Role in Integrated Case Studies

The equity and environmental justice component also entails participation in integrated case studies for each sector. (These case studies are presented in full in each of the sector chapters.) In some instances, these case studies explore impacts of past climate extremes, such as a past flood event or heat wave. Such cases serve as historical analogues, whereby the research teams may consider the equity and environmental justice consequences of a past climate event in order to extract lessons on how to reduce distributional inequalities in planning for future climate change. Other case studies project future climate change impacts on various sectors and industries and explore potential future equity issues

that may arise under various scenarios. Generally speaking, the historical and scenario-based case studies are also intended to provide guidance on what to plan for in order to ensure that disadvantages do not fall disproportionately on specific groups or individuals, or to develop appropriate compensation mechanisms.

The equity and environmental justice contribution to each of the case studies entails a combination of descriptive and mapping analyses of existing data to explore potential inequalities in vulnerability or adaptive capacity, and also includes a qualitative evaluation of suggested future adaptation plans to identify potential equity and environmental justice issues.

The descriptive analysis explores such questions as: Are there systematic inequalities in spatial patterns of vulnerability based on income and demographic characteristics of the affected populations? Are there other types of systematic inequalities associated with vulnerability or adaptive capacity among firms within the sector or communities that depend upon the sector?

The qualitative analysis emphasizes future adaptation plans and considers the potential equity impacts of various adaptation options and policies. Questions include: Are the negative effects or costs of adaptation policies likely to be felt or borne by particular spatial areas, communities, or groups? What options are available to mitigate or compensate for these effects?

Although a full assessment of past environmental justice activities and activism for each case study topic was beyond the scope of the present study, in-depth examination of lessons from past experiences with responding to environmental issues represents an important area for further research. It is likely that past experiences with addressing local environmental concerns will offer lessons for efforts to adapt to climate change, particularly in those regions of the state that have a strong and vibrant history of community activism around environmental topics.

Stakeholder Participation

The third component of the equity and environmental justice theme entails putting procedural elements of equity and environmental justice into place as part of the execution of the ClimAID assessment. More specifically, the goal of this component is to encourage

broad stakeholder participation, particularly from members of environmental justice groups throughout the state and from other groups that may be disadvantaged as a result of climate change or negatively affected by adaptation policies. To accomplish this goal, sector leaders were asked to include, where possible, environmental justice representatives in their stakeholder meetings. Results of the stakeholder discussions are incorporated into the sector chapters.

3.1.3 Key Findings of Equity and Environmental Justice Assessment

This section highlights some key equity and environmental justice findings from each of the sector assessments and case studies and identifies a number of common themes that cut across all sectors. As noted above, the full equity and environmental justice assessment for each sector and the case study analyses are presented in each of the eight sector chapters.

Water Resources

Communities using larger water systems in New York State are generally less vulnerable to drought and other types of water supply disruption than the 1.9 million people who rely on domestic well water and several hundred thousand others connected to small public water systems. Because larger systems have greater storage capacity, they are more able to withstand drought-related shortages. Increased flood risks as the result of more frequent and severe storm events are a concern in many areas of the state, and there are also disparities between small and large communities in their capacity to respond to flood events. Among different population groups, the elderly and disabled tend to be more vulnerable to immediate flood hazards due to limited mobility, while renters may be more subject to long-term displacement following a flood event. Adaptation efforts need to take into account differences in community and population flood vulnerabilities.

Within the state's urban areas, two other critical water-related equity concerns include siting and operation of waste treatment facilities and the widespread use of combined sewer systems. Wastewater treatment facilities are often located in lower-income, minority communities. Under climate change, such facilities may

need to be relocated due to rising sea levels or expanded to address new threats to water quality. Combined sewer systems, which collect and treat both municipal wastewater and stormwater, are disproportionately concentrated in the state's older, urban areas (and particularly in neighborhoods with high concentrations of low-income, minority residents). Combined sewer systems contribute to localized flooding and serious water quality problems during periods of heavy rainfall. These flooding events, known as combined sewer overflows (CSOs), are likely to become worse with more frequent heavy rainfall events under climate change. Adaptation planning needs to take into account the concerns of environmental justice communities that are affected by siting decisions and/or CSOs.

Coastal Zones

Coastal zone populations in New York State are increasing and becoming more dense relative to other regions in the state (see discussion of coastal zones in the economics section below). Coastal populations living within floodplains in New York City and Long Island tend to be more affluent than populations living outside the floodplains. These differences are largely due to amenity appeal, which makes property near the water more desirable. However, there are pockets of poverty across the New York State coastal zone, and many of these areas are home to concentrations of minority populations. These areas are also often the sites where infrastructure facilities such as wastewater treatment plants and solid waste management facilities are located. Within the coastal zone, elderly and disabled residents and households without cars are particularly vulnerable to flood hazards. Adaptation strategies, such as relocation of critical infrastructure away from coastal areas, need to take into account the needs of disadvantaged environmental justice populations.

Ecosystems

Outdoor recreation regions and communities dependent on natural resources may be negatively affected by higher temperatures and reduced snowfall or snowpack as the result of climate change. Communities in the Adirondacks region that depend on tourism associated with cold-water fisheries (e.g., trout) or wintertime snow-based activities (e.g., skiing and snowmobiling) may be particularly vulnerable. The difficulty in putting

economic values on ecosystem goods and services may make some issues of concern for ecosystems more challenging to develop as policy priorities as compared to climate change impacts in other sectors. One area of policy priority for low-income communities living in flood-prone regions throughout the state is re-evaluation of local land use and development policies in order to prevent the destruction of natural buffers such as wetlands and dunes. These natural buffers help prevent flooding and offer protection to these communities from future flood hazards associated with climate change.

Agriculture

Differences in farm characteristics, including farm size, productivity, and production costs, are likely to play a significant role in determining which farmers and which regions are most vulnerable to the negative effects associated with climate change. Smaller farms are particularly vulnerable to climate change, because they typically have less capital to invest in on-farm adaptation strategies (such as stress-tolerant plant varieties or increased chemical and water inputs) and less ability to take advantage of cost-related scale economies associated with such measures. While climate change is also likely to create new opportunities for farmers that have enough capital to take risks on new crops or new production technologies, many of the state's farmers may lack the resources or information needed to make strategic adaptations (such as increased irrigation or cooling capacity on dairy farms) that will be required to remain profitable.

For low-income communities throughout the state, the connection between climate change and issues of food justice is an area of growing concern. Food justice issues, such as lack of access to grocery stores in lower-income urban and rural communities, and inability of lower-income individuals to afford healthy, fresh foods, may be exacerbated if adaptation to climate change leads to substantial increases in food prices. Increased incidence of extreme heat or prolonged droughts may also undermine community gardens and other local food production systems that serve lower-income areas.

Energy

Climate change is likely to increase summer energy demand for air conditioning throughout the state. For

lower-income residents, increased energy costs associated with air conditioning may be difficult to afford. Residents living in urbanized areas that are already subject to urban heat island effects may bear a disproportionate burden with respect to energy costs. Potential synergies exist between adaptation and equity strategies for developing smart grids and solar power as well as for combining retrofitting with local green jobs programs. The siting of new energy facilities, including those producing alternative energy, such as wind farms, may raise new environmental justice concerns.

Transportation

Transport-disadvantaged populations, including the elderly, the disabled, and those without a car, are vulnerable to climate-change-related disruptions in public transportation systems. Within urban areas of the state, lower-income individuals without cars who depend on public transportation to get to work may be especially at risk. Making roads and transportation infrastructure climate-resilient (e.g., by relocating roads or public transport lines and financing such improvements via higher tolls or fares) has the potential to reinforce existing inequalities in access or to create new patterns of inequalities.

Telecommunications

The availability of communication services in New York State is largely a function of the uneven density of the state's population. Cell phone coverage and broadband service tend to be more complete and comprehensive in urban areas than in rural areas. Restoration of communication services following a storm event (e.g., an ice storm) typically happens first in urban areas and then in rural areas, with smaller, remote communities likely to be restored last. Within remote rural areas, elderly, disabled, and health-compromised populations are especially vulnerable to communication service disruptions associated with storm events.

Public Health

Increasing temperatures and increasing frequency of heat waves raise a number of equity-related issues in the health sector. Those at higher risk for heat-related mortality (death) and morbidity (illness) include

elderly and infirm populations, children, low-income residents of urban areas, certain racial groups, and communities in the northern parts of New York State that are not yet well adapted to heat (e.g., rates of air conditioning are 30 percent higher in New York City than in Buffalo) (U.S. Census Bureau, 2004 and 2003). Diseases such as asthma are also highly climate-sensitive. The threshold of asthma severity differs by socioeconomic status, in large part due to differences in health-care access. Lower-income residents and racial minorities living in urban areas tend to have a higher incidence of asthma and may be adversely affected by higher temperature regimes.

Cross Cutting Equity and Environmental Justice Results

The equity and environmental justice analysis reveals a number of crosscutting issues that are common to many of the sectors. Most notably, the analysis shows that the same New York State regions and populations are often at risk for adverse impacts of climate change across multiple sectors. Concerning spatial regions, communities located in the state's coastal zones are vulnerable to sea level rise and storm surge. Densely populated urban coastal areas, where rapid evacuation may be difficult in the event of hurricanes or other large storms, are especially at risk. Rural areas, in general, and small rural towns, in particular, tend to be more vulnerable and have less capacity to cope with all types of extreme climate events (e.g., floods and ice storms) and other types of climate stressors, such as droughts or changes in snowfall or snowpack. Small rural communities with limited government resources and rural areas that depend on outdoor tourism (e.g., cold-water fishing) or on agricultural industries (e.g., dairy farming) may be especially in need of adaptation assistance. Within the state's urban areas, lower-income neighborhoods, particularly those subject to urban heat island effects or located in flood-prone areas, typically have limited local institutional capacity to cope with climate risks and may, therefore, need adaptation assistance.

Among demographic groups, elderly, disabled, and health-compromised populations tend to be more vulnerable to climatic hazards, such as floods and heat waves. Low-income groups are also vulnerable on several counts, including limited ability to meet higher energy costs, dependence on public transportation, and

lack of access to affordable health care for management of climate-related diseases such as asthma. Although there is little evidence of a distinct pattern of vulnerability to flood hazards along traditional environmental justice lines (i.e., race and ethnicity), there are notable pockets of vulnerability, particularly in New York City, with respect to the impacts of coastal storms. It is also important to note that mental stress associated with climate change is an issue for underprivileged, environmental justice populations. These populations are already concerned about how everyday environmental stresses are affecting their neighborhoods; climate change adds another layer of uncertainty.

Across firms and industries, the general pattern is that smaller enterprises (e.g., small farms, small tourism operators, small retail businesses) are less able to cope with climate-related business interruptions and stresses than larger enterprises. Smaller firms tend to have more limited capital reserves and are, therefore, less able to withstand loss of revenue associated with power and communication service disruptions. Small businesses also tend to have less capital available to make investments to promote adaptation, such as the use of snowmaking machines in ski areas.

In addition to overlapping vulnerabilities across regions, populations, and firms, another common theme across the sectors concerns the need for attention to the secondary equity and environmental justice effects of adaptation. Many adaptation strategies have indirect equity and environmental justice impacts. For example, increased air conditioning usage during heat waves is an important adaptation from a public health standpoint. However, more air conditioning will also mean increased energy demand, which may potentially increase air pollution and asthma cases among vulnerable groups. Within the agriculture sector, increased use of pesticides as an adaptation to climate change may lead to increased chemical exposure for farm workers (many of whom are international migrants or members of minority groups).

Finally, concerning the legislative process, there is a need for attention to distributional environmental justice issues in all climate-change-related legislation; just as important, there is a need to ensure that environmental justice groups have a voice in the policy process. Climate policy formation should take into account the needs of disadvantaged populations in

adaptation planning and should also include representatives of these communities in the adaptation planning process.

3.2 Economics

Economics plays a critical role in understanding climate change impacts, vulnerability, and adaptation. Climate change will bring additional economic costs to New York State. Fundamental to this discussion are questions of: How much will climate change impacts and related adaptation measures and vulnerability issues cost? How will these costs be distributed throughout the state? In the ClimAID assessment, potential economic costs are analyzed broadly across each sector and within the case studies in more detail. The focus is largely on direct costs rather than indirect or secondary/tertiary costs. Where relevant, the economic benefits of climate change impacts and adaptation are also highlighted. As noted above, the economic costs of climate change for the ClimAID sectors are examined in more detail in Annex III.

3.2.1 Concepts

The way economists address the relationship between the economy and the environment—and, in particular, global climate change—can be framed in terms of three broad issues: 1) tradeoffs between natural capital, such as wetlands, and manufactured capital; 2) tradeoffs between the needs of the present and those of the future; and 3) tradeoffs between economic efficiency and equity.

Ecologists and economists address the tradeoff between natural capital (e.g., health of fish populations for recreation and commercial industries) and manufactured capital (e.g., dams, roads, factories) very differently. This tradeoff can be viewed through the lens of two alternative paradigms: the theories of weak sustainability versus strong sustainability.

With regard to the weak sustainability criterion, one analysis notes that “[t]he weak sustainability position, held by many mainstream neoclassical economists (such as Solow and Weitzman), is that almost all kinds of natural capital can be substituted by man-made capital” (Ayres, 2007). The neoclassical view of sustainability is

informed by a faith in the workings of markets coupled with a technological optimism. These premises assure society that as an exhaustible natural resource is depleted, its price will rise exponentially and demand will ultimately go to zero. During this inexorable process, society will make transitions to other technologies, and ultimately the use of the exhaustible resource will be displaced by an inexhaustible backstop technology (e.g., solar, wind, or hydrogen energy) that is expected to meet all our future needs (see Solow, 1974).

The strong sustainability criterion for sustainable development rejects the notion that natural and man-made capital are freely substitutable. The strong sustainability criterion requires that society preserves minimum quantities of natural capital stocks and ecosystem services, rather than allowing man-made capital to displace natural capital stocks over time. (For a full exposition of the ecological economic critique of neoclassical environmental economics, see Daly, 1997a; Solow, 1997; Stiglitz, 1997; and Daly 1997b.)

Another analysis clearly frames the implications of these alternative paradigms for climate change mitigation policy: A policy based on strong sustainability requires that a cap on greenhouse gas emissions be based on the assimilative capacity of the global ecosystem. A policy based on weak sustainability is based on the presumed tradeoffs between economic activities and the value of ecosystem services. For example, we might as a society accept a loss of biodiversity or an increase in coastal erosion if these costs are outweighed by other economic benefits.

In practical terms, cost-benefit analysis, which lies at the foundation of neoclassical economic policy analysis, acknowledges tradeoffs among human capital (e.g., labor), manufactured capital, and natural capital. This cost-benefit analysis must weigh the cost of adaptation and mitigation strategies against the costs associated with climate change.

The second point of contention in the climate change debate within economics is the tradeoff between the needs of the present and those of future generations. One report, the Brundtland Commission report, incorporates this tradeoff within the report's definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and

Development, 1987). This debate has practical implications for climate change policy and, in particular, the cost-benefit analyses that economists use to critique alternative adaptation and mitigation strategies. In applying cost-benefit methods to the study of global climate change, it first must be acknowledged that: 1) the costs of increasing atmospheric concentrations of carbon dioxide (and other greenhouse gases) will be felt gradually over a number of decades; and 2) the benefits of reducing greenhouse gas emissions will be realized over a long time period.

One economic analyst who explicitly addresses the issue of intergenerational equity argues that we should treat present and future generations equally; thus he proposes that we should weight the benefits of mitigation and adaptation policies equally, whether they occur now or in the distant future (Solow, 1974).

A recent analysis reviews the ongoing debate between those who believe that the discount rate used in climate policy studies should reflect the real return on investments (the "descriptive" approach) and those who feel that it should be based on intergenerational equity concerns, i.e., the relative weight placed on the needs of current versus future generations (Dietz and Maddison, 2009). In the context of the ClimAID assessment, the intergenerational equity approach would justify increased investments in greenhouse gas adaptation and mitigation policies.

Finally, an economic analysis of global climate change policy must account for distributional equity. Although cost-benefit analysis essentially compares the total costs of climate change versus the total costs of adaptation and mitigation strategies, any policy intervention will have winners and losers. In practice, neoclassical economists have focused on economic efficiency and have tended to neglect issues of equity as being outside the realm of their analysis. The equity and environmental justice analyses in the ClimAID assessment, however, explicitly address the issue of distributional equity.

3.2.2 Methodological Foundations of Cost-benefit Analysis

The standard neoclassical economic criterion for a Pareto-optimal allocation of resources requires that there be no possible reallocation of resources that could

make at least one person better off while making no individual(s) worse off (Bergson, 1938; Boulding, 1952; Tietenberg, 2000). As a rule, any policy change will have both winners and losers. Hence, the practical criterion for evaluating government policies and programs is whether the policies and programs result in a potential Pareto improvement, i.e., that, in principle, the winners should be able to compensate the losers. Consider, for example, a project to prevent riverine flood damage by selective retreat from the flood plain. If the projected benefits (avoided damage, ecosystem benefits) exceed the value of the property within the flood plain, the beneficiaries (society, in this instance) should pay the losers (property owners) to compensate them for their property losses, and create parklands or open space.

The social welfare maximization criterion does not require that any particular outcome will satisfy the ClimAID assessment's criterion for social justice (or distributional equity). Neoclassical welfare economics, however, enables the analysis to address the issue of equity within a market economy, as follows.

Economists often act as if the issues of economic efficiency and equity can be addressed independently. Economists prefer to leave issues of equity to the political process, through taxation and public finance. Once the government has addressed issues of equity through the budgetary process, the free market should be left to "work for itself" (Stiglitz, 1991). In practice, however, neoclassical environmental economists have addressed almost exclusively the issue of efficiency, arguing that actual compensation as it relates to equity issues is outside the realm of economics (Splash, 1993).

The basic tool of cost-benefit analysis in applied welfare economics is an implementation of this social welfare maximization criterion: If the benefits of a proposed policy change exceed their costs (i.e., if the benefit-cost ratio exceeds 1), then it would clearly be possible for the winners to compensate the losers.

It should be noted that an alternative framework for project evaluation has long been available that takes into account not only efficiency but also other objectives such as redistribution. (For an example of a classic study that takes this approach, see Dasgupta et al., 1972.) While this approach has many advantages, it is not used within the economics component, which is designed to study the efficiency costs and benefits of impacts and adaptations.

The choice of an appropriate social discount rate must accommodate the issues of economic efficiency, intergenerational equity, and the global nature of climate risk. As these issues remain unresolved, the ClimAID assessment performs sensitivity analyses with rates of 0 percent and 3 percent, reflecting lower rates of discount used in many climate studies, most notably in the Stern Report (Stern, 2007). Some analysts advocate higher rates, for example Nordhaus (2007a; 2007b). Stern (2009) argues that such higher rates are inappropriate for large-scale social decisions where the risks of inaction are to a significant extent unknown (and possibly very high), and the costs of present action are relatively low.

3.2.3 Economic Analysis in the ClimAID Assessment

For sectors whose goods or services are traded in organized markets, the ClimAID assessment relies on market data on observed input-output quantities and prices in order to directly estimate the social marginal benefits (i.e., the value to society of a small increase in the scale of an adaptation measure, such as an additional mile of shoreline protected from storm damage) and social marginal costs (i.e., the cost of that same adaptation measure, in this case the cost to protect an additional mile of coastline). With sufficient available data, social marginal benefits and social marginal costs can be estimated with conventional statistical economic modeling. When adequate data are not available, existing estimates from reliable sources are included in the analysis. In the case of sectors whose goods or services are not traded in markets, widely accepted techniques to represent values for such goods and services are used, as summarized below:

- 1) For sectors in which statistics on economic activity are available (e.g., energy, agriculture), a regression-based approach is followed. The relationship between demand and supply in a market are statistically estimated from price, quantity, and other data.
- 2) When market data are not available, the assessment follows a different approach, based on survey information and other sources. Various techniques are available to estimate the economic value of non-traded goods and services, including direct methods such as contingent valuation (surveys that provide a gauge of people's willingness

to pay, for example, to preserve a particular ecosystem from being developed). Indirect measurement techniques of consumer preference include the following:

- *Travel costs.* This approach may be used, for example, to estimate the economic losses associated with a decrease in tourism or sport fishing because of likely declines in trout populations in New York State.
- *Hedonic prices.* For example, we can compare the prices of similar houses within the flood plain and outside it, and estimate the economic value placed on the risk of flood damage.
- *Defensive expenditures* (e.g., costs incurred by wastewater treatment facilities to guard against flooding or costs to install cooling equipment at dairy farms).
- *Cost of illness/health production function* (morbidity/mortality). For example, in the public health sector, the economic assessment uses the Environmental Protection Agency's model of cost of illness and/or the human capital approach to estimate lost wages with appropriate modifications. Defensive expenditures to avoid illness, such as expenditures on air conditioning or inhalers for asthma sufferers, may also be estimated, as required.

3.2.4 Key Findings of Economics Assessment

This section highlights some key economics findings from each of the ClimAID case studies.

Water Resources

Flooding is already a major problem in the United States, with estimated damages of \$50 billion during the 1990s. During that same period, flood losses in New York State were estimated at \$441 million (Pielke et al., 2002).¹ It is possible that flood losses will be exacerbated by climate change. The majority of New York State flood events consistently occur in the ten Southern Tier counties. The case study for the water resources sector examines the 2006 flooding along the Susquehanna River within Broome County, with a specific focus on Binghamton, its population center, and surrounding rural areas. During the 2006 flooding, approximately

3,350 parcels with an aggregate value of \$560 million were flooded. (The actual property losses were much less than the total value of property within the flood zone.) In the absence of adaptation measures, it is expected that flood losses may become both more frequent and severe. Planned withdrawal from the flood zone, together with floodplain management, is expected to minimize the risk to people and property.

Coastal Zones

The baseline metrics used to determine New York's vulnerability to storms and coastal flooding are the total population and value of real estate within the 100-year floodplain. Climate-change-induced sea level rise will, over the next century, increase the size of the 100-year floodplain. Moreover, at the current rate of natural population increase and residential construction within the coastal zone, an increase in both population and property at risk from a 100-year storm surge can be projected. Conservative estimates of the population and property at risk, based on the Long Beach and Great South Bay case studies, suggest that the population and property at risk will have increased by as much as 20 percent from 2000 to 2080. Within the two case study areas, the population at risk in 2080 may approach 150,000 and the value of real estate at risk may be approximately \$9 billion. Coastal storms also cause considerable damage to beaches and dunes. For example, for the November 2009 Nor-Ida storm, the costs of beach replenishment and repair of damaged groins on a 5,000-foot segment of beach at Point Lookout totaled approximately \$5.6 million (U.S. Army Corps of Engineers, 2010).

Ecosystems

Ecosystem services benefit millions of people both in the state of New York and beyond the region. These benefits include air and water purification, drought and flood mitigation, generation and preservation of soils, cycling of nutrients, maintenance of biodiversity, partial stabilization of climate, control of agricultural pests, and many others. Because most of these services are provided by nature free of charge, most economic indicators do not track their value. Nevertheless, there are other ecosystem services that are more pecuniary (able to be quantified financially) and/or that directly result from healthy ecosystems in New York State. Total

annual combined expenditures for these services in New York State are significant. In 2006, expenditures on these services surpassed \$3.2 billion, including \$926 million on fishing, \$716 million on hunting, and \$1.57 billion on wildlife-watching recreational activities (U.S. National Fish and Wildlife Service, 2008). Trout fishing is prominent in most of the state's major fishing areas, and trout is the second most popular species for recreational fishing in the state after black bass (Connelly and Brown, 2009a).

Potential adaptations to ameliorate rising temperature effects include maintaining or increasing shading vegetation along stream, river, and lake shorelines and minimizing disturbances that would impede water flows and groundwater inputs. More elaborate interventions for high-priority regions could include piping cold water from springs or lakes located at higher elevations to shoreline locations of lakes at risk for heat stress, and manipulations that might darken the color of the water and therefore increase the propensity to form stable thermal stratification. Adding lime to some Adirondack lakes has already been practiced in order to partially compensate for pollutant acidity and promote primary production. This practice also tends to darken water color, which shades deeper waters and allows thermal stratification to occur.

Coldwater fish habitat conditions are an important determinant in the extent of climate change impacts that these species are likely to experience. As a result, other studies have proposed a holistic approach to ensure that the integrity and diversity of habitat conditions are maintained or restored. Such strategies often focus on management of the entire watershed rather than improvements to particular streams or lakes (Williams et al., 2009). Costs for such comprehensive measures depend on the size of the watershed and/or the extent of the effort. An initiative to restore a 153,000-acre watershed in the Upper Colorado River Basin over the course of 10 years, for example, was estimated to cost close to \$2 million. Similar costs (\$2.01 million) were estimated for the 10-year restoration effort of the South Branch of the Potomac River (Williams, 2009).

Agriculture

In 2007, dairy products were ranked as the top agricultural commodity in New York State—valued at

more than \$2.3 billion and representing more than half of the state's total farm receipts.² However, increasing temperatures over the next several decades have the potential to affect milk production. As average temperatures increase, milk output is likely to decrease, in particular among high-producing herds (85 pounds per day per cow) with substantially greater sensitivity to heat stress. The decrease in milk production for cows that produce 65 pounds per day is estimated to be on the order of 30 percent, but the amount of lost production is more than twice that much for a cow producing 85 pounds per day by the end of this century.³ By the 2050s and certainly by the 2080s, heat stress on cows alone is predicted to generate notable losses unless effective cooling systems are in place. While such systems represent added investments, the investment costs are relatively modest. For example, the cost of investing in a forced evaporative cooling system for a 48-cow milking herd was calculated at ~ \$1,600. Total operating costs amounted to \$0.23 per cow per day, including increased food intake of 5 to 6 pounds/cow/day and \$0.20/cow/day for both water and electricity costs, assuming 800 hours of run time during the summer season. With an increased milk yield of 4 pounds/cow/day, and the milk valued at \$0.50/cow/day, the estimated payback period for the cooling system was 124 days, given a net income of \$0.27/cow/day (Turner et al., 1997). These costs have a high likelihood of paying for themselves through increased milk production over a short time span (one to three years depending on the number of days that require farmers to use the cooling systems) (Turner, 1997). Many barns in New York currently have extensive ventilation systems to promote healthful conditions. Given the current animal types and barn configurations prevalent in New York's dairy industry, farms will increasingly need such cooling systems as temperatures increase.

Energy

Economic losses from electric service interruptions are not trivial, as indicated by estimates of damage costs resulting from major power outages, which have occurred in the past during extreme events such as heat waves and ice storms. The economic impact of the 25-hour blackout that affected most of New York City in July 1977 was assessed at \$60 million,⁴ while the cascading blackout on August 14, 2003, was estimated to affect approximately 22,000 restaurants, which cumulatively lost between \$75 million and \$100 million in foregone business and/or wasted food. In addition,

the City of New York reported losses of \$40 million in lost tax revenue and \$10 million in overtime payments to city workers.

Other localized service outages in New York City include the July 3–9, 1999, blackout that affected 170,000 Con Edison customers, including 70,000 customers in Washington Heights (New York State PSC, 2000), and the nine-day blackout that began on July 16, 2006, in Long Island City, Queens, and affected 174,000 residents (Chan, 2007). Total claims paid by Con Edison in 2006 as a result of the outage amounted to \$17 million. An estimated additional \$100 million was spent by the utility on recovery costs to repair and replace damaged equipment (New York State Office of the Attorney General, 2007). Preventing the losses described above, as well as the number of mortality cases due to heat stress, will require further strengthening the reliability of the electric grid in order to minimize the number of power outages under changing climate conditions.

Transportation

Among the consequences of coastal flooding resulting from a 100-year coastal storm surge are possible inundation of transportation infrastructure—including airports, bridge and tunnel access ramps, highway and rail tunnels, and marine ports. The economic losses associated with coastal flooding include damage to infrastructure, costs of service restoration, and economic activity that is lost for the duration of the storm and, to a lesser extent, the recovery period. The severity of coastal flooding and, hence, associated economic losses increase with sea level rise. The coastal storm case study estimates losses for three scenarios: a base-case scenario (current sea level), a 2-foot sea level rise scenario, and a 4-foot sea level rise scenario. (The 2-foot and 4-foot sea level rise scenarios are roughly equivalent to the GCM and rapid-ice-melt scenarios, respectively, for the 2080s.) The total costs—infrastructure damages and economic losses—for a 100-year coastal storm range from \$58 billion in the base-case scenario to \$84 billion in the 4-foot sea level rise scenario.

Telecommunications

The Telecommunications infrastructure case study examines the economic losses associated with a winter (ice and snow) storm in central, western, and northern

New York. Because communication and power outages typically occur simultaneously in New York State, these loss estimates may be understood as the combined costs associated with an outage in both sectors. As is the case in the Transportation sector, the losses are associated both with damage to infrastructure as well as the economic losses associated with interruption of service. As data on telephone outages are limited, the estimates of service restoration times and economic losses are based on data collected for the electric utility sector. (Because telephone and electrical wires within the study area are co-located on the same telephone poles, this is a realistic assumption.) The analysis estimates that the time to fully restore service following a major winter storm is five weeks, with 10 percent of households restored in the first 24 hours and 50 percent restored within 10 days. The total estimated cost of a major winter storm is nearly \$2 billion, of which nearly \$900 million comprises productivity losses (due to service interruption) and \$900 million comprises direct damage (e.g., spoiled food, damaged orchards, replacement of downed poles and electric and phone/cable wires, medical costs, emergency shelter costs).

Public Health

Prolonged heat waves have the potential to result in increased mortality cases, in particular in metropolitan areas such as New York City, where the heat island effect in the summer exacerbates the increased temperature periods. Mortality costs associated with heat stress in New York City can be estimated by multiplying the Environmental Protection Agency's value of a statistical life (VSL) estimate of \$7.4 million (i.e., the economic value of a person's life based on earning potential) by the number of increased mortality cases (U.S. EPA 2010, 2004, 2000). While this estimate places a numeric value on the loss of a person's life, it is important to recognize that VSL measures do not take into account the emotional and social impacts and tolls that are incurred by a family and community following the loss of a loved one. Such impacts cannot be measured in quantitative terms.

A common adaptation measure during heat waves is the use of air conditioners.⁵ While in New York City most people are prepared to endure heat waves (approximately 86 percent of New York City residents have some type of air conditioning system in place), one concern is that vulnerable populations (e.g., the elderly

and people with mental disabilities) require additional measures to prevent heat-stress-related mortality. New York City and several other cities across the United States have instituted emergency response plans to address increased mortality rates during extreme heat events. Within New York City, a network of cooling centers is currently in place to help residents cope with extreme heat. The city has also initiated a program to provide free air conditioners to elderly residents who are unable to afford them. Benefits associated with implementing such systems are seen to outweigh their costs (Ebi et al., 2004), and such systems may need to be expanded in response to climate change.

- There are adaptations in all sectors for which the benefits are likely to exceed the costs, especially if the adaptations are carefully planned, timed correctly, and tailored to conditions in each sector.

As New York State addresses climate change, incorporating equity concerns and balancing these concerns with economic efficiency will be a key challenge for adaptation decision-making. Ensuring broad and inclusive participation in adaptation decisions will be critical for ensuring that the outcomes of these decisions are both equitable and economically feasible. Further details of the equity and economic analyses are presented in each of the sector chapters.

3.3 Conclusions

Attention to issues of equity and economics is vital to the development of responses and adaptations to climate change in all sectors of New York State. As described in this chapter, equity issues arise in terms of the distribution of the impacts of climate change, the capacity to adapt to climate change, the effects of mitigation and adaptation policies, and the processes associated with how decisions are made with regard to adaptation. Economic issues center around the costs associated with the impacts of climate change, the costs of adapting to climate change, and the residual effects associated with those impacts that cannot be avoided. The key findings from the equity and economic analysis are as follows:

- Within New York State, many regions are at risk for adverse impacts of climate change across multiple sectors. Coastal zones, small rural communities, and lower-income urban neighborhoods are especially vulnerable.
- Among demographic groups in the state, low-income residents and elderly, disabled, and health-compromised populations are generally more vulnerable to climatic hazards than other groups.
- Across the state's firms and industries, smaller enterprises are less able to cope with climate-related business interruptions and stresses than larger enterprises.
- Without adaptation, many sectors may experience significant economic losses as the result of climate change.

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¹ Both estimates are in inflation-adjusted 1995 dollars.

² <http://www.ers.usda.gov/StateFacts/NY.htm>.

³ As reported in the Dairy Farm Case Study in the Agriculture Chapter of this report.

⁴ It is not clear whether the costs associated with the riots and looting during the blackout are accounted for in this estimate. Information from Blackout!; Spotlight archives, July 13, 2005; <http://www.answers.com/topic/new-york-city-blackout-of-1977>.

⁵ This adaptation measure depends on the reliability of the electric grid system. As described in the energy section, increased electricity demand during a heat wave may cause power outages, thus the importance of investing in electric power infrastructure.

Chapter 4

Water Resources

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Introduction

This ClimAID chapter covers climate change vulnerabilities and possible adaptation strategies for four major water resource themes: 1) flooding in non-coastal regions, 2) drinking water supply, 3) water availability for non-potable uses (primarily agriculture and hydropower), and 4) water quality. Ensuring reliable water supplies, minimizing the disruptive and destructive impacts of flooding, and maintaining the recreational and aesthetic value of water bodies are fundamental needs, critical to the well-being of communities and businesses throughout New York State.

4.1 Sector Description

New York State has an abundance of water resources. Despite having only 0.3 percent of the world's population, the state is bordered by lakes containing almost 2 percent of the world's fresh surface water: Lake Erie, Lake Ontario, and Lake Champlain. It is home to the Finger Lakes in central New York, which are the largest of the state's 8,000 lakes as well as some of the largest inland water bodies in the United States. The state has several high-yielding groundwater aquifers, particularly those underlying Long Island. It has an average annual rainfall of almost 40 inches, readily supplying numerous small municipal reservoirs as well as the extensive New York City water supply system with surface water impoundments in the Catskill Mountains and the Croton watershed east of the Hudson River. The state contains the headwaters of three major river systems in the Northeast: the Hudson River, the Delaware River, and the Susquehanna River.

In 2000, New York State's 19 million residents consumed approximately 2,200 million gallons per day of fresh surface water and 890 million gallons per day of fresh groundwater for public water supply, irrigation, and industrial uses (Lumia and Linsey, 2005). Of this nearly 3,100 million gallons per day of consumption, only about 10 percent was for industrial and agricultural use.

4.1.1 Economic Value

There is no direct way to describe the economic value of water resources in the state. One could

attempt to place an approximate market value on the water consumed. Treated water costs approximately \$3 per 1,000 gallons; given that New Yorkers consume around 3,100 million gallons per day, this works out to more than \$3 billion in revenue per year. Another way to look at economic value is in terms of infrastructure. An estimated value of this part of the sector can be gathered by considering that the New York City Department of Environmental Protection's capital program for 2010 through 2019 is just over \$14 billion (NYCMWFA, 2009, p. 24). Conversely, it is important to consider negative economic consequences associated with water. For instance, disaster assistance for a large flood event in the Susquehanna Basin in 2006 topped \$225 million; such a flood event typically occurs every few decades. Overall, a clean, reliable source of potable water is an essential underpinning of community stability and a necessity for numerous other economic activities.

4.1.2 Non-climate Stressors

There are several non-climate factors that will interact with possible changes in climate. First, much of the water resource infrastructure in New York is old and requires updating and rebuilding. Failing infrastructure can contribute to water pollution and reduce the reliability of treatment and distribution systems. Recent estimates suggest that over \$36 billion is needed to update wastewater treatment infrastructure in the next 20 years (NYSDEC, 2008a). Second, even without any possible changes in water supply with climate change, rapidly developing regions face increasing water demands. Continued increases in population are projected, particularly in the New York City metropolitan area. New York City alone anticipates an increase of about 0.7 million people by 2030 (NYCDEP, 2006). Newly developing suburban and exurban regions can face unique challenges. In many cases, older cities that built water infrastructure more than 100 years ago were able to develop water sources in undeveloped regions outside their immediate borders (e.g., New York City reservoirs, City of Troy Reservoir, Albany Reservoir). Newly developing communities face more extensive regulations, few undeveloped areas to claim for their use, and competition from other neighboring communities that may also have rapid growth.

4.2 Climate Hazards

This section focuses on the temperature, precipitation, sea level rise, and extreme event hazards of particular concern to the water resources sector.

4.2.1 Temperature

Increases in air temperature will lead to increases in water temperature. Up to a water temperature of approximately 77°F, water temperature directly increases with air temperature, with a proportionality constant of 0.6–0.8. For instance, an air temperature increase of 9°F would result in a water temperature increase of 5–7°F. Thus, increases in water temperature will be slightly less than increases in air temperature. Higher water temperatures will have direct impacts on certain elements of water quality such as oxygen content.

Additionally, increases in temperature are likely to decrease the fraction of precipitation falling as snow. This will lead to shifts in seasonal stream flows. Many observational and modeling studies suggest that late winter and early spring flows will increase and that spring snowmelt will occur earlier in the year (Hayhoe et al., 2007; Burns et al., 2007; Hodgkins et al., 2003; Neff et al., 2000). Thus, even if there is more annual streamflow, it may be distributed unevenly over the year, with lower flows in the late summer and autumn and higher flows in the late winter and spring. This shift in timing of flow magnitudes has already been observed in stream records.

Temperature will also have some impact on evaporation rates, either by extending growing seasons or by increasing the potential rate of water vapor transfer to the atmosphere from soils, vegetation, or open water. Although evaporation has some dependency on air temperature, the primary driver of evaporation in humid temperate regions such as New York State is the net amount of energy from sunlight plus the net amount of energy emitted from the Earth's own atmosphere (as demonstrated, for example by Brutsaert, 2006). Some models used to estimate evaporation (such as the Thornthwaite Equation) only consider temperature; we suggest that these temperature-based models may overestimate changes in future evaporation. Studies have long indicated the greater sensitivity of temperature-based evaporation equations to changes in

temperature relative to more physically based equations for estimating evaporation (McKenney and Rosenberg, 1993). More accurate estimate of changes in evaporation will come from equations that consider the complete energy balance at the land surface (such as in the work by Hayhoe et al., 2007).

4.2.2 Precipitation

Precipitation feeds the hydrologic cycle. Changes in precipitation amounts and frequency can cause changes in stream and river discharges, lake levels, and groundwater levels. However, as discussed further in 4.2.4, hydrology is dependent on a number of interacting factors; changes in precipitation alone rarely explain likely changes to water resources. Based on historical observations, precipitation in New York State has been increasing both in total annual amount and in intensity. As noted in Chapter 1 (“Climate Risks”), annual average precipitation has been increasing by 0.37 inches per decade since 1900. In terms of intensity, increases in the frequency of heavy rainfall have been observed across much of the United States, with such upward trends strongest in the Northeast (DeGaetano, 2009; USGRC, 2009). For instance, in New York State, the number of rainfall events each year with greater than 1 inch of precipitation in 24 hours has increased over time (Figure 4.1, black line).

As discussed in Chapter 1, climate models indicate that annual average precipitation in New York State will

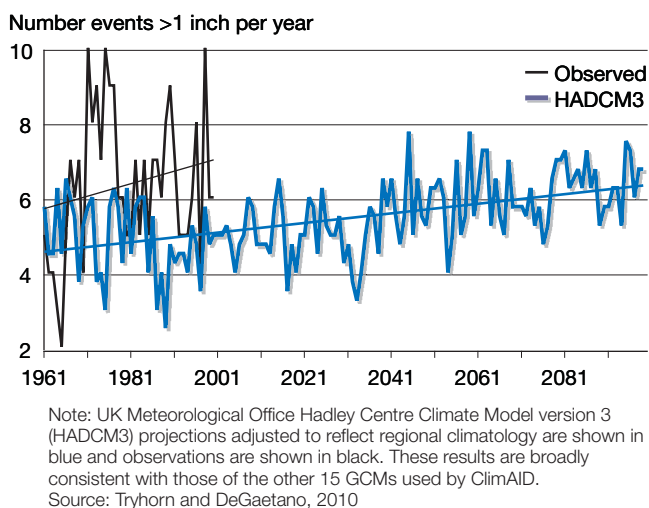


Figure 4.1 The observed and projected (by one global climate model) number of rainfall events exceeding one inch from 1960 to 2100, averaged over four stations in New York State

increase by 5 to 10 percent by 2080. Based on climate modeling, the frequency of heavy rainfall events is projected to increase as well. Applying a model (the Statistical Downscaling Model, or SDSM, Version 4.2) that relates large-scale circulation patterns and atmospheric moisture to local weather conditions, Tryhorn and DeGaetano (2010) simulated daily rainfalls from 1961 to 2100. By the end of this century, precipitation from storms that now occur on average every 100 years is projected to increase by 0.2 inch (**Figure 4.2**). With these increased event rainfall amounts, storms that now occur on average every 100 years are likely to become more frequent, recurring on average every 80 years by the end of the century. These trends, however, likely underestimate the future changes, given that the model upon which these predictions are based is underestimating current trends.

It is important to note that only recently have researchers started to investigate changes in the intensity of sub-daily precipitation events (Berg et al., 2009; Lenderink and Van Meijgaard, 2008). The intensity of sub-daily rainfall (particularly in periods of less than an hour) is of particular relevance. It is usually these intense short events that exceed a landscape's ability to allow water to infiltrate. Particularly in urban areas or steep basins, these intense rainfall events can result in flooding. For example, 1 inch of steady rainfall spread evenly over a day would likely produce less surface runoff than 0.5 inch of rain in an intense 15-

minute event. There is evidence from historical data and regional climate modeling to suggest that the intensity of sub-daily rainfall events will increase in a warming climate. For example, one study found that 1-hour rainfall amounts increased 7 percent for every degree Fahrenheit that the air temperature increased in the Netherlands (Lenderink and Van Meijgaard, 2008). Similar analyses of sub-daily rainfall intensities have not yet been carried out for New York State.

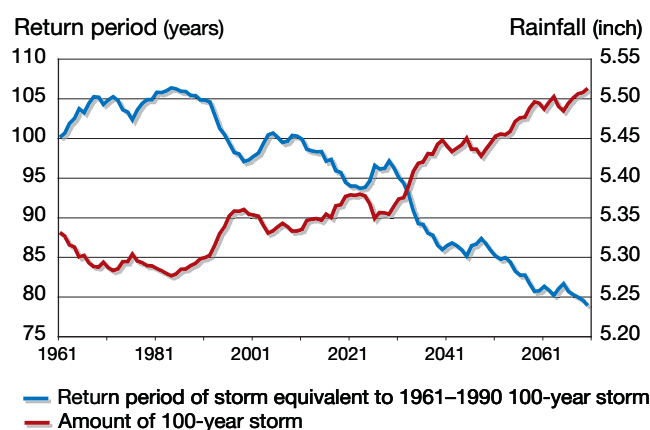
If storm rainfall amounts increase in the future, the frequency of storm events could decrease (Trenberth et al., 2003; Hennessy et al., 1997), leading to longer periods with no rainfall. However, to date, an analysis of the time interval between historical storm events indicated no change in the Northeast despite increasing dry periods in other regions (Groisman and Knight, 2007).

4.2.3 Sea Level Rise

By the 2080s, sea levels could rise under rapid ice-melt as much as 55 inches (see Chapter 1, "Climate Risks"), with important implications for coastal storm flooding potential. With the additional water under the high-end scenario, the current 1-in-100-year flood could occur approximately an order of magnitude more frequently along the New York State coast (see Chapter 5, "Coastal Zones"). This shift will have ramifications for a broad set of coastal management processes including those for coastal water resources, groundwater protection from saltwater intrusion, and operation of wastewater treatment facilities.

4.2.4 Other Climate Factors

Changes in water resources rarely have a one-to-one link with a single climate factor. Numerous processes combine to determine the level of discharge seen in a stream or the amount of water available to a well. This can be illustrated by comparing typical monthly rainfall and stream discharge amounts for a stream in New York (see **Figure 4.3**). Rainfall is relatively even over most of the year, with the exception of lower amounts in the winter months. However, most evaporation and transpiration (water loss from plants) occurs between May and October when plants are active, making streamflows lower and soils dryer during summer and early fall. In addition, winter and spring streamflows



Note: The rainfall amount of the 100-year storm computed for each 30-year period beginning at the date in the graph (red) and the change in the return period associated with the amount of the 1961–1990 100-year storm (blue). The return period is the average interval of time between storm events of a given magnitude; a decreasing return period indicates that a given storm event occurs more often. These results from the HadCM3 model are broadly consistent with those of the other 15 GCMs used by ClimAID. Source: Tryhorn and DeGaetano, 2010.

Figure 4.2 Projected rainfall and return period of the 100-year storm

may be further increased by the contribution of melting snow, causing streamflow to peak in the spring despite lower precipitation amounts. Thus, streamflows combine the effects of many interacting climate factors, as well as the water catchment's capacity for infiltration and storage.

A study of streamflows at 400 U.S. sites from 1941 to 1999 documented an increase in annual minimum and median daily streamflow beginning around 1970, particularly in the East. Notably, peak streamflow (i.e., floods) did not show a consistent increase in the studied streams (McCabe and Wolock, 2002). This is consistent with findings specific to New York. In the Catskill Mountain region, runoff increased from the 1950s to 2000s with an increase in annual warm-season streamflow (June to October) (Burns et al., 2007). Also, a study in Monroe County noted an increase in seven-day low-flows in rural streams from 1965 to 2005 (Coon, 2005).

There have also been efforts to project future streamflows in the northeastern United States. The basic approach in these studies is the same: 1) global climate models project future temperature and precipitation amounts for large-scale regions of the globe, 2) a downscaling procedure is used to adjust these projections for the climate conditions of the areas of interest, and 3) the downscaled climate data are incorporated into a hydrologic model that predicts streamflows and groundwater levels. Within each study, several scenarios comprising different emission levels, global climate models, downscaling techniques, and model parameterizations may be chosen, resulting in an

average and range of possible outcomes. However, there is a growing recognition that a large number (on the order of thousands) of equally plausible scenarios could be used. For example, one study in the United Kingdom demonstrated that streamflow projections are most dependent on the choice of global climate model, but that each global climate model and hydrologic model can also be parameterized slightly differently to result in additional variation in possible outcomes (New et al., 2007). In brief, no one outcome based on a single scenario should be granted much weight. Instead, multiple models can be used, as in the ClimAID study, to suggest the direction and relative magnitude of possible changes in hydrology.

In general, nearly all modeling studies that have assessed water bodies in the northeastern United States have estimated that, on average, annual streamflow should change little. However, studies do differ in their estimates of the largest and smallest possible amounts of change, as would be expected given the widely different choices of modeling approaches. One study using nine different global climate models predicted an increase in annual streamflow of 9 to 18 percent for 2070–2099 in the New York State/Pennsylvania region (Hayhoe et al., 2007). Another study that used projections from the United Kingdom Meteorological Office Hadley Centre Climate Model version 2 (HADCM2) and the Canadian Centre for Climate Modeling and Analysis Coupled Global Climate Model (CGCM1) estimated a -4 to +24 percent change in annual streamflow in the Susquehanna River by 2099 (Neff et al., 2000). Using four different scenarios from the same models, a different study estimated changes in annual streamflow of -28 to +12 percent for the 2080s for the Cannonsville Basin in Delaware County (Frei, 2002). More recently, another study estimated little annual streamflow change for Moodna Creek in Orange County when using high-end and low-end estimates of climate change from 16 different climate models (Frei et al., 2009).

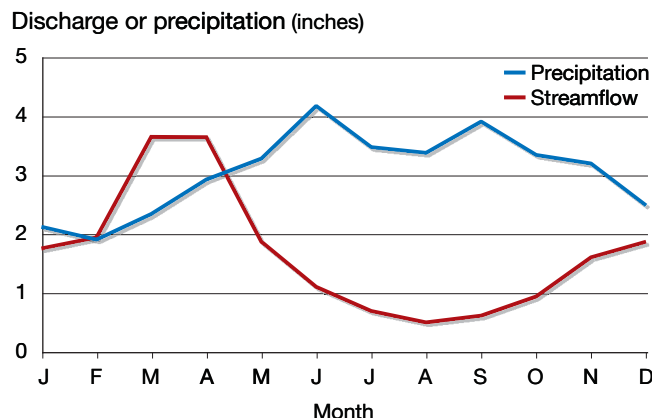


Figure 4.3 Average monthly streamflow discharge and precipitation for the Fall Creek watershed in Central New York

4.3 Vulnerabilities and Opportunities

This section gives an overview of the likely consequences of climate change on flooding, water supply, and water quality. It discusses the certainty of different outcomes and speculates on possible favorable opportunities that could arise with a changing climate.

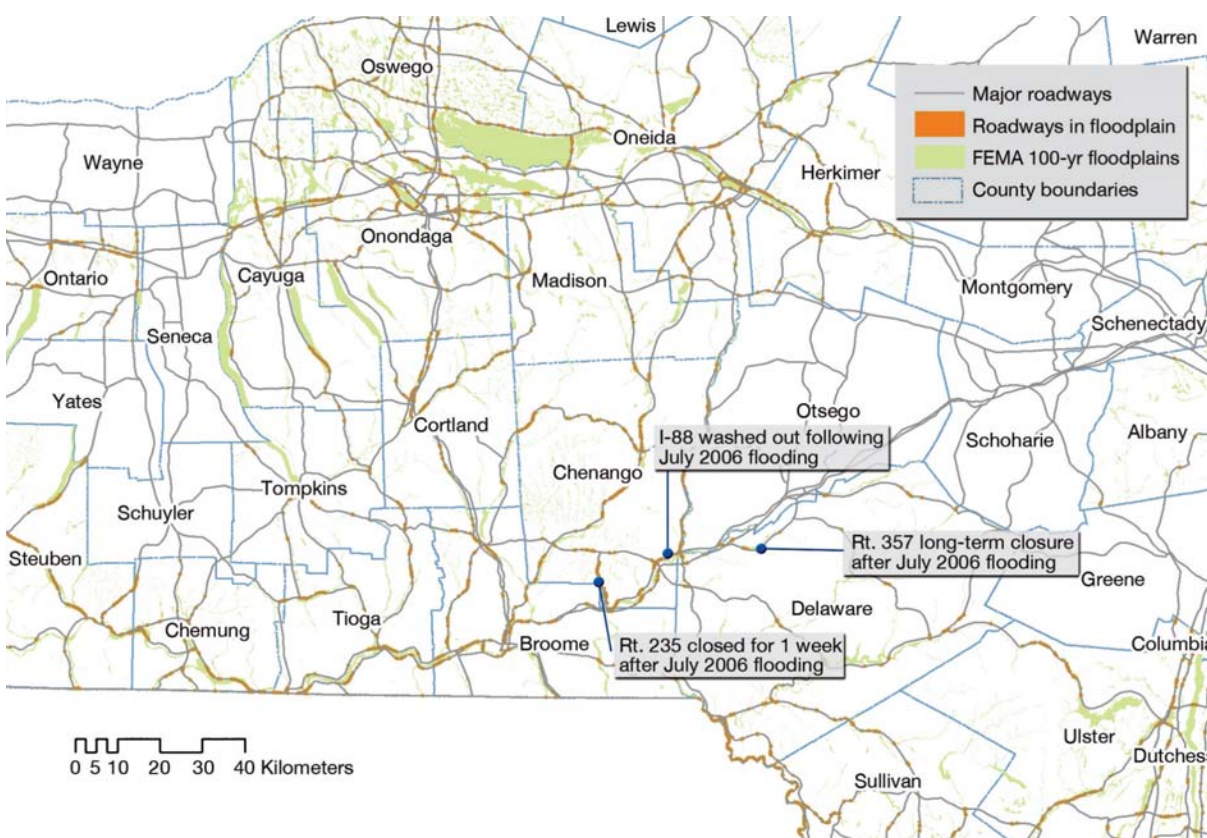
4.3.1 Flooding

Non-coastal floods occur when rivers or streams overflow their channels, flooding the adjacent land or floodplain (coastal flood issues are discussed in Chapter 5, “Coastal Zones”). In areas prone to river and stream flooding, damage is contingent on the presence of humans and infrastructure. In New York State many original settlements were concentrated within the most viable transportation corridors, typically along rivers and their valleys, and much of the state’s infrastructure reflects these early patterns of development. Many major roadways in Central New York lie within the Federal Emergency Management Agency’s (FEMA) 100-year floodplain (**Figure 4.4**). Wastewater treatment plants are also at risk during floods (**Figure 4.5**). These plants are typically located at the lowest point in a landscape so that sewage can be conveyed by gravity.

Across the state, flooding continues to be an expensive and disruptive phenomenon. Record flooding in the Susquehanna Basin in 2006 required more than \$225

million in disaster assistance, as reported by FEMA. Over a recent 12-year period, nine New York counties in the Southern Tier and Catskill regions experienced more than four FEMA-designated flood disasters; Delaware County had flood damage in 7 of the 12 years (**Figure 4.6**). However, the question of whether flooding will increase with climate change remains inconclusive.

Increases in total annual rainfall as well as higher rainfall intensities—both likely as a result of climate change—are often used as justification for predictions of an increased likelihood of flooding. For some parts of the country, this direct link between precipitation and flooding is likely to be the case. For example, a study looking at the relationship between precipitation and flooding at a national scale found that a 13.5-percent increase in overall annual precipitation could increase future flood damage by approximately 130 percent (Choi and Fisher, 2003). However, large-scale flood damage predominantly occurs in the Mississippi Basin and such a study at the national scale is probably more reflective of the central United States than New York.



Note: Roads are highlighted that were temporarily closed after severe flooding along the Susquehanna River in July 2006. Sources: FEMA Q3 Flood Zone Data, Census 2000 Railroads, USGS NYS Transportation Coverage

Figure 4.4 Major roadways in proximity to FEMA-mapped 100-year floodplains

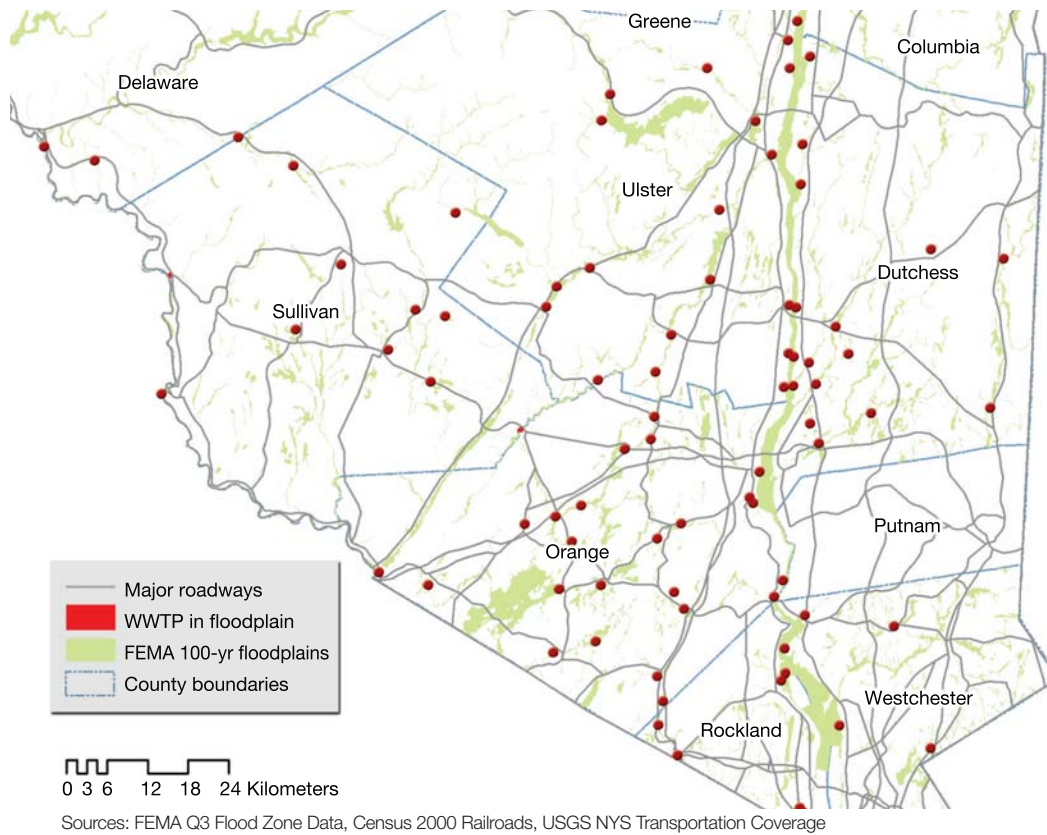


Figure 4.5 Wastewater treatment plants (WWTP) in proximity to floodplains in the Hudson Valley and Catskill Region

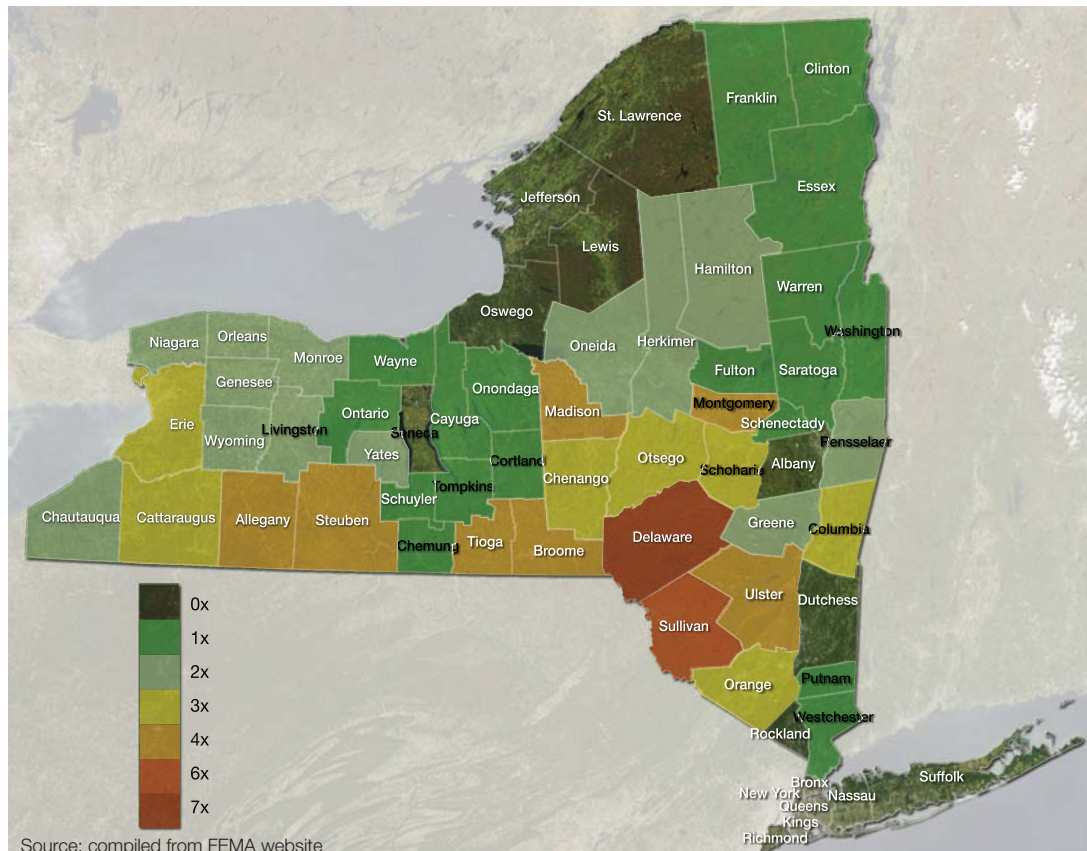


Figure 4.6 Number of FEMA-declared (Federal Emergency Management Agency) flood disasters in New York counties

To appropriately assess whether flooding in New York State may increase, it is important to focus on the dominant processes leading to large flows in streams and rivers in the New York region and to realize that studies carried out in other regions may not be applicable. For example, one study suggests that different flooding factors dominate in different regions: Damage in the Northeast is related to three-day heavy rainfalls, while damage in the central United States is related to the number of wet days across a season (Pielke and Downton, 2000).

To better understand flood processes in New York State, linkages among stream discharge, precipitation, and snowmelt were examined for three moderately sized watersheds in three different regions. The three watersheds generally reveal the same patterns in flooding. Most notably, less than 20 percent of the largest yearly stream flows correspond to the largest yearly rain events. Most large rainfall events occur between May and October when soils are dry and able to store rain. Instead of being associated with large rainfall amounts, many floods in New York State occur from snowmelt or moderate rainfall amounts on very wet soils. Given the number of interacting factors that affect flooding (snowmelt, precipitation, growing season length, soil wetness), it remains uncertain whether the magnitude of annual maximum flows will increase with climate change. Further details of this flood assessment are described in Appendix B.

There are some cases in which changes in flooding can be predicted with more certainty. More-frequent, larger-magnitude floods as a result of climate change are possible in areas in which flooding is directly linked to the intensity and amount of rainfall, such as in urban areas and steep basins. Urban areas tend to have impervious surfaces, reduced vegetative cover, and compacted soils that minimize the ability of soil to store water; thus, intense precipitation events can increase streamflows quickly. Similarly, small, steep basins, such as those found in the Southern Tier of New York State, rapidly collect water and have a limited capacity to lessen the impacts of rainfall, increasing the likelihood of flash floods following increases in rainfall intensity.

4.3.2 Drinking Water Supply

To assess the vulnerability of water supplies due to climate change, we assume that long-term average

water supply will remain largely the same, but, consistent with the ClimAID climate projections, the duration and/or frequency of dry periods may increase. To compare vulnerability, water systems in the state have been classified based on the amount of time over which they can handle a temporary, but sizable, decrease in water supply.

For both surface water supplies and groundwater supplies, the systems are divided into three categories: 1) sensitive to short droughts (two months) and longer, 2) sensitive to moderate droughts (six months) and longer, and 3) relatively insensitive to any droughts. This provides a basic sense of the population and the characteristics of communities likely to be most vulnerable to the uncertain changes in water supply. This analysis was conducted for water systems that serve more than 3,000 people; thus, very small water systems are not directly represented.

Surface Water Supplies

Water supply systems that are relatively insensitive to droughts draw from a water source that greatly exceeds any potential demand. For instance, the City of Buffalo draws approximately 200 million gallons of water per day from Lake Erie. Lake Erie has a total volume of 128 trillion gallons, making Buffalo's daily withdrawal 1/10,000 of the total lake volume. Many other communities also fall into this category (**Table 4.1**). For instance, numerous small towns with demands less than 5 million gallons per day draw water from the Finger Lakes (containing nearly 1 trillion gallons). This analysis does not include possible emergency interconnections; the cities of Rochester and Syracuse as well as additional portions of the

Source	Population
Lake Erie & Niagara River	930,000
Lake Ontario	486,000
Hudson River*	122,000
Finger Lakes	115,000
Mohawk River	94,000
Susquehanna River	68,000
Chemung River	65,000
Other major rivers	53,000
Total	1,933,000

* Hudson River water withdrawn at Poughkeepsie could potentially be threatened by upstream movement of the salt front, as the division between saltwater and freshwater moves inland. Source: NYSDOH Public Water Supply Database

Table 4.1 Large New York water bodies and their dependent community populations

Onondaga County Water Authority's supply region could potentially use Lake Ontario water, adding upwards of 300,000 people within this category. Cumulative demands from communities outside New York State can also reduce Great Lakes' water availability. Nonetheless, on a relative basis, the water supplies within this category can generally be considered highly resilient to climate change. That is, although lake levels will likely be affected by climate change, lake volume is not expected to be altered enough to constitute a risk for these supplies.

Most water suppliers drawing from major river systems in New York State, such as the Niagara River, also fall under the category of relatively insensitive to any drought since the rivers' minimum flows greatly exceed the maximum likely demands given existing uses. Although municipalities drawing from large rivers, such as the Hudson, have been classified in this report as water supply systems with low sensitivity to drought, there could be circumstances in which this classification should change. On the Hudson, approximately 75,000 people rely on Hudson River withdrawals at Poughkeepsie. While this withdrawal of 10 million gallons per day is only a small fraction of total river flow, the intake is located far enough downriver that the saltwater/freshwater interface (salt front) could move above the City of Poughkeepsie's intake as a result of reduced freshwater inflows or sea level rise. Such a shift in the salt front would cause the supply to no longer meet regulatory standards for drinking water. Historical measurements during periods of low flow on the Hudson River give some indication of the possible movement of the salt front. During the 1960s drought, average freshwater flow as measured at Green Island was only 2,090 million gallons per day (the annual mean is 9,000 million gallons per day), and the salt front was observed at the Poughkeepsie intake (de Vries and Weiss, 2001).¹ See the "Coastal Zones" chapter in this report for additional information on salt fronts (Chapter 5).

Surface water supplies sensitive to short-drought periods are those served by what are called run-of-the-river systems (i.e., where water is pumped directly from the river) within a small drainage basin. A run-of-the-river system has either no storage reservoir or a very small storage reservoir. This design assumes that the minimum river flow always exceeds human demand, plus some required conservation flow necessary to sustain fish and other aquatic organisms and the needs

of any downstream communities or other permitted users (e.g., industries) that rely on the same river.

Of primary concern are communities that use smaller rivers and streams. As a consequence of shifts in the timing of stream discharge (i.e., more discharge in winter time and less in summer time) and reduced frequency of summer rainfall, there may be new lows in streamflow. A brief period of very low water flows could greatly disrupt the habitability of a community relying on a small run-of-the-river supply. Only six water supplies in the state appear to rely solely on a single small stream, and the population served in most cases is below 5,000 people (Cornell University, Village of Warsaw, Village of Saugerties, Village of Herkimer, Village of Carthage, and the City of Hudson). The Cornell University supply is the largest such system and currently supplies about 20,000 people at an average demand of 2 cubic feet per second, with water being drawn from the 126-square-mile Fall Creek watershed in the Cayuga Lake basin. Based on the 84-year historical record for Fall Creek, the lowest recorded flow was 3.3 cubic feet per second in September 1999, slightly more than normal demand. It seems probable that a shift in streamflow timing could lead to periods when demand does exceed supply; however, the Cornell water system has proactively addressed this risk by recently completing an interconnection with a nearby municipality. Without secondary sources, these run-of-the-river systems with small drainage basins are considered to be at risk for occasionally running out of water under conditions of climate change.

Other surface-water systems in New York are those with a reservoir located on a stream or river and fall into the category of sensitive to moderate drought. A reservoir is constructed when the long-term average surface water supply is sufficient to meet long-term average demand but when short-term variations (from months to years, depending on the system) may lead to deficits between supply and demand. For example, runoff is generally much higher in the winter, while demand is much higher in the summer (for uses such as lawn watering, car washing, pools, commercial air chillers). Reservoirs are frequently constructed to store high winter and spring runoff for use in the summer and autumn. Inherently, reservoirs are only designed to extend supply over a dry period of a certain length. All reservoir systems will be stressed if there is a downward shift in their long-term average supply (although this appears unlikely based on the ClimAID and other

climate projections for New York) or a large increase in demand associated with population influx, increased irrigation, or growth of water-dependent industries. Water systems with sufficient reservoir storage will face limited negative consequences even if short-term variations change, as long as the long-term mean inflows and demands remain similar to historical conditions.

There are approximately 40 reservoir systems in New York that each serve at least 3,300 people. These systems range in size from the New York City system, serving more than 9 million (NYCDEP, 2008; p. 34) and consisting of 580 billion gallons of storage, to a municipality such as the City of Mechanicville with a population of 5,000 and less than 100 million gallons of storage. An exact determination of each system's sensitivity to droughts of differing duration cannot be made without a thorough study of each system's infrastructure, demands, supplies, and operational procedures.

To provide a simplified picture of the vulnerability of reservoir systems across the state to droughts of varying durations, we calculated the number of days it would take for the maximum storage volume in a reservoir system to be depleted given historical rates of demand, adjusted down by 20 percent to account for conservation (**Table 4.2**). This approach notably ignores factors such as inflows during the dry period, required discharges to protect fisheries, and the fraction of the total storage volume that is not usable. The days of supply range from 99 to more than 1,000. Most systems with a supply of less than 200 days also have

alternate sources that can provide at least a portion of daily demand. (Note: Days of supply is only intended as a simple metric to allow for comparison across systems of greatly varying size and should not be interpreted as a definitive measure of system resilience to drought.)

Reservoir systems provide a measurable quantity of stored water. With reasonable estimates on the timing of additional inflows, reservoirs can be conservatively operated by adjusting releases long before severe shortages occur. As an example, the Drought Management Plan for the New York City water supply system has three operational phases: drought watch, drought warning, and drought emergency. Different phases lead to different use restrictions. Phases are determined based on the probability that a major reservoir will fail to fill by the end of spring, which is typically when reservoirs reach their maximum water storage. For instance, a drought watch is declared when there is a 50-percent probability that a major reservoir will not be filled by June 1. However, while New York City has a formal protocol for monitoring supply sufficiency, most other water suppliers in New York State operate on an *ad hoc* basis. In conjunction with the New York State Department of Health, the New York State Department of Environmental Conservation tracks drought indicators across the state and issues drought declarations for regions outside of New York City. Individual water supplies may have more or less stored water per capita than suggested by these types of general drought declarations; in any case, it is up to individual water suppliers to decide how stressed their actual systems are and whether to implement appropriate management responses to these conditions. Water suppliers with limited technical resources or insufficient risk aversion in their operating procedures may fail to reduce releases to a point where an imminent shortage is unlikely.

New York City Water Supply System

The New York City water supply system supplies nearly half the state population with water. The system consists of 18 supply reservoirs located in three different drainage basins: the Delaware River, the Hudson River, and the Croton River. Located up to 125 miles north of New York City, the reservoirs are connected to the city by three aqueducts. In the last five decades (since the completion of the current upstate reservoir system in the early 1960s), drought

Municipality	Demand (million gallons/day)	Storage (million gallons)	Secondary Source	Days of Supply w/ No Inflow
Ithaca	3.3	261	Yes	99
Oneonta	1.5	140	Yes	117
Beacon	2.3	218	Yes	118
Ilion	1.97	225	Yes	143
Rome	9.5	1,419	No	187
Colonie	10.4	1,797	Yes	216
Plattsburg	2.3	457	Yes	248
Guiderland/Watervliet	7.3	1,700	Yes	291
Fredonia	1.4	335	No	299
Albany	18.5	13,500	No	912
Troy	14.4	12,912	No	1121

Note: Storage volume information was taken from a USGS inventory of large dams in New York and from a New York State Department of Health (1974) report

Table 4.2 Average daily demand, total storage, and approximate days of supply for a sample of reservoir systems in New York State

emergencies have been declared for New York City in 1962–65, 1980–82, 1985, 1989, and 2002 (DeGaetano, 1999). The most severe was the 1962–65 drought. Based on the rain gauge in Walton (Delaware County), annual precipitation was at least 10 inches below normal for three consecutive years during the early 1960s. Paleoclimatological reconstructions in the region dating back several centuries (Leathers et al., 2008; Zhao et al., 2010) suggest that droughts similar to that of the 1960s have historically only occurred on average every 100 to 200 years and thus originate in very out-of-the-ordinary conditions likely related to changes in sea surface temperature patterns (Koster et al., 2009). Since it is not yet known whether the sea surface temperature patterns (and perhaps other factors) that likely underlie rare droughts will become more or less frequent in the coming century, it remains difficult to project changes in these drought events that occur once per 100+ years.

Even without considering changes in available surface water, other complicating factors in the New York City water supply systems could stress the available water supply in the coming decades. For instance, the New York City water supply system diverts water from the Delaware River Basin, which is also the drinking water source for the cities of Trenton and Philadelphia as well as many smaller communities in New Jersey. Operating rules that are responsive to water levels in the Delaware River require specific discharge rates from New York City's reservoirs into the river in order to maintain minimum river flows. Different declared drought phases allow for decreased releases downstream but also reduce the maximum diversion to New York City, requiring greater reliance on Catskill and Croton sources. The releases to the Delaware River during periods of dry weather are in large part intended to ensure that the Delaware River salt front remains below the Philadelphia water intakes and areas of recharge of New Jersey wells. Rising sea levels associated with climate change could result in a need to increase the minimum required discharge from New York City water supply reservoirs during droughts, in order to keep the salt front at a safe position relative to drinking water supplies (although such a change could require modification of a 1954 U.S. Supreme Court decree on water sharing in the Delaware River Basin). Thus, even if droughts per se do not become more severe, other factors such as sea level rise could put indirect pressures on the New York City water supply system.

New York City is currently undertaking an extensive modeling effort to better understand possible water supply (as well as water quality) challenges in a changing climate, including the implications of sea level rise. Also, as a preventative measure, the New York City Department of Environmental Protection has aggressively worked to reduce water demands—effectively enlarging the system storage—and is seeking other means (such as regional interconnections and groundwater storage) to increase system reliability (NYCDEP, 2008; Major and O'Grady, 2010).

Groundwater Supplies

Groundwater sources can be categorized in the same way as surface water: sensitive to short droughts (two months) and longer, sensitive to moderate droughts (six months) and longer, and relatively insensitive to any droughts. As with annual streamflow, average annual recharge (the amount of groundwater replenished from surface water sources) is considered to remain approximately the same with climate change, but there may be changes in yearly timing of recharge. Additionally, compared to studies of surface water, studies that assess groundwater recharge under a changing climate remain scarce, and there is a considerable amount of uncertainty surrounding the assumption of no change in recharge.

Municipal-scale groundwater systems generally only exist in areas overlying high-yielding glacial sediments, such as the Long Island aquifers. Coarse glacial sediments have a large capacity to transmit and store water, unlike bedrock or finer-textured silt and clay deposits that underlie other areas. These glacial sediments act as an underground reservoir, accumulating and storing water during periods of recharge. Drier soil moisture conditions during the summer and autumn, however, may reduce annual recharge. But decreases in recharge under a changing climate would likely be minimal since the majority of recharge to aquifers occurs during the late winter and early spring and not in the summer. A comparison of methods to estimate recharge in an upland watershed in central Pennsylvania (Risser et al., 2005) found that at most 10 percent of annual groundwater recharge traditionally occurred in July and August. Thus, a complete loss of this summer recharge under changing climate conditions would only reduce annual groundwater supplies by a limited amount, and wetter

springs may be able to compensate for these summer declines, as suggested by a recent study in southern Ontario, Canada (Jyrkama and Sykes, 2007).

Long Island Aquifers

Nearly 3 million people in New York State rely on Long Island aquifers as a source of water. Long Island consists of deep, highly permeable (porous) glacial deposits. The high permeability leads to ready infiltration of precipitation, with a sizable portion of precipitation contributing to groundwater recharge (in comparison to less than 10 percent in many other areas that are representative of New York State [Risser et al., 2005]). Since infiltration and groundwater recharge occur over nearly all pervious surfaces, the entire surface area of a region can act to capture precipitation for human use in these systems. Furthermore, the deep deposits provide a large storage volume for water. In brief, the geology of Long Island makes it highly efficient at collecting and storing precipitation.

The Long Island groundwater system consists of a large pool of stored water plus a smaller fraction of water that cycles through the system and ends up as stream discharge, subsurface ocean outflow, or well water. This actively cycled water consists of the annual recharge and is equivalent to precipitation minus runoff and the loss of water from evaporation from the soil and transpiration from plants. As long as water users only draw from the annual recharge, the stored water amounts do not change and water use for drinking water remains sustainable.

Currently, approximately 400 million gallons of water per day are withdrawn from about 1,000 municipal and industrial wells in Nassau and Suffolk counties. Prior to extensive development on Long Island, groundwater was replenished at a rate of 1,100 million gallons of water per day each year—nearly three times greater than current annual demand. The addition of sewers to reduce pollutant loading to groundwater decreased recharge by nearly 240 million gallons per day between the 1960s and 1980s, lowering water table levels (Busciolano, 2005). Annual demand, however, still remains far below annual recharge (about half). This is in contrast to regions in the western United States where water is knowingly “mined” (with demand consistently exceeding recharge) and where groundwater levels continually decline each year.

Climate change has the potential to further reduce recharge rates. However, the primary impact of reduced recharge thus far has been to reduce streamflows. The 240-million-gallons-per-day reduction in groundwater recharge due to the addition of sewers led to a significant decrease in streamflow (reduced by 135 million gallons per day). According to long-term measurements, streamflows in Long Island streams and rivers have declined as levels of groundwater recharge in developed areas have decreased. Several streams in Kings and Queens Counties have all but dried up and others have just a fraction of their predevelopment flows. However, a decrease in streamflow has no direct impact on the reliability of water supplies, as long as wells are significantly deeper than the streambeds (Buxton and Smolensky, 1998).

The possibility of saltwater intrusion adds an additional complication to considering the resiliency of Long Island aquifers to climate change. Fresh water overlies salt water in the Long Island aquifers. When the water table elevation is greater than the ocean surface elevation, the fresh water can resist the inward and upward push of the more dense salt water. However, near the shoreline, where the land surface and water table elevations approach the ocean elevation, the denser salt water pushes into the freshwater aquifer at a relatively shallow depth. Thus, if water tables decline, near-shore wells that currently extend into fresh water may start to withdraw the intruding salt water. This impact would primarily be felt by shoreline communities. For example, a study of the North Fork of Long Island (a narrow peninsula that is representative of much of the shoreline area of Long Island) found that a 20-percent reduction in the historical groundwater recharge rate, combined with a 20-percent increase in the pumping of groundwater over a five-year drought period, could result in saltwater contamination of multiple well fields (Misut et al., 2004). Sea level rise will further increase the risk of saltwater contamination, especially under a worst-case scenario of approximately 2 meters of sea level rise by 2100 (see Chapter 1, “Climate Risks”).

Other Primary Aquifers

Several cities in New York overlie large aquifers that provide the municipalities’ primary water source. Many of these aquifers are located in valley bottoms with extensive glacial deposits. These include aquifers

associated with the Susquehanna River (Johnson City and Endicott), the Chenango River (Elmira, Corning, and Bath), the Mohawk River (Schenectady), the Tioughnioga River (Cortland, Homer, and Preble), and Cassadaga Creek (Jamestown). These systems have been particularly well studied, since three of the five (all but the Cassadaga Creek and Chenango River aquifers) have been designated as sole source aquifers. The U.S. Environmental Protection Agency (USEPA) designates a sole source aquifer as one that supplies at least 50 percent of drinking water to a population, with no alternative source.

To provide a sense of the possible vulnerability, **Table 4.3** summarizes the ratio of storage to demand for four large aquifers in New York State. Aquifer systems with low daily demands relative to daily recharge rates and storage capacities are less vulnerable than those that have relatively high or near-equal daily demands. Jamestown, Endicott/Johnson City, and Cortland regions all have extensive storage relative to demand. However, in some cases, available storage does not entirely indicate the availability of water. Schenectady/Mohawk has limited storage, but much of the well water inflow is from induced infiltration of Mohawk River water. The average August flow (the lowest monthly discharge of the year) on the Mohawk River at Cohoes is 1,176 million gallons per day, so daily demand (26 million gallons per day) constitutes a small fraction of available water even during dry periods.

Numerous smaller aquifers serve many additional communities throughout the state, many of which are villages in rural areas. Well water has traditionally been preferable to many surface water sources, since it typically requires less treatment to be suitable for human consumption and it does not require construction of a reservoir. Rapidly developing areas outside of cities and towns also tend to rely on groundwater resources, since doing so avoids the political and regulatory complications of developing new surface water supplies. Approximately 79,000

people in Orange County and 200,000 in Rockland County rely on groundwater.

However, the groundwater supply is linked to, and limited by, the land area over which recharge occurs. As development intensifies, demand can exceed supply both due to the density of settlement and by an increase in runoff and associated reductions in recharge. This trend could be potentially exacerbated by climate change in smaller aquifers with limited recharge.

Homeowner Wells and Small Community Water Systems

Approximately 1.9 million people rely on household well water throughout New York State (Lumia and Linsey, 2005), and several hundred thousand others are connected to small public water systems that rely on wells. Residential wells range from low-yielding wells (such as those in glacial till or deep bedrock) to high-yielding wells (>5 gallons per minute) in sand and gravel fill. Wells also range in depth, from shallow dug wells to very deep bedrock wells.

Although recently drilled wells must be registered with the New York State Department of Environmental Conservation, well owners are ultimately responsible for ensuring that their wells can supply sufficient water. Most wells are tested for their average yield at the time of installation; however, this may not be representative of water availability during dry periods. Due to the large number of wells serving individuals or small populations and the unique hydrogeologic conditions at each well, it is difficult to make any predictions concerning the populations that are particularly sensitive to the types of drought periods that may increase with climate change.

As a simple illustration of existing well sensitivity to water depletion, we analyzed long-term records of several unpumped wells routinely monitored by the U.S. Geological Survey (USGS) in New York State.³ Of the

System	Daily Demand (million gallons/day)	Daily Recharge (million gallons/day)	Well Field Storage (million gallons)	Days of Supply with No Inflow
Jamestown – Cassadaga Creek (Crain 1966)	4.8	30.1	3,000	625
Schenectady – Mohawk River (Winslow et al. 1965)	26	15 (plus Mohawk River infiltration)	500	19
Endicott/Johnson City – Susquehanna River (Randall 1977)	16	41	1,700	106
Cortland Homer Preble – Tioughnioga River (Miller 2004)	6.5	24	>1,000	~150

Table 4.3 Summary of major New York aquifer systems, including demand, recharge, and storage²

four wells, one would likely have gone dry sometime during the 18 years that observations were available. Thus, inter-annual variability within the current climate can already impact groundwater levels. In addition to individual homeowner wells, several small community well systems in New York (such as those associated with mobile home parks) have historically gone dry in years with severe summer droughts. However, temporary alternative supplies can typically be arranged (e.g., by trucking in water or drawing from a nearby surface water source). Groundwater levels can also be strongly influenced by excessive pumping in areas with continued development, resulting in the need to drill existing wells deeper. In these areas, climate change may exacerbate water supply shortfalls.

Summary of Water Supply Issues

This summary provides an inter-comparison of potential vulnerabilities in drinking water supplies across the state, giving perspective on how limited resources could potentially be targeted to build resilience to climate variability and change. **Table 4.4** lists each water source category discussed in the preceding section, identifies the categories' sensitivity to climate change, and highlights the population served by each source. Sensitivity to climate change is related to the length of drought that a water system could endure without being severely stressed, as estimated from system storage and demands. Systems with low sensitivity have sizable storage relative to demand while systems with high sensitivity have minimal storage relative to demand.

Category	Sensitivity to Climate Change	Population Served
1 Withdrawal from large water bodies	Low	2,000,000
2 New York City system	Moderate	9,300,000
3 Other reservoir systems	Moderate	1,300,000
4 Run-of-the-river on small drainage	High	62,000
5 Long Island groundwater	Moderate	3,200,000
6 Other primary aquifers	Moderate	650,000
7 Homeowner well water	Moderate to high	1,900,000
8 Other small water supply systems (groundwater/surface water)	Moderate to High	600,000
Total		19,012,000

Note: Water supply sensitivity is related to the length of drought that a water system could endure without being severely stressed, as estimated from system storage and demands. This analysis is only intended to provide a general assessment of vulnerability within broad categories. Ultimately, individual water supply systems would require system-specific analysis.

Table 4.4 Vulnerability of water supplies in New York State to climate change

The least vulnerable populations to climate change are those that draw from larger water bodies such as the Great Lakes, Finger Lakes, or large rivers (category 1). Most of the state's population has a water supply that falls into the category of moderate sensitivity to climate change. Reservoir systems (categories 2 and 3) and major aquifers (categories 5 and 6) are presumed to have moderate sensitivity because while most systems do have sizable stores, these stores are still finite. The determination of sensitivity to climate change for a wide array of systems in New York is a broad generalization; the actual sensitivity of individual systems will depend on many factors, including management.

Systems with little storage are likely to be the most sensitive to an increase in droughts that may be experienced in New York State. Run-of-the-river systems on small streams (category 4), shallow wells (a portion of category 7), wells in only moderately productive aquifers (a portion of category 8), and systems with small reservoirs relative to demand (a portion of category 8) will be the most affected by climate change.

4.3.3 Water Availability for Non-potable Uses

Hydroelectric generation is already a primary user of water resources in the state. However, agriculture may start to require a larger share, and there are other emerging uses of water, such as for natural gas well development and for supporting possible shifts in national population. This section primarily considers possible changes in demand for non-potable water brought on at least in part by climate-related factors.

Hydroelectric

Hydroelectric power plants in New York State supply about 15 percent of the state's electricity during a typical year, about twice the national average. Of the 5,800-megawatt capacity of the state's hydro facilities, 3,400 megawatts of the capacity comes from facilities on the Niagara and St. Lawrence rivers. The next-largest facility is the 1,000-megawatt Blenheim-Gilboa pumped-storage plant on Schoharie Creek used for generating power during peak demand periods. The remainder of the 1,400-megawatt generating capacity comes from approximately 150 small facilities spread across the state. Due to the unique facilities and operating conditions at these small plants and the

minimal information available for them, this analysis only addresses the large facilities.

The Blenheim-Gilboa facility recycles much of its water by simply transferring water between an upper and lower reservoir. Since its water is reused, the plant is only minimally impacted by climate change. The three hydro facilities on the Niagara and St. Lawrence Rivers are unique in that they rely on discharge from the 29,000-square-mile Great Lakes Basin. Although Lake Ontario and its drainage basin comprise only 10 percent of the total Great Lakes Basin, Lake Ontario acts as a conduit, discharging the accumulated flow of the upper Great Lakes. Any changes in water supply throughout the entire Great Lakes Basin will, therefore, result in a change in water levels in Lake Ontario. As discussed more extensively in the case study in Chapter 8 (“Energy”), several studies suggest there is a likelihood for a future decrease in the Great Lakes’ water levels and discharge. This would result in a decline in power production. However, a shifting of some water currently allocated for recreational use could buffer possible losses in hydropower production. Thus, changing water availability may require new discussion of a reasonable balance among competing uses of a water source.

Thermoelectric Withdrawals

Cooling water at power generation facilities constitutes the largest water withdrawal in New York (but not consumptive use), withdrawing more than 4,000 million gallons per day (Lumia and Linsley, 2005). When considering the 20 largest thermoelectric power facilities in the state, much of this withdrawal is non-consumptive, and all of the large facilities draw from large water bodies in which the withdrawn water is a small fraction of the total flow or volume (DOE Energy Information Administration Report 869). These water bodies include Lake Ontario, Lake Erie, Long Island Sound, the Hudson River, and the East River. Most facilities use low-consumption, once-through cooling in which water is returned to the same water body at a higher temperature. This method consumes very little water, but the discharged water can be upwards of 95°F in the summer (based on DOE Energy Information Administration Report 767). Although the temperature of the discharged water will not be markedly affected by climate change, this additional heat load, in combination with higher ambient water temperatures in the receiving waters, may result in additional stress to aquatic organisms.

The Nine Mile Point and James A. Fitzpatrick nuclear plants located on Lake Ontario do use water consumptively with wet cooling towers that function through evaporation. Based on water consumption factors reported by Feeley et al. (2008), these plants consume around 30 million gallons per day, a negligible fraction of Lake Ontario water.

Agricultural Water Use

In most environments, rain-fed agriculture is inherently risky. Even on the best lands in the state, crop yields currently vary by as much as 60 percent from year to year, in part because of the damaging influence of mid-summer droughts. At present, only 2.5 percent of the cropped acreage in New York is irrigated (NASS-USDA, 2002). However, as discussed in Chapter 3 (“Equity and Economics”) and Hayhoe et al. (2007), projected increases in the frequency of summer drought may increase the water requirements to obtain optimal crop production in some years. These issues are discussed more extensively in Chapter 7 (“Agriculture”).

If economic factors in a changing climate favor expanding irrigation in New York State, key elements to enable or inhibit expansion in different regions of the state will be the proximity of arable land resources to stable water supplies and potential conflicts with other users. The types of water supplies used to feed irrigation dictate their reliability. Namely, unlike most drinking water supplies that have a source of storage (e.g., a reservoir), most irrigation currently draws directly from rivers and streams, and this approach would be unlikely to change given the costs and regulatory difficulties of constructing new reservoirs. As discussed in the water supply section above, these run-of-the-river type withdrawals that have no storage are sensitive to short-term variations in discharge. Other than on the largest water bodies, periods of agricultural drought would be likely to correspond to periods of low flow on streams and rivers that would be the most available sources of irrigation water.

Natural Gas Drilling in Deep Shales

An emerging consumptive water use in the region stretching from the Finger Lakes east to the Hudson River and south to the Pennsylvania border may be the drilling for natural gas in deep shale formations such as

the Marcellus, which currently requires a hydraulic fracturing process. Hydraulic fracturing involves pumping water down the wells at high pressures to open up fractures through which trapped natural gas can be extracted. As much as 7 million gallons of water may be required to hydraulically fracture a well. The Susquehanna River Basin Commission, which in 2008 permitted the withdrawal for all consumptive uses of 563 million gallons per day of water from the Susquehanna, estimated that, at its peak, gas well drilling would consume 28 million gallons per day (5 percent of the total current allocation). While hydraulic fracturing is not likely to be a sizable use relative to the entire supply of basins in New York State overlying the Marcellus shale, withdrawals will not be spread uniformly across a basin and intensive withdrawals from smaller headwater streams may lead to localized low flows if not managed properly. It is important to ensure that these withdrawals do not affect established users (such as public water suppliers) and ecosystem services and that the potential impact of climate change on low flows is accounted for in the permitting process.

Other Competing Uses: A Shift from the West?

Severe water shortages in western states, which are likely to become worse with climate change, may shift populations to eastern states, including New York. If so, New York could experience new population and economic growth with an associated increased demand for water. There is a relatively strong likelihood that the Colorado River Basin will experience a decline in river flows in the future (Rajagopalan et al., 2009; Barnett and Pierce, 2009). The Colorado River provides water to more than 27 million people in seven states, including high-growth regions such as Nevada, Arizona, California, and Colorado. One study suggests that even if demand remains steady, there is a 58-percent chance of shortage by 2050 if the minimum expected decrease in runoff of 10 percent occurs as a result of climate change (it is likely that the decrease in runoff will be larger) (Barnett and Pierce, 2009).

Additionally, water rights conflicts and depletion of groundwater are already affecting agricultural production from California to the Corn Belt. The Ogallala Aquifer, which supplies irrigation water for 10 midwestern states, has been drawn down more than 100 feet in many places. The East is the only region of the United States that is likely to experience an increase in

the summer rainfall that is vital to crop production (IPCC, 2007), potentially requiring less supplemental irrigation water than in other places to maintain maximum production. There are more than 1.5 million acres of idle or underused agricultural lands in New York State, and approximately 65 percent of the entire state is forested. Coupled with longer growing seasons, there is some possibility new agricultural land could be brought into production and that agricultural water demands could increase.

4.3.4 Water Quality

Climate could affect water quality, both directly and indirectly. Warmer temperatures tend to lower water quality directly. Changes in precipitation that result in more frequent low-flow periods in the summer may impact permitting for point discharges of pollutants that are discharged into surface water. Climate change also could lead to changes in non-point-source pollution associated with changes in land use, including a possible increase in the amount of land used for agriculture if yields in western U.S. states decrease due to water shortages (see section 4.3.3).

Combined Sewer Overflow and Non-point Source Pollution

In many older cities, a single sewer line is used to convey both sanitary sewage and stormwater to a wastewater treatment plant. During periods when there is little rain, the sewer and treatment plant have the capacity to handle incoming flows. However, when there is sizable rainfall, the capacity of the sewer and treatment plant is frequently exceeded, and the mixture of sewage and storm runoff is released into nearby waterways to keep the sewer from backing up and flooding basements or streets. These discharge events are referred to as combined sewer overflows. As would be expected, this sewage contains pathogens (disease-causing agents), excess nutrients (nitrogen and phosphorous), metals, and large debris that can harm aquatic organisms as well as curtail recreational use of waterways. In New York State, more than 60 municipalities have sewage systems that generate combined sewer overflows, and most are located in major cities (NYSDEC, 2008). The City of Rochester has greatly reduced these events; the cities of Buffalo and Syracuse are in the process of implementing mitigation plans. Cities on the upper

Hudson (Albany, Cohoes, Green Island, Troy, and Rensselaer) and New York City are still in the process of developing mitigation plans. **Figure 4.7** indicates communities in New York with combined sewer systems.

The degree to which combined sewer overflows may increase in frequency in a changing climate is dependent on the rainfall threshold at which a combined sewer overflow is initiated in a given sewage system. For instance, the City of Rochester reduced combined sewer overflows by constructing 34 miles of 12-to-16-foot diameter tunnels that can store sewage until it can be treated. While these tunnels will store the combined sewage generated by most rainfall events, Environmental Protection Agency regulations allow up to four combined sewer overflow events per year. An EPA study of the upgraded systems concluded that daily combined sewer overflow discharges could increase by 50 percent with climate change due to two additional large storm events (USEPA, 2008). However, as is often not clearly noted, this 50-percent increase assumes that only four combined sewer overflows currently occur each year.

In contrast, in combined sewage systems that have had no upgrades, a combined sewer overflow can be initiated with little rainfall, and upwards of 50 combined sewer overflows may already occur per year in certain locations. We reviewed design reports assessing sewer systems in the Harbor Brook watershed in Syracuse and in a portion of the Gowanus Canal watershed in Brooklyn. For the Gowanus Canal watershed, simulations predicted 50 combined sewer overflow

events each year (Montalto et al., 2007). For the Harbor Brook watershed, modeling predicted 58 combined sewer overflow events each year. In these cases, two additional large rainfall events each year due to climate change would only slightly increase the total number of combined sewer overflow events.

Besides sewer overflows, pollutants enter waterways from other sources. In particular, precipitation falling onto urban or agricultural land can pick up pollutants and transfer them to surface waters. However, with climate change, changes in discharge are not likely to be dramatic enough to greatly alter existing pollutant loads. In watersheds with little impervious surface, such as on agricultural land, the largest increase in intense rainfall events could occur during the warm season, when soils would be relatively dry and runoff would be limited. Additionally, as discussed previously in terms of water supply, annual average discharges are projected to only increase slightly.

Even in urban areas with impervious surfaces where runoff is more directly linked to precipitation, increases in pollutant loading would likely be limited because pollutant loads mainly depend on total runoff volume and only weakly on the intensity of runoff or precipitation (Sartor, 1974; Alley, 1981; Shaw et al., 2010). Furthermore, as mentioned earlier, more high intensity rainfall events would reduce the number of moderate events, likely leading to fewer total rainfall events. While speculative, if the interval between storms did increase in the future, this could result in a decreased summer frequency of acute pollution events, such as those that cause beaches near urban areas to close due to high pathogen levels. A Natural Resource Defense Council report on beach water quality notes that year-to-year decreases in beach closings are often associated with a shift from a wetter to a dryer year (Dorfman and Rosselot, 2009).

Impacts of Increased Water Temperatures

Increased water temperature can directly stress aquatic biota, in particular coldwater fish species such as trout. Warmer water also holds less dissolved oxygen (DO). Water bodies that are near the threshold for being DO limited, even for non-trout species, may drop below a critical point more often with climate change. For a water body with a mean summer stream temperature of 68°F, a 9°F increase in mean summer temperature could

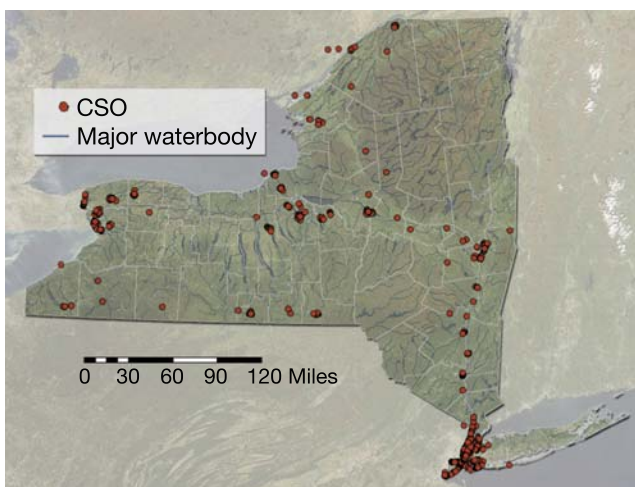


Figure 4.7 Communities with combined sewer overflow (CSO) systems in New York State

result in a 7-degree increase in temperature and a change from 9.1 milligrams per liter DO saturation to 8.4 milligrams per liter DO saturation (USGS TWRI Book 9). Streams that already experience oxygen depletion (the potential for DO depletion is measured as biological oxygen demand, or BOD) will start from a lower saturation point and may more frequently reach DO levels that are detrimental to aquatic organisms.

Increasing temperatures may also have both direct and indirect effects on nutrient export from watersheds. Indirectly, as mentioned earlier, factors such as changing water availability in western farming regions may lead to increased agricultural land use in New York State. In a study of Lake Michigan basins, Han et al. (2009) predicted that the presence of nitrogen in rivers could increase by up to 24 percent with climate change and expansion of corn acreage. In terms of direct impacts of temperature increases, Schaefer and Alber (2007) found that 25 percent of anthropogenic nitrogen inputs in northeastern U.S. watersheds reached coastal waters but only 9 percent of inputs in southeastern watersheds reached the coast. They hypothesize that higher temperatures in southeastern watersheds encourage gaseous loss of nitrogen to the air and decrease nitrogen loss to water bodies, and therefore reduce water pollution. Other studies have indicated that wetter conditions over the long term may increase nitrogen loss from watersheds to water bodies (Howarth et al., 2006). Thus the degree of change in nutrient loss from watersheds remains uncertain, since the outcome is dependent on several processes (land use change, temperature change, and soil moisture change) that may counteract each other.

Increased water temperatures are also sometimes associated with greater pathogen survivability in water. However, there does not appear to be a single general conclusion that can be drawn about the potential impact of climate change, since pathogen viability varies widely among organisms and is also influenced by other environmental conditions. Brookes et al. (2004) note that *Cryptosporidium parvum* (*C. parvum*) viability decreases with increasing temperature and that while freezing can kill *C. parvum*, ice cover formation on lakes only affects a small fraction of the stored water volume. A study of *E. coli* concentrations at 23 Chicago beaches noted that *E. coli* increased as temperature increased, but found that other factors, such as wave intensity, were also important in explaining variations (Whitman and Nevers, 2008). From a study of the occurrence of

Vibrio cholerae (the cause of cholera) in the Chesapeake Bay, *V. cholerae* was found up to 10 times more frequently when water temperature was greater than 66°F than when below 66°F, but this also depended on salinity levels (Louis et al., 2003).

Finally, increased temperatures may also lead to increased algal growth in water bodies (French and Petticrew, 2007) as well as increased dissolved organic matter transported from soils and wetlands (Futter and Wit, 2008). Besides impairing recreational use and normal ecosystem function, this increased organic matter may result in increases in the concentration of disinfection byproducts (DBP) in drinking water (potentially harmful chemicals that form when chlorine added to kill pathogens reacts with organic matter). However, DBP formation is dependent on a number of variables (Chowdhury et al., 2009), and there is still limited definitive evidence whether DBP would significantly increase in a changing climate.

Wastewater treatment plants remove the vast majority of, but not all, pollutants in sewage. Federal regulations for sewage treatment balance water-quality objectives against what can be achieved with cost-effective technology. Most wastewater treatment plants (WWTPs) in New York receive a “general” State Pollutant Discharge Elimination System (SPDES) permit that allows them to discharge effluent with a biological oxygen demand (BOD) of up to 30 milligrams per liter (background in-stream BOD is around 1 milligram per liter). High BOD in a water body depletes dissolved oxygen levels, stressing fish and other aquatic organisms. The addition of BOD in a water body results in a decrease in stream-dissolved oxygen near the effluent point and an eventual recovery in stream-dissolved oxygen farther downstream from the discharge point as stream water mixes with air (reaeration). Increased temperatures could increase the rate at which BOD (and, consequently, dissolved oxygen) is consumed (Huber, 1993). But increased temperatures could also increase the rate of reaeration, the rate at which dissolved oxygen is reintegrated into the water from the air (Huber, 1993). While BOD consumption and reaeration push dissolved oxygen levels in opposite directions, BOD consumption is generally assumed to be more sensitive to temperature than rates of reaeration. Therefore, with the same amount of BOD released to a river at a higher temperature under a changing climate, more rapid BOD (and dissolved oxygen) consumption could decrease dissolved oxygen

concentrations below current levels, although dissolved oxygen depletion would be limited to a shorter section of river.

Among the 100 water bodies in New York listed as having “impaired” water quality, 26 were noted as being impaired due to low dissolved oxygen (NYSDEC, 2008). Many were in the lower Hudson region or in urban areas of central New York. Most of the impaired water bodies were not associated with WWTP discharge but with non-point source loads, suggesting most of the thousands of WWTPs throughout New York do not currently have a strong impact on stream-dissolved oxygen under normal stream flow conditions. Presumably, an increase in temperature by only several degrees would not result in a dramatic increase in point-source-related dissolved oxygen depletion in waterways.

Impacts of Decreased Flows

Climate change will not only increase stream water temperatures but also potentially result in decreased stream flows, particularly during the summer when stream flow is already at its lowest for the year. At low-flow levels there is less dilution and the pollutant concentration is effectively higher. For water-quality-based SPDES effluent permits (issued in place of a general permit when the water body has an obvious impairment related to the pollutant for which a release permit is being sought), the in-stream concentration of the emitted pollutant is determined from the dilution capacity of the seven-day, ten-year return period of low-flow (which are based on data from the 1940s to 1975). Thus, decreases in low-flows may require reconsideration of these water-quality-based permits as well as a reconsideration of which facilities should still receive general SPDES permits. There are no direct means for estimating low-flows in streams across New York State under a changing climate. Existing regression models for predicting low-flows do include mean annual rainfall as a predictor (Ehlke and Reed, 1999), but the relationships behind these regression models were established from historical records (Eissler, 1979) and do not reflect possible changes in the frequency and size of summer storm events likely with climate change. More accurate predictions of low-flows will only be possible with a better understanding of how the temporal distribution of rainfall will likely change in the future.

4.4 Adaptation Strategies

A variety of adaptation strategies is possible for the water resources sector. Potential strategies span a range of temporal and spatial scales and system-level adjustments.

4.4.1 Flood Adaptation Strategies

As part of an ongoing effort to improve water quality, federal stormwater management regulations under the National Pollutant Discharge Elimination System stormwater program—applicable to both large and small communities—are in the process of being implemented. When retrofitting existing developments and designing new developments, a continued emphasis should be placed on encouraging cost-effective stormwater-management infrastructure that enhances natural hydrologic processes (infiltration into soils, recharging groundwater, evaporation) and slows the movement of stormwater instead of rapidly conveying it to water bodies.

Due to multiple interacting factors (snowmelt, rainfall amount, ability of soil to store moisture, evaporation rates), changes in flooding in large, rural-to-forested basins is uncertain. However, because of the steep slopes, convergent topography, and narrow valley bottoms, the Chemung, Susquehanna, and Delaware River basins have historically been subject to damaging floods. Consideration could be given to moving development out of floodplains as buildings, infrastructure, and flood-protection structures age and it becomes time to rebuild. This strategy of phased withdrawal from the highest-risk, flood-prone areas is currently recommended by the National Association of Floodplain and Stormwater Managers and was publicly endorsed by the New York State Department of Environmental Conservation commissioner at the 2008 Flood Summit.

In particular, wastewater treatment plants within floodplains may require a more thorough examination, even with a limited degree of change in flood risk. A brief interruption of operations during infrequent floods may be acceptable (high floodwater would dilute and rapidly transport discharge from the plant), but floods that routinely interrupt operations for an extended time pose a risk to public health as well as water body health. Many wastewater treatment plants are located in

floodplains, since this often coincides with a topographic low point in a municipality and sewage can be conveyed to the plant by gravity. Relatively simple siting modifications or the raising of the facility by several feet may prevent severe inundation and entail little additional cost if incorporated at the time of construction. Since many aging wastewater treatment plants are in need of replacement, the possibility of moving a plant out of the floodplain should be considered when new facilities are designed.

4.4.2 Drinking Water Supply Adaptation Strategies

Many reservoir systems lack the type of formal operating rules that are useful for mitigating the risk of shortages. Accordingly, one adaptation strategy that would be useful for managing current and future climate risks would be to require public water suppliers to establish “rule curves” for water supply reservoirs and aquifers (e.g., a rule curve sets specific guidelines for reservoir releases given the amount of stored water at different times of the year). Currently, New York City is one of the few entities in the state that has a drought-response plan triggered by set water-related thresholds. For the rest of the state, the New York State Department of Environmental Conservation, in conjunction with the New York State Department of Health, determines when to make regional drought declarations. Ultimately, local municipalities are responsible for avoiding shortages based on their own judgment and operational practices. The development of rule curves would provide a systematic, unbiased protocol for managing water supplies under current and future drought.

Additionally, while there are numerous stream gauging stations throughout New York, there are few routine measurements of reservoir, aquifer, or lake levels. Consideration should be given to developing an automated gauging network or, at a minimum, a formal reporting network (e.g., routine manual measurements submitted to a central online clearinghouse) of water levels in public water supply reservoirs and aquifers. This would provide the basis for an improved, statewide early-warning system for recognizing supply shortages, while also establishing a long-term record for better understanding the link between the hydrology of specific watersheds and climate.

Nearly 4 million people in the state rely on homeowner or small public water systems. These individual homeowners or small water utilities may lack the expertise or resources to make proactive decisions prior to running out of water. However, due to the dependence of such small systems on localized conditions, it is unlikely these systems will fail simultaneously or that all systems in a given geographic region will run dry. Given that failures are likely to be small and localized, there should be sufficient resources to assist in developing temporary alternate water sources, either by trucking in water or by tapping a nearby store of surface water. The New York State Department of Health currently maintains a stockpile of equipment (mobile pumps, water tanks, filters, etc.) that can be used by municipalities to assist in supplementing critically low water supplies. Given the potential vulnerability of small water supply systems to climate change, the New York State Department of Health should consider updating and possibly enlarging its stockpile of drought emergency equipment.

In regions with large or growing populations, a possible adaptation could involve creating new water management commissions to oversee water allocations among multiple competing users. The Delaware and Susquehanna River basins already have such commissions. Basin-level commissions could be established for other major rivers in the state, in particular the Hudson and Mohawk Rivers, where population density and growth are the greatest. Other major rivers (the Genesee River, Black River, and Oswego River/Finger Lakes Region) have fewer users and already fall into the Great Lakes Basin, and so will be subject to some oversight due to the Great Lakes Compact (an agreement among eight U.S. states and two Canadian provinces that will ultimately require more extensive reporting of water use in regions of New York located in the basin). There is already an existing Hudson/Black River Regulating District, although it is tasked with an important, but relatively narrow, set of responsibilities. In the upper Hudson River basin, the Regulating District manages discharge from the Great Sacandaga Lake and Indian Lake (two tributaries of the upper Hudson) in order to reduce flood risks and increase summertime low-flows. This regulation only has a moderate impact on the lower Hudson, since the portion of the Hudson below Troy is dominated by tidal flows rather than freshwater inflows. A Hudson and Mohawk River commission

could more broadly consider water allocations as well as potential water quality impacts within the entire basin.

Finally, across the state the threat posed by less certain water supplies can be most readily addressed by reducing consumption. In addition, measures to reduce consumption can help control possible increases in water demand due to higher temperatures that arise from increased landscape irrigation, opening of fire hydrants, and water use in commercial air conditioning. Comprehensive water conservation plans have already been developed for certain regions of the state (e.g., New York City) as well as other parts of the country; measures often include the use of low-flow showerheads, toilets, and washing machines; limited car washing and lawn watering; and increased use of rain barrels for gardens. New York City's efforts during the 1980s probably served to avoid drought emergencies during the 1990s. From a review of water use data for 40 larger municipalities in the state, per capita water consumption varies between 89 and 237 gallons per day with a median value of 148 gallons per day. In many cases, a large portion of water usage is related to nonessential uses such as landscape irrigation, swimming pools, and car washing. For example, in Rockland County, water demand rises to upwards of 37 million gallons per day in the summer from around 27 million gallons per day during the winter (Haverstraw Water Supply Project, 2009; DEIS, United Water NYS). Thus, if demands must be cut, water usage could be greatly reduced in some locales without directly affecting basic activities related to hygiene and sanitation.

Western states that experience frequent water shortages have experimented with pricing schemes to modify consumptive behavior. An important consideration is the sensitivity of water demand to the price of water. Studies consistently find that increasing the price of water leads to only small declines in consumption (Kenney et al., 2008). This has been attributed to people's general lack of knowledge of water rates, presumably because water bills are such a small percentage of their total annual expenses. A new technology that is currently being evaluated for its ability to raise awareness of water rates and to modify consumer behavior is the smart water meter. These meters allow different rates to be charged when overall system demand is higher. Dubuque, Iowa, will be one of the first cities in the United States with widespread

implementation of these meters (*New York Times*, October 11, 2009, "To do more with less, governments go digital"). A pilot study of smart-meter users in Colorado found that homes with smart meters increased consumption, but they did so by using more water during less expensive periods (Kenney et al., 2008). This suggests that water consumers' behavior is malleable and that with the right pricing structure, overall water use could be reduced.

4.4.3 Non-potable Water Supply Adaptation Strategies

While average annual water supplies are likely to remain at current levels, there may be greater variability in flows throughout the year. Water users with sizable storage capacity (such as most public water supplies) are not likely to be significantly affected by temporary low-flow periods, but water users that depend on run-of-the-river withdrawals (agriculture, power plants, commercial users such as golf courses) may face periods of critical shortages. Thus, it may be important to implement measures to better coordinate water use on shared water bodies. Starting in 2010, the New York State Environmental Conservation Law Article 15 Title 33 will require all water withdrawals that exceed 0.1 million gallons per day to be reported to the New York Department of Environmental Conservation. This will result in more complete information on water usage, in part to comply with elements of the Great Lakes Compact. Consideration could be given to developing a publicly accessible, online system for tracking water usage of all users across the entire state. A complete inventory of water usage across the state will be critical to planning and conflict resolution if competing demands for water usage for drinking water supply, agriculture, energy, industry, export for bottled water, or other uses intensify with climate change. Allocation records are currently maintained by the Department of Environmental Conservation, the Susquehanna River Basin Commission, and the Delaware River Basin Commission; however, a more open system would enhance accountability and potentially allow for more input from additional stakeholders groups (e.g., for recreation and/or ecosystem conservation).

Currently, agricultural, industrial, and commercial users do not need permits to withdraw water in New York State outside the Delaware and Susquehanna River basins. Therefore, water withdrawals from rivers

and streams throughout much of the state are not subject to minimum flow requirements. Given that droughts and, consequently, low-flow periods may become more frequent, establishing minimum flow requirements using biological criteria could help to better determine and permit the maximum amount of water that can be withdrawn from a water body during different times of the year. As mentioned in the drinking water supply subsection, basin-level commissions could be established in areas of the state outside of the Delaware River Basin Commission and Susquehanna River Basin Commission boundaries to implement water allocations. The commissions already have guidelines for determining acceptable withdrawals during low-flow periods, and other possible guidelines have recently been proposed in the generic environmental impact statement related to shale gas drilling in New York State.

Finally, more severe climate changes in other parts of the United States (relative to the Northeast) could shift population growth and water-intensive economic activities from western and southern states to eastern states, including New York. Despite relatively plentiful water resources in the state as a whole, the state's most densely populated regions have few additional water sources with which to meet increased demand. A statewide water plan could provide an overview of which areas of the state have excess existing capacity or, at a minimum, have the potential for the development of additional water resources. Specifically, a statewide water plan could provide guidance to commercial and industrial entities, as well as homebuilders and home buyers, on which communities are most likely and least likely to face water shortages, particularly with the additional stress of climate change.

4.4.4 Water Quality Adaptation Strategies

Nearly all major cities in the state have or are developing plans to address impacts from combined sewer overflows. However, overflows are difficult and expensive to eliminate. For example, the City of Rochester began planning its tunnel system in the early 1970s; implementation took more than 20 years and half a billion dollars (75 percent of the funds were provided by the federal government). Due to the cost and complexity of such infrastructure, recent plans for handling combined sewer overflows have often emphasized the removal or elimination of pollutants

instead of the attenuation of runoff volumes. For instance, Buffalo has implemented systems to capture large, floatable debris and to disinfect the discharges to kill pathogens (Di Mascio et al., 2007). Syracuse is in the process of constructing facilities that store volume from smaller combined sewer overflow events and that disinfect and remove solids from larger-volume events (see Onondaga County Department of Water Environment Protection Documents: www.ongov.net/lake/index.htm).

In terms of meeting regulatory requirements, communities designing to allow only four overflow events per year may need to consider design modifications to ensure this standard can be met in the future, as indicated above (see section 4.3.4) by the USEPA study (2008). Communities planning on using mitigation measures that remove the majority of the pollutant load in the combined sewer overflow likely have systems that can be scaled up without great difficulty, because these systems treat flows, not volumes. Disinfection and primary filtering facilities would have to operate longer or more often during high-flow events, but would not necessarily have to increase in size.

Gaps remain in the scientific and regulatory communities' understanding of certain basic water quality issues related to climate change. There is a clear need to better understand the impact of low-flows and higher temperatures on the pollutant assimilative capacity of streams and rivers in the State. This entails better understanding of the in-stream chemistry at higher water temperatures (the fundamentals are well established but should be evaluated on actual streams) as well as improving means to predict low-flows on streams so that the most-vulnerable streams can be identified. Improving low-flow estimates would require better accounting of the changes in the temporal distribution of rainfall, and in understanding fundamental subsurface geologic characteristics that create differences in low-flows among streams. There has been recent work to develop methods to estimate low-flows on streams with a minimum of two measurements during periods of stream recession (Eng and Milly, 2007) that could be employed on streams in New York.

An additional potential source of deteriorating water quality in the future will be shift in land use motivated by climate-related factors (e.g., addition of new farm land

for biofuels production, unconventional gas well drilling to replace coal). Some of this new development will likely be on marginal land with steep slopes or wet soils, traits that may increase the potential for pollutant generation. Thus there is a need for additional applied research to identify areas that create a disproportionate amount of pollution relative to their size. This research would also allow for more targeted implementation of management measures directed to the critical areas and processes rather than intervening with multiple management options across entire watersheds without regard to the primary pollution source (Garbrecht et al., 2007). For instance, farm-scale research in the Catskills has demonstrated that fencing streams to keep cows out can be as effective at managing water quality as more extensive and costly changes to soil and manure management (Easton et al., 2008).

Potential changes to nutrient, sediment, and pathogen pollution in a changing climate are difficult to predict due to multiple interacting processes and other drivers of change, including urbanization and agricultural intensification. Currently, there is sparse and infrequent pollutant sampling, which limits our ability to separate the impact of the climate and changing land use on water quality. As a starting point, frequent monitoring of primary nutrients, turbidity, and pathogen indicators on major rivers (Chemung, upper Susquehanna, and Delaware) would enable a clearer picture to emerge of the associations among climate factors, land use, and water quality in New York State at a large spatial scale. This effort could integrate with ongoing work to manage nutrient loads in the Chesapeake Bay Region.

4.5 Equity and Environmental Justice Considerations

The anticipated impacts of climate change on livelihoods and ecosystems will be distributed unevenly, depending both upon changes in physical parameters and institutional and socioeconomic conditions that influence local capacity to adapt. Efforts to manage the effects of climate change may create new patterns of winners and losers, further emphasizing the need to consider social equity in adaptation planning.

Equity and environmental justice issues are likely to arise with regard to local management capacity, adaptive flood management, and water supply and

quality. Because water resources are closely coupled to other sectors, particularly coasts and agriculture, a number of equity issues overlap and are addressed in more depth elsewhere (see Chapters 3, 5, and 7).

4.5.1 Local Management Capacity

The capacity of local municipalities to manage water resources is a critical indicator of ability to adapt to climate change. This capacity varies widely across local governments (Gross, 2003), and whether new policies that consider climate change are enacted depends largely upon the importance placed on water resource management by local governments, access to technology and information, and the willingness of water resource managers. The demographics and other characteristics of the community also play a role, including income levels, social capital, level of education, and institutional and political contexts, such as relative power and influence in policy-making. In the Great Lakes Basin, local governments taking the most action to manage water resources were in suburban areas around urban centers and in the Finger Lakes region (Gross, 2003). They tended to have larger populations that were more educated and economically healthier. Thus certain populations will be more prepared than others for climate impacts, and strategies to build adaptive capacity need to be locally tailored.

4.5.2 Equity and Flooding

Adaptation to flooding is another key challenge for local and regional governments. There are a variety of adaptations available, ranging from developing or expanding levees and other flood-control structures, to moving homeowners and public infrastructure out of high-risk, flood-prone areas. (See Case Study A for a more detailed discussion.) Each of these options is associated with varying levels of risk exposure and expense burdens, which have strong equity implications. For example, land-use controls that would modify property rights or values, such as remapping a floodplain, enacting new zoning and building codes, relocating infrastructure, or limiting developments, need to be weighed carefully against the burden on property owners and whether compensations are being distributed fairly, relative to market value. Among local governments in the Great Lakes Basin, 28 percent control floodplain development on a case-by-case basis

(Gross, 2003). Case-by-case decision-making that is not informed by established plans, policies, or regulations may increase the probability that the process is co-opted by those with greater power or elites or biased against ill-informed owners or low-income residents. In addition, cost-sharing responsibilities and cascading effects at the local and regional levels need to be considered prior to making these modifications. Ensuring an open and fair process is essential.

4.5.3 Equity and Water Supply

Communities that have limited water storage will be more vulnerable to periods of reduced water availability as the frequency and duration of summer droughts increases. Specifically, some of the 1.9 million people who rely on domestic well water and several hundred thousand others connected to small public water systems may experience periods of scarce or no water. Many of these people, including farmers, are located in more rural areas and may be economically more vulnerable. Conversely, rapidly developing, higher-income exurban communities (those that are located outside the city and suburbs) may also experience water scarcity as increasing demands overwhelm local supplies. Management options to address water supply limitations include conservation programs, water-pricing schedules, or infrastructure development. Policy choices should carefully consider the costs associated with each option relative to economic capacity of the specific community.

4.5.4 Equity and Water Quality

Water quality is already a serious concern for most regions of New York State. Problems associated with pollutant and nutrient loading, toxic and waste runoff, and disease-causing pathogens affect water quality in the state's rivers and lakes. Water-quality vulnerabilities include a number of equity-related issues. For example, nitrogen loading from New York City wastewater treatment plants has impacts on fishing and ecosystem management in places such as Jamaica Bay, Queens. In addition to geographic differences (e.g., upstream versus downstream), poor water quality can be associated with socioeconomic and racial status (Calderon, 1993). Lower socioeconomic groups are more likely to access contaminated waterways for swimming and fishing (Evans and Kantrowitz, 2002). Lower-income or non-

English-speaking populations may be particularly vulnerable to increasing levels of pathogens in water or contaminants in groundwater wells, both from lack of insurance and lack of awareness about government programs and warnings. Recreational fishing, particularly among Latinos, is common from the piers and shores of Brooklyn (Corburn, 2002). The Water Working Group of the New York State Environmental Justice Interagency Taskforce unanimously rated combined sewage overflow (CSO) improvement as an urgent priority (NYS Department of Environmental Conservation, 2008). The confluence of these water quality vulnerabilities within specific water bodies in New York State, including Newtown Creek, the Gowanus Canal, and the Bronx River, is, in the current climate, a noteworthy environmental justice concern.

The specific impacts that climate change will have on water quality across the state are less certain. The degree to which increasing rainfall amounts will translate to increased pollutant loads remains unknown. Existing research documenting temperature controls on pathogen survival is also ambiguous. More research on the impacts of climate change on water quality is seriously needed. However, any climate change policies regarding water quality management will need to take into account education, literacy, ethnicity, and income characteristics of the relevant communities, as these factors will drive the success of the programs. One example of a successful water quality management strategy is the adoption of "Green Infrastructure" approaches designed to divert or slow storm water. Such approaches, which fall under a broad spectrum of low-impact development strategies and practices (LIDs), have gained increasing attention and support of environmental justice communities in New York State. Environmental justice communities are supportive of green infrastructure measures because of the ancillary benefits they can provide, including beautification, open space, air quality improvements, and shade, as well as the mitigation of CSOs.

4.6 Conclusions

This section highlights the key points from this ClimAID chapter, summarizing them under key existing and future climate risks, vulnerabilities and opportunities, adaptation options, and knowledge gaps.

4.6.1 Key Existing and Future Climate Risks

Although there are several water-quality issues directly linked to higher average air temperatures, in general, hydrologic processes are dependent on multiple interacting climate factors. In addition to temperature, possible future changes in timing and quantity of snow, rainfall, and evaporation will all have impacts on the state's water resources.

- Rising air temperatures intensify the water cycle by driving increased evaporation and precipitation. The resulting altered patterns of precipitation include more rain falling in heavy events, often with longer dry periods in between. Such changes can have a variety of effects on water resources.
- Heavy downpours have increased over the past 50 years, and this trend is projected to continue, causing an increase in localized flash flooding in urban areas and hilly regions.
- Flooding has the potential to increase pollutants in the water supply and inundate wastewater treatment plants and other vulnerable development within floodplains.
- Less-frequent summer rainfall is expected to result in additional, and possibly longer, summer dry periods, potentially impacting the ability of water supply systems to meet demands.
- Reduced summer flows on large rivers and lowered groundwater tables could lead to conflicts among competing water users.
- Increasing water temperatures in rivers and streams will affect aquatic health and reduce the capacity of streams to assimilate effluent from wastewater treatment plants.

Water resources in New York State are already subject to numerous human-induced stresses, and these pressures are likely to increase over the next several decades. For instance, water supplies are more likely to be stressed by increasing demands and insufficient coordination of supplies rather than by a dramatic downward shift in the availability of water. Water quality is more likely to be harmed by aging wastewater treatment plants, continued combined sewer overflow events, and excess polluting nutrient loading in agricultural regions. Therefore, nearly all the suggested adaptation strategies are intended to address these non-climate-change factors in tandem with the challenges posed by climate change.

4.6.2 Main Findings on Vulnerabilities and Opportunities

In **Table 4.5**, vulnerabilities have been divided into categories that parallel the major sections in this chapter: flooding, drinking water supply, commercial and agricultural water availability, and water quality. No single vulnerability takes precedence, since no vulnerability can be identified at this time as having a disproportionate societal or economic impact on the state. Additionally, some items listed are only potential vulnerabilities that require additional time and information before a more definitive determination of their importance can be made.

The New York City water supply stands as a special case when considering potential climate change impacts. Neither current hydrologic trends nor climate model projections suggest that a dramatic decline in water availability is likely (particularly since the system has a large storage capacity that provides resilience to increased intra-annual variability in stream flows to its reservoirs). However, since this single system serves such a large number of people and since it is also strongly impacted by several factors external to climate (population growth, interstate agreements on discharges to the Delaware River, aging infrastructure), even slight decreases in water availability could couple with other factors to constrain available water supplies to a large amount of the state's population.

Notably, the New York City Department of Environmental Protection has already been highly proactive in assessing its system reliability and is in the process of conducting additional in-depth studies of impacts on water quantity and quality at a level of detail far beyond the scope of this chapter. The Department of Environmental Protection will presumably maintain this proactive stance in dealing with the uncertainties of climate change. Some vulnerabilities and adaptation strategies in **Table 4.5** loosely encompass the New York City supply (i.e., increased frequency of deficits in systems with moderate-to-large storage volumes).

4.6.3 Adaptation Options

In this section, adaptation strategy options for the State are summarized and potential recommendations put forward. To make it easier for stakeholders and

Section	Vulnerability	Adaptation
Flooding	1. Uncertain changes in flooding in large basins	Consideration of moving development from flood-prone areas when infrastructure reaches end of life span
	2. Increased flooding in smaller, urbanized watersheds	Implementation of infrastructure that replicates natural hydrologic processes
	3. Uncertain potential for increased flooding of wastewater treatment plants	Design modification of new WWTPs
Drinking water supply	1. Likely increased frequency of deficits in homeowner wells, small community well systems, and run-of-the-river systems	i. Enhanced monitoring of groundwater levels; ii. Stockpiling of equipment for emergency withdrawals; iii. Water conservation
	2. Possible increased frequency of deficits in systems with moderate-to-large storage volumes	i. Enhanced monitoring of reservoir and aquifer levels; ii. Use of rule curves in reservoir or aquifer operation; iii. New basin commissions; iv. Water conservation
Commercial & agricultural water availability	1. Increased demand from additional agricultural irrigation	i. Establish minimum streamflow requirements; ii. Statewide inventory of water withdrawals
	2. Competition for water among human consumption, commercial uses, and ecological needs	i. New basin commissions; ii. Establish minimum streamflow requirements; iii. Statewide inventory of water withdrawals
Water quality	1. Decreased stream low-flows and higher water temperatures decrease assimilative capacity of waterbodies receiving waste	i. Modify waste discharge permits (given further study of likely changes); ii. Further study of low-flow characteristics of streams
	2. Uncertain changes in pathogen levels	Long-term monitoring and data analysis
	3. Uncertain changes in nutrient loading with no land use change	Long-term monitoring and data analysis
	4. Possible changes in CSO frequency (particularly in systems with high thresholds for CSO initiation)	Monitoring of possible changes in CSO frequency and implementation of scalable CSO mitigation plans
	5. Increased sediment and nutrient loads due to expanded agricultural production in water-rich region	Better targeted water and soil conservation measures

Table 4.5 Summary of vulnerabilities and adaptation options

decision-makers to evaluate, the strategies are grouped according to robustness.

Resources and Current Status of Implementation

There is considerable natural variability in hydrologic systems even without climate change. Water resource managers have long dealt with this innate climate variability, as well as changes in other factors such as land use and population. Nearly all suggested adaptation options are an extension or expansion of existing strategies for managing this variability. While most adaptation options are not yet being formally implemented, many are related to ongoing water-resource-related projects at the federal, State, and local levels.

Several adaptation options are extensions of existing State and interstate institutions and policies. For instance, a Hudson River Commission could be developed modeling the format and successful strategies of the existing Delaware and Susquehanna River Basin commissions and expanding on the powers of the

Hudson River/Black River Regulating District to control releases from the upper Hudson Basin. Minimum streamflow requirements already exist in the Susquehanna and Delaware River basins, and guidelines could similarly be established throughout the rest of the state if the Generic Environmental Impact Statement for shale gas extraction is accepted (although State laws would need to be changed for them to apply to all water users). Water use reporting by industrial and commercial users (although not permitting) is required as of February 1, 2010, under a new State law. The National Weather Service already operates an effective flood-warning system, and the U.S. Geological Survey already measures numerous water bodies throughout the state.

Other possible adaptation options follow from existing operating protocols at the municipal level. In terms of water supply, most water utilities already make some attempt to encourage water conservation, although many appear to have only an *ad hoc* approach to reducing demands in time of drought. In terms of urban flooding and water-quality issues, many municipalities have long had laws restricting heightened peak runoff

following new development, and nearly all have had to comply recently with federal stormwater management regulations.

Potential adaptation options

There are many adaptation pathways that can reduce the potential detrimental consequences of climate change for water resources. A challenge to building resilience, however, is the lack of certainty in the degree, pace, and even direction of water-related climate changes anticipated for New York State. Water resource managers will need to make decisions based on climate projections that reflect this uncertainty, which is very different from current approaches that rely on the historic record and the assumption of a stationary climate. One approach to making such decisions under uncertain conditions is to apply the concept of robustness. In the context of decision-making science, the term robustness is defined as a strategy that is effective (in terms of cost, societal impact, and risk reduction) under a range of possible future outcomes (Lempert et al., 2006). Recent research has identified several robust decision-making strategies (Hallegatte, 2009), and we supplement them with several categories of our own; although the adaptations are placed in distinct groups for organizational purposes, many have relevance in more than one category:

Strategic expenditures on adaptation options with co-benefits that result in a net public benefit with or without climate change.

- 1) Continue to encourage the development of cost-effective stormwater management infrastructure for use in urban and suburban landscapes that enhances natural hydrologic processes (infiltration, recharge, evaporation), instead of rapidly conveying stormwater to receiving water bodies.
- 2) The New York State Department of Health currently maintains a supply of equipment (mobile pumps, water tanks, filters, etc.) that can be used by municipalities to assist in temporarily supplementing critically low water supplies. The New York State Department of Health should assess and augment the adequacy of its inventory of emergency equipment if needed.
- 3) Encourage water conservation strategies that guarantee water sufficiency without increasing

supplies through building reservoirs or other new infrastructure. Ultimately, increased water availability may provide economic benefits to New York State by increasing the viability and sustainability of water export or virtual trade through agricultural and industrial products.

- 4) Establish minimum flow requirements using biology-based criteria to determine and permit the maximum amount of water that can be withdrawn from a water body during different times of the year. Such minimum-flow criteria will also be important to make water allocation decisions for water bodies.

Taking advantage of low-cost margins of safety in new construction to avoid more expensive retrofits and modifications in the future.

- 1) Devise wastewater treatment plant upgrades and combined sewer overflow mitigation strategies (for communities that do not have one in place) to address possible changes in flood risk, sea level rise, and increases in large rainfall events. Modest water infrastructure design changes at the planning stage will avoid more costly modifications to constructed infrastructure later.
- 2) Consider moving development out of floodplains as buildings, infrastructure, and flood-protection structures age and it becomes time to rebuild.

Soft strategies (in contrast to hard infrastructure solutions) that seek to build new institutional or organizational frameworks.

- 1) Basin-level commissions could be established for major rivers in the state without them. The Hudson and Mohawk Rivers would likely be high-priority areas, as other major rivers (the Genesee River, Black River, Allegheny River, Oswego River/Finger Lakes region) have fewer users, already fall into the Great Lakes Basin, and will be subject to some oversight due to the Great Lakes Compact. Such basin commissions could provide oversight of supplies as well as water quality and fisheries issues.
- 2) Many adaptations to climate variability are implemented and coordinated at a local scale. The presence of a lead town or other entity can play a key role in mobilizing efforts in the surrounding region by providing leadership in education, best management practices, and fundraising. State-level recognition as well as funding support to leading local entities could enhance adaptation activities at

the local scale, which will build adaptation capacity that will help address future climate change.

- 3) Water demand data could be more widely reported even during non-drought periods through mass communication, but also through innovative technologies, such as smart water metering. Such efforts might help break the entrenched mentality that water supply systems should supply 100 percent of demand at all times (Rayner et al., 2005) and shift public behavior to recognize variations in demand and appreciate years when water is plentiful and conserve it in years when it is scarce. This also falls under the more general adaptation option of increasing water conservation.
- 4) Public water suppliers could establish formal rule curves for water supply reservoirs and aquifers. This involves no new infrastructure but entails establishing a new framework for system operation (likely to include the enactment of well-defined conservation measures at certain drought levels) understood by water managers, other municipal decision-makers, and residential and commercial water users.

Extensive monitoring efforts that expand the collection of environmental data, which are critical for making informed management decisions.

- 1) Starting in 2010, New York State Environmental Conservation Law Article 15 Title 33 will require all water withdrawals that exceed 0.1 million gallons per day to be reported to the New York Department of Environmental Conservation. Consider developing a publicly accessible online system for tracking water allocations to all users (water supply, industrial, thermoelectric, agricultural) across the entire state. A more open system would enhance accountability and potentially allow for more input from additional stakeholders groups (e.g., recreational, habitat).
- 2) Consider developing an automated gauging network or, at a minimum, a formal reporting network (e.g., routine manual measurements submitted to a central online clearinghouse) of water levels in public water supply reservoirs and aquifers. This would assist the New York State Department of Environmental Conservation and Department of Health in making drought declarations. More importantly, it would encourage water suppliers to more systematically track water storage and would complement the suggestion for

suppliers to develop rule curves to regulate reservoir and aquifer operations.

- 3) Expand the extent and types of monitoring by the U.S. Geological Survey or other entities to provide additional data for decision-making. This could include additional measurements of groundwater levels, low streamflows, temperatures, and dissolved oxygen.
- 4) Additionally, there may be the possibility of leveraging widespread Internet connectivity and inexpensive data storage in order to enlarge informal data collection networks. The GLOBE data project (www.globe.gov) set a precedent for students collecting assorted weather data. With nominal funding, a water-quality program could be developed among community colleges, colleges, universities, public-interest groups, and watershed organizations to collect and analyze water data for specific water bodies, feeding it into a central clearinghouse. Such efforts would help engage the public, which is essential for building resilience.

4.6.4 Knowledge Gaps

There are several areas that require additional fundamental research to make educated policy and management decisions. These research areas are discussed below.

There are several fundamental hydrologic processes that need more in-depth assessment. In particular, groundwater recharge, stream low-flows, evaporation, and flooding need to be better understood in light of a changing climate. Such studies need to be process based, instead of simply drawing conclusions from historic data. Additionally, they need to specifically look at processes within the region and avoid making generalizations from other areas, a typical limitation of many existing studies. Such region-specific studies would benefit from additional data, much of which could come from a refinement of existing monitoring networks. The existing rain-gauge network could be expanded to ensure there is a satisfactory density of rain gauges in each basin with a stream gauge, providing a better understanding of the hydrologic response in gauged basins. Potential evapotranspiration as well as soil moisture could also be measured at several sites across the state to better understand how evaporation is affected by changing climate factors. Finally, snow depth measurements could start to include snow-water

equivalents (which report snow as a depth of liquid water to account for snow compaction and differences in density) in order to provide a more objective measure of how snowfall and snowpacks are changing over time.

To protect water quality, research that identifies additional critical pollutant-contributing areas and processes is needed. Adaptation measures for water-quality protection in a changing climate should be targeted to the critical areas and processes rather than intervening with multiple management options across entire watersheds without regard to the primary pollution source (Garbrecht et al., 2007). At small scales, a critical field-based assessment of the effectiveness of best-management practices is needed. At larger scales, improved monitoring of primary polluting nutrients, turbidity (cloudiness of water caused by suspended sediment), and pathogen indicators on major rivers (Chemung, upper Susquehanna, and Delaware) would enable a clearer picture to emerge of the relationships among climate factors, land use, and water quality in New York State.

Many pollutant discharge permits for wastewater treatment plants are based on streamflow and temperature data from decades ago. An assessment is needed to estimate future streamflow and water temperature scenarios and to model what impact these changes will have on the quality of water bodies receiving treatment plant effluent.

There is often a desire for actionable future climate information for making decisions on infrastructure needs or policy changes. Results could be provided by downscaling global climate model projections and using these as inputs to a hydrologic or ecology model, but the reality is that this model estimate would be far from certain. Therefore, there is a need for a fundamental shift in the way engineers, planners, and policymakers make decisions. Instead of devising a strategy optimized for one outcome, the strategy should instead perform effectively (in terms of cost, societal impact, and risk reduction) across many outcomes (robustness). There needs to be both basic research as well as educational outreach to decision-makers to expand the concept of robust decision-making.

More severe climate changes in other parts of the United States (relative to the Northeast) could shift population growth and water-intensive economic activities to New York. A statewide water plan could provide guidance to

commercial and industrial entities as well as homebuilders and homebuyers. The plan could detail which communities in the state have the most excess water supplies, even with the additional stress of climate change. Additionally, a state water plan could initiate thinking into potential economic opportunities, and the private sector would presumably have an incentive to further investigate these possibilities.

Case Study A. Susquehanna River Flooding, June 2006

Flooding is already a major problem across New York State and it may be exacerbated by climate change. Currently flood damage costs an average of \$50 million a year in the state (Downton et al., 2005). The majority of the flood events consistently occur in the ten Southern Tier counties. The June 2006 Susquehanna River flood provides insights into the pros and cons associated with different strategies that can be used to reduce future flooding risks and impacts. Record precipitation during June 2006 culminated in significant flooding throughout the Susquehanna and Delaware River basins in New York and in northeastern Pennsylvania. Twelve counties in New York and thirty in Pennsylvania were declared disaster areas. This ClimAID analysis and summary focuses on Broome County, New York, which incurred the largest portion of damages throughout the entire flooded area.

Climatological and Hydrologic Drivers

The flood resulted from significant, intense precipitation falling on already-saturated soils throughout the 4,000-square-mile Upper Susquehanna basin. A total of 4.29 inches of rain fell in the 25 days before the most intense rain began, with varying amounts of rainfall almost daily, which prevented the soils from drying out. A stalled low-pressure system began contributing intense rainfall on June 25, and from June 25 to 28 total rainfall ranged from 3 to 11 inches throughout the basin (Suro et al., 2009).

Runoff from the steep hillslopes led to a record rise in river water levels. On the Susquehanna River at Conklin, river levels were less than 5 feet in elevation on June 26 (**Figure 4.8**). Flood stage was reached at 2:15 p.m. on June 27. Nine hours later, it reached the

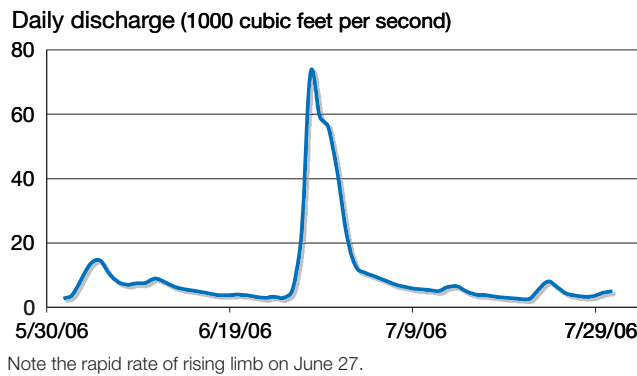


Figure 4.8 Water level of the Susquehanna River at Conklin, New York, during the June 2006 flood

previous high-water record of 20.83 feet. Rainfall stopped early in the morning Wednesday, June 28, but the river level continued to rise as a result of the water already in the basin, reaching its peak of 25 feet by 11:30 a.m. This flood is the largest recorded on the Susquehanna River at Conklin since gauging began in 1912. However, Broome County had experienced only slightly smaller floods in 2004, associated with Hurricane Ivan, and again in April 2005 when a combination of extreme rainfall and snowmelt very quickly flooded parts of the upper Susquehanna River.

Social and Economic Impacts

The city of Binghamton and a number of smaller rural towns in Broome County were flooded during the June 2006 event. This area included the majority of the FEMA-designated 100-year floodplain and portions of the 500-year floodplain (**Figure 4.10**).



Source: E. Aswald, used with permission.

Figure 4.9 Aerial photograph of Endicott Sewage Treatment Plant during June 2006 flood

There are thousands of properties at risk from flooding in Broome County (**Table 4.6**). Though it is difficult to determine exactly which properties were damaged by the flood and to what degree, an estimate was made by overlaying the flood extent on parcel level data from Broome County's 2004 property tax register. Because of data restrictions, the City of Binghamton is excluded from this dataset and from all of the associated analysis. Also, since there is no way to judge how well individual properties fared during the 2006 flood, aggregate market values should be taken as a maximum estimate of risk. Actual flood damage was a fraction of these estimates. Approximately 3,350 properties were in the flood zone, distributed largely among commercial (10 percent) and residential (58 percent) uses (**Table 4.6**). Two sewage treatment plants, a public works facility, a hospital, and several hundred miles of roads were also in the flood zone (**Figure 4.9**). Approximately 8 percent of the aggregate value of property in the county was at risk, amounting to nearly \$563 million.

Despite the rural nature of the county as whole, less than 1 percent of the flooded parcels was agricultural. The Susquehanna River has been a historic beacon for growth, with significant and disproportionate development occurring along its banks. A large amount of commercial property value was within the flood inundation zone, accounting for about 19 percent of the county's total (**Table 4.6**). This helps explain why a number of critical commercial classes were flooded in greater number than would be expected given the size of the county as a whole. For example, nearly 30 percent of the neighborhood shopping area in the county was within the flood zone, as was more than a quarter of the county's warehouse and storage facilities.

	Number of Parcels		Aggregate Market Value	
	Not flooded	Flooded	Not flooded	Flooded
Agricultural	675	12	\$39,883,239	\$933,359
Commercial	2,870	319	\$876,156,504	\$210,199,932
Community services	763	55	\$1,405,660,897	\$61,987,704
Industrial	197	44	\$277,401,671	\$34,041,765
Public services	353	69	\$75,659,552	\$110,578,336
Recreational	158	30	\$52,536,817	\$11,270,494
Residential	47,134	1,954	\$3,929,664,223	\$123,055,714
Vacant	13,392	804	\$169,609,828	\$9,748,270
Wild/forest	250	21	\$16,173,424	\$1,033,142
No data	488	40	\$0	\$0
Total	66,280	3,348	\$6,842,746,155	\$562,848,716

Table 4.6 Land use and value of properties in Broome County, broken out by flooded and non-flooded parcels in June 2006

Of all the towns that experienced flooding, Conklin was hit the hardest, with 30 percent of its properties flooded, followed by 13 percent in Kirkwood and 10 percent in Port Dickinson. Of the remaining eight towns, flooding ranged from 6.9 percent in Johnson City to 0.1 percent in Binghamton. The difference in flooding across localities is a reminder of the range of exposures that local governments face during a regional flood event and the importance of cost-sharing mechanisms in the aftermath.

Flood Insurance and FEMA Designation

The extent of the flood draws attention to the limitations of current flood insurance and the uncertainty of FEMA's modeled 100-year floodplain versus actual flooding. The FEMA boundaries are important, not just because they indicate areas where insurance is federally mandated, but also because these boundaries often become the definitive communication

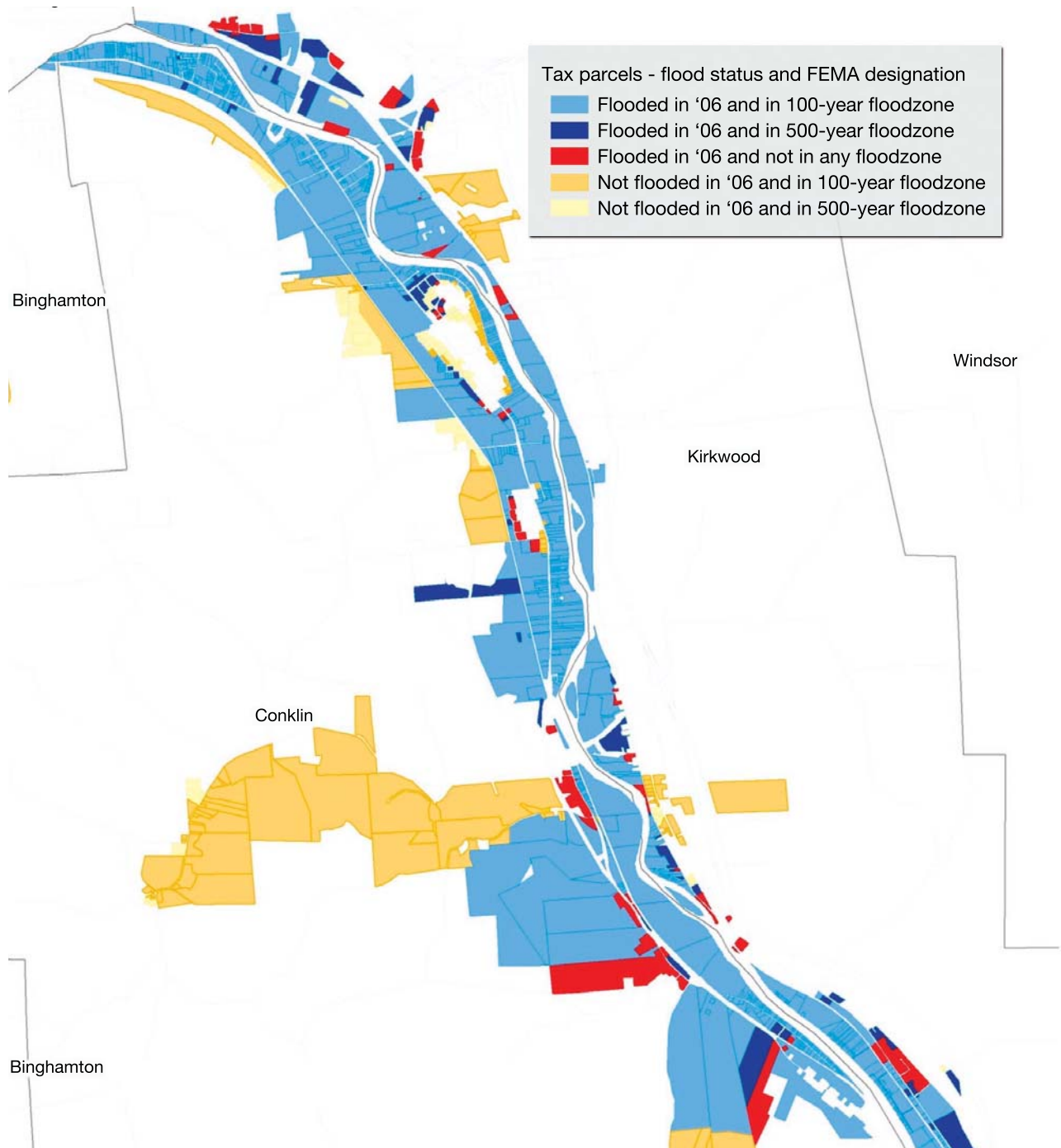


Figure 4.10 Distribution of flood risks in a select area in Broome County: Properties flooded in 2006 relative to FEMA designation

of perceived risk and thereby serve to define the range and limits of a homeowner's or community's response to potential flooding. In total, 1,020 properties were located within the 2006 flood extent but not included within FEMA's Special Flood Hazard Area (the 100-year floodplain) (Table 4.7). Of these, 723 were residential and comprised about \$46,316,088 worth of property that was exempt from the federally mandated insurance requirements. Large numbers of homeowners outside of FEMA's Special Flood Hazard Area who were devastated by the flood did not have flood insurance (Figure 4.10).

Approximately 6,200 people were living within the extent of the flood. Across the entire flood extent, more than 30 percent of housing units were renter-occupied, amounting to more than 920 in total (Table 4.8). Conklin and Dickinson had especially high rates of renters in the area inundated, with blocks located on the western side of the river containing 50 to 100 percent renters. Displacement of renters had widespread impacts, including difficulty finding suitable affordable accommodations near places of work or their children's schools. Availability of rental units also decreased as displaced homeowners and renters competed for viable alternative housing.

Patterns of seniors at risk, defined as individuals 65 years or older, varied among communities. Seniors are

considered particularly vulnerable due to higher rates of impaired mobility, difficulties with communication, and potential lack of awareness of warning and evacuation systems. More than 30 percent of households in the flood area had at least one member who was 65 years or older, but these households were not concentrated in any one area. The dispersed nature of this vulnerable population may complicate evacuation and response.

There was not a distinct relationship between the flooded area and where nonwhite residents lived. The highest densities of the nonwhite populations were located in Binghamton, but very few were located in the flooded area. In Conklin, there were several blocks composed of nonwhite communities, and more than 25 percent of that population resided within the flooded areas.

In order to gain some measure of systematic inequities between flooded tracts and concentrations of vulnerable populations, we compared block groups within the extent of the flood to those block groups in the rest of the county outside of the flood. Apart from slightly higher rates of renters in the floodplain (perhaps a reflection of the more urban housing context along some parts of the river), the profile of the two populations did not differ significantly in terms of demographics.

	Number of Parcels	Aggregate Market Value
Total		
Flooded and within 100-year flood zone	2,328	\$373,050,159
Flooded but outside 100-year flood zone	1,020	\$189,798,557
Not flooded but within 100-year flood zone	4,651	\$499,763,169
Residential		
Flooded and within 100-year flood zone	1,231	\$76,739,626
Flooded but outside 100-year flood zone	723	\$46,316,088
Not flooded but within 100-year flood zone	2,717	\$184,005,238

Table 4.7 Distribution of flooded and unflooded properties within FEMA's flood zones

	Population
Total population within flood extent	6234
Latino	87
African American or black	101
Non-white	317
Households	2650
Households with one or more members over 65 years of age	845
Housing units, renter-occupied	921

Table 4.8 Select demographic profile of population within the 100-year flood⁴

Adaptation Response Options

Various options are available to increase resilience and reduce risks from the flood-related impacts of climate change, each with its own benefits and disadvantages. A few options are presented here. A complete assessment should evaluate damages due to structural losses or costs of new construction, costs due to loss of work-related productivity, and offsets provided by insurance. However, there are impacts, such as from losses in human lives or subsequent short-term and long-term illness, as well as loss of ecosystem services, to which it is much more difficult to assign dollar values.

Option A: Maintain Status Quo

Despite the very rapid onset of the flood and the thousands of properties that were inundated, there were only four deaths (Suro et al., 2009), which is sometimes viewed as the real measure of a disaster. The

success was due to the excellent warning-and-response system coordinated by NOAA's National Weather Service that is linked to local communities. This system depends on the availability of real-time data on streamflow for the Susquehanna River and several tributaries measured at USGS gauges. Notably, some of these gauge sites were recently at risk of being eliminated due to budget constraints, but currently most have been continued with other funding sources. The response included pre-flood community-wide warnings and evacuations, water pumping and sand bag efforts, and emergency evacuations and medical services during the flooding. Such flood-warning systems are not cheap. For example, it costs about \$17,000 per year to operate and maintain a single USGS streamflow station in New York (Ward Freeman, personal communication, 2009). Additional costs for manpower, communications, computer resources, vehicles, and other emergency-response equipment total in the hundreds of thousands of dollars or more (Ward Freeman, personal communication, 2009).

If the status quo approach is taken, similar levels of damage are likely to occur when the next flood of similar magnitude occurs on the Susquehanna River. Properties that are within the 2006 flood area constitute an estimated 8 percent of the value of all property in the county. And while the rates of socially at-risk populations are not extremely high, the raw numbers suggest that thousands of people with potential vulnerabilities were located within the flood zone. A no-action scenario is likely to lead to similar or worsening impacts, especially if floods become more frequent or severe. Uncertainty about flood forecasting, due to climate change or inadequate emergency systems elsewhere in the state, will also raise the likelihood that people and their property will be caught off guard.

Option B: Increase Levees, Dams, and Other Barriers to Reduce the Flooding Risk

Extensive levees and dams were built in the 1950s. This system has been highly successful at preventing flooding for several decades along the Susquehanna River. However, in some locations the current system is no longer adequate to deal with potential higher-magnitude floods. Additionally, development within the floodplains behind these barriers has intensified, perhaps due to an artificial perception of safety, making communities more vulnerable and damages greater

when floods do occur. Developing or upgrading existing levees to support floodplain development is extremely expensive. This is being demonstrated in parts of Broome County, where recent updates to FEMA flood mapping will soon require upgrades to existing levees. If levees are not updated, thousands of residents will have to purchase flood insurance policies for the first time. Costs for the planning stage and subsequent renovation of the levees by the U.S. Army Corps of Engineers are estimated to be in the tens of millions of dollars (William Nechamen, personal communication, 2009).

Both options A and B are strongly influenced by the availability of flood insurance to property owners as it offsets a significant portion of flood-damage expenses. Current FEMA regulations require some level of flood "proofing" (e.g., constructing elevated buildings to reduce damages within insured communities). However, the global insurance industry has recently recognized the potential risk increase given the impacts of climate change (Geneva Group, 2009). Future insurance options will have significant ramifications for homeowners' willingness to accept risks, housing values, and future land uses within high flood-risk areas.

Option C: Phased Withdrawal from the Highest Flood-risk Areas Over Time

Moving out of the highest flood-risk areas has been successfully accomplished by using homeowner buyouts following floods in multiple places nationwide, including Conklin in 2007. Payouts have been set at pre-flood fair market value or at pre-flood value minus the estimated costs of damage repairs. The local government takes over the land, which is deeded for recreation or open space. At a minimum, towns may consider moving infrastructure, such as wastewater treatment plants, out of floodplains. The withdrawal strategy reduces all subsequent flood risk, both to human lives and buildings. Monetary costs can be comparable to or less than costs to expand levees. It has the added benefit of expanding natural flood-control processes by increasing floodplain storage and not "bouncing" floodwaters downstream. It also improves water quality and aquatic ecosystem health. However, one of the strongest deterrents to greater adoption of a withdrawal policy has been the strong sense of place or "roots" that people feel for their locations (homes and communities); another is a desire to live near water.

Option D: Improve Watershed Management

Improving watershed management should be considered in conjunction with any of the options listed above and can play a significant role in reducing the amount of runoff that contributes to flooding. Best-management practices, including improving soil infiltration capacity, expanding vegetated surfaces, decreasing impervious cover, and uncoupling roadside ditch systems, have been documented to reduce downstream flooding.

In all of these options, the critical question is, How will decisions about new infrastructure, buyouts, or land management be made? The largest infrastructure projects are possible only with regional and national collaboration, while local and individual property protections can be cobbled together by local governments or individual property owners. Whichever path is pursued will determine who bears responsibility for the costs of these measures, including impacts on livelihoods, and who controls the safety nets in the event of system failure. Whichever option is chosen, the process must be inclusive of those living in affected neighborhoods and sensitive to underlying socioeconomic conditions and indirect economic impacts

Case Study B. Orange County Water Supply Planning

A portion of future population growth in New York State will occur in higher-income exurban regions. Unlike traditional suburbs, these areas are farther from established major city centers and in recent decades have grown mainly through low-density residential development. Much of the growth in Rockland, Orange, and Putnam counties, located 20 to 40 miles outside of New York City, has been in exurban areas. In terms of water resources, these areas frequently have higher per capita water usage due to greater landscaping demands. These areas may face major challenges in developing new larger-scale sources of water, particularly surface water reservoirs, in part due to regulatory constraints. In some parts of the state, exurban areas have emerging regional governmental entities that are just becoming established enough to plan and finance centralized water supplies. In contrast, Orange County has had a legally established and active water authority (Orange County Water Authority, or OCWA) for more than two decades.

Orange County is in many ways representative of other areas of exurban growth in the state that face water-resource supply issues, many of which could be complicated or exacerbated by climate change. However, it is also one of the few locations to have proactively undertaken a recent study of water resources that has included the impacts of future climate change in addition to socioeconomic, geographic, and political constraints. Much of the following information in this ClimAID analysis is drawn from the proposed Orange County Water Master Plan Amendment of July 2009 (OCWA, 2010).

Water Supply Planning in the County

In 2007, Orange County's population was 377,000. It was partially concentrated within several small cities (Middletown, Newburgh, and Port Jervis) and in smaller villages, but also was widely dispersed throughout the county. By 2018, the population is projected to grow to 436,000 (OCWA, 2010). With this increase in population, water demand is expected to rise from 29.9 million gallons per day in 2008 to 34.1 million gallons per day in 2018 (OCWA, 2010). While there are no estimates of longer-term growth, given the projected rise in the U.S. population it would seem reasonable to assume that the county would continue at its current growth rate, adding about 45,000 additional people per decade and thereby increasing the demand for water by about 5 million gallons per day each decade. These projections and others in the OCWA Water Master Plan are based on an assumption that per capita demand will remain approximately constant over the next 10 years (OCWA, 2010).

As of 2007, approximately 101,000 people in the county (spread over 80 percent of the land area) were served by individual homeowner wells (OCWA, 2009). The remaining people were supplied from groundwater and surface-water sources by 63 municipally operated water districts and 89 community water suppliers. These groundwater and surface-water supplies are almost exclusively owned and operated by the individual entities, with limited sharing of water-supply infrastructure. Thus, there are more than 150 independent and decentralized water suppliers in Orange County alone.

The OCWA is the county's primary agency responsible for planning and development of drinking

water supply resources and infrastructure. Other county and State agencies—notably the Department of Health and Department of Environmental Conservation—have key roles and authority over certain aspects of drinking water supplies as well. The OCWA was formed in 1987 to implement a county-wide wholesale water system that would be composed of new reservoirs, treatment plants, and a looped transmission pipeline throughout the central part of the county (“the water loop”). The water loop project was the culmination of several decades of planning for a centralized supply. As early as 1959, an engineering firm created plans for damming creeks and rivers to create reservoirs. Based on a 1977 water supply study, the county purchased three possible reservoir sites: Black Meadow, Dwaar Kill, and Indigot. Then, a 1987 study laid the foundation for the OCWA and loop project. In addition to the water loop centralized distribution system, this study called for construction of 1) the Dwaar Kill Reservoir with flood skimming from the Shawangunk Kill in order to provide an increased capacity of 18 million gallons per day, and 2) a siphon to the Catskill Aqueduct that could provide 21 million gallons per day. However, the water loop project was never implemented, largely due to the unwillingness of local municipalities to commit to long-term contracts to purchase water from the OCWA. These proposed contracts were the basis of the OCWA’s plan to finance the project, which was estimated to cost \$142 million in 1990 dollars (\$236 million in 2010 dollars). Despite not having its own facilities, the OCWA has certain legal and financial powers not available to municipalities. The OCWA is still establishing its place in coordinating the water supply in the county, with the recent report an example of the evolving process of trying to provide centralized planning.

Instead of a large centralized project, smaller-scale projects have been developed by local municipalities to provide additional supplies. These smaller projects have largely been based on groundwater sources, primarily because of their much lower capital costs and their ability to be phased in as demand increases. Orange County is currently evaluating the potential for additional groundwater supplies from two basins originally planned for reservoir development (Dwaar Kill and Indigot). It is estimated that each of these two basins could supply 600 to 800 gallons per minute, enough water for 2,000 homes. Additionally, interconnections have been suggested among several

municipal systems to help better distribute supplies. The OCWA’s water conservation programs, especially a leak detection program, have contributed to controlling demand.

County Vulnerability to Water Supply Shortages

The current drinking water supply capacity is 50 million gallons per day with a demand of 30 million gallons per day. In 2018, the projected supply capacity is 53 million gallons per day with a demand of 32 million gallons (OCWA, 2010; Table 2). Supply estimates are based on the so-called safe-yield projection, the amount of water available during the drought of record. In Orange County and other parts of the region, the drought of record is based on the 1960s drought. Thus, according to this supply estimate, in 2018 there will be a county-wide surplus of 20 million gallons per day.

However, since the water supply sources are localized, certain municipalities are projected to have deficits in supply. Some of these deficits would be eliminated if planned or existing back-up systems come online. But based on projections, the Village of Goshen, the City of Middletown, and the Village of Kiryas Joel would have a deficit in water supply by 2018 (OCWA, 2010; Table 2).

While there is a significant range of possible futures in current modeling projections, climate change projections that are within the most-likely range suggest that average annual surface-water supplies will stay near their current levels (Frei et al., 2009). But these projections also indicate reduced groundwater and soil moisture, and there is certainly the possibility of decreases in surface-water supplies as well. With certain systems in the county already approaching a threshold at which demand may exceed supply in the next decade, additional population growth, combined with even slight changes due to climate, could lead to deficits in these already-stressed systems. During the drought of 2001–2002, five municipal water systems had to activate emergency supplies (including using water from New York City’s Catskill Aqueduct). And even if average annual supplies remain relatively constant, increased variability in summer precipitation and evaporation could temporarily stress small water systems (which largely serve small residential developments) that have little storage. During the drought of 2001–2002, four

water districts (Walton Lakes Estates, Arcadia Hills, Hambletonian Park, and Pheasant Hill) serving residential developments (with a total population of only several hundred each) needed to truck in water from neighboring communities and empty it into district wells in order to replenish the supply.

Case Study Conclusions

The examination of drinking water planning in Orange County provides a glimpse at some of the bureaucratic, political, and financial challenges that are intertwined with any assessment of the impacts and possible adaptations to climate change in an exurban region.

Orange County as a whole probably has sufficient drinking water supplies to meet demand in the near future, but certain areas within the county do not. While the development of major centralized water sources now (such as new reservoirs) could reduce the risk of water shortages from a changing climate in the future, the economic costs and regulatory challenges involved suggest that this is not likely. The water loop plan of the late 1980s or other large-scale centralized supply and distribution plans may not be reinvigorated given the high overall cost and lack of demonstrated benefits to many of the numerous communities that would have to agree to participate.

Future strategies to ensure there is sufficient water in all communities would benefit from addressing population growth and potential climate change impacts. They will most likely be similar to past and current efforts of the OCWA. The proposed Water Master Plan recommends planning limited interconnections between nearby municipalities to address localized shortfalls, the ongoing use of water from New York City's aqueducts, and studying new small-scale sources, such as groundwater wells. The plan also recommends increased conservation programs, though it does not factor potential water-efficiency gains into projected water demand. This is a conservative approach that seems aimed at ensuring adequate supplies in case conservation programs have a limited impact. The county's ongoing ownership of several potential reservoir sites may become more important in the future if water availability becomes more limited and there is a heightened political willingness to fund reservoir development.

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Appendix A. Stakeholder Interactions

The major issues of vulnerability and associated potential adaptations were identified in conjunction with seven stakeholder workshops involving about 200 stakeholders held during the ClimAID project. These workshops included presentations and discussions with lake association leaders at the annual conference of the Federation of Lake Associations, with engineers and planners at the annual conference of the American Public Works Association, with forestry and wildlife professionals in a regional ForestConnect webinar, and with multiple workshops for Cornell Cooperative Extension educators and rural landowners. Given the breadth of professions and stakeholders that are involved with water resources across New York State, these efforts need to be viewed as the beginning of an ongoing and expanding engagement with all water stakeholders statewide as New York prepares to cope with the challenge of climate change.

List of Workshops

- 1) **Date:** 4 May 2009
Venue: New York State Lake Associations Annual Conference, Hamilton, NY
Lead: Rebecca Schneider, Cornell University, Dept. Natural Resources
Participants: 16 directors of lake associations across NY
- 2) **Date:** 27 March 2009
Venue: American Public Works Association – Ann. Conference, Canandaigua, NY
Lead: Rebecca Schneider, Cornell University, Dept. Natural Resources
Participants: 28 municipal engineers, town planners, watershed council program managers, private engineering consultants
- 3) **Date:** 10 March 2009
Venue: Cornell Cooperative Extension Advisory Council Workshop for Natural Resources and Environment
Lead: Rebecca Schneider, Cornell University, Dept. Natural Resources
Participants: 20 CCE directors, members – American Wildlife Conservation Foundation, member – Federation of NYS Solid Waste Assoc.,

biologist – Ontario Dune Coalition, assoc. director of state wetland managers and state floodplain managers; president – NY Forest Owners Assoc.

- 4) **Date:** 18 March 2009
Venue: ForestConnect Webinar
Lead: Kristi Sullivan, Cornell University, Dept. Natural Resources
Participants: 149 including 46 percent landowners, 29 percent foresters, 20 percent educators and 12 percent specialists responsible for ~11,000,000 acres of land in 21 states
- 5) **Date:** 12 November 2009
Venue: Rural Landowner Workshop on Climate Change, Arnot Forest, Newfield, NY
Lead: Rebecca Schneider, Kristi Sullivan, Cornell University, Dept. Natural Resources.
Participants: 12 private landowners
- 6) **Dates:** 11 November and 8 December 2009
Venues: Ecosystems Climate Change Workshop, Ithaca, NY Ag and Food Systems CALS In-service, Ithaca, NY
Lead: David Wolfe, Cornell University, Dept. of Horticulture

Stakeholders

Adirondack Mountain Club
 Akwesasne Task Force on the Environment
 Alley Pond Environmental Center
 American Wildlife Conservation Foundation, Inc.
 Association of State Wetland Managers
 Au Sable River Association
 Basha Kill Area Association Hudson Basin River Watch
 Battenkill Conservancy
 Beacon Sloop Club
 Black Creek Watershed Coalition
 Boquet River Association (BRASS)
 Bronx River Working Group
 Buffalo Niagara Riverkeeper
 Building Watershed Bridges in the Mid-Hudson Valley
 Butterfield Lake Association
 Cornell Cooperative Extension
 Canandaigua Lake Improvement Association
 Canandaigua Lake Watershed Task Force
 Catskill Center for Conservation and Development
 Cayuga Lake Watershed Network
 Cedar Eden Environmental

Central New York Watershed Consortium
 Chautauqua Lake Conservancy
 Chautauqua Watershed Conservancy, Inc.
 Coalition to Save Hempstead Harbor
 Coalition to Save the Yaphank Lakes
 Columbia County Lakes Coalition
 Community Water Watch Program
 Cornell Cooperative Extension - all counties
 Croton Watershed Clean Water Coalition
 Dutchess County Soil and Water Conservation District
 Esopus Creek Conservancy, Inc.
 Executive Director of Catskill Watershed Corporation
 Fed. of NY Solid Waste Associations
 Finger Lakes Land Trust, Inc.
 Friends of Jerome Park Reservoir
 Friends of the Bay
 Genesee Land Trust
 Groundwork Yonkers/Saw Mill River Coalition
 Honeyoe Valley Association
 Horseshoe Pond/Deer River Flow Association
 Hudson River Foundation
 Hudson River Environmental Society
 Hudson River Sloop Clearwater
 Hudson River Watershed Alliance
 Jamaica Bay Watershed Alliance
 Java Lake Colony, Inc.
 Keep Putnam Beautiful
 Lake Colby Association
 Lake Erie Alliance
 Lake George Association
 Lake George Land Conservancy
 Land Trust of the Saratoga Region
 Metropolitan Waterfront Alliance
 Mirror Lake Watershed Association
 Mohawk River Research Center
 Mohegan Lake Improvement District
 Monroe County Stormwater Coalition
 Natural Resources Defense Council
 Nature Conservancy Great Swamp Program
 Nature Conservancy Neversink River Program
 New York Agricultural Land Trust
 New York Forest Owners Association
 New York Rural Water Association
 New York Rivers United
 New York State Federation of Lake Associations, Inc.
 New York State Lakes
 North River Community Environmental Review
 Oatka Creek Watershed Committee
 Onesquethaw/Coeymans Watershed Council
 Onondonaga Creek Revitalization Committee
 Ontario Dune Coalition

Peconic Bay
 Peconic Baykeeper
 Peconic Estuary Program
 Plymouth Reservoir Association
 Protect the Plattekill Creek & Watershed
 Quassaick Creek Coalition
 Riverkeeper, Inc.
 Saranac Lake River Corridor Commission
 Saranac Waterkeeper/Upper Saranac Lake Foundation
 Save Our Seashore
 Sawkill Watershed Alliance Scenic Hudson, Inc.
 Saw Mill River Coalition
 Seneca County
 Skaneateles Lake Watershed Agricultural Program
 Snyder Lake Association
 South Bronx River Watershed Alliance
 Sparkill Watershed Conservancy
 St. Regis Mohawk Tribe
 The River Project
 The Urban Divers Estuary Conservancy
 Upper Delaware Council, Inc.
 Upper Saranac Lake Association
 Upper Susquehanna Coalition
 Wallkill River Task Force
 Westchester Land Trust
 Western New York Land Conservancy

Appendix B. New York State Flood Analysis

To better understand flood processes in New York State, linkages between stream discharge and precipitation and snowmelt were examined for three moderately sized watersheds in three different regions of the state: Ten Mile River in the lower Hudson Valley, Fall Creek in the Finger Lakes Region, and the Poughkeepsie River in the Lake Champlain Valley. The three water bodies were selected because they have at least 50 years of stream gauge and precipitation records and do not have any major impoundments or diversions.

For each water body, the following indicators were examined: the annual maximum daily average flow, the daily average flow associated with the annual maximum two-day precipitation event, and the annual maximum daily flow associated with the maximum three-day snowmelt event. The intent was to investigate the relationship between maximum stream

discharges and two of the most important causes of flooding, large precipitation events and melt of a sizable snowpack (**Table 4.9**).

The three watersheds generally reveal the same patterns in flooding. Most notably, less than 40 percent of annual maximum daily discharges correspond to either two-day maximum rainfalls or maximum snowmelts. To explain this outcome in terms of snowmelt, the largest snowpacks are usually only on the order of 20 inches in depth (it would be preferable to know the actual water content of the snowpack, but this is not routinely measured), and they typically melt over at least several days (the largest one-day melt in any of the watersheds was 13 inches but the median was only 6 inches). An inch of snow typically contains about 0.1 inch of water, so melting of a large snowpack is only equivalent to a moderate rainfall event and not sufficient to result in very large stream discharges.

To explain this outcome in terms of precipitation maximums, most two-day maximum rainfall events occurred between May and October. During this time of year, moisture-laden air from the south reaches New York State and causes two-day rainfall amounts that can exceed 5 inches. However, counteracting these larger rainfall amounts is an increase in available soil-water storage capacity due to the drier soil conditions and lowered water tables that are common in the same timeframe. Using data from the Fall Creek watershed in central New York State, **Figure 4.11** shows the correlation between the two-day storm precipitation amount and the resulting average daily discharge in the stream. Although there is a general upward trend (larger stream discharges occur with larger precipitation amounts), rainfall is clearly not the only factor related to peak discharge. For instance, there are three days with discharges around 6,000 cubic feet per second, but these correspond to medium-sized storm rainfall amounts ranging anywhere from 3 to 5 inches. Though the rainfall amounts of the largest storms will likely increase, impacts on peak flows are

Watershed	% Annual Maximum Discharge Events Occurring When:		
	2-day annual max rainfall	3-day annual max snowmelt	May to October
Ten Mile River	15	10	14
Fall Creek	20	20	5
Poultney River	17	9	10

Table 4.9 Causative conditions of annual maximum discharges on three watersheds representative of conditions in New York State

uncertain due to hydrologic buffering from possible increases in soil dryness.

Rather than snowmelt or large precipitation events, approximately 60 percent (**Table 4.9**) of the annual maximum discharges in these New York watersheds typically result from a combination of limited soil-moisture storage capacity (i.e., wet soils) and moderate rainfall events (1-to-3-inch two-day events). In all three watersheds only 15 percent of annual maximum daily discharges occur between May and October—at most—because the soils are relatively dry (**Table 4.9**, column 3). Ultimately, the degree of change in flooding will likely be dependent on the timing of projected increases in spring rainfall when soils tend to be saturated. If it entails moderate amounts of rainfall on more days, streamflows will be higher more often but will not necessarily reach new maxima. If, however, the number of spring rainfall events remains the same but their maximum potential size increases, flood magnitudes could increase. Such an increase could be partially offset by a lengthened growing season that narrows the window in which a large storm event on wet soils could occur. In brief, given the number of interacting factors, it remains uncertain whether the magnitude of annual maximum flows will increase with climate change. If it does, it would seem probable that wetter spring conditions would likely increase the number of moderate floods (10- to 25-year return periods).

The largest floods of record (50- to 100-year return periods) in the three watersheds can be attributed to distinct hydrometeorological conditions. In the

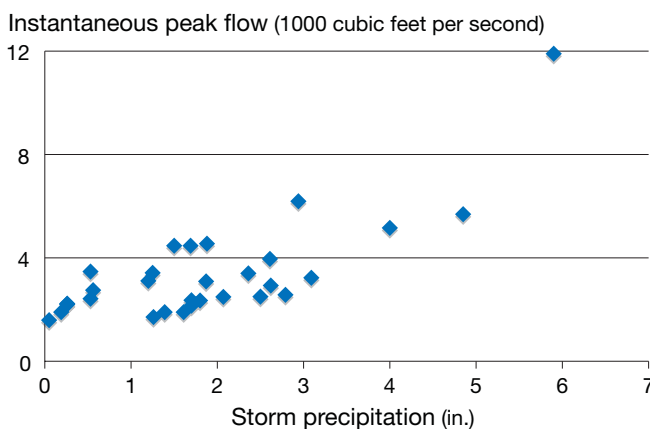


Figure 4.11 Storm rainfall amount and resulting instantaneous peak discharge on Fall Creek, Tompkins County, for the annual peak discharges from 1974 to 2007

Poultney River watershed—the watershed expected to have the most snow—the largest flood (7,010 cubic feet per second) was caused by a combination of snowmelt and rain on presumably still frozen soils (snow remains at the end of the flood event). Surprisingly, this is one of only five annual maximum discharges with rain on snow in this watershed. In Fall Creek, the largest discharge (7,060 cubic feet per second) was caused by a 5.9-inch rainfall event during a month with unusually wet antecedent conditions. In the Ten Mile River watershed, the two largest maximum discharges were associated with a hurricane (10,700 cubic feet per second) and several consecutive days of rainfall (9,930 cubic feet per second). In all these cases, the large flow events were caused by relatively rare conditions. The historical record is too short to observe a trend in the occurrence of these conditions, and projecting future trends is currently beyond the skill of coarse-scale climate models. Additional research is needed to determine the change in probability of these large floods.

-
- ¹ The salt front is not a sharp division between freshwater and ocean water; rather it is the point at which chloride concentration exceeds 100 mg/L. This concentration has been selected to minimize the negative impacts of high salt intake on human health, but it is far lower than a level where it would be entirely unfit to drink for temporary periods (ocean water is 200 times saltier). In extenuating circumstances, withdrawing water even if the salt front had moved upriver beyond the Poughkeepsie intake could still be done with minimal short-term consequences.
- ² The vulnerability of reservoirs to drought was assessed by dividing storage volume by daily demand, and a similar analysis can be accomplished for aquifers by comparing subsurface storage to daily demand. Demand data were determined from the annual water quality reports mandated by the Safe Drinking Water Act. Days of supply with no recharge may be exaggerated because water will not be perfectly redistributed to well fields and the area around a well field may experience localized depletion. Since only the surface area of an aquifer is typically given, stored water is determined by assuming 30 percent of aquifer volume consists of recoverable water and by taking an average aquifer thickness (typically ~40 feet).
- ³ This assessment of wells includes the following: A 16-foot-deep sand and gravel well in Madison County (M-178 Valley Mills) had its water level drop to 11 feet below the surface in the summer of 1999, the lowest point reached in its 27-year history. A 31-foot well in sand and gravel in Oneida County (Oe-151 Woodgate) dropped to 30 feet below ground surface in late 2002, the lowest point in its 18-year history; if subject to pumping, it is presumed that this well would probably have run dry. A 79-foot sand and gravel well (Re-703 East Greenbush) dropped to 42 feet below ground surface in 1986, the lowest point in its 18-year history. A 126-foot bedrock well (364TRNN) (Du-321 Hyde Park) dropped to 72.5 feet below land surface in late 1981, the lowest point in its 24-year history.
- ⁴ Table 4.8 was constructed by comparing 2000 census block data to areas of inundation to determine the vulnerability of certain populations to flooding, specifically renters, seniors, and non-white populations. Demographic data were weighted by the area of the block that was inundated in 2006. The results provide some measure of the human profile of flooding and highlight the presence of a few populations with potential vulnerabilities.

Coastal Zones

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Introduction

The anticipated global sea level rise due to climate warming will greatly amplify risks to the coastal population of New York State, leading to permanent inundation of low-lying areas (including wetlands), more frequent flooding by storm surges, and potential for increased beach erosion. Saltwater could reach farther up estuaries, such as the Hudson River, potentially contaminating urban water supplies, while increased water depth could alter the propagation of both the tide and storm surges up the Hudson River to the Federal Dam in Troy. These hazards will continue to be exacerbated by development in the coastal zone.

The Intergovernmental Panel on Climate Change (IPCC) concluded in 2007 that global sea level will likely rise between 7 and 23 inches by the end of the century (2090–2099), relative to the base period (1980–1999), not counting unexpected rapid changes in ice flow from the Greenland and Antarctic ice sheets. However, these projections may be too low, as they do not consider the uncertainty associated with ice sheet melting processes or cover the full likely temperature range given in the Fourth Assessment Report (up to 6.4°C) (Rahmstorf et al., 2007; Rohling et al., 2008; Pfeffer et al., 2008; Horton et al., 2008). Regional sea level rise projections used in the assessment explicitly include a “rapid ice-melt scenario” based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies (See Chapter 1, “Climate Risks,” for a complete description of this method). Most of the observed current climate-related rise in global sea level over the past century can be attributed to expansion of the oceans as they warm; however, it is anticipated that the melting of land-based ice may become the dominant contributor to global sea level rise in the future.

Historically, the rise in regional (or relative) sea level—a measurement of sea level height that includes local effects such as the vertical movement of land, local ocean temperatures, atmospheric pressure, and tides—has varied through time and accelerated during the 20th century as global temperatures have increased (Gornitz et al., 2002; Gehrels et al., 2005; Donnelly et al., 2004; Holgate and Woodworth, 2004; IPCC, 2007). Regional sea level was rising at rates of 0.34 to 0.43 inch per decade over the past thousand years; however, current rates are ranging between 0.86 and 1.5 inches per decade with a 20th century average rate of 1.2 inches per decade (see Chapter 1, “Climate Risks”).

5.1 Sector Description

The U.S. Coastal Zone Management Act of 1972, as amended in 1996, defines the coastal zone as the land inward of the shoreline needed to control or manage uses that are likely to directly and significantly impact coastal waters or are likely to be “affected by or vulnerable to sea level rise.” New York State considers coastal waters to extend three miles into the open ocean, and up to the state lines of Connecticut and New Jersey along the shore.

In the ClimAID assessment, we consider the coastal zone to include the shoreline of New York State, including coastal wetland areas and inland areas adjacent to the shoreline that are likely to be affected by sea level rise and coastal storms. We also consider impacts and adaptation strategies for Great Lakes coastlines were not included in this assessment even though these regions are clearly part of the coastal zone, as they could not be properly analyzed given scheduling and budgeting constraints. Additional resources should be made available to conduct a comprehensive assessment of climate-change-related impacts and adaptation strategies specifically targeted at the Great Lakes regions (an investigation that would require multi-state collaboration). In particular, this assessment effort focuses on identifying 1) climate change risks affecting the coastal zone, arising from sea level rise, storm surges, increased water temperatures, and changes in precipitation; 2) critical vulnerabilities (populations, ecosystems, and regional coastal communities); and 3) potential adaptation strategies for coastal communities.

The New York State coastline is composed of a combination of glacial bluffs, pocket beaches, and extensive barrier island/bay systems. Long Island is particularly vulnerable to the effects of shoreline erosion since it is largely formed of sand and gravel deposits left by the retreating glaciers, after the end of the last Ice Age around 20,000 years ago. The South Shore of Long Island is a sandy environment consisting largely of barrier islands, spits, and back-barrier salt marshes that are very erodible and subject to inundation.

Coastal ecosystems include nearshore subtidal areas, the low marsh intertidal zone (**Figure 5.1**, top), high marsh (**Figure 5.1**, bottom), beaches, dunes, stream channels, rocky platforms (**Figure 5.2**), seagrass meadows, algal beds, and tidal flats (Nordstrom and

Roman, 1996). Even in a densely populated urban environment such as New York City these coastal ecosystems provide numerous functions and values. These include wildlife habitat, storm surge protection, wave attenuation, pollution absorption, and aesthetic appeal. More than 300 bird species spend part of their life cycle in New York's coastal shores, feeding, resting, or nesting. Every May and June, thousands of horseshoe crabs come to spawn on the sandy beaches of Long Island, New York City, and Westchester County. Many bird species depend on the horseshoe crab eggs or other invertebrates of the tidal zone to replenish their fatty reserves and continue on migration routes along the Atlantic flyway.

New York State's coastal marshes are limited to the north and south shores of Long Island (Suffolk and Nassau Counties), New York City (Queens, Brooklyn, Staten Island, and the Bronx), Westchester County, and up the Hudson River. In the tidally influenced portion of the Hudson River Estuary (up to the Troy Dam), the

dominant ecological communities are freshwater and brackish tidal marshes, freshwater tidal swamps, tidal creeks, mud and sand flats, and freshwater subtidal aquatic beds (Edinger, 2002). However, these are limited to north of the Tappan Zee Bridge as there is little or no break in shoreline armoring (bulkheads and riprap) from Manhattan to the bridge.

5.1.1 Economic Value

The coastal zone is not a category in the North American Industrial Classification System (NAICS) (U.S. Bureau of Economic Analysis, n.d.), since values produced by economic activity in the coastal zone are distributed among a wide variety of industry, government, commercial, and private activities. One way to consider value is the estimated insured value of properties in coastal counties in the state in 2004. This was nearly \$2 trillion: \$1,901.6 billion, or 61 percent of the total insured value in the state of \$3,123.6 billion (AIR, 2005; see Annex II, "Economics," of full ClimAID Report).

Insured losses from previous storms can give a general idea of the current costs of climate-related impacts to the sector. This information is available for hurricanes, winter storms, and thunderstorms. The losses from winter storms and hurricanes are principally located in the coastal zone, whereas losses from thunderstorms occur throughout the state. The largest insured loss since 1990 (in 1992) was approximately \$1 billion (in present dollars) from winter storms; from 1990 to 2010 there are nine other years with losses of more than \$0.4



Location: Idlewild Park, Queens, NY. Photo credit: Mike Feller



Location: Pelham Bay, Bronx, NY. Photo credit: Ellen Kracauer Hartig

Figure 5.1 Salt marshes in the urban environment



Photo credit: Mike Feller

Figure 5.2 Rocky shoreline at Pelham Bay Park, Bronx

billion (ISO, 2010). Additionally, Pielke et al. (2008, p. 35) adjusted the losses from the 1938 hurricane to account for inflation, changes in population density (and thus exposures), and asset value, and estimated that the 1938 storm, if it occurred today, would cause \$39.2 billion (2005 dollars) in economic damages (see Annex III, “Economics,” of full ClimAID Report).

This information gives a picture of the order of magnitude of coastal zone storms losses without further adaptation measures. As sea level rises, the probability of any given amount of flooding rises so that a storm in the future may cause a larger amount of flooding than the same storm today. See Annex III, “Economics,” of full ClimAID Report for further details.

5.1.2 Non-Climate Stressors

The ClimAID assessment is focused on climate-related stresses influencing the coastal zone of New York State. However, as in any complex system, there are multiple

forces interacting to produce the observed behavior. Often it is difficult to attribute the response of the system to any particular forcing function; therefore, it is necessary to briefly mention some of the non-climate stressors impacting the various coastal components described in this sector. Many of these stresses are associated with human consumption of natural resources and land-use practices. For example, coastal development, construction of drainage alterations, and impervious surfaces have led to a reduction in groundwater recharge and degraded coastal water quality (Bavaro, 2005). The interconnection among precipitation, land use, and local fish populations has also been documented, suggesting increased urbanization may lead to a reduction in stream biodiversity and migratory fish run sizes (Limburg and Schmidt, 1990). A number of human-induced factors (including sewage discharges and contaminated stormwater runoff from developed and agricultural areas) cause pollution and pathogen outbreaks that can lead to closures of shellfish harvesting areas. The relationship between agricultural lands, storm-water

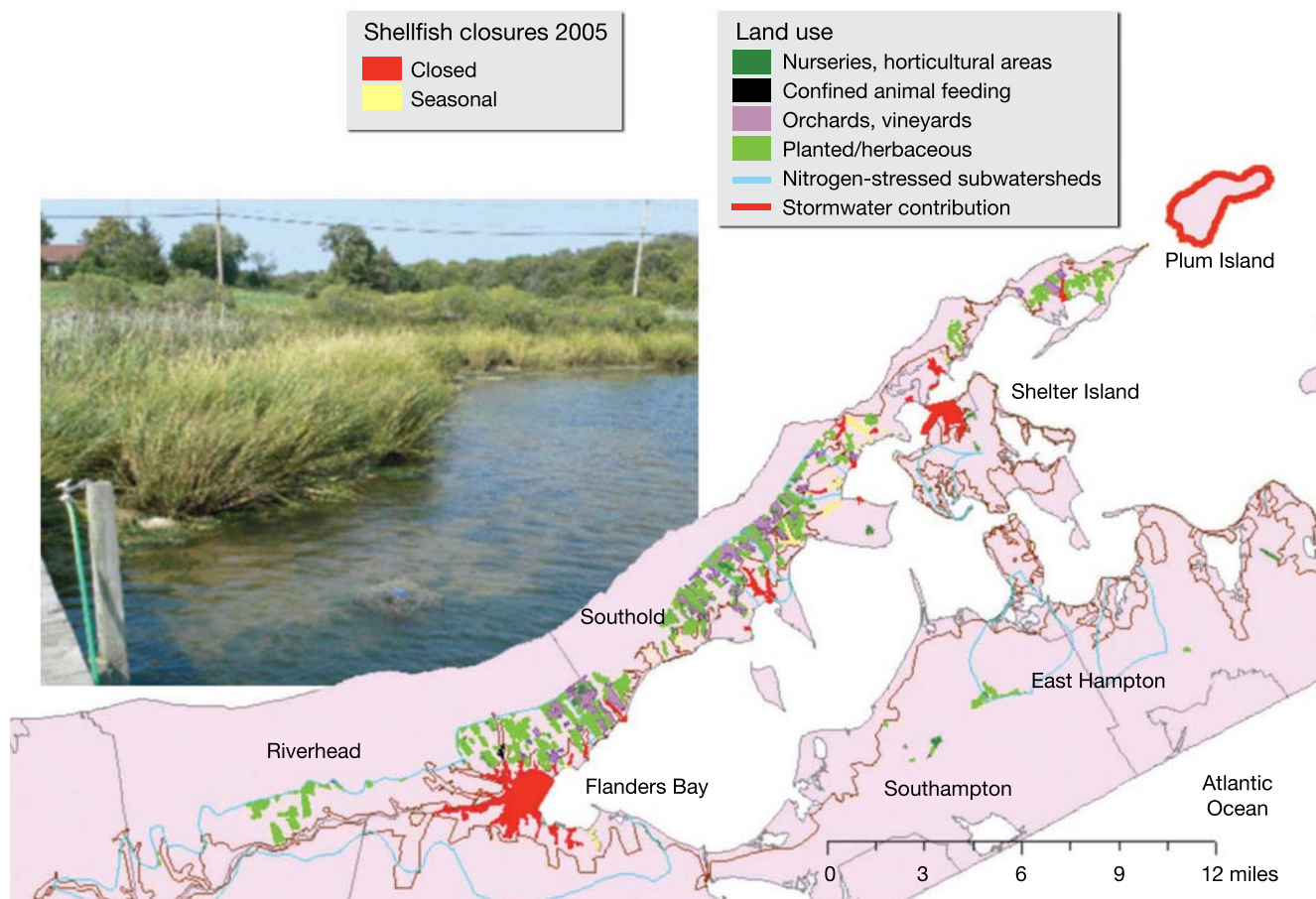


Photo of Flanders Bay wetlands. Figure courtesy of Frank Buonaiuto

Figure 5.3 Peconic River Estuary shellfish closures and land use practices

drainage, nitrogen additions, and shellfish closures for the Peconic River Estuary for 2005 is illustrated in **Figure 5.3**. In addition to stresses related to water quality, fish stocks (as well as other marine ecosystem components) may be affected by harvesting practices, diseases (not necessarily climate related), and normal population dynamics (e.g., predation, competition, and recruitment variability). Intense development along the coast increases vulnerability to inundation as well as the demand for groundwater, which could lead to drawdown of aquifers and increased saltwater intrusion. Coastal infrastructure also inhibits natural geographic migration of wetlands and barrier islands.

5.2 Climate Hazards

For the ClimAID assessment, three climate risks were considered of particular importance for the Coastal Zone: rising sea levels, increasing coastal water temperatures, and changes in precipitation patterns.

5.2.1 Sea Level Rise

Sea level rise projections were constructed for New York City and up the Hudson River Estuary to the Troy Dam. The projections, which were downscaled from IPCC global climate model (GCM) simulations for various greenhouse gas emission scenarios, were limited in resolution, which resulted in very little difference between New York City and Montauk Point (refer to Chapter 1, “Climate Risks,” for details on calculation methodology). In addition to the IPCC GCM calculations, a rapid ice-melt scenario was included as a result of current trends. The range of sea level rise projections for Regions 4 and 5 of the ClimAID Assessment is summarized in **Table 5.1**. See

Region 4: New York City and Long Island	2020s (inches)	2050s (inches)	2080s (inches)
GCM-based ¹	+2 to +5	+7 to +12	+12 to +23
Rapid ice-melt scenario ²	~5 to +10	~19 to +29	~41 to +55
Region 5: East Hudson and Mohawk River Valleys	2020s (inches)	2050s (inches)	2080s (inches)
GCM-based ¹	+1 to +4	+5 to +9	+8 to +18
Rapid ice-melt scenario ²	~4 to +9	~17 to +26	~37 to +50

¹ Shown is the central range (middle 67%) of values from global climate model-based probabilities rounded to the nearest inch.

² The rapid-ice melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies.

Table 5.1 ClimAID Assessment sea level rise projections

Chapter 1 for a more complete discussion of the model scenarios used to construct the central range estimates.

The rapid ice-melt sea level rise scenario is based on extrapolation of recent accelerating rates of ice melt from the Greenland and West Antarctic ice sheets and on paleoclimatic studies that suggest sea level rise on the order of ~0.39 to 0.47 inch per year may be possible. The potential for rapid ice-melt should be considered in part because of the large magnitude of consequence should it occur. To assess the risk of accelerated sea level rise over the coming years, scientific understanding as well as many key indicators should be monitored and reassessed. For example, one component of the monitoring efforts should focus on properties of the coastal zone, such as the geographic extent and health of coastal wetlands and the distribution of certain marine organisms like blue crabs and lobsters. Monitoring of coastal landforms, such as the barrier islands along the south shore of Long Island, is also necessary as the response of these systems to accelerated sea level rise has yet to be determined.

5.2.2 Increasing Coastal Water Temperatures

Water temperature plays a dominant role in shaping marine ecosystems. As ocean temperatures continue to rise, the range of suitable habitat in the Northeast for many commercially important fish and shellfish species is projected to shift northward. However, it is not clear what the local production of those species would be during such transitions (Frumhoff et al., 2007). Regional surface and bottom water temperatures are influenced in part by large-scale oceanic and atmospheric circulation (which exhibits annual, inter-annual, and inter-decadal variability), annual cycles in solar radiation, migrating weather systems, and, more locally, by freshwater discharge.

Over the course of the 20th century, regional sea-surface temperatures have risen more than 1.0°F. Water temperature changes can result in shifts in faunal assemblages (groupings of organisms) that affect marine ecosystems and economic activities in unknown ways. Every species has a thermally suitable range for habitat that, when compromised, induces a forced migration to seek another location suitable to its life cycle. Water temperatures influence organism survival and growth,

egg and larvae development, and spawning and feeding behavior. When water temperatures rise, ecosystems become vulnerable to shellfish diseases, harmful algae blooms, and exotic species that force indigenous species to compete for resources, including dissolved oxygen (DO). Oxygen solubility will decrease as water temperatures increase, further stressing marine organisms. Understanding the impact of increased water temperatures is critical to planning for ecosystem stresses associated with climate change.

Regional sea-surface temperature projections were developed for the 2050s (the 30-year average from 2040 to 2069) for comparison with a 1980s baseline derived from the Community Climate System Model (CCSM) and the Geophysical Fluid Dynamics Laboratory (GFDL) models under the A2 and B1 Special Report on Emissions Scenarios (SRES) emissions scenarios. All show substantial increases on the order of 1.8–2.5°F for near-shore waters, depending on the model and emissions combination. However, global climate models (GCMs) represent only some of the complex connections between ocean and atmosphere when determining water-temperature projections and are often limited in resolution.

5.2.3 Change in Regional Precipitation

The spatial and temporal distribution of precipitation will inevitably impact New York State's coastal regions. Changes in local precipitation in areas such as Nassau and Suffolk counties will affect rates of groundwater recharge, lake levels, stream flow, and the delivery of nutrients and pollutants to coastal waters. Changes in temporal and spatial precipitation patterns for the northernmost counties will also influence the tributary inflows and discharge of the Hudson River. During periods of increased precipitation and discharge, the position of the salt front will move downstream. Droughts, particularly in summer when air temperatures would increase rates of evaporation, would force the salt front to migrate upstream. Increases in annual precipitation for coastal regions in New York State (New York City and Nassau and Suffolk counties), which is currently about 47 inches, are expected to range from 0 to 5 percent by the 2020s, 0 to 10 percent by the 2050s, and 5 to 10 percent by the 2080s (see Chapter 1, "Climate Risks," for details). Changes in the amount of precipitation will not be uniformly distributed throughout the year, and some of

the expected variability in precipitation will be associated with extreme events. Similar changes in precipitation are anticipated for the other ClimAID regions, with Regions 5, 6, and 7 (East Hudson and Mohawk River Valleys; Tug Hill Plateau; Adirondack Mountains) potentially experiencing a 5 to 15 percent increase in precipitation by the 2080s. In addition, increases in precipitation would alter near-shore salinities, potentially impacting fish and shellfish populations.

5.2.4 Other Climate Factors

Additional climate factors considered important for the coastal zone are coastal storms and floods. For storm track frequency and variations in river discharge, the climate models used for this assessment effort are not able to predict with the necessary degree of certainty changes in either of these factors.

Coastal Storms

While permanently lost land is projected to occupy a relatively narrow coastal strip by the 2080s higher storm surges associated with higher sea levels could periodically engulf a much greater area. Also, wave action will erode and reshape the shoreline, affecting the location and extent of storm surge inundation. The current 1-in-100-year flood (also known as the 1 percent annual chance flood and defined as a flood that has a 1-percent chance of being equaled or exceeded in any given year) will occur more frequently, with future 1-in-100-year flood events achieving higher flood elevations. The greater frequency of severe flooding events affecting the increasing number of waterfront residences may lead to abandonment of ground floors (as in Venice) or ultimately of entire buildings. Evacuation of vulnerable populations in high-risk areas during major storms may pose difficulties in that many evacuation routes may themselves become flooded.

Low-lying coastal regions throughout New York are vulnerable to surge (elevated water levels) from both tropical (originating in the tropics, e.g., tropical storms and hurricanes) and extratropical (mid-latitude) storm systems. Elevated coastal water levels, strong winds, and large amounts of precipitation during these storm events result in billions of dollars in damages. In addition to flooding, some of the more severe storms

have disrupted transportation and power distribution systems. A partial list of the more severe historical storms to impact New York appears in **Table 5.2**.

Historic hurricanes in New York State include the “Great September Gale of 1815” and the category 2 hurricane of 1821, which flooded lower Manhattan as far north as Canal Street (Ludlum, 1963). The “Midnight Storm” of 1893 destroyed Hog Island, and the 1938 “Long Island Express,” a category 3 hurricane, passed across eastern Long Island and generated a storm surge ranging from 10 to 15 feet along the south shore. This single event dramatically altered the barrier island system by overwashing dunes (e.g., storm waters overtopping the barrier island) lower than 20 feet above mean sea level and creating numerous inlets, including the present-day Shinnecock Inlet. Even though other severe storms have impacted the state, there have been no other direct hits by major hurricanes (> cat 3; see **Table 5.3** for a description of hurricane categories) across New York City and Long Island since the 1938 Long Island Express (National Hurricane Center, 2008). Even though it is unclear if the changing climate will result in more frequent hurricanes in the Atlantic, warming ocean temperatures throughout the surface mixed layer have the potential to produce stronger storms. New York State should consider hurricane threats when reviewing and adopting adaptation strategies, even though their occurrence is less predictable than that of extratropical storm systems.

In contrast to hurricanes, in which storm surge damage is generally confined to the coastal areas near landfall, extratropical storms (regionally referred to as nor’easters) can cause millions of dollars in damage over a larger region along the coast. In addition, extratropical storms often span several tidal cycles, increasing the risk of flooding to coastal communities. For example, there was \$300 million in property damage and major coastal erosion along the mid-Atlantic coast during the March 1962 extratropical cyclone (Dolan, 1987), while the 1993 March Superstorm effectively shut down transportation along the entire U.S. East Coast (Kocin et al., 1995). More locally, the December 1992 nor’easter, which generated water levels in excess of 8 feet above mean sea level, flooded parts of the New York City subway and Port Authority Trans-Hudson (PATH) train systems (Colle et al., 2008).

Scale Number (category)	Winds (mph)	Typical Characteristics of Hurricanes by Category*			
		Barometric Pressure		Surge	Damage
		(Millibars)	(Inches)	(Feet)	
1	74–95	>979	>28.91	4–5	Minimal
2	96–110	965–979	28.50–28.91	6–8	Moderate
3	111–130	945–964	27.91–28.47	9–12	Extensive
4	131–155	920–944	27.17–27.88	13–18	Extreme
5	>155	<920	<27.17	>18	Catastrophic

* This revised version of the Saffir-Simpson Hurricane Wind Scale assigns hurricane category based on the maximum sustained surface wind speed only. Central pressure values are no longer used as proxy for wind speed, and storm surge is currently forecast using multiple factors such as storm size, forward speeds, and local bathymetry and topography.

Source: Blake et al., 2007 and NOAA

Table 5.3 The Saffir/Simpson Hurricane Scale

Tropical Storms			Extratropical Storms		
Date	Name	Cat.	Date	Name	Cat.
9/3–9/5/1815	Great September Gale of 1815	3	3/6–3/8/1962	*Ash Wednesday Storm	
9/3/1821	Norfolk and Long Island Hurricane	1-2	2/6/1978	Major blizzard	
9/1858	New England Storm	1	3/28–3/29/1984	Major blizzard	
9/1869	Eastern New England Storm	1	10/29–11/2/1991	*Halloween Storm, “Perfect Storm”	3
8/23/1893	Midnight Storm	1–2	12/11–12/12/1992	*Major nor’easter	3
9/21/1938	Long Island Express	3	3/13–3/14/1993	“Storm of the Century”	3
9/15/1944	Great Atlantic Hurricane	1	2/17/2003	Major blizzard	
8/1954	Hurricane Carol	3	3/12/2006	Major blizzard (record snow, but little surge)	
9/12/1960	Hurricane Donna	3	11/11–11/14/2009	Nor’easter (“Nor’Ida”)	3
9/21/1961	Hurricane Esther	1-2			
6/1972	Hurricane Agnes	1			
8/10/1976	Hurricane Belle	1			
9/27/1985	Hurricane Gloria	2–3			
8/1991	Hurricane Bob	2			
9/1999	Hurricane Floyd	2			

* Extratropical storms with the highest surges since 1960.

Note: Levels are based on intensity scale developed by Salmun et al., 2009.

Source: NPCC Climate Risk Information Workbook, FIMP; Gornitz and Couch, in Rosenzweig and Solecki (2001); NOAA NOS <http://tidesandcurrents.noaa.gov>; NY Times

Table 5.2 New York State tropical and extratropical storm systems

Extratropical storms frequently occur on the East Coast of the United States; as a result, several studies have been conducted in order to determine typical characteristics of these systems, including timing and regions of formation, structure, and general tracking patterns (Reitan, 1974; Colucci, 1976; Zishka and Smith, 1980; Hayden, 1981; Hirsch et al., 2001). Approximately 12 strong extratropical cyclones are generated each year, with the maximum number of storms occurring during the month of January. Although, as expected, extratropical storms exhibit interannual variability (Davis et al., 1993; Colle et al., 2008), the number (Hirsch et al., 2001) and intensity (DeGaetano, 2008) of extratropical storms generally increase during El Niño years and the positive phase of the North Atlantic Oscillation (DeGaetano et al., 2002).

Intensity scales have been developed for East Coast winter storms using atmospheric and oceanographic conditions. These research efforts highlight the regional variability of storm strengths and the need for sustained local monitoring of the meteorological conditions and resulting coastal impacts (Dolan and Davis, 1992; Zielinski, 2002; Salmun et al., 2009). Moderate coastal flooding appears to be associated with northward-tracking cyclones along the East Coast (Colle et al., 2010), but the relationship between extratropical storm intensity and storm surge has been difficult to quantify. In addition to the regional-scale atmospheric circulation associated with extratropical cyclones, coastal flooding also depends on local factors, such as waves (Salmun et al., 2009), winds, coastline configuration, and bathymetry.

Coastal Floods and Recurrence Intervals

New York State's complex coastal geometry and bathymetry make modeling and forecasting coastal floods extremely difficult. Approximately 85 percent of the coastal flood warnings issued by the National Weather Service for New York from 2001 to 2006 did not materialize (Colle et al., 2010). This high false alarm rate is attributed in part to the general lack of information and understanding about the movement of water and waves near the shore. There have been recent advances in ocean and surge modeling to help researchers and emergency managers operating in New York State (Colle et al., 2008). However, the link between the detailed meteorological evolution of the storm systems and the

development of surge (atmospherically forced elevated water levels) in this region requires additional investigation, making it even more difficult to understand how storm systems and their impacts on the New York region will evolve as the climate changes.

The National Weather Service issues coastal flood advisories and coastal flood warnings for New York State when storm systems elevate regional water levels approximately 2 feet (minor surge event) and 3 feet (moderate surge event) above mean high water (MHW) at the Battery, respectively (Colle et al., 2010). During the period 1959–2007, New York experienced 244 minor and 46 moderate surge events, which combined with the observed tide to produce 174 minor (flood advisory) and 16 moderate (flood warning) flooding events. This illustrates how sensitive the flooding of low-lying coastal regions is to the timing of storm surges and tides. Similar to extratropical storm activity, the most active surge years have been associated with El Niño events. The number of minor surge events has decreased gradually from a relatively active period during the 1960s to noticeably fewer events in the late 1980s and 2000–2007 (Colle et al., 2010). In particular, the 10-year period from 1997 to 2007 was one of the calmest moderate surge periods in the last 50 years, which may indicate that the cyclone intensity and/or tracks may be different than 10 to 20 years ago. It is not clear at this time if the change in cyclone characteristics is a direct result of climate change or part of a natural multi-decadal cycle.

Since 1990, the frequency of minor surge events (water levels elevated 2 feet above astronomically predicted tide) has been decreasing, yet the number of minor flood events (flood advisories, water levels elevated 2 feet above mean high water) has been steadily increasing. This suggests that sea level rise over the last few decades has already been enhancing the number of nuisance flooding (coastal flood advisory) events in New York State (Colle et al., 2010).

Currently the number of moderate flooding events (coastal flood warnings) does not appear to be influenced by climate change and resulting sea level rise. However, assuming a surge pattern similar to the 1997–2000 period, central sea level rise projections (see Chapter 1, “Climate Risks”) of 5, 12, and 23 inches at the Battery for the 2020s, 2050s, and 2080s, respectively, would result in 4, 16, and 136 moderate flooding events annually. Under a rapid ice-melt

scenario, New York State could experience between 200 and 275 moderate flooding events each year by 2080 (Brian Colle, personal communication, 2009).

Coastal flooding is a dynamic process, and individual storm events can exhibit large variations in regional water levels along the coast. Flood levels can be computed from water level observations if a sufficient record is available, or from a combination of deterministic modeling and probability analysis. Several methods for determining flood levels and associated recurrence intervals are available, and when the computation is for insurance purposes, a certified flood plain manager ensures the analysis is in accordance with Federal Emergency Management Agency (FEMA) standards.

Still water levels (not including waves) associated with 1-in-10-year and 1-in-100-year events for New York City (Horton et al., 2010) and Westhampton Beach for various time horizons are shown in **Table 5.4**. It should be noted that changes in the still water levels are for illustrative purposes and are expected to vary geographically, being influenced by offshore bathymetry and shoreline configuration. Coastal communities should conduct more localized gauge and modeling investigations to improve water level calculations. As an example, projected changes in the 1-in-10-year coastal flood for Long Beach and the surrounding bay communities for GCM-based and rapid ice-melt scenarios are presented in **Figure 5.4**. A detailed investigation of the 1-in-100-year coastal flood for communities on Long Beach and along Great South

Bay is presented in Case Study A: 1-in-100-year Flood and Environmental Justice.

As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. The changes in coastal flood intensity listed in **Table 5.4** are solely due to gradual changes in sea level through time. Any increase in the frequency or intensity of storms themselves would result in even more frequent and damaging future flood occurrences relative to the current 1-in-10- and 1-in-100-year coastal flood events. By the end of the 21st century, sea level rise alone would increase the frequency of coastal flood levels that currently occur on average once per decade to once every one to three years for New York City and once every one to two years for Westhampton Beach. In addition, water levels associated with these events are likely to increase by 1 to 2 feet. The more severe current 1-in-100-year event, which is less well characterized than that of the 1-in-10-year event, may

New York City Extreme Event	Baseline (1971–2000)	2020s	2050s	2080s
1 in 10 yr flood	~10 yr	~8–10 yr	~3–6 yr	~1–3 yr
1 in 10 yr swl	6.3 ft	6.5–6.8 ft	7.0–7.3 ft	7.4–8.2 ft
1 in 100 yr flood	~100 yr	~65–80 yr	~35–55 yr	~15–35 yr
1 in 100 yr swl	8.6 ft	8.8–9.0 ft	9.2–9.6 ft	9.6–10.5 ft
Westhampton Beach Extreme Event	Baseline (1971–2000)	2020s	2050s	2080s
1 in 10 yr flood	~10 yr	~7–8 yr	~2–5 yr	~1–2 yr
1 in 10 yr swl	4.9 ft	5.1–5.3 ft	5.5–5.9 ft	5.9–6.7 ft
1 in 100 yr flood	~100 yr	~80–90 yr	~60–70 yr	~35–60 yr
1 in 100 yr swl	8.5 ft	8.7–8.9 ft	9.1–9.5 ft	9.5–10.3 ft

Note: SWL = Still water level.

Source: NPCC 2010 and Columbia Center for Climate Systems Research

Table 5.4 Current and projected recurrence intervals and flood levels for New York City and Westhampton Beach based on ClimAID model-based sea level rise projections from 7 GCMS for the 2020s, 2050s, and 2080s.

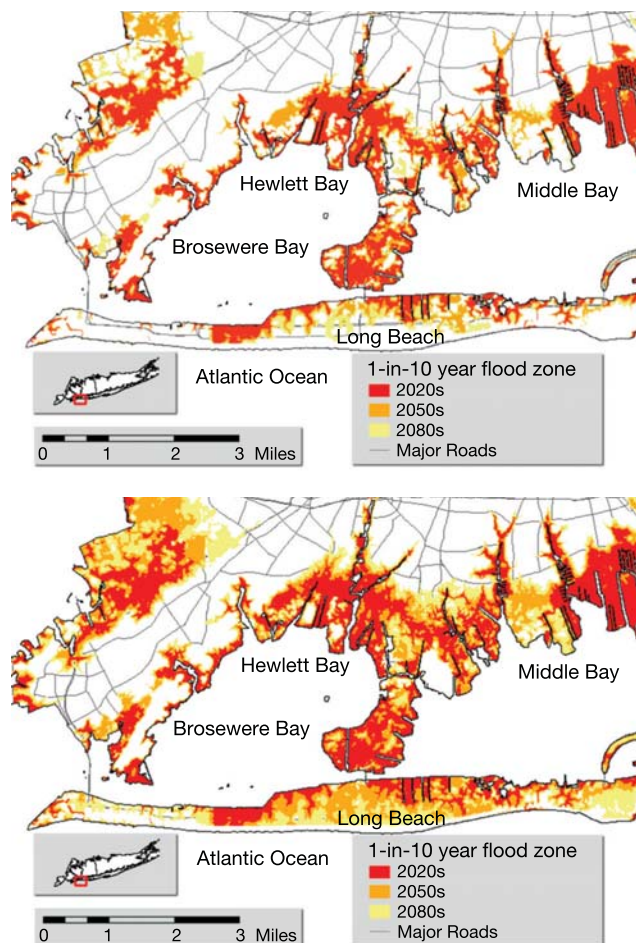


Figure 5.4 Projected flood maps for 1-in-10-year storm event for Long Beach and surrounding bay communities for the ClimAID GCM-based (top) and rapid ice-melt scenarios (bottom)

occur on average approximately four times as often by the end of the century (NPCC, 2010).

Low-lying coastal communities on Long Island and New York City could find themselves repeatedly under water at high tide, with consequent property damage. The greater likelihood of coastal flooding (as well as heavier rainfall) would result in an increase in street, basement, and sewer flooding; an increase in flood risk to low-elevation transportation, energy, and communications infrastructure; more frequent delays on low-lying highways and public transportation; increased structural damage and saltwater exposure to infrastructure, commercial, and residential property; increased inflow of seawater to storm sewers and wastewater treatment plants and reduced ability of gravity discharge of sewer-effluent overflows; encroachment of saltwater into freshwater sources and ecosystems; and increased beach erosion and sand placement needs.

Many of the entrances to bridges and tunnels, segments of the highways and railroads, and similarly, many wastewater treatment plants and sewer outfall systems lie at or below the 10-foot contour and are potentially vulnerable to severe present-day coastal storm flooding, let alone projected higher future levels (See Chapters 9 and 10, “Transportation” and “Telecommunications”). Even brief but heavy precipitation downpours, as exemplified by the August 8, 2007 storm, have led to shutdowns of portions of the New York City subway system (Metropolitan Transportation Authority, 2007) and highway flooding. Even greater transportation disruptions, affecting not only subways and some highways, but PATH trains, railways, and air transportation, occurred during the December 1992 nor’easter and hurricanes such as Hurricane Donna in 1960, Hurricane Gloria in 1985, and Hurricane Floyd in 1999.

A recent study prepared for the New York City Department of Environmental Protection found that sea level rise and coastal inundation could affect the heights of tide gates designed to prevent the inflow of seawater and backing up of outfall sewers (NYCDEP, 2008). More tide gates may need to be installed at outflow locations to prevent such inflows, and more frequent repairs of the gates may become necessary. If high tide levels during storms cause backup of sewage, more could be forced into wastewater treatment plants, necessitating the throttling of flows to protect the plants from flooding. Increased street, basement, and sewer

flooding could result. Coastal flooding could increase salinity of influent into wastewater pollution control plants (WPCPs) and lead to corrosion of equipment. More delays and service interruptions on public transportation and low-lying highways can be expected. More frequent flooding and wave action could increase structural damage to infrastructure.

5.3 Vulnerabilities and Opportunities

Because of the highly developed nature of the coast in New York State, a considerable portion of population, private property, and infrastructure in the coastal zone will be potentially at risk to enhanced inundation and flooding due to sea level rise associated with climate change.

5.3.1 Coastal Erosion

Waves, currents, and tides constantly reshape the shoreline, and as sea level rise accelerates, these forces have the potential to dramatically alter New York State’s coast. Even at present rates of sea level rise, over 70 percent of the world’s sandy beaches are eroding (Bird, 2008). Beach erosion is frequently intensified by human activities, such as interrupting littoral drift by jetties or groins, and beach sand mining. Ultimately, the rate of erosion is typically several orders of magnitude greater than the vertical rise in sea level itself (Frumhoff et al., 2007). Any narrowing and potential loss of barrier islands due to sea level rise would place many waterfront communities at higher risk to the effects of storm flooding.

Long Island has had an extensive history of beach erosion dating from at least the 19th century, which has been exacerbated in some areas by 20th century construction of hard structures (e.g., groins, jetties, etc.). Many of these structures were put in place after the disastrous 1938, 1944, and 1953 hurricanes. These were intended to prevent erosion, but interrupted the natural flow of sand carried by longshore currents from Montauk Point to New York City, which led to erosion of beaches downdrift. If not for periodic beach nourishment (addition of sand from off-shore to the beach) by the U.S. Army Corps of Engineers, the beaches would have already narrowed considerably, making the shorelines much more vulnerable to coastal storm damage.

Though effective, beach nourishment programs are quite costly. Nor-Ida (the November 11–14, 2009, nor'easter combined with remnants of Hurricane Ida) resulted in major beach erosion along the south shore of Long Island, including the Rockaways and Plumb Beach in Brooklyn. Point Lookout, the eastern end of Long Beach Island, lost over 219,000 cubic yards of sand from a 5,000-foot stretch of shoreline. In the same storm a 10,000-foot length of shoreline along Robert Moses State Park lost approximately 260,000 cubic yards of sand (David Yang, personal communication, August 2010). At a sand placement cost between \$25 and \$35 per cubic yard, damages associated with erosion just at these two locations were estimated at \$12–17 million. In addition, structural damage to groins along Point Lookout was estimated to be around \$6 million. For Rockaway Beach, the Army Corps of Engineers and other government agencies have committed to conducting beach replenishment to maintain these public resources. For Plumb Beach, used primarily for passive recreation, the USACE is designing a beach nourishment and breakwater project to protect a section of the Belt Parkway that is rapidly eroding (David Yang, personal communication, May 2011).

Other features subject to erosion induced by sea level rise are the glacial bluffs of the north shore and eastern south shore of Long Island (**Figure 5.5**). Bluff erosion supplies sediments to the beach and near-shore coastal system. The amount of material supplied depends on the height of the bluff and the rate of erosion. There are many factors contributing to bluff erosion, but some of the most severe erosion events occur during storms when high water levels allow large waves to attack the base (i.e., toe), removing material and destabilizing the bluff face. The coarse material usually remains on the beach (**Figure 5.5**), while sand and fine-grained materials are transported offshore and to neighboring beaches by waves and currents. In addition to toe erosion by wave action, intense rainfall erodes the bluff face, while percolating rainwater increases the potential for mass wasting.

The few existing studies on the eastern shore of Long Island suggest that only a relatively small portion of the sand eroded from the bluffs is required to maintain the longshore transport system and beaches (Buonaiuto and Bokuniewicz, 2005). Most of the fine-grained material appears to be transported offshore, but a small portion may be deposited in local marshes.

Increased sea level rise may be expected to raise water levels and increase the frequency of wave attack at the base of bluffs. Initially, this would tend to accelerate bluff recession and increase the rate of supply of sediment and other material to the near-shore system. Depending on the type of material and rate at which it is delivered relative to the magnitude of other coastal processes, this change in the supply could have different impacts that are difficult to predict, given our limited understanding of these systems in terms of sediment budgets and transport pathways.

In areas where the bluff composition is primarily fine-grained material not suitable for beach building, sea level rise may be expected to cause increased bluff recession and release more silts and clays. Most of this material will be delivered offshore but some will also be deposited in harbors and marshes. In areas with bluffs composed primarily of sand and other coarse material, increased rates of sea level rise may change



Photo credit: Frank Buonaiuto

Figure 5.5 Bluff coastline near Montauk Point

the present “equilibrium” between sediment supply and other processes, resulting in enhanced spit accretion, possible beach widening, and/or the formation of other sedimentary structures such as offshore bars, which, in turn, could reduce the rate of bluff recession.

Some of the sands derived from bluff erosion, combined with sand supplied from the continental shelf, contribute to the littoral transport that maintains the state’s barrier island system. Over thousands of years, the barrier islands on the south shore of Long Island have migrated landward in response to rising sea level. Barrier-island migration is primarily controlled by the slope of the coastal plain, sediment supply, the rate of sea level rise, and energy supplied by storms. Some portions of the barrier islands have not migrated over the last 750 to 1,300 years, while others appear to be migrating on timescales of hundreds of years, driven primarily by large storm events (Leatherman and Allen, 1985). It is not certain whether the islands migrate solely by a relatively continuous process (rollover) or by a combination of processes that include continuous rollover punctuated by periods where the barrier essentially drowns in place and then skips or jumps to a new position further landward depending on the rate of sea level rise and sediment supply. This is primarily due to the fact that both the processes driving these systems and the history of barrier island migration and barrier island shoreline changes are poorly documented and understood. Although continuous rollover appears to be the most likely process over the last 6,000 years, there may even have been periods of time when islands didn’t exist.

Inlets that persist for more than several years are believed to be the primary mechanism for transporting sand from the ocean to the bay side of the barrier and providing the platform that allows the barrier to move landward. Overwash processes lower the dune but maintain or raise the elevation of the barrier behind the dune. Massive dune destruction and overwashing have been reported after many historic storms but overwash sediments rarely reach the bay shore, except after major hurricanes and occasionally along the easternmost barriers (Jay Tanski, personal communication, November 2009).

In some areas, marshes have formed on the flood tidal deltas of former inlets. The relative contributions of the

various sources of inorganic sediment used for marsh building (mainland runoff, re-suspension from the bay bottom, breaching, and inlets, etc.) are not known.

Shoreline change rates measured over the last 100 years show that generally the shoreline is receding at relatively low average rates of 1 to 2 feet per year. The largest shoreline changes, both accretion and erosion, are found in the vicinity of stabilized inlets and other structures and are related to the disruption of the longshore transport of sediment along the coast (Kana, 1995). The shoreline change rates in these areas are significantly larger than what would be expected due to sea level rise alone. On decadal timescales, storms and human and natural disruptions of the longshore transport of sand are more important than sea level rise in determining shoreline behavior.

Accelerated sea level rise will tend to exacerbate barrier island erosion problems. At low-to-moderate increases in the rates of rise, the effects of sea level rise will still be of lesser magnitude than storm events and disruptions of the longshore sediment transport in those areas experiencing the most severe erosion problems over the next 30 to 50 years. At the higher rates of projected sea level rise (e.g., the rapid ice-melt scenario), the migration of barrier islands landward should accelerate, but this migration may not be initiated in some sections of the barrier island for hundreds of years due to the present volume of sand in the barrier profile.

Barrier migration would be preceded by narrowing and lowering of the barriers and increased breaching (in which water intrusion splits islands into two or more parts) and new inlet formation, resulting in changing conditions in the back barrier lagoons. At the most extreme rates of increased rate of rise, the barriers islands may not be able to maintain themselves if sea level rise outpaces the ability of the system to supply sediment naturally. This will expose the bay and mainland shoreline to more oceanic conditions as the barrier disappears.

5.3.2 The Hudson River Estuary

The Hudson River Estuary is a narrow, 152-mile arm of the sea that extends from the southern tip of Manhattan north to the Troy Dam (**Figure 5.6**). The river, which has a maximum width of 3 miles in the

Tappan Zee (along the boundary between Rockland and Westchester counties), is influenced by rising sea levels and storm surge up to the dam at Troy. The total length of exposed, eroding river bank along the Hudson appears to be small, only a few miles in aggregate. Much of the shoreline is rock or it has been stabilized by the construction of the railroad lines. The Hudson River Estuary's shoreline has been dramatically altered over the last 150 years to support industry and other development, contain channel dredge spoils, and to withstand erosive forces of ice, wind, and waves. About half of the natural shoreline has been engineered with revetments, bulkheads, or cribbing, or reinforced with riprap. Many shorelines contain remnant engineered structures from previous human activities. The remaining "natural" shorelines (which have been affected by human activities such as disposal of dredge spoil, invasive species, and contaminants) include a mix of wooded, grassy, and unvegetated communities on mud, sand, cobbles, and bedrock.

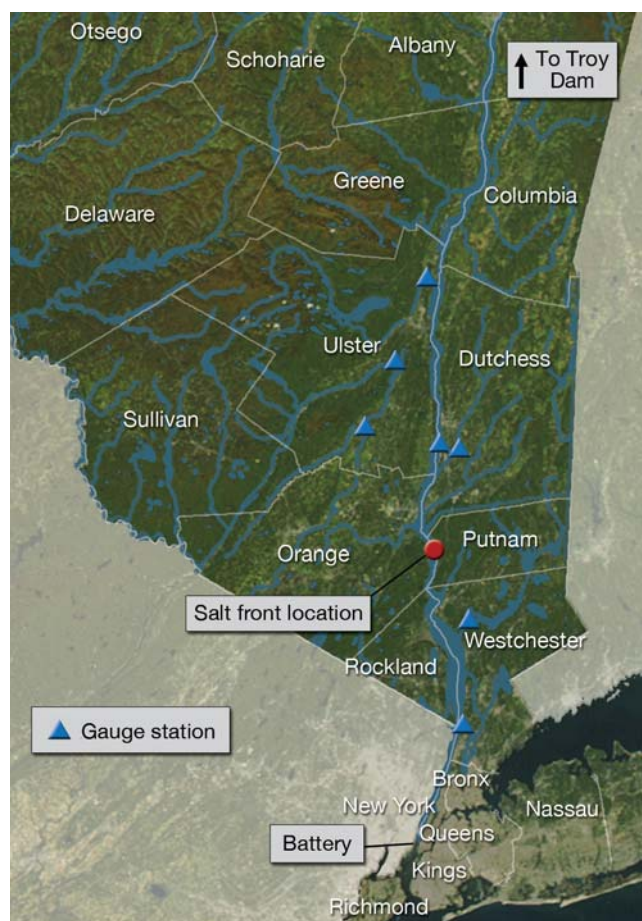


Figure 5.6 Hudson River Estuary with location of salt front on 10/30/2009

The average tidal range along the Hudson River is about 4 feet, peaking at 5 feet at either end of the estuary. The transition from freshwater to saltwater occurs in the lower half of the river, and the position of the salt front (interface between saltwater and freshwater) depends in part on the deposition of sediment on the river bed and the flow of freshwater down the Hudson River (discharge). As the climate changes and sea levels rise, the position of the saltwater and propagation of tide and storm surge throughout the estuary will be altered (see Case Study B. Modeling Climate Change Impacts in the Hudson River Estuary).

Climate change could affect the location of the salt front in three ways: 1) reduction in precipitation can reduce stream flow, allowing the salt front to move upstream, 2) increase in temperature can increase evaporation, reducing freshwater runoff, which in turn would cause the salt front to migrate upstream, and 3) rising sea level may push the mean position of the salt front upstream (Rosenzweig and Solecki, 2001). The rates of northward salt front migration could be higher especially for the rapid ice-melt scenario. However, even in the face of recent, post-glacial sea level rise, there is evidence that saltwater has retreated out of the estuary slightly over the last 6,000 years (Weiss, 1974).

Vertical land movements, tributary inputs, and channel characteristics influence local rates of sea level rise and the propagation of tides and storm surge in the estuary. In addition, changes in channel characteristics associated with increased water levels would alter shoaling (wave transformation) processes, which might lead to changes in tide and surge amplitudes.

Hurricanes and nor'easters are generally accompanied by strong winds, surge, and heavy rain. Not only is the influence of surge propagation throughout New York Harbor and the Hudson River Estuary critical, but the impact of increased freshwater discharge to the coastal regions during storm events is also critical. The timing of freshwater input from the New York and northern New Jersey rivers and direct runoff from the surrounding urban landscape will influence overall water levels around New York City as well as supply nutrients and other land-deposited pollutants to coastal waters. Depending on the time of the year, the excess nutrients and pollutants could lead to further degradation of water quality.

Major river systems discharging into New York Harbor include the Hackensack, Passaic, and Raritan Rivers in New Jersey, as well as the Hudson River. Combined, these river systems constitute a drainage area of approximately 16,640 square miles. This complicated drainage system can influence harbor water levels for several days following a rainfall event, a process that was well documented for Hurricane Floyd (Bowman et al., 2004).

5.3.3 Freshwater Resources

In addition to influencing the position of the salt front and storm surge propagation within the Hudson River, sea level rise and changes in precipitation will impact Long Island's water table. The water table will gradually rise at approximately the same rate as sea level. As a result, depending on local conditions, the geographic extent of ponds and wetlands and the carrying capacity of streams may change. This will depend partly on the amount and timing of precipitation in the region. Saltwater entering the aquifers (salt water intrusion and salinization) is a slow process. It is likely that much less than 1 percent of the freshwater reserves would be affected in 100 years. Quantifying the impact that changes in sea level and precipitation patterns will have on Long Island's water table is difficult given the much larger effects of anthropogenic forces such as flood control, groundwater withdrawal, and sewerage.

5.3.4 Coastal Ecosystems

Coastal ecosystems are at risk from rising sea levels. Already many tidal marshes are receding in horizontal extent and appear to be collapsing internally as if they are drowning in place (Hartig et al., 2002). Indications include a "Swiss cheese" appearance as they become increasingly ponded (see the Mississippi Delta for an example). While the exact cause of wetland loss is not known, future sea level rise will exacerbate the losses. Current losses are being blamed on multiple stressors, including channelization and armoring of the shoreline (causing sediment starvation), boat waves, excess nutrient loadings (e.g., nitrogen from treated sewage effluent), changes in tidal range (Swanson and Wilson, 2008), excessive bird grazing, overabundance of mussels and sea lettuce, as well as sea level rise.

For coastal ecosystems north of the Tappan Zee Bridge, substantial marsh loss has not been recently documented, although inventories do show loss of native subtidal aquatic beds. These aquatic beds, which are strongly light-limited in the turbid Hudson, are also likely to be sensitive to rising sea levels.

New challenges in protecting remaining coastal ecosystems come from accelerated sea level rise. Where slopes are gradual and land can accommodate the change (even at the expense of forested habitat), under an accelerated sea level rise regime vegetated tidal habitats will shift inland. However, where squeezed between rising sea levels and either human infrastructure or steep slopes, these systems will diminish in size or disappear. The effect is that a previously diverse habitat lying between the deeper waters and uplands (that included the beaches, coastal shoals, mudflats, or marshes) becomes converted to a more simplified, deeper water habitat. A recently released report on coastal sensitivity in the Mid-Atlantic region included the following findings (US EPA/CCSP, 2009):

- Rising water levels are already an important factor in submerging low-lying lands, eroding beaches, converting wetlands to open water, and exacerbating coastal flooding. All of these effects will be increased if the rate of sea level rise accelerates in the future.
- Most coastal wetlands in the Mid-Atlantic would be lost if sea level rises 3 feet in this century. Even a 20-inch rise would threaten most wetlands.

In the New York region, tidal marshes developed over the last 5,000 years after the last glaciers melted and the rate of sea level rise slowed down. Coastal wetlands usually maintain a delicate balance among rates of sea level rise, upward accretion, wave erosion, and sediment deposition, any changes in which could affect the stability of the marsh (Burger and Shisler, 1983; Orson et al., 1985; Allen and Pye, 1992; Varekamp et al., 1992; Nydick et al., 1995; Nuttle, 1997). A salt marsh lies very close to mean sea level and experiences frequent inundation by the tides, which provide nutrients and suspended sediments for accretion. If the marsh grows too high, tidal inundation decreases, with a corresponding decrease in nutrient and sediment supply, thus slowing down accretion and upward growth. Given a sufficient inorganic sediment and nutrient supply, as well as accumulated organic

material, accretion rates for some marshes along the U.S. Gulf of Mexico and Atlantic Coasts can match or exceed present-day local sea level rise (Dean et al., 1987; Titus et al., 1988; Nuttle, 1997). However, where relative rates of sea level rise are too rapid and exceed rates of mineral sedimentation and/or organic accretion, the marsh may begin to drown in place, a process observed in many East Coast wetlands (Downs et al., 1994; Wray et al., 1995; Leatherman and Nicholls, 1995; Kearney et al., 2002; DeLaune et al., 1994; Anisfeld and Linn, 2002; Warren and Niering, 1993). Shifts in marsh vegetation distributions are also sensitive indicators of sea level rise and accretion rates (Bertness, 1991; Donnelly and Bertness, 2001).

In New York, while some marshes are thriving, recent studies indicate dramatic losses of other salt marshes over the last several decades (**Table 5.5**). At Jamaica Bay (Gateway National Recreation Area), island salt marsh area declined by 20 percent between the mid-1920s and mid-1970s; since then this trend has accelerated and close to 30 percent has subsequently been lost (Hartig et al., 2002; Rosenzweig and Solecki, 2001; Gornitz et al., 2002; NYSDEC, 2003). Only 7 out of 13 salt marsh islands in Shinnecock Bay (southeastern Long Island) that were present in 1974 remained by 1994 (Fallon and Mushacke, 1996). The apparent submergence of these islands was partially compensated by inland migration of salt marshes, an indicator that sea level rise is a contributing factor.

Location	Acres	Acres and Year of Observation		Change Since 1974		
	(1974)	(1995 to 2000)		(% Loss)	(% Loss / Year)	
North Shore and Long Island Sound						
Alley Pond Park/Flushing Bay	18	17	1999	3	0.1	
Manhasset Bay	25	9	1994	60	3.0	
Marshlands Conservancy	35	24	2000	31	1.2	
Pelham Bay Park						
Hutchinson River near Coop City	51	28	1999	45	1.8	
Orchard Beach/City Island	77	51	1999	33	1.3	
Stony Brook Harbor Area	299	190	1999	36	1.5	
Udalls Cove Park	20	13	1999	38	1.5	
South Shore						
Jamaica Bay	1969	1223	1999	38	1.5	
Oyster Bay Area	1300	1016	1998	22	0.9	
Shinnecock Bay—Islands only	30	17	1995	40	1.9	

Note: Coastal marsh acreage in New York State observed in 1974 and the late 20th century, and percentage change in area. Source: (Hartig et al., 2002, 2004; Fallon and Mushacke, 1996; and NYSDEC, 2004)

Table 5.5 Reductions in extent of vegetated salt marshes, NY, between 1974 and 2000

More recently, Mushacke (NYSDEC, 2004) has documented additional marsh loss on the north and south shores of Long Island. Multiple factors, including dredging, bulkheading, and excessive nutrient enrichment, may be dominant at these sites. The New York State Department of State (NYS DOS), under the Coastal Zone Management Act, is also recording coastal wetland changes on Long Island's south shore. In the areas examined, there were losses as well as gains, although gains were not enough to compensate for losses (Jeffrey Zappieri, personal communication, 2003).

Marsh loss in Long Island and New York City has been documented through GIS analysis of historic aerial photographs (**Table 5.5**). By comparing 1974 images with those from between 1994 and 2000, a percent loss per year was derived. Marsh losses over the period were mainly between 1 and 2 percent per year. These losses were unexpected prior to the analysis, and the exact causes have yet to be determined. While sea level rise is among several stressors that may be acting together on vulnerable marshes, it may become the dominant factor in future decades as it outpaces sedimentation and vertical accretion.

Table 5.6 indicates the rate of sea level rise according to local tide gauges, the oldest of which was installed in 1856 and is located at the Battery in New York City. According to this tide gauge, sea level rise has been approximately 0.109 inch per year, or almost 1 foot per century over this period. In order for marshes to be sustainable, they need to at least keep pace with sea level rise. As indicated in **Table 5.5**, many marshes are already not keeping pace and are receding. The wetland loss rate, for example, at Jamaica Bay, Udalls Cove Preserve, and Stony Brook Harbor is 1.5 percent per year.

Station	Sea Level Rise (inches/yr)	Sea Level Rise (ft/century)	Record Length (years)
Bridgeport, CT	0.101	0.84	1964–2006
New London, CT	0.089	0.74	1938–2006
Montauk, NY	0.109	0.90	1947–2006
New York City, NY	0.109	0.90	1856–2006
Port Jefferson, NY	0.096	0.80	1957–1992
Willels Point, NY	0.093	0.78	1931–2006
Atlantic City, NJ	0.157	1.31	1911–2006
Cape May, NJ	0.160	1.33	1965–2006
Sandy Hook, NJ	0.154	1.28	1932–2006

Source: <http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml>

Table 5.6 Relative sea level rise for the Atlantic coastal areas of New York, New Jersey and Connecticut according to local tide gauges

Table 5.7 gives known accretion rates for different marshes together with the rate of sea level rise according to the nearest tide gauge station. This provides a first-order guide in assessing the ability of these particular marshes to keep pace with increasing water levels. It should be noted that this analysis does not include subsurface compaction, which may be occurring.

Additional measurements are being taken at some marshes using sediment elevation tables (SETs) together with marker horizons. At Fire Island National Seashore SETs were placed together with feldspar markers to measure both shallow subsidence and accretion at the surface (Roman et al., 2007). As measured over a five-year period at three different marsh locations, there was a net loss of elevation. At two of the locations, surface accretion was greater than the rate of sea level rise; nevertheless, the rate of accretion was not enough to compensate for the overall land subsidence plus sea level rise. Likewise, in Jamaica Bay, initial data analysis indicates that while accretion is occurring beyond the rate of sea level rise, low marsh-dominated areas are subsiding at accelerated rates (Elders Point Marsh), while high marsh areas are experiencing more minimal loss rates (JoCo Marsh) (Jim Lynch, personal communication, 2009). As described in Case Study C: Salt Marsh Change at New York City Parks and Implications of Accelerated Sea Level Rise, Elders Point Marsh is

being supplied with sediment supplements to raise the marsh elevation artificially.

The impacts of GCM-based and rapid ice-melt sea level rise scenarios on tidal wetlands for the 2020s, 2050s, and 2080s (**Table 5.1**) are evaluated for Long Island, New York City and Lower Hudson Valley, and separately for the Mid-Hudson Valley and Capital Region (**Table 5.8**). A sensitivity study was performed in order to evaluate the ability of marshes to keep pace with sea level rise alone (not accounting for subsurface

State	Marsh Zone	Accretion Rate (in/yr)	SLR (in/yr)	Source
Alley Pond (Queens, NY)	high	0.14	0.09	Cochran et al. (1998)
Caumsett Park (Nassau, NY)	high	0.16	0.09	Cochran et al. (1998)
Goose Creek (Bronx, NY)	high	0.09	0.09	Cochran et al. (1998)
Hunter Island (Bronx, NY)	high	0.04	0.09	Cochran et al. (1998)
Jamaica Bay (Queens, NY)		0.11-0.17	0.11	Kolker (2005)
Jamaica Bay (Queens, NY)	high	0.2	0.11	Zeppie (1977)
Jamaica Bay (Queens, NY)	low	0.31	0.11	Zeppie (1977)
Stony Brook, Youngs Island (Suffolk, NY)	high to low	0.09-0.11	0.09	Cademartori (2000)
Stony Brook, Youngs Island (Suffolk, NY)		0.14-0.19	0.09	Cochran et al. (1998)

Note: Lead 210 was used as method for determining accretion rates from soil cores. As SET/marker horizon data become available marsh accretion rates will be accompanied by rate of subsurface subsidence to determine change in net marsh elevation.

Table 5.7 Surface accretion rates measured in the salt marshes of the New York city region compared with the mean rate of sea level rise

Decade	2020s			2050s			2080s		
Accretion Rate (in)	L	M	H	L	M	H	L	M	H
Lower Hudson Valley, New York City & Long Island									
Central Range									
lower range	-0.50	1.00	2.50	-2.50	2.00	6.50	-4.50	3.00	10.50
upper range	-3.50	-2.00	-0.50	-7.50	-3.00	1.50	-15.50	-8.00	-0.50
Rapid Ice-Melt									
lower range	-3.50	-2.00	-0.5	-14.50	-10.00	-5.50	-33.50	-26.00	-18.50
upper range	-8.50	-7.00	-5.50	-24.50	-20.00	-15.50	-47.50	-40.00	-32.50
Mid-Hudson Valley & Capital Region									
Central Range									
lower range	0.50	2.00	3.50	-0.50	4.00	8.50	-0.50	7.00	14.50
upper range	-2.50	-1.00	0.50	-4.50	0.00	4.50	-10.50	-3.00	4.50
Rapid Ice-Melt									
lower range	-2.50	-1.00	0.50	-12.50	-8.00	-3.50	-29.50	-22.00	-14.50
upper range	-7.50	-6.00	-4.50	-21.50	-17.00	-12.50	-42.50	-35.00	-27.50

Note: L = Low (0.1 inch/yr), M = Medium (0.2 inch/yr), and H= High (0.3 inch/yr) accretion rates. Negative numbers indicate drowned marshes; positive numbers in bold indicate marsh survival. This simple model accounts only for sea level rise and accretion; subsurface compaction, subsidence, and other potential causes of marsh loss are neglected. Accretion calculated from 2010 to 2020s (15 years); 2010 to 2050s (45 years); 2010 to 2080s (75 years). Numbers represent the difference in assumed accretion rates and rates of sea level rise from Table 5.1.

Table 5.8 Chances for marsh survival given projected sea level rise (inches) and low, medium, and high rates of accretion for the 2020s, 2050s, and 2080s

compaction). The range of sea level rise projections from **Table 5.1** is used in combination with observed low (0.1 inch per year), medium (0.2 inch per year), and high (0.3 inch per year) accretion rates to offer a simple model of marsh survival in the coming decades. In order to construct the projections, each accretion rate was multiplied by the time span from the year 2010 to the mid-point of each decade (i.e., 2025, 2055, and 2085), and the accumulated accreted elevation is compared with the projected sea level rise. If sea level is greater than the potential accreted marsh, the marsh is considered drowned (negative numbers). If the potential accreted marsh has an elevation at least as great as the projected sea level, the marsh survives (positive numbers).

For Long Island, New York City, and Lower Hudson Valley, results indicate that only given medium or high accretion rates would marshes survive under the central range of projected sea level rise by the 2020s. None would survive the rapid ice-melt scenario. According to the analysis, the marshes have a slightly better chance in the Mid-Hudson Valley and Capital Region, with more marshes surviving in the GCM-based scenarios. In addition, marshes could survive a rapid ice-melt scenario only until the 2020s if they had a high-enough marsh accretion rate.

The marshes of New York State provide a dense urban population close access to a natural ecosystem rich in wildlife and recreation opportunities, function as buffering protection against coastal storm damage, furnish important habitat for migratory birds along the Atlantic Flyway, and act as productive nurseries for local fisheries (Wells, 1998). Losing marsh acreage to submergence at a rate of 1 percent and more per year compromises their function and value. Further research is needed to improve our understanding of the underlying causes of marsh loss in New York State in order to be able to conserve these marshes for future generations.

5.3.5 Fish and Shellfish Populations

New York has an extensive marine coastline, composed of Long Island Sound, all of Long Island's south shore, and portions of New York City. The lower Hudson River also is saline, grading toward freshwater northward. New York's marine waters lie in the northern portion of the Virginian Zoogeographic Province (Cape Cod to

Cape Hatteras). This province is situated between the colder Acadian and the warmer Carolinian provinces. Fish diversity in New York's marine waters is high. Briggs and Waldman (2002) list 326 recorded marine and estuarine species.

The Marine Environment of New York

The high biodiversity in New York State marine waters is due in part to the great variety of habitats (e.g., estuaries, coastal bays, tidal straits, ocean beaches, continental shelf) and to the pronounced seasonal temperature changes that occur (Briggs and Waldman, 2002). The inner New York Bight has a range of about 25°C between summer and winter surface temperatures (from 1°C to 26°C) and bottom temperatures vary from a maximum of about 21°C in summer to less than 1°C in winter. Although many temperature-tolerant fish occur in New York waters year-round, these large seasonal temperature changes favor migratory rather than sedentary fish fauna (Grosslein and Azarovitz, 1982).

A relevant ecological feature of the lower Hudson River and Long Island's south shore bays is that they receive warm waters as eddies that pinch off from Gulf Stream meanders. These warm-core rings, approximately 100 kilometers in diameter, also carry early life stages of "tropical" fish that mature in New York waters through summer and early autumn. Although species composition varies, this is an annual phenomenon, and regularly includes groupers (*Epinephelus*), snappers (*Lutjanus*), butterflyfishes (*Chaetodon*), and jacks (*Carangidae*).

New York also lies at the juncture of the commercially viable ranges of two important crustaceans: American lobster and blue claw crab. Lobster is a cold water species that is harvested in numbers as far south as Long Island Sound and the New York Bight. Blue claw crab is a southern species that is abundant as far north as Long Island Sound.

To date, little attention has been focused on the biological effects of sea temperature changes in New York waters. Circumstantial evidence indicates that some faunal shifts already have occurred, most notably the extirpation late in the 20th century of a boreal species, rainbow smelt, in the Hudson River (Waldman, 2006) and in tributary streams to Long Island Sound. Another cold water species, Atlantic tomcod, also is

showing declines in the Hudson River (Waldman, 2006) and is rare or absent in other former New York habitats. In contrast, a euryhaline (tolerates fresh to salt waters) species, gizzard shad, once found north only to Sandy Hook, has since the 1970s colonized the Hudson River and has become established as far north as the Merrimack River, Massachusetts.

Predicted Effects of Climate Change on Temperatures of New York Waters

Water temperatures in the Hudson River already have shown substantial warming. Although their data from Poughkeepsie do not include the past 20 years, Ashizawa and Cole (1994) found a statistically significant trend of 0.22°F per decade between 1920 and 1990, a change they believed was consistent with global increases.

For the New York Bight, our forecasted sea surface temperature changes for the 2050s in comparison with a 1980s baseline derived from the CCSM and GFDL models under two emissions scenarios all show substantial increases for its near-shore waters. These increases are on the order of 1.8 to 3.2°F, depending on the model and emissions combination. Visual inspection of sea surface isotherms from the mid-1900s at 1°F resolution (Fuglister, 1947) indicates that differences of these magnitudes between Long Island and warmer waters to its south correspond geographically with points between the southern tip of the Delmarva Peninsula and Delaware Bay, varying by month. Thus, the present-day fish community of the Delaware coast provides a glimpse of what the fish community of New York may resemble in the 2050s.

Likely Responses of Fish and Shellfish to Temperature Changes in New York Waters

There is considerable overlap in marine fish communities between the Delmarva region and New York, but there also are differences. Warm-water fish frequently seen in this southern region (Hildebrand and Schroeder, 1928) that are only rarely observed in New York include tarpon, cobia, and cownose ray. A higher-order difference is the greater prominence of members of the drum family (Sciaenidae) rarely seen in New York, including croaker, spotted seatrout, and red drum. The Delmarva region also does not support inshore

winter fisheries for gadoids seen in New York Bight waters in cold months, such as Atlantic cod, pollock, silver hake, and squirrel hake.

Among important macrocrustaceans, blue claw crabs flourish in the warmer waters of the mid-Atlantic and should not decline because of higher temperatures. However, lobsters are at the southern edge of their inshore range in New York and have already shown declines that may be linked to warming waters (Howell et al., 2005).

Other fish whose northern ranges have extended to New York in the past include black drum and sheepshead. Both were recreationally and commercially harvested in New York Harbor and New York Bight waters in the 1800s but have been exceedingly scarce since. The reason may be habitat loss: Both are closely associated with oyster reefs, which declined sharply at the same time (Waldman et al., 2006). Both warming waters and increasing numbers of oysters (naturally occurring and through restoration projects) may result in increased abundances of these fish in New York.

A difficulty in discerning climate-driven changes in marine fish distributions is that the signal from the climatic effects may be highly confounded by other factors. Even under nearly constant environmental conditions, fish distributions are not static. Population theory and observations indicate that fish populations occupy the most optimal habitats under low abundances but also disperse into less optimal habitats at high abundances (MacCall, 1990). This means that mainly mid-Atlantic species that are only rarely or periodically seen in numbers in New York waters may occur there largely as a function of density dependence (relative population size within an area) and not because of favorable temperatures. Primarily southerly fishes that have appeared in New York during high population abundances include spot and Spanish mackerel (Waldman et al., 2006). Bluefish and weakfish are two other economically important fishes that are numerous in New York waters only during periods of high coast-wide abundances.

Another source of complexity is changes in fish and crustacean communities that occur because of ecological regime shifts, of which climate change may be a major driver. At nearly the same latitude as Long Island Sound in the waters of Rhode Island, Oviatt (2004) showed that modest increases in water

temperatures caused large ecological shifts, in which macrocrustaceans (e.g., crabs, lobster) and southern pelagic fish (e.g., bay anchovy, butterfish) were favored at the expense of boreal demersal fishes (e.g., winter flounder, red hake).

A challenge in assessing changes in New York's marine fish community in the future will be to parse the effects of climate change from the normal seasonal and density-dependent vagaries of fish population dynamics. Annual long-term monitoring of fish and macrocrustaceans is critical to detecting climate-associated faunal changes in New York's marine waters. Both tracking fish community assemblages over time and observing the annual abundances of certain key species that are on the edges of their northern or southern distributions are important.

Impact of Increased CO₂ Concentrations and Ocean Acidification in New York Waters

The ocean is becoming more acidic as increasing atmospheric carbon dioxide is absorbed at the sea surface. Models and measurements suggest that surface pH has decreased by 0.1 pH unit since 1750 (Bindoff et al. 2007). It has been estimated that approximately half of the increased carbon dioxide emissions due to burning of fossil fuels since the Industrial Revolution has been absorbed in the ocean's surface waters (Sabine et al. 2004). However, continued acidification will reduce the ability of the ocean to take up atmospheric CO₂ and have potential negative impacts on finfish, shellfish, and plankton populations.

Much of the early research has been focused on calcifiers, which are believed to be most vulnerable during early developmental and reproductive stages of their life cycles. Kurihara (2008) notes that ocean acidification has negative impacts on the fertilization, cleavage, larva, settlement, and reproductive stages of several marine calcifiers, including echinoderm, bivalve, coral, and crustacean species. In addition, this research suggests that future changes in ocean acidity will potentially impact the population size and dynamics as well as the community structure of these species, influencing the overall health of marine ecosystems.

For New York coastal water, the relatively minor increases in ocean acidity brought about by high levels of carbon dioxide are likely to have significant

detrimental effects on the growth, development, and survival of hard clams, bay scallops, and Eastern oysters (Talmage and Gobler, 2009). Recent research has shown that the larval stages of these shellfish species are extremely sensitive to enhanced levels of carbon dioxide in seawater; under carbon dioxide concentrations estimated to occur later this century, clam and scallop larvae showed a more than 50 percent decline in survival (Talmage and Gobler, 2009). These larvae were also smaller and took longer to develop into the juvenile stage. Oysters also grew more slowly at this level of carbon dioxide, but their survival was only diminished at carbon dioxide levels expected next century. The more time these organisms spend in the water column, the greater their risk of being eaten by a predator. A small change in the timing of the larval development could have a large effect on the number of larvae that survive to the juvenile stage and could dramatically alter the composition of the entire population (Talmage and Gobler, 2009).

Although it appears that fish are able to maintain their oxygen consumption under elevated carbon dioxide levels, the impacts of prolonged CO₂ exposure on reproduction, early development, growth, and behavior of marine fish are important areas that need urgent investigation (Ishimatsu et al., 2008). Changes in ocean chemistry might also affect marine food webs and biogeochemical cycles but are less certain because of their complexity (Haugan et al., 2006). Important global biogeochemical cycles (e.g., of carbon, nutrients, and sulfur) and ecosystem processes (changes in community structure and biodiversity) other than calcification may be vulnerable to future changes in carbonate chemistry and to declining pH.

5.4 Adaptation Strategies

As beaches retreat, wetlands disappear, and storm damage becomes more severe, coastal development and infrastructure will face increasing threats, regional tourism and fishing industries could suffer, and the insurance industry will increasingly be called upon to buffer economic losses (Frumhoff et al., 2007). Communities and industries must be able to adapt to these changes over the long term, in a manner that is economically, socially, and environmentally sustainable.

5.4.1 Adaptations for Key Vulnerabilities

It is difficult to determine an effective course of action, since natural processes within these dynamic systems operate on different time scales and are poorly understood. Implementation of adaptation strategies is further complicated by the division of power and jurisdiction in the coastal zone between various levels of government and different agencies. Regional-scale adaptation strategies presented in the ClimAID report assume that the legal and institutional changes necessary for implementation can be achieved. However, there will likely be competing and/or conflicting adaptation strategies depending on the objective. This will require a public process to achieve resolution. This section introduces some basic adaptation strategies and frameworks for evaluating the most effective methods to reduce vulnerability.

Coastal Storms, Coastal Floods, and Coastal Erosion

For coastal flooding and storm damage reduction, regional adaptation strategies will depend on economic, social, and environmental factors such as the desired level of protection, level of development, presence of critical infrastructure and natural resources, and consequences to the environment and neighboring communities. An example framework for evaluating possible adaptation strategies from the perspective of storm damage reduction to infrastructure is provided in **Table 5.9**. For example, beach nourishment (addition of sand from offshore or inland areas) is often used to protect coastal communities from flooding, and the level of protection depends on the design criteria, which

are often constrained by financial resources and stakeholder/sponsor requirements. Sand can be placed on beaches relatively quickly (less than one year) and the projects are usually designed to last around five years. The actual life of the project depends strongly on the rate of erosion, which is associated with storm activity. As the rate of sea level rise increases, the rates of erosion increase and sand placement projects will become more expensive. Approximately 1 million cubic yards of sand are placed on New York beaches each year (Lynn Bocamazzo, personal communication, 2009). It has been estimated that the additional sand volume needed to compensate for sea level rise could range between 2.3 percent and 11.5 percent of the total current placement for the 2020s and 18 percent to 26 percent by the 2050s (Gornitz and Couch, in Rosenzweig and Solecki, 2001). A substantial volume of suitable sand (approximately 10 billion cubic yards) is present on the continental shelf and could be mined for this purpose (Bliss et al., 2009).

Depending on the level of development, communities may choose to implement a slow retreat or phased withdrawal from the coast. This could entail the use of hard (e.g., seawalls, storm surge barriers, rip rap) and soft (e.g., beach nourishment and beach drainage, beach vegetation) engineering solutions as well as the adoption of more policy-based strategies. For example, coastal communities may periodically place sand on beaches or use seawalls and groins to protect critical infrastructure. Coastal development and storm damage could be reduced by re-evaluating the delineation of coastal erosion hazard areas, improving building codes to promote more storm-resistant structures, increasing

Adaptation Strategy	Level of Development	Level of Protection	Time Imp/Life*	Potential Consequences	SLR**	
					GCM	RIM
Beach Nourishment	All	Up to 1-in-100 yr flood	< 1-yr/ 3-7 yrs	Steeper profile, reduce overwash sediments to bay, habitat disruption	X	X
Moderate Engineering Solutions [#]	Urban to suburban	Up to 1-in-100 yr flood	2-5 yrs/ 20-50 yrs	Reduced littoral sediments creates downdrift erosion	X	
Macro Engineering Solutions ^{##}	Urban	> 1-in-100 yr flood level	10-15 yrs/ 75-150 yrs	Alter regional hydrodynamics, habitat disruption		X
Slow Retreat	Suburban to rural	NA	NA	Depends on strategies used	X	
Rapid Retreat	Suburban to rural	NA	NA	Loss of equity, decreased property values		X
Do Nothing	All	NA	NA	Catastrophic loss of property and natural resources	X	X

* Time necessary for implementation of adaptation measure and life expectancy of project. Estimates do not include the political/legal/scientific processes necessary for design and implementation.

** Sea level rise scenarios, GCM for central range and RIM for rapid ice-melt.

[#] Moderate engineering structures such as seawalls, revetments, groins, and bulkheads.

^{##} Macro engineering structures such as storm surge barriers and dikes.

Table 5.9 Example adaptation strategy framework for flood-damage reduction

building setbacks, and implementing rolling easements in regions of new development. In addition, depending on the financial resources and land availability, communities may institute buyout or land swap programs to encourage migration out of flood-prone regions. These strategies could be coupled with re-establishment of natural shoreline habitats to promote tourism and ecosystem services.

For urbanized areas, phased withdrawal may not be possible and communities may choose to use micro- (e.g., bulkheads, groins, seawalls) and macro-engineering (e.g., storm surge barriers, system of levees and dikes) solutions to prolong the use of coastal properties and infrastructure. For example, lower Manhattan is home to such critical transportation infrastructure as FDR Drive, West Street, the West Side Highway, the Port Authority Trans-Hudson (PATH) tunnels linking Manhattan and New Jersey, and the Brooklyn-Battery auto tunnel entrance.

The 2010 report of New York City Panel on Climate Change (Rosenzweig and Solecki, 2010) recommends that sea level rise projections should be incorporated into regulatory maps of coastal areas, including FEMA Flood Insurance Rate Maps (FIRMs) and their A- and V- Zones, the SLOSH model, and the delineation of the Coastal Zone Boundary and Coastal Erosion Hazard Areas.

Currently concrete bulkheads and seawalls protect much of this region; however, higher projected ocean levels may mean that these structures will need additional protection. Rather than armor the coastline of New York City and the surrounding boroughs, it may be more cost effective to construct storm surge barriers and dikes. Initial hydrodynamic studies have explored

the feasibility of such a project; however, the economic, social, and environmental impacts have not been assessed (Bowman et al., 2004). Regardless of the adaptation strategy a community chooses to institute, a strong public outreach component should be undertaken for successful implementation.

Coastal Ecosystems

The framework presented in **Table 5.9** could be expanded to include various sustainable technologies or criteria for evaluation, or developed for other coastal components. For example, some possible adaptation strategies for saltwater wetlands are illustrated in **Table 5.10**. These strategies are applicable for a wide range of rates of sea level rise and therefore may not include sea level rise as a critical evaluation criterion.

5.4.2 Co-Benefits, Unintended Consequences, and Opportunities

Coastal systems are dynamic, and a loss of beach or habitat in one area may result in the gain or opportunity for expansion of habitats in another area. For example, increased beach erosion may lead to dune overwash and, in more severe cases, barrier island breaching and migration. Breaching and the creation of new inlets could adversely impact existing marshes but could also provide areas for the potential creation of new marshes under the right conditions. However, not enough is known about the sedimentary systems or budgets within the state's bays to make predictions about the relative importance of these features in terms of supplying inorganic sediments necessary for marsh maintenance and accretion.

Adaptation Strategy	Level of Development	Level of Protection	Time Imp/Life*	Potential Consequences
Wetland restoration	All	Appropriate waterfront sites where tidal inundation can be restored	2–5 yrs/ 10–100 yrs	Convert former wetlands along the waterfront that had been used for other land uses
Wetland creation	All	In newly established flood zones as SLR continues	2–10 yrs/ 10–100 yrs	Where new flooding is occurring, convert upland sites along the waterfront to wetlands
Sediment augmentation in submerging marshes	All	Up to mean higher high water (MHHW) line	2–5 yrs/ 10–100 yrs	Sediment must be diverted/taken from elsewhere
Wetland regulations: Use maximum allowable buffer area to allow for inland migration of marshes	All	150–300 feet beyond the wetland boundary	5–10 yrs/ 10–40 yrs	Development community will challenge tighter controls on wetland adjacent area permits

* Time necessary for implementation of adaptation measure and life expectancy of project. Estimates do not include the political/legal/scientific processes necessary for design and implementation.

Table 5.10 Example strategy framework for wetland adaptation

Warmer waters will also be more hospitable to fish species that normally range near New York, but rarely reach it under current conditions. For example, blue claw crabs are becoming more abundant in New York waters, and this particular fishery should be enhanced as the climate changes.

5.5 Equity and Environmental Justice Considerations

As climate change progresses, New York State's coastal ecosystem will undergo physical, chemical, and biological transformations. These transformations will have uneven impacts on coastal residents and coastal communities.

5.5.1 Vulnerability

The coastal vulnerability index (CVI) provide a comprehensive summary of vulnerability arising from geologic and hydrodynamic processes; however, they do not incorporate socioeconomic interactions (Thieler and Hammar-Klose, 1999). A combination of both physical and social factors can provide some measure of coastal resilience of a population or region and begin to identify potential inequities.

Flooding and natural hazards can disproportionately impact certain socioeconomic groups, such as people of color and low-income communities (Wu et al., 2002; Fothergill et al., 1999). Often this is an expression of physical vulnerability, such as pre-Katrina New Orleans, where low-lying areas at risk of inundation were home largely to African Americans. Frequently, physical vulnerability to a hazard is compounded by intrinsic individual vulnerabilities—related to age and physical immobility, for example—as well as a host of contextual vulnerabilities that can surface in every phase from prevention to relief, recovery, and reconstruction (Morrow, 1999). Contextual vulnerabilities are frequently an expression of underlying socioeconomic inequities and barriers: Low-income communities are less likely to have access to a full range of preventative strategies, such as resources to fortify property, prepare emergency provisions, and acquire insurance (Morrow, 1999; Yarnal, 2007).

Discriminatory practices and policies—from insurance redlining to constrained transportation options—may create systematic barriers to communities of color (Wright and Bullard, 2007). Other groups, such as renters, may lack the proper incentives to make precautionary investments, while people who speak English as a second language may be particularly vulnerable to miscommunications about preventative strategies and risks (Fothergill et al., 1999). Even when the risks have been made clear, housing discrimination or lack of affordable options may prevent certain groups from accessing the full range of relocation options (Wright and Bullard, 2007).

Some subsets of women may also have particular vulnerabilities. In general, women earn lower average incomes than men, tend more than men to be single parents, and are more likely to perform the labor of childcare, housework, and caring for elderly family members (Root et al., 2000). During extreme events and post-disaster recovery, these burdens and responsibilities may manifest as a disproportionate amount of hardship, lost income, increased labor, and emotional stress related to family care (Bolin et al., 1998; Morrow, 1999).

Relief, recovery, and reconstruction efforts are often associated with unequal access to emergency and recovery loan assistance and inadequate resources for compensation of health and property losses. At a community or city level, planning for sea level rise and increased coastal flooding at this stage requires an inherently strong equity framework: Both real and perceived inequities have plagued rebuilding following past hurricanes and coastal storms, when victims have often found themselves confronted with pre-planned packages of redevelopment doled out in top-down fashion to a handful of influential corporations (Wright and Bullard, 2007). Furthermore, federal disaster funds often focus first on issues of critical regional connectivity (restoring major arteries and highways), which increases the likelihood that local jurisdictions with little capacity will have to take responsibility for the finer-grained service restoration, the scale at which inequities often play out.

Table 5.11 shows an estimated breakdown of the population living in the 100-year floodplain in New York City and Long Island. Population estimates were generated using data from the 2000 census aggregated at the block group level and weighted by the area of

each block group located within FEMA's 100-year floodplain boundaries. These estimates likely underestimate both the current total population in the floodplain and the affected subpopulations.

While it is difficult to discern precisely how a 1-in-100-year storm event would impact the regional economy of Long Island and New York City, **Table 5.11** gives some indication of the stakes. It also offers a snapshot of fundamental regional differences in household economies and demographics. Estimated aggregate value of all owner-occupied housing located within the 100-year floodplain in ClimAID Region 4 (New York City and Long Island) topped \$27.5 billion in the 2000 census (not adjusted for inflation). In contrast to the

distribution of vulnerable renters, which is skewed heavily toward the urban centers of New York City, approximately half the regional value of owner-occupied housing is located in Nassau County. This graduated pattern of suburban homeownership and urban renting parallels differences in population density across the coastal region of Region 4. Of the more than 500,000 people estimated to reside in the 100-year floodplain, a majority lives in coastal New York City with density decreasing gradually across Nassau and Suffolk (**Figure 5.7**).

Many coastal communities on the south shore of Long Island are fairly affluent. Indeed, **Table 5.12** indicates that residents within FEMA's 100-year floodplain tend

	New York City	Nassau County	Suffolk County	Total
Population				
Total population	286,374	159,644	70,523	516,541
Over 65	41,305	24,188	9,882	75,375
Below poverty line	61,260	8,895	4,550	74,703
African American	72,559	7,932	2,013	82,504
Latino	64,447	13,652	4,745	82,844
Foreign born	77,036	21,542	6,114	104,691
Housing				
Occupied housing units	110,194	58,206	27,103	195,503
Renter occupied housing units	77,003	13,930	5,428	96,360
Aggregate value of owner-occupied housing (Millions)	\$8,255	\$13,342	\$6,171	\$27,768

Source: US Census 2000; authors' calculations as described above

Table 5.11 Profile of the population residing in the 100-year floodplain (ClimAID Region 4—New York City and Long Island)

	In Floodplain	Out of Floodplain
Median Income	\$56,132	\$48,551
Median housing value, owner occupied housing	\$235,297	\$229,149
Female head of households as percentage of total	20.2	26.5
% in poverty	12.8	17.1
% less than high school	18.7	25.5
% over 65	14.2	12.2
% African American	12.6	23.0
% Hispanic	15.4	22.1
% renter	41.5	54.1
% vacant housing	9.5	5.2
% foreign born	18.9	30.2

Source: U.S. Census 2000; weighting by authors' calculations

Table 5.12 Area-weighted characteristics of population in census block groups in and out of the 100-year floodplain for New York City and Suffolk and Nassau Counties

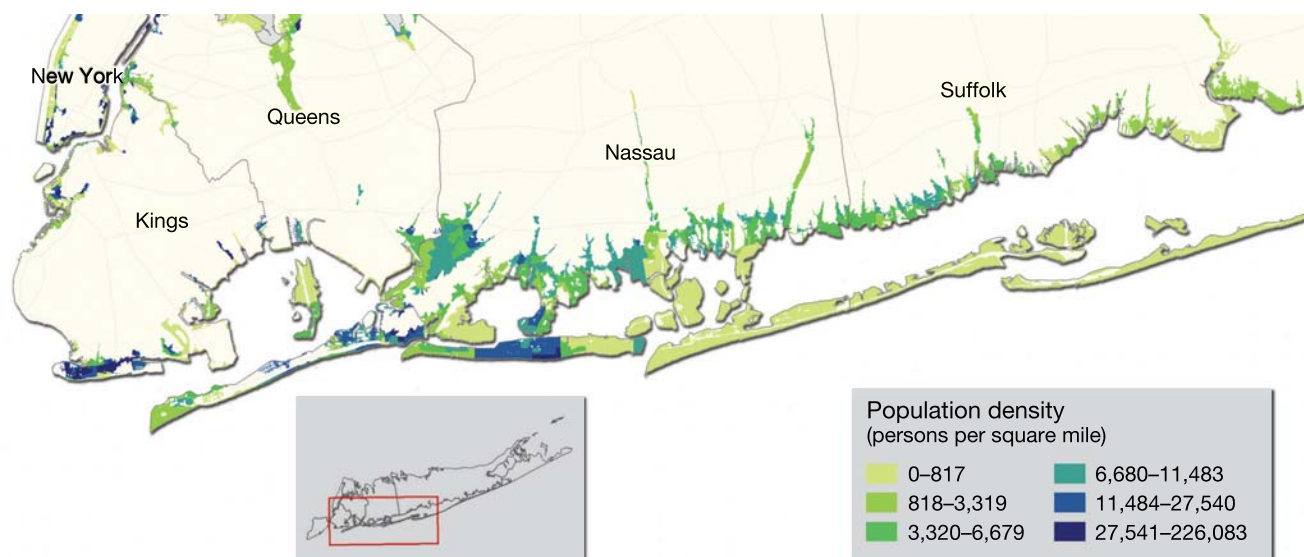
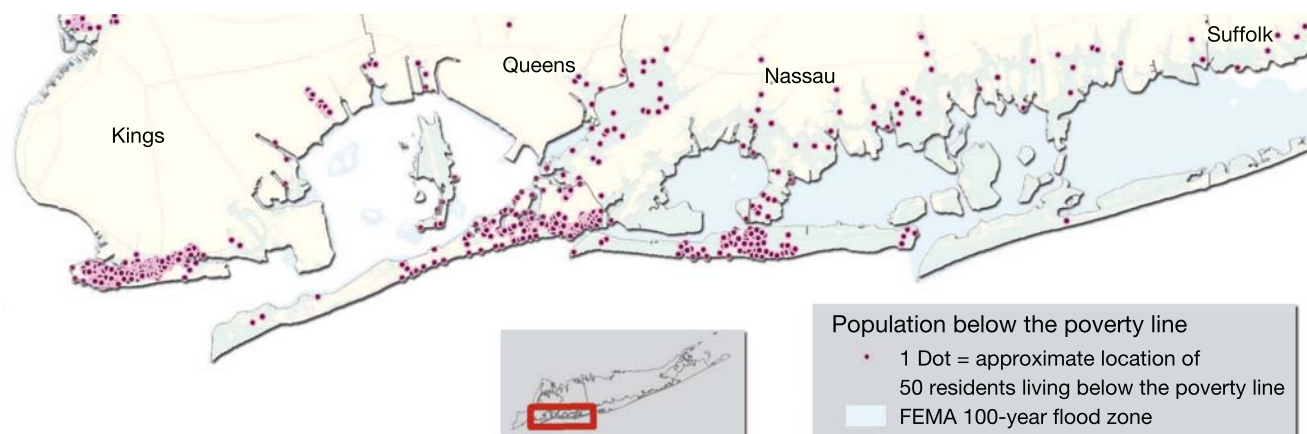


Figure 5.7 Population density within the FEMA 100-year floodplain boundaries

Source: US Census 2000

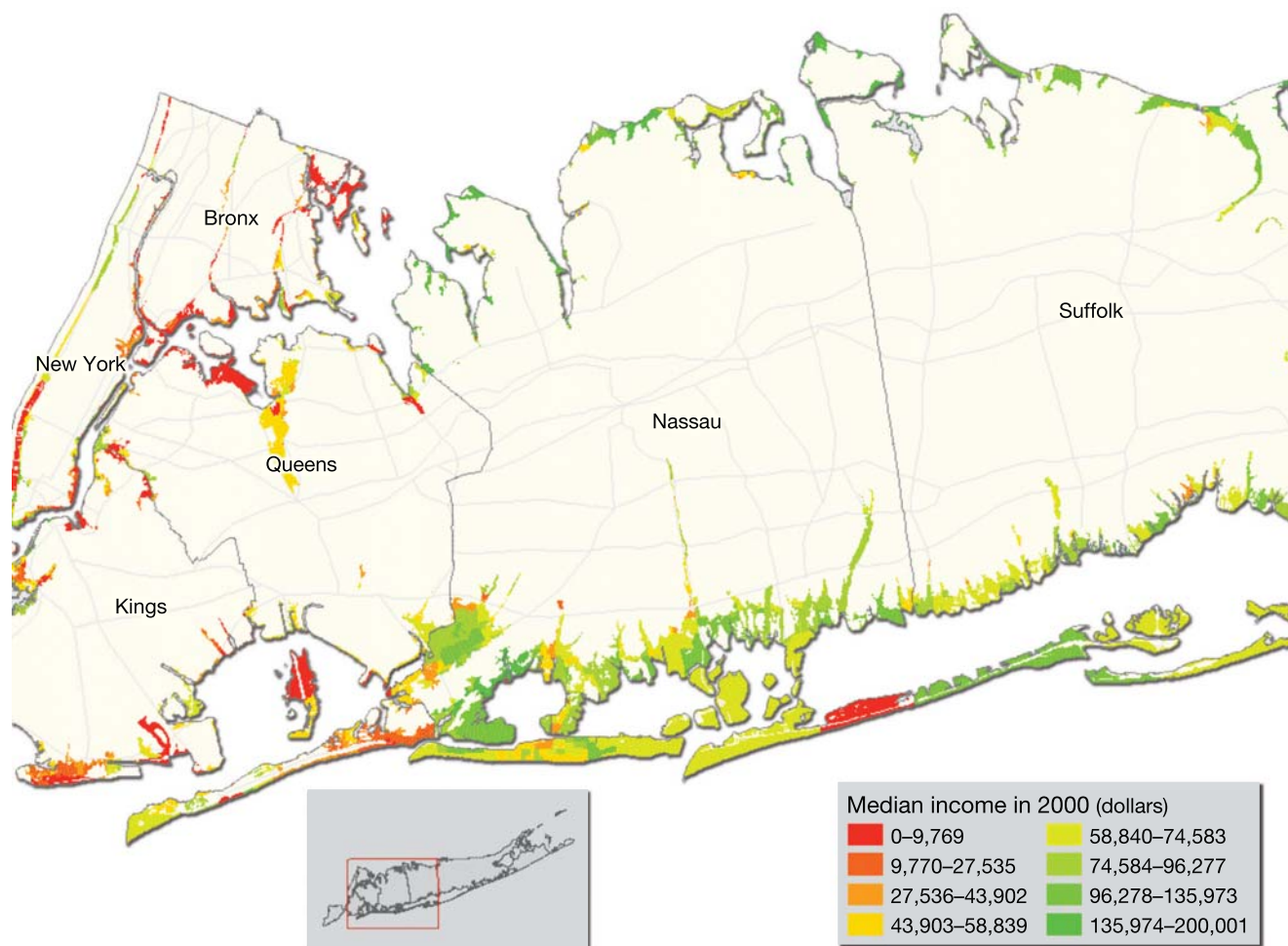
to have higher incomes, live in more expensive homes, and represent a lower minority population than those outside the floodplain. Examining the distribution of certain higher-risk subsets within this population can help locate potential environmental injustice effects. Low-income households, for example, are confronted

with constrained resource options for both long-term adaptation and immediate coping (Wu et al., 2002). In the coastal floodplain of ClimAID Region 4, nearly 75,000 people live under the poverty line. More than 80 percent of this population resides in New York City. In New York City in particular, wealthier and poorer



Source: US Census 2000

Figure 5.8 Population in FEMA's 100-year floodplain living below the poverty line



Source: US Census 2000

Figure 5.9 100-year floodplain and household income by census block group

neighborhoods often co-exist in close proximity near the shore (e.g., Coney Island, Brighton Beach, the Rockaways) and are thus potentially equally exposed to the physical consequences of flooding from a major storm or hurricane (**Figure 5.8**). Equity issues may arise in the form of structural damage associated with variations in construction, ease of timely evacuation and availability of transportation, or the ability to recover after a storm.

Previous research also has suggested that racial and ethnic minorities are more vulnerable when exposed to similar events than non-minority populations (see for example, Fothergill et al., 1999). Hurricane Katrina provided a vivid reminder of this uneven burden in 2005 (Yarnal, 2007). In coastal New York City and Long Island, just over 82,000 African Americans and nearly the same number of Latinos live in the 100-year floodplain. Examination of **Table 5.11** suggests that African Americans and Latinos are significantly overrepresented in New York City's flood zone relative to the distribution of the total population in coastal New York, which likely reflects a legacy of suburban settlement patterns on Long Island (i.e., fewer minorities the further away from New York City). This population distribution, in combination with the disproportionately high concentration of poverty and the greater proportion of renters, suggests that New York City would face fundamentally different equity challenges than Nassau and Suffolk counties. In contrast, proportionally higher rates of home ownership and greater income may signal a measure of resilience across more wealthy regions of Long Island (**Figure 5.9**).

5.5.2 Equity Issues in Adaptation

Several alternative adaptation strategies—managed retreat, beach nourishment, and engineering solutions—have varying economic impacts. Earlier studies have shown that beach nourishment preserves the recreational values of coastal beaches, while engineering solutions may be needed to maintain fixed structures. Landry et al. (2003) and Kriesel et al. (2005) estimate the relative value (willingness to pay) for alternative adaptation strategies. Their basic finding is that the relative value of the three basic adaptation strategies is a function of the value of coastal property to be protected. Preemptive planning for flood security should evaluate the specific distributional burdens and

benefits of each adaptation strategy. For illustrative purposes a few adaptation strategies are discussed in the following section, along with a review of critical equity issues.

Infrastructure

Building climate-secure hard infrastructure offers an amenity that may create new patterns of winners and losers. Which communities will be protected and in what ways? Who bears the cost of building hard infrastructure, such as seawalls or levees? Where are they placed and whom do they protect? What areas of a city or town are treated as critical while others are deemed non-priorities? These equity issues extend into strategies that include “softer” design. Choosing which wetlands to restore, beaches to fortify with additional sand, or structures and lands to elevate are not simple issues of exposure to risk. They involve making difficult decisions about distributing benefits and costs among communities and prioritizing some areas potentially at the expense of others.

Managed Relocation

Managed relocation from floodplains is another adaptation strategy that is accompanied by a portfolio of equity concerns related to the specific measures employed in the policies, from the relocation incentives to the environmental restoration of reclaimed lands. For example, if retreat will be a rapid buy out of highest risk areas, how does one choose these areas and the specific properties within them? What mechanisms are in place to hedge against the risk of redlining and inequitable selection of properties for priority buy-out?

Upland areas could be transformed by migration and localized population pressures. These communities may experience gentrification, increased cost of services from in-migration, and burdens of displacement from lowland areas. The viability and cohesion of low-income communities tend to be vulnerable under these conditions. Retreat from the southern coast of Long Island, for example, where housing issues are already a critical concern, may displace households, increase housing demand, and push up property values, a process that may indirectly burden the low-income population.

Managed retreat may materialize less as proactive planning and more as reactive incrementalism or planned obsolescence, such as service cutbacks, squeezing areas into shrinkage, or “choking” growth. In effect, such strategies outsource adaptation planning to individuals, meaning that those with the widest range of job and residence options and the ability to forecast policy changes would be the most quick to migrate. Lower-income populations could find themselves at an adaptive disadvantage, because they lack either the capital to invest in new housing or the socioeconomic flexibility allowing them to transfer jobs and livelihoods locations. Relocation can be difficult for any business, but minority-owned businesses may be especially vulnerable. They tend to be smaller, less well capitalized, less able to get loans, and subject to discrimination.

Adaptation, Insurance, and Equity

Existing risk-spreading mechanisms are in flux. The insurance industry is undergoing changes in the way it approaches insuring high-risk regions, and in some areas, such as parts of Long Island, companies have withdrawn their products, limiting insurance options for property owners (Insurance Journal, 2007). What options will be available in their place, and for what level of risk government will bear responsibility are long-range distributional issues. Coastal erosion and increasing inundation of areas with infrastructure will take their toll in repair, recovery, and replacement costs. Similarly, the need for increased emergency management has a price tag that has to be distributed. Whether monies are distributed as community-level preparedness programs versus federally budgeted disaster aid, for example, has different implications in terms of the distribution of responsibility, the allocation of labor, and differential resource burdens.

5.6 Conclusions

This section details the basic findings on vulnerabilities and opportunities associated with climate change for the coastal zone of New York State, summarizes potential adaptation measures, and identifies some critical knowledge gaps that hinder more effective planning efforts, as identified in the ClimAID assessment.

5.6.1 Main Findings on Vulnerabilities and Opportunities

Coastal Storms

- Because of the highly developed nature of the coast in New York State, a considerable portion of population, private property, and infrastructure will be potentially at risk of enhanced inundation and flooding due to sea level rise associated with climate change.
- While permanently lost land is projected to involve a relatively narrow coastal strip by the 2080s, the higher storm surges associated with higher sea levels could periodically engulf a much greater area. Also, wave action will erode and reshape the shoreline, affecting the location and extent of storm surge inundation.

Coastal Floods and Recurrence Intervals

- Moderate flooding events may become more frequent. Sea level rise projections of 5, 12, and 23 inches at the Battery for the 2020s, 2050s, and 2080s would result in 4, 16, and 136 moderate flooding events annually, respectively. Under a rapid ice-melt scenario, New York State could experience between 200 and 275 moderate flooding events each year by the 2080s.
- As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. By the end of the 21st century, sea level rise alone would increase the frequency of coastal flood levels that currently occur on average once per decade to once every one to three years for New York City and once every one to two years for Westhampton Beach, with water levels associated with these events increasing by 1 to 2 feet. The more severe current 1-in-100-year event may occur on average approximately four times as often by the end of the century.
- The greater likelihood of coastal flooding (as well as heavier rainfall) would result in an increase in street, basement, and sewer flooding; an increase in flood risk to low-elevation transportation, energy, and communications infrastructure; more frequent delays on low-lying highways and public transportation; increased structural damage and saltwater exposure to infrastructure, commercial, and residential property; increased inflow of seawater to storm sewers and wastewater treatment

plants and reduced ability of gravity discharge of sewer-effluent overflows; encroachment of saltwater into freshwater sources and ecosystems; and increased beach erosion and sand placement needs.

- Sea level rise and coastal inundation could affect the heights of tide gates designed to prevent the inflow of seawater and backing up of outfall sewers.

Coastal Erosion

- Waves, currents, and tides constantly reshape the shoreline, and as sea level rise accelerates, these forces have the potential to dramatically alter New York State's coast.
- Sea level rise may increase the frequency of wave attack at the base of glacial bluffs, accelerating recession and erosion and increasing the rate of supply of sediment and other material to the near-shore system. This change in sediment supply could have different impacts that are difficult to predict given the limited understanding of sediment budgets and transport pathways.
- Shoreline change rates measured over the last 100 years show that generally the shoreline is receding at relatively low average rates of 1 to 2 feet per year, but that some areas are stable and others are accreting.
- Accelerated sea level rise will tend to exacerbate barrier island erosion. At low-to-moderate increases, the effects of sea level rise will still be of lesser magnitude than storm events and disruptions in longshore sediment transport. At higher rates of projected sea level rise, the migration of barrier islands landward should accelerate, but this migration may not be initiated in some sections of the barrier island for hundreds of years. At the most extreme rates of increased rate of rise, the barrier islands may not be able to maintain themselves if sea level rise outpaces the ability of the system to supply sediment naturally

The Hudson River Estuary

- Climate change could affect the location of the salt front of the Hudson River Estuary in three ways: 1) reduction in precipitation could reduce stream flow, allowing the salt front to move upstream, while an increase in precipitation would have the opposite effect; 2) increase in temperature could increase evaporation, reducing freshwater runoff, which in

turn would cause the salt front to migrate upstream; and 3) rising sea level may push the mean position of the salt front upstream.

- Sea level rise and storm surge will continue to affect the entire Hudson Estuary up to the dam at Troy.

Freshwater Resources

- Sea level rise and changes in precipitation will cause Long Island's water table to rise at approximately the same rate as sea level. As a result, the geographic extent of ponds and wetlands could change along with the carrying capacity of streams.
- Saltwater entry into aquifers would be slow, with less than 1 percent of the freshwater reserves affected over 100 years.

Coastal Ecosystems

- Coastal ecosystems are at risk from rising sea levels, which may impose additional stress and exacerbate wetland losses in some sensitive regions.
- At Jamaica Bay Gateway National Recreation Area, New York, island salt marsh area declined by 20 percent between the mid-1920s and mid-1970s. Since then this trend has accelerated, and close to 30 percent has subsequently been lost. The wetland loss rate at Jamaica Bay, Udalls Cove Preserve, and Stony Brook Harbor is 1.5 percent per year. Only 7 out of 13 salt marsh islands in Shinnecock Bay (southeastern Long Island) that were present in 1974 remained by 1994. Since the 1970s, rate of marsh losses on Long Island and New York City have been between 1 and 2 percent per year. According to the tide gauge at The Battery in New York City, sea level has been rising at a rate of approximately 1 foot per century. While sea level rise is among several stressors that may be acting together on vulnerable marshes, it may become the dominant factor in future decades as it outpaces sedimentation and vertical accretion.
- For Long Island, New York City, and Lower Hudson Valley, marshes would only survive under the central range of projected sea level rise by the 2020s, given medium or high accretion rates. None would survive the rapid ice-melt scenario. Marshes have a slightly better chance in the Mid-Hudson Valley and Capital Region, with more marshes surviving in the central-range set of scenarios and

some potentially surviving a rapid ice-melt scenario until the 2020s.

Fish and Shellfish Populations

- Water temperatures in the Hudson River already have shown substantial warming on the order of 0.22°F per decade between 1920 and 1990, which is projected to be consistent with global increases.
- For the New York Bight, projected sea surface temperature changes for the 2050s in comparison with a 1980s baseline show substantial increases on the order of 1.8 to 3.2°F, depending on the climate model and greenhouse gas emissions combination.
- Blue claw crabs flourish in the warmer waters of the mid-Atlantic and should not decline because of higher temperatures. However, lobsters are at the southern edge of their inshore range in New York and have already shown declines that may be linked to warming waters.
- Warming waters and increasing numbers of oysters (naturally occurring and through restoration projects) may result in increased abundances of black drum and sheepshead in New York.
- Warmer waters around New York will be more hospitable to fish species that normally range near New York but rarely reach it under current conditions.
- For New York coastal waters the relatively minor increases in ocean acidity brought about by high levels of carbon dioxide may have significant detrimental effects on the growth, development, and survival of hard clams, bay scallops, and Eastern oysters.

5.6.2 Adaptation Options

This section briefly introduces some basic adaptation options that could increase coastal community and ecosystem resilience to climate-induced hazards.

- Incorporate climate change and sea level rise information into State and local adaptation strategies and planning related to coastal land use, waterfront development, open space and natural habitat preservation, and emergency response and evacuation.
- Identify coastal area responses to sea level rise impacts at multiple timescales, such as more

frequent and extensive storm flooding, areas of permanent inundation, land loss due to erosion, various wetland responses, barrier island migration and breaching, and the migration of the salt front in estuarine environments. Evaluate the level of risk to human and natural systems, infrastructure, and population in these areas to prioritize and guide risk reduction and adaptation responses.

- Compile a detailed inventory of shoreline assets located in at-risk areas, their elevations, and the design lifetime for all sectors of coastal communities throughout New York State.
- Acquire currently vacant shorefront property in high-risk areas to serve as buffer zones against coastal flooding and sea level rise. Re-zone these for low-density use, recreation, and/or potential wetlands migration.
- Encourage responsible shoreline development in view of increasing sea level rise and coastal storm risks by providing guidance, incentive programs, and financial assistance to localities and sectors most at risk.
- Develop tools such as flood maps to effectively communicate sea level rise risks and community vulnerability to decision makers and the public.
- Establish a network of stakeholders and volunteers to assist in monitoring for sea level rise impacts and to coordinate outreach and education efforts.
- Coordinate regional efforts to update and re-evaluate periodically the range of risks associated with sea level rise and coastal storms, and modify existing environmental regulations and permitting accordingly.

In addition, the New York State Sea Level Rise Task Force (SLRTF) offers a comprehensive set of policy recommendations to reduce vulnerability from sea level rise and coastal hazards. Its recommendations include legal and regulatory changes as well as strategies for developing funding mechanisms for research, monitoring, and adaptation, and an evaluation of the public health risks associated with sea level rise and coastal hazards (New York State Sea Level Rise Task Force, 2010).

5.6.3 Knowledge Gaps

Climate change assessment efforts are often limited by the level of understanding of natural processes (barrier

island evolution, ecosystem functions, and interactions), the lack of spatial and temporal monitoring data, the availability and quality of existing data, and modeling capabilities. As new research methods emerge and scientific understanding of natural systems evolves, climate adaptation strategies and existing regulations (building codes, setbacks) should be reconsidered. Recommendations to improve assessment tools and understanding of natural processes operating in coastal regions specific to New York State are listed below.

- The responses of barrier islands and tidal wetlands to accelerated rates of sea level rise, such as the rapid ice-melt scenario, are currently unknown. Monitoring barrier island and tidal wetland evolution and determining the influence of regional geologic controls on their spatial variability would improve process-level understanding of these systems.
- Regional sediment management strategies require an understanding of transport processes along the coast as well as across the continental shelf. Presently the quantity of sand and processes by which it moves from the inner shelf to the littoral zones are unknown. This will influence the selection of “borrow” sites for sand that may be placed on beaches.
- Quantifying and monitoring land use and coastal water quality will help determine the most suitable land-use practices and adaptation strategies to improve coastal environments and increase resiliency.
- Assessment of ecosystem services for natural and engineered shorelines will aid in identifying potential adaptation strategies for more urbanized sections of the coastline.
- Establishing a monitoring program for submarine groundwater discharge throughout Long Island with particular focus on low-lying areas will allow tracking of the influence of submarine groundwater discharge on submerged aquatic vegetation.
- Systematic and standardized protocols (every two to five years) for all New York State coastal regions are needed. Mapping could include bathymetry, topography to the 500-year floodplain, and the extent of existing wetlands.
- Development of a comprehensive, easily accessed GIS-based data repository will facilitate interagency collaboration and future assessment efforts. The repository should include all monitored and modeled data, such as an inventory of hardened

shorelines, land use, critical infrastructure, sea level rise rates, distribution of habitats and species, historic shorelines, and storm water level recurrence intervals.

- Hydrodynamic modeling capability for the Hudson River is required to investigate the effect of climate change on the position of the salt front and on nutrient loads associated with extreme precipitation events.
- Research on climate-related impacts and adaptation strategies for Great Lakes coastlines is critical, since these regions were not included in this assessment.

Case Study A. 1-in-100-year Flood and Environmental Justice

New York coastal communities are vulnerable to both tropical and extra-tropical storms. As the climate changes there is a potential for more-intense storm systems to impact New York State, and coupled with an accelerating rate, of sea level rise the likelihood of experiencing what is currently considered a 1-in-100-year event is increasing. The highly developed nature of the coast, the large population, and considerable private property and infrastructure at risk require society to develop holistic adaptive management strategies that promote community resilience. The implementation of various strategies will depend strongly on population and critical infrastructure density, as well as societal priorities. This particular ClimAID case study is focused on flood adaptation strategies for the urban and suburban regions of Long Beach (**Figure 5.10**) and communities along the mainland coastline of Great South Bay (**Figure 5.11**). In particular, a severe coastal storm consistent with the 1-in-100-year event (the theoretical storm that produces the 100-year floodplain) is considered for this analysis. The purpose is to illustrate where New York State and coastal communities may need to transition from phased withdrawal or managed relocation to fortification strategies, while highlighting community vulnerabilities associated with socioeconomic conditions. This case study suggests that managed relocation might be the appropriate strategy for agricultural or low-density residential land; engineering strategies might be required for urbanized lands; and an intermediate strategy (beach nourishment, for example), for moderate-density residential areas.

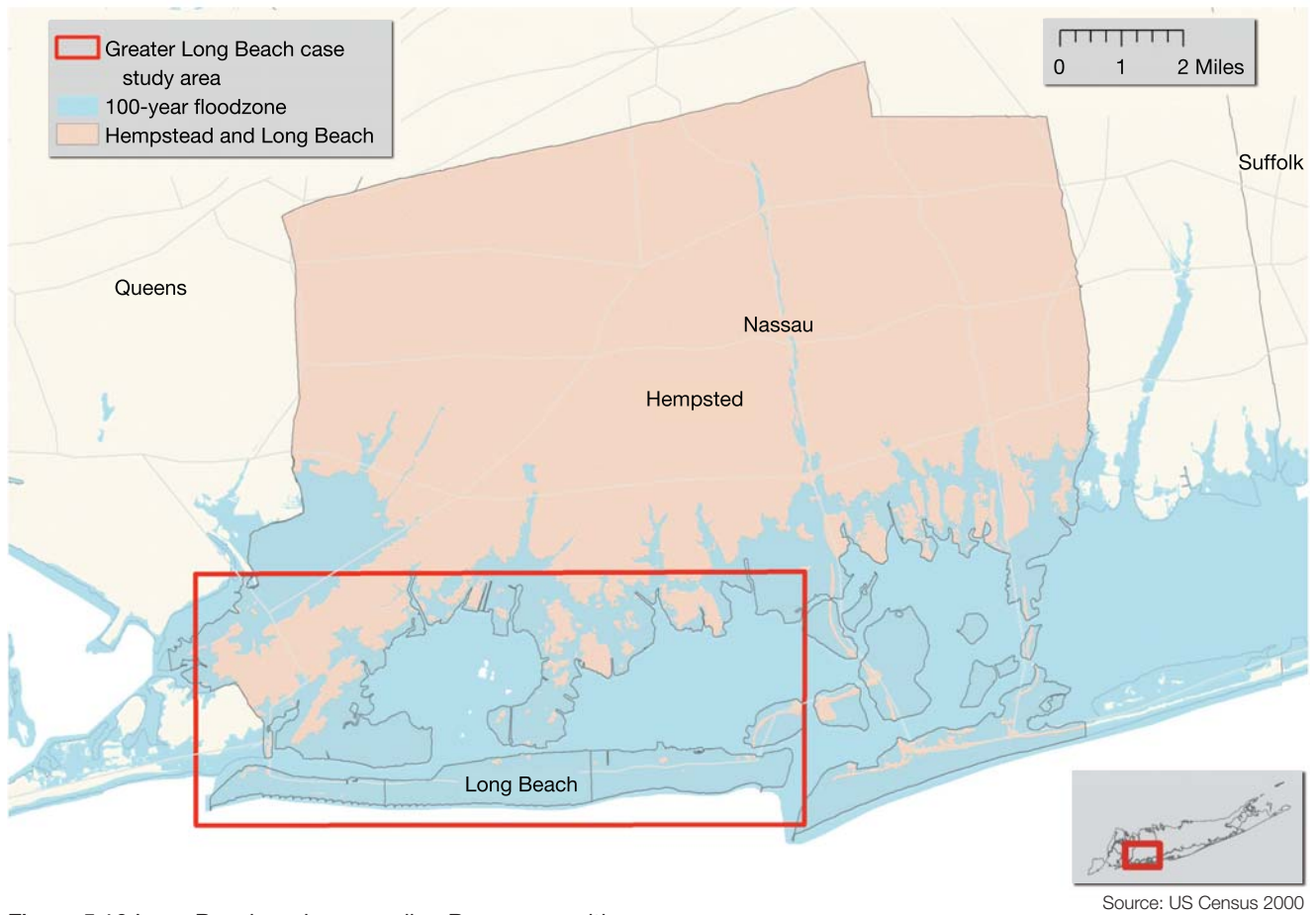


Figure 5.10 Long Beach and surrounding Bay communities

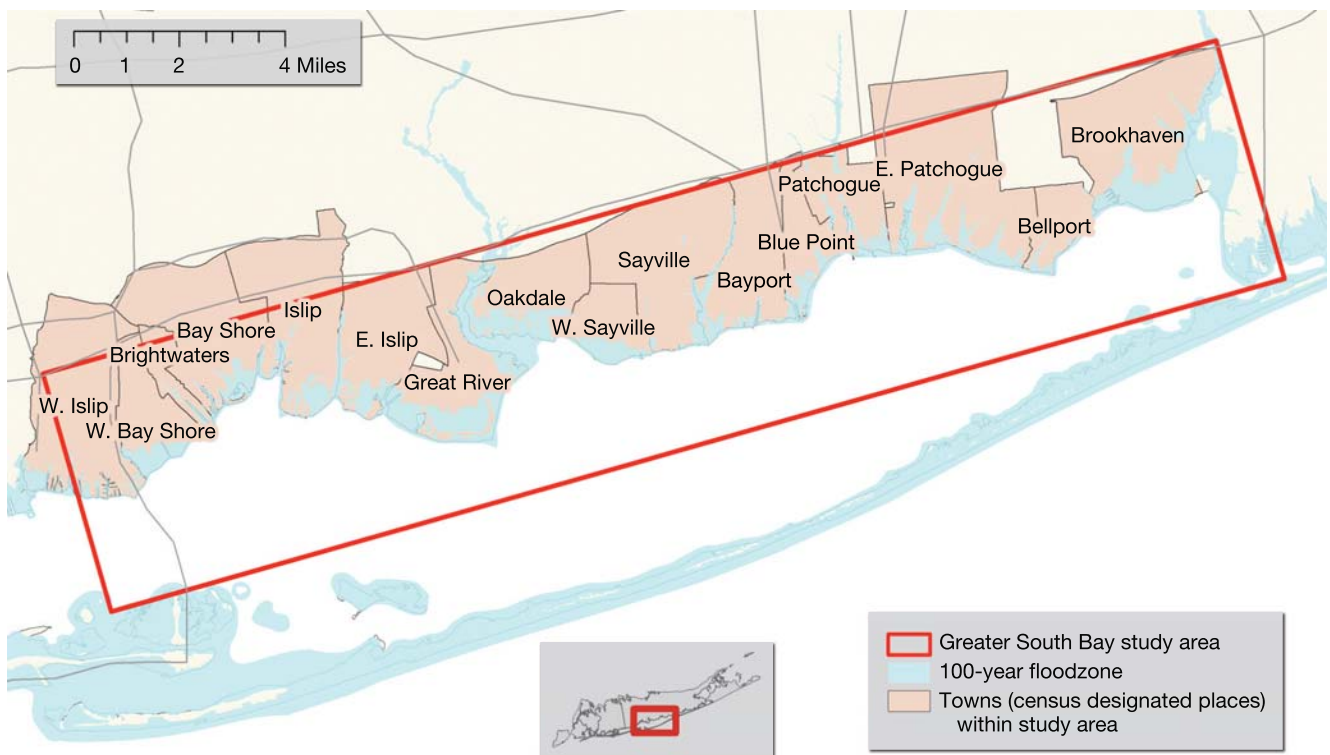


Figure 5.11 Mainland coast of Great South Bay

Social vulnerabilities are generally expressed at a more local or household level. Land use and coastal decision making is also done at a local scale. Still, one of the unique challenges of climate change is that it frequently is regional in exposure, so climate change adaptation strategies require a wider regional planning focus. Being attuned to who is excluded by the telescoping of scale and regionalization of focus will help make the planning process more inclusive, valid, and responsive.

Analysis of Vulnerability to Storm Events

A number of variables generally associated with vulnerability were chosen from the 2000 census at the census block group level.¹ A comparison was made of mean values in the 100-year floodplain and means outside the floodplain. For Long Beach, the 100-year floodplain was compared to block groups within the Town of Hempstead, as defined in Census 2000 as a Minor Civil Division (**Figure 5.10**). For Great South Bay, the present-day 100-year floodplain was compared to block groups falling within the Census Designated Places of the case study area: Bayport, Bay Shore, Bellport, Blue Point, Brightwaters, Brookhaven, East Islip, East Patchogue, Great River, Islip, Oakdale, Patchogue, Sayville, West Bay Shore, West Islip, and West Sayville (**Figure 5.11**).

In general, for both case study areas, differences between the populations in the floodplain and those outside were relatively small (**Tables 5.13** and **5.14**).

However, median household incomes and the values of homes were slightly higher within the floodplain in both case studies, which likely reflects the amenity value of living by the coast. Key indicators of vulnerability or inequity in the distribution of burdens and benefits, such as race, poverty, and educational attainment, showed slight differences, but are not concentrated in flood-prone populations.

At a finer scale within the case study regions, there nevertheless is a wide range in the incidence of potential vulnerability from neighborhood to neighborhood. For example, **Figure 5.12** suggests that much of the disabled population in and around Long Beach is clustered in a few distinct locations. Patterns such as these may present opportunities for targeted emergency planning. Other social indicators, such as percent poverty, percent non-white, and the number of female-headed households, tend to cluster spatially and occur concurrently, which may indicate concentrated populations that are likely to be more sensitive to the impact of flood events (**Figure 5.13**, for example).

Social disparities are evident within Great South Bay as well. The highest rates of poverty and greatest proportion of renters, minorities, and foreign-born residents tend to center in Bay Shore and Patchogue (**Figures 5.14** and **5.15**). In general, the less densely populated areas between these centers are wealthier, better educated, and enjoy higher rates of home ownership.

	In Floodplain	Out of Floodplain
Median income	\$75,653	\$72,014
Median housing value, owner occupied housing	\$287,262	\$224,955
Female head of households as percentage of total	14.7	16.5
% in poverty	6.7	5.2
% less than high school	11.1	14.1
% over 65	14.7	14.2
% African American	5.4	15.1
% Hispanic	9.6	10.6
% renter	24.7	16.7
% vacant housing	5.7	1.8
% foreign born	14.1	17.4

Source: U.S. Census 2000; authors' calculations

Table 5.13 Characteristics of population in census block groups in and out of 100-year floodplain for the Long Beach case study area

	In Floodplain	Out of Floodplain
Median income	\$73,323	\$65,834
Median housing value, owner occupied housing	\$238,480	\$176,489
Female head of households as percentage of total	13.3	15.1
% in poverty	6.2	4.8
% less than high school	11.4	12.4
% over 65	14.1	12.0
% African American	2.5	4.7
% Hispanic	7.5	8.7
% renter	22	21.1
% vacant housing	5.4	2.8
% foreign born	8.4	7.4

Source: U.S. Census 2000; authors' calculations

Table 5.14 Characteristics of population in census block groups in and out of 100-year floodplain for the Great South Bay case study area

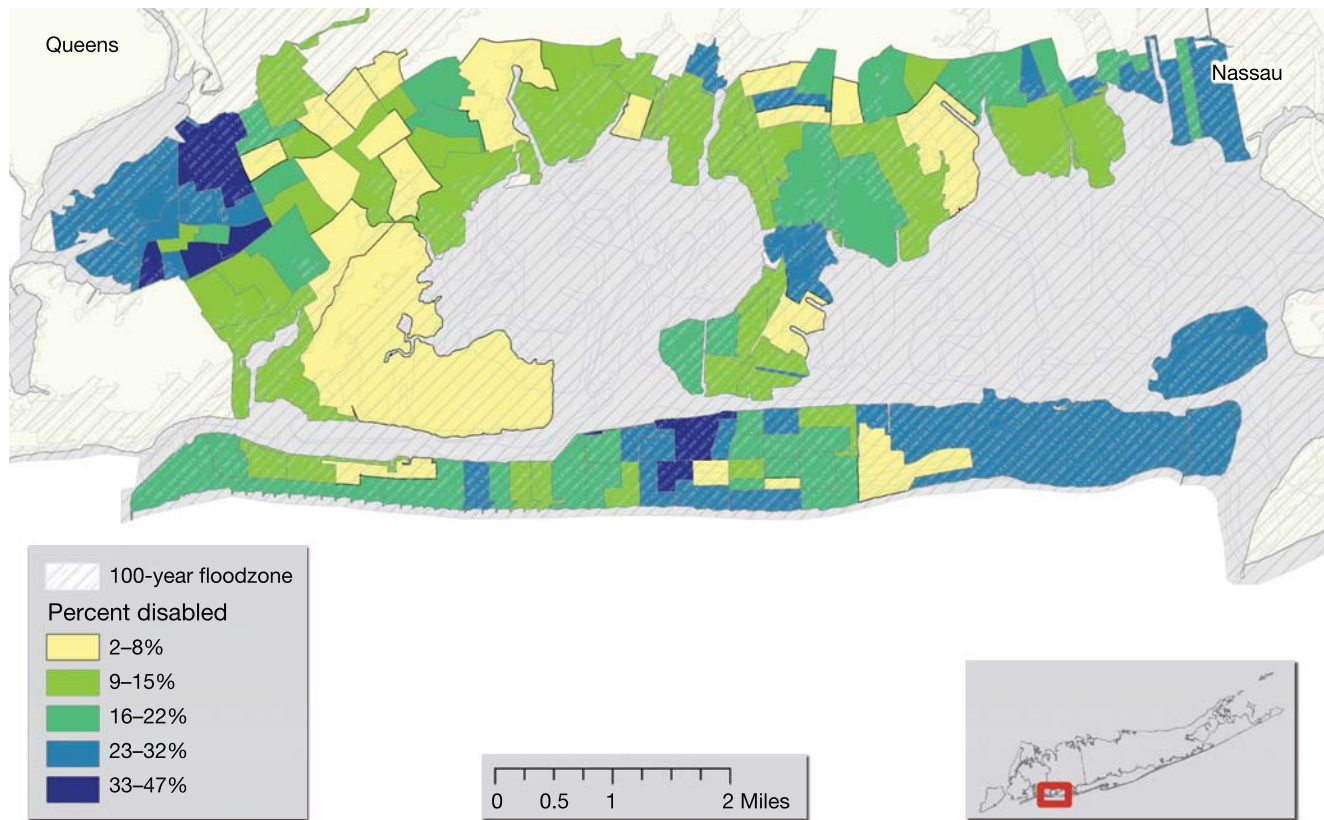


Figure 5.12 Concentration of disabled population in Long Beach region

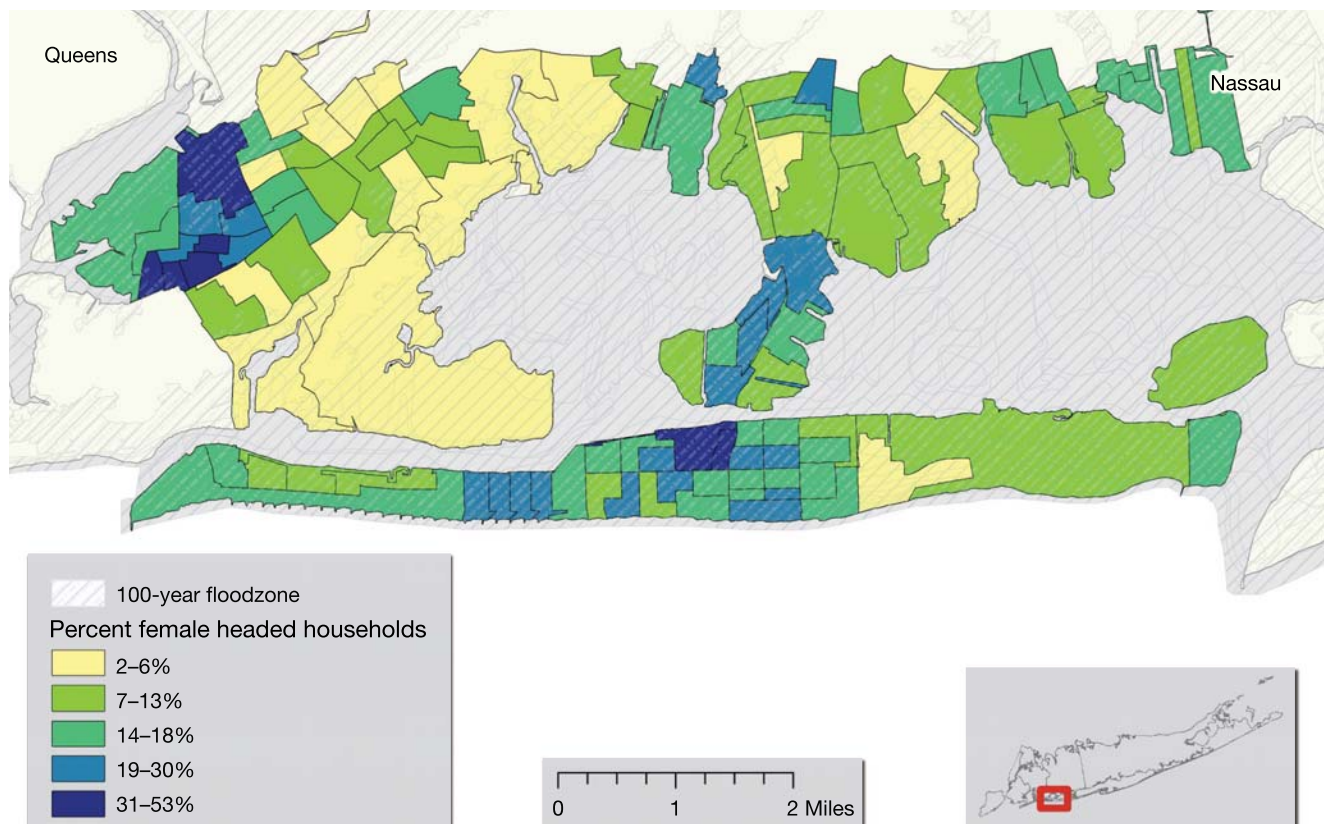


Figure 5.13 Female-headed households in Long Beach region

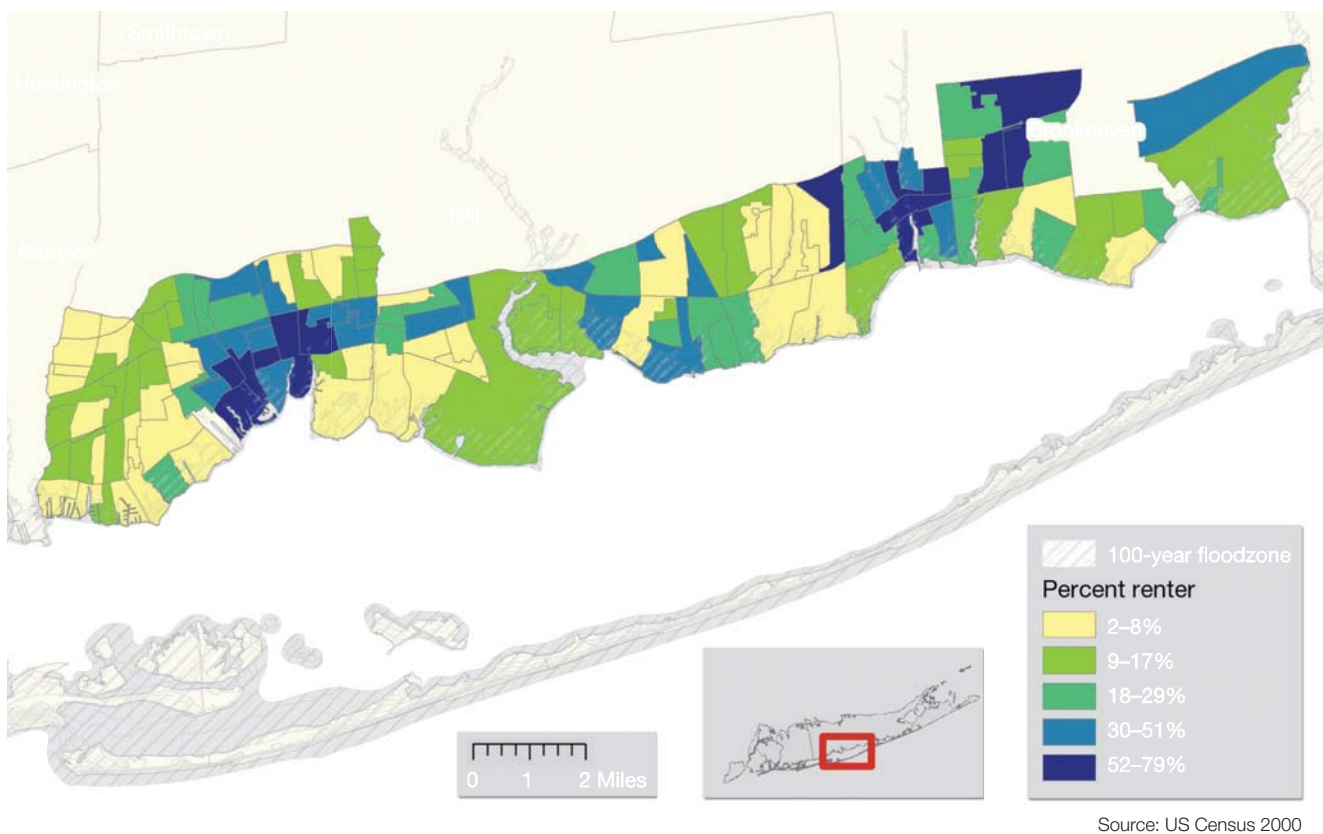


Figure 5.14 Local variation in density of renters in Great South Bay

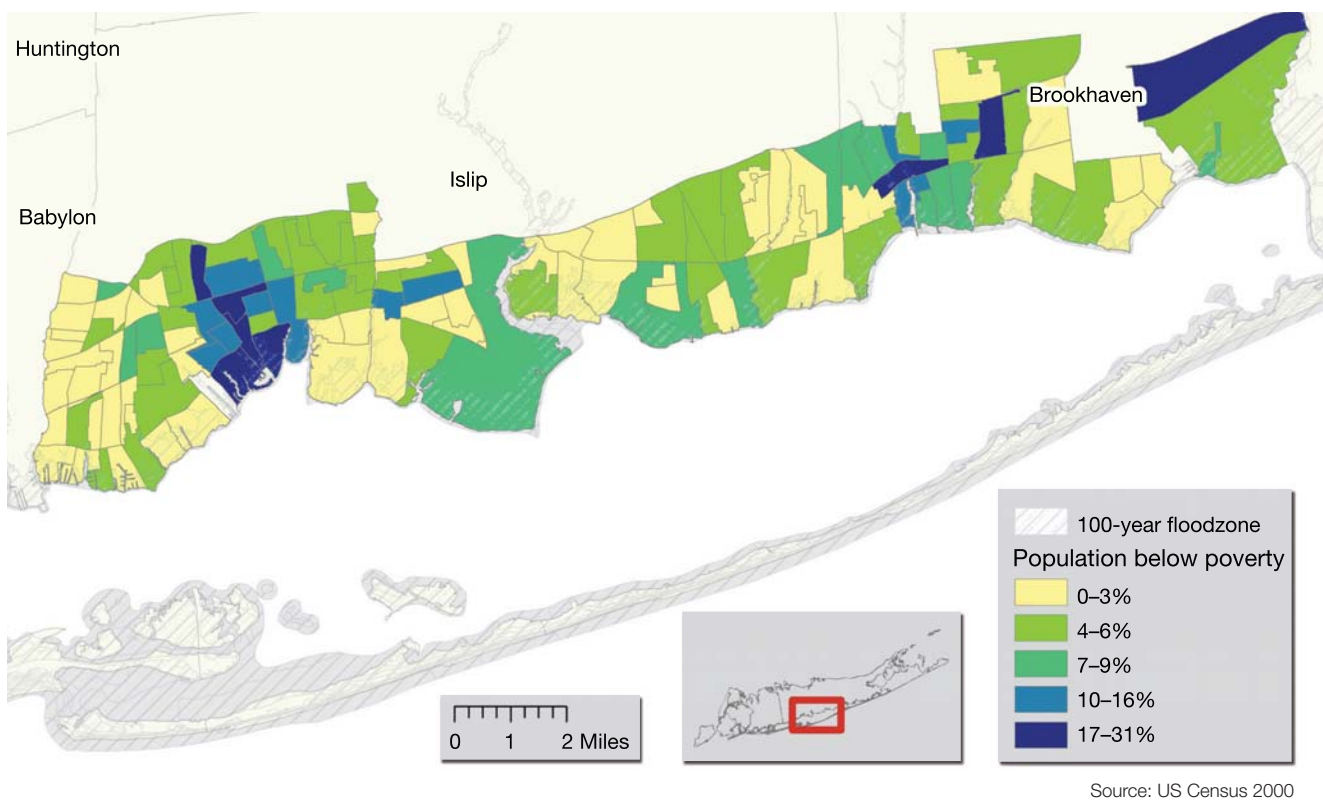


Figure 5.15 Concentrated poverty in Great South Bay

Adaptation, Economic Impacts, and Distributional Inequities

Identifying and understanding how economic impacts associated with severe coastal storms will change

temporally under different sea level rise scenarios is critical for developing effective adaptation and sustainable management strategies. For the Long Beach and Great South Bay study regions, two sea level rise scenarios were considered, the GCM-based central

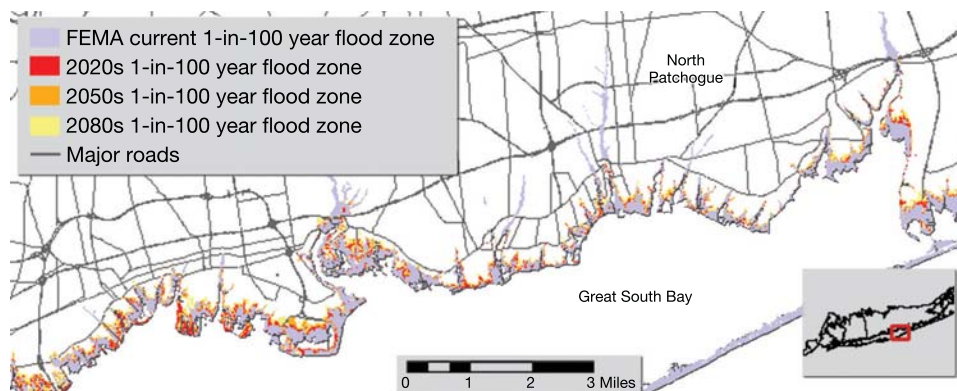


Figure 5.16 1-in-100-year flood zone for Great South Bay based on the GCM-based central range sea level rise scenario

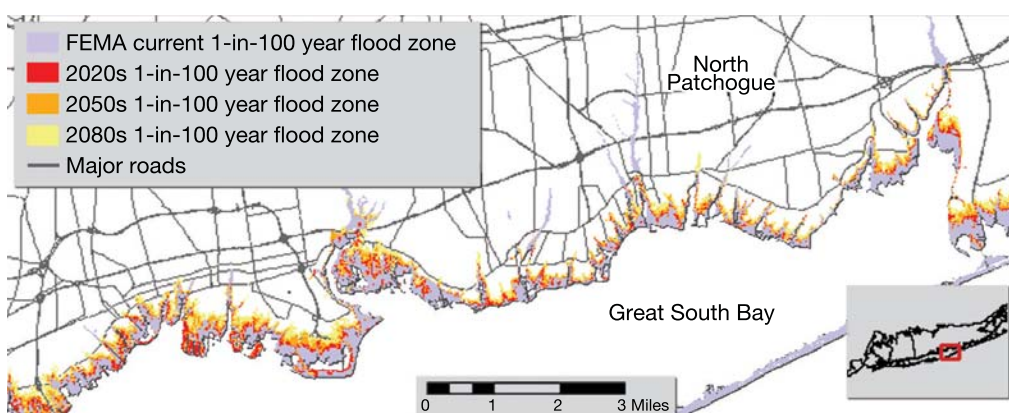


Figure 5.17 1-in-100-year flood zone for Great South Bay based on the rapid ice melt sea level rise scenario

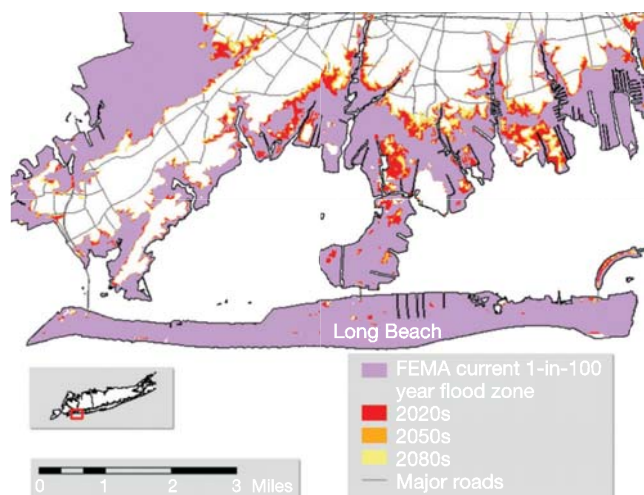


Figure 5.18 1-in-100-year flood zone for Long Beach based on the GCM-based central range sea level rise scenario

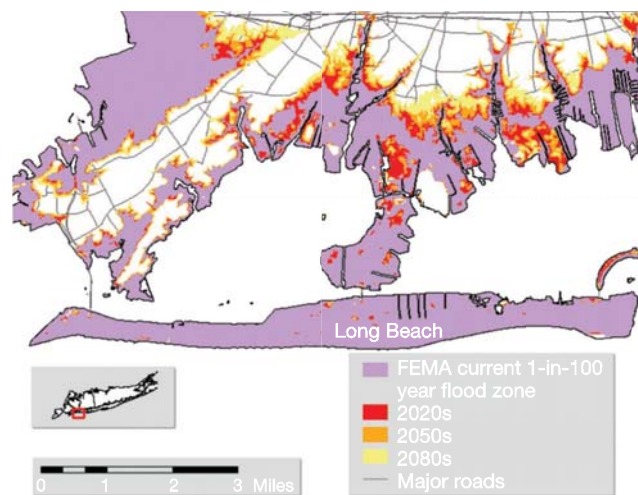


Figure 5.19 1-in-100-year flood zone for Long Beach based on the rapid-ice-melt sea level rise scenario

range forecast and a rapid ice-melt scenario. The GCM-based and rapid ice-melt scenarios are consistent with approximate 2-foot and 4-foot sea level rise by the 2080s, respectively. Corresponding 100-year floodplains for Long Beach and Great South Bay for each of the scenarios are shown in **Figures 5.16** through **5.19**.

Over the 2000–2080 forecast period, sea level rise is expected to place a growing population and increasing property at risk from flood and storm damage. These base-case analyses take as their starting point the 2000 U.S. Census estimates for population and property values within the study areas (U.S. Census Bureau Population Division, 2005). **Table 5.15** lists the base-case forecasts for the Long Beach and Great South Bay coastal regions.

Case Study B. Modeling Climate Change Impacts in the Hudson River Estuary

The Hudson River extends unimpeded from The Battery in New York Harbor north to the Federal Dam at Troy just above Albany. The river coastline is highly populated. As the river has become cleaner over the last several decades, development pressure along its shores has increased. The goal of this case study is to describe the relative impact of sea level rise, storm surge, and large precipitation events on estuary water levels using a publicly available hydrodynamic computer model to determine which of the impacts of climate change are likely to be of greater significance to

the planners, regulators, and communities along the estuary shoreline.

The National Oceanic and Atmospheric Administration (NOAA) currently makes short-term forecasts of water levels using predictions of tides and watershed inflows. Cornell researchers used a variant of the NOAA National Weather Service model that employs the U.S. Army Corps of Engineers software HEC-RAS (Hydrologic Engineering Center-River Analysis System) to predict water level rise due to conditions outside those normally addressed by NOAA. This ClimAID assessment included three scenarios: 1) a scenario with 2 or 4 feet of sea level rise on top of tidal fluctuations, 2) high freshwater inflow scenarios, and 3) a storm surge scenario. The study also considered the relative value of improved topographic data (bathymetry, land elevation, hydraulic channel characteristics, and tributary flows) for understanding the impacts of climate change.

Sea Level Rise and Impact on Tidal Range

Because of the low topographic gradient along the river, not counting the effect of land subsidence south of Kingston, a change in sea level at New York Harbor results in nearly the same change in water level at Albany. For example, a 3-foot increase in water level at The Battery would coincide with a roughly 3-foot increase in water levels at Albany. Thus, any change in mean water level due to sea level rise would be imposed upon the regular tidal fluctuation of 4 to 5 feet in Albany. Additionally, an increase in sea level of 2 or 4 feet will result in deeper water in the Hudson River estuary, allowing the estuary to better transmit tidal energy from The Battery to Albany. Model simulations suggested that this would effectively increase the tidal range at Albany by as much as 0.3 feet.

Large Rainfall Events

The high freshwater inflow scenario used the 2008 annual peak flow at the Troy Dam (an approximately 5-year return period flow) and found that only water levels in the uppermost part of the tidal river above Castleton-on-Hudson changed appreciably. This conclusion is corroborated by discharge data directly measured at different points on the river. A measured 2008 peak flow of 104,000 cubic feet per second at the Troy Dam (a measure of the majority of watershed

Risk of Sea Level Rise: Long Beach Case Study Area			
	2020s	2050s	2080s
Population at risk			
GCM-based forecast	94,526	101,188	107,934
Rapid-ice-melt forecast	95,859	105,836	114,515
Property at risk (millions)			
GCM-based forecast	\$6,266	\$6,485	\$6,739
Rapid-ice-melt forecast	\$6,376	\$6,814	\$7,163
Risk of Sea Level Rise: Great South Bay Case Study Area			
	Year 2020	Year 2050	Year 2080
Population at risk			
GCM-based forecast	17,387	20,512	24,606
Rapid-ice-melt forecast	18,822	25,222	33,560
Property at risk (millions)			
GCM-based forecast	\$1,159	\$1,348	\$1,585
Rapid-ice-melt forecast	\$1,262	\$1,669	\$2,162

Table 5.15 Population and property at risk for GCM-based and rapid ice-melt scenarios

inflows to the river) is only one-third the normal peak tidal flow in the Hudson near Poughkeepsie (300,000 cubic feet per second peak flow). The annual mean flow at Troy of 14,000 cubic feet per second is 20 times less than the 2008 peak flow. The tidal flow in the river is much larger than the largest freshwater inflows to the river. This suggests that changes in precipitation and resulting freshwater inflows to the river associated with climate change will have a more localized influence on the water levels.

Storm Surge

A trial storm surge scenario assumed a 10-foot increase in water level on top of normal tidal fluctuations at The Battery over a 36-hour period. Storm surge is often slow relative to the dynamics of the estuary and the model indicated that the surge would travel up the river to the Troy Dam with relatively little diminishment or increase in magnitude. Thus, a storm surge can be thought of as a temporary sea level change, with all areas of the tidal Hudson affected nearly equivalently. However, Albany and the Battery are likely to have a slightly greater tidal maximum than areas at mid-river due to channel characteristics. The results indicated that these conclusions were insensitive to modest changes in the

bathymetry of shallow regions of the river or expansion of wetlands. However, finer-scale modeling along with detailed elevation and topographic data is still a critical need in order to determine which areas of which communities will be most vulnerable to the impacts of climate change on the estuary.

Case Study C. Salt Marsh Change at New York City Parks and Implications of Accelerated Sea Level Rise

For the ClimAID assessment case study, historical aerial photographs were used to help evaluate marsh sustainability at two New York City Department of Parks and Recreation (NYCDPR) salt marshes: Udalls Cove Park Preserve (Queens) and Pelham Bay Park (Bronx). Prior evidence of New York State-wide marsh losses during the 25-year time span 1974 to 1999 was documented by NYSDEC (2004), including at these parks (Table 5.5). The current research used aerial photography obtained from 1951, 1974, 1999 (panchromatic), and 2005 (infrared) to quantify progressive marsh loss over the last half century. On-the-ground observations, sampling, and monitoring were used to gain an understanding of the observed

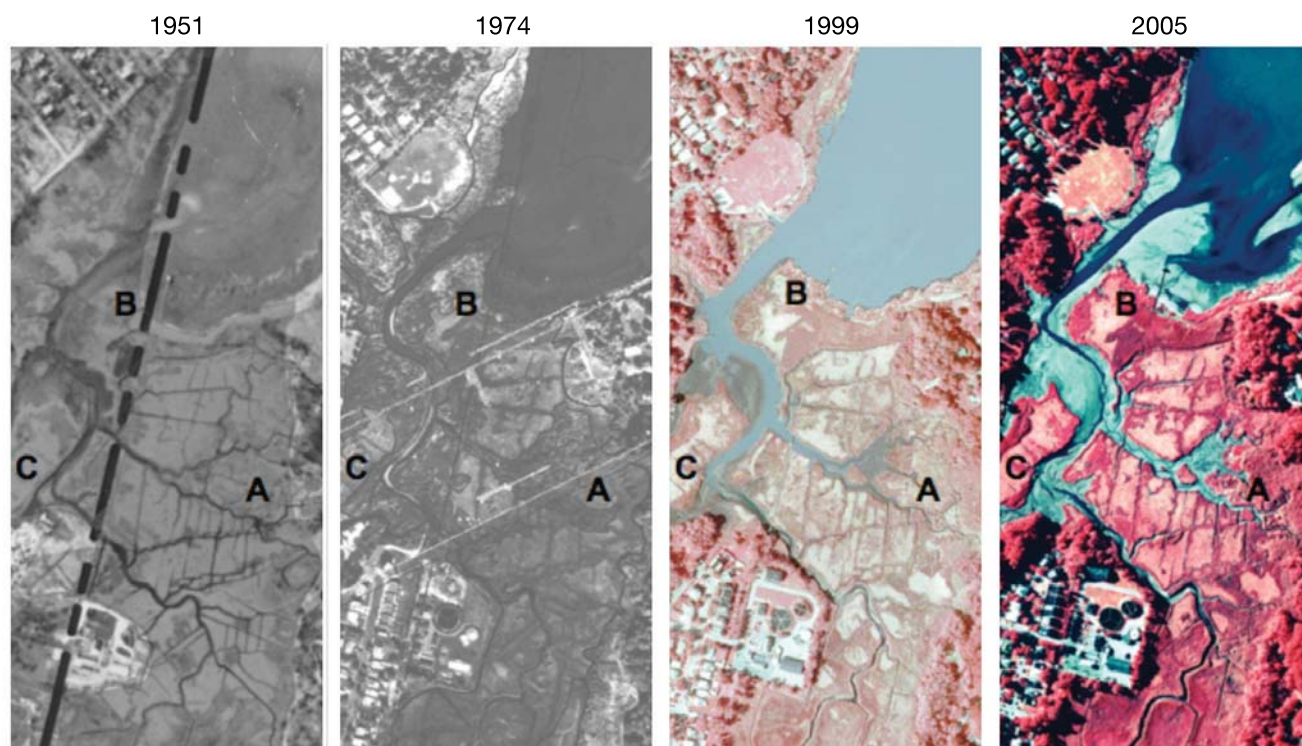


Photo credit 1951: Aero Service Corp. Photogrammetric Engineers, Phila. Pa; Photo credit 1974, 1999, 2005: NYSDEC

Figure 5.20 Marsh loss comparisons at Udalls Cove Park Preserve, Queens

rates of loss. The results were compared with marsh loss elsewhere along the eastern United States.

For long-term monitoring, NYCDPR installed sediment elevation tables (SETs) in clusters of three at Udalls Cove Park Preserve and Pelham Bay Park in cooperation with NYSDEC and U.S. Geological Survey (USGS). These platforms have been used internationally and are effective at separating the components of surface accretion and shallow subsidence in the marshes (together with feldspar markers placed on the surface in 0.25-meter squares near the SETs). Over the next several years and decades, NYCDPR will be comparing the results from the selected parks with accretion rate data at Jamaica Bay and Fire Island, New York (Roman et al., 2007), Mashomack Preserve (Shelter Island, New York), Hackensack Meadowlands (New Jersey), and Narragansett Bay (Rhode Island).

While **Table 5.8** offers a sensitivity study on marsh survival using low, medium, and high rates of accretion in the face of projected sea level rise, on-the ground determinations of accretion and subsidence rates from SETs will offer data on how to manage specific marsh sites. The combination of aerial photo analysis and SET data from sampling stations can aid park managers, scientists, and public advocates in managing, and thereby perhaps minimizing, salt marsh loss in the coming decades.

Udalls Cove Park, Queens

At Udalls Cove, initial analysis indicates significant land loss, including breaking up of previously contiguous marshland (see **Figure 5.20**, point A), eroding embankments (see point B), and widening of channels (see point C) (**Figure 5.20**). The amount of loss already under way was compared with projections of future loss over the next century (**Table 5.8**).

Jamaica Bay Wildlife Refuge, Queens

Since 1998 there has been much speculation as to the cause of salt marsh deterioration and submergence at Jamaica Bay National Wildlife Refuge, part of Gateway National Recreation Area in New York City and New Jersey (Hartig et al., 2002; NYSDEC, 2006). While the exact cause is unknown, the marsh loss at Jamaica Bay

has been attributed to multiple stressors, including nutrient inputs from WPCPs (water pollution control plants for sewage treatment), deepening of navigation channels, shoreline armoring, increased tidal range (Swanson and Wilson, 2008), sea level rise, and more. Whatever the cause (or causes acting synergistically), the loss was extreme and action was taken to stem the loss.

In a pilot project at Big Egg Marsh conducted in part by local activists the Jamaica Bay Ecowatchers, the National Park Service, and many volunteers, a degraded marsh was restored by spraying sediment at a thickness of up to 3 feet and replanting with *Spartina* plugs. More recently, using sand from maintenance dredging, the U.S. Army Corps of Engineers conducted large-scale restoration at Elder's Point East for \$13 million. At both sites the artificially elevated *Spartina alterniflora* stands are thriving. A priority list has been generated through a Jamaica Bay Task Force for follow-up locations; the next restoration with sediment supplements is planned for Elder's Point West, to be followed by Yellow Bar Hassock.

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Appendix A. Stakeholder Interactions

Stakeholder interaction is a key component of the ClimAID assessment design, integrating scientific knowledge with local experience and allowing the prioritization of vulnerabilities and provision of tangible adaptation strategies that decision-makers can use. The Coastal Zones Sector interacted with relevant stakeholders through meetings and phone conferences, and through a more regularly engaged focus group.

Meetings

The Coastal Zones Sector held its first stakeholder meeting on January 9, 2009, at the City University of New York Graduate Center in New York City. The following agencies, stakeholders, and academic institutions were represented: National Park Service, Stony Brook University, New York State Department of State, Suffolk and Nassau Counties, the New York District Army Corps of Engineers, New York City Department of Parks and Recreation, Department of Environmental Conservation Hudson River Estuary Program and New York State Climate Change Office, The Nature Conservancy, New York State Emergency Management Office, and the New York Sea Grant Extension. The meeting included a presentation by the New York State Department of State on its emerging post-storm redevelopment plan.

We held our second stakeholder meeting as a webinar on February 10, 2010. The following agencies, stakeholders, and academic institutions were represented: CUNY Institute for Sustainable Cities, City University of New York, New York State Department of State, NASA Goddard Institute for Space Studies, New York City Department of Parks and Recreation, Department of Environmental Conservation Hudson River Estuary Program and New York State Climate Change Office, Suffolk County Department of Environment and Energy, The Nature Conservancy, New York State Emergency Management Office, and New York Sea Grant Extension.

Focus Group and Related Assessment Efforts

From the initial stakeholder meeting a focus group was constructed from members of The Nature Conservancy

(point of contact [POC] Sarah Newkirk), New York Sea Grant (POC Jay Tanski), New York City Department of Parks (POC Ellen Hartig), New York State Department of Environmental Conservation (NYS DEC) Region 2 (POCs Kristin Marcell, Betsy Blair), and Stony Brook University (POC Henry Bokuniewicz). The members of the focus group served as regional experts, contributed text to the Coastal Zone chapter, and provided feedback on the overall sector assessment progress and methodology. Several of the focus group members also act as liaisons between ClimAID and related regional assessment efforts in order to coordinate work products and recommendations to policy makers.

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

In August 2008, Mayor Michael Bloomberg launched the Climate Change Adaptation Task Force and the New York City Panel on Climate Change (NPCC) as part of his PlaNYC 2030, to develop adaptation strategies to protect the city's infrastructure from climate change impacts (Rosenzweig and Solecki, 2010). Experts on the NPCC from academic institutions and from legal, engineering, and insurance industries advised the Adaptation Task Force in developing comprehensive and inclusive strategies to protect the city's infrastructure against the effects of climate change. Of the many products developed from the NPCC work, the sea level rise information and mapping strategies were most critical to the development of the ClimAID Coastal Zones chapter, forming the foundation of case study flood projections and illustrations.

New York State Sea Level Rise Task Force

The New York State Sea Level Rise Task Force, established by the state legislature and chaired by the NYSDEC Commissioner, was charged with providing New York State with the best available science as to sea level rise and its anticipated impacts. Its tasks were to develop inventories of at-risk assets, describe the impacts of sea level rise and prepare guidance for the

development of risk and adaptation strategies. The final report and website includes recommendations for protective standards and adaptive measures to be used by state and local governments as they move forward with planning for sea level rise and climate change. The Task Force adopted projections developed by the NPCC for sea level rise and coastal inundation (Rosenzweig and Solecki, 2010). These projections, which were also adopted for the ClimAID assessment, were refined for the Hudson River (see section 5.2.1 and Chapter 1, "Climate Risks") and included a rapid ice-melt scenario.

Rising Waters

The Rising Waters project was a multi-stakeholder scenario planning project to prepare for climate change in the Hudson Valley (Aldrich et al., 2009). The Nature Conservancy was the lead on the effort along with five major partners: the Cary Institute for Ecosystem Studies, the NYS DEC Hudson River Estuary Program, NYS DEC/NOAA Hudson River National Estuarine Research Reserve, the Cornell University Water Resources Institute, and Sustainable Hudson Valley. The process, based on a scenario planning process developed by Royal Dutch Shell aimed to develop realistic plausible scenarios or stories of the future based on the best available information today on the drivers of environmental, social, economic, and technological change and how they relate to one another (Aldrich et al., 2009). The scenarios are designed to serve as a tool to evaluate adaptation strategies that will work best across the range of possible futures. Four future scenarios were developed for the Hudson Valley for the year 2030. Two primary variables were explored in the scenarios. The first was whether the Hudson Valley opted to adapt to climate change in a way that tends to work with nature (using greener, non-structural solutions) or more engineered structural solutions. The second variable is the level of effort (large or small) in preparing for climate change. Climate information for the scenarios was based upon the best available scientific projections at the time and was the same for all four scenarios. A list of adaptation strategies was developed and evaluated based on criteria set by stakeholders and performance of the strategy in each scenario.

¹ Census tracts are small, relatively permanent statistical subdivisions of a county delineated by local participants as part of the U.S. Census Bureau's Participant Statistical Areas Program. A census block group is a cluster of census blocks having the same first digit of their four-digit identifying numbers within a census tract.

Ecosystems

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Introduction

Valuable ecosystem services provided by New York's landscapes include harvested products (food, timber, biomass, maple syrup), clean water and flood control, soil conservation and carbon sequestration, biodiversity support and genetic resources, recreation, and preservation of wild places and heritage sites. Ecosystems recharge groundwater supplies and reduce soil erosion by creating catchments that enhance rainwater infiltration into soils as opposed to allowing rapid runoff of storm water into streams. The healthy vegetation of landscapes helps to stabilize and conserve soils, and also sequesters carbon above ground in the standing biomass of trees and perennial plants and below ground in the form of roots and soil organic matter. The diverse flora and fauna supported by New York landscapes play a role in maintaining Earth's biological heritage, and the complex interactions among species benefit society in many ways, such as natural control of insect pests and disease. Genetic diversity will be essential for the natural adaptation of our ecosystems

to environmental stresses such as high temperatures and drought that will be exacerbated by climate change. In addition, genetic diversity has potential economic value for new pharmaceuticals, or for organisms or compounds with biotechnology applications.

Figure 6.1 depicts a conceptual framework for how these services are related to ecosystem function, species composition, and habitat integrity. As this framework indicates, the impacts of climate change cannot be viewed in isolation, as other stressors are also affecting ecosystems and will affect vulnerability to climate change. While society and policy-makers are likely to focus on ecosystem services, adaptation interventions by natural resource managers often will be implemented at the level of species, communities, and habitats. As climate changes and the habitable zones of wild species continue to shift northward and/or upward in elevation throughout the century, natural resource managers will face new challenges in maintaining ecosystem services and difficult decisions regarding change in species composition.

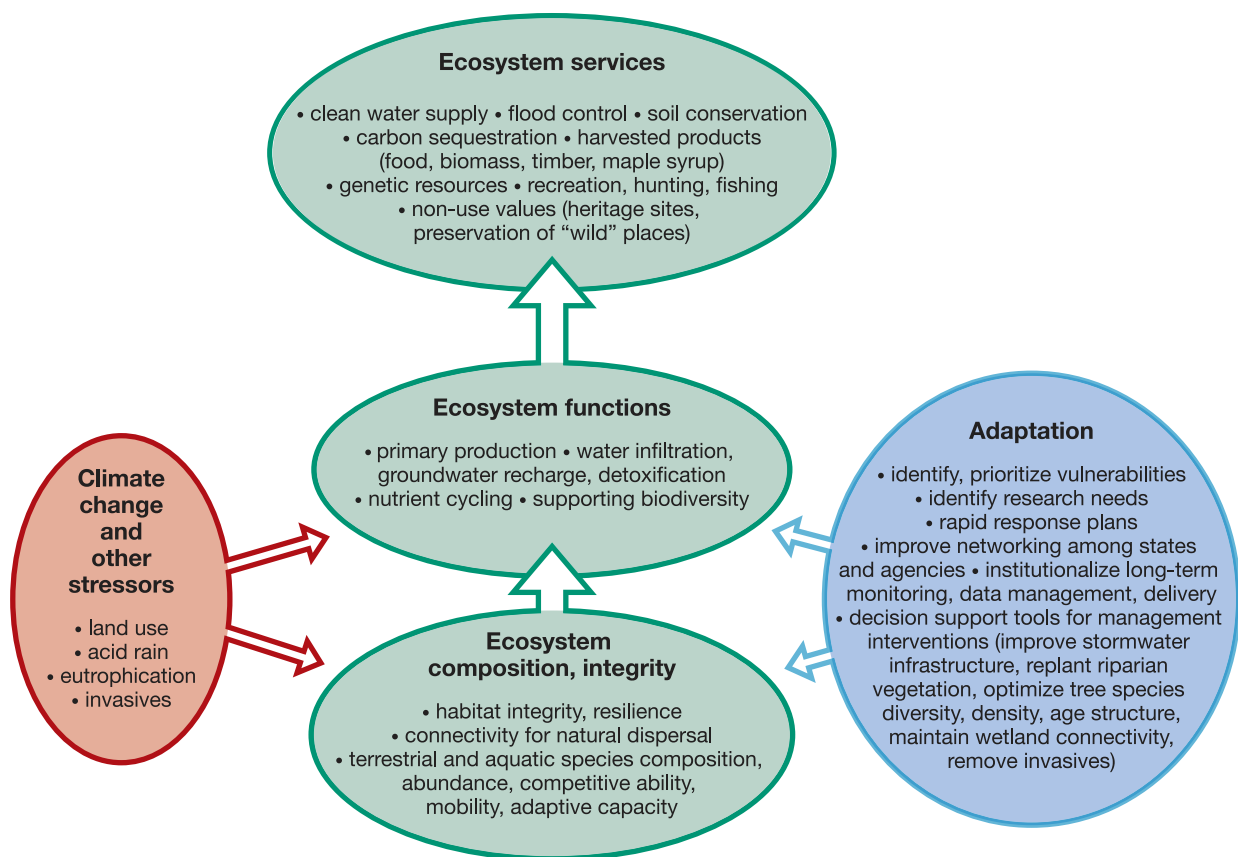


Figure 6.1 Ecosystem services in relation to climate change and adaptation

6.1 Sector Description

New York State covers an area of 54,556 square miles comprised of 47,214 square miles of land and 7,342 square miles of inland waters, including extensive lake and river systems throughout the state as well as substantial portions of Lake Erie and Lake Ontario. Variation in topography and proximity to bodies of water cause large climatic variations and distinct ecological zones (**Figure 6.2**) that support the complex web of biological diversity and provide important ecosystem services.

Ecosystems, as defined in this ClimAID report, encompass the plants, fish, wildlife, and resources of all natural and managed landscapes (e.g., forests, grasslands, aquatic systems) in New York State except those land areas designated as agricultural, coastal, or

urban. This sector includes timber and maple syrup industries and tourism and recreation businesses conducted within natural and managed ecosystems. It also encompasses interior wetlands, waterways, and lakes as well as their associated freshwater fisheries and recreational fishing. Water resources per se are covered in Chapter 4, “Water Resources.” Marine fisheries are covered in Chapter 5, “Coastal Zones,” as are coastal wetlands and marine shoreline ecosystems.

6.1.1 Terrestrial Ecosystems (forests, shrublands, and grasslands)

Sixty-one percent of New York’s land area (18.5 million acres) is covered by forest canopy. This reflects considerable forest regrowth since the late 1800s when forest cover was at a low point (about 25 percent of

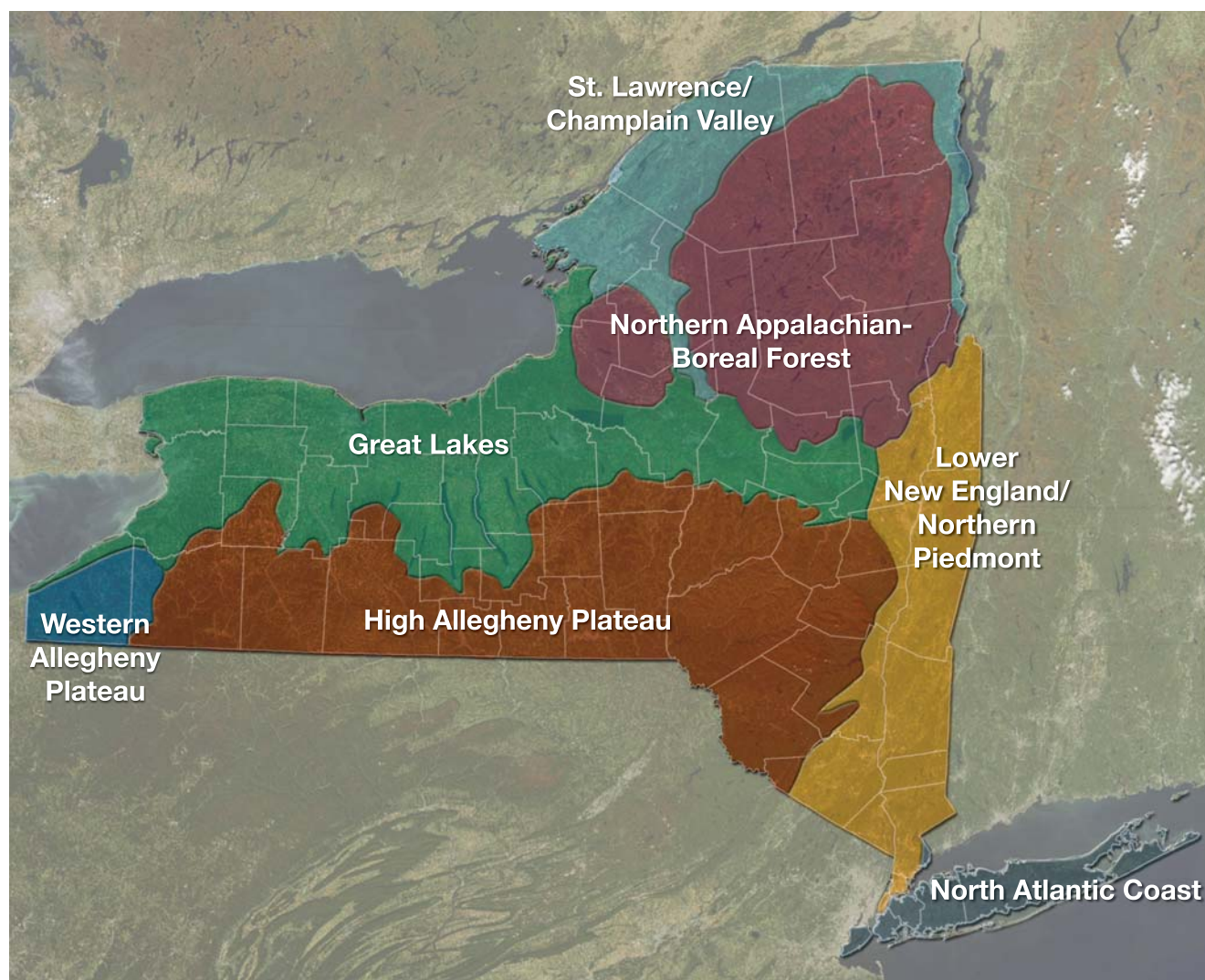
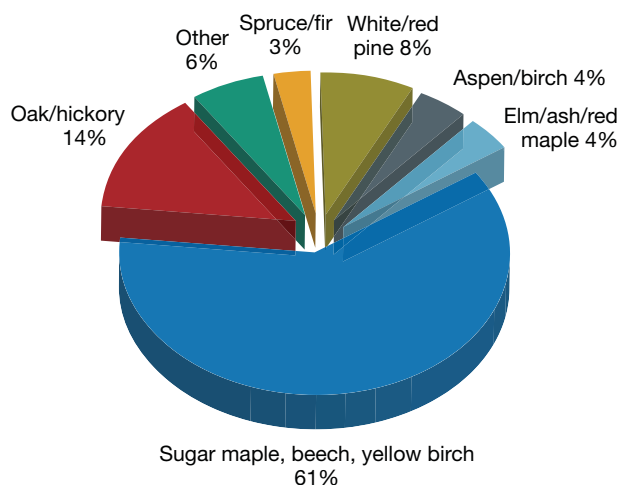


Figure 6.2 New York State Department of Environmental Conservation ecoregions

total land area) due to agricultural expansion during European settlement. Those tree species categorized as northern hardwoods by the U.S. Forest Service form the most common type of forest in New York, occupying 7.4 million acres or 40 percent of total forested area, but many other tree species are important (**Figure 6.3**). The state also is home to many shrub and woodland acres, representing various stages of forest succession on abandoned farmland and recently harvested forestlands.

Among the tree species inhabiting these forests, some have particularly important functional roles. Spruce and fir trees are key components of the unique and cherished high-elevation forests of the Adirondacks, although they occupy just 1 percent of the state's forested land. White pine and hemlock are important evergreen species found throughout the state. Hemlock trees often provide shade to stream banks (which is important for coldwater fish species) and are essential habitat to many species. While hemlock stands have largely recovered from heavy logging during the previous centuries (when they were used in the tanning industry), more recently they are under threat by infestations in some areas by the hemlock wooly adelgid insect pest (Paradis et al., 2008; and see Case Study A: Hemlock).



Note: Oak/hickory forest is defined as containing a mixture of red oak, black oak, scarlet oak, white oak, chestnut oak, pignut hickory, bitternut hickory, shagbark hickory, flowering dogwood, blueberry, mountain laurel, and hawthorn. The other categories are defined as containing high proportions of the two or three species named in the type title. The "Other" category includes oak/pine, exotic softwood, loblolly/shortleaf, pinyon/juniper, and oak/gum/cypress trees. Source: Data for figure were taken from the USDA Forest Inventory and Analysis 2005 webpage <http://fia.fs.fed.us>

Figure 6.3 New York State forest types

New York's terrestrial ecosystems also include meadows, grasslands, and wetlands. The wetlands in particular are home to many vulnerable species. The mountainous high elevations of the Adirondack State Park and the Catskills are the only regions of the state with a cool climate suitable for alpine boreal communities and alpine bogs, containing many specialist species that are limited to habitats within 5°F of current temperatures (Jenkins, 2010). The Adirondacks are home to unique alpine tundra communities with additional specialist species found nowhere else within New York State.

6.1.2 Aquatic Ecosystems

New York's rich assemblage of water resources provides a wide array of habitat types and supports a high diversity of plant and animal species. There are 70,000 miles of streams and rivers and 4,000 lakes and ponds spread over New York's 17 major watersheds (DEC website, www.dec.ny.gov/61.html) and seven ecoregions (**Figure 6.2**). There are more than 2.4 million acres of wetlands widely distributed throughout the state, with 1.2 million acres legally protected and administered by the Department of Environmental Conservation and 0.8 million administered by the Adirondack Park Agency.

Wetlands are distinguished from stream and lake habitats by the presence of emergent vegetation (e.g., cattails, sedges, shrubs, and trees). Wetlands are most extensively developed in the more level topography of the western Lake Plains and in the Adirondacks, which together account for 74 percent of all New York's wetlands. Seventy-five percent of New York's wetlands have a forested cover, but this figure does not reflect the full diversity of the different wetland types, which have distinctive flora and fauna (Edinger et al., 2002) and differing levels of vulnerability to climate change. Wetlands are distinguished by the degree to which they are fed directly by precipitation, runoff, and/or groundwater seeps and by their hydroperiod, the length of time each year that the soils are submerged. Wetlands with short or intermediate hydroperiods, such as forest vernal pools (shallow seasonal pools in woodland depressions where wood frogs and some salamanders breed) and intermittent headwater streams, lack fish and are extremely important for the reproductive success of some amphibians. Small, isolated wetlands are home to a disproportionate number of rare and endangered species.

6.1.3 Fish and Wildlife

New York's diverse ecosystems are habitat for abundant wildlife, including 165 freshwater fish species, 32 amphibians, 39 reptiles, 450 birds, 70 species of mammals, and a variety of insects and other invertebrates. The Comprehensive Wildlife Conservation Strategy is a collaborative effort led by New York State Department of Environmental Conservation's Division of Fish, Wildlife, and Marine Resources. The Comprehensive Wildlife Conservation Strategy lists 537 "Species of Greatest Conservation Need," which includes federally endangered or threatened vertebrate and invertebrate species occurring in New York State, as well as state-listed species of special concern (**Table 6.1**) (for species added by Department of Environmental Conservation staff based on status, distribution, and vulnerability, visit www.dec.ny.gov/animals/9406.html).

In all, 70 mammal species inhabit the state (NYSDEC, 2007). Two mammals—the New England cottontail (*Sylvilagus transitionalis*) and the small-footed bat (*Myotis leibii*)—are state species of concern. In

addition, the Indiana bat (*Myotis sodalis*) is federally endangered.

The breeding bird atlas (McGowan and Corwin, 2008) lists 251 species that breed in the state and 125 additional species that spend the winter or visit occasionally. Several forest and grassland bird species are area-sensitive and depend upon large, unfragmented areas of habitat to breed and successfully raise young (Herkert, 1994). Important migratory and stopover habitats occur for waterfowl, raptors, and songbirds. The Shawangunk Ridge is a well-known raptor migration route. Waterfowl and other birds migrate along the shores of Lakes Ontario and Erie. Similarly, the Montezuma National Wildlife Refuge is significant regionally as a major staging, feeding, and resting area for an estimated 1 million migratory birds.

Information on amphibians and reptiles is found in the New York State "Herp Atlas" (Gibbs et al., 2007). Diverse habitats support 32 amphibian and 33 native reptile species (excluding sea turtles). The amphibians include 18 salamander species and 14 frogs and toads

Table 6.1 Endangered (E), threatened (T) and special concern (SC) fish and wildlife species in New York State (continued on next page)

Common Name	Scientific Name	Federal Status	State Status	Primary Habitat
Amphibians				
Hellbender	<i>Cryptobranchus alleganiensis</i>		SC	Streams and rivers
Marbled salamander	<i>Ambystoma opacum</i>		SC	Forest habitat, seasonal pools
Jefferson salamander	<i>Ambystoma jeffersonianum</i>		SC	Forest habitat, seasonal pools
Blue-spotted salamander	<i>Ambystoma laterale</i>		SC	Forest habitat, seasonal pools
Eastern tiger salamander	<i>Ambystoma tigrinum</i>		E	Pine barrens, seasonal or permanent pools
Long-tailed salamander	<i>Eurycea longicauda</i>		SC	Forest, shale banks, streams, springs
Eastern spadefoot toad	<i>Scaphiopus holbrookii</i>		SC	Sandy soils, seasonal pools
Northern cricket frog	<i>Acris crepitans</i>		E	Shallow ponds, slow-moving water
Southern leopard frog	<i>Lithobates sphenocephala</i>		SC	Freshwater ponds
Eastern mud turtle	<i>Kinosternon subrubrum</i>		E	Fresh or brackish water with vegetation
Spotted turtle	<i>Clemmys guttata</i>		SC	Bogs, swamps, marshy meadow
Bog turtle	<i>Clemmys muhlenbergii</i>	T	E	Open, wet meadow, shallow water
Wood turtle	<i>Clemmys insculpta</i>		SC	Forest, riparian areas
Eastern box turtle	<i>Terrapene carolina</i>		SC	Fields and forest
Blandings turtle	<i>Emydoidea blandingii</i>		T	Shrub swamps, open field
Eastern spiny softshell	<i>Apalone spinifera</i>		SC	Rivers, lakes
Northern fence lizard	<i>Sceloporus undulatus</i>		T	Rocky areas surrounded by forest
Queen snake	<i>Regina septemvittata</i>		E	Streams with rocky bottoms
Eastern hog-nosed snake	<i>Heterodon platirhinos</i>		SC	Barrens, woodlands
Eastern worm snake	<i>Carphophis amoenus</i>		SC	Barrens, woodlands
Eastern massasauga	<i>Sistrurus catenatus</i>		E	Bog, swamps, barrens
Timber rattlesnake	<i>Crotalus horridus</i>		T	Deciduous forest, rocky ledges

Common Name	Scientific Name	Federal Status	State Status	Primary Habitat
Mammals				
New England cottontail	<i>Sylvilagus transitionalis</i>		SC	Shrubland, early successional forest
Small-footed bat	<i>Myotis leibii</i>		SC	Caves, rock crevices, forest
Indiana bat	<i>Myotis sodalis</i>	E		Caves, forest
Allegheny woodrat*	<i>Neotoma magister</i>		E	Rocky outcrops, oak forest
Birds				
Spruce grouse	<i>Falcapennis canadensis</i>		E	High elevation spruce/fir forest
Common loon	<i>Gavia immer</i>		SC	Lakes
Pie-billed grebe	<i>Podilymbus podiceps</i>		T	Ponds, marshes, estuarine wetlands
Manx shearwater	<i>Puffinus puffinus</i>	T		Pelagic, small islands
American bittern	<i>Botaurus lentiginosus</i>		SC	Marsh
Least bittern	<i>Ixobrychus exilis</i>		T	Marsh
Osprey	<i>Pandion haliaetus</i>		SC	Lakes, rivers, marshes
Bald eagle	<i>Haliaeetus leucocephalus</i>	T	T	Lakes, rivers
Northern harrier	<i>Circus cyaneus</i>		T	Grasslands
Sharp-shinned hawk	<i>Accipiter striatus</i>		SC	Forest
Cooper's hawk	<i>Accipiter cooperii</i>		SC	Forest
Northern goshawk	<i>Accipiter gentilis</i>		SC	Extensive mature forest
Red-shouldered hawk	<i>Buteo lineatus</i>		SC	Forest near water
Golden eagle	<i>Aquila chrysaetos</i>		E	Grassland
Peregrine falcon	<i>Falco peregrinus</i>		E	Cliffs, buildings
Black rail	<i>Laterallus jamaicensis</i>		E	Coastal marshes
King rail	<i>Railus elegans</i>		T	Coastal and freshwater marshes
Piping plover	<i>Charadrius melodius</i>	E	E	Beaches
Upland sandpiper	<i>Bartramia longicauda</i>		T	Grasslands
Roseate tern	<i>Sterna dougallii</i>	E	E	Beaches, salt marsh islands
Common tern	<i>Sterna hirundo</i>		T	Beaches, grassy uplands
Least tern	<i>Sterna antillarum</i>		T	Beaches, river sandbars
Black tern	<i>Chlidonias niger</i>		E	Wetlands, lakes, river edges
Black skimmer	<i>Rynchops niger</i>		SC	Coastal
Short-eared owl	<i>Asio flammeus</i>		E	Grasslands
Common nighthawk	<i>Chordeiles minor</i>		SC	Rooftops, open habitats
Whip-poor-will	<i>Caprimulgus vociferus</i>		SC	Open forest
Red-headed woodpecker	<i>Melanerpes erythrocephalus</i>		SC	Open forest, forest edge, beaver meadows with dead standing trees
Loggerhead shrike	<i>Lanius ludovicianus</i>		E	Hedgerows, hayfields, pasture
Horned lark	<i>Eremophila alpestris</i>		SC	Grassland
Sedge wren	<i>Cistothorus platensis</i>		T	Damp meadows and marshes
Bicknell's thrush	<i>Catharus bicknelli</i>		SC	High elevation spruce/fir forest
Golden-winged warbler	<i>Vermivora chrysoptera</i>		SC	Early successional forest
Cerulean warbler	<i>Dendroica cerulea</i>		SC	Large deciduous forests, tall trees
Yellow-breasted chat	<i>Icteria virens</i>		SC	Shrubland
Vesper sparrow	<i>Poocetes gramineus</i>		SC	Grasslands
Grasshopper sparrow	<i>Ammodramus savannarum</i>		SC	Grasslands
Henslow's sparrow	<i>Ammodramus henslowii</i>		T	Grasslands
Seaside sparrow	<i>Ammodramus maritimus</i>		SC	Marsh

*The Allegheny woodrat, classified as Endangered, has not been found in New York State since the mid-1980s and is already considered to be extirpated at this point. <http://www.dec.ny.gov/animals/6975.html>
Source: www.dec.ny.gov/animals/7494.html

(NYSDEC, 2007). Six salamanders and three of the frogs and toads are endangered or of special concern (Table 6.1). The reptiles include four lizards, 17 snakes, 11 species of freshwater or land turtles, and one turtle that inhabits saltwater or brackish water. Seven of the 12 turtles, one of the 4 lizards, and five of the 17

snakes are endangered, threatened, or of special concern at the state and/or federal levels. Amphibians and reptiles exhibit the greatest species richness values (number of species per given area) in the Hudson River Valley, which is globally significant for its high diversity of turtles (www.dnr.cornell.edu/gap/land/land.html).

New York is currently home to approximately 165 freshwater fish species, dominated by north temperate species living in watersheds draining to the Great Lakes and the St. Lawrence River. The coldwater fish range throughout lakes and rivers in the northern United States and Canada. New York also has many freshwater fish species representative of southern fauna found in watersheds that extend southward to the Gulf of Mexico and Middle Atlantic.

6.1.4 Non-climate Stressors

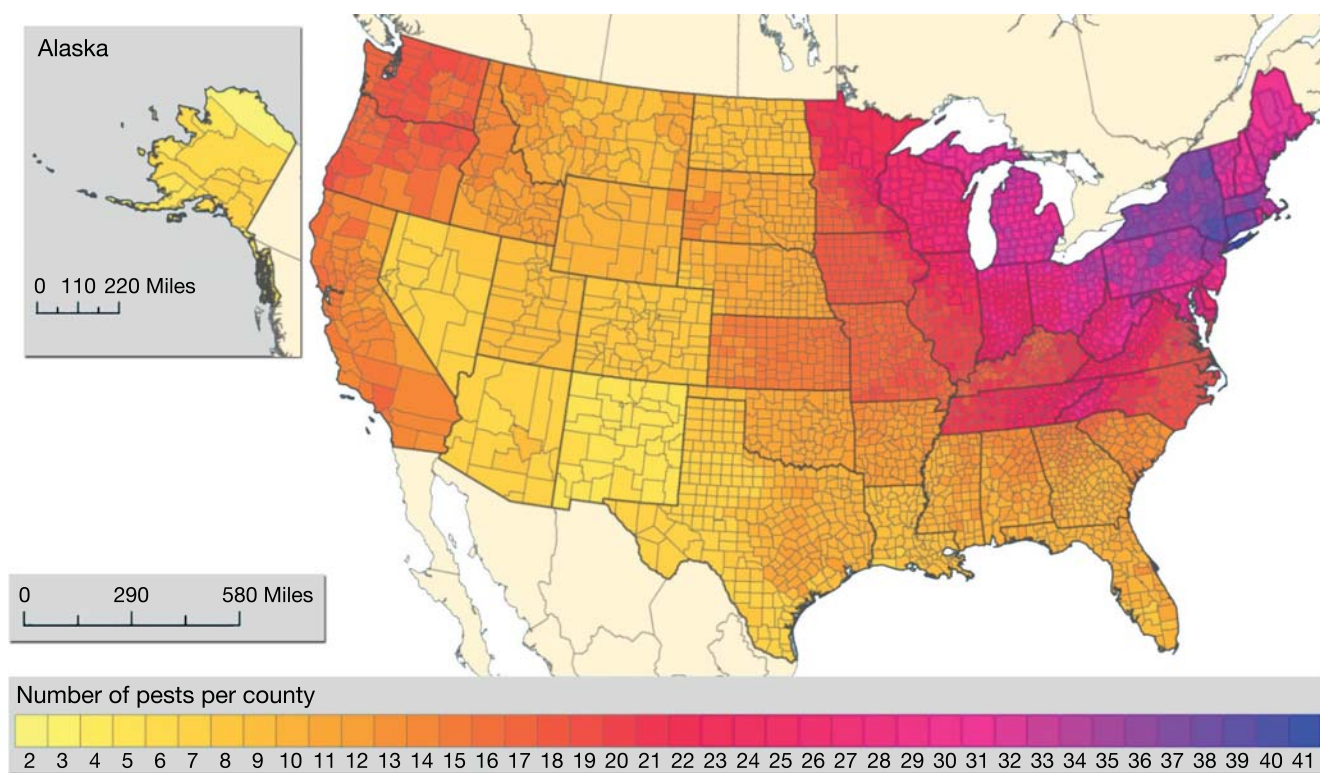
Several factors currently negatively impact natural ecosystems in New York State with various levels of severity. Some of these may be exacerbated by climate change, or may reduce the adaptive capacity of ecosystems or certain species to respond to climate change.

Invasive Species

As a major port of entry, New York State, with its vast natural and agricultural resources, is particularly vulnerable to damage from many invasive species (Table 6.2, Figure 6.4). Increases in global commerce and human travel have led to increasing rates of species

invasion (Mack et al., 2000; Liebhold et al., 2006) that show no sign of slowing down in the years to come (Levine and D'Antonio, 2003; Liebhold et al., 2006; McCullough et al., 2006; Tatem, 2009) and pose serious threats to the integrity of the state's lands and waters. Most recently, the devastating emerald ash borer (*Agrilus planipennis* Fairmaire), an invasive forest pest from Asia, was detected in Cattaraugus County in western New York in June 2009 (NYSDEC, 2009), and the invasive aphid-like insect pest, hemlock wooly adelgid (*Adelges tsugae*), has been observed in some hemlock stands of the state.

Invasive species have altered and continue to alter the ecological structure and function of New York's ecosystems. Invasive understory shrubs and plants, like Amur honeysuckle (*Lonicera maackii* (Rupr.) Herder) and pale swallow-wort (*Vincetoxicum rossicum* (Kleopow) Barbar.), commonly crowd out or smother native vegetation, impeding forest regeneration (Gorchov and Trisel, 2003) and reducing understory plant diversity (DiTommaso et al., 2005). Invasive pests and pathogens, including gypsy moth (*Lymantria dispar*) and beech bark disease, can intensely impact the productivity, nutrient cycling, and food-web structure of the forests (Lovett et al., 2006).



Source: Alien Forest Pest Explorer, USDA Forest Service

Figure 6.4 Number of invasive forest pest and pathogen species established per county throughout the United States

Table 6.2 Invasive species of management concern across New York ecosystems and the predicted direct impacts of climate change on those species based on current scientific information

Species	Habit	Origin (date introduced or detected)	Habitat	Impact	Management Options	Possible Direct Impacts of Climate Change on Species
Plants						
Common reed <i>Phragmites australis</i> (Haplotype M)	Perennial clonal grass	Europe (late 1800s)	Freshwater & brackish tidal wetlands	↓ native biodiversity & habitat; alters nutrient cycling & hydrology	M, C, B*	↑ CO ₂ may stimulate growth (Farnsworth & Meyerson 2003; Meyerson et al., 2009); sea level rise may aid restoration of <i>Phragmites</i> -invaded coastal wetlands (Hellmann et al., 2008)
Eurasian watermilfoil <i>Myriophyllum spicatum</i> L.	Submerged aquatic perennial herb	Europe (~1900)	Freshwater ponds, lakes, & pools	Displaces native vegetation; negative impacts on macroinvertebrate & fish communities; impedes recreation	M, C, B	Higher water temperatures may ↑ growing season & require control actions to be implemented earlier & longer (Rahel & Olden, 2008)
Giant hogweed <i>Heracleum mantegazzianum</i> Sommier & Levier	Biennial or perennial herb	Caucasus Mtns, between Black & Caspian Seas (1917)	Wet areas (e.g., stream & river banks, along RRs & roads)	Displaces native vegetation; toxic sap causes severe photodermatitis and burns	M, C	Requires low winter temperatures for seeds to germinate in the spring (Pyšek et al., 1998)
Japanese knotweed <i>Polygonum cuspidatum</i> Siebold & Zucc.	Perennial herbaceous shrub	Japan (late 1800s)	Riparian areas, ditches & disturbed areas	Spreads rapidly, forming dense thickets that crowd and shade out native vegetation; adversely affects species diversity and wildlife habitat	M, C, B*	Milder winters may result in increased seedling survival (Forman and Kesseli, 2003)
Mile-a-minute <i>Persicaria perfoliata</i> (L.) H. Gross	Annual herbaceous vine	India, East Asia, Japan to Philippines (1930s)	Open & disturbed areas	Crowds out native species	M, C, B, G	No information available
Swallow-wort Black: <i>Cynanchum louiseae</i> Pale: <i>Cynanchum rossicum</i>	Perennial herbaceous vine	Europe (mid-1800s)	Upland areas, including old fields & woodland ground layers	Crowds out native vegetation & adversely affects native wildlife, including grassland birds and monarch butterflies	M, C, B*	No information available
Water chestnut <i>Trapa natans</i> L.	Annual aquatic herb	Western Europe, Africa to Asia (late 1870s)	Ponds, shallow lakes & river margins	Displaces native vegetation; impedes recreation; reduces dissolved oxygen	M, C, B*	No information available
Invertebrates						
Asian long-horned beetle <i>Anoplophora glabripennis</i>	Generalist wood-boring beetle	China & Korea (1996)	Urban & natural forests	Attacks and kills hardwood trees including: maples (<i>Acer</i> spp.), horsechestnut (<i>Aesculus hippocastanum</i>), willows (<i>Salix</i> spp.), American elm (<i>Ulmus americana</i>) birches (<i>Betula</i> spp.) and poplars (<i>Populus</i> spp.)	Tree removal, C (limited), B*	No information available
Emerald ash borer <i>Agilus planipennis</i> Fairmaire	Specialist metallic wood-boring beetle	Eastern Russia & Asia, including Japan & Taiwan (2002)	Urban & natural forests	Attacks and kills all North American ash (<i>Fraxinus</i> spp.) trees	Tree removal, C (limited), B*	No information available
Hemlock woolly adelgid <i>Adelges tsugae</i>	Aphid-like insect	Southern Japan (1951, eastern United States)	Deep-shade riparian forests	Attacks and kills eastern hemlock trees (<i>Tsuga canadensis</i>)	C, B	↑ temperatures may release hemlock woolly adelgid from overwintering constraints and promote range expansion (Paradis et al., 2008)
Zebra mussel <i>Dreissena polymorpha</i> Pallas	Bi-valve mollusks	Black, Caspian & Aral Seas; Ural drainage in Eurasia (1988)	Zebra: hard substrates along lakeshores & river bottoms; Quagga: deeper waters & softer substrates	Excess removal of plankton & detritus from water column, resulting in changes to food web, lake productivity & water clarity; displacement of native mussel communities; colonization & obstruction of water pipelines and canals; ship hull fouling	M, C, B*	Increased water temperatures may ↑ growing season & require control actions to be implemented earlier & longer (Rahel & Olden, 2008)
Quagga mussel <i>Dreissena rostriformis bugensis</i>						

Below ground, invasive earthworms from Europe and Asia alter soil structure and nutrient retention, with cascading impacts on the soil food web and native plant

communities that can be detrimental (Bohlen et al., 2004). Invasive plants, such as purple loosestrife (*Lythrum salicaria*) and common reed (*Phragmites australis*), have

Species	Habit	Origin (date introduced or detected)	Habitat	Impact	Management Options	Possible Direct Impacts of Climate Change on Species
Vertebrates						
Feral swine <i>Sus scrofa</i>	Mammals	Eurasia (1500s)	Rural & natural areas	Damage to croplands & sensitive natural areas including riverbanks & springs; degrades wildlife habitat; competition with & predation of native species; can transmit diseases to domestic swine, including pseudorabies & swine brucellosis	Trapping & shooting	No information available
Northern snakehead fish <i>Channa argus</i>	Air-breathing freshwater fish	China, Russia & Korea (2002)	Shallow ponds, swamps & slow streams	Voracious predator; competes with native species for food & habitat	C	No information available
Pathogens						
Beech bark disease	A complex syndrome involving attack by beech scale (<i>Cryptococcus fagisuga</i> Lind.) followed by invasion of <i>Nectria</i> fungi	Europe (1890)	Deciduous forests	Decline and death of American beech, <i>Fagus grandifolia</i> (Ehrh.)	Tree removal, C (at local scales)	Fungal cankering may be worse after mild winters, favoring survival & spread of the scale insect and infection (Harvell et al., 2002)
Viral hemorrhagic septicemia	Aquatic rhabdovirus	Eastern & Western Pacific coasts; Atlantic Coast of North America	Freshwater & saltwater	Infects at least 50 freshwater & saltwater fish species, including commercially & recreationally important brook trout, Chinook salmon, lake trout, rainbow trout, walleye, smallmouth bass, northern pike, yellow perch & muskellunge	None but regulations to prevent spread (e.g., prohibiting transport of live fish, restricting use of baitfish)	VHS virus is less active in warmer water (higher than 59°F) (Meyers & Winton, 1995)

Note: While this is not an exhaustive list, it provides a selection of species of concern that are the focus of management efforts statewide. Abbreviations for management options are: M, mechanical; C, chemical; B, biological control; B*, biological control in development; G, grazers. See <http://nyis.info> for additional information.

replaced diverse wetland plant communities with monocultures, leading to cascading consequences on wetland food webs and biogeochemical cycles. Over the last century, invasive aquatic plants like Eurasian water milfoil (*Myriophyllum spicatum* L.) and water chestnut (*Trapa natans* L.) have spread extensively throughout New York's lake and river systems (Boylen et al., 2006), displacing native vegetation (Boylen et al., 1999), negatively impacting fish and invertebrate communities (Keast, 1984), and impeding recreational activities like swimming, boating, and fishing (U.S. Congress, 1993). The filter-feeding zebra and quagga mussel species (*Dreissena polymorpha* and *Dreissena rostriformis bugensis*), introduced to the Great Lakes from the Pontic-Caspian region via ballast water, have transformed the food webs in Lakes Erie and Ontario from largely pelagic systems (where fish and other organisms thrive throughout the water column) to benthic systems (where fish and other organisms are all concentrated near the lake bottom).

The economic impacts of invasive species are equally as profound as the ecological impacts, with a cost to the United States by one estimate of \$120 billion per year in damage and control expenditures (Pimentel et al., 2005). The economic impact of a single species, the emerald ash borer (*Agrilus planipennis* Fairmaire), which

is now established in 13 states including New York, is projected to amount to \$10.7 billion from urban tree mortality alone over the next 10 years (Kovacs et al., 2009). Specifically in New York State, invasive species pose serious economic threats to agriculture, forestry, maple sugar production, and recreation.

Increasing Deer Populations

High deer populations in many areas of New York State cause concern for resource managers, farmers, and homeowners. In addition to damage caused to residential landscape plants and agricultural crops, selective feeding of white-tailed deer alters plant community structure and can negatively affect the health and diversity of forests and other natural areas. Through their direct effects on plants, deer have cascading effects on many other wildlife species.

Many of the preferred forage species of deer, such as sugar maple and oaks, are valued for timber or as food-producing trees for wildlife. Deer also feed on wildflowers like trillium and lady slipper, but they tend to avoid ferns, invasive species like garlic mustard and barberry, and native tree species such as American

beech and striped maple. Selective feeding of deer has led to dominance of ferns and grasses (Horsley and Marquis, 1983), along with invasive species and monocultures of beech in some New York forests (Stromayer and Warren, 1997). Over-browsing by deer leads to loss of forest understory vegetation that is an important habitat and food source for many songbirds and other forest wildlife.

Land Use Change, Land Ownership, and Habitat Fragmentation

Management of New York's "natural" ecosystems ranges from minimal to intensive depending on land use and ownership. While public lands are important habitats for abundant birds, wildlife, and fish, private land owners and nonprofit organizations control the vast majority of non-agricultural land. For example, 90.2 percent of the 15.8 million acres available for timber production is privately owned (NEFA, 2007). Less than 10 percent of terrestrial vertebrates in New York State are on public lands. This has important implications for developing adaptive management strategies for coping with climate change or other environmental changes. In addition, land in New York supporting natural plant and animal communities is becoming increasingly urbanized and suburbanized, altering its ability to support these communities and the water and other resources supplied by these lands to neighboring habitats.

Urbanization and other forms of human land-use change threaten some habitats and lead to fragmentation—the breaking up of large, connected terrestrial or aquatic habitats. Habitat fragmentation constrains plant and animal dispersal patterns across habitats, alters plant and wildlife community composition, and increases vulnerability to pathogens, insect pests, and invasive species. It can also reduce nesting habitat for forest interior birds and area-sensitive grassland bird species, and increase rates of predation and parasitism on nesting songbirds.

Acid Rain, Nitrogen Deposition, and Ozone

Acid rain is produced when nitrogen and sulfur compounds, emitted primarily from power plants and automobiles, react with water in the atmosphere and are deposited as acidic precipitation and dry deposition. The

Adirondacks, Catskills, Hudson Highlands, Rensselaer Plateau, and parts of Long Island are particularly sensitive to acid deposition because they lack the capacity in the soil to neutralize the acid (Adams et al., 2000). Acidic compounds damage leaf tissue, leach vital nutrients from the soil (Rustad et al., 1996; Fernandez et al., 2003), and mobilize toxic aluminum that damages roots and impairs decomposition in forests (USEPA, 2010). Acid rain also negatively affects some fish and other aquatic species and can increase the sensitivity of both aquatic and terrestrial species to other stresses, such as high temperatures. Extended periods of nitrogen deposition can lead to saturation and consequent leaching of nitrogen from soils with negative effects on water quality (Stoddard, 1994). While environmental regulations have reduced emissions of contributing air pollutants in recent years and enabled substantial recovery of many forest and aquatic systems (NYSERDA, 2009), acid rain remains an important stressor in some parts of the state.

Excess quantities of nitrogen deposition also can disrupt ecosystems by fertilizing the growth of a few plant species to the detriment of others (Howarth et al., 2006; Aber et al., 2003). The most common examples of this are stream and lake eutrophication, where algal and other populations grow rapidly to the detriment of many others. Ozone is also a product of high nitrogen emissions reacting in the atmosphere. High levels of ozone impede the growth of key plant species, disrupting the normal competitive relationships among species (Krupa, 2001).

6.1.5 Economic Value and Ecosystem Services

Linking ecosystem goods and services to ecosystem structure and function and identifying the best approach for placing a value on those goods and services is a major challenge of this century. **Figure 6.1** describes a conceptual framework for placing ecosystem services, values, and functions into context with adaptation to climate change and multiple stressors.

Valuation Challenges

The economic value of some ecosystems goods and services is relatively straightforward, such as recreational value and value of commodities including timber and

maple syrup (see more details, below). However, many services fall under the category of ecological functions, which have indirect value, such as carbon sequestration, water storage and water quality maintenance, flood control, soil erosion prevention, nutrient cycling and storage, species habitat and biodiversity, and dispersal/migration corridors for birds and other wildlife. These functions clearly have value, but quantifying them is much more complex. Even more difficult to quantify are the existence or non-use values associated with concepts such as preservation of cultural heritage, resources for future generations, charismatic species, and wild places.

The National Research Council recently commissioned a review of ecosystem value by experts in the field (NRC, 2005). It lays out the challenges of valuation in the context of uncertainty. It also describes various approaches such as nonmarket valuation, revealed- and stated-preference methods, and the use of production functions. The review also discusses how the results of valuation analysis can be linked to policy. More recently, new modeling tools are being developed that use ecological production functions and valuation methods to examine the impact of projected changes in land use and land cover on ecosystem services, conservation, and the market value of commodities produced by the landscape (Daily et al., 2009; Nelson et al., 2009). A recent study conducted in New Jersey used several approaches and concluded ecosystem services within the state had a value of \$11.6–19.4 billion per year (Costanza et al., 2006).

Recreation and Tourism

Hunting, fishing, and wildlife viewing have a significant impact on the economies of New York State. More than 4.6 million state residents and nonresidents fish, hunt, or watch wildlife in the state (USFWS, 2006), spending \$3.5 billion annually on items such as equipment, trip-related expenditures, licenses, contributions, land ownership, and leasing and other items. The 2007 New York State Freshwater Angler Survey (www.dec.ny.gov/outdoor/56020.html) indicated that there were more than 7 million visitor-days fishing for warmwater game fish (predominantly smallmouth and largemouth bass, walleye, and yellow perch) and nearly 6 million days spent in pursuit of coldwater game fish (predominantly brook, brown, and rainbow trout). About 20 percent of the freshwater angling effort was directed toward Great Lakes fisheries, with the remainder directed toward inland fisheries.

Winter recreation is another major component of the economic value of the state's natural ecosystems. New York has more ski areas than any other state in the nation. Lake Placid in the Adirondacks is known internationally as a former winter Olympics site. Combined, the state's ski areas host an average of 4 million visitors each year, contributing \$1 billion to the state's economy and employing 10,000 people (Scott et al., 2008). New York is also part of a six-state network of snowmobile trails that totals 40,500 miles and contributes \$3 billion each year to the Northeast regional economy.

The local economies of the Adirondacks, Catskills, Finger Lakes, coastal, and other recreation areas are dominated by tourism and recreation. The Northeast State Foresters Association, using U.S. Forest Service statistics for 2005, found that forest-based recreation and tourism provided employment for ~57,000 people and generated a payroll of \$300 million in the region (NEFA, 2007).

Timber and Forest-based Manufacturing

In 2005, the estimated value of timber harvested in the state exceeded \$300 million (NEFA, 2007). The manufactured conversion of these raw timber components into wood products such as commercial-grade lumber, paper, and finished wood products adds considerably to the value of this industry to the state. The total forest-based manufacturing value of shipments in 2005 was \$6.9 billion (NEFA, 2007). Each 1,000 acres of forestland in New York supports three forest-based manufacturing, forestry, and logging jobs. This industry is particularly important to the regional economies of areas like the Adirondacks, where wood- and paper-product companies employ about 10,000 local residents (Jenkins, 2010).

Maple Syrup Industry

Sugar and red maple are New York's most abundant forest tree species and, historically, the state's climate has been conducive to profitable maple syrup production. It is estimated that less than 1 percent of New York's maple trees are currently used for maple syrup production (compared to about 2 percent in Vermont) (personal communication, Michael Farrell, Director, Uihlein Forest). In 2007, New York produced 224,000 gallons of syrup (making New York second in

the United States, after Vermont) at a value of \$7.5 million (New York State Agriculture Statistics Service, www.nass.usda.gov/ny).

6.2 Climate Hazards

Several climate change factors that are particularly relevant to New York's ecosystems are highlighted and briefly introduced below. These factors are discussed in more detail in section 6.3 and in the case study analyses. See Chapter 1, "Climate Risks," for further information about climate change factors.

6.2.1 Temperature

Increased temperatures will have numerous effects on both plants and animals. Some effects are very direct, like the physiological tolerances of different organisms to specific temperature ranges. Some are indirect, such as increased water requirements at higher temperatures or changes in habitats due to less snow and ice cover.

Warmer Summer Temperatures and Longer Growing Seasons

Warmer summer temperatures and longer growing seasons will affect plant and animal species non-uniformly, and thus will affect species composition and interactions. Primary productivity of some ecosystems could potentially increase if other environmental factors do not limit plant growth. Changes in ecosystem processes are expected, such as the timing and magnitude of the depletion of soil water and nutrients by vegetation. Some insect pests and insect disease vectors will benefit in multiple ways, such as more generations per season and increased over-winter survival, and weaker resistance of stressed host plants (Rodenhouse et al., 2009).

In aquatic systems, warmer waters and a longer summer season could increase vegetative productivity, but also increase the risk of algal blooms and other forms of eutrophication, leading to low dissolved oxygen (Poff et al., 2002) and negative effects on fish and other aquatic species. Many aquatic organisms mature more quickly but reach smaller adult sizes at higher temperatures. Rising temperatures are likely to be particularly harmful to coldwater fish, including brook and lake trout, while favoring warmwater species, such as large-mouth bass.

Increased Frequency of Summer Heat Stress

Increased frequency of summer heat stress will negatively affect many plant and animal species, constraining their habitable range and influencing species interactions. Temperature increases will drive many changes in species composition and ecosystem structure, most notably leading to eventual complete loss or severe degradation of high-elevation spruce and fir, and alpine bog and tundra habitats.

Warmer Winters

Warmer winters will have substantial effects on species composition, as the reproductive success and habitable ranges of many plant, animal, and insect species currently south of New York are now constrained by winter temperatures. Warmer winters will also increase the winter survival and spring populations of some insect, weed, and disease pests that today only marginally overwinter in the New York region. If climate change leads to more variable winter temperatures, perennial plants may be negatively affected. Variable winter temperatures may make them more vulnerable to mid-winter freeze damage (due to de-hardening) or spring frost (due to premature leaf out and bud break). Variable winters could also have negative effects on hibernating animal species, including some threatened and endangered species.

6.2.2 Precipitation

Changes in precipitation can include changes in total annual precipitation, its seasonal distribution, how much of it comes as rain versus snow, and the intensity of individual storms.

Reduced Snow Cover

Reduced snow cover will have numerous cascading effects on species and habitats. Winter survival of many small mammals (e.g., voles) that depend on snow for insulation and protective habitat will be at risk. This could protect some trees and other vegetation from winter damage by these mammals, but it will have negative implications for predators that depend on them as a winter food source (e.g., fox). In contrast, reduced snow cover will favor herbivores such as deer

by exposing more winter vegetation for browsing, to the detriment of those plant species preferred by the herbivores. Less snow-cover insulation in winter will affect soil temperatures, with complex effects on soil microbial activity, nutrient retention (Rich, 2008; Groffman et al., 2001), and winter survival of some insects, weed seeds, and pathogens (see section 6.3.4 on pests).

Changes in Rainfall, Evapotranspiration, and Hydrology

Changes in rainfall, evapotranspiration, and hydrology are described in detail in Chapter 1 (“Climate Risks”) and Chapter 4 (“Water Resources”) and in Case Study C: Drought in Chapter 7 (“Agriculture”). Increased frequency of high rainfall events and associated short-term flooding is currently an issue and is projected to continue. This leads to increased runoff from agricultural and urban landscapes into waterways, which can lead to pollution or eutrophication effects, erosion and damage to riparian zones, flood damage to plants, and disturbance to aquatic ecosystems. Summer water deficits are projected to become more common by mid- to late-century, and the impacts on ecosystems could include reduced primary productivity (vegetation growth), and reduced food and water availability for terrestrial animals. Summer water deficits could lead to a reduction of total wetland area, reduced hydroperiods of shallow wetlands, conversion of some headwater streams from constant to seasonal flow, reduced summer flow rates in larger rivers and streams, and a drop in the level of many lakes. Late winter and spring will continue to be the seasonal period of peak groundwater recharge and stream flow rates, but the total snowpack accumulation will be lower, so stream and river flows directly associated with spring thaw are likely to decrease. If spring rainfall increases, however, this could compensate for low snowpack. Thus, it is uncertain whether spring flood events will be more or less common than they are today.

6.2.3 Other Climate Factors

The lack of robust projections for some climate factors makes assessment of some vulnerabilities and planning adaptive management for them difficult. (See Chapter 1, “Climate Risks,” for further discussion.) Factors of particular concern are discussed here.

Climate Variability and Frequency of Extreme Events

Most climate scenarios assume no change in climate variability per se, but there is not a high degree of certainty that this will be the case. Changes in winter temperature variability could have profound effects on hibernating animals and on the risk of cold damage to plants. The frequency of crossing environmental thresholds (e.g., freezing temperatures) and storms and extreme events can cause a cascade of effects leading to disruption of entire communities and ecosystem function (Fagre et al., 2009), particularly if they occur in clusters. We currently are not able to determine whether such events are part of a long-term climate change trend, and climate models cannot yet project these trends reliably.

Changes in Cloud Cover

Current climate models cannot reliably project changes in cloud cover, yet such changes can have profound effects on the surface radiation balance (the net balance of solar radiation and exchanges of thermal radiation between the Earth’s surface and the sky), which influences vegetation water use and total photosynthetic production.

Higher Atmospheric Carbon Dioxide Levels

Higher atmospheric carbon dioxide levels can potentially increase growth of many plants, particularly those with the C_3 photosynthetic pathway growing under optimum conditions. The magnitude of the carbon dioxide effect varies widely among species and, even without climate change, could alter species composition in some ecosystems by favoring some species over others. Many fast-growing species, including many invasive plants and aggressive weed species, tend to show greater growth stimulation than slow-growing species and can gain a competitive advantage at high carbon dioxide concentrations (Ziska, 2003). An analysis by Mohan et al. (2007) suggested that in the understory of temperate forest ecosystems some late successional, shade-tolerant species benefit more than shade-intolerant species. In general, when plant growth is constrained by nutrients, high or low temperature stress, or environmental factors, the absolute magnitude of the carbon dioxide benefit is reduced or not apparent (Wolfe, 1995).

6.3 Vulnerabilities and Opportunities

The initial impacts of climate change on species are already apparent, with documented accounts of changes in phenology (i.e., seasonal timing of events like bud-break or flowering) and species range shifts across the Northern Hemisphere (Backlund et al., 2008; Parmesan and Yohe, 2003; Parmesan, 2007). Within the northeastern United States, researchers have documented earlier bloom dates of woody perennials (Wolfe et al., 2005; Primack et al., 2004), earlier spring arrival of migratory birds (Butler, 2003), and other biological and ecological responses discussed in more detail below. Species and ecosystems are responding directly to climate drivers and indirectly to secondary effects, such as changes in timing and abundance of food supply, changes in habitat, and increased pest, disease, and invasive species pressure. Ultimately, biodiversity, net primary productivity, vegetation water use, and biogeochemical cycles could be affected by climate change. To date, however, there is not unequivocal evidence of climate change impacts on ecosystem services such as carbon sequestration or water storage and quality in New York State. The certainty in projecting climate change impacts diminishes as projections are scaled up from individual species and ecosystem structure to ecosystem function and services.

6.3.1 Criteria for Determining Vulnerability of Species, Communities, and Ecosystems

Criteria for determining vulnerability of species, communities, and ecosystems to climate change have been discussed by a number of studies (e.g., Bernardo et al., 2007; Foden et al., 2008; Pörtner and Farrell, 2008; Kellerman et al., 2009). The vulnerability criteria encompassed in the ClimAID analysis include:

- location currently near the southern border of habitable range;
- low tolerance for environmental change or stress;
- specialized habitat requirements;
- specialized food requirements;
- specialized interactions with other species that will be disrupted by climate change;
- poor competitor with species infringing on range;
- susceptibility to new pests or disease infringing on range;

- poor dispersal ability;
- limited genetic diversity; and
- low population levels or current status as an endangered species or species of concern.

Species and Communities Identified as Highly Vulnerable

Species and communities identified as highly vulnerable to climate change projected for New York, as defined by the metrics above, include:

- boreal and spruce- and fir-dominated forests;
- high-elevation alpine tundra communities of the Adirondacks;
- brook trout, Atlantic salmon, and other coldwater fish;
- snow-dependent species such as the snowshoe hare;
- moose;
- some bird species, such as Bicknell's thrush, Baltimore oriole, and rose-breasted grosbeak; and
- amphibians and other wetland species.

Species Likely to Benefit

Species likely to benefit include habitat and food generalists that are currently constrained by cold temperatures, as well as some invasive species. Examples include:

- white-tailed deer;
- warmwater fish species such as bass;
- some bird species such as northern cardinal, robin, and song sparrow;
- invasive insect pests such as the hemlock wooly adelgid; and
- invasive plant species such as kudzu.

See below for a more detailed discussion of each of these.

6.3.2 Forest, Grassland, and Alpine Communities

The distribution of most vegetation types is strongly influenced by the interactions of climatic variation with elevation, latitude, lake effects, topography, etc. Climate

change is therefore expected to cause substantial changes in habitable range and plant community structure throughout the state.

Northern Hardwood Forests

Climate change is not expected to cause a net loss of forested land in New York, but slow change in forest composition over this century is expected as the state's forests disassemble and reassemble into new forest types that have combinations of species different than those today (Rock and Spencer, 2001; Iverson and Prasad, 2002; Iverson et al., 2008; Mohan et al., 2009). The extent to which each species can persist or shift its range into more suitable locations will depend on a combination of factors, including competition from other species, rates and distance of seed dispersal, habitat fragmentation affecting seed supply and dispersal, suitability of soils, soil microbial populations (beneficial or pathogenic), tolerance to stress caused by drought or warmer temperatures, and changes in disturbance frequency and duration. Survival and migration (dispersal) may also be restricted or increased by invasive plants and pests, air pollution, overgrazing by deer, forest fire suppression, and urban sprawl or other land-use change.

Some climate change factors have the potential to increase tree growth. A recent analysis of hardwood forests in Maryland found that growth rates have increased in the past 20 years (McMahon et al., 2010). Rising atmospheric carbon dioxide levels can increase photosynthesis and/or permit more efficient water use during photosynthesis. Whether or not this translates into increased growth depends on availability of soil nutrients, other stressors affecting plant growth, and a plant's genetic capacity to increase growth with increased supply of sugars produced by photosynthesis (Wolfe, 1995; Mohan et al., 2009). A recent study determined that atmospheric nitrogen deposition has important effects on the ability of northern forest tree species to use carbon dioxide (Thomas et al., 2010). Species differ in their responses to carbon dioxide and nitrogen, with the type of mycorrhizal association (symbiosis between roots and certain species of fungi) seeming to affect the response. Studies such as these illustrate the complexity of potential responses to climate change. A recent modeling study for northeastern forests suggested an increase in forest productivity in regions dominated by deciduous

hardwoods through the first half of the century, assuming a substantial beneficial effect of the increased atmospheric carbon dioxide and longer growing seasons projected under a lower-emissions climate change scenario (Ollinger et al., 2008). The same was not true for regions dominated by spruce-fir forests, because projected temperature increases significantly constrained their growth and response to increased carbon dioxide.

One study of the likely abundance of tree species across the Northeast indicated that oak forests will have the climatic opportunity to dominate many areas of New York presently occupied by maple and other valuable hardwood species, including black cherry, yellow birch, paper birch, quaking aspen, bigtooth aspen, American beech, and white ash (Iverson et al., 2008). The study's models, which are based on species environmental preferences and a range of future climate scenarios (**Table 6.3**), assumes that as the climate envelope in which species currently exist moves northward, so will the species.

Interactions between species will affect the northward advance of some species as climate changes. For example, while the climate may become more suitable for oak, at the seedling stage they are a favored food for deer, whose populations are also likely to increase with a warming climate. Elevated deer browsing pressure has already been observed to be retarding oak seedling establishment in some areas of New York (Todd Forrest, New York Botanical Garden, personal communication).

For many species the pace of climate change could exceed the pace at which they can disperse and shift to new locations to stay within their optimum climate zone. The pace of climate change projected over the next 100 years (e.g., a 6- to 13°F temperature increase) is an order of magnitude or more faster than the pace of change during recent ice age transitions that occurred over 10,000 to 30,000 years. To remain in the same climate zone throughout the projected change for this century, trees would have to shift their ranges by more than 9,800 to 16,400 feet per year (Petit et al., 2008)—a pace much faster than those documented in the paleobiological record (up to 1,650 feet per year) in response to the relatively slow changes in climate that occurred over the past 10,000 years (Clark et al., 2003). Such complexities could lead to a transition period in this century marked by degraded forests and increased opportunities for invasive species and non-timber species to become established.

Climate change may alter the coordination of timing between tree reproductive events, such as flowering and pollen production, and the availability of pollinators (Mohan, 2009). Further, if extreme storms were to increase in frequency this would have large effects on the activity of pollinators and seed dispersers. These effects are even more likely in the northern part of species' ranges where migratory/dispersal pathways will be most needed (Mehlman, 1997). Reductions in snowpack could also have a marked effect on overwintering pollinators and seed dispersers (Inouye and McGurie, 1991).

A longer growing season and warmer temperatures are likely to increase water use by vegetation and lead to mid- to late-season soil water deficits by mid- to late-century (Hayhoe et al., 2007; also see Case Study C: Drought in Chapter 7, "Agriculture"). In addition, changes in tree species composition of New York's forests will alter biogeochemical cycling through their effects on forest productivity, water and nutrient use, and other factors (Campbell et al., 2009). Direct climate effects and indirect tree species effects on soil biological processes such as decomposition, mineralization, and nitrification (conversion of soil ammonia to nitrite and then to nitrate) are likely to lead to increases in nitrate leaching out of the forests into streams and rivers. Changes in the services that forested ecosystems provide, such as their ability to regulate water resources and retain nitrogen in the soil, could be profound impacts of climate change, although the level of certainty about the timing and magnitude of such effects remains low.

Spruce-fir, Boreal, and Alpine Plant Communities

Among the most vulnerable of New York's ecosystems are the cool-climate boreal communities and red spruce/balsam fir forests of the Adirondacks (Jenkins, 2010) and the Catskills. A recent study projected that balsam fir will lose from 40 to 70 percent of its suitable habitat across New York by the end of this century; red spruce is projected to lose 55 to 64 percent of its suitable habitat (Table 6.3; Iverson et al., 2008). Another study indicated that 67 percent of the current Adirondack boreal species are not likely to survive more than a 5°F rise in temperature, based on environments where they are found today (Jenkins, 2010). It also found that of the 246 common Adirondack forest species, only 34 percent are found at temperatures more than 10°F warmer than those in the Adirondacks today (Jenkins, 2010).

The cold-adapted, high-elevation trees and other perennials in New York will be particularly vulnerable to month-to-month variations in winter temperatures, which can cause mid-winter de-hardening or late-winter premature leaf-out, an effect that can increase their susceptibility to cold damage. Winter temperature fluctuations in the eastern United States in 2007 led to increased freeze damage in many woody perennials (Gu et al., 2008). Although this has not yet become a widespread problem and there is not a high degree of certainty that climate change will increase winter temperature variability, freeze damage may occur more frequently if such temperature fluctuations do increase with climate change. Acid rain exposure can also reduce cold hardiness of red spruce trees (Schaberg and DeHayes, 2000).

Black spruce/tamarack swamps, high-elevation open river shores, and peatlands common in the Adirondacks are rare in more southern locations. Ice meadows are a high-northern habitat that are rare in the Adirondacks and are unknown elsewhere at latitudes similar to that of New York. All of these habitats support animal populations that are highly dependent on specific

Species Most Likely to Decrease	Percent (%)
Quaking aspen	-92.3
Black ash	-80.5
Balsam fir	-68.9
American beech	-68.9
Yellow birch	-66.3
Black cherry	-63.4
Sugar maple	-62.9
Red spruce	-61.6
White ash	-57.9
Eastern white pine	-53.2
Species Most Likely to Increase	Percent (%)
Eastern red cedar	930.0
Flowering dogwood	759.7
Black walnut	466.2
Black oak	405.6
Sassafras	380.2
Yellow poplar	328.2
White oak	240.9
Chestnut oak	134.5
Post oak	134.5
American elm	59.3

Note: Percentages are based on changes in each species' area-weighted importance value for a high carbon dioxide emission scenario. Area weighted importance values are an index that includes both geographic area and the relative abundance of a species in different areas.

Source: Iverson and Prasad 2002

Table 6.3 Important tree species in New York predicted to show the most dramatic decreases or increases in habitable area with climate change by the end of the century

environments and are not likely to be capable of supporting themselves if these climate-maintained habitats disappear.

Vegetation changes are expected to be large in the alpine tundra found at high elevations in the Adirondacks (Walker et al., 2001; Arctic Climate Impact Assessment, 2004). Alpine plants will become rare, and tundra will likely eventually disappear in New York as timberline moves to higher elevations and the mountaintops are taken over by boreal trees. A field experiment of Arctic plant communities, which increased plant-level air temperatures by 1.8–5.4°F, found that within two growing seasons there were significant changes in the plant communities, including increased height and cover of deciduous shrubs and grasses, decreased cover of mosses and lichens, and decreased species diversity (Grime et al., 2008). This suggests that observed increases in shrub cover in many alpine tundra regions in recent years may be attributed to warming.

Grasslands

Soil fertility may play an important role in determining the vulnerability of grasslands to climate change. One study found that plant composition in low-fertility grasslands in England did not change over a 13-year period in which experimental manipulations increased temperature and reduced rainfall (Grime et al., 2008). Long-lived, slow-growing grasses, sedges, and small forbs maintained their dominance, with only minor shifts in the abundance of other species. Only minor species losses occurred in response to drought and winter heating. In montane meadows elevated temperatures have been observed to cause a decrease in forb cover and an increase in woody shrub cover (Harte and Shaw, 1995). The response of more fertile grasslands could be quite different, because they tend to be dominated by more rapidly growing species that are more sensitive to temperature changes. Currently, low temperatures often prevent the few fastest growers from taking over these grasslands. This limitation will be removed by increasing temperatures. Fast-growing invasive species may also find more opportunities to successfully invade fertile grassland communities as temperatures increase, at the expense of native species. The number of invasive species becoming established in open forest-grassland ecosystems has been shown to be directly correlated with the decrease in the number of frost-free days in a year (Walther, 2000).

6.3.3 Aquatic Ecosystems and Wetlands

Diverse aquatic systems extend throughout New York State, providing extensive wildlife habitat as well as critical services for human populations. (See also Chapter 4, “Water Resources,” and Chapter 5, “Coastal Zones”).

Rivers and Streams

River and stream systems are abundant in New York and have predominantly perennial flow regimes. With climate change, a larger fraction of small streams could become seasonally dry. Flow regimes are likely to show greater seasonal and temporal variation with a similar likelihood of high, spring-flood conditions and considerably lower low-flow conditions during summer dry spells. Intense mid-summer storms may also contribute to sudden, intermittent flooding, especially near urban areas or natural areas of thin rocky soils where water infiltration rates are low. Large aquifers are primarily recharged during the winter and early spring, and thus their annual recharge is less in jeopardy than shallower and higher-elevation perched groundwater, which will be more sensitive to the length of dry summer conditions.

High variation in flow regime is often associated with reduced diversity of fish and other aquatic species due to intense scouring of the river bottom during high-flow periods, damaging eggs and reproductive activity. It also can lead to low-flow water-quality issues, including high water temperature, low dissolved oxygen, high concentrations of pollutants, and more eutrophic conditions (which reduces dissolved oxygen content, negatively affecting many species). Siltation and scouring during more frequent flood conditions may affect invertebrate populations that are primary foods for fish, birds, and amphibians.

Because New York’s river systems are divided into many separate watersheds, few of which have great north-south extent, and many of which are further fragmented by the presence of some 6,000 dams, there are limited options for aquatic species in the state to adapt to rising temperatures via dispersal and range shifts. Sections of low water quality can also severely limit movement of aquatic species up and down stream. Species that are already restricted to headwater regions because these areas tend to be the coolest are most immediately at risk.

Lakes and Ponds

New York has a tremendous diversity of water bodies—both large and small, shallow and deep. In some regions of the state, lake levels may show increased seasonal variation. A recent study of the Lake Champlain watershed (Stager and Thill, 2010) found that peak, springtime levels in Lake Champlain had risen by a foot in the last 30 years due to increases in rainfall. Further increases in peak lake level are projected with increases in rainfall projected for this century, but this may be moderated somewhat by warmer winter temperatures, less snow pack, and lower water volume in spring thaw events. Many lakes will show major alterations in their patterns of temperature stratification (sharp temperature boundaries with depth) and seasonal turnover under climate change, features that are essential determinants of lake ecology. Turnover events (periods of great water exchange between surface and deeper volumes of the lake during freeze and thaw periods) bring nutrients up to surface waters, stimulating primary production (e.g., plankton) and affecting the depth of suitable habitat for fish. Fundamental changes in stratification and turnover dynamics may occur due to failure to form surface ice in winter. Warmer waters may further reduce oxygen availability in deeper levels, especially in more eutrophic lakes. While refuge locations of suitable habitat for coldwater fish are likely to continue to be present year-round in the state's deepest lakes, the total number of lakes sustaining suitable habitat for viable populations year-round will be reduced (see Case Study D: Brook Trout, this chapter).

Wetlands

Increased summer evapotranspiration and increasing water deficits projected for mid- to late-century (See Case Study C: Drought, "Agriculture," Chapter 7) are likely to reduce the total extent of wetlands in the state and shorten the hydroperiod of many remaining wetlands. A recent study concluded that seasonal wetlands in the Northeast will be most vulnerable, drying faster and remaining dry longer with warming (Brooks, 2009). Those ephemeral wetlands that are not fed by permanent springs are important amphibian breeding habitat and currently rely on melting snow to fill pools and initiate the breeding season at the end of winter. Reduced snowpack may make this pattern less

reliable, but late winter and early spring is also predicted to be a season of increased precipitation with a likelihood of high runoff and river flooding. Ephemeral ponds may still fill, and earlier spring temperatures could allow earlier biological activity, possibly compensating for earlier summer dry-down. It is difficult to predict how reliably these altered dynamics and seasonal cues will affect amphibians and other wetland species (see Section 6.3.4 for more discussion).

Wetlands supported by reliable groundwater sources will be more buffered from summer droughts than rain-fed wetlands (Poff et al., 2002). Seeps associated with reliable groundwater springs are also buffered from extreme summer temperature fluctuations. Groundwater seeps associated with lower elevation, thick till deposits, or other reservoirs capable of storing large volumes of water may be expected to continue to enjoy full winter-spring recharge and provide such stability. Aquifers perched on relatively shallow impermeable layers or thin till deposits, such as those found in higher-elevation basins in the Adirondacks, are less certain to have the storage volume to cope with longer, hotter summer conditions. They may be more affected by lack of summer recharge, becoming less reliable water sources. In such areas, rain-fed depressions could benefit from high intensity rainfall and associated runoff, even in summer, and may fare better. These dynamics require case-by-case studies to make firm predictions, and are very sensitive to rainfall patterns, which are currently predicted with less certainty than temperature changes.

6.3.4 Fish and Wildlife

In recent decades, climate change has affected the distribution, abundance, and behavior of wildlife species in the Northeast (Rodenhouse, 2009) and throughout the northern hemisphere (Parmesan and Yohe, 2003). Winter-resident species in the Northeast that remain active during winter, as well as species that hibernate, may be particularly vulnerable as winters have been warming more and have been more variable than annual average temperatures (Rodenhouse et al., 2009). Future range shifts will depend on factors such as the inherent capacity of species to migrate and on the availability of dispersal corridors, suitable new habitats, and food resources. Land-use change and habitat fragmentation can present significant barriers to species range shifts and may limit the potential for some species

to move northward, particularly those with low dispersal abilities. As a result, the effects of climate change on wildlife may be profound, affecting common species, rare species, and species that provide important ecological services such as pollination and insect control (Inkley et al., 2004).

Mammals

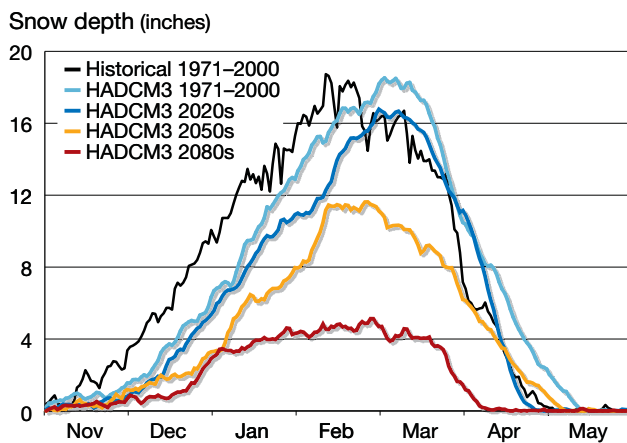
Changes in temperature, water and food availability, and habitat structure will tend to favor habitat and food generalists such as the white-tailed deer (*Odocoileus virginianus*). Generalists are species that forage and browse on numerous kinds of plants, or use a wide range of habitats. It will be important to monitor the response to climate change of species with potential widespread impact on ecosystem structure, such as deer and beaver. Currently, climate plays a role in limiting deer population growth in some regions (e.g., the Adirondacks) where prolonged winter snow cover reduces availability of winter vegetation as a food source. As annual snow cover diminishes during this century (Figure 6.5), areas where deer populations currently are kept in check by climate may experience increasing deer populations and less protection for winter vegetation from deer feeding damage. Oaks,

which otherwise are likely to be favored by warming trends (Iverson et al., 2008), are currently difficult to establish in high-deer areas because their seedlings are a food favored by deer.

In contrast to deer, mammals on the southern edge of their range under the current New York climate or with specialized habitat requirements may not fare well with projected warming. Moose will be particularly vulnerable to climate change, because they are currently at the southern edge of their range in New York and will be adversely affected by the direct effects of warming, as they are cold-adapted and intolerant of summer heat. During hot summer periods, moose reduce food consumption and lose significant body weight. When winter temperatures rise above 23°F their energy requirements increase, demanding increased food consumption to maintain body temperatures (Renecker and Hudson, 1986).

Predicted declines in the extent and duration of snow cover could negatively affect specialized animals like the snowshoe hare and small mammals that can better survive and remain active in winter under insulating snowpack (e.g., voles). Their predators (e.g., mink, weasels, fisher, and bobcat), which rely on subnivean (living in or just under the snowpack) animals for winter food, also may be affected negatively by declines in snow cover. As the extent of snow cover decreases over time, changing host-parasite relationships are likely. For example, moose are well adapted to snow cover, while deer avoid areas with heavy snow cover. As the extent of snow cover declines, moose and deer winter ranges will overlap more than they do today. Deer carry a brain parasite (*Parelaphostrongylus tenuis*) that is harmless to deer, but lethal to moose (Murray et al., 2006). As deer and moose habitats begin to overlap more, this parasite may cause increased mortality in the state's moose populations.

Changes in temperature, soil moisture, and stream flow will alter the quantity and quality of food available to many mammals, primarily by their impact on plant species composition and plant productivity. Warmer, drier summers may make it difficult for some mammals to put on enough fat reserves to make it through winter hibernation (Rodenhouse et al., 2009). Cumulative precipitation during the period of bat activity (April–October) is strongly associated with annual survival because of its impact on insect abundance (Frick et al., 2010). High precipitation is associated with increased



Note: Based on the United Kingdom Meteorological Office Hadley Centre Climate Model version 3 (HadCM3; Pope et al. 2000) using the A2 high emissions scenario. Regional downscaling and calculation of snowpack dynamics was done at Cornell University (Tryhorn and DeGaetano, unpublished). Each line represents an average over a 30-year period. The climate model correctly estimates the amount of maximum snow-cover and the shape of the distribution for the baseline period (observations are shown in black and the model is shown in teal); however, the model distribution is shifted slightly to later in the season. Future projections of snowpack at Wanakena for the 2020s (blue), 2050s (orange) and 2080s (red) are also shown. These projections are broadly consistent with those of other climate models used in ClimAID.

Figure 6.5 Seasonal snow depth at Wanakena (Adirondacks), showing projected changes in snow depth

abundance of insects, including culicids (mosquitos), dipterans (flies), and lepidopterans. In addition, while elevated levels of carbon dioxide may increase productivity of some plants (section 6.3.1), they also can reduce the nutritional (protein) quality and digestibility of many plants that herbivores feed on.

Birds

Twenty-seven of 34 Northeast bird species for which range shifts have been documented in recent decades show a northward shift in range (Rodenhause et al., 2009). These shifts include an assortment of permanent residents, short-distance migrants, and neotropical migrants (e.g., birds from South and Central America, Caribbean islands, and southern Florida). Between 1980 and 2005, the range of many New York bird species extended northward, with the ranges of more northerly species, like the Carolina wren (*Thryothorus ludovicianus*), contracting at the southern edge of their distribution as well (McGowan and Corwin, 2008). These northward shifts occurred across habitats and regardless of food preference. In black-throated blue warbler (*Dendroica caerulescens*) populations, habitat degradation due to climate change has altered nestling survival and growth by altering vegetation structure and the abundance of food and nest predators. For gray jays (*Perisoreus Canadensis*) nesting in high-elevation spruce/fir forests, increased fall temperatures result in the loss of perishable food hoarded for winter. This leads to poor health condition of adults, later breeding, and lowered reproductive success (Waite and Strickland, 2006).

At the Mohonk Preserve, long-term data collection has shown that migratory birds such as the fox sparrow (*Passerella iliaca*), eastern phoebe (*Sayornis phoebe*), eastern towhee (*Pipilo erythrophthalmus*), and whip-poor-will (*Caprimulgus vociferous*) now arrive more than a week earlier than they did in the 1920s (<http://www.mohonkpreserve.org>). Some birds not found in the Shawangunks in the 1930s have moved north, such as the brown-headed cowbird (*Molothrus ater*), northern cardinal (*Cardinalis cardinalis*), turkey vulture (*Cathartes aura*), black vulture (*Coragyps atratus*), and red-bellied woodpecker (*Melanerpes carolinus*). Others that once migrated are now becoming year-round residents or migrate inconsistently, such as the robin (*Turdus migratorius*), song sparrow (*Melospiza melodia*), chipping sparrow

(*Spizella passerine*), white-throated sparrow (*Zonotrichia albicollis*), and northern flicker (*Colaptes auratus*).

In the future, habitat generalists—species able to withstand a wide range of habitat conditions—are likely to flourish at the expense of habitat specialists. Birds like the Bicknell's thrush (*Catharus bicknelli*), which breed only in high-elevation spruce/fir forests, have little opportunity to shift to new locations and are expected to decline in abundance. Notable declines are expected for some of New York's popular northern resident species, such as the black-capped chickadee (*Poecile atricapillus*) and ruffed grouse (*Bonasa umbellus*). Short-distance migrants, such as the Baltimore oriole (*Icterus galbula*), and colorful neotropical migrants, such as the Blackburnian warbler (*Dendroica fusca*) and rose-breasted grosbeak (*Pheucticus ludovicianus*), are also expected to have notable declines (Rodenhause et al., 2008).

A number of wetland bird species, such as the American bittern (*Botaurus lentiginosus*), common loon (*Gavia immer*), and sora (*Porzana Carolina*), are projected to decline as a result of climate-driven changes, including degradation of inland wetlands (due to summer drought and winter or spring flooding) and loss or degradation of coastal wetlands (due to rising sea levels).

There is evidence that a number of phenological changes have already occurred in bird populations. For example, some populations of American black duck (*Anas rubripes*) have shifted their historical migration patterns farther north and east (Brook et al., 2009). Tree swallows (*Tachycineta bicolor*) are laying eggs nine days earlier than they did in the 1950s in response to increasing spring temperatures (Dunn and Winkler, 1999).

Amphibians

While not all species of amphibians are aquatic and their tolerances vary, all amphibians depend at least on the availability of humid refuges. The projected increased frequency of summer drought and shorter periods that wetlands and seasonal pools hold water (Section 6.3.2) will negatively affect amphibians dependent on these habitats for part or all of their lifecycle. If breeding pools dry earlier, this will increase competition for resources, decrease the size of young

when they leave the pool, hamper dispersal from the pool, and strand young that have not yet metamorphosed (Rodenhouse et al., 2009). Decreasing soil moisture may also limit surface activity of terrestrial and stream salamanders, reduce feeding opportunities, and increase competition for refugia.

On the other hand, increased winter and early spring temperatures may lead to increased foraging opportunity for salamanders and other amphibians early in the year, provided that their prey respond similarly and are available earlier. Also, earlier springs associated with climate change could lead to earlier breeding and larger amphibians with competitive advantages. In Ithaca, an analysis of historical records documented that four frog species are initiating spring mating calls an average of 10 to 13 days earlier now than they did in the early 1900s (Gibbs and Breisch, 2001). Earlier breeding will not compensate for possible negative effects associated with drier conditions and loss of aquatic habitat, but it further complicates attempts to project the magnitude of climate change effects on growth and reproductive success of amphibians (Rodenhouse et al., 2009).

Reptiles

The physiology of reptiles is temperature sensitive and could be influenced profoundly by climate change. For example, painted turtles (*Chrysemys picta*) grow larger during warmer years and reach sexual maturity more quickly (Frazer et al., 1993). Therefore, increasing temperatures may result in a higher rate of reproduction. However, for some species (like the painted turtle), the sex ratio of hatchlings is determined by the average July temperature in the nest. A change of as little as 3–4°F could skew the sex ratio in favor of female hatchlings (Janzen, 1994), with very few or possibly no males being produced. In addition, a decrease in the amount of snow cover (which serves as insulation) could lower overwinter survival of turtle hatchlings (Breitenback et al., 1984).

Many species of turtle in the state are already of special concern. Their limited dispersal abilities, combined with relatively small, isolated populations of animals, make them more prone to local extirpations than larger, more widespread populations of animals. Landscape changes that alter or fragment habitats will limit the potential for these animals to move across the

landscape in response to environmental stresses such as climate change.

Fisheries

Temperature plays a primary role in governing most life processes in fish (Brett, 1971). The potential for climate change impacts on freshwater fisheries in New York has generally focused on coldwater fish species, which require year-round access to water temperatures below 68°F. The most prominent New York coldwater fisheries target both native (e.g., brook trout, lake trout, Atlantic salmon) and non-native (e.g., brown trout, rainbow trout, and Chinook salmon) trout and salmon. Fish populations in rivers and shallow lakes will experience relatively significant reductions in coldwater refuges with continued warming and, thus, will be particularly vulnerable to climate change. Coldwater fish in many New York streams and shallow lakes currently require coldwater refuges provided by shaded stream banks, upwelling groundwater, and lakes with sufficient depth to stratify (maintain a stable zone of cold water) during summer. Any reduced availability of these refuges during warm summer conditions will reduce the future distribution and abundance of coldwater fish in New York (see Case Study D: Brook Trout, this chapter). Although New York coldwater fish communities in cooler, high-elevation regions of the Adirondacks and Catskills have already suffered population declines due to acid rain, these well-documented impacts—and subsequent 30-year efforts to reduce those losses of coldwater fish—provide a useful foundation to address the negative impacts of climate change on freshwater fisheries.

In contrast to the climate warming effects on rivers and shallow lakes, sufficient bottom coldwater regions are likely to be maintained in deep, large lakes (such as the Great Lakes, Finger Lakes, Lake Champlain, and the larger Adirondack lakes) and be able to support breeding populations of coldwater species even after decades of projected warming climate trends. However, other aspects of these large lake habitats will be affected by other stressors, such as eutrophication and changes in water chemistry.

Two native coldwater fish species appear to be particularly susceptible to climate-risk factors: brook trout and round whitefish. Brook trout (*Salvelinus fontinalis*) are popular for recreational fishing and have

been designated as New York's state fish. Brook trout have disappeared from many New York waters in response to non-native fish introductions, acid rain, habitat destruction, and hydrological disruption. The thermal preferences and effects of temperature on brook trout and closely related species are well known (Baldwin, 1956; Hokanson et al., 1973; Reis and Perry, 1995; Schofield et al., 1993; Selong et al., 2001). Brook trout populations are particularly vulnerable because this species requires cool water temperatures and relies on upwelling groundwater for reproduction and thermal refuge during hot summers (Curry and Noakes, 1995; Borwick et al., 2006). Brook trout populations have already been greatly reduced in their native range, and changes in thermal regimes are one of the greatest threats to their continued persistence (Hudy et al., 2005). Several studies have provided information regarding the potential impact of temperature increases on stream (Meisner, 1990a; Meisner, 1990b; Wehrly et al., 2007) and lake populations of brook trout (Robinson, 2008). Water temperature changes associated with a warming climate and human modifications to watersheds have been shown to reduce brook trout growth (Reis and Perry, 1995; King et al., 1999), available thermal habitat (Meisner, 1990a), and range (Meisner, 1990b).

Round whitefish (*Prosopium cylindraceum*) is another key coldwater species that could suffer from projected climate changes, though the single largest reason for the disappearance of New York round whitefish populations to date is the presence of non-native species, such as smallmouth bass and yellow perch. If changing climate conditions favor bass and perch by providing more abundant warmwater habitat, round whitefish would be affected indirectly, even without the loss of suitable coldwater refuges.

New York's threatened and endangered species include both southern species that were never widely distributed in the state (e.g., bluebreast darter and mud sunfish) and northern species (e.g., round whitefish and deepwater sculpin) that have been disturbed by habitat changes and introductions of non-native species. The coldwater threatened and endangered species are likely to be susceptible to projected warming trends in climate conditions. In contrast, a few southern species that were historically rare in New York, but remain abundant in suitable southern habitats (e.g., longear sunfish), could increase in distribution in New York if warmer conditions prevail.

6.3.5 Pests, Pathogens, and Invasive Species of Concern

It is likely that New York wildlife and land managers will experience new challenges with insect and disease management as longer growing seasons increase the number of insect generations per year, warmer winters lead to larger spring populations of marginally over-wintering species, and earlier springs lead to earlier arrival of migratory insects. New invasive species (discussed below) will also be an issue as habitat ranges of some pests shift northward. Numerous studies throughout the northern hemisphere have already documented changes in spring arrival and/or geographic range of many insect and animal species due to climate change (Parmesan and Yohe, 2004). Also, those plants and wildlife negatively affected by changes in climate will become more vulnerable to insect pests and disease, which could increase both individual mortality and in some cases promote widespread outbreaks. This is of particular concern with regard to forest stands made up of potentially long-lived individuals, because climate changes are likely to be much faster than adaptive changes in species composition through natural dispersal, competition, and gradual replacement (Dukes et al., 2009).

Climate factors such as warmer temperatures, increased frequency of heavy rainfall events, and wet soils in spring will tend to favor some leaf and root pathogens (Coakley et al., 1999). However, increases in short- to medium-term drought during some summer seasons would tend to decrease the duration of leaf wetness and wet soils and reduce some forms of pathogen attack on leaves and roots, respectively.

While there is not a high level of certainty regarding projections of humidity and precipitation events, it is possible to make some generalizations for New York: 1) higher winter temperatures are likely to result in larger populations of pathogens surviving the winter that can initially infect plants, 2) increased temperatures are likely to result in the northward expansion of the range of some diseases because of earlier appearance and more generations of pathogens per season, and 3) more frequent and more intense rainfall events will tend to favor some types of pathogens over others and also cause wash-off from leaves of fungicide or other pesticides.

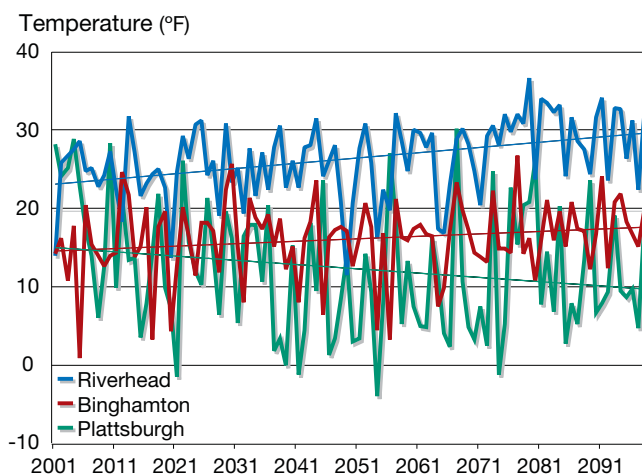
Climate change may have serious implications for diseases affecting wildlife and people. Vector species, such as mosquitoes, ticks, midges, and other biting insects, respond dramatically to small changes in climate, which in turn alters the occurrence of diseases they carry. For example, Lyme disease, erlichiosis, and other tick-borne diseases are spreading as temperatures increase, allowing ticks to move northward and increase in abundance. Epizootic hemorrhagic disease, a viral disease affecting white-tailed deer, spread to New York State in 2007. Epizootic hemorrhagic disease is transmitted by the bites of infected midges, commonly referred to as gnats. During periods of drought, animals congregate around limited water sources where midges occur in greatest numbers, allowing for the rapid spread of the virus (Sleeman et al., 2009). Outbreaks end with the onset of the first hard frost in fall. The combination of drought and delayed first frost allows for the spread of this disease.

Snow Cover Effects on Overwintering

Minimum winter air temperature has often been used to assess the potential overwinter survival of insect pests, weed seeds, and disease pathogens. However, this does not account for possible climate change effects on snow cover, which has an insulating effect on soil temperatures. **Figure 6.6** shows simulations predicting the annual minimum soil temperature at ground level underneath snow for three locations in New York. Currently, these locations vary in the number of their average annual snow cover days (DeGaetano et al., 2001). At Riverhead, the southernmost and least snowy location, temperatures at the soil surface show a projected increase that is similar to that of the air temperature. At the snowier Binghamton location, the increase in soil surface temperature is muted relative to the air temperature, with air temperature increasing more quickly than soil temperature (0.04°F per year for the soil surface versus 0.07°F per year increase in air temperature). The difference in the soil-temperature relationship between Riverhead and Binghamton is presumably a result of the greater impact of the reduction in winter snow cover at the snowier Binghamton relative to less-snowy Riverhead. At Plattsburgh, the northernmost (and snowiest) location, air temperature increases are similar to the other locations, but the ground surface temperature decreases through time at a rate of -0.05°F per year. Thus, winter soil temperatures at

Plattsburgh are projected to actually become colder than they are today because the air temperature warming trend is not enough to compensate for the loss of snow cover depth and duration and, thus, the insulating effect of snow cover.

The results of **Figure 6.6** illustrate the complexities of projecting climate change impacts on survival of insects and pathogens overwintering in the soil. For regions of New York that currently have low snow cover, using projections of winter air temperature to project winter survival of insects and pathogens in soil may be reliable. In these locations, overwintering insect populations may increase. However, for historic high-snow regions in which snow cover is projected to decline during the coming decades, winter soil temperatures could remain the same or actually become colder than they are today despite a trend for warming winter air temperatures because of the loss of the snow-cover insulation effect. In locations where soil temperatures decrease, overwintering insect populations may decrease.



Note: These sites differ in current winter snow cover, which affects the response of future soil temperatures to rising air temperatures. Riverhead is the southernmost and least snowy location; Plattsburgh is the northernmost and snowiest location; Binghamton is between the two, both in terms of its location and amount of snow. As snow depth decreases in Plattsburgh, ground-level temperatures are projected to decrease as air temperature increases, because the ground will lose some of the warming effect of the insulating snow cover. National Center for Atmospheric Research, USA (PCM) model simulations for the A1F1 emission scenario. These projections are broadly consistent with those of other climate models used in ClimAID.

Figure 6.6 Minimum annual temperature ($^{\circ}\text{F}$) at ground level under ambient snow cover for grids near Riverhead (blue), Binghamton (red), and Plattsburgh (green)

Invasive Species

Invasive species are defined as those species that are not currently native to New York's ecosystems and cause harm to the economy, environment, or human health (U.S. Executive Order 13112, 1999; Laws of New York, 2008, Chapter 26). For the analyses reported here, we are primarily concerned with “transformer” invasive species (*sensu* Richardson et al., 2000)—those species not native to North America that have the capacity to profoundly change the structure and function of ecosystems, as the chestnut blight did in the early 1900s (Gravatt, 1949; Anagnostakis, 1987) and as the emerald ash borer threatens to do now. Furthermore, we suggest that spending significant management effort on native species migrating within the continent in response to climate change may not be a good use of limited resources. Climate change is already resulting, and will continue to result, in the northward range expansion of some native southern species, and efforts to halt the movement of these species would be counterproductive. Strategically directing attention and prevention/ management actions toward those species known to be aggressively invasive elsewhere, and that will increase ecosystem vulnerability to climate change (Crooks, 2002), would be more sensible.

There is some recent evidence regarding the impacts of climate change on invasive species. Predictions that the hemlock woolly adelgid (*Adelges tsugae*), an invasive insect whose range is largely constrained by overwintering temperatures, would spread more rapidly throughout the Northeast with a warming climate (Paradis et al., 2008) have already come to pass in New York's Finger Lakes Region (USDA Forest Service, 2008). Recent work examining the flowering time of native and non-native species over 150 years in Concord, Massachusetts, indicates that non-native plants—particularly invasive species—have adapted better to long-term temperature increases than native plants. Over the last 100 years, invasive plants, on average, are flowering 11 days earlier than native plants. This may confer greater advantage to the invasive species (Willis et al., 2010).

Native communities stressed by climate change and other elements of global change (e.g., land-use change, habitat fragmentation, and nitrogen deposition) may become even more vulnerable to species invasions (Dukes and Mooney, 1999; Shea and Chesson, 2002). Further, invasive species may stand poised to exploit the

changing climate via new transport pathways, overcoming previous environmental constraints, expanding ranges, and increasing competitive abilities. Although the specific outcomes of invasive species/climate-change interactions may be difficult to predict, it is certain that the combinations of species composing New York's ecosystems will look and interact differently than they do presently (Williams and Jackson, 2007).

By changing patterns of tourism and commerce, climate change may alter mechanisms of transport and introduction of invasive species (Hellmann et al., 2008). For example, expected air traffic increases and climatic convergence between China and parts of northern Europe and North America may result in increased invasion risk (Tatem, 2009). Loss of Arctic sea ice could open new shipping channels, shorten transport time, and connect new geographic regions via the Northwest Passage (Hellmann et al., 2008). Particularly relevant for New York State, climate change could allow for longer shipping seasons in the Great Lakes and, thus, more opportunities for detrimental species introductions, such as the monkey goby, an invasive fish species (Kolar and Lodge, 2002).

Before a new invasive species can become established and spread, it must first overcome a number of environmental and ecological constraints. Projected warmer winters and hotter summers facing the Northeast in the coming century (“Climate Risks,” Chapter 1) will allow invasive species previously unable to persist to overcome temperature constraints. For example, kudzu (*Pueraria montana*), a prevalent invasive plant species in the southeastern United States, may expand its range northward (Wolfe et al., 2008). Additionally, increasing temperatures, precipitation, and humidity may benefit invasive forest pathogens (Dukes et al., 2009). Elevated carbon dioxide concentration, temperature, and precipitation may all contribute to increasing the competitive ability and dominance of some invasive plants over native species (Dukes and Mooney, 1999; Song et al., 2009). Furthermore, climate stress, the loss of species poorly adapted to future climate changes, and altered biotic interactions between species may open new niches and increase a native ecosystem's vulnerability to invasion. Increased incidence of extreme weather events, such as floods and drought, may also create additional windows of opportunity for the establishment and spread of invasive species, many of which are well-adapted to disturbed environments (Hobbs and Mooney, 2005).

The impacts of species currently invading New York's ecosystems will be exacerbated by climate change (Table 6.2). Some invaders, particularly herbivorous insects that have a physiology sensitive to temperature, may increase in abundance and impact within their range as a result of faster development times and longer growing seasons for plant hosts (Dukes et al., 2009). Climate change may also affect the phenology and efficacy of natural enemies to invasive species (e.g., parasites) and introduced biological control agents, with the potential to indirectly benefit invasive species (Burnett, 1949; Dukes et al., 2009). Increased water temperatures could result in earlier and longer growing seasons for aquatic invaders like Eurasian watermilfoil (*Myriophyllum spicatum*) and zebra mussels (*Dreissena polymorpha*), which in turn would require more frequent (and costly) implementation of control actions (Rahel and Olden, 2008). Additionally, there is some evidence to suggest that climate change may lead to increased per capita impact of invasive species. For example, one study observed that Japanese beetles (*Popillia japonica*) increased their feeding on soybean plants grown under elevated carbon dioxide concentrations, because plant leaves had increased sugar levels that served as a feeding stimulant (Hamilton et al., 2005). Undoubtedly, the impacts of invasive species under climate change will interact, perhaps synergistically, with other elements of global change in unpredictable ways. Thus, it is important to keep in mind that there remains very high uncertainty in the ability to predict what, how, and where new species will invade and existing invaders will spread.

6.3.6 Effects on Natural Resource Use and Human Communities

Climate change will also make products and activities based on natural resources, such as timber, maple syrup, and winter recreation, more vulnerable.

Timber Industry

Those managing forests for timber harvest will be faced with new challenges as climate change favors the competitive ability of some tree species over others and as range shifts occur in potential insect, disease, and invasive plant pests. Foraging and selective feeding by increasing deer populations will remain a problem and could become exacerbated by climate change. Some hardwoods currently grown in the region will not be suited

to the new climate emerging this century (Table 6.3) (Iverson et al., 2008). However, there will be considerable variability among hardwoods. A modeling effort discussed previously (Section 6.3.1) suggests that longer growing seasons and increasing atmospheric carbon dioxide concentrations could increase productivity and growth rates of some hardwoods (Ollinger et al., 2008), while spruce and fir would not benefit because of their sensitivity to projected high temperatures.

Maple Syrup Industry

Although one study projected that the distribution of sugar maple will largely shift out of New York and into Canada during this century (Iverson et al., 2008), trees managed for sugar production are protected from competition, much as are agricultural crops, and are likely to remain part of the New York landscape. The majority of sugar maple in unmanaged forests could have a different future.

Maple sap flow requires days with alternating freezing and thawing. Currently the period with the greatest likelihood of such days is mid-March to early April, but this period is gradually shifting to occur earlier in the year. One study of sap production in four northeastern states, including New York, shows that as average winter temperature increases, sap production decreases (Rock and Spencer, 2001). Another study, which examined 40 years of weather records, found significant increases in potential sap-flow days for three Quebec stations and non-significant trends in the same direction for other Canadian stations, two sites in Vermont, and one site at Watertown, New York (MacIver et al., 2006). A study that compiled sap production records for the past 30 years in four northeastern states, including New York, found a trend for fewer sap-flow days, because the end of sap-flow has advanced by more days (come earlier in the year) than the onset of sap-flow (Perkins, personal communication). This study projects adverse impacts from climate warming on sap production should these trends continue. A study that drew on similar evidence concluded that climate warming is already contributing to a northward shift in maple sugar production (Frumhoff et al., 2007). A more recent analysis considering all these factors suggests that impacts of climate change on sap production in New York will vary greatly by region (Skinner et al., 2010), but that the industry should remain strong in many parts of New

York State through the end of this century and beyond. For a more detailed analysis, see Case Study C: Maple Syrup Industry, this chapter.

Winter Recreation and Lake-Effect Snows

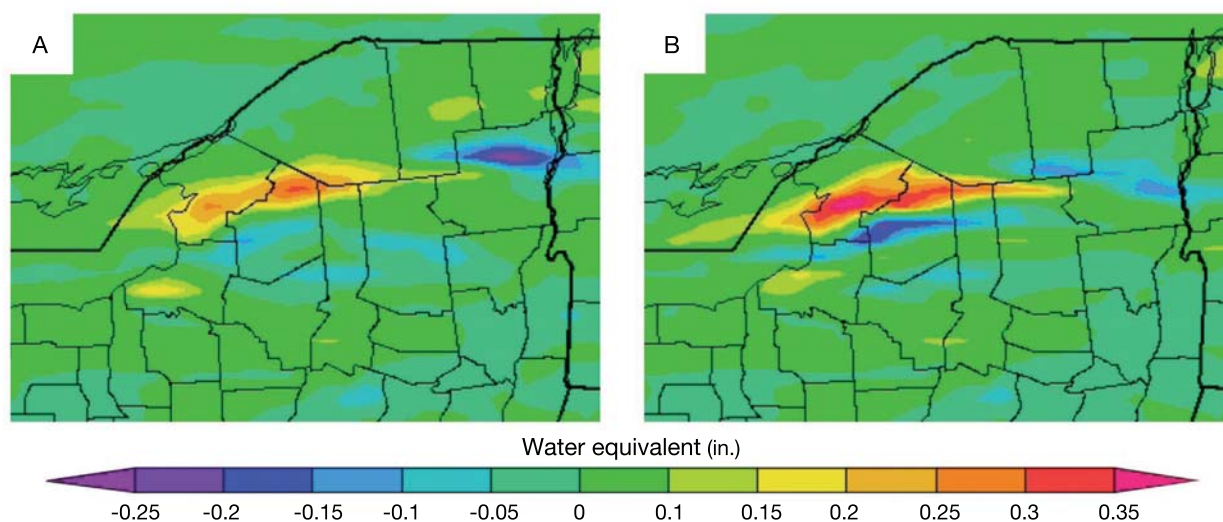
The ski industry in New York will be vulnerable to climate change and the reductions in snow cover projected for the region. Increasing the use of artificial snowmaking is an adaptation that already is being used by the industry. However, a recent analysis concluded that the number of ski resorts that could continue to maintain a reasonable profit margin using this strategy will diminish to only those located at the highest elevations by end of century as snowfalls and snow cover duration continue to decline (Scott et al., 2008). Snowmaking may provide a sufficient number of years of buffer for some resorts to diversify and survive, such as by developing alternative winter activities and expanding summer recreation offerings. Even with adaptation, certain communities and individual operations that rely on ski tourism are likely to suffer. Those communities with economies linked with snowmobiling recreation will be particularly vulnerable because of their inability to compensate by making snow.

Although reductions in snow cover have already been occurring and are expected to continue for much of the state, the analysis is more complex for those regions

subject to lake-effect snows. In the near term, warming lake temperatures and decreased ice cover will increase air humidity above the lakes, with the potential to cause increases in lake-effect snow during cold events that trigger snowfall, and this is consistent with observed increases in lake-effect snow in the recent years (Burnett et al., 2003). **Figure 6.7** presents a new analysis that illustrates how increasing lake temperatures above those recorded during a recent historical Lake Ontario snow event (November 9, 2008) would increase water-equivalent precipitation from the event by as much as 0.35 inches. The modeling study projected that this phenomenon of increased lake-effect snow with climate change would continue in the short term; by the end of this century, however, lake-effect snows are expected to decline by 50 to 90 percent, becoming lake-effect rain events as winter air temperatures become too warm to trigger snow (Kunkel et al., 2002).

6.4 Adaptation Strategies

New York ecosystems have adapted to climate change in the past, but the pace of change projected for this century is faster by several orders of magnitude than that of the most recent ice age transition and other historical events in the paleobiological record. There is a lack of reliable information and consensus regarding the future resilience and capacity of ecosystems to maintain



Note: Areas of increased and decreased lake effect snow are color coded showing inches of water equivalent. A) Weather conditions of wind and temperature gradients identical to an historic event recorded Nov. 9, 2008, but with lake and air temperatures uniformly increased by 1.8°F. B) The same conditions as A, but lake temperatures (not air) increased an additional 1.8°F (3.6°F total). Areas of red color show increases in lake-effect snow. These increase with further warming of water temperatures (B). (Weather Research and Forecasting model)

Figure 6.7 Simulations of the effects of climate change on lake-effect snow, in inches of water equivalent¹

function through the replacement of lost species with new species that serve similar functions or by redundancy of function among species currently present.

The capacity of resource managers to facilitate ecosystem adaptation to rapid climate change is uncertain. A concern is that, to date, prior to the confounding effects of climate change, we have had only limited success with management interventions attempting to control species declines or invasions or undesirable damage by individual species. Many potential management interventions for coping with climate change exist, but most of these have not been tested on a wide scale and some are controversial even among experts in the field. The adaptation strategies proposed below are generally supported in the science literature and among the experts consulted for this study, but some may be considered too expensive or not cost-effective by policy-makers, unless better and more persuasive methods for documenting the value of ecosystems can be developed.

A few fundamentals for building the adaptive capacity of communities and ecosystems have emerged in this analysis:

- Maintain healthy communities and ecosystems more tolerant or better able to adapt to climate change by minimizing other biotic (e.g., insect infestations) and abiotic (e.g., acid rain, nitrogen deposition, drought) stressors.
- Manage primarily for ecosystem function and biodiversity rather than attempting to maintain indefinitely the current mix and relative abundance of species present today.
- Facilitate natural adaptation to climate change by improving connectivity among habitats to allow species dispersal, migration, and range shifts.

Below, we first describe adaptation options for specific habitats (Sections 6.4.1 to 6.4.4), followed by adaptations that would be implemented at the institutional or agency level (Section 6.4.5).

6.4.1 Forest, Grassland, and Alpine Communities

A recent review suggests that, in the context of climate change in the Northeast, it will be preferable to focus on future desired ecosystem function rather than aiming

for specific species mixes (Evans and Perschel, 2009). Management strategies might, therefore, emphasize maintaining a diverse suite of species with some redundancy in function to hedge against loss of individual species. Diversity in species and tree age distribution will also help buffer against losses due to biotic or abiotic disturbance. Thinning and planting of trees can be designed to reduce the dominance and dependence of ecosystem function on tree species that are most vulnerable. However, the majority of older, intact forests should be maintained and allowed to evolve in their own way because of their ability to resist invasive species. Goals might include retaining selected legacy trees with heritage value, or habitats that can provide a seed source or refuge for plant and animal communities that are underrepresented in the landscape and are under stress due to climate change.

A key to adaptation is maintaining healthy tree stands, and from this standpoint many “best management practices” already suggested will be beneficial. This includes emphasis on low-impact harvest techniques, such as minimizing soil compaction (e.g., harvest when soils are relatively dry or frozen), and directional felling and careful removal of harvested trees. Biological or chemical control may be warranted in some cases for rapid-response containment of pests, disease, or invasive species, particularly for protection of unique habitats or species with irreplaceable function. Intervention solutions in alpine systems, however, will likely be problematic because of the multitude of sensitive and unique species.

6.4.2 Aquatic Ecosystems and Wetlands

Adaptation options exist for aquatic ecosystems and wetlands and include restoring and expanding riparian buffer zones, improving habitat connectivity, restoring legal protection, limiting water withdrawals, limiting invasives, and minimizing eutrophication.

Restoration and Expansion of Riparian Buffer Zones

Riparian (streamside) zones provide natural corridors for dispersal and migration of terrestrial and aquatic species and thus are vital to species shifting range in response to climate change. Other co-benefits of riparian zones include providing a unique and valuable terrestrial habitat, moderating flood and erosion

damage, contributing to the energy and food web of adjacent aquatic communities, and shading streams and pools and thus providing cool-water refuges for coldwater fish in summer. The goals should be both to protect currently intact riparian zones and to restore those that have been degraded wherever practical. Options to accomplish this could include support of local governments with model ordinances, education and outreach, and support of voluntary conservation easement efforts. The New York State Open Space Conservation plan recommends a 100–300 foot (or more) zone around all streams that is free from physical development or high-impact activities, such as forestry, farming, or animal husbandry (www.dec.ny.gov/lands/47990.html).

Improve Habitat Connectivity by Removing Dams, Replacing Culverts

Dams and culverts (pipe-like constructions passing under roads) fragment habitats and limit dispersal potential for both animals and plants, which may make it difficult for them to shift their ranges in response to climate change. Programs at the federal and State level to develop inventories of abandoned and derelict obstructing dams that are barriers to fish and wildlife could be further developed. It would be beneficial to remove dams that are no longer necessary. Most culverts were not designed with consideration of their effects on aquatic and terrestrial species. Many are too long, some do not carry water year-round, and some are set at an elevation the wildlife and fish cannot access (L. Zicari, U.S. Fish and Wildlife Service, personal communication). For high-priority regions or species affected by climate change, redesign and replacement of these culverts to minimize barriers to aquatic and terrestrial species will be an important approach to building ecosystem adaptation capacity.

Restore Legal Protection to Isolated Wetlands

The New York State Department of Environmental Conservation protects wetlands larger than 12.4 acres, but this does not cover many small isolated wetlands, particularly fens and vernal pools that support a disproportionate amount of biological diversity relative to their total acreage (Comer et al., 2006). As a result of their scattered distribution across the landscape, these smaller wetlands also provide connectivity for the

dispersal of many wetland species. These isolated wetlands need protection, as called for in the New York State Open Space Conservation Plan of 2009.

Limit Water Withdrawals that Affect Wetlands

Many wetland systems may be negatively affected by increased agricultural water use as summer soil water deficits intensify with climate change (see “Agriculture,” Chapter 7, Case Study C: Drought). Land-use change and groundwater depletion by rural populations may also adversely affect many wetlands. A current high priority is to develop an inventory of wetlands and their landscape position in relation to hydrology and current and projected land and water use.

Limit Transport of Aquatic Invasive Species

Given that climate change is likely to increase the number of invasive species that will be able to survive and spread throughout New York’s waters, limiting the transport of invasive species via infested boats and angling gear and from bait and aquarium releases will be increasingly important. A number of boat launch steward programs are currently in place in the Adirondacks (Adirondack Park Invasive Plant Program, personal communication); similar programs should be considered statewide. Regulatory approaches, such as enforceable aquatic invasive species transport laws, may be warranted.

Minimize Eutrophication

The impact of climate change on pollutant and nutrient loads to New York waterways is uncertain (see “Water Resources,” Chapter 4). While increase in pollutant-laden runoff is possible in winter and early spring, algal growth response will be constrained by low temperatures during this time of the year. Of more concern might be diminished low-flows in late summer that lower dilution potential, increase summer water temperatures, and reduce dissolved oxygen. The State Pollutant Discharge Elimination System permitting processes and guidelines for combined sewer overflow releases may need to be revised in recognition of lower dilution potential in summer and fall. Excluding cattle from riparian zones can sometimes be more effective than more costly manure-management options (Easton et al., 2008).

6.4.3 Fish and Wildlife

Adaptation options for fish and wildlife include management of core habitat and connecting corridors, hunting seasons and bag limits, wildlife disease surveillance, conservation priorities, and coldwater refuges.

Core Habitat and Connecting Corridors

Range shifts of wildlife will depend, in large part, on the availability of dispersal or migration corridors (e.g., connected habitats, riparian zones), suitable habitats, and the concurrent movement of forage and prey. Minimizing landscape changes that result in habitat fragmentation and barriers to species range shifts will be key to helping New York State's wildlife adapt to climate change. A strategy for facilitating wildlife adaptations to climate change includes closely coordinated landscape- and regional-level approaches, complemented by on-the-ground management and conservation efforts carried out on a variety of scales. Conserving or creating newly connected, contiguous habitats from north to south, and ensuring connection of east-west gradients as well, can assist movement of habitats and wildlife by providing northward migration corridors (Inkley et al., 2004). Corridors could focus on connecting key diversity hotspots for specific taxa between regions (e.g., Pennsylvania and New York, New York and Canada), as identified from sources such as Gap Analysis Program data and USDA Forest Service Highlands Project data. Examples of local and regional projects that could serve as templates include the Wildlife Habitat Connectivity in the Hudson River Valley (a joint project of the New York Natural Heritage Program and the Hudson River Estuary Biodiversity Program) and the Finger Lakes Land Trust's Emerald Necklace Project, a proposed greenbelt that could link 50,000 acres of protected open space in and around Ithaca.

Hunting Seasons and Bag Limits

A changing climate is likely to affect the state's popular game species. Resulting changes could include earlier breeding seasons, earlier migration, and/or altered migration pathways and changes in habitat suitability and productivity. If the timing and/or pattern of seasonal movements or breeding changes, maintaining hunting seasons during their historical time period

could mean that harvest levels are either over- or underachieved. Adaptations to such changes include increased flexibility in setting hunting seasons and bag limits, combined with a monitoring program designed to detect relevant population changes and inform decision-making.

Climate change may increase the impact of game species on the landscape. Increasing deer populations and damage from deer are likely to be exacerbated by reduced snow cover exposing more winter vegetation for browsing (Section 6.3.3). Promoting increased harvest of this species is one adaptive approach to better control. Conversely, stressed populations of other species, such as waterfowl and ruffed grouse, may need temporary protection from harvest until populations recover. Hunting seasons may change to correspond with changing migration dates.

Wildlife Disease Surveillance and Monitoring

With warmer fall temperatures and later fall frosts, diseases vectored by biting insects and ticks will likely be of greater importance. For example, epizootic hemorrhagic disease is spread between white-tailed deer by biting midges. The disease may have locally severe impacts on deer herds. Other diseases that affect species in southern states may spread northward with warmer and milder winters. Enhanced surveillance can help identify and reduce impacts of disease hotspots. A monitoring network at the state and regional levels can provide an early warning system in years with potentially severe outbreaks.

Prioritizing Conservation Efforts

While a focus on preserving ecosystem function may be the most cost-effective adaptation strategy in many cases, some individual species may deserve special attention, such as "responsibility species"—species that have their core populations in New York or species for which a significant proportion of the world's breeding population is found in New York. This might include common species such as the scarlet tanager or rare species such as the Chittenango ovate amber snail, a species whose entire global population can be found within the state. New York also supports species on the northern edge of their current distribution, including animals such as the long-tailed salamander and the bog

turtle. Currently, New York is in the early planning stages for identifying and managing species of responsibility. Such priorities may be reflected in the future in the State's list of Species of Greatest Conservation Need.

Fisheries

An overall adaptation strategy for sustaining the survival, growth, and abundance of coldwater fisheries is to maintain the provision of coldwater refuges during seasonal periods in which warm water temperatures prevail throughout lakes and flowing water ecosystems. Maintaining well-vegetated, canopied riparian zones and lake shorelines is one approach to meeting this objective. Maintaining flow of relatively cold groundwater inputs to waterways and lakes is another strategy. This would require landscape management practices that minimize disturbance to surface vegetation, soils, and hydrological flow paths. A more complex and expensive approach would be to artificially increase cold groundwater flow by piping cold water from higher elevation water sources to lower elevation lakes or stream shorelines where coldwater fish populations require augmented cold thermal refuges in order to survive. For example, Cornell University fisheries biologists have developed such water sources to enhance groundwater upwelling required for brook trout reproduction; brook trout have been observed during warm summer periods at these locations of cool groundwater inputs.

An additional general adaptation strategy for sustaining the survival, growth, and abundance of coldwater fisheries is to manage specific competing fish populations at lower densities so that available food resources can sustain the target population size. For example, Cornell University fisheries biologists have observed that a smaller population of self-sustaining brook trout exhibited greater growth, survival, and reproduction than a larger population in the same thermally stressed Adirondack lake during a series of recent warm summers. The larger brook trout population was the result of stocking fish in a lake which already had a substantial self-sustaining population of brook trout. Greater population abundance reduced the relative amount of available forage for each fish in the population, leading to reduced growth during stressful warm summer conditions. Reduced growth can also result in reproductive failure during the subsequent spawning season.

6.4.4 Invasive Species

Changing conditions associated with climate change are likely to allow some invasive species to overcome environmental and ecological constraints that previously prevented their establishment in New York's ecosystems. For transformer species (i.e., those invasive species that may fundamentally change the structure and function of ecosystems), in particular, increased vigilance will be necessary for successful early detection and rapid management response. Current invasive species monitoring (from the large-scale USDA-sponsored Cooperative Agricultural Pest Survey to small community-based programs) and mapping efforts (e.g., iMapInvasives; see Case Study B: Creative Approaches to Monitoring and Adaptive Management) must consider the consequences of climate change on species invasion (see **Table 6.2**) and may need to adapt monitoring protocols and mapping tools accordingly. Further, these programs should be coordinated and integrated with other state and regional biological monitoring programs to provide natural resource managers and policy-makers with necessary high-quality, comprehensive information for decision-making. The eight Partnerships for Regional Invasive Species Management (PRISMs) may provide a useful infrastructure for implementing climate-related monitoring, education, outreach, and citizen science programs (see Case Study B: Creative Approaches to Monitoring and Adaptive Management).

Climate change will necessitate an adaptive-management approach, where management actions are paired with data collection and subsequent evaluation and learning, particularly with respect to the management of invasive species. Current control practices used to contain invasive species populations may lose effectiveness under the future climate change scenario. For example, the efficacy of some herbicides used to treat terrestrial invasive plants may decline if plants experience increased herbicide tolerance with increasing atmospheric carbon dioxide concentrations (Ziska et al., 1999). Particularly in aquatic ecosystems, increased temperatures may necessitate more costly and aggressive control tactics for invasive species. Manually removing locally distributed invasive aquatic plants that were previously limited by ice cover may no longer be sufficient to control populations if climate change enables these plants to survive the winters (Hellmann et al., 2008). Furthermore, the effectiveness of biological control agents may decline with climate change,

particularly if there is a mismatch in climate tolerances between the control agent and the target invader (Hellmann et al., 2008). This scenario could be played out in the Finger Lakes region, where researchers are in the process of establishing a population of *Laricobius nigrinus* beetles, derived from a cold-tolerant population in Idaho, to control the recently detected hemlock woolly adelgid (*Adelges tsugae*). Increasing temperatures may alter the phenology and interaction of these species, potentially resulting in reduced adelgid control.

Prevention of species introductions, in some cases by regulation, is the most cost-effective invasive species management tool (Wittenberg and Cock, 2001). To date, prevention efforts have consisted largely of the following: monitoring the pathways on which invasive species are introduced (particularly those related to transportation, e.g., container and ballast water inspections); species risk assessments prior to importation of goods and merchandise (Gordon et al., 2008); and regulatory actions (e.g., quarantines and New York State's firewood movement regulation, which restricts transporting firewood from areas with known infestations of pests like the emerald ash borer or Asian long-horned beetle). With climate change and accompanying altered mechanisms of transport and species introduction, prevention efforts (particularly risk assessments and regulatory species lists) must be expanded to include a growing pool of potential invasive species.

6.4.5 Larger-scale Adaptations

In addition to strategies that can be implemented at an organization or agency level, some adaptation strategies should be considered at a state or region-wide scale. These larger-scale adaptation options are discussed here.

Institutionalize a Comprehensive and Long-term Monitoring and Data Dissemination Program

This will involve monitoring from the scale of individual species (e.g., movement of invasives) to monitoring indicators of ecosystem function vulnerable to climate change. Data management and dissemination would be centralized, perhaps within a government agency or other institution, but to be effective the design and implementation would require collaboration among multiple agencies, scientists, resource managers, and

individual stakeholders and citizen scientists. Components and activities of this program could include:

- gathering and organizing baseline data, including collecting existing datasets, identifying information gaps, gathering economic and other data for valuation of ecosystem services, and securing funding to fill gaps;
- identifying and prioritizing indicators to monitor specific goals;
- improving and coordinating monitoring efforts, including training for citizen scientists;
- creating a task force of scientists to synthesize data and to produce reports and maps on a regular basis;
- centralizing data management, data quality control, and user-friendly data dissemination; and
- actively engaging with resource managers and policy-makers to continually refine the research agenda and improve access to meaningful data for decision-makers.

Develop Prioritization Criteria

These would be used to identify those species, populations, habitats, and ecosystems requiring concerted monitoring, adaptive management, or protection. Criteria might be based on the following:

- vulnerability assessment results
- high level of certainty of climate change impacts and/or near-term impacts
- economic valuation
- maintenance of biodiversity
- provision of ecosystem services (e.g., water supply and quality)
- habitat importance as a dispersal corridor
- habitat importance for one or more endangered or species of concern

Develop Adaptive Management Plans and Improve Adaptive Capacity of Land Managers

This would rely on the input from the monitoring and prioritization activities described above in the two prior recommendations. Specific components could include:

- incorporating up-to-date climate change information into all government planning activities

(as opposed to using out-dated historical climate data);

- developing rapid response plans for emerging challenges (e.g., for control of new invasive species);
- improving data sharing and other networking with other states and agencies;
- improving adaptive capacity of land managers through development of new decision tools and training and education; and
- developing policies to facilitate interventions by resource managers.

Develop Better Regulation and Incentive Programs

These should be created as needed for specific purposes, such as incentive programs to encourage private landowners to maintain key habitats and new regulations to control the transport of invasive species into New York ecosystems.

Expand Educational Outreach and Citizen Science Programs

Educational outreach to private landowners should be a high priority to raise their awareness of the issues and their critical role in minimizing negative impacts of climate change on New York biodiversity, habitat integrity, and maintenance of important ecosystem services. All sectors of society will benefit from sound information on climate change, its potential impacts on natural areas, its implications for ecosystem services affecting human communities, and what they can do to participate in adaptation and mitigation.

6.5 Equity and Environmental Justice Considerations

Climate change will modify the character and quantity of ecosystem services, creating both direct and indirect vulnerabilities and new distributions of winners and losers. The most immediate impacts will be felt by those who draw directly on ecosystem services for well-being, subsistence, and income. Some communities are deeply dependent on one particular type of resource, such as fisheries, and will be uniquely challenged by its increased scarcity or its degraded quality. In other

cases, a change in ecosystem services will be felt as an indirect property loss. For example, one study used hedonic modeling (an economics method that estimates value by breaking an item into its constituent parts) to demonstrate the significant impact that forest disturbances can have on residential property values (Huggett et al., 2008).

Changes in the character and quantity of ecosystem services will expose differences in the ability of people and communities to anticipate these changes and to adapt. Those land owners and local managers with the resources to invest in the upkeep of amenity and ecosystem services on local private and public property will be able to take advantage of these changes and maintain the value of their resources to the extent possible. In some cases, climate change will change the basis by which entire landscapes are valued, which could put pressure on alternative development strategies or create emergent contexts for new ones, each with differential outcomes and inherent equity issues. Within urban areas, equity issues also emerge with respect to creation and preservation of open space and access to environmental amenities such as water bodies. Some examples from a few industries—forestry, winter recreation, and maple syrup production—illustrate these issues.

6.5.1 Forests, Parkland, and Urban Ecosystems

Whether forests are valued as an inherent aesthetic whole or as a select portfolio of constitutive economic services (e.g., timber products) has bearing on how ecosystem change can and will be managed and which users will be affected. Changes in forest ecosystems may devalue the existing natural resources and amenities, potentially driving regional deforestation and commercial development. Changes may also exacerbate existing fragilities. Around the Adirondacks, for example, managing a patchwork of public and private land amid a transition from natural resource extraction to tourist economies is already a challenge for park managers, land managers, and local communities (Hubacek, 2002). As climate change affects the physical composition of the forests and the regional tourist industry, it may increase tensions over the rights to development. It may also cause increasing burdens on those private property owners who are forced to internalize the regional economic impacts of

climate change because of regulatory constraints on their development options. Currently, perceived inequities in conservation interventions and regulations are latent concerns (Michaels et al., 1999).

Within urban settings, ecosystems services associated with forests, parklands, and wetlands play a vital role but are frequently contested (Gandy, 2002). For example, a frequent source of dispute in New York City and in other cities is the inequitable distribution of urban forests and lack of access to open space for health and well-being. Several communities in New York City have been strong advocates of preserving and restoring wetlands for the various ecosystem services they provide. For example, on the North Shore of Staten Island, community leaders have fought to conserve Arlington Marsh from a variety of threats and development pressures. Research suggests some of the best-maintained urban forests tend to be in the more wealthy areas (Heynen et al., 2006). Under climate change scenarios, park vegetation will potentially require more water, fertilizer, and pesticides. The increased costs of maintenance could exacerbate differences in quality of park vegetation and urban forests between wealthy and non-wealthy areas. Which urban parks and forests should be maintained in light of the impacts of climate change, and who is serviced by the park system, are questions that will become ever more important under the fiscal constraints of a budget impacted by climate change.

6.5.2 Winter Recreation, Resource Dependency, and Equity

In a review of the ski industry's vulnerability, one study notes that the ski operations that are smaller and less well capitalized or more southerly and at lower altitude may have more difficulty keeping up with increasing demands on artificial snowmaking capacity (Scott et al., 2008). Also, when faced with warm spells, larger establishments are more likely to be able to absorb losses without going under and afford measures for spreading risk, such as taking advantage of new markets for weather derivatives (i.e., financial instruments that can be used to reduce risk associated with adverse weather conditions). A further consolidation of the industry, a current trend likely to intensify under multiple pressures from climate change, then could create barriers to entry for smaller businesses.

Any consolidation of the industry would have cascading localized and regional effects on employment and related tourist businesses. The survival of certain communities will depend on anticipating the double exposure of warmer temperature and economic vulnerability. The timing of adaptation strategies, therefore, becomes critical, as does early planning to diversify local economies through new ventures or retraining.

6.5.3 Maple Syrup Industry: Vulnerability and Inequity

The maple syrup industry may be affected in a variety of ways (for additional information, see Case Study C. Maple Syrup Industry: Adaptation to Climate Change Impacts). Climate change effects on sap flow may vary in different parts of New York State, requiring some regions to increasingly rely on more expensive technology. The industry also provides a good example of the difficulty in anticipating nonlinear economic feedbacks and how these will combine with climate change to create differences in vulnerability across regions and states. In recent years, Canada has begun aggressively marketing maple syrup and introducing technological improvements that have reduced the competitiveness of maple production in the northeastern United States (New England Regional Assessment Group, 2001).

In 2009, a cold winter followed by a warm spring caused a decrease in Canadian maple production. This led to a rise in maple syrup prices. In the short term, this produced a good year for the New York maple industry, with expanded production by established producers and the development of new producers. At the same time, restaurants and retailers have passed on the price increases to customers by charging more for pure maple syrup, in some cases switching to corn syrup products (Schwaner-Albright, 2009).

As climate warming proceeds, New York maple syrup producers will need to consider how the industry should be structured to deal with increased seasonal variability in sap production, to increased variability in supply between regions, and to price and supply competition with alternative sugar sources.

6.6 Conclusions

This ClimAID analysis of ecosystems focuses on those aspects of climate change already occurring in New York or anticipated to occur within this century and that have known biological and ecological effects. **Table 6.4** summarizes selected climate factors, as linked to vulnerabilities/opportunities and adaptation strategies. A qualitative level of certainty is assigned to all three of these components (see Chapter 1, “Climate Risks”). The relative timing of when specific climate change factors and their associated impacts are projected to become pronounced is also indicated in the table, as these features will be critical in setting priorities for adaptation. **Table 6.4** illustrates an approach and a possible tool for setting priorities and for climate action planning, but is not meant to be comprehensive. It can and should be modified as new information and expertise become available.

Below, key findings regarding vulnerabilities and opportunities, adaptation options, and knowledge gaps are highlighted and discussed in more detail.

6.6.1 Main Findings on Vulnerabilities and Opportunities

The ClimAID study found that certain ecosystems are already undergoing changes or are vulnerable to the projected changes in climate while others may be less negatively affected or even benefit from climate change.

Vulnerable Ecosystems

Some species-level responses are already being observed in New York. Current species responses that are consistent with climate change include:

- northward expansion of the range of some birds, insects, and other species, including invasive species such as the hemlock wooly adelgid;
- increased winter survival and feeding of deer populations;
- earlier spring arrival of some migrating bird and insect species;
- earlier spring breeding of some animals and insects; and
- earlier spring bloom of some woody perennials.

The particular characteristics of species that make them vulnerable to climate change include:

- habitat or food specialization;
- location at the southern fringe of their habitable range;
- narrow environmental tolerances;
- poor dispersal ability;
- low population levels or current endangerment;
- lack of competitive advantage with species infringing on their range; and/or
- high dependence on snow cover for survival.

The major ecosystems vulnerabilities for New York include the following:

- Within the next several decades there are likely to be widespread shifts in species composition of forests and other natural landscapes. By mid- to late-century the Catskill and Adirondack mountain ranges of New York will no longer have a climate suitable for spruce/fir forests, alpine tundra, or boreal plant communities.
- Climate change will favor the expansion of some invasive species into New York, such as the notoriously aggressive weed kudzu, and the aphid-like insect pest hemlock wooly adelgid, which has already devastated hemlock stands to the south.
- Warming water temperatures will negatively affect brook trout and other native coldwater fish species, except in water bodies that are deep enough, have sufficient shade, or cold groundwater inputs to maintain coldwater refuges in summer.
- Lakes, streams, inland wetlands, and associated aquatic species will be highly vulnerable to changes in the timing, supply, and intensity of rainfall and snowmelt, groundwater recharge, and duration of ice cover. An increase in summer water deficits is likely by mid- to late-century, but for many of the climate change factors relevant to aquatic habitats we cannot project with a high degree of certainty the future magnitude or timing of change.

Species Likely to be Less Negatively Affected by Climate Change, or Even to Benefit

These species include those that are habitat and food “generalists,” those whose habitable range is currently constrained in New York due to current winter temperatures, and some invasives. Specific examples include the following:

Climate Factor	Climate Certainty	Associated Vulnerabilities/ Opportunities	Certainty*	Timing	Adaptation Strategies	Adaptation Capacity
Increasing carbon dioxide	High	Potential increase in plant growth, with large differences between species affecting plant community structure, potential for invasive species	Response dependent on other environmental constraints to growth that are difficult to predict	Now	Increase timber production by identifying and selecting carbon dioxide-responsive tree species; regionally coordinated monitoring and rapid response eradication of invasive species	Low to Moderate
Warmer summers; longer growing seasons	High	<i>Plants:</i> Potential increase in plant growth, with large differences between species affecting plant community structure, potential for invasive species; will increase plant water use and soil water deficits	Moderate to High, but water availability or other factors may constrain response	Early to mid-century	Increase timber production by identifying and selecting responsive tree species; regionally coordinated monitoring and rapid response control or containment of invasive species; prepare regionally for effects on hydrology	Low to Moderate
		<i>Insects:</i> More generations per season; shifts in species range	Moderate to High	Early to mid-century	Regionally coordinated monitoring and rapid response control or containment of insect pests and invasive species	Low to Moderate
		<i>Coldwater fish species:</i> Negative effects on populations of brook trout and other native species	Moderate to High	Early to mid-century	Maintain coldwater refuges through shading and by maintaining groundwater flows	Low
		<i>Summer recreation:</i> Increased opportunities	Moderate to High	Early to mid-century	Investment in and policies to facilitate summer recreation business	Moderate to High
Increased frequency of summer heat stress	High	High-elevation species: Eventual loss of spruce/fir forests, boreal communities; negative effects on other cold-adapted plant and animal species	Moderate to High	Mid to late century	Few options except facilitate species dispersal by maintaining corridors (e.g., riparian zones)	Low
Warmer winters	High	Northward shift in range of many plant, animal, insect species, including undesirable pests, diseases and vectors of disease, invasive species	High	Now	Facilitate dispersal, with monitoring and containment of undesirable species; wildlife disease surveillance	Low
		Increased winter survival of deer populations, increasing deer damage	High	Now	Modify hunting seasons and bag limits	Low to Moderate
		Increased survival of marginally overwintering insect pests	High	Now	Monitor and rapid response control or containments	Low to Moderate
		Negative effects on maple syrup production	Moderate	Early to mid-century	Earlier tapping; new tapping equipment; bring more trees into production	High
Reduced snow cover	High	Negative effects on winter recreation	High	Now	Increased snowmaking; diversification toward warm-season recreation business	Moderate to High
		Negative effects on survival of snow-dependent animals and insects	Moderate to High	Now	Few options	Low
		Increased vegetation damage from winter deer feeding	Moderate to High	Now	Few options except reducing deer populations through hunting season and bag limits	Low
Increased flooding	Moderate to High	Erosion and damage to stream banks; flood damage to plants; disturbance to aquatic ecosystems	Moderate to High	Now	Expansion of riparian zones and wetland protection; infrastructure (culvert, dam, etc.) planning to minimize damage	Low to Moderate
Increased summer drought	Moderate	Loss of some native plant species in severe years; Increased vulnerability to invasive species; negative effects on wetlands, streams, lakes, and aquatic species	Moderate to High	Mid to late century	Infrastructure planning to maintain water supplies to high priority regions; facilitate species dispersal and establishment of more drought-tolerant species.	Low
Changes in frequency of extreme events	Low	Sudden and severe devastation to entire communities and ecosystem services	Moderate to High	Unknown	New climate science research to determine current trends and predict extreme events	Low to Moderate
Increased climate variability	Low	Increased freeze damage of woody plants due to loss of winter hardiness or premature leaf-out and frost damage; disruption of winter hibernation negatively affecting winter survival	Moderate	Unknown	New climate science research to determine current trends and predict climate variability	Low to Moderate
Changes in cloud cover and radiation	Low	Important factor affecting plant growth and plant water use, primary production as food supply to animals	High	Unknown	New climate science research to determine current trends and better model these factors	Low to Moderate

* Climate certainty in this table is qualitatively consistent with more quantitative assessments in Chapter 1, "Climate Risks," and formulated from expert opinion from chapter authors and stakeholder groups.

Table 6.4 Summary table for climate factors, vulnerabilities/opportunities, and adaptation strategies for ecosystems in New York State

- Productivity of some tree species (e.g., oak, hickory, pine) adapted to warmer temperatures could benefit from longer growing seasons and increasing atmospheric carbon dioxide concentrations, provided that other environmental factors such as drought, nutrient deficiency, pests, or invasive plant infestations, do not limit their growth
- White-tailed deer could benefit from warmer winters and less snow cover, which will expose more winter vegetation as a food source
- Warm-water fish species such as bass
- Plant and animal species currently inhabiting regions south of New York, which will benefit from the state's warming temperatures and/or may be relatively tolerant to periodic droughts
- Some bird species, such as northern cardinal, Canadian goose, robin, and song sparrow
- Invasives with northward expanding range due to climate change, such as the insect pest hemlock wooly adelgid and the aggressive weed kudzu

With the exception of a few highly vulnerable communities (such as high-elevation plant communities and some coastal zones vulnerable to flooding), projecting future climate impacts on biodiversity and on ecosystem function and services is relatively uncertain compared to future impacts on specific species within ecosystems. While historical evidence such as the most recent ice age transition suggests ecosystems have responded to climate change in the past with some maintenance of function, the pace of change projected for this century is faster by several orders of magnitude than that of the ice age transition, which occurred over many thousands of years. Current habitat fragmentation due to human land use will make species dispersal more difficult. The human spread of invasive species also will complicate ecosystem-level adjustments to climate change in some areas. There is a lack of reliable information regarding the future resilience and capacity of ecosystems to maintain function through replacement of lost species by new species with similar function, or through redundancy of function among the species currently present.

The general lack of certainty regarding the broader effects of climate change on ecosystem function is not meant to suggest these impacts can be ignored. Impairment or loss of ecosystem services in the future could have profound effects on human health and on local and regional economies. Identifying reliable indicators of such impacts should be a high priority for

future climate change research and assessment (see also Knowledge Gaps, section 6.6.3, below).

6.6.2 Adaptation Options

The context for adaptation will be one of uncertainty, not only about the climate but also about the degree to which observed species and ecosystem changes are due to climate versus other factors, such as land-use change and human transport of invasive species. Also, management interventions can be expensive, and there is limited experience and only a few historical examples of success in controlling species declines or invasions. Based on current knowledge, some adaptation strategies for specific land and aquatic vulnerabilities are as follows (see also **Table 6.4**):

- Maintain healthy ecosystems more tolerant or better able to adapt to climate change by minimizing other stressors (e.g., invasive pests, acid rain).
- Manage primarily for important ecosystem services and biodiversity rather than attempting to maintain indefinitely the exact mix of species present today.
- Facilitate natural adaptation to climate change by minimizing habitat fragmentation and protecting stream (riparian) zones and other avenues for dispersal and migration of species adjusting to changes in the climate. Policies to encourage the development or maintenance of migration or dispersal corridors should be a high priority. Protection and expansion of riparian zones will serve this need and have many other positive co-benefits, such as flood and erosion control. Policies will need to address human land-use patterns and the challenge that more than 90 percent of New York forests are privately owned.
- Institutionalize a comprehensive and coordinated monitoring effort at multiple scales to track species range shifts and indicators of habitat and ecosystem responses to climate change. Identifying and prioritizing what to monitor and, in some cases, developing new indicators, will be required. Land managers, policy-makers, and other potential users should play a central role in developing plans for research, data synthesis and format, and mechanisms for data dissemination.
- Develop or modify processes and criteria for prioritization of management interventions in the context of a changing climate. Decisions at small

spatial scales can often be made by land managers, but those with ecosystem and large geographic range implications will involve policy decisions and require inputs from advisory groups such as the New York State Climate Action Council.

- A well-planned, comprehensive educational outreach program is needed. A high-priority sector to target for such a program would be private landowners and land managers, but all sectors of society will benefit from sound information on climate change science, potential impacts on natural areas, and implications for ecosystem services affecting human communities.
- Industries and supporting agencies should be poised to take advantage of any benefits from climate change in New York State. Examples include the possible increase in productivity of some northern hardwood forests and an extended summer outdoor recreation season.

6.6.3 Knowledge Gaps

The capacity of resource managers to facilitate ecosystem adaptation to rapid climate change is uncertain. A concern is that, to date, prior to the confounding effects of climate change, there has been only limited success with management interventions attempting to control species declines or invasions, or undesirable damage by individual species. Many potential management interventions for coping with climate change exist, but most of these have not been tested on a wide scale, and some are controversial even among experts in the field. Following are some examples of research needs to improve climate change ecosystem impact assessments and build adaptation capacity:

- Develop reliable indicators of climate change impacts on biodiversity and ecosystem functions, and cost-effective strategies for monitoring these impacts.
- Design management interventions to reduce vulnerability of high-priority species and communities, and determine the minimum area needed to maintain boreal and other threatened ecosystems.
- Evaluate techniques for rapid and reliable assessment of vertebrate abundance at the landscape scale.
- Improve the techniques used to identify and target invasive species likely to benefit from climate change.

- Create citizen science programs that can provide accurate and reliable data on change in species distributions and movements.
- Focus climate science research on the potential for changes in variability and on the frequency and probability of clustering of extreme events, which can have widespread impacts on ecosystems.
- Develop better spatial resolution of climate projections for land managers, encompassing even microclimate effects.

Case Study A. Hemlock: Cascading Effects of Climate Change on Wildlife and Habitat

Characteristically shaded and cool, hemlock forests are highly valued for their aesthetic qualities as well as the unique wildlife habitat they provide. The eastern hemlock (*Tsuga canadensis*) is the single most prevalent conifer species in New York State. It adds structural diversity to the state's forest habitats, provides winter thermal cover for a variety of wildlife, shades and maintains lower water temperatures in streams, and serves as an important food source for many animals.

According to the U.S. Forest Service Climate Change Atlas, habitat suitability for the eastern hemlock is expected to decline in New York as a result of climate change, primarily in response to warmer projected average July temperatures as well as other factors (United States Forest Service, 2011). The extent of these changes depends largely on emission levels over the next century, with less dramatic changes under a low-emission scenario.

The effects of climate change on hemlock forests is further complicated by the spread of the hemlock woolly adelgid (*Adelges tsugae*). A small, aphid-like invasive insect from Japan, the hemlock woolly adelgid first arrived in Virginia in the 1950s and in New York State in 1985. The adelgid is now well established and recently spread to the central part of the state (**Figure 6.8**), in part due to warmer winter temperatures that are allowing the insect to survive. Hemlock mortality is already occurring in the southeastern parts of the state. However, it is uncertain how quickly mortality will occur in more northern and western parts of New York State. While trees in the southern part of the hemlock's range die within a few years following infestation, trees

in the north may live for 10 years or more. Though scientists are working on ways to combat this pest, currently there is no way to prevent its spread or its effects. Extensive loss of hemlock forests will have cascading, far-reaching effects on a variety of wildlife species within New York State.

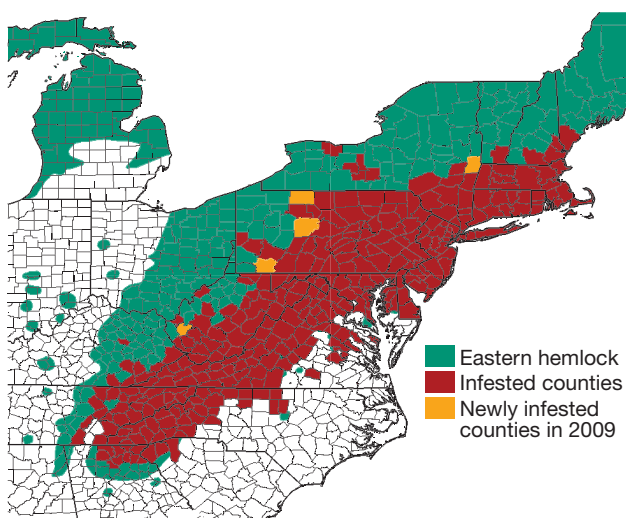
One group of wildlife with a high probability of being affected is New York's stream salamanders. Hemlocks often grow in riparian zones adjacent to our headwater streams. Widespread mortality of hemlock in these areas will lead to erosion and sedimentation, decreased shading, warmer water temperatures, and lower dissolved oxygen levels. These changes are likely to lead to the loss of quality stream and streamside habitat for species such as the spring salamander (*Gyrinophilus porphyriticus*), which completes its entire lifecycle in highly oxygenated, coldwater streams, as well as the two-lined (*Eurycea bislineata*) and northern dusky (*Desmognathus fuscus*) salamanders, which find refuge under the forest cover adjacent to streams.

The eastern hemlock also has unique structural characteristics that provide important habitat for many birds. Ninety-six bird species are associated with hemlock forest types in the northeastern United States (Yamasaki et al., 2000). Although none of these birds is

limited only to hemlock forest, a number of species are strongly associated with this forest type. The black-throated green warbler (*Dendroica virens*), Acadian flycatcher (*Empidonax virens*), blackburnian warbler (*Dendroica fusca*), hermit thrush (*Catharus guttatus*), and solitary vireo (*Vireo solitarius*) are strongly associated with intact hemlock stands during the breeding season (Tingley et al., 2002; Yamasaki et al., 2000). During the winter, others benefit from hemlock forests as well as the presence of individual trees or clumps of trees contained within other forest types. Ruffed grouse (*Bonasa umbellus*) and wild turkey (*Meleagris gallopavo*) often roost in hemlocks under the protection of the thermal cover they provide. The great horned owl (*Bubo virginianus*), barred owl (*Strix varia*), and goshawk (*Accipiter gentilis*) use hemlock branches as hunting perches. Eastern hemlock trees provide an important winter seed source for pine siskin (*Carduelis pinus*), goldfinch (*Carduelis tristis*), evening grosbeak (*Coccothraustes vespertinus*), and others.

Some mammals, such as the red squirrel (*Tamiasciurus hudsonicus*), also benefit from the food provided by hemlock seeds. Other small- to mid-sized mammals that prefer hemlock include the snowshoe hare (*Lepus americanus*), deer mouse (*Peromyscus maniculatus*), southern red-backed vole (*Clethrionomys gapperi*), and porcupine (*Erethizon dorsatum*). Hemlock trees with internal cavities are an important source of summer roosts for forest bats such as the hoary bat (*Lasiurus cinereus*). Four carnivore species—red fox (*Vulpes vulpes*), black bear (*Ursus americanus*), marten (*Martes Americana*), and bobcat (*Lynx rufus*)—also have some seasonal preference for hemlock forest (Yamasaki et al., 2000).

Loss of hemlock cover may significantly affect the future occurrence and distribution of wildlife across the state. In the near term, the most vulnerable areas of the state are those where hemlock is abundant and where increased average January temperatures are expected to allow for more rapid rates of adelgid infestation (Paradis et al., 2008). Replacement of hemlock forests will be complicated by other wildlife-related issues. For instance, in New Jersey and Pennsylvania forests where high levels of hemlock mortality overlapped with high deer densities, invasive species were more likely to take hold (Eschtruth and Battles, 2009). Adapting to forest changes resulting from hemlock woolly adelgid will require attention to direct effects as well as other interacting factors.



Note: The native range of eastern hemlock is shown in all colors but white. The color scheme distinguishes counties where hemlocks currently are uninfested by the hemlock woolly adelgid (green) from those with severe and prolonged infestation (red). Newly infested counties (orange) are mostly along the northern boundaries of the infested zone, and warming temperatures may be playing a role in the further expansion of the insect range. Source: U.S. Forest Service, Northeastern Area State and Private Forestry, Forest Health Protection Program.

Figure 6.8 Counties with existing and new infestations of hemlock woolly adelgid as of 2009²

iMap Invasives is an online, GIS-based, invasive species mapping tool (<http://imapinvasives.org>). This website now provides real-time information on the locations of numerous invasive species in New York State and allows individuals to report new locations of invasive pests. Private landowners, volunteers, and State and federal agencies all can play a role in monitoring for the hemlock woolly adelgid.

Adaptations for dealing with hemlock woolly adelgid include monitoring the spread of hemlock woolly adelgid and its impacts on forests and dependent wildlife species, education on control options as they emerge, and managing to reduce other stressors currently affecting hemlock forests, including overabundant deer populations and invasive plant species, both of which threaten forest regrowth following hemlock mortality.

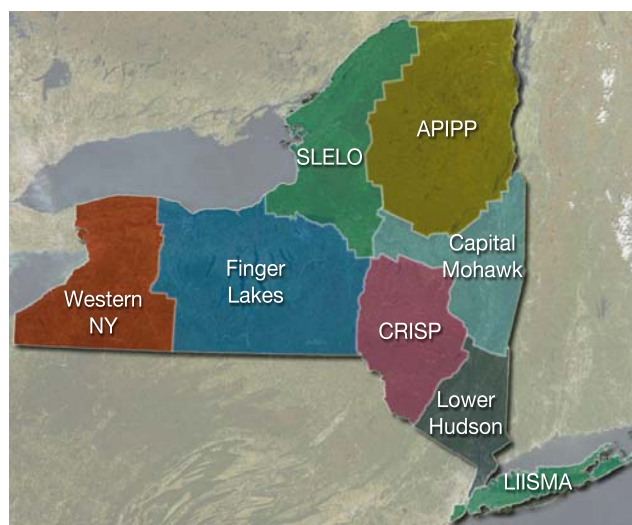
Case Study B. Creative Approaches to Monitoring and Adaptive Management: New York's Invasive Species Program as a Model

The comprehensive adaptive management approach New York State has employed toward invasive species may serve as a useful model for adaptation to a wider range of emerging climate change challenges. The State's invasive species program provides a framework for coordination among local, State, and regional efforts; a broad educational outreach program; and research, information management, and regulatory policy recommendations.

In 2003, Governor George Pataki signed legislation convening the Invasive Species Task Force (ISTF, Laws of New York, 2003; Chapter 324). The Task Force was composed of representatives from diverse stakeholder groups, including key State agencies, environmental advocacy and non-profit organizations, academia, and trade and industry groups. In November 2005, the Invasive Species Task Force released a final report that outlined the invasive species problem, identified existing efforts and, most significantly, provided 12 strategic recommendations for action (ISTF, 2005). These recommendations have been codified into New York State law (Laws of New York, 2008; Chapter 26) and have significant funding from the state's Environmental Protection Fund.

To coordinate all invasive species efforts at the State level, a permanent leadership structure, which was modeled after the federal approach to invasive species, was established. It consists of an agency executive-level council and an advisory committee of non-government stakeholders. The council, advisory committee, and day-to-day statewide coordination are supported by the Office of Invasive Species Coordination at the Department of Environmental Conservation.

Building on existing grassroots partnerships that formed to address local invasive species concerns, the Invasive Species Task Force recommended the formation of eight Partnerships for Regional Invasive Species Management (PRISMs) (Figure 6.9). These partnerships coordinate local invasive species management functions, including engaging partners, recruiting and training citizen volunteers, delivering education and outreach, establishing early-detection monitoring networks, and implementing direct eradication and control efforts—all within the context of the local landscape. The Adirondack PRISM, also known as the Adirondack Park Invasive Plant Program, has served as a successful model for the other PRISMs, delivering educational programs and coordinating volunteer monitoring programs for terrestrial and aquatic invasive species since 1998 (<http://www.adkinvasives.com>). Due to the State fiscal crisis, most PRISMs have not yet received intended State funds, but do benefit from voluntary



Note: Abbreviations are as follows: APIPP—Adirondack Park Invasive Plant Program; CRISP—Catskills Regional Invasive Species Partnership; LIISMA—Long Island Invasive Species Management Area; SLELO—St. Lawrence – Eastern Lake Ontario. Source: Brad Stratton, The Nature Conservancy.

Figure 6.9 The eight Partnerships for Regional Invasive Species Management (PRISMs)³

coordination and the in-kind support of partners. A strong communication network has also developed within and among PRISM partners to share educational resources, promote outreach events, and rapidly disseminate information about new invasions.

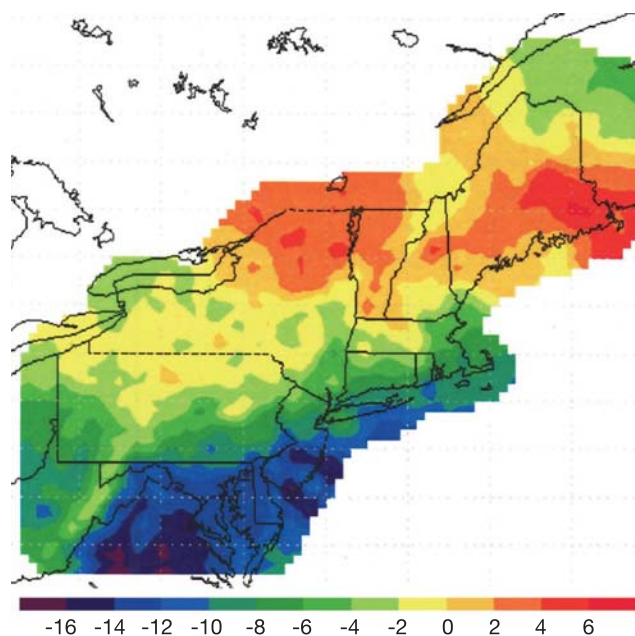
Other key Invasive Species Task Force recommendations now implemented as part of the State invasive species program include the following:

- The New York Invasive Species Research Institute, located at Cornell University. This group serves the scientific research community, natural resource and land managers, and State offices and State-sponsored organizations by promoting information-sharing and developing recommendations and implementation protocols for research, funding, and management of invasive species (<http://nyisri.org>).
- Use of iMapInvasives, an online, GIS-based, all-taxa invasive species mapping tool, coordinated by the New York Natural Heritage Program. The tool aggregates species records and locations from new observations and previously existing databases to provide a real-time, fully functional tool to serve the needs of volunteers and professionals working to manage invasive species (<http://imapinvasives.org>).
- The New York Invasive Species Information Clearinghouse, which is coordinated by the New York Sea Grant and Cornell Cooperative Extension. The Clearinghouse website is a comprehensive, online information portal (<http://nyis.info>) that provides stakeholders with links to scientific research, State and federal invasive species management programs and policy information, outreach education, and grassroots invasive species action in and around New York.

Case Study C. Maple Syrup Industry: Adaptation to Climate Change Impacts

Production of maple sugar products is based on sap flow from maple trees caused by positive internal sap pressures. These pressures are mostly from a physical process caused by freezing and thawing of a tree's woody tissues (Tyree, 1983). One analysis used historical data and climate models for individual states to project maple distribution and sugar production (Rock and Spencer, 2001). The study predicted an end to both the presence of sugar maple and to the maple industry in

the northeastern United States by the end of this century. Another analysis, which used historical data from four northeastern states, concluded that, over the past 30 years, trees are being tapped for sap increasingly earlier and that sap flow is also ending earlier (Perkins, personal communication). The sap flow season is becoming shorter; the movement of the end of the season to earlier in the year is outpacing its earlier onset. A more recent study coupled a simple model for sap flow with downscaled global climate model results to project the number of sap flow days during the spring period and annually for about 10,000 locations across the northeastern United States (Skinner et al., 2010). This fine-scale analysis revealed that different parts of New York are likely to experience different impacts of climate warming on sugar production (**Figure 6.10**). Areas in New York at lower elevations and in southern counties have fewer days with freezing temperatures. In these areas, climate warming will force a continuing decrease in freezing temperatures with a resulting loss of sap production. In contrast, cooler parts of the state, at higher elevations and in northern New York, currently have fewer thawing days. The model predicts that, with warming, the number of days with sap flow will initially increase in these areas through the end of this century,



Note: The average change shown here is based on climate projections from the HadCM3 climate model (one of the 16 used in ClimAID), using the B1 emissions scenario. Northern areas in New York show an increase in sap flow days and southern areas a small decrease. Source: Based on data from Skinner et al., 2010

Figure 6.10 Average change in the total number of days (see color-coded scale at bottom) of modeled sap flow per season comparing the 1969–1999 historical climate data with projections for 2069–2099 period

followed by a decrease of days with sap flow with further warming after the end of this century. This analysis also shows that the sap flow season is moving earlier in the year such that by the end of the century tapping will begin in January rather than March. Eventually, it will merge with temperature conditions in November and December that are favorable for sap production.

Contrary to the prediction that the maple industry in New York will disappear by the end of the century (Rock and Spencer, 2001), this ClimAID analysis suggests that with adaptation to climate change the industry can remain viable for at least the next 100 years. There are several approaches to adaptation:

- 1) *Maintain attention on tree health through good forest management.* Competition from other tree species and pest impacts can be substantially reduced by existing management options. Research projects are under way to examine the optimal tree spacing for maximal growth and sugar production. Effective methods to control competing woody vegetation are also being studied.
- 2) *Begin tapping trees earlier in the year.* It is both essential and possible to move the sap production period to earlier in the season as the climate warms. Maple producers already pay considerable attention to weather forecasts to determine when to begin tapping. One analysis mentioned above (Skinner et al., 2010) predicts that the loss of production could amount to 14 days, if tapping begins at traditional times; normal seasons are 24 to 30 days long. If tapping begins earlier, there could be no net loss in number of sap flow days in warmer areas and there could be a net gain of sap flow days in cooler areas.
- 3) *Increase the sap yield from trees.* Recent research regarding why tap holes “dry up” has led to the introduction of a new type of spout. The main cause for loss of production from a tap hole relates to microorganisms plugging the xylem elements, which are the water-conducting elements of the tree. This is accelerated by increases in temperature and, thus, could be affected by a warming climate. The new spout has a check valve that prevents backflow of sap from the tubing into the tree, thus reducing the rate of microbial plugging. Initial results show a substantial production increase that could offset declining production from climate warming.
- 4) *Bring more maple trees into production.* One study, which uses U.S. Forest Service Forest Inventory

Analysis data, estimates that in New York there are about 138 million sugar and 151 million red maples that are the correct size for tapping (Farrell, 2009). About 0.5 percent of these are currently used in sugar production. Vermont taps about 2 percent of its potential trees; Quebec taps about 30 percent of its trees. Thus, the potential to compensate for loss of production by bringing more trees into production and better utilizing red maples is enormous. Increasing the number of trees tapped seems to be occurring in response to economic incentives, as the price of syrup has increased dramatically in recent years.

- 5) *Increase use of red and silver maples for sugar production.* Whereas producers are currently tapping roughly 80 percent of the sugar maples on their own property, they are only using 20 percent of the available red maples (Farrell and Stedman, 2009). One of the main objections to using red and silver maples has been the lower sugar concentrations in the sap. However, with increased use of reverse osmosis to remove 80 to 90 percent of the water before boiling, this concern is not as great as it once was. Red maple (*Acer rubrum*) has a broader environmental tolerance than does sugar maple and is becoming the dominant tree species throughout the Northeast. It will be affected less by climate warming and tends to grow faster than sugar maple on a variety of sites. Thus, even if sugar maple disappears from New York's forests, syrup production could continue with better use of red maples.

Case Study D. Brook Trout: Reduction in Habitat Due to Warming Summers

The historical abundance of brook trout, New York's state fish, is likely to be severely reduced by climate warming, since it is currently located near the southern extent of its habitable range.

To examine the effects of regional warming on brook trout populations, three classes of water bodies in the Adirondack region were considered by ClimAID: 1) unstratified lakes, which have extensive water mixing during the summer and minimal temperature gradients with depth, 2) stratified lakes, which have deep zones that remain cold and unmixed with surface waters throughout mid-summer, and 3) streams and rivers.

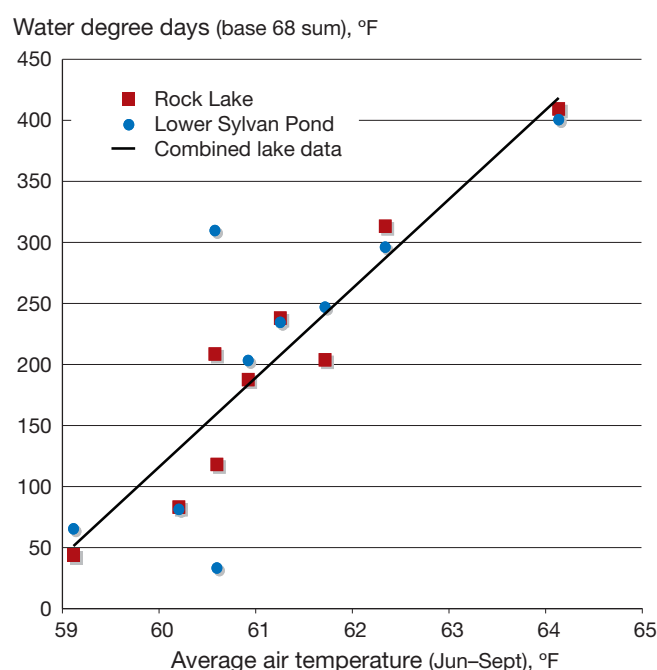
Details of the analysis, including economic and social equity issues are provided below.

Unstratified Lakes

Primary findings are that brook trout in unstratified lakes, which represent about 41 percent of brook trout lakes in the Adirondacks (Scofield et al., 1993), will be most vulnerable to continued warming associated with climate change because of the lack of cold water refugia. Brook trout in streams and rivers will also be vulnerable, but may be less vulnerable than those in unstratified lakes. Least vulnerable will be those brook trout in stratified lakes where large, deep coldwater refugia are maintained (e.g., Great Lakes, Finger Lakes). However, the deep coldwater refugia in large stratified lakes can become oxygen depleted, and this stress may be

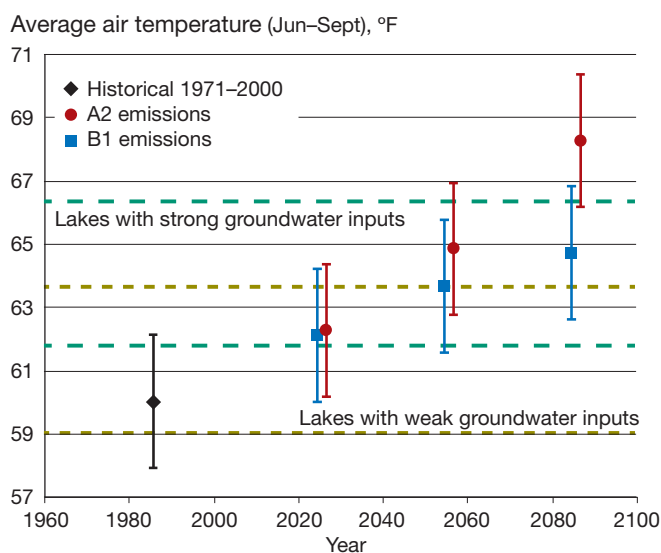
exacerbated in many lakes by the lengthening summer season as a result of global warming.

A brook trout seasonal heat-stress index (Robinson et al., 2008 and 2010) was developed based on Rock Lake, an unstratified lake in the Adirondacks. The index uses a water degree-day metric that sums daily average lake-bottom temperatures above 68°F (e.g., a daily water temperature of 67°F would contribute 0 to the total, 68.5°F would contribute 0.5, and 71°F would contribute 3 degree-days). Annual reproductive success correlates with cumulative water degree-days over the summer ($r^2 = 0.85$). Reproductive success drops to zero at a water degree-day value of 365, i.e., years in which the average temperature at the lake bottom is much higher than 68°F for prolonged periods. Full mortality of the oldest age classes of brook trout was also observed in years with this heat index level. **Figure 6.11** illustrates that, for this class of unstratified lakes, the average air temperature observed from June 1 to September 30 accurately predicts lake temperature water degree-days. This is important because it indicates that climate model projections of air temperature can be reliably



Note: Water degree days are a measure of predicted temperature stress on brook trout that takes into account both the amount of warming on single days and the total amount of time spent at the high temperatures (see text for more details). The y-axis is calculated from daily water temperature data throughout the summer using temperatures at maximum lake depths—6 meters (about 20 feet) for Rock Lake and 4 meters (about 13 feet) for Lower Sylvan Pond. Air temperature data are taken from the nearby Indian Lake weather station and daily values have been averaged into seasonal values on the x-axis. The regression line shown is fit to all data from both lakes and shows that the seasonal stress index can be accurately predicted from the average summer temperature of the air. Brook trout are predicted to be free of high temperature stress (degree days = 0) when average summer air temperature is below 58.4°F, and increases by 73 degree days for every one degree rise in the average summer temperature.

Figure 6.11 Cumulative water degree days related to seasonal air temperature for two Adirondack lakes: Rock Lake and Lower Sylvan Pond



Note: Temperature projections for the lower-emissions B1 scenario and the higher-emissions A2 scenario by year, for the Adirondacks region. Projections are based on the B1 and A2 greenhouse gas emissions scenarios as indicated in the legend and utilizing five global climate models (GFDL, GISS, MIROC, CCSM and UKMO), a subset considered broadly representative of the full suite of 16 GCMs used by ClimAID. The green and brown horizontal lines represent the upper and lower boundary of the air temperature range where injury to brook trout will occur for unstratified lakes with strong groundwater inputs (green) and weak groundwater inputs (brown). Air temperatures exceeding the upper boundary of either range would lead to complete mortality for that lake class.

Figure 6.12 Climate projections for air temperatures under two emissions scenarios and potential damage to brook trout populations

used as indicators of trends in water temperature for unstratified lakes in the region.

Figure 6.12 illustrates the summer air temperature changes predicted for the Adirondack region for two different greenhouse gas emission scenarios and the effect this is likely to have on brook trout reproduction and survival. The lower threshold is the temperature where negative effects on brook trout reproduction would first be detected and the upper threshold is the temperature at which there would be complete elimination of reproduction and lethal effects on adult fish. The lower and upper thresholds for two unstratified lakes with differing levels of cold groundwater inputs are compared (groundwater inputs will have an overall cooling effect). The magnitude of groundwater inputs is controlled by soil depth in the surrounding basins, as determined by the thickness of till from past glaciations (Newton and Driscoll, 1990). Rock Lake is an example of an unstratified lake formed in thin glacial till, which results in weak groundwater inputs. Such lakes represent 56 percent of all unstratified Adirondack brook trout lakes. The vulnerability of these lakes to climate change is indicated by brown threshold lines in **Figure 6.12**. Thermal regimes in most years during the historical record from 1971 to 2000 were warm enough to adversely affect reproduction, but even the hottest years would not have caused full adult mortality. In contrast, by the 2020s, the hottest years will produce full mortality. While one single such year in isolation will not extirpate brook trout from a lake (because first-year fish can find thermal refuges in small shoreline groundwater seeps), two or three such years in succession would effectively eliminate all age cohorts. After the 2050s, even the average year will result in lethal temperatures, and brook trout will most likely not be viable in these lakes.

Temperatures monitored in lakes formed in thick glacial till and having high groundwater inputs (e.g., Panther Lake) indicated that cold groundwater was able to reduce average lake temperatures by 3.0°F relative to lakes in areas with thin till. This class represents only 20 percent of all unstratified lakes. The vulnerability of resident brook trout in lakes with high groundwater inputs to climate change is indicated by the green threshold lines in **Figure 6.12**. Under a high emissions scenario, none of these lakes would retain viable brook trout habitat, but under a low emissions scenario lethal temperatures occur in only the most

extreme years, which would allow some brook trout populations to persist.

Stratified Lakes

Deep lakes and lakes with more color from algae and dissolved organic compounds develop a thermocline, which separates warm surface water from cold deeper water (i.e., become stratified). Weakly and strongly stratified lakes represent 59 percent of Adirondack brook trout lakes. Stressful warm temperatures are unlikely to occur below the thermocline in these lakes. However, these lakes are prone to oxygen depletion in deep waters that lack contact with the lake surface (Schofield et al., 1993). Oxygen levels often drop throughout the summer, and this stress may be exacerbated in many lakes by the lengthening summer season under global warming. Such dynamics require further study to determine how many lakes may develop serious oxygen deficiencies in the zones favorable to coldwater fish.

Rivers and Streams

Finally, rivers and streams make up a large fraction of the Adirondack waters fished for trout, though many of these bodies are stocked with hatchery-reared brown trout. One study, which examined brook trout that were released into a fifth-order river with radio transmitters and temperature sensors, showed that brook trout maintained body temperatures that averaged 4°F cooler than the temperature of the bulk river water; this difference increased to more than 7°F during periods when bulk river water was more than 68°F (Baird and Krueger, 2003). The brook trout were able to maintain lower body temperatures than that of the bulk river water by using cool refuges where tributary streams fed the larger river or pool bottoms were fed by groundwater seeps. Studies such as this emphasize the ability of brook trout to use thermal refugia when available. These studies also indicate, however, that bulk river temperatures are similar to the unstratified lakes discussed above and already are crossing thermal stress boundaries in mid-summer, with possible effects on brook trout reproduction success and adult mortality. Another study showed a similar pattern by which stocked brown trout also used thermal refuges during mid-summer in the Hudson River upstream from North Creek (Boisvert, 2008). Both surface-flow waters (e.g.,

where tributary streams feed the larger river) and groundwater seeps will increase in temperature with regional warming, and many rivers are likely to become too hot for brook or brown trout. More thermal monitoring is needed to define the prognosis for Adirondack rivers through the coming century.

Groundwater seeps are crucial to the thermal properties of the thick-till lakes discussed above and for the presence of thermal refugia in rivers and streams. Leaving aside the direct effects of climate change on air temperatures, groundwater supply is likely to become less reliable in the Adirondacks as global warming progresses. While the Adirondacks is likely to remain the wettest region of the state, it may nonetheless experience greater and more frequent levels of soil drying in the coming century. As a result, it may have a decrease in the abundant groundwater resource that supports thermal refugia.

Adaptation Options

Possible adaptations to ameliorate rising temperature effects on brook trout include maintaining or increasing vegetation that provides shade along stream, river, and lake shorelines, and minimizing disturbances that would impede water flows and groundwater inputs. More elaborate interventions for high-priority regions could include piping cold water from springs or lakes located at higher elevations to shoreline locations of thermally stressed lakes, and manipulations that might darken the “color” of the water in order to darken the propensity to form stable thermal stratification. Adding lime to some Adirondack lakes has already been practiced to partially compensate for pollutant acidity and promote primary production; primary production and a healthy level of natural algae also tends to darken water color and, thus, also shades the depths and promotes thermal stratification. This practice has not been approved in the context of thermal modification and could only be implemented if justified by further evaluation and after lake policy review.

Economics, Equity, and Environmental Justice Issues

Trout fishing is prominent in most of the state’s major fishing areas, and trout is the second most popular group of species for recreational fishing in the state after

black bass (Connelly and Brown, 2009a). To highlight the economic and equity issues associated with possible reduction of brook trout with climate change, a geographic region in the Adirondacks where brook trout are a key species for recreational fishing is analyzed (**Figure 6.13**). As described in Chapter 3 (“Equity and Economics”), the economy of the Adirondacks region depends heavily upon natural resource-related activities and tourism. Among the counties in the case study region, Herkimer, Lewis, and St. Lawrence are especially dependent on natural resources and agriculture as a share of total county employment (see Chapter 3, **Figure 3.4**). It also is important to note that all counties in the Adirondacks region have relatively high poverty rates and lower median income levels than the state overall (see Chapter 3, **Figures 3.1** and **3.2**), suggesting that these regions may face significant challenges adapting to all types of climate-change-related stresses.

Concerning fishing-related economic activities, **Figure 6.14** illustrates total fishing-related expenditures across all counties in New York in 2007 for all fish species. The map reveals that nearly all counties in the state benefit from fishing-related revenue, but counties in the case study region generally tend to have higher fishing-related expenditures than other counties. As illustrated in **Figure 6.15**, which estimates expenditures related specifically to trout fishing (based on estimates of percentage of angler days devoted to trout), trout represent an important component of fishing-related expenditures in the case study region. While the data used to construct **Figure 6.15** combine brook, brown,

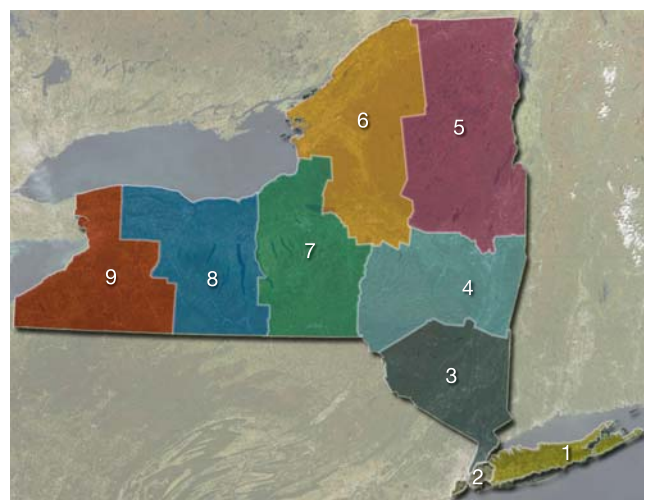


Figure 6.13 New York State Department of Environmental Conservation fishery management regions used for regional classification; the Adirondacks are located within regions 5 and 6

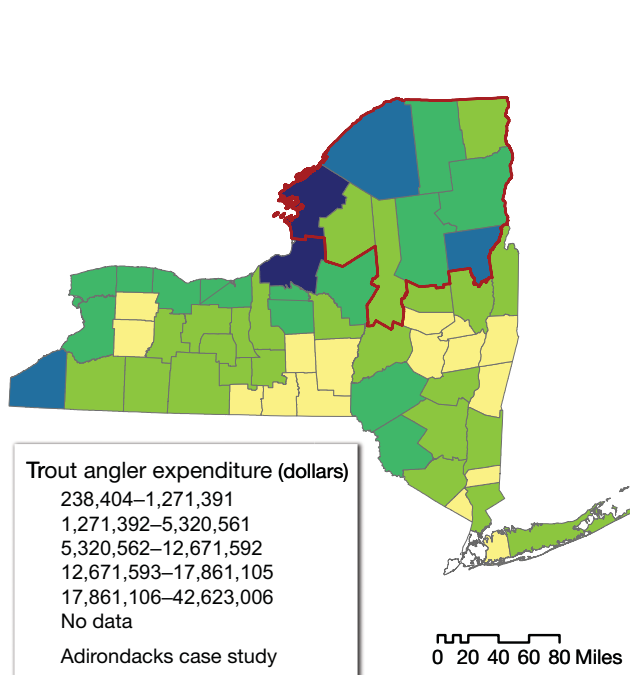
and rainbow trout, brook trout represent the most popular species of trout for anglers within the Adirondacks region. Moreover, anglers who are fishing specifically for brook trout are often willing to travel significant distances to lakes where this species is plentiful. Although other species are likely to replace brook trout under warmer temperatures, such species (e.g., bass) may not have the same type of appeal for out-of-town anglers—and particularly out-of-state anglers—who are willing to travel to the region for brook trout, but who would be able to fish for warm water species, such as bass, in areas closer to home.

Total expenditures in New York by anglers fishing in the Adirondacks case study region was estimated at \$112 million in 2007 (**Table 6.5**) (personal communication, Nancy Connelly, based on 2007 New York Statewide Angler Survey). To determine how much of this was associated with the trout lakes identified above as being most vulnerable to loss of brook trout, this analysis assumes the following: 1) the fraction of the total expenditure related to trout fishing is proportional to the days spent fishing for trout (32.2 percent), and 2) trout fishing is equally divided in the Adirondacks between rivers and lakes. Together, there was an estimated \$17.8 million in economic activity in 2007 associated with fishing for trout in Adirondack lakes. Forty percent of these lakes have been identified above

as unstratified lakes, which are likely to lose their brook trout populations by the 2050s. The loss of brook trout in these lakes is associated with a total economic activity loss of \$7.2 million annually, of which \$4.8 million is spent at or near the fishing locations. Brook trout in summer-stratified lakes and in the river and stream systems are also threatened by rising temperatures as previously discussed, but specific predictions for these trout are not yet available.

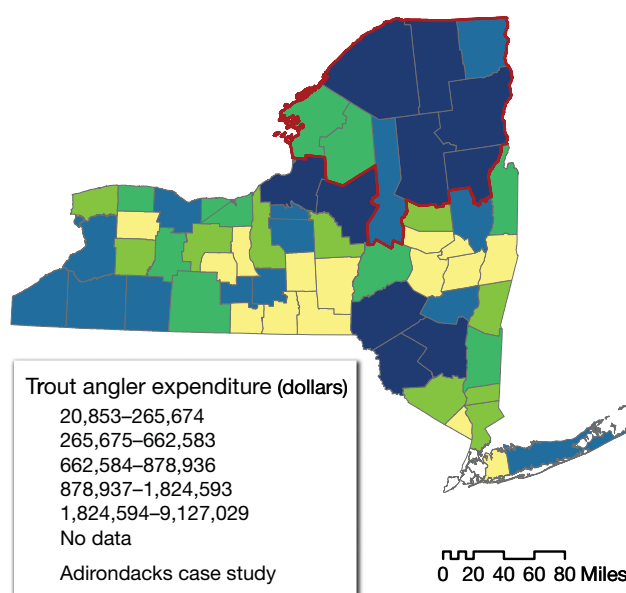
The counties within the case study region may be especially vulnerable to loss of tourism revenue, as each has a significant presence of anglers from other regions in the state as well as from other states. Nearly half of the total angler days spent in the region are accounted for by anglers who live outside the region (**Table 6.5**). In terms of fishing-related expenditures within the region, which were estimated at approximately \$74.5 million in 2007, local expenditures by anglers from other regions in the state and out-of-state regions represented more than 85 percent of this total (**Table 6.5**). The loss of revenue that is associated with anglers from other regions and states would represent a significant economic blow to the area's tourism-related industries, such as hotels, gas stations, and restaurants.

While loss of brook trout would hurt the region's fishing economy overall, such losses may have a



Source: Connelly and Brown (2009b) Statewide Angler Survey, NYSDEC

Figure 6.14 Total angler expenditure by county



Note: Total fishing expenditures in the survey were translated into an estimate of expenditures for trout fishing by assuming that the percent of days spent fishing for different kinds of fish was equal to the percent of expenditure attributable to each kind of fish. Source: Connelly and Brown (2009b), Statewide Angler Survey, NYSDEC (authors' calculations)

Figure 6.15 Angler expenditure by county for trout fishing

Residence Areas of Anglers	Angler days		At-location Expenditures		En-route Expenditures	
	Number	Confidence limit $\pm$	1,000s of \$	Confidence limit $\pm$	1,000s of \$	Confidence limit $\pm$
Total	2,912,938	200,203	\$74,564	\$6,613	\$45,464	\$4,761
Live in selected Adirondack region	1,241,905	150,836	\$10,602	\$2,601	\$6,761	\$1,431
Regions 5, 6—outside selected region	380,184	58,798	\$6,878	\$1,743	\$5,030	\$1,129
Regions 1, 2	59,995	9,826	\$4,199	\$1,551	\$1,325	\$292
Regions 3, 4	421,745	60,643	\$14,698	\$3,231	\$9,762	\$2,602
Regions 7, 8, 9	509,327	80,505	\$17,763	\$2,930	\$11,902	\$2,511
Out-of-state	299,794	36,001	\$19,455	\$3,134	\$9,012	\$2,256

Note: The selected Adirondack region was defined as the Department of Environmental Conservation regions 5 and 6, not including Washington, Saratoga, Fulton, and Oneida counties and not including fishing effort originating in the region on Lake Ontario, Lake Champlain, and the St. Lawrence River.

Table 6.5 Estimated number of angler days with at-location and en-route expenditures for fishing in the selected Adirondack region in 2007

disproportionate effect on small, fishing-dependent communities. Those areas that are dominated by unstratified lakes (which are likely to lose all of their trout) may also be particularly hard hit. Within fishing communities of the region, smaller tourism operators (e.g., fishing guides) may be most affected. They are likely to have limited ability to withstand any reduction in angler visits and may have limited capital to shift to other types of recreational businesses. Small, independently owned restaurants and hotels may be similarly vulnerable to reductions in angler expenditures by those living outside the region.

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Appendix A. Stakeholder Interactions

The Ecosystems team gathered information and enlisted participation from key stakeholders in this sector through existing relationships and collaboration with the New York State Department of Environmental Conservation; other State and federal governmental organizations (e.g., U.S. Geological Survey, U.S. Fish and Wildlife Service); Cornell Cooperative Extension (natural resources specialists); non-governmental organizations (e.g., The Nature Conservancy, National Wildlife Federation, Audubon NY, Wildlife Conservation Society, Adirondack Mountain Club); business associations (e.g., New York Forest Landowners Association, Empire State Forest Products Association, Olympic Regional Development Authority); land, fish, and wildlife managers; and maple growers.

Meetings and Events

On December 8, 2008, a meeting was held with over 50 stakeholders, including representatives of State and federal government organizations, leaders of non-government organizations, leaders of recreational-user organizations, representatives from affected industries, and academics. After a series of presentations, there was a two-hour breakout session with small groups. Each group provided its input regarding high-priority vulnerabilities and potential opportunities; feasible adaptation strategies; and needs for additional information, decision tools, and/or resources to help stakeholders cope with climate change and protect the state's natural resources. These data were summarized and sorted into groups of statements with thematic similarity, and contributed to the development of the chapter.

On August 6, 2009, the Ecosystems and Water Resources sectors and representatives of the ClimAID team at Columbia University met with stakeholders at the New York State Department of Environmental Conservation headquarters in Albany for an all-day workshop. This meeting was used to update stakeholders on ClimAID activities and progress and, especially, to collect input on needs and current relevant activities and planning by Department of Environmental Conservation and related stakeholder groups.

On November 6, 2009, an expert panel was assembled to meet with the Ecosystems sector team in Albany to review initial findings and provide suggestions regarding the project. The meeting included introductory presentations, followed by discussions focused on climate factors and key vulnerabilities, adaptation strategies, prioritization, and broad issues and recommendations. The 25 people in attendance included scientists from non-governmental organizations, State and government agencies, and research institutes within the state.

Web-based Survey Tool and Analyses

The results from early-phase stakeholder input were used to create a Web-based survey that cast a wider net among stakeholders and gathered expert opinion regarding the current state of knowledge regarding climate change; evidence of climate change impacts; high-priority vulnerabilities; high-priority climate change factors; importance and feasibility of various adaptation strategies; current efforts to adapt to climate change; research, monitoring, and communication gaps; and needed decision tools (Chatrchyan et al., 2010).

The survey was reviewed by several experts and stakeholders before dissemination in November 2009. The survey was sent to research scientists; land and water resource managers, educators, and others from State and federal government agencies; elected officials; private industry and landowners; non-government organizations; and universities and other research institutes. One section of the survey allowed participants to choose among several areas of specialization: water resources; forests, grassland, wetland, and riparian zones; fish and wildlife; and invasive species.

After survey responses were collected, the analysis characterized how issues were conceptualized by stakeholders and identified issues of priority/importance, using an approach similar to that described by Cabrera et al. (2008). Results were integrated into this report.

Appendix B. Relevant Ongoing Adaptation-planning Efforts

This section discusses ongoing adaptation-planning efforts related to climate change and ecosystems in New York State.

New York State Department of Environmental Conservation 2009 “Climate Change Steering Committee Adaptation Strategy Outline”

In 2009, the New York State Department of Environmental Conservation Division of Fish, Wildlife, and Marine Resources identified a climate change steering committee to initiate the development of an adaptation strategy. The outline of their report, still in progress in 2011, includes sections on the following:

- current trends (observed impacts, other stressors, downscaled climate models)
- vulnerability analysis (exposure, sensitivity analysis, adaptive capacity, levels (e.g., high, medium, low))
- risk assessment
- uncertainties
- forecasted impacts by sector
- prioritized vulnerabilities, habitats, ecosystem processes
- adaptation strategies (planning, acquisition, restoration and management, regulation, incentives, research, monitoring, education outreach)
- data gaps and research needs
- monitoring for adaptive management

New York State Department of Environmental Conservation 2009 Open Space “Climate Change Adaptation Plan”

This report has recommendations specific to riparian buffers and wetlands (11 recommendations), forests (15), climate-smart communities (17), and eight other recommended initiatives.

(<http://www.dec.ny.gov/lands/47990.html>)

U.S. Forest Service “Global Change Research Strategy 2009–2019”

This document by Birdsey et al. (2009) identifies research priorities to:

- enhance ecosystem sustainability (adaptation);
- increase carbon sequestration (mitigation); and
- provide decision support for policymakers and land managers.

A fourth objective of this Forest Service plan is to develop a shared infrastructure for researchers (e.g., strengthen remote sensing, simulation modeling, data management, and delivery capacity) and promote collaboration for research and education outreach to effectively reach natural resource planners and management.

-
- ¹ Areas of increased and decreased lake effect snow are color coded showing inches of water equivalent. A) Weather conditions of wind and temperature gradients identical to an historic event recorded Nov. 9, 2008, but with lake and air temperatures uniformly increased by 1.8°F B) The same conditions as A, but lake temperatures (not air) increased an additional 1.8°F (3.6°F total). Areas of red color show increases in lake-effect snow. These increase with further warming of water temperatures (B).
- ² The native range of eastern hemlock is shown in all colors but white. The color scheme distinguishes counties where hemlocks currently are uninfested by the hemlock wooly adelgid (green) from those with severe and prolonged infestation (brown). Newly infested counties (yellow) are mostly along the northern boundaries of the infested zone, and warming temperatures may be playing a role in the further expansion of the insect range. Source: U.S. Forest Service, Northeastern Area State and Private Forestry, Forest Health Protection Program.
- ³ Abbreviations are as follows: APIPP—Adirondack Park Invasive Plant Program; CRISP—Catskills Regional Invasive Species Partnership; LIISMA—Long Island Invasive Species Management Area; SLELO—St. Lawrence – Eastern Lake Ontario. Source: Brad Stratton, The Nature Conservancy.

Chapter 7

Agriculture

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Introduction

Agriculture is a significant component of the New York economy that includes large wholesale grower-shippers selling products nationally and internationally, a substantial dairy industry, and thousands of small farm operations selling direct retail and providing communities throughout the state 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 state's economy. While climate change will create unprecedented challenges, there are likely to be new opportunities as well, such as emerging markets for new crop options that may come with a longer growing season and warmer temperatures. Taking advantage 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.

7.1 Sector Description

Agriculture, as defined in the ClimAID report, includes livestock, dairy, and crop production, as well as the economically important flower cultivation, nursery, and turf industries. The timber, maple syrup, and fishing industries are not included here; they are covered in Chapter 6 ("Ecosystems") and/or Chapter 5 ("Coastal Zones").

7.1.1 Economic Value

The agriculture sector in New York State encompasses more than 34,000 farms that occupy about one-quarter of the state's land area (more than 7.5 million acres) and contribute \$4.5 billion annually to the state's economy. **Table 7.1** summarizes some recent New York agriculture statistics (USDA, 2007). The annual value of dairy products alone approached \$2.4 billion in 2007. Hay value (primarily realized through sale of milk and livestock) was \$327 million, while New York ranked third nationally in grain silage production with a value of \$262 million. The vegetable industry

Commodity	2007 Value (1,000 dollars)	2007 Harvested Acres (1,000's)	National Rank
Dairy Products	\$2,377,987	N/A	1 (cottage cheese) 3 (milk)
Poultry, eggs	122,643	N/A	26 (poultry) 22 (eggs)
Cattle, hogs, sheep	118,742	N/A	2 (calves) 6 (lambs sheep)
Other	107,927		
Total Livestock	2,727,299		
Apples (fresh)	198,467		
Apples (processed)	50,432		
Apples (Total)	286,000	42	2
Grapes (fresh)	3,600		
Grapes (juice)	25,200*		
Grapes (wine)	14,842		
Grapes (Total)	49,222	34	3
Tart cherries	4,369	1.7	4
Sweet cherries	3,518	0.7	8
Peaches	3,995	1.7	10
Pears	5,120	1.2	4
Strawberries	7,590	1.5	7
Blueberries	3,373	0.7	10
Red raspberries	5,723	0.45	N/A
Other fruits and nuts	4,440		
Total Fruit Crops	373,350	84.25	
Cabbage (fresh)	101,190	12.6	2
Cabbage (kraut)	4,460	2.6	N/A
Sweet corn (fresh)	72,600	27.5	4
Sweet corn (processed)	15,286	17.2*	N/A
Snap bean (fresh)	49,749	9.9	4
Snap bean (processed)	14,990	19.9*	N/A
Pumpkins (fresh)	22,694	6.4	4
Onions (fresh)	94,182	12.3	5
Peas (processed)	9,033	17.4*	N/A
Beets (processed)	1,824	2.4	N/A
Other	189,815		
Total Vegetable Crops	575,823	109.1	
Grain corn	300,355	550	22
Silage corn	262,548	495	3
Potatoes (Total)	64,372	18.3	11
Soybeans	75,212	203	24
Dry beans	8,557	16.5	12
Wheat	29,835	85	31 (winter wheat)
Oats	7,866	60	8
Hay (Total)	322,128	1,360	22
Total Field Crops	1,070,873**	27695	
Floriculture	199,028	N/A	6
Nursery	63,343*	N/A	N/A
Other greenhouse	125,000	N/A	N/A
Total Other	357,661		
Total Livestock & Crops	\$4,454,294	(actual cash receipts)	

* 2006 data (2007 not available).

** Field crop total includes estimated values of silage, hay, and seed corn that was not sold but was used directly for animal and dairy production.

Source: USDA National Agricultural Statistics Service: www.nass.usda.gov/ny

Table 7.1 2007 NY agriculture value, harvested acres, and ranking

contributed \$648 million and the fruit industry more than \$368 million.

New York is the dominant agricultural state in the Northeast and typically ranks within the top five in the United States for production of apples, grapes, fresh-market sweet corn, snap beans, cabbage, milk, cottage cheese, and several other commodities. In addition to many large-scale wholesale operations, small farms throughout the state are vital to the economy of rural areas and fill an important market niche for fresh, high-quality, affordable local produce. About half of all New York farms have sales of less than \$10,000 (www.nass.usda.gov/ny), while 18 percent have sales exceeding \$100,000. This 18 percent accounts for about half of all land area occupied by farms (3.77 million acres).

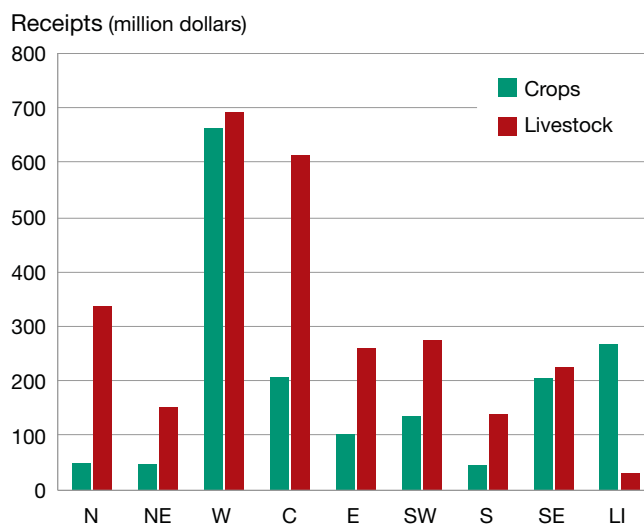
The value of agriculture to the state goes beyond direct farm revenue statistics. For example, a recent analysis of the value of the New York grape and wine industry, which included multipliers such as regional tourism and supporting industries, estimated that the total economic impact of this industry was more than \$6 billion in 2004 (MKF Research, 2005). Also, farm landscapes can be managed in a sustainable manner to provide important “ecosystem services” such as preservation of soil and water resources, habitat to enhance biodiversity, carbon sequestration to mitigate climate change, and a land-

base resource for wind turbine development (Bennet and Balvanera, 2007).

The economic value of the greenhouse/nursery industry is significant, with cash receipts exceeding \$347 million in 2007. Data for turf were not available for 2007, but an analysis of that industry conducted in 2003 by the New York Agriculture Statistics Service found more than 3.4 million acres of turf in the state (82 percent in private residences); more than \$5 billion was spent on maintenance expenses for all turf sectors combined. There were 8,148 “sod” acres devoted to the actual production of turf, employing 140 laborers with a payroll of \$4.2 million and selling a total of 2,226 acres in 2003 at a value of \$14.9 million.

Regional Variation of the New York Agriculture Economy

Agriculture is important throughout the state, including regions near urban centers such as Long Island adjacent to the New York City metropolitan area and the counties near Rochester, Buffalo, Syracuse, and Albany. Farming near these urban centers has unique challenges, including educating the public about farm operations, addressing human health concerns, and changing land values, tax structures, and land-use restrictions. Overall, only a very small fraction of New York State voters are either farmers or directly involved in the agriculture industry. Dairy farms are located throughout the state and are the dominant component of the agricultural economy of many counties in the northern, central, and southern regions (**Figure 7.1**). In some of these more rural regions, a large fraction of the total economy is affected by the fate of the dairy sector. Many dairy farms also produce hay and corn (for grain and silage) and maintain some pastureland to support their own livestock and to sell hay. A large fraction of the high-value fruit and vegetable crops are grown in western New York. Long Island and the Hudson Valley region are also important fruit and vegetable crop areas.



Note: Abbreviations are for counties in geographic areas: e.g., N = Northern, NE = Northeastern, etc. C = Central, LI = Long Island.¹ Source: USDA National Agricultural Statistics Service: www.nass.usda.gov/ny

Figure 7.1 Total cash receipts for crops and livestock in 2007, by region

7.1.2 Non-climate Stressors

Numerous economic and other forces will shape the response of New York agriculture to climate change. Some major trends, like the ongoing consolidation of the dairy industry, have been included in the ClimAID

analysis of climate change impacts. Others, such as changes in market conditions due to altered growing conditions elsewhere, are mentioned briefly but are too uncertain to build into current analyses.

Dynamic Market Demands, Competition, and Economies of Scale

New York farmers are affected by often rapidly changing consumer preferences and demands of supermarket buyers. Increasingly, farmers must consider global market forces and international competition as well as competition from neighboring states. Climate change will exacerbate these challenges. Farmers will have to adapt their own practices to climate change impacts and also will need to assess the effects (either beneficial or detrimental) of climate change on their competitors as well as their competitors' ability to adapt.

The dairy industry at both the state and national levels has been undergoing significant consolidation and other changes in recent years due, in part, to the fact that milk production per cow is increasing more rapidly than demand. Between 1998 and 2007, the average annual milk production per cow in New York rose by 2,624 pounds to a total of 19,859 pounds (www.nass.usda.gov/ny). During this same time interval, the dairy cow population in the state decreased by 16 percent, but the size of an average herd rose from 85 to 110 cows, and total milk production for the state was almost constant at around 12,500 million pounds per year. This continues a linear national trend since 1950 that has resulted in an almost 300-percent increase in milk production per cow, generally fewer cows per state across the country, and yet constant or increased total production (Blaney, 2002).

An analysis for New York (not accounting for possible climate change effects) projected that the state's competitive position will remain strong, but the number of dairy farms would decline from 7,900 in 2000 to 1,800 in 2020, and the average herd will have about 250 cows producing more than 25,000 pounds of milk per cow per year (LaDue et al., 2003). (Current statistics show this projection to be on track with 5,495 dairy farms in 2009 [NYSDAM, 2010]). At the time of that study (2003), large farms in New York were estimated to have an economic advantage, with a 50-cent profit margin per 100 pounds of milk over that of small farms. Although the price of milk has fallen considerably since

then, the same economies of scale are likely to continue the trend toward larger farms. Some factors could potentially constrain the future size of herds, such as increased health risks to the animals and regulations for large operations (LaDue et al., 2003). Numerous ways in which climate change might interact with these trends are discussed in the sections on dairy vulnerability (7.3.5) and adaptation (7.4.1), and in Case Study D. Dairy Heat Stress.

Changes in some sectors of the horticulture industry (such as apple production) have included a shift in structure from primarily mid-sized farms to a bimodal distribution structure that includes large commodity-style and small diversified farms. This has been driven by the rise of local marketing that has occurred simultaneously with some producers entering global markets. The New York wine grape industry has experienced rapid growth in recent decades, despite winter cold limitations on growing some popular non-native European wine grapes. The industry has focused on more cold-hardy varieties such as Riesling and hybrid grapes. A warming climate will provide new opportunities and challenges for grape growers (see Sections 7.3.5 and 7.4.2, and in Case Study A. Frost Damage to Grapes).

Rising Energy Costs, Renewable Energy, and Emerging Carbon Markets

Like farmers elsewhere, New York farmers have been faced with highly volatile and rising energy costs and inputs that are sensitive to energy prices, such as nitrogen-based fertilizers. This makes business planning and maintaining profit margins difficult. New York energy prices are higher than in some states, affecting the competitive ability of New York farmers. It is quite difficult to predict future energy prices and the effect that future government policies might have on the price of carbon-based fuels. On the benefit side, incentives and low-cost loans for expanding the use of renewable-energy sources, and emerging carbon markets (e.g., receiving carbon "offset" payments for agriculture practices that sequester more soil carbon or reduce greenhouse gas emissions), could create important new economic opportunities for farmers and buffer them from the detrimental effects of rising energy costs. The use of farmland and marginal woodlot acreage for biomass "fuel" crops is likely to become increasingly important in coming years. A

Renewable Fuels Roadmap, intended to guide State policy on renewable fuels, was recently issued by the New York State Energy Research and Development Authority (NYSERDA, 2010).

Water Issues

New York has historically been characterized as a humid region with significant summer rainfall that, in most years, provides for acceptable productivity of rain-fed grain and forage crops. In the context of a changing climate, however, the state lacks an inventory of drought-vulnerable locations, clearly defined agricultural water rights, and regional infrastructure for water delivery to farmland in dry years.

An analysis of historical data for New York reveals that even with today's climate in an average year, summer rainfall does not completely meet seasonal crop water requirements; supplemental irrigation is required for maximum productivity (Wilks and Wolfe, 1998), particularly on sandy or compacted soils with low water-holding capacity. Only a small percentage of farm acreage is irrigated in the state, most of this occurring on the relatively high-value vegetable and fruit acreage that accounts for about 6.5 percent of total cultivated land area. However, even farmers producing high-value fruit and vegetable crops often lack sufficient irrigation capacity to meet water needs of their entire acreage during extended periods of summer drought. Such drought events are projected to increase in frequency (Hayhoe et al., 2007; and see Chapter 1, "Climate Risks," and Case Study C. Drought). The substantial rain-fed grain crop, corn silage, and hay acreage of the state (often providing low-cost feedstock for dairy and other livestock) would be particularly vulnerable to potential increases in summer drought frequency because the value of such crops is not likely to warrant investment in irrigation equipment.

Too much as well as too little rainfall is currently a recurrent problem for farmers in New York. The recent historical trend for increased frequency of high rainfall events (see Chapter 1, "Climate Risks") has adversely affected some vegetable growers in recent years by direct reductions in yields and also by delaying spring planting or other farm operations. Additionally, use of heavy farm equipment on wet soils is detrimental to soil structure and quality and further limits crop yield.

7.2 Climate Hazards

Below are aspects of climate change projected for New York that will be particularly relevant to the agriculture sector (see Chapter 1, "Climate Risks"). Several high-priority vulnerabilities and opportunities associated with these factors are discussed in more detail in section 7.3.

7.2.1 Temperature

Warmer summer temperatures and longer growing seasons may increase yields and expand market opportunities for some crops. Some insect pests, insect disease vectors, and disease-causing pathogens may also benefit in multiple ways, such as having more generations per season and, for leaf-feeding insects, an increase in food quantity or quality.

Increased frequency of summer heat stress will be damaging to the yield and quality of many crops and will adversely affect health and productivity of dairy cows and other livestock.

Warmer winters will affect the suitability of various perennial fruit crops and ornamentals for New York. The habitable range of some invasive plants, weeds, and insect and disease pests will have the potential to expand into New York, and warmer winters will increase survival and spring populations of some insects and other pests that currently marginally overwinter in the state.

7.2.2 Precipitation

Projections of future precipitation patterns are inherently less certain than projections of future temperature. ClimAID analyses for New York suggest total annual precipitation may increase somewhat, primarily in the winter months, but the magnitude of this change is quite uncertain. Of greater certainty are expected changes in qualitative aspects such as the fraction of precipitation coming as snow and the intensity of individual rainfall events (see Chapter 1, "Climate Risks").

Less snow cover insulation in winter will affect soil temperatures and depth of freezing, with complex effects on root biology, soil microbial activity, and nutrient retention (Rich, 2008), as well as winter survival of some insects, weed seeds, and pathogens.

Snow cover also will affect spring thaw dynamics, levels of spring flooding, regional hydrology, and water availability.

Increased frequency of late-summer droughts will adversely affect productivity and quality and will increase the need for irrigation (see Case Study D. Drought). Rain-fed crops, for which irrigation is not economically feasible, would be particularly vulnerable. Despite new challenges with water deficits, New York is not threatened with the severity of drought projected for many other agricultural regions in the United States and internationally.

Increased frequency of heavy rainfall events is already being observed with adverse consequences, such as direct crop flood damage, non-point source losses of nutrients and sediment via runoff and flood events, and costly delays in field access.

7.2.3 Sea Level Rise

Sea level rise will have few direct effects on agriculture in most parts of the state. Issues such as increased potential for saltwater intrusion into groundwater or coastal flooding in agricultural areas in Long Island and the Hudson Valley are discussed in Chapter 5, “Coastal Zones.”

7.2.4 Other Climate Factors

There are some climate factors, such as 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 factors is low (see Chapter 1, “Climate Risks”). Although not a climate factor, the continued increase in atmospheric carbon dioxide has direct effects on plants separate from its influence on climate, as described briefly below with other factors of particular concern.

Most climate models project little change in climate variability per se, but there is not a high degree of certainty that this will be the case and, in fact, there is observational evidence of increased winter variability in recent years. More variable winter temperatures can adversely affect perennial plants and winter crops by making them more vulnerable to mid-winter freeze

damage (due to de-hardening) or spring frost (due to premature leaf out and bud break). There is a need for new climate research and monitoring to determine whether such events are part of a long-term climate change trend, and there is a need for new extreme-event early warning systems for farmers.

Current climate models cannot project changes in cloud cover reliably, yet cloud cover changes can have profound effects on crop productivity and quality and on crop water demands.

While great strides have been made by climate modelers and computing power in improving the spatial resolution of climate projections, it will be important for farmers to have even higher resolution to encompass microclimate effects.

Higher atmospheric carbon dioxide levels can potentially increase growth and yield of many crops under optimal conditions. However, research has shown that many aggressive weed species benefit more than cash crops, and that weeds also become more resistant to herbicides at higher carbon dioxide concentrations (see Section 7.3.2).

7.3 Vulnerabilities and Opportunities

Warmer temperatures, a longer growing season, and increased atmospheric carbon dioxide could create opportunities for farmers with enough capital to take risks on expanding production of crops adapted to warmer temperatures (e.g., European red wine grapes, peaches, tomatoes, watermelon), assuming a market for new crops can be developed. However, many of the high-value crops that currently dominate the state’s agriculture economy (e.g., apples, cabbage, potatoes), as well as the dairy industry, benefit from the state’s historically relatively cool climate. Some crops may have yield or quality losses associated with increased frequency of late-summer drought, increased summer high temperatures, increased risk of freeze injury as a result of more variable winters, and increased pressure from weeds, insects, and disease. Dairy milk production per cow will decline in the region as temperatures and the frequency of summer heat stress increase, unless farmers adapt by increasing the cooling capacity of animal facilities. Below are some high-priority vulnerabilities for New York.

7.3.1 Increased Insect and Disease Pressure

Insects are cold-blooded organisms; the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. It has been estimated that with a 3.6°F temperature increase, insects might experience one to five additional lifecycles per season (Yamamura and Kiritani, 1998). Other researchers have found that moisture and carbon dioxide effects on insects may also be important considerations under global climate change conditions (Hamilton et al., 2005; Coviella and Trumble, 1999; Hunter, 2001).

More frequent intense precipitation events projected for climate change may negatively impact many insects such as onion thrips, known to be killed or removed from crops by heavy rains (Reiners and Petzoldt, 2009). As with temperature, precipitation changes can affect insect pest predators, parasites, and diseases, resulting in a complex dynamic. Fungal pathogens of insects are favored by high humidity; the populations of these fungi would increase under climate changes that lengthen periods of high humidity and be reduced by those that result in drier conditions.

Soybean insects have been observed in increased numbers and have caused increased damage under elevated carbon dioxide and elevated ground-level ozone concentrations (Dermody et al., 2008). Some invasive insect pests, including pests of important crops, are predicted to increase under future climate change scenarios (Ward and Masters, 2007).

As a result, it is likely that New York farmers will experience new challenges with insect management, as longer growing seasons increase the number of insect generations per year, warmer winters lead to larger spring populations of marginally overwintering species, and earlier springs lead to the earlier arrival of migratory insects. Numerous studies throughout the northern hemisphere have already documented changes in the spring arrival and/or geographic range of many insect and animal species due to climate change (Parmesan, 2006; Montaigne, 2004; Goho, 2004; Walther et al., 2002).

In New York, a network of pheromone traps to monitor corn earworm (*Helicoverpa zea*) throughout the central

and western parts of the state has documented a trend for its earlier arrival over the past 10 years (with its early arrival date moving from mid-July to early June). This has required earlier initiation of insecticide sprays to control the pest and has increased costs to the growers (Abby Seaman, personal communication, January 2007).

Temperature also has potential impacts on plant diseases through both the host crop plant and the pathogen. Downy mildew of grapevine is predicted to occur earlier in the season, resulting in more severe infections (Salinari et al., 2007). Many mathematical models that have been useful for forecasting plant disease epidemics are based on increases in pathogen growth and infection within specified temperature ranges. Generally, fungi that cause plant disease grow best in moderate temperature ranges. Temperate climate zones that include seasons with cooler average temperatures are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction as the climate warms.

Increased carbon dioxide levels can affect both the host and the pathogen in multiple ways. Some of the observed carbon dioxide effects on diseases may counteract others. Researchers have shown that higher growth rates of leaves and stems observed for plants grown under high carbon dioxide concentrations may result in denser canopies with higher humidity that favor pathogens. Lower plant decomposition rates observed in high carbon dioxide conditions could increase the crop residues on which disease organisms can overwinter, resulting in higher inoculum levels of the disease organisms at the beginning of the growing season and earlier and faster disease epidemics. Higher carbon dioxide concentrations can also result in greater fungal spore production, affecting pathogen growth. However, increased carbon dioxide can also result in physiological changes to the host plant that can increase host resistance to pathogens (Coakley et al., 1999).

An increase in the frequency of heavy rainfall events projected for New York will tend to favor some leaf and root pathogens (Coakley et al., 1999; Garrett et al., 2006) and, depending on the timing, wash off chemical sprays. However, short- to medium-term droughts will tend to decrease the duration of leaf wetness, thereby reducing some of the ways in which pathogens attack leaves. Although the specific impacts of climate change

on plant diseases are difficult to predict given current knowledge, it is possible to make several generalizations for farmers in the Northeast:

- Increased winter temperatures are likely to result in more pathogens surviving the winter and earlier infestation of plants in spring.
- Increased temperatures will likely result in northward expansion of the range of some diseases.
- More frequent heavy rainfall events will tend to favor some types of pathogens over others.

Two pathogens important in the northeastern United States, Stewart's Wilt and late blight, illustrate some of these effects. Stewart's Wilt (*Erwinia stewartii*), a bacterial disease that generally has sporadic importance in sweet corn in the Northeast, is vectored (carried) by the corn flea beetle (*Chaetocnema pulicaria*). Survival of the vector through winter is considered key to the severity of Stewart's Wilt infections the following year. A recent analysis projected increased severity of the flea beetle and Stewart's Wilt in the Northeast throughout this century, based on climate change projections for the region and a disease-severity forecast model based on winter temperatures (Wolfe et al., 2008).

Late blight infects potatoes and tomatoes in the Northeast. It can be a devastating disease for both crops and farmers, with complete crop loss a possibility if control measures are not employed. Infection is triggered by high moisture conditions within a fairly specific temperature range. Annually, 5 to 20 fungicide applications from as early as June through August are used in the northeastern United States to control potato late blight. This represents a significant expense to farmers and an important environmental risk. Predictive models for potato and tomato late blight show that the fungus infects and reproduces most successfully during periods of high moisture that occur when temperatures are between 45°F and 80°F. Earlier onset of warm temperatures could result in an earlier threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control. Work in Finland, which is considered to be in a similar late blight risk zone to the northeastern United States, has predicted that for each 1.8°F increase in temperature late blight would occur four to seven days earlier and the susceptibility period of the plants would extend by 10 to 20 days (Kaukoranta, 1996). This would likely translate into an additional one to four fungicide

applications for northeastern United States tomato and potato farmers—increasing both costs to farmers and environmental risks (see Case Study B. Potato Late Blight).

7.3.2 Increased Weed Pressure

Many weeds have a stronger growth response to increasing carbon dioxide concentrations than most cash crops, particularly “invasive” weeds with the C_3 photosynthetic pathway, and with rapid and expansive growth patterns, including large allocation of biomass below ground to roots, stolons, and/or storage organs (Ziska and George, 2004; Ziska, 2003). Recent research also suggests that glyphosate (e.g., Roundup), the most widely used herbicide in the United States, loses its efficacy on weeds grown at the increased carbon dioxide levels likely to occur in the coming decades (Ziska et al., 1999). While there are many weed species that have the C_4 photosynthetic pathway and therefore show a smaller response to increased atmospheric carbon dioxide concentrations relative to C_3 crops, in most agronomic situations, crops compete with a mix of both C_3 and C_4 weeds. In addition, the worst weeds for a given crop are often similar in growth habit or photosynthetic pathway. To date, all weed/crop competition studies where the photosynthetic pathway is the same for both species favor weed growth over crop growth as carbon dioxide is increased (Ziska and Runion, 2006).

The habitable zone of many weed species is largely determined by temperature, and weed scientists have long recognized the potential for northward expansion of weed species' ranges as the climate changes (Patterson et al., 1999; McDonald et al., 2009). Kudzu (*Pueraria lobata*, var. *montana*), an aggressive invasive weed that currently infests more than 2 million acres in the southeastern United States, has a habitable range determined in part by the minimum winter temperature boundary of -4°F (Sasek and Strain, 1990). A recent study used high-resolution climate model projections for the northeastern United States and documented the potential for northward expansion of this invasive weed into New York within the next few decades (Wolfe et al., 2008). While temperature is not the only factor that could constrain the spread of kudzu and other invasive weeds, a more comprehensive assessment of potential weed species migration into New York seems warranted.

7.3.3 Too Little Water

Yield and quality losses due to increased frequency of late-summer drought could have a major impact on some sectors of the New York agriculture economy. This would most severely affect rain-fed agriculture, which in New York State includes most of the corn grain and silage acreage used as feedstock for dairy, as well as other grain crops (e.g., wheat) and hay. While many producers of high-value fruit and vegetable crops have some irrigation equipment, few have adequate capacity to meet water requirements of all of their acreage during severe summer droughts. Presumably, farmers will adapt by increasing irrigation capacity and use, but this may put demands on water resources and may eventually require development of new water supplies, storage and delivery systems within and between watersheds, and water policies to determine water rights during periods of low supply (see also Case Study C. Drought).

7.3.4 Too Much Water

The recent historical trend for increased frequency of high rainfall events (more than 2 inches in 48 hours) is projected to continue (Chapter 1, “Climate Risks;” Chapter 4, “Water Resources”). This can have negative economic consequences such as direct crop flood damage; delayed spring planting, reducing high-value early season production of vegetable crops; lack of access to the field during other critical periods; soil compaction because of tractor use on wet soils; increased crop foliar and root disease; increased soil erosion losses; and increased runoff of chemicals or manures into waterways or crop-growing areas, with negative implications for human health.

7.3.5 Issues of Concern for Key Industries

Here we focus on dairy (see also Case Study D. Dairy Heat Stress) because this is the major component of the New York agricultural economy. Farmers in this industry will be particularly vulnerable to new stresses associated with climate change because many are already operating close to the edge economically. Apples and grapes have also been selected for focus, below (and see Case Study A. Frost Damage to Grapes), because these are representative of our high-value horticultural industry, and distinctions between apples and grapes illustrate how even similar

crop species can differ in their vulnerabilities (and opportunities) associated with climate change.

New Challenges for the Dairy and Livestock Industries

All livestock are affected by rising temperatures, but dairy cows are of special concern both because of their economic importance in New York State and their relatively low thresholds for temperature stress.

Heat Stress and Productivity

A number of environmental factors such as temperature, humidity, and sunlight can all contribute to the degree of heat stress experienced by livestock. The response of dairy cattle to heat stress includes lower feed intake, lower milk production, decreased calving, and an increased risk for other health disorders. Even relatively moderate warm temperatures (e.g., greater than 80°F) combined with moderate humidity (e.g., greater than 50 percent relative humidity) reduce milk productivity of dairy cows and have a long-term economic impact by reducing calving rates (Klinedinst et al., 1993).

Scientists have developed a “thermal heat index” (THI), which is based on temperature and humidity data and indicates the potential for heat stress in many livestock (Klinedinst et al., 1993):

$$\text{THI} = \text{Temp}(\text{°C, dry bulb}) + 0.36(\text{Temp}(\text{°C, dew point})) + 41.2.$$

Threshold THI values, above which reduced animal performance is predicted to cause production losses, have previously been ranked at approximately 70 to 72 for dairy cows, 72 to 75 for beef cows (*B. taurus*), 72 to 74 for pigs (*Sus domestica*), and 70 to 78 for chickens (*Gallus domestica*) (St. Pierre et al., 2003). A study in 2003 used THI calculations to estimate historical economic losses due to heat stress for dairy and other livestock industries in New York at \$24.9 million per year (St. Pierre et al., 2003). Field observations in the unusually warm summer of 2005 in New York found a milk production decline of 5 to 15 pounds per cow per day at many dairy operations (an 8 to 20 percent decrease in normal production) (Larry Chase, personal communication, January 2007). Heat stress in dairy cattle can be exacerbated by the number of consecutive high-temperature days and the ability of the cows to cool off at night.

The recent Northeast Climate Assessment used a THI threshold of 72 to model dairy cow performance associated with climate model projections for the region and concluded that adverse economic impacts on the dairy industry will be substantial by mid-century unless growers adapt by making capital investments to increase cooling capacity of dairy barns (Wolfe et al., 2008). This study may have underestimated the economic consequences of climate warming, however, based on recent research that suggests that the THI threshold for decline in milk production should be 68 rather than 72 for the high-producing dairy cows (producing more than 77 pounds of milk per day) common in many of the state's dairy herds today (Zimbelman et al., 2009; Berman, 2005).

An additional factor regarding heat stress on cows is that if stressful conditions occur for even a few days during critical periods, the impacts may persist for many months. Early-lactation cows are most susceptible to the effects of heat stress, and the impact could persist for the complete lactation. If peak milk production is decreased by only 2 pounds per day, as might be seen under mild heat stress, 400 to 500 pounds of milk could be lost for the lactation period. This would amount to a \$48 to \$60 loss per cow at the current milk price of \$12 per 100 pounds of milk. However, if more severely stressed, early-lactation cows may experience decreases of 5 to 15 pounds of peak milk production per day.

The New York dairy industry will be more affected by heat stress in the future than in the past, not only because of the warming trend, but also because today's high milk-producing cows are more sensitive to heat stress in terms of milk productivity (Fox and Tylutki, 1998). Dairy producers will benefit from working closely with their farm advisors and extension personnel to develop heat stress abatement practices and strategies for their specific situation (see Adaptations, Section 7.4.1, and Case Study D).

Feed Availability and Prices

Climate change could also indirectly affect livestock and dairy industries by altering the availability and price of crops used for animal feed. Yields of hay, grain, corn, and silage will be affected by multiple factors associated with climate change. Yields may increase and prices may go down due to opportunities to grow longer-growing-season varieties. On the other hand, yields may decline

and prices may increase due to crop losses associated with the increased frequency of crop heat stress, late-summer drought, and heavy precipitation events projected for New York. Increased use of corn biomass as a renewable energy source could potentially reduce availability of corn grain and/or silage for feedstock, also increasing prices. However, a recent report commissioned by NYSERDA addresses many of these renewable fuels issues with initial recommendations for how to develop biomass fuel resources in a sustainable manner and with a minimum of adverse indirect effects (NYSERDA, 2010).

The combined uncertainties regarding climate change impacts on feedstock, future biofuel markets, and other factors make it difficult to predict the potential effects of climate change on the dairy industry. Monitoring these factors will be important for effective adaptive management.

Opportunities and Challenges for Perennial Fruit Crops

Perennial fruit crops are particularly vulnerable to climate change because they are exposed to and affected by the climate year round. Over the past 30 to 40 years, spring bloom dates for apples and grapes in New York have occurred several days earlier compared to the historical record, indicating that climate change effects are already in evidence (Wolfe et al., 2005). Changes in winter temperatures as well as summer temperatures affect the physiology, development, productivity, and fruit quality of perennial fruit crops (Howell, 2000; Gu et al., 2001).

Perennial fruit crops and the industries that produce them have several unique characteristics that affect their responses to climate change. For example, both previous season growth and over-wintering conditions can affect flowering potential the following spring. Thus, climate stresses in one season may have effects for two or more years. Since fruit crops are grown for quality as well as quantity, processes such as coloration, flavor, and appearance are valued, and these are very sensitive to environmental stresses (e.g., drought, heat spells).

Apples

Among the perennial fruit crops grown in New York, apples may be particularly vulnerable to climate change

and a high priority because of their economic value and the state's historical national leadership in productivity and quality (Table 7.1). The growth and potential productivity of apple trees should increase with increased atmospheric carbon dioxide and the longer, warmer growing seasons (Lakso et al., 2001) that are projected for New York. However, increased frequency of summer heat stress periods and droughts are likely to reduce fruit quality, especially if the capacity for irrigation is inadequate (Lakso, 1994).

Several analyses have indicated that apples tend to have reduced fruit set and yields in summers following warmer winter conditions (Jackson and Hamer, 1980; Jackson et al., 1983; Lakso, 1987), or due to heat during critical fruit set periods (Kondo and Takahashi, 1987; Greene, 2002). In some recent years with variable winter temperatures, apples have had increased spring frost damage because they leafed out and bloomed earlier in the spring. Hail damage has also been unusually severe in some recent years, although it is not clear if this is associated with any long-term climate trend.

Although climate warming will provide some opportunities to grow longer-season varieties (Fuji, Granny Smith), it may also mean that some of the state's cool-season signature varieties (McIntosh and Empire) may no longer be commercially viable due to poorer fruit quality in warmer climates, as seen today in the climates of the mid-Atlantic and Southeast, where McIntosh and Empire have performed poorly. One study projected possible negative effects on yields of some apple varieties by the end of century, as a result of warmer winters and inadequate winter-chill hours for optimum spring bloom and fruiting (Wolfe et al., 2008).

Overall, for apples, there is likely to be a reasonable balance of beneficial and detrimental impacts from climate change, assuming farmers adapt with new varieties or other strategies as any negative effects become apparent (see Section 7.4.2).

Grapes

For grapes, particularly the non-native *Vitis vinifera* red wine grape varieties for which the historical New York climate is at the cold margin of production, the net effects of a longer growing season and warmer winters are likely to be beneficial over the long term in terms of yield and wine quality. Late-summer drought, however, could limit

yields or require greater irrigation, and increases in summer temperatures will have a range of effects that favor many new varieties but might decrease quality in some current favorites. Relative to other major wine regions in the United States and the world, the New York industry appears to be in less jeopardy and may benefit overall (White et al., 2006; Jones et al., 2005).

Although cold-tender *vinifera* grape varieties (e.g., Cabernet, Shiraz, Zinfandel) may do better with warmer winters over the long term, recent winter temperature variability has led to incidents of severe winter freeze damage, costing the Finger Lakes wine industry millions of dollars (Levin, 2005). Freeze damage can occur when excessively warm winter periods de-harden vines and make them more susceptible to damage during subsequent cold periods (Howell, 2000; Gu et al., 2001). There also can be the problem discussed for apples, above, where premature leaf out or bloom increases the risk of spring frost damage to young shoots or buds (Hanninen, 1991). The paradoxical phenomenon of increased freeze or frost damage to perennial plants in a warming world has been observed in other parts of the United States (Gu et al., 2008; Rochette et al., 2004). For New York growers, this phenomenon poses a new challenge in the short term, prior to the potential longer-term benefits of warmer winters being fully realized (see Adaptations, Section 7.4.2; and Case Study A. Frost Damage to Grapes).

7.4 Adaptation Strategies

Farmers have numerous adaptation strategies for minimizing the negative effects of climate change and for taking advantage of the opportunities. These range from changing crop varieties or diversifying cropping systems, to improving pest monitoring and pest control measures, to capital investments for expanded irrigation capacity or improved cooling capacity of dairy barns. Some adaptations will involve institutions and agencies beyond the farm gate, such as development of new crop varieties for the region, new information delivery systems and decision tools for farmers, improved crop insurance programs, financial incentives and assistance for adaptation investments, and policies to deal with inequities in climate change impacts and farmer capacity to adapt. A number of these are described in more detail below.

7.4.1 On-Farm Adaptation for Dairy and Other Livestock

The dairy producer has three avenues for adaptation to minimize the effect of heat stress: adjust diet and feeding management, increase use of existing fans and other cooling systems, and improve cooling capacity of existing housing facilities (also see Case Study D. Dairy Heat Stress).

Adjust Diet and Feeding Management

Cows housed in modern dairy barns often receive carefully formulated feed, which is nutritionally balanced and may include vitamins and nutritional supplements to optimize the cows' health and milk production. The ration should be regularly adjusted to reflect the animals' changing needs under different environmental conditions. Potential diet adjustments under heat-stress conditions include adding fat as an energy source to partially counteract the lower feed intake (Staples, 2007; Baumgard and Rhoads, 2009). Other adjustments include the following:

- Use more-easily-digested forages (plants eaten by livestock) to lower heat produced in the rumen (first large compartment of the stomach).
- Minimize overfeeding of rumen-degradable protein.
- Lower total diet protein and improve amino acid balance.
- Add buffers to the ration to improve the rumen environment.
- Add yeast or fungal cultures to improve feed digestibility.
- Add encapsulated niacin, which can help ameliorate heat stress.
- Add additional potassium, sodium, and chloride to the ration to replace these minerals lost by the cow due to increased respiration, sweating, and panting.
- Add propionic acid-based products to the ration to decrease heating and potential spoilage.
- Shift feeding times to the cooler parts of the day.
- Ensure adequate water supply. Daily water intake may increase by 20 to 50 percent under heat-stress conditions. The water system needs to be checked to determine if it is capable of delivering this additional quantity of water. In some herds, the water system may need to be modified to provide for the extra flow and pressure needed to supply the additional water.

These adjustments should be evaluated and considered on individual dairy farms. Even though research results have not always been consistent when these changes were applied under heat-stress conditions, they reflect current understanding of physiological processes.

Increase Use of Fans, Sprinklers, and Other Cooling Systems

Installing and increasing the use of cooling systems is an obvious adaptation to heat stress on livestock, but will bring with it increased expenditures for labor and energy costs. High energy costs in New York may put New York dairy farmers at a disadvantage compared to some other important dairy states. For example, in 2006, the retail electricity price was 5.2 cents per kilowatt-hour in Idaho, the fourth largest dairy state, compared with 16.3 cents per kilowatt-hour in New York. Some of these costs could potentially be offset by expanding the use of renewable-energy sources, such as solar (on large roofs of dairy barns), wind (many dairy operations have large land areas), and electricity production from anaerobic manure digesters (extracting energy from the abundant supplies of manure).

Improve Cooling Capacity of Housing Facilities

Barn design, ventilation systems, and water sprinklers are examples of components that can be altered to reduce heat stress on the cow (Brouk et al., 2005). The cost of these alterations can range from minimal to expensive (e.g., construction cost of a new barn). A dairy barn being built today should be designed for the heat loads expected in this century and not the last century. (For papers and tools that can be used to examine cow facility considerations related to heat stress, see www.ansci.cornell.edu/prodairy.program/facilities.html.) One study evaluated the pounds of milk production that had to be jeopardized by heat stress (per cow per day) to make it economically advantageous to use different fan types and install a tunnel-ventilation system in a number of freestall barn configurations, assuming a five-year payback period for the equipment installation. The study compared these calculations for 20, 40, 60, and 80 days of benefit from the tunnel-ventilation system. The benefit required to break even, in pounds of milk per cow per day, ranged from 2.6 to 6.6 for a 600-cow herd (Gooch et al., 2000). For an economic analysis of this discussion, see Case Study D. Dairy Heat Stress.

Options for Other Livestock

While the economic impacts of heat stress on other livestock species (including poultry, swine, beef, and sheep) in New York will be less than those on dairy cattle, they may still be significant. Most of the commercial poultry production (primarily chickens and turkeys) is already housed in confinement facilities with environmental controls to control temperature. The primary impact on these facilities of increasing temperatures would be higher energy costs. A majority of the swine produced is also housed in similar facilities. The majority of the beef cattle and sheep produced in New York are on extensive pasture-based systems during the summer months when heat stress could be a problem. As long as pasture-based systems continue to be used for these animals, there are limited opportunities for mitigation of heat stress. Simple structures to provide shade could be built. However, these would only be in a small area of the total pasture and would encourage animals to bunch up, thus reducing grazing activity and potential weight gains.

7.4.2 On-Farm Adaptation for Crops

A wide range of climate adaptations will be needed by New York farmers. Many are responses to challenges to maintain basic productivity, while some represent new opportunities in a warmer climate. Both kinds of adaptations may be associated with new costs and/or uncertainties.

Shifting Planting Date

Among farmer adaptation options, changing planting and harvest date can be an effective, low-cost option to take advantage of a longer growing season or to avoid crop exposure to adverse climate (e.g., high temperature stress, low rainfall). Predicting the optimum planting date for maximum profits will be very challenging in a future with increased uncertainty regarding climate effects on not only local productivity but also on supply from competing regions and on market prices.

Diversification of Crop Varieties and Crops

Given uncertainties regarding climate change projections, a more diversified farm may be buffered

from negative climate change effects and be able to capitalize on opportunities. Some crops that are currently marginally produced in New York State, such as stone fruits, watermelons, cantaloupes, pears, and other warmer-season products, may become production opportunities for New York farms. A warming climate and longer growing season will also expand the list of winter cover crop options for farmers, and in some situations may open the door to double-cropping (two cash crops in a single year).

Varieties with improved tolerance to heat or drought or those adapted to take advantage of a longer growing season for increased yield will be available for some crop species. New molecular-assisted crop breeding strategies may provide new genetic types more tolerant of environmental stress, pests, and pathogens. However, to date, many such efforts have focused on a few major world food crops, such as corn and wheat, while high-value fruit and vegetable crops important to the New York agriculture economy have received less attention.

Changing varieties, like changing planting date, is a first line of defense for farmers to consider. There are a number of situations in which this might not be an effective strategy, however. Changing varieties for perennial crops, for example, is extremely expensive and new plantings take several to many years to reach maximum productivity. Whenever possible, changing varietal composition of plantings of perennials, such as grapes or apples, should be anticipated when existing stands are in age-related decline and need renewal. Capturing such opportunities will require forward-looking assessment of how climate change will impact the expected lifespan of each new planting. Breeding fruit crops also requires a much longer effort than is required for annuals. Additionally, consumers of fruit crops recognize and value specific varieties (i.e., McIntosh apples or Riesling wine grapes), so it is much more difficult to introduce new varieties of fruit crops than it is for beans, wheat, or corn. Even for annual crops, changing varieties is not always an easy or low-cost option.

In some cases, it may not be possible to identify an alternative variety that is adapted to the new climate, *and* is also adapted to local soils and farming practices, *and* meets local market demand regarding timing of harvest and quality features such as fruit size, color, and flavor. For example, resistance to Stewart's Wilt, a disease projected to increase in frequency and severity

with climate change, has been identified in some sweet corn varieties, but in general these varieties do not currently meet market demands for taste, texture, and appearance.

Chemical and Non-chemical Control of Insects, Diseases, and Weeds

Climate change effects on the crop-weed-pest complex may favor the crop in some cases and lead to reduced usage of chemical controls by farmers. However, in general, as the New York climate warms, insect and disease pressure and pesticide applications are likely to resemble current conditions in more southern states. If this assumption is correct, increased pesticide loads are likely unless alternative control measures can be identified. For example, New York conditions currently result in 0 to 5 insecticide applications against lepidopteran (larval, caterpillar-like) insect pests to produce marketable sweet corn; Maryland and Delaware conditions result in 4 to 8 insecticide applications; Florida conditions result in 15 to 32 applications. For sweet corn pests, warmer temperatures translate to increased pest control measures to produce a marketable crop. This is cause for concern, since insecticides and their applications have significant economic costs for growers and environmental costs for society. Additionally, some classes of pesticides (pyrethroids and spinosads) have been shown to be less effective in controlling insects at higher temperatures. Reduction in the negative economic and environmental impacts of a trend for increased pesticide loads will require pre-emptive development of alternative non-chemical weed, insect, and disease-control strategies, as well as improved monitoring and rapid-response plans for targeted control of new weeds or pests before they become widespread.

Choices in types of pest control could also become an issue for debate under projected climate change. It is possible that genetically modified Bt sweet corn varieties will become a more economical choice for farmers if lepidopteran pest pressure in New York fields becomes similar to that in states to the south. It is also possible that genetically modified crops will become more acceptable in the marketplace as a result of the need to respond to higher pest pressure. However, one recent study shows that Bt plants grown in a carbon-dioxide-rich atmosphere had a 25 percent reduction in their insect resistance (Trumble and Butler, 2009).

Organic farmers may face particular challenges due to climate change since they rely heavily on cultural practices and biological control to manage pests, and will have fewer options for rapid response to new pests (Stacey, 2003). On the other hand, these systems may, in some cases, have increased natural resilience (e.g., more natural predators) because of their inherent crop and biological diversity.

Farmers who closely monitor the occurrence of pests in their fields and keep records of the severity, frequency, and cost of managing pests over time will be in a better position to make decisions about whether it remains economical to continue to grow a particular crop or use a certain pest-management technique. Those farmers who make the best use of basic integrated pest management (IPM), such as field monitoring, pest forecasting, recordkeeping, and choosing economically and environmentally sound control measures, are more likely to be successful in dealing with the effects of climate change. Adaptive management is likely to require increased investment in agricultural consultants and skilled employees by farms, as well as applied research and extension programs by universities. Intensive crop and pest monitoring is not free of costs. While this activity has the potential to provide jobs for pest and crop experts as farm consultants, the costs will need to be incorporated into production accounting and planning.

Freeze and Frost Protection for Perennial Fruit Crops

Numerous strategies to avoid damage to spring frost events are well tested and have been recently reviewed (Poling, 2008). These strategies include careful site selection and the use of wind machines, helicopters, heaters, and overhead sprinklers. For mid-winter freeze problems, approaches might include changes in pruning strategies and mulching to insulate the trunk of young plantings. New research will be required to integrate weather forecasts into early-warning systems for extreme events like hard freezes and spring frosts to help perennial fruit crop growers through a phase of climate change transition that may include increased frequency of winter cold-damage risk. These warning systems could be linked to “cold hardening” models (Anisko et al., 1994) by tracking crop susceptibility to damage and the timing of hardening, end of dormancy, and bud break (Seeley, 1996). Also see Case Study A. Frost Damage to Grapes.

Expanded Irrigation Capacity and Other Major Capital Investments

Climate change could require significant capital investment to ensure survival of agricultural businesses or to take advantage of new opportunities. Examples include new irrigation or drainage systems, new planting or harvesting equipment for new varieties, new crop storage facilities, new equipment to allow more timely management, and improved cooling facilities for livestock. The challenge will be strategic investment in relation to the timing and magnitude of climate change.

7.4.3 Adaptation Beyond the Farm: Institutions, Agencies, and Policy

Climate change impacts on crops and livestock will have human health and societal impacts beyond the individual farmer. For this reason, adaptations that involve societal investment or private industry responses are also likely to be necessary.

Technological/Applied Research Developments

Technological/applied research developments might involve seed company development of new varieties and university development of decision-support tools and of cooling and irrigation technologies.

Information Delivery/Extension Systems

Examples of an information delivery/extension system might include delivery of real-time local weather data for integration into farm-management decision-support tools and better integrated pest management (IPM) monitoring of potential invasives. Improved delivery of state-of-the-art weather forecasts will be needed to prepare growers for extreme weather events and can be used for various farm management decision tools. A state- and grower-funded, weather-based pest-prediction network (NEWA) is active in parts of the state providing near real-time pest forecasts (<http://newa.cornell.edu>). However, many more than the current 50 stations will be needed for adequate coverage of all agricultural areas of the state. Current IPM programs will need to be strengthened and better linked at the regional level.

Locally Available Design and Planning Assistance

Assistance could be made available for farmers or for farm regions to help in designing new heat-resistant barns and on-farm drainage systems.

Disaster Risk Management and Insurance

Current crop insurance programs are not adequate for accurate and uniform assessment of economic losses associated with weather-related disasters. This is particularly true for high-value fruit and vegetable crops, where insurance personnel are not adequately trained on the diverse range of crops grown in the state.

Financial Assistance

Examples of financial assistance include low-cost loans and State and federal cost-share programs for adaptation investments. Many aspects of adaptation are potentially expensive even when solutions are clearly available, such as capital investments for new water management systems or livestock facility renovations to improve cooling capacity.

Major Capital Investments

Major capital investments could be required at a regional or State level and might include new dams or reservoirs and new large-scale flood-control and drainage systems.

Policy and Regulatory Decisions

These could be designed to facilitate adaptation by farmers, to alter regulations, to create financial incentives for adaptation investment, and/or to stimulate local renewable energy production. For example, Section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) currently allows the U.S. Environmental Protection Agency to approve emergency use of an unregistered pesticide in cases where new pests create several specific types of crises. Section 24C discusses Special Local Need applications, which are a second method to address crisis pesticide situations under the Act. Both of these processes, which can be initiated by land-grant

universities, faculty, or industry groups, are likely to be used to address new agricultural pest arrivals under climate change conditions. A 24C pesticide application is reviewed on a state-by-state basis and requires an environmental risk assessment by a State agency (e.g., the New York State Department of Environmental Conservation), thus adding burden to State regulatory agencies in addition to adding pesticide load to the New York State environment.

Research on New Crops and Pests

Building adaptive capacity for the agriculture sector will require investment in new information, crops, and adaptation strategies (See Knowledge Gaps, Section 7.6.3, in Conclusions).

7.4.4 Co-benefits, Unintended Consequences, and Opportunities

Adaptations made to address specific climate change vulnerabilities may have additional effects beyond their primary intentions. In some cases these may raise new problems, while in others it is possible to design actions with multiple simultaneous benefits and to provide opportunities to New York State farmers.

Co-benefits

Climate change may provide an incentive for farmers and consumers to take advantage of some adaptation strategies that benefit both the farmer and the environment. Some of these may eventually be applicable to carbon-offset payments in emerging carbon-trading markets. New York State farmers could consider any or all of the following actions:

- 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 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 the greenhouse gas nitrous oxide increase with nitrogen fertilizer use).

- Improve manure management (reduces nitrous oxide, methane, and carbon dioxide emissions; also can be used as renewable energy in manure digesters).

Unintended Consequences

Described here are potential unintended consequences of adaptation strategies, which could potentially have cascading negative effects on rural economies.

Increased Water Use and Chemical Loads to the Environment

Increases in water and chemical inputs will not only increase costs for the farmer, but may also have society-wide impacts in cases where the water supply is limited, by increasing the reactive nitrogen and pesticide loads to the environment or by increasing the risks to food safety and increasing human exposure to pesticides.

Increased Energy Use

Higher energy use (and its attendant greenhouse gas emissions) may be associated with some adaptation strategies. Examples include increased running of cooling fans in livestock facilities, more energy to pump irrigation water as more farmers expand irrigation capacity (and in some cases pump from deeper wells), and increased energy use associated with greater use of products that are energy intensive to manufacture, such as some fertilizers and pesticides.

Changes in Land Use

Such shifts could result from changes in cropping systems and other farm adaptations. Harvesting of wooded areas for biofuel crops is possible, or increased diversion of corn acreage for biofuel markets. Such effects can be averted with appropriate strategic planning, and efforts towards this end have been initiated in the *Renewable Fuels Roadmap* (NYSERDA, 2010). Land clearing for expansion of food or forage crop acreage may occur, particularly if other production regions of the country are harder hit by climate change than New York due to water shortages or other factors.

Cascading Negative Effects on Rural Economies

These may be likely where farmers lack capital for adaptation (see Equity and Environmental Justice Considerations, Section 7.5).

Opportunities

Opportunities for NYS farmers could include the following:

- Possible extension of agricultural production on idle and under-used agricultural lands due to shifts in comparative advantage vis-à-vis other regions (see Chapter 4, “Water Resources”).
- 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).
- Increase consumer support—from households to large institutional food services—of local “foodshed” networks, which can reduce greenhouse gas emissions from transportation of agricultural goods.

7.5 Equity and Environmental Justice Considerations

In New York State, there is a range of equity and environmental justice issues at the intersection of climate change and agriculture. Particular agricultural sectors, regions, and crops will be more at risk from exposure to climate change and burdened by the effort and costs associated with adaptation measures. Meeting the costs of adaptation to climate change will put additional stresses on the fragile and economically important dairy industry in the state. Regional vulnerabilities include farmers on Long Island facing a disproportionate risk of crop damage from sea level rise, saltwater intrusion, and coastal flooding. Finally, certain crops have disproportionate vulnerabilities, such as perennials for which the cost and economic risk of changing crops as an adaptation strategy is sometimes much higher than for annual crops.

Of these regions and groups, those most vulnerable to climate change include small family farms with little capital to invest in on-farm adaptation strategies, such as new infrastructure, stress-tolerant plant varieties, new crop species, or increased chemical and water inputs. Small family farms² also are less able to take advantage of cost-related scale economies associated with such measures. Small farmers, particularly those in the dairy sector, already face severe competitive pressures due to rising production costs and flat or declining commodity prices. Indeed, as noted earlier,

current trends suggest that the total number of dairy farms will decline from approximately 7,900 in 2000 to 1,800 in 2020, with most of this decline resulting from closure or consolidation of smaller farms³ in New York State (LaDue, Gloy, and Cuykendall, 2003; USDA, 2007). Climate change is likely to exacerbate cost pressures on small farmers, particularly if adaptation requires significant capital investments, thus accelerating trends toward consolidation within the industry. Survival for many smaller farms will hinge, in part, on making good decisions regarding not only the type of adaptation measures to take but also in the timing of the measures. The most vulnerable farmers will be those without access to training about the full range of strategies or those who lack adequate information to assess risk and uncertainty.

In addition to supply-side dimensions, climate change also may impact agricultural demand. These effects can be associated with both long-term regional disinvestment such as out of high-risk areas (floodplains), or one-time extreme events in areas with high demand for New York State produce (like a hurricane in the New York metropolitan region). These conditions may disrupt supply chains, close retail centers, or otherwise cut consumer access to markets, with especially detrimental effects on low-income or mobility-constrained residents. Low-income farmers with insufficient information and training or without access to credit or infrastructure are particularly at risk when conditions demand immediate flexibility, such as requiring quickly lining up alternative supply lines and retail locations.

Under such conditions, rural, resource-dependent communities may feel pressure to supplement incomes or diversify their business beyond agriculture, but may lack the training or capital necessary to engage such strategies. Decreasing yields and the high costs of adaptation may translate into significant downstream job losses and cascading economic effects across rural communities. Low-wage, temporary, seasonal, and/or migrant workers are particularly exposed to these shifts.

Examining equity in adaptation involves evaluating existing vulnerabilities, but it also requires evaluating the unintended outcomes, externalities (secondary consequences), and emergent processes of specific adaptation strategies. Successful adaptation by individual farmers or regions may create downstream inequities. As some farmers successfully adapt, other

farmers may experience relative increases in inequality related to rural income and agricultural productivity. Certain industries (such as the grape and wine industries) also may consolidate in such ways that it becomes difficult for smaller businesses to enter the market. Increasing chemical inputs, such as fertilizers and pesticides, may create or exacerbate inequitable distributions of human health burdens, or negatively affect waterways, disproportionately impacting low-income or natural resource-dependent communities involved in hunting- and fishing-related revenue. Furthermore, degrading land and community health could drive down property values, exacerbating geographic inequities. Finally, increasing natural resource use, whether it is water for irrigation or energy for cooling, is likely to raise utility prices. These increases are felt the most by low-income families who proportionally spend more on these basic goods than middle- and upper-income families.

Addressing and avoiding spillover effects in the implementation of adaptation measures requires engaging local communities and agricultural managers in each stage of the planning process. This includes mechanisms for expressing and addressing property disputes and conflicting claims to resources, collaborative regional planning across sectors and communities, and training or retraining to provide information regarding strategies and best practices. In particular, adaptation strategies focused at regional or state scales have the capacity to marginalize local actors who are unable to capitalize on social or economic networks or access policymaking procedures.

Equity issues should be considered along every part and process of the agriculture food-supply chain. For low-income communities throughout the state, the connection between climate change and issues of food justice is an area of growing concern. Food justice issues, including lack of access to grocery stores in lower-income urban and rural communities, and inability of lower-income individuals to afford healthy, fresh foods, may be exacerbated by climate change. For example, climate stress on agriculture could affect the quality, accessibility, and affordability of local produce. This has implications for food security among low-income groups, those communities with fragile connections to markets offering nutritional options, or those otherwise burdened by pre-existing poor nutrition. Increased incidence of extreme heat or

prolonged droughts may also affect the cost structures and productivity of community gardens and other local food production systems that serve lower-income urban areas.

7.6 Conclusions

Those aspects of climate change already occurring in New York or anticipated within this century that have known effects on crops, livestock, weeds, insects, and disease pests have been the primary focus of this ClimAID analysis. **Table 7.2** summarizes selected climate factors as linked to vulnerabilities or opportunities for the agriculture sector and adaptation strategies. A qualitative level of certainty is assigned to each of these components. The relative timing of when climate change factors and impacts are anticipated to become pronounced is also indicated, as this will be critical in setting priorities for adaptation. The table illustrates an approach and a possible useful tool for setting priorities and for climate action planning, but is not meant to be comprehensive. It can and should be modified for specific purposes and as new information and expertise become available.

Below, key findings regarding vulnerabilities and opportunities, adaptation options, and knowledge gaps are highlighted and discussed in more detail.

7.6.1 Main Findings on Vulnerabilities and Opportunities

The climate risks, crop or livestock responses, and relative certainties indicated in **Table 7.2** have been integrated to develop this list of main vulnerabilities and opportunities.

- *Summer heat stress.* Warmer summers will bring an increase in the frequency of days that exceed high temperature thresholds negatively affecting crop yields, crop quality and livestock productivity. The ClimAID analysis for the dairy industry indicates significant milk production declines by mid- to late century; 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. New York farmers are already experiencing earlier arrival and increased populations of some insect pests, such as corn earworm.

- *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 Finger Lakes wine grape growers millions of dollars in losses in the winters of 2003 and 2004. 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. 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. This latter phenomenon may explain, in part, the lower apple yields in summers following warm winters. There is a low level of certainty regarding whether variability per se associated with recently observed freeze damage is a component of overall climate change in New York State (**Table 7.2**). This, however, will be a concern for tree fruit crops and other perennial species, at least in the short term (the next few decades).
- *Increased risk of summer drought* (defined here as crop water requirements exceeding water available from rainfall plus stored soil water) is projected for New York by mid- to late century. Compared to some agricultural regions, such as the western U.S.,

however, New York State is likely to remain relatively water rich. As indicated in **Table 7.2**, projections for future rainfall and drought severity are not as certain as those for temperature.

- *Increased frequency of heavy rainfall events and flood damage.* In addition to direct crop damage, wet springs delay planting and subsequently delay harvest dates. 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.
- *New crop options.* While climate change will add to the physical and economic challenges of farming in New York, there are likely to be new opportunities as well as vulnerabilities, such as developing new markets for new crop options that will come with longer growing seasons and warmer temperatures. The expansion in New York 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. Some New York field corn growers are already experimenting with slightly longer growing-season varieties that produce higher yields.

Table 7.2 Climate factors, vulnerabilities and opportunities, and adaptation strategies for agriculture in New York State

Climate Factor	Climate Certainty	Associated Vulnerabilities/Opportunities	Certainty*	Timing	Adaptation Strategies	Adaptation Capacity
Increasing carbon dioxide	High	Variable plant response affecting growth, competitiveness, yield. Under optimum conditions, yield increases are possible. Some C ₃ weeds will benefit more than crops and be more resistant to herbicides.	High, but large variation in effects depending on other environmental constraints to plant growth	Now	Minimize water, nutrient constraints to crop growth to take full advantage of any beneficial effects. Develop varieties that take advantage of the effect of increases of carbon dioxide concentrations. Increased weed control and new approaches to minimize chemical inputs.	Moderate
Warmer summers; longer growing seasons	High	<i>Crops and weeds</i> Opportunities to obtain higher yields with current crops and grow higher-yielding varieties and new crops. Eventual double-cropping opportunities. Weeds will grow faster and will have to be controlled for longer periods. Increased seasonal water and nutrient requirements.	Moderate to high	Now, with some effects occurring later this century	Cautiously explore new varieties, new crops; develop markets for new crops. Increased weed control and new approaches to minimize chemical inputs. Increased water and fertilizer applications.	High
		<i>Insects</i> More generations per season; shifts in species range.	Moderate to high	Now	Better regionally coordinated monitoring through integrated pest management. Increased pest control. Proactively develop new approaches to minimize chemical inputs.	Moderate

Climate Factor	Climate Certainty	Associated Vulnerabilities/Opportunities	Certainty*	Timing	Adaptation Strategies	Adaptation Capacity
Increased frequency of summer heat stress	High	<i>Livestock (dairy)</i> Reduced milk production; reduced calving rates.	High	Serious by mid-century	Increase cooling capacity of existing dairy barns. Increase use of fans and sprinklers. Change feed rations. Provide plenty of water. Design new barns based on projected future heat loads.	Moderate to High
		<i>Crops</i> Could negatively affect yield or quality of many cool-season crops that currently dominate the agricultural economy, such as apple, potato, cabbage, and other cole crops.	High	Serious by mid-century	New heat-tolerant varieties when available. Change plant dates to avoid stress periods. Explore alternative crops.	Moderate to high
Warmer winters	High	<i>Crops</i> Could increase productivity or quality of some woody perennials (e.g., European wine grapes), while by mid to late century negatively affecting those adapted to current climate (e.g., Concord grape, some apple varieties). More winter cover crop options. Depending on variability of winter temperatures, can lead to increased freeze or frost damage of woody perennials	High	Now, with some effects occurring later in century	Explore new cash crops and varieties; explore new cover crop options.	High
		<i>Insect and weed pests</i> Increased spring populations of marginally overwintering insects. Northward range expansion of invasive weeds.	High	Now	Better freeze and frost warning systems for farmers; new winter pruning strategies. Better regionally coordinated monitoring through integrated pest management. Increased pest control. Proactively develop new approaches to minimize chemical inputs.	Moderate
Increased frequency high rainfall, flooding	High	Delays in spring planting and harvest, negatively affecting market prices. Increased soil compaction, which increases vulnerability to future flooding and drought. Increased crop root disease, anoxia and reduced yields. Wash-off of applied chemicals.	High	Now	Increase soil organic matter for better drainage. Shift production to more highly drained soils. Install tile drains. Shift to flood-tolerant crops. Change plant dates to avoid wet periods. Increased disease control and new approaches to minimize chemical inputs.	Low to moderate; some options are expensive
Increased summer drought	Moderate	Reduced yields and crop losses, particularly for rain-fed agriculture. Inadequate irrigation capacity for some high-value crop growers.	Moderate to high	Mid to late century	Increase irrigation capacity. Shift to drought-tolerant varieties. New infrastructure for regional water supply.	Moderate, assuming capital available and economics warrant investment
Changes in hydrology, groundwater	Moderate	Dry streams or wells in drought years. Increased pumping costs from wells.	Moderate	Mid to late century	Deeper wells, new pumps.	Moderate
Frequency of extreme events	Low	Major crop and profit loss due to hail, extreme temperatures, flooding, or drought. Particularly devastating if extreme events occur in clusters.	Moderate to high	Unknown	New climate science research to determine current trends and develop early-warning systems for farmers.	Moderate
Increased seasonal variability	Low	Crop damage due to sudden changes, such as increased freeze damage of woody plants as a result of winter variability and loss of winter hardiness or premature leaf-out and frost damage.	Moderate	Now, but not clear if part of climate change	New climate science to determine relation to climate change and better predict variations.	Low
Changes in cloud cover and radiation	Low	Important factor affecting plant growth, yields and crop water use. Cloudy periods during critical development stages reduces yields.	High	Unknown	New climate science research to determine current trends and better model these factors.	Low to moderate

* Climate certainty in this table is qualitatively consistent with more quantitative assessments in Chapter 1, "Climate Risks," and formulated from expert opinion from chapter authors and stakeholder groups.

7.6.2 Adaptation Options

Adaptation options are available for many of the vulnerabilities summarized above and listed in **Table 7.2**. A challenge for farm managers, however, will be uncertainties regarding the optimum timing of adaptation investment, and the optimum magnitude of adaptation investment relative to the risks. Also, adaptations will not be cost- or risk free, and inequities in availability of capital or information for strategic

adaptation may become an issue to resolve at the policy level (see also Knowledge Gaps, 7.6.3, below).

- *Improved cooling capacity of livestock facilities.* Increasing the summer use of fans and sprinklers for cooling will be an early adaptation strategy for the dairy industry. New barns should not be designed based on the 20th century climate, but rather for the increased heat loads anticipated in the 21st century.

- *Increased pest control and new approaches to minimize chemical inputs.* 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 a first-step adaptation strategy in New York, and investment in expanded irrigation capacity will likely 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 New York 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.
- *Drainage for wet conditions.* Adaptations for 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.
- 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 New York 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.

7.6.3 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 New York economy will have the necessary tools for strategic adaptation to meet the challenges and take advantage of any opportunities associated with climate change. Some relevant needs include the following:

- *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

Case Study A. Frost Damage to Grapes

Warmer winters bring opportunities with the potential to introduce higher-value but less cold-hardy fruit varieties and may in the long term be beneficial to European wine grapes (*V. vinifera*) that are not native to the region. However, particularly in the near term, challenges associated with cold injury to crops may be problematic, as explored in this ClimAID analysis. In recent years these events have cost the New York agriculture industry millions of dollars (Levin, 2005). Warmer temperatures at the beginning of winter reduce cold hardiness and can raise the probability of mid-winter damage. In late winter or early spring (after the winter-chilling requirement has been met), a prolonged warm period may lead to premature bud break and

increased spring frost vulnerability. Decisions related to variety selection thus require information on recent trends in winter-chill accumulation and projections of these values into the future. Assessing changes in spring-frost vulnerability is also necessary; typically, the lower the winter-chill requirement, the higher the risk of early bud break. Projecting such changes is important for New York State agriculture to meet its full economic potential in the context of a changing climate.

The date of the last spring freeze is a potential hazard for plants that have broken bud dormancy and begun active growth. **Figure 7.2** shows historical and projected values for last freeze dates at Fredonia. Fredonia's climate is currently moderated by its proximity to Lake Erie, making it a favorable location for tree fruit production and concord grapes. Since 1971, the date of the last occurrence of 28°F (the last spring freeze) at Fredonia has shifted from approximately April 25 (day 115) to April 15 (day 105). Overnight temperatures less than 28°F are now less likely to occur during April. This trend toward earlier last-freeze dates is expected to continue into the future. For example, based on downscaled minimum temperatures from the Hadley Centre Coupled Model, version 3 (HadCM3), under the low-emissions B1 scenario, the steady shift in the date of the last freeze reaches April 5 (day 95) by the end of this century. Under the high-emissions A2 scenario, this date moves

into March, with the last freeze expected to occur on day 85 (March 26). This is nearly a month earlier than the 1971 date.

The projected trend for an earlier date of last frost does not necessarily reduce risk of spring frost damage if grapes are responding to an earlier spring with earlier leaf out and bloom (Wolfe et al., 2005). In fact, frost risk could possibly increase with climate warming because leaf and flower emergence are driven by a cumulative factor—the accumulation of daily average temperatures above 50°F (degree-days)—but it just takes a single frost event, occurring within the bounds of natural spring temperature variability, to cause severe damage.

Figure 7.3 shows the recent historical and projected growing degree-day accumulation in the interval preceding the last spring freeze for a region in western New York. It compares this to a threshold line of 133 degree-days, the average growing degree-days required for bud break of Concord grapes. Historical data from the 1971–2007 period indicate that, on average, only 50 growing degree-days accumulate prior to the last spring freeze, and the 133 degree-day threshold leading to bud break before the last frost was observed in only two growing seasons. There is some indication that the average value of pre-frost growing degree-days begins to increase in the post-2060 period, and there is a

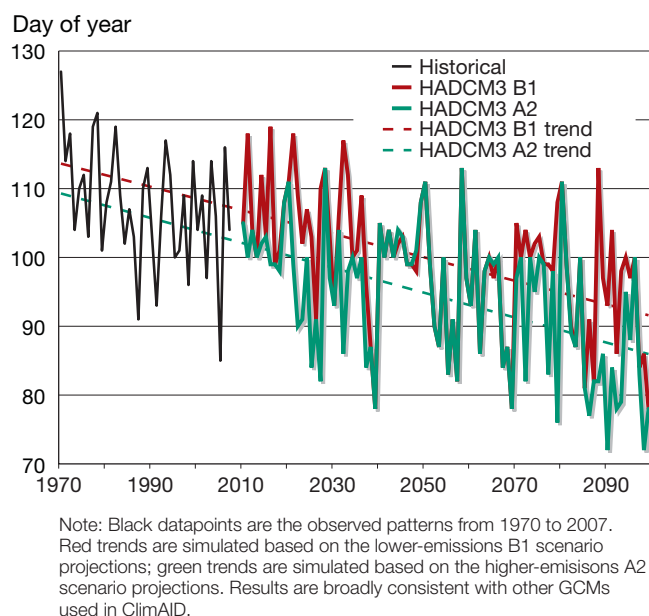


Figure 7.2 Changing date of the day of last frost; vertical axis indicates the number of days after January 1 (Julian Day)

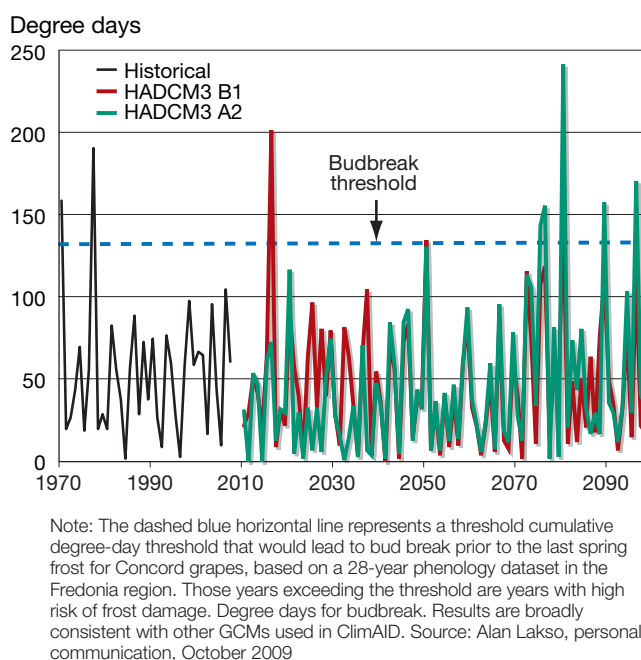


Figure 7.3 Degree-day accumulations above 50°F occurring prior to the last frost dates shown in Figure 7.2

notable increase in year-to-year variability. For the higher-emissions scenario (A2), this results in a significant increase in the frequency of years near the end of the century with risk of frost damage—sufficient degree-day accumulation prior to the last frost to cause bud break (i.e., the 133 degree-day accumulation threshold line is crossed).

The projections in **Figure 7.3** reflect the interaction between climate change effects on earliness of bud and fruit development and the date of last spring frost, within the context of spring temperature variability. Results suggest that spring frost risk will not only persist, but could even increase by late century. Numerous strategies for avoiding damage from spring frost events are well tested and reviewed (Poling, 2008). Section 7.4.2 provides on-farm crop adaptation strategies and more details regarding freeze- and frost-protection strategies for perennial fruit crops.

Case Study B. Potato Late Blight

The potato late blight disease is a severe disease caused by the pathogen *Phytophthora infestans* (Fry, 2008). This is the same disease that caused the Irish potato famine starting in the 1800s. The disease is most severe in moderately cool, wet weather. Extended periods (typically more than 10 hours) of leaf wetness with moderate temperatures (54–72°F) are particularly favorable to the pathogen and lead to severe disease. This disease is a problem all over the world where potatoes are grown. There are about 20,000 acres of

potatoes in New York. Based on the estimate that chemical costs are \$250 to \$500 per acre per year (Haverkort et al., 2008), New York growers spend \$5–10 million annually on fungicides to protect their crops from this disease.

Climate change could influence the severity of potato late blight disease in a variety of ways. Elevated temperatures could have the indirect effect of reducing the duration of wet periods, thus lessening disease severity. Less frequent rainy periods might also reduce the number and duration of wet periods, also lessening disease severity. Alternatively, heavier rainfall events would remove protective fungicide from the foliage and thus increase the disease severity. Also, disease might begin earlier and/or be more prolonged with climate change.

This ClimAID case study uses an extensively tested mechanistic simulation model (Andrade-Piedra et al., 2005) of potato late blight to estimate the impacts of New York climate change on fungicide use for control of this disease. The model uses weather data to predict pathogen development and is currently used to provide disease severity forecasts for farmers. The model also contains a sub-model of fungicide dynamics (Bruhn and Fry, 1982a; Bruhn and Fry, 1982b), so that the amount of fungicide necessary to suppress disease in any given environment can be assessed. We compare the fungicide load for protecting potato plants under current weather conditions with the fungicide load required for a similar level of control under weather conditions projected during the coming century, under the business-as-usual (A2) and lower (B1) emissions scenarios.

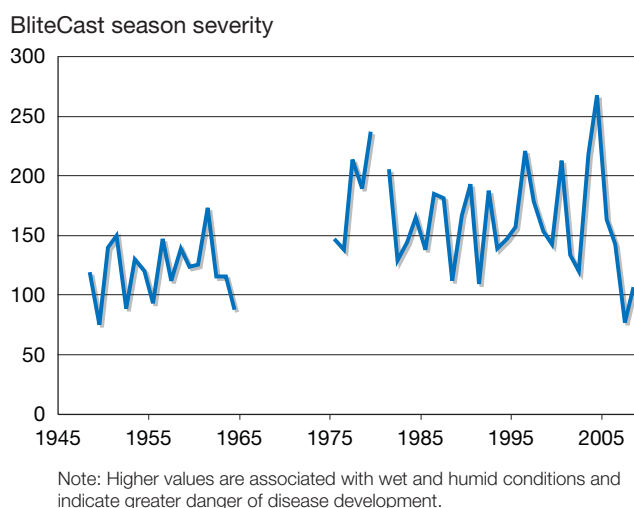


Figure 7.4 BliteCast severity values based on historical weather records for Rochester

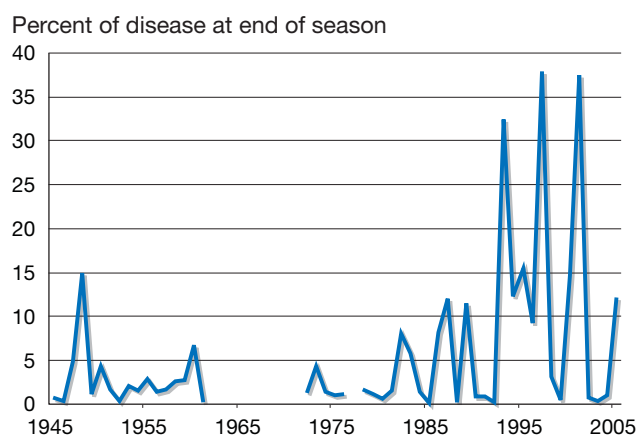


Figure 7.5 Likely prevalence of potato late blight disease forecast by BliteCast at the end of the season, considering both weather conditions and expected crop-management responses

First, weather data for Rochester from 1947 to 2008 were used to investigate the impact of historical weather on severity index values for potato late blight (i.e., potential for disease) predicted by the disease severity model, BliteCast (**Figure 7.4**). In general, during the latter part of this period (1977–2008) weather conditions led to higher disease severity. This period also showed greater year-to-year variability compared to 1947–1966.

The percent of potatoes with disease at the end of the growing season and the predicted amount of fungicide necessary to suppress the disease were also examined for the historical period. These predictions were obtained using the complex simulation model of the potato late blight disease (Andrade-Piedra et al., 2005). This model identifies the impact of weather on disease development and also identifies the impact of fungicide on disease development (Bruhn and Fry, 1982a). In agreement with the BliteCast severity index values (**Figure 7.4**), the percent of potatoes with disease was generally more severe with greater variance in the later (1977–2008) period compared to the earlier (1947–1966) period (**Figure 7.5**). Additionally, the amount of fungicide necessary to achieve adequate suppression of disease in the later period was greater than in the earlier period (**Figure 7.6**).

Using the same statistical models and approach as for the historical analysis describe above, projections of future disease severity and fungicide application needed for control were computed for the period 2040–2065. The models consist of three climatological input parameters: hourly temperature, hourly relative humidity, and daily precipitation to predict potato blight severity. Except for humidity, these variables were

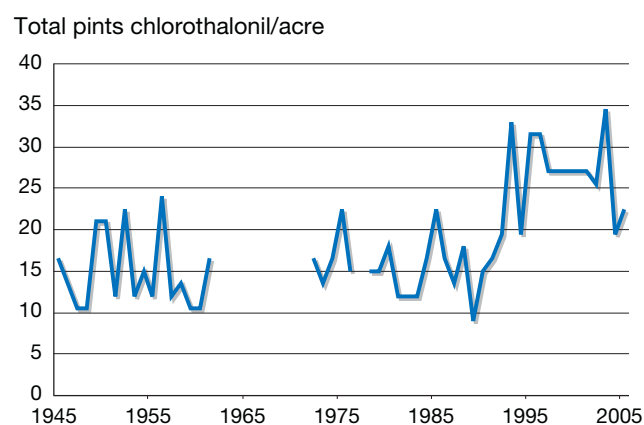


Figure 7.6 Total fungicide application recommended by BliteCast for each season of the historical record

available from the standard suite of ClimAID climatological parameters discussed in Chapter 1, “Climate Risks.” For humidity, the ClimAID Climate Team employed a statistical downscaling technique similar to that used for precipitation applied to global climate model grid-scale projections of specific humidity from five models (GISS, GFDL, UKMO, CCSM, and MIROC). Observed values of temperature and relative humidity at Rochester were converted to specific humidity and the delta change (1970–1995 versus 2040–2065) method applied to the specific humidity projections from the global climate models. The delta change in specific humidity was then applied to the three-hourly observations. The corresponding downscaled three-hourly temperatures were also obtained and used to calculate relative humidity projections. A cubic spline was fit to the three-hourly data to obtain the hourly resolution required by the potato late blight model.

Averaged across the five models, the projected BliteCast seasonal severity index for the A2 and B1 emissions scenarios for 2040–2065 (data not shown) was similar to the observed values in the 1995–2008 period of **Figure 7.6**. Despite an increase in temperature in both scenarios (favoring disease), relative humidity actually decreases slightly in the projections and, as a result, disease severity shows little change. Nonetheless, projected fungicide application rates required for adequate control (based on the models by Andrade-Piedra et al., 2007 and Bruhn and Fry, 1982a) significantly increased in most years in the higher-emissions A2 scenario (**Figure 7.7**). On average, the

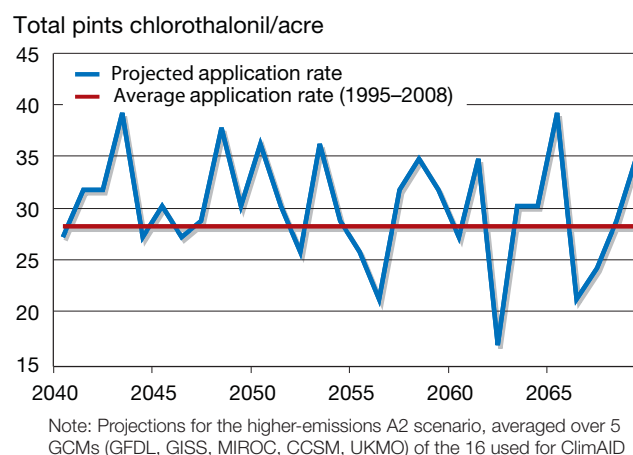


Figure 7.7 Projected total seasonal fungicide (chlorothalonil) application rate required for control of late blight for years 2040–2065 in comparison to the average application rate required for control during the 1995–2008 period

application rates for the 2040–2065 period under the A2 scenario increased to 34 pints per season, i.e., higher than the average of 28 pints for the latter half of the historical period (1995–2008, **Figure 7.6**). For the lower-emissions B1 scenario, the simulations suggest that application rates will remain similar—less than 30 pints—to the rates observed during the 1995–2008 historical period.

This analysis projects a significant increase in fungicide application required for control of late blight in 2040–2065 under the higher-emissions A2 scenario compared to today. There are several possible explanations regarding why the simulation projects an increased need for fungicide application, despite little change in the projected BliteCast severity index. Warmer temperatures in the A2 scenario may speed up pathogen development and, perhaps, cause disease outbreak to occur earlier, thus expanding the duration of required fungicide application without necessarily affecting severity values. Fungicide effectiveness is particularly sensitive to the occurrence and amount of precipitation and resulting wash-off of residual fungicide from the plant surface. This is not captured by the BliteCast seasonal severity index, but it is captured by the fungicide application models.

Case Study C. Drought

New York currently benefits from a moderately humid climate with a relatively uniform distribution of precipitation throughout the year. However, a considerable amount of winter precipitation is lost as runoff from saturated soils, and summer precipitation is

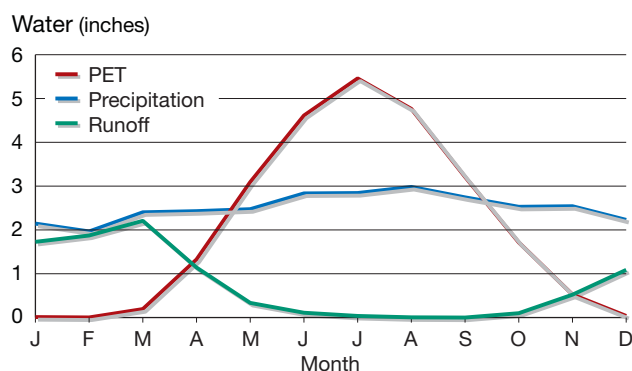
not, on average, adequate to meet all potential evapotranspiration (PET) of a fully developed crop canopy or other dense vegetation (**Figure 7.8**). Depending on soil-water storage capacity, timing of rainfall, and crop growth stage, supplemental irrigation is currently warranted in many years to fully meet crop water requirements for maximum yield (Wilks and Wolfe, 1998). This case study examines the effect of climate change on future summer water deficits in seven climatic regions (**Table 7.3**) chosen because they had more than 100 years of weather records for evaluating drought frequency. **Figure 7.9** provides a graphical representation of three of these regions: Indian Lake (Adirondacks, northern New York with a relatively wet climate), Elmira (southern New York), and Rochester (western New York, an area with major production of high-value fruit and vegetable crops as well as dairy).

For this analysis, the ClimAID Climate Team provided a tailored product, in which climate projections from five global climate models (GFDL, GISS, MIROC, CCSM, and UKMO) were used for calculation of the Palmer Drought Severity Index (Palmer, 1965). These results are used to estimate seasonal water deficits. The water deficit index values (in inches of water) in **Table 7.3** and **Figure 7.9** were calculated from PET (June to September) minus precipitation (Pcp), Runoff, and available soil water (ASW) (the amount of total soil water stored that plants can extract without negative effects on growth):

$$\text{Deficit}_{\text{jun-sep}} = \text{PET}_{\text{jun-sep}} - (\text{Pcp}_{\text{jun-sep}} - \text{Runoff}_{\text{jun-sep}} + \text{ASW})$$

It is important to note that PET provides an estimate of water demand by mature plants at or near full canopy ground cover (i.e., maximum light interception and transpiration potential). This analysis assumes that actual evapotranspiration is equal to potential water demand for the entire June through September period. This is most applicable to perennial plants, grasslands, and ground covers, but tends to overestimate water deficits for early (June) or late (September) parts of the growing season for annual row crops, when actual crop water demand is less than PET because plants have reduced transpirational surface (leaf) area. Future planned analyses, discussed in more detail at the end of this section, will address this issue for row crops.

Maximum soil-water storage of 6 inches was assumed in the original Palmer Drought Severity Index calculations, and, in New York State, soils often begin



Note: PET is the potential evaporation from soils and plants

Figure 7.8 Historical (1901–2006) average monthly soil-water balance parameters at Rochester⁶

the growing season in June near this level. Maximum available soil water was assumed to be half of total stored water, or 3 inches. This was based on prior work from many regions that has documented that, for many crops, depletion of soil water below 50 percent of maximum is a threshold at which plants become

stressed and irrigation is recommended to maintain growth and productivity.

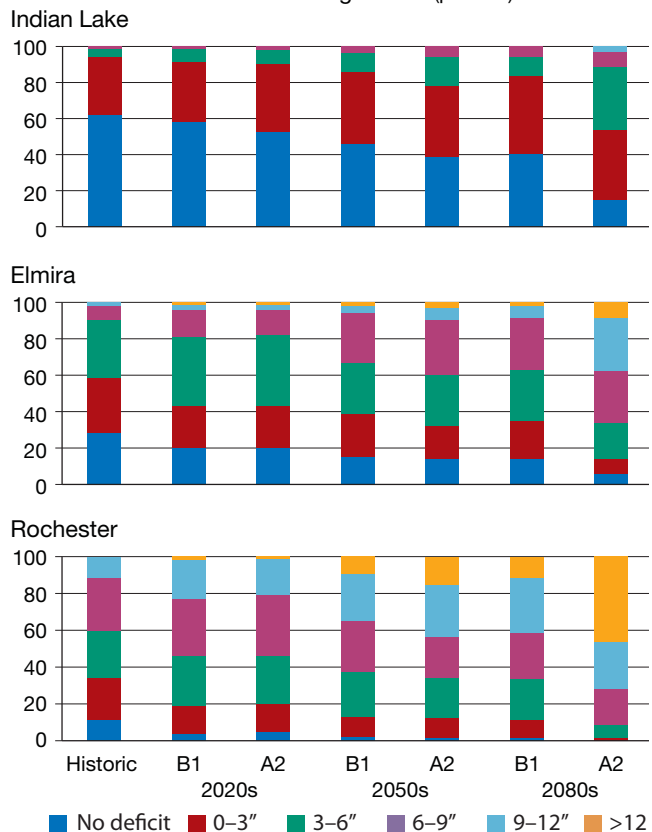
Warm season water deficits vary across the state, primarily due to variations in summer precipitation and summer temperatures used to calculate PET (Table 7.3). Current June through September cumulative precipitation averages 14.4 inches across the state for the seven weather stations used in this analysis, with a high of 16.1 inches in Port Jervis and a low of 11.4 inches in Rochester. In general, summer precipitation decreases from east to west across the state and is particularly low along the shoreline of Lake Ontario in the western half of the state. The cumulative deficit from June through September currently averages 2.1 inches for the seven stations representing the state,

Re- gion	Station	June to September Average Temperature °F						
		His- torical	B1; 2020s	A2; 2020s	B1; 2050s	A2; 2050s	B1; 2080s	A2; 2080s
1	Rochester	66.9	69.2	69.2	70.7	71.9	71.8	75.5
2	Port Jervis	68.5	70.5	70.7	72	73.1	72.9	76.2
3	Elmira	67.3	69.5	69.6	71	72.2	72.1	75.7
4	NYC	72.6	74.6	74.7	76.1	77.2	77.1	80.3
5	Albany	67.4	69.4	69.6	70.9	72.1	72	75.3
6	Watertown	65.6	67.8	67.9	69.3	70.5	70.4	74.1
7	Indian Lake	60.2	62.3	62.5	63.9	65.1	64.9	68.5
All	Average	66.9	69.1	69.2	70.5	71.7	71.6	75.1
		June to September Total Precipitation, inches						
		His- torical	B1; 2020s	A2; 2020s	B1; 2050s	A2; 2050s	B1; 2080s	A2; 2080s
1	Rochester	11.4	11.4	11.6	11.5	11.6	11.5	10.8
2	Port Jervis	16.2	17.1	16.8	16.9	17.3	17.2	16.9
3	Elmira	14.1	14.6	14.6	14.9	14.6	14.8	14.2
4	NYC	16	16.7	16.4	16.8	16.9	16.6	16.9
5	Albany	14	14.7	14.3	14.7	14.9	14.9	14.6
6	Watertown	13.9	14.5	14.3	14.4	14.5	14.5	13.8
7	Indian Lake	15	15.8	15.5	15.6	15.7	16	15.5
All	Average	14.4	15	14.8	14.9	15.1	15.1	14.7
		June to September Cumulative Water Deficits, inches						
		His- torical	B1; 2020s	A2; 2020s	B1; 2050s	A2; 2050s	B1; 2080s	A2; 2080s
1	Rochester	4.7	6.2	6	7.1	7.8	7.7	11.1
2	Port Jervis	1.2	1.7	2	2.7	3	2.9	5.3
3	Elmira	2.2	3.2	3.2	3.9	4.8	4.4	7.5
4	NYC	2.9	3.7	4	4.8	5.5	5.6	7.9
5	Albany	2.4	3.1	3.4	3.9	4.5	4.5	7
6	Watertown	1.8	2.5	2.7	3.5	4	4	6.9
7	Indian Lake	-0.6	-0.2	0	0.6	1	0.8	2.9
All	Average	2.1	2.9	3.1	3.8	4.4	4.3	7
		Absolute Increase in Precipitation Deficit Relative to Historical Average, inches						
		His- torical	B1; 2020s	A2; 2020s	B1; 2050s	A2; 2050s	B1; 2080s	A2; 2080s
1	Rochester		1.54	1.35	2.39	3.14	3.03	6.46
2	Port Jervis		0.44	0.77	1.43	1.75	1.68	4.06
3	Elmira		0.91	0.99	1.62	2.52	2.21	5.24
4	NYC		0.8	1.11	1.9	2.56	2.7	4.95
5	Albany		0.68	1.03	1.5	2.15	2.07	4.61
6	Watertown		0.74	0.91	1.68	2.25	2.2	5.16
7	Indian Lake		0.35	0.59	1.16	1.54	1.42	3.53
All	Average		0.78	0.97	1.67	2.27	2.19	4.86

Figures for representative stations from all seven climate regions of New York, assuming maximal plant water demand (i.e., potential evapotranspiration), calculated assuming full canopy cover for the entire period; see text for more discussion). Historical temperature and precipitation values represent averages of weather station data over the period 1901–2006 using 5 GCMs (GFDL, GISS, MIROC, CCSM, and UKMO) of the 16 used in ClimAID.

Table 7.3 Current and projected summer (June to September) water deficits and related temperature and precipitation

Chance of deficit of different magnitudes (percent)



Note: Each multi-colored bar adds up to 100 percent probability of what a given year will be like, and the chance of a water deficit of a particular size is shown by the lengths of different colored segments within each bar. The distribution of colors within a single bar illustrates the underlying variability of weather patterns from year to year during a particular current or future time period. Different bars moving from left to right show how climate change will progressively alter these distributions, increasing the likelihood of years with larger summer water deficits.

Figure 7.9 Magnitude (inches) of total summer water deficit (June through September) under current and projected future conditions⁵

ranging from a minimum of -0.6 inches at Indian Lake to a high of 4.7 inches in Rochester. The slightly negative value for Indian Lake indicates that available soil water is, on average, not sufficiently depleted during the summer to compromise plant growth in that region.

Warming temperatures under global climate change will affect summer water deficits primarily by increasing PET through higher temperatures. Precipitation is actually predicted to increase somewhat for New York, but most of this increase is expected to come in the winter months when it will contribute to increased runoff and do little to offset summer moisture deficits. Both the monthly magnitude and average number of months with net deficits will increase due to warming temperatures and cause seasonal water deficits to become more severe throughout the state. It is clear from **Table 7.3** and **Figure 7.9** that the frequency of years with high water deficits is projected to increase across the state, including in historically wet locations such as Indian Lake as well as regions with historically a relatively more dry climate (e.g., Rochester).

While New York is likely to remain a state relatively rich in water resources (see Chapter 4, “Water Resources”), summer water deficits are projected to increase. The fundamental trend is in qualitative agreement with the assessment of another study (Hayhoe et al., 2007) that used a different hydrological modeling approach, and projected that the frequency of short-term droughts (one to three months in duration and defined by low soil moisture contents) will occur as often as once per year in the northeastern United States by end of century under a high emissions scenario. The ClimAID analysis provides a more detailed analysis for regions of New York State that have different historical rainfall patterns.

It would be premature to place a high degree of certainty on the exact magnitude or time course of the drought development projected. Results are very sensitive to how PET is calculated, for example, and further analysis and research is needed. As emphasized in the introduction to this case study, the results presented here are a worst-case scenario for annual row crops, because the analysis assumes maximum crop water demand (actual crop water use is at full potential, i.e., equal to PET) throughout the June to September growing season. Further analyses are refining the estimates of seasonal crop water demand by multiplying PET by a crop coefficient (between 0.2 and 1.0) determined from crop growth stage and canopy

development. This will probably have little impact on water deficits for July and August when crops are typically at full canopy (and therefore at PET levels), but it will reduce the magnitude of water deficits for the early and late parts of the growing season for annual row crops and for the whole season to values below those reported in **Table 7.3** and **Figure 7.9**. Also, numerous algorithms and modeling approaches exist for estimating PET (Hatfield, 1990). The Palmer Drought Severity Index, and thus this analysis, is based on the Thornthwaite PET model (1948), which primarily relies on temperature inputs. The Penman-Montieth model (Penman, 1948; Allen et al., 1998), includes solar radiation and other parameters and is more widely used for irrigation scheduling. The Penman-Montieth model, however, is difficult to use for climate projections because of the uncertainties in the projections of the inputs required for the model (e.g., radiation, humidity). A preliminary comparison of the two PET models using Rochester climatic data suggests that Thornthwaite may underestimate current PET and summer deficit values, but predicts twice the level of increase in deficits compared to Penman-Montieth model in response to climate change projections.

Further analysis will refine the projections of future water deficits, but it is not likely that these additional analyses will alter the fundamental conclusion that there will be increasing soil water deficits with climate change by mid- to late century. Supplemental irrigation is already recommended in New York State during most years in order to fully meet crop water requirements (Wilks and Wolfe, 1998; **Figure 7.8**). The results of the analysis indicate that increased irrigation capacity, particularly for production of high-value horticultural crops, will become essential for New York farmers in the coming decades.

Case Study D. Dairy Heat Stress

To assess heat stress impacts on cows with different baseline milk production potential, ClimAID used the Cornell Net Carbohydrate and Protein System (CNCPS) simulation model of dairy cow physiology and productivity (Fox and Tylutki, 1998), parameterized for herds of average and high productivity (65 and 85 pounds of milk per cow per day, respectively). High-producing cows are becoming more common and are inherently more sensitive to

Current Temperature, °F	Previous Temperature, °F	Predicted Milk, lbs/cow/day		Predicted Dry Matter Intake, lbs/cow/day		Income Over Feed Cost, \$/cow/day	
		65 lb max	85 lb max	65 lb max	85 lb	65 lb max	85 lb max
68	68	65	85	45.4	51.2	4.90	6.66
76	70	62.3	85.5	44	50.5	4.54	6.33
84	76	59	75	43.9	49.5	4.12	5.91

Table 7.4 Effect of temperature on dairy cattle performance

Climate Conditions — Historical Conditions (1970-2000)					Impact on Milk Production			
Current week		Previous month			lbs/cow/day		lbs/cow/year	
°F	RH	°F	RH	days/yr	65 lbs	85 lbs	65 lbs	85 lbs
79.1	68.0	70.3	68.0	0.9	-3.0	-5.1	-2.7	-4.6
77.8	71.2	70.9	71.2	1.9	-3.3	-4.4	-6.3	-8.4
76.0	71.4	69.0	71.4	5.4	-2.4	-3.5	-13.0	-18.9
74.3	71.8	69.3	71.8	7.9	-1.8	-2.4	-14.2	-19.0
72.3	72.6	68.9	72.6	12.1	0	-1.4	0	-16.9
70.7	72.2	68.3	72.2	17.0	0	-0.2	0	-3.4
total lbs/cow/yr							-36.2	-71.2
\$ /cow/yr(\$0.15/lb)							-5.4	-10.7

Climate Conditions — 2050s with A2 emissions					Impact on Milk Production			
Current week		Previous month			lbs/cow/day		lbs/cow/year	
°F	RH	°F	RH	days/yr	65 lbs	85 lbs	65 lbs	85 lbs
84.4	70.8	76.4	70.9	0.5	-6.9	-9.0	-3.4	-4.5
83.2	66.2	76.5	66.9	2.6	-5.5	-7.4	-14.3	-19.2
81.3	68.9	74.4	67.9	4.0	-4.5	-6.4	-18.0	-25.6
79.7	67.5	74.1	68.1	8.2	-3.5	-5.1	-28.7	-41.8
77.8	70.5	74.2	68.3	9.1	-2.5	-4.3	-22.8	-39.1
76.2	68.8	73.6	68.7	18.2	-1.4	-3.0	-25.5	-54.6
74.3	69.0	73.1	68.7	16.1	-0.6	-2.1	-9.7	-33.8
72.6	69.9	72.0	69.1	16.1	0	-1.2	0	-19.3
70.7	70.5	69.0	68.9	15.2	0	-0.5	0	-7.6
total lbs/cow/yr							-122.4	-245.5
\$ /cow/yr(\$0.15/lb)							-18.4	-36.8

Climate Conditions — 2080s with A2 emissions					Impact on Milk Production			
Current week		Previous month			lbs/cow/day		lbs/cow/year	
°F	RH	°F	RH	days/yr	65 lbs	85 lbs	65 lbs	85 lbs
88.1	62.5	81.0	63.0	0.7	-8.1	-10	-5.7	-7.0
86.8	63.4	82.1	64.4	2.6	-8	-9.4	-20.8	-24.4
84.9	64.9	81.1	65.1	5.4	-6	-8.2	-32.4	-44.3
83.2	63.4	79.8	64.3	7.9	-4.9	-6.6	-38.7	-52.1
81.3	65.6	79.2	66.1	10.7	-3.9	-5.9	-41.7	-63.1
79.7	65.7	78.2	65.5	16.6	-3	-4.8	-49.8	-79.7
77.9	65.3	77.3	65.1	16.3	-1.9	-4.1	-31	-66.8
76.2	66.4	76.1	66.6	14.0	-1.4	-2.9	-19.6	-40.6
74.3	67.7	73.2	67.1	13.8	-0.6	-2.1	-8.3	-29
72.5	68.5	71.8	67.8	12.4	0	-2.1	0	-26.0
70.7	71.1	71.1	68.7	10.5	0	-0.4	0	-4.2
total lbs/cow/yr							-248	-437.3
\$ /cow/yr(\$0.15/lb)							-37.20	-65.6

Table 7.5 Heat- and humidity-based reductions in milk production for Rochester, under historical conditions and projected to the 2050s and 2080s for the A2 emissions scenario averaged over 5 GCMs (GFDL, GISS, MIROC, CCSM, and UKMO) of the 16 used in ClimAID

heat stress due to their high metabolic rate. The model uses as inputs relative humidity, “previous” temperature (average over the prior month), and “current” temperature (a weekly average). Current feed and milk prices are also used to evaluate the economic impact of these changes. **Table 7.4** illustrates the model sensitivity to average temperature when relative humidity is constant (68 to 71 percent for all runs). At 68°F, the cows are not stressed and give milk at their specified production levels of 65 or 85 pounds per day. As average temperature increases to 84°F, there is a decrease in dry matter intake, milk, and income over feed cost. When fat was added to the ration, milk production was partially restored back toward unstressed values by 1 to 5 pounds per cow per day (data not shown), improving income over feed cost by \$0.15 to \$0.35 per cow per day over the range of rations used in this evaluation. Thus, manipulation of the ration allows partial amelioration of heat stress effects, but not full recovery.

The CNCPS simulation model was used to compare heat-stress-induced milk reductions for historical conditions (1970–2000) and air temperature and relative humidity projections to the 2050s (2040–2069) and the 2080s (2070–2099) derived from five global climate models (GFDL, GISS, MIROC, CCSM, and UKMO) and the high-emissions A2 scenario. The model runs assume dairy barns with standard ventilation cooling capacity for today’s conditions. **Table 7.5** shows the predicted lost milk production based on the number of days per year with various weekly average values of temperature and relative humidity. Historical (1970–2000) values are compared to future A2 emissions scenarios where the proportion of days at higher temperature increases. Two levels of milk production are considered, with unstressed baselines of 65 versus 85 pounds per day. The first two columns on the left show the effect per day of different temperature categories on production, and the second two columns show the annual impact weighted by the average number of days spent in each temperature category during a summer. Total annual milk loss in pounds per cow per year was translated into an estimate of monetary loss that assumed a price of \$15 per 100 pounds of milk. All values for milk loss reported in **Table 7.5** assume that the cows have already had temperature-appropriate feed adjustments (e.g., adding fat to the ration) as discussed above to partially ameliorate the stress effects.

Effects of Climate Change on Milk Production

Based on this simulation, the average yearly losses in milk production associated with heat stress for the historical period was 36.2 pounds per cow per year for the 65-pound-per-day cows and 71.2 pounds per cow per year for the 85-pound-per-day cows (**Table 7.5**). Projections of climate change effects on future milk production decline show more than a six-fold increase compared to the historical average by end of century (2080s), with milk production dropping by 248 pounds per cow per year for the 65-pound-per-day cows and 437 pounds per cow per year for the 85-pound-per-day cows. The projected end-of-century economic losses associated with heat stress are approximately \$37 and \$66 per cow per year. For both levels of milk production, the greatest impact on annual milk losses does not come from the highest stress levels experienced, but from intermediate stress levels that occur for a larger number of days over the season. Even relatively low losses experienced in a chronic manner can result in substantial cumulative losses.

The simulated historical values in **Table 7.5** seem low based on observation of actual losses during the 1970–2000 period, suggesting the model may be conservative in estimates of heat stress on milk production decline. This may be, in part, due to the focus of this model on short-term milk production decline, but not on potential long-term impacts from stress during critical periods as mentioned above and discussed in more detail in the Vulnerability section (7.3.5). Also, this analysis assumes good barn ventilation and that barn temperatures are the same as ambient temperatures. However, barn temperatures can become higher than ambient temperatures in poorly ventilated barns, and this could become a more significant problem as the climate warms.

The projections used in this analysis involved a drop of relative humidity by the 2080s by as much as 5 percent on an annual basis and 7 or 8 percent in the hottest months of the summer (**Table 7.5**). This has a natural compensatory effect, because the lowered relative humidity improves evaporative cooling and makes the cows less susceptible to high temperature stress. Again, this makes the results presented conservative, because the depression in milk production is attributable to a future condition projected with high confidence (temperature increases), while the ameliorating factor

(relative humidity) is one with much lower confidence (relative humidity decreases). If the analysis assumed no change in relative humidity in the future, milk losses would be greater.

Costs of Adaptation: Improving Cooling Capacity

Modifying feeding management and providing adequate water can help to ameliorate heat stress in cows (see Adaptation, Section 7.4.1), but improving cooling capacity of the housing system is typically a more effective approach. Important features characterizing barn cooling systems include 1) air turnover capacity per hour, to prevent the build-up of heat, humidity, toxic fumes, and airborne pathogens, 2) air speed at cow level, and 3) the possible injection of mist and sprinkled water to provide evaporative cooling.

Most of the smaller herds (less than 100 cows) in New York are housed in tie-stall barns. Many of these are older facilities that can be difficult to modify. Tunnel ventilation is an option for cooling cows housed in some styles of tie-stall barns. In tunnel ventilation, a group of fans is located at one end of the barn and draws air from inlets at the other end of the barn, cooling the animals.

A “partial budget” analysis or a simple payback methodology is commonly used to calculate benefits of relatively small investments. Such analytical frameworks, when used at a microscale, provide straightforward evaluation of the net returns ensuing from a particular change in operation, such as investing in cooling systems. Their value lies in the nature of the information required, which is usually available. For example, partial budget analysis only requires estimation of the potential changes in revenues and costs resulting from a particular investment (Turner et al., 1997; Dhuyvetter et al., 2000). An interactive web-based program is available to calculate the costs and the pounds of avoided milk production decline needed to pay for the tunnel ventilation system (www.pro dairy facilities.cornell.edu/TunnelVent/Intro.aspx).

An example simulation was done for a 70-cow dairy herd producing 75 pounds of milk per cow per day. The cost for the tunnel ventilation system was \$7,694 (\$110

per cow). This included the operational cost and the interest on a five-year loan to pay for the system. It was assumed that the system would run 16 hours a day for 40 days during the year. It would require a change of 5 pounds of milk per cow to break even with this system. If the system ran 60 days per year, the pounds of milk required to break even would be reduced to 4 pounds per cow. This interactive model can be used to estimate payback period with each specific herd using their data for number of cows, milk production, system costs, and days of operation. A number of herds have installed tunnel systems in tie-stall barns and paid for them in one to two years.

When ventilation systems alone cannot keep cows from overheating, sprinkler and mister systems can be added to provide evaporative cooling. Sprinklers can be used as an option with tunnel ventilation and other configurations that provide high airspeeds at cow level. In these systems, the cow’s skin is soaked with water at periodic intervals and then the water is removed by the use of fans. This is an effective method of cooling cows in climates with moderate to low humidity. The cost of these systems is relatively low at about \$5 to \$10 per cow (Dhuyvetter, 2000). One concern of dairy producers is the quantity of water required. These systems use about 25 to 50 gallons of water per cow per day. There are two primary considerations: making sure that an adequate supply of water is available, and making sure the quantity of additional water that enters the manure system is stored and later hauled to the fields. Although much of the water applied, especially that which directly wets the coats of the animals, is evaporated away, a large amount of residual water becomes mixed with the manure. On a large dairy farm, this can be a significant quantity of water and is likely to be a concern in the future with potential drought due to climate change.

As herds get larger in free-stall barns, they tend to be placed into groups of animals that are at different stages of development or different stages of the production system. Each such group has unique sensitivities and potential responses to heat stress and reduction techniques. As dairy producers consider providing ventilation systems to change the environment in their barns, they need to consider each group of animals and the potential for response and economic return. The following is a list of areas and animal groups in approximate order of priority for cooling during hot periods:

- holding area (area where cows wait to enter the milking parlor)
- milking area
- close-up dry cows (cows within three to four weeks of calving)
- calving area
- fresh cows (cows that have recently calved)
- high-producing cows
- low-producing cows

Cows in the holding area typically are very close together, touching each other. Even though they may be in this area for only a short time, heat stress and the thermal heat index (THI) can be very high. The preferred option for this area is to provide both fans and sprinklers. One report indicated that cows cooled in the holding pen produced 1.7 to 4 pounds more milk per day than cows not cooled in the holding area. A 1993 trial in Arizona indicated that cows cooled in the holding area produced 1.9 pounds more milk per cow per day than cows that were not cooled (Armstrong, 2000).

Priorities can be set for where the fans should be placed in barns. If funds are limited, the first choice would be to place fans over the feed bunk area. In addition, fans could be placed over the cow resting area (stalls). Ideally, fans would be placed over both areas. Tunnel ventilation is sometimes a good option (Gooch, 2008), but several other styles of ventilation system may be more appropriate depending on barn structure and site configurations.

Herd Size and Economies of Scale in Ventilation Systems

Many ventilation systems are inherently more cost-effective when deployed for larger animal housing situations. An interactive program available from Cornell University's Pro dairy website can be used to calculate the costs and pounds of milk needed to break even with a tunnel ventilation system. This program calculates initial investment, operating costs, loan payments, days of fan operation, and the pounds of milk needed to break even. Using a five-year loan period and a milk price of \$15 per 100 pounds of milk, model runs for both a small, tie-stall barn (50 or 100 cows) and a free-stall barn (300 or 600 cows), and assuming that the fans would operate 50, 100, or 150 days per year, provide the following results for initial investment (not including loan interest):

- 50 cow tie-stall barn = \$262 per cow
- 100 cow tie-stall barn = \$132 per cow
- 300 cow free-stall barn = \$144 per cow
- 600 cow free-stall barn = \$72 per cow

The degree to which milk production must be increased through avoidance of heat stress effects in order for the cooling systems to pay for themselves over a five-year payback period is shown in **Table 7.6** for each combination of barn style and herd size and considering three different scenarios of how many days per year reached stressful temperatures. Larger numbers for milk production in the same column imply that higher, more stressful outside temperatures would have to be experienced before installing a cooling system for a given barn style and herd size represented a cost-effective investment. In both styles of barns, there is a distinct economy of scale, with larger herds reaching cost-effectiveness at smaller minimum savings in milk production.

To summarize, to adequately ameliorate the effects of high temperatures, both adequate ventilation at high airspeeds directly over the cows and appropriately deployed sprinkler systems will be needed in the future. Many dairy barns already have both fans and sprinklers, but a significant number do not. The greatest cost in this configuration lies in the fans, but sprinklers without fan systems are not effective. While these cooling systems represent added investments, the literature shows that they have a high likelihood of paying for themselves over time through increased milk production. With projected climate change, adequate cooling systems will be increasingly important for the future of New York's dairy industry.

	Milk Production Savings (lbs/day) Needed to Pay Back Investment in Cooling Fans		
	50 heat stress days/yr	100 heat stress days/yr	150 heat stress days/yr
50 cow tie-stall barn	10.94	7.12	5.75
100 cow tie-stall barn	5.47	3.63	2.87
300 cow free-stall barn	5.9	3.9	3.1
600 cow free-stall barn	2.97	1.97	1.56

The values in the body of the table are levels of milk production increase (lbs per cow per day) that must be realized when cooling fans are employed in order to make the fan investment cost-effective, as described in the text. Three scenarios are considered showing that if fewer days of heat stress are experienced per year, the impact per day must be high to make installation cost effective. Tie-stall and free-stall barns are compared, each at two relevant herd sizes.

Table 7.6 Magnitude of potential heat stress losses required for fan and cooling systems to pay for their own installation and operation over a five-year pay-back period

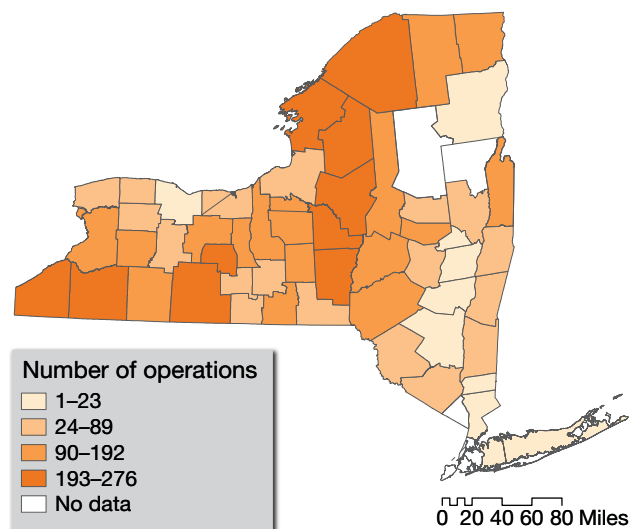
Equity and Environmental Justice Issues

Vulnerability and capacity to adapt to climate change may vary substantially across different dairy regions in New York State (**Figure 7.10**) due to differences in climate change exposure, regional cost structures, farm sizes, and overall productivity. Should climate change have a highly detrimental effect on dairy farming in the state overall, those regions with higher concentrations of dairy farms are likely to experience a more substantial economic disruption. On the other hand, farmers in regions with higher concentrations of farms may also have some advantages associated with external economies of scale that facilitate adaptation to climate change, such as ability to learn from other farmers in the area regarding best adaptation practices or pooling of resources for different types of services that are needed to foster adaptation.

Regional comparison of the location of dairy operations in New York in 2007 (**Figure 7.11**) reveals that dairy farms are particularly abundant in the western parts of the Northern New York and Central Valleys Dairy Regions and in the Western and Central Plateau Region. Measured in terms of annual sales of milk and dairy products (**Figure 7.12**), the regional pattern is slightly different. The counties with the highest concentrations of dairy sales are located in the western portion of the Northern New York Region (also a region with the highest number of operations) and in the Western and Central Plain Region. According to the

U.S. Census of Agriculture, the three New York counties with the highest sales in milk and other dairy products in 2007 are Wyoming County (\$179 million) and Cayuga County (\$140 million), both located in the Western and Central Plain Region, followed by St. Lawrence County (\$113 million in sales) in the Northern New York Region.

In addition to differences in numbers of farms and total sales, the major dairy regions within the state also exhibit different characteristics in terms of size and profitability. Detailed data that permit comparisons



Source: U.S. Agricultural Census, 2007

Figure 7.11 Locations of dairy operations in New York State

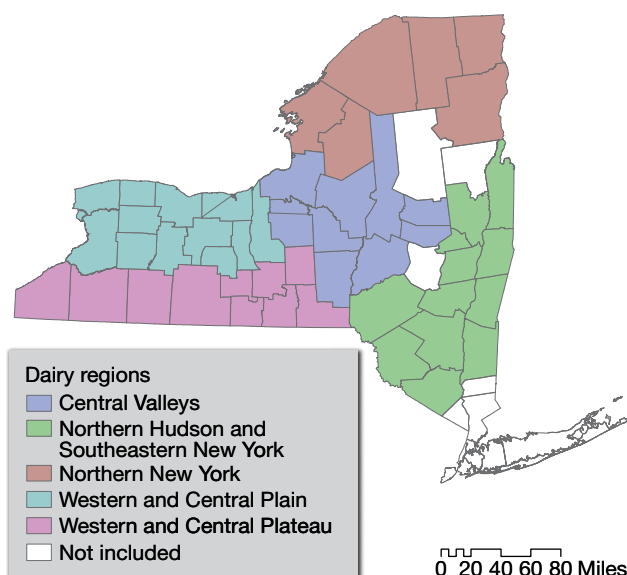
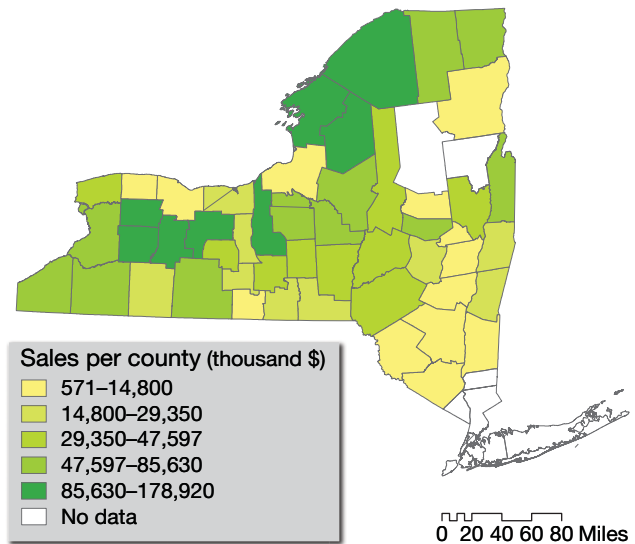


Figure 7.10 Dairy regions in New York State



Source: U.S. Agricultural Census, 2007

Figure 7.12 Dairy sales by county for New York State

among regions in New York are available from the Cornell Cooperative Extension's Dairy Farm Business Summary and Analysis Project. Because participation in the survey is voluntary, these data do not represent a statistically robust sample. In particular, the data may contain some overrepresentation of farms with better organization and record keeping, as these farms are more likely to participate in the survey on a continuing basis. Nonetheless, the data provide useful insights into some of the major differences in the characteristics of dairy farms among the regions of the state (**Table 7.7**).

Examination of **Table 7.7** suggests that larger farms are concentrated in the Western and Central Plain region, where the average farm size within the Cornell sample has 673 cows and more than 1,200 tillable acres. The smallest average farm size is in the Western and Central Plateau region, where the average farm within the sample has 168 cows on 417 tillable acres. Costs of milk production range from \$17.04 per hundredweight of milk in Northern New York to \$18.63 per hundredweight in the Northern Hudson and Southeastern New York Region. Some factors that account for these regional differences include land and labor costs, which are likely to be higher in the areas

closer to metropolitan New York. The Western and Central Plateau Region (which also has the smallest farms) is another region with relatively high costs of \$18.03 per hundredweight of milk sold. These differences in milk production costs across regions may influence capacity to adapt to climate change, particularly in cases where adaptation requires additional expenditures for energy and pest control due to higher summer temperatures.

Differences in farm and herd size are also potentially significant factors in determining vulnerability and capacity to adapt to climate change. Comparison of small versus large farms throughout the state reveals significant differences in costs, milk sales per cow, capital efficiency, income, and profitability (**Table 7.8**). All of these differences may affect the overall capacity of smaller farms to adapt to climate change, particularly if such adaptation requires significant new outlays of capital for purchase and installation of ventilation systems in dairy barns, as well as additional costs associated with energy for operating this equipment.

While it is difficult to know precisely how different-sized dairy farms will be affected by climate change, the

	West & Central Plateau	West & Central Plain	Northern New York	Central Valley	North Hudson & Southeastern NY
Average number of cows per establishment	168	673	372	289	210
Tillable acres	417	1241	848	707	495
Total cost of producing milk (\$ per hundredweight)	\$18.03	\$17.16	\$17.04	\$17.33	\$18.63
Average price received (\$ per hundredweight)	\$20.62	\$20.09	\$20.06	\$20.77	\$20.95

Source: Cornell University, Dairy Business Summary and Analysis Project (Knoblauch et al., 2008)

Table 7.7 Characteristics of dairy regions in New York State

Farm Size	Small Farms (39 farms)			Large Farms (83 farms)		
	2007	2008	% chg	2007	2008	% chg
Average number of cows	52	52	0.0	773	797	3.1
Total tillable acres	40	41	2.5	1,482	1,595	7.6
Milk sold (lbs)	975,626	976,710	0.1	18,500,129	19,671,976	6.3
Costs						
Grain and concentrate purchases as a percent of milk sales	24%	31%	29.2	24%	30%	25.0
Total operating expenses per hundredweight sold	\$16.29	\$17.51	7.5	\$16.32	\$17.87	9.5
Capital Efficiency						
Farm capital per cow	\$11,880	\$12,576	5.9	\$7,981	\$8,772	9.9
Machinery and equipment per cow	\$2,152	\$2,382	10.7	\$1,309	\$1,467	12.1
Income and Profitability						
Gross milk sales per cow	\$3,817	\$3,678	-4.4	\$4,870	\$4,753	-2.4
Net farm income (w/o appreciation)	\$54,680	\$28,117	-48.6	\$939,605	\$483,799	-48.5
Income per operation per manager	\$20,267	-\$5,257	-126	\$388,494	\$128,755	-67
Farm net worth	\$498,120	\$502,664	0.9	\$4,421,159	\$4,658,105	5.4

Source: Cornell University, Dairy Business Summary and Analysis Project, Knoblauch et al., 2009 and Karszes et al., 2009

Table 7.8 Small versus large dairy farms in 2007 and 2008

effects of other types of shocks can help to illustrate which types of farmers might be more or less vulnerable to climate change. Comparison of how farms in the Cornell study performed in 2007 (a relatively profitable year) versus 2008 (a more challenging year due to spikes in input prices including feed, energy, and fertilizer) provides a glimpse into how shocks affect farms of different sizes. Similar types of input price shocks may also occur under climate change, because more frequent extreme weather conditions could lead to higher feed and energy prices. Policies intended to reduce emissions may also contribute to higher energy prices, though such effects are likely to be more gradual as taxes or other mechanisms to mitigate climate change are put into place.

Data from the Cornell dairy survey reveals that both small and large farms experienced significant challenges in coping with these conditions in 2008, but small farms appear to have fared worse (**Table 7.8**). Small farms experienced no increase in milk sold and had a 4.4 percent decline in gross milk sales per cow from 2007 to 2008. By contrast, large farms increased sales by 6.3 percent and experienced a 2.4 percent decline in gross milk sales per cow. Small farms also experienced relatively larger increases in purchased input costs (29.2 percent for small farms compared to 25 percent for large farms), but smaller increases in total production costs (7.5 percent for small farms compared to 9.5 percent for large farms). While net farm income for both small and large farms declined by approximately 48 percent between 2007 and 2008, income per farm operator or manager declined much more precipitously for small farms. Overall, the typical small farm operator experienced an income loss of 126 percent, while large farms operators experienced losses of 67 percent.

Collectively, these ClimAID results suggest that small farms may be less able to withstand shocks related to climate change without some type of adaptation assistance.

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Appendix A. Stakeholder Interactions

The ClimAID Agriculture team gathered information and enlisted participation from key stakeholders in the agriculture sector through existing relationships and collaboration with the New York State Department of Agriculture and Markets, Cornell Cooperative Extension and Integrated Pest Management specialists, crop consultants, farmer commodity groups (e.g., Sweet Corn Growers and Finger Lakes Grape Growers Associations), and individual farmer collaborators. Below are some specific aspects of stakeholder involvement associated with the project.

Meetings and Events

Two important half-day meetings were held with stakeholders early on to gather expert opinions, with formal presentations followed by an opportunity to provide feedback:

- 1) Conference with approximately 35 Cornell Cooperative Extension staff from across the state, held in Ithaca on November 11, 2008. The expertise of these specialists ranged from fruit and vegetable crops to dairy and grain crops. The conference included presentations and breakout group input on high-priority vulnerabilities and potential opportunities, feasible adaptation strategies, and needs for additional information, decision tools, and/or resources to help farmers cope with climate change.
- 2) Briefing at New York State Agriculture and Markets headquarters (Albany, November 12, 2008) attended by the Agriculture Commissioner and approximately 15 other key department leaders.

Other presentations of preliminary results have included the 2009 November “In-Service” training for Cornell Cooperative Extension staff in Ithaca, and the NYSERDA Agriculture Innovations Conference in December, 2009, held in Albany.

Focus Group and Technical Working Groups of the Climate Action Plan

A focus group of several stakeholders has been used for frequent feedback as this project proceeds. In addition, results have been shared with individuals at New York State Agriculture and Markets.

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- ¹ Abbreviations are for counties in geographic areas: N = Northern (Jefferson, Lewis, St. Lawrence); NE = Northeastern (Clinton, Essex, Franklin, Hamilton, Warren); W = Western (Erie, Genesee, Livingston, Monroe, Niagara, Ontario, Orleans, Seneca, Wayne, Wyoming, Yates); C = Central (Cayuga, Chenango, Cortland, Herkimer, Madison, Oneida, Onondaga, Oswego, Otsego); E = Eastern (Albany, Fulton, Montgomery, Rensselaer, Saratoga, Schenectady, Schoharie, Washington); SW = Southwestern (Allegany, Cattaraugus, Chautauqua, Steuben); S = Southern (Broome, Chemung, Schuyler, Tioga, Tompkins); SE = Southeastern (Columbia, Delaware, Dutchess, Greene, Orange, Putnam, Rockland, Sullivan, Ulster, Westchester); LI = Long Island (Nassau, New York City, Queens, Richmond, Suffolk).
- ² Small farms in New York State are defined as those with total acreage of less than 100 acres and/or annual sales of less than \$50,000. Approximately 51 percent of farms in New York State are less than 100 acres in size, and approximately 75 percent of New York farms have revenue of less than \$50,000 (USDA, 2007).
- ³ Within the dairy sector, small farms are defined as having 80 or fewer cows and no milking parlor (Knoblauch et al., 2009).
- ⁴ Precipitation is in liquid-water equivalents for rain or snow; PET is the potential evapotranspiration (evaporative water loss from soil and plants); runoff is the fraction of precipitation that exceeds soil holding-capacity and passes either into deep groundwater or into streams. PET calculations in this figure assume full leaf-area development throughout the growing season and are not specific to any particular crop's growth and development.
- ⁵ Predictions are shown for Indian Lake in the Adirondacks, Elmira, and Rochester, and include historic values (based on the period 1901–2006) and climate change projections for two different carbon dioxide emissions scenarios, B1 (low emissions) and A2 (high emissions). Calculations were derived from the same dataset as Table 7.3, which assumes maximal plant water demand (i.e., potential evapotranspiration, calculated assuming full canopy cover for the entire period; see text for more discussion). Projected changes in monthly temperature and precipitation used to calculate deficit probabilities were derived from ClimAID data generated from (GFDL, GISS, MIROC, CCSM, and UKMO) GCMs as appropriate for each of the timeslices and emissions scenarios.

Chapter 8

Energy

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Introduction

This ClimAID chapter considers how global climate change may improve or exacerbate existing weather-related stresses on the energy sector and reviews possible short- and long-term adaptation strategies.¹ The chapter broadly groups specific vulnerabilities and opportunities into supply-side issues and demand-side issues, with a particular emphasis on the power sector. Transport-related energy considerations are covered in Chapter 9, “Transportation,” of this report.

Research for this chapter was conducted both as a literature review and through direct stakeholder engagement with a range of energy companies operating in different parts of the state (see Appendix A).

8.1 Sector Description

Reliable energy systems are critical to commerce and quality of life. New York State’s electricity and gas supply and distribution systems are highly reliable, but weather-related stressors can damage equipment, disrupt fuel supply chains, reduce power plant output levels, or increase demand beyond the energy system’s operational capacity.

8.1.1 Brief Profile of the New York State Energy System

Energy is derived from a wide variety of fuel sources and technologies in New York State. Roughly 49 percent of the state’s electricity is generated in-state using fossil fuels; nuclear power (30 percent) and renewables² (21 percent) account for the balance (NYISO, 2009) (**Figure 8.1**). The generation mix varies widely in

Energy Unit	Description
Kilowatt (kW)	A measure of electrical power equal to 1,000 watts
Megawatt (MW)	A measure of electrical power equal to 1,000 kW (or 1 million watts)
Gigawatt (GW)	A measure of electrical power equal to 1,000 MW (1 billion watts)
Kilowatt or Megawatt peak (kWp or MWp)	Peak power plant generation capacity
Kilowatt hours (kWh), Megawatt hours (MWh), or Gigawatt hours (GWh)	A time-related measure of electrical energy. Running a 3,000 MWp power plant at 100% capacity for 1 hour would produce 3,000 MWh of energy.

Table 8.1 Definitions of key energy terms used in this chapter

different parts of the state. For example, approximately 50 percent of the fossil-fired power plant capacity is located in New York City and Long Island, while most hydropower capacity is located in the northern and western part of the state (USEPA, 2009). **Table 8.2** presents generation capacity by fuel type in each ClimAID region.

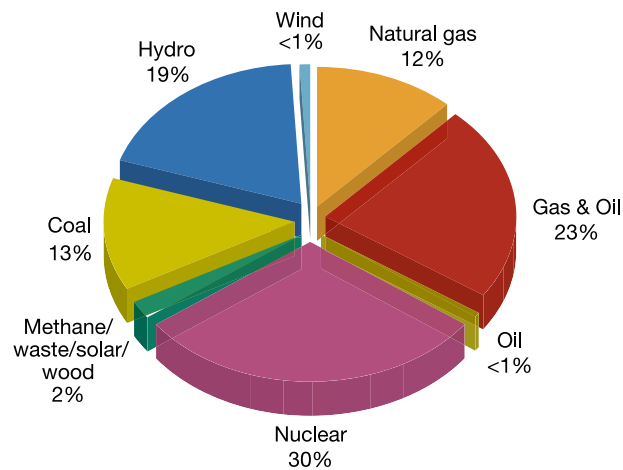
New York State is divided into 11 electricity load zones, which are managed by the New York Independent System Operator (NYISO) (**Figure 8.2**). These zones are drawn by primarily administrative boundaries and do not reflect unique geographic or operating characteristics. They do differ significantly from the seven ClimAID regions highlighted in this report (see Appendix B, and Chapter 1, “Climate Risks”).

New York City is by far the largest load zone in the state, responsible for approximately one-third of total annual electricity demand statewide (**Table 8.3**). Between 2002 and 2008, the period for which data are readily available, load growth (in total gigawatt-hours) has occurred in nine of the 11 zones around New York State. Growth has not been consistent, as load has declined in one or more years in most zones, but on average the total annual electricity load has increased by 4.3 percent each year statewide (NYISO, 2009a).

Thermal energy needs are satisfied in a variety of ways. New York State is home to more than a dozen district energy systems, which centrally generate steam, hot

ClimAID Region	Number of Power Plants (by fuel type) and Peak Generation Capacity (MWp)			
	Fossil fuel	Nuclear power	Renewables	Total
Region 1	19 2,761 MWp	1 517 MWp	14 2,628 MWp	34 5,905 MWp
Region 2	11 3,548 MWp		13 1,106 MWp	24 4,654 MWp
Region 3	10 775 MWp		4 11 MWp	14 786 MWp
Region 4	49 12,996 MWp		7 137 MWp	56 MWp
Region 5	14 1,350 MWp	2 2,339 MWp	50 594 MWp	66 4,283 MWp
Region 6	13 3,968 MWp	2 2,784 MWp	42 304 MWp	57 7,056 MWp
Region 7	6 566 MWp		52 1,263 MWp	58 1,829 MWp
New York State	122 25,964 MWp	5 5,640 MWp	182 6,043 MWp	309 37,647 MWp

Table 8.2 New York State power plant data by ClimAID Region

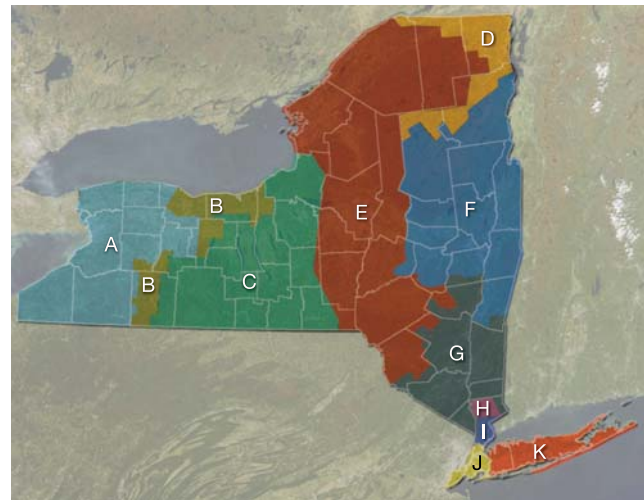


Source: NYISO, 2009, p 61

Figure 8.1 New York State electricity generation by fuel type

water, or cold water and distribute it to customers via a series of underground pipes. New York City hosts one of the largest district energy systems in the world, with seven in-city plants producing steam that is distributed to 100,000 business, residential, and institutional customers through 105 miles of pipes traversing Manhattan (Ascher, 2005; Bevelhimer, 2003). Other large district energy systems can be found in Jamestown, Rochester, and Nassau County.

Natural gas is the most commonly used source of heating fuel in buildings around the state (**Figure 8.3**). There is a small amount of natural gas production in New York, primarily in the Finger Lakes region, which is sufficient to meet the needs of approximately 728,000 households (NYSDEC, 2010b). This could change



Source: NYISO (2009a), basemap NASA

Figure 8.2 New York Independent State Operator (NYISO) load zones

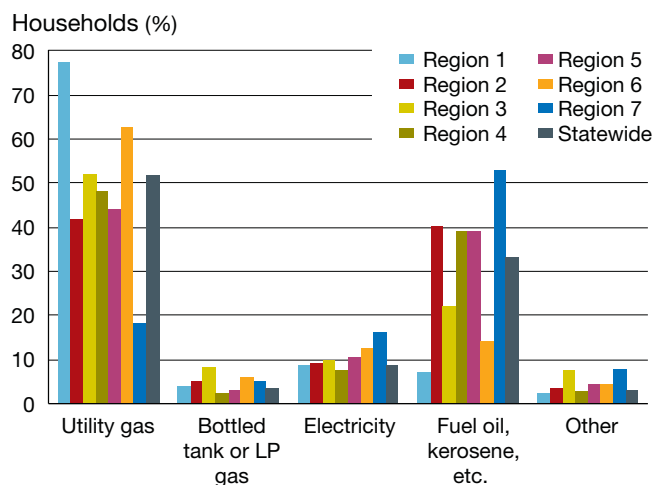
significantly with the development of the Marcellus Shale, a vast natural gas deposit extending along the state's southern tier from western New York to the Catskills region. Access to this gas is currently being reviewed by State officials. There are currently no liquefied natural gas unloading terminals in the state, although several have been proposed (State Energy Planning Board, 2009b). The vast majority of the state's natural gas supply is obtained from the large national natural gas distribution system, which has several large feeders crossing the state.

The state's electricity, natural gas, and steam markets are regulated by the New York State Public Service Commission (2009), which is responsible for ensuring "safe, reliable [energy] service and reasonable, just

NYISO Load Zone	Average Annual Load (2002–2008) (GWh)	Annual Load (2008) (GWh)	Percent of State Annual Load (2008)	Average Peak Load (2002–2008) (MWp)	Peak Load (2008) (MWp)	Percent Load Growth Change (2002–2008)	Percent Average Annual Change
Zone A (Buffalo)	16,129	15,833	10%	3,113	2,611	-3.8%	-0.59%
Zone B (Rochester)	10,002	10,088	6%	2,143	2,001	1.72%	0.31%
Zone C (Syracuse)	16,863	16,719	10%	3,153	2,939	2.4%	0.45%
Zone D (Plattsburgh)	6,336	6,733	4%	1,493	949	4.22%	1%
Zone E (Utica, Watertown)	7,393	7,855	5%	1,569	1,388	9.45%	1.75%
Zone F (Albany)	11,452	11,594	7%	2,381	2,302	2.59%	0.51%
Zone G (Hudson Valley)	10,594	10,607	6%	2,496	2,344	3.77%	0.7%
Zone H (Upper Westchester)	2,467	2,935	2%	2,204	665	26.36%	5.55%
Zone I (Lower Westchester)	6,186	5,944	4%	1,641	1,440	-0.24%	0.02%
Zone J (New York City)	30,344	54,830	33%	11,347	11,262	3.1%	1.6%
Zone K (Long Island)	12,642	22,459	14%	5,748	5,281	1.33%	0.69%
Total	130,407	165,595	100%	37,288	33,181		

Note that prior to February 2005, Zone J and Zone K were a single, combined load zone.
Source: NYISO 2009a

Table 8.3 Load zones in New York State



Source: Adapted from NYSDERDA, 2009

Figure 8.3 Fuels used for residential space heating in New York State by ClimAID Region

rates.” In the late 1990s, the Public Service Commission oversaw the restructuring of New York State’s electricity and gas markets, shifting from a system of vertically integrated, regulated monopolies to one involving separate power generators, distribution utilities, and energy service companies that sell power or gas to customers and pay fees to distribution utilities for the use of their pipes or wires.

Energy prices vary widely, with prices higher in eastern New York than in western parts of the state. Long Island and New York City (ClimAID Region 4) have the highest energy prices (Potomac Economics Ltd., 2009), due to transmission constraints; high real estate value, labor, and other utility operating costs; and past decisions to bury transmission and distribution system assets, making them more costly to service (City of New York, 2007). High voltage electricity transmission constraints create a situation where New York City and Long Island are considered to be a load pocket, meaning the region’s electricity needs cannot be satisfied solely by electricity imports; some level of generation must occur within the city or region itself (NYISO, 2002).

The New York State Energy Research and Development Authority (NYSDERDA), a public benefit corporation whose aim is to help New York meet its energy goals, has greatly influenced New York’s energy system over the past 35 years. Its primary focus is on reducing energy consumption, promoting the use of renewable energy sources, and protecting the environment (NYSDERDA, 2010). Through its investments in technology and market research and

development projects, demand-side energy programs, and policy research, NYSDERDA has changed the way New Yorkers obtain and use energy and has helped build the foundation for a cleaner energy future. Climate change issues have been on NYSDERDA’s radar screen since the late 1980s, when the agency financed one of the first-ever studies looking at how climate change will affect the New York State energy system (Linder et al., 1987). The ClimAID project, of which this chapter is one key part, offers a more updated analysis of many of these same issues.

8.1.2 Economic Value

New York households, businesses, and industries spent more than \$72.2 billion on different forms of energy in 2008 (NYSDERDA, 2010b). This was the seventh

	1994	1999	2004	2008
Residential				
Coal	3.3	2.5	1.6	1.7
Petroleum	2221.1	1950.4	3540.3	5072.0
Natural Gas	4891.3	4365.5	5592.9	6566.2
Electricity	7886.2	7354.3	7849.7	8973.2
Subtotal	15001.9	13672.7	16894.5	20613.1
Commercial				
Coal	9.5	6.9	7.7	8.8
Petroleum	1219.7	726.0	1854.1	2373.9
Natural Gas	2110.3	2394.7	4136.0	3765.7
Electricity	9617.6	9066.8	10999.7	13036.8
Subtotal	12957.1	12194.4	16997.5	19185.1
Industrial				
Coal	185.1	135.9	87.1	115.7
Petroleum	293.4	238.4	401.0	688.9
Natural Gas	1225.1	515.1	723.2	1070.5
Electricity	2896.9	1588.8	1658.2	1489.1
Subtotal	4600.5	2478.2	2869.5	3364.2
Transportation				
Coal				
Petroleum	11942.0	11535.8	17884.4	28688.7
Natural Gas				
Electricity	353.0	278.8	239.1	368.8
Subtotal	12295.0	11814.7	18123.5	29057.5
Total				
Coal	197.9	145.3	96.4	126.2
Petroleum	15676.2	14450.6	23679.8	36823.5
Natural Gas	8226.7	7275.3	10452.1	11402.4
Electricity	20753.8	18288.7	20746.7	23867.9
Total	44854.6	40160.0	54885.0	72220.1

Source: NYSDERDA, Patterns and Trends: New York State Energy Profiles 1994–2008 (January 2010)

Table 8.4 New York State energy expenditures by sector and fuel type

NAICS Industry Code	Description	Paid Employees (March 2008)	Annual Payroll	Total # Establishments
21111	Oil and Gas Extraction	289	\$21,432,000	52
22111	Electric Power Generation	6539	\$699,298,000	124
22112	Electric Power Transmission, Control, and Distribution	28695	\$2,702,645,000	272
22121	Natural Gas Distribution	3475	\$308,945,000	97
23712	Oil and Gas Pipeline and Related Structures Construction	1530	\$178,872	34
23713	Power and Communication Line and Related Construction*	4731	\$315,972	179
23821	Electrical Contractors	53318	\$3,177,234,000	5019
23822	Plumbing, Heating, and Air Conditioning Contractors*	57729	\$3,291,321,000	6503

*Overstates energy sector figures due to inclusion of non-energy related employees.

Source: U.S. Census Bureau, CenStats Database: 2008 County Business Patterns (NAICS) – New York

Table 8.5 New York State energy sector employment and payroll (2008)

consecutive year energy expenditures have increased. (In contrast, total energy spending in New York State in 2002 was \$38.45 billion, slightly more than half of current levels (NYSERDA, 2005).) **Table 8.4** details energy expenditures in the state for selected years by sector and fuel type.

Spending in 2008 on power and heating fuels was fairly evenly distributed between the residential and commercial sectors, with industrial energy use lagging far behind (NYSERDA, 2010b). Transportation fuel use is not broken out by sector in NYSEDA's most recent profile of state energy use, so it is difficult to ascertain if it is primarily household or business-related.

Residential Sector	Coal (\$/ton)	Heating Fuel (¢/gal)	Propane (¢/gal)	Natural Gas (\$/Mcf)	Electricity (¢/kWh)
1994	110.30	145.81	182.95	12.70	19.67
1999	98.99	130.04	156.21	11.77	17.12
2004	91.51	193.18	202.92	14.34	16.56
2008	122.35	385.23	314.67	16.75	18.30
Commercial Sector					
1994	56.15	103.70	136.60	9.46	16.36
1999	41.37	84.27	114.34	6.65	13.33
2004	47.54	153.53	162.43	11.59	14.78
2008	70.86	314.95	255.90	12.91	16.84
Industrial Sector					
1994	70.51	70.51	74.76	5.22	6.78
1999	64.79	64.79	82.04	3.90	4.76
2004	127.39	127.39	144.82	8.11	7.04
2008	82.27	317.99	268.16	12.97	10.14
Transport Sector					
	Gasoline (¢/gal)	Diesel (¢/gal)	Electricity (¢/kWh)		
1994	165.60	186.14	12.60		
1999	153.25	157.55	10.50		
2004	212.92	212.70	9.02		
2008	327.81	399.35	12.64		

Note: All figures in constant 2008 dollars. Source: NYSEDA, 2010b

Table 8.6 Average energy prices by fuel type and sector in New York State

The energy sector is directly responsible for tens of thousands of jobs around the state, with a payroll totaling in the billions. There are nearly 400 firms and more than 35,000 employees involved in electric power generation and transmission in New York, and another 3,800 jobs involved in oil and gas extraction and natural gas distribution (U.S. Census Bureau, 2008). Adding in oil and gas and power construction-related employment, along with electrical and heating, ventilation, and air conditioning contractors, nearly triples the size of this sector, although the data are distorted by the inclusion of trades that are not energy related (See **Table 8.5**). Payrolls for these jobs are sizable, totaling billions of dollars per year.

Average energy prices for different fuel sources are noted in **Table 8.6**. The prices of all fuel types have increased significantly over the years in New York State, with the exception of electricity, which has stayed relatively constant.

8.1.3 Non-climate Stressors

Non-climate stressors on the energy sector in New York State include rising demand due to growing population, more energy use for cooling and electronic devices, aging infrastructure, and rapidly changing technologies and policies.

8.2 Climate Hazards

Global climate change is expected to alter both average climate and the frequency and intensity of extreme weather events in New York State, affecting energy demand, system efficiency, and power supply potential.

Chapter 1 of the ClimAID report, “Climate Risks,” discusses the key projected changes for different regions of New York State in the 2020s, 2050s, and 2080s.

Energy supply and demand projections are typically developed for a 20-year timeframe. Projections further

into the future are affected by population and economic growth, the pace of technology change, and the policy environment, all of which are difficult to predict over longer time periods. Therefore, this chapter’s assessment of climate risks emphasizes the near term (2020s), though we discuss expected changes in the

Vulnerability		Principal Climate Variable(s)	Specific Climate-related Risks	Location	Crosscutting Links
Energy Supply and Distribution					
Power Supply	Thermoelectric power plants	Temperature	The thermal efficiency of power generation is affected by air temperature.	Statewide	Coastal Zones
	Coastal power plants (including cogeneration at wastewater treatment facilities)	Extreme weather events & sea level rise	Flood risk at individual facilities depends on the likelihood and intensity of storm surges associated with extreme weather events and their interaction with sea level rise. Operational impacts may be different than impacts on fuel storage or fuel unloading operations.	Statewide	
	Water-cooled power plants	Temperature	Water-cooled nuclear plants are affected by changes in the temperature of intake and discharge water, which is affected by changes in temperature.	Statewide	
	Hydropower systems	Precipitation & temperature	Hydropower availability at individual plants is affected by the timing and quantity of precipitation, as well as snowmelt; snowmelt is also affected by seasonal temperature.	Western, Central, and Northern NYS	Water Resources, Ecosystems, Agriculture
	Wind power systems	Wind speed and direction	Availability and predictably of wind power	Western, Central, and Northern NYS	
	Solar power systems		Availability and predictably of solar power	Statewide	
	Biomass-fueled energy systems	Temperature & precipitation	Biomass availability depends on weather conditions during the growing season.	Western, Central, and Northern NYS	Ecosystems
Energy Transmission and Distribution Assets	Transmission lines (winter)	Extreme weather events	Frequency, duration, and spatial extent of outages are affected by winter storms, particularly ice storms and high winds.	Western, Central, and Northern NYS	Communications
	Transmission lines (summer)	Temperature	Sagging lines can result from increased load associated with higher temperatures.	Statewide	Communications, Public Health
	Transformers	Temperature	Transformers rated for particular temperatures may fail during prolonged periods of increased temperature.	Statewide	Communications, Public Health
	Natural gas distribution lines	Temperature, extreme weather events, & flooding	Changing temperatures may affect vulnerability to frost heave risks, which can threaten structural stability of the pipeline. Flooding risks can also jeopardize pipeline stability/operations. Extreme weather events may threaten underwater pipelines in the Gulf Coast region, a large source of natural gas supply for New York.	Statewide	
Energy Demand and Consumption					
Electricity Demand	Total demand	Temperature (heating degree days & cooling degree days) & extreme weather events	Temperature affects demand for electricity in winter, summer, and shoulder-season periods. Extreme weather events may temporarily or permanently change demand patterns.	Statewide	Public Health
	Peak demand in summer	Temperature and humidity (cooling degree days, heat index, & heat waves)	Temperature and humidity affect demand for electricity for cooling and can increase the summertime peak; increasing frequency, intensity, and duration of heat waves could be particularly problematic, leading to more brownouts and blackouts.	Southern NYS	
	Power sharing	Temperature (heating degree days)	Warming temperatures can increase summer demand in traditional winter-peaking areas, leading to reduced availability of power for downstate regions.	Statewide	
Building-sited Energy Systems*	Cooling systems	Temperature	Cooling capacity may not be sufficient if the period of days with high temperatures is lengthy.	Statewide	Public Health
	Heating systems	Precipitation	Flood risk for boilers located in basements	Statewide	
	Building envelopes	Extreme weather events	Increased severity of storm regime may reveal weaknesses in building envelopes.	Statewide	
	Mechanical and electric systems	Extreme weather events	Failure of mechanical-electrical elements is related to extreme weather conditions.	Southern NYS	Public Health

* Building-sited energy systems are not discussed in detail in this report.

Table 8.7. Summary of climate risks to the New York State energy system

2050s and 2080s as appropriate. To project changes in temperature, heating-degree days, and cooling-degree days, historical trends are used with global climate model projections and are extrapolated linearly. Other climate variables, including wind speed and cloud cover, affect the availability of energy resources, but are difficult to model and are, therefore, considered qualitatively (see Chapter 1, “Climate Risks”).

Table 8.7 provides a high-level summary of key climate-change-related vulnerabilities associated with the energy sector. This chapter does not explore each of these issues in equal depth, reflecting different levels of information availability and the fact that certain vulnerabilities are likely to be more consequential than others.

A recent study notes the importance of indirect impacts that climate change may have on the energy sector, some of which may actually be greater than the direct impacts noted above (Bhatt et al., 2008). These include the financial impacts on investors or insurance companies linked to vulnerable energy system assets, and the financial impact on customers forced to grapple with changing energy prices or overall expenditure levels resulting from changing climate conditions. These issues are taken up as appropriate over the course of this chapter. A more lengthy discussion of the economic impacts climate change may have on the energy sector can be found in Chapter 3, “Equity and Economics.”

8.2.1 Temperature

More frequent heat waves will cause an increase in the use of air conditioning, stressing power supplies and increasing peak demand loads. Increased air temperature will affect the efficiency of power plants. Warmer temperatures in the winter will decrease demand for heating.

8.2.2 Precipitation

Changes in precipitation patterns will affect hydropower, especially changes in droughts. Inland flooding could affect transformers and distribution lines, although little information is available documenting flooding impacts or potential in non-coastal regions, that is, along rivers used for cooling water or fuel delivery purposes (see Chapter 4, “Water Resources”).

8.2.3 Sea Level Rise

Power plants were historically located along waterways to facilitate fuel delivery or for cooling purposes, making them vulnerable to anticipated sea level rise or storm surges associated with extreme weather events. However, there has been little study of how storms and tidal surges have affected New York State power production assets over the past several decades. One case where problems did arise was a 1992 nor’easter, which flooded generators that provided power for safety signals on the New York City subway system (Dao, 1992). Past climate change studies focused on New York State make almost no mention of sea level rise impacts on the energy sector, although they do extensively assess impacts on other important infrastructure around New York City and Long Island (Rozenzweig and Solecki, 2001).

8.2.4 Other Climate Factors

In addition to temperature, precipitation, and sea level rise, there are other climate factors that have the potential to influence the energy industry in years to come, including water temperature, ice and snow storms, hydrology and stream flow, and wind.

Water Temperature

In New York, thermal discharge rules are established by the Department of Environmental Conservation’s (DEC) Part 704 standards (Criteria Governing Thermal Discharges). The rules include several general rules applicable to all types of receiving waters (e.g., the need to avoid large day-to-day temperature fluctuations) as well as more specific criteria that vary by type of water body. These include several different surface water temperature standards (NYSDEC, 2010a):

- Non-trout waters: Water temperature at the surface of a stream shall not be raised to more than 90°F at any point.
- Trout waters: No discharge at a temperature over 70°F shall be permitted at any time, and during the period June–September, no discharge can raise the temperature of the stream by more than 2°F over the baseline spring water temperature.
- Lakes: Water temperature at the surface of a lake shall not be raised by more than 3°F over the previous water temperature.

- Coastal waters: Water temperature at the surface shall not be raised more than 4°F from October through June and more than 1.5°F from July through September.
- Estuaries: Water temperature at the surface shall not be raised to more than 90°F at any point.

Part 704 rules also specify limits on temperature changes in the “mixing zone,” which is the water in the immediate vicinity or downstream of the discharge pipe.

Ice and Snow Storms

At the other end of the temperature spectrum are problems associated with ice and snow storms, which can weigh down and destroy power transmission and distribution equipment. Ice storms occur when snow formed high in the atmosphere passes through a warm atmospheric layer, melting completely before it enters a shallow cold layer near the ground. The raindrops freeze once they hit branches, wires, or the ground (Risk Management Solutions, 2008). Between 1949 and 2000, New York endured 31 ice storms, more than any other state in the country (Changnon and Changnon, 2002).

It is unclear whether the frequency or severity of ice storms will change across the state over the next few decades. By later this century, southern parts of the state, more likely than not, will experience fewer ice storms than they currently experience. The impact on the frequency or severity of ice storms in northern New York later this century is uncertain (see Chapter 1, “Climate Risks,” for more details).

Hydrology and Stream Flow

Given the importance of this power source to the New York State energy system, past hydrologic studies have focused on the hydropower network’s vulnerability to climate change, projecting that stream flow around the state could decline by 5 to 7 percent by 2015, resulting in a 6–9 percent drop in hydropower generation levels (Linder et al., 1987)³. Estimates made at the time suggested that non-hydro generation assets in the state must increase 1–2 percent by 2015 to offset this predicted loss in hydropower availability (see Chapter 4, “Water Resources,” for current understanding of stream flow projections).

Wind

There is limited research examining how climate change will affect wind patterns or speeds in New York in the coming decades (see Chapter 1, “Climate Risks”). Studies in the Pacific Northwest project that there will be strong seasonal differences there; wind power potential in spring and summer months is projected to decline by 40 percent or more, while winter and fall month levels change very little, by the end of the 21st century (Sailor et al., 2008). One study examining both national and regional scales projects that wind speeds could decline by between 1 and 15 percent over the next 100 years, depending on which climate projections are used (Breslow and Sailor, 2002). A second analysis projects wind power decreases during all seasons across the majority of the United States, with typical decreases in the 10–20 percent range (Segal et al., 2001). None of these studies specifically highlights anticipated changes in New York or the Northeast, although maps included in the 2001 study show seasonal wind speed decreases in New York averaging 0–10 percent (Segal et al., 2001). There is also little information available on how climate change may affect wind speeds in the Atlantic Ocean offshore of New York City and Long Island. Given the interest in developing offshore wind farms in this region, this topic is worthy of further study.

8.3 Vulnerabilities and Opportunities

In certain cases, climate change may help New York’s energy system function more smoothly—by eliminating weather-related supply chain problems through milder winter weather in some areas, for example—but it is more commonly projected that climate change will adversely affect system operations, increase the difficulty of ensuring supply adequacy during peak demand periods, and exacerbate problematic conditions, such as the urban heat island effect (Rosenzweig and Solecki, 2001). In the sections that follow, the chapter explores how climate-change-related risks may affect different aspects of the state energy system.

8.3.1 Energy Supply

Climate-change-related impacts on energy supply must first be differentiated between the impacts on

thermoelectric power plants and those affecting different renewable power sources. Thermoelectric power plants generate electricity by converting heat into power. Conversion processes vary based on fuel sources at the power plant (e.g., nuclear, gas, oil, coal). Renewable power technologies harness naturally occurring resource flows (e.g., solar power, flowing water, wind) to generate electricity. Some forms of biomass—often considered a renewable resource—may be combusted in thermoelectric power plants, converted to liquid fuels, or used to generate heat for buildings or industry.

Impacts on Thermoelectric Power Generation and Power Distribution

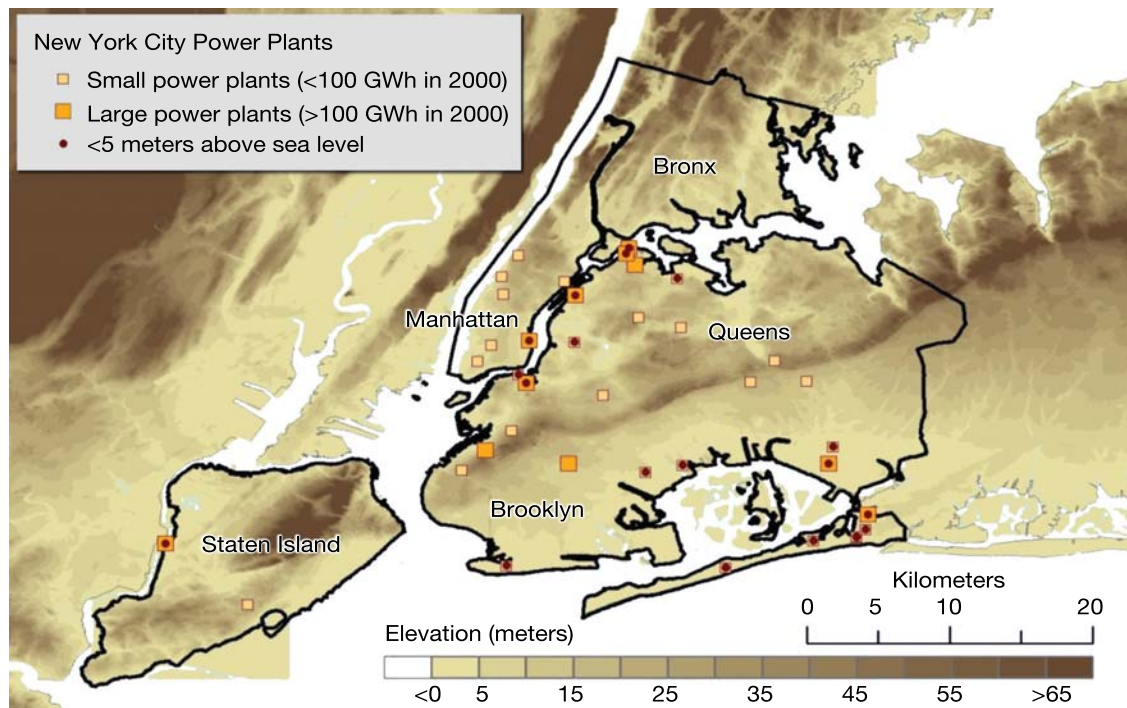
Thermoelectric power plants are vulnerable to increases in flooding, droughts, water temperature, air temperature, and other extreme weather events. Plants located along coastal areas may be affected by rising sea levels and storm surges.

Flooding

Vulnerability is largely a function of the elevation of power plants and their proximity to the path that any storm-related tidal surge would follow during extreme

weather events. To get a sense of the scale of vulnerability, this analysis overlaid New York City power plant locations obtained from the U.S. Environmental Protection Agency's (USEPA) eGrid database on a U.S. Geological Survey digital elevation model and identified power plants within 5 meters (about 16.4 feet) of current sea level. **Figure 8.4** shows that a majority of the city's largest power plants are at an elevation below 5 meters, which means they currently could potentially be affected by Category 3 or higher hurricane-induced storm surges.

A different flooding risk involves the elevation of the cooling water intake and outflow pipes at thermoelectric power plants. To the extent that these pipes become clogged by debris during flooding or storm surges, power plants may be forced to shut down (Aspen Environmental Group and M Cubed, 2005; Union of Concerned Scientists, 2007). One power plant operator with a facility fronting on a large lake in the northwestern part of the state noted that high winds can stir up debris that clogs their intakes located at the shoreline. The operator contrasted this situation with another of its plants, which has intakes extending much farther into an adjacent lake. The latter facility is far less vulnerable to this type of debris problem.



Sources: Data: Power plant data for 2000 were extracted from CARMA 2008; New York City digital elevation model is from the USGS 1999, which has a vertical error of +/- 4 feet. Map credit: Lily Parshall 2009.

Figure 8.4 Location and elevation of power plants in New York City

Table 8.8 presents the intake pipe depth at a number of power plants around New York State (NETL, 2009). Whether these intake depths may prove vulnerable to debris problems from flooding events is unclear, although deeper intakes are presumably less vulnerable than shallower intakes.

Drought

A recent U.S. Department of Energy study seeking to highlight potential drought-related water intake problems across the United States provided data on 12 large power plants around New York. The report did not pass judgment on whether current intake pipe depth levels were inadequate, because this is largely a location-specific issue (NETL, 2009).⁴ New York State facilities tend to have shallower intake depths when compared to other plants around the U.S.; whether this will create problems at these facilities in the future is unclear. To date, there do not appear to be any instances where drought has created problems of this nature.

Water Temperature

The DEC thermal discharge rules may create challenges during extended heat waves, when the receiving waters may already be close to the upper temperature limit defined in the facility's operating permit. This situation may force the power station to reduce production to decrease the heat content of the water leaving the condenser (ICF, 1995). During Europe's deadly 2003 summer heat wave, several nuclear power plants in Spain and Germany closed or cut output to avoid raising the temperature of rivers cooling the reactors. The French government allowed nuclear power plants to discharge cooling waters at above-normal

temperatures as an emergency measure to avoid blackouts (Jowit and Espinoza, 2006).

The five nuclear power plants in New York State are located either on the Great Lakes or the Hudson River. In both cases, these facilities draw cooling waters from deep-water sources less vulnerable to dramatic temperature rises. The situation at other thermoelectric power plants around state, several of which draw from shallower water sources, is less clear.

A different, and under-researched, topic relates to how climate change may affect biota levels in New York waterways currently used for power plant cooling. To the extent that biota levels increase, changes may be required in the screening processes currently employed at these facilities to ensure that the water flow into the facility is not inhibited in any way.

Air Temperature

Changes in ambient air temperature and air density levels resulting from climate change may affect power plant output levels. One potential temperature-related impact occurs at combined-cycle gas turbine facilities (Hewer, 2006). These units are designed to fire at a specific temperature, and when ambient air temperatures rise, air density declines, which reduces the amount of oxygen available to achieve peak output (ICF, 1995). Similar problems exist at steam turbine facilities.

Three studies discount the importance of these impacts, arguing that capacity and/or output reductions will be less than 1 percent under most climate scenarios (Stern,

Facility Name	Primary Fuel	Water Source	Intake Depth Below Surface (feet)	Intake Depth for this Type of Facility ¹ (feet)		Intake Depth for this Type of Water Source ¹ (feet)	
				Mean	Median	Mean	Median
AES Cayuga	Coal	Cayuga Lake	44	16.1	12	21.6	17
AES Greenridge	Coal	Seneca Lake	11	16.1	12	21.6	17
AES Somerset	Coal	Lake Ontario	16	16.1	12	21.6	17
Dunkirk Generating Station	Coal	Lake Erie	21	16.1	12	21.6	17
Danskammer Generating Station	Coal	Hudson River	5	16.1	12	13.2	10
Roseton Generating Station	Gas	Hudson River	29	14.4	12	13.2	10
Fitzpatrick	Nuclear	Lake Ontario	12	16.8	13.5	21.6	17
OR Huntley Generating Station	Coal	Niagara River	10	16.1	12	13.2	10
Oswego Harbor Power	Oil	Lake Ontario	20	16.1	12	21.6	17
PSEG Albany Generating Station	Gas	Hudson River	24	14.4	12	13.2	10
Ginna	Nuclear	Lake Ontario	15	16.8	13.5	21.6	17
Rochester 7	Coal	Lake Ontario	36	16.1	12	21.6	17

¹ Based on nationwide data.
Source: NETL/DOE 2009, pp 20, A-10

Table 8.8 Cooling water intake depth at selected New York State power plants compared to national data

1998; Bull et al., 2007; and Linder et al., 1987). Several New York State utilities and power plant operators interviewed for this report also noted that the impacts of changing temperature levels are likely to be negligible, because the equipment is already designed to handle wide temperature swings between the winter and summer months. It may well be that changes in extreme temperatures are more relevant, since during such conditions the equipment's design parameters are more likely to be breached (David Neal, personal communication, October 30, 2009; Victoria Simon, personal communication, October 15, 2009). Moreover, depending on the rate at which climate change progresses, many vulnerable facilities will reach the end of their useful lives and be replaced with better-adapted ones before these long-term power generation impacts are felt (ICF, 1995; Victoria Simon, personal communication, October 15, 2009).

The New York State Reliability Council⁵ reports that there is some decline in power output levels at higher temperatures, but the Council also characterizes the impact as rather small. As part of their technical assessment of the reliability of the state's power system, the New York State Reliability Council quotes the NYISO research finding that for each degree above 92°F, combustion power plants around the state collectively lose approximately 80 megawatts in production output (New York State Reliability Council, 2004). This decrease is built into their estimates of how much power will be available around the state under certain operating conditions. Given that the state has more than 37,000 megawatts of generation capacity overall and roughly 26,000 megawatts of fossil-fired combustion facilities (USEPA, 2009), this decrease is relatively minor (Table 8.2).

Rising ambient air temperatures may also affect the electricity transmission and distribution system. Because transmission and distribution lines and electrical transformers are rated to handle certain amounts of voltage for a given period of time, climatic conditions can lead to equipment failure by driving energy demand beyond the rated capacity. For instance, an extended heat wave in the summer of 2006 led to the failure of thousands of transformers in southern and northern California. Sustained high nighttime temperatures meant that the transformers could not cool down sufficiently before voltage levels increased again the next morning. Insulation materials within the transformers burned and circuit breakers tripped,

knocking out the devices and causing more than a million customers around the state to lose power (Miller et al., 2008; Vine, 2008).

Power lines both above and below ground may also suffer mechanical failure as a result of higher ambient air temperatures. Power lines naturally heat up when conducting electricity; ordinarily, relief is provided by the cooler ambient air. Lines below ground rely on moisture in the soil to provide this cooling function. In both cases, as temperatures increase, the cooling capacity of the surrounding air or soil decreases, potentially causing above-ground lines to fail altogether or sag to levels where the public is placed at risk (Hewer, 2006; Mansanet-Bataller et al., 2008). The extent to which this is a problem in New York State is unclear. The New York Power Authority (NYPA) reports it regularly conducts sophisticated aerial surveys to assess hazards presented by sagging transmission lines (Victoria Simon, personal communication, October 15, 2009), but no data were available on how distribution line conductivity may change as a result of climate change.

The most newsworthy blackouts in New York City in recent years have tended to occur when heat waves extend over several days (Revkin, 1999; Waldman, 2001; Chan and Perez-Pena, 2006; Newman, 2006). In the past, two different State agency analyses have expressed concern about the age of local distribution network equipment and how this compounds system vulnerabilities on hot days when peak load levels increase dramatically (NYS Attorney General, 2000; NYS Department of Public Service, 2007). Little information has been published on this topic, however, so the extent of the problem is unknown.

One area where additional research may be beneficial is the link between the average temperature of extreme heat events and the duration of the heat event. For example, one distribution utility provided anecdotal information suggesting that the frequency of distribution system service interruptions appeared to be higher for multi-day heat events above 95°F than for multi-day heat events above 90°F. The company did not have evidence about the statistical significance of this finding, although an analysis of such tipping points (beyond which the likelihood of distribution system service interruptions significantly increases) might prove helpful in terms of system design, equipment ratings, or the development of operating procedures during extreme heat events (see Chapter 1, "Climate Risks").

Ice and Snow Storms

New York State's energy system has long been vulnerable to impacts of ice and snow storms. The great blizzard of 1888 led to the decision to bury most electric wires around New York City (*New York Times*, 1888). Ice storms typically affect a wide geographic area, making repair work a sizable task (John Allen, personal communication, September 29, 2009; James Marean, personal communication, September 29, 2009). With more than 15,000 miles of electric transmission lines and 200,000 miles of distribution lines across the state (New York State Public Service Commission, 2008), ice storms are particularly problematic.

In 1998, a massive multi-day ice storm resulted in more than \$1 billion in damage across the northeastern United States and eastern Canada. In New York State alone, dozens of high-voltage transmission towers, 12,500 distribution poles, 3,000 pole-top transformers, and more than 500 miles of wire conductor required replacement, affecting 100,000 customers from Watertown to Plattsburgh. Most of the repairs were completed within two months, although some areas were not completely repaired for four months (EPRI, 1998). Subsequent research found that much of the equipment was not rated for a storm of that magnitude. Another major ice storm in December 2008 resulted in the loss of power to 240,000 customers in the state's capital region (Gavin and Carleo-Evangelist, 2008).

Impacts on Natural Gas Distribution Infrastructure

Ninety-five percent of the state's natural gas supply is imported via grid pipeline from other states and Canada. Underground storage facilities (primarily depleted gas wells) in western New York and Pennsylvania are important features of the state's natural gas system, ensuring that adequate supplies are available during the peak-demand winter months. They also provide some level of insurance against natural disasters that may disrupt the production or delivery of natural gas to the state at other times of the year (State Energy Planning Board, 2009b), although the extent of this benefit is unclear. For example, an extensive amount of underwater pipeline damage occurred in the Gulf Coast region during hurricanes Katrina and Rita in 2005. Buried onshore pipelines were also damaged (Cruz and Krausmann, 2008). As a result of these supply chain disruptions, natural gas prices spiked to

unprecedented levels in New York in 2005 (State Energy Planning Board, 2009b).

The impacts of climate change on in-state gas distribution infrastructure are unclear. Gas distribution pipes are buried for safety reasons. Although this does not make them immune to flooding risks associated with extreme weather events (Associated Press, 1986; *New York Times*, 1994), there is little published evidence that this has been a significant problem in New York in recent decades. Gas pipelines are also vulnerable to frost heaves (Williams and Wallis, 1995), although the extent to which climate change may alter current frost heave risks is unclear. Both of these subjects may require additional research, although the research need not examine all regions of the state. Currently, large swaths of ClimAID regions 2, 5, and 7 (Catskill Mountains and West Hudson River Valley, East Hudson and Mohawk River Valleys, and Adirondack Mountains) lack gas distribution service because of the low population levels in these areas.

Impacts on Renewable Power Generation

Climate change may also affect renewable power output around the state by affecting the timing or level of the natural resource responsible for power generation.

Hydropower

New York's 338 conventional hydropower facilities collectively generate more hydropower than any other state east of the Rocky Mountains. With a peak generation capacity of 5,756 megawatts, they currently satisfy 15 percent of the state's total annual electricity requirements (State Energy Planning Board, 2009). Three facilities operated by the New York Power Authority are responsible for 80 percent of the state's total hydropower capacity. Two are fed by the Great Lakes watershed, while the third is a pumped storage facility located in the Catskills. The potential exists to deploy another 2,500 megawatts of hydropower around the state by 2022, but "environmental, siting, financial, and regulatory barriers suggest that relatively little new development is likely to occur" (State Energy Planning Board, 2009).

In a changing climate, power supply availability must be considered. In projecting power supply availability from different sources, the New York Independent System Operator assumes that non-New York Power

Authority hydropower generators around the state—which represent approximately 1,000 megawatts of installed capacity—experience power generation output declines of approximately 45 percent in July and August due to reduced water availability during the summer months (NERC, 2008; NYISO, 2004). This 45 percent de-rate factor (the output decline) assumes the state is not experiencing drought conditions; under such conditions, the de-rate figure might be even higher. (For comparison purposes, when the northeastern United States suffered from drought in 2001, actual output from these same non-New York Power Authority facilities declined by 65 percent during summer months compared to their peak-rated capacity (NYISO, 2004).)

Case Study A examines how climate change may affect hydropower output levels at two large New York Power Authority-owned facilities near Niagara Falls and on the St. Lawrence River in Massena, New York, noting the correlation between precipitation levels and the level of power produced by these facilities. To the extent precipitation levels are expected to increase across the state by 2080 (see Chapter 1, “Climate Risks”), hydropower production levels may actually increase over time, although there are likely to be seasonal differences.

As Chapter 1 notes, however, New York State is also expected to experience more frequent late-summer drought conditions over the coming decades, which could lead to sizable reductions in hydropower output levels. This would have significant cost repercussions around the state, as lost capacity would likely be replaced by more expensive forms of power generation (Morris et al., 1996). Moreover, because the impacts of climate change are likely to be felt at hydropower in surrounding states (and Canada) as well, New York may not be able to rely on the same level of electricity imports it has previously, exacerbating already tight local power supply markets and raising prices even higher.

Solar Power

Although there is relatively little solar photovoltaic technology currently deployed around New York (approximately 14.6 MW), estimates are that the state enjoys significant solar resources, exceeding that of any other renewable energy source in the state (State Energy Planning Board, 2009). Whether climate change will enhance or hinder local solar resources is unknown. One study modeled solar radiation in the United States through 2040, projecting that increased

cloud cover attributable to rising carbon dioxide levels could reduce solar radiation levels by as much as 20 percent, particularly in the western United States (Pan et al., 2004). No clear trends were projected for the Northeast. Another study focused on Nordic (Scandinavian) cities estimates that a 2-percent decrease in solar radiation could reduce solar cell output by 6 percent (Fidje and Martinsen, 2006). A solar expert at SUNY Albany, Dr. Richard Perez, reviewed this literature but discounted these impacts, noting that because of differences in latitude between New York, Nordic areas, and other parts of the United States, New York State should “expect, in the worst case, a 1 to 2 percent decrease in [solar] PV yield, and the best case, no change at all” (Dr. Richard Perez, personal communication, September 9, 2009).

More research is necessary to examine the potential impacts of climate change on solar power, as decreases in solar photovoltaic system output in New York State would increase the per-kilowatt cost of solar power, reducing the cost competitiveness of photovoltaic systems compared to other forms of electricity. Research should also examine the extent to which such losses may be offset by advances in solar panel efficiency that will likely occur over time.

Wind Power

New York State’s proximity to the Atlantic Ocean and Great Lakes places it close to excellent conditions to support wind power development. According to the American Wind Energy Association (2009), New York ranks 15th nationally in terms of its overall wind power potential, although support from New York State’s Renewable Portfolio Standard and favorable federal tax rules have helped the state achieve a seventh-place ranking with regard to its current wind power deployment. Already, there are 791 large wind turbines installed around the state, with a peak generation capacity of 1,264 megawatts (American Wind Energy Association, 2009), and forecasts are that this could increase to more than 8,500 MW by 2015 (State Energy Planning Board, 2009). The majority of this capacity will come in the form of large wind turbine installations, as opposed to small rooftop turbines that are more scale-appropriate for urban areas.

Because wind turbine power output is a function of the cube of the wind speed, small changes in wind speed can translate into large changes in output. For example, a recent study notes how a 10-percent

change in wind speed can lead to a 30-percent change in energy output (Pryor and Barthelmie, 2010). The consequences of changing wind patterns can thus be sizable in terms of the state's ability to rely on large quantities of wind power.

The same study also notes a dearth of research examining extreme wind speeds and gusts and their relationship to wind turbine design protocols (Pryor and Barthelmie, 2010). Given that current industry design criteria generally call for turbines to withstand 1-in-50-years wind speed events lasting no more than 10 minutes, more research may be necessary to assess whether these standards should be upgraded or whether they can be relaxed in the coming decades.

Biomass

Forestry and agricultural products currently make a very minor contribution to the state's overall electricity picture, combusted in biomass-only facilities near Utica and Chateaugay or co-combusted with coal at a power plant near Niagara Falls. These facilities have a peak generation capacity of 65 megawatts, and collectively generate approximately 440,000 megawatt hours of power per year (State Energy Planning Board, 2009a).

Biomass is also used as a primary fuel for heating purposes in some New York homes and businesses. In 2007, approximately 94 trillion British thermal units (TBtus) of heat were generated statewide from wood resources (State Energy Planning Board, 2009a), the vast majority of which was consumed in homes. Some of this wood is shredded and then reprocessed into uniform-sized pellets, which are designed for use in more efficient boilers and wood stoves.

Recently, interest has grown in the conversion of biomass into liquid fuels, some of which is blended with fuel oil for use in residential or commercial heating systems. As of 2008, there was one biodiesel manufacturing facility in the state, although there are more than a dozen fuel oil companies around the state that blend biodiesel with their fuel oil to sell to customers (State Energy Planning Board, 2009a). Most of their biodiesel is purchased from refiners located outside of the state.

The effects of climate change on New York's biomass-based energy systems is unclear. As the "Ecosystems" chapter (Chapter 6) notes, some species of trees may do

better than others, a function of the level of temperature change, vulnerability to vectors, and level of drought conditions. Homes and businesses that rely on downed trees as the source of their wood may or may not find changes in the level of available supply; the impacts of climate change on wood resources is likely to be very local in nature. The effects on power plants or pellet manufacturers, which rely on managed forests or waste wood from manufacturing operations, are similarly unclear and may ultimately depend on the characterizations of different wood species, as the impacts are expected to vary (see Chapter 6, "Ecosystems"). These facilities tend to source their material many months or even years in advance from a range of suppliers, which may help offset any adverse impacts attributable to climate change, although this is an area where more research would be beneficial.

The impacts of climate change on biodiesel production or blending operations in New York State is similarly unclear, as production facilities tend to source material from an international feedstock market. The extent to which the supply chain will be affected is uncertain, and as the market for biodiesel fuel grows across the state, this may also be an area where further research would be beneficial.

8.3.2 Energy Demand

Climate change may affect energy demand for space heating and cooling. Electricity demand is most sensitive to changes in summer climate, whereas heating fuel demand is most sensitive to changes in the winter climate. Impacts may have multiple dimensions, including changes in total demand, seasonal variability, and peak demand (Amato et al., 2005; Wilbanks, 2007; Scott and Huang, 2007). Overall, in the northern United States, net energy demand is likely to decrease as a result of warmer winters. This effect is expected to outweigh air conditioning-related increases in summertime energy demand in the southern United States, leading to a net national reduction in total energy demand (Scott and Huang, 2007).⁶

To understand how climate change may affect energy demand in New York State, the ClimAID climate team first provided current trends and expected changes in heating degree days and cooling degree days, metrics that affect demand for space heating and cooling, respectively (see Chapter 1, "Climate Risks," for an

analysis of current trends and expected changes in average temperature).⁷ Next, the sensitivity of energy demand to changes in temperature was analyzed. This analysis was carried out only for electricity demand, as data are not available to analyze heating fuels. Finally, to project changes in electricity demand the analysis combined the information on projected changes in climate with information on the sensitivity of demand to those changes. The focus is on the 2020s because non-climate drivers dominate energy planning in the medium and long terms. The 2020s is defined as the 2011–2039 time period (consistent with Chapter 1, “Climate Risks”), so projections for the 2020s are an average of the projections for each of the 30 years in that time period.

Linear regression was used to estimate historical changes in temperature. Linear forecasts for future climate are then based on the assumption that the observed trend in climate over the historical period will continue into the future. This assumption may be reasonable over short time periods (up to 10 years). An advantage of linear forecasts is the ability to make projections for a specific geographic location using hourly, daily, and/or monthly data from a local weather station. The benefit of temporal specificity is offset by inclusion of only a limited number of variables. Therefore, these forecasts are compared with global climate model (GCM) projections that account for the dynamic relationships among many different climate variables.

New York State Heating and Cooling Seasons

In New York State, the heating season is longer than the cooling season, and 50 to 55 percent of heating degree days occurs during the winter peak months of December, January, and February, with the other 50 percent occurring during the fall and spring “shoulder” seasons. There is substantial variation among different regions of the state. For example, Binghamton, Utica, and Watertown have more than 7,000 heating degree days per year, whereas New York City has fewer than 5,000 (**Table 8.9**). On the other hand, New York City has more than 1,000 cooling degree days, whereas Binghamton, Albany, and Buffalo have 400 to 600 cooling degree days.⁸ The direction and magnitude of changes in energy demand depend on changes in heating degree days, cooling degree days, and other climate-related changes as well as the sensitivity of demand to climate factors. In some cases, sensitivities

may be nonlinear, for example if higher temperatures in the summertime lead to a significant increase in air-conditioning saturation rates (the number of households with some form of air conditioning).

Projected Changes in Heating Degree Days

In all regions of the state, heating degree days have significantly declined over the past few decades (**Figure 8.5**). Annual heating degree days are expected to decline by between 5 and 8 percent in the 2020s compared to the current (1970–2007) average; expected changes are relatively consistent across all regions of the state. Global climate model projections for the number of heating degree days in the 2020s are broadly consistent with the linear forecasts. Agreement between these two methods should help to address the skepticism with which global climate models have historically been viewed by energy sector stakeholders. The two methods would not necessarily be expected to agree over the medium to long term.

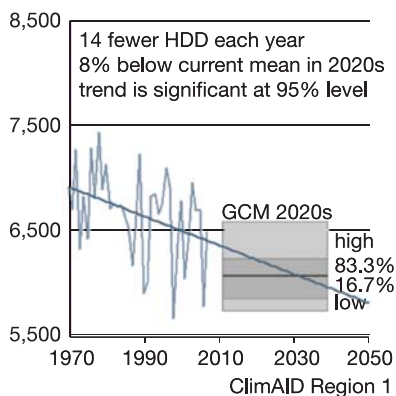
Warmer winters may reduce electricity demand for heating, although just 10% of New York State's heating demand is met with electricity. Declining heating degree days may also put downward pressure on demand for utility gas and fuel oil, the two primary sources of space heat in the state (**Figure 8.2**), although climate is just one of many drivers of demand for these resources. Additional research is needed to better understand how climate change may affect the breakdown of demand for natural gas for building heat versus power generation.

Weather Station	ClimAID Region	NYISO Zone	Heating Degree Days (per year)	Cooling Degree Days (per year)
Buffalo	Region 1	Zone A	6,654	557
Rochester	Region 1	Zone B	6,663	585
Elmira	Region 3	Zone C	6,904	479
Binghamton	Region 3	Zone C	7,211	409
Utica	Region 5	Zone E	7,229	483
Watertown	Region 6	Zone E	7,457	521
Albany	Region 5	Zone F	6,813	567
NYC (Central Park)	Region 4	Zone J	4,740	1,158

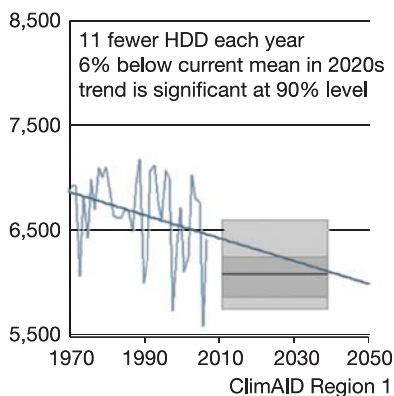
Note: Maps showing the relationship between NYISO zones and ClimAID regions are shown in Appendix B. Note that these seven stations were selected for the analysis presented in this table as well as for Figures 5 and 6 because global climate model projections for heating degree days and cooling degree days were available for each of these stations. Source: Historical climate data obtained from NOAA

Table 8.9 Average annual heating degree days and cooling degree days, 1970 to 2007

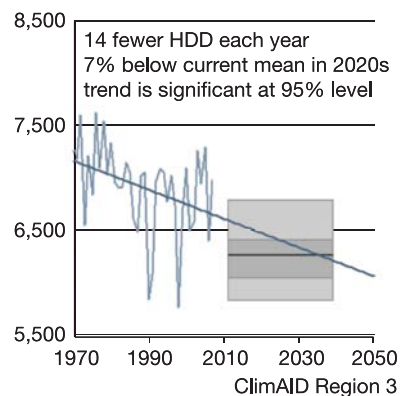
Zone A, Buffalo



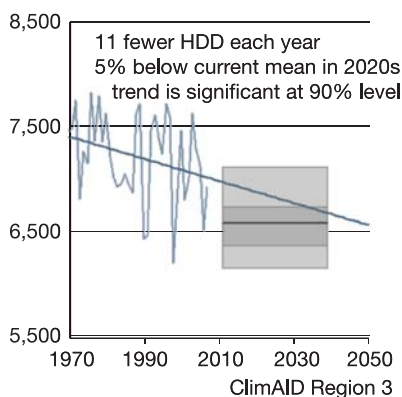
Zone B, Rochester



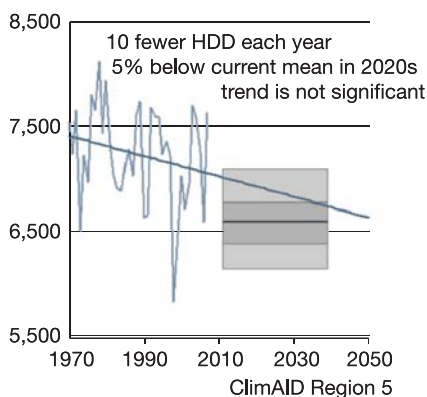
Zone C, Elmira



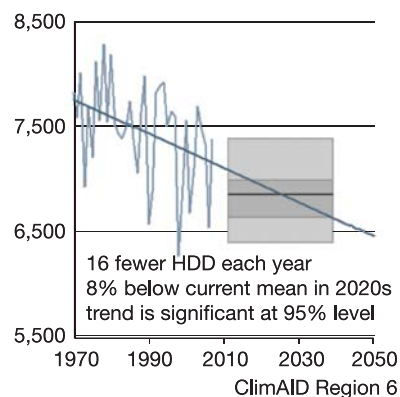
Zone C, Binghamton



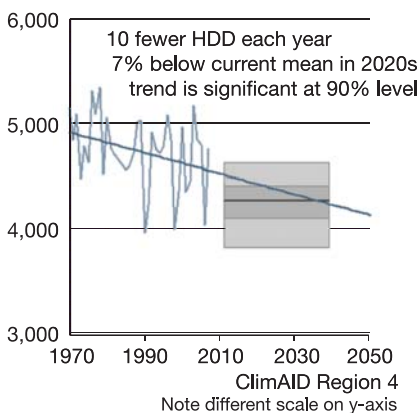
Zone E, Utica



Zone E, Watertown



Zone J, Central Park



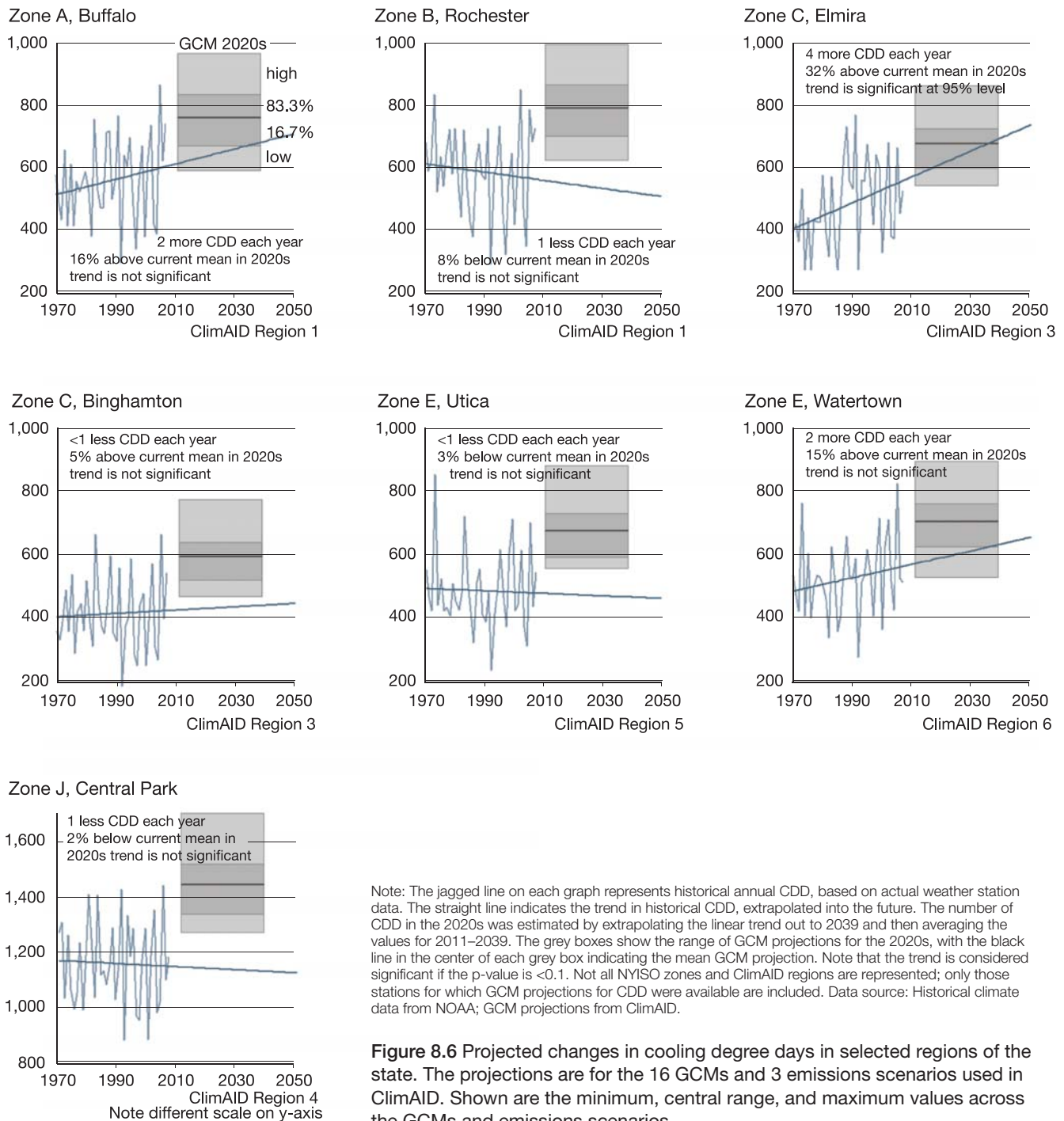
Note: The jagged line on each graph represents historical annual HDD, based on actual weather station data. The straight line indicates the trend in historical HDD, extrapolated into the future. The number of HDD in the 2020s was estimated by extrapolating the linear trend out to 2039 and then averaging the values for 2011–2039. The grey boxes show the range of GCM projections for the 2020s, with the black line in the center of each grey box indicating the mean GCM projection. Note that the trend is considered significant if the p-value is <0.1. Not all NYISO zones and ClimAID regions are represented; only those stations for which GCM projections for HDD were available are included. Data source: Historical climate data from NOAA; GCM projections from ClimAID.

Figure 8.5 Projected changes in heating degree days in selected regions of the state. The projections are for the 16 GCMs and 3 emissions scenarios used in ClimAID. Shown are the minimum, central range, and maximum values across the GCMs and emissions scenarios.

Projected Changes in Cooling Degree Days

New York State has a relatively short cooling season. In New York City, 79 percent of annual cooling degree days occur during the summer months; in many cities in northern and western New York, the figure is closer to 85 percent. Although the global climate models used in ClimAID project increases in cooling degree days on

the order of 24–47 percent, depending on the region, these projections generally exceed forecasts based on linear extrapolation of current trends (**Figure 8.6**). Also, in most regions, historical trends in cooling degree days are not statistically significant, reducing confidence in the linear extrapolations.⁹ Of the weather stations for which data were obtained, only Elmira has a statistically significant upward trend over



the 1970–2007 period. Note that patterns of urban development can affect local temperature trends through heat island formation, an effect that was not accounted for in the data analysis.¹⁰

Electricity Demand

A key question for the power sector is whether climate change will require a significant shift in energy planning or will remain a small demand driver relative to population and economic growth, efficiency projects, and other factors. The need for new generation and/or transmission capacity depends on the geographic location

and timing of the increases. All else being equal, warmer nighttime temperatures in the summer and/or a longer cooling season would not necessarily require new generation capacity.¹¹ However, if summertime peak demand increases at a faster rate than overall demand,

the likelihood of brownouts or blackouts increases (Miller et al., 2008).¹² Also, although increases in average daily demand might not require new capacity, they can still affect energy prices, since more expensive generation sources may need to be online more frequently.

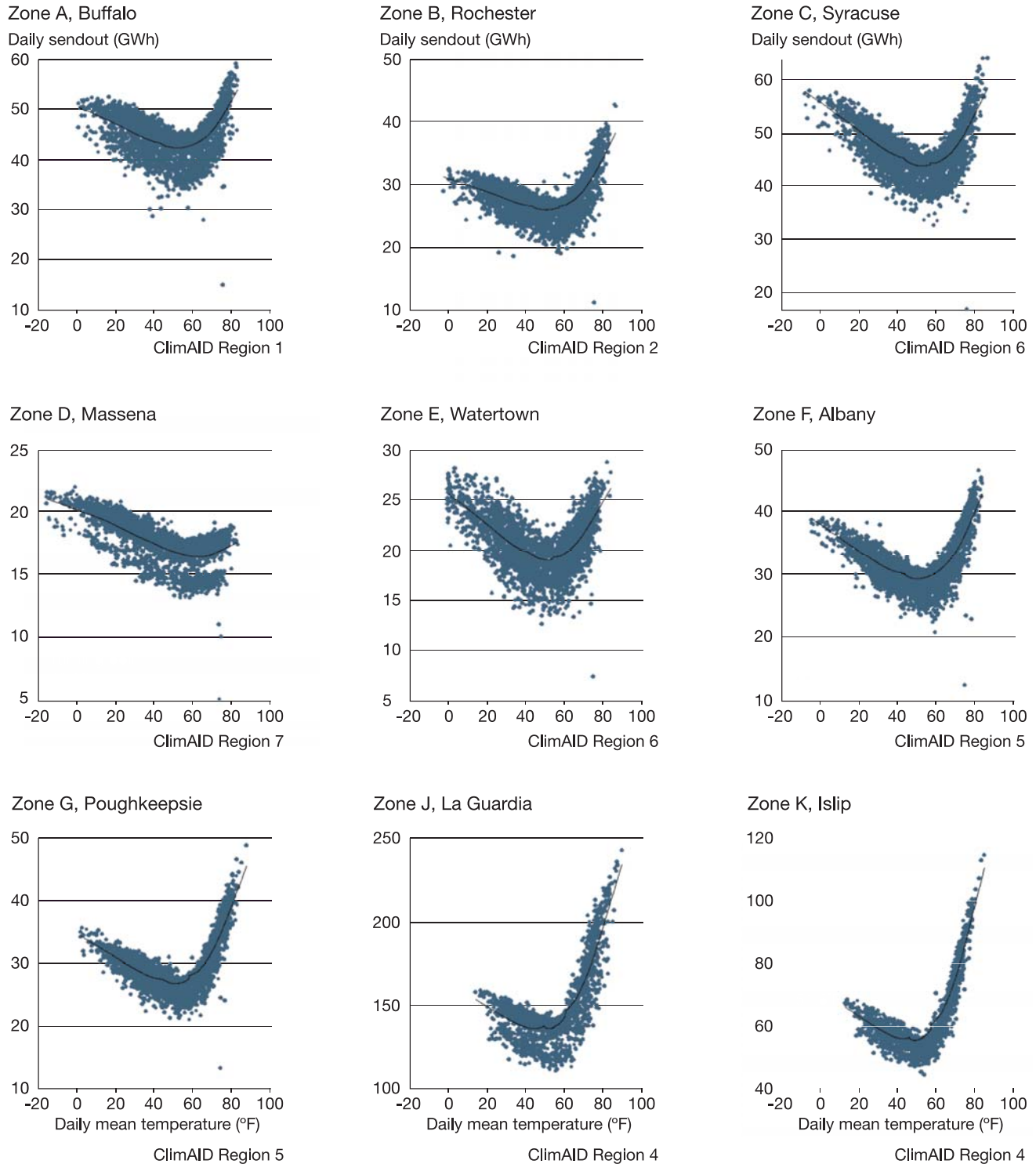


Figure 8.7 Daily average temperature versus daily electricity demand (GWh) for each NYISO Zone

A few previous studies have analyzed how climate change may affect electricity demand and generation capacity in the United States. One of the first energy sector climate change assessments concluded that total electricity consumption in the United States would grow 4 to 6 percent between 1989 and 2055 as a result of increased temperature, with peak demand projected to grow 13 to 20 percent and capacity requirements (including reserve margin requirements) expected to increase 14 to 23 percent (Smith and Tirpak, 1989). Several studies analyzing different utility service areas have found that peak demand is likely to increase faster than annual electricity sales, but none of these studies analyzed New York State (Baxter and Calandri, 1992; Franco and Sanstad, 2008; ICF, 1995).¹³

Two previous studies have analyzed electricity demand in New York. A 1987 study of New York State used a range of climate and demand growth models, concluding that by 2015 peak demand would grow by 8 to 17 percent while overall demand attributable to climate change would equal 2 percent in the region of New York City, Long Island, the Hudson Valley, and other suburban and rural areas northwest of New York City (Linder et al., 1987).¹⁴ The Metro East Coast study, which examined the New York metropolitan region, projected a 17 percent increase in summertime daily peak demand by the 2080s, based on results from several models and climate change scenarios (Hill and Goldberg, 2001).¹⁵

The ClimAID analysis of temperature and load data from 2002 to 2008 shows that all NYISO load zones have higher average daily electricity demand during the cooling season than during the heating season, with the exception of Zone D in the northernmost corner of the state (**Table 8.10**). This reflects the low penetration rate of electric heating relative to electric air conditioning.¹⁶ This feature of the data should not be confused with the fact that most parts of New York State consume more energy for heating than cooling each year.

Each load zone has unique heating and cooling seasons that differ based on the timing and temperature range experienced during the winter, summer, and shoulder-season periods. **Figure 8.7** illustrates the relationship between daily average temperature and daily electricity demand. In each zone, there is a unique turning point below which load increases as temperature decreases in the winter. For most zones, the turning point occurs at

an average daily temperature of between 49 and 54°F (maximum daily temperature between 53 and 63°F).¹⁷ From this turning point until about 65°F, there is typically a flat zone over which electricity demand neither falls nor rises, representing the short shoulder seasons in late spring and early fall. Above 65°F, demand rises, typically by a larger amount per degree Fahrenheit than during the heating season. Note that some zones—most notably NYISO Zone E (Watertown)—span a large latitudinal range, so load may reflect a combination of different heating and cooling seasons in the southern versus the northern part of the zone. As **Figure 8.7** makes clear, the sensitivity of heating and cooling loads to temperature varies across the zones. **Tables 8.10** and **8.11** show the sensitivities for each zone, assuming a linear relationship between daily average temperature and demand below the turning point for the heating season (**Figure 8.7**) and above 65°F for the cooling season. Although the sensitivity calculations are confined to temperature, other climatic variables interact with temperature to affect demand. Principal among these is relative humidity, and further research is needed to incorporate humidity into the electricity demand analysis.

Electricity Demand Sensitivity to Temperature During the Heating Season

During the heating season, electricity demand typically decreases by 0.4 to 0.8 percent for every 1°F increase in temperature, corresponding to absolute demand changes of between 72 megawatt hours (Zone D—Massena) and 560 megawatt hours (Zone J—New York City). The zones with the largest percent changes do not necessarily have the largest absolute changes, which are related both to the zone's total load and the percentage of heating demand met with electricity. Load size is more important than electric heating penetration. For example, Zone D, which has both the smallest load size and the largest share of heating demand met with electricity, is less sensitive to temperature than Zone J, which has the largest load size and smallest share of heating demand met with electricity.

Electricity Demand Sensitivity to Temperature During the Cooling Season

Combining information on projected changes in climate with information on the sensitivity of demand to those changes can give a sense of how electricity demand may be affected by climate change, all else being equal. Electricity demand is more sensitive to temperature during the cooling season (i.e., summer). NYISO Zones

F, G, J, and K (Albany, Poughkeepsie, New York City, and Long Island) account for nearly two-thirds of total daily demand during the cooling season. In Zone K (Long Island), changing the temperature by 1°F results in a demand change of 2.0 to 2.9 percent. Absolute changes in these NYISO zones are also much larger. For example, in New York City, daily demand rises by 3,427 megawatt hours with each additional 1°F rise in temperature. This is more than six times larger than heating-season (i.e., winter) sensitivity. Peak demand is more sensitive to temperature than total daily demand. For example, in Rochester, peak demand increases by 2.3 percent with each additional 1°F versus a 1.8-percent increase in total daily demand. The largest absolute increase in peak demand is in NYISO Zone J (New York City), which experiences a 166-megawatt increase for each additional 1°F. This is lower than the sensitivities reported in two earlier studies, which found demand increases on the order of 404 to 740 megawatts (Linder et al., 1987) and 240 to 309 megawatts (Hill

and Goldberg, 2001) for each additional 1°F rise in temperature. This sensitivity value, however, corresponds well with the 2001 study estimate (Hill and Goldberg, 2001) after accounting for the fact that Zones J and K were previously a single zone. This adjustment gives a combined sensitivity of 295 megawatts, within the range reported by the 2001 study (Hill and Goldberg, 2001).

The number and type of air conditioners within each zone are the primary determinants of sensitivity during the cooling season, and the zones differ widely in terms of the percentage of residential households with air conditioning. For example, in 2003, 84 percent of housing units in New York City and Long Island (Zones J and K) had either window or central air conditioning systems installed. This saturation rate is much higher than that found in either Rochester or Buffalo (Zones B and A), although the data for those cities reflect slightly earlier time periods (U.S. Census Bureau, 2004).

NYISO zone	Weather station	Heating Season			Cooling Season		
		Average daily electric demand (MWh)	Standard deviation daily electric demand (% of average)	Peak electric load (MW)	Average daily electric demand (MWh)	Standard deviation daily electric demand (% of average)	Peak electric load (MW)
Zone A	Buffalo	44,255	8%	2,870	46,260	10%	3,113
Zone B	Rochester	27,107	8%	1,609	29,693	12%	2,143
Zone C	Syracuse	46,576	9%	3,061	48,078	10%	3,153
Zone D	Massena	17,636	10%	1,493	16,565	9%	1,219
Zone E	Watertown	20,509	13%	1,569	21,468	12%	1,436
Zone F	Albany	31,075	9%	2,370	34,417	12%	2,381
Zone G	Poughkeepsie	28,128	8%	1,794	32,892	13%	2,496
Zone J*	NYC (LGA)	137,109	7%	7,761	169,186	14%	11,347
Zone K*	Islip	56,850	7%	3,633	74,821	14%	5,748

*In zones J and K, calculations are based on data from February 2005 to 2008.

Sources: Load data were obtained from NYISO (2009a); weather station data were obtained from NOAA and NYISO (2009b)

Table 8.10 Average daily electricity demand and average annual peak load for each NYISO Zone for the 2002–2008 period

NYISO zone	Weather station	Heating Season			
		Change in daily electricity demand and peak load with respect to a 1°F increase in average daily temperature			
		Change in daily electricity demand (MWh)	% change in daily electricity (%MWh)	Change in daily peak electricity load (MWp)	% change in daily peak electricity load (%MWp)
Zone A	Buffalo	-191	-0.4%	-9	-0.4%
Zone B	Rochester	-119	-0.4%	-6	-0.5%
Zone C	Syracuse	-262	-0.6%	-12	-0.6%
Zone D	Massena	-72	-0.4%	-3	-0.4%
Zone E	Watertown	-157	-0.8%	-7	-0.7%
Zone F	Albany	-201	-0.6%	-10	-0.6%
Zone G	Poughkeepsie	-171	-0.6%	-8	-0.6%
Zone J*	NYC (LGA)	-560	-0.4%	-27	-0.4%
Zone K*	Islip	-338	-0.6%	-18	-0.6%

*In zones J and K, calculations are based on data from February 2005 to 2008.

Sources: Load data were obtained from NYISO (2009a); weather station data were obtained from NOAA and NYISO (2009b)

Table 8.11 Heating season sensitivity of electricity demand to a 1°F increase in temperature over the 2002–2008 period

During the cooling season, peak demand increases as more and more air conditioners come online, up to the point at which all air conditioners have been turned on and/or demand response or other load management programs are initiated to prevent demand from rising above system capacity. An increase in the air conditioning saturation rate is the largest potential impact of climate change on electricity demand, because it would increase demand by larger amounts than what is implied by the sensitivities in **Tables 8.10** and **8.11**.

In western New York, air conditioning saturation rates are relatively low, so there is greater potential for climate-related summertime demand growth (Sailor and Pavlova, 2003). This could lead to local increases in the sensitivity of demand to temperature as well as system-wide impacts on demand levels and pricing. Impacts on peak demand and overall system capacity depend on the breakdown between room air conditioners, which tend to be used more heavily when owners are home (including at night), and central air conditioning, which is used more evenly over the course of the day (Linder et al., 1987). Increases in residential central air conditioning would likely have a larger impact on peak demand because additional load would be added to the system at the time of the commercial peak in the mid-afternoon.

Projected Changes in Statewide Electricity Demand in the 2020s

Based on the ClimAID team's global climate model projections, an average annual temperature increase of 1.5 to 3.0°F is expected in most parts of the state by the 2020s (see Chapter 1, "Climate Risks"). Assuming these changes are consistent across both the heating and the cooling season and that daily average changes are approximately equal to the annual average change in temperature, and using the sensitivities shown in **Table 8.12** (and assuming they remain unchanged), global climate change may increase summertime peak demand by up to 497 megawatts in New York City in the 2020s, a 4-percent increase over current peak demand. In other parts of the state, peak demand increases attributable to climate change will be much lower (**Table 8.14**). Note that the global climate models project a significant departure from historical trends in summertime cooling degree days (**Figure 8.6**).

The estimated changes in peak demand shown in **Table 8.14** assume that the sensitivity of demand to temperature is linear (i.e., an increase in temperature from 80 to 85°F has the same impact on demand as an increase from 90 to 95°F) and that the sensitivities observed today will remain unchanged in the future.

NYISO zone	Cooling Season				
	Change in daily electricity demand and peak load with respect to a 1°F increase in average daily temperature				
	Weather station	Change in daily electricity demand (MWh)	% change in daily electricity (%MWh)	Change in daily peak electricity load (MWp)	% change in daily peak electricity load (%MWp)
Zone A	Buffalo	632	1.3%	37	1.6%
Zone B	Rochester	569	1.8%	35	2.3%
Zone C	Syracuse	686	1.4%	41	1.7%
Zone D	Massena	91	0.5%	5	0.7%
Zone E	Watertown	338	1.5%	19	1.7%
Zone F	Albany	723	2.0%	42	2.4%
Zone G	Poughkeepsie	786	2.3%	48	2.8%
Zone J*	NYC (LGA)	3,427	2.0%	166	2.0%
Zone K*	Islip	2,256	2.9%	129	3.2%

*In zones J and K, calculations are based on data from February 2005 to 2008.

Sources: Load data were obtained from NYISO (2009a); weather station data were obtained from NOAA and NYISO (2009b)

Table 8.12 Cooling season sensitivity of demand to a 1°F increase in temperature over the period 2002–2008

Metropolitan Region	Percentage of Housing Units with Window AC Units						Percentage of Housing Units with Central AC Units					
	1994	1995	1998	1999	2002	2003	1994	1995	1998	1999	2002	2003
Buffalo	20%				26%		15%				24%	
New York City/Nassau/Suffolk/Orange		57%		63%		67%		11%		13%		17%
Rochester			27%						26%			

Source: U.S. Census Bureau (1996, 1997, 2000, 2001, 2003, 2004); weather station data are from NOAA and NYISO (2009b)

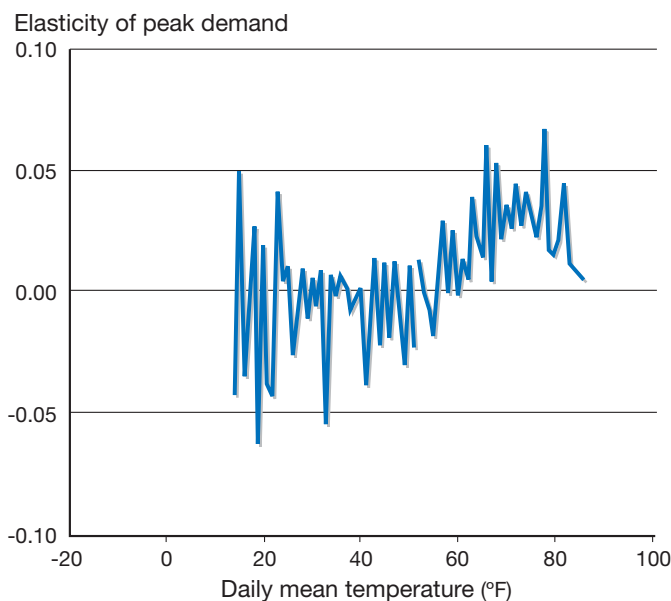
Table 8.13 Air conditioning saturation rates for select metropolitan regions in New York State (1994–2003)

NYISO Zone	Weather Station	Heating Season: Decrease in MWp electricity demand in 2020s	Cooling Season: Increase in MWp electricity demand in 2020s
Zone A	Buffalo	14–27	55–111
Zone B	Rochester	9–18	53–105
Zone C	Syracuse	19–37	61–122
Zone D	Massena	5–10	7–15
Zone E	Watertown	11–21	29–57
Zone F	Albany	15–29	63–126
Zone G	Poughkeepsie	12–25	72–145
Zone J	NYC (LGA)	40–80	249–497
Zone K	Islip	27–58	194–387

Note: Based on global climate model projections for changes in average temperature and the demand sensitivities in Tables 8.10 and 8.11. Global climate models project that average annual temperature will increase by 1.5 to 3.0°F in the 2020s compared to 1970–2000 baseline period. Climate projections from ClimAID.

Table 8.14 Projected changes in peak electricity demand in the 2020s compared to current peak demand

An example of a case where current sensitivities may not reflect future sensitivities is an increase in air conditioning saturation rates, which would increase the sensitivity of demand to increases in temperature. Two examples of cases where the relationship between temperature and demand is nonlinear can be seen in **Figures 8.8** and **8.9**. In NYISO Zone K (Long Island), demand is increasingly sensitive to temperature as



Note: Elasticities are expressed as percentages, with 0.05 indicating a 5% increase in peak demand with respect to a 1°F increase in temperature. Time period is February 2005–2008.

Figure 8.8 Elasticity of peak electricity demand in Zone K (Long Island) with respect to mean daily temperature recorded at Islip

temperature rises during the cooling season (**Figure 8.8**). In this case, the source of the nonlinearity is likely related to the prevalence of summer homes on Long Island, with the largest number of homes occupied during the hottest months of the year. **Figure 8.9** shows the relationship between maximum daily temperature and peak demand in Zone J (New York City). Demand starts to flatten after all air conditioners in the zone are already running and/or demand response programs have been activated. Appendix B shows the relationship between maximum daily temperature and peak demand in all zones. With the exception of Zone J (New York City), patterns are similar to what is shown in **Figure 8.7**.

In general, projected changes of the estimated linear sensitivities should be viewed as a starting point for assessing how climate change may affect demand, but with the understanding that climate change may have nonlinear impacts on demand drivers that are not captured by the sensitivities, such as the increased saturation of air conditioners.

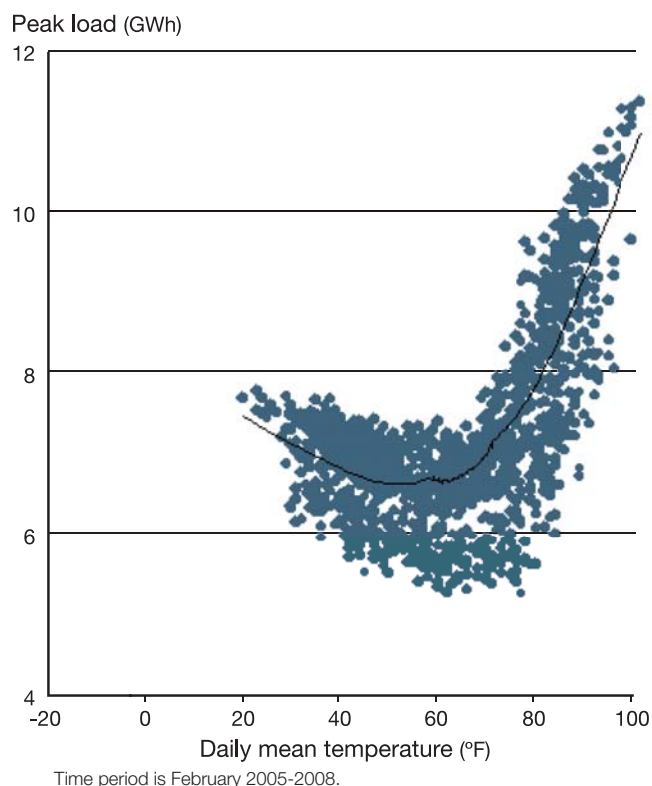


Figure 8.9 Daily maximum temperature recorded at LGA versus daily peak load (MW) for Zone J (New York City)

Sectoral Impacts

Within each NYISO zone, the mix of building types—industrial, commercial, and residential—affects the sensitivity of electricity demand to temperature, because different types of buildings vary in their demand for space conditioning (Amato et al., 2005). In the United States, just 6.8 percent of industrial energy use is related to space-conditioning functions, reflecting the greater energy intensity of the sector's various production processes. The residential and commercial sectors use far more energy on heating and cooling, at 49.3 percent (residential) and 27.3 percent (commercial) of their total demand (EIA, 2007; EIA, 2009a; EIA, 2009b). If supply becomes more constrained or if costs increase because of rising demand, impacts may disproportionately fall on the residential and commercial sectors.

In most energy models, commercial buildings are assigned a lower balance point temperature (Rosenthal and Gruenspecht, 1995), the threshold at which a building must be heated or cooled to maintain occupant comfort. Some argue the lower balance point is justified because commercial buildings tend to experience a higher internal heat gain from office equipment and lighting than the residential sector (Amato et al., 2005). Rising temperatures due to climate change are likely to compound the problem, increasing the level of cooling necessary to address this heat gain.

Studies examining differences among the energy sectors are somewhat contradictory, perhaps reflecting location-specific circumstances. One study found the residential sector will experience a greater percentage increase in per-capita demand than the commercial sector, although the residential sector has a lower base demand (Amato et al., 2005). In contrast, a different analysis of electricity consumption in eight states (including New York) that used three different global climate models found the impact of climate change on the sectors varies widely. For New York State, the study found that the residential sector would increase energy consumption by 2.9 to 6.3 percent per person compared to a commercial sector increase of 4.8 to 7.6 percent per person, by the middle of the 21st century (Sailor, 2001).

Additional Data and Research Needed to Support NYISO Demand Forecasting

The analysis presented above, as well as the large database of New York State climate data assembled by the ClimAID team, lays a foundation for additional research. A more detailed follow-up analysis could address how to systematically incorporate long-term climate change—and particularly changes in extreme conditions that affect peak demand—into zone forecasts. A combination of global and regional models and statistical analysis of historical data with extrapolation of the results into the future would provide a suite of methods for understanding how extreme changes may alter short-term (10-year) demand forecast.

8.4 Adaptation Strategies

There is an extensive literature discussion on steps the energy sector might take to adapt to climate change. Strategies are both descriptive (e.g., “a guiding principle should be resilience” (Franco and Sanstad, 2006)) and prescriptive (e.g., plant trees to shade homes and reduce heat uptake; use reflective surfaces on rooftops (Vine, 2008)). Adaptation strategies emphasize different temporal scales, cost levels, target audiences, technologies, and policy decisions and decision rules. Many adaptation strategies proffered serve a dual role as climate change mitigation strategies. As an example, steps to reduce cooling demands in buildings, a common climate change mitigation strategy, can eliminate or reduce energy system failures or generation capacity growth requirements.

An area of some commentary is the role uncertainty plays in adaptation planning. One study notes the challenge of making climate change adaptation investment decisions in the face of uncertainty over what future energy demand will look like, even in the absence of climate change (Linder et al., 1987). Recall that the modeling exercises discussed earlier all sought to isolate climate-change-related demand impacts from normal demand growth trends, which are affected by household income levels, population patterns, technology innovation, efficiency mandates, etc. (Scott and Huang, 2007). The confidence interval surrounding future demand

projections can, thus, be quite wide, exceeding the anticipated impacts of climate-change-related demand growth (ICE, 1995).

A recent analysis offers advice on how to proceed in the near term in light of this situation, highlighting the benefits of a “no-regret[s]” approach (Hallegatte, 2008). Under this approach, adaptation strategies are pursued that prove beneficial regardless of whether the anticipated climate risk ultimately materializes. Energy efficiency initiatives are “no-regret measures par excellence” (Mansanet-Bataller et al., 2008), because there are energy savings and other cost-saving benefits accrued, regardless of whether climate-change-related impact projections prove accurate. However, monitoring climate changes over time is essential to implementing effective adaptation measures in the longer term, as projected impacts could exceed the ability of no-regrets strategies to cope.

Because this system requires constant refurbishment and eventual replacement over long timescales, it makes sense to align implementation of adaptation measures into the natural replacement cycle of vulnerable system assets.

8.4.1 Key Adaptation Strategies

Past analyses of climate change impacts on New York City have described a range of potential adaptation strategies. One analysis presents a list of energy-efficiency measures for buildings, in rank order based on payback period (Audin, 1996). Others note the need for additional investment in generation capacity (Morris and Garrell, 1996). Conservation is characterized as being of paramount importance, including passive building design strategies that reduce or avoid the need for air conditioning. A more recent study concurs, offering a range of policy and technology responses appropriate at both the community and building scales (Hill and Goldberg, 2001).

In general, adaptation strategies target either energy supply or energy demand. Supply-related measures are fairly straightforward, focused on enhancing the capacity of the power generation, transmission, and distribution system to operate under a range of future climatic conditions (Franco and Sanstad, 2006). Known as “hardening” strategies, these tend to emphasize physical improvements, such as the use of higher

temperature-rated transformers and wiring and the construction of flood-prevention berms around power plants (Mansanet-Bataller et al., 2008).

Local hardening strategies are already being implemented. In 2002, the New York Power Authority constructed a new 500-megawatt power plant in Queens near the East River. FEMA 100-year flood maps identified the location as being vulnerable to flooding and, therefore, the facility would need to meet flood-proofing standards. To address this issue, the New York Power Authority decided to raise the facility to 20 feet above sea level as a precaution against future sea level rise and storm surges (Victoria Simon, personal communication, October 15, 2009). Since 2007, Con Edison has also been proactive on this front, voluntarily launching a 10-year plan to replace 186 underground transformers located in Category 1 floodplains around the city, at a cost of \$7 million. The new transformers are saltwater submersible and can thus better handle intrusion from storm surges than the equipment currently in use (New York State Department of Public Service, 2007).

Tree-trimming management programs by utilities are considered an important deterrent to ice- and snow-related problems, reducing the likelihood that falling trees or limbs will damage distribution wires. Warmer average temperatures may ironically exacerbate this winter threat, extending the growing season for trees and shrubs, forcing utilities to shorten the visitation cycle (i.e., how frequently an area is trimmed) along their transmission and distribution network (Karl Schoeberl, personal communication, October 28, 2009).

Resilience can also be delivered via soft approaches. Such strategies focus on managing risk and specific climate change impacts without making extensive (or expensive) capital improvements. Soft strategies include adjusting reservoir release policies to ensure sufficient summer hydropower capacity (Aspen Environmental Group and M Cubed, 2005) and shading buildings and windows or using green roofs (Gaffin, 2009) or high-albedo roof paints and surfaces to reduce solar gain within a building (Amato et al., 2005; Hill and Goldberg, 2001; Vine, 2008).

Demand-related measures found in the literature are more varied, reflecting traditional demand-side strategies targeting all types of energy consumption,

such as a carbon tax (Overbye et al., 2007) or improved public education programs (Vine, 2008), as well as those more narrowly focused on reducing air conditioning demand growth.

Table 8.15¹⁸ presents a wide range of adaptation strategies included in the literature, broken out by whether they focus on energy supply or demand and by

which stakeholders are in a position to implement these strategies. Most articles and reports detailing these ideas offer little insight into such matters. Several studies do note barriers to the implementation of adaptation strategies, such as cost, the number of actors involved in specific decisions (Vine, 2008), and market structure (Audin, 1996), but these studies largely ignore governance concerns.

Source	Adaptation Strategy	Agency/Organization with Primary Responsibility for Implementation						
		Other NYS Agencies	NYISO	NYS PSC	NYSERDA	Consumers	Power Plant Owners	Distribution Utilities
Energy Supply								
(Mansanet-Batlaller et al., 2008)	Protect power plants from flooding with dykes/berms.			X			X	
	Bury or re-rate cable to reduce failures.			X				X
(Stern, 1998)	Establish new coastal power plant siting rules to minimize flood risk.	X		X				
	Change water management rules to protect hydropower supply availability.	X						
(Sanstad, 2006)	Install solar PV technology to reduce effects of peak demand.				X	X		X
(Aspen Environmental Group and M Cubed, 2005)	Use increased winter stream flow to refill hydropower dam reservoirs.	X						
	Develop non-hydropower generation resources to reduce need for hydropower generation during winter.	X		X	X		X	
(Hill and Goldberg, 2001)	Construct additional transmission line capacity to bring more power to New York City to address peak demand periods.		X					X
	Upgrade existing local transmission and distribution network to handle increased load.		X					X
(Overbye et al., 2007)	Retrofit/reinforce existing energy infrastructure with more robust control systems that can better respond to extreme weather and load patterns.		X				X	X
	Automate restoration procedures to bring energy systems back on line faster after weather-related service interruptions.		X				X	X
Energy Demand								
(Miller et al., 2008)	Design new buildings and retrofits with improved flow-through ventilation to reduce air conditioning use.	X			X	X		
	Use fans for cooling to decrease air conditioning use.					X		X
(Commonwealth of Australia, 2007)	Increase use of insulation in new buildings and retrofit existing buildings with more insulation and efficient cooling systems.					X		X
	Reduce lighting and equipment loads.					X		
(Vine, 2008)	Improve information availability on climate change impacts to decision makers and the public.	X	X	X	X			X
	Use multi-stage evaporative coolers to reduce energy consumption in new buildings.					X		X
(Stern, 1998)	Establish stricter window-glazing requirements in new buildings.	X						
	Plant trees for shading and use reflective roof surfaces on new and existing buildings.				X	X		X
(Morris and Garrell, 1996)	Establish price-response programs to achieve behavioral response on energy use.		X					X
	Reduce or eliminate energy subsidies so prices reflect true cost.	X	X					
(Audin, 1996)	Establish new air-conditioning efficiency standards.	X						
	Improve and rigidly enforce energy-efficient building codes.	X						
(Hill and Goldberg, 2001)	Install power management devices on office equipment.				X	X		X
	Upgrade building interior lighting efficiency.				X	X		X
(Hill and Goldberg, 2001)	Improve domestic hot water generation and use.				X	X		X
	Improve HVAC controls.				X	X		X
(Hill and Goldberg, 2001)	Upgrade elevator motors and controls.				X	X		X
	Design HVAC improvements (e.g. variable flow, thermostats on individual radiators).				X	X		X
(Hill and Goldberg, 2001)	Install more efficient HVAC equipment.				X	X		X
	Improve steam distribution.			X	X		X	X
(Hill and Goldberg, 2001)	Weatherize low-income households.	X			X	X		X

Table 8.15 Selected climate-change adaptation strategies for the energy sector

8.4.2 Larger-scale Adaptations

The ClimAID team's interactions with stakeholders including a range of energy utilities and power generation firms made clear that there is wide divergence in the level of attention paid to climate change issues by New York's energy sector. Climate change mitigation has been on most of these firms' radar screens for some time, because of the requirements of the Regional Greenhouse Gas Initiative, audit filings such as the Carbon Disclosure Project, or their need to interconnect with new renewable-energy installations proposed in their service territories (see www.rggi.org and www.cdproject.net). In contrast, many of the energy companies characterized climate change adaptation as a relatively new area of focus. Climate change does not appear to be identified as the source of any current operating challenges or changes in operating conditions. Few have engaged in comprehensive assessments of their potential climate-change-related operating vulnerabilities. There were some exceptions, principally among companies with operations in New York City, as many of the firms were involved in the climate change adaptation initiative spearheaded by the city's Office of Long Term Planning and Sustainability (NPCC, 2010). Those companies were more likely to have convened internal working groups, hired or appointed a climate change coordinator, developed new policies and procedures, or actually begun to make operational changes or procurement decisions with adaptation considerations in mind. New York State might similarly benefit from multiple regional climate working groups or a comprehensive statewide initiative aimed at ensuring key utilities and large-scale power generation facilities are taking steps to reduce their climate-change-related vulnerabilities. A regional approach might allow for better targeting of localized issues or challenges. However, because many energy companies operate in multiple regions of the state, a statewide approach might be logistically easier for the climate teams at each company by avoiding unnecessary repetition.

Additionally, stakeholders expressed interest in an authoritative climate-risk database that could be used by a regional working group. Regardless of the organizational structure chosen for statewide climate change adaptation planning for the energy sector, such a database is central to this planning work. Stakeholders agreed that such data would be most helpful if it were

updated on a regular schedule, and if it were officially sanctioned by State officials as the basis on which operating plans and investment strategies are to be made. This would eliminate the potential for disagreements by officials at different regulatory agencies over the quality of data, methodology, etc.

Finally, New York might also benefit from a formal review process that examines whether the state's currently regulatory and market policies for electric, gas, and steam utilities will continue to be appropriate in the wake of future climate change. Several issues arose in the course of this chapter's research that suggest the need for thoughtful consideration of this question.

First, because of expected long-term reductions in heating degree days around the state, there may be a disproportionate economic impact on natural gas customers in some regions, as the full cost of maintaining the system may ultimately be shouldered by a smaller rate base. Understanding the extent of this problem and how it might be addressed would likely prove important both to local ratepayers and the utilities involved.

Second, State regulators and distribution utilities may increasingly find themselves in situations where, because of uncertainty over the exact severity or timeliness of climate risks in different parts of the state, it is unclear whether capital investments proposed by utilities to enhance the climate resilience of their distribution system will be eligible for rate reimbursement. State regulators must balance the need for a safe and reliable system with the imperative of keeping prices at reasonable levels. Guidelines clarifying this matter might prove helpful for utility capital investment and maintenance planning purposes.

Similarly, the current NYISO wholesale market dispatch system satisfies statewide electricity demand based on a formula that essentially prioritizes the lowest cost sources of power. In the future, the reliability of a provider may prove equally important, particularly during extreme weather events. Power generators may be more willing to make capital investments that enhance their climate resilience if they knew there was a way to account for these expenditures in the dispatch system.¹⁹

In all of these cases, the issues link directly to the fundamental nature of the market and regulatory system in New York. A comprehensive review may find

that no significant structural changes are necessary, but it may also uncover specific issues that can be addressed more satisfactorily under an amended market or regulatory regime.

The final area where the state may benefit from some type of policy review or activity is demand-side management. This chapter highlights the impacts changing temperatures may have on the state electricity system by the 2020s, some of which may be disproportionately felt in certain ClimAID regions. It was beyond the scope of this analysis to assess the efficacy of NYSERDA's current demand-reduction initiatives or funding programs, but it may prove informative to assess whether climate change should be more explicitly factored into the agency's program model. For example, given that climate-change-related temperature increases are likely to have the greatest impact on electricity demand in ClimAID Region 4 (New York City and Long Island), NYSERDA might consider prioritizing demand-side funding in that region because of the sizable system-wide benefits that would be achieved. Conversely, because air conditioning saturation rates are likely to grow at a faster rate in certain sections of northern, central, and western New York State, NYSERDA may decide to dedicate funds aimed at addressing this growth rate.

8.4.3 Co-benefits, Unintended Consequences, and Opportunities

Prioritization of efficiency and demand-side management to reduce the impacts of climate change on the energy sector will reduce greenhouse gas emissions, yielding mitigation co-benefits. Shading buildings and windows, use of highly reflective roof paints and surfaces, and green roofs will also create adaptation and mitigation synergies. These actions will keep building occupants and residents cooler while reducing the use of air conditioners, thereby lowering fossil fuel emissions from power plants. However, adoption of such programs needs to be distributed across the state and its citizens in order to avoid unintended consequences to vulnerable groups. The existing equipment replacement cycle provides opportunities to increase system resiliency, while climate change may provide New York State with opportunities in regard to biomass, hydropower, and other renewable energy sources.

8.5 Equity and Environmental Justice Considerations

Although large-scale blackouts are relatively rare, these events typically occur during the summer months, when electricity demand is highest. The effects of climate change on the frequency of large-scale blackout events is uncertain, yet examination of such events nonetheless highlights important equity concerns. For example, although not solely heat related, an analysis of the 2003 blackout that affected much of the Northeast revealed that even in a case where a very large region is affected, the impacts are felt unevenly across sectors and households (Anderson et al., 2007). Using a modified input-output analysis to model the effects of the 2003 blackout, Anderson et al. found that apart from the utilities themselves, retail trade suffered the greatest aggregate financial loss.

Larger businesses with backup energy sources are more likely to withstand the shock associated with a large-scale outage or a major blackout. Of those businesses that suffered losses in 2003, perhaps 10 to 15 percent had supplementary insurance to cover the damage; the smallest businesses were less likely to hold such insurance, meaning they had to absorb the losses and hope for government loans (Treaster, 2003). Another important consideration is workforce impact. In the Anderson et al. analysis, loss of labor was estimated to account for two-thirds of the total financial losses in the blackout. The people most likely to bear these losses are those living farther from their jobs or more dependent on inoperable forms of transportation, which tends to be people of color and low-income individuals (Bullard, 2007). Those who can afford to take a few days or weeks off and absorb lost wages are most likely to be resilient (Chen, 2007).

In addition to business closures, an important cross-cutting element with the health sector involves increased health risks and the vulnerability of health services (see Chapter 11, "Public Health"). The Northeast blackout significantly increased EMS calls and ambulance responses, as well as high rates of failure on respiratory devices (Prezant et al., 2005). Anderson et al. estimated that the health services sector had the second highest workforce losses in the blackout due to business closures. Decreased availability of health workers at times of increased service needs raises further questions about the capacity of the health sector to care for the infirm, elderly, and disabled in the event of a

blackout. Especially critical is care of heat-related health stress, since power outages are most likely to occur during extreme heat events. Heat-related health vulnerabilities are detailed in Chapter 11, “Public Health”.

8.6 Conclusions

ClimAID's main findings on vulnerabilities and opportunities, adaptation strategies, and knowledge gaps are described below.

8.6.1 Main Findings on Vulnerabilities and Opportunities

- Impacts of climate change on energy demand are likely to be more significant than impacts on supply. Climate change will adversely affect system operations, increase the difficulty of ensuring adequate supply during peak demand periods, and exacerbate problematic conditions, such as the urban heat island effect.
- More frequent heat waves will cause an increase in the use of air conditioning, increasing peak demand loads and stressing power supplies.
- Increased air and water temperatures may affect the efficiency of power plants, with impacts varying across the state.
- Energy infrastructure in coastal areas of southern New York State is vulnerable to flooding as a result of sea level rise and severe storms.
- Hydropower, located primarily in northern and western New York State, is vulnerable to drought and changes in precipitation patterns.
- The availability and reliability of solar power systems are vulnerable to changes in cloud cover, although this may be offset by advances in technology; wind power systems are similarly vulnerable to changes in wind speed and direction. However, changes in cloud cover and wind speed and direction are uncertain.
- Transformers and distribution lines for both electric and gas supply are vulnerable to extreme weather events, temperature, and flooding.
- Decreases in heating demand will primarily affect natural gas markets, while increases in cooling demand will affect electricity markets; such changes will vary regionally.

- The indirect financial impacts of climate change may be greater than the direct impacts of climate change. These indirect impacts include those to investors and insurance companies as infrastructure becomes more vulnerable and those borne by consumers due to changing energy prices and the need to use more energy.

8.6.2 Adaptation Options

- Equipment replacement cycles present opportunities to improve system resiliency.
- Transformers and wiring may require derating to ensure they continue to function as expected at higher temperatures.
- Berms and levees can protect infrastructure from flooding. It may also help to raise the elevation of sensitive energy technology in flood-prone locations.
- Saltwater-resistant transformers may help protect against electric system damage from sea level rise and saltwater intrusion.
- Tree-trimming programs are of critical importance to protect power lines from wind, ice, and snow damage.
- Reservoir release policies may need to be adjusted to ensure sufficient late-summer hydropower capacity.
- Demand-side management and energy efficiency initiatives may provide “no regrets” benefits to the state energy system in the near term, regardless of how climate change ultimately manifests itself across the state. Monitoring of impacts on the energy system is needed in the long term.
- Solar gain in buildings can be reduced by shading buildings and windows, using highly reflective roof paints and surfaces, and installing green roofs.
- Regional or statewide working groups may help increase the level of attention paid to climate change issues by power generators and utilities around the state.
- Power generators and utilities may benefit from the creation of an authoritative climate risk database to ensure that State regulators and other agencies rely on the same information in their rulemaking.
- New York may benefit from a formal review of how well climate change considerations are factored into the State’s regulatory and market programs for electric, gas, and steam utilities.

8.6.3 Knowledge Gaps

Throughout the chapter, areas where additional research is needed have been noted. These include:

Energy Supply

- Potential vulnerabilities associated with cooling waters at thermoelectric power stations around the state. These include vulnerabilities associated with water temperature increases during heat waves; blockages to cooling water intakes during other extreme weather events; and impacts on biodiversity in waterways used for cooling water purposes that might necessitate changes in the cooling system design. Such a review would help policymakers considering whether intake or discharge rule changes are in order.
- The existence of temperature tipping points, beyond which the likelihood of distribution system service interruptions significantly increases. Given anticipated changes in the number and duration of heat waves around the state, this information could prove helpful in identifying deficiencies in current equipment rating or system design practices.
- Potential impacts of climate change on wind patterns and speeds in selected areas of the state currently used or proposed for wind farm development. Given anticipated growth in wind system deployment around the state, this information would be helpful for energy planning purposes.
- Potential impacts of climate change on biomass-based heat production around the state (either at a large central station or co-firing facilities) and on a more localized basis in regions of the state that depend heavily on biomass combustion for heat production in residential and commercial facilities.
- Potential impacts of climate change on ice storm frequency in different parts of the state over the coming decades. This information would be useful in assessing whether design rule changes are required for electricity transmission and distribution towers and poles.
- Potential impacts of climate change on hydropower availability in different parts of the state. This information could also be helpful in informing policymakers about the potential need for rule changes regarding water releases from hydropower facilities at different times of the year or day. This

information might also prove important in assessing the need to pursue rule changes governing releases on the Niagara River, given the priority currently placed on the allocation for Niagara Falls during tourist season.

Energy Demand

- Potential impacts on the demand for natural gas and other heating fuels around the state, given anticipated decreases in heating degree-days over the coming decades. Such information would prove helpful in determining the economic impact on individual customers and local gas distribution utilities in different regions of the state.
- Ways to better incorporate climate change into demand forecasts for each load zone, and to enhance models' incorporation of the impacts of extreme events on electricity demand. Such information would be helpful to State energy planners, because this will clarify how much additional generation capacity must be developed over the coming decades or whether it can be addressed by other means, such as demand-reduction initiatives.

Case Study A. Impact of Climate Change on New York State Hydropower

There are nearly 370 large and small hydropower developments in New York, and their collective output gives the state more hydropower than any other state east of the Rockies (EIA, 2009).

Two projects are responsible for the lion's share of the state's hydropower production; both are operated by the New York Power Authority (NYPA), the largest state-owned power operation in the United States. The Niagara Power Project, located on the Niagara River between Lake Erie and Lake Ontario, is the hydropower leader in the state, generating more than 13,000 gigawatt-hours (GWh) of electricity in 2007. The second project, the St. Lawrence-FDR Project²⁰, generated another 6,600 GWh that same year (NYPA, 2007).

Both projects are fed by water from the massive Great Lakes Basin, a 300,000-square-mile watershed that

extends 2,000 miles from end to end (Croley, 2003). Because four of the five Great Lakes are bisected by the U.S.-Canada border, the governance of the lakes (and thus operations at these two large hydropower systems) is bound up in a web of international treaties and bilateral and multi-lateral agreements designed to satisfy the competing interests of two countries, eight states, and one Canadian province.

The Boundary Waters Treaty of 1909 established the International Joint Commission (IJC), an important adjudicator in Great Lakes hydropower issues. Under the Boundary Waters Treaty, the IJC acts on applications for hydropower dams and other projects in waters along the U.S.-Canadian border, seeking to balance the impacts of the projects on different stakeholders. The IJC has jurisdiction over Great Lake water management issues, with day-to-day responsibilities for water flow levels and other important operating decisions delegated to different IJC-created Boards.

Some of the most important jurisdictional decisions arise from a 1950 treaty between Canada and the United States that establishes baseline guarantees on how much water must flow over Niagara Falls during daytime hours in the tourist season. The IJC's International Niagara Board of Control oversees implementation of the 1950 treaty. Key decisions about the Robert Moses Power Dam are handled by the International St. Lawrence River Board of Control.

Both Boards have "Orders of Approval" that guide water-release planning at their respective facilities. The goals are relatively straightforward: to balance river or lake height at different locations to generate hydropower, satisfy municipal water system needs, accommodate commercial navigation, and protect private property and wildlife from flooding and erosion (International Lake Ontario/St. Lawrence River Study Board, 2006). In practice, however, this means regular fine-tuning of water release levels at different hydro system assets. On a weekly basis, orders are sent out to NYPA and other hydro dam owners/operators to open or close water intake and release gates to meet water height and release targets. Factors influencing these decisions include local climate circumstances, including wind, rain, snow, ice, drought, etc.

At Niagara, guidance comes from a 1993 Board of Control Directive focused on maintaining a mean surface elevation of 171.16 meters (562.75 feet) in the

Chippawa/Grass Island Pool upstream of Niagara Falls, balancing this target against treaty obligations for water release over the falls a few miles downstream that vary between day and night and tourist/non-tourist seasons (FERC, 2006). On the St. Lawrence River, Plan 1958-D calls for reduced flow rates during ice formation in early winter to allow more stable ice covers to form on Lake St. Lawrence, reducing the potential for ice jams that would lead to upstream flooding problems on the St. Lawrence River and Lake Ontario²¹ (FERC, 2003).

Effects of Potential Changes in Great Lakes on Hydropower

Understanding how climate change may affect the Great Lakes is a topic of increasing interest to stakeholders around the region. Because of the interconnected nature of the lakes—water from Lake Superior eventually finds its way to the Atlantic Ocean via the other lakes and the Niagara and St. Lawrence Rivers—climate studies must necessarily examine the entire Great Lakes Basin.

The earliest studies dating back to the 1980s and 1990s all note the likelihood that temperatures in the Great Lakes Basin will gradually warm and that precipitation and water levels will change. (For example, see Croley, 1983; Cohen, 1986; Quinn, 1988; USEPA, 1989; Mortsch and Quinn, 1996; Chao, 1999). For example, the EPA analysis applied three different general circulation models (GCMs) to assess future impacts on the basin. Under all three climate models, the EPA projected that precipitation levels would stay relatively constant, but that snowmelt and runoff would decline and lake evaporation levels would increase, resulting in a net decrease in overall lake levels.

Lofgren et al. (2002) found more variable results. Under one model (CGCM1)²², lake levels were expected to drop by an average of 0.72 meters by 2030 and 1.38 meters by 2090 compared to a 1989 baseline. Another model (HADCM2)²³, in contrast, forecast sizeable precipitation increases, which ultimately lead to lake level increases of 0.01 meters by 2030 and 0.35 meters by 2090. Croley's (2003) simulation using four different climate models found high levels of absolute variability, although the trends clearly fall in the same downward direction under the majority of the scenarios (see **Table 8.16**).

More recent work carried out for the International Joint Commission has begun to look at both annual impacts (in terms of lake level changes and outflow rates) and more discrete seasonal impacts. For instance, in the case of Lakes Erie, Ontario, and Superior, Fay and Fan (2003) note that mean annual lake outflow may decline by 5 to 24 percent on Lake Ontario and 5 to 26 percent on Lake Erie, depending on which climate model is applied. Mean lake level changes also decline, by 0.10 to 0.85 meters on Lake Erie and by 0.04 to 0.54 meters on Lake Ontario (see **Table 8.17**).

Given the depth of the Great Lakes, such changes appear quite modest in terms of absolute elevation, but there are implications for the New York State energy sector.

A 2006 IJC report examining alternatives to the 1958-D Order of Approval estimated that the economic impact of climate change on hydropower production at NYPA's St. Lawrence/FDR project could vary from -\$28.5 million to \$5.86 million, depending on which GCM is employed (personal communication. Victoria Simon, New York Power Authority, February 19, 2010). The "not-as-warm-and-wet" scenario was the only one of the four models to produce a positive economic impact. Data are not presented in that study to explain what this translates into in terms of increases or decreases in overall power production. However, NYPA has developed two alternative estimates, calculating that a 1-meter decrease in the elevation of Lake Ontario would result in a loss of roughly 280,000 megawatt-hours (MWh) of power production at the St. Lawrence/FDR project. NYPA also estimates that a 5–24 percent reduction in water flow from Lake Ontario

	Base Case	Warm & Dry	Not-as Warm & Dry	Warm & Wet	Not-as Warm & Wet
	HadCM3A1FI	CGCM2A21	HadCM3B22	CGCM2B23	
Superior	841	-180	54	-161	-80
Michigan	818	-273	-232	-232	-59
Huron	572	-173	-135	-168	-21
Erie	843	-350	-330	-266	45
Ontario	1926	-272	-223	-254	21

Note: CGCM2 is a global climate model from the Canadian Center for Climate Modeling and Analysis. Results from ensemble simulations related to the SRES A2 greenhouse gas scenario (A21—warm and dry) and the SRES B2 greenhouse gas scenario (B23—not as warm but dry) are shown. HADCM3 is a global climate model from the United Kingdom Meteorological Office's Hadley Centre. Results from the SRES A1FI greenhouse gas scenario (A1FI—warm and wet) and from the SRES B2 greenhouse gas scenario (B22—not as warm but wet) are shown. Source: Crowley, 2003, p. 62

Table 8.16 Projected changes in Great Lakes net basin supply (mm) for four climate change scenarios, through the 2050s

would result in production losses of approximately 340,000 to 1,650,000 MWh/year (Victoria Simon, personal communication, June 9, 2010).

There is evidence that during times of drought, power output at the Niagara Project has been curtailed because of the pre-eminence of the obligation to ensure adequate flow over Niagara Falls. According to the New York Power Authority, in the 1960s, when the Great Lakes basin endured one of the most severe droughts of the century, generation levels at the Niagara Power Project dropped "dramatically while [Niagara] Falls retained its full flow" (Victoria Simon, personal communication, December 10, 2009). **Figure 8.10** compares the annual power output levels at the Niagara Power Project²⁴ with the Niagara River's mean monthly discharge level near Buffalo. Although the annual power output data make exact month-to-month comparisons difficult, there are discernable changes in power production levels that correlate closely ($r=0.89$) to periods when the river's discharge rates increase or decrease. To the extent climate change increases the incidence of drought in the Great Lakes Basin, hydropower production levels across the state will likely decline.

NYPA's hydropower is sold through contracts to business customers participating in NYPA economic development programs, municipal and rural electric

	Base Case	Warm & Dry	Not-as Warm & Dry	Warm & Wet	Not-as Warm & Wet
	HadCM3A1FI	CGCM2A21	HadCM3B22	CGCM2B23	
Lake outflow (annual mean, in cubic meters/second)					
Lake Erie	6576	4867 (-26%)	5410 (-18%)	5153 (-22%)	6263 (-5%)
Lake Ontario	7770	5890 (-24%)	6460 (-17%)	6170 (-21%)	7420 (-5%)
Change of lake level from base case (m)					
Lake Erie					
Winter		-0.79	-0.55	-0.69	-0.15
Spring		-0.79	-0.53	-0.62	-0.10
Summer		-0.83	-0.54	-0.64	-0.13
Autumn		-0.85	-0.57	-0.73	-0.21
Annual		-0.81	-0.55	-0.67	-0.15
Lake Ontario					
Winter		-0.45	-0.27	-0.32	-0.07
Spring		-0.54	-0.30	-0.29	-0.04
Summer		-0.49	-0.23	-0.30	-0.08
Autumn		-0.40	-0.19	-0.36	-0.12
Annual		-0.47	-0.25	-0.32	-0.08

See note on models for Table 8.16. Source: Fay and Fan 2003 in Mortsch, Croley and Fay, 2006

Table 8.17 Lake outflows and change of lake levels from base case (m) for various climate scenarios

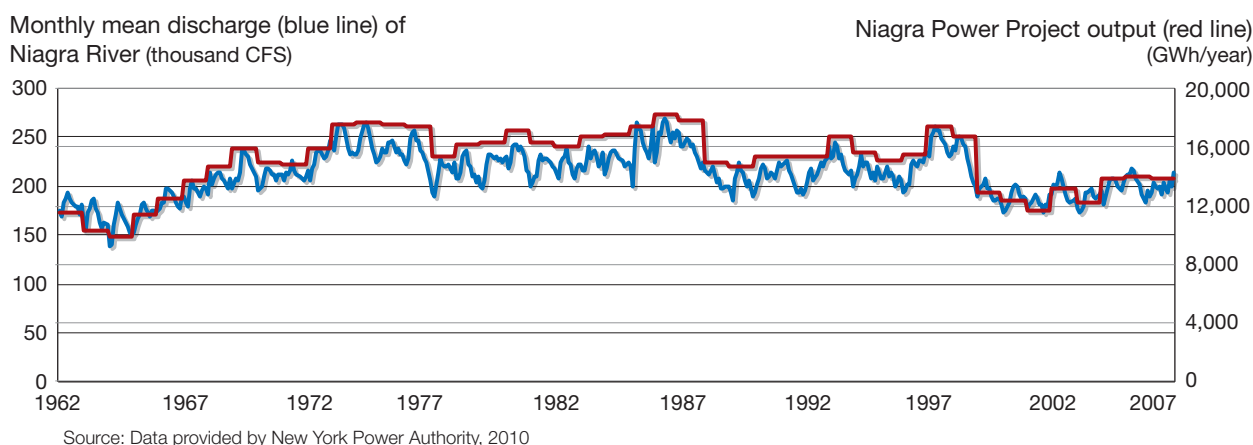


Figure 8.10 Comparison of power output levels of Niagara Power Project and monthly mean discharge rate of Niagara River (1962–2006)

cooperatives, investor-owned utilities, and other contractual arrangements. Any substantial reduction in water levels in the Great Lakes could potentially have an impact on these customers and others throughout the state. For “firm”²⁵ hydropower service customers, low water levels mean NYPA satisfies production shortfalls with higher-priced electricity purchased on the NYISO wholesale markets. For “interruptible”²⁵ service customers, low water levels mean that 100 percent of their interruptible power needs will be met through wholesale market purchases. The economic impact of a significant drought may also extend to non-NYPA customers, as greater demand for non-hydropower sources will tend to drive up prices across New York and in adjacent wholesale markets.

Cast Study B. Climate-change-induced Heat Wave in New York City

Coping with summer heat waves is a key challenge for the energy sector in New York State. Under climate change, heat waves affecting New York are likely to become more frequent and to increase in duration (see Chapter 1, “Climate Risks”). Within New York City, where urban heat island effects are already prominent during warm periods of the summer, worsening heat waves under climate change pose a challenge for the city’s energy sector (Rosenzweig et al., 2006). With these worsening heat waves, it is likely that blackouts may occur somewhat more frequently (although to an extent reduced by the regular, ongoing investment of the electricity industry). This cross-cutting example considers the social equity and economic implications of

energy outages associated with summer heat waves in New York City, although the effects will likely be similar in urban regions around the state. This ClimAID case study is specifically designed to illustrate equity and economic issues that have arisen in the past during heat-wave-related outage events, in order to highlight those that may potentially arise under climate change. (The public health effects of heat waves in New York State are addressed in Chapter 11, “Public Health.”)

Sustained high temperatures contribute to increased energy usage during heat wave events, primarily for cooling of indoor space and industrial equipment. When high temperatures persist overnight during these extended heat waves, the likelihood of outages increases. The design of the local grid system will affect whether the outages will be geographically isolated or more widespread. However, heat waves can also be associated with multiple outages across the city under conditions of prolonged heat stress.

Equity and Environmental Justice Issues

In considering potential equity and environmental justice issues associated with heat-wave and outage events in New York City, we consider three types of impacts: 1) effects of sustained high temperatures, 2) effects of outages, and 3) effects of adaptation measures.

Heat waves place a physical and financial burden on nearly all segments of the population in New York City. Concerning the spatial distribution of heat wave impacts, heat waves under climate change are likely to intensify existing urban heat island patterns, meaning

that areas that are already warmer due to heat island effects will become relatively hotter during a heat wave (Rosenzweig et al., 2005). While heat island effects occur in many parts of the city, a NYSEDA study of heat effects in New York City noted that heat island effects are prominent in many lower-income neighborhoods, such as Fordham in the Bronx and Crown Heights in Brooklyn (Rosenzweig et al., 2006). Such areas tend to have fewer street trees than other neighborhoods, leading to hotter conditions at the sidewalk level. Researchers in other cities have also noted similar correlations between locations of poor neighborhoods and more severe urban heat island effects due to higher settlement density, lack of open space, and sparse vegetation (e.g., Harlan et al., 2006).

Differential prevalence of indoor air conditioning may also exacerbate the effects of extreme heat. As noted earlier, 84 percent of housing units in New York City had some form of air conditioning in 2003. However, these rates are not uniform across the city. Results of the New York City Community Health Survey indicate that higher poverty areas, particularly in northern Manhattan, the South Bronx, and areas of Brooklyn, have lower rates of home air conditioning than many other parts of the city (see **Figure 8.11**).

Heat waves mean higher energy costs for all consumers, but these costs are not borne equally by all residents.

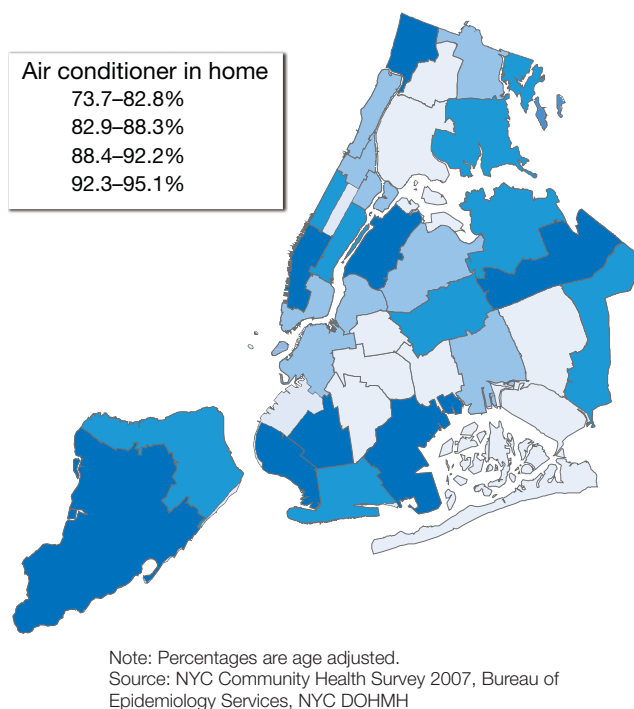


Figure 8.11 Home air conditioner use in New York City, 2007

These costs represent a larger share of household income for lower-income customers. As a result, lower-income households with air conditioners may be more reluctant to use them in times of extreme heat. During the Chicago heat wave of 1995, reluctance by low-income households to use air conditioning due to concerns about energy costs was a significant factor contributing to mortality (Klineberg, 2003). Furthermore, while heat wave events lead to increased energy usage throughout New York City, locations in the city with greater heat island effects (i.e., the hottest locations) have been found to experience greater increases in energy demand (Gaffin et al., 2008). These spatial differences may exacerbate energy cost burdens on those lower-income areas that are subject to heat island effects.

Higher energy usage due to sustained high temperatures may also contribute to increased air pollution during heat wave events. Under heat wave events, less efficient and more highly polluting sources of power may be used to meet peak demand. High levels of ozone due to the combination of high temperatures and air pollution are particularly harmful for the elderly and ill, as discussed in Chapter 11, “Public Health”.

Historically, heat waves in New York City have been associated with sustained power outages in some neighborhoods. For example, the Washington Heights/Inwood blackout of July 1999 was a summertime, heat-related outage that affected more than 200,000 residents living north of 155th Street in Manhattan (Office of the Attorney General, New York State, 2000). Within the affected region, which is dominated by high-poverty areas, among those hardest hit by the outage were elderly residents of high-rise apartments, where elevator service failed and fans and air conditioners for cooling were inoperable (Office of the Attorney General, New York State, 2000).

Concerning adaptation of the energy sector to heat waves, some current options are expansion of smart grid initiatives, demand management, load reduction efforts, and on-site generation. All of these measures have the potential to raise social equity issues. For example, different households will have different capacity to invest in the equipment needed for on-site generation. Such differences in capacity to adapt represent an important type of equity issue that needs to be taken into account as adaptation strategies are put into place.

Economic Analysis of Heat Wave Impacts

Electric power generation, transmission, and distribution systems play an important role in supporting the economy of the United States. Hence, power outages and other disruptions are likely to negatively affect economic activity, mainly by restricting infrastructure and other services on which the economy relies. Power failures, which may take place when electricity demand exceeds supply such as during a heat wave, have both direct and indirect impacts on the economy, national security, and the environment.

Economic losses from electric service interruptions are not trivial, as illustrated by different studies. A 2001 report that extrapolated from surveyed businesses the losses due to poor power quality, outages, and other disruptions (referred to collectively as “reliability events”) estimated costs to U.S. consumers to range from \$119 billion to \$188 billion per year (EPRI, 2004). The Pacific Gas & Electric Company (PG&E) used direct costs of reliability events (based on a combination of direct cost measures and willingness-to-pay indicators) to assess that such power disruptions cost its customers approximately \$79 billion per year (USEPA, 2010). A 2004 Berkeley National Laboratory comprehensive study of end-users focusing on power outages alone²⁶ estimated annual losses to the national economy of approximately \$80 billion (LaCommare and Eto, 2004). The figures provided by these studies coincide with estimates by the U.S. Department of Energy, ranging from \$25 billion to \$180 billion per year (USDOE, 2009).

Given the number of major power outages, including those in the Northeast in 1965, 1977, and 2003, different methodologies have been developed to estimate their associated economic costs. While much of the earlier research has focused on calculating physical damage and cost of replacement of major infrastructure systems, fewer studies have been conducted to assess the overall economic impacts.

Estimates of the economic impact of the 25-hour blackout that affected most of New York City on July 13 and 14 of 1977 are sketchy, with damage costs assessed at \$60 million. More information is available on the costs of the cascading blackout that started on August 14, 2003, and affected 55 million people. Initial reports projected that economic losses would range

from \$4 billion to \$6 billion. Others estimated that this major power outage translated into a \$10 billion loss for the national economy, and an ICF Consulting report put the price tag between \$7 billion and \$10 billion (Knowledge@Wharton, 2003; USEPA, 2010; The Public Record, 2008; ICF, 2003; Anderson and Geckil, 2003; ELCON, 2004). Moreover, this blackout contributed to at least eleven fatalities, including six in New York City (Knowledge@Wharton, 2003).

Certain sectors of the economy were particularly affected during the 2003 blackout, with the airline industry losing an estimated \$10–\$20 million, mostly because of grounded flights. In New York City, where over 14 million people were affected, it has been estimated that approximately 22,000 restaurants collectively lost \$75–\$100 million in foregone business and wasted food. In addition, the City of New York reported losses of \$40 million in lost tax revenue and \$10 million in overtime payments to city workers (Knowledge@Wharton, 2003). Adding to the losses was the cost of using “defensive measures” such as backup generators as well as servicing them, given that half of New York City’s 58 hospitals experienced some kind of failure during the blackout (USEPA, 2009).²⁷

While cascading blackouts have significant impacts, the majority of power outages are localized blackouts and brownouts, and the cumulative impact to the national economy may be quite large.²⁸

Localized service outages in New York City include the July 3–9, 1999, blackout that affected 170,000 Con Edison customers, including 70,000 in Washington Heights, as well as the nine-day blackout that started on July 16, 2006, in Long Island City (in Queens) and affected 174,000 residents (New York State Public Service Commission, 2000; Chan, 2007). Most reports of economic losses focus on customer claims, which for the 1999 blackout amounted to \$100 each to compensate residents for spoilage of food and medicine and \$2,000 each to business customers. These fees were raised to \$350 and \$7,000, respectively, in 2006. Total claims paid by Con Edison in 2006 amounted to \$17 million; an additional \$100 million was estimated to be spent by the utility on recovery costs to repair and replace damaged equipment (Cuomo, 2007).

However, economic compensation paid by utilities to affected customers represents only a portion of total economic losses to society, and does not even take into

account the value of unsold (or unserved) electricity to communities and businesses. Several approaches have been developed to attempt to estimate the overall economic cost of blackouts. In general, most methods focus on calculating the value added that customers place on power reliability, which can be quantified by the consumers' willingness to pay, taking into account their income, or in the case of businesses, their revenues net of economic losses due to power failures. Nevertheless, the value-added approaches do not account for all the societal benefits that result from reliability improvements, as they fail to estimate the associated improvements in public safety and health or environmental benefits. These societal benefits must be incorporated separately.

The value added of electricity reliability is often presented as customer damage functions that may take into account a number of variables. Such values may be estimated by 1) calculating the direct costs of power outages based on customers' experience, 2) conducting surveys to estimate the consumer's willingness-to-pay (WTP) or willingness-to-accept compensation (WTA) to avoid such outages, and 3) estimating by indirect analytic methods.

The first approach attempts to estimate the value that electricity services represent to each customer, based on losses experienced to particular facilities operations. What is referred to as the customer's value of service (VOS) can be measured in terms of the direct costs of an outage, which may include damaged plant equipment and/or replacement costs, spoiled products, additional maintenance costs, production losses/lost revenue, costs of idle labor, and potential liabilities.

The WTP/WTA approach provides another measure of the "cost of reliability" of electrical services considered in terms of how consumers value such services, or more precisely the value assigned to the lack of survey interruptions. Various studies provide survey-based estimates of the WTP for different groups of electric power customers. While economic losses to commercial and industrial facilities from power interruptions may be monetized in a straightforward manner (e.g., on the basis of lost profits), assessing the direct costs to residential customers may be more complicated, in part because surveyed customers do not always describe economic losses in monetary terms but rather as disruptions or hassles. Rather than assigning values to such inconveniences (which go

Sector	Annual kWh
Medium and large C&I	7,140,501
Small C&I	19,214
Residential	13,351

Table 8.18 Average kWh usage per year by customer class

Interruption Cost	Interruption Duration				
	Momentary	30 min.	1 hour	4 hours	8 hours
Medium and Large C&I					
Morning	\$8,133	\$11,035	\$14,488	\$43,954	\$70,190
Afternoon	\$11,756	\$15,709	\$20,360	\$59,188	\$93,890
Evening	\$9,276	\$12,844	\$17,162	\$55,278	\$89,145
Small C&I					
Morning	\$346	\$492	\$673	\$2,389	\$4,348
Afternoon	\$439	\$610	\$818	\$2,696	\$4,768
Evening	\$199	\$299	\$431	\$1,881	\$3,734
Residential					
Morning	\$3.7	\$4.4	\$5.2	\$9.9	\$13.6
Afternoon	\$2.7	\$3.3	\$3.9	\$7.8	\$10.7
Evening	\$2.4	\$3.0	\$3.7	\$8.4	\$11.9

Note: C&I = Commercial and Industrial. Source: Lawrence Berkeley National Laboratory (2009), Estimated Value of Service Reliability for Electric Utility Customers in the United States; prepared by Michael J. Sullivan, Ph.D., Matthew Mercurio, Ph.D., Josh Schellenberg, M.A., Freeman, Sullivan & Co.; June, 2009. Accessed online on 1/12/10 from: <http://certs.lbl.gov/pdf/lbnl-2132e.pdf>

Table 8.19 Estimated average electric customer interruption costs per event in US 2008\$ by customer type, duration, and time of day

Interruption Cost	Interruption Duration				
	Momentary	30 min.	1 hour	4 hours	8 hours
Medium and Large C&I					
Agriculture	\$4,382	\$6,044	\$8,049	\$25,628	\$41,250
Mining	\$9,874	\$12,883	\$16,368	\$44,708	\$70,281
Construction	\$27,048	\$36,097	\$46,733	\$135,383	\$214,644
Manufacturing	\$22,106	\$29,098	\$37,238	\$104,019	\$164,033
Telecommunications & Utilities	\$11,243	\$15,249	\$20,015	\$60,663	\$96,857
Trade & Retail	\$7,625	\$10,113	\$13,025	\$37,112	\$58,694
Fin., Ins., & Real Estate	\$17,451	\$23,573	\$30,834	\$92,375	\$147,219
Services	\$8,283	\$11,254	\$14,793	\$45,057	\$71,997
Public Administration	\$9,360	\$12,670	\$16,601	\$50,022	\$79,793
Small C&I					
Agriculture	\$293	\$434	\$615	\$2,521	\$4,868
Mining	\$935	\$1,285	\$1,707	\$5,424	\$9,465
Construction	\$1,052	\$1,436	\$1,895	\$5,881	\$10,177
Manufacturing	\$609	\$836	\$1,110	\$3,515	\$6,127
Telecommunications & Utilities	\$583	\$810	\$1,085	\$3,560	\$6,286
Trade & Retail	\$420	\$575	\$760	\$2,383	\$4,138
Fin., Ins., & Real Estate	\$597	\$831	\$1,115	\$3,685	\$6,525
Services	\$333	\$465	\$625	\$2,080	\$3,691
Public Administration	\$230	\$332	\$461	\$1,724	\$3,205

Note: C&I = Commercial and Industrial. Source: Lawrence Berkeley National Laboratory (2009), Estimated Value of Service Reliability for Electric Utility Customers in the United States; op. cit.

Table 8.20 Estimated average electric customer interruption costs per event in US 2008\$ by duration and business type (summer weekday afternoon)

beyond the cost of food and medicine spoilage), economists often rely on WTP or WTA surveys in order to assess losses to residential customers (Lawton et al., 2003). Such surveys describe different scenarios and ask residential customers how much they would be willing to pay for power reliability or the amount of money they would require to accept service interruptions.

A 2009 report (Sullivan et al., 2009) that conducted a metadata analysis using 28 different customer-value-of-service reliability surveys that had been carried out by 10 major U.S. electric utilities between 1989 and 2005 provides average estimates of the value of service reliability for electricity customers in the United States (except in the Northeast). The information collected is classified by customer types surveyed, including both

medium and large commercial and industrial (C&I) non-residential consumers with sales greater than 50,000 kilowatt-hours (kWh) per year, with an average of 373 employees; small commercial and industrial non-residential customers with sales $\leq 50,000$ kWh per year; and residential customers. The metadata analysis provides an average kWh usage per customer type, as summarized in **Table 8.18**.

Summary results for the cost of power interruptions are given in **Tables 8.19–8.21**, including estimates of the costs of power interruptions per event by customer class, business type, size of the facility and time of the event, and geographical location. Information is also available on the expected cost of unserved energy, which is a metric widely used for expressing interruption costs, as shown on **Table 8.22**, which provides another example of the value of service (VOS) direct cost estimation approach.

The information summarized in the tables shows that large commercial and industrial customers experience losses averaging \$20,000 and \$8,166 for a 1-hour power interruption during a winter afternoon and summer afternoon, respectively. As the power outage increases in duration, so do costs, sharply during the winter and significantly in the summer.

Heat Wave and Power Outage Adaptation Measures

According to a 2009 report by the American Society of Civil Engineers, electricity demand since 1990 has grown approximately 25 percent but construction of transmission facilities has declined by roughly 30 percent (American Society of Civil Engineers, 2009). In 2003, other reports estimated that investment in high-voltage transmission lines had decreased by 45

Interruption Cost	Interruption Duration				
	Momentary	30 min.	1 hour	4 hours	8 hours
Medium and Large C&I					
Summer Weekday	\$11,756	\$15,709	\$20,360	\$59,188	\$93,890
Summer Weekend	\$8,363	\$11,318	\$14,828	\$44,656	\$71,228
Winter Weekday	\$9,306	\$12,963	\$17,411	\$57,097	\$92,361
Winter Weekend	\$6,347	\$8,977	\$12,220	\$42,025	\$68,543
Small C&I					
Summer Weekday	\$439	\$610	\$818	\$2,696	\$4,768
Summer Weekend	\$265	\$378	\$519	\$1,866	\$3,414
Winter Weekday	\$592	\$846	\$1,164	\$4,223	\$7,753
Winter Weekend	\$343	\$504	\$711	\$2,846	\$5,443
Residential					
Summer Weekday	\$2.7	\$3.3	\$3.9	\$7.8	\$10.7
Summer Weekend	\$3.2	\$3.9	\$4.6	\$9.1	\$12.6
Winter Weekday	\$1.7	\$2.1	\$2.6	\$6.0	\$8.5
Winter Weekend	\$2.0	\$2.5	\$3.1	\$7.1	\$10.0

Note: C&I = Commercial and Industrial. Source: Lawrence Berkeley National Laboratory (2009), Estimated Value of Service Reliability for Electric Utility Customers in the United States; op. cit.

Table 8.21 Estimated average electric customer interruption costs per event in US 2008\$ by customer type, duration, season, and day type

Facility Outage Impacts			Annual Outages		Annual Cost	
Power Quality Disruptions	Outage Duration per Occurrence	Facility Disruption per Occurrence	Occurrences per Year	Total Annual Facility Disruption	Outage Cost per Hour*	Total Annual Costs
Momentary Interruptions	5.3 Seconds	0.5 Hours	2.5	1.3 Hours	\$45,000.00	\$56,250.00
Long-Duration Interruptions	60 Minutes	5.0 Hours	0.5	2.5 Hours	\$45,000.00	\$112,500.00
Total			3	3.8 Hours		\$168,750.00
Unserved kWh per hour (based on 1,500 kW average demand)			1,500 kWh			
Customer's Estimated Value of Service, \$/unserved kWh			\$30 /unserved kWh			
Normalized Annual Outage Costs, \$/kW-year			\$113 \$/kW-year			

Note: Outage costs per hour estimated based on facility data and include production losses, increased labor, product spoilage, and other costs. Source: USEPA – Combined Heat and Power Partnership; Calculating Reliability Benefits, <http://www.epa.gov/CHP/basic/benefits.html>

Table 8.22 Value of service direct cost estimation

percent over the previous 25-year period (ELCON, 2004). Moreover, the Energy Department expects that electricity use and production will increase by 20 percent over the next decade but the nation's high-voltage electric network will only increase by 6 percent in the same time period. After the major blackout of 2003, there have been calls for investments ranging from \$50 billion to \$100 billion to reduce severe transmission bottlenecks and increase capacity (Knowledge@Wharton, 2003).

While long-term planning and investments are necessary, significant improvements are needed over the next few years to ensure that operators can have access to the necessary information to properly manage power flows and transmission systems. Investments to upgrade the grid can provide network operators with clearer metrics of the potential risks in order to avoid major power outages (Apt et al., 2004). The costs of installing sensors nationwide are much smaller than those for a single blackout event. A recent report made the case for installing sensors every 10 miles over the existing 157,000 miles of transmission lines in the United States and found that, at a cost of \$25,000 per sensor, total costs would amount to \$100 million if all sensors were replaced every five years. Such investment would increase the average residential electricity bill by 0.004 cents per kilowatt hour. The total would be roughly one-tenth the estimated annual cost of blackouts (Apt et al., 2004).

Other adaptation measures to prevent power outages include reducing demand and distributed generation. Load-shedding strategies may be used during heat waves in advance of peak-demand episodes and include broad calls for consumers to reduce demand as well as voluntary and mandatory load reduction programs, for which customers receive a number of incentives. Customers participating in voluntary options such as the "Distribution Load Relief" program must reduce at least 50kW or 100kW (for individuals or aggregators respectively) to receive compensation of at least \$0.50 per kWh after each event. Other mandatory programs are similarly structured with additional incentives such as reservation (capacity) fees and bonus payments (Con Edison). Other, long-term strategies to increase overall network capacity include demand-side management, which decreases the need for investments in additional power generation.²⁹

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Appendix A. Stakeholder Interactions

The ClimAID Energy team interacted with relevant stakeholders around the state through meetings and one-on-one interviews. Drafts were shared with selected stakeholders to obtain their feedback on different topics and to ensure the accuracy of specific information contained in the report.

The first stakeholder meeting was held at NYSERDA's office in Albany in March 2009. Stakeholders invited to the meeting included a range of power plant operators, officials from New York-based energy and environmental organizations, distribution utilities, and New York State officials, including the New York Independent System Operator. Of the 38 invitations sent out, 18 individuals from 15 organizations were represented. A list of participating stakeholders is included at the end of this appendix.

The first meeting introduced the ClimAID project and solicited feedback on the first draft of the energy sector analysis that was completed in early 2009. A draft stakeholder survey was also shared to obtain feedback on its length and content. Based on feedback provided by the stakeholders, the survey was shortened considerably and tailored to reflect the unique perspective of each sector participant (e.g., utility, power plant operator, etc.).³⁰

Energy demand forecasting was also discussed at the meeting, with the stakeholders providing important information regarding their concerns about the ClimAID team's efforts to forecast climate-change-related demand impacts beyond a 20–30 year timeframe, arguing that longer-term forecasts were subject to other factors (e.g., technology changes, population changes, climate change mitigation policies) that made it difficult to forecast demand with a high level of certainty. As a result, a decision was made by the ClimAID Energy team to concentrate on demand impacts, taking into account only those climate change impacts projected for the 2020s, and to convene a separate demand modeling working group.

Following the initial meeting, individual meetings and phone calls were conducted with six different stakeholders representing distribution utility and/or power generation operations in different parts of the state. These conversations were in-depth, lasting between 45 minutes and two hours. In some cases, a

single company representative was interviewed, while in other cases there were six company participants, each with a different area of specialization.

In most cases, follow-up questions were submitted to these companies to clarify information raised in the original meeting or to solicit additional information. These interviews were helpful both in validating many of the conclusions drawn by the literature review, and in identifying nuanced differences or more recent information specifically relevant to New York State.

The demand modeling working group met in June 2009 to solicit input from stakeholders on priorities with respect to understanding how climate change may affect energy demand in New York State. After this meeting, a follow-up call was held to discuss methodological issues and further refine the objectives. During this call and subsequent communications, the group determined that additional statistical analysis of historical climate data should be prioritized over producing demand forecasts for the state. There are some efforts to incorporate climate change into demand forecasts, so the group saw an opportunity for the ClimAID team to provide data and analysis to support these efforts. The results of the demand modeling research are included in the Energy Demand section of the chapter (section 8.3.2).

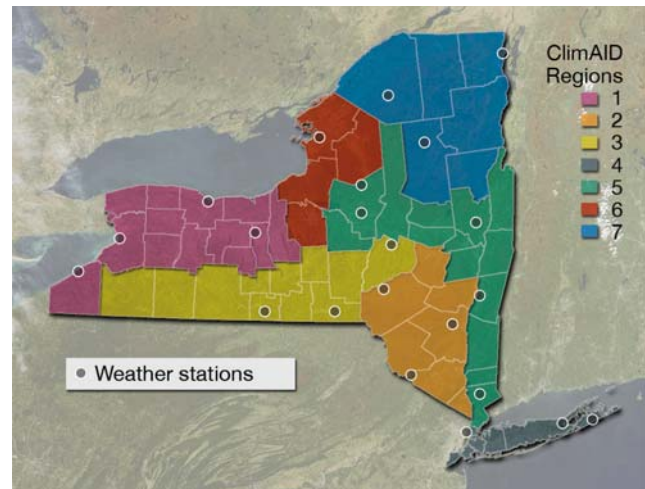
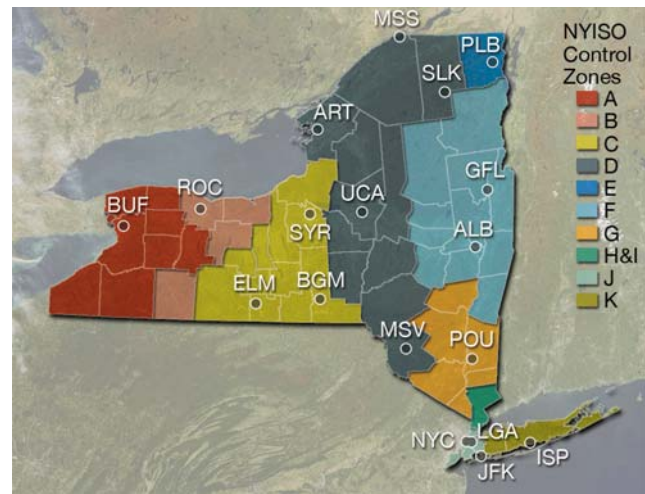
Stakeholder Meeting Participants, March 2009

- AES
- Alliance for Clean Energy New York
- Environmental Energy Alliance of New York
- Cogentrix
- Con Edison
- Dynegy
- FirstLight Power/Suez GDF
- Long Island Power Authority
- National Grid
- NRG Energy
- New York Independent System Operator
- New York Power Authority
- TransCanada/Ravenswood
- US PowerGen

Demand Modeling Meeting Participants, June 2009

- Con Edison
- New York State Department of Public Service
- National Grid
- New York City Office of Long-Term Planning and Sustainability
- New York Independent System Operator
- New York Power Authority
- New York State Department of Environmental Conservation
- New York State Energy Research and Development Authority

Appendix B. Relationship between NYISO Load Zones and ClimAID Regions



ClimAID Regions: 1. Western New York Great Lakes Plain; 2. Catskill Mountains and West Hudson River Valley; 3. Southern Tier; 4. New York City and Long Island; 5. East Hudson and Mohawk River Valleys; 6. Tug Hill Plateau; 7. Adirondack Mountains. Source: NYISO (2009a), basemap NASA

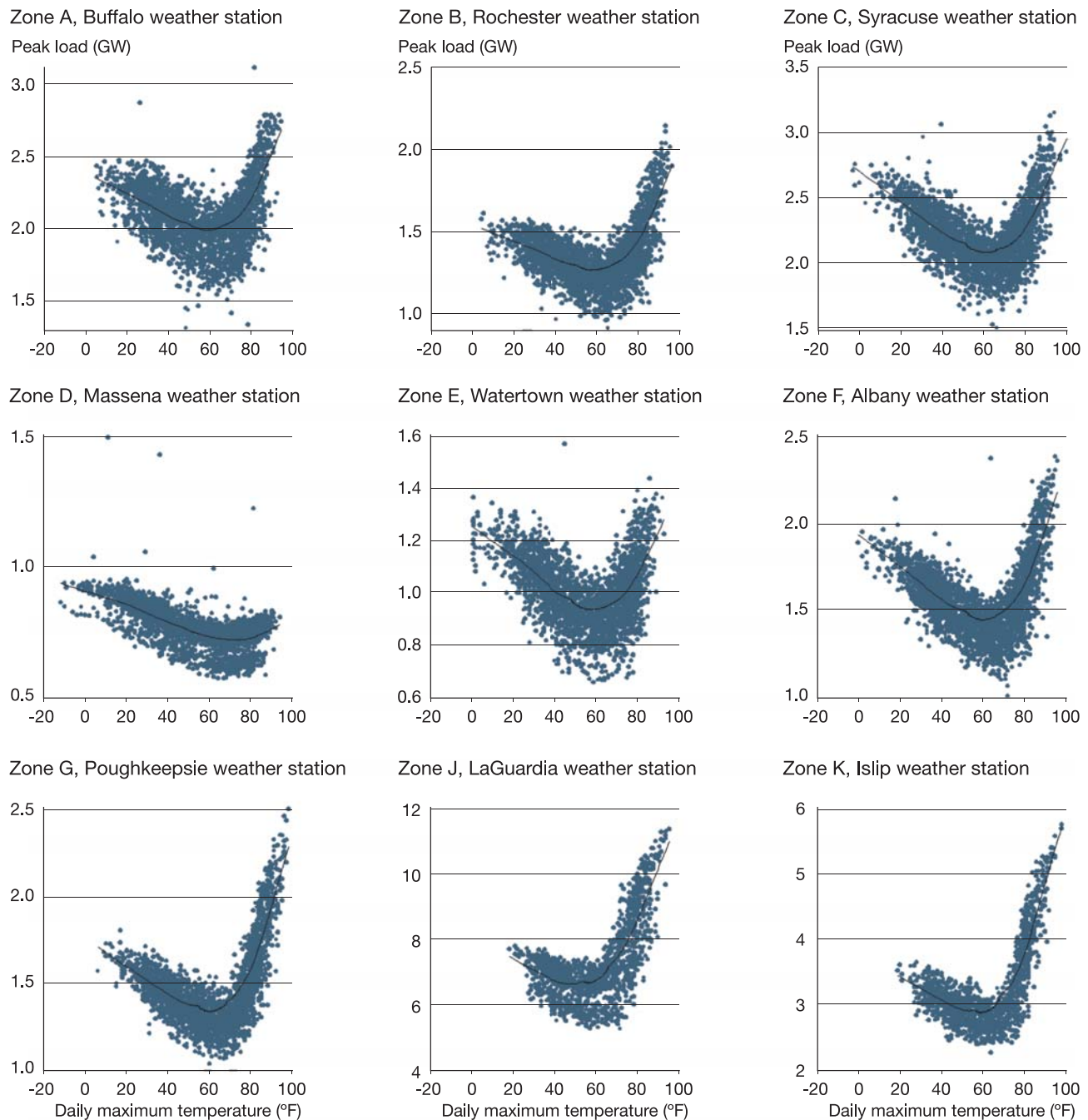
Figure 8.12 Locations of weather stations used in ClimAID climate analysis related to NYISO load zones

¹ Interactions with out-of-state infrastructure may be discussed, but are not a direct focus of the ClimAID report.

² The New York Independent System Operator (NYISO) Gold Book characterizes conventional hydropower plants as a renewable resources, although it acknowledges this does not match the definition used in other New York State policies, including the Renewable Portfolio Standard.

³ There has not been any follow-up analysis examining the accuracy of these projections.

⁴ In general, the DOE report suggested there is a heightened vulnerability at power plants with shallow intake depths, because of the risk that water levels may be inadequate, exposing the intake pipe or resulting in limits in how much water the power plant may siphon off. Drought conditions may also result in higher water temperature levels at depths close to the intake, creating problems at facilities requiring specific intake water temperatures.



Time period is 2002-2008, except for Zones J and K, for which the time period is February 2005-2008.

Figure 8.13 Maximum daily temperature (°F) versus daily peak electricity demand (mw) for each NYISO Control Zone

⁵ The Reliability Council is the official entity authorized by the Federal Energy Regulatory Commission to analyze supply and demand levels in New York State on a periodic basis, identifying conditions that may affect future system reliability and issuing rules that the New York Independent System Operator and other entities must abide by when making supply and power distribution decisions.

⁶ Assessment of the overall net energy demand impact is clouded by the wide range of scenarios and assumptions used in different studies, as well as different approaches to energy accounting. For example, some studies assess impacts on delivered (on-site) energy consumption whereas other studies assess impacts on primary energy demand, after accounting for generation, transmission, and distribution losses.

⁷ $HDD = 65 - T_{mean}$ if $T_{mean} < 65^\circ F$. $CDD = T_{mean} - 65$ if $T_{mean} > 65^\circ F$, where T_{mean} is the mean daily temperature. Total annual HDD/CDD is the sum of daily HDD/CDD.

⁸ Cooling degree days (CDD) are calculated as the mean daily temperature minus 65 deg F. For example, if the mean temperature is 75 deg F, then there are 10 CDD. Total annual CDD are the sum of daily CDD. Similarly, heating degree days (HDD) are calculated as 65 deg F minus mean daily temperature, and total annual HDD is the sum of daily HDD.

- ⁹ Chapter 1, “Climate Risks,” provides some additional analysis of historical climate data that is in general agreement with our findings. Historical temperature trends for different weather stations around the state are shown for several different periods: 1900–1999, 1970–2000, and 1970–2008 (see Table 1.2 in the climate chapter). In general, significant upward trends in mean annual temperature are driven by significant increases in winter temperature, although significant increases in summer temperature are observed for some stations and time periods. The 1970–2008 period is comparable to the CDD trends covering 1970–2007 shown in Figure 6; over this period, with the exception of Elmira, trends in summertime temperature are not significant (see Table 2c in the climate chapter).
- ¹⁰ Gaffin et al. (2008) estimate that one-third of the observed increase in mean annual temperature in New York City of 2.7°F is attributable to a strengthening urban heat island, with two-thirds of the increase attributable to global climate change. Urban development can lead to a higher concentration of heat-trapping built surfaces and a lower concentration of vegetation, which can increase local temperature. Heat island mitigation strategies include urban forestry, planting of street trees, and incorporating more reflective surfaces into the urban environment.
- ¹¹ This is true because nighttime demand levels will remain lower than afternoon demand levels and because “shoulder season” peak demand will still be lower than the summertime peak. Shoulder season refers to the months between peak demand and low demand (late spring and early fall in New York).
- ¹² This is partly a function of where a city or region derives its power. Because most cities can and do draw on power generated outside of the city limits, it is common for areas with surplus capacity to sell power to areas experiencing a shortfall. (For example, Morris et al., 1996 noted that Con Edison’s summertime peak demand was 40 percent higher than its winter peak demand, freeing up winter-time generating capacity in New York City.) To the extent warming temperatures drive up peak summer demand in traditional winter-peaking areas (and vice-versa), there may be less power available to share, creating the need for additional generation capacity across the system.
- ¹³ Baxter and Calandri (1992) and Franco and Sanstad (2008) analyzed impacts on electricity sales in California. ICF (1995) analyzed the service territories of six utilities in different parts of the U.S. and Japan.
- ¹⁴ To carry out this study, NYSEDA partnered with the U.S. Environmental Protection Agency, the Electric Power Research Institute, and the Edison Electric Institute. Climate change impacts on both “upstate” and “downstate” electric systems were examined. There has not been any follow-up analysis examining the accuracy of these projections.
- ¹⁵ The MEC report’s study region was comprised of 31 counties in the New York Metropolitan area, which extends into Connecticut and New Jersey, so results are not directly comparable to estimates for New York City or New York State. Also, Hill and Goldberg (2001) focused on projecting impacts on peak demand, rather than annual demand.
- ¹⁶ Note that a small portion of the rise in electricity demand in the winter, relative to shoulder seasons, may be related to additional lighting demand on shorter, winter days.
- ¹⁷ Turning points were computed by running locally weighted (Lowess) regressions of demand on temperature and saving the Lowess smoothed estimate for each temperature observation. The temperature value corresponding to the minimum of the Lowess smoothed variable was defined as the turning point.
- ¹⁸ NYSEDA has long been active in funding research and deployment of many of the strategies listed in Table 12. Since its inception, NYSEDA has provided support for renewable energy technology deployment and market development efforts, including solar PV technology. For example, by the end of 2006, NYSEDA had provided financial support for nearly three-fourths of all of the solar PV systems installed outside of the Long Island Power Authority (LIPA) service territory, although the number is likely even higher now. (A separate funding program sponsored by LIPA targets PV deployment on Long Island.) Demand-side management efforts are another long-time focus of NYSEDA, and most of the demand-side strategies listed in Table 12 have recently been or are currently eligible for funding from various NYSEDA programs.
- ¹⁹ Under the current system, suppliers are penalized if they fail to deliver supply they had formally committed to the NYISO system, meaning the system suggested here might prove redundant. Such penalties do little to protect against climate-related system failures, however, and may encourage firms to underbid their capacity to deliver power during extreme events, artificially increasing prices beyond levels otherwise justified.
- ²⁰ The St. Lawrence–FDR Project includes the Moses-Saunders power dam (a single structure featuring 32 turbines divided equally between the New York Power Authority and Ontario Power Generation), the Long Sault Dam, and the Iroquois Dam.
- ²¹ Since 2000, the IJC has been examining alternatives to Plan 1958-D, and one plan known as Plan 2007 is currently awaiting final approval; its prospects are unclear.
- ²² Canadian Center for Climate Modeling and Analysis (model version CGCM1)
- ²³ United Kingdom Meteorological Office’s Hadley Centre (model HadCM2)
- ²⁴ The Niagara Power Project includes generation output from both the Robert Moses Niagara Power Plant and the adjacent Lewiston Pump Generation Plant.
- ²⁵ “Firm” power customers can expect power to be available at all times, except possibly in emergencies. “Interruptible” power customers may pay a lower rate, but the utilities have the right to curtail their power for periods of time if necessary (e.g., due to high demand and/or reduced power availability).
- ²⁶ Excluded from this calculation are estimated losses due to power-quality events.
- ²⁷ As reported in the *New York Times*, August 16, 2003.
- ²⁸ As described above, nationwide costs may reach up to \$180 billion annually, much more than the cost of the 2003 major blackout.
- ²⁹ This may include investments in distributed generation, which has been defined as the electricity production that is on-site or close to the load center and is interconnected to the utility distribution system (http://www.energy.ca.gov/papers/2004-08-30_rawson.pdf).
- ³⁰ Because the survey was primarily aimed at soliciting New York State-specific information to supplement the original literature review that formed the basis for much of this chapter, the Energy Team decided to narrow the stakeholder survey to power plant operators and distribution utilities in different regions of the state.

Transportation

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Introduction

The transportation sector, as defined in the context of the ClimAID report, consists of the built assets, operations, services, and institutions that serve public and private needs for moving goods and people within, to, and from the State of New York. The transportation sector and the energy and communications sectors are highly interdependent (see Chapter 8, “Energy,” and Chapter 10, “Telecommunications”).

Transportation occurs by different *modes*: land, air, and water. On land, it can be divided into road, rail, and pipeline systems. Transported goods are people and freight (the latter includes raw materials, supplies, finished products, and waste). In urban areas, mass transit systems serve commuting populations traveling to and from daily work, school, shopping, etc. In suburban and rural areas, largely private vehicular transportation on roads and highways dominates, but this also reaches the central business districts of cities. Long-distance and interstate traffic on roads is complemented by railway, water, and air transport.

The purposes of this chapter are 1) to provide a comprehensive overview of the vulnerabilities of the state’s transportation system to changing climate, and 2) to present the adaptation options that can turn the challenges posed by the changing climate into opportunities to revitalize and modernize the state’s transportation systems while at the same time improving their climate resilience. This chapter is structured based on climate hazards and risks. This means that regions with the highest concentration of transportation assets located in the most vulnerable places, and hence representing the largest risks for potential losses from climate change, will be scrutinized in much greater detail than those regions with fewer assets at risk and with lesser climate change impacts on the state’s economy.

9.1 Sector Description

Transportation is a lifeline fundamental to modern developed societies. Provided in this section is an overview of the transportation sector in New York State. This section includes a description of the many transportation systems in the state and discusses the agencies that are responsible for managing them.

9.1.1 Economic Value

Nationally, transportation contributes on the order of 10 percent to the economy. Translated to New York State’s annual gross state product (in excess of \$1 trillion), this would correspond to a contribution of about \$100 billion per year to the state’s economy.¹ Without an effective transportation infrastructure, the economy of a state cannot function and grow.

9.1.2 Statewide Overview

Transportation in New York State is a complex system in which the public and private sectors interface by different transportation modes, including roads, rails, aviation, and shipping.² The New York State Department of Transportation (NYSDOT) is the state’s transportation lead agency and has the following functions:³

- Developing and coordinating comprehensive transportation policy for the State; assisting in and coordinating the development and operation of transportation facilities and services for highways, railroads, mass transit systems, ports, waterways, and aviation facilities; and formulating and keeping current a long-range, comprehensive statewide master plan for the balanced development of public and private commuter and general transportation facilities.
- Administering a public safety program for railroads and motor carriers engaged in intrastate commerce;



Source: National Atlas, modified

Figure 9.1 Interstate and major state highways in New York State

directing state regulation of such carriers in matters of rates and service; and providing oversight for the safe operation of bus lines, commuter railroads, and subway systems that are publicly subsidized through the Public Transportation Safety Board.

Highways and Bridges

New York State DOT designs, operates, and maintains the majority of the Interstate and State Highway system (**Figure 9.1**). It consists of about 113,000 miles of highways and more than 16,000 bridges,⁴ associated ramps, underpasses, drainage systems, other related structures, and signage and signal systems. The combined state and local highway system annually handles over 100 billion vehicle miles.

The New York State Thruway Authority operates the toll-collecting Thruway and related bridges connecting New York City via Albany and Rochester to Buffalo; it also operates the state's canals. The Thruway Authority manages 2,818 lane miles of highway and more than 800 bridges. More than 246.7 million trips were taken on the Thruway in 2009, representing more than 8.1 billion miles traveled.

The New York State Bridge Authority is responsible for five toll bridges in the Mid-Hudson Valley:⁵ Bear Mountain Bridge; I-84 Bridge near Newburgh/Beacon; Franklin Delano Roosevelt Mid-Hudson Bridge near Poughkeepsie; George Clinton Kingston-Rhinecliff Bridge; and Rip van Winkle Bridge at Catskill, Hudson. Not included is the Thruway Berkshire Spur Bridge (about 10 miles south of Albany), which is overseen by the New York State Thruway Authority.

County and Local Roads

County and local roads and bridges are a vital and indispensable part of the state's transportation infrastructure. Local roads and bridges account for 87 percent of the roads, 52 percent of the bridges, and 48 percent of the vehicle mileage logged in New York State.⁶

Railways

The state is home to a 4,600-mile rail network over which 42 million tons of freight are shipped each year,

consisting of equipment, raw materials, manufactured goods, and produce (for details see Section 9.1.6). Long-distance intercity passenger rail is provided by Amtrak. Commuter rail mass transit is provided by several agencies largely in the New York City metropolitan region, further discussed below.

Aviation

The state has over 500 public and private aviation facilities through which more than 31 million people travel each year.

Shipping

The state is home to 12 major public and private ports, which handle more than 110 million tons of freight annually. Of these, five major ports handle 50 million tons of freight annually.

Mass Transit

Over 130 public transit operators serve over 5.2 million passengers each day. They include the Capital District Transportation Authority (CTDA), serving the region in and around Albany; the Central New York Regional Transportation Authority (CNYRTA), serving the region centered on Syracuse; the Rochester Genesee Regional Transportation Authority (RGRTA); the Niagara Frontier Transportation Authority (NFTA), serving the greater Buffalo region; and many county-based transit systems, plus private bus operators. In the most transportation-intensive New York City metropolitan area, several major authorities are charged with operating multiple modes of travel. (For a schematic plan of the combined passenger rail systems, visit <http://www.columbia.edu/~brennan/subway>).

9.1.3 Metropolitan Transportation Authority

The Metropolitan Transportation Authority (MTA) is the largest transit operator in the nation. It provides about 8.5 million passenger trips per day at twice the energy efficiency of advanced hybrid cars (MTA, 2008a). The approved MTA operating budget for 2009 was \$11 billion. The actual capital project work committed for 2009, as reported in January 2010 to the

MTA Board, was \$4.688 billion. MTA includes a number of operating agencies, which are described below (MTA, 2008b):

New York City Transit

New York City Transit (NYCT) operates the subway, which has 26 lines, 468 stations, and 6,241 cars; a bus division with 4,538 buses on 208 local and 36 express routes; and the Staten Island Railway (SIR) with 22 stations and 64 cars. NYCT's subway comprises 228 route miles in Manhattan, the Bronx, Queens, and Brooklyn, of which about 62 percent is below grade in tunnels, about 28 percent on elevated tracks, and 10 percent at grade. NYCT also operates the (entirely at grade but road-crossing-free) 14 mile-long Staten Island Railway (SIR). Staten Island commuters to Manhattan may choose from three public transit options: the Staten Island Ferry, NYCT express buses, or the private Atlantic express buses. The total replacement value of the NYCT tunnel, elevated, and roadbed route structures (excluding stations) is on the order of \$190 billion (all values in 2007 dollars). The length of rail tracks is 628 miles, valued at \$11 billion. There are nearly 300 pump stations, 200 fan plants, and more than 200 electric substations, with a combined asset value of \$22 billion. There are nearly 280 underground stations (valued at \$11 billion) and about 200 elevated stations (valued at \$5 billion), plus some 20 station complexes (e.g., Times Square, Grand Central Terminal) that serve multiple subway or railway lines and other connections. The rolling stock is worth nearly \$11 billion. There are also rail yards and maintenance shops, many at low elevations near the waterfront.

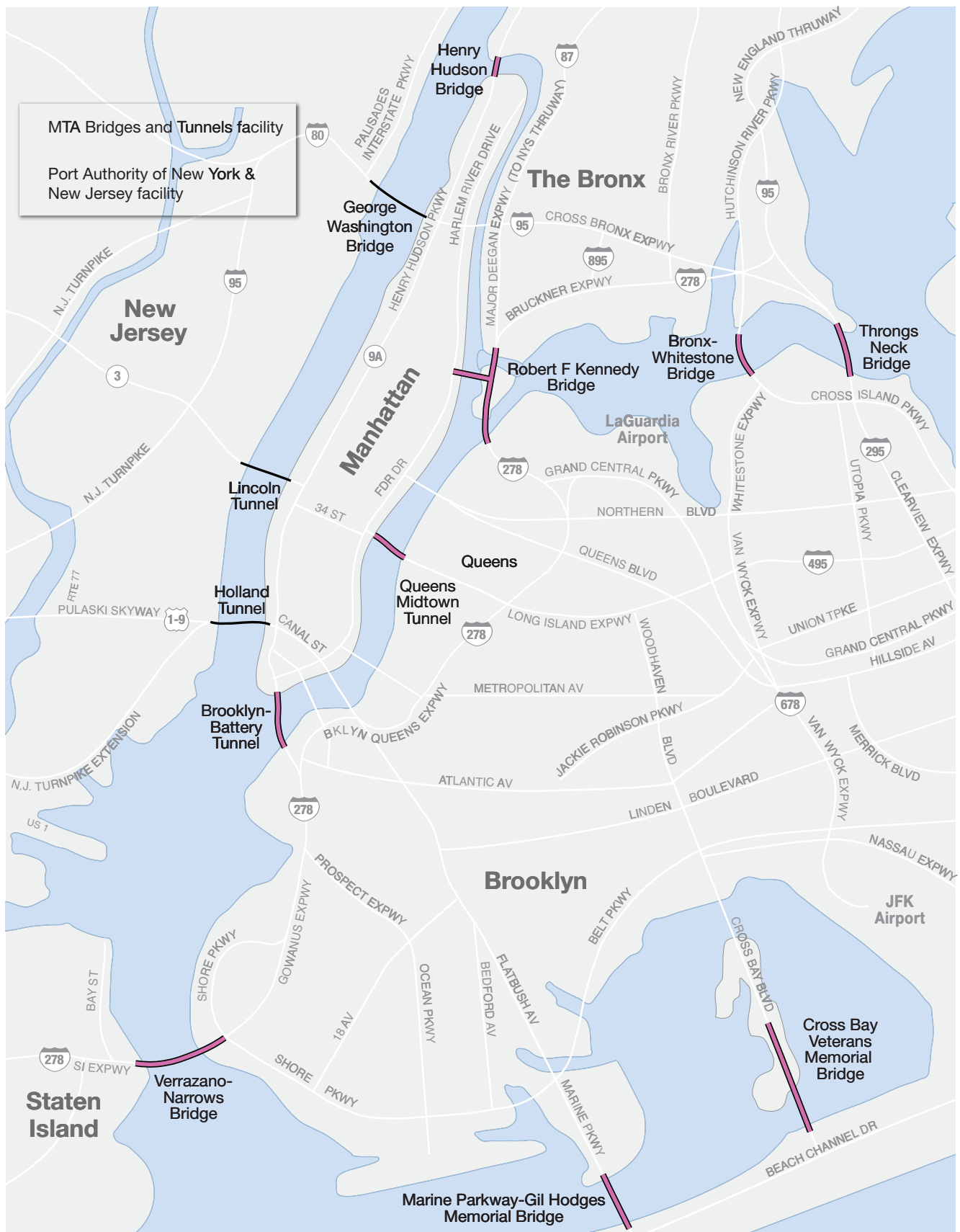
MTA Metro-North Railroad

The MTA Metro-North Railroad has total assets worth on the order of \$10 billion. They include 800 miles of track and roadbed, terminals, stations, yards, bridges, movable bridges, tunnels, stone and steel viaducts, rolling stock, third rail and catenary power systems, communications and signals, and other facilities. Metro-North operates three passenger rail lines in New York State, each of which originates at Grand Central Terminal in New York City. The Hudson, Harlem, and New Haven Lines are co-located underground from Grand Central Terminal at 42nd Street to 98th Street, where they continue northward aboveground until they split in Mott Haven Yard, Bronx. The Hudson Line

continues north along the Hudson River to Poughkeepsie. From Spuyten Duyvil to Poughkeepsie, Metro-North maintains its track structure to support the speed required for the Amtrak service, as well as the loads imposed by the CSX freight traffic. The Harlem Line continues northward to Wassaic. The Beacon Line operates for freight and equipment traffic only, from Beacon east to Danbury, Connecticut. The New Haven Line splits off the Harlem Line in Woodlawn and continues eastward to New Haven, Connecticut, along the Long Island Sound. Along the New Haven Main Line, Amtrak trains travel the northeast corridor. The New Haven Line also supports loads imposed by local freight traffic. Off the New Haven Main Line there are three branch lines: the Danbury, the Waterbury, and the New Canaan Lines. Metro-North owns a portion of the Northeast Corridor (NEC) from New Rochelle to the New York/Connecticut state line. The Connecticut Department of Transportation owns the NEC from the state line to New Haven. Each owner is responsible for maintenance and operations of their respective segments. For the West of Hudson Line, Metro-North has contracted NJ TRANSIT to operate the New York portions of the two commuter lines, the Pascack Valley and the Main & Bergen Lines (the Port Jervis Line). Although Metro-North leases the West of Hudson Line, Metro-North is also responsible for maintaining the track, bridges, and stations for the Port Jervis Line. The track and bridges are maintained for passenger cars as well as the Norfolk Southern freight traffic. Metro-North is also responsible for a number of unique structures, such as historic Grand Central Terminal. The Terminal's train shed continues north to become the Park Avenue Tunnel, which runs under Park Avenue from 57th Street to 98th Street. The Park Avenue Viaduct is a stone structure from 98th Street to 110th Street and a steel structure from 110th Street to 138th Street. Metro-North has six movable bridges in its territory, including the Harlem River Lift Bridge in New York City. There are four tunnels along the Hudson Line. The Otisville Tunnel is one-mile long and is located on the Port Jervis Line. Also unique to the Port Jervis Line is the Moodna Viaduct. At 3,200 feet long and 200 feet high, it is the highest and longest railroad trestle east of the Mississippi River.

Long Island Rail Road

MTA's Long Island Rail Road (LIRR) owns and operates structures, shops, and yards with an asset value on the



Source: MTA B&T

Figure 9.2 Major bridges and tunnels in New York City

order of \$19 billion, and almost 600 miles of track, stations, and power facilities whose value exceeds \$20 billion. Rolling stock is valued in excess of \$3 billion. LIRR uses Penn Station in Manhattan as its western anchor with transfers to/from Amtrak, NJ TRANSIT, NYCT subways, and the nearby Port Authority Trans-Hudson (PATH) system (see below). LIRR trains leave Manhattan heading eastward via the East River Tunnels, owned and co-used by Amtrak for its Washington-Boston NE Corridor. The East Side Access project, currently under construction, will use a tunnel below the East River from Queens to Manhattan into Grand Central Terminal. It will directly connect commuting locations on Long Island with Manhattan's mid-town East Side. Beyond Queens, the LIRR operates, along the North Shore of Long Island, the Port Washington, Oyster Bay, and Port Jefferson Lines; beyond the Jamaica Station, Queens, the central spine of Long Island is served by lines that terminate easterly in the island's North Fork; Long Island's southern shores are served by the Long Beach Branch and the Babylon and Montauk Lines that straddle the Great South Bay.

MTA Bridges and Tunnels

MTA Bridges and Tunnels (MTA B&T) owns nine large toll-collecting facilities (two tunnels and seven bridges, **Figure 9.2**). The value of total built assets approaches \$25 billion. Annual toll revenues from all B&T facilities amount to about \$1.2 billion (URS, 2008). The nine key assets are: Queens Midtown Tunnel, Brooklyn Battery Tunnel, Verrazano Narrows Bridge, Throgs Neck Bridge, Bronx-Whitestone Bridge, the Robert F. Kennedy (formerly Triboro) Bridge, the Marine Parkway and Cross Bay Bridges in Queens, and the Henry Hudson Bridge across the Harlem River in northern Manhattan.

MTA Long Island Bus Service

The MTA Long Island Bus Service operates North America's largest compressed-natural-gas bus fleet with 316 buses on 56 routes, and several fixed structures, such as depots and shops. It provides more than 100,000 trips per day among nearly 100 Long Island communities, including Nassau County, western Suffolk County, and into eastern Queens with 53 routes, and serves 48 Long Island Rail Road stations plus colleges, museums, parks, theaters, and beaches throughout the service area.

MTA Bus Company

The MTA Bus Company was formed in 2006 by merging seven private lines. It operates extensive bus routes in New York City (except Staten Island), and has eight fixed facilities in Brooklyn, Queens, the Bronx, and Westchester County. Of the MTA bus routes, 46 are local routes in Brooklyn, Queens, and the Bronx, and 35 are express bus routes between Manhattan and the Bronx, Brooklyn, and Queens. It has a fleet of 1,336 buses serving a ridership of approximately 394,000 on an average weekday (2009).

MTA Capital Construction

MTA Capital Construction was formed in 2003 to centrally manage the largest capital construction projects for the entire MTA family of agencies. Current projects in planning or under construction are: the first phase of the 2nd Avenue subway, the East Side Access project bringing LIRR into Grand Central Terminal, extension of the Number 7 (Flushing Line) subway to the West Side of Manhattan, and the Fulton Street Transit Center serving 12 lines in downtown Manhattan.

9.1.4 Port Authority of New York and New Jersey

The Port Authority of New York and New Jersey (Port Authority) fulfills multiple bi-state functions. It owns and operates international and domestic airports and marine ports, as well as interstate ground transportation facilities serving New York and New Jersey. With the exception of Stewart Airport, all the facilities the Port Authority operates are located within its originally assigned 25-mile radius from the Statue of Liberty. According to its 2008 annual report (PANYNJ, 2008):

On a day-to-day basis, the Port Authority operates one of the most complex sets of transportation services in the nation. The agency's airports, bridges, tunnels, bus terminals, its Port Authority Trans-Hudson (PATH) rail system, AirTrain services, and seaports help move people and cargo at a pace and on a scale that life in the New York-New Jersey region demands....Nearly 1 million people each day rely on Port Authority transportation facilities to help them get to where they are going.

The Port Authority has four operating divisions: 1) Aviation; 2) Tunnels, Bridges, and Terminals; 3) Rail Transit; and 4) Port Commerce.

Major ground transportation facilities include the following Hudson River and other water crossings (**Figure 9.3**):

- PATH commuter rail (ridership about a quarter-million people per day)
- George Washington Bridge (GWB)
- Lincoln and Holland Tunnels
- Bayonne Bridge, Goethals Bridge, and Outerbridge-Crossing

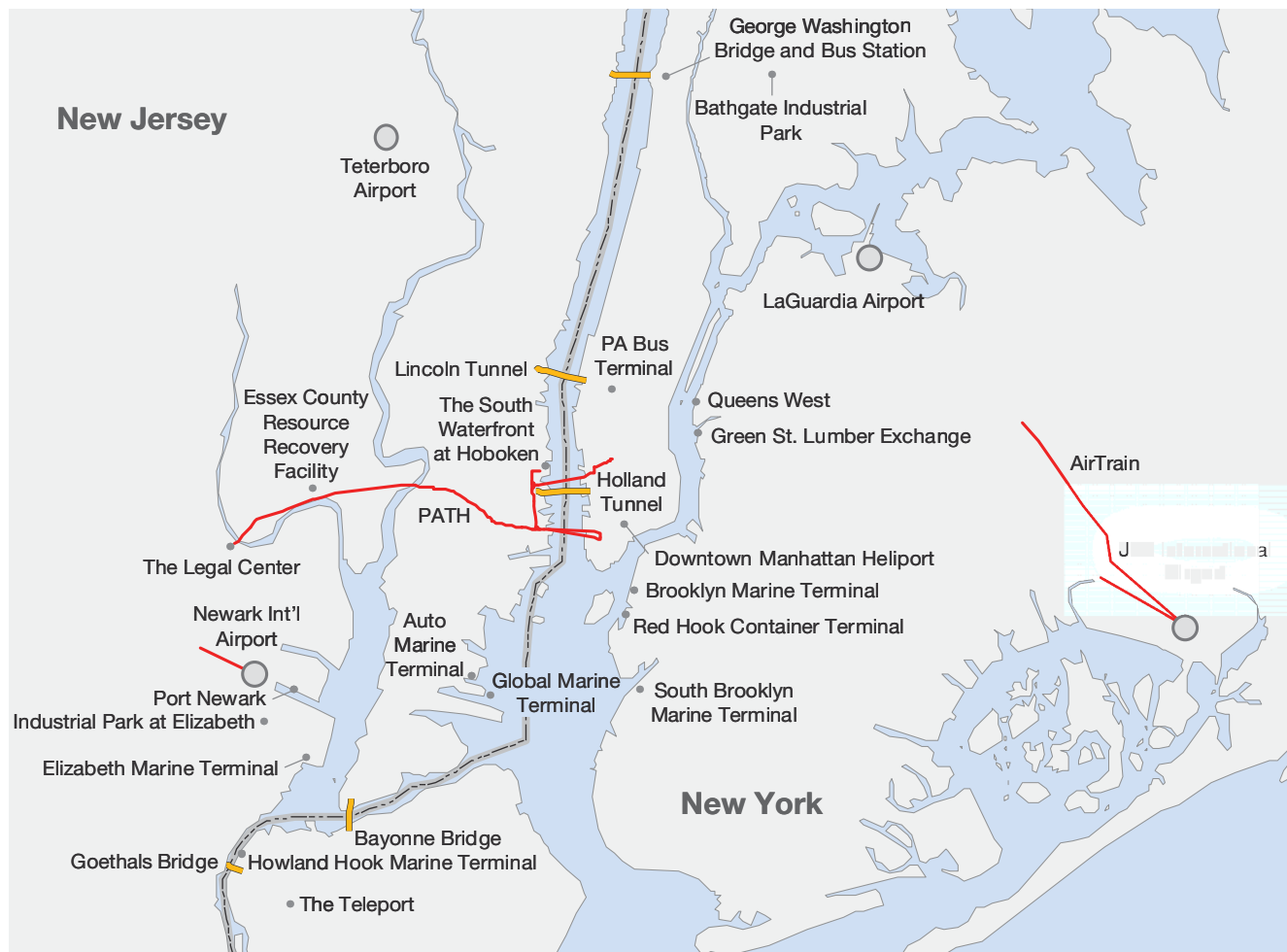
Total eastbound vehicle volume on these tunnels and bridges in 2008 was about 124 million per year, with GWB alone accounting for 53 million vehicles per year.

The Port Authority owns three regional bus terminals:

- George Washington Bridge Bus Station
- Mid-town Manhattan Port Authority Bus Terminal
- Journal Square Transportation Center Bus Terminal in Jersey City

These are used by private and public bus operators. Total combined passenger volume (in 2008) was nearly 72 million passengers per year. The total interstate (NY/NJ) ground transportation network produced gross operational revenues (largely tolls and fares) of about \$1.1 billion, of which the George Washington Bridge (GWB) contributed about 40 percent.

The Port Authority operates three major international / national airports (JFK, Newark, and LaGuardia), and two smaller airports (Teterboro and Stewart). Combined total passenger volume at these airports fluctuates between 100 and 110 million passengers per year. Of these, JFK (47 million passengers in 2008) and Newark airport (35.4 million passengers in 2008) are important



Source: The Port Authority of New York and New Jersey, 2001; Bureau of Transportation Statistics, Transportation Atlas of the United States

Figure 9.3 Facilities operated by the Port Authority of New York and New Jersey (PANYNJ)

gateways for international flights to and from the U.S. The combined air cargo for 2008 was 2.4 million tons.

Combined airport gross operating revenues in 2008 were about \$2 billion (with JFK accounting for \$0.951 billion, Newark about \$0.718 billion, and LaGuardia about \$0.307 billion).

The Port Authority operates major marine port facilities and container terminals in the NY/NJ harbor. In 2008 the port facilities handled 5.27 million TEU (20-foot Trailer Container Equivalent Units), or 33.6 million metric tons, with a value of about \$190 billion (about \$51 billion in exports and \$139 billion in imports). The ports' gross operating revenues in 2008 were about \$0.21 billion.

The Port Authority owns the World Trade Center (WTC) site in downtown Manhattan, and owns and operates many other facilities (**Figure 9.3**).

The Port Authority had a \$6.7 billion budget for 2009, which provided for \$3.3 billion in capital projects; this was set at \$3.1 billion for 2010.

9.1.5 Other Transportation Operators Serving the New York Metropolitan Area

NJ TRANSIT brings commuters by rail from New Jersey into Penn Station on Manhattan's midtown West Side via tunnels under the Hudson that are also used by Amtrak for its Washington, D.C.–New York–Boston rail passenger service. NJ TRANSIT, with funding participation by the Port Authority, is in the process of increasing trans-Hudson transportation capacity by constructing a new rail tunnel under the river between New Jersey and Manhattan. This Access to the Region's Core (ARC) project also includes a new underground station that will have a pedestrian connection to Penn Station, New York, where there will be no interconnection at track level.

The ARC project will more than double commuter rail capacity between New Jersey and New York. The availability of more and improved train service is expected to remove 22,000 cars from the region's highways. Additionally, NJ TRANSIT and the private bus carriers it supports transport 127,000 people every weekday for a total of 254,000 passenger trips each weekday into and out of New York City. The ARC project was put temporarily on halt in 2010; alternatives

to increase trans-Hudson commuter rail capacity at reduced capital spending are being explored.

The City of New York operates the Staten Island Ferry and all toll-free bridges between four of the five boroughs of New York City, including the Brooklyn, Manhattan, Williamsburg, and Queensboro bridges, and several smaller bridges crossing the Harlem River between Manhattan and the Bronx.

New York Waterway and other private ferry and water taxi services provide growing passenger service between points in and to the central business districts of New York City and on routes connecting them to communities along the lower Hudson River, Long Island Sound, Great South Bay within New York State, and to nearby Connecticut and New Jersey shore points.

9.1.6 Freight Railway Services in New York State

Freight services by railroads are in resurgence (see NYSDOT, 2009).⁷ According to Railroads of New York (RONY), a trade association of New York State freight railroads, and data collected by NYSDOT, approximately 45 railroads operate in the state, although only four are Class-1 freight railroads (CSX, CN, CP, NS), in addition to the four commuter/intercity railroads (Amtrak, LIRR, Metro-North, NJ TRANSIT).

According to the American Association of Railroads (AAR),⁸ in 2005, total miles of track operated in New York were about 3,600 miles, of which 65 percent is Class-1⁹ railroad mileage. Amtrak owns about 150 miles of track in New York. In comparison, Metro-North and LIRR operate nearly 800 and 600 miles of track, respectively. According to the AAR, in 2005 carload tons originating in New York totaled almost 10.5 million, transporting major products including chemicals, waste and scrap, and nonmetallic minerals. Tons terminated in New York totaled over 25.3 million, including coal, chemicals, and food products.

Actual rail carloads originating and terminating within the state totaled 196,000 and 375,000, respectively. A map of all rail lines currently operating in the state is depicted in **Figure 9.4**. Major freight rail facilities and yards are located in Buffalo, Rochester, Albany, Binghamton, and New York City. Smaller yards and facilities are distributed throughout the rest of the state.



Source: New York State Department of Transportation, Office of Integrated Modal Services, Freight Bureau

Figure 9.4 Operating rail lines in New York State in 2008

9.2 Climate Hazards

The impacts of climate change (see Chapter 1, “Climate Risks”) have significant consequences for the transportation sector. Sea level rise, the intensity and frequency of some extreme weather events, mean precipitation, flooding, and coastal erosion are all projected to increase, putting transportation infrastructure and operations at risk. (For an assessment by transportation mode, see Section 9.3.)

9.2.1 Temperature and Heat Waves

Increases in both the annual average temperature (see Chapter 1, “Climate Risks,” Section 1.3) and the number of days per year with extreme high temperatures will affect transportation systems in

several ways. Materials such as asphalt pavements; other road, bridge, and runway surfaces; and railroad tracks, electrified third rail, and catenary wires will need new performance specifications to cope with higher extremes and more frequent high temperatures. Air conditioning requirements for rolling stock and stations and ventilation requirements for tunnels will increase. Some runways of airports may need to be lengthened, since hotter air provides less lift and hence requires higher speeds for safe takeoff and landing.

A good example of the impact of heat waves on transportation systems is given by the European heat wave of 2003:¹⁰

- Britain’s transport system suffered during the heat wave, particularly the railways. Widespread speed restrictions were imposed because of rail buckling,

which becomes a problem when rail temperatures reach 36°C (97°F). Official figures show 137 cases of rail buckling in 2003/4, compared with 36 the year before and 42 the year after. However, the authors caution that confounding factors such as maintenance cannot be discounted.

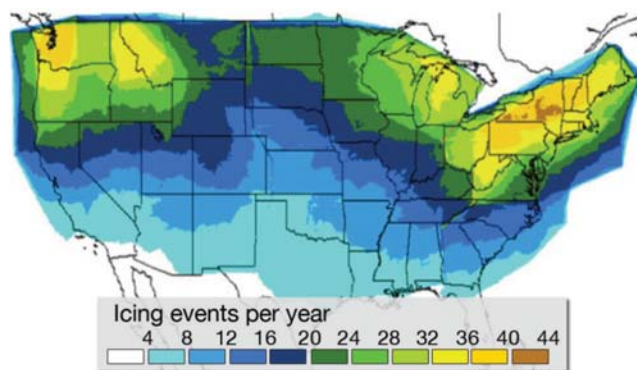
- The resulting delays are estimated to have cost passengers £2.2 million (\$3.6 million) in lost time, while the National Network Rail had to pay £6.5 million (\$10.7 million) to the train companies in compensation. The researchers also found that disruptive fires at the side of the tracks jumped 42 percent in 2003 compared to the following year, which also might be due to the hot weather.
- Britain's road network bore the brunt of the searing heat. Sections of the M25 highway melted, and the total costs of repairs across the country are estimated at £40 million (\$66 million), of which the government contributed £23 million (\$38 million). The rest of the burden fell on local authorities.
- Temperatures on the London Underground passed 41°C (106°F) and passenger numbers dropped 1–1.5 percent during the hottest two weeks, reducing revenue by £500,000 (\$0.8 million).

9.2.2 Precipitation

The central and northern regions of New York (with elevations that exceed 5,000 feet) currently are prone to more frequent and severe ice and snowstorms than near-coastal regions of the state. Air- and land-based transportation systems and operations are susceptible to freezing rain (icing) and snow. In fact, New York State is the most vulnerable to icing of all of the lower 48 states (**Figure 9.5**) (NOAA, 2004).

Icing can affect transportation systems in many different ways. It is a direct, serious hazard for aviation and for vehicular traffic on the ground. Indirectly, icing can also affect transportation by loss of electric power and/or, to a lesser degree, communication systems.

Freezing rain, black-ice conditions, and severe snow pose hazards to highway transportation and increase accident rates under current climate conditions. Climate change is likely to bring changes to these hazards. For instance, increasing winter temperatures are likely to shorten the duration of ice cover of the Great Lakes and, therefore, potentially allow more moisture to be drawn from the ice-free lakes, which



Note: Icing hazards are particularly severe in New York State, with the highest icing hazard in the central and western regions of the state. Note that warmer colors in this map indicate a greater icing hazard. Source: NOAA 2004

Figure 9.5 Estimated rendering of the likelihood of icing events across the United States

would then fall as snow in western New York during the cold season (see Chapter 1, “Climate Risks”).

While the severity of such extreme snowfalls is likely to increase, the number of days per year with snow on the ground is likely to decrease. In the estuary and coastal regions, nor'easter storms, which in the past caused blizzards, may more often turn into severe rainstorms rather than severe snowstorms. On the benefit side, it is more likely than not that the need for snow removal and salting of highways will gradually decrease for low-elevation, southern, and coastal areas of the state. The need for snow removal and salting under future climate conditions may change little in northern New York, though it may increase in western New York in the next couple of decades in areas that are subject to episodes of extreme winter lake effects (see Chapter 1, “Climate Risks”).

9.2.3 Sea Level Rise and Storm-Surge Hazards in Coastal Regions, Tidal Estuaries, and Rivers

All transportation systems—roads, tunnels, railways, subways, airports, and seaports—are at risk from coastal storms and related coastal storm-surge flooding hazards. In New York, a number of these systems are located along the water at low elevations, and some subways, railroads, and highways are located in tunnels below sea level.

Storm-surge hazards along New York's shores (and the tidal Hudson River from New York Harbor to the Federal Dam at Troy) arise from tropical cyclones—

hurricanes, tropical storms, tropical depressions—during the summer and fall, and from nor’easter storms during winter and early spring. Coastal storm surges have caused damage in the past, and based on their historic frequency and severity of occurrence, these hazards have been quantified for the historic record.¹¹

Climate change, especially its effect on sea level rise, will significantly raise coastal storm-surge hazard levels, as described in Chapter 1, “Climate Risks.” Many near-shore transportation systems are at risk already (e.g., to coastal storm surges that reach the 100-year base flood elevations in coastal zones as currently mapped by FEMA). Sea level rise will increase the probability of flooding dramatically. Projections show¹² that the storm elevations now reached by the 100-year flood (i.e., a 1-percent annual probability of occurrence) will be reached before the end of the century by a flood with an approximately 3 to 10 percent annual probability of occurrence—about a three- to ten-fold increase. These changes will require the flood maps in near-shore areas to be updated to reflect new flood elevations that account for sea level rise. The flood-risk zones will need to be extended farther inland accordingly. These updates will place many transportation facilities that are currently safely located above and/or outside designated flood zones and related flood elevations within the newly assessed coastal flood zones. Additional details are discussed in Case Study A.

Sea level rise will eventually inundate low-lying areas permanently if no mitigation or adaptation measures are taken, and it may also accelerate saltwater intrusion in some areas. For most transportation facilities, the increased coastal storm surge hazard, however, will dominate over these permanent inundation hazards for most of this century.

9.2.4 Other Climate Factors

Additional climate hazards that impact the transportation sector are extreme storms events and droughts. These hazards and how they are projected to change in the future are described here.

Increased Storm Intensities

While it is unclear whether the total number of storms (hurricanes, nor’easters, thunderstorms, tornados,

wind storms) will significantly change, it is more likely than not that the most extreme hurricanes and nor’easters will become more frequent. (see Chapter 1, “Climate Risks,” and Chapter 5, “Coastal Zones”). The increase in intensity will affect air transportation: More storms (of any kind) may increase the number of delayed or cancelled flights, cause the temporary shutdown of airports, and/or result in flight detours to alternate airports. High winds may result in more frequent temporary closures or restricted use of larger bridges.

Intense storms redistribute existing sediments in the periodically dredged New York Harbor and Hudson River shipping lanes and bring increased sediment loads into them. These processes may increase the frequency of needed dredging operations. On the other hand, sea level rise tends to increase the available water depth. However, sediment transport in the Hudson and New York/New Jersey harbor is not sufficiently understood, and the understanding of sediment transport for these waterways under future climate conditions is even less well understood. Thus, it is not known whether sediment clogging or sea level rise will dominate over time or over which spatial distribution.

Urban Flash Flooding and Inland River Flooding

ClimAID projections show that the number of days per year with extreme precipitation (e.g., more than 2 inches per day) is likely to increase.¹³ Projections for annual average precipitation rates (inches per year), however, show no clear trends in New York State for some time. An increase in extreme precipitation events will increase the hazards for urban and river flooding, with associated risks for transportation in cities and in rural areas along many rivers. This will necessitate increases in street stormwater drainage and processing peak capacity and/or result in environmentally undesirable combined sewer overflow events in those communities (including New York City) where street runoff is channeled into the public sewage system. The scouring potential for bridge foundations in some rivers is also likely to increase.

Droughts and Great-Lakes Climate Effects

Droughts can affect New York State’s transportation systems in several ways. Extended droughts may lower

the water levels of the Great Lakes and canals, and reduce the shipping capacity to the Atlantic coast via the St. Lawrence River Seaway (Millerd, 2007). For the Great Lakes, climate change is expected to result in lower water levels, higher surface water temperatures, and shorter duration of ice cover—all of which will affect shipping.

To maintain sufficient water depth along shipping routes (i.e., keel clearances), vessels may need to reduce the total weight of cargo carried on each voyage to mitigate the effects of reduced water levels. On average, shipping between Lake Ontario and Montreal (passing through the Welland Canal that connects Lake Ontario and Lake Erie) amounts to about 2,700 transits, carrying about 31 million tons per year. Transporting a given weight of a commodity with reduced under-keel clearance will require additional trips, thus increasing total shipping costs. Lake Erie's water level has been projected to decrease by 1.97 feet by 2030 and 2.62 feet by 2050, using the Canadian Centre for Climate Modelling and Analysis (CCCMA) climate model, and by 4.59 feet assuming stabilization of atmospheric carbon dioxide concentration after it doubles (Millerd, 2007). The water level of Lake Ontario has been projected to drop by 1.15 feet by 2030 and by 1.64 feet by 2050, and by 4.27 feet under the same stabilization conditions (these lake level changes are relative to the International Great Lakes Datum of 1985.) The decrease in load capacity from these reduced water levels in the navigable channels may require an increase in the number of trips needed to ship the same tonnage, resulting in increased shipping costs. For example, the cost to ship grain under these lower-water conditions is projected to increase by 5 to 10 percent per ton of grain.

On the other hand, a warming climate may increase the shipping season since the duration of ice cover in the winter will be shortened. Ice breaking is currently shared between two Canadian and one U.S. Coast Guard ice breaker. Due to warmer temperatures, the time at which winter ice is cleared at the beginning of the shipping season may occur earlier, but no quantitative estimates are currently available. The closure of shipping in the winter has been used in past decades for lock maintenance of the Welland Canal. If year-round shipping becomes possible, then consistent twinning (doubling up the number of locks in each direction) may be needed to allow maintenance without impeding shipping.

Droughts can also affect land transportation by leading to fires along railroad tracks and interstate and state highways. They can cause temporary closures, traffic delays, and slowdowns, and can increase highway traffic accidents because of reduced visibility (apart from undesirable pulmonary health effects; see Chapter 11, "Public Health").

Extended droughts may affect the availability of water for washing buses and mass transit rolling stock fleets—a water-intensive operation. These activities may be curtailed during extended droughts that lead to water shortages. Measures to mitigate this consequence may include recycling gray water.

9.3 Vulnerabilities and Opportunities

Earlier reports have addressed the vulnerabilities of transportation systems to climate change on national,¹⁴ regional,¹⁵ and some New York City¹⁶ scales. The national and regional reports provide an excellent background to major vulnerabilities, but need to be modified for statewide climate projections and transportation systems across New York State. Lessons learned from extreme weather events at other locations across the United States (e.g., Hurricane Katrina and other major storms along the Gulf Coast)¹⁷ and Canada (e.g., the ice storm of 1998)¹⁸ also provide useful information for New York, if modified to meet the needs of the state. This section of the ClimAID analysis addresses climate change vulnerabilities of transportation systems by mode of transportation. In Section 9.4 the risks from climate change are described from the perspective of the type of climate hazards. For each transportation mode, it is important to distinguish between the vulnerabilities of operations and those of physical assets. Information on generic vulnerabilities to climate change is largely based on the Transportation Research Board's report on the potential impacts of climate change on the transportation sector in the United States (TRB, 2008a).

9.3.1 Ground Transportation

One specific area of the transportation sector that is vulnerable to climate is ground transportation. This section discusses the vulnerabilities of ground transportation systems, which include roads, highways, and railways.

Roads and Highways (including bridges, tunnels, drainage, and signal systems)

The physical assets and structures of the transportation system are vulnerable to climate change amplified precipitation and flooding and related erosion of road embankments near inland rivers and streams. Gradually increasing severe coastal storm surge flooding (because of anticipated sea level rise) along coasts and estuaries, including the tidal portions of the Hudson River, also put transportation structures at risk. Heavy rains can also cause mud and landslide hazards. High temperatures require heat-resilient asphalt mixtures for road and highway pavements.

There are also a number of other structure-related vulnerabilities. Drainage systems may have insufficient capacity to cope with the heavier precipitation events. Bridge foundations in some streams will likely experience increased scour potential. Clearances of some bridges across waterways subject to sea level rise may be diminished below the limits set by the U.S. Coast Guard or other jurisdictions. Bridge access ramps, tunnel entrances and ventilation shafts, and highway beds may need to be raised in coastal zones to prevent frequent coastal storm-surge flooding, amplified over time by sea level rise. The same hazards may make ineffective the collision fenders protecting bridge foundations in navigable rivers from impacts of ships or barges during high-water events; the fenders may have to be vertically extended to accommodate sea level rise (e.g., for the Tappan Zee Bridge¹⁹ main span, relying on the buoyancy of caissons vulnerable to impact by out-of-control ships or barges). Road surface materials and bridge decks will need to be resilient to virtually certain higher and more frequent peak temperatures. Roadbeds and surfaces may experience winter temperatures nearer the freeze and thaw cycle, rather than steady below-freezing conditions (TRB, 2008a).

For highway operations and construction activities, more extreme weather events will increase traffic interruptions, may increase the number of extreme-weather-related traffic accidents, and may slow down or interrupt summer construction activities at temperatures above 105°F, largely because of worker heat exhaustion. Heat-resistant pavements will need to be used where they were not needed before as the number of days per year with average temperatures above certain thresholds increases substantially (Chapter 1, “Climate Risks”). Power outages during

summer heat waves may affect signals, and hence slow traffic, especially in urban areas.

Freezing rains at higher elevations are more likely than not to become more frequent, and so may snow hazards, mostly in western New York. Both snow and freezing rains, however, may diminish in the southern portions of the state and along the coast, thereby reducing snow removal and salting costs. Closures of roads due to wildfires and related diminished visibility from smoke during extreme and extended droughts are likely to increase in frequency and geographic extent. High winds are likely to require more frequent temporary closures of major bridges, may cause more damage to traffic signs, and may call for increased fallen-tree and debris removal from roads and highways.

Coastal evacuation routes may have to be prepared to accommodate reverse traffic flow to speed up evacuations out of coastal flood zones by using all traffic lanes to direct flow from coastal to safe inland or higher locations. Road tunnels and sub-grade underpasses in coastal areas and other flood-prone zones relying on pumped drainage will very likely need increased pump capacity and back-up power, especially if they serve as designated evacuation routes and/or need to stay open for first-responder emergency services.

Railways (subways and commuter, passenger, and freight railroads)

Rail systems in coastal zones and tidal estuaries are subject to storm surges, whether at grade or partially elevated, or running in tunnels below grade and/or below sea level when crossing bodies of coastal or estuary waters. These vulnerabilities will become ever more amplified by sea level rise. To reduce or remove these vulnerabilities in the coastal and estuary zones will require large long-term investments and, in some instances, either vertical or even horizontal relocation. For the latter option, this may require new rights-of-way and related land-use decisions for communities served by rail services.

Vulnerabilities to flooding, washouts and erosion, mud- and landslides in steep terrain of some railroads running along inland rivers and streams, and insufficient or marginal drainage capacity of culverts and catch basins will need attention. Increased river flooding is not always due to more extreme climate events, but can be

caused by changed land use, i.e., developments that increase rapid runoff and reduce infiltration of rain into natural ground cover and soils.

Extreme heat events also increase the vulnerability of railroads. Extreme heat can cause rail buckling. Routes along wooded areas may see increased wildfire hazards during extended droughts and heat waves. Power and related signal and/or communication failures during heat waves, floods, or windstorms can contribute to interruptions in rail and commuter services, with related economic effects.

In the New York City metropolitan area, coastal emergency evacuation plans partly rely on mass transit to provide evacuation capacity in the hours before severe coastal storms make landfall.

9.3.2 Aviation

Another area of the transportation sector that is vulnerable to climate is aviation. Vulnerabilities to aviation structures and facilities and operations are discussed in this section.

Structures and Facilities

Airports and related technical aviation facilities located in coastal areas at low elevations (e.g., La Guardia, Newark, JFK) and serving the greater New York City metropolitan region are all to some degree vulnerable to coastal storm-surge flooding amplified over time by sea level rise. Existing flood-protection levees (e.g., for LaGuardia) may have to be raised or new ones installed, to the extent that raised levee elevations are compatible with the clearance height required for takeoffs and landings. Over time, some runways and other airport facilities located at low elevations above sea level, such as fuel-storage farms, terminals, sewage treatment plants, and maintenance sheds, may have to be raised or protected in place to keep up with sea level rise and increased coastal storm-surge hazards. Drainage of runways is generally designed such that it is likely to keep up with increased intense precipitation events.

More frequent weather-related power failures might require improved back-up capacity at airports. Runway materials will need to resist higher and more frequent peak temperatures. Indoor airport facilities may need

additional air conditioning capacity to deal with more extreme hot days. To determine effective adaptation strategies, each facility will need to conduct its own evaluation to assess its respective vulnerabilities (see TRB, 2008a).

Operations

Aviation operations will more likely than not have to cope with more severe weather conditions (high winds, thunderstorms, extreme precipitation, high temperatures) that generally lead to flight delays, cancellations, or detours to unscheduled landing destinations. These outcomes have economic implications for airlines, airports, and travelers alike. Loaded planes waiting excessive times for takeoff under extreme heat conditions can cause passenger discomfort and health emergencies. Extreme high air temperatures reduce the lift capacity of planes during takeoff and landing (TRB, 2008a), thus requiring, in some locations, longer runways, lower passenger or freight loads, or lower fuel loads that reduce distance range and reserve safety margins. In-flight icing conditions or deicing needs before takeoff could become more acute for airports and flight routes, especially in western and central New York.

9.3.3 Marine Transportation, Hudson River, and Great Lakes/St. Lawrence River Seaway Shipping

In coastal and estuary ports, including along the tidal portions of the Hudson River, vulnerabilities to coastal storm surges, amplified over time by sea level rise, will need to be assessed and addressed. Sea level rise, tides, and coastal storm surges propagate up the Hudson River estuary to Albany and the Federal Dam in Troy. The magnitude of the inland effects of sea level rise on the estuary is the same as for the coast; the inland effects of storm surge and tides decrease very little in force and amplitude.²⁰ This virtually certain increase in hazard related to sea level rise may affect pier heights, base elevation of loading cranes, power supply substations, access roads and rail tracks, open air storage (for containers or automobiles), and warehouse facilities located at low elevations along all shores subject to tides. In particular, the frequency of the 1-in-10-year coastal flood may triple over the next century, depending on sea level rise (see Chapter 1, "Climate Risks", and Chapter 5, "Coastal Zones").

On the other hand, for Great Lake ports (and related St. Lawrence River Seaway shipping lanes), increased lake evaporation under severe and prolonged drought conditions and extended heat waves are likely to lower the lake levels to such a degree that it may impede shipping capacity to the Atlantic Ocean and, via out-of-state routes, to the upper Great Lake states and Canada.²¹ During extended droughts, the canal and lock systems in central, western, and northern New York, which currently serve largely recreational purposes (Erie-Mohawk and St. Lawrence-Lake Champlain-Hudson systems), may also not be able to accommodate as much traffic in the future as a result of periodic water scarcity needed to operate the locks. On the benefit side, the expected climate warming is likely to prolong the ice-free shipping season on the Great Lakes and St. Lawrence Seaway and make the navigable portions of the Hudson River less prone to the ice floes or shore-to-shore freezes that occurred more commonly in past centuries and on occasion interrupted the transport of fuel and other supplies to Albany and mid-Hudson terminals.

9.4 Adaptation Strategies

Adaptation to climate change involves a complex multi-dimensional array of options (See Chapter 2, “Vulnerability and Adaptation”). Typically adaptation is specific to a particular mode of transportation and to the specific climate hazards that pose the threats. Options may differ across the geographical, land use, and climatic zones within the state. They can differ in scale and granularity, from statewide to regional to local and site-specific solutions. Short-, medium-, and long-term solutions must be balanced against each other. Adaptation should be risk-based and consider benefits versus costs. In this context, the questions of who pays the costs and who gets the benefits raises social and environmental (and intergenerational) justice issues with fiscal, economic, and ecological consequences (see Chapter 3, “Equity and Economics”). How and where current investments in infrastructure are planned, engineered, and constructed affects their future vulnerabilities. If existing infrastructure is not upgraded and adapted to the new demands posed by climate change (just as infrastructure needs periodic upgrades to demographic and economic demands) it will put the neglected regions, their economies, and, in the worst cases, lives in jeopardy.

Transportation adaptation strategies are intertwined with land-use issues. The question of whether land use leads to transportation demands or transportation capacities lead to land use must be approached holistically (TRB, 2008a). Land use has implications for both climate change mitigation (i.e., limiting greenhouse gas emissions) and for climate change adaptation (e.g., of transportation corridors along flood-prone coasts and inland rivers). There exists a vast literature that has detailed the relationship between land use and natural disaster risk management (see e.g., Mileti, 1999; Godschalk et al., 1999). Climate change add an additional dimension to managing natural hazard risks in the context of land use over the long term.

The connection of climate change adaptation to land use is clearest in the coastal zones that are at an increasing risk from sea level rise and related coastal storm surge inundations. This connection is discussed in the coastal storm surge case study. The issue of “home rule”²² is embedded in the culture and legal foundations of the nation, states, counties, cities, and villages and puts local communities in the critical position of primary decision-maker. As a tool to guide states and, in some cases, local communities toward an environmentally sustainable path, the federal government can attach conditions to transportation financing. The actual authority for designs and planning generally lies, however, with the state or local community. Hence, states and local communities are key partners for sustainability. Federal guidance via the financing option is limited, and the project-by-project approval process, including how environmental impact statements are prepared, reviewed, and approved, is not yet well suited to sustainable adaptation to climate change and sea level rise.

In this context, transportation agencies having active roles in the state’s coastal zones (including New York State Department of Transportation, MTA, the Port Authority, and many others in the public and private transportation sector) will need to balance their adaptation efforts to cope with sea level rise on a project-by-project basis with a more regional approach. Such balancing will include difficult decisions for communities and, consequently, transportation agencies. Such decisions include determining whether engineered defensive levees, pumping stations, and estuary-wide protective storm surge barriers are sustainable adaptation solutions, or if such defensive structures are only temporary solutions. Such structures

could be combined with long-term exit strategies involving carefully staged and equitable retreats from, and relocation of assets in, communities that are at risk. FEMA's National Flood Insurance Program includes an option to buy out properties; a potential strategy would be to extend such buyout programs beyond the National Flood Insurance Program to include critical infrastructure systems exposed to repetitive risks. This may require new federal initiatives, but states could help to bring about such changes.

Transportation agencies will be at the center of a systematic river and coastal flood-risk assessment, land-use planning, and ultimately a consensus-forming decision process. Without such an overarching process—and with challenges to the *status quo* on home rule and other land-use practices—it will be difficult to shape a sustainable future for communities and for the transportation systems that serve them, and to build resilience to river flooding and sea level rise. At-risk communities may be given some assurance that government will assist in creating a safer future, if the communities recognize and act upon managing responsibly their exposure to the risks from sea level rise and increased coastal, estuary, and river flooding.

A likely outcome will be that well-organized, large transportation organizations (such as the New York State Department of Transportation, MTA, the Port Authority, several New York City agencies, and others, including some county and community governments) will initially plan for, seek financing, and implement interim adaptation measures at their existing facilities, often as part of their regular maintenance plans, capital budgets, and operations. Private operators and owners of properties will do the same, sometimes motivated by the availability (or lack) and pricing of insurance in high-risk coastal zones. This insurance effect is already starting to become operative in local development projects by the private sector. Over time, it will gradually affect future demographic and transportation patterns and related demands for infrastructure. The public sector may be supportive of these self-regulating market forces. Transportation planning agencies should collaborate with these positive developments, even if they occur only on a project-by-project basis.

With time, as climate stresses increase, more central, coordinated, regionally planned yet grassroots-supported, integrated planning will be needed to more cost-effectively and safely address coastal adaptation

measures. Local decisions may eventually be replaced by a comprehensive approach that aims at flexible, adaptive solutions with sustainable outcomes.

There are precedents for such overarching efforts, some successful. The Netherlands' Delta Waterworks and the London/Thames Estuary Project (TE2100) are well-planned, flexible, and foresighted projects. Both protect land already at or below sea level.

Currently, New York State has virtually no land with built-at-grade structures at elevations below sea level. However, a large and often critical portion of its transportation (and some other) infrastructure—largely in the New York City metropolitan area—is already well below sea level and, therefore, increasingly at risk. Agencies such as MTA and others are in the initial stages of an evolving process to include climate adaptation principles in their planning, design, capital construction, and financing procedures. A similar planning process needs to include the transport infrastructure along the Hudson River below the Federal Dam in Troy and the Great Lakes and St. Lawrence River shipping routes. Any initial administrative and exploratory steps that have been undertaken (e.g., MTA, 2009a) require additional attention in the pertinent institutions. They also require endorsements from their governing boards and by society at large. This will require corporate leadership. Even then, however it may take time before climate change adaptation is firmly embedded into the normal functioning and decision making of the transportation institutions. The seeds are sown,²³ but in order to take root, sustained leadership, financing, political and public support, and implementation is required.

The rising technical awareness of changing climate conditions in the transportation community will need to be echoed by public and its representative political institutions. Their strong support for a broadly based sharing, for the common good, of the costs for safeguarding the public transportation infrastructure—especially in the coastal and estuarine risk zones—will be important to ensure effectiveness of agencies' adaptation efforts. The State of New York is in a position to provide leadership. The formation of the State's Sea Level Rise Task Force (SLRTF)²⁴ and the Climate Action Plan are good first steps. Near-term implementation of adaptation measures is the next step.

9.4.1 Key Adaptation Strategies

The technical and procedural tasks for climate change adaptation at hand will include the following steps:

- A full inventory of the hazards as a function of time related to climate change (e.g., NPCC, 2010; and Horton and Rosenzweig, 2010; also see Chapter 1 of this report, “Climate Risks”).
- A full inventory of the transportation infrastructure at risk to these climate change hazards (and benefits where applicable) and a systematic assessment of transportation system vulnerabilities to these hazards.
- A well-planned effort of technical and fiscal evaluation of adaptation options and their local, regional, social, and environmental implications. An important part of developing these multiple options is to allow flexible implementation along multiple, time-staggered decision paths (e.g., see NPCC, 2010).
- This approach requires, in turn, institutionalization of a scientifically based monitoring and decision-support system and process that can inform decision-makers of when the climate risks reach trigger (or tipping) points where decisions cannot be any longer delayed without potentially dire consequences (NPCC, 2010).
- The above steps need to be reassessed regularly until it is clear that full consideration of short- and long-term effects of climate change are effectively embedded in infrastructure planning and decision making at all levels of government and by the operating transportation agencies.

9.4.2 Large-Scale Adaptations

The following sections provide medium- to long-term technical options for adaptation to various types of climate change, i.e., those that go beyond temporary emergency measures (such as sandbagging or pumping by mobile units). They are organized by type of climate hazard.

Adaptation for Coastal Hazards

- Constructing local flood proofing by building local levees, sea walls, floodgates, and pumping facilities. For truly low-lying areas such measures may be only temporarily effective (in some instances only for

several decades). Site-specific studies for different time horizons will be needed.

- Raising structures or rights of way. For instance, commuter rail tracks could be put on elevated structures as part of a regional rejuvenation to a new generation of commuter and intercity rail systems, like those already implemented in Japan, Taiwan, and parts of Europe or as currently under widespread construction in China. Privately owned freight rail systems (e.g., along the west shore of the Hudson River) may need to consider equivalent options.
- Sealing of ventilation grates of belowground facilities (e.g., NYCT subway system) only in those locations that are in potential and future storm surge inundation zones. These sealed tunnel sections will need a newly engineered, forced ventilation system not open to the normal street grade, with consideration of fire safety.
- Designing innovative gates at subway and road/rail tunnel entrances, unless other options to extend the entrances to higher elevations exist, are practical, and can be implemented.
- Designing road and rail embankments as super-levees that could provide a double function: flood protection and transportation corridors.
- Conducting a feasibility study for a system of storm-surge barriers to assess their potential position and ability to provide protection for New York State’s waterfront and transportation systems.
- Retreating and relocating critical systems out of and/or above flood zones.
- Raising bridge landings along shorelines to ensure there is sufficient clearance for the transportation systems (highways, roads, rail systems) they cross over, given the need to potentially raise these systems as a result of sea level rise and related storm surge inundation hazards. Site-specific studies are needed to develop solutions for this seemingly intractable problem. Preventive solutions (sufficient clearances) need to be planned for any new bridge structures that cross bodies of water controlled by tides and rising sea levels (e.g., the currently planned new Tappan Zee Crossing).
- Vertically extending collision fenders to higher elevations on bridge foundations in tidal waters.

Adaptation for Heat Hazards

- Confirming that currently used heat-resistant road surfacing and rail track materials are capable of

withstanding additional, more extreme heat conditions.

- Upgrading air conditioning of rolling stock (trains, subways, buses) to meet the demand on extreme hot days.
- Inspecting bridge expansion joints, since they tend to lock with age, imposing extra stresses under extreme heat. This condition needs attention during bridge inspections. Ensuring adequate bridge clearances, as very large bridges tend to sag during extreme heat. Sea levels will rise, and modern ships often stack containers to heights that use as much of the clearance available, so it must be ensured that the available clearances continue to conform to U.S. Coast Guard limits for bridges across tide-controlled waterways. New height limitations may have to be imposed.
- Modifying airport and airplane functions. The aviation industry may encounter more frequent extreme weather events, with respective travel delays for airlines and their customers, and related economic impact. Airport runway lengths, extreme high air temperatures (hot air provides less lift), and required takeoff speeds of airplanes must be in balance to provide sufficient safety margins for takeoff. New generations of planes with more powerful engines are able to overcome this issue, but older planes may have to face load limitations or be phased out.
- Preparing for power and communication failures. Transportation agencies may need to be prepared for more frequent power failures (and related potential communication failures (see Chapter 10, “Telecommunications”). This applies especially during extended summer heat waves, when peak power demands exceed what electric utilities can supply due to increased need for air conditioning, unless the utilities’ adaptation plans cover these needs or plans are in place to reduce public demand during such times (see Chapter 8, “Energy”).

Adaptation for Precipitation Hazards

- Increasing the carrying capacities of culverts, retention basins, and other drainage systems in accordance with future precipitation normals (i.e., new averages and extremes, to be issued on a regional basis by NOAA’s National Climatic Data Center). It may also require changes in American Association of State Highway and Transportation

Officials (AASHTO) drainage guidelines and other applicable engineering standards.

- Raising road and rail embankments and/or strengthening their slopes to be resilient to flow dynamics and bank erosion in river flood zones prone to high flow velocities.
- Relocating rights of way out of new and future flood zones.
- Monitoring and remediating scour action at bridge foundations in rivers as flood and related flow conditions become more severe and frequent as a consequence of more extreme precipitation events (often further amplified by inappropriate upstream land use and development).
- Working with local agencies to reduce runoff from nearby properties and other rights of way onto transportation systems. This may involve creation of permeable surfaces and retention basins, restoring marshlands, increasing sewer or pumping capacities, and regrading slopes to direct runoff away from critical transportation infrastructure.

Adaptation for Winter Storms (Snow and Ice)

Overall snowfall and days per year with snow cover, especially in the more southern portions of New York, are expected to decrease gradually as snow will be more frequently replaced by rain. On the other hand, individual snowstorms and ice storms (with freezing rain) may become more intense, especially in higher elevations, in more northern regions, and those in areas prone to the lake effect, which may be amplified by a shorter duration of ice cover on the Great Lakes. These geographically diverse trends across the state may require potential reallocation of operational resources for snow clearing and sanding/salting. One alternative includes increasing the amount of intelligent signage that warns drivers about high-hazard road conditions. On average, across the state, a net reduction in snow hazard is more likely than not, but no clear trend is yet forecast for future freezing rain and icing conditions (see Chapter 1, “Climate Risks”).

Other Adaptation Options

Other climate-related risks that require adaptation measures may originate from more frequent extreme winds (characterized as hard to quantify, see Chapter 1, “Climate Risks”). Transportation agencies may want to

keep track of whether the design wind speeds need to be adjusted with time on a regional basis. A practical adaptation measure to cope with higher wind speeds is operational. Anemometers measuring wind conditions may be installed on bridges of a certain length and height above ground or water, and wind velocity limits may need to be set, above which bridge traffic will be allowed only at reduced speeds or, for higher wind speeds, will need to be suspended entirely to avoid excessive accident rates. Such limitations are already in place on some bridges in New York State and are, for instance, included as constraints in the New York City Office of Emergency Management hurricane evacuation plan.²⁵ MTA Bridges and Tunnels, and operators of other large bridges in the region, also have protocols in place for traffic restrictions during high winds.

Adaptation Options Related to Federal/State/Agency Policies and Cooperation

Intrastate Cooperation

At this time the major transportation agencies, authorities, owners, or operators in New York State do not yet have publicly accessible, internally approved master plans for how to adapt to those aspects of climate change that are currently known. The New York City Climate Change Adaptation Task Force (City of New York, 2011) in conjunction with the NPCC (2010) assessments come close to producing a roadmap and a technical/scientific foundation on which such a master plan can be based. This ClimAID project contributes to fulfilling a similar goal statewide. The MTA's *Greening Mass Transit & Metro Regions* report (MTA, 2009) provides the recommendations for such a plan. Actionable and internally approved plans can become an integral part of a long-term capital-spending budget to which the respective entity is committed.

For the private sector, and for the first time, the Securities and Exchange Commission (SEC) issued in January 2010 a statement²⁶ that “public companies should warn investors of any serious risks that global warming might pose to their businesses.” An equivalent rule (or even law) may be developed by the State to go one step further and request that each transportation operator doing business in New York State produce every few years an updated actionable plan on how it intends to manage the emerging risks from climate change over short to medium time horizons. A less detailed but mandatory long-term outlook for up to a century should also be included.

The federal and state governments could use such agency plans as a precondition for financing climate change adaptation assistance. There are many precedents for such conditional financial assistance, ranging from the multi billion dollar federal sponsorship to reform state and local education systems, to DHS/FEMA's disaster mitigation assistance grants given to states (and in earlier times, directly to communities), conditional on their having developed a FEMA-approved disaster mitigation plan.

Given this situation, the State could consider establishing a ruling that each Transportation Agency operating in the State of New York should develop by a certain deadline (say, 2015) a climate change adaptation master plan with an institutional management, operational, engineering, and capital spending project component, for short (years), medium (a few decades), and long-term (50–100 years) time horizons laid out in various degrees of detail, respectively. The basis of the report should be a science-based hazard assessment pertinent to the transport agency's assets and operations, an engineering-based vulnerability (fragility) and risk assessment, and a ranking of options to manage these risks, with estimates of costs for adaptation measures and of potential costs (risks) for incurring gradual and/or potential catastrophic losses if no action is taken. Such plans should be updated on a regular basis, perhaps on the order of, say, 5 years, or commensurate with agency-specific planning cycles.

In many of the major urban or metropolitan centers across New York State, multiple agencies are responsible for operating various modes of transport systems, whether they are public or private entities. Since transportation is a networked system, delays, failures, or (at worst) catastrophic failures in one system can affect the other systems, and in such cases the customer may not be able to get from point A to point B within a reasonable time at reasonable cost.

Especially in the case of floods in connected underground structures, system vulnerability is often determined by hydraulic connectivity between tunnels, stations, and other structures. Any effort by one agency to adapt to a certain climate change performance standard can be made ineffective by others adhering to a lower standard. The weakest link in the system may critically control the system's overall performance, even if it is a very diverse and redundant system.

There are examples of how transportation agencies have worked together to coordinate joint planning, set performance standards, or solve other coordination issues for the benefit of the public at large. The EZ-Pass is one such example of an interagency practical, successful solution.

Another example of interagency coordination occurred in the post-9/11 cleanup and recovery phase. Due to the urgency of rebuilding several high-priority projects in Lower Manhattan, the Federal Transit Administration (FTA) set up an FTA Lower Manhattan Recovery Office²⁷ that worked with project sponsors on innovative, streamlined project delivery processes in the areas of development, oversight, and environmental management. This approach was developed early, with a consensus among federal and local partners. In the arena of environmental oversight it led to a memorandum of understanding between EPA and other federal agencies defining roles and response times. It also developed agreement among project sponsors to a common Environmental Analysis Framework and Environmental Performance Commitments as well as to coordinated cumulative effects analysis.

An organization potentially suited to take on this regional coordination for climate change adaptation standard and performance goals in the state's coastal region could be the New York Metropolitan Transportation Council, an association of governments, transportation providers, and environmental agencies that is the Metropolitan Planning Organization for New York City, Long Island, and the lower Hudson Valley.

In regions of the state with dense and diverse transport systems operated by multiple agencies and owners, an alliance of operators should be formed to coordinate climate change adaptation measures to ensure a coherent systematic approach with mutually agreed-upon performance goals and standards. In addition, the alliance may coordinate policy, oversight, and other issues with federal and state agencies to streamline a regional approach and to put the region in a better competitive position when applying for federal technical and financial support for climate change adaptation.

A particular task for coordination could be delegated to an "adaptation moles" technical working group. This group should be charged to ensure that the underground connectivity between multi-agency below-ground rail-based transportation systems in the NY/NJ

metro region (including NYCT subway, LIRR, MNR, the Port Authority, New Jersey Transit, Amtrak, and others) will become flood-resilient as a whole. The working group would also engage with experts from vehicular tunnel operators (Port Authority and MTA Bridges and Tunnels), and state, county, and city agencies including DOTs, and power and communications utilities to ensure that a flood protection and general adaptation plan, with special emphasis on sea level rise, is comprehensive, system-wide, and performs in accordance with an agreed-upon performance standard for the benefit of all agencies and the public at large.

National Cooperation

Of course, New York State is not isolated, which is particularly relevant in the transportation sector. Not all regions of the nation will be affected equally by climate change. Those regions that are population centers and vital drivers of the national and global economy have generally the highest concentration of transportation infrastructure. If these major nodes of the transport systems fail and become unreliable, redundancy and diversity of the transport links between such centers cannot maintain the system capacity. These centers also serve to maintain a large state and federal tax base that needs to be stable. Their gradual or catastrophic failure could bring disproportionately large losses to state and national economies. Therefore these centers deserve special scrutiny and attention to sustain the economic viability of the state and nation at large, especially in the context of global economic competition. Without a climate-change-resilient transportation infrastructure, these economic centers cannot fulfill their role as reliable engines for the state and national economies, and hence warrant state and national support. Assessment of priorities is most effective when ranking is risk-based. Consequently, New York State may want to work closely with the federal government to pursue the following adaptation options:

- Set priorities for policies for providing sound knowledge and data, and direct financial support, to strengthen the nodes of transport infrastructures to make them climate-change-resilient.
- Consider a comprehensive program of research and technological development for advancing innovative and cost-effective climate-resilient urban and inter-urban transportation infrastructure.
- Devise incentives for states, regions, and cities with vital nodes and concentrations of transport

infrastructure to partner and exchange best practices in climate change adaptation, and to help set the national agenda for sustainable, energy-efficient transport systems.

Ground transport systems (roads and rails) of coastal population centers and estuaries (controlled by tides and brackish waters), are often placed underground in tunnels very close to or below sea level. Such systems, especially when built many decades ago without anticipating rising seas, are vulnerable to the combination of accelerating sea level rise and coastal storm surges. It is vital to make these low-lying transportation systems flood proof and to avoid systemic damage from saltwater intrusion before it is too late. To relocate such systems would require exorbitant resources. This poses new technological challenges and requires adequate resources to find innovative engineering solutions to protect these underground systems from the rising and encroaching seas. Consequently, it would be helpful for the federal government, in cooperation with states, to sponsor a technology assistance program to develop and install engineered protective measures targeting underground and near-shore transport systems that are under threat from sea level rise and saltwater damage.

Other transport facilities near New York State's coastline, and along the nation's coasts, including harbor facilities and their interfacing ground transportation links such as road, rail, storage, and freight transfer facilities, and many industries such as refineries and chemical plants that rely on marine shipping access, are also at risk from coastal storm-surge flooding amplified by accelerated rising seas. Inundation would not only damage these ports, ground transport, and industrial facilities, but also pose potentially severe environmental risks from spreading debris and toxic substances to nearby coastal population centers. Consequently, it would be helpful for the federal government to provide assistance to regions like New York State, with major port facilities and related industries that serve the nation's import/export demands. Such assistance should be aimed to develop and implement cooperative solutions among port operators, connecting transport systems, proximal industries, and nearby population centers and communities, with a goal of safeguarding them from coastal storm-surge flood hazards that will increase with rising sea levels. Federal assistance would greatly foster the development and installation of technical solutions

that can reduce related environmental and health risks from potentially toxic materials and debris being carried by flood waters into communities, natural and developed land, ground-water, beaches, and/or fisheries.

FEMA flood insurance rate maps (FIRM), whether near rivers or coasts, have become an important guiding tool for local zoning, planning, land-use, construction permits, environmental impact statements, etc. These now-widespread uses are far beyond the original intent of FIRM maps for guiding the National Flood Insurance Program (NFIP) aimed mostly at residential housing in flood-prone areas. FIRM maps are based on *past* data and information, in terms of land use and climate. Therefore they are not suited for planning *future* sustainable development of communities and the transport systems that need to serve these communities under new and *changing* climate conditions.

Consequently, the federal government could establish a technical assistance program to help states and communities and their transportation agencies develop sound science-based flood zoning tools that allow forward-looking adaptation to climate change, including the associated engineering guidelines. Such guidance tools would be more appropriate than the FIRM maps for coastal zones and other flood-prone areas to cost-effectively plan and design new, or to modify existing, transportation and other critical infrastructure, and to support future community development that is sustainable for periods of time not shorter than the expected lifetime of the respective infrastructure.

Other needs exist, as well, that could best be met with coordination between New York and federal organizations. For example, accurate, high-resolution LIDAR (light detection and ranging) surveys need to be flown to facilitate the development of digital elevation models (DEM) of sufficiently high vertical and horizontal resolution to perform forward-looking flood risk assessments and regional planning of sustainable developments.

A similar need exists for forward-looking climate normals (in contrast to traditional climate normals, which are produced by NOAA based on past climate data). Future temperature normals are needed to guide the design of transportation cooling and ventilation systems that can meet increased demand, for heat

resistant pavements on roads and airport runways, and for designing airport runways with sufficient length to ensure safe takeoff during extremely hot days. Future precipitation normals are needed to design drainage systems that can handle future extreme rainfalls. New York State should undertake formal steps to work with the respective federal agencies to produce these products in a timely fashion, with clear presentation of uncertainties and regular updates as new climate projections are produced.

Regional Cooperation

Regional transportation agencies own and operate assets that are often fully or partly self-insured. Insurance against climate-related disaster losses works best when the risk is spread geographically, by diversity in asset ownership, and by exposure to diverse, independent, and uncorrelated hazards and risks. The risks to regional transportation agencies from climate change are instead highly concentrated geographically and exposed to process-related climate hazards. Therefore, the principles for effective self-insurance are violated since all assets can be hit by the same event. Furthermore, one event may entail a number of correlated perils (e.g., wind, lightning, flood, debris impact, power outages, and saltwater damage), which may strike at the same time caused by the same event (e.g., the same hurricane).

Consequently, regional transportation authorities may want to spread their risks from climate-related weather events by entering insurance pools of transportation owners spread over diverse geographical regions across the nation. This may be achieved by a blend of mutual and self-insurance (with or without participation of federal or state governments and/or the private insurance and reinsurance sectors), or by floating catastrophe bonds on capital/equity markets. The federal and/or state governments may provide the regulatory framework for such sharing of the risks to public transportation lifelines across the entire nation, and set standards by which the insured and insurers shall abide. Another option is for federal and/or state governments (i.e., the taxpayers) to become the ultimate bearers of climate-change-induced risks for regional public transportation systems. In either case, a federal or joint federal/state program for assessing the climate change risk exposure of regional transportation agencies and of insurance options vis-à-vis climate change risks appears to be a desirable and much needed risk management measure.

9.5 Equity and Environmental Justice Considerations

Transportation planning is a longstanding priority of environmental justice advocates. In transportation analyses, core equity concerns often include unequal access to different types of transportation, the spatial mismatch of jobs and residences, the disproportionate health burden of automobile pollution, and a commitment to affordable public transportation (Bullard, 2007; Sze and London, 2008; Chen, 2007). Constructing adaptive, climate-secure transportation provides opportunities to build social equity into the infrastructure, but with less care it may exacerbate some of these existing inequities as well as create emergent burdens.

9.5.1 Social Vulnerability and Equity

Social, economic, and geographic marginality add to the challenges of transportation planning. For the United States as a whole, the poorest 20% of households spend more than 13 percent of their income on transport (U.S. Bureau of Labor Statistics, 2010). In urban centers, and increasingly the inner suburbs, lower-income people of color are disproportionately dependent on public transportation to get to their jobs (Pucher et al., 2003). African Americans and Latinos, in particular, are less likely than whites to own a car (Sanchez et al., 2004). Across most cities in the country, including New York City, there is a correlation between carless populations and poverty and minority status (Milligan, 2007). While reliance on public transport has positive implications for environmental quality and mitigation of climate change, reliance on public transport also creates vulnerabilities in times of natural disasters and climate-stress events. In one extreme example, Hurricane Katrina exposed the severity of this transport disadvantage: Upper-income populations left New Orleans by car, while disabled, low-income, and African American populations were stranded (Litman, 2005).

Some of the largest urban centers in the United States, including New York City, have detailed evacuation plans incorporating varied levels of social disadvantage. The strengths and limitations of New York City's plans are discussed in the case study later in the chapter. In contrast, one analysis discovered that central cities elsewhere in New York State were even less prepared to deal with transport disadvantage (Hess and Gotham,

2007). In general, they found that most evacuation plans did not seriously consider multimodal transport strategies or incorporate carless populations. At the same time, the rates of households without cars in Albany (28 percent), Buffalo (31 percent), Rochester (25 percent), and Syracuse (27 percent) are similar to rates in New Orleans at the time of Katrina (27 percent). Two of the case studies in this ClimAID report involve climate-related disasters in central and northern New York (i.e., ice storm in Chapter 10, “Telecommunications,” and a Susquehanna river flood in Chapter 4, “Water Resources”). As cities in these areas contemplate emergency measures and adaptation strategies in the context of climate-related disasters, one possible way to improve equitable opportunity is to place additional emphasis on the needs of carless populations.

Even less catastrophic failures, such as localized power disruptions or small-scale flooding, can have uneven effects if they cause cutbacks or interruptions in transportation service or limit affordable options. Low-income people are likely to be more dependent on limited service options and less able to take advantage of a range of transport systems. At the same time, they tend to live farther from their places of work, so they are the most likely to be affected by lost wages (Chen, 2007). Of the three-quarters of a million New York City workers who commute more than an hour, two-thirds of them earn less than \$35,000 per year (Byron, 2008).²⁸ Many low-income individuals living at the periphery of the outer boroughs, especially parts of Queens and Staten Island, have access only to unreliable, inefficient, or inconvenient public transit (NYMTC, 2009). Even minor service disruptions create hardship for them relative to individuals in areas with transit redundancies. Transport interruptions take a particular toll on working women, who tend to have less spare time because of child and family care and on average earn less than men (Root et al., 2000; Morrow, 1999).

9.5.2 Adaptation and Equity

A particular challenge for developing an environmental justice component to transportation adaptation is the need to project into the future for many decades. Because transportation design is generally locked into the landscape, an array of equity dilemmas extends throughout the lifecycle of the infrastructure. Most

immediate questions include, where is a new or upgraded route going to be sited? Who will be displaced by the construction? In the medium term, what demographic groups or regions will benefit from the adaptation? Decommissioning highways, roads, and other infrastructure for climate protection could involuntarily leave communities isolated from job centers or otherwise stranded. Some communities may have increased traffic and demand for services, while others experience shrinkage. And in the long term, how will new transportation flows induce new patterns of mobility and new patterns of migration into and out of an area? Who are the winners and losers in this process? Land-use changes are likely to follow, and how will these changes benefit some and not others?

These questions raise the fundamental challenge of balancing the need to prioritize climate-proofing system-wide transportation flows against particular transportation imbalances that may decrease access to opportunities for various groups. Questions of whether to retrofit and renovate old infrastructure versus building new climate-adaptive infrastructure may also raise equity issues. For example, an adaptation policy concentrating on designing new road construction outside of floodplains could be biased toward exurban, high-income fringe suburbs of the various cities at the expense of inner-ring suburbs and central city areas that are more set in place and would most benefit from other types of measures such as increasing bus capacity.

9.6 Conclusions

Transportation in New York State is vulnerable to and consequently at risk from climate change as shown by the statewide survey in this ClimAID chapter and, in particular, by the case study analysis (following Section 9.6) of storm surge risks of the metropolitan and coastal regions. The degree of vulnerability statewide is, at present, still largely indeterminate since it requires extensive engineering analyses. Therefore, the most effective adaptation solutions cannot be selected with confidence until the vulnerabilities are fully explored. Nevertheless, certain general patterns of vulnerabilities and opportunities (for details see Section 9.3), of adaptation options (Section 9.4), and of knowledge gaps can be discerned, given the current state of knowledge. These findings and recommendations are summarized below.

9.6.1 Main Findings on Vulnerabilities and Opportunities

- Ground transportation is vulnerable to increased flooding during extreme precipitation events inland, and to coastal storm surges combined with sea level rise in coastal regions (and along the tide-controlled sections of the Hudson River below the Troy Dam).
- Port facilities, including piers, warehouses, and transshipment facilities to rail and road, may be exposed to sea level rise and coastal storm surges.
- More frequent and more severe extreme high temperatures may require more heat-resistant materials and design criteria for highways, bridges, rails, and catenaries; high temperatures can cause heat exposure to maintenance and construction crews and to commuters in subways. High temperatures also can impede airplane lift during takeoff and landing.
- In coastal regions, less salting and snow removal may create benefits.
- The Great Lakes shipping season may be lengthened and may eventually be year-round, but it may become vulnerable to lower lake levels necessitating shallower vessel drafts.
- More extreme weather conditions may require traffic restrictions (e.g., on bridges exposed to high winds), and may cause delays and cancellations in air traffic.
- Raise or relocate to higher ground, where necessary and feasible, critical infrastructure to avoid current and future flood zones. Elevating infrastructure may apply to bridge landings, roads and railroads, and collision fenders on bridge foundations.
- Evaluate, and where found feasible and sustainable, create engineering-based solutions to protect against coastal hazards by constructing levees, sea walls, barriers, and pumping facilities, and by designing innovative gates at subway-, rail-, and road-tunnel entrances.
- Develop engineering-based solutions to protect against heavy precipitation hazards, including increasing the capacity of culverts and other drainage systems, raising and/or strengthening road and rail embankments to make them more resistant to flood-related erosion and river scour, and creating more permeable surfaces or regrading slopes to direct runoff away from critical transportation infrastructure.
- Create strategies to protect against heat hazards, e.g., by increasing the seat length of expansion joints on bridges, lengthening airport runways, and increasing and upgrading air conditioning on trains, subways, and buses.

9.6.2 Adaptation Options

- Perform engineering-based climate change risk assessments of assets and operations and develop adaptation master plans based on these assessments.
- Form alliances between agencies to set region-wide performance standards and work together to reduce physical risks and intermodal weather-related traffic problems propagating through the interconnected systems. Also, form mutual insurance pools that spread risks across time, space, and type of peril.
- Implement operational measures based on incorporating weather forecasts and climate projections into operations and construction planning, on posting warnings, and on intelligent signs, which in some cases may be linked to monitoring devices (e.g., measuring wind speed on bridges).
- Accurate, high-resolution LIDAR surveys of current and expected future coastal and inland flood zones to facilitate the development of digital elevation models of sufficiently high vertical and horizontal resolution to perform forward-looking flood risk assessments and regional planning of sustainable developments.
- Development of updated region-specific climate information that includes climate change scenarios (and forward-looking climate normals) for design standards, regulations, and technical design guidelines (e.g., for proper design of culverts and drainage systems).
- A comprehensive federal/state/private-sector program of research and technological development for advancing innovative, cost-effective, and climate-resilient urban and inter-urban transportation infrastructure.

9.6.3 Knowledge Gaps

Measures needing to be undertaken to fill existing knowledge gaps include the following:

Case Study A. Future Coastal Storm Impacts on Transportation in the New York Metropolitan Region

The purpose of this ClimAID case study is to provide a largely qualitative assessment of the geographic reach and of the impacts of a 100-year Base Flood, and how the flooding conditions and impacts change as a function of sea level rise. The quantification of risks and losses are attempted where possible within the scope of the study. We use three scenarios, which are consistent with the ClimAID projections:

- Scenario S1—current sea level with a 100-year coastal flood along the coast and tide-controlled estuary
- Scenario S2—2-foot rise in sea level, combined with a 100-year coastal flood along the coast and tide-controlled estuary
- Scenario S3—4-foot rise in sea level, combined with a 100-year coastal flood along the coast and tide-controlled estuary

While the 2-foot and 4-foot sea level rise increments are not tied to any particular time horizon via a specific sea level rise forecast, these two sea level rise increments would be attained in the 2050s (2 feet) and 2080s (4 feet) under the rapid ice-melt (RIM) sea level rise scenario put forward by the New York City Panel on Climate Change (NPCC, 2010; see also Chapter 1, “Climate Risks”). Slower sea level rise, which is more likely than not, would delay the arrival of these sea level increments. A faster sea level rise than RIM, which is less likely, would advance the arrival of these increments to earlier times during this century.

The coastal flood scenario used in this case study for baseline purposes is that which occurs, on average, once every 100 years (i.e., a chance of 1 in 100 in any given year) at any given location along the coastal or estuarine waterfront of New York State. It is conceivable, but not likely, that two or three such 100-year storm surge heights are reached or exceeded only a few years apart. It is also possible that such coastal storm surges and related flooding do not occur for a period of more than 100 years.²⁹

The 100-year storm, as assumed in this case study, is similar to a non-direct but nearby hit of a category 1 to 2 hurricane, or to the conditions at the marginal periphery of a category 3 hurricane (e.g., one that

makes landfall in southern New Jersey or in Rhode Island). This case study storm could also be a severe winter nor’easter storm that stalls for a few days off the mid-Atlantic coast, especially if it coincides with a period of high tides (i.e., during a new or full moon). The Dec. 11–12, 1992, nor’easter was just below, but close to, this strength.

This case study only addresses flooding due to coastal storm surges along the coast and estuarine (i.e., tide-controlled) shorelines. It does not address any inland urban, street, or non-estuary river flooding that often occurs simultaneously during nor’easters or hurricanes because of heavy rainfall and runoff that may exceed the carrying capacity of drainage areas and stream-beds. The impacts of these types of inland floods are not amplified by sea level rise. But the impacts and losses from this urban street and river flooding must be added to the impacts and losses assessed in this case study if a full assessment of climate-related risks is undertaken.

Study Parameters and Focus

The parameters for this case study were developed by the ClimAID Transportation, Climate, and Coastal Teams, with inputs from the Energy and Telecommunications teams.

The climate hazards considered are sea level rise in combination with coastal storm surges. The scenario storm is assumed to be one that produces a coastal storm surge consistent with the 100-year flood along New York State’s Atlantic shorelines and estuaries, as defined in FEMA Flood Insurance Rate Maps.

Affected Area (see Figure 9.6):

- *Primary focus:* New York City
- *Secondary focus:* The New York City metropolitan area, including Long Island (ClimAID region 4), Westchester (part of ClimAID region 2) and the lower and mid-Hudson Valley tide-controlled shorelines (part of ClimAID region 5). Note: for ClimAID climate regions see Chapter 1, “Climate Risks.”

Impacts:

- *Primary focus:* Transportation infrastructure

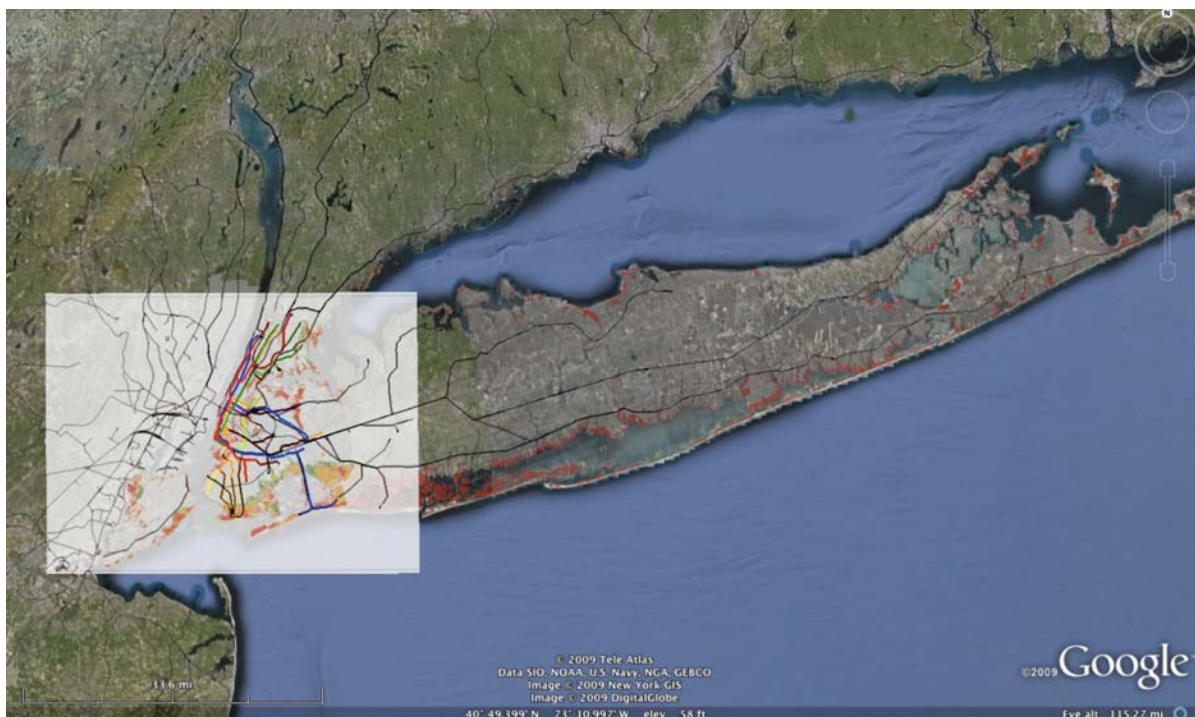
- *Secondary focus:* Communication infrastructure, electric power grid

The ClimAID team did *not* select a hurricane of category 3 for this case study for a number of reasons. Such a hurricane struck Long Island and New England in 1938. If such a hurricane were to directly strike New York City today or in the coming decades, it would cause losses of several hundred billions of dollars and, less certainly, several hundred lives (Jacob et al., 2000, 2001). The probability for such a hurricane-3 direct-hit disaster to occur is less than 1 in 1,000 in any given year. Instead, the ClimAID team chose a more moderate storm about 10 times more likely than a 1938-type hurricane. The scenario storm is more severe, and 10 times less likely than, for instance, the December 1992 nor'easter storm that flooded many transport systems (including a commuter transit tunnel under the Hudson) and coastal areas. The case study chose a coastal flood scenario commonly used for planning, zoning, and design and code decisions on a daily basis: It is a coastal storm that produces a storm surge consistent with flood heights and inland reach as mapped by FEMA's 1 percent per year flood zone maps, better known as the "100-year" flood.

The case study focuses on the Metropolitan Area of New York City, but extends to Long Island, Westchester County (and adjacent parts of Connecticut), and the entire mid-Hudson Valley to the Federal Dam at Troy, that is, the extent of the tide-controlled Hudson River Estuary. Since the metropolitan area is linked by transport to New Jersey, storm effects there need to be considered too. The area of general interest for this case study is shown in **Figure 9.6**. The primary focus area around NYC is highlighted.

Use of FEMA Flood Insurance Maps

Individual storms are unique. They follow a given path, have an associated wind field, their eyes have a specific forward speed, etc. Storm surge heights depend on exposure to wind, waves, the effects of near-shore water depth in the ocean (i.e., bathymetry), shoreline geometry, and nearby land topography. Because such physical details determine local storm surge heights along the coast, any scenario-specific storm surge heights will differ for an actual storm from the flood elevations mapped by FEMA on its flood insurance rate maps (FIRM). These maps are probabilistically derived and show the outlines



Note: The three scenarios considered comprise a 100-year coastal storm surge: S1 at current sea level, and no sea level rise; S2 with a 2-foot sea level rise; and S3 with a 4-foot sea level rise. The highlighted inset is the primary focus area around New York City. Black lines are railroads; colored lines are subways. For details of the three-colored scenario flood zones in the highlighted area, see Figure 9.7. The red zones outside the highlighted area (in Long Island and Westchester County) depict low-lying coastal areas below about 10 feet in elevation (NAVD 1988 vertical datum). Source for Base Map: Google Earth

Figure 9.6 New York State coastal zone and Lower-Hudson Estuary for which the case study analyzes the impacts on transportation by a 100-year coastal storm surge in combination with sea level rise

of the base flood elevations (BFE) for the 100-year flood probability (**Figure 9.7**, red areas). Importantly, these base flood elevations are not scenario-specific. Thus, variations from the portrayed FEMA flood map estimates can and will occur. The reach of the added flood zones due to sea level rise and the added impact of sea level rise on the transportation infrastructure are also uncertain.

The FEMA maps are used as a starting point for a number of reasons, despite the fact that some locations have been flooded more than once during the last 100 years at flood levels higher than depicted by the maps, and other locations have not been flooded during the last 100 years to the degree that the maps predict. A number of the deviations can be explained by changes

that have occurred since the FEMA maps were created. For example, many of the floods that are more severe than expected by FEMA's baseline flood elevation standards have occurred along inland rivers, where upstream development and changes in land use have increased runoff since the FEMA maps were produced. Along some coastal locations, beach erosion and, in a few cases, ill-conceived coastal management practices, have increased coastal flood hazards since FEMA completed its flood mapping. Adding to these hazards, local sea level along New York State shorelines has been rising at a rate of almost 1 foot during the last century. On the other hand, new sea walls and other protective structures may have reduced flood hazards in some locations. Lastly, the 100-year flood is a statistical

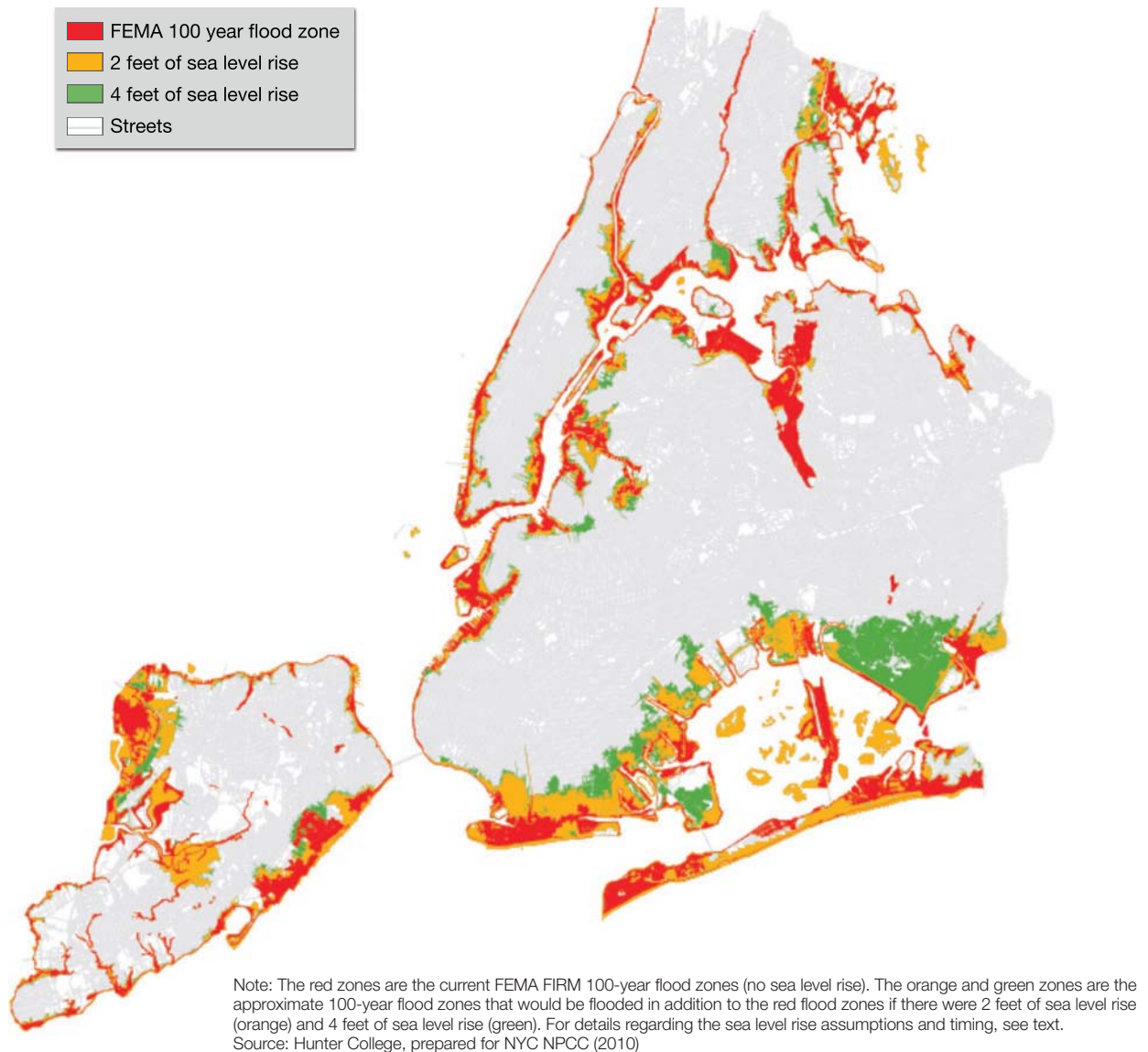


Figure 9.7 100-year flood zones in New York City (i.e., with a probability of being flooded of 1 percent per year) for current and two different ClimAID sea level rise scenarios

estimate that describes the *average* occurrence of a randomly distributed sample of flood occurrences; each location has only a 63-percent chance of experiencing a 100-year flood within the 100-year timeframe.³⁰

Methods: Averaged 100-year Flood Elevations and Sea Level Rise Added

This case study uses sea level rise estimates of 2 and 4 feet, which are added to FEMA's 100-year base flood elevations (for details, see Appendix B). For convenience, the base flood elevations were rounded, within the boundaries of New York City only, to the nearest full foot. The method involves averaging the flood heights into an average flood elevation³¹ for each of the waterways surrounding New York City, as depicted in **Figure 9.8** and listed in **Table 9.13** in Appendix B.

To determine the risk that flooding poses to transportation infrastructure, the elevation of the structures relative to the elevation of the floodwaters according to FEMA's 100-year flood maps were analyzed. The new flood zones that account for the anticipated 2- and 4-foot sea level rise were then used to assess the vulnerabilities of transport structures and systems.

Note that the original base flood elevations from FEMA's Flood Insurance Rate Maps are generally (at least for New York) referenced to the National Geodetic Vertical Datum of 1929 (NGVD, 1929). The investigators chose, however, for their newly computed, averaged sea level rise-dependent flood-zone elevations to reference to the more recent, and now more commonly used, North American Vertical Datum (NAVD, 1988). Note that in contrast to FEMA maps in New York, FEMA maps for New Jersey use the NAVD 1988 datum. A constant difference of 1.1 feet between the two datums was applied throughout the New York City area such that the numerical elevations above the two vertical datums relate to each other by Equation 1:

Equation 1. Elevation (ft) above NAVD'88 = Elevation (ft) above NGVD'29 - 1.1 ft

The area-weighted average base flood elevations (in the NAVD 1988 reference frame) were, for the New York City waterways, rounded to the nearest integer foot for assessing the flood and sea level rise impact on transport in the region. The averaged flood elevations, Z_i , were

then compared to the lowest critical elevations (LCE) of the transportation systems.

In the regions outside New York City, including Long Island (Nassau and Suffolk Counties), Westchester County and the Lower Hudson Valley, and Connecticut, more generalized approaches were used, for a number of reasons. First, no high-resolution digital elevation model with a 1-foot vertical resolution was uniformly available for these regions outside of New York City (Suffolk County is an exception). Additionally, for these areas, the lowest critical elevations are not known for many of the transportation systems and related structures as well as they are known within New York City. The New York City estimates were largely obtained from the Hurricane Transportation Study (USACE, 1995), and the metropolitan east coast (MEC) climate change infrastructure study (Jacob et al., 2000, 2001, and 2007).³²

This lack of basic information points to the need for accurate, accessible digital elevation models in all the storm-surge-prone coastal zones of New York State. These models need a vertical resolution of substantially less than 1 foot.

Case Study Results for General Inundation Patterns

A 2-foot rise in sea level would have significant impacts in many parts of New York City, and especially along the Brooklyn and Queens shorelines, around Jamaica Bay, and on the Rockaway Peninsula. As shown in **Figure 9.7**, the increase in additionally flooded area from a 2-foot rise to a 4-foot rise in sea level is less significant than the increase in flooded areas from current sea level to the first 2-foot sea level rise. This is a result of the topography of the area and has to do with the presence of glacial landforms. In the subject regions, the terrain slopes between the 100-year base flood elevations (at current sea level) and the next 2 feet of higher elevations tend to be minimal, while terrain slopes tend to become steeper at elevations above base flood elevations of 2 feet. This is typical for former flat glacial-outwash regions. They are interspersed with remnants of glacial end moraines that stand above the plains and are now coastal flats or marshes, after more than 400 feet of sea level rise during the last 18,000 years of glacial retreat.

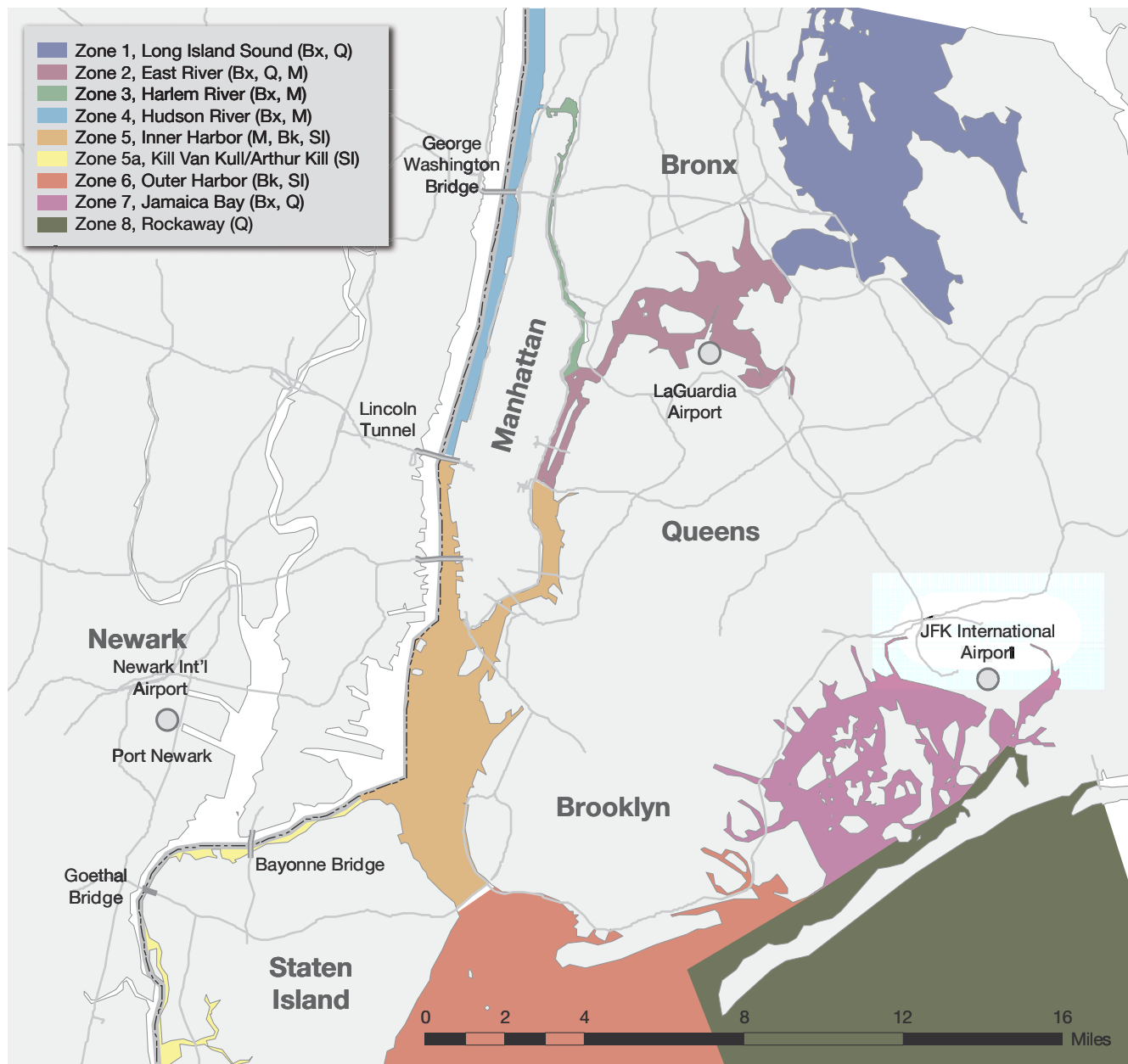
The areas indicated as additionally flooded zones under the 2- and 4-foot sea level rise scenarios in **Figure 9.7** will be flooded only if protective measures such as levees and/or sea walls are not kept in good repair where available or newly constructed. Such measures could diminish the additional flooding, but issues of sustainability (discussed below) will need to be considered.

A sea level rise of 2 or 4 feet will cause more streets to be flooded during a coastal storm surge (**Figure 9.9**).³³ The increase in total length of streets flooded during

the first 2 feet of sea level rise over the current sea level is almost twice as much as the increase in the total length of streets flooded during the second 2 feet of sea level rise (from 2 feet to 4 feet of sea level rise).

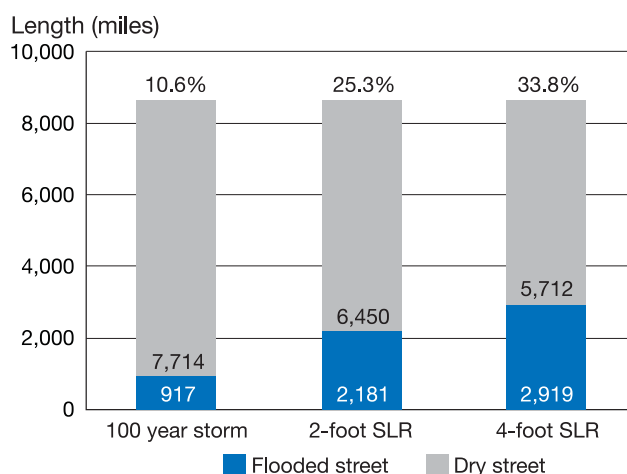
Flooding of Transportation Infrastructure and Expected Impacts

Flooding of city streets affects the flow of vehicular and pedestrian traffic, parking patterns, and many of the



Note: Legend gives color code and ID number for the nine zones, and lists the boroughs (in parenthesis) that share a shoreline with the zone. The obtained numerical AW BFEs (Z_v values) are listed in Table 9.13 (Appendix B). Legend abbreviations are: Bx = Bronx, Q = Queens, M = Manhattan, Bk = Brooklyn, SI = Staten Island. Sources: Base map, The Port Authority of New York and New Jersey, 2001; Overlays, by ClimAID team

Figure 9.8 Delineation of waterway zones for which area-weighted base flood elevations (AW BFE) are calculated



Note: The length of flooded streets that fall into the three flood zones increases from 917 to 2,181 to 2,919 miles, or from 10.6, to 25.3 and 33.8 %, respectively, of the total NYC street length, which measures about 8,600 miles.

Figure 9.9 Total length (miles) of NYC streets that fall inside (blue) and outside (gray) the respective flood zones as a function of sea level rise, for current sea level and with 2-ft and 4-ft sea level rise, respectively

MTA-NYCT bus routes. It also can slow access by first responders and emergency vehicles.

There are currently no centralized GIS- or CAD-based (computer-aided design) or other digital databases that show the as-built elevations of engineered transportation systems, including subways, railroads, state highways and/or major bridge access ramps, roads, toll plazas, tunnels, and airports and seaports in the New York City metropolitan region. It is generally very difficult to compile the needed information from hardcopy blueprint plans that must be retrieved from archives one by one. ClimAID transportation stakeholders, and in particular the Port Authority, MTA, NYSDOT, and NJ TRANSIT, provided the needed information, in addition to data already available from the U.S. Army Corps of Engineers (USACE, 1995), including tunnel elevations, volumes, pumping capacity, etc. As climate adaptation efforts advance, the assembly of such a database on a statewide basis is urgently needed, but should at least be developed on an agency-by-agency basis. This points to data and information needs we address later.

Focus of Impact Analysis and Assumptions

The only structures considered in this case study are those that are near or below sea level and are potentially

vulnerable to coastal storm surge inundations. Where available, the lowest critical elevations are listed, indicating the elevation at which water will inundate a portion or all of a given structure if storm surge waters reach it. Water damage at these elevations is likely to occur and operation will be impeded. Lowest critical elevations are given in feet and are referenced to NAVD 1988.

The case study assumes that no adaptation or protection measures are taken now or in the future, unless indicated. Implementation of any structural or protective adaptation options or, in some cases, operational protective emergency measures, could diminish to various degrees the extent and impact of flooding depicted here.

Tunnels and Underground Structures

For tunnels and other underground structures, once storm waters reach the lowest critical elevation, water will flow down into the tunnel or underground structure. If the floodwaters stay above this critical elevation for sufficiently long, the tunnel and connected structures can fill completely to at or below the lowest critical elevation.³⁴

The flood potential of the transportation systems listed below can be inferred by comparing the flood scenarios for the respective waterways listed in column 4 of **Table 9.13** (Appendix B) with the lowest critical elevations given, to determine whether the base flood elevation (2 and 4 feet, respectively) exceeds the lowest critical elevation (see **Table 9.13**, Appendix B).

Note that all elevations are uniformly relative to the NAVD 1988 datum. For all listings below, it can be inferred in conjunction with the data from **Table 9.13** whether:

- the lowest critical elevation is at or below the area-weighted average (Z_i) (or below Z_i for the 2-foot or 4-foot sea level rise scenarios, respectively), implying that the structure is within the 100-year flood zone for the given sea level, now or in the future; or
- the lowest critical elevation is above the area-weighted average (Z_i) (or above Z_i for the 2-foot or 4-foot sea level rise scenarios), implying that there is no 100-year flood hazard for the structure under the given sea level scenarios.

When the flood potential of a structure located outside New York City and outside the mapped waterways is assessed where no area-weighted average value Z_i was computed, the current FEMA 100-year base flood elevation is used directly (corrected for NAVD 1988 datum where needed) to allow similar inferences.

These methods were used to assess the flood potential for each of the structures discussed below.

New York City Transit Subway System

Most of the tunnel flooding analysis focused on the following three areas (**Figure 9.10**):

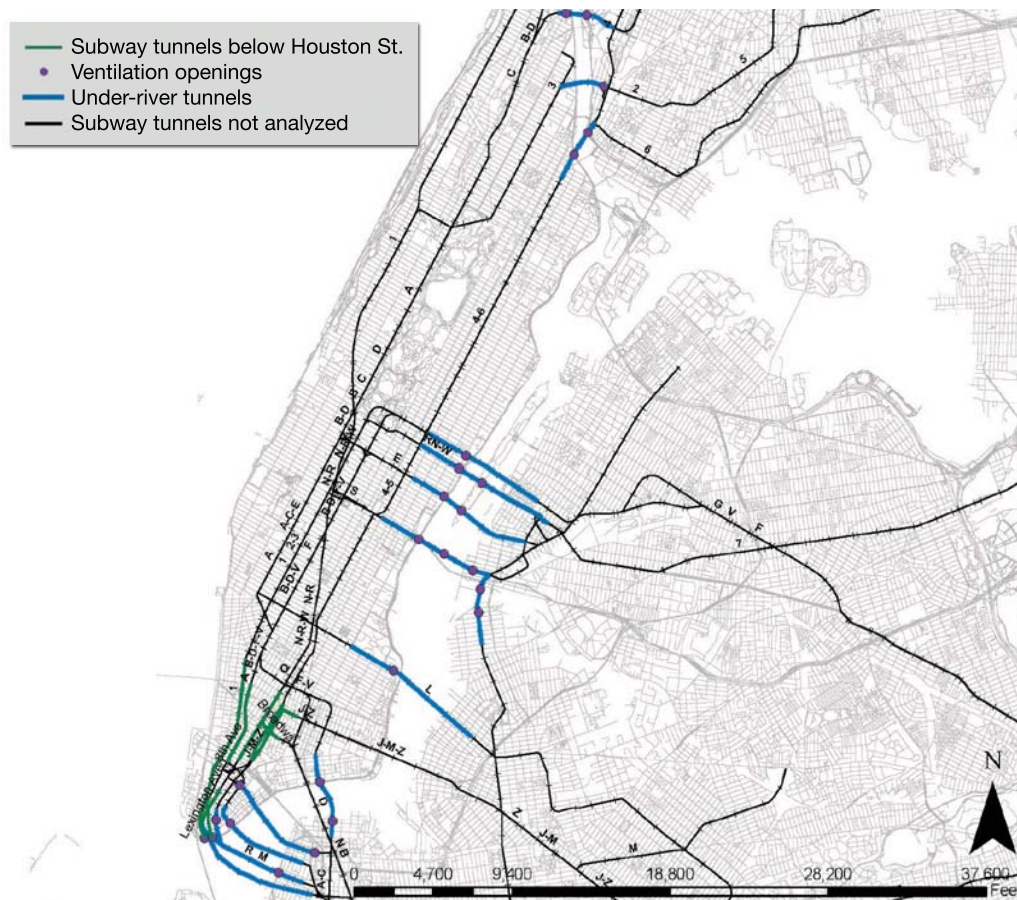
- Downtown Manhattan, with tunnels connecting below the East River to Brooklyn (six river crossings) (**Figure 9.11**)
- Midtown East Side Manhattan, with four tunnels crossing below the East River to Queens (Long

Island City) with one nearby additional river-crossing tunnel segment (**Figure 9.12**) across the Newtown Creek at the boundary between Brooklyn and Queens

- Uptown Manhattan, with three tunnels crossing beneath the Harlem River into the Bronx (**Figure 9.13**)

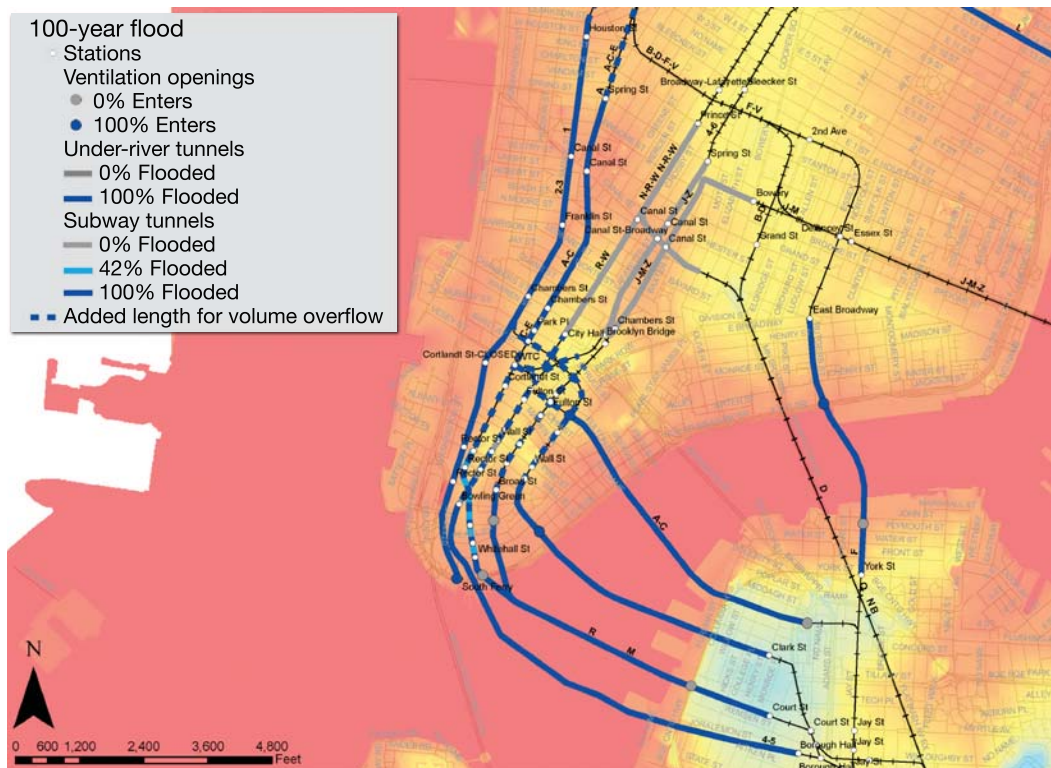
The ClimAID subway flood study was cross-checked against an MTA-internal flood mapping effort,³⁵ which was carried out in 2006 for developing storm emergency plans. The study modeled the effects of the storm surge heights for “worst track” (i.e., direct hit) hurricanes of categories 1, 2, 3, and 4 as given by USACE (1995) based on NOAA’s SLOSH (Sea, Lake, and Overland Surges from Hurricanes) computations then available. We reproduce here only the MTA map for the category-1 hurricane scenario (**Figure 9.14**).

This storm scenario has coastal storm surge elevations roughly comparable to the 100-year coastal storm



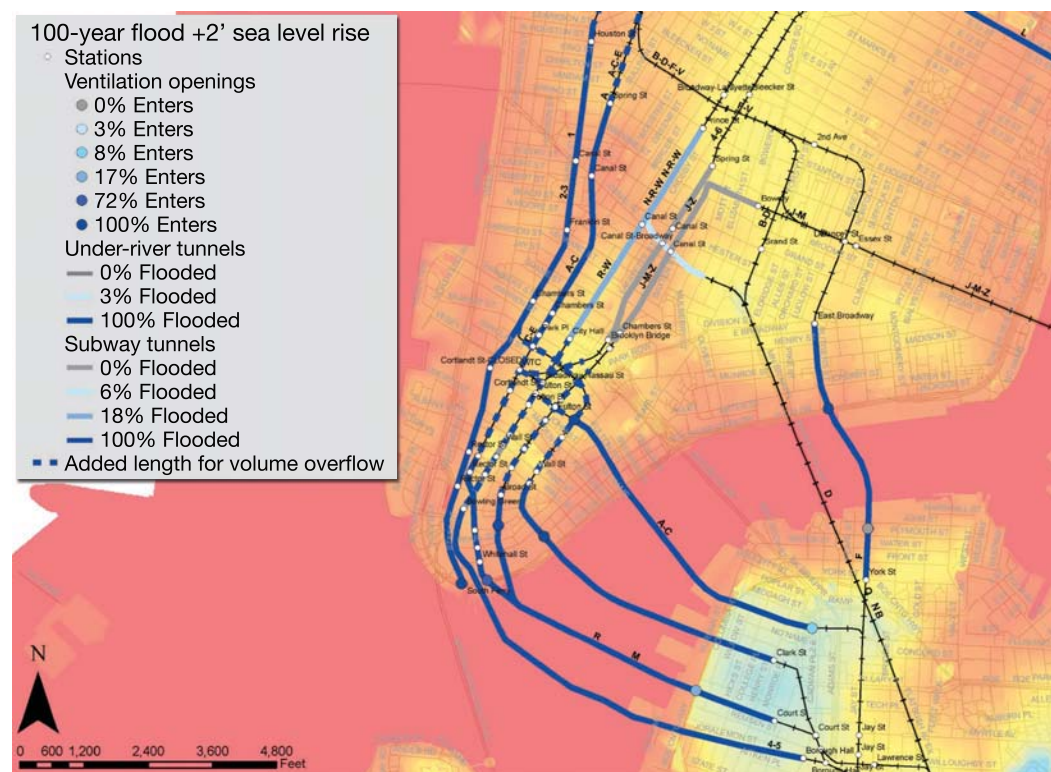
Note: Only the colored segments were considered in the ClimAID flood analysis. Purple lines are river-crossing tunnels and adjacent segments to the nearest land stations; green lines are analyzed tunnel segments on land, near or beneath flood zones. Subway stations are not shown, but non-station openings subject to potential flooding are indicated by circles. Source: LDEO/Civil Engineering, Columbia University

Figure 9.10 NYCT subway lines analyzed in the case study



Source: LDEO/Civil Engineering, Columbia University

Figure 9.11A 100-year flooding without sea level rise of Lower Manhattan subways and adjacent East River tunnels crossing to Brooklyn; the heavy blue lines indicate fully flooded tunnels, and broken lines show overflow into tunnels located in areas that are not flooded above-ground; background colors show topographic surface elevations (yellow ≥ 30 ft)



Source: LDEO/Civil Engineering, Columbia University

Figure 9.11B Same as A, but with 2-ft sea level rise; light blue lines are partially flooded

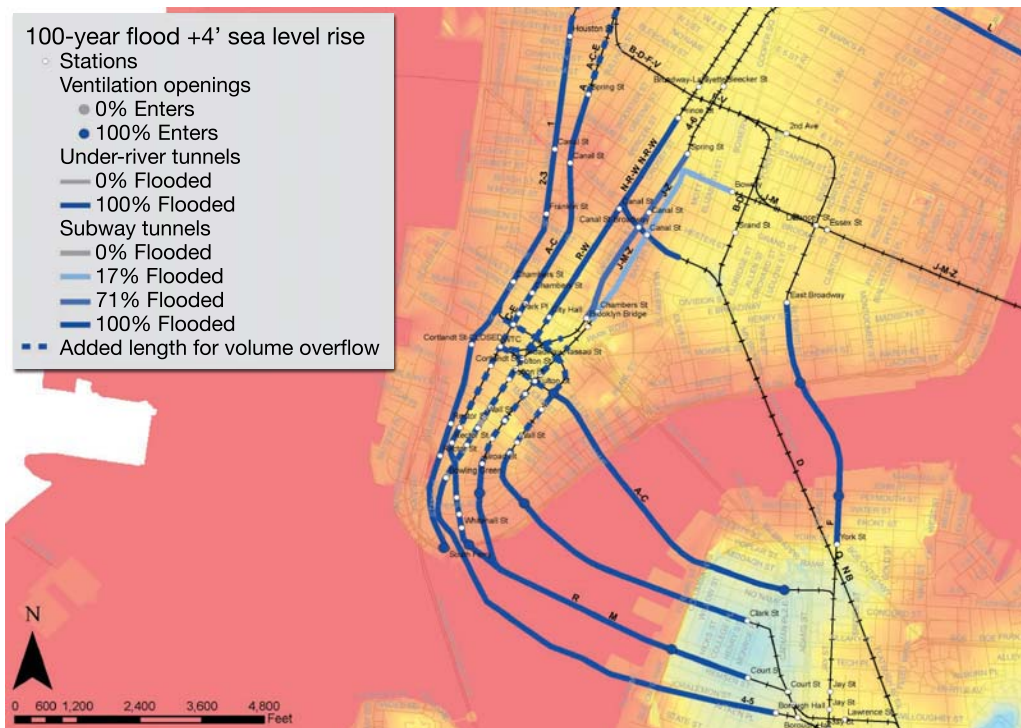


Figure 9.11C Same as A, but with 4-ft sea level rise; blue lines show additional partial or full flooding near Canal Street (Lines 4-6, J, M, Z); in all three cases East River tunnels for the 4, 5, R, M, 2, 3, and F lines are fully flooded

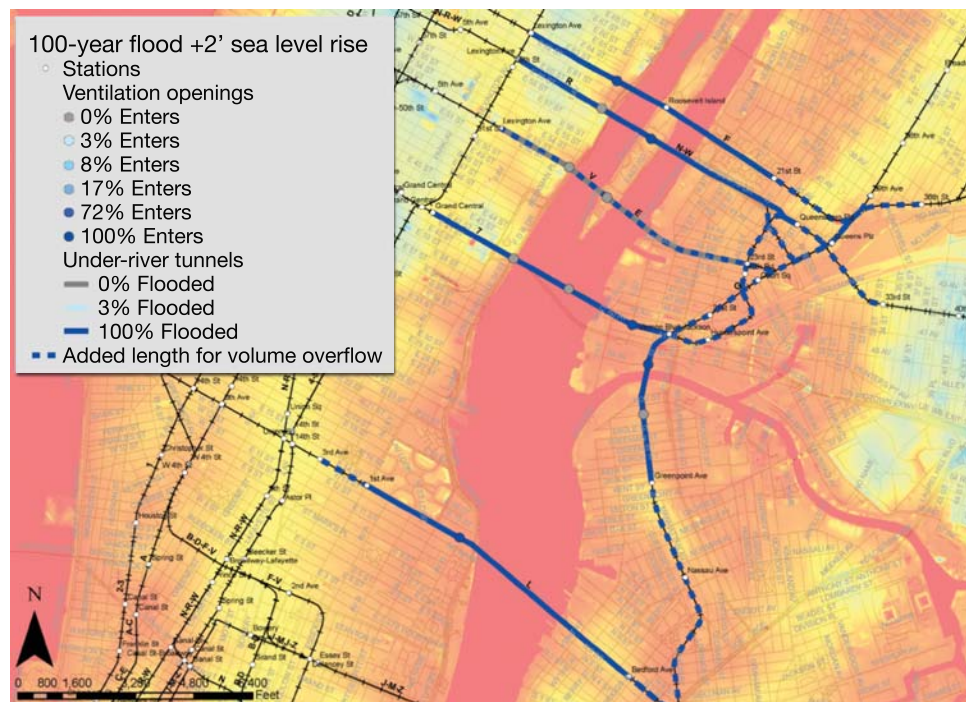


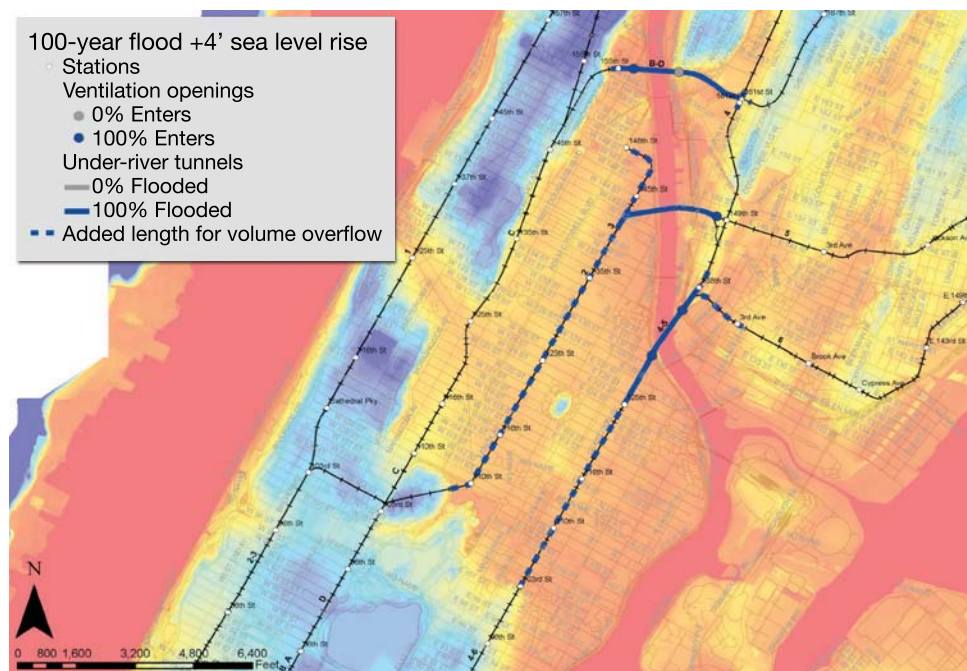
Figure 9.12 100-year flooding with 2-ft sea level rise of Midtown Manhattan subways and tunnels across the East River to Brooklyn (L line) and Queens (F, N-W, V-E, and 7 lines), and across the Newtown Creek between Queens and Brooklyn (G line).

surge of the ClimAID case study S1, without sea level rise, but the MTA study assumed that the maximum flood height would be sustained sufficiently long to fill the tunnels to the full surge elevation. Therefore the map shows the maximum extent of tunnel flooding possible for the MTA category-1 hurricane scenario. Nevertheless, the map (**Figure 9.14**) shows a striking similarity in tunnel flooding extent to the ClimAID maps (**Figures 9.11 to 9.13**), despite the different coastal storm surge elevation patterns for this hurricane-1, storm-track-specific scenario used in the MTA study, and the more elaborate, time-dependent hydraulic flooding computations by the ClimAID team. The findings of very similar results of the two studies using different storm surge patterns and methodologies support two important points:

- It provides some validation of the results of either study carried out entirely independently from each other.
- It shows that, to a first order, the subway system in certain low-lying areas is flooded or not flooded depending on whether the flood surge height exceeds the critical ground elevations of 8 to 9 ft

(NAVD, 1988). Any additional flood elevations somewhat extend the underground reach of the tunnel flooding, but not by very much. The reasons for this similarity of outcomes are twofold: 1) the effect of topography (discussed in more detail in Appendix B; extreme flood heights such as from category-3 or -4 direct-hit hurricanes would, however, extend the flooding considerably, especially on lines with modest tunnel climbing slopes); and 2) flooding of the tunnels occurs very fast to virtually the full height that the time-dependent storm surge elevations allow (see Appendix B).

One major difference between the MTA and ClimAID flood analyses is that ClimAID calculated, using hydraulic equations, the water entering the subway system as a function of time-dependent surge behavior. This approach tells how fast the tunnels are flooded, and how fast and far the flooding will spread, dependent on the amount of water that can enter the system, as long as the surge height is above the tunnel opening's lowest critical elevation (LCE). The LCE can be a station entrance, emergency exit, ventilation



Note: The most northern tunnel (B-D lines), flooded for the 4-ft SLR scenario shown here, does not flood without SLR, and only partially floods with 2-ft SLR. Also the overflow extending towards midtown Manhattan is entirely absent along the #2/3 lines for 0 and 2-ft SLR, but extends for all 3 storm scenarios to 103rd Street along the #4, 5, and 6 lines. Subway tunnel and track elevations tend to follow the surface topography (track elevations are typically about 20ft below street grade; but many exceptions exist). It is therefore not surprising that where surface topography reaches an elevation of about ≥ 30 ft (yellow shading), it creates a “dam” against underground flooding to proceed further, at least for these three storm scenarios [$30 \text{ ft (topography)} - 20 \text{ ft (track depth)} = 10 \text{ ft (approximate surge height)}$]. The ClimAID team also performed hydraulic computations for S1 and S2 scenarios (0 and 2-ft SLR). Blue shadings: ≥ 60 -ft elevations. Source: LDEO/Civil Engineering, Columbia University

Figure 9.13 100-year flooding with 4-ft sea level rise of Uptown Manhattan subways and tunnels crossing into the Bronx beneath the Harlem River

shaft, or string of street-level ventilation grates or, as in most cases, combinations thereof.

The ClimAID hydraulic calculations show that *in most instances the tunnels fill up in less than 1 hour* as long as outside flood heights exceed the LCE, almost regardless of by how much. The total volume of water that needs to be pumped from the tunnels is discussed below.

The MTA analysis (**Figure 9.14**) for the category-1 Hurricane Flooding Scenario assumes that the flood surge and the corresponding high water level takes place for several hours; in other words, there is ample time for the subway flooding to occur, at least without any prevention response (e.g., possible sandbagging, or covering of vulnerable entry points such as entrances, vents, emergency exits, etc.). Thus, the extent of flooding depicted in **Figure 9.14** could be considered the “worst case” scenario for NYCT’s system flooding for a category-1 hurricane.

Neither the MTA nor the ClimAID flood analyses take into account, however, recent ameliorative measures begun by the MTA, on a location-by-location basis, to address the propensity for storm-related flooding. For instance, planning is currently under way within the MTA to raise the Harlem River seawall along the 148th Street and Lenox Avenue subway train yard to protect the subway portal to the tunnels at that location. A program to raise ventilation grates to prevent water entry is also under way at some locations subject to recurrent flooding from high precipitation events.

Highway and Non-Subway Rail Tunnels

Discussed in this section are the potential flooding impacts to highway and non-subway rail tunnels. Critical parts of the road and rail system are vulnerable to flooding from sea level rise.

Highway Tunnels

There are four major highway tunnels connecting Manhattan with two other NYC boroughs: the Brooklyn-Battery (LCE=7.5 feet, Z1=9 feet) and Queens-Midtown (LCE=9.5 feet, Z2=11 feet) tunnels across the East River and its extension into the NY Inner Harbor (for locations see **Figures 9.2** and **9.3**); and two highway tunnels that connect Manhattan with New

Jersey beneath the Hudson River, i.e., the Holland (LCE=12.1 feet*,³⁶ Z5=9 feet) and Lincoln (LCE= 22.6 feet*, Z5=9 feet) tunnels. The Lincoln tunnel has three tubes; all others have two tubes, with two lanes per tube.

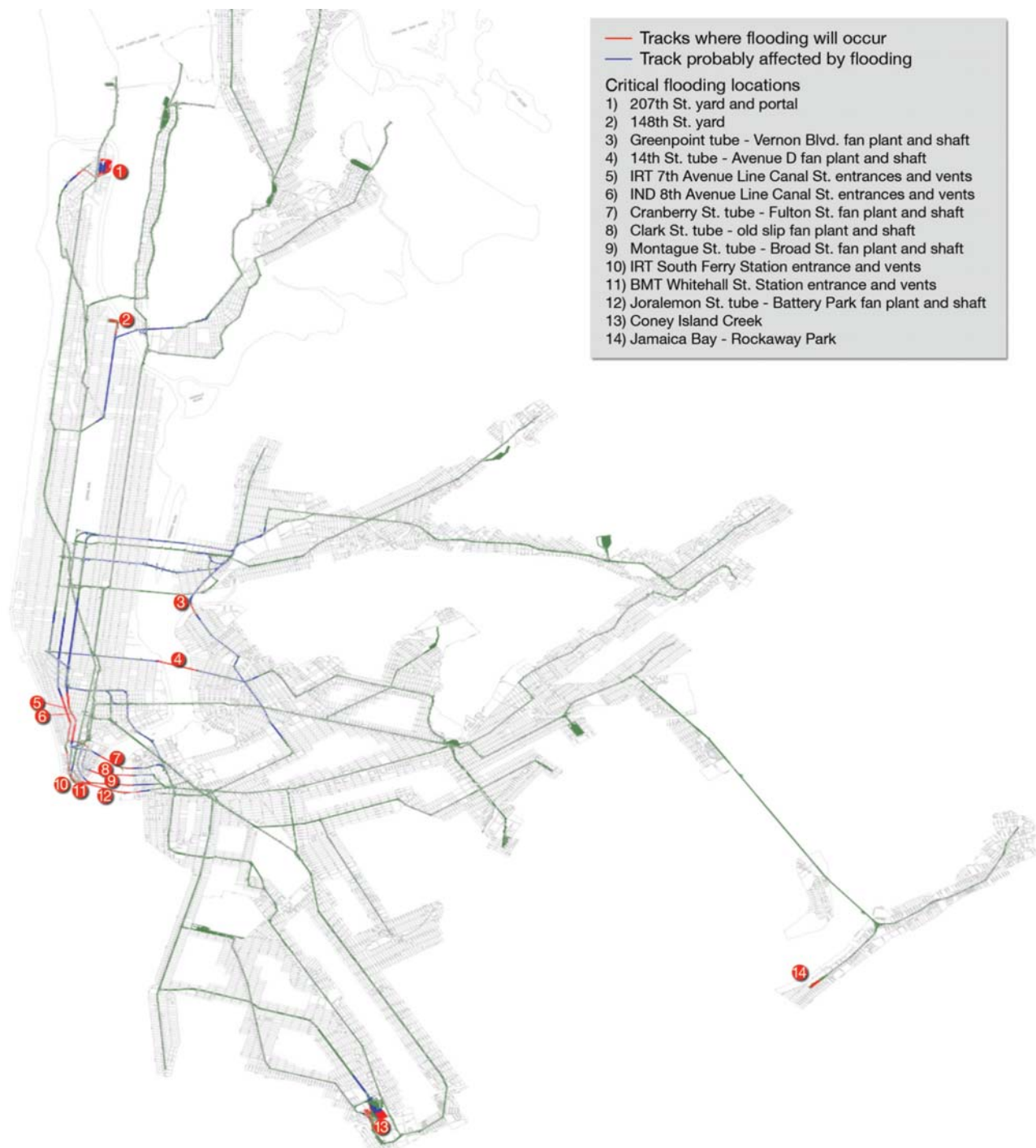
Railroad Tunnels

In addition to the subway tunnels, the following river-crossing railroad tunnels exit from Manhattan and are used by Amtrak, Long Island Rail Road (MTA-LIRR), Metro-North (MTA-MNR), Port Authority Trans-Hudson (PATH), and NJ TRANSIT:

- **North River (Hudson) Railroad Tunnel**—The North River railroad tunnel has two tubes from New Jersey into Penn Station used by Amtrak and NJ TRANSIT. The tubes are connected into Penn Station, and therefore flooding could also potentially affect LIRR facilities in Penn Station and the West Side Rail Yard (LCE = 8.9 feet, Z5=9 feet). The top-of-rail (track) elevation in Penn Station is below sea level (LCE = -7.4 feet).
- **Two Pairs of PATH Tunnels**—Two pairs of PATH tunnels cross beneath the Hudson River with LCE=9.9 feet*, and Z5=9 feet. The critical elevations are located in New Jersey and imply closing the installed floodgates at the Hoboken station (without the Hoboken station flood gates, LCE would be 6.5 feet). Parts of the PATH system, both in Manhattan, and the much longer, also entirely below-ground system in New Jersey, are in their current configuration nominally flood prone, once the surge exceeds the LCE at various locations. Also note that PATH stations have internal passages that connect to NYCT subway stations along 6th Avenue at 14th, 23rd, and 33rd Streets, Manhattan.

All PATH tunnels are interconnected in New Jersey and extend below grade into the Hackensack/Passaic River basin subject to tides and coastal storm surges. Several projects are currently under design to locally raise LCEs for some of the system openings (e.g., Washington Street Powerhouse and 15th Street Shaft, both in New Jersey). Until *all* lowest critical elevations within the system are raised above the respective base flood elevations plus sea level rise, the system may still remain vulnerable to floods, albeit may flood more slowly and hence potentially with less water to pump out.

* All LCE with an asterisk* attached are dependent on emergency operational measures (e.g., by sealing ventilation shaft doors etc.).



Note: Red symbols indicate definite flooding, blue ones potential flooding, the latter corresponding closely to the “overflow” segments in Figures 9.11–13. Green areas near the line tracks indicate locations of yards. Two yards along the Harlem River (upper left) are flooded, and so are facilities in Coney Island and Rockaway (bottom center and right). Source: MTA—NYCT, 2006, A. Cabrera (see Endnote 35)

Figure 9.14 MTA subway flooding map for a category-1 hurricane based on surge heights listed in USACE (1995)

The ClimAID team did not have proper terrain data (detailed digital elevation model data) to verify the flood potential of all New Jersey-based PATH stations and other potential entry points. While the Port Authority provided the lowest critical

elevations for all stations, the topography by which the floodwaters may reach these potential entry points needs further investigation to fully assess their flood potential under the 100-year storm height and the 2-foot and 4-foot sea level rise

scenarios. According to FEMA's Flood Insurance Rate Maps, several PATH system entry openings appear to be flood-prone. But it should be noted that during the December 1992 nor'easter storm, only the Hoboken station was flooded (then LCE=6.7 feet), while the next lowest entry point, Exchange Place (LCE=7.6 feet), was not. The World Trade Center PATH station, in New York, and adjacent terrain are currently in a state of reconstruction and, therefore, their current and future flood potentials are highly uncertain at this time. Based on the previous lowest critical elevation of the PATH system (USACE, 1995), this system appears to be flood-prone at the various states of sea level rise without additional protective measures. A more detailed analysis of all PATH entry points with updated digital elevation models and floodways is needed to better understand the flood vulnerability under current sea level and future sea level rise scenarios.

Flood vulnerability in tunnels varies, depending on whether adaptive or preventive structural (or even just operational emergency) measures are undertaken. They can best be implemented where only a limited number of openings provide flood access to the underground structures and systems. Such engineering measures are the prototype model for effective, albeit perhaps temporary, adaptation to sea level rise for tunnel systems with closed ventilation. This is unlike the ventilation system of the New York City subway, which is largely open to, and connected with, the street grade

Other Tunnel Systems

- **East River Tunnel**—This railroad tunnel is used by Amtrak and LIRR. It has a lowest critical elevation of 7.9 feet ($Z_2=11$ feet), located in Long Island City, Queens. The tunnel provides an access route westward across midtown Manhattan into Penn Station and could potentially lead to flooding there into LIRR, Amtrak, and NJ TRANSIT facilities. The North River (Hudson) and East River tunnels and Penn Station have sump and ejector pump systems. Penn is also protected from flooded river tunnels by floodgates at the east and west ends of the station.
- **Access to the Region's Core (ARC) Mass Transit Tunnel**—A new tunnel system, the ARC Mass Transit Tunnel across the Hudson River, is currently under construction.³⁷ It will increase the capacity for NJ TRANSIT commuter trains and more than double commuter rail capacity between New Jersey and New York. The ARC project also includes a new expansion to Penn Station, New York. There is no interconnection between the ARC Mass Transit Tunnel tracks and the existing New York Penn Station tracks. However, NJ TRANSIT is building a pedestrian connection between the expansion and the existing Penn Station (the LCE of the pedestrian connection is 9.7 feet, while $Z=9.0$ feet, both relative to NAVD 88). Therefore the new Penn Station extension may become vulnerable to flooding via the pedestrian connector to the existing Penn Station for the scenario that assumes a 2-foot sea level rise (S2), or whenever sea level rise exceeds 0.65 feet. The ARC rail tunnel itself has the same LCEs (11.553 feet at both its Hoboken and the 12th Avenue, NYC, shafts). It therefore may become directly vulnerable to flooding from either end for a 100-year flood for scenario S3 (which assumes a sea level rise of 4 feet) or whenever sea level rise exceeds about 2.5 feet. Modifications to the Hoboken and 12th Avenue shaft designs and to the pedestrian connector design may have to be made to avoid future flooding on either side of the Hudson.
- **The 63rd Street Tunnel**—Another new railroad tunnel under construction is the MTA-LIRR's 63rd Street Tunnel. It crosses the East River as part of the East Side Access Project. Construction began in 1969 and the tubes making up the river-crossing tunnel were in place in 1972. The tunnel runs from the intersection of 63rd Street and 2nd Avenue in Manhattan to the intersection of 41st Avenue and 28th Street in Queens. The tunnel can accommodate four tracks on two levels (two for the subway on the upper level and two for the LIRR on the lower level). The MTA connected subway lines to the tunnel in 1989. The current East Side Access Project will build new tunnels in Manhattan to connect the LIRR portion of the 63rd Street Tunnel to Grand Central Terminal and the LIRR tracks in Queens. This connection brings the LIRR into Grand Central Terminal. The original 63rd Street Tunnel (used only for the B&Q subway lines) has an LCE of 11.6 feet ($Z_2=11$ feet) on the Queens side. The new LCE is unknown at this time. The new LIRR train platforms in Grand Central Terminal will be at levels below the Metro-North track. Grand Central Terminal's current flooding potential is via the Steinway subway tunnel across the East River (42nd Street, No. 7 Line) (LCE=9.9 feet; $Z_2=11$ feet).



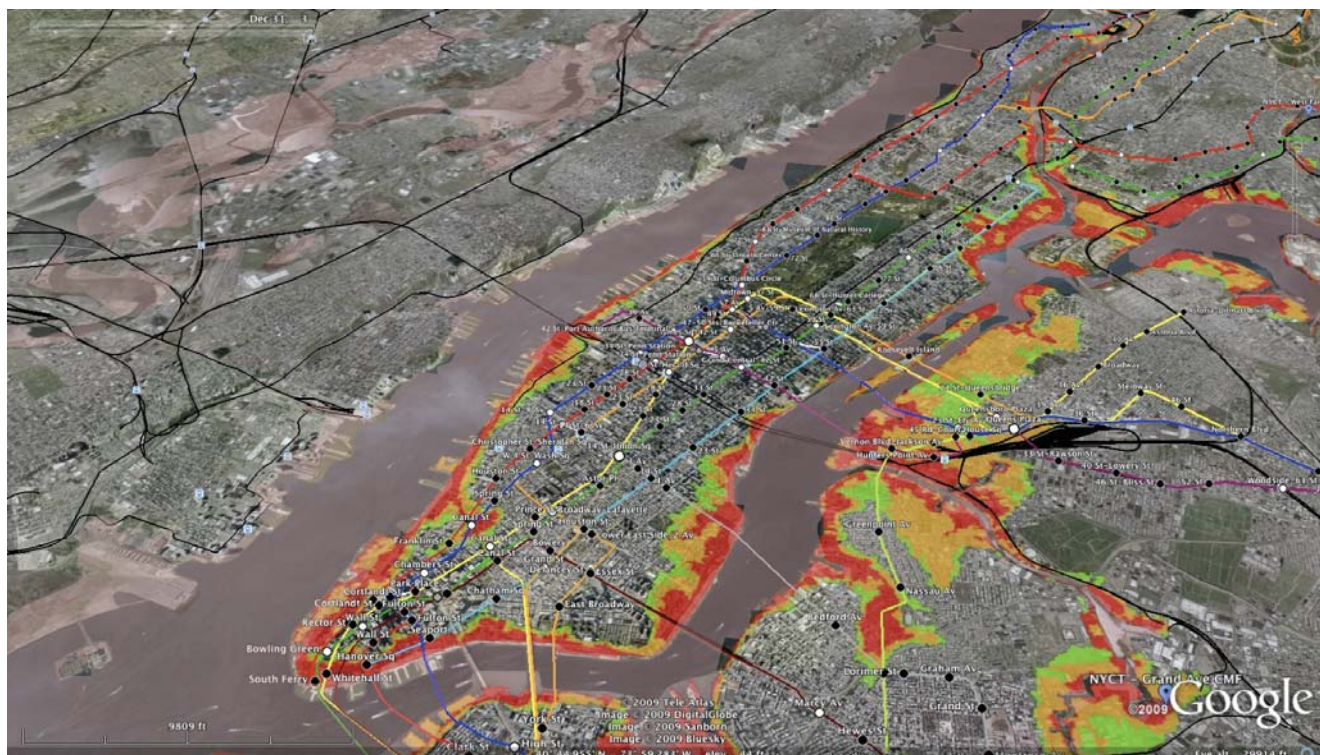
Notes: The red arrow shows the lowest critical elevation, LCE=6.6 feet, of the rail tracks located in waterway zone Z3=9 feet. The elevated concrete structures are the passenger platforms at an elevation near 11 feet. Note the low-lying parking lot in background.
Source: [http://en.wikipedia.org/wiki/Spuyten_Duyvil_\(Metro-North_station\)](http://en.wikipedia.org/wiki/Spuyten_Duyvil_(Metro-North_station))

Figure 9.15 Lowest critical elevation of the MTA-Metro-North Railroad Spuyten Duyvil Station, Bronx, next to the Harlem River

At- and Above-Grade Railroads (Commuter, Passenger, and Freight)

Outside Manhattan, many of the NJ TRANSIT and (below-ground) PATH tracks in the Hudson, Hackensack, and Passaic River Basins are flood prone, as demonstrated by the December 1992 nor'easter (USACE, 1995). MTA Metro-North trains can encounter flood-prone segments. Examples are near Spuyten Duyvil on the Harlem River (Bronx; LCE=6.6 feet; Z4=8 feet, see **Figure 9.15**) and Croton on Hudson (Westchester County, LCE=5.2 feet; 1%BFE=5.9 feet in 2000) for the Hudson Line. The LIRR may encounter flooding in Oceanside (Nassau County; LCE=8.5 feet; near Z7=8 feet; 1%BFE=6 feet) along the Long Beach Line; at Flushing (Queens, LCE=8.1 feet; Z2=11 feet) for the Port Washington Line; at low points along the Far Rockaway Line (LCE=8.1 feet; Z7=8 feet); and at the Oyster Bay Station (Nassau County, LCE=8.4 feet; near Z1=14 feet).

Hell Gate is a massive railroad bridge over the East River, connecting Astoria (Queens) with the now-joined



Notes: For Manhattan and parts of the Bronx and Queens (red=100-year base flood elevation at pre-2000 sea level; yellow=2-foot sea level rise scenario; and green=4-foot sea level rise scenario). The red-colored water-flooded areas in the Hudson River represent 9-foot sea levels (all measured in NAVD, 1988). The black lines represent railroads; the colored lines indicate various subway lines. Note that many of the railroads and subways traverse the outlined flood zones or natural bodies of water. For the details of their lowest critical elevations relative to the flood elevations, grouped by waterways in Table 9.13, see text. Source: Image from Google Earth (©2009 Google; ©2009 Tele Atlas; Image ©2009 DigitalGlobe; Image ©2009 Sanborn; Image ©2009 Bluesky); added data by ClimAID team

Figure 9.16 The Hudson, East, and Harlem Rivers and adjacent flood zones

Randall and Ward's Islands (located near the confluence of the Harlem and East Rivers, **Figure 9.16**). The two islands are politically part of the borough of Manhattan. The bridge is owned and used by Amtrak as part of its electrified Washington-to-Boston Northeast Corridor. The bridge is also used by freight trains, including CSX and various other operators, and currently provides the only rail connection from the mainland (i.e., the Bronx) to Long Island. As the elevated tracks descend northward over a narrow arm of the East River into the Bronx, the tracks approach ground level in a 1-percent-per-year flood zone (Z2=11 feet). Therefore, they are likely to be flood prone and block access to the bridge under sea level rise. However, their exact LCE is not known at this time.

CSX operates a freight line along the west shore of the Hudson River of the tidal Mid-Hudson Valley. The exact LCEs for various segments of the freight line between Haverstraw Bay and Albany are not well known at this time. But some track segments are suspected to be prone to flooding at multiple locations at the 100-year flood level, if not at current sea levels then very likely for the 2-foot and 4-foot sea level rise scenarios.

Yards and Depots for Subway, Commuter Rail, and Bus Maintenance and Storage

The MTA-NYCT, MNR, LIRR, and LI Bus Agencies operate extensive yards and shops for storing and maintaining their rolling stock used in the greater New York City metropolitan area. Most of these are located at low elevations. Subway yards on 207th and 148th Streets in Manhattan bordering the Harlem River and Coney Island Creek Yard in Brooklyn are vulnerable (**Figures 9.13 and 9.14**). A systematic evaluation of railroad yards (MNR, LIRR) and of bus depots has not been made for this case study, but needs to be performed in the future.

Major Highways and Access to Major Bridges

The following information is compiled from data provided by NYSDOT (Arthur Sanderson, personal communication, August 2009), USACE (1995), and MTA B&T. NYSDOT compiled a list of locations along interstate highways and state highways crossing locations where the digital elevation model (DEM) gave ground elevations at or below 10 feet above sea level (**Figure 9.17**; **Box 9.1**). This determination was performed using a USGS digital elevation model with 10-meter (about 33 feet) *horizontal* grid spacing. The vertical reference datum is NAVD 1988.



Notes: These sections may be flood-prone either now or become so in the future with elevated sea level, since the terrain on which they are built is at or below about 10 feet in elevation (NAVD, 1988). A more labor-intensive analysis of as-built plans and elevations will be required to determine the exact pavement elevations and their vulnerability as a function of flood probability and sea level rise. County and town roads are not considered. Black lines are railroads. Airports are also indicated. Potential flood points in New Jersey, Connecticut, and Rhode Island are not shown. Source: Base map from Google Earth (©2009 Google; ©2009 Tele Atlas; Data SIO, NOAA, U.S. Navy, NGA, GEBCO; Image ©2009 New York GIS; Image ©2009 DigitalGlobe); NYS DOT data added by ClimAID team

Figure 9.17 The 123 sites identified by NYSDOT as potentially flood-prone state highway or interstate highway sections

Box 9.1 Number of interstate and major state highway segments in potentially flood-prone terrain

- 35 locations within the 5 boroughs (counties) of NYC
- 13 locations within Nassau County, Long Island
- 56 locations within Suffolk County, Long Island
- 6 locations in Westchester County (5 along Long Island Sound, 2 along the Hudson).
- 2 locations in Orange County, Mid-Hudson Valley
- 3 locations in Greene County, Mid-Hudson Valley
- 4 locations in Columbia County, Mid-Hudson Valley
- 1 location in Albany County, Mid-Hudson Valley
- 3 locations in Rensselaer County, Mid-Hudson Valley

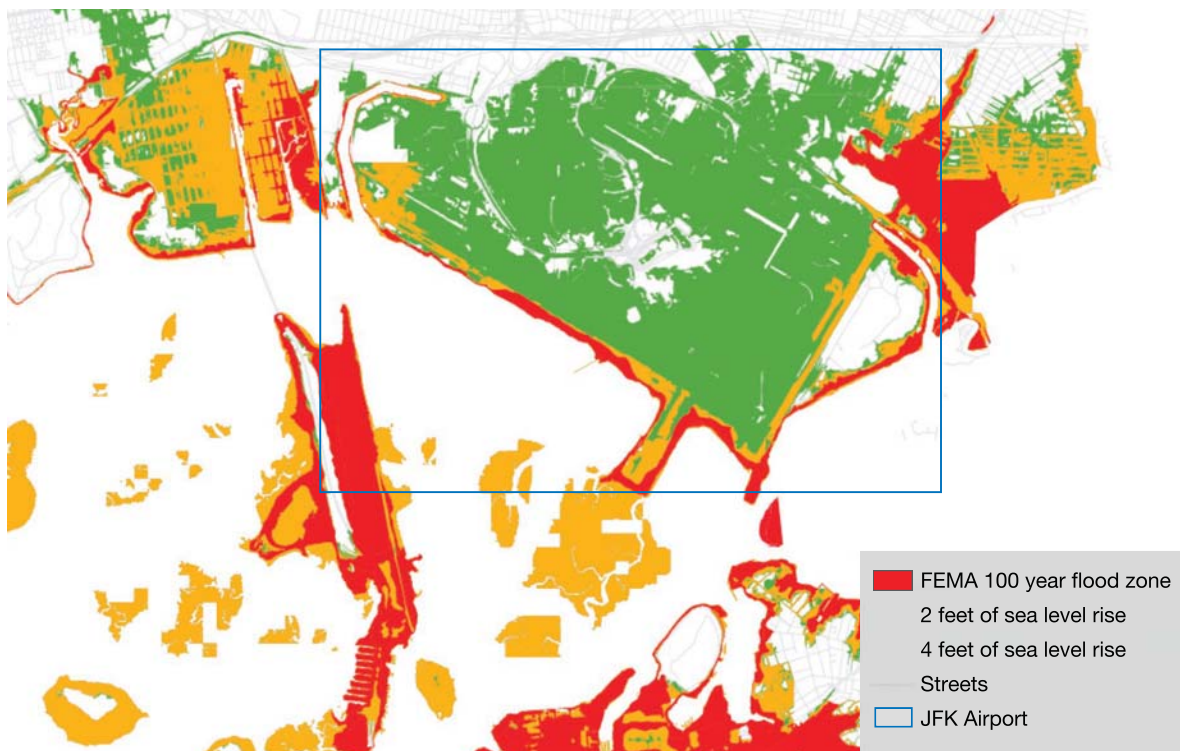
Name	Location	LCE	Z
Marine Parkway Bridge	Brooklyn to Rockaway/Queens	6.9 feet	Z8 = 9 feet
Cross Bay Bridge	Broad Channel to Rockaway, Queens	6.9 feet at north approach	Z8 = 9 feet
Bronx Whitestone Bridge	Bronx to Queens across East River	10.9 feet on Bronx side	On the border between Z1 = 14 feet and Z2 = 11 feet
Throgs Neck Bridge	Bronx to Queens across East River	8.9 feet on Bronx side	Z1 = 14 feet
Robert F. Kennedy (formerly Triboro) Bridge	Manhattan and Bronx with Queens	13.9 feet in Manhattan	On the border between Z3 = 9 feet and Z2 = 11 feet
Verrazano-Narrows Bridge	Brooklyn to Staten Island	7.6 feet	Z5 = 9 feet, only for its Shore Parkway approach, in Brooklyn

Table 9.1 Metropolitan Transportation Authority - Bridges & Tunnels bridge access ramps in potentially flood-prone terrain, with lowest critical elevation (LCE) and base flood elevation (Z)

Note that county, town, and village roads are not included in this list. Also, engineered road surface elevations are different from terrain elevations and this difference is not accounted for at this time. It will require considerable personnel efforts for this information to be extracted from as-built engineering drawings. Since most highway roadbeds are slightly elevated above the surrounding terrain (excluding road cuts), the list may overestimate the number of highway segments at potential flood peril from sea level rise and coastal storm surge.

While not located in New York State, there are about two dozen New Jersey locations in the tidal Hackensack/Passaic River Basin listed as flood prone (some of them were flooded during the December 1992 nor'easter storm; USACE, 1995). This flooding could affect the return of New-Jersey-bound commuters from New York City and impede disaster assistance transport into the city during and after a storm surge.

The MTA B&T bridge access ramps and/or some related toll plazas listed in **Table 9.1** are potentially



Note: For 100-year base flood elevations under current sea level conditions (red) as well as flooded areas under the 2-foot sea level rise scenario (yellow) and the 4-foot sea level rise scenario (green). JFK is in the center upper half, with a nominal runway lowest critical elevation equal to 10.6 feet and Z7 = 8 feet (NAVD 1988). Flooding at much of JFK for the 100-year storm is largely limited to the 4-foot sea level rise scenario (green shading). Map source: Hunter College, prepared for NYC NPPC, 2010

Figure 9.18 Flood zones near Jamaica Bay, Broad Channel, and JFK Airport

flood prone, either for current conditions or for the 2-foot or 4-foot sea level rise scenarios (LCE and Z in NAVD, 1988).

Airports

Seven airports serve the greater New York City metropolitan region and southeastern New York State area: JFK and LaGuardia (both in Queens), Newark, Teterboro, McArthur (Town of Islip, Suffolk County, Long Island), Westchester County Airport, and Stewart Airport (Orange County, New York). The first four and the last one are operated by the Port Authority, while the two others are owned by the Town of Islip and by Westchester County, respectively. Of these, only the first four are located close to sea level and need assessment regarding the exposure to coastal storm surge and sea level rise (Table 9.2).

There are several heliports on the waterfront in Manhattan, but because their fixed infrastructure is minimal they are not considered here.

The lowest critical elevations of the four airports serving the New York metropolitan region that are potentially vulnerable to coastal storm surge are as follows:

- **LaGuardia**—LaGuardia already has levees and pumping systems to protect major portions of the facility. While the runway has a lowest elevation of 5.7 feet (range of 5.7 to 20.8 feet), the actual lowest critical elevation is raised by the levees to about 10.0 feet, which nominally is still below the average Z2=11 feet. Sea level rise will eliminate the existing levee's effectiveness even for lesser storms.
- **Teterboro**—Teterboro airport largely serves private and business jet air traffic. It has the lowest nominal LCE of any of the facilities (USACE, 1995): LCE=3.9 feet; Z5a=8 feet.
- **JFK**—As can be seen from Table 9.2 and Figure 9.18, most of JFK airport is susceptible to a 100-year storm only in the 4-foot sea level rise scenario (Figure 9.18, green area). Hence its runways should be relatively safe from coastal storm surge flooding, at least for 100-year and lesser storms, for several decades into the future. There may be street and underpass flooding potential during more frequent heavy precipitation events at access roads, but this is unrelated to sea level rise.

- **Newark**—Newark Airport has a nominal LCE of 9.2 feet (USACE, 1995). Since it is located in New Jersey, no Z value for the 100-year flood has been determined for this study. However, it is located close to a Z5a of 8 feet and therefore is assumed to be nominally subject to flooding for the S2 scenario (SLR of 2 feet).

Shipping Ports

Most major shipping ports, container storage, and transfer facilities (to road or rail) for the greater NYC metropolitan area are operated by the Port Authority and are located in New Jersey (see Figure 9.19), except for the Howland Hook Marine Terminal (Staten Island, LCE=8.5 feet; Z5a=8 feet) and Brooklyn Marine Terminal/Red Hook Container Terminal, both in Brooklyn (LCE=8.7 feet; Z5=9 feet). There are many other independently owned and operated port facilities associated with petroleum, dry, and liquid bulk cargos in the greater metropolitan area that are not associated with the Port Authority.

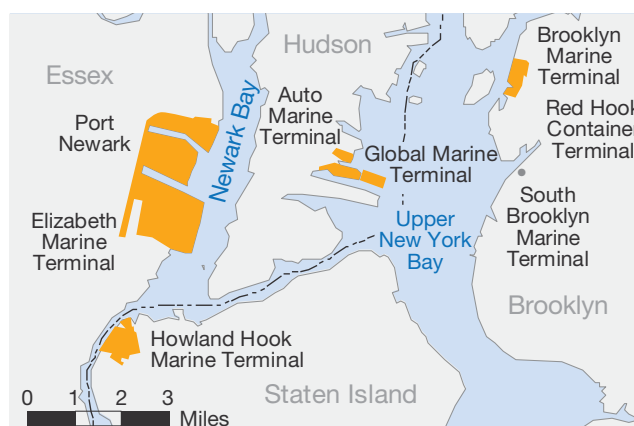
Name	Location	LCE	Z
JFK International	Queens, NY	10.6 feet	Z7 = 8 feet*
La Guardia	Queens, NY	10.0 feet**	Z2 = 11 feet
Newark International	New Jersey	9.2 feet	Z5a = 8 feet
Teterboro	New Jersey	3.9 feet	Z5a = 8 feet***

* See Figure 9.18

** Levee crest; The elevation range for the runways is between 5.7 feet and 20.8 feet in NAVD 1988.

*** Partly sheltered from Z5a and hence attenuated to probably 4 to 5 feet.

Table 9.2 Lowest critical and base flood elevations (LCE, Z) of airports



Notes: For smaller port facilities, see text. Source: The Port Authority of New York and New Jersey, 2001

Figure 9.19 Major port facilities in the Greater New York City Metropolitan Area operated by the Port Authority

Other port facilities serve the Staten Island Ferry (Manhattan to Staten Island); the New York Waterway Commuter Ferries leaving Manhattan from West 39th Street, World Financial Center, and Pier 11/Wall Street; and various water taxi services throughout the New York Inner Harbor and lower Hudson Valley. The International City Passenger Terminal (west side of Manhattan between W48th and W54th Streets; LCE=7.8 feet; Z4=8 feet) is a privately operated facility mostly serving large cruise ships.

Most of the piers themselves can accommodate, or could be modified to accommodate, coastal storm surges and sea level rise, although under severe storm conditions their services may be curtailed or stalled because of wind and wave safety conditions. However, the freight and container storage and transfer facilities, (including derricks, cranes, access roads, and rail tracks), may be flooded. The flood conditions for such harbor facilities and their potential vulnerabilities are not yet sufficiently researched and need future attention. Most of these facilities in the New York/New Jersey harbor area appear to have their lowest critical elevations near 8 to 9 feet, while their baseline flood elevations are: Z4=8 feet; Z5=9 feet, and Z5a=8 feet (see **Table 9.13** of Appendix B, and **Figure 9.8**). Thus some are at risk of flooding.

Other Facilities

For transportation systems to operate properly, support systems are needed. The most prominent among these—and potentially vulnerable to coastal storm-surge flooding—are the following:

Electric Grid Power

This is either needed for direct propulsion (e.g., via supply from the third rail of the NYCT subway, or the MTA-MNR and Amtrak overhead line contact wire), pumping out of tunnels, signal and control systems, fuel supply and storage pumps, and other support functions (e.g., general communications, ticketing, toll plazas, lighting, office operations, etc.).

Pipelines

Pipelines, either local or regional, provide the necessary fuel supplies to airports, power plants, and heating/cooling and other facilities, and often have pumping and control systems that depend on grid power.

Communication Systems

Many transport systems are dependent on communication systems working properly, from Federal Aviation Administration flight controllers relying partly on long-distance lines for airport-to-airport control tower communication, to intelligent road signs, wireless dispatchers' communications with bus drivers, and for monitoring safety control systems.

Many of the above-listed transportation support systems (e.g., communication, air traffic control systems) have uninterruptible power supply units for finite-duration back-up power, but such power supply systems are not available for transportation systems with large demands, such as subways, electrified trains, tunnel water pumping and ventilation, or even their signal and control systems. As long as the electricity grid is not functional for such priority users, these transportation systems cannot be restored and repaired to functionality, nor operated once restored.

Regional Impacts and Restoration Times

A risk assessment of the full impacts of flooding resulting from a 100-year coastal storm surge on the regional transportation infrastructure has yet to be made. The U.S. Army Corps of Engineers (1995) hurricane transportation study evaluated the New York City metropolitan area's emergency preparedness and ability to evacuate people given a category-1 through -4 hurricane along a worst-track trajectory, i.e., a direct hit. A very similar approach was taken by a study sponsored by the Department of Homeland Security (NISAC, 2006). The study, conducted by Sandia's National Infrastructure Simulation and Analysis Center (NISAC), focused on a direct hit by a category-3 hurricane on New York City, with landfall in a northerly direction crossing Staten Island and affecting the Mid-Hudson Valley and adjacent regions up to Albany. The analysis assumed a coastal maximum storm surge height of up to 19 feet, substantially higher than the proposed 100-year surge of this case study.

The Corps of Engineers study (USACE, 1995) and the NISAC study (NISAC, 2006) use scenario events that, in contrast to the ClimAID case study, have no probabilistic assessments attached. For this reason, the results of these studies are generally difficult to use for engineering decisions, unless a specific infrastructure owner opts to design according to worst-case scenarios,

which is rarely the case. Most engineering design standards and practices use probabilistic rather than deterministic hazard and risk characterizations. This is why the ClimAID analysis uses a probabilistic base for its case study—i.e., the 100-year coastal storm-surge base-flood elevation. Deterministic scenario events like those constructed by the Corps of Engineers (1995) and NISAC (2006) studies are, however, commonly used for emergency response and preparedness planning exercises. For these, worst-case scenarios at various levels (e.g., hurricanes of categories 1 through 4) are commonly used. This reflects a difference between the emergency and engineering professions.

Nevertheless, deterministic and probabilistic assessments are useful. Therefore, the ClimAID analysis builds on insights gained from the 1995 and 2006 studies. Another benefit to such studies is that the general public can understand a deterministic, “real” scenario much better than the conceptually more sophisticated and abstract probabilistic approach.

One of the pertinent results of the NISAC (2006) study emerges from its focus on the vulnerability of the electric power grid (see Chapter 8, “Energy”). The study estimates that it will take up to 15 days after determining the damage for the electric grid to be fully restored throughout the entire affected area (**Figure 9.20**). It did not, however, estimate how long it would take to sufficiently assess the damage after a coastal storm surge.

Other studies that looked at the total financial losses to the region from coastal storms are presented in the Metropolitan East Coast (MEC) study (Rosenzweig and Solecki, 2001; Jacob et al., 2000, 2007). Losses from direct hits of category-1 hurricanes for the New York City metro region were about \$5 billion; losses from direct hits of category-4 hurricanes were about \$250 billion (in 2000 dollars; in 2010 dollars, these figures would nearly double). These losses were derived without detailed technical risk- and vulnerability assessments of the major infrastructure systems. The costs associated with a direct hit of a category-3 hurricane on New York City, considered by the NISAC study (2006), were between \$29 billion and \$42 billion, including coastal storm surge and wind damages.

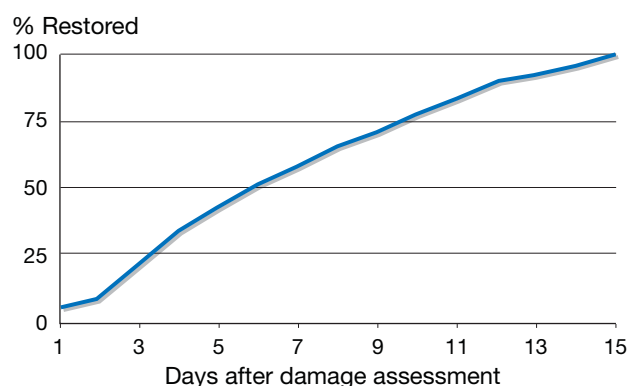
The ClimAID analysis takes a different approach to timing of recovery after a storm and valuation of damage, asking the question: How long would it take

to restore the transportation system to nearly full functionality after a 100-year storm under the three sea level rise scenarios? This outage time is then considered in the estimated economic impact on the region. A summary of the approach is given in **Box 9.2**.

A number of uncertainties are included in this analysis.³⁸ Currently, estimates of system vulnerability, repair, and restoration times and/or associated costs are not available because there are too many unknowns. Another uncertainty is whether grid power will remain uninterrupted and, if interrupted, how long it will take to restore. The analysis is site- and system-dependent, given the lack, to date, of a rigorous engineering risk and vulnerability assessment. The case study’s findings need to be verified in the future through more comprehensive engineering risk assessments.

Underground Rail Systems

Many of the underground rail systems—especially the NYCT subways, NJ TRANSIT and Amtrak passenger systems, and the PATH, MTA-MNR, and LIRR commuter rails—are highly interconnected underground, and extend to considerable depth below sea level as they traverse bodies of water by tunnels or below ground. Even if some of the rail, commuter, and passenger systems are closed to the open air or to grade



Notes: The analysis is based on a direct hit of a category-3 hurricane on New York City. The study estimates that priority users in New York City may have their power restored within 11 to 129 hours (a half day to five days after damage assessment). For the purpose of the 100-year coastal storm surge scenario considered in the ClimAID analysis, it is assumed that an average power outage for New York City’s priority customers is at least one day after the floods recede, with a range of one to two days depending on sea level rise scenario (see Table 9.5, row 2). Note that the NISAC study largely considers damage to the distribution system (including substations) and not to the electric generation system; it also includes wind damage in addition to flood damage. Source: NISAC, 2006

Figure 9.20 Percent of electricity service restored for the amount of time after the storm damage has been assessed in New York City

Box 9.2 Methodology to estimate transportation and related system outage times (see Table 9.5)

- 1) Take the surge elevations of the three scenarios (1%/y base flood elevation, and add 2 feet and 4 feet sea level rise).
- 2) Map out which transportation systems above and below ground would be flooded.
- 3) Obtain the volume of below-ground flooded tunnel structures from the ClimAID team's hydraulic calculations.
- 4) Combine the volumetric information with available pumping capacity to arrive at time estimates of how long it would take to pump out the floodwater.
- 5) Consider the time it would take to restore electricity and for logistic and environmental preparations before pumping could actually start; in some instances it is possible that some limited pumping can be maintained throughout the flood event if mobile generators can feed some of the pumps.
- 6) Estimate the times it would take to repair the flood damage in the submerged structures.
- 7) Combine all the above times that result in total transportation outage (or the times needed to reach certain percentages of transportation capacity to be restored).
- 8) Estimate the economic impact from this sequence of events and outages and restoration of transportation systems.
- 9) Conclude what adaptation and protective options exist and what strategies and policies could be taken to adapt to the hazards and risks and make the systems resilient and sustainable.

Note: The time it takes to fill the tunnels at those locations where the flood surge can reach unobstructed openings is typically very short (less than an hour) and in most cases shorter than the time the surge exceeds the LCE. These calculations have shown that if floodwaters can reach tunnel openings at all, the tunnels typically flood to underground elevations that are approaching the maximum storm-surge elevations that the storm has reached outside the tunnel system.

level, except for their engineered and in some cases protected entrances and vents, they still may be prone to flooding by their connectivity (in many instances) to other tunnel systems. For example, over large portions of their length the New York City subway tunnels are open to street level, via ventilation grates and other openings. Once flooding starts in one of the systems at its lowest critical elevation, flooding will quickly spread to other low-elevation systems below ground, regardless of their respective surface (at-grade) lowest critical elevations. This was demonstrated in the ClimAID scenario analysis for the subway system (**Figures 9.11–9.14**).³⁹ The question that arises is: Will the installed pumping systems be able to maintain their pumping capacity? While no definite answer could be obtained, the consensus in stakeholder discussions was that, at least in the case of the subway pumps, they would likely cease to function. This would mean that pumping capacity, including power, would need to be provided from other sources in most cases. Currently NYCT has only three mobile pump trains available for the entire system. Each has a 5,000 gallons/minute pumping capacity.

Road Tunnels

Road tunnels across the Hudson and East Rivers are isolated from these interconnected rail systems and can therefore be more readily evaluated. The Lincoln Tunnel (across the Hudson) is not likely to flood

because operational emergency measures are in place that seal those openings that would be submerged. Despite similar measures, the Holland Tunnel is expected to flood under the 4-foot sea level rise scenario (i.e., only for scenario S3). Hydraulic computations for the two East River Tunnels show the results for total flooding, i.e., flood water influx exceeds 100 percent of the tunnel volume, for the three sea-level scenarios S1 through S3 (current sea level, 2-foot rise and 4-foot rise) (**Table 9.3**).

The ClimAID analysis then posed the following question: Assuming that grid electricity is fully available and the installed tunnel pumps would work without interruption, how long would it take to pump out one of the tunnels if it had filled 100 percent? The results are shown in **Table 9.4**. These times apply only for the assumptions stated and are not necessarily used later on in other parts of the scenario case study, where it is assumed that additional pumping capacity can be brought in, or tunnels are not completely filled (**Table 9.5**).

Flooding Via	Brooklyn Battery Tunnel			Queens Midtown Tunnel		
	S1	S2	S3	S1	S2	S3
Portals	36%	167%	254%	0%	22%	105%
Ventilation	0%	3%	49%	0.30%	4%	45%
Total	36%	170%	303%	0.30%	26%	150%

Note: Percentage volume of flooding in the tunnel by flood entry location under S1, S2, S3 sea level rise scenarios.

Table 9.3 Total flooding for the two East River Tunnels

For those tunnels that fully flood under the three scenarios, it would be desirable to shorten pumping times by bringing additional mobile pumping capacity to accelerate the process. Such options are discussed below in the context of subway tunnels.

The current and future interconnectivity between Penn Station and Grand Central Terminal is poorly defined. As a result, no technically based pumping time estimates can be provided for the Amtrak/NJ TRANSIT Hudson Tubes and the Amtrak/LIRR East River 42nd Street Tunnels and connected systems. The NJ TRANSIT ARC tunnel across the Hudson (postponed in 2010), leading to a new Penn Station, has not been fully assessed at this time. This is also true of the future LIRR 63rd Street Tunnel (across the East River) as part of the LIRR connection into Grand Central Terminal. Any time estimates for these facilities are therefore very preliminary (Table 9.5).

Pumping Time for NYCT Subway Tunnels

With respect to NYCT subway tunnels, it is convenient to differentiate between land-based sub-grade subway tunnels with elevations prone to flooding in the three scenarios, and those subway tunnels leading to and including river crossings.

The estimated total volume of flood-prone subway tunnel and station volumes *below grade and on land*, assuming unobstructed access of the floodwaters to tunnels at elevations below the respective flood heights,

for the three flood scenarios (current sea level, 2-foot rise and 4-foot rise) is shown in Table 9.6.⁴⁰

There are currently 14 operating subway tunnel crossings below the following rivers: East River (10), Harlem River (3), and Newtown Creek (1). Some of these tunnels are sunk from above into the excavated river mud, some are driven through hard rock, and some are shield-driven through deep, silty river sediments. The estimated total volume of flood-prone subway tunnels below rivers and their connections to the nearest land stations for the three flood scenarios has been found to be equal to or larger than the flood volume of on-land flooded tunnels. The total water volume to be pumped from the subways after a 100-year storm event is, therefore, estimated to be about 1 billion gallons. This is equal to one day of the entire New York City's average water consumption. The City water supply, however, does not need to be pumped; it is supplied by gravity from reservoirs farther north at higher elevations. However, water has to be pumped to tanks on buildings above 6 stories.

The volumes and lengths of flooded tunnels, whether below ground or rivers, are projected to increase slowly with sea level rise. This indicates that a) whether a tunnel floods depends on whether the lowest critical elevations have been reached by the flood waters (about 7 feet above NAVD 1988, for current system properties); and b) sea level rise increases the annual probability of flooding more than the impact of a given flooding event, once the critical flooding stage is reached.

Tunnel	Pumping time
PATH (Rail) Tunnels and all connected systems in NJ & NY*	5 to 7 days*
Lincoln (Road) Tunnel**	does NOT require pumping**
Holland (Road) Tunnel***	3 to 4 days***
Queens Midtown (Road) Tunnel (QMT)	approx. 16 days****
Brooklyn Battery (Road) Tunnel (BBT)	approx. 3 days
Pumping times for North (Hudson) and East River Tunnels, and connected Penn Station used by Amtrak, NJ TRANSIT and LIRR, were not yet considered for this Report, but need attention based on engineering assessments of floodways and flood gates.	

Note: Some of the listed tunnels (see * through ****) do not flood at all under the Scenarios S1 through S3, and others flood only partially as described above. For the actually used scenario pumping times see Table 9.5, which takes into account the flooding potential for S1 through S3 scenarios, and other factors such as availability of mobile pumps. BFE = base flood elevation.

* Note that the PATH tunnel system in NY and NJ does not flood for the S1 scenario, provided that protective gates installed at some locations in the system are fully effective. Its partial or full flood potential for S2 and/or S3 scenarios is discussed in the text, but has not been confirmed at this time.

** Note that the Lincoln Tunnel does not flood for scenarios S1 through S3, provided emergency operational measures of sealing ventilation shaft doors are fully effective.

*** Note that the Holland Tunnel does not flood for scenarios S1 and S2, provided emergency operational measures of sealing ventilation shaft doors are fully effective. Holland Tunnel may flood, however, under scenario 3 (BFE+4ftSLR); internal pumps would require ~3–4 days pumping. For both, Holland and Lincoln Tunnels mobile pumps are available that can significantly increase pumping capacity when needed.

**** Lower scenario times used for QMT in Table 9.5 in this chapter use calculated hydraulic flood volumes leading to only partial flooding, and use of additional mobile pumps in case of full flooding.

Table 9.4 Estimates of pumping times for fully filled major river-crossing, non-subway tunnels, and assuming use of only internally installed pumps