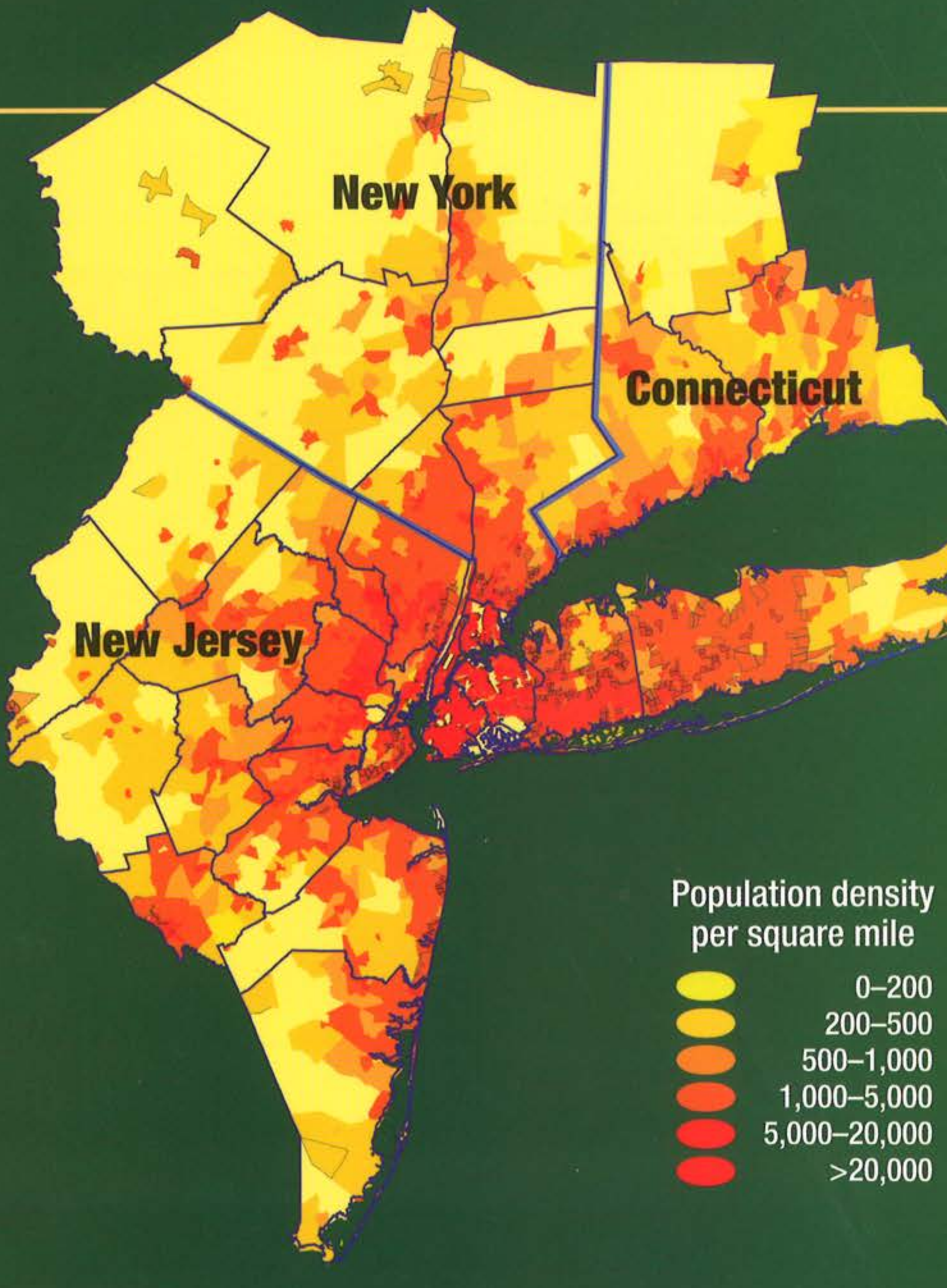
Climate Change and a Global City

The Potential Consequences of Climate Variability and Change



Metro East Coast

A Report of the Columbia Earth Institute

For the U.S. Global Change Research Program

July 2001

METRO EAST COAST CONTRIBUTION TO THE NATIONAL ASSESSMENT OF THE POTENTIAL CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE FOR THE UNITED STATES

This volume is the Metropolitan East Coast contribution to the National Assessment of the Potential Consequences of Climate Variability and Change for the United States.The overall goal of the National Assessment is to evaluate what is known about the potential consequences of climate variability and change in the context of other pressures on the public, the environment, and the Nation's resources. The National Assessment process has been inclusive, drawing on inputs from academia, government, the public and private sectors, and interested citizens. Starting with broad public concerns about the environment, the Assessment explores the degree to which existing and future variations and changes in climate might affect issues that people care about. The National Assessment has three major components: regional analyses, sectoral analyses, and a national overview. Each of the regional, sectoral, and synthesis activities is led by a team comprised of experts from both the public and private sectors, from universities and government, and from the spectrum of stakeholder communities.

CLIMATE CHANGE AND A GLOBAL CITY

The Potential Consequences of Climate Variability and Change

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METRO EAST COAST

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*Stakeholders are institutions whose activities are and will be impacted by present and future climate variability and change, and thus have a stake in being involved in research of potential impacts. Although stakeholders are an integral part of the research process, the findings that result from this research do not necessarily represent the opinions or policy positions of the stakeholder institutions.

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EXECUTIVE SUMMARY

Large cities are at the forefront of both vulnerability and adaptation to climate impacts. These cities are commonly located on coastlines and are home to a rapidly growing percentage of the earth's people. The need for understanding climate impacts in urban areas is growing, as urban dwellers and decision-makers are being challenged to devise new types of adaptations and adjustments. For a global city such as the New York Metropolitan Region, climate variability and change present complex challenges and opportunities.

The Metropolitan East Coast (MEC) Regional Assessment is one of the regional components of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, organized by the U.S. Global Change Research Program. The goal of each regional assessment is to investigate potential impacts of climate variability and change on the natural systems and human activities of a specific geographical area of the United States. Major objectives are to identify sectors that are vulnerable to the additional stresses that climate change and increased climate variability will introduce and to examine feasible adaptation strategies. The Metro East Coast Regional Assessment focuses on climate variability and change in a major urban center.

The Assessment covers the 31 counties of the New York City Metropolitan Region (Figure E-1). The area consists of 13,000 square miles, with jurisdictions involving 1,600 cities, towns, and villages in the three states of New York, New Jersey, and Connecticut. The 2000 U.S. Census numbered the total regional population at 21.5 million, of which 8 million live in New York City.

The MEC Regional Assessment examines how three interacting elements of large cities react and respond to climate variability and change (Figure E-2). The three elements are: *people* (i.e., socio-demographic conditions), *place* (i.e., physical and ecological systems), and *pulse* (i.e., decision-making and economic activities). Seven sector studies form the core of the interacting elements: Sea-Level Rise and Coasts, Infrastructure, Wetlands, Water Supply, Public Health, Energy Demand, and Institutional Decision-Making. The sector studies address climate impacts through analysis of historical climate trends, responses to extreme climatic events, and scenario projections. Key to the assessment process is the focus on identification of vulnerabilities, adaptation strategies, policy recommendations, and gaps in knowledge. Each sector of the MEC Assessment collaborates with representatives from one or more relevant stakeholder institutions (Table E-1).

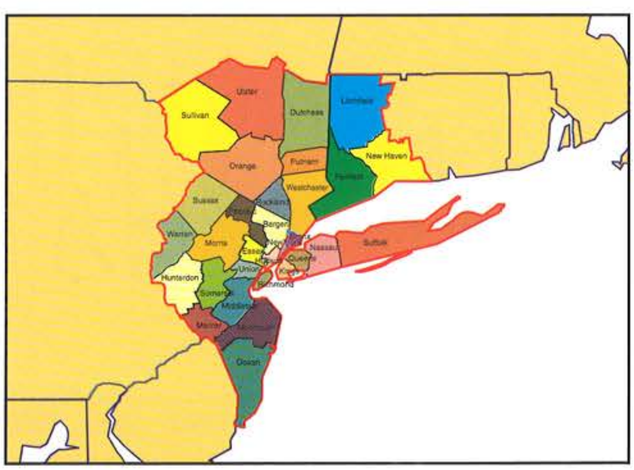


FIGURE E-1 Metropolitan East Coast Region.

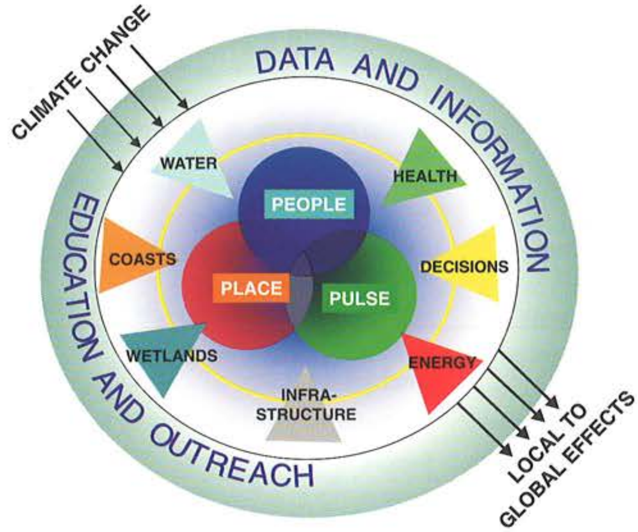


FIGURE E-2 Assessment framework and study sectors.

CLIMATE VARIABILITY AND CHANGE IN THE METROPOLITAN EAST COAST REGION

Climate is changing in the New York Metropolitan Region. Over the past 100 years, temperature in the region has warmed nearly 2°F. The rate and amount of temperature rise is projected to increase over the 21st century due to anthropogenic greenhouse warming. Gradual changes may be punctuated by changes in extreme climate events. A range of plausible climate change scenarios enabled the Metro East Coast Assessment researchers to project possible impacts created by climate variability and change as

Submitted as part of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change

TABLE E-1
Stakeholder Partners*

Sector	Partner
Coasts	New York District of U.S. Army Corps of Engineers
Infrastructure	Federal Emergency Management Agency, Region II The Port Authority of New York and New Jersey
Wetlands	National Park Service, Gateway National Recreation Area New York State Department of Environmental Conservation
Water Supply	Southeastern New York Intergovernmental Water Supply Advisory Council
Public Health	New York City Department of Health
Energy Demand	New York State Energy Research and Development Authority
Meta-Stakeholder	U.S. Environmental Protection Agency Region 2
General Stakeholder	Regional Plan Association

*Stakeholders are institutions whose activities are and will be impacted by present and future climate variability and change, and thus have a stake in being involved in research of potential impacts. Although stakeholders are an integral part of the research process, the findings that result from this research do not necessarily represent the opinions or policy positions of the stakeholder institutions.

well as to evaluate the region's responses. Such assessments are useful in improving preparedness for extreme climate events in the present, as well as developing readiness for a changing climate.

The results of the Metro East Coast Assessment indicate that the biophysical and societal impacts of projected climate change will be primarily negative over the long term. The impacts of climate change throughout the region and on its people will be widespread yet uneven. The costs of the impacts will be potentially significant and will increase as the amount of climate change increases.

Substantial uncertainties about climate change remain, including the rate and magnitude of projected regional changes. Possible changes in variability add to these uncertainties.

Key urban impacts of climate variability and change are likely to occur simultaneously at the intersection of sectors. For example, heat stress in the poor and elderly (a concern of the public health sector) will probably increase during energy blackouts (the responsibility of the energy sector). The varying impacts will be dynamic and their intersections will change over time.

KEY FINDINGS

Climate

- There is a long-term warming trend in the Metro East Coast region. While there are fluctuations on interannual and decadal time-scales in the average temperatures of the past century, the annual temperature (averaged over 23 stations, corrected for urban heat island effect) has increased by ~2°F since 1900 (Figure E-3). Over the past century, annual precipitation in the region has increased by ~1 inch.
- The rate and amount of temperature rise is projected to increase over the 21st century, due to anthropogenic greenhouse warming. The global climate models (GCMs) utilized in the U.S. National Assessment of the Potential Consequences of Climate Variability and Change project warming for the New York Metropolitan Region, ranging from 1.7–3.5°F in the 2020s, 2.6–6.5°F in the 2050s, and 4.4–10.2°F by the 2080s (United Kingdom

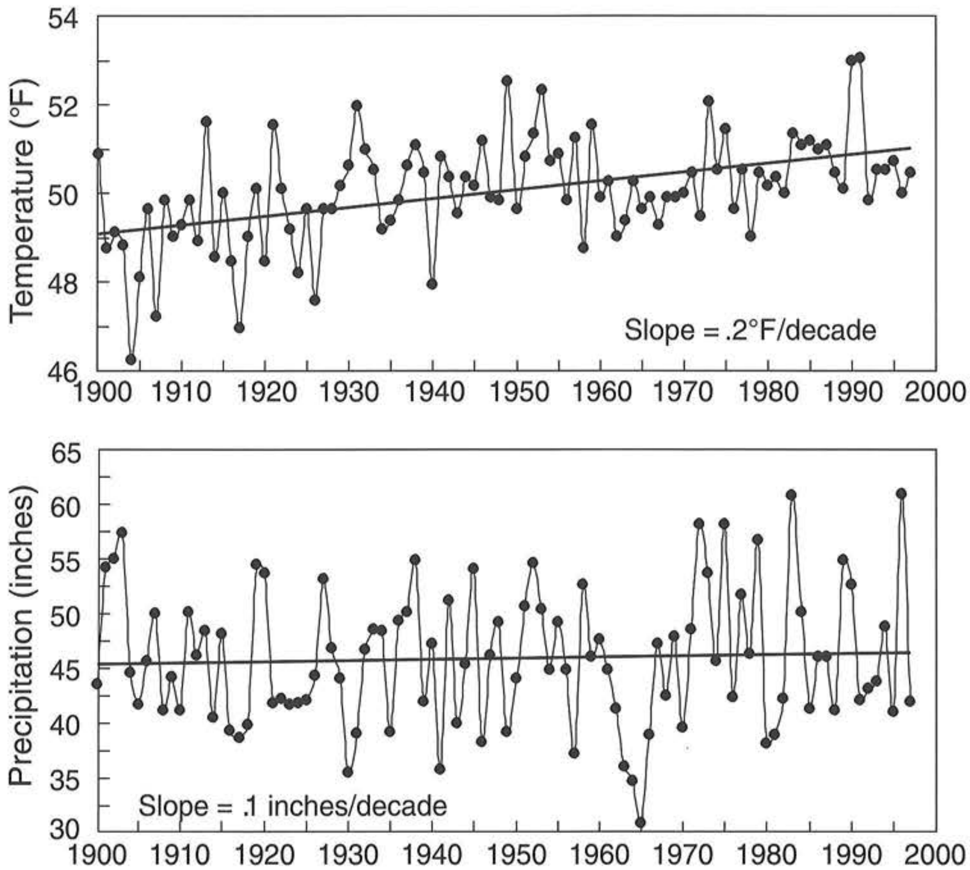


FIGURE E-3 Observed annual temperature and precipitation trends for the MEC region (1900–1997). Note: Twenty-three station average, corrected for the urban heat island effect. Source of data: NOAA NCDC/HCN.

- Hadley Centre and the Canadian Centre for Climate Modeling and Analysis, Figure E-4).

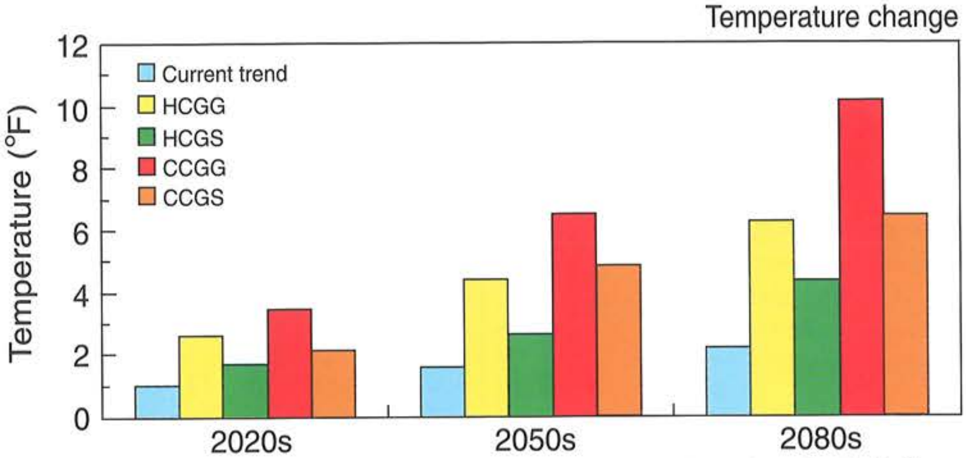


FIGURE E-4 Annual temperature changes in the Metropolitan East Coast Region projected by the Hadley Centre (HC) and Canadian Centre (CC) climate change scenarios with greenhouse gases (GG) and with greenhouse gases and sulfate aerosols (GS), and the Current Trends scenario.

- Precipitation projections of the global climate model scenarios do not agree in magnitude or direction (+1% to +9% in the 2020s; –16% to +14% in the 2050s, and –2% to +30% by the 2080s). The Hadley Centre scenarios show increasing levels of precipitation, while the Canadian Centre scenarios project varying precipitation changes over time. The Palmer Drought Severity Index in general shows more droughts in future decades, particularly for the Canadian Centre scenarios.
- Climate change is projected by global climate models to cause warming in both winter and summer. In the 2050s, the range of winter temperature rise is 3.3 to 5.6°F. In the 2050s, summer temperature rise is projected to range between 2.7 and 7.6°F.
- Global climate models project that the number of days with the National Weather Service Heat Index (a combined index of temperature and relative humidity used as a proxy for the discomfort caused by heat waves) above 90°F will increase from 14 days (1997–1998 base) to a range of 24–40 days in the 2020s, 30–62 days in the 2050s, and 40–89 days in the 2080s.
- There is still considerable uncertainty about the rate and magnitude of projected climate changes. There is substantial potential that gradual changes could be punctuated by increases in extreme events such as floods and droughts.

Sea-Level Rise and Coasts

- Sea level has risen 0.09–0.15 inches per year in the Metro East Coast Region over the last 100 years. About half the observed rise is related to ongoing geologic subsidence following the end of the last glacial period and about half is related to the warming trend of the 20th century.
- With projected climate change, sea level in the MEC Region may rise 4.3–11.7 inches by the 2020s, 6.9 to 23.7 inches by the 2050s, and 9.5 to 42.5 inches by the 2080s.
- Future sea-level rise would lead to more damaging storm floods and a marked reduction in the flood return period in coastal regions. In the MEC Region, the 100-year flood would have a probability of occurrence, on average, once in 80 to 43 years by the 2020s, once in 68 to 19 years by the 2050s, and once in 60 to as often as every 4 years by the 2080s (Figure E-5).
- Rates of beach erosion would double at sites within the region by the 2020s, increasing 3 to 6 times by the 2050s, and 4 to 10 times by the 2080s, relative to the 2000s. Additional sand would have to be placed on the beaches to compensate for these losses. Beach nourishment will become significantly more costly as the century progresses, particularly in the case of the high-end warming scenarios.

Infrastructure

- Most of the region's low-elevation transportation infrastructure will be at risk to flooding in the 21st century (Figure E-6). By the end of this century, for two-thirds of facilities with elevations at or below 10 feet above sea level, flooding may occur at least once every decade,

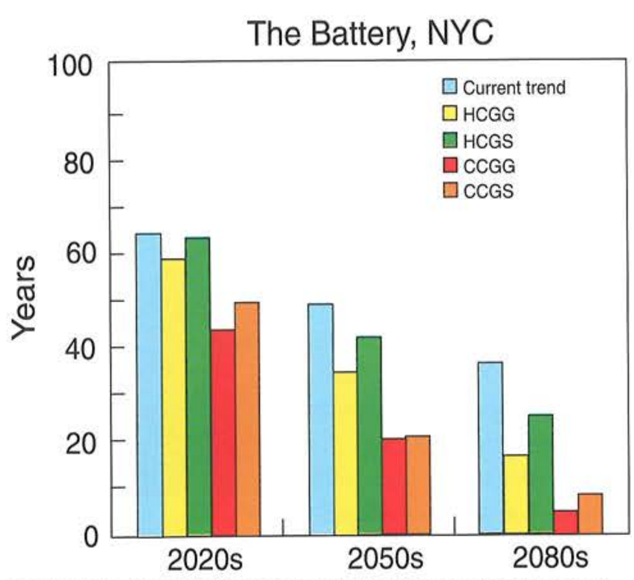


FIGURE E-5 Reduction in 100-year flood return periods due to sea-level rise in lower Manhattan.

and at some facilities it will occur every few years.

- While annualized losses from storms in the region are estimated to be only $100–300 million per year, losses from a single, devastating storm may be up to $100 billion, about 10% of the almost $1 trillion gross regional product.

Wetlands

- Studies of selected salt-marsh islands in Jamaica Bay Wildlife Refuge indicate that they have lost roughly 12% in area since 1959, with sea-level rise a possible causative factor (Figure E-7).

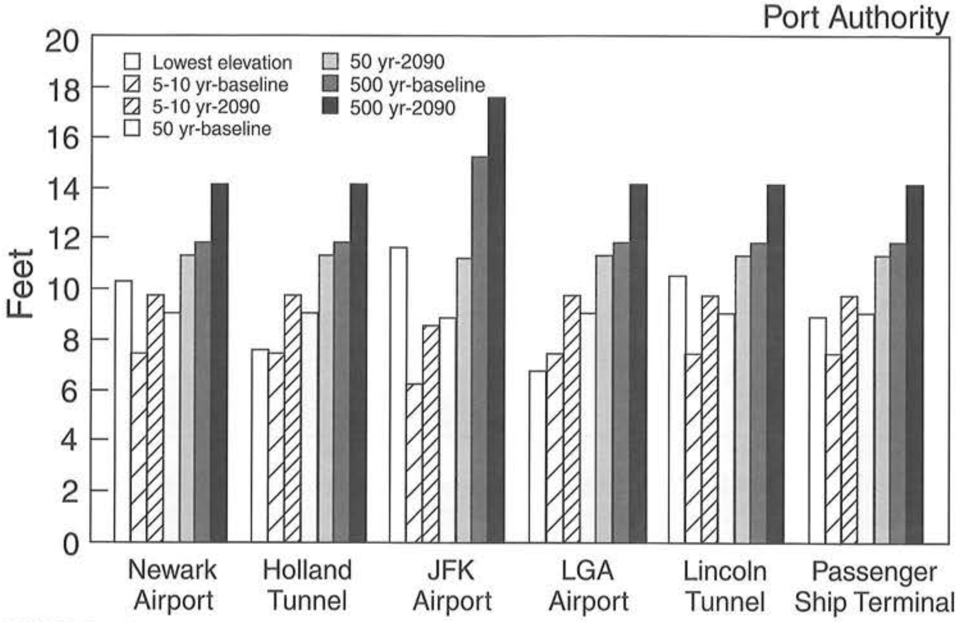


FIGURE E-6 Comparison of the lowest critical elevation for facilities of the Port Authority of New York and New Jersey with surge heights for three recurrence periods—5, 50, and 500 years—at the beginning (baseline) and end (2090s) of the 21st century.

- Sea-level rise associated with global climate change brings a significant additional risk to already threatened coastal wetlands in the region.
- Salt marshes in Jamaica Bay are at risk to increased inundation under some scenarios of climate change and accretion rates. Projected mean sea-level rise exceeds observed historical rates of salt-marsh accretion in most GCM scenarios.
- Coastal wetland losses will disrupt current habitats of birds, fish, and other wildlife.

Water Supply

- Climate change projections indicate that the variability of the hydrological systems in the region will increase, with more frequent droughts and floods.
- New York City's water supply systems should be able to cope with climate uncertainty over the next several decades, but there will be significant challenges in the long term.
- Current fish populations and other ecosystem functions linked to watersheds are likely to be affected.
- Increased uncertainty will require a range of adaptations from water management institutions.
- An effective planning process needs to be organized soon in order to consider future adaptations. The implementation of new institutional and infrastructure measures is likely to require long-term institutional planning and resource commitment.
- Inter-regional cooperation offers opportunities to utilize water resources more efficiently (Figure E-8).

Public Health

- The most direct health effect to be associated with warming and more variable climate is an increase in summer-season heat stress morbidity and mortality, particularly among the elderly poor.
- Climate change in the MEC Region will contribute to at least three classes of indirect health outcomes: inci-

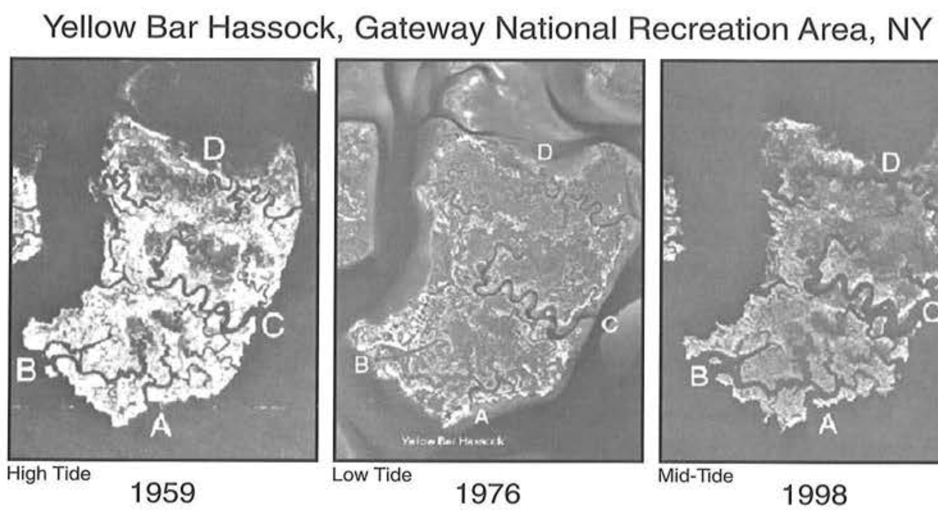


FIGURE E-7 Aerial photographs of Yellow Bar Hassock, part of Jamaica Bay Wildlife Refuge, dated April 7, 1959 (high tide), March 29, 1976 (low tide), and March 13, 1998 (mid-tide). Sources: Robinson Aerial Surveys, Inc. and AeroGraphics Corp., Bohemia, NY.

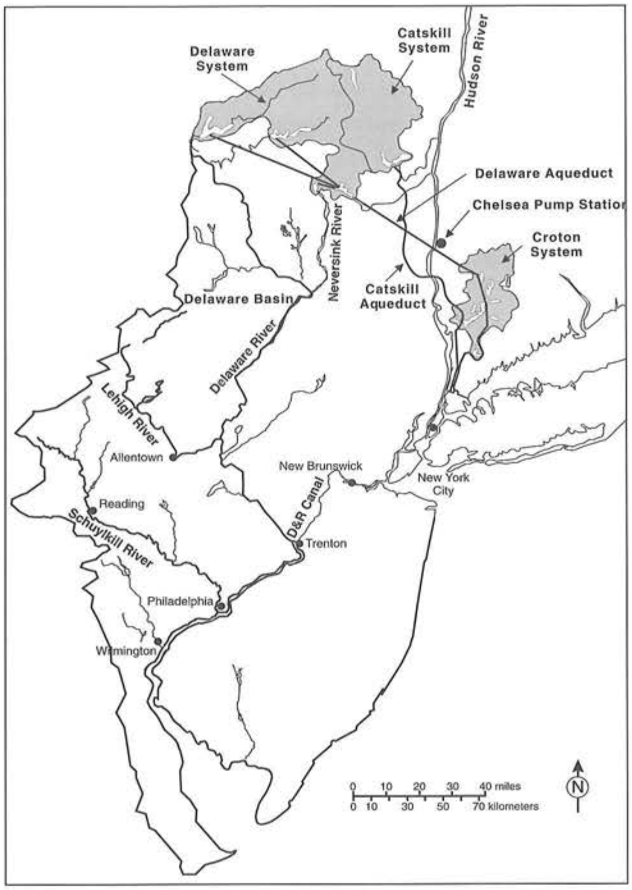


FIGURE E-8 Opportunities for inter-regional adaptation: New York City Water Supply System and the Delaware River Basin.

dence of certain vector-borne diseases may rise; water-borne disease organisms may become more prevalent; and increased formation of photochemical air pollutants may be fostered.

- Over the next several decades, impacts of climate change on ground-level ozone concentrations are not likely to be a major public health concern in the MEC Region. By the year 2100, asthma-related hospital admissions are expected to increase slightly (Table E-2).
- Health effects of climate change will be distributed unequally across the MEC Region's inhabitants, both spatially and socio-economically.

Energy Demand

- A warming climate will raise the demand for electricity because the increase in summer cooling outweighs the decrease in winter needs. Because peak summer electricity loads already far exceed winter peaks, the electric system will be increasingly stressed during summer heat waves.
- The urban heat island effect already causes cities to be warmer than the surrounding countryside due to the absorption of heat by buildings during the day and reradiation at night. Under a warming climate, the urban heat island effect will increasingly become an issue of regional concern in regard to energy demand and air quality.
- GCM climate change scenarios and an energy forecasting model project that daily peak load increases will range from 7 to 12% in the 2020s, 8 to 15% in the 2050s, and 11 to 17% in the 2080s (Figure E-9).
- The emphasis on adapting to climate change should be on improved energy efficiency, particularly to reduce summer peak electricity loads, and enhanced passive cooling in buildings and communities. Local lines that distribute electricity to customers need to be upgraded, and the adequacy of transmission lines to bring more power into the metropolitan area should be assured.
- The "weatherization" program that exists to save energy costs in housing for low-income people should be extended to provide summer cooling in urban areas as well as winter heating.

Institutional Decision-Making

- Involvement of decision-making institutions is critical in adaptation to or reduction of the consequences of global climate change.

TABLE E-2
Projected increases in hospital admissions resulting from increased ground-level ozone concentrations in 2030 and 2100 associated with climate change

Region	Hospital Admissions Category	2030			2100		
		O_3 Increase	New Hospital Admissions	Percent Change in Admissions	O_3 Increase	New Hospital Admissions	Percent Change in Admissions
MEC	Total Respiratory	12.15 ppb	995	*	50.65 ppb	4,149	*
	Asthma		819	*		3,319	*
NY State Counties	Total Respiratory		804	+0.6%		3,552	+2.5%
	Asthma		643	+1.6%		2,682	+6.5%

*Unable to calculate due to the unavailability of hospital admissions statistics for NJ.

- Responses to climate are triggered by sudden, large, extreme events. Institutions should prepare for the possibility of climate-related impacts in the future.
- Effective institutional response to climate change will require increased inter-agency cooperation and coordination.
- It is important to link adaptive response to climate change to opportunities for institutional change, such as new investments, relocation of structures, and major rehabilitation projects being undertaken for purposes other than adaptation to climate change.

POLICY LESSONS AND RECOMMENDATIONS

- Social and political responses to the impacts of climate variability and change have already begun and should accelerate and strengthen in order to avoid greater impacts in the future.
- Current major capital reinvestment activities and structural shifts in management in the Metro East Coast Region provide opportunities for integration of climate variability and change adaptation and mitigation strategies into stakeholders' decision-making practices.
- A regional Climate Awareness Program would be effective to inform decision-makers and the general public about current climate processes, lessons learned in responding to climate extremes, and future climate change.
- The development of a set of cost-based, urban-focused Climate Change Impact Indicators would make a significant contribution. For example, what will sea-level rise mean in terms of increased costs of beach renourishment and what will temperature increases mean to acute asthma sufferers.
- A regional Climate Inter-Agency Task Force should be formed to identify potential climate-related events and conditions (e.g., coastal infrastructure at risk, disease outbreaks, water supply vulnerabilities) and proactively propose responses. The taskforce should also consider events that would require emergency actions and/or large-scale societal responses.

THE CLIMATE CHANGE CHALLENGE

The complex nature of potential climate change impacts in urban regions poses tremendous challenges to urban managers to respond cooperatively, flexibly, and with far longer decision-making timeframes than currently practiced. Given the already fragmented nature of urban environments and jurisdictions, the political and social responses to the global climate issue in cities should begin at once. Transforming urban management to better prepare for climate change will safeguard against negative feedbacks in the Metro East Coast Region and around the world.

In summary, the Assessment illustrates that the future environmental conditions of the Metro East Coast Region will be much more dynamic than in the recent past. The environmental management and response strategies that evolved during the 20th century were based largely on the idea that the ecological and environmental baselines were static, although ranging within the conditions of dynamic equilibrium. Local environmental change was seen as being brought about largely through direct human action.

Global climate change forces a fundamental reassessment of these assumptions. In the 21st century, the baselines will change and local decision-makers will have limited ability to control the pace of this transformation. The gases already emitted into the global atmosphere are projected to cause some degree of warming and environmental change regardless of the implementation of any comprehensive policy designed to reduce greenhouse gas emissions (the root cause of projected climate change). For the citizens and stakeholders of the Metro East Coast Region, the challenge will be to adapt to and mitigate climate change simultaneously and equitably.

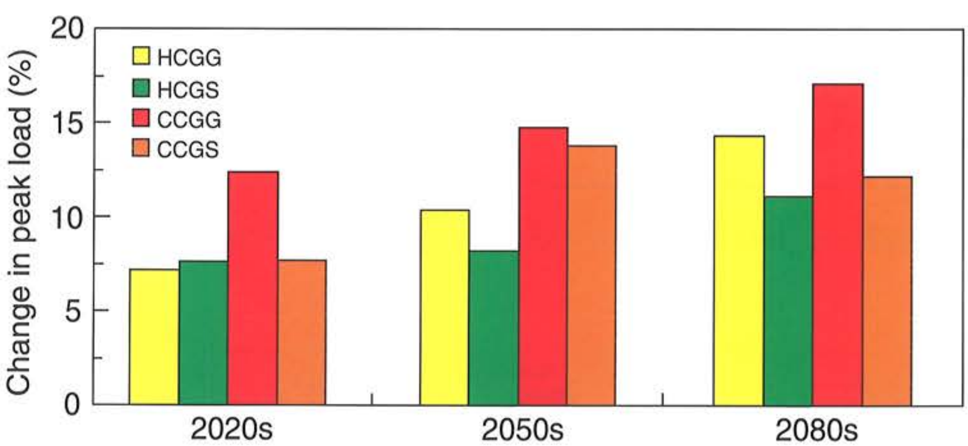
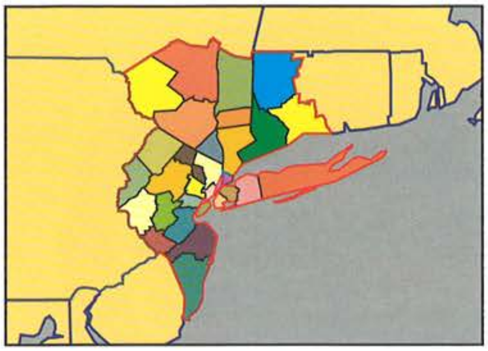


FIGURE E-9 Increase in peak electricity demand under July 1999 conditions with temperatures and relative humidity projected for future decades.

Note: Bars represent low and high range of two global climate models, the Hadley Centre (HC) and the Canadian Centre (CC) models.

PART 1

INTRODUCTION



CHAPTER 1

ASSESSING THE METROPOLITAN EAST COAST REGION

The Metropolitan East Coast (MEC) Assessment is one of the regional components of the National Assessment of the Potential Consequences of Climate Variability and Change for the United States. The goal of each regional assessment is to understand the impacts of climate variability and change on the physical systems and human activities of a specific area of the United States. Key to the process is the identification of sectors that are vulnerable to the additional stresses that increased climate variability and change will introduce and the potential for adaptation strategies to cope with them.

The Global Change Research Act of 1990 created the U.S. Global Change Research Program (GCRP) in order that the nation analyze and evaluate global climate change. The U.S. GCRP initiated the National Assessment in 1997. The National Assessment process involves examination of potential impacts of climate change at a regional level as well as a sectoral level across the United States, synthesizing the results into a final Assessment Report (National Assessment and Synthesis Team, 2001).

For the regional assessments, the GCRP divided the United States into regions, each of which was charged with engaging researchers and stakeholders from a variety of sectors and disciplines in the exploration of the current and future impacts of climate on the region. The Metropolitan East Coast Assessment is the primary assessment activity that focuses specifically on the impacts of climate change and variability in an urban area. Understanding climate impacts in urban areas is becoming increasingly important, since human populations are more concentrated in cities, and the number and size of cities are growing.

The U.S. GCRP provided a template to guide the regional assessments, consisting of topic areas (e.g., current stresses, potential impacts, and coping mechanisms). However, each of the regions developed its assessment independently, focusing on different sectors of activity, involving stakeholders in unique ways, and creating a variety of products for scientific, technical, and general audiences.

The first step for the Metro East Coast Assessment was a two-day workshop hosted by and held at the Columbia University Earth Institute. The *Metro East Coast Climate Impacts Assessment Workshop* on March 23–24, 1998, brought regional stakeholders, government representatives, scholars, non-governmental organizations (NGOs), and members of the general public together to explore the creation of an integrated regional assessment of climate impacts. The charge to the workshop was to develop a network of stakeholders, to initiate assessment of vulnerabilities and opportunities, and to recommend future steps to develop partnerships among stakeholders, researchers, and the federal government regarding climate variability and change.

Four questions from the National Assessment provided the foundation for the workshop:

1. Independent of climate, what are the dominant stresses and issues currently of concern to stakeholders in the region?
2. How might greater climatic variability or climate change increase or decrease those stresses?
3. What kinds of information do we need to help us think about climate change and climate variability in the region?
4. Given our current knowledge, what coping mechanisms might be taken to minimize stresses and at the same time address the climate change issue?

The goal of the initiating workshop was to promote discussion between researchers and stakeholders in order to develop a method of research that focuses on relevance and utility. Through the workshop proceedings, specific areas of research were identified as the most important foci of a regional assessment in the New York metropolitan area: Coastal Resources, Infrastructure, Water Resources, Public Health, and Institutional Decision-Making.

Since the initial workshop, the research foci have evolved to include: Sea-Level Rise and Coasts, Infrastructure, Wetlands, Water Supply, Public Health, Energy Demand, and Institutional Decision-Making. Researchers examine vulnerabilities and coping strategies in each of these sectors. With the involvement of stakeholders throughout the research process, sector teams have identified potential physical and social impacts, decision-making challenges, and opportunities for possible adaptation measures.

After review by technical experts, the draft Assessment Report was presented at the *Climate Change and a Global City Conference* held June 19, 2000 at the Columbia Earth Institute, followed by a one-month period for public comment. Comments and responses were documented, with relevance to this and future urban region assessments.

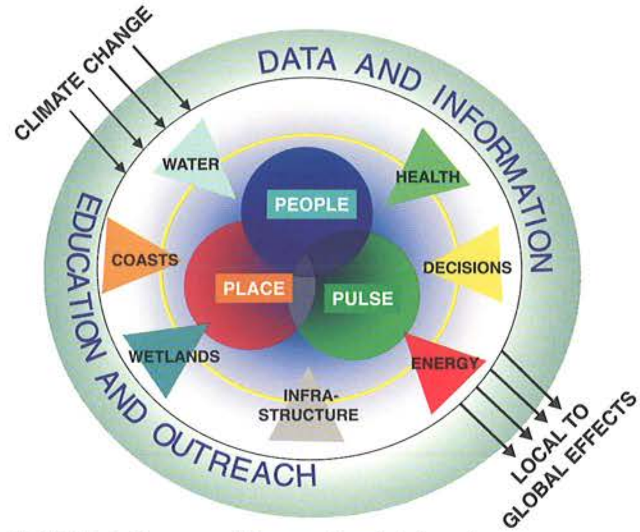


FIGURE 1-2 Assessment framework and study sectors.

FRAMEWORK AND METHODS: PEOPLE, PLACE, AND PULSE

The Metro East Coast Assessment focuses on the issues of climate change in a major urban center. The region is defined as a global city, i.e., a mega-city that constitutes a key site for international business and enterprise. With its cultural and political dominance, New York is positioned atop the global urban hierarchy. Other global cities include London, Tokyo, and São Paulo.

The study area covers the thirty-one counties of the New York City Metropolitan Region (Figure 1-1). The area consists of 13,000 square miles (33,670 square kilometers), with jurisdictions involving 1,600 cities, towns, and villages in the three states of New York, New Jersey, and Connecticut. The total regional population is 21.5 million, of which 8.0 million live in New York City, according to the 2000 U.S. census.

Building on interactions at the initiating workshop, the research objectives and study framework were developed. The objective is to assess the potential climate variability and change impacts on the New York City metropolitan area. The study aims to apply state-of-the-art climate science to a set of linked sectoral analyses for the Metro East Coast region.

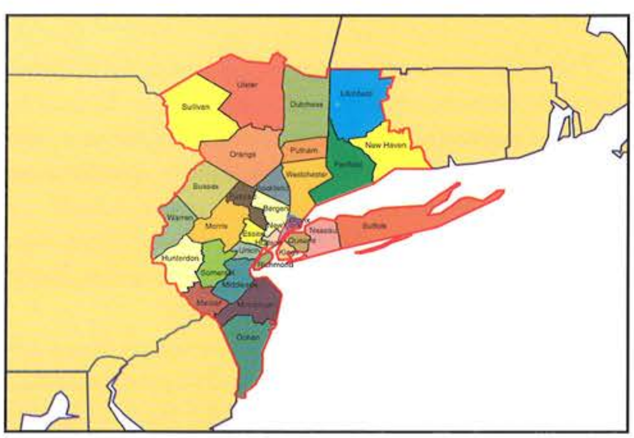


FIGURE 1-1 Metropolitan East Coast Region.

The MEC Regional Assessment examines how three interacting elements of global cities react and respond to climate variability and change (Figure 1-2). The three elements are: *people* (i.e., socio-demographic conditions), *place* (i.e., physical and ecological systems), and *pulse* (i.e., decision-making and economic activities).

The Assessment focuses on seven sector studies: Sea-Level Rise and Coasts, Infrastructure, Wetlands, Water Supply, Public Health, Energy Demand, and Institutional Decision-Making. Each sector study assesses historical and potential climate impacts through analysis of current conditions, lessons and evidence derived from past climate variability, and scenario predictions. Coping strategies, policy recommendations, and knowledge gaps are identified for the individual sectors and for the region as a whole.

Each study assesses potential climate change impacts on the sector and on the intersecting elements, through the analysis of the following parts:

1. Current conditions of sector in the region.
2. Lessons and evidence derived from past climate variability.
3. Scenario predictions affecting the sector; potential impacts of scenario predictions.
4. Identification of adaptation strategies—i.e., resilience building, new technologies, education that affects decision-making, and better preparedness for contingencies.
5. Critical issues, including identification of additional research questions, effectiveness of modeling efforts, equity of impacts, potential non-local interactions, and policy recommendations.
6. Knowledge and information gaps, e.g., effectiveness of modeling methods, identification of additional research questions.
7. Recommendations for the region—activities, programs, and policies.

Stakeholder Involvement

The assessment mandate from the U.S. GCRP emphasized the involvement of key stakeholders at the regional level. The MEC Assessment has defined stakeholders as: institutions whose activities are and will be impacted by present and future climate variability and change, and thus have a stake in being involved in research of potential climate impacts. Through a research partnership that involves collaboration, ongoing feedback, and product review, the MEC Assessment hopes to make its research relevant and useful in decision-making across sectors of activity in the New York Metropolitan Region.

Each of the MEC Assessment's seven sectors collaborates with representatives from one or more stakeholder institutions. Table 1-1 illustrates the stakeholder institutions that are involved in the Assessment process.

The stakeholder representatives have been involved in the Metropolitan East Coast Assessment since its inception. Key to the success of the relationships between the researchers and the stakeholders is regularly scheduled outreach. Every other month, the MEC team met at the offices of a stakeholder to present the Assessment and its findings and to discuss the areas in which the stakeholders' activities and the Assessment's foci interface. During outreach meetings, several questions help to frame the discussions:

1. Which activities of the stakeholder agency are most relevant to the issue of climate change?
2. What are the time-frames of stakeholders' decision-making horizons?
3. Is the potential for climate change taken into account explicitly in any decision-making processes?
4. What information (relevant to any aspect of climate impacts) can the MEC Assessment provide to the stakeholder? Are there data that MEC researchers can collect that would be of use to the stakeholder?
5. Does the stakeholder have data that would be useful to the MEC team?
6. How can we make the information that we create useful, relevant and specific to the stakeholder?

TABLE 1-1
Stakeholder Partners*

Sector	Partner
Coasts	New York District of U.S. Army Corps of Engineers
Infrastructure	Federal Emergency Management Agency, Region II The Port Authority of New York and New Jersey
Wetlands	National Park Service, Gateway National Recreation Area New York State Department of Environmental Conservation
Water Supply	Southeastern New York Intergovernmental Water Supply Advisory Council
Public Health	New York City Department of Health
Energy Demand	New York State Energy Research and Development Authority
Meta-Stakeholder	U.S. Environmental Protection Agency Region 2
General Stakeholder	Regional Plan Association

*Stakeholders are institutions whose activities are and will be impacted by present and future climate variability and change, and thus have a stake in being involved in research of potential impacts. Although stakeholders are an integral part of the research process, the findings that result from this research do not necessarily represent the opinions or policy positions of the stakeholder institutions.

Data and Information

As part of the Regional Assessment, the Center for International Earth Science Information Network (CIESIN) developed and managed the Metro East Coast Assessment Geographic Information System (GIS) and website (http://metroeast_climate.ciesin.columbia.edu). The Assessment also included the development of educational modules and materials. CIESIN created an educational module related to climate variability and change in the Metro East Coast region. See Appendix MEC Region 1 for a description of the data, information, and educational activities developed for the MEC Assessment.

METROPOLITAN EAST COAST REGION

The New York Metropolitan Region is one of the most important urban areas in the world. It is characterized by great physical and demographic diversity. The largest financial trading market of the world controls the economic heartbeat of the region. The general economy is mostly based on service industries, which depend on modern, sophisticated means of communication and transportation. Approximately $10 trillion of stock and bonds were exchanged in New York in 1999 (Warf 2000) The gross regional product (GRP) is estimated at approximately $1 trillion.

The activities of this urban conglomeration place tremendous pressure on the regional land and water resources. Approximately 30% of the land area have been fully converted to urban uses. The regional water demand is 1,500 mgd, which presents decision-makers with increasing concerns about the quality and quantity of the regional water supply.

A complex web of formal and informal processes that involve the public, nonprofit, and private sectors governs the MEC Region's institutional framework for land use and development. The overarching considerations of environmental protection, health, and safety often intertwine. Institutional adaptation and flexibility must arise in order for links to form that will allow integrated decision-making regarding climate change.

With close to 1,500 miles (2,413.5 kilometers) of coastline, the region's development has been intimately connected to the ocean. For example, four of the five New York City boroughs are located on islands. Infrastructure has emerged to adapt to this situation. More than 2,200 bridges and a system of tunnels that carries rails and roads connect them with each other and the mainland. The region maintains a versatile, high-volume transportation system by air, roads, and rails (above and below ground), as well as on the water. These and other essential infrastructure elements are often used to capacity.

People

The Metropolitan East Coast Region has a rich demographic history and is ever evolving. Its population grew dramatically throughout the latter part of the 19th century, largely through massive immigration from Europe. While the region remained mostly rural through the mid-part of the 20th century, several large urban concentrations developed. Predominant among the urban centers on the eastern seaboard was New York City, which held by far the largest percentage of the region's population. In 1950, the City made up 56.6% of the region's 13.9 million people. Other significant urban concentrations included Newark, NJ; Jersey City, NJ; Yonkers, NY; and Bridgeport, CT, among other sites.

Since 1950, the population growth of the region has lagged behind that of other metropolitan areas in the United States. Even so, the population continued to increase and reached 21.5 million by 2000. By that time, New York City lost some of its dominance in the region. Population decentralization was an important demographic trend during this period. The city, by 2000, made up only 37.2% of the region's population. Rapid suburbanization and associated white flight fostered a dramatically changed physical and social landscape. The rate of per capita land demand increased steadily during this period. Land conversion increasingly took place on more vulnerable land including flood-prone areas and coastal locations. Coastal development was particularly intense along the Atlantic Ocean coasts of New Jersey and Long Island.

These shifts have been associated with changes in regional employment patterns. Employment growth in the older urban counties has been very slow (and in many cases has shown absolute declines), while employment growth in the outer suburban counties has been very strong. For example, urban counties lost 307,000 jobs from 1970 to 1995; suburban counties gained 2,018,400 (U.S. Bureau of Economic Analysis, U.S. Census of Population).

Both of these shifts have meant a significant change in the overall level of wealth in the region. While some neighborhoods in New York City, particularly in Manhattan, remain extremely wealthy, the out-migration of the middle and upper middle class from older, urban areas along with a relocation of jobs has meant increasing spatial inequity within the region with respect to income levels. As of 1995 census estimates, almost 24% of the population lived below the poverty level in New York City. The population living below poverty level in Connecticut was about 8%, and in New Jersey it was nearly 9%. Nearly 16% of New York State's total population (including the City) lived under the poverty level, according to 1995 census data. For a large percentage of the region's population, the high poverty levels correspond with lower access to adequate health care and other social services.

Another important characteristic of the region is the racial and ethnic diversity of the population. While the New York metropolitan region has always been defined as a region of immigrants, the recent period of increased international migration has meant a further diversification of the population. Many areas, both urban and suburban, have significant ethnic, African-American, and Hispanic populations. In New York City, non-Latino whites now make up less than 50% of population. Recent estimates note that 40% of the population in the City is foreign-born. The region also has large populations of elderly and immuno-compromised people, particularly people living with HIV/AIDS.

Place

The New York Metropolitan Region has a very diverse landscape. It is dominated by water. Several large waterways and water bodies—the Newark Bay/Hackensack Meadowlands, the Hudson River, East River and Long Island Sound, Peconic Bay, Jamaica Bay, the Arthur Kill, and the Raritan River estuary—cut deeply into the land area.

Three physiographic regions are present: the coastal plain, the piedmont, and the Appalachian highlands. Given its coastal location, much of the land area is at relatively low elevation. A limited amount of land (~1.0%) is below 10 feet (3 meters) in elevation. This land includes some of the most heavily developed areas and regionally important infrastructure, such as lower Manhattan and portions of the three major regional airports.

The ecology of the region has been tremendously modified and it is now a heavily human-dominated landscape. Some exurban areas, such as extreme eastern Long Island, northwestern New Jersey, and parts of Connecticut and upstate New York, more distant from New York City, still maintain extensive wildlife habitat and ecological function. The ecological function of the more settled part of the region is low. However, the few remaining larger-scale (i.e., greater than 1,250 acres or 500 hectares) habitat sites—for example the Hackensack Meadowlands and the Great Swamp in New Jersey and Jamaica Bay in New York—provide habitat for aquatic species and critical stopovers for migratory bird species.

Vulnerable habitats in the region have been heavily degraded. The vast majority of the region's wetlands have been lost. Buffer areas around wetlands or rivers typically are not present. In many areas, smaller rivers and streams have been filled, channelized, or diverted into culverts. Surface water and groundwater supplies, particularly in the more heavily urbanized areas, have been compromised and typically exceed federal water pollution standards. In the region, there are more than 100,000 leaking underground fuel tanks, spill sites, or former industrial sites included on the federal government's register of known or potential toxic sites (Yaro and Hiss, 1996). Many are located in lowland locations where coastal wetlands were used as landfill sites. There are 131 active Superfund hazardous waste sites in the region.

The built environment comprises the most prominent feature of the region. As of 2000, the region maintained 8.3 million housing units, and current estimates include approximately 2,000 miles (3,218 kilometers) of major highway, and 1,250 miles (2,011 kilometers) of railway (U.S. Census, 2000). Much of the built environment in New York City itself and adjacent older urban and suburban areas pre-dates 1950. Maintenance of the infrastructure and buildings is a massive and continuing process. In the outlying counties, the majority of the construction is more recent. Currently, the greatest amount of new construction is taking place in these outlying areas. Revitalization and redevelopment is taking place in selected areas in the older urban core, such as the Hudson River waterfront area in New Jersey.

Pulse

The region is highly dynamic. Complex socio-economic systems form the basis of the region's pulse. The region is organized around high-volume inflows as well as outflows and intraregional flows. As a largely urban site almost all of the food supply has to be imported into the region, and increasingly much of the solid and hazardous waste is exported out. In the case of the New York City water supply, fresh water is also brought into the region. Energy is imported into the region via the Northeast and Mid-Atlantic grid.

Population migration has been a significant component of the region's pulse. In the past three decades, more than 3 million people have migrated into the region. As a major port, the region is tied to the world through shipping. In 1999, over 40 million tons of bulk cargo passed through the ports of New York, Newark and Elizabeth (Port Authority of New York and New Jersey 2000).

Another important component of the region's pulse is the financial services industry. The MEC region is one of the most important financial and business centers in the world. Forty-three percent (861 billion) of all stock shares traded in the United States are traded on the New York Stock Exchange. New York is also the world's largest advertising center, with transactions of $37.7 billion in 1998 (Warf, 2000).

Local decisions and transactions that take place in the region everyday have important implications for locations throughout the world. Furthermore, any significant disruption to the communication and transportation systems can have dire economic consequences, not only locally, but also nationally and globally. An assessment of potential climate change impacts must take into account the possibility that future extreme weather events in the MEC region could disrupt these activities.

CURRENT AND FUTURE STRESSES

The region faces several stresses, besides climate change, that limit its current and future viability. The Regional Plan Association, a leading metropolitan regional planning organization, has labeled it as a "region at risk" (Yaro and Hiss 1996). The stresses facing the region include the need for maintaining continued economic growth, inequity among the region's residents, aging and inadequate infrastructure, and threats to environmental quality.

Throughout the latter part of the 20th century, the region experienced a dramatic shift in economic activity. The metropolitan area's manufacturing sector declined significantly, while the service sector grew. Hundreds of thousands of manufacturing jobs were lost. From 1970 to 1994, the manufacturing jobs as a percent of total employment declined from roughly 26% to 12% (Conn., NJ, and NY Depts of Labor). This trend is expected to continue over the next two decades. The service sector employment is expected to continue to show the most dramatic increase.

While the New York Metropolitan Region will remain a global economic and cultural center, its position will be under increased pressure resulting from the further development of a mobile, electronic-based economy, which could promote the decentralization of economic activity from more expensive, older urban areas. A poorly trained workforce is another factor that might encourage regional stagnation and decline.

The economic bifurcation or "hourglass economy" with increasing numbers of both high- and low-income jobs, with a dwindling middle class has created a situation of growing inequity in the MEC Region. This is similar to other urbanized populations in the United States, which are becoming more divided as the gap emerges between high wage-high skill and low wage-low skill residents.

Large disadvantaged underclass populations are present in degraded communities throughout older urban centers in the region. These areas of poverty have persisted even during the current era of unprecedented prosperity and will likely continue into the future. Meanwhile, rapid income growth has taken place in the outer suburban counties. Income decentralization is expected to continue into the future, although recent redevelopment in selected urban areas might temper this movement.

The spatial restructuring of the region has helped reveal another stress—the lack of appropriate infrastructure. The tremendous infrastructure that has been developed is now aging, in need of significant redevelopment, inadequate to handle the current demand, or otherwise under threat. For example, the regional water supply systems will have to adapt to the changing patterns of development. The integrity of the New York City water quality is being challenged by increasing development around its upstate New York water supply areas, while in northwestern New Jersey new water supplies need to be developed as populations in the area grow. The energy supply infrastructure also needs to be upgraded. Recent increases in regional energy demand have resulted in proposed new power plants and new distribution systems.

The region also continues to face many challenges that threaten regional ecosystem function, environmental conditions, and daily quality-of-life. The most critical environmental issues for the region include air and water pollution, and suburban sprawl. The regional air quality still exceeds federal mandates for several pollutants. Surface and ground water supplies, and coastal waters face constant threat. Recent years have seen much of the remaining open space and farmland present at the distant edges of the region became sites for significant land speculation and conversion. These sites include northwestern New Jersey, the farthest eastern edges of the North and South Forks of Long Island, the lower Hudson River Valley, and southwestern Connecticut.

DECISION-MAKING IN A CHANGING CLIMATE

The MEC Assessment poses the questions: how can the people of the New York Metropolitan Region start to respond to the potential challenges and opportunities of climate change, and how can we bring the issue into our everyday decision-making processes? To respond to these challenges, the Metropolitan East Coast Assessment seeks to create a partnership with regional stakeholders and researchers, educators, and the general public to improve the city's responses to climate extremes today and prepare for a changing climate in the future.

The integration of stakeholders into the research process has promoted an awareness and understanding of climate impacts research in the stakeholder community. By working closely with the researchers, the representatives from the stakeholder agencies have been able to incorporate their specific data and concerns into the climate impact research of the Assessment, with the result that climate variability and change may begin to be considered in the decision-making processes of the involved stakeholders.

The ongoing involvement of stakeholders in the MEC Assessment has been beneficial in strengthening the research process and results and in building a regional network of interests around the discussion of climate impacts. The representatives from stakeholder agencies have been able to forge working relationships with each other around the concerns of climate impacts. Interagency interactions, along with interdisciplinary interactions, have emerged as one of the prime by-products of the process. Just as climate impacts cannot be successfully addressed by a single academic discipline, institutional responses to potential climate change cannot occur independently. Climate impacts cross sectors and necessitate integrated institutional attention.

The Metropolitan East Coast study, along with the other regional components of the National Assessment, is a necessary first step in building a decision-making community that is informed about potential impacts of climate change and variability and that has the tools to act in preparation and response to these potential impacts. In order to build further upon the Metro East Coast Assessment there must be continuing commitment to focus on the issue of climate impacts on the New York Metropolitan Region and other urban environments.

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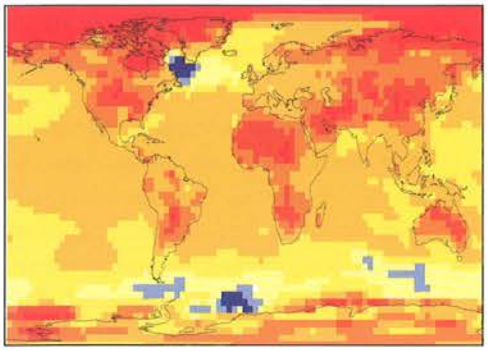

CHAPTER 2

REGIONAL CLIMATE AND POTENTIAL CHANGE

The climate of the Metropolitan East Coast Region is temperate, with rain evenly distributed throughout the year. Winters are cold, with a mean temperature of December, January, and February of 29°F, and summers are hot, with a mean temperature of June, July, and August of 70°F. Mean annual temperature is 50°F. Total annual precipitation, including rainfall and snow, averages 46 inches.

In the winter, weather patterns are dominated by high-pressure systems bringing outbreaks of cold air from Canada. In the summer, the subtropical Bermuda high-pressure system brings large-scale storms to the region, while local heating creates low-pressure systems that lead to convective thunderstorms. Nor'easters, large-area and long-duration extratropical storms prevalent between January and March, are the major cause of coastal flooding and beach erosion in the region. Hurricanes, intense cyclones that develop over the tropical oceans, strike the region much less frequently than nor'easters, but they can be even more destructive, due to storm surges and waves, high wind speeds, and heavy rainfall.

Within the region, the climate varies due to the natural and built environment. Cooling sea breezes occur along the coast, an effect that helps to dampen thunderstorms as they approach New York City. Higher topography over northwestern New Jersey amplifies snowfall and summer precipitation. The urban heat island effects causes New York City and the other cities in the region to be warmer than the surrounding areas due to the absorption of sunlight by buildings during the day and reradiation at night. Radiation trapped by non-reflective surfaces such as stone and concrete during the day is reradiated later, slowing the cooling process and keeping urban surface temperatures high relative to suburban and rural areas (Figure 2-1).

Heating of buildings on winter nights, and air conditioning during the summer also creates excess heat in the cities. Human inputs of moisture and pollutants into the atmosphere further alter the urban climate. Air pollution, in particular, increases absorption of radiation at the boundary layer, contributing to the creation of thermal inversions. Inversions prevent rising air from cooling at the normal rate and affect the dispersion of pollutants that are produced in the urban area.

A changing global climate is likely to affect the regional climate in complex and dynamic ways, altering both mean climate and the frequency and intensity of extreme events. In the Metro East Coast Assessment, researchers and stakeholders studied the impacts of and adaptation to regional climate variability and change relevant to seven sectors—Sea-Level Rise and Coasts, Infrastructure, Wetlands, Water Supply, Public Health, Energy Demand, and Institutional Decision-Making. In order to understand the role of climate in the sectors, impacts and adaptation strategies were analyzed relative to historical climate trends in the region, extreme events, and future climate scenarios.

1. *Historical trends*. Regional temperature and precipitation data over the past century were examined to determine the answers to several questions: Is the region undergoing warming already? Is long-term precipitation changing? How do regional trends in climate compare to national and global changes? How do projected changes compare to changes already experienced?

2. *Extreme events*. During the course of the Metro East Coast Assessment (1999–2000), the region experienced multiple heat waves, a prolonged drought, and notable severe storms, including Hurricane Floyd. We monitored these extreme climate events, their impacts on the region, and the region's responses. Such events provide case studies for examining the adaptive capacity of the region to potential climate variability and change in the future.

3. *Climate change scenarios*. Climate change scenarios specific to the Metro East Coast Region were developed from observed current trends and from global climate models. In the sector studies, these scenarios were used to project climate impacts, test adaptation strategies, and analyze policy responses. The historical climate trends and extreme events experienced under current climate conditions provide the context for evaluating future climate change scenarios in the region.

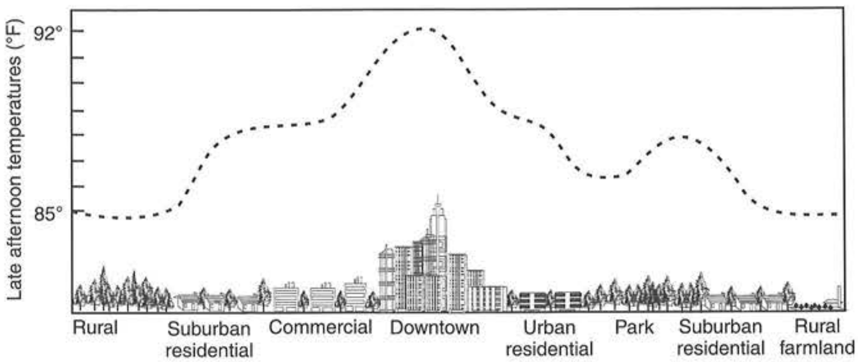

FIGURE 2-1 The urban heat island effect.

HISTORICAL TRENDS

Twenty-three climate stations in the Metropolitan East Coast region were used to assess historical trends over the last century and to project change in the current century (Figure 2-2) (See Appendix Climate 1 for details). The data are from the NOAA/NCDC USHCN, U.S. Historical Climate Network (http://www.ncdc.noaa.gov/ol/climate/research/ushcn/ushcn.html#KDK88). The temperature data have been corrected to remove the effect of the urban heat island (Karl et al., 1988), in order to allow the examination of climate trends not related to the processes of urbanization.

Historical trends of temperature and precipitation in the Metro East Coast region since 1900 are shown in Figures 2-3 and 2-4. While there have been considerable fluctuations on interannual and decadal time-scales in the average annual temperature of the past century, there is a discernible long-term warming trend, even without the effect of the urban heat island.

The average annual temperature over the last 100 years has increased by almost 2°F, or ~0.2°F per decade. Long-term warming has occurred in every season, but has been greatest in winter, particularly in recent decades. The ~2.0°F rise in temperature in the Metro East Coast region over the last century is greater than the rise of about 0.7°F observed for the nation as a whole, and also greater than the rise in global surface temperature of about 1.1°F (Karl et al., 1996; IPCC, 2001). It is very difficult to determine the cause of observed regional climate trends and their relationship to global scale warming.

Over the last 100 years, precipitation has increased by an average of about 0.1 inch per decade, causing a small overall increase of about 1 inch. However, snow falling on the region has diminished in recent decades due to a combination of the warmer winter temperatures noted above and a slight decline of precipitation in the winter.

CLIMATE EXTREMES IN THE METROPOLITAN EAST COAST REGION

The most prevalent climate extremes in the Metropolitan East Coast Region are flooding events either occurring from heavy precipitation or, in coastal areas, from storm surges. Tropical Storm Floyd in September 1999 was one of the largest storms on record with respect to damages. It caused an estimated $1 billion worth of damage in the region. Other significant floods occurred in September 1882, October 1903, September 1966, and November 1977.

The region is also subject to moderate droughts. The drought of record was in 1965, during which the region received 55% of the average rainfall (46 inches/year). Other significant drought events occurred in 1910, 1935, 1964, and 1999.

From 1999 to 2000, the Metropolitan East Coast Region experienced several heat waves, a major drought, and two severe flooding events, one due to a late summer thunderstorm and one due to Hurricane Floyd. We monitored these events, their impacts, and the

FIGURE 2-2 Climate stations used in the Metropolitan East Coast Regional Assessment.

region's responses, working with the relevant stakeholder partners, e.g., Southeastern New York Intergovernmental Water Supply Advisory Council (SENYIWSAC) for the drought and the Federal Emergency Management Agency, Region II (FEMA) for Hurricane Floyd. (See, in particular, the *Infrastructure*, *Water Supply*, *Public Health*, and *Energy Demand* chapters for further details).

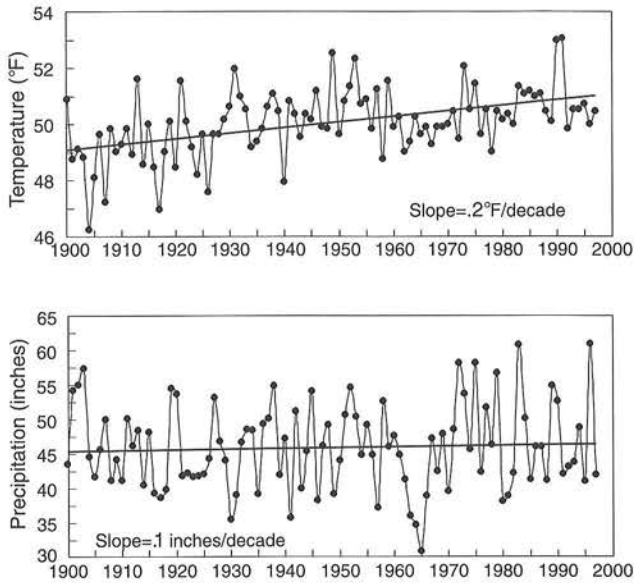

FIGURE 2-3 Observed annual temperature and precipitation trends for the MEC region (1900–1997). Note: Twenty-three station average, corrected for the urban heat island effect. Source of data: NOAA NCDC/HCN.

Heat Waves

The summer of 1999 was punctuated by a series of heat waves that imposed heat stress and extra energy demands on the New York Metropolitan Region. High temperatures were widespread throughout most of the eastern portion of the nation in July (NCDC, NOAA) (Figure 2-5). Over the course of the summer, New York City experienced 27 days of 90°F or higher, 14 days of extreme heat more than the usual 13 days of such high temperature. According to NOAA's National Weather Service, the year 1999 is ninth on the list of the top 10 number of >90°F days per year in the region.

From July 4 through July 7, sequential days of high humidity and temperatures above 90°F created Heat Indices (a combined index of temperature and relative humidity used by the National Weather Service as a proxy for the discomfort caused by heat waves) above 100°F. Stores across New York City quickly sold out of air-conditioning units. During the four days of continuous above normal temperature, the intense regional need for cooling produced energy demands that could not be met by either the cooling systems themselves or by the regional electricity infrastructure. This resulted in rolling blackouts, i.e., losses of electricity in neighborhood-wide system failures.

Eighty thousand households (more than 200,000 residents) and businesses in northern Manhattan and the Bronx experienced a blackout for 19 hours from the night of July 7 through the morning of July 8. On the same evening, areas in New Jersey lost power for 12 hours. In Hartford, Connecticut, neighborhood-wide blackouts occurred from July 6 through the July 8, affecting more than 2,000 homes and businesses.

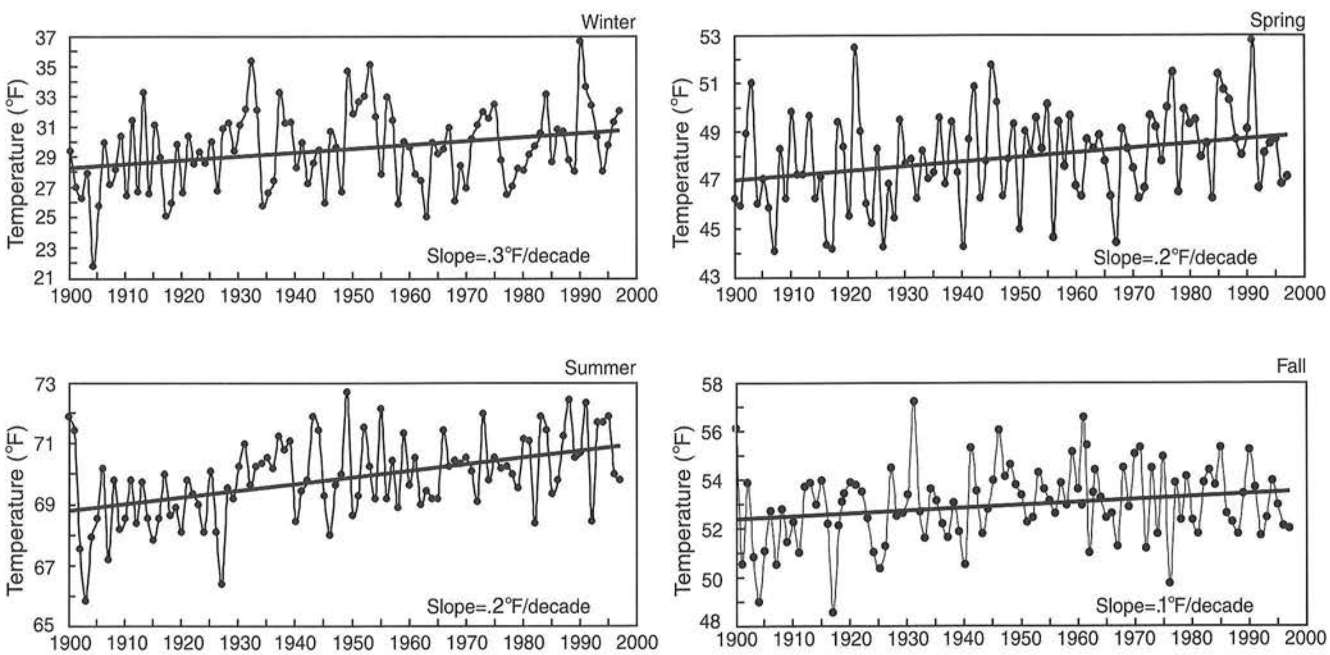

FIGURE 2-4 Observed seasonal temperature trends for the MEC region (1900–1997). Note: Twenty-three station average, corrected for the urban heat island effect. Source of data: NOAA NCDC/HCN.

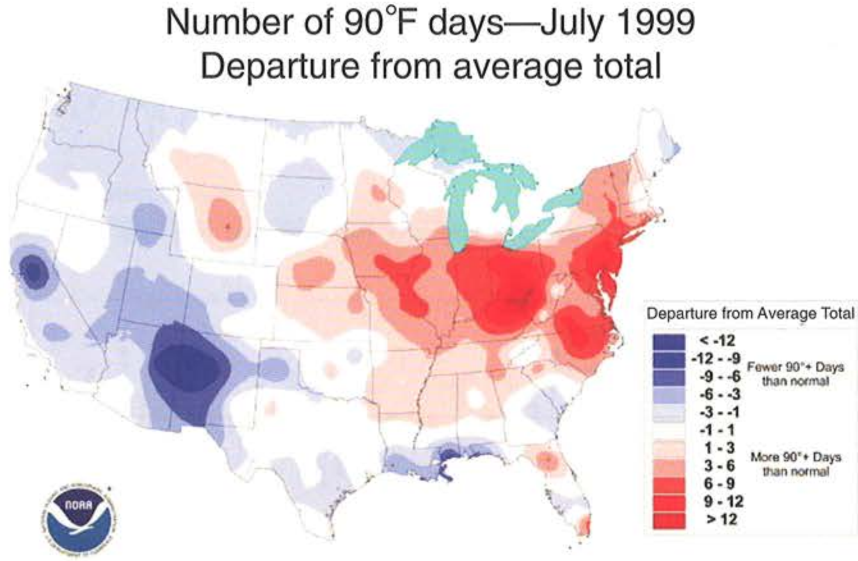

FIGURE 2-5 Departure from average total number of 90°F days in July, 1999. Note: Base period 1961–1990. Source: National Climatic Data Center/NESDIS/NOAA.

During the four days of the first heat wave, 33 people died of heat-related causes. The *New York Post* reported that July 6, 1999 broke records of water consumption, Emergency Medical Service runs, and power usage.

July 17 and July 18 brought the second heat wave of the season. The third wave came only a week later, from July 23 through August 2. The third heat wave was the second longest heat wave on record for the region. High energy demand caused a power connection failure on Staten Island on July 27 and left 4,000 households without power.

Drought

Accompanying the summer heat was a major drought that affected most of the Northeast. It was the worst drought in the United States since the Dust Bowl of the late 1930s. In some parts of the Metro East Coast region, there was no measurable rain for more than two months (May 24 to August 1). It was the driest and warmest July on record. In New York City, combined rainfall amounts were almost 8 inches below normal for the summer months (Figure 2-6), and reservoir capacities were 15% below normal.

In the face of the prolonged drought, regional water managers requested that homeowners not water lawns, wash cars, or refill swimming pools. New Jersey declared a drought emergency. Widespread ground fires broke out in the Hudson Highlands, endangering New York City's neighboring counties. The intense summer drought and responses to it may also have contributed to the fatal outbreak of the West Nile virus by affecting the habitat of mosquitos and crows carrying the virus. Beyond the Metro East Coast region, the dryness threatened fall-foliage tourism in upstate New York and New England.

Late Summer Flooding

After months of drought, the skies opened over the New York metropolitan area on August 27, 1999. Between 2.5 and 6.1 inches fell in flash floods that crippled the region's mass transport system during next morning's rush hour. Major roads were flooded, including the highly trafficked Westside Highway, Harlem River Drive and FDR Drive in Manhattan, the Bronx River Parkway, the Hutchinson River Parkway, and the Grand Central Parkway. Up to five feet of water covered the power tracks in various parts of the New York City subways, stopping service and stranding passengers on numerous lines. Service on New Jersey PATH trains was delayed due to track inundation.

Hurricane Floyd

In mid-September, after moving northwest from the Caribbean Ocean and traveling up the eastern coast of the United States, Hurricane Floyd was projected to hit the coastal areas of New York and New Jersey with precipitation that it carried from the sea (Figure 2-7). As it approached the New York City area on September 16 and September 17, the storm system shifted westward and inundated Rockland, Dutchess, Putnam, and Westchester counties in New York as well as inland counties in Northern New Jersey. The storm dropped between 12 and

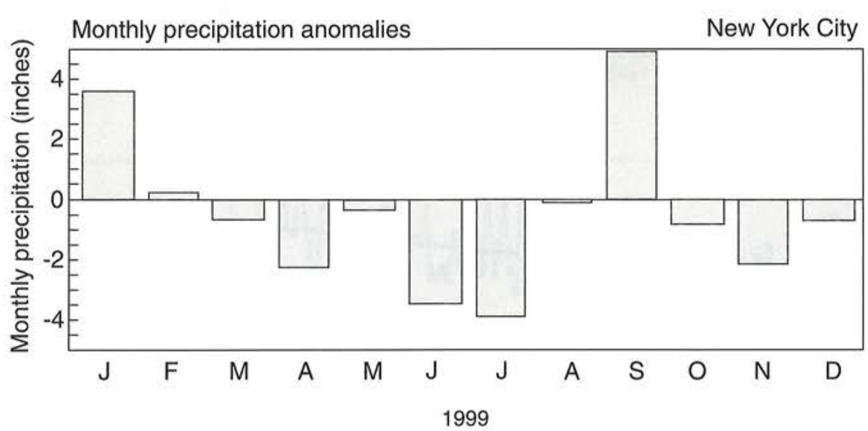

FIGURE 2-6 The drought of 1999. Monthly departures from normal precipitation (mean of 1961–1990) in New York City, January to December, 1999. Source of data: NOAA NCDC/HCN.

16 inches of rain in the areas west of the Hudson. The property damage in the region from the hurricane is estimated at $1 billion (one-sixth of its total estimated damage). September 16, 1999 is the fifth greatest daily precipitation in Central Park on record, with 5.02 inches. One death and several injuries were associated with the flooding from Hurricane Floyd in the region.

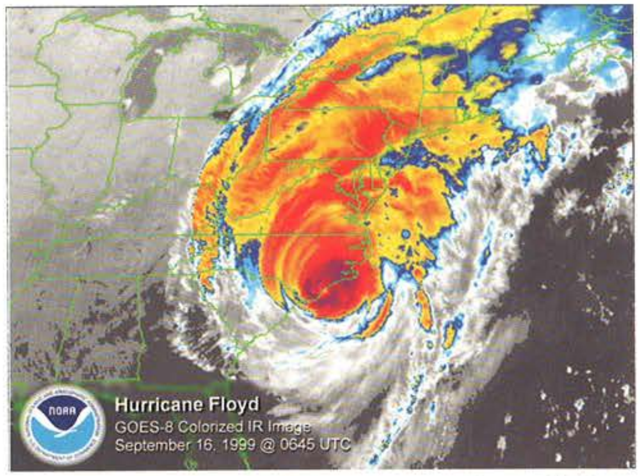

FIGURE 2-7 Hurricane Floyd, September 16, 1999. Source: NOAA.

CLIMATE CHANGE SCENARIOS

The design of impact studies often includes a set of scenarios consistent with the current state of knowledge regarding global climate change, spanning a range of possible future climate conditions. Future climate change scenarios are defined as plausible combinations of climatic conditions that may be used to test possible impacts and to evaluate responses to them. By analyzing multiple scenarios, the direction and relative magnitudes of potential impacts may be assessed and adaptation strategies evaluated. Scenarios may be used to define the vulnerability of different sectors or groups to climate change and to identify thresholds at which impacts become negative or severe. They are also used to evaluate the relative vulnerability among sectors in the same region, among similar sectors in different regions, or among different regions.

Several types of climate scenarios are utilized in the Metro East Coast Assessment: (1) Sensitivity tests to arbitrary changes in climate variables; (2) Trends in historical climate data; and (3) Projections based on results from global climate models. All scenarios used in the Assessment were developed specifically for the New York Metropolitan Region.

Sensitivity Tests

Sensitivity tests analyze how systems respond to arbitrary changes in climate variables, e.g., +1, +2, and +3°F and/or +/– 10% change in precipitation. Testing responses to such simple changes in climate can help identify the sensitivities of systems to changes in the defined variables. However, such tests do not offer a comprehensive and consistent set of climate variables, since in reality precipitation, evaporation, wind and other variables are all likely to change concurrently and interactively with change in temperature. Sensitivity tests do provide an opportunity, however, to define possible thresholds beyond which impacts may become severe, and to develop a set of system responses to which other types of scenarios may be compared.

Several of the Metro East Coast Regional Assessment sector studies carried out impact analyses using sensitivity tests to arbitrary changes in climate variables. The Water Supply sector tested the sensitivity of the Palmer Drought Severity Index (a meteorological index of moisture supply and demand used to assess the severity of dry or wet spells of weather) to uniform changes in annual temperature and precipitation. The Energy Demand sector tested the sensitivity of total and peak energy demands to arbitrary combinations of temperature and relative humidity. (See Chapter 6 *Water Supply* and Chapter 8 *Energy Demand.*)

Current Trends Scenario

The Current Trends scenario reflects a possible future climate if the temperature and precipitation trends were to continue as they have been over the last century, without major changes in the climate system. The Current Trends scenario does not assume any additional forcing from increasing greenhouse gases or sulfate aerosols.

If the average warming trend of the past century were to continue over the next century, the average annual temperature for the Metro East Coast region would increase over the 1961–1990 mean temperature by almost 1.0°F by the 2020s, 1.5°F by the 2050s, and over 2.5°F in the 2080s. If the average precipitation trend from the past century were to continue into the 21st century, precipitation would increase slightly, resulting in increments of 1% in the 2020s, 1.6% in the 2050s and 2.3% in the 2080s, compared to 1961–1990 levels. The years 1961–1990 were selected as the baseline for comparison with future climate change scenarios.

Global Climate Model Scenarios

Global climate models (GCMs) are mathematical formulations of the processes that comprise the climate system, including radiation, energy transfer by winds, cloud formation, evaporation and precipitation of water, and transport of heat by ocean currents (Figure 2-8). The equations of the models are solved for the atmosphere, land surface, and oceans over the entire globe. The models are used to simulate the climate system's future responses to additional

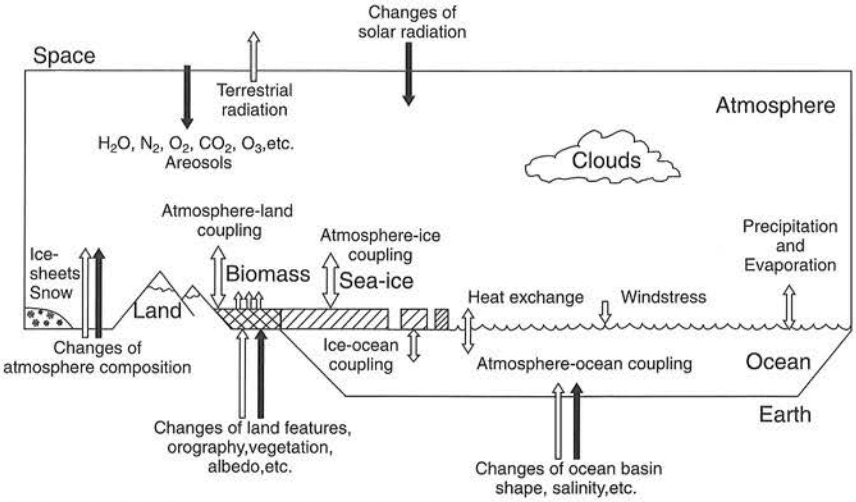

FIGURE 2-8 The climate system. Source: World Meteorological Organization.

Centre (HC) and the Canadian Centre for Climate Modeling and Analysis (CC) (Table 2-1; Johns et al., 1997; Flato et al., 1997). GCMs project global climate responses at relatively coarse-scaled resolutions (2.5 –3.75 degrees latitude by ~3.75 degrees longitude). (See http://www.nacc.usgcrp.gov for further description of the global climate models used in the U.S. National Assessment).

There are two types of scenarios for each GCM: the first accounts for the effects of greenhouse gases on the climate (GG) and the second accounts for the effect of greenhouse gases and sulfate aerosols (GS) (Table 2-2). Greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)—from burning of fossil fuels, land-use change, and other anthropogenic activities absorb longwave radiation and tend to warm the climate. The GCM simulations for the 21st century are forced with a 1% per year increase of equivalent CO_2 concentration in greenhouse gases and sulfate aerosols emitted into the atmosphere by human activities (Figure 2-9).

The global climate models used in the Metro East Coast study are those designated by the U.S. National Assessment of the Potential Consequences of Climate Variability and Change: the United Kingdom Hadley

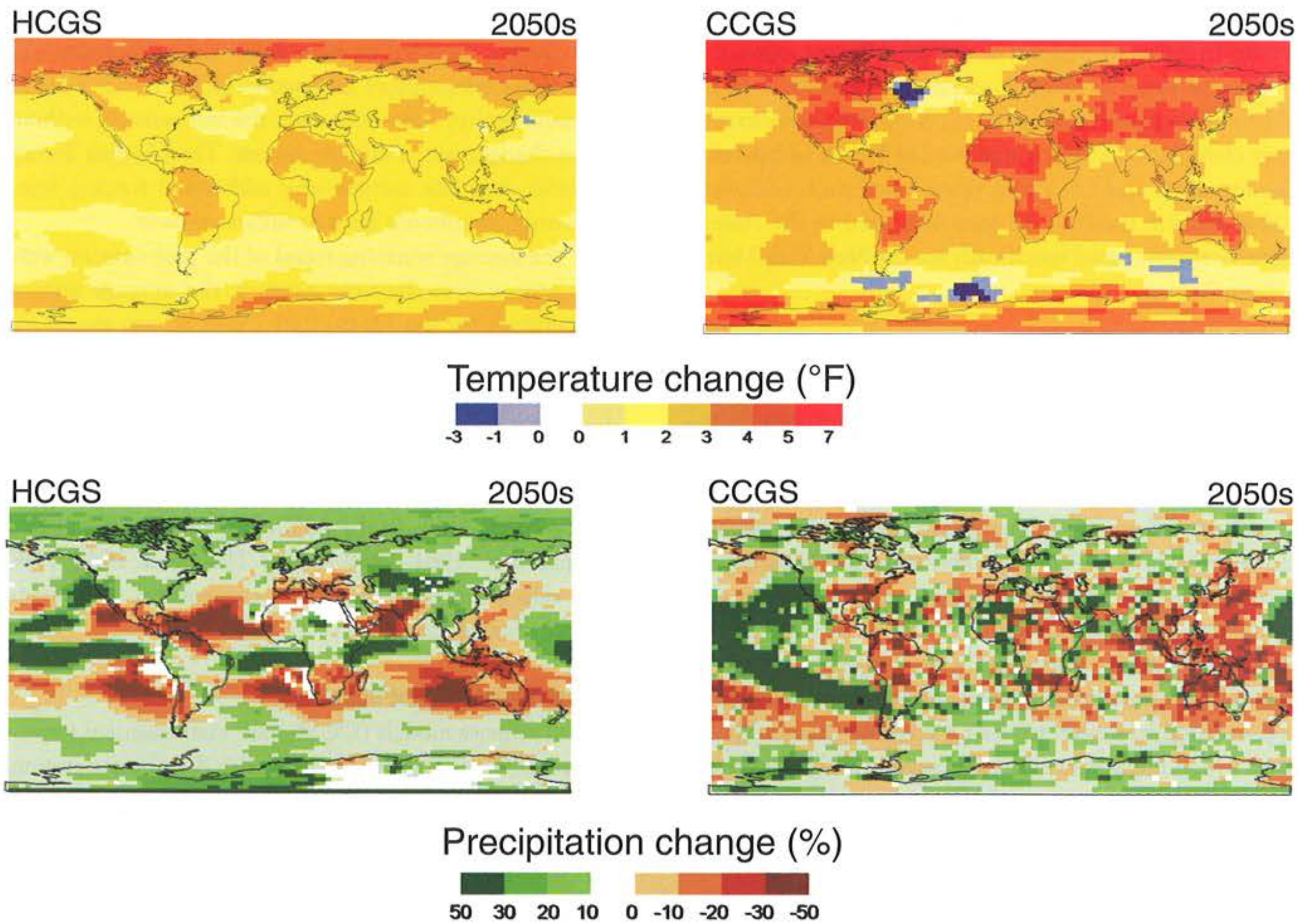

FIGURE 2-9 Global temperature and precipitation changes in the 2050s projected by the Hadley Centre (HC) and Canadian Centre (CC) global climate models with greenhouse gases and sulfate aerosols (GS).

TABLE 2-1
Global climate models used in the Metro East Coast Regional Assessment.

Scenario	Resolution	Sensitivity[a]
	(lat. x long.)	°F
Hadley Centre (HC)	2.5° x 3.75°	4.7
Canadian Centre (CC)	3.75° x 3.71°	6.3

[a] The global mean temperature change resulting from a doubling of atmospheric carbon dioxide in a global climate model simulation.

the atmosphere. These simulations are based on "business-as-usual" greenhouse gas emission scenarios of the Intergovernmental Panel on Climate Change and account for changes in other greenhouse gases besides CO_2 (IPCC, 1996). Sulfate aerosols are emitted as by-products of industrial activities and create a cooling effect as they reflect and scatter solar radiation. The scenarios that incorporate both greenhouse gases and sulfate aerosols tend to be slightly cooler than those with greenhouse-gas forcing alone.

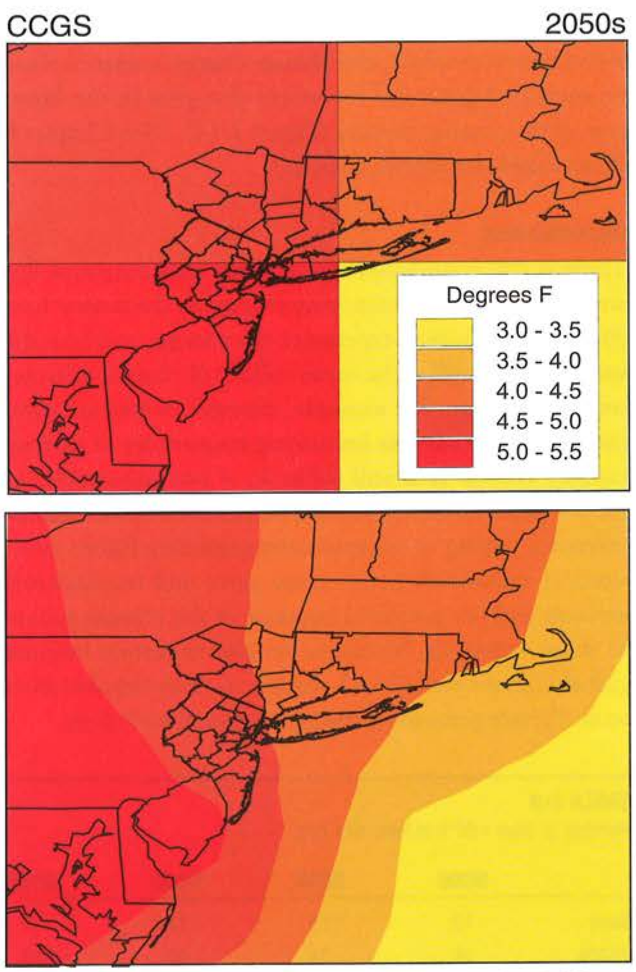

FIGURE 2-10 Projected change in annual temperature for the Metro East Coast region in the 2050s for individual gridboxes and with linear interpolation. Canadian Centre global climate model with greenhouse gases and sulfate aerosols (CCGS).

TABLE 2-2
Climate change scenarios used in the Metro East Coast Regional Assessment.

Scenario	Description
Current Trends	Projection of historical temperature and precipitation trends (1900–1999)
HCGG	Hadley Centre, with forcing from greenhouse gases
HCGS	Hadley Centre, with forcing from greenhouse gases and sulfate aerosols
CCGG	Canadian Centre, with forcing from greenhouse gases
CCGS	Canadian Centre, with forcing from greenhouse gases and sulfate aerosols

The climate change scenarios were created for each decade of the 21st century, with a focus on the designated study periods of the 2020s, 2050s, and 2080s. Simulated monthly temperature and precipitation were linearly interpolated across the GCM gridboxes in the Metro East Coast region to the mean latitude and longitude of the 23 climate stations (Figure 2-10). Monthly differences in temperature and ratios of precipitation from the GCMs were obtained by comparing the simulated decadal averages to the simulated 1961–1990 averages. These changes between the GCM climate variables simulated for the study periods and those simulated for 1961-1990 were then applied to the observed mean regional climate variables for 1961–1990 to create the regional climate change scenarios.

The five scenarios (Current Trends, HCGG, HCGS, CCGG, CCGS) provide a range of future possible climates for the Metro East Coast region (Figures 2-11 and 2-12). The scenarios vary in the magnitude of the projected temperature changes, but they all follow a warming trend. The projected temperature changes of the Current Trends scenario are lower than those of the GCM scenarios, because they do not account for increasing feedback from greenhouse-gas warming.

The GCM models project temperature changes greater than the Current Trends scenario, ranging from 1.7–3.5°F annual temperature rises in the 2020s, 2.6–6.5°F in the 2050s, and 4.4–10.2°F by the 2080s. The Canadian Centre scenario consistently projects higher temperatures for the region than the Hadley Centre, while the scenarios that combine greenhouse gases and sulfate aerosols are consistently cooler than those with greenhouse gases alone.

On a seasonal basis, the climate models project that regional warming will occur in all seasons. In the 2050s, the range of winter temperature rise is 3.3 to 5.6°F, while summer temperature rise is projected to range between 2.7 and 7.6°F.

Precipitation projections of the global climate model scenarios are greater than the small increases found in the Current Trends scenario, but do not agree in either

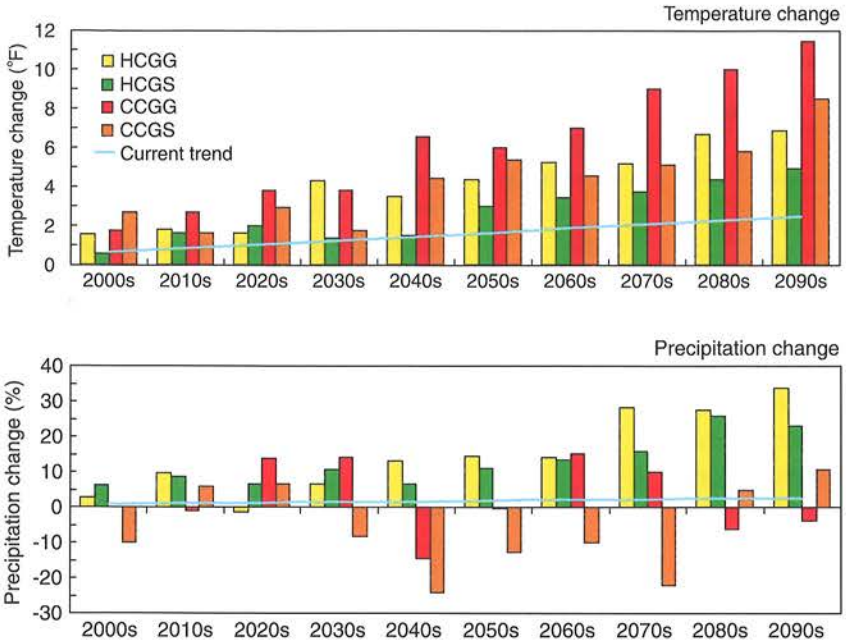

FIGURE 2-11 Decadal temperature and precipitation changes in the Metropolitan East Coast Region projected by the Hadley Centre (HC) and Canadian Centre (CC) climate change scenarios with greenhouse gases (GG) and with greenhouse gases and sulfate aerosols (GS), and the Current Trends scenario.

A warmer climate will bring greater temperature extremes in the summer. In the current climate (1979–1996), New York City has an average of 13 days per year with maximum temperature over 90°F. By the 2050s, such days are projected to range from 28 to 51 (Table 2-3). When the effects of relative humidity are added to the temperature rise, the number of days with the National Weather Service Heat Index above 90°F increases from 14 days (1997–1998 base) to a range of 24 to 40 days in the 2020s, 30 to 62 days in the 2050s, and 40 to 89 days in the 2080s (Figure 2-13). (See Chapter 8 *Energy Demand* for further discussion.)

The Palmer Drought Severity Index (PDSI) calculates the combined effect of the temperature and precipitation changes, allowing an assessment of the potential for droughts and floods in the region (Palmer, 1965). Since warmer temperatures increase evaporative demand on soil moisture, the climate change scenarios show an increased potential for severe droughts in the latter part of the coming century (Figure 2-14). (See Chapter 6 *Water Supply* for further analysis).

magnitude or direction (+1% to +9% in the 2020s; –16% to +14% in the 2050s, and –2% to +30% by the 2080s). The Hadley Centre scenarios show increasing levels of precipitation, while the Canadian Centre scenarios project varying precipitation changes over time. Both annual and seasonal projections indicate the potential for precipitation increases or decreases in the future.

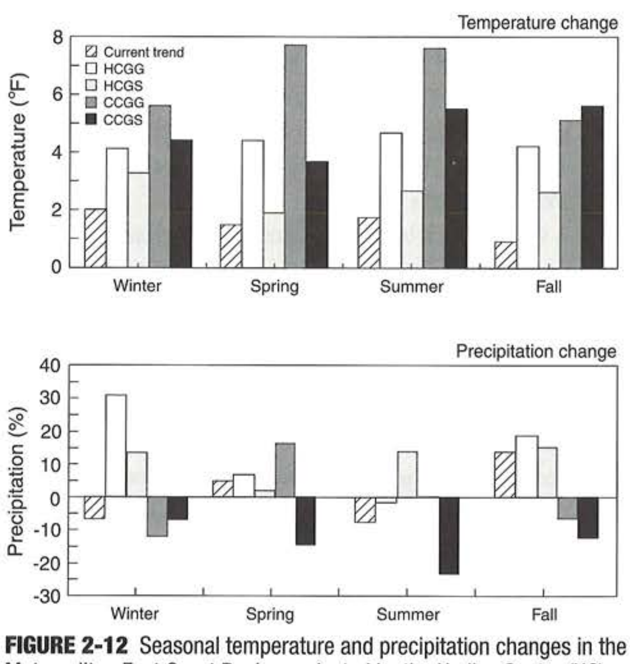

FIGURE 2-12 Seasonal temperature and precipitation changes in the Metropolitan East Coast Region projected by the Hadley Centre (HC) and Canadian Centre (CC) climate change scenarios with greenhouse gases (GG) and with greenhouse gases and sulfate aerosols (GS), and the Current Trends scenario.

Uncertainties

There is still considerable uncertainty regarding how fast and by how much climate may change in the future, how different regions may experience the change, and how the variability (as well as the mean values) of climatic parameters may change. For example, changes in precipitation may be experienced as increasing frequencies of intense rainfall events. It is still difficult, if not impossible, to ascribe probabilities to any of the various climate change scenarios, owing to uncertainties regarding future emissions of radiatively active trace gases and tropospheric aerosols and the potential response of the climate system to those emissions. Scenarios are also uncertain because global climate models lack realism in their simulation of some climate processes, especially regional hydrology.

TABLE 2-3
Number of days >90°F in New York City.

	HCGG	HCGS	CCGG	CCGS
Base	13	13	13	13
2020s	26	24	32	28
2050s	37	28	51	38
2080s	46	35	71	60

Note: Base period 1979–96.

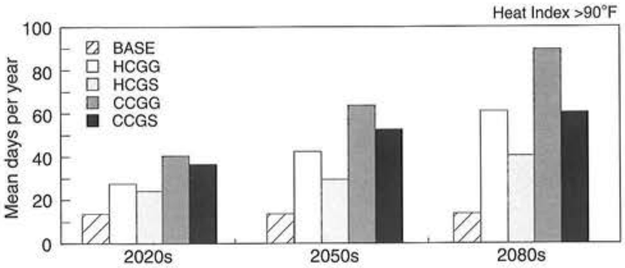

FIGURE 2-13 Days per year with Heat Index greater than 90°F in the Metropolitan East Coast Region for base period (1997–1998) and the 2020s, 2050s, and 2080s projected by the Hadley Centre (HC) and Canadian Centre (CC) climate change scenarios with greenhouse gases (GG) and with greenhouse gases and sulfate aerosols (GS).

For these reasons, impact and adaptation studies based on climate scenarios are not viewed as predictions, but rather descriptions of possible futures. Nonetheless, they can be useful in defining, for critical biophysical and socio-economic systems, directions and relative magnitudes of change, as well as potentially critical thresholds of climate-sensitive processes. By these means, researchers and decision-makers are able to conduct "practice" exercises, which may help them to improve responses to current climate extremes, anticipate future climate conditions, and prepare appropriate adaptations in an effective and flexible manner.

FURTHER RESEARCH

Further research is needed to develop finer-scale climate change scenarios, utilizing regional climate models and downscaling techniques. Also needed is improved characterization of the risks posed by changes in the urban heat island effect, especially in regard to energy demand and air quality. Other areas of further study include how storm tracks may change and how the frequencies and intensities of extreme events may be altered under changing climate conditions. Development of such tools will enable better identification of the relative vulnerabilities of the people and places in the Metro East Coast Region, and continued evaluation of the regional activities required to prepare and adapt.

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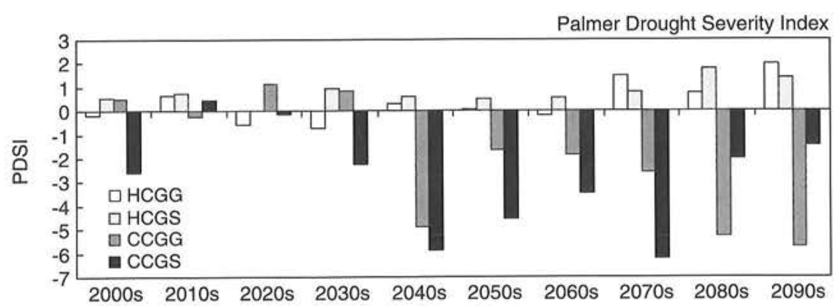

PDSI classes for wet and dry periods

>4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to -0.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
<-4.00	Extreme drought

FIGURE 2-14 Palmer Drought Severity Index for the Metropolitan East Coast Region projected by the Hadley Centre (HC) and Canadian Centre (CC) climate change scenarios with greenhouse gases (GG) and with greenhouse gases and sulfate aerosols (GS).

PART 2

SECTOR REPORTS

CHAPTER 3

SEA-LEVEL RISE AND COASTS

Anticipated climate changes will greatly amplify risks to coastal populations. By the end of the century, a two to five-fold increase in rates of global sea-level rise could lead to inundation of low-lying coastal regions, including wetlands, more frequent flooding due to storm surges, and worsening beach erosion (IPCC, 1996a,b). Saltwater could penetrate further up rivers and estuaries and infiltrate coastal aquifers, thereby contaminating urban water supplies.

In the metropolitan New York, Connecticut, and New Jersey region, as elsewhere, the coastal zone is squeezed between the hazards of flooding, beach erosion, and sea-level rise on the one hand, and development pressures on the other hand. In the region, ongoing sea-level rise and land subsidence have historically contributed to beach erosion, narrowing of barrier islands, and storm-related damages. These processes will continue and possibly worsen, if projected climate changes materialize.

This report focuses on potential impacts of sea-level rise on the Metropolitan East Coast (MEC) Region and how natural processes interact with increasing urbanization and other land-use changes. We present the results of a suite of sea-level projections for several plausible scenarios of climate change in the MEC Region. Estimates are also made of future coastal flood heights, return intervals, increases in sand volumes and costs for beach nourishment under these scenarios at selected case study sites (Figure 3-1). Implications of these findings for coastal management are also discussed.

Global Sea-Level Trends

Mean global sea level has been increasing by 0.04 to 0.1 inches/year (1–2.5 millimeters/year), for the last 150 years, with 0.07 inches/year (1.8 millimeters/year) considered the "best estimate" (Warrick et al., 1996; Gornitz, 1995a). This is the most rapid rate within the last few thousand years (Varekamp and Thomas, 1998; Gornitz, 1995b) and is probably linked to the 20th century global warming of over 1°F (0.6°C) (IPCC, 2001). Additional evidence of warming comes from the world's oceans, where water temperatures have risen an average of 0.1°F (0.06°C) between 1955 and 1995, down to a depth of around 10,000 feet (3000 meters); (Levitus et al., 2000).

Most of the observed sea-level rise can be attributed to thermal expansion of the upper ocean layers and melting of mountain glaciers, with nearly zero contributions from polar ice sheets at present (Warrick et al., 1996). Human modification of the hydrologic cycle could also affect sea-level rise. Sequestration of water on land in reservoirs and through irrigation losses could exceed amounts transferred seaward by groundwater mining and increased runoff due to urbanization and deforestation. The net effect of these processes could slow sea-level rise by 0.04±0.02 inches/year (0.9±0.5 millimeters/year) (Gornitz et al., 1997; Gornitz, 2000).

Closely linked atmospheric-oceanic processes such as the El Niño-Southern Oscillation or the North Atlantic Oscillation generate considerable interannual variability in ocean heights, superimposed on longer-term trends (Nerem, 1999; Hurrell, 1995). Above-average sea levels, coastal storms, and cliff erosion are associated with El Niño events on the U.S. West Coast (Komar and Enfield, 1987). While above-average sea levels occur in the southeastern United States and northwestern Europe during the positive phase of the North Atlantic Oscillation, its effects on the MEC Region are less clearly defined (Maul and Hanson, 1991; V. Gornitz, unpubl. data).

The future of the Antarctic ice sheet introduces a major uncertainty into sea-level projections. Most global climate models anticipate higher rates of Antarctic snow/ice accumulation than melting. This would remove water from the ocean and reduce sea level (Warrick et al., 1996). On the other hand, a large part of the West Antarctic ice sheet is potentially unstable because it rests on land now

Vivien Gornitz, Center for Climate Systems Research, Columbia University and Goddard Institute for Space Studies, with contributions from Stephen Couch, U.S. Army Corps of Engineers, New York District

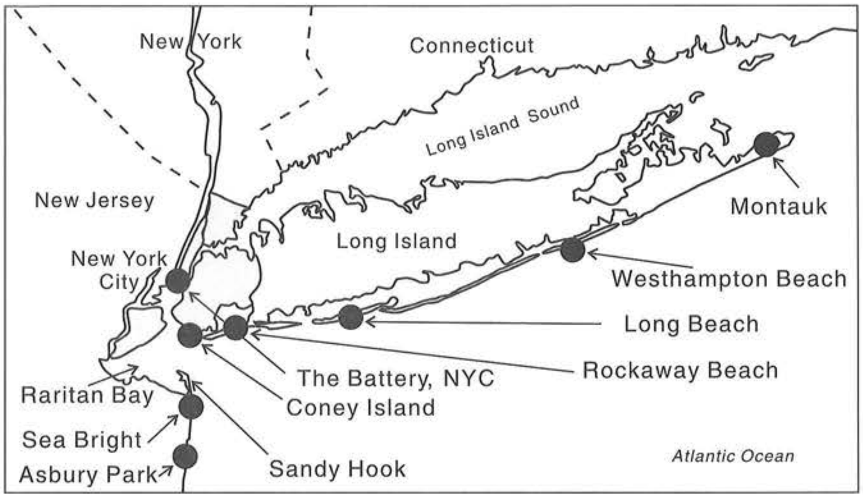

FIGURE 3-1 Study site locations.

below sea level or forms floating ice shelves, which are locally "pinned" or stabilized by submarine ridges. These prevent rapid discharge of ice from fast-moving ice streams. Ocean warming could eventually thin and "unpin" these shelves, which would accelerate the calving of icebergs into the ocean. The melting of this additional ice over several centuries could raise sea level by some 16.4–19.7 feet (5–6 meters). This process, although considered very unlikely, would have devastating consequences on low-lying coastal areas worldwide, if it were to occur (Oppenheimer, 1998).

Regional Sea-Level Trends

Sea level has been rising along the U.S. East Coast since the end of the last glaciation. Although most deglaciation ended over 6,000 years ago, sea level has continued to change due to the time lag with which the earth's crust has responded to the redistribution of mass on its surface following the removal of the ice (i.e., glacial isostatic changes). These sea-level changes are spatially non-uniform over time scales of thousands of years to the present.

The MEC region lies at the southern edge of the last ice sheet. The area to the south was upwarped during the Wisconsinan glaciation 20,000 years ago (the "peripheral bulge"), while land to the north was depressed beneath the weight of the ice. As land formerly under the ice sheet rebounded, most of the Atlantic Coast has subsided. (The zone of subsidence due to the collapsed peripheral bulge has migrated northward over time to the Canadian Maritime Provinces. The area north of the St. Lawrence valley is currently rebounding). Geophysical models have been used to filter these crustal motions from tide-gauge data in the eastern United States (Peltier, 1999; Davis and Mitrovica, 1996).

Tide gauges measure *relative* sea-level change, which includes glacial isostatic and other geologic signals, in addition to the more recent global sea-level signal (Gornitz, 1995b). Indicators of former sea level (e.g., mollusks, corals, peats, woods, etc.) going back thousands of years can be used to derive a long-term sea-level curve, which includes these geologic trends. Subtraction of long-term trends from the recent sea-level data leaves the climate-related *absolute* sea-level change. The absolute average sea-level rise for eastern North America is 0.05±0.03 inches/year (1.3±0.7 millimeters/year; Appendix Coast 1).

At present, the rate of relative sea-level rise in the MEC region varies between 0.09 inches/year (2.20 millimeters/year) in Port Jefferson, Long Island and 0.15 inches/year (3.85 mm/yr) in Sandy Hook, New Jersey (Table 3-1). In New York City, the rate is 0.11 inches/year (2.73 millimeters/year, Table 3-1). These values lie above the estimated global mean sea-level rise, because of the ongoing regional subsidence, but vary slightly from place to place due to various local factors.

Coastal Stressors Independent of Climate

The coastal zone in the MEC region is subject to a number of natural and human-induced pressures. Beaches are continually changing as sand is shifted by waves, tides, and currents. Beaches are eroding and barrier islands narrowed or driven landward, in part due to ongoing sea-level rise and land subsidence.

The relative vulnerability of different coastal environments to sea-level rise has been quantified at regional to national scales using information on coastal geomorphology, rates of relative sea-level rise, past shoreline movement, topography, and other factors (Gornitz and White,

TABLE 3-1
Relative sea-level trends—New York, Connecticut, New Jersey Tri-State region

Station	Relative Sea Level Rise		Record Length Year
	mm/yr	*in/yr*	
New London, CT	2.10	0.083	64
Bridgeport, CT	**2.57**	**0.101**	**32**
New Rochelle, NY	**2.05**	**0.081**	**25**
Montauk, NY	**2.27**	**0.089**	**49**
Port Jefferson, NY	**2.20**	**0.087**	**32**
Willets Point, NY	**2.30**	**0.091**	**64**
New York City, NY	**2.73**	**0.107**	**140**
Sandy Hook, NJ	**3.85**	**0.152**	**64**
Atlantic City, NJ	3.97	0.156	85

Stations lying within the Metro East Coast region are in **bold**.

1992; Gornitz et al., 1994). These physical variables are then combined into a *Coastal Vulnerability Index* (CVI), which ranks the relative vulnerability of the coast into one of four risk categories from High to Low. This methodology has recently been updated and refined by the U.S. Geological Survey (Thieler and Hammar-Klose, 1999).

Most of the south shore of Long Island and the New Jersey coast, which consist predominantly of barrier islands, lie in the High to Very High risk categories. On the other hand, the north shore of Long Island and the Connecticut coasts, with more varied landforms (including rocky headlands in Connecticut), are ranked at a relatively lower risk.

Some of the highest population growth rates in the United States occur in coastal counties. In the Tri-State region, coastal populations have grown by around 17% between 1960 and 1995, with seven coastal counties displaying growth rates exceeding 100% (Culliton, 1998). High-rise residential complexes are sprouting at water's edge in Jersey City, Hoboken, and Edgewater, New Jersey (Figure 3-2; Garbarine, 1999), and Battery Park City in lower Manhattan (Figure 3-3). New houses are being built on the dunes of the Hamptons, in eastern Long Island, where many expensive homes were lost during severe nor'easters in the winter of 1992–1993 (Figure 3-4; Maier, 1998).

Beaches and other open coastal areas represent a prime recreational resource, that offers the urban population of the MEC region relief from summer heat and leisure activities including swimming, fishing, and boating. As population continues to grow and additional land is converted to higher density urban uses, less area remains to expand existing public parks and beaches. Furthermore, many seaside communities, particularly on Long Island, limit beach access to non-residents, thus augmenting utilization pressure on existing public facilities. This raises an important equity issue: to what extent should coastal towns benefit from beach maintenance that is largely supported by taxpayers who live elsewhere?

The historic regional tendency toward coastal erosion, particularly following major storms as shown below, needs to be periodically counteracted by beach replenishment projects (Dean, 1999; NRC, 1990). A number of such projects have been undertaken by the U.S. Army Corps of Engineers in New Jersey and the south shore of Long Island (Table 3-2, Valverde et al., 1999).

Although not considered in detail in this report, water pollution is another coastal stressor. Pollution often reaches levels that necessitate closure of beaches. Pollution comes from various sources, such as oil slicks and tar balls from

FIGURE 3-2 Waterfront development on the Hudson River, Jersey City, NJ.

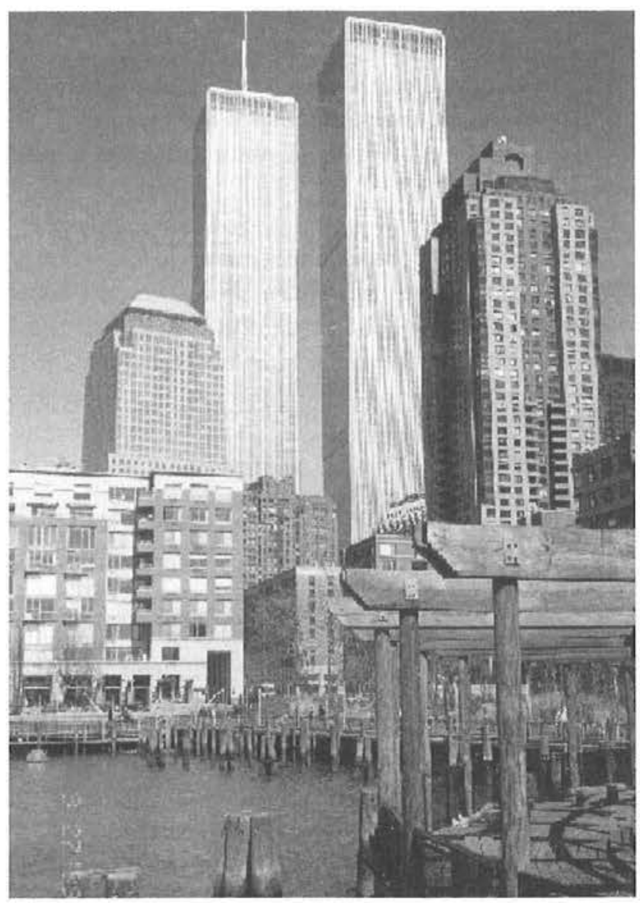

FIGURE 3-3 Battery Park City and the World Trade Tower, looking north.

tankers, and industrial and urban refuse, including contaminated medical waste. Noxious algal blooms (e.g., "red tides") occasionally force beach closings. These events are often triggered by warmer than average sea surface temperatures and high pollutant levels.

POTENTIAL IMPACTS OF SEA-LEVEL RISE

This report investigates impacts of climate change on sea-level rise and coastal hazards in the MEC region and how these natural processes interact with shoreline development and land-use changes. Coastal hazards examined include sudden, high impact events—storm surges and shoreline erosion, as well as slow-onset hazards—sea-level rise and resulting land loss. Consequences of saltwater intrusion will be briefly discussed. Impacts on coastal wetlands are covered in Chapter 5.

Research Questions

Questions to be addressed are:

1. What is the likely range of sea-level rise in the MEC region, taking into account local subsidence effects?
2. What are the maximum flood heights that can be expected, superposed on sea-level rise, and what is their frequency of occurrence?
3. What additional beach nourishment requirements and associated costs are anticipated due to sea-level rise?
4. How will these changes in natural hazards impact coastal communities?

A set of sea-level projections is presented for a number of plausible scenarios of climate change for the MEC region. Estimates are also made of future coastal flood heights, return intervals, and increases in sand volumes and costs for beach nourishment under these scenarios at selected case study sites. Implications of these findings for coastal management are discussed.

TABLE 3-2
Cumulative beach nourishment costs for case study sites

Location	Time Period	Adjusted Cost (1996)
Coney Island	1923–1995	$25,220,000
Rockaway Beach	1926–1996	$134,344,956
Lido Beach (Long Beach)	1962	$1,492,010
Westhampton Beach	1962–1996	$47,167,821
Sea Bright-Monmouth Beach	1963	$8,212,536
Sandy Hook-Deal (includes Sea Bright)	1995–1996	$35,973,000
Total		**$252,410,323**

Sources: Duke University Program for the Study of Developed Shorelines; Valverde et al. (1999).

Existing Coastal Hazards in the MEC Region

This section reviews current coastal hazards, such as shoreline erosion and flooding caused by tropical and extratropical storms (hurricanes and nor'easters, respectively).

COASTAL EROSION

The shore is an inherently dynamic environment, shaped by waves, tides, and winds, over days, years, centuries, and longer. The amount of sand on a natural beach is a balance between the amount supplied by rivers, cliff erosion, longshore currents, or overwash during major storms vs. the amount removed by longshore currents, transport into tidal inlets, lagoons, and the inner shelf, or wind (Figure 3-5; Viles and Spencer, 1995). Manmade interference with transport will disrupt these natural processes.

Overview. Over 70% of the world's sandy beaches are retreating (Bird, 1985). In the MEC region, beaches and barrier islands are narrowing or shifting landward, in part due to ongoing sea-level rise and land subsidence (see Regional Sea-Level Trends and Historical Erosion Trends). Accelerated sea-level rise may intensify the rate and extent of coastal erosion.

While sea-level rise is an important factor, beach erosion is frequently exacerbated by human activities, such as trapping of silt and sand in upstream reservoirs, disruption of longshore drift by groins and breakwaters, and sand mining. Examples of such effects in the MEC region are presented below.

Historical erosion trends—Long Island. Long Island formed from glacial outwash plains, stream deposits, and moraines at the end of the last Ice Age,

FIGURE 3-4 House on stilts built after the December 1992 nor'easter, on the site of the Little Pikes Inlet breach, Dune Road, Westhampton Beach.

18,000 years ago. During the marine incursion following the last Ice Age, glacial sands and gravels were eroded and redeposited into ridges and swales on the inner continental shelf and onshore. Barrier islands have migrated landward and upward more or less continuously during the Holocene by "rolling over", i.e., through dune overwash and inlet formation. The modern barriers are geologically young—not more than ~1000 years old, although the ancestral islands lay lower and seaward of their present locations (Leatherman and Allen, 1985).

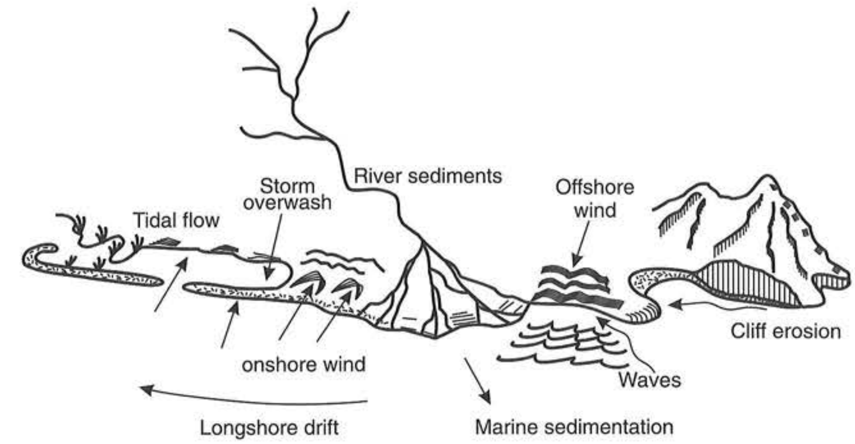

FIGURE 3-5 Sand transport processes.

The south shore of Long Island is now flanked by a string of barrier beaches and islands extending from the Rockaways in the west to Southampton in the east. Headland beaches and bluffs constitute the remainder of the eastern Long Island shoreline toward Montauk Point. Littoral currents move sand from Montauk Point westward toward New York City, except where intercepted by "hard" structures, such as groins or jetties.

Most of the southern Long Island coastline has been eroding since the 1830s (Leatherman and Allen, 1985). One exception is the western end of Fire Island, which has accreted seaward, especially since construction of the Fire Island inlet jetties in 1941. Major coastal erosion also followed construction of the Moriches Inlet and Shinnecock Inlet jetties (1952–1954), and groins near Westhampton in the late 1960s. These structures have interrupted the natural westward longshore drift (Kana, 1995).

Recent high-resolution sea-floor mapping of the inner continental shelf off Long Island has revealed important geologic and geomorphologic differences between the inner shelf east and west of Watch Hill at the middle of Fire Island. The steeper shelf and lower sediment supply east of Watch Hill, have led to relatively rapid landward migration and formation of inlets towards the east, in contrast to the western portion of Fire Island (Schwab et al., 2000).

Historical erosion trends—northern New Jersey. The northern New Jersey ocean shoreline extends from Sandy Hook in the north to Asbury Park in the south. Sandy Hook is a spit attached to the mainland near Long Branch. The middle portion of the Sandy Hook spit accreted landward prior to 1900. Serious erosion has occurred at the southern end of the spit near Sea Bright. The area south of Sandy Hook, between Monmouth Beach and Asbury Park, is a cliffed coastline. The historic mean erosion rate for the whole northern New Jersey coast was 2.6 feet/year (0.8 meters/year) between 1836 and 1985 (Gorman and Reed, 1989). The coast south of Sea Bright has generally retreated over the period, except between 1932 and 1953. Between 1953 and 1985, the shoreline of northern New Jersey remained fairly stable, except for two erosion "hotspots," around Asbury Park and north of Sea Bright (Gorman and Reed, 1989).

Major beach nourishment projects were undertaken in Sea Bright and Asbury Park in the early 1990s (Bocamazo, 1991), and at Sandy Hook during the 1980s and early 1990s (Psuty and Namikas, 1991). A seawall/groin complex in the Sea Bright area, south of Sandy Hook, has significantly reduced northward longshore sediment flow to Sandy Hook and steepened the nearshore slope. These factors have enhanced natural erosion due to the long-term sea-level rise (0.15 inches/year or 3.85 millimeters/year at Sandy Hook). These adverse conditions necessitate periodic beach replenishment (Psuty and Namikas, 1991).

The Raritan Bay estuarine coast has receded landward at an average rate of 7.9 feet/year (2.4 meters/year) during the mid-19th century (Jackson, 1996). The shoreline expanded seaward by 1.7 feet/year (0.53 meters/year) until the 1930s, due to extensive development, and construction of bulkheads, seawalls, and groins designed to protect the shoreline. The period of the 1930s, 1940s, and 1950s saw a slight erosion (or negative) trend of 1.05 feet/year (0.32 meters/year). Since 1957, the shoreline has remained relatively stable, except for some growth near beach nourishment projects.

COASTAL STORMS

Nor'easters (extratropical cyclones) are the dominant type of storm producing major coastal flooding and beach erosion north of Chesapeake Bay (Zhang et al., 2000). Nor'easters are most prevalent between January and March. Although wind speeds are lower than in hurricanes, nor'easters generate considerable damage because of their greater areal extent and duration over several tidal cycles at a particular location (Davis and Dolan, 1993; Dolan and Davis, 1994).

Storm frequencies along the East Coast over the last 50 years peaked in the late 1960s, diminished in the 1970s, and rose again in the early 1990s (Zhang et al., 2000; Dolan and Davis, 1994). However, the number or severity of storms has not increased discernibly over this period. Twentieth century tide-gauge records from Atlantic City, NJ and Charleston, SC show no statistically significant trends in either the number or duration of storm surge events, after removing tidal components and long-term sea-level rise (Zhang et al., 2000; 1997). The apparent secular increase in flooding is largely a consequence of the regional sea-level rise, beach erosion, and coastal development during this period. Thus, rising ocean levels are likely to exacerbate storm impacts.

Significant nor'easters within the last 40 years include the Ash Wednesday storm (March 6–7, 1962), the Halloween storm (October 31, 1991), and two other powerful coastal storms December 11–12, 1992 and March 13–14, 1993. The Ash Wednesday storm, with flood levels over 7 feet at the Battery, lower Manhattan, was particularly destructive over the entire Mid-Atlantic States region because it lasted for five tidal cycles. However, the December 1992 storm produced some of the worst flooding seen in the New York Metro area in 40 years. The water level at the Battery tide-gauge peaked at 8.5 feet above NGVD (7.8 feet above mean sea level; U.S. ACOE/FEMA/NWS, 1995), when tides were already above normal due to full moon. Flooding of lower Manhattan and portions of the FDR Drive together with near hurricane-force wind gusts led to the almost complete shutdown of the New York metropolitan transportation system. Coastal flooding also forced evacuation of many seaside communities in New Jersey, Connecticut, and Long Island (*New York Times*, December 12, 1992; Storm Data, December 1992).

The December 1992 storm provided a "wake-up" call, heralding the vulnerability of the metropolitan New York-New Jersey-Connecticut transportation systems to major nor'easters and hurricanes. Most area rail and tunnel points of entry, and airports lie at elevations of 10 feet or less (U.S. ACOE/FEMA/NWS, 1995). This elevation represents a critical threshold. Flood levels of only 1 to 2 feet (0.3–0.61 meters) above those of the December 1992 storm could have resulted in massive inundation and loss of life.

The vulnerability of the regional transportation system to flooding was demonstrated again on August 26, 1999, when a brief, but severe thunderstorm dumped 2.5 to 4 inches of rain on the New York metropolitan area, nearly paralyzing the system (see *New York Times*, August 27, 1999; also Chapter 4 *Infrastructure*). With future sea-level rise, even less powerful storms could inflict considerable damage (see Results—Storm surges and coastal flooding).

Hurricanes are major tropical cyclones or low-pressure systems that intensify over the open ocean. The destructive power of hurricanes derives from their very high wind speeds (minimum wind speeds of at least 119 kilometers/hour (74 miles/hour), flooding due to the high storm surge and waves, and heavy rainfall. The storm surge is a dome of water produced by the low barometric pressure and strong wind shear, particularly on the right side of the low-pressure system. The height of the surge is amplified if it coincides with the astronomical tide. Waves add to the flooding.

Atlantic basin hurricane records show no secular trends between 1944 and 1996, although distinct multidecadal variations exist (Landsea et al., 1999). For example, many severe hurricanes (Saffir-Simpson categories 3-5; Table 3-3) occurred between the 1940s through the 1960s. This period was followed by a relative lull during the 1970s through early 1990s and an upswing in hurricane activity in the late 1990s.

Atlantic hurricanes are influenced by the El Niño-Southern Oscillation (ENSO). During the El Niño phase, tropical vertical shear increases due to stronger upper-atmosphere westerly winds, which inhibit the development and growth of tropical hurricanes. Therefore, Atlantic tropical storms and hurricanes are 36% more frequent and 6% more intense during the La Niña phase of ENSO than during an El Niño (Landsea et al., 1999). The probability of sustaining at least $1 billion in damages is 77% during a La Niña year, as compared to only 32% in an El Niño year, and 48% in a "neutral" year (Pielke and Landsea, 1999).

While hurricanes are much less frequent than nor'easters in the Northeast, they can be even more destructive. At least nine hurricanes have struck the metropolitan New York City region within the last 200 years, including major ones in 1938, 1893, and 1821 (Coch, 1994). Effects include severe coastal flooding, damage and destruction of beachfront property, severe beach erosion, downed power lines and power outages, and disruption of normal transportation. A powerful hurricane in August, 1893 completely destroyed Hog Island, a barrier island that once existed seaward of Rockaway Beach (Onishi, 1997).

The worst natural disaster to strike the northeastern United States was the hurricane of September 21, 1938, which claimed almost 700 lives and injured several thousands more. This storm, striking with little warning, raised a wall of water 25 to 35 feet (7.6–10.7 meters) high (surge plus waves), which swept away protective barrier dunes, and the buildings behind them, on the shores of eastern Long Island, eastern Connecticut, and Rhode Island (Ludlum, 1988).

TABLE 3-3
The Saffir-Simpson Hurricane Scale

Category	Central Pressure (millibars)	Wind mph (m/sec)	Surge feet (meters)	Damage
1	≥980	74–95 (32–42)	4–5 (1.4)	Minimal
2	965–979	96–110 (43–49)	6–8 (2.1)	Moderate
3	945-964	111–130 (50–58)	9–12 (3.2)	Extensive
4	920-944	131-155 (59–69)	13–18 (4.7)	Extreme
5	<920	>155 (>69)	>18 (>5.5)	Disaster

The right-angle bend between the New Jersey and Long Island coasts funnels surge waters toward the apex—the New York City harbor. Surge waters also pile up at the western end of Long Island Sound.

Surge levels have been computed using a numerical model (SLOSH) that simulates the effects of a hurricane surge for a worst-case scenario Category 3 hurricane (with wind speeds of 111–130 miles/hour on the Saffir-Simpson scale (Table 3-3; U.S.ACOE/FEMA/NWS, 1995). Maximum surge levels could reach 25 feet (7.6 meters) above the National Geodetic Vertical Datum (Appendix Coast 2), not including astronomical tides, at JFK airport; 21 feet (6.4 meters) at the Lincoln tunnel entrance; 24 feet (7.3 meters) at the Battery; 23 feet (7.0 meters) at Liberty Island, NJ; 18 feet (5.5 meters) at West 96th Street; flooding the West Side Highway; and 15.6 feet (4.75 meters) at the New York-Connecticut state line. These figures do not include the additional heights of waves on top of the surge.

Hurricane Preparedness. The National Weather Service of NOAA provides technical data on hurricanes and issues frequently updated storm bulletins and forecasts. TV and radio news broadcasts (especially the Weather Channel) deliver in-depth storm coverage, including recommendations for individual emergency preparations.

Although NOAA-operated weather satellites routinely track major hurricanes, accurate prediction of the most dangerous path cannot be made more than several hours to half a day in advance. The strongest, most damaging winds occur within a relatively narrow strip to the right of the eyewall. Given the large uncertainty in tracking the path of the danger zone and the huge urban population of the MEC region potentially at risk, evacuation must focus on people living in the most exposed shorefront locations and flood-prone low-lying areas.

State and/or municipality emergency management offices (e.g., the NY/NJ/CT State Emergency Management agencies and the New York City Office of Emergency Management) declare a storm emergency and recommend closing of government offices, private businesses, and schools. Selected schools and other safe structures are authorized to be designated as emergency shelters for evacuees. Each emergency management office has its own "command center" where the technical information (e.g., storm track maps) is provided to the emergency management decision-makers, and is then forwarded as operational directives to the police and fire departments, and to the Red Cross. The state and city local government agencies coordinate their disaster mitigation plans with FEMA (Federal Emergency Management Agency).

FEMA assesses damages following a natural disaster and also manages the National Flood Insurance Program, designed to assist communities affected by flood damage (see also Challenges and Opportunities below).

Methods and Data

Impacts of climate change on the coastal zone are studied by applying a suite of sea-level rise projections to selected localities in New York City, Long Island, and northern New Jersey (Appendix Coast 3). U.S. Army Corps of Engineers models are then applied to calculate future coastal flood heights, return intervals, and increases in sand volumes and costs for beach nourishment under these scenarios (see Storm Surge Heights, Shoreline Changes and Beach Nourishment below).

Datasets utilized in this study include sea-level observations, meteorological data, historic shoreline data, U.S. Geological Survey 7.5′ (and higher resolution) Digital Elevation Models, aerial photos, geological formations. Thematic maps produced by the Geographic Information Systems laboratory and CIESIN at Lamont-Doherty Earth Observatory show topography, population density, household income levels, and housing values. These maps are overlaid on sea-level and flood data to assess areas, populations, and assets at risk.

SEA-LEVEL RISE SCENARIOS

Sea-level rise projections for the MEC region are calculated from historical tide-gauge data and several global climate model (GCM) simulations. U.S. sea-level data are available from the NOAA National Ocean Service (website: www.opsd.nos.noaa.gov); international data come from the Permanent Service for Mean Sea Level (Spencer and Woodworth, 1993). Sea-level rise scenarios are based on an extrapolation of current sea-level trends and on the following GCMs recommended by the U.S. National Assessment of Potential Climate Change Impacts: the Canadian Centre for Climate Modelling and Analysis (CCCMA) (Boer et al., 2000) and the United Kingdom Hadley Centre (Johns et al., 1997).

Climate model outputs are adjusted for local land subsidence. The local subsidence rate is derived by subtracting the relative sea-level rise at each station from the regional absolute mean sea-level trend. The difference between decadal mean subsidence (2000s, 2010s, ...2090s) and that of the base period (1961–1990) is then added to the projection of sea-level rise for each GCM scenario, for the corresponding decade. Sea-level projections are for the GCM grid cells enclosing New York City and environs.

The following scenarios are used in this study:

1. *Current Trend*. A linear extrapolation of current sea-level trends. The *current trend* is the least-squares linear fit through the annual means of sea level from tide-gauge data (Coast Appendix 2, column 1). Mean annual sea levels are averaged in 10-year intervals starting in 1961, to minimize effects of year-to-year variations. Projected sea levels are decadal means above the 1961–1990 mean.

2. CCGG. The CCCMA first-generation coupled model CGCM1 transient climate simulation for greenhouse gas warming. Only the steric (temperature/salinity) component of sea-level rise is given. Contributions from mountain glaciers and ice sheets are calculated using static sensitivities: 0.063 cm/yr/°C (glaciers), 0.03 cm/yr/°C (Greenland), and –0.03 centimeters/year/°C (Antarctica) (Gregory and Oerlemans, 1998).

3. CCGS. The same as scenario 2 with sulfate aerosols. In addition to the steric component of SLR, contributions from mountain glaciers and ice sheets are calculated as above, except for Greenland (0.035 cm/yr/°C).

4. HCGG. Hadley Centre HadCM2; the first of an ensemble of four greenhouse gas integrations. The four runs differ only in the year the control integration uses to initialize the first member of the run. (Differences among the four runs is relatively small—R. Goldberg, priv. comm.).

5. HCGS. Hadley Centre HadCM2; the same as scenario 4 with sulfate aerosol.

STORM SURGE HEIGHTS

Plots of flood levels for given return periods (i.e., 2, 5, 10, 25, 50, and 100 years) were prepared for each sea-level rise scenario at each site, using the WES Implicit Flooding tidal hydrodynamic Model (WIFM) (Butler, 1978; Butler and Sheng, 1982). WIFM solves vertically integrated dynamic, shallow-water wave equations of fluid motion, incorporating information on bathymetry, topography, wave, and meteorological data in order to simulate coastal flooding. An important feature of the model is its ability to stretch the numerical grid, which allows a denser grid resolution in areas of interest.

For this study, flood heights include combined nor'easter and hurricane storm surges, high tide, and sea-level rise. Since wave runup can be significant, omission of wave height leads to a conservative estimate of flood water levels. Storm climatology is assumed to remain unchanged. (Flood heights are relative to the NGVD datum). Projected sea-level rise for the Coney Island and Rockaway Beach study sites was based on the New York City (Battery) tide gauge; the northern New Jersey coast between Sea Bright—Asbury Park was referenced to the Sandy Hook gauge; SLR for Long Beach and Westhampton were calculated by linear interpolation between the NYC and Montauk tide gauges (see case studies). Average flood heights were calculated for each decade between 2000 and 2090. Maximum flood levels (surge + mean high water + sea-level rise) for the 100-year storm events were compared with flood levels during major historic storm events, such as the December 1992 nor'easter.

SHORELINE RESPONSE TO SEA-LEVEL RISE

The shoreline's response to sea-level rise is often estimated using the Bruun Rule, which states that a typical concave-upward beach profile erodes sand from the beachfront and deposits it offshore, so as to maintain constant water depth (Figure 3-6). Shoreline retreat depends on the average slope of the shore profile. Thus, from Maine to Maryland, a one-meter sea-level rise would cause the beach to retreat by as much as 50 to 100 meters.

The Bruun Rule assumes no longshore transport of sand into or out of the study area, nor does it account for washover or inlet sedimentation, two important processes shaping barrier islands. It has been modified to account for landward migration and upward growth of a barrier island ("rollover"; Dean and Maurmeyer, 1983). Other shoreline models, such as three-dimensional sediment budget analysis or dynamic approaches require detailed measurement of local parameters (NRC, 1987). The lack of this information, except at a few sites, limits the widespread applicability of these models. Alternatively, projections may be made from correlations between historical shoreline erosion trends and local sea-level changes (Douglas et al., 1998).

The Bruun Rule remains one of the most widely used methods of estimating shoreline reponse to sea-level rise, in spite of the above-cited limitations. It has recently received support from long-term observations of coastal erosion on the East Coast (Leatherman et al., 2000). Hence, the Bruun Rule is used here to estimate shoreline changes in the absence of sand replenishment for the case study sites.

The Bruun Rule can be stated mathematically as:

$S = (A*B)/d$

where:

S Shoreline movement

A Sea-level rise

d Maximum depth of beach profile, measured from the berm elevation for each project location to the esti-

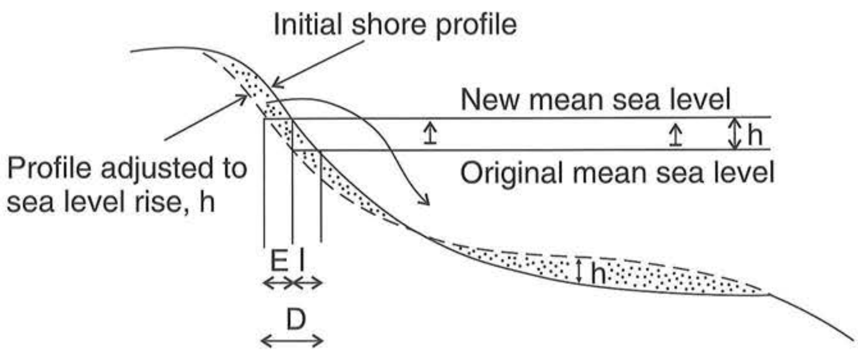

FIGURE 3-6 Application of the Bruun Rule to erosion.

mated depth of closure. (A berm is a ridge of sand, produced by wave action, at the upper part of a beach).

B Horizontal length of the profile, measured from the beginning of the berm to the intersection with the estimated depth of closure.

The depth of closure is generally defined as the minimum water depth at which no significant measurable change occurs in sediment motion (NRC, 1995). "Closure" is a somewhat ambiguous term in that it can vary, depending on waves and other hydrodynamic forces. Depth of closure in this study was based on measured beach profiles taken perpendicular to the shore.

The annual shoreline translation due to sea-level rise was calculated from the Bruun Rule and converted to a volumetric change, using the height of the beach profile and the length along the shore.

BEACH NOURISHMENT

The U.S. Army Corps of Engineers methodology to estimate sand volumes needed to maintain a beach employs physical characteristics, such as measured beach profiles, the average profile depth, and length of shoreline in the project. Sand losses are computed for historic rates (i.e., "Current trends") of sea-level rise. Also considered are losses due to long-term erosion and storm-induced erosion over the life of the project. (In the MEC area, project lifetimes range between 25 and 50 years.) The required sand volume is the sum of the volumes for each of these factors. These processes interact with each other. Yet, by separating them, quantifying the results individually and then summing them, one obtains an upper bound estimate of expected renourishment requirements. Such an estimate provides an adequate safety margin to ensure the maintainance of the project design.

The standard Army Corps procedure has been modified in several ways for this study. Projected shoreline retreat is calculated from the Bruun Rule, using our scenarios of future sea-level rise. Long-term erosion losses are based on measurement of beach profiles and volumetric changes. Storm-related losses are determined from damage by a storm event with 50% probability of occurring during the time between renourishment episodes, using the SBEACH model (Larsen and Kraus, 1989). (SBEACH is an empirically-based numerical model used to predict storm-induced beach erosion). Increasing flood heights due to projected sea-level rise over this time are also factored into the calculation.

Changes in volumes of beach sand renourishment are tabulated for selected time intervals. Beach replenishment due to sea-level rise is compared with that from historic erosion trends and storms for these periods.

Socio-economic Data

Maps of population densities, average housing values, and household income for 1995 TIGER Census Tracts were overlaid on five-foot contour plots, using U.S. Geological Survey 7.5 minute Digital Elevation Model (DEM) data for the case study sites. (Horizontal accuracy of the topographic data is within a fraction of an inch [root-mean-square-error]. Vertical accuracy is within 5 feet.) The flood risk zone is defined as land lying within the 100-year flood zone. The expansion of this zone inland with sea-level rise is discussed.

Case Study Sites

The case study sites differ in degrees of urbanization and biogeophysical characteristics. Nearly all sites lie in the high to very high-risk classes of the Coastal Vulnerability Index (Figure 3-1). All localities (except for the Battery) lie within boundaries of U.S. Army Corps of Engineers beach nourishment projects, which are designed to reduce storm damages. Army Corps projects include an initial construction component, as well as scheduled renourishment fill operations. Storm surge elevations, shoreline erosion, and beach nourishment requirements for the given sea-level rise scenarios are presented for the following sites:

- The Battery, New York City, NY[1]
- Coney Island, Brooklyn, NY
- Rockaway Beach, Queens, NY
- Long Beach, Long Island, NY
- Westhampton Beach, Long Island, NY
- Sea Bright, Manasquan, NJ

THE BATTERY, NEW YORK CITY

Lower Manhattan covers high-density prime commercial real estate in the heart of the New York City financial

[1] Sea level, surge and flood data only.

district, residential areas, such as Battery Park City (Figure 3-3), and major tourist attractions, such as historic Battery Park, and the South Street Seaport. Battery Park City and the Seaport area have been constructed on landfill over the years. Most of the waterfront is bulkheaded and protected by a low sea wall. The tide-gauge, located on a pier at the U.S. Coast Guard Battery Park Building, next to the Staten Island Ferry station, has been in operation since 1856.

Important transportation infrastructures vulnerable to flooding include the FDR Drive, West Street, entrances to the PATH tubes, Brooklyn-Battery Tunnel, approaches to the Brooklyn and Manhattan Bridges, and several subway stations. Portions of this area have already been under water during major storms, such as the 1992 nor'easter (*New York Times*, December 12, 1992; see also old newspaper accounts in Wood, 1986).

CONEY ISLAND

Coney Island is an older, high-density urban seashore neighborhood (Figure 3-7). The beach lies at the western terminus of littoral drift along the south shore of Long Island (Kana, 1995; Leatherman and Allen, 1985).

Coney Island was attached to the mainland during reclamation projects from the 1870s to the 1920s. Serious erosion problems began to occur after the construction of groins at Rockaway Beach, to the east, in the 1920s (Wolff, 1989). Over $25 million has been spent on beach nourishment at Coney Island between 1923 and 1995 (Table 3-2).

The Coney Island study area extends from the east end of Brighton Beach to Seagate in the west—a total of 2.95 miles (4.75 kilometers). The initial phase of the most recent Army Corps project began in October 1994–January 1995. The beach is scheduled to be renourished for a period of 50 years, with periodic renourishment of approximately 990,000 cubic yards (757,350 meters^3) of sand every 10 years.

ROCKAWAY BEACH

Rockaway Beach, Queens, is a barrier spit (mean elevation 5.5 feet [1.68 meters] above sea level) attached to Long Island at its eastern end at Far Rockaway (Figure 3-8). The central section of the barrier is another long-established, high-density, urbanized shorefront community. Nearly the entire barrier, including the residential area, lies below 10 feet (3.3 meters). A rock jetty built to the east in the 1940s, curtailed littoral drift to the Rockaways and intensified erosion rates there (Wolff, 1989). A total of $134 million has been spent on beach replenishment between 1926 and 1996 (Table 3-2) .

The study area covers a 6.4 mile (10.3-kilometer) stretch of shoreline from Beach 149th Street to Beach 19th Street. This U.S. Army Corps project was initiated in 1975–1977. It may be maintained for an additional 25 years, with beach renourishment operations scheduled every 3 years, requiring approximately 1.75 million cubic yards (1.34 million meters^3) of sand per cycle.

FIGURE 3-7 Aerial view of Coney Island. Source: USACE

LONG BEACH

Long Beach, Nassau County, is a medium- to high-density, urbanized residential community located on a barrier island, east of Rockaway Beach (Figure 3-9). Hard structures include a series of rock groins built in the 1950s and a jetty at Jones Inlet to the east (Wolff, 1989). The towns of Lido Beach and Point Lookout, at the eastern end of Long Beach Island, have attempted to protect and revegetate their dunes, but wave refraction around the jetty has led to further beach erosion. $1.5 million has been spent on beach nourishment in Lido Beach in 1962. A renourishment project over 7.77 miles (12.5 kilometers) is planned to start in 2002–2003, covering a 50-year period. It would have a six-year renourishment cycle, using approximately 2.1 million cubic yards (1.6 million meters^3) of sand per cycle.

WESTHAMPTON BEACH

Westhampton Beach is an affluent low-density residential area with prime recreational beaches. The entire barrier lies below 10 feet except for the narrow strip of dunes. Private houses, beach clubs, and hotels have been built on the dunes. Historically, it has been very vulnerable to storm erosion and washover. Overall, $47 million has been spent between 1962 and 1996 on beach maintaintance (Table 3-2). Erosion began after stabilization of the Shinnecock Inlet further east in 1942 (Wolff, 1994). Following extensive flooding and erosion from the Ash Wednesday nor'easter in 1962, a series of 15 groins was built between 1965 and 1970 to protect the shore from further erosion. However, for various reasons, several additional planned groins and beach fill were not constructed.

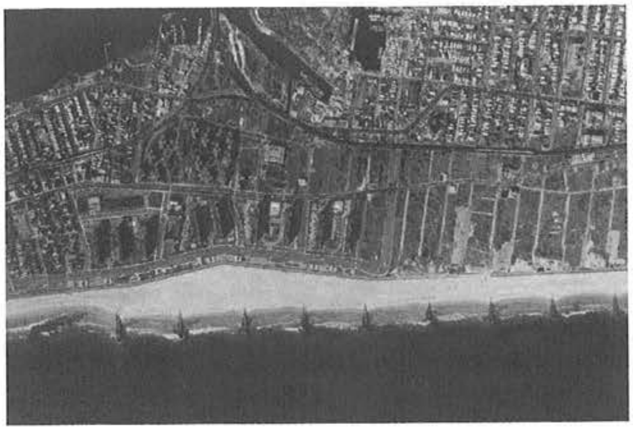

FIGURE 3-8 Aerial view of Roackaway Beach. Source: USACE

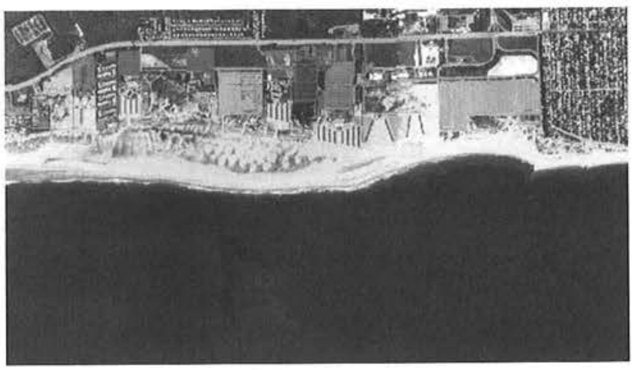

FIGURE 3-9 Aerial view of Long Beach. Source: USACE

The barrier was breached in two locations during the December 1992 nor'easter and around 60 homes were destroyed (Figure 3-10). The smaller, western opening—Pikes Inlet—closed in January 1993. The larger, eastern opening—Little Pikes Inlet—developed 1,000 feet from the westernmost groin (Fig 3-10; Terchunian and Merkert, 1995). An 18-foot deep channel formed, allowing tidal currents to erode the inlet and carry sediments bayward, forming a tidal delta and a sand spit that extended northeastward into Moriches Bay. This breach was repaired in late 1993 with sand dredged from offshore sand sources and reinforced with steel sheeting. While the presence of the groin field may have contributed to the 1992 washover, this section of the barrier was already susceptible to storm damage due to lack of bayside salt marshes, sand bars, and overwash lobes (Wolff, 1994). The curved spit extending into Moriches Bay is all that remains of the short-lived Little Pikes Inlet. New homes are being constructed on the site of the former breach (Figure 3-4).

In addition to the factors mentioned above, the Westhampton Beach barrier may be especially vulnerable to storm damage because of particular offshore physiographic characteristics (Schwab et al., 2000). In particular, formation of inlets and bayside sediment accretion following storms induce a more rapid landward migration of the bar-

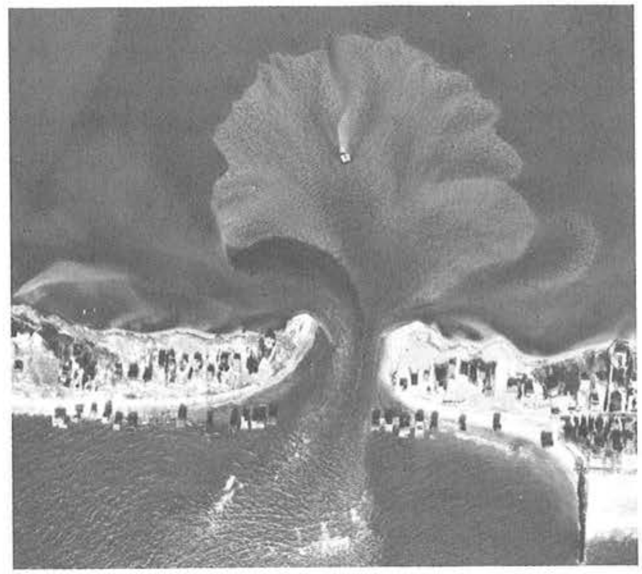

FIGURE 3-10 Aerial view of Little Pikes inlet, Westhampton beach, after the December 1992 nor'easter. Printed with permission of NYSDEC.

rier-island system east of Watch Hill, Fire Island, relative to the west. The somewhat steeper offshore bathymetry also exposes the beach to higher energy storm-wave events.

The U.S. Army Corps project covers a stretch of 4 miles (6.4 kilometers). It was initiated in 1997 and is scheduled to run for a period of 30 years. The expected renourishment cycle is three years, using approximately 1.18 million cubic yards (0.90 million meters^3) of sand per cycle.

SEA BRIGHT-MANASQUAN, NJ

Sea Bright, a residential community on the narrow, sandy barrier spit south of Sandy Hook at the northern end of the New Jersey shore, has a long history of exposure to storm and wave action (Figure 3-11). Starting in 1913, a set of 85 groins was constructed throughout the area, and in 1922 a 120-meter breakwater was completed in Sea Bright. In 1898, a sea wall was built along the Highland and Navesink beaches. In the 1950s, additional seawall construction was undertaken between Sea Bright and Monmouth Beach (Gorman and Reed, 1989). By the late 1980s, the seawall had seriously deteriorated and repairs were undertaken in 1990 (Bocamazo, 1991).

The U.S. Army Corps initiated a beach nourishment program between 1994 and 1998 covering an 11.8-mile (19.0-kilometer) reach between Seabright and Ocean Township. The project has a planned six-year renourishment cycle, over a fifty-year period, requiring 3.5 million cubic yards of sand per cycle. Another project extends over 9 miles (14.5 kilometers) further south, between Asbury Park to Manasquan. It began in 1997–1999 and is expected to continue 50 years, with periodic renourishment every 6 years, consuming 2.6 million cubic yards of sand per cycle.

Results

SEA-LEVEL RISE

The regional mean relative sea-level rise for the East Coast is 0.11±0.3 inches/year (2.7±0.7 millimeters/year); the corrected sea-level rise, after removal of geologic trends, is 0.05±0.3 inches/year (1.3±0.7 millimeters/year; Appendix Coast 4). Tide-gauge stations within the MEC region include: New York City—the Battery, Montauk Point, Sandy Hook, Willets Point, and Port Jefferson (Table 3-1). Projected sea levels for these stations in the 2020s, 2050s, and 2080s are summarized in Table 3-4.

Modest rises in sea level of 4.3 to 7.6 inches (11 to 19 centimeters) could occur by the 2020s at current rates (Table 3-4). For the GCM projections, sea level could reach 4.4 to 11.7 inches (11 to 30 centimeters). By the 2050s, sea level could rise by 6.9 to 12.1 inches (18 to 31 centimeters) under current trends, or could climb by 8.5 to 23.7 inches (22 to 60 centimeters) for the GCM projections. By the 2080s, sea level could rise by 9.5 to 16.7 inches (24 to 42 centimeters), at current rates, or could exceed 3 feet (>1 meter) at some localities in the Canadian Centre model. While sea levels are not expected to rise dramatically within the next two to three decades, the rise accelerates sharply after the 2050s, except for the "current trend" scenario (Figure 3-12). Furthermore, sea-level rise trajectories diverge widely in the second half of the century.

Coastal managers and planners need information on the likelihood of future sea-level rise. Titus and Narayanan (1996) estimate the probability of sea-level rise, based on a combination of Monte Carlo statistical techniques and expert opinion review. For New York City, they find a 50% chance that sea level will rise 6 inches over 1990 levels by 2025, 10 inches by 2050 and 22 inches by 2100 (Table 1 in Titus, 1998). They assign a 5% probability that sea levels will exceed 9 inches by 2025, 17 inches by 2050 and 38 inches by 2100.

Comparing these probabalistic estimates with our sea-level rise projections (Table 3-4) suggests that the Canadian Centre's scenarios have a likelihood of 5% or less of occurring over the next 100 years. On the other hand, the Hadley Centre's HCGS scenario has better than a 50% chance of occurring in the next 100 years. Extrapolating current trends, a sea-level rise of 8.6 inches or more is approximately 75% likely by the 2050s, and a rise of ~12.9 inches or more is about 85% likely by the end of the century.

FIGURE 3-11 Aerial view of Sea Bright, NJ. Source: USACE

TABLE 3-4
Sea-level rise projections-Metro East Coast Region (inches; cm).

Scenario	Station				
	New York City	*Willets Point*	*Port Jefferson*	*Montauk*	*Sandy Hook*
			2020s		
Current trend	5.4 (13.7)	4.5 (11.5)	4.3 (11.0)	4.5 (11.4)	7.6 (19.3)
CCGG	9.5 (24.1)	8.6 (21.9)	8.4 (21.4)	8.6 (21.8)	11.7 (29.7)
CCGS	8.5 (21.7)	7.7 (19.5)	7.5 (19.0)	7.6 (19.4)	10.7 (27.3)
HCGG	6.3 (16.1)	5.5 (14.0)	5.3 (13.5)	5.4 (13.8)	8.5 (21.7)
HCGS	5.5 (13.9)	4.6 (11.7)	4.4 (11.2)	4.6 (11.6)	7.7 (19.5)
			2050s		
Current trend	8.6 (21.8)	7.2 (18.4)	6.9 (17.6)	7.6 (19.2)	12.1 (30.8)
CCGG	20.1 (51.1)	18.8 (47.7)	18.5 (46.9)	18.7 (47.5)	23.7 (60.1)
CCGS	18.7 (47.5)	17.4 (44.1)	17.0 (43.3)	17.2 (43.8)	22.2 (56.5)
HCGG	12.8 (32.5)	11.5 (29.1)	11.1 (28.3)	11.4 (28.9)	16.3 (41.5)
HCGS	10.2 (25.8)	8.8 (22.4)	8.5 (21.6)	8.7 (22.1)	13.7 (34.8)
			2080s		
Current trend	11.8 (30.0)	10.0 (25.3)	9.5 (24.2)	9.8 (25.0)	16.7 (42.4)
CCGG	37.5 (95.5)	35.7 (90.8)	35.3 (89.7)	35.6 (90.5)	42.5 (107.9)
CCGS	29.9 (75.9)	28.0 (71.2)	27.6 (70.1)	27.9 (70.9)	34.8 (88.3)
HCGG	21.4 (54.4)	19.6 (49.7)	19.1 (48.6)	19.4 (49.4)	26.3 (66.7)
HCGS	16.7 (42.6)	14.9 (37.9)	14.5 (36.8)	14.8 (37.6)	21.7 (55.0)

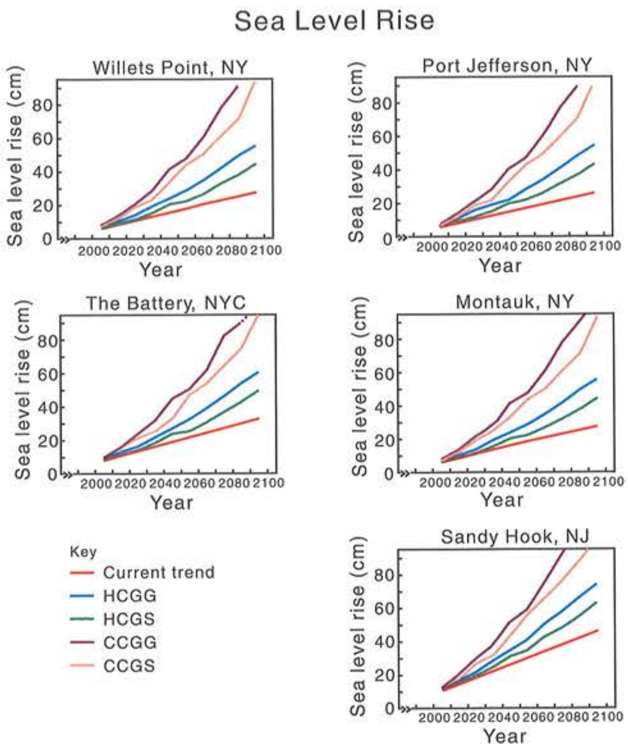

FIGURE 3-12 Trajectories of sea-level rise for the MEC Region.

STORM SURGES AND COASTAL FLOODING

Flood heights are presented for the 100-year storm (combined extratropical and tropical cyclones) in Figure 3-13 (see also Appendix Coast 5). The regional 100-year flood levels could rise from 9.8 to 11.5 feet (3.0 to 3.5 meters) in the 2020s, to 10.1–12.4 feet (3.1–3.8 meters) in the 2050s, and up to 13.8 feet (4.2 meters) in the worst-case scenario by the 2080s. Inasmuch as these figures do not include the additional height of waves on top of the surge, these estimates of flood water levels are somewhat conservative.

The marked decrease in the flood return period will become a major concern to coastal residents. Among the case study sites, the likelihood of a 100-year flood could become as frequent as once in 43 years by the 2020s, once in 19 years by the 2050s, and once in four years by the 2080s, on average, in the most extreme case (Figure 3-14).

At present, the 100-year flood level in New York City and environs is 9.7 feet (2.96 meters)—very close to the area outlined by the 10-foot (3-meter) contour (Figure 3-15). By the 2080s, the return period for a flood of this magnitude could shrink to between 5.5 years in the worst-case scenario (CCGG) and 50 years—extrapolating current trends. More frequent flooding episodes would adversely affect major transportation arteries, including highways, rail and air transportation, not to mention the viability of waterfront structures (see Chapter 4 *Infrastructure*).

The projected sea-level rise for the MEC region (a maximum of 1½–2 feet [48–60 centimeters] by the 2050s, and 3–3½ feet [90–108 centimeters] by the 2080s; Table 3-4) lies below the five-foot contour (shown in yellow, Figures 3-16A to 3-16D). Thus, at most of the case study sites, only a relatively narrow coastal strip would be permanently inundated. However, wetlands could sustain marked reductions in area (see Chapter 5 *Wetlands*). Furthermore, as shown in the next section, coastal erosion be several times greater than that of simple inundation. For example, while sea level in the New York City area could rise approximately 1 to 2 feet by the 2050s, the nearby beaches of Coney Island and the Rockaways could retreat landward some 2 to 6 feet (0.6 to 1.8 meters) during this decade, if not renourished (Table 3-4; Figure 3-17).

In addition, areas at risk to severe flooding would expand considerably. Within two decades, the 100-year flood zone would equal or exceed 10 feet (3 meters) at the case study sites (Figure 3-13). By the 2080s, the 100-year flood zone could reach 11–14 feet (3.4–4 meters). The areas at risk could embrace significant segments of lower Manhattan, most of Coney Island, Rockaway Beach and Jamaica Bay. In addition to the Westhampton barrier, nearly the entire bayside shoreline around Moriches and Shinnecock Bays could also become vulnerable to flooding. While the flood risk zone near Sea Bright and Asbury Park, New Jersey would lie fairly close to the coast, it could extend much further inland along the estuaries. The dark and light blue lines outline the 10- and 15-foot contours, respectively (Figures 3-16A, 3-16B, 3-16C, 3-16D).

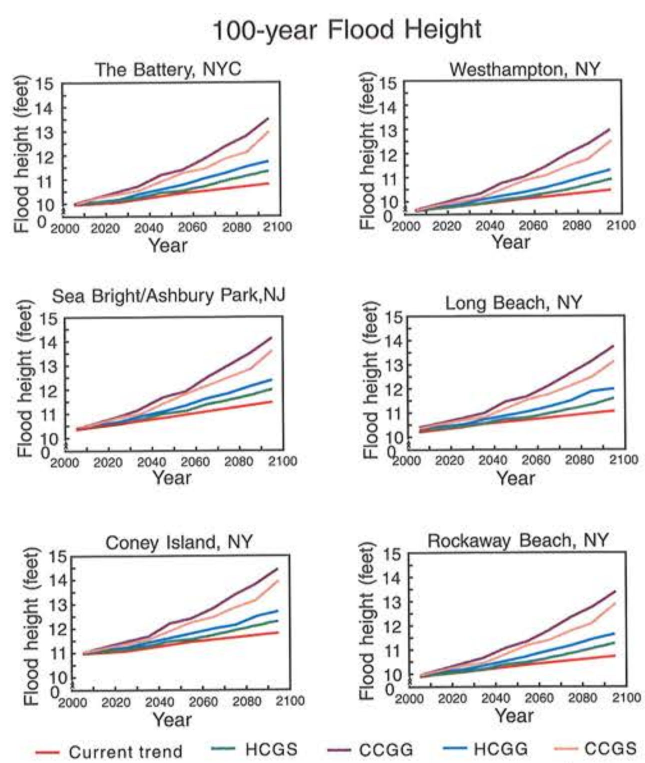

FIGURE 3-13 Storm flood height trajectories for six case study sites in the MEC Region.

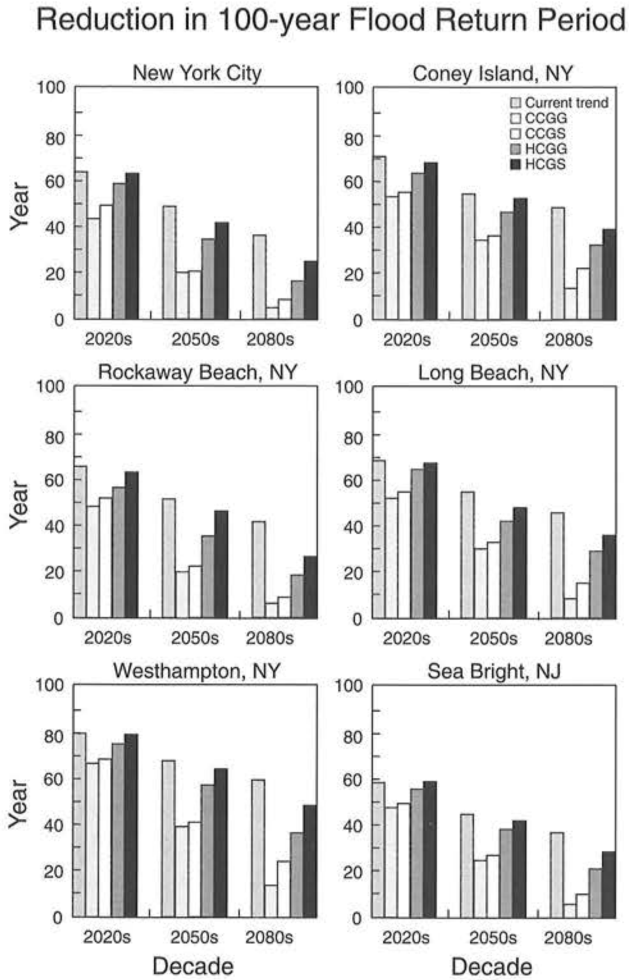

FIGURE 3-14 Reduction in 100-year flood return periods due to sea-level rise.

SHORELINE CHANGES

Figure 3-17 summarizes rates of shoreline retreat due to sea-level rise that would occur at the case study sites, without additional sand replenishment. (The Battery in New York City is omitted here, since it is armored by seawalls). Among these sites, Rockaway Beach experiences the most severe rates of beach attrition, closely followed by Asbury Park, NJ and Westhampton Beach. Coney Island beaches shrink the least under all sea-level rise scenarios.

These site-to-site variations reflect differences in underlying geology, geomorphology, sediment particle size distributions, beach profiles, and wave characteristics. But at any given locality, and holding these other variables constant, erosion rates are roughly proportional to sea-level rise. Thus, by the 2080s, erosion rates range between two to four times above those of the 2020s, and four to 10 times above those of the 2000s (see Appendix Coast 6). With rising sea level but no sand replacement, Long Island and northern New Jersey beaches could move landward nearly 1.4 to 3.0 feet/year (0.4-to 0.9 meters/year) by the 2020s, increasing to as much as 2.8 to 12.0 feet (0.85 to 3.6 meters/year) by the 2080s (Figure 3-17).

An empirical test of the Bruun Rule is a comparison with long-term (~century) erosion trends (Leatherman et al., 2000). The average ratio of erosion rates calculated from the Bruun rule to current rates of sea-level rise for our four Long Island test sites is 98.3. This agrees reasonably well with a ratio of 110 for historical data on Long Island that excludes the influence of nearby inlets, coastal engineering, and sediment accretion (Leatherman et al., 2000). But the average calculated ratio for the New Jersey sites is only 83.1 as compared to 181 for the historical data. The discrepancy in northern New Jersey may be due to oversteepened offshore topography and higher wave energies, making the Bruun Rule a less reliable predictor of erosion in New Jersey than in Long Island.

BEACH NOURISHMENT

In general, estimated sand volumes based on our Current Trends sea-level rise scenario differ by only a few percent from those calculated using standard Army Corps methodology, over the design lifetime of the project (25 to 50 years).

Table 3-5a summarizes beach renourishment requirements for our case study sites due to sea-level rise over selected time intervals. At any given site, volumes of sand pumped onto the beaches increase by factors of two to seven times from 2050 to 2080 relative to the 2000 to 2020 period. Sea Bright, due south of Sandy Hook, lies in an area with the highest rate of relative sea-level rise (Table 3-1) and sand replenishment needs in the MEC region (Table 3-5a). On average, Sea Bright will consume around double the sand volume as Westhampton Beach (the site with the lowest sand needs) between 2000 and 2020, and two to three times as much between 2050 and 2080.

To put these figures in perspective, the additional sand needed because of sea-level rise remains a relatively small percent of the total beach replenishment due to all factors (long-term erosion, storms, SLR) until the latter half of the century (Table 3-5b). By the 2020s, the percent due to SLR represents only 2.3% to 11.5% of the overall total. By the 2050s, the percent rises up to 18.7%. But after the 2050s, SLR could be responsible for a significant percent (up to 26% at some localities) of the additional sand placement.

COASTAL STORMS AND GLOBAL WARMING

Estimates of increased storm surge level and coastal flooding have been made for several climate change scenarios, assuming no changes in the characteristics of extratropical and tropical cyclones (Figures 3-13 and 3-14). How are the number and strengths of such storms likely to change as the world heats up? Climate model simulations of cyclonic behavior under conditions of global warming yield contradictory results.

Nor'easters. Beersma et al. (1997) find a small decrease in the number of strong North Atlantic depressions (<975 hPa) in a CO_2-doubled world, as compared to the present-day control simulation. There is also a tendency toward a greater number of weaker storms. Yet these differences remain small with respect to the natural variability. On the other hand, Lunkeit et al. (1996) observe an intensification of upper troposphere eddy activity—a proxy for storm tracks—and also cyclone frequency over the eastern North Atlantic and Europe, as greenhouse gas concentrations increase by 1.3%/year. In yet another study, cyclone frequency in a doubled-CO_2 run decreases northeastward of North America and Greenland into northern Europe (Schubert et al., 1998). Cyclone intensity, however, shows little change.

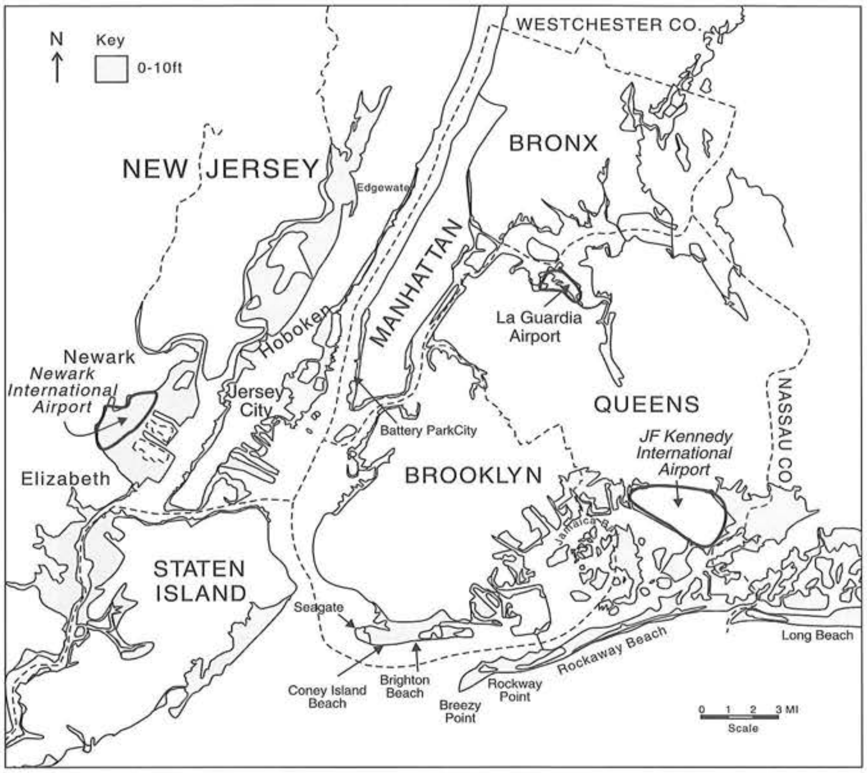

FIGURE 3-15 Flood risk zone, New York City metropolitan area.

Hurricanes. Henderson-Sellers et al. (1998) review the factors that contribute to the genesis of tropical cyclones. These include sea surface temperatures greater than 26°C (79°F), weak vertical shear of horizontal winds, atmospheric instability, high relative humidity at lower atmospheric levels, and location a few degrees poleward of the equator. Although the area of oceans warmer than 26°C is likely to increase as the earth warms, the minimum temperature at which tropical cyclones develop will increase by 2°C to 3°C. Therefore, the geographic region in which hurricanes form may not change significantly.

Henderson-Sellers et al. detect no discernible historic trends in tropical cyclone numbers, intensity, or location (see also Landsea et al., 1999). While some climate models suggest increases in the maximum potential intensity of tropical cyclones in a doubled-CO_2 climate, changes in other climatological variables may counteract these increases.

In summary, the extent to which changes in storm behavior will impact coastal regions and wetlands remains unclear, since intensities of weaker storms may not alter significantly. However, a potential exists for the most severe storms to become more intense and frequent, thereby causing greater damage. A detailed analysis of the effects of storm changes under global warming requires further modeling studies. For example, the frequency of storms in the Metro East Coast region could change either as a result of an actual increase in the number of storms generated (increase in cyclogenesis), or simply due to a shift in the mean position of extratropical storm tracks (which would concurrently decrease storm frequency elsewhere).

As yet, no consensus has emerged among climate models. Therefore, we report changes in storm recurrence intervals, flood heights, and beach erosion trends (e.g., Figures 3-13, 3-14, and 3-17), under the assumption that storm climatology remains unchanged, for the purposes of this assessment.

POPULATION AND COASTAL PROPERTY AT RISK

Unavailability of high spatial resolution topographic and socioeconomic data precludes quantitative assessment of people and property at risk to sea-level rise and flooding, at this time. However, vulnerabilities can be qualitatively outlined by overlaying topography at 5 feet (1.5 meters) contour intervals with census tract data (Figures 3-16A to 3-16D), together with sea level and storm flood projections.

Because of the highly developed nature of the coast within the MEC region, a large population and considerable private property and infrastructure will be potentially at risk to inundation and flooding (see also Chapter 4 *Infrastructure*). While permanently lost land occupies a relatively narrow coastal strip (generally below the five-foot contour, yellow line, Figures 3-16A to 3-16D), flooding due to storms could periodically engulf a much greater area.

Projected 100-year flood zones lie between the 10- and 15-foot contours (Figures 3-16A to 3-16D). High population densities are presently concentrated near water's edge at three urban sites—lower Manhattan, Coney Island, and Rockaway Beach (New York City). Flood risk zones at these sites cut across wide differences in income and housing values. If population growth follows present trends, evacuation of vulnerable populations in these high-risk areas during major storms will pose serious problems, inasmuch as many evacuation routes lie close to present-day storm flood levels (see Hurricane Preparedness above, and Chapter 4 *Infrastructure*). The greater frequency of severe flooding episodes affecting waterfront residences (e.g., Figures. 3-2, 3-3, 3-4, and 3-14) may lead to abandonment of lower floors, as in Venice, or ultimately of entire buildings.

Suburban areas such as Westhampton, NY, Sea Bright and Asbury Park, NJ, typically exhibit much lower population densities and higher income levels (Figures 3-16A and 3-16D). These land-use characteristics could make zoning setbacks and/or relocation to higher ground more feasible options as compared with highly urbanized areas. However, such measures are likely to be controversial and politically unpopular. At least in the short term, continuing defense of the shoreline will be more likely.

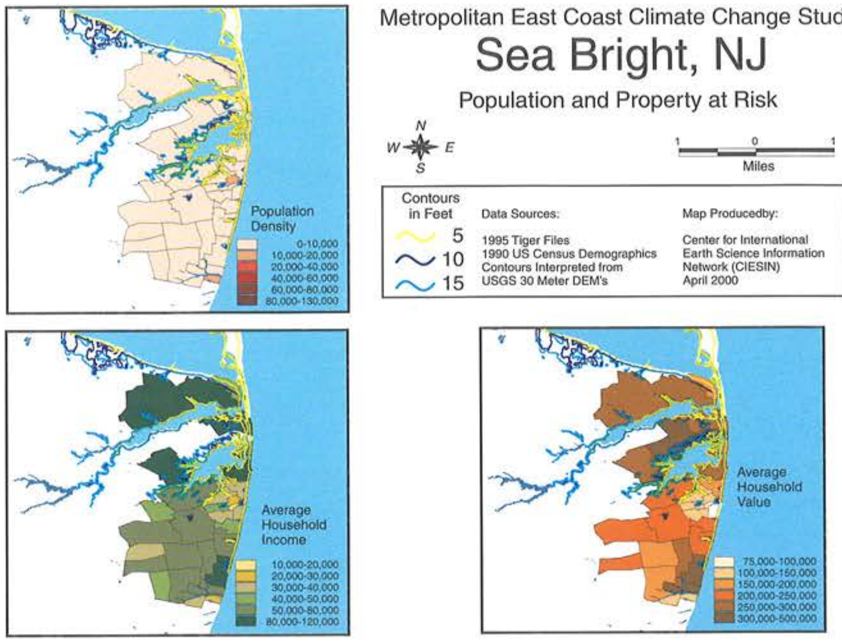

FIGURE 3-16A Flooding of Sea Bright, NJ case study site according to sea level rise projections.

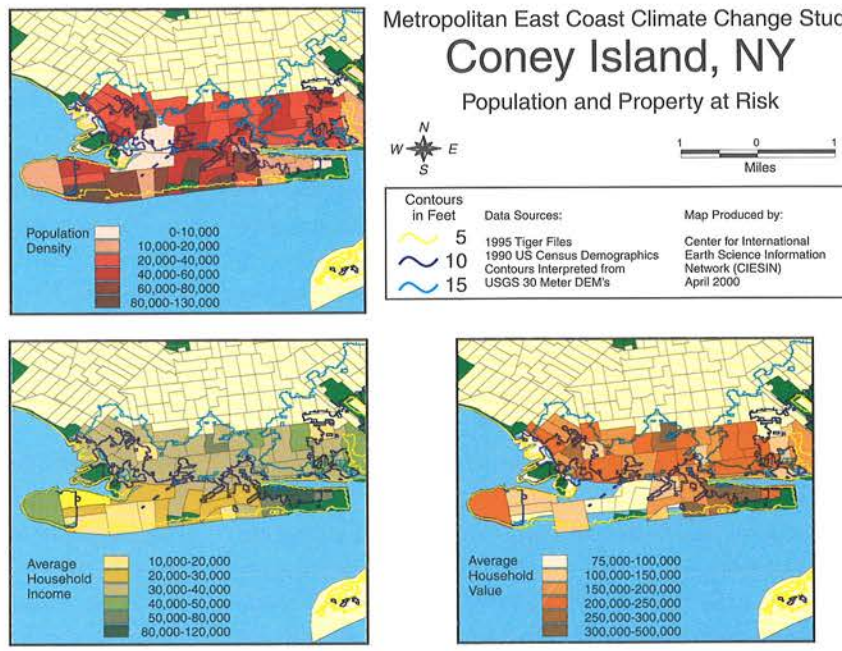

FIGURE 3-16B Flooding of Coney Island case study site, according to sea-level rise scenarios.

CHALLENGES AND OPPORTUNITIES

Strategies for coping with coastal erosion and flood damages associated with a rising sea level include defending the shoreline by means of protective structures, beach restoration, and ultimately, retreat (NRC, 1995; 1990; 1987). Even at present rates of sea-level rise, most of the shoreline of the MEC region is eroding (see Existing Coastal Hazards—Coastal Erosion). Many beaches must be artificially maintained by the U.S. Army Corps of Engineers (Table 3-2).

Shoreline armoring is typically applied where substantial assets are at risk. Hard structures include seawalls, groins, jetties, and breakwaters. Seawalls and bulkheads, a common form of shore protection in urban areas, often intercept wave energy, increasing erosion at their bases, which eventually undermines them. Erosion can be reduced by placing rubble at the toe of the seawall. Groins, often built in series, intercept littoral sand moved by longshore currents, but may enhance beach erosion further downdrift, if improperly placed (e.g., at Westhampton Beach). Similarly, jetties, designed to stabilize inlets or to protect harbors, may lead to erosion (as at beaches downdrift west of the Moriches, Shinnecock, and Fire Island Inlet jetties).

In response to sea-level rise, existing hard structures will need to be strengthened and elevated repeatedly, and beaches will require additional sand replenishment. The

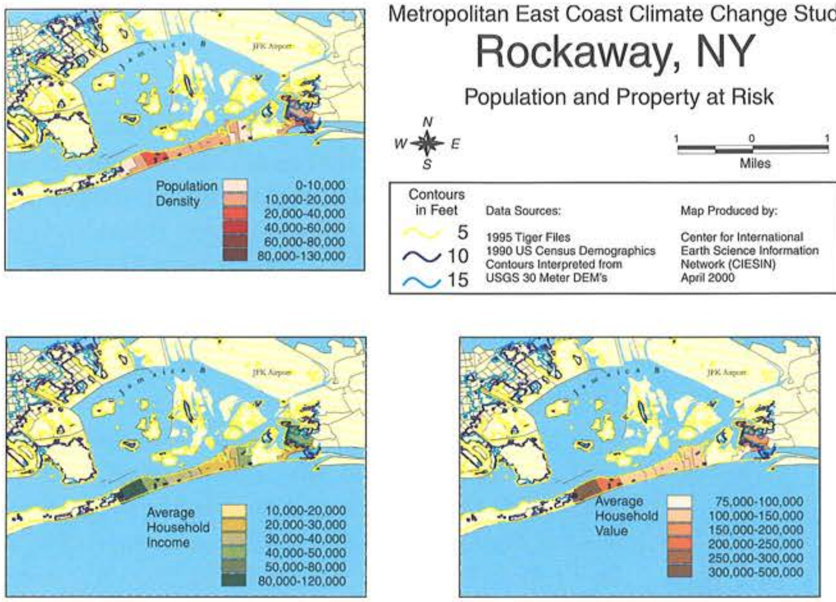

FIGURE 3-16C Flooding of Rockaway Beach, NY case study site, according to sea-level rise projections.

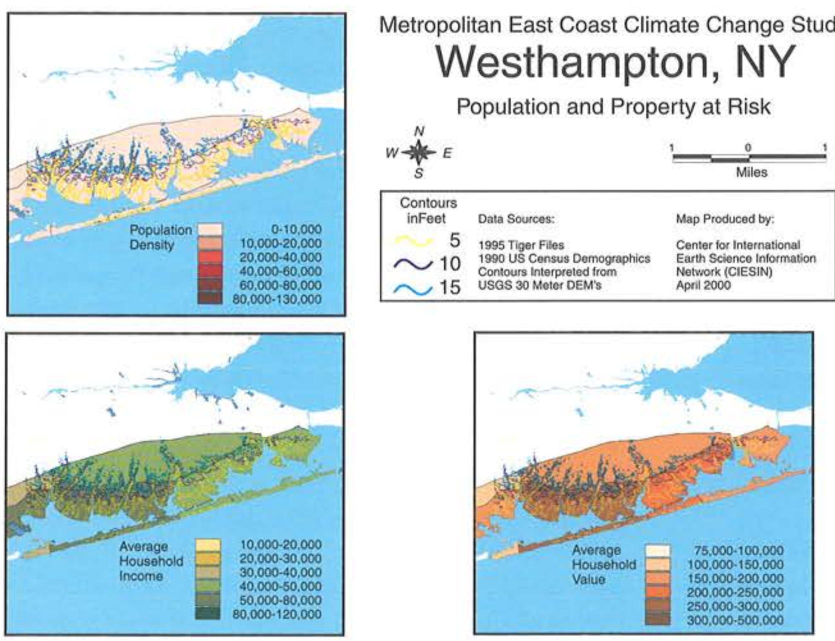

FIGURE 3-16D Flooding of Westhampton Beach, NY case study site, according to sea-level rise scenarios.

increased costs of retrofitting existing structures or armoring selected portions of the coast may be viable in high population density or high property-value areas of MEC, such as Manhattan or Jersey City/Hoboken, NJ (Figures 3-2, and 3-3).

In some locations, affluent shorefront property owners or seaside communities may also be willing to incur the additional expenses to save their beaches, as for example in Southampton and East Hampton, Long Island (Figure 3-4; Maier, 1998).

Because of erosion problems associated with hard structures, a soft approach involving dune restoration and beach nourishment has emerged as the preferred means of shoreline protection (NRC, 1995). Beach nourishment or restoration consists of placing sand that has usually been dredged from offshore or other locations onto the upper part of the beach. Since erosional processes are continual, beach replenishment must be repeated frequently (see Results—Beach Nourishment).

Beach dunes act as a major line of defense against sea attack. Since many natural dunes in the MEC region have been destroyed by housing construction and sand mining, they have frequently been replaced by artificial dunes. These can be stabilized by replanting natural dune vegetation, building protective fences, and mulching with discarded Christmas trees.

The U.S. Army Corps of Engineers has spent a cumulative total of \$2.4 billion[2] nationally and \$884 million within the Tri-State region on beach nourishment projects since the 1920s. Over half a billion dollars have been spent in New York State alone (mostly along the south shore of Long Island)—the largest expenditure for any single state (Duke University, Program for Study of Developed Shorelines, 1999). Over \$250 million has been spent to date on our case study sites (Table 3-2).

Estimates of future beach nourishment needs for our suite of sea-level rise scenarios (see Data and Methods) suggest that sand volumes needed for beach replenishment could increase by 2 to 11.5% (by volume) over that needed in the absence of SLR through the 2020s, and by another 4 to 19% between 2020 and 2050. These supplementary sand needs could probably be accommodated during the typical 50-year project lifetime, starting now. However, as shown on Figures 3-12 and 3-13, by the latter half of the century, an additional 5 to 26% volume of sand would be necessary (Table 3-5B). Thus, projects may have to design for potentially higher erosion rates and water levels than those experienced until now. The adequacy of onshore/offshore sand resources

[2] Adjusted to 1996 dollars.

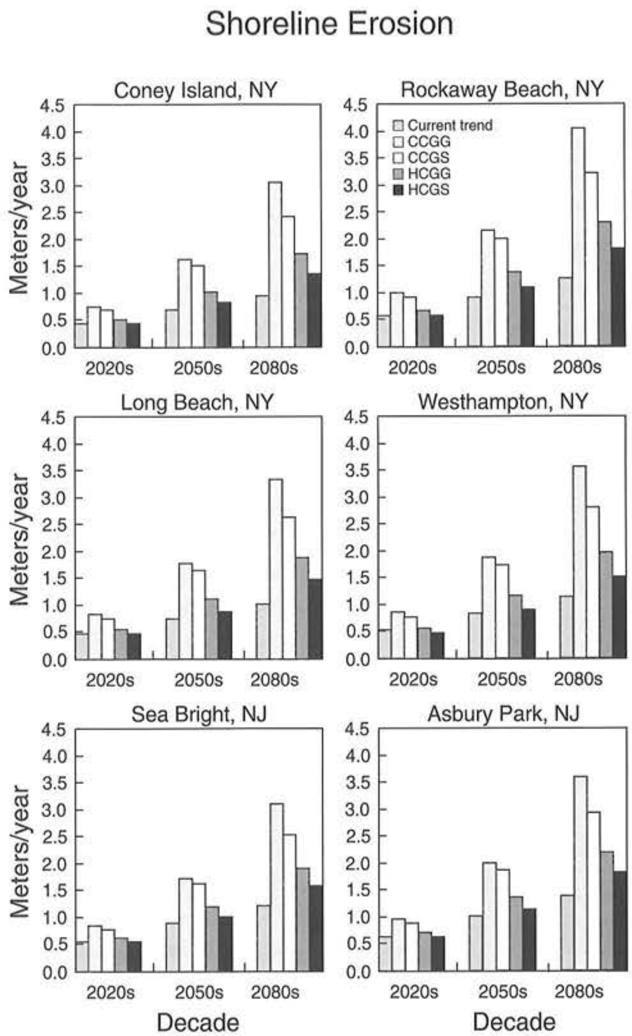

FIGURE 3-17 Rates of shoreline erosion in the Metro East Coast Region.

on Long Island and northern New Jersey to meet future demands may also need to be re-evaluated.

Rising beach nourishment costs could intensify related equity issues. For example, to what extent will taxpayers living elsewhere continue to be willing to support beach nourishment programs from which they benefit indirectly, if at all?

Retreat or pulling back from the shore may become an appropriate option in areas of lower population densities, or land values, or in high risk areas subject to repeated storm damage. The retreat may be a gradual process or a sudden abandonment following a catastrophic storm.

Possible mechanisms of retreat would need to be governed by zoning or land-use regulations and other policies that would:

1. Establish construction setback lines, extrapolating historic erosion rates to future SLR scenarios.

2. Remove buildings or hard structures that are in imminent danger of collapse into the sea.

3. End repeated subsidization to rebuild structures in designated coastal hazard zones.

A number of federal programs affect the coastal zone. These include the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP), the NOAA Coastal Zone Management Act (CZMA), U.S. Department of the Interior Coastal Barriers Resource Act (CBRA), and the Army Corps of Engineers' mandate to provide storm protection, stabilize shorelines, and insure navigability of waterways (NRC, 1990). In particular, NFIP provides flood insurance to communities that adopt and enforce measures to reduce future flood risks in hazardous areas (defined as the 100-year flood zone, or A-zone; FEMA, 1997). In coastal areas, the V-zone (seaward of the A-zone) consists of the area subjected to at least a three-foot breaking wave during a 100-year storm or hurricane. NFIP also calls for designation of erosion zones (or E-zones) and providing setbacks or buffer zones. Several states outside the MEC region have enacted their own setback legislation (Edgerton, 1991).

The Upton-Jones Amendment, enacted in 1987, compensates owners to relocate or demolish buildings in danger of imminent collapse (i.e., located in a zone extending seaward of 10 feet plus 5 times local average annual erosion rate). New construction would only be permitted landward of the area expected to erode within the next 30 years (small houses) or 60 years (larger buildings). The Upton-Jones amendment is a reasonable approach for responding to immediate coastal hazards (NRC, 1990). However, because only several hundred claims had been filed by the mid-1990s, this program was terminated.

Another way of pulling back is the concept of rolling easement, in which human activities are required to yield to the landward migrating shoreline (Titus, 1998). The state could prohibit bulkheads or other hard structures that would interfere with the natural shoreline movement. Alternatively, the state could acquire private land when the sea rises by some specified amount. Several states (e.g., New Jersey, Maryland, and Florida) already have acquisition programs for existing coastal hazard areas (Godschalk et al., 2000). These programs could be modified to include the role of future sea-level rise.

Another approach would be notification or disclosure of potential coastal hazards before property purchase. Several states have such disclosure requirements, including Massachusetts, South Carolina and Texas (Godschalk et al., 2000). Here too, the potential effects of sea-level rise could be written into the disclosure document. The California Alquist-Priolo Earthquake Fault Zone Act, although applying to earthquake hazard notification, can serve as a useful precedent.

TABLE 3-5A
Beach nourishment volumes due to sea-level rise for the case study sites (in 10^6 cubic yards[a]).

Scenario	Current Trends	CCGG	CCGS	HCGG	HCGS
Locality		***2000–2020***			
Coney Island	0.099	0.245	0.206	0.131	0.112
Rockaway Beach	0.240	0.672	0.610	0.292	0.261
Long Beach	0.307	0.783	0.676	0.397	0.342
Westhampton Beach	0.229	0.589	0.514	0.292	0.252
Sea Bright	0.489	1.053	0.913	0.617	0.538
Asbury Park	0.480	1.034	0.914	0.670	0.602
		2020–2050			
Coney Island	0.158	0.483	0.453	0.293	0.218
Rockaway Beach	0.799	2.319	2.140	1.455	1.192
Long Beach	0.702	1.939	1.828	1.236	0.977
Westhampton Beach	0.473	1.382	1.230	0.825	0.569
Sea Bright	1.279	3. 008	2.790	2.074	1.655
Asbury Park	0.919	2.436	2.267	1.564	1.223
		2050–2080			
Coney Island	0.164	0.774	0.517	0.395	0.320
Rockaway Beach	1.129	4.683	3.484	2.138	1.875
Long Beach	0.859	3.345	2.401	1.767	1.425
Westhampton Beach	0.658	2.938	2.327	1.446	1.175
Sea Bright	1.885	5.808	4.473	3.528	2.679
Asbury Park	1.405	4.557	3.391	2.513	2.120

[a] To convert to m^3, multiply by 0.765×10^6.

TABLE 3-5B
Percent of total beach renourishment volume due to sea-level rise

Scenario	Current Trends	CCGG	CCGS	HCGG	HCGS
Locality		***2000–2020***			
Coney Island	4.9	11.4	9.7	6.4	5.5
Rockaway Beach	2.3	6.1	5.5	2.7	2.4
Long Beach	4.8	11.4	10.0	6.1	5.3
Westhampton Beach	3.2	7.9	6.9	4.1	3.5
Sea Bright	4.6	9.4	8.3	5.8	5.1
Asbury Park	5.7	11.5	10.3	7.8	7.1
		2020–2050			
Coney Island	5.2	14.4	13.6	9.3	7.1
Rockaway Beach	4.9	12.9	12.0	8.5	7.1
Long Beach	6.5	16.0	15.3	10.9	8.8
Westhampton Beach	4.4	11.8	10.6	7.4	5.2
Sea Bright	8.7	18.3	17.2	13.3	10.9
Asbury Park	8.0	18.7	17.7	12.9	10.4
		2050–2080			
Coney Island	5.4	21.3	15.3	12.1	10.0
Rockaway Beach	7.5	25.2	20.0	13.3	11.9
Long Beach	7.8	24.8	19.1	14.8	12.3
Westhampton Beach	6.0	22.1	18.4	12.3	10.2
Sea Bright	10.1	25.7	21.0	17.3	13.7
Asbury Park	9.6	25.7	20.4	16.0	13.8

How and when to arrive at the optimal decision in the face of rising ocean levels is explored by Yohe and Neumann (1997). Several options are given—advanced foresight, wait-and-see, and protect regardless, for three SLR scenarios: 33 centimeters, 67 centimeters, and 100 centimeters by 2100. The first option assumes sufficient advance warning of SLR and fairly rapid market response to the perceived threat. The second option reacts to the imminent loss of property at the time of inundation, while the last option accepts protection as given and simply seeks to minimize its costs. In general, costs for the advanced foresight option are lower than for the wait-and-see option, especially for the two higher SLR scenarios, but this advantage requires more precise knowledge of the course of SLR and effective market-based retreat policy. Costs are highest for permanent protection.

Implementing a rational and equitable strategy for coastal retreat from high-risk zones will be difficult and politically unpopular. Pressures arising from stakeholders' diverse interests will probably intensify as shorelines shrink and land is inundated (e.g., Figures 3-15 and 3-16A through 3-16D). Adaptation to changing conditions will require the cooperation and coordination of various disparate groups.

INTEGRATION ACROSS SECTORS

Impacts of sea-level rise and exacerbated flooding from storm surges have repercussions on several of the other sectors of the MEC climate change assessment. The findings of the Coastal Zone sector intersect with the Water Resources, Infrastructure, and Institutional Decision-Making sectors. Several examples of such overlapping areas of interest are now presented.

Water Resources

An emergency source of water for New York City during periods of drought is the Chelsea Pump Station, located on the Hudson River south of Poughkeepsie (see also Chapter 6 *Water Supply*). The salt front (defined as 100 milligrams/liter chloride) currently lies south of this station, on average. But its position changes daily with the tides, also seasonally, and due to interannual fluctuations in temperature and precipitation. For example, the salt front reached the Chelsea Pump Station at several times during the drought of 1999, particularly during the months of July and August. The front even reached the Poughkeepsie water-supply intake during late August-early September 1999. Historic sea-level rise may have caused an upstream migration of the salt front, which was apparently located near Tarrytown in 1903, but which since the 1960s ranges between Beacon and Poughkeepsie (Hahl, 1988).

Climate change could affect the location of the salt front in three ways:

1. Reduction (increase) in precipitation can reduce (increase) stream flow, allowing the salt front to move upstream (downstream).
2. Increase in temperature can increase evaporation, reducing freshwater runoff, which in turn would cause the salt front to migrate upstream.
3. Rising sea level may push the mean position of the salt front upstream.

If any of these climate changes, whether singly or in concert, would cause the salt front to reach the Chelsea Pump Station permanently, or even for a significant percent of the year, its continued use as an emergency water resource would be seriously jeopardized.

The U.S. Geological Survey operates five gauges that monitor tide stage, water temperature, and specific conductance (directly correlated to salinity levels). The gauges closest to the Chelsea Pump Station are West Point (south) and near the IBM Center, south of Poughkeepsie (north of Chelsea).

A major research issue will be to model the rise in sea level and its effect on the position of the Hudson River salt front over time, for various climate change scenarios. Results of such modeling studies will help determine which of several options should be adopted, for example, whether to move the intake station upriver, or how to adjust the pumping regime.

Wetlands, Infrastructure and Institutional Decision-Making

Jamaica Bay represents another example of cross-cutting issues involving the Wetlands (Chapter 5), Infrastructure (Chapter 4), and Institutional Decision-Making (Chapter 9) sectors. JFK Airport, situated on the northeastern shore of Jamaica Bay, is a key global transportation facility. Jamaica Bay Wildlife Refuge, at the Bay's center, forms part of Gateway National Recreation Area. It provides critical habitat for several state and federally recognized endangered species. Planes and birds literally compete for the same airspace. Therefore, coordinated management of aviation safely and protection of wildlife becomes paramount.

Sea-level rise will place additional pressures on this delicate coexistence between man, machine, and nature. Preliminary studies by the New York State Department of Energy Conservation finds a loss of 400 acres of former *Spartina alterniflora* low marshes over a 20-year period (1974–1994). These wetlands have now become coastal shoals. Ongoing sea-level rise, together with other factors, such as land subsidence, channel dredging, or boat activity, may be contributing to the marsh losses. If current trends continue, the survival of the *Spartina alterniflora* wetlands will be in question within the next three decades. JFK Airport, on the other hand, will continue to operate, regardless. Runways and other critical facilities can be raised; dikes and seawalls can protect other areas. These protective measures, however, would prevent landward migration of salt marshes in response to sea-level rise.

Comprehensive management of sea-level rise impacts in Jamaica Bay would involve a large number of local, state, and federal agencies and stakeholders, often with diverse interests. For example, the National Park Service, the Army Corps of Engineers, U.S. Fish and Wildlife, the Federal Aviation Agency, and the Port Authority of New York and New Jersey would have to cooperate on issues of air safety vs. preservation of bird sanctuaries in close proximity to flight runways. The extent and timing of human intervention will become an important consideration. Improved procedures of interagency, communication, coordination and decision-making will become a high priority.

The Coastal Zone

A large number of local, state, and federal organizations and institutions within the MEC region have mandates that, fully or in part, involve the coastal zone. Their authority or function encompasses infrastructure operations, emergency response actions, and environmental regulation.

Key components of the MEC regional transportation system have been identified as being particularly vulnerable to sea-level rise and coastal flooding (see Chapter 4 *Infrastructure*). A number of agencies are concerned with management of the regional transportation network (see also Chapter 9 *Institutional Decision-Making*). Among these are:

The Port Authority of New York and New Jersey, which manages bridges, tunnels, PATH railway, shipping and airport facilities; the New York City Department of Transportation, which operates city roads and bridges; the New York State Department of Transportation, which operates state highways and bridges; the Metropolitan Transportation Authority, which runs New York City subways and buses; and the U.S. Army Corps of Engineers, which maintains and dredges harbor ship channels.

Emergency responses to severe coastal flooding, along with other weather-related disasters, are handled by a number of agencies, among which are the New York City Office of Emergency Management, the New York State Office of Emergency Management and its counterparts in New Jersey and Connecticut. On the federal level, the Federal Emergency Management Agency (Region II) assesses flood and wind damages, and provides relief to affected homeowners through the National Flood Insurance Program.

Environmental regulation is the province of diverse state, city, and federal agencies, such as New York State Department of Environmental Conservation, New Jersey Department of Environmental Protection, which oversee wastewater treatment facilities and regulate construction activity in waterfront locations and coastal wetlands. The New York City Department of Environmental Protection manages wastewater treatment plants and sewers, which are located near the waterfront. On the federal level, the U.S. Environmental Protection Agency (Region 2) requires water pollution control plants to meet Federal standards regarding release of effluents; manages the NY/NJ Harbor Estuary Project; also has oversight authority under the Clear Water Act, Section 404 for filling/dredging in wetlands. The U.S. Army Corps of Engineers (New York District, which includes portions of northern New Jersey) dredges the New York/New Jersey harbor for shipping, replaces sand on eroded beaches, regulates filling of wetlands through its permit program (Clear Water Act, Section 404), and plans restoration of wetlands, as in Jamaica Bay.

Given the fragmentation of coastal zone issues among diverse agencies, at different government levels, with differing jurisdictions and mandates, there will be a pressing need to improve channels of communication and develop institutional arrangements that facilitate the promotion of coherent coastal zone management policies, in the face of rising sea level.

INFORMATION AND RESEARCH NEEDS

This study has raised a number of issues that require further investigation, either because of limitations in data availability, uncertainties in the models used, or incompleteness in our fundamental understanding of the physical and socioeconomic processes at work. Some of the more pressing needs are described below.

A major need exists for higher vertical resolution topographic data. The U.S. Geological Survey 7.5 minute Digital Elevation Models used in this study are inadequate for accurately delineating the land area, infrastructure, and waterfront property at risk to permanent inundation or flooding. Although the New York City Department of Environmental Protection has obtained higher resolution topographic data (1 foot) for New York City, the data were not available in time for this study.

Reducing the uncertainties associated with future sea-level rise requires improved understanding of a wide range of diverse climatological and oceanographic processes. For example, we need to know how fast atmospheric warming will penetrate into the oceans (e.g., Levitus et al., 2000) and how much thermal expansion will result, how rapidly mountain glaciers will melt, how human regulation of river runoff and land water storage will affect sea level, and how much the Greenland and Antarctic ice sheets will contribute to sea-level rise. In addition, we need to be able to anticipate changes in tropical and extratropical storm frequencies and intensities, and how such changes will affect coastal flooding and beach erosion.

An important issue, not fully treated here, is the migration of the salt front up the Hudson River under various sea-level rise scenarios, with potentially adverse consequences to the Chelsea Pump station. A major research task will be to model the relationship between sea-level rise and the mean position of the Hudson River salt front over time. Another task will be to model infiltration of saltwater into the Long Island aquifers, which could endanger that region's water supply.

Furthermore, we need to develop more physically based relationships describing the shoreline's response to sea-level rise. Existing models of coastal erosion or beach nourishment requirements have become important tools for investigating coastal processes, for coastal engineering design, and even policy decision-making. However, these models contain a number of shortcomings; for example, they often employ empirical relationships based on over-simplifications of incompletely understood complex physical processes (Thieler et al., 2000). Thus, further studies are required to gain more insight into the interactions between waves, littoral currents, and movement of sand—their sources and sinks, and how these processes would be modified by sea-level rise.

Finally, we need better tools to integrate physical and socioeconomic models. Data needs include improved, higher resolution population projections and economic forecasting. Further work should be undertaken to investigate economic cost/benefit analysis and decision-making under uncertainty. For example, how, when and where to defend the coast and at what cost? At what point in time do higher flood levels and their increasing frequency make it uneconomical to continue beach nourishment, raise seawalls or dikes, etc.? What is the cost threshold in present dollars above which it would be prohibitively expensive to defend the coast? (e.g., Yohe and Neumann, 1997).

POLICY RECOMMENDATIONS

This study raises some concerns over potential increases in future coastal hazards in the MEC region arising out of global climate change, including increased coastal flooding, shoreline erosion, beach nourishment requirements, and land loss (see Tables 3-4, 3-5 and Figures 3-12 through 3-17). On the positive side, these changes would not increase significantly beyond current rates until several decades from the present. This should allow adequate time to plan future mitigation and adaptation responses. However, educating and informing the public of potential risks, beginning with concerned stakeholders and policy-makers, should start now. This report provides the scientific background that will enable coastal managers, planners, educators, and other concerned stakeholders to develop appropriate policies and make well-informed decisions. Based upon the initial findings of this study, the following are some recommendations for further action.

- Stakeholder groups and appropriate government agencies within the MEC region should be informed on the latest scientific findings on future sea-level rise and their implications for coastal management and planning.
- Agencies involved in coastal management should begin to factor sea-level rise into their long-term planning decisions.
- Designation of coastal hazard zones, adaptation of erosional setback requirements, rolling easements, and limits to development in high hazard coastal zones should be considered.
- Provision should be made to acquire empty space inland for beaches and wetlands to "roll over."
- Remaining open coastal space for future recreational needs should be purchased.
- Educational outreach to inform the general public and concerned stakeholders of the issues raised by this study and various adaptation and mitigation options should be provided.
- Coherent coastal zone management policies by promoting increased interagency communication and cooperation should be developed.
- NFIP reimbursement policy to limit repeated claims payments to homeowners living within high hazard zones should be revised.

SUMMARY AND CONCLUSIONS

The vulnerability of the Metropolitan East Coast Region to coastal hazards, such as more frequent storm flooding, beach erosion, submergence of coastal wetlands, and saltwater instrusion, will intensify as sea-level rises. The reduction in flood return period is very sensitive to small increases in sea level, independent of any changes in storm patterns.

Historic storms striking the Northeast show pronounced interdecadal variability, but no secular trends (Zhang et al., 2000; Dolan and Davis, 1994; Landsea et al., 1999). On the other hand, the soaring coastal flood damages of recent decades reflect increasing development in high-risk areas, rather than any fundamental changes in storm behavior (Changnon and Changnon, 1999; van der Vink et al., 1998). This intense coastal development has occurred during a relatively quiescent period of hurricane activity (e.g., Landsea et al., 1999).

Climate models vary widely in their simulations of future cyclone behavior, pointing to the need for further research. Calculations presented in this report assume a fixed storm climatology.

In the MEC region, sea level has increased steadily by 22 to 39 centimeters during the 20th century. Projections based on historical trends and climate model simulations (Hadley Centre, UK and Canadian Centre for Climate Modelling and Analysis) suggest that sea-level rise will remain fairly modest in the next 20 years, ranging between 4.3 and 11.7 inches (11 to 30 centimeters, Table 3-4; Figure 3-12). However this temporary respite should not induce a false sense of complacency—more pronounced increases could appear by the 2050s (6.9 to 23.7 inches [18 to 60 centimeters]) and especially by the 2080s (9.5 to 42.5 inches [24 to 108 centimeters]).

As a result of sea-level rise, storm floods would be higher, cover a wider area, and occur more often. The 100-year floods, ranging between 9.9 and 11.5 feet (3–3.5 meters) in the 2020s would rise to 10.1–12.4 feet (3.1–3.8 meters) by the 2050s, and 10.4–13.8 feet (3.2–4.2 meters) by the 2080s (Figure 3-13).

A significant corollary will be the marked reduction in the flood return period. The 100-year flood would have a probability of occurring once in 80 to 43 years, on average, by the 2020s, 68 to 19 years by the 2050s, and 60 to four years, by the 2080s (Figure 3-14). The area outlined by the 10-foot contour (3 meters) in New York City and environs could have a likelihood of flooding once in 50 to as often as every 5.5 years, on average, by the 2080s (Figure 3-15).

A narrow strip of shoreline in the case study sites would be permanently under water, particularly by the 2080s (compare Table 3-4 and Figures 3-16A through 3-16D). However, projected storm floods would cover a more substantial fraction of these sites after the 2050s (compare Figures 3-13 and 3-16A through 3-16D). More frequent floods, even if storminess did not change, would threaten seaside communities, as well as evacuation routes along major transportation arteries, including highways, rail and air routes (e.g., Figure 3-15; see also Chapter 4 *Infrastructure*).

Rates of beach erosion would double or triple by the 2020s, increasing three to six times by the 2050s, and four to 10 times by the 2080s, relative to the 2000s. To compensate for these losses, we calculate that 2.3 to 11.5% more sand (by volume) would be needed by the 2020s to offset increased erosional losses due to SLR alone, relative to total sand replenishment requirements (Table 3-5). Sand volumes increase by 4.4 to 18.7% by the 2050s. Thus, periodic sand nourishment will probably remain a viable option for maintaining the beaches of the south shore of Long Island and northern New Jersey through mid-century. By the 2080s, however, sand replenishment, and associated costs, grows more substantially by 5.4% to 25.7%.

Another serious impact of rising sea levels could be the northward migration of the salt front up the Hudson River, possibly reaching the Chelsea Pump Station over a major portion of the year; saltwater may also seep into Long Island aquifers, endangering its water supply.

In response to SLR, armoring of the shoreline will be necessary to protect vital infrastructure, such as entrances to bridges and tunnels, airport runways, and also areas of high population density and property value. However, hard or soft defense measures will not be a practical option for the entire MEC coastal zone. In particular, the bay shorelines are potentially even more vulnerable to inundation and storm-related damages, because of their generally low elevation and absence of natural or artificial buffers. Thus, zoning or land-use policies would need to be implemented to enable an orderly and equitable pull-back from the most vulnerable areas.

This could be accomplished by a number of mechanisms, for example: designation of setback lines, removal of buildings or structures in imminent danger of collapse, and acquisition of empty space inland for beaches and wetlands to "roll over," or migrate landward. Other options include the use of rolling easements, in which human activities are required to yield to the landward migrating shoreline (Titus, 1998), or allowing the state to purchase private land when the sea rises by some specified amount.

Although adjustments to sea-level rise would be relatively minor within the next 20 years (Figure 3-12), this period of grace should be utilized to prepare future mitigation and adaptation responses. Educational outreach should begin now, involving concerned stakeholders and policymakers. This report provides an initial scientific framework to enable coastal managers, planners, educators, and other concerned stakeholders to develop appropriate policies.

Our initial recommendations include the following:

- Inform stakeholder groups and relevant government agencies within the MEC region of the latest scientific findings on future sea-level rise and their implications for coastal management and planning.
- Encourage coastal managers to incorporate sea-level rise into their planning decisions.
- Adopt erosional setbacks or rolling easements and limit development in high coastal hazard zones.
- Acquire empty space inland for beaches and wetlands to "roll over."
- Purchase remaining open coastal space for future recreational needs; encourage land conservancy.
- Develop coherent coastal zone management policies, by promoting increased interagency communication and cooperation.
- Require notification of coastal hazard conditions, including sea-level rise, in sale or purchase of coastal property.

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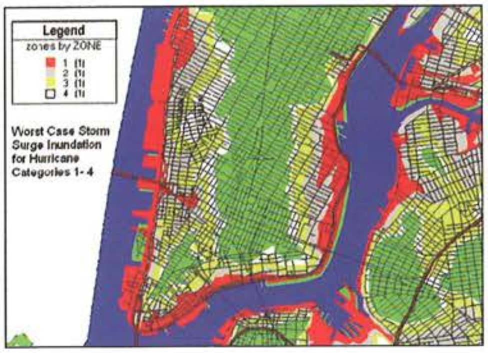

CHAPTER 4

INFRASTRUCTURE

The Metropolitan East Coast (MEC) Region is a prime example of a mega-city in a coastal setting (Figure 4-1). Four out of five boroughs of New York City are located on islands (Brooklyn and Queens on Long Island, Staten Island, and Manhattan); only one (the Bronx) is located on the mainland. Bridges and tunnels are critical bottlenecks of the dominant transportation paths to the suburbs and counties located in the tri-state MEC Region of New York (NY), New Jersey (NJ) and Connecticut (CT). Bridge access roads, entrances to road and rail tunnels (including subways and ventilation shafts), and non-transportation infrastructures such as storm sewers and wastewater processing plants are located at critical low elevations. They are exposed to coastal or riverine flooding and hence can be subject to interruptions of services. The MEC Region is particularly vulnerable to climate-dependent sea-level rise. Many coastal cities in the United States and the world face similar problems. Sea-level rise is a global issue of increasing concern to many major coastal cities and populations.

Infrastructure provides the engineered foundation for the socio-economic functioning of population centers. Infrastructure systems consist of interconnected networks of facilities that deliver resources, remove waste, move people, information and goods, and create, to a large degree, the cultural ambiance. Infrastructure includes bridges, roads, buses, subways, railroads, water lines, sewage systems, power lines, and telephone lines. The robustness of infrastructure systems depends on their design, state of maintenance, and the human and natural stresses to which they are exposed. Besides human stresses, weather, climate, and extreme natural events such as floods, earthquakes, and wind or ice storms test the vulnerability of these systems.

In this chapter we pose the following questions: Given a set of expected climate changes, how will the existing infrastructure of the Metropolitan East Coast Region respond? Will stresses on the systems increase or diminish? What costs or benefits, if any, will be incurred from the climate changes? Are there cost-effective actions that can be taken to minimize negative effects on the systems or maximize the benefits?

The answers to these questions relate to the topics addressed in companion sectors of the MEC Regional Assessment. Since the questions posed above are very broad, and the resources and time to study them were limited, we narrowed the scope of this study by taking the following stepwise approach:

1. First, we review the state of knowledge about *current* risks from climate hazards to the infrastructure in the Metropolitan East Coast Region. In particular, we focus on the hazard of *coastal storm surge inundation* and its effect on *transportation systems*. Transportation was chosen because of information availability. Public transportation in the MEC is one of the most developed in the nation and hence is a good proxy for characterizing the MEC infrastructure as a whole.

2. Second, we extrapolate storm surge risks into the future, accounting for effects of climate change. We superimpose on the existing hazards the incremental hazards expected to be associated with global warming and sea-level rise (SLR). At the same time, we introduce probabilistic concepts into the assessment of the storm surge risk.

3. Our third activity is to assess the consequences of SLR in terms of likely losses and impacts on the economy of the metropolitan region. This is an initial effort since neither the necessary computer algorithms exist in the public domain at this time, nor do current databases exist in the public domain on infrastructure asset values, fragilities, storm track probabilities or surge height statistics. This applies whether the missing information concerns the mere dollar value of assets, the technical details necessary to assess fragility (vulnerability) due to storm surge hazards, or the frequency of storm tracks and their associated

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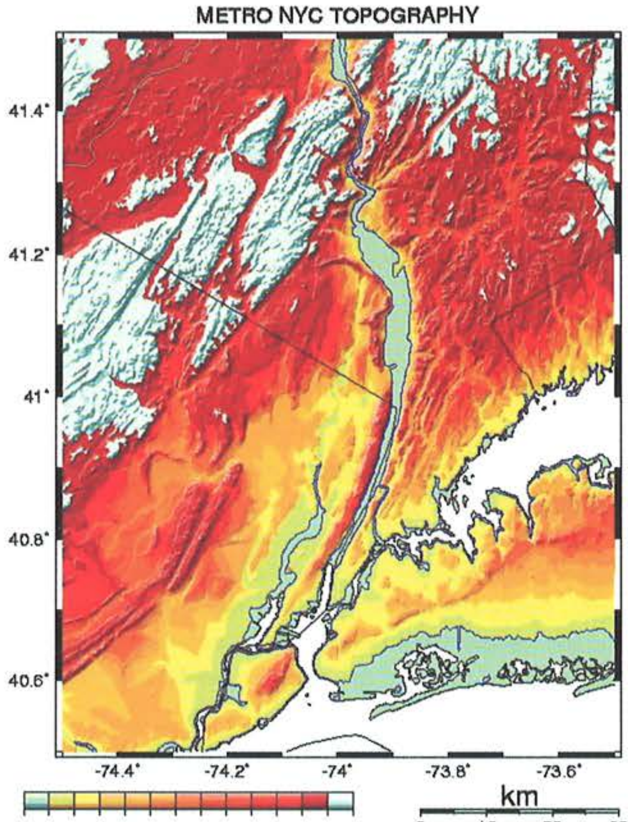

FIGURE 4-1 Topography of Metropolitan East Coast Region (elevations in meters). Source: USGS

magnitude. This lack of refined data, information and knowledge allows at this time only qualitative loss estimates. **4.** Our aim is to explore coping and adaptation strategies. Although there is quantifiable uncertainty associated with the expected increase in risk, it becomes clear that even without climate-change-related increments of risk, coping strategies are needed because the volume and aggregate value of exposed assets are increasing with time. The coping strategies explored include a mixture of modern engineering solutions, regulatory measures, taxation and/or financial or insurance discounting, and innovative land use combined with buyouts and relocations. Costs and benefits of these various options, including the mounting costs of not facing these issues at all, need to be addressed quantitatively in forthcoming studies. This Assessment begins to characterize the magnitudes of problems that will need to be tackled.

The importance of this study is that risk is evaluated not just looking backward in time to assess current risk levels. Instead it looks forward in time by about a century. This futuristic outlook is important because capital-intensive infrastructure has a typical lifetime of about a century or more. Therefore, investments made today create infrastructures that will have to meet the climate (and other) demands of a 100 years later. If the hazards and risks are not assessed on the same time scales, and the infrastructure is not built to take the time-dependent hazards into account, then it is likely that many of the current investments may engender losses. This study contributes to the need for knowledge of what is needed to engineer the region's transportation infrastructures safely rather than haphazardly for the 21st century.

BACKGROUND

The Metro East Coast Region is defined in this study as the metropolitan area centered on New York City. We adopt the Regional Plan Association's (http://www.rpa.org) spatial definition, based largely on work-related commuter patterns moving a large workforce to and from a central business district. The so-defined MEC region consists of 31 counties in three states: 14 counties in New York (NY), 14 in New Jersey (NJ) and 3 in Connecticut (CT). Five of the 14 New York counties are located in New York City (NYC) and make up the city's five boroughs known as Manhattan, Brooklyn, Queens, the Bronx, and Staten Island. As can be seen from the regional land use (Figure 4-2), Manhattan is the central business district around which the MEC urban conglomeration has evolved. Commercial and mixed urban use dominate at the center, surrounded by primarily residential land use, punctuated by very sparse, patchy industrial usage. Urban to suburban satellite business centers (commercial and mixed urban land use) are interspersed throughout the region.

The total population of the MEC region is just short of 20 million, more than 7% of the U.S. population. About one-third of the MEC population lives in New York City, the remainder in largely suburban settings except for several larger urban centers that include the cities of Yonkers, NY; White Plains, NY; Newark, NJ; Jersey City, NJ; New Haven, CT; Bridgeport, CT; and Stamford, CT.

The total built assets of the MEC region are estimated to have a value of about $2 trillion (HAZUS, 1999), nearly half of it concentrated in New York City. About half of the $2 trillion of built assets are buildings, and most of the other half consists of "infrastructure" to be defined below in more detail. The gross regional product (GRP) measuring the region's annual economic output approaches nearly $1 trillion. If one divides the total built asset value by the total population one obtains average assets of about $100,000 per person; and about half of that amount—about $50,000 per year—as the region's per capita annual contribution to the GRP. These few economic statistics are used later to assess the significance of climate-related disaster losses that can be expected during extreme meteorological events such as hurricanes or nor'easter storms.

Substantial corridors and areas of land are reserved for transportation facilities (Figure 4-2) (HAZUS, 1999). Many of the major transportation facilities either cross bodies of water or are located along the water's edge. They do so either by necessity (e.g., harbor facilities) or by evolution, since the low-lying marshy lands were generally the only unsettled areas left on which to build airports, highways, rail tracks, and train and bus service depots. In Manhattan, heavily used commuter highways are located along the waterfront: FDR Drive, Henry Hudson Parkway, and Westside Highway. Farther inland, some of the transportation systems cross or run along glacially carved mostly N-S striking valleys (e.g., the Saw Mill, Sprain Brook and Bronx River Parkways), which are subject to periodic riverine flooding.

A More Detailed Definition of Infrastructure

Infrastructure is the aggregate engineered and built environment on which the functioning of a complex urban society depends. Infrastructure consists of the connected systems, lifelines, and conduits that provide transportation, energy, communication, and water, and enable such basic services as solid and liquid waste disposal.

Economic life, public safety and health are based, and have come to depend, on complex infrastructures. In this broader sense the MEC's financial service industry, better known as "Wall Street," for instance, is largely a privately built infrastructure and economic "lifeline" for New York City and the surrounding region, and arguably for the nation and the world. But without a properly functioning regional public infrastructure, private "Wall Street" and other major business sectors of the region could not exist.

The MEC region centered on New York City is the prime U.S. example of a global mega-city. Its highly developed infrastructure, especially a well performing public transportation system, allows New York and the MEC region to function as a global mega-city. Growth and modernization of the infrastructure will maintain this global role, and lack of upkeep or adaptation to changing circumstances, including climate change, is likely to undermine the MEC's global role.

MEC's Transportation Systems Infrastructure

The vast majority of New York City's and the MEC Region's basic infrastructure was built and developed 50 to 100 years ago. This buildup occurred during the time of largest population influx, primarily driven by immigration. Today, with about 20 million people living, working, and commuting in its 31 counties, the MEC region is home to the largest public transportation system in the United States. Many organizations are part of this "system": the Metropolitan Transportation Authority (MTA), NJ Transit (NJT), and the Port Authority of New York and New Jersey (PANYNJ), to name but a few. These important components of the region's transport system provide and maintain a large-scale public service: (http://www.mta.nyc.ny.us/index.html):

- MTA (with an annual operating budget of about $6.4 billion) operates subways, buses, and railroads that move 1.7 billion riders a year (about 5.7 million on an average workday), or about one in every four users of mass transit in the United States; and two-thirds of the nation's rail riders.
- MTA bridges and tunnels carry upwards of a quarter of a billion vehicles annually, more than any bridge and tunnel authority in the nation. (http://www.mta.nyc.ny.us/bandt/html/btmap.htm).
- The MTA transportation network, North America's largest, serves a population of 13.2 million people (about two-thirds of the MEC population) in the 4,000-square-mile area fanning out from New York City through Long Island, southeastern New York State, and Connecticut (Figures 4-3A and 4-3B).
- The Port Authority of New York and New Jersey (PANYNJ; http://www.panynj.gov/) and New Jersey Transit (NJT, http://www.njtransit.state.nj.us/mainterm.htm) are the primary providers of public transportation to the remaining one-third of the MEC population. They provide feeders covering predominantly

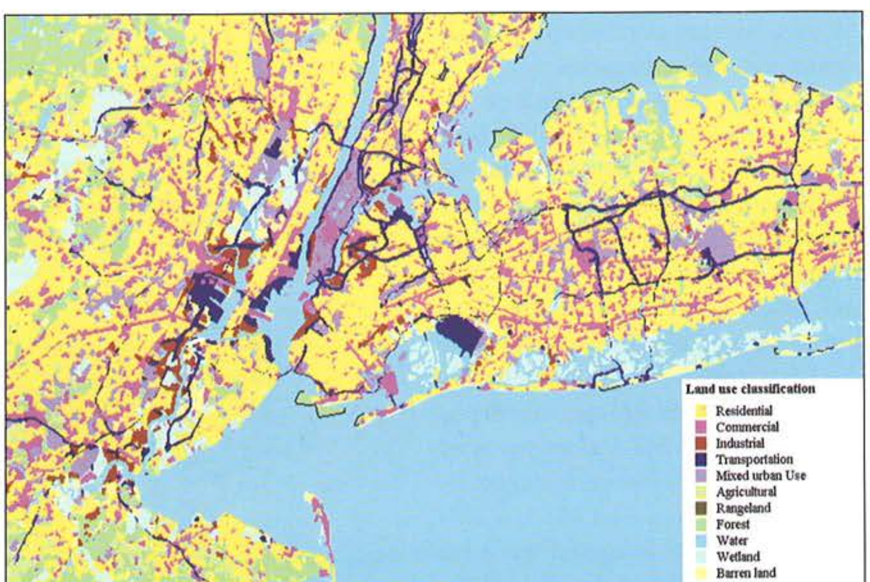

FIGURE 4-2 Land use map (HAZUS, 1999).

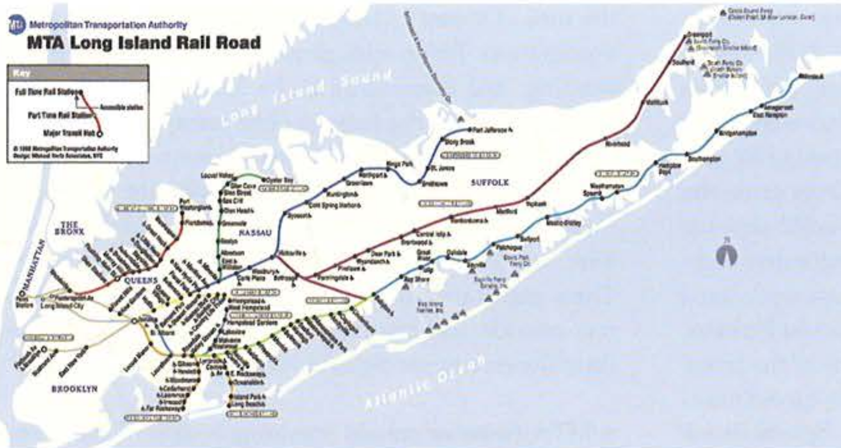

FIGURE 4-3A Long Island Railroad (map: http://www.mta.nyc.ny.us/lirr/html/lirrmap.htm).

the western and southern sectors, across and west of the Hudson River estuary (for PA Maps see: http://www.panynj.gov/facframe.htm;http://www.panynj.gov/path/patmfram.htm).

- Air transportation and Amtrak rail systems add services primarily beyond the immediate MEC region.

Current System Stresses and Windows of Opportunity for Adaptation

Existing stresses on the region's infrastructure stem primarily from overuse, marginal capacity, aging, neglect of maintenance, undercapitalization, and lack of interagency coordination/intermodal integration. Most of the basic systems (i.e., tunnels, bridges, tracks, stations, and terminals, but not the rolling stock and control systems) were built early in the 20th century, some of them (e.g., subways) privately financed and operated for the first few decades. All were later transformed into publicly owned and operated systems.

The heavy usage of, and lack of capital improvements for, some of these public systems led, especially in the 1970s, to the "deferred maintenance" problem. The systems' state of health severely deteriorated until the 1980s and 1990s, when major capital funds had to be urgently invested to rescue the key components from potentially catastrophic failures and system collapse. For instance, the MTA alone invested during the 1982–1999 period approximately $32 billion. The MTA is currently proposing a capital program totaling $16.5 billion for the 2000–2004 period.

Capital infusion is and will remain key to upgrading and modernizing critical system components needed to satisfy growing rider needs and to maintain safety. Partial successes now prevail and operational improvements continue. Examples are increased ridership, the electronic MetroCard allowing NYC Transit subway/bus intermodal transfers, and interagency EZ-Pass road, tunnel, and bridge toll collection. But many bridges, tunnels, stations and other basic transportation system components are still in dire need of capital improvements requiring tens of billions of dollars during the next decade alone for repair, replacement, and expansion. Just for the City of New York alone, the Office of the Comptroller identified infrastructure capital investment needs that amount to $92 billion in the next decade. Major capital investments provide unique opportunities to include environmental and climatic factors into the planning, engineering and implementation of infrastructure upgrades. Conversely, if these opportunities are missed, then the modernized systems may not be adapted well to environmental changes. They could be difficult to maintain, and may pose major liabilities that could cost tens to hundreds of billions of dollars in future direct and indirect economic losses, as we explore below.

FIGURE 4-3B Metro North Commuter Rail System (map: lirrmap.htm; http://www.mta.nyc.ny.us/mnr/html/mnrmap.htm).

RESEARCH METHODS

Having narrowed the task to assess the MEC's storm surge risk to the transportation infrastructure, how can one approach this still quite complex task? The first question we ask is: How is risk, i.e., the potential to incur losses, defined and how can it be assessed and quantified? The simplest definition of risk is the regional sum (spatial integration) over the local products of three spatially variable factors: the hazard, the asset value, and the fragility:

RISK = Sum of (HAZARD x ASSETS x FRAGILITY)

In this case the *hazard* concerns the storm surge flood heights (and in some instances duration) as modified over time by sea-level rise. The *assets* are the dollar values of the various transportation systems and/or of their components. The *fragility* is a value (between zero and one) that determines the fractional loss of each facility or systems component, given the hazard at its location during the extreme event. A fragility of 1 means a total loss, while a fragility of zero means no loss, given the particular hazard (say, storm surge height). Let us turn to the three risk elements (hazard, assets, and fragility) in more detail.

Hazard: Difference between Deterministic and Probabilistic Hazard Assessments

A deterministic hazard assessment poses only the "what if?" question rather than the "how often?" or "how likely?" question. It assumes essentially one or more scenario events at given locations (or along given storm tracks) with given magnitudes (resulting in certain storm surge heights and duration) without asking about the rate of their occurrence or their probability. For these deterministic scenarios we use those based on historic events or on computed worst-case scenarios described below.

When using probabilistic principles of hazard assessment we ask what are the rates of occurrences or their annual probabilities. In this study, we specifically ask how does the probability for a given storm surge height change as a function of time due to the expected sea-level rise (SLR). The SLR is projected in several different ways: (1) as an extrapolation into the future using local historic SLR observations, and (2) via SLR projections based on the four climate models (CCGG, CCGS, HCGG, HCGS) used in the National Assessment. In the latter case, SLR must be corrected for local tectonic subsidence, while the former includes the tectonic subsidence inherently (see Chapter 3 *Sea-Level Rise and Coasts*).

Ideally, any probabilistic assessments should include an evaluation of the uncertainties. These include both epistemic model uncertainties and aleatoric (random) uncertainties inherent in observations of most natural processes. Since the data sets so far available for this study are very sparse, a comprehensive probabilistic assessment with complete evaluation of uncertainties must be reserved for the future. More detailed studies will require a much-needed thorough compilation of the historic storm and associated loss data for the region. Elements of such compilations are available (Coch, 1995; Wood, 1986), but do not cover fully the storm surge hazards (i.e., height and duration as a function of locality) needed for a probabilistic assessment. We provide in Appendix Infrastructure 1 a brief outline of a basic probabilistic hazard definition and its use in probabilistic risk assessments.

The remaining two elements of risk are:

Assets

Asset values are generally taken to be the infrastructure systems' current replacement value. For details see Appendix Infrastructure 1.

Fragility

Fragility is defined as the fractional loss (loss incurred divided by replacement value) associated with a damage state of the asset after the event has passed. The fragilities for coastal storm surges of the MEC's transportation infrastructure are poorly or at best incompletely known, because during a given facility's lifetime only a few of the severest possible events have occurred. For more details see Appendix Infrastructure 1.

Risk

The empirical loss data from past coastal storms that we use for calibrating the risk or estimates of expected losses for the MEC region represent aggregate losses caused by storm surge, wind, and riverine flooding effects (where applicable). Since each of these three storm elements has its own spatial hazard distribution, and the fragilities of the assets are also distinct for these three hazards, the aggregate risk consists of three risk or loss components that rarely can be disaggregated in the historic loss reports. Therefore, when estimating storm-related losses, we deal with aggregate losses per storm, rather than separating out the storm surge component by itself.

RESULTS

1. Prior Flood and Storm Surge Assessments Based on Current Climate Conditions

FEMA'S Q3 FLOOD ZONE MAP

A map of the riverine and coastal flooding, known as the Q3 maps, was commissioned by FEMA for its National Flood Insurance Program (NFIP) (Figure 4-4). It shows the extensive areas potentially subjected to 100-year floods (red), the additional areas expected to be flooded by coastal wave action (magenta), and additional areas affected by 500-year floods (yellow). Taking this map and the land use map (Figure 4-2) together, we find that many areas, including many transportation corridors and systems, lie in the flood zones so identified. The question arises: what are the lowest critical elevations of many of the built assets and transportation facilities located in and near the mapped flood zones, and of some of their key operational components, relative to the expected flood heights? In other words: what is the critical flooding level that poses the threat of lost services and/or serious damages? These questions cannot be answered from the Q3 maps alone, but require additional information for each facility.

Caution is appropriate when using the Q3 maps. The map is undergoing periodic upgrading (http://www.fema.gov/mit/tsd/MM_main.htm). In the future, the upgrading may benefit from modern airborne LIDAR survey technology to speed up the digital mapping process while obtaining better resolved (cm to dm) topography and digital elevation models (DEM). Many areas were last mapped several decades ago. Meanwhile land use has changed in many of them, generally reducing natural areas and wetlands that have the ability to absorb the runoff from major precipitation events. As a consequence, what would have been a 100-year flood prior to land-use change may reach flood heights that are equivalent to what is mapped as a 500-year flood zone, although the precipitation event itself may have represented a 100-year event. Especially in the fast-growing suburban areas of the MEC region, such flood-increasing land use change, generally by development of both commercial and residential spaces—including highways, malls and parking lots—has been a common occurrence. Q3 maps need to be adjusted accordingly, placing structures and lifelines retroactively into newly defined flood zones.

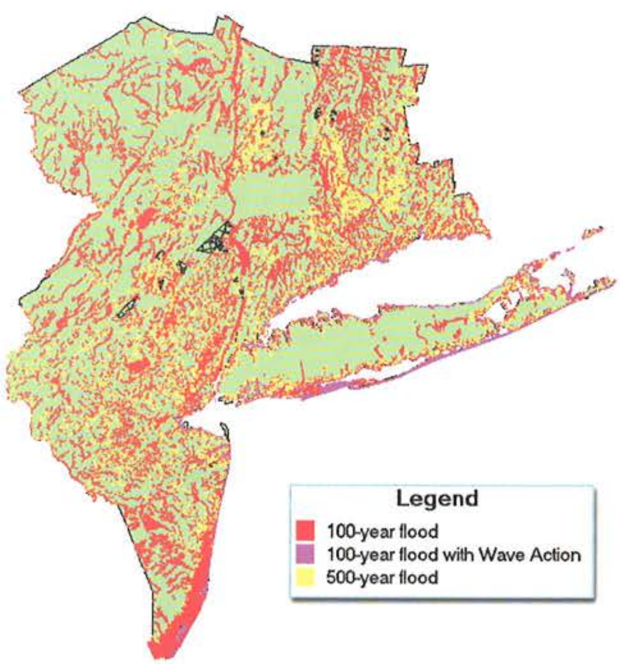

FIGURE 4-4 FEMA Q3 Flood Zone Map for the MEC Region

METRO NY HURRICANE TRANSPORTATION STUDY

The most comprehensive study available on coastal storm flooding risks of transportation systems in the NYC/MEC region is the "Metro New York Hurricane Transportation Study, Interim Technical Data Report." The U.S. Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA), the National Weather Service (NWS), and other state and local agencies produced it jointly in 1995. We refer to the study report as MNYHTS (1995). In this work, we rely heavily on this landmark study. The MNYHTS has several limitations. First, the hurricane study was performed primarily to help develop *short-term emergency plans* for the timely evacuation and "safe shutdown" of the MEC in case of an approaching storm. It did not attempt to address what *long-term mitigation strategies* should be pursued to minimize future loss exposure, increase resilience, and avoid—to the extent possible—future exposure to flooding. It does not evaluate such mitigation measures as enacting new land-use policies, zoning, construction codes, and/or engineered protection.

Second, the MNYHTS took a *static* view of climate. In particular, it did not take note of the possible impact of rising sea level, an essential aspect of future climate scenarios. In this study, we therefore have the opportunity to extend the scope of the MNYHTS by accounting for sea-level rise that may affect the safety and operations of the region's transportation infrastructure systems.

Third, the MNYHTS took a deterministic approach, avoiding probability estimates and instead emphasizing worst-case scenarios. This provides an opportunity for this and future studies to incorporate a probabilistic approach covering a range of scenarios with their associated probability. Such an approach is helpful when decisionmakers are asked to make sustainable decisions on the basis of uncertain costs and benefits to the public.

U.S. ARMY CORPS OF ENGINEERS/NATIONAL WEATHER SERVICE SLOSH MODEL WORST-CASE STORM SURGE SCENARIOS

The Metro New York Hurricane Transportation Study (MNYHTS, 1995) takes a deterministic, worst-case scenario approach. It computes the storm surge heights associated with worst-case storm tracks for hurricanes that measure Category 1, 2, 3, or 4, respectively on the Saffir-Simpson (SS) scale, regardless of their frequency of occurrence. For definition of the SS scale see Chapter 3 *Sea-Level Rise and Coasts* and http://www.nhc.noaa.gov/aboutsshs.html. The

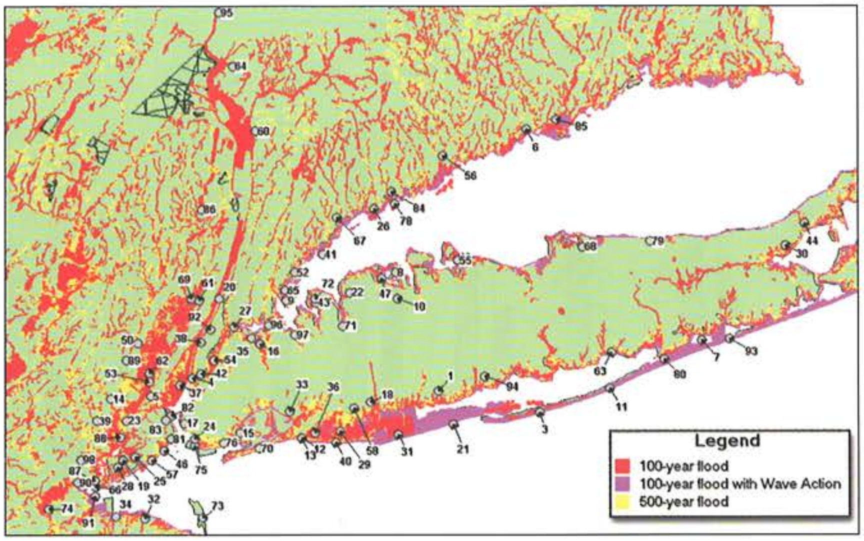

FIGURE 4-5 FEMA Q3 Flood Zone Map. Numbers of gray dots are locations listed in Appendix Infrastructure 1.

Metro Transportation Study excludes Category 5 hurricanes because they occur in the United States only at more southern latitudes, and hence their probability approaches nil. Even category SS4 storms are only marginally sustainable in the cool waters offshore the MEC region. Even so, the 1938 hurricane that crossed Long Island (Coch, 1995), did exceed SS3, may have been borderline SS=3 to 4, and probably just fell short of a genuine SS4.

For the MEC region, the worst-case scenarios are those associated with a storm track that has a NNW forward direction of the storm's eye and a landfall north of Atlantic City, NJ. Such a storm passes just west of New York City. Its landward sweeping right arm of the counterclockwise spiraling winds drives waves and water into the New York bight, the NY Harbor/Hudson River estuary, the Long Island Sound/East River, and towards the Long Island barrier islands facing the open Atlantic off Long Island. The beaches of the latter (Jones Beach, Fire Island, etc.) are some of the nation's most popular recreation facilities, visited by millions every year.

The worst-case storm surge heights in the MEC region for SS Categories 1 through 4 hurricanes at various coastal and estuary waterfront locations (Figure 4-5; Appendix Infrastructure 2) are reported in the MNYHTS (1995), relative to the National Geodetic Vertical Datum (NGVD) of 1929. NGVD was the then nationally adopted reference sea-level datum. We added the geocoded approximate latitudes and longitudes to the locations using largely the positions given in geographical place name catalogues of the U.S. Geological Survey (http://mapping.usgs.gov/www/gnis/index.html).

The storm surge heights given in MNYHTS (1955) are based on the SLOSH model computations (Sea, Lake and Overland Surge from Hurricane model), and vary throughout the region measuring up to 10, 17, 24, and 29 feet above NGVD for Category 1 through Category 4 hurricanes, respectively. The SLOSH model is a hydrodynamic model which uses the pressure and wind shear with offshore bathymetry/onshore topography to compute the storm-driven flow of water. It yields—for a given storm track, intensity, and forward speed—the spatio-temporal variations of the sea surface and adjacent overland surge heights at a set of computational grid points. For an overview of the SLOSH worst-case surge heights in the MEC region, see Figures 4-6A and 4-6B. It is important to note that these surge heights are for worst-case tracks at each SS storm category and these storm tracks have low probabilities of occurring, compared to less damaging storm tracks.

The MNYHT study also compiles the lowest critical elevations of transportation systems in the MEC region (Table 4-1). They are defined as the lowest points of entry to tunnels, subways, or ventilation shafts. The lowest points of airport runways, roadways and bridge approaches which will cause flooding at or above this level are vulnerable to shut downs of the systems' operations. The majority of critical elevations of the transportation systems are at elevations above NGVD between 6 and 20 feet, well within the range of many of the SLOSH storm surge heights. We plot the combined data presented in MNYHTS (1955), i.e. SLOSH surge heights and critical transportation system elevations (Figures 4-7A and 4-7B). Even under current or recent climate conditions, many of the major transportation facilities' operations will be flooded during worst-case track scenarios of hurricanes of SS Categories 1 through 4. We have grouped the transportation facilities by operating agency in accordance with MNYHTS (1995). Table 4-2 gives a more detailed listing of storm surge data and facility elevations for the Holland and Lincoln Tunnels.

To provide a more detailed map view of the extent of flooding in a particularly sensitive area of the MEC region, we show in Figure 4-8 how severely Lower Manhattan, including the Wall Street financial district, would be affected under the SLOSH scenarios for SS category 1–4 and the worst-case storm tracks. Note that for worst-case scenario storms stronger than Category 2, Lower Manhattan will be split into two islands, along Canal Street; i.e., the financial district would be entirely cut off from any escape routes. Entrances to subway, road or rail tunnels or ventilation shafts will be at or below flood levels as well as building stock and other assets that are located in the flooded areas.

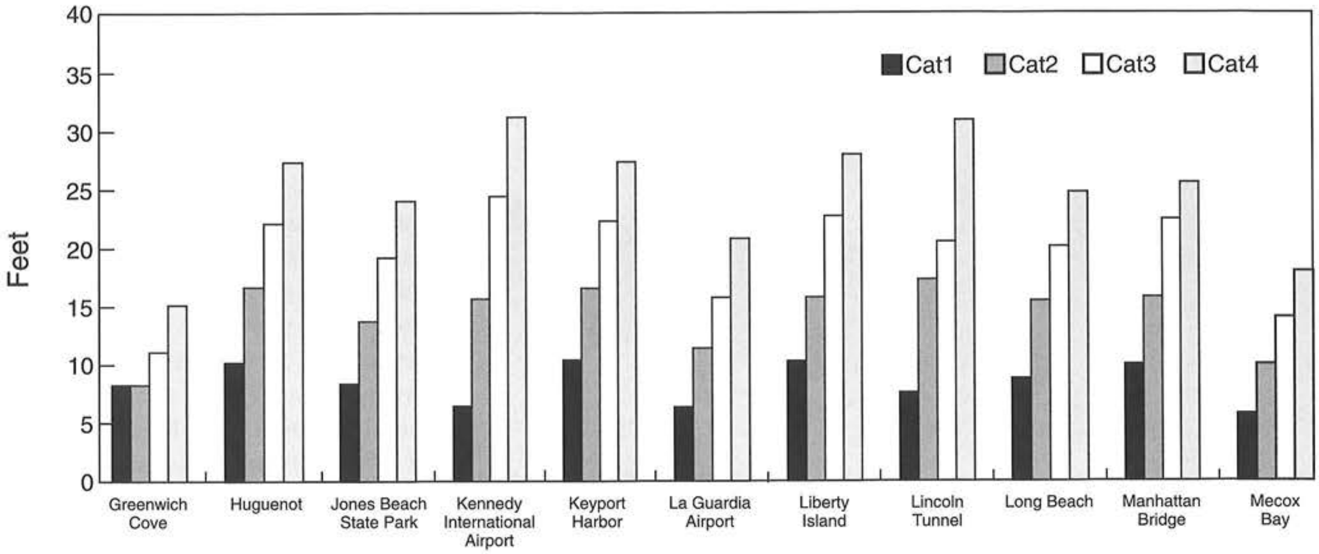

FIGURE 4-6A Surge heights (feet) above NGVD for category 1–4 storms at key Metro East Coast locations. Source: MNYHTS (1995)

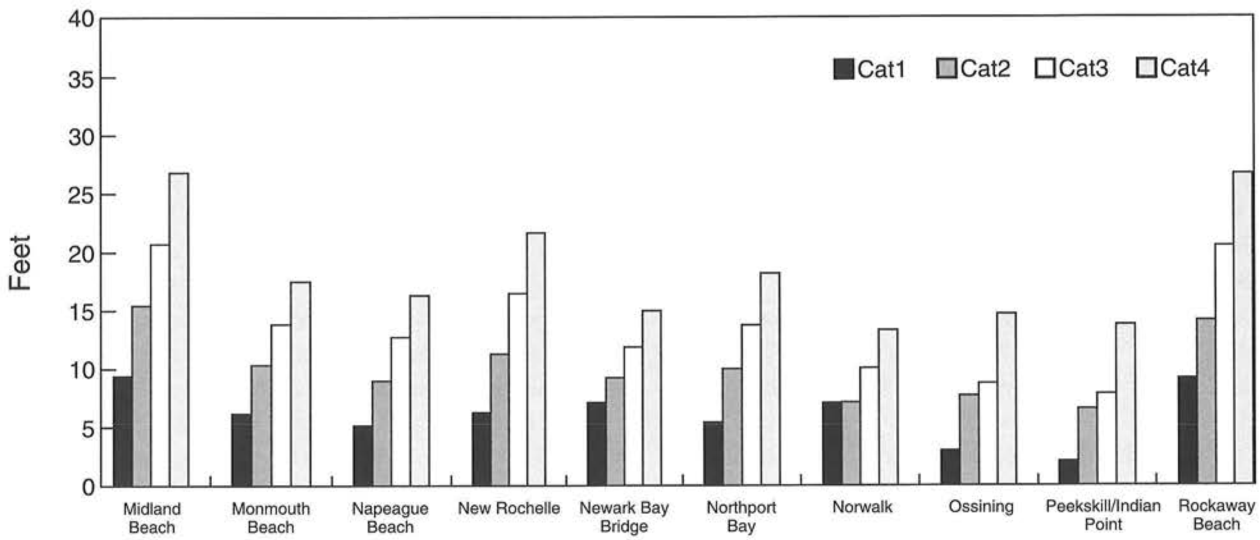

FIGURE 4-6B (Continuation)

MNYHTS (1995) dramatically illustrates the expected flood levels in this area and at other key locations in New York and New Jersey by superimposing them onto photographs for selected facilities. We reproduce a sampling of these as Figures 4-9A through 4-9D.

Nor'easter Storms and Surge Statistics

Nor'easters are extratropical storms affecting the MEC region that can cause potentially severe flooding. Nor'easters typically occur in the mid-Atlantic region during late fall and throughout the winter season. They form when a major low-pressure system becomes nearly stationary off the mid-Atlantic coast. These storms can last several days, and their persistent duration makes them surprisingly damaging. While a 30- to 70-mile-per-hour forward-moving hurricane may create a surge crest that typically lasts at most a few hours, nor'easters can linger for several days. This allows the water to distribute more evenly in the flooded zones, and the volume of water entering tunnels and shafts is time-proportionally large. While the cresting height of nor'easters is generally less than hurricanes, their damage potential, including from wave action, is considerable. They tend to visit the MEC region at least as frequently as hurricanes.

In recent decades the MEC region was hit by severe nor'easters during November 24–25, 1950, and December 11, 1992 (Figure 4-10A through Figure 4-10D), with lesser events at other times. These severe nor'easters flooded airports and roadways. In addition the 1992 storm interrupted service on the PATH train "tubes," on one line for 10 days and on other sections for two days, because of flooding of the Hoboken station on the New Jersey side. The flooding damaged equipment and took ten days to repair before all lines of this important commuter link could be brought back to operation. Afterwards, PANYNJ

TABLE 4-1
Lowest critical elevations of transportation systems (ft above NGVD), or of components there of. In cases of bridges it usually is the elevation of the lowest approach road. Source: MNYHTS (1995).

ID	Port Authority (NY & NJ)	Lowest Elevation (ft)
TEB	Teterboro Airport	5.0
LGA	LGA Airport	6.8
HT	Holland Tunnel	7.6
PNE	Port Newark & Elizabeth	9.6
RHMT	Red Hook Marine Terminal	9.8
EWR	Newark Airport	10.3
LT	Lincoln Tunnel	10.6
JFK	JFK Airport	11.7
GB	Geothals Bridge	15.0

ID	MTA Bridges and Tunnels	Lowest Elevation (ft)
VNB	Verrazano-Narrows	8.0
BBT	Brooklyn-Battery Tunnel	8.6
TNB	Throgs Neck Bridge	10.0
QMT	Queens-Midtown Tunnel	10.6
BWB	Bronx-Whitestone Bridge	12.0
TB	Triborough Bridge	15.0

ID	NYC Transit Auth. Subways	Lowest Elevation (ft)
A, C	A & C Lines	7.0
M, N, R	M, N & R Lines	7.5
WTC	World Trade Center	8.1
1, 9	1 & 9 Lines	9.1
2, 3	2 & 3 Lines	9.1
4, 5, 6	4,5 & 6 Lines	9.9
E, F	E & F Lines	10.0
B, Q	B & Q Lines	12.7

ID	LIRR	Lowest Elevation (ft)
LBBr	Long Beach Branch	6.2
ERT	East River Tunnel	9.0
FRBr	Far Rockaway Branch	9.2
PWBr	Port Washington Branch	9.2
PST	Penn Station Tunnel	10.0

ID	Metro North	Lowest Elevation (ft)
HL	Hudson Line	6.5
NHL	New Haven Line	9.8
GCTe	Grand Central Terminal	11.0

ID	NY & CT Hwy	Lowest Elevation (ft)
FDR	FDR Drive	6.0
MP	Marine Parkway	8.0
WS	West Street	9.0

TABLE 4-2
Storm surge details for Lincoln and Holland Tunnels

Lincoln Tunnel

Critical Elevations (NGVD)	
New Jersey Vent Shaft	10.6 ft.
New York 3rd Tube Vent Shaft	10.6 ft.
New York River Vent Shaft	11.6 ft.
New York Land Vent Shaft	19.6 ft.
New York Top-of-Ramp	22.6 ft.
New Jersey Top-of-Ramp	27.6 ft.
Potential Hurricane Surge	
Cat. 1	7.5 ft.
Cat. 2	17.2 ft.
Cat. 3	20.5 ft.
Cat. 4	30.8 ft.

Time Hazards (Hours before closest approach of the eye)

	Surge Flooding	*Sustained Tropical Storm Winds*
Cat. 1	—	—
Cat. 2	0.5 hours	—
Cat. 3	1.0 hours	—
Cat. 4	1.2 hours	—

Holland Tunnel

Critical Elevations (NGVD	
New Jersey Land Vent Shaft	7.6 ft.
New Jersey Top-of-Ramp	7.6 ft.
New York River Vent Shaft	8.6 ft.
New York Land Vent Shaft	8.6 ft.
New York Top-of-Ramp	9.5 ft.
New Jersey River Vent Shaft	10.6 ft.
Potential Hurricane Surge	
Cat. 1	10.9 ft.
Cat. 2	17.7 ft.
Cat. 3	23.3 ft.
Cat. 4	28.2 ft.

Time Hazards (Hours before closest approach of the eye)

	Surge Flooding	*Sustained Tropical Storm Winds*
Cat. 1	0.2 hours	—
Cat. 2	1.0 hours	—
Cat. 3	1.6 hours	—
Cat. 4	1.9 hours	—

Source: MNYHTS (1995)

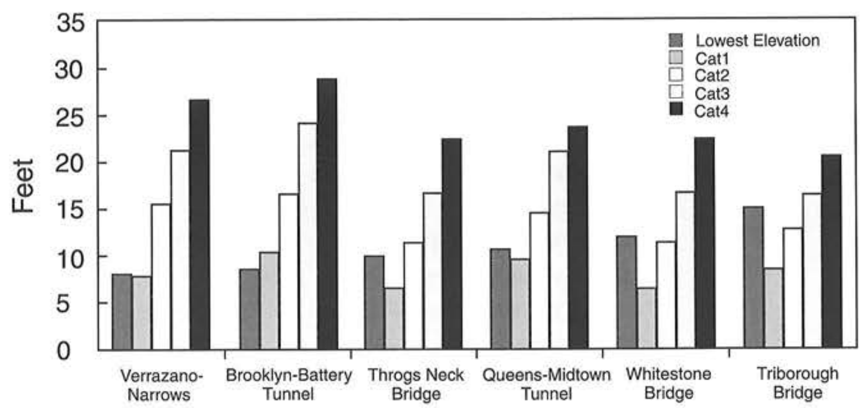

FIGURE 4-7A Comparison of lowest critical elevation (feet above NGDV) for selected MTA bridges and tunnel facilities with storm surge heights for Categories 1 through 4 storms. Bar for lowest facility elevation is on the left of each group. Source: NMYHTS, 1995

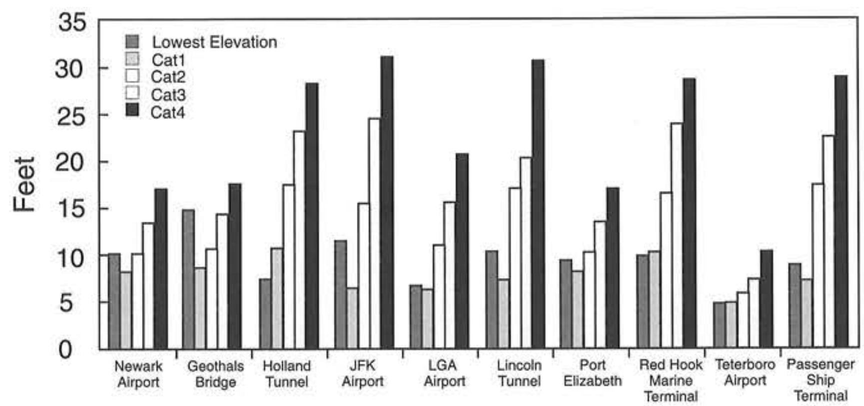

FIGURE 4-7B Same as Figure 4-7A, but for PANYNJ facilities.

undertook corrective action at the Hoboken, NJ station with the installation of floodgates at the top of the stairways leading to the station platforms. In addition, design of any new openings to the platform levels now accounts for current flood elevations.

Riverine Flooding—Floyd

Severe riverine flooding is often associated with hurricanes, nor'easters, and other less well-defined storm systems. Sometimes hurricanes take a track just landward of the coast of the mid-Atlantic states. In this case, the hurricane loses force and is downgraded to a "tropical storm" or to the lesser category of "tropical depression." Because of the decreased winds they usually do not cause severe coastal surges, but still may deliver considerable precipitation. There are many areas in the MEC region that are prone to such riverine flooding, especially in northern New Jersey along the Passaic and Raritan Rivers, and many other streams feeding into the New York Harbor estuary.

A recent example is the Tropical Storm Floyd (downgraded from hurricane) that passed through the MEC region on September 15–17, 1999. The total and local damages from Floyd are currently not yet fully evaluated. For the entire U.S. east coast, damages exceed $6 billion, most of them incurred along the coast south of the MEC region, especially in the Carolinas. Our preliminary estimate for the precipitation-related damage (i.e., riverine flood-related damage) combined with some wind damage in the MEC region is on the order of $1 billion, which is one-sixth of the total estimated damages. Most damage bypassed New York City and occurred in northern New Jersey and a few adjacent counties in New York and Connecticut, 30 to 100 miles west, north, and northeast of New York City.

(Web Sources: http://nj.usgs.gov/floyd.html, http://www.nhc.noaa.gov/1999.html, http://www.nhc.noaa.gov/1999floyd_text.html, http://www.ncdc.noaa.gov/ol/climate/extremes/1999/september/extremes0999.html, http://www.nysemo.state.ny.us/hurricane/floyd/index.html#meteor)

2. Projected Storm Flood Hazard

To account for the frequency of occurrence of both tropical (hurricanes) and extratropical storms (nor'easters) with flood potential for the MEC region we utilized empirically calibrated models of coastal and estuary storm surges. The U.S. Army Corps of Engineers (see Chapter 3 *Sea-Level Rise and Coasts*) has provided such models, combining tropical and extratropical storms for several coastal sites in the MEC region. We use the surge height projections based primarily on past Coney Island surge data as the main reference data set for this Assessment.

The 1999/2000 updates of earlier USACE storm surge statistics in the MEC region account for five different scenarios of sea-level rise (see Chapter 3 *Sea-Level Rise and Coasts*). The first of the scenarios extrapolates the linear trends of SLR observed in the past century (data ending with 1991) to the end of the new century (2000–2100). The other four scenarios use the SLR based on the four standard climate models (CCGG, Canadian Centre with forcing from greenhouse gases; CCGS, Canadian Centre with forcing from greenhouse gases and sulfate aerosols; HCGG, Hadley Centre with forcing from greenhouse gases and sulfate aerosols; and HCGS, Hadley Centre with forcing from greenhouse gases; respectively) recommended for the U.S. National Assessment. The USACE lists the storm surge heights under the assumption that the storm surge coincides with high tide, but additional surge heights due to intermittent wave action are ignored (i.e., "without wave setup").

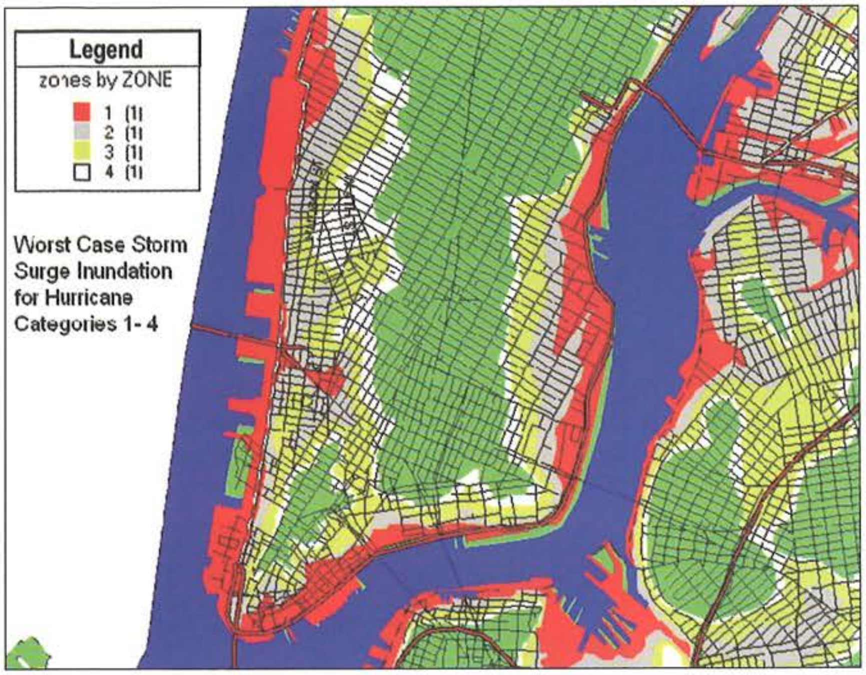

FIGURE 4-8 Portions of lower Manhattan and adjacent Brooklyn with areas flooded during worst-case storm tracks for category 1 (red), 2 (gray), 3 (yellow) and 4 (white). Only the green areas avoid flooding. Source: Daniel O'Brien, New York State Emergency Management Office

Figure 4-11A shows that the lowest critical elevation of the runway at the Newark Airport is positioned such that the runway should not be flooded at all by storms with five-year recurrence periods. But for 50-year recurrence-period floods, a storm occurring at the end of the 21st century will flood the runway, while such a storm at the beginning of the century will not do so. On the other hand, both 500-year floods will submerge the runway, whether they occur near 2000 or near the end of the century.

These graphs may begin to provide each agency with criteria for setting priorities to adopt adaptation measures, facility by facility. Among the Port Authority facilities, Teterboro Airport is at most at risk. The JFK airport runways and the approaches to the Goethals Bridge become exposed, if at all, only during the largest floods with recurrence periods of 500 years, and the Staten Island, NY approaches of the Goethals Bridge only towards the end of the century.

The sites examined by the Sea-Level and Coasts sector team include: Sandy Hook , NJ; the Battery at the southern tip of Manhattan, NY; Willets Point in Queens, NY, facing the East River; Port Jefferson, NY, on the north shore of Long Island, NY, facing Long Island Sound; and Montauk, NY, at the eastern tip of Long Island. From these points, one can extrapolate SLR change at other sites throughout the MEC region.

3. Sea-Level Rise and Transportation Facilities

To calculate the increased flooding potential of the various infrastructure systems with time, we first average the five sea-level rise scenarios. The averaged scenario is very close to the HCGG scenario. We then select the probabilistic sea-level rise curves for three recurrence periods of 5, 50 and 500 years. We sample them at two points in time: During the first and last decades of the century, the two points designated 2000 and 2090. We then plot a bar graph for each infrastructure facility with seven vertical bars (Figures 4-11A through 4-11C).

The first bar is the lowest critical elevation (from Table 4-1). The next six bars come in three groups of two bars each. The three pairs are the surge heights for the recurrence periods (from left to right) of 5, 50, and 500 years, respectively. And in each pair, the left bar applies to the decade beginning in Year 2000 (also referred to as "baseline"), while the right bar in the pair applies to the decade beginning in 2090. The difference within each pair indicates the surge height increase over the hundred years for each of the three flood recurrence periods.

4. Estimates of Probabilities of Storm-Related Losses

We now develop an approximate method for constraining the range of possible losses and their frequency of occurrence.

We proceed in the following way:

1. *Historic Storm Rate*. We estimate the approximate frequency of storm activity for the MEC region with guidance from an unrefined historical record. At least nine, but possibly more, hurricanes (presumably of Saffir-Simpson Category 1 or larger) have struck the MEC region in the last 200 years (Coch, 1995), implying on average, one SS≥1 storm about every 20 years. The 1821 hurricane (SS Category 1 or 2) followed a worst-case track, as did an unnamed hurricane in 1893. From this we can infer that worst-track hurricanes of SS≥1 occur in the MEC region roughly five times less frequently than average storms of the same SS category, or once every 100 years for a worst-track SS≥1.

The 1938 hurricane, probably an SS3 to 4, was not a worst-case path event since its eye passed east of New York City. The storm caused its severest damage on Long Island and New England (total of about $.3 billion in 1938 dollars [Munich Re, 1998], or $6 billion in Year 2000 dollars, adjusted for 5% annual inflation, but not adjusted for asset

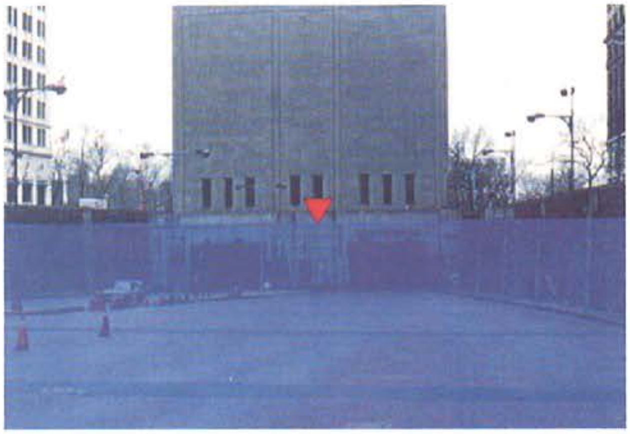

FIGURE 4-9A Potential Category 1 hurricane surge at Brooklyn-Battery Tunnel Manhattan entrance.

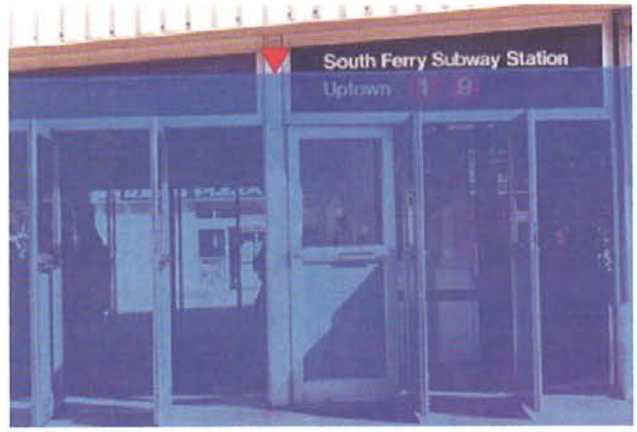

FIGURE 4-9B Potential Category 2 hurricane surge at South Ferry (Battery) subway station.

FIGURE 4-9C Potential Category 2 hurricane surge at Holland Tunnel Manhattan entrance.

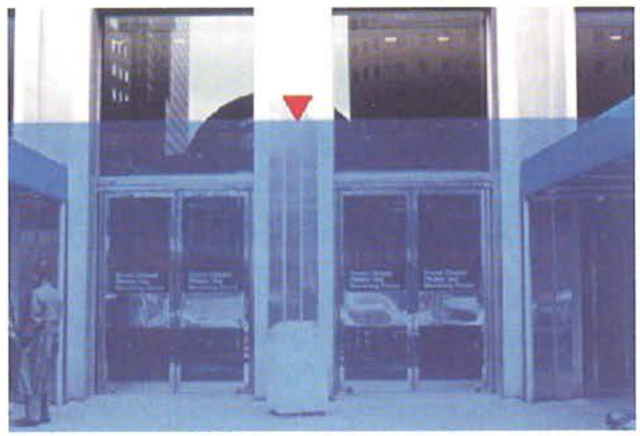

FIGURE 4-9D Potential Category 3 hurricane surge at World Trade Center, West Street.

Source: New York City Office of Emergency Management

growth). Allowing for an annual asset increase of 5%, the total loss under current conditions would amount to $124 billion in today's valuation. All these estimates are dependent on the assumed annual growth and inflation rates. In any case, it is clear that a repeat of the 1938 storm would have an impact that is much worse today because of the extensive development in its strike area. For more details on the hurricane history in the MEC area, and future risk potentials see N. Coch (1994).

2. *Consistency Check with Probabilistic Model Recurrence Periods*. According to MNYHTS (1995), a Category 1 worst-case track storm causes, under sea-level conditions prior to Year 2000, a flood crest of about 10 feet in Lower Manhattan. According to the probabilistic model provided by the USACE (Chapter 3 *Sea-Level Rise and Coasts*), which also accounted for nor'easters in addition to hurricanes, a 10-foot surge above NGVD corresponds to a 50-year event under Year 2000 sea-level conditions. If we assume roughly the same rate of hurricanes as for nor'easters, these three recurrence estimates seem to be consistent in terms of orders of magnitude for SS≥1 storms or their equivalent. They are: 20 years for an average track (not worst-case) SS≥1 hurricane, 100 years for a worst case SS≥1 10-foot surge hurricane, and 50 years for a probabilistic 10-foot surge from either hurricane or nor'easter based on data prior to the Year 2000.

Taking into account these three estimates and averaging them, a 50-year recurrence period for a 10-foot surge is the result for the beginning of the 21st century time frame, i.e. around the Year 2000. The equivalent storm category would be SS1, although it may be produced by a nor'easter of equivalent strength to which the Saffir-Simpson scale traditionally does not apply.

3. *Estimates of the Magnitude of Losses*. We estimate total losses associated with various categories of storms with guidance from historic sources. We use Floyd, 1999, losses in the MEC as the lower threshold event just below Category 1; a scaled version of the Category 3 Hurricane Andrew of 1992 hitting Florida; and the Category 3 to 4 hurricane of 1938, which missed the core of the MEC region. Scaling of the losses can be done by keeping the

FIGURE 4-10A Lower East Side, Manhattan. November 24, 1950.

FIGURE 4-10B La Guardia Airport, Queens. November 25, 1950.

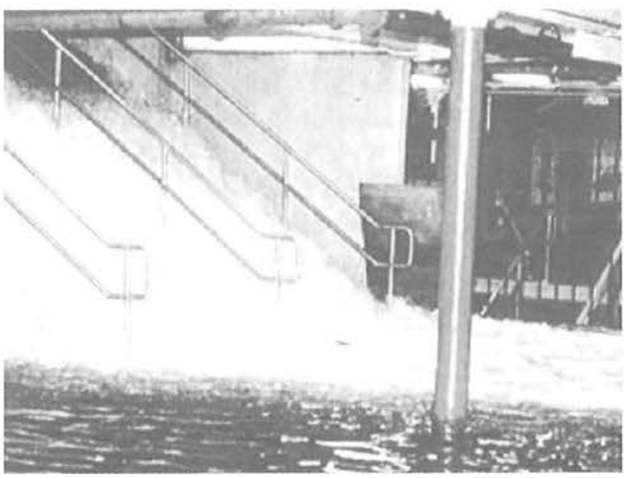

FIGURE 4-10C Hoboken PATH Station, New Jersey. 1992 Nor'easter.

FIGURE 4-10D FDR Drive Northbound at 80th Street, East River, Manhattan. 1992 Nor'easter.

Source: New York City Office of Emergency Management

ratio of losses to total assets the same for various storm categories in the US, and then applying them to the MEC region. Absolute loss numbers from past storms in the MEC region are prorated for inflation and for the growth of assets since the historic storms occurred.

If one were interested in only the contribution of the transportation infrastructure to the total losses, one could then apportion a fraction of these losses to the transportation sector, although the overall economic losses and their impact on the region are obviously more consequential. We do not attempt such an apportioning but rather use the estimated total losses directly to avoid the additional uncertainties associated with the apportioning of losses to infrastructure damage and failures.

Hurricane Floyd. Hurricane Floyd of September 1999, downgraded to a tropical storm and then a depression by the time it reached the MEC region, caused virtually no coastal surge. But due to excessive precipitation inland, it caused severe riverine flooding. This in turn caused severe losses that amounted along the entire Atlantic East Coast to about $6 billion, most of them apparently uninsured losses. We assume that the losses from Floyd in the MEC region of New Jersey, New York, and Connecticut were on the order of one-sixth or about $1 billion. We extrapolate from this loss that a direct hit of a Category 1 hurricane or equivalent nor'easter would cause in the MEC region higher losses than those caused by Floyd and for this reason we assign losses in the order of $5 billion.

Hurricane Andrew. Hurricane Andrew, a Category 3 hurricane, hit the Florida coast in 1992 and caused total losses of nearly $30 billion (in 1992 dollars, corresponding to nearly $50 billion in Year 2000 dollars) of which about $23 billion were reportedly property-insured losses (http://www.Colorado.EDU/hazards/dr/dr317.html#13). We estimate that the combination of larger assets and potentially larger fragilities in the MEC region may provide at least a 1.5 times larger loss potential for the same SS category 3 as Andrew represented, for a peripheral storm track, and perhaps a factor of 3 for a worst-case track.

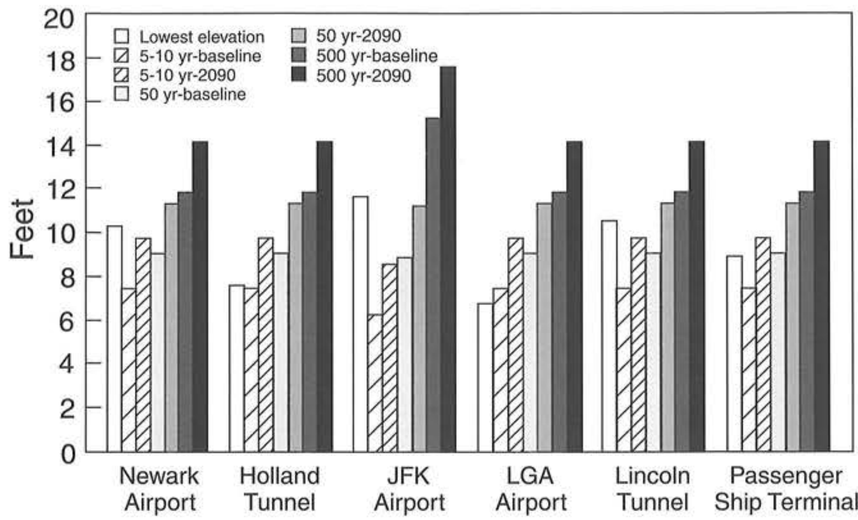

FIGURE 4-11A Comparison of the lowest critical facility elevation with surge heights for three recurrence periods: 5, 50, and 500 years (from left to right) and at the beginning (baseline) and end (2090) of the 21st century. This graph is for the PANYNJ facilities.

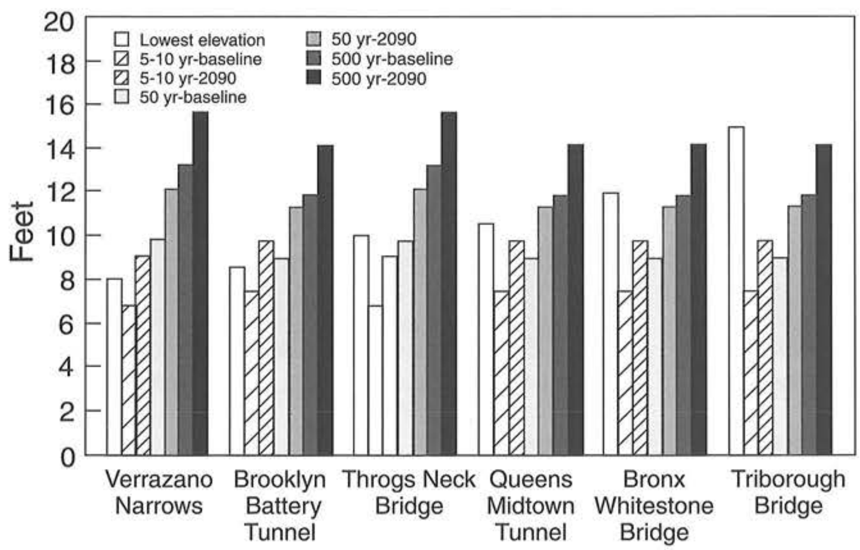

FIGURE 4-11B Comparison of the lowest critical facility elevation with surge heights for three recurrence periods: 5, 50, and 500 years (left to right), for the MTA facilities (bridges and tunnels).

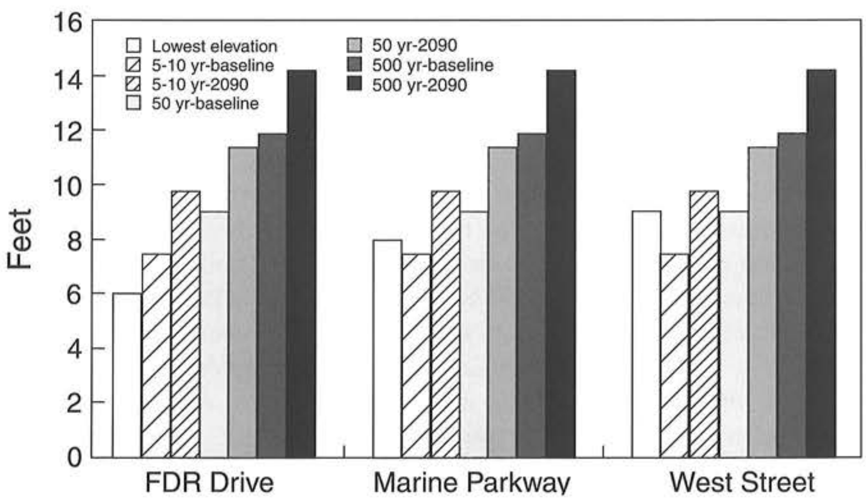

FIGURE 4-11C Comparison of the lowest critical facility elevation with surge heights for three recurrence periods: 5, 50, and 500 years (from left to right), for NYC-DOT highways.

With these assumptions, we infer that total losses from an equivalent Category 3 storm hitting the MEC region may amount to from $50 billion to $100 billion. The upper-bound estimate is corroborated by Dlugolecki (1996). A large portion of the damage was wind- rather than surge-related. In our later tabulation we use $50 billion.

1938 Hurricane. As shown above, the 1938 Category 3 to 4 losses of $300 million are adjusted for inflation to Year 2000 losses to become $6 billion. Further adjustment for an annual 5% growth rate of built assets over 62 years leads to a factor of about 20.6 in available assets, implying expected losses of about $124 billion at current values. While this loss includes large portions of New England outside the MEC region, a $100 billion loss for a storm track more central to the MEC region is a reasonable order of magnitude because of the higher asset density in the smaller MEC region, compared to the 1938 strike area. We use a $100 billion loss in the MEC for the SS3 to 4 storm category as the tabulated estimate.

Category 4 Storm Estimates. We assume a Category 4 storm may cause more than twice the losses of a SS3 to 4., i.e., perhaps $250 billion or more in the MEC region. An unpublished study prepared by FEMA assumed a hypothetical scenario of a worst-track Category 4 hurricane dubbed "Rudy." The estimated total losses in the States of New York and New Jersey were in excess of $500 billion. For the MEC Assessment we use only half of this FEMA estimate.

Losses Relative to Total Assets and Gross Regional Product. The $50 billion assumed total loss for a category SS3 storm represents about a 2.5% loss of all exposed MEC assets (≈$2 trillion) and about 5% of the annual GRP (nearly $1 trillion). The corresponding loss for the low-probability category SS4 scenario (estimated to be $250 billion) yields corresponding percentages on the order of 12% of assets, and 25% of annual GRP, respectively. The probabilities of these large loss events are independently estimated below from other information. For that purpose we use low-loss estimates from Category SS1 storms together with the slope of a hurricane loss curve for the entire US to extrapolate to the frequency of occurrence of large storm losses.

4. *Using the Slope of US Hurricane Loss Curve*. We use the known loss statistics for storms (and other disasters in the United States) to check how the magnitude of losses scales with cumulative frequency of occurrence. The slope of a nationwide loss curve is then applied to the MEC region. A study that attempts to establish this slope for different types of disasters (floods, hurricanes and earthquakes) is that by Barton and Nishenko (http://coastal.er.usgs.gov/hurricane_forecast/ and personal communication, 1999). The data only contain hurricane losses up to 1989 and thus exclude the largest modern loss event, i.e., Hurricane Andrew of 1992. According to the study, the logarithm of the annual probability vs. the logarithm of losses is –1. We apply this slope of –1 in conjunction with the recurrence period of 50 years for an SS1 storm causing $5 billion in the MEC region, and extrapolate to larger losses at lower annual probabilities (and longer recurrence periods). Using the so-obtained direct relation between loss and frequency, we check these results against a similar relation that emerges from the estimates made using the historic data directly. The orders of magnitude from these two approaches are fairly consistent.

All losses discussed here are total losses related to a given event. They include insured and uninsured losses. They include losses from coastal surge, riverine flooding and wind damage. They apply to the entire built environment, not just infrastructure or transportation infrastructure. The results obtained from these procedures are summarized in rounded values in Table 4-3. Note that Category 5 storms are considered unlikely for this northern latitude.

Annualized Losses vs. Probable Maximum Loss. Table 4-3 also shows nominal *Annualized Losses*. They are obtained by dividing the *Estimated Total Losses* by the corresponding *Average Recurrence Periods*. Performing this operation, one obtains nearly constant annualized losses of $100–300 million per year for most storm categories. Summing up the binned annualized losses for all storm categories yields a total annualized loss in the order of about $0.5–1.5 billion per year (say, $1 billion per year on average).

Given the annual gross regional product of almost $1 trillion per year for the entire MEC region, these total annualized losses constitute only about 0.1% of the gross regional product. The losses expressed as percentage of assets are about half the GRP-based percentages because the MEC assets (about $2 trillion) are roughly twice the GRP dollar value. These annualized percentage losses of

TABLE 4-3
Estimates for recurrence periods (for the years 2000 and 2100) and for expected total losses from storms in the MEC Region in year-2000 dollars and for year-2000 asset inventories

Equivalent Saffir-Simpson Category[a]	Surge Heights[b] (ft)	Average Recurrence Period (Years) in Yr. 2000	2100	Estimated Total Losses (Billion$)	Annualized Losses[c] (Million$)
(Extratropical Storm)	8	20	6	$1B	$ 50–170M
1	10	50	15	$ 5B	$100–330M
2	11	100	30	$10B	$100–300M
3	13	500	150	$50B	$100–300M
3-4	14	1000	300	$100B	$100–300M
4	16	2500	800	>$250B	$100–300M
All Categories	—	—	—	—	approx. $0.5–1.5B

[a] Use only the year 2000 recurrence period for this column. The recurrence period for 2100 does not apply to this column since the frequency of storms is kept the same, and only the surge frequency shortens due to SLR. Both recurrence periods, for 2000 and 2100, do apply however to the column for surge height and the two loss columns. See text below for details on relations between climate and storm frequency and intensity.

[b] Surge height in feet above the National Geodetic Vertical Datum (NGVD) of 1929.

[c] The lower bound value applies to the year 2000, the upper bound to the year 2100.

0.1% of GRP, or 0.05% of assets, are sufficiently low to be of little consequence for the large economy of the region—provided those losses were distributed as constant annualized losses. However, this is not the case.

Potential Climate Effects on Storm Frequency and Intensity. Although the climate change scenario does not allow for changes in the frequency of storm occurrence or intensity, we obtain a change in average recurrence periods of flooding stages or surge elevations (Table 4-3). This increase results solely from sea-level rise. The intensity of storms could increase since both the atmosphere and the oceans are warming, and hence more heat may be available to drive storms to more northern latitudes. There are indications that shorter-term phenomena, such as interannual or seasonal ENSO (El Niño-Southern Oscillation) processes do correlate with North Atlantic hurricane activity and losses (Pielke and Landsea, 1999). These authors find that La Niña years correlate well with higher U.S. losses from Atlantic hurricanes. The positive correlation applies to both the frequency of storms in La Niña years and the average loss per storm. Both frequency and intensity do rise compared to El Niño years. If this relation holds, it will be important to research relationships between global warming and La Niña frequency.

PML. The probable maximum loss (PML) is the largest loss considered possible for a region to experience. Because of the high assets, the PML can be very large for the MEC region, in the range of $100 billion to $250 billion (Table 4-3). This implies that the PML can measure 5% to 12.5% of the entire asset value of the MEC region, and 10% to 25% of the annual GRP. Such huge losses would be devastating to the region's assets and economy. There would also be severe fiscal and economic ripple effects throughout the national and global financial markets and the economy. For comparison, it has been estimated that the magnitude 6.9 1995 Kobe, Japan, earthquake caused losses in excess of $100 billion, and that a recurrence today of the Great 1923 Tokyo earthquake (magnitude 8 or larger) may cost under current valuations as much as $1 trillion.

Loss of Lives. We have not addressed the issue of loss of lives. From recent experience in the United States, we expect that the loss of lives—while not trivial—should be relatively small compared to the material and financial losses. This is so because of the technical capability to give ample forewarning of an approaching storm, and because of a fairly well developed emergency management system. In contrast, high ratios of lives lost to economic losses must be expected for lesser-developed countries. There, the monetary losses are often paled by the lives lost. Bangladesh is the prime example where tens, even hundreds of thousands of lives have been lost in a single tropical cyclone, related coastal surges, and countrywide floods.

5. Integration and Adaptation Strategies

The estimated future losses for the MEC region from coastal flooding are modest on an annualized basis, but could be large for single extreme events, albeit with low probabilities. We note that actual losses will increase without climate change and sea-level rise, merely from the future growth of assets that were not addressed here. We have shown that sea level rise will *accelerate* losses over the next century (independent of future asset growth) by factors averaging around 3, but which may range from 2 to 10 depending on which climate and sea-level rise scenarios apply. Global warming contributes about one-half of the total rate of SLR in the MEC region, and about one-half is of tectonic origin. The increasing potential for storm-related losses due to population and asset growth is already reason enough to address those risks and to assess coping and adaptation strategies. Climate change adds urgency to the existing issues, and will do so increasingly with time.

What coping and adaptation strategies are available? Clearly, the infrastructure issues are tied to broader social and urban issues, and must be seen in connection with the broader climate implications discussed in the other MEC assessment sectors. For instance, coastal wetlands in the MEC region often provide the natural buffer zones for coastal storm surges, but have been encroached on by transportation systems and other urban development for many decades. For information on the wetlands in Jamaica Bay, Queens, NY see Chapter 5 *Wetlands*.

The infrastructure in the Metro East Coast, as in many other large U.S. cities with aging inventories, has suffered for many decades from deferred maintenance. This has created a demand for capital spending to restore and expand the infrastructure systems in the MEC region and elsewhere. These conditions provide cost-effective opportunities to mitigate the climate-induced risks by including storm-surge and other natural-hazard mitigation costs in regular capital spending programs. The questions of how to cope with, and adapt to, climate change-induced hazards are strongly tied to issues of public policy and prudent institutional decision-making about infrastructure. These issues are addressed in Chapter 9 *Institutional Decision-Making*. Chapter 9 is particularly relevant to infrastructure issues because of the complicated public/private relations between, responsibilities for, and governance and ownership of most of the MEC's infrastructure systems.

Efforts to cope with climate change impact on the region's infrastructure systems will require an integrated regional approach. This integrated approach should be based on sound technical understanding that in turn may require a coordinated series of individual studies to address risk exposure and possible mitigation options, across agencies. These agency-specific assessments could then be integrated across the range of governments and stakeholders involved to develop and implement a regional response and action plan.

Options for reducing the increased coastal storm surge hazards and risks to the MEC's infrastructure (and to other built assets) fall into two categories: protective engineered solutions and land-use changes. The challenge will be to accelerate mitigation before the losses start to drastically increase in frequency and magnitude.

1. *Short-term "Protective" Measures Using Local Engineering*. Individually engineered solutions can be achieved by raising individual structures and systems or critical system components to higher elevations. This may be done without moving them laterally to higher ground. Alternate solutions my include surrounding the exposed structures with local sea-walls and dykes, as for instance has been done by the PANYNJ for the La Guardia Airport.

The problem with such engineered solutions is that after completion, they may give a potentially false sense of security and encourage new asset concentrations behind the protective defenses. They often postpone rather than eliminate renewed flooding. When flooding recurs during the most extreme events, they tend to be associated with even larger losses when the engineered protections are overwhelmed. This phenomenon, together with some earlier flood insurance programs, has led to the newly coined term "Disasters by Design" (Mileti, 1999).

2. *Regional Mega-Engineering*. The model for the mega-engineering approach is provided by the Netherlands where a large portion of the land, population and infrastructure is "protected" from the North Sea by major regional dam, dyke and levee systems, rather than by individually built local systems. In the United States. the Mississippi River dyke and levee system built largely by the U.S. Army Corps of Engineers protecting New Orleans and many other cities (at least for the time being). If applied to the MEC region, mega-engineering would mean the gating of the entrances to the New York harbor estuary, while providing passage of ship traffic and outflow of freshwater and sediments from the Hudson, Passaic, and Raritan river systems. Such solutions have occasionally been suggested, but have been rejected as far-fetched, utopian, and in the long run environmentally unsustainable. The silting of the New York Harbor is one such cause for concern. Also such a "solution" could lead to the ultimate disaster by design, if the protective system were to fail by an extraordinarily extreme event.

3. *Long-Term Remedy—Changed Land Use*. Perhaps the most effective solution is a fundamental change in land use. This would entail moving, when and wherever possible, the infrastructures and other assets to higher ground. In some instances it may be possible to put the infrastructure systems underground and have only their entrances located at sufficiently safe high ground. The freed water front spaces could then be turned into parks and recreational areas with low asset density where flooding losses can be kept minimal. Obviously such measures require large fiscal resources, long-term planning, political will and foresight.

Mitigation measures, especially those associated with changes in land use and rezoning, may be more readily implemented in small incremental steps rather than in single large-scale political actions. Post-disaster conditions often provide windows of opportunity. But typically they do so only if sound plans are ready and widely known before the disaster strikes. Therefore one should not wait to begin planning until after the disaster strikes. The time for assessment and planning is now. Planning must also ensure that the solutions and actions for the future link with actions for solving today's problems. Once the planning is in place, administrative implementation could be incremental and hence affordable, if correctly prioritized. This would require concentrating first on the most exposed and most essential assets, and then steadily addressing less exposed and less important or less valuable assets and systems.

Largely lacking at this time are the technical and scientific damage assessments that provide sufficient detail, spatial resolution. The technical findings must be widely accessible to ensure an equitable discourse building towards a public consensus.

Data Needs

To reduce uncertainties, the following data and analysis elements are needed:

- A catalog of historic storm reports, with emphasis on information about wind speeds, spatial distribution of coastal flood elevations, wave action, and damages and losses near-shore and inland.
- A high-resolution digital elevation model (cm to dm) of the near-shore topography (DEM).
- Improved climate scenarios that not only account for sea level rise, but also account for variations of storm frequency and intensity with changing climate;
- Accurate inventories of the major infrastructure systems and components; their exact location (in three dimensions) in geographic information system (GIS) formats;
- Infrastructure component fragility and network fragility with respect to storm surge, flooding and wind hazards;
- Infrastructure asset (dollar) values and operational cost and revenue streams—if applicable;
- A GIS-based computer algorithm for computing the losses both probabilistically and for individual scenario events.

Stakeholder Input

While the early historic record of storm activity and effects may be best searched in old newspaper reports and archives, the modern records of the last, say, 50 years are most likely held by a large group of stakeholders that own and operate infrastructures and keep internal records for various purposes. They are the source for information on system properties, system performance, and asset and operational cost and revenue valuation pertinent to climate change risk analyses. A mode for sharing at least some of this information for the common concern of future storm damage needs to be found that respects the often-sensitive nature of the information. In the long run, most stakeholders benefit greatly from taking an active part in broadly based regional assessments. It is especially important that the diversity of infrastructure systems be covered since the operational state or failure of one system often affects another. If this connectivity and interdependence is to be accounted for in regional impact analyses, it will require the input from a wide roster of stakeholders in the region, and may require participation of more than one professional discipline within each stakeholder organization.

CONCLUSIONS AND RECOMMENDATIONS

The Metropolitan East Coast region with New York City at its center has nearly 20 million people, a $1 trillion economy, and $2 trillion worth of built assets, nearly half of which are invested in complex infrastructure.

Many elements of the transportation and other essential infrastructure systems in the MEC region, and even some of its regular building stock, are located at elevations from 6 to 20 feet above current sea level. This is well within the range of expected coastal storm surge elevations of 8 to more than 20 feet for tropical and extratropical storms. Depending on which climate scenarios apply, the sea-level rise over the next 100 years will accelerate and amount to at most 3 feet by the year 2100. This seemingly modest increase in sea level has the effect to raise the frequency of coastal surges and related flooding by factors of 2 to 10, with an average of about 3.

The rate of incurring losses from these coastal floods will increase accordingly. Expected annualized losses from coastal storms, on the order of about $1 billion per year, would be small enough to be absorbed by the $1 trillion economy of the region. However, actual losses do not occur in regular annualized doses. Rather, they occur during infrequent extreme events that can cause losses of hundreds of billions of dollars for the largest events, albeit with low probability. Such large losses would deprive the economy of tens of percent of the gross regional product, a forfeiture that will be hard to bear. Insurers, policyholders and non-insured will be stretched to the brink. If the frequency of these and lesser events increases by factors of 2 to 10 due to accelerating sea-level rise, mitigating actions will become urgent. The region will be in a race between increasing losses and rising costs of mitigation and remediation.

The region is already in the process rebuilding its basic infrastructure at costs approaching about $100 billion per decade. Therefore, the most cost-effective way to protect the infrastructure against future coastal storm surge losses would be to build into the capital projects protection against the increased flood potentials. A coherent policy is needed that should be based on technical input. Uncertainties exist and will persist. However, these uncertainties must not be used to justify inaction since it is inevitable that the losses will accelerate just from the sheer growth of built and newly exposed assets alone.

The most effective mitigation is to avoid placing new or refurbished assets at low elevations. This requires an innovative land use plan, zoning enforcement, and would best be combined with new engineering codes that place all critical components at sufficiently high elevations. This objective could be achieved by a Voluntary National Model or Reference Code. The usual local privileges to adopt the recommended standard into local law should be preserved. The National Flood Insurance Program's (NFIP) Q3 mapping effort administered by FEMA may have a new and innovative role to play in this respect. We recommend that Congress put the necessary resources in place for NFIP to produce improved accurate digital maps on an accelerated pace.

The problem of sea-level rise that New York City and the MEC region face will be shared by coastal cities and populations all around the U.S. and around the globe, in rich and poor countries alike. New York City and the surrounding MEC region are in the position to provide financial and intellectual resources to set a world-class example for how to prepare for the climate change issue.

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CHAPTER 5
WETLANDS

This chapter examines the impact of future wetland loss from sea-level rise, storm surges, and other forces over the next 20 to 100 years, with an emphasis on a case study in Jamaica Bay, New York City. Change over the previous 100 years is documented through use of historic maps, aerial photography and field observations. Projections of future change are extrapolated from current trends and several global climate models (GCMs). Intertidal wetland plant communities are discussed in relation to their zonation, which is strongly correlated with extent of tidal flooding. Flooding is projected to accelerate with global warming (IPCC, 1998; Titus, 1988 and 1998; and Allen and Pye, 1992).

Coastal salt marshes of the northeastern United States (Maine to New Jersey) formed within the last 4,000 to 7,000 years, following deglaciation of the last Ice Age initiated about 15,000 years ago, as the rise in sea level slowed (Teal and Teal, 1969; Redfield, 1972; Thomas and Varekamp, 1991). Included in these shoreline alterations was the development of a string of highly productive coastal wetland marshes extending from the easternmost tip of Long Island to what is now New York City, and north along the Hudson River (Tiner, 1987). More recently however, alterations in marsh geomorphology appear to have reversed the marsh-building process through land loss from marsh erosion and inundation.

Tidal wetland loss through shoreline erosion and related water-induced processes is well documented in Louisiana, Chesapeake Bay, Southern New Jersey and Cape Cod (Dean et al., 1987; Titus, 1988; Downs et al., 1994; Wray et al., 1995). However the phenomenon has not yet been reported in the Metropolitan East Coast (MEC) Region where losses cannot be easily compensated for through expansion of the salt marsh onto adjacent upland or freshwater zones. Intertidal marshes associated with Jamaica Bay in New York City offer an opportunity to study a well-mapped coastal area with an available historic record from aerial photographs, in part because of its location within the highly urbanized MEC Region (Figure 5-1).

Most research of sea-level rise (SLR) in salt marshes is based on long-term age-depth profiles in accreted layers of peat. Studies have shown that long-term surface deposition rates are correlated with historical changes in sea level (Orson et al., 1998; Bricker-Urso et al., 1989; Redfield, 1972). Many marsh-dating techniques have a resolution of several years (i.e., feldspar markers) and these may be useful in documenting continued marsh loss in Jamaica Bay. Radioisotope analysis can establish vertical accretion in the marsh for periods of more than thirty years (^{210}Pb and ^{137}Cs) (Orson et al., 1998).

This study seeks to compare the extent of marsh in Jamaica Bay before and after protective regulatory mechanisms were promulgated, and to project future impacts of sea-level rise. Since past changes occurred rapidly within the last 100-year time period, including major dredge and fill operations for navigation and upland construction, emphasis for this analysis relies on historic charts, maps and aerial photography. In addition, climate change scenarios based on extrapolation of historic trends and continued increase of simulated anthropogenic emissions of CO_2 and other greenhouse gases into the atmosphere are used to project future land loss in local marshes. The results are analyzed in the context of current federal and state wetland regulatory policies in order to consider preparedness for sea-level rise and other climate change impacts.

Study Area

This report concentrates on the saltwater marshes of Jamaica Bay, one of the largest coastal ecosystems in New York State (Hart and Milliken, 1992). Jamaica Bay encompasses the Jamaica Bay Wildlife Refuge (JBWR), protected

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FIGURE 5-1 View eastward of low marsh *Spartina alterniflora* with Jesse Thomas, Columbia University Research Assistant, at the northern tip of Broad Channel Island, Gateway National Recreation Area, Queens, NY.

since 1948 as a sanctuary by New York City Department of Parks and Recreation, and since 1972, by legislation as part of the Jamaica Bay Unit of Gateway National Recreation Area (GNRA) administered by the National Park Service (Tanacredi and Badger, 1995). Located near John F. Kennedy International Airport, the geographical coordinates of Jamaica Bay are 41° N, 74°W (Figure 5-2).

While other units of GNRA are found in Staten Island and New Jersey, the Jamaica Bay Unit includes the uplands, wetlands and waters south of the Belt Parkway in Brooklyn and Queens. While most of the island marshes are part of the Jamaica Bay Wildlife Refuge within the GNRA, some shoreline marshes are located outside the refuge boundaries and some are located outside the GNRA boundaries.

Jamaica Bay is an estuary with diverse habitats including open water (littoral zone), coastal shoals, bars, and mudflats, intertidal zone low and high marshes and upland areas. (For description of these wetland types see http://www.dec.state.ny.us/website/dfwmr/marine/twcat.htm).

JBWR is internationally recognized as an Important Bird Area (Wells, 1998). With the World Trade Center Towers as a backdrop, birdwatchers regularly observe the black-crowned night-heron, green heron, yellow-crowned night-heron, snowy egret and glossy ibis rookeries (Figure 5-3). More than 300 species of birds have been sited on the islands of JBWR. Laughing gull, great black-backed gull, American oystercatcher, and clapper rail colonies congregate to build nests on the island marshes. The intertidal mudflats are principal feeding grounds for migratory shorebirds such as black skimmers, plovers, and knots (Hart and Milliken, 1992). The Bay is prime wintering grounds for Brant (2000 in a peak year), mallards, American black duck, canvasback duck (more than 2,500 in a peak year) and other waterfowl. Reptiles, amphibians, and small mammals can be found at JBWR; the diamond-backed terrapin feeds on the marshes and nests on its beaches and sandy uplands.

Much of the original tidal wetlands of Jamaica Bay have disappeared due to human activities for infrastructure development. According to Englebright (1975), Jamaica Bay in 1900 encompassed 24,000 acres (9,717 hectares) of waters and marsh islands, as well as an extensive network of shoreline marshes extending beyond today's Belt Parkway. Marshes covered an estimated 16,170 acres (6,549 hectares). Waters of the Bay covered 7,830 acres (3,170 hectares), much of it shallow channels averaging 3 feet (1 meter) in depth. By 1970, total acreage with remaining shoreline marshes covered 13,000 acres (5,263 hectares) of which 4,000 acres (1,619 hectares) were marshland. Waters covered approximately 9,000 acres (3,642 hectares), much of it dredged for filling (e.g., Grassy Bay) or for navigation maintained to depths greater than 30 feet (10 meters).

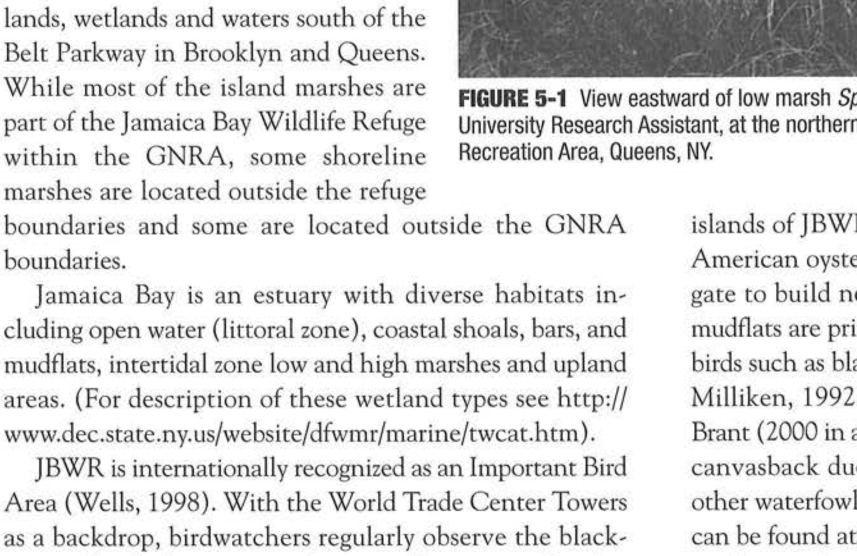

FIGURE 5-2 The Jamaica Bay study area. Source: Engelbright, 1975.

FIGURE 5-3 Snowy egret taking flight at JBWR salt marshes with the World Trade Center towers in the background. Photo by Don Riepe (GNRA, National Park Service).

Wetland Value and Function

Wetlands and their adjacent areas serve a number of economic and environmental functions. They form a protective barrier for coastal urbanized areas, buffering buildings and transportation networks from wave impacts during storm surges (Cowardin et al., 1979; Tiner, 1984; Mitsch and Gosselink, 1993; and Bertness, 1999). Tidal wetlands can serve to improve degraded waters by recycling nutrients, processing chemical and organic wastes and capturing sediment loads; the cleansed water helps maintain aquatic organisms. The intertidal zone serves as breeding and over-wintering grounds for migratory waterfowl and other birds. Thick layers of carbon-rich peat play a role in the global carbon cycle by binding poorly decomposed plant material into the substrate (Mitsch and Wu, 1995; Patterson, 1999). Each of these wetland functions diminishes when loss of marsh acreage occurs.

While their benefits to terrestrial ecosystems are now better understood, their contributions to marine ecosystems remain a subject of research. Since *Spartina alterniflora* salt marshes are highly productive, the detritus has long been recognized as important for marine ecosystems (Teal, 1962; Odum and de la Cruz, 1967). Detritus is a protein-rich mixture of bacteria, epiphytic algae, free-flowing eggs and larvae, and digested *Spartina* particles (Tanacredi and Badger, 1995). The detritus from salt marsh vegetation contributes to the base of the food chain of estuarine and marine environments, although the extent of their role as nutrient supply for nekton assemblages has not been wholly determined (Kneib, 1997). In the aquatic ecosystem, stable isotope analysis has also revealed that in many cases phytoplankton primary production can be equal to, or greater than, *Spartina alterniflora* production (Haines, 1977, Peterson and Howarth, 1987). Accounting for the *S. alterniflora* in marine ecosystems has been complicated by the difficulty in determining the forms in which it enters marine ecosystems. Kneib (1997) has suggested that trophic relays may carry the organic plant material seaward. In this system, small juvenile fish consume *S. alterniflora* near the intertidal zone and these are then consumed by larger fish further out to sea.

Different wetland types vary in function, contour, biota, tidal action, water quality, and in their contribution to the marine and terrestrial food webs. The high marsh areas of New York City tend to be confined to narrow strips in the landscape because often all but the most waterward edges have been filled for urban development. Along shoreline areas the high marsh and accessible low marsh were filled for development. However, as exemplified by Jamaica Bay, island marshes tended to be left free of development activity. Remaining wetlands are predominantly intertidal low marsh areas, coastal shoals, bars and flats, and the littoral zone. The contribution of these wetland types to the marine ecosystem is highly variable. Under a rising sea level, the more aquatic wetland types are likely to gain in extent as the intertidal zone becomes submerged. Concerns regarding continued loss of intertidal marshes are in part due to the relatively small acreage remaining, their vulnerability to filling activity, and their relatively high wetland value (they are still considered to be among the most productive of all tidal wetlands areas ranging from 700–2000gm m^{-2}). The wetlands studied in the Metro East Coast Assessment encompass mainly the intertidal, or low marsh zone.

Salt Marsh Ecology

The dominant plant species of the low marsh intertidal zone is the salt marsh cordgrass, *Spartina alterniflora* (Figure 5-4). *S. alterniflora* provides food and nest material for birds, shelter for diamond-backed terrapins and other animals, and physical structure for peat accretion to the marsh. *S. alterniflora* may be useful as a prime indicator of habitat vulnerability (e.g., erosion damage) and of adaptation (e.g., inland migration of *S. alterniflora*) during periods of global warming-induced sea-level rise because of its unique characteristics and responsiveness.

Coastal plants form distinct zones in response to a combination of physical and biological factors. *Spartina alterniflora* is replaced by the high marsh species *Spartina patens* (salt hay) at mean high water (MHW) (Bertness, 1991a).

Flooding becomes irregular in the high marsh portion of the intertidal zone. While *S. patens* is rarely found in the low marsh because oxygen flow to its rhizomes becomes limited by frequent inundation, *S. alterniflora* is restricted from the high marsh by *S. patens* competition. *Salicornia virginica* (glasswort) can also be present in the low marsh (Bertness and Ellison, 1987). Floristically the high marsh is much more diverse than the low marsh, although all are halophytes—plants adapted to saline environments. The dryer high marsh zone contains species such as *Juncus gerardii* and *Distichlis spicata* (Bertness, 1991a). In the highest regions of marsh, *Iva frutescens* (high tide bush) and *Phragmites australis* (common reed) are found. In lower regions of the marsh, physical and chemical forces dictate the species composition. Higher up in the marsh, interspecific competition determines the plant community.

Frequency of tidal flooding is the dominant force in determining species location (Bertness, 1991b; Cowardin et al., 1979). The correlation between inundation time and zonation is strong enough that changes in salt-marsh plant community zonation may themselves be useful as indicators of sea-level rise. Responses of wetland plant communities to sea-level rise include shifts from high marsh to low marsh, shifts from low marsh to coastal shoals, bars, and mudflats, and migration of marshes inland. On an unobstructed coastal plain, upland habitat will be converted to salt marsh.

Warren and Niering (1993) described the transformation of marsh zones in a Connecticut salt marsh. In 1987 and 1988, they resurveyed an area of which the vegetation had been studied more than 30 years earlier by Miller and Egler (1950) and compared the species. At the site, sea levels had risen by 2.5 mm yr^{-1}, approximately 1.5 mm yr^{-1} faster than in the previous thousand years. High marsh plant communities were replaced by low marsh communities. The high marsh community of *Juncus gerardii* had been converted to a lower elevation high-marsh community consisting of *Spartina patens* and forbs such as *Triglochin maritima*. *S. patens*-dominated marshes had been converted to short *S. alterniflora*, *Distichlis spicata*, and forbs. Warren and Niering's study demonstrates that modest rates of sea-level rise, of even less than 3 mm/yr, can have a detectable and ecologically significant effect on salt marshes.

In Long Island's Shinnecock Bay, island marshes have either become reduced in size or have disappeared altogether while shoreline marshes have expanded landward, indicating a discernible inland migration of the marshes (Fallon and Mushacke, 1996). Thirteen intertidal marsh islands covered 30 acres in 1974. Of these, seven marshes covering 15 acres remained as of 1994; the other six became submerged. In former nontidal areas including adjacent acreage and dredged spoils, wetland extent gained 161 acres of high marsh formation. Projected increases in sea-level rise is likely to further inundate marshes vulnerable under current accretion rates, and may cause adjacent uplands to be converted to wetlands. The Connecticut and Long Island examples may serve as models for how wetland communities will respond to future sea-level rise.

Role of Climate

Global climate change may alter hydrologic parameters upon which wetlands, and the species that inhabit them, depend (IPCC, 1996). Future projections, extrapolated from both current trends and climate change scenarios, indicate that Metropolitan East Coast tidal wetlands are at risk from sea-level rise and increased storm surges.

While marshes can withstand some environmental stress, more frequent storm surges and greater wave action superimposed on rising sea level will exacerbate marsh erosion. Ice and storm events create significant disturbances by scouring the vegetated marsh surface thus disrupting peat formation (Bertness, 1999; Richard, 1978). If not balanced by new accretion, salt marsh inundation and erosion could lead to permanent loss of this productive ecosystem through conversion to a more aquatic wetland type. Marsh-drowning events have been documented in marshes at Clinton, Connecticut during previous periods of rapid sea-level rise, such as between 1200 A.D. and 1450 A.D. (Varekamp et al., 1992).

Climatic events such as freezes and storms can affect habitat diversity and

FIGURE 5-4 View of low marsh *Spartina alterniflora* grasses and tidal channels at Yellow Bar Hassock, Jamaica Bay, with Manhattan in the background.

distribution of organisms. Ice formation is a distinguishing feature between northern salt marshes, such as those found in the New York Metropolitan region, and more southern salt marshes (Bertness 1999). Ice acts as both an erosive and depositional force on the salt marsh. Richard (1978) found that freezes in Flax Pond, a Long Island salt marsh, pull chunks of marsh off the land to create little islets of marsh, called tussocks. The tussocks hold growing *Spartina alterniflora* plants and can be important for extending the range of marshes seaward. However, ice can also scour and remove plant material and sediments from salt marshes. A single severe freeze in Flax Pond, Long Island, destroyed 16 months worth of accretion. While ice-scoured regions may create habitats for microinvertebrates in crevices and muddy strata in the marsh, repeated extensive scouring can diminish marsh landmass over the long-term. GCM projections indicate less severe winters, which would lead to less frequent icing events during the 21st century. The marshes may therefore be less affected by the erosive and depositional forces of ice and freezing temperatures in the future.

Sea-Level Rise and Accretion Rates

The rate of local sea-level rise in Jamaica Bay is about 2.7 mm/yr as determined by tide gauge data (1961–1990) from Battery Park in Manhattan. This can be compared to the mean global sea-level rise of 1.8 mm/yr since the 1900s, due in part to anthropogenic causes (IPCC, 1996; Gornitz, 1995, also see Chapter 3 *Sea-Level Rise and Coasts*). The difference between the global and the New York average sea-level rise is due, in part, to local subsidence resulting from crustal readjustments to the removal of ice following the last glaciation. Erosion of Jamaica Bay marshes could be caused by a combination of SLR, changes in inshore wave energy (particularly during storms), dredging and channel modification for navigation, and reduced sediment loads available for vertical marsh accretion, due to channelization of streams and tributaries that prevent upland sediments from reaching the Bay.

Saltwater inundation and erosion from SLR will affect coastal wetlands and the wildlife they support. Elevated sea levels may enlarge tidal pools and channels. While marshes can withstand wave action to a certain degree, erosion may escalate with more frequent storm surges (e.g., nor'easters, tropical storms and hurricanes) superimposed on a higher sea level (Brampton, 1992; Gornitz, 1995; Rosenzweig et al., 1999). With a rising sea level, salt marsh vegetation may become inundated for more hours in the tidal cycle than can be tolerated for sustained growth.

It should be noted that a salt marsh requires some sea-level rise to maintain itself; the process is somewhat self-regulating and salt marsh accretion rates, at a minimum, approximate SLR (Allen and Pye, 1992). The correlation between accretion rates and SLR has been used as a tool to determine historical SLR (Nydick et al., 1995; Varekamp et al., 1992; and Nuttle, 1997). Present rates of marsh accretion in the Eastern seaboard and Gulf Coast have been reported as exceeding or keeping pace with sea-level rise except in Louisiana, parts of Chesapeake Bay (e.g., Blackwater Marsh, Maryland), and Barn Island, Connecticut (Boesch et al., 1994; Dean et al., 1987; Downs et al., 1994; Stevenson and Kearney, 1996; and Wray et al., 1995).

Wetland Policy

Federal and state legislation protects wetlands through a regulatory process whereby an environmental assessment is conducted to evaluate impacts of government projects in environmentally sensitive areas. An environmental impact statement (EIS) may be required and permit applications will be reviewed prior to project construction. A federal and state determination to deny or grant permits for filling and dredging for construction, navigation and other activities is conducted. In addition, permits, notifications and determinations from federal, state, and local government agencies may be required.

- New York State enacted the Tidal Wetlands Act, Article 25 of the Environmental Conservation Law (ECL), effective September 1, 1973, in order to "... preserve as much as possible the remaining wetlands in their present natural state and to abate and remove the sources of their pollution."
- New York State Department of Environmental Conservation (NYSDEC) regulates filling activities within wetlands and up to 300 feet upland of the wetland boundary except in New York City where this buffer area is limited to 150 feet beyond the wetland boundary.
- The U.S. Army Corps of Engineers (ACE) regulates dredging, the discharge of dredged or fill material, and construction of structures in waterways and wetlands through Section 404 of the Clean Water Act (1977).
- By Act of Congress, Gateway National Recreation Area (GNRA) was established stating in Section 3 "that the Secretary shall administer and protect the islands and waters within the Jamaica Bay Unit with the primary aim of conserving the natural resources, fish, and wildlife located therein and shall permit no development or use of this area which is incompatible with this purpose."

METHODS

Aerial Photograph Interpretation and Mapping

To determine if marshes of Jamaica Bay are stable or undergoing erosion, three sets of historic photographs of a center section of Jamaica Bay, from 1959, 1976, and 1998, were

TABLE 5-1
Changes in area of three salt marshes at Jamaica Bay Wildlife Refuge, Gateway National Recreation Area, Queens, New York

Marshes	1959 Acres (Ha)	1976 Acres (Ha)	1976 % Loss Since 1959	1998 Acres (Ha)	1998 % Loss Since 1976	1998 % Loss Since 1959
Yellow Bar Hassock (Low)	189 (76.5)	173 (70)	8	165 (66.8)	5	13
Black Wall Marsh (Low)	44 (17.8)	43 (17.4)	2	41 (16.6)	5	7
Big Egg Marsh (Low)	75 (30.4)	76 (30.8)	–1	64 (25.9)	16	15
Total area	**308 (125)**	**292 (118)**	**5%**	**270 (109)**	**8%**	**12%**

Note: Acres are listed first, then hectares (ha) in parentheses.

examined. Stereopairs with greater than 60% overlap were obtained from two aerial photograph companies. For two island marshes, Yellow Bar Hassock and Black Wall Marsh, and one marsh associated with Broad Channel Island (Big Egg Marsh), landmass was calculated using a transparent grid overlay, 4x4 squares to the inch, over the photographs. Squares with greater than 50% vegetated land cover were counted three times for each year-interval, and the average of the counts for each marsh was recorded (Figure 5-5, Table 5-1).

For a trends analysis over the longer term covering all of Jamaica Bay, land loss or gain was quantified by computerized Geographic Information System (GIS) analysis. Navigation charts and topographic maps dating from 1899 and 1900 have been digitized by the Army Corps of Engineers (ACE) (Stephen McDevitt and Bob Will), and by New York State Department of Environmental Conservation (NYSDEC) (Fred Mushacke and Dave Fallon). The maps were being compared with more recent aerial photographs for proposed restoration projects and regulatory purposes. Determination of marsh size between different periods over the century with the aid of the GIS help to clarify wetland losses. The NYSDEC map series, covering years 1900, 1974, and 1994, was used to compare wetlands extent prior to and after the 1970s. A comparison of losses before and after the 1970s when stricter regulation limited filling activities in and adjacent to wetlands and marshes is discussed. Land loss of wetlands of up to 75% through the early 1970s, were primarily due to human activity (Black 1981).

The New York State Official Tidal Wetlands Inventory is maintained by the New York State Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, Bureau of Marine Resources, Geographic Information System Unit. The tidal wetlands were first mapped in 1974 during the New York State tidal wetlands mapping inventory as required under Article 25 of the ECL. The inventory is based on aerial infrared photography 1 inch = 1,000 feet. The wetlands are defined by a combination of tidal influence and vegetation. They are divided into three vegetative categories—intertidal marsh (IM), high marsh (HM), and fresh marsh (FM)—and two non-vegetated categories—littoral zone and coastal shoals, bars and flats.

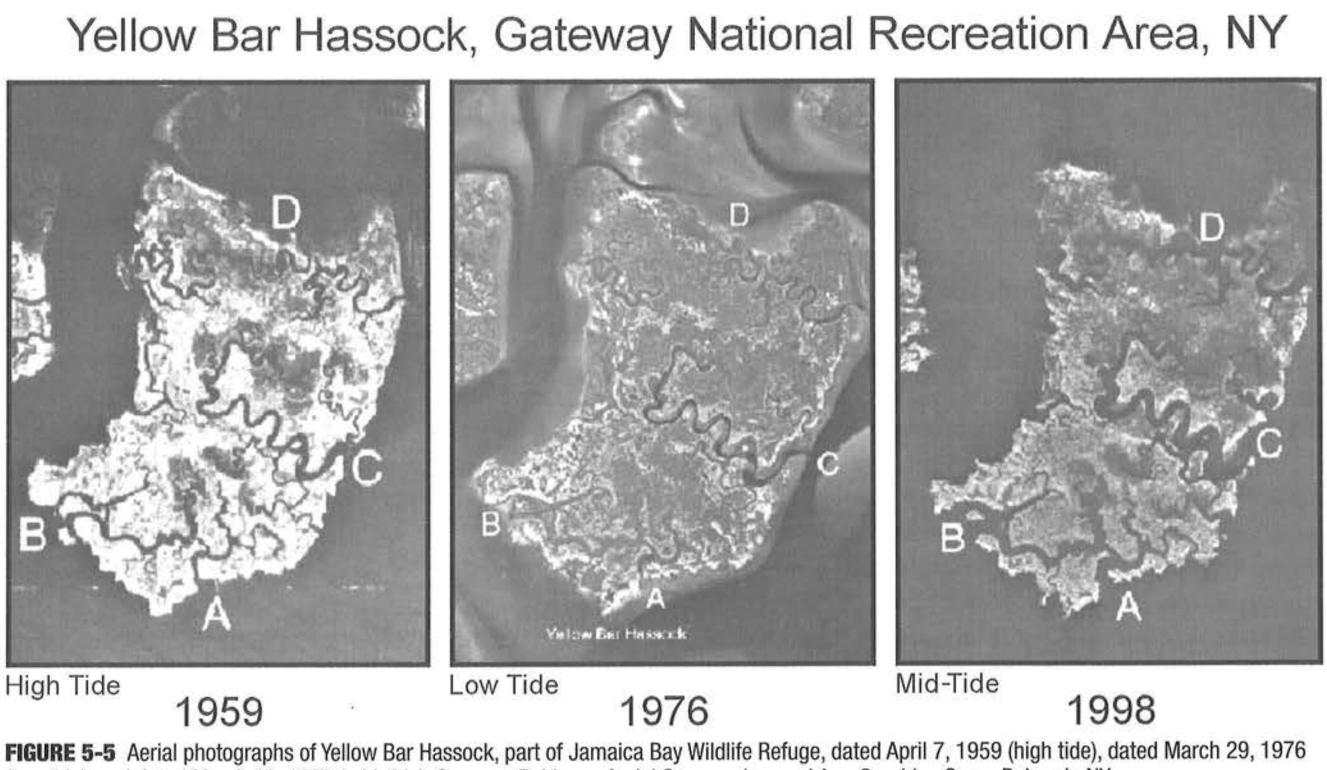

FIGURE 5-5 Aerial photographs of Yellow Bar Hassock, part of Jamaica Bay Wildlife Refuge, dated April 7, 1959 (high tide), dated March 29, 1976 (low tide), and dated March 13, 1998 (mid-tide). Sources: Robinson Aerial Surveys, Inc. and AeroGraphics Corp., Bohemia NY.

Using GIS software (ArcView) and digitizing the Tidal Wetlands Boundary (TWB) from historic photos and maps confirmed that wetland boundaries had changed and that wetland types had shifted significantly. All digital data were referenced to the 1974 TWB, then overlain onto the USGS quad for reference. Color overlays are shown in Figure 5-6 with the 1900 USGS TWB in green, the 1974 TWB in red, and coverage of the TWB developed by using the 1994 NYS Digital Ortho Quads in yellow. The outer perimeter of all vegetated wetlands was digitized and used for the TWB, even though the 1974 wetlands delineation defined the islands into high and intertidal marsh categories.

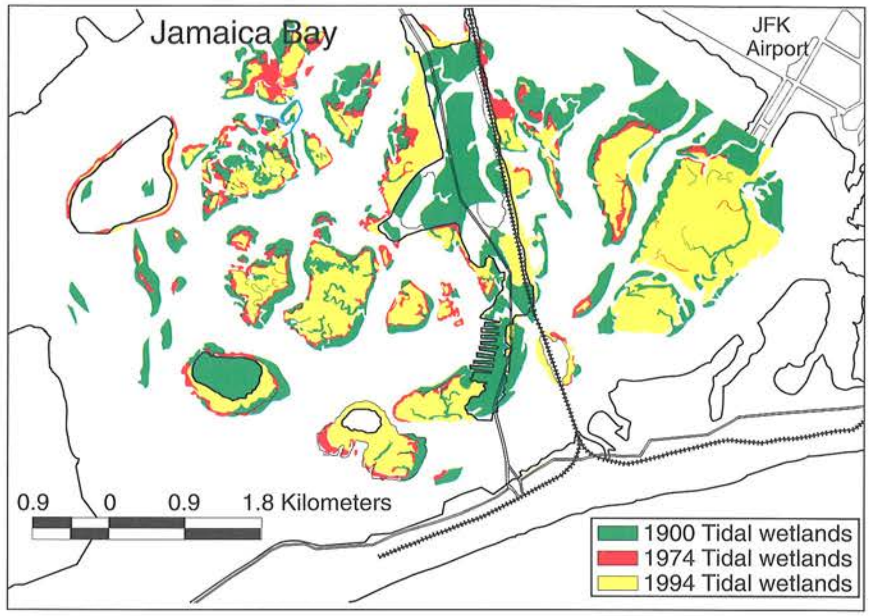

FIGURE 5-6 Jamaica Bay tidal wetlands lost 1900–1994, digitized by Fred Mushacke, NYSDEC, Division of Fish, Wildlife and Marine Resources. Sources: Topographic map of 1900 and color infrared aerial photographs 1974 and 1994.

Four marshes where acreage revealed the scope of loss are given as examples in Table 5-2. Three small marshes were measured that were greatly diminished in size, including Elders Point Marsh, Nestepol, and Fishkills Hassock. For comparison, Jo Co marsh was measured because its losses appeared minor. Total marsh losses for all 15 islands are given in Table 5-2. The GIS map overlays for 1974 are compared to 1900, and year 1994 is compared to year 1974. Cumulative losses for the entire period 1900–1994 are also given.

In order to evaluate the effectiveness of the New York State's tidal wetlands program from 1974 to 2000 in protecting total acres of wetlands, a tidal wetlands trends analysis (TWTA) using geographic information system (GIS) technology is being conducted for the tidal area in New York State south of the Tappan Zee Bridge. This chapter presents preliminary results for the Jamaica Bay island complex.

TABLE 5-2

Trends analysis of 1) Estimated loss in several individual island marshes of Jamaica Bay, 1900–1994; 2) Wetland loss for more than 15 named island marshes of Jamaica Bay 1900–1994

	1900	1974		1994		
Marshes	Acres (Ha)	Acres (Ha)	% Loss Since 1900	Acres (Ha)	% Loss Since 1974	% Loss Since 1900
Nestepol (Low)	36.6 (14.8)	5.7 (2.3)	84	0.6 (0.24)	91	98
Jo Co (High and Low)	485.0 (196.4)	414.0 (167.7)	15	374.0 (151.5)	10	23
Elders Point (Low)	120.0 (48.6)	93.0 (37.6)	23	37.6 (15.2)	60	69
Fish Kill Hassocks (Low)	4.9 (2.0)	1.3 (.53)	73	0.05 (0.02)	96	99
Total Island Marshes (>15 named islands)	**3146 (1274)**	**1972 (799)**	**37%**	**1572 (637)**	**20%**	**50%**

Note: Acres are listed first, then hectares (ha) in parentheses.

Sea-Level Trends Analysis and Forecast Modeling

A trends analysis was conducted because sea-level rise could be an increasingly major contributing factor of shoreline change and land loss (Wray et al., 1995). A rise in temperature of 1–5°C, mainly due to increased CO_2 and other greenhouse gases, will cause thermal expansion of ocean waters and melting of alpine and high-latitude glaciers. This would result in a sea-level rise of more than 3 feet (1 meter) above mean sea level at certain MEC localities by the end of the century (see Chapter 3 *Sea-Level Rise and Coasts*). The tide gauge at Battery Park, New York City was used to determine recorded historic changes in sea level at Jamaica Bay (as yet there are no permanent tide gauges within Jamaica Bay itself). An advantage of the one at Battery Park is that measurements for the location have been recorded since 1856, one of the longest records available in the United States.

The historic rate of SLR of 2.7 mm/yr was compared with known accretion rates of the MEC region (Table 5-3). A survey of the literature indicated that accretion rates ranged from 2.0 to 10.0 mm for low marsh intertidal zones. The only sediment core for accretion rate analysis from within Jamaica Bay was taken by Christopher Zeppie in 1977. At that time the 100-year record indicated that the low marsh accreted at 8 mm/yr, and the high marsh accreted at 5mm/year (Zeppie, 1977). These accretion rates can be compared with scenarios of future SLR given in Table 5-4. Global climate models (GCMs) were used to project the

TABLE 5-3
Surface accretion rates measured in the Metropolitan East Coast region compared with the mean rate of sea-level rise

State	Salt Marsh Zone	Accretion Rate (mm/yr)	Time (years)	Method	SLR (mm/yr)	Source
CT	low	8.0–10.0	10	Particle layer	2.6	Bloom (in Richard 1978)
CT	high	2.0-6.6	10	Particle layer	2.6	Harrison & Bloom 1977
CT	high low	1.8-2.0 3.3	58	^{210}Pb	2.2	Orson, Warren & Niering, 1998
NY	low	4.7-6.3	103	^{210}Pb	2.9	Armenanto & Woodwell 1975
NY	low	4.0	88	^{210}Pb	2.9	Muzyka 1976
NY	high Low	5.0 8.0	100	^{210}Pb	2.7	Zeppie 1977
NY	low	2.5	171	Historic record	2.9	Flessa et al. 1977
NY	low	2.0-4.2	1	Particle layer	2.9	Richard 1978

Sources: Harrison and Bloom, 1977; Zeppie, 1977; Orson, 1998; and Titus, 1988 for all other listings.

rate of sea-level rise per year until the 2090s. GCM climate change scenarios are based on a gradual increase of CO_2 and other greenhouse gases over time. Observed sea-level trends have been adjusted for local land subsidence (see Chapter 3 *Sea-Level Rise and Coasts*).

To study impacts of sea-level rise (SLR) on tidal marshes in New York City, we use a suite of sea-level rise scenarios based on 1) current trends, and 2) outputs from two GCMs. The GCMs are those of the Canadian Climate Center with greenhouse gases (CCGG) and greenhouse gases with sulfates (CCGS), and of the United Kingdom Hadley Center (HCGG and HCGS). Since salt marsh accretion must, at a minimum, keep pace with sea-level rise for the marsh to be sustainable, accretion would need to occur at least at similar rates of rise. The relationship between rate of accretion and sea-level rise can vary, and a single marsh can go through erosive and accreting periods, but to sustain itself overall accretion must approximate or exceed SLR (Nuttle, 1997). This assumption can be used to compare local accretion rates and SLR to help document current marsh gain or loss (Bricker-Urso et al., 1989). The assumption is used herein to compute local marsh loss with projected rates of SLR over the next 100 years (Titus, 1988). Local SLR projections indicate that mean sea-level rise is estimated to be between 2.7 and 7.3 mm/yr by the 2020s, and between 2.7 and 13.7 mm/yr by the 2050s (Table 5-4).

Field Investigations

Of more than 15 named marshes in Jamaica Bay, three were selected for sampling and observation and are listed in Table 5-5 with mean biomass obtained by oven-drying to constant weight (Nixon and Oviatt, 1973). Big Egg Marsh and Rulers Bar Hassock border on upland zones associated with the Broad Channel Island community and the Jamaica Bay Wildlife Refuge. An initial selection on the west side of West Pond was deemed inappropriate as it would have required leaving heavily visited marked trails within Jamaica Bay Wildlife Refuge. Instead Rulers Bar Hassock, a more secluded site on the same island near its northern tip was selected. Adjacent to Rulers Bar Hassock Marsh are the uplands dominated by shrubs and thickets, including extensive stands of Northern Bayberry (*Myrica pennsylvanica*) within the Jamaica Bay Wildlife Refuge. Bordering on Big Egg Marsh are baseball fields in use by the Broad Channel residential community. As of June 2000, small berms were being replaced by higher berms greater than 3 feet (1 meter) in height on the waterward portions of the baseball fields. Yellow Bar Hassock and Big Egg are peat-rich marshes with extensive meandering tidal channels, whereas Rulers Bar Hassock is a sandy shore tidal marsh with limited channel inlets. All three marshes are dominated by *Spartina alterniflora*. The tidal range for Jamaica Bay is typically 1.6 meters (5 feet).

GEOMORPHOLOGY

Field investigations were planned in cooperation with National Park Service for access, after ongoing erosional processes were noted in the aerial photographs. Noting that significant changes in marsh size had occurred between 1959 and 1976, and 1976 to 1998, evidence was searched and identified during field observations. The geomorphological changes resulting from erosion can have a profound effect on vegetation ecology and conservation value. Similar observations have been described for the Mississippi Delta in Louisiana, marshes of Black-

TABLE 5-4
Projected mean sea-level rise in mm/yr. Calculations are based on 1961-1990 tide gauge data from New York City (Battery Park)

	2000s	2010s	2020s	2030s	2040s	2050s	2060s	2070s	2080s	2090s
Cur.Tr.	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
CCGG	6.4	8.2	7.3	13.3	6.4	13.7	17.5	13.0	19.0	—
CCGS	6.9	5.3	3.6	11.4	10.8	6.6	11.3	10.5	22.7	—
HCGG	4.1	3.4	6.0	5.0	5.4	6.4	7.4	8.1	6.2	—
HCGS	3.5	2.8	4.1	5.6	2.2	4.9	6.2	5.7	6.9	—

Source: Data are derived from Chapter 3 *Sea-Level Rise and Coasts.*

TABLE 5-5

Mean biomass of *Spartina alterniflora* (grams dry weight per square meter) during 1999 field investigations at Jamaica Bay, Queens County, NY

Location	Sampling period	Mean biomass gms × 1.0m^{-2}	Mean biomass gms × 1.0m^{-2}
Big Egg Marsh	July	1065	
	August/Sept	768	
	October	1053	962
Rulers Bar Hassock	July	1442	
	August/Sept	1156	
	October	1012	1203
Yellow Bar Hassock	July	695	
	August/Sept	998	
	October	744	812
Total			**992**

water National Wildlife Refuge in Maryland, and the Dengie marshes in Great Britain where combined local subsidence and sea-level rise have resulted in dramatic marsh loss (Dean et al., 1987; Allen and Pye, 1992; Downs et al., 1994; and Wray et al., 1995). In 1999, field investigations at Jamaica Bay included photograph records of erosive forms.

Vegetation Sampling

BIOMASS DATA COLLECTION

In order to provide estimates of general salt marsh productivity and to establish a baseline for future measurements of the 4,000 acres of salt marshes in Jamaica Bay, a study of *Spartina alterniflora* standing crop biomass was conducted from the middle, to close to the end, of the growing season, from July through September 1999. At three marsh sites in Jamaica Bay (Big Egg Marsh, Rulers Bar Hassock and Yellow Bar Hassock) quadrats were placed 50 feet apart along belt transects for sampling. On the island marsh, Yellow Bar Hassock, transects were conducted with the aid of a compass from the point where the field team disembarked from the National Park Service-supplied boat, in a northwest direction facing the World Trade Towers in Manhattan, to where a large channel prevented further sampling. Shoreline transects at Rulers Bar Hassock were traversed from the end of the most seaward vegetated zone accessible by foot, to the wetland-upland boundary, and vice versa at Big Egg Marsh. Within preselected swaths based on accessibility, transect starting locations were randomly selected.

Transects were conducted at least three times within the growing season at each location. Sampling of the three sites was conducted over two non-consecutive days in July, six weeks later in August and September, and again in October. For each transect species composition was recorded in 1-meter-square quadrants; Spartina *alterniflora* was clip-harvested from a 0.25 m^2 corner of each plot. Collected material was dried to constant weight at 105°C (Nixon and Oviatt, 1973).

TABLE 5-6

Plant species observed in 1.0m^2 plots along belt transects conducted in three intertidal marshes and during field surveys (Jo Co Marsh) at Jamaica Bay, Queens County, NY

Scientific name	Common name	Indicator status	Marsh
Spartina alterniflora	Smooth cordgrass	OBL	Big Egg, Rulers Bar Hassock, Yellow Bar Hassock, Jo Co
Spartina patens	Salt hay grass	FACW+	Big Egg, Rulers Bar Hassock, Yellow Bar Hassock, Jo Co
Spartina cynosuroides	Big cordgrass	OBL	Big Egg
Phragmites australis	Common reed	FACW	Big Egg, Rulers Bar Hassock
Distichlis spicata	Spike grass, Seashore saltgrass	FACW+	Jo Co
Juncus gerardii	Black grass	FACW+	Jo Co
Salicornia virginica	Glasswort, samphire	OBL	Big Egg, Yellow Bar Hassock
Iva fructescens	Marsh elder, Big-leaf sumpweed	FACW+	Big Egg, Rulers Bar Hassock
Aster tenuifolius	Marsh aster, Perennial salt marsh aster	OBL	Jo Co
Myrica pensylvanica	Northern bayberry	FAC	Big Egg
Toxicodendron radicans	Poison ivy		Big Egg
Fucus sp.	Brown seaweed, Rockweed	NL	Yellow Bar Hassock
Ulva sp.	Sea lettuce	NL	Big Egg, Yellow Bar Hassock, Rulers Bar Hassock

Notes:

1. OBL = Obligate wetland species-occurrence more than 99% of the time is in wetland habitats.
2. FAC, FAC+ = Facultative wetland species-occurrence more than 66-99% of the time is in wetland habitats.
3. NL = Not Listed-aquatic algae are not included in the National List for wetland species.

SPECIES COMPOSITION

Species composition at Big Egg Marsh, Rulers Bar Hassock and Yellow Bar Hassock was recorded from 1 m^2 plots during transect sampling procedures. Additional species observed during a field survey at Jo Co Marsh were also recorded. Species were listed on field data sheets (Table 5-6). Indicator status was recorded according to the 1988 National List of Plant Species that occur in wetlands (Reed, 1988). The National List provides regional species listings with their percent chance of occurrence within the range of wetland to upland habitats. Obligate species occur within wetlands 99% of the time. Facultative species occur 66–99% of the time observed in wetlands. Further facultative species divisions include FACW+ for those that are nearest to the obligate species in wetland zonation.

Habitats were divided by vegetation into low marsh, high marsh and transitional upland areas depending on the species found during field observation or as determined by aerial photo interpretation. Low marsh, located between mean sea level (MSW) and Mean High Water (MHW) contained *Spartina alterniflora*. High marsh, located between Mean High Water and Mean Higher High Water (MHHW) contained *Spartina patens*, *Iva fructescens*, and *Distichlis spicata*. The transitional upland area located in the interface between MHHW and upland areas contained *Phragmites australis*.

RESULTS

Aerial Photograph Interpretation and Historic Mapping

Land loss was apparent from inspection of aerial photographs in the three-marsh analysis. Two features were clearly identified: 1) loss of shoreline on outer island edges and 2) loss of internal marshland along large meandering tidal inlets and their tributaries. These two processes were separately examined to rule out erosion caused solely by barge and boat action or by maintenance dredging of navigation channels. Table 5-1 lists acreage and percent remaining since 1959, accounting for land loss from outer banks and within channels. Given that the 1959 photograph was taken at high tide when more of the marsh is inundated, the percent reduction calculated from later photographs taken during mid- to low tide is regarded as a conservative estimate.

A comparison of points A-D in Figure 5-5 reveals changes at Yellow Bar Hassock. At point A the sliver of land mass remaining in 1998 was larger in 1976 and 1959. Correspondingly the estuarine channel has widened. Whereas in 1959 at point B, four land masses, including one small island are visible; by 1998 one island has disappeared entirely, and the second, once-inner island, is now isolated with much larger channelization. Along the island located between points A and B on Yellow Hassock Marsh, marshland has narrowed or disappeared by 1998. At point C, the channel width has increased. By 1998, the land mass at the south section of the channel inlet at point C is reduced to a sliver. The smaller channel to the north has also become enlarged. At point D, by 1998 a marsh section with a meandering U-shaped channel curving around it is replaced by a much larger channel.

For the three-marsh study of Yellow Bar Hassock, Black Wall Marsh, and Big Egg Marsh, there was an approximate 12% reduction in landmass between 1959 and 1998. The more recent period, between 1976 and 1998, showed greater percent erosion than during the earlier period from 1959 to 1976 (Table 5-1).

The trends analysis conducted for more than 15 island marshes of Jamaica Bay from 1900 to 1974, and between 1974 and 1994 is given in Figure 5-6. Tidal wetlands remaining according to 1994 color infrared photography are shown in yellow in Figure 5-6. Wetlands lost between years 1900 and 1974 are shown in green. The difference between the wetlands remaining in 1974 and those remaining in 1994 is shown in red. Acreages for selected islands and totals from the 15 marshes are given in Table 5-2. From 1900 to 1974, a total of more than 1,174 acres were lost, or approximately 16 acres per year. From 1974 to 1994, approximately 400 acres, or 20 acres per year, were lost. The causes of the former were primarily filling, dredging, or draining activities. However, by 1974, these activities were stopped through environmental regulations and the creation of the Gateway National Recreation Area. Therefore, the more recent 20-acre-per-year loss appears to be due to other causes, such as erosion. Both aerial color infrared photography and field studies suggest that much of the 400 acres of *Spartina alterniflora* marshes appear to have been converted to more aquatic wetland types such as coastal shoals, bars and mudflats, or littoral zone.

Udel et al. (1969) calculate that vegetated tidal wetlands produce about 3 tons of organic material per acre per year. Therefore, the 400 lost acres would have produced 1,200 tons of tidal wetland biomass between 1974 and 1994. Thus the equivalent of at least 60 tons of organic material are being lost each year. To identify possible causes of this loss, and to obtain baseline information for future study in the Bay, a number of measurements were initiated. Possible factors affecting the loss of the vegetated wetlands such as erosion, sea-level rise, storms and ice flows were examined.

The type of erosion found from the outer marsh edges extending into the most inland tributaries was consistent throughout the areas studied. This suggests that it is unlikely that erosion could be caused primarily from barge and boat traffic along the navigation channels. If boat traffic or dredging for navigation near the islands' perimeter were the prime cause, inland tributaries should have been spared. If the loss was from subsidence within a locally sediment-starved embayment, then island marshes in Long Island would not also have been undergoing loss, and there would be no inland migration of marshes along Long Island's South Shore where open space allows such shifts to occur. These effects have been observed in coastal wetlands on the south shore of Long Island (Fallon, 1996).

Geomorphology

Erosion observed during the field investigations showed undercutting of peat at island and channel edges. At the edge of a wide channel of Big Egg Marsh, small clumps of peat have detached completely, following a storm (Figure 5-7). Note that *Spartina alterniflora* stems are still attached in the hand-held example. Numerous clumps of peat were found strewn on the mudflat. More than six inches of peat overhangs beyond the connected substrate (Figure 5-8). At Yellow Bar Hassock, a large fallen rhombus-shaped segment of marsh peat was observed during low tide, carved from the adjacent intact marsh (Figure 5-9A). Figure 5-9B shows the same site later in the tidal cycle, when the detached peat segment has submerged, while the intact adjacent marsh temporarily remains above the water line.

FIGURE 5-7 Peat hand-held by attached *Spartina alterniflora* stems found strewn on mudflat along wide channel of Big Egg Marsh.

Vegetation Sampling

Mean biomass in the three selected marshes ranged from 812 gm/m^2 to 1,203 gm/m^2 with a total mean of 992 gm/m^2 (Table 5-5). Where microgeographic features such as pools and creeks crossed the transect, the nearest vegetated edge was sampled. Where these features were most frequent, the total standing crop was diminished. This was most evident in Yellow Bar Hassock. The resulting low biomass nearest the pools was averaged with all other samples. High marsh communities were restricted or missing in the communities sampled, particularly Yellow Bar Hassock.

Species composition in low marsh areas, including all of Yellow Bar Hassock, was predominantly *Spartina alterniflora*. *Spartina patens* and *Salicornia virginica* were observed in a few higher elevation portions of the island, while *Ulva sp.*, was found in the mudflats and interspersed in bare areas of *S. alterniflora* (Table 5-6). If Yellow Bar Hassock once had high marsh areas, as was suspected upon inspection of texture of some vegetation in the 1959 photographic print, then they were no longer in evidence during field visits. All species were either obligate wetland species (found in wetlands more than 99% of the time it is observed) or facultative species (found in wetland habitats more than 66% of the time it is observed). Additional facultative species were found in the high marsh zones of Big Egg Marsh and Rulers Bar Hassock, including *Iva frutescens*, *Myrica pensylvanica*, and *Phragmites australis*. Due to logistical and budgetary constraints, field observations in Big Egg Marsh were limited to the more landward marshes, as the large channels were not passable by foot during low tide.

FIGURE 5-8 Extent of undercutting of low marsh embankment greater than 6 inches (15 centimeters) as indicated on carpenter's ruler.

To illustrate change over time, a cross-section of Big Egg Marsh was constructed (Figure 5-10). Field observations of the wetland vegetation and upland land-use (1999 and 2000) were used in conjunction with a 1900 navigation chart, 1988 aerial photograph (available as a large-scale paper print 1 inch=400 feet), and GCM scenarios for sea-level rise. These were developed into transects representing three time periods 1900, 2000 and 2001. To illustrate future conditions, accretion rates previously estimated from sediment cores taken in Jamaica Bay as well other sites in or near the MEC region were used together with a climate change scenario to project the inland

FIGURE 5-9A Sloughed-off segment of peat carved from the adjacent intact marsh at Yellow Bar Hassock as observed during low tide.

FIGURE 5-9B Mid-tide view after sloughed-off peat becomes submerged under water while the intact adjacent marsh temporarily remains exposed above the water line.

shift in vegetation community types and the estimated loss of marsh acreage to tidal inundation.

Accretion Rates and Climate Change Scenarios

Table 5-3 lists known accretion rates for the intertidal zone in Connecticut and New York; these are used to calculate rates of marsh accretion needed to keep pace with sea-level rise (Table 5-7). For Jamaica Bay, a single study documents low marsh accretion rate at 0.8 cm/yr and for high marsh the accretion rate was 0.5 cm/yr (Zeppie, 1977). The rates lie toward the upper range of those found in the region by others. The sampling covered a 100-year time span when accretion may have been especially high due to dredging and filling activity such as construction of John F. Kennedy International Airport, land filling (Penn and Fountain Avenues, and Edgemere landfills), and uncontrolled outfall from sewage treatment plants and combined sewage overflow (CSO). New controls presently in effect, particularly at the 26th Ward Water Pollution Control Plant (at Hendrix Creek) and installation of above-ground CSO tanks (at the headwaters of a tributary to Spring Creek) have likely reduced the accretion rate, in addition to landfill closure and completion of major construction activities around the Bay. The accretion rate at Jamaica Bay has not been measured since Zeppie's 1977 measurements, and new determinations are urgently needed. To test the sensitivity of accretion rates, the GCM scenarios were applied to low (0.2 cm), medium (0.5 cm), and high (0.8 cm), sedimentation rates (Table 5-7).

Table 5-4 presents SLR in millimeters/year for five scenarios—Current Trends (Cur.Tr.), CCGG, CCGS, HCGG, and HCGS using the tide gauge data from New York City at Battery Park. Rates are relative to 1961–1990 sea-level data. With a continuation of current trends, which accounts for current levels of atmospheric greenhouse gases, the rate of local sea-level rise is 2.7 mm/yr throughout the next 100 years. Scenarios from global climate models (GCMs) indicate, for the most part, ever-increasing rates of sea-level rise over time. We first assume that accretion rates approximately equal sea-level rise (Table 5-4), and then assume low, medium, and high rate of rise (Table 5-7).

For the Current Trends scenario, Jamaica Bay marshes will need to accrete on average 2.7 millimeters each year (Table 5-4). To accommodate accelerating rates of sea-level rise projected using the GCMs, Jamaica Bay marshes will require ever-increasing rates of accretion. For example, under the CCGG scenario, the minimum rate of accretion will need to nearly triple to 7.3 by the 2020s, and almost double again to 13.7 mm/yr by the 2050s. By the end of the century, under the Canadian Climate Center scenarios, with and without sulfates, (CCGG and CCGS), rates of SLR may reach and exceed the upper bound of salt marsh accretion. Under the Hadley Center

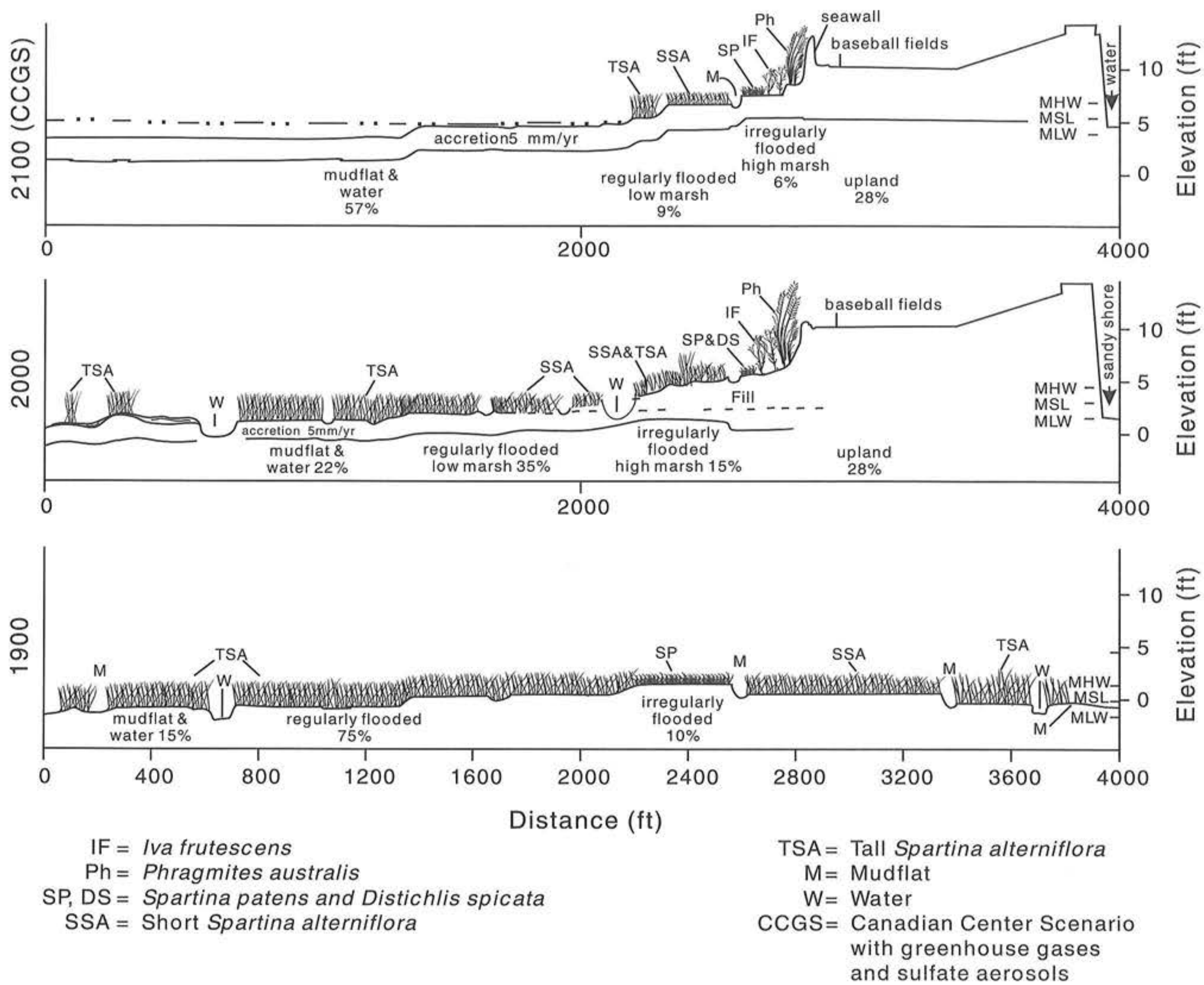

FIGURE 5-10 Transect of historic, current and future conditions (years 1900, 2000 and 2100) in Big Egg Marsh. Source: Adapted from Kana et al. 1988 and Titus 1988.

scenarios the rate of SLR is projected to be slower. The minimum accretion rates would need to go from 3.5 mm/yr in 2005, to nearly double—6.9 mm/yr by 2085.

In a separate sensitivity test, low (0.2 cm/yr), medium (0.5 cm/yr), and high (0.8 cm/yr) accretion rate are used independently at fixed rates over the next 100 years. Table 5-7 indicates the amount of sediment (and plant material) that would accumulate as peat over four time periods: 2020s, 2050s and 2080s and then to 2100. The amount accreted is then subtracted from the amount of sea-level rise projected in Table 5-3.

In the Canadian Center scenarios, sea-level rise almost always surpasses the accretion rate. In some cases, particularly in the Hadley Center projections (HCGG and HCGS), where the calculation is below zero, the accretion rate is higher than the projected change in sea level. Since

TABLE 5-7
Projections for inundation (cm) at Big Egg Marsh accounting for sea-level rise and low, medium, and high rates of accretion

GCM	2020s			2050s			2080s			2100		
	L	*M*	*H*	*L*	*M*	*H*	*L*	*M*	*H*	*L*	*M*	*H*
CCGG	13.2	5.7	−1.8	35	18.9	2	81	50	25	101.8	71.8	41.8
CCGS	9.0	1.5	−6	30.3	13.8	−2.7	61	35.5	10	92	62	32
HCGG	5.5	−2	−9.5	16.1	−.4	−16.9	31.9	6.4	−19.1	38.2	8.2	−21.8
HCGS	3.3	−4.2	−11.7	9.6	−6.9	−23.4	21.4	−4.1	−29.6	28.9	−1.1	−31.1

Note: L = Low (0.2cm/yr), M = Medium (0.5cm/yr), and H= High (0.8cm/yr) accretion rates.

field observations and aerial photograph analysis demonstrate that accretion is not keeping pace with tidal inundation and erosion, a Canadian Climate Center scenario was used to demonstrate the impact of sea-level rise on marshes.

The more conservative of the two Canadian Climate Center models was selected for a cross-section of Big Egg Marsh (Figure 5-10). The figure illustrates the scenario for year 2100, for the CCGS GCM under a medium sediment accretion rate. The medium 5 mm/yr rise was selected and applied to both the past 100 years and the next 100 years as an average measurement of accretion. Figure 5-10 illustrates a 62 cm (24 in) rise in water under the medium scenario. The result indicates that 57% of the marsh will be covered in water compared to 17% in 1900 and 24% in 2000. The low marsh is reduced in extent to 9% in year 2100, compared with 33% coverage in year 2000 and 75% in year 1900.

DISCUSSION

Most of the tidal wetlands losses in Jamaica Bay between 1900 and 1974 were caused by direct man-made factors: e.g., filling and dredging, residential development in Queens and Brooklyn in and around the bay including Broad Channel Island and JFK International Airport, and rail and road construction. The current losses are likely caused by several factors, including sea-level rise, erosion, and storms. While these more recent losses may not be entirely anthropogenic, nonetheless the losses are real and they are rapid.

These losses are likely to have significant effects on the Jamaica Bay ecosystem as it relates to wildlife habitat, marsh productivity, and biodiversity. These losses may be only partially compensated by the gains through conversion to more aquatic wetland types on the seaward side; compensation through shifts in vegetation landward is limited by urban development. It is unlikely that salt marshes of Jamaica Bay will accrete rapidly enough in the next decades to keep pace with projected rates of sea-level rise—particularly given the diminishment in size that is already evident.

Erosion processes can be expected to accelerate with rise in sea level. According to Dean et al. (1987), shoreline erosion accounts for only about one percent of marsh loss annually because "most marshes will be long since submerged before extensive shoreline erosion occurs." The primary mechanism of marsh loss due to SLR will be from formation of extensive interior ponds accompanied by general tidal creek bank erosion. Rapid interior ponding has been documented in the Mississippi Delta and in Chesapeake Bay. At the Blackwater Wildlife Refuge in Maryland, over one third of the total marsh area (5,000 acres) was lost between 1938 and 1979 by the growth of interior ponds, largely occurring during the 20-year period after 1959 (Dean et al., 1987). Oxygen deprivation and root death occur as sea level outpaces the ability of the marsh to maintain elevation.

Erosional forms observed at Jamaica Bay and elsewhere were categorized by form as follows:

1. Shoreline erosion of the marsh edge.
   - Undercutting of peat.
   - Sloughing off of peat in-situ from bank ledge. This can be caused by enlargement of biogenic holes until peat is carved away.
2. Tidal creek bank erosion.
   - Residual mud mounds formed by internal marsh erosion, by bank collapse and headwall retreat, leading to coalescence and appearance of extensive areas of bare mudflat with residual vegetated hummocks (e.g., Tollesbury marshes, Essex, Great Britain, Allen and Pye, 1992).
   - Series of ever-smaller residual mounds of mussel beds, some with low density, but growing, *Spartina alterniflora* stems (closest to intact marsh), ending in residual mud mounds with no mussels or vegetation attached.
   - Flat layer of coastal shoals at tidal creek bank replacing once vegetated S. *alterniflora* salt marsh.
   - Chunks of peat displaced or strewn at a distance from bank ledge.
3. Enlargement of internal tidal pools.
   - Steady widening of creeks at their landward edge resulting in near circular or elongated pools at the head of many creeks (Pethick, 1992).
4. Widespread deterioration of marsh vegetation, leading to generalized scour and surface lowering.

As enlargement of tidal pools occurs over time, total biomass production by the marsh will be reduced. Some of this loss may be compensated by productivity of aquatic organisms such as phytoplankton. The impacts of future climate change on variability in productivity are a matter for future research.

During a period of marsh retreat, a shift inland can theoretically preserve marsh extent. However human infrastructure severely restricts such occurrences in Jamaica Bay. The transect shown in Figure 5-10 demonstrates how the Big Egg Marsh baseball fields and bridge supports for Cross Bay Bridge limit marsh migration. The area was converted to additional ball fields by 1999. Comparisons of the 1988 aerial photograph with field conditions in 1999 showed that ball fields also extended waterward. New and old fencing accompanied by rock riprap and sand berms were in evidence. Such fill activity will prevent new marsh from forming along the wetland/upland boundary.

These initial studies support our recommendations that attention be given toward managing tidal wetlands in response to changes in tidal inundation (Fallon and Mushacke, 1996). Additional studies should be conducted to determine the causes of wetlands changes and plans should be developed to address the losses.

ADAPTATION AND POLICY

Climate change scenarios project a range of higher sea levels through the next century that are likely to cause inundation of local marshes in the New York region. These marshes, if they are not on publicly owned land, are under state and/or federal jurisdiction. More frequent storms superimposed on higher sea levels may cause marshes to erode rapidly enough that they may be unable to compensate through accretion between storms. Historic photograph interpretation indicates that progressive loss of marsh has already occurred. Adaptation strategies, such as adherence to state regulatory policies that establish buffer zones beyond the wetland boundaries to allow for inland migration of shoreline marshes, are suggested (Titus, 1998; Titus et al., 1991; and Titus and Narayanan, 1995).

REGULATORY POLICIES

Over the last 25 years, federal and state regulations have slowed filling of coastal wetlands and improved water quality. Federal regulations require a permit for most alterations of wetlands. Many state environmental laws and local ordinances in New York, New Jersey, and Connecticut require permits for alterations in upland adjacent areas in addition to protecting the wetland itself. Such buffers will aid in climate-change preparedness by allowing for shifting of vegetation types along an elevation gradient. For New York State regulations see: Tidal Wetlands Land Use Regulations 6 NYCRR Part 661, Article 25 (available at http://www.dec.state.ny.us/website/regs/661a.htm). While not originally intended for the purpose of increasing climate change preparedness, many of these regulations may indeed be helpful. In many cases, stricter enforcement or changes in regulatory guidelines may increase the utility of the regulations already in effect.

The federal government has jurisdiction over waters of the United States granted by the Rivers and Harbors Act of 1899. Since the Clean Water Act of 1977, wetlands have been considered waters of the United States. This allows the federal government to regulate wetlands; however, their jurisdiction stops at the wetland/upland boundary. Titus (1988, 1998) examines options that would allow coastal states to "retain some of their public trust tidelands in perpetuity, no matter how much the sea rises." Currently landowners (public or private) develop sites just inland of the wetland line, the shorefront owner may protect that property from flooding, often by constructing seawalls and other features.

As the sea rises and the bay waters encroach landward, citizens lose once-protected public wetland area along the newly eroded shoreline. Among several options, Titus recommends rolling easements, which would allow development according to regulation at today's distance from the shoreline, but would prohibit construction that holds back the sea such as seawalls, rip-rap, and other hard armoring. Thus, as the sea comes inland the regulated wetland area would roll back landward. Such a plan would require major changes in land rights that are beyond the scope of this report. Titus (1998) recognizes the difficulties in such options, and recommends that a combination of adaptations to sea-level rise be incorporated in future land use planning.

In New York City, while an estimated 75% of the wetlands have already been developed through filling activity, there remain wetlands and adjacent areas in Queens, Staten Island and the Bronx that are undeveloped. These undeveloped areas, where privately owned, could be subject to new adaptive land use regulations. Publicly owned sites could be transferred to one of several agencies that oversee parks and wetlands including: New York City Department of Parks and Recreation, New York City Department of Environmental Protection, National Park Service. Alternatively, land can be transferred to Trust for Public Land—a not-for profit institution that manages wetlands, community gardens and other open spaces in urban areas—much like the Nature Conservancy does in less urban locations. These options would need to be carried out fairly soon as open space at the shoreline is shrinking rapidly. Land values are high, development is fast-paced, and the city is currently selling many of its publicly owned open-space parcels for private development.

A timely report published in the January–February 2000, National Wetlands Newsletter, entitled "Coast 2050: A Master Plan for Louisiana's Coastal Wetlands" by Robert Viguerie Jr., proposes a number of strategies to achieve vegetative tidal wetland sustainability. A similar route could be taken for Jamaica Bay to ensure its productivity and value for future generations.

To date, there are no guidelines that promote analysis of climate change impacts for use in environmental assessments or environmental impact statements during government project reviews. The development of such guidelines is recommended as part of adaptation to sea-level rise and other climate change impacts. Guidelines for wetlands at the federal, state and city levels include:

- Council on Environmental Quality (CEQ) federal guidelines under the National Environmental Policy Act (NEPA);

- NYSDEC guidelines under the State Environmental Quality Review Act (SEQRA) and;
- Guidelines of the Mayor's Office of Environmental Coordination under New York City's City Environmental Quality Review (CEQR).

Other wetlands regulations include:

- Section 404 of the Federal Clean Water Act (1977) limits development in wetlands.
- Tidal Wetlands Land Use Regulations limits development within 150 feet of the tidal wetland boundary within NYC (300 feet outside of NYC).
- Coastal Consistency Certification from New York State Department of State may be required for certain activities along designated waterways.

INLAND MIGRATION OF SALT MARSHES AT JAMAICA BAY

Potential for inland migration of marshes may be feasible at several of fourteen sites adjoining Jamaica Bay. Each was selected for potential acquisition or otherwise recommended for protection from development by Trust for Public Land and New York City Audubon Society in their "Buffer the Bay Revisited: An Updated Report on Jamaica Bay's Open Shoreline and Uplands" (Blanchard and Burg, 1992). These tracts range in size from 2 to 230 acres and include filled but abandoned upland areas as well as some salt marshes. Several of these sites may offer some limited compensation for what would be lost from present marshes under future conditions if protected from development.

Visits to two "Buffer the Bay" sites showed that restoration by removal of existing barriers could be conducted to promote inland migration of *Spartina alterniflora* marshes. These sites are contiguous with the Rockaway peninsula at the southern shoreline of Jamaica Bay. Bayswater Point State Park, part of the Mott Peninsula, and Dubos Point Wetlands Sanctuary (45 and 25 acres, respectively) consist of low and high marshland with undeveloped wooded areas. These sites are not within the GNRA; Dubos Point Wetlands Sanctuary is under ownership by NYC Department of Parks and Recreation, and Bayswater Point State Park is under ownership by New York State Office of Parks, Recreation and Historic Preservation. Both sites have been periodically managed by New York City Audubon Society. At Bayswater Point State Park, removal of a deteriorating sea wall may stimulate marsh growth inland along 3,600 feet of shoreline (Figure 5-11). While not specifically sought as preparation for sea-level rise, site restoration has been proposed by the Army Corps of Engineers, NYSDEC and New York State Office of Parks, Recreation and Historic Preservation. At Dubos Point removal of large amounts of rusting debris and paved surface could extend salt marsh vegetation (Figure 5-12).

FIGURE 5-11 *Spartina alterniflora* marsh thriving waterward of deteriorating seawall at Bayswater Point State Park, part of the Mott Peninsula, Queens. NY.

FUTURE RESEARCH

Future research needs relate to marsh geomorphology and structure, and the functioning of the marsh ecosystem.

MARSH GEOMORPHOLOGY AND STRUCTURE

- *Accretion rates*. The capacity of the salt marsh to persist in future decades will depend on accretion rates keeping pace with sea-level rise. The accretion rate is, in part, a function of the sediment load, the biological input, and the hydraulic movement of particles. These factors are largely unknown in Jamaica Bay. Historic accretion rate determinations are limited to a single study at low and high marsh (Zeppie, 1977). Research is needed to increase data at a number of locations within Jamaica Bay to determine current accretion. Several methods can be employed to determine accretion rates including establishing feldspar marker horizons, radioisotope geochronology, and installing Sediment Erosion Tables (SETs). To monitor changes in marsh accretion and subsidence, SETs have been proposed within Jamaica Bay in collaboration with USGS. These platforms have been used internationally and are effective at separating the components of surface accretion and shallow subsidence in marshes.

- *Geomorphology and disturbance*. Research is needed on how storms (e.g., changing patterns and periodicity), wave action, and freezes (e.g., a decrease in scouring freezes from warmer winters) may influence salt marsh geomorphology in MEC marshes.
- *Dynamic systems modeling*. A biogeophysical model could be created that integrates the fundamental components of wetlands and estuaries under climate change scenarios. This model would incorporate ecological characteristics such as *Spartina alterniflora* production, and links with geological properties, such as sediment budgets and transport systems. Climatic components should include changes in sea level, temperature, CO_2, and rainfall. Changes in *Spartina alterniflora* production could be generated through field studies and use of DSSAT (Decision Support System for Agrotechnology Transfer) software adapted for use in natural wetland ecosystems.

MARSH ECOLOGY

- *Historic plant community changes*. Salt marsh plant communities form distinct zones, largely in response to flooding periodicity. This zonation makes plant communities excellent bio-indicators of sea-level rise. Knowledge of historic plant communities would enhance our understanding of recent sea-level rise impacts. Historic plant communities can be assessed through historic aerial photographs, rhizome and pollen analysis, scientific literature, and historical documents.
- *Future habitat change*. As sea-level rise floods marshes in the future, marsh habitats will change. High marsh will be converted to low marsh and low marsh will be converted to coastal shoals, bars and mudflats. Quantitative predictions of habitat change under sea-level rise are undeveloped. Techniques using GCM outputs to predict habitat change need further development.
- *Impacts on wildlife*. As marsh habitats change with sea-level rise, the fauna that use these areas will likely change. How populations of birds, fish and other wildlife will be altered is largely unknown.

CONCLUSIONS

Although the Metropolitan East Coast tidal wetlands remain legally protected through regulation, they appear to have become reduced in extent by erosion and inundation. Losses to salt marshes will continue if accretion fails to keep pace with sea-level rise. In addition, in New York's urban environment where rock rip-rap, sea walls and other armored or unarmored defenses prevent marshes from shifting landward in response to sea-level rise, inland migration of marshes cannot occur (Titus 1991 and 1995; Boesch et al., 1994; National Wildlife Federation, 1998).

FIGURE 5-12 At Dubos Point Wildlife Sanctuary in Far Rockaway, Queens, future removal of large amounts of rusting debris could extend salt marsh growth inland.

At the study site in Jamaica Bay Wildlife Refuge, a reduction in area of about 12% in sampled salt marshes has already occurred since 1959. Aerial photographs taken in 1959 at or near peak high tide contain significantly more visible land than the 1976 or 1998 photographs taken at low and mid-tide respectively. Additional studies comparing color infrared aerial photographs of more than 15 island marshes from 1974 and 1994 indicate overall losses of 20%. On-site field observations include: sloughing off of large peat sections along embankments, smaller-sized peat sections strewn along mudflats following a storm event, internal pooling, and undercutting of peat along tidal channels. Indicators of SLR have been described in coastal salt marshes on the east coast and in England and elsewhere (Boesch et al., 1994; Allan and Pye, 1992). The same indicators were observed at Jamaica Bay. Limited opportunities exist for inland expansion of the Jamaica Bay shoreline marshes.

In summary:

1. Salt marsh study sites in Jamaica Bay Wildlife Refuge have been reduced by 12% or more since 1959, with sea-level rise a possible causative factor.

2. Sea-level rise associated with global climate change brings a significant additional risk to already threatened tidal wetlands in the region. In study areas examined, evidence of erosion took several forms:

- erosion of the outer marsh edge,
- enlargement of tidal creeks and internal ponds, and
- widespread deterioration of marsh vegetation (scour and surface lowering).

3. Projected mean sea-level rise exceeds observed historical rates of salt marsh accretion in most GCM climate change scenarios.

4. Coastal wetland losses will disrupt current bird, fish, and other wildlife habitats.

5. A wetland regulatory framework exists within New York City for limited protection from storm events and sea-level rise, but strict application and enforcement are required. In addition, guidelines that promote analysis of climate change impacts for use in environmental assessments or environmental impact statements during government project reviews are needed. The development of such guidelines is recommended as part of adaptation to sea-level rise and other climate change impacts. Guidelines are needed at the federal (CEQ), state (SEQRA), and city (CEQR) levels.

6. Opportunities exist for wetland restoration and enhancement. In addition, inland expansion of marshes may be enabled in New York City and vicinity through acquisition, interagency transfer of public land for permanent easements, and land-use planning changes.

While the benefits of wetlands are well recognized by an increasingly aware public, and regulations have been pursued since the 1970s to protect these areas, the national policy of "no net loss" of wetlands will become more difficult to achieve in view of projected sea-level rise and continuing development pressures.

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CHAPTER 6

WATER SUPPLY

This chapter assesses potential impacts of climate change on the New York City water supply system. It suggests types of adaptive measures that might be undertaken to cope with the effects of climate change. It is now generally assumed that global climate change is likely and that it will include temperature increases, changes in precipitation, and a measurable rise in sea levels. These changes will have impacts both on demand and on supply in the New York City water supply system and other water supply systems in the region, including those of Long Island and the Delaware River.

While temperature increases and sea-level rises are expected, there is a range of forecasts with respect to the timing and level of these variables. Moreover, forecast changes in regional precipitation vary widely, from positive in some global climate models (GCMs) to negative in others. Thus, there is a substantial degree of uncertainty about climate change and its impacts on regional water systems.

Urban water supply systems have large infrastructures, substantial customer bases, and long lead times for planning. Planning must therefore be a matter of considering what elements of the system might be affected by global warming, what information will be needed to make adaptations, and what the timing of such adaptations should be. In most cases, both institutional and infrastructure responses will be required, for example in increasing the interconnectivity of regional systems.

Background

The New York City water supply system stretches from upland reservoirs in the Catskills down through all parts of New York City. Figure 6-1 shows this system. Water is collected from upland watersheds, held in storage reservoirs, and sent via a system of tunnels and aqueducts through balancing and distribution reservoirs to distribution mains in the city and other user areas. User areas are shown in Figure 6-2. The system operates almost entirely by gravity (the highest reservoir, Neversink in the Delaware system, has its spillway at 1,440 feet (439 meters) above mean sea level). About 97% of the total water supply is delivered to the distribution system by gravity; only 3% is electrically pumped to maintain desired delivery pressures.

Water is collected and stored in three upland reservoir systems: Croton, which began service in 1842 and was completed as a system prior to World War I; Catskill, completed in 1927; and Delaware, completed in 1967. The total area of the watersheds is nearly 2,000 square miles. The three systems meet respectively about 10%, 40%, and 50% of the total daily system demand. The systems deliver water to the city via the New Croton, Catskill, and the Delaware Aqueducts. The New Croton Aqueduct delivers water from the Croton System to the Jerome Park Reservoir in the Bronx. Catskill and Delaware water flows via Kensico Reservoir to Hillview Reservoir, just north of the City line.

From Hillview Reservoir, City Tunnels #1 and #2 deliver system water to the City distribution system, which includes some 6,000 miles of mains varying in size from 6 to 96 inches in diameter. City Tunnel #3 is now under construction. Its first stage, which runs from Hillview Reservoir in Yonkers through the Bronx and Manhattan and under Roosevelt Island to Queens, has been completed. When the tunnel is completed through its second stage it will provide not only additional capacity but also the opportunity to shut down City Tunnels #1 and #2 for inspection and rehabilitation.

The 18 impounding reservoirs, three controlled lakes, aqueducts, tunnels and water mains that make up the city water supply and distribution systems together constitute a monumental hydraulic and civil engineering achievement. Detailed descriptions of the system can be found in the documents issued in connection with proposed bond sales (New York State Environmental Facilities Corporation, 1998); see also Major (1992); New York City Mayor's Intergovernmental Task Force on New York City Water Supply Needs (1992); and U.S. Geological Survey (1997).

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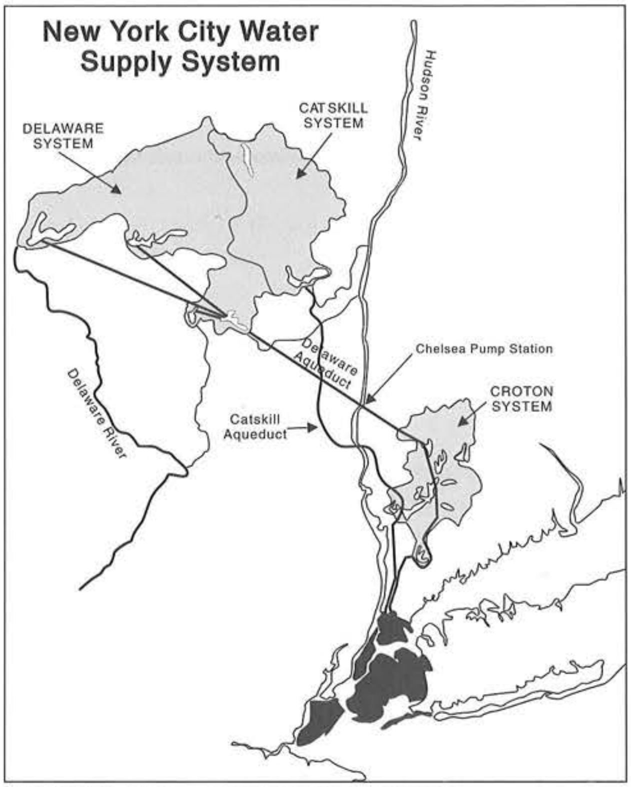

FIGURE 6-1 The New York City water supply system.

The total storage capacity of the upland system is 547.5 billion gallons. Safe yield is defined as the amount of water that could be supplied on a continuous basis by the system should there be a recurrence of the worst drought of record (in the mid-1960's). The safe yield of the upstate elements of the system is currently estimated to be 1,290 million gallons per day (mgd), with 240, 470, 480 and 100 mgd available from the Croton, Catskill, Delaware and Rondout watersheds, respectively. (Rondout watershed is in the Hudson River Basin but is operationally part of the Delaware System.) In addition, there are now 33 million gallons per day of safe yield from the formerly investor-owned groundwater well-based systems in Southeast Queens. System safe yield could be lower than that currently calculated as a result of future droughts and changes in the City's releases to meet Supreme Court and New York State requirements (New York City Mayor's Intergovernmental Task Force on New York City Water Supply Needs, 1992).

Mean annual precipitation on the city's watersheds has been approximately 44½ inches (1,130 mm) during the period of record (about 60 years). During this period, maximum yearly precipitation was 55.67 inches (1,414 mm), in the 1977–1978 water year (the system water year begins on June 1), and the minimum precipitation was 27.97 inches (710 mm) in the 1964–65 water year, during the drought of record. The maximum precipitation was thus almost exactly twice the minimum.

Water from the system is used to supply all of New York City, including to the service area of the former Jamaica Water Supply Company in Queens. In addition, the City system supplies 85% of the water used in Westchester County and 5–10% of the water used in Orange, Putnam, and Ulster Counties. There are also upstate communities that do not regularly use water from the City system but are connected to it for emergency use. Upstate municipal corporations and water districts in counties (except Dutchess) in which the City has water supply facilities have certain legal entitlements to provide connections to the system and to take water, at a price set by the New York State Department of Environmental Conservation, in quantities no greater than their population times the city's per capita use.

The average daily system water supply provided to users in recent years has been on the order of 1400 mgd, reflecting a downward trend since 1989. In 1997, system supply was 1,307 mgd; the reduction is attributable in part to metering and conservation measures. In addition to water supply to New York City and other user areas, the system also provides augmentation and conservation releases upstate and to the Delaware Basin. The annual demands on system yield are, in order of magnitude: demands from New York City; augmentation and conservation releases; and upstate demands. The distribution of use for water year 1988–89, for example, was 78% for New York City

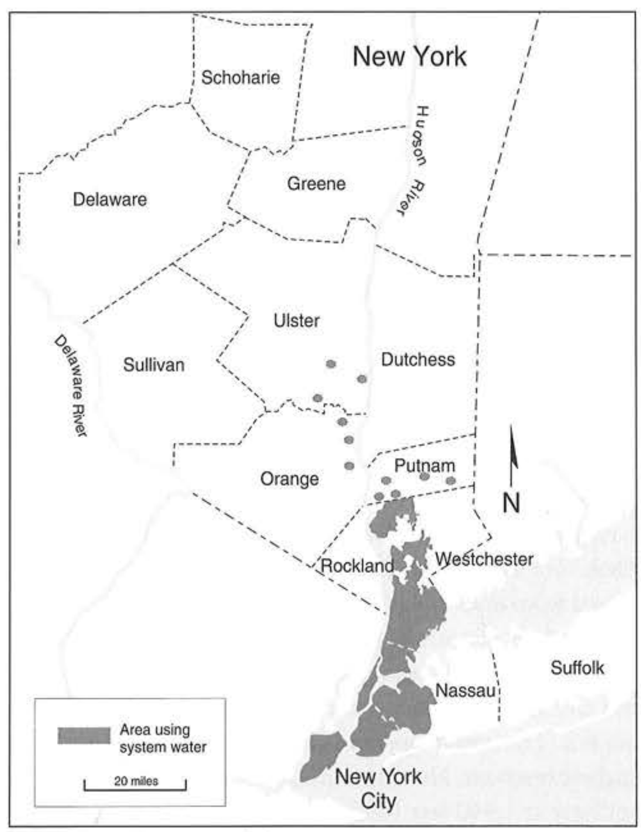

FIGURE 6-2 User areas of the system.

water supply; 15% for the two categories of releases; and 7% for outside community water supply.

The water quality of the system has been high, and the only treatment procedures routinely used to maintain quality have been detention, screening, addition of caustic soda for pH control, and chlorination for disinfection. Fluoridation is also used, and alum is applied in the Catskill Aqueduct to control turbidity when necessary. Corrosion inhibitors may also be added to control corrosivity in the water. There are laboratories that monitor water quality in the system; about 80,000 samples a year are collected, and approximately 1,000,000 analyses made. Routine checks are made for some 60 substances. There are inspectors who maintain surveillance of the watersheds and city-owned and operated upstate sewage treatment plants to prevent the discharge of untreated sewage into the watersheds.

New York City maintains a drought management plan to control water use and supplement water supply during periods of drought; this is currently being updated. Generally, drought management has included three phases, invoked sequentially as a drought becomes more serious. The three phases are Drought Watch, Drought Warning, and Drought Emergency. The last includes four stages with increasingly severe mandated use restrictions. (The phases and stages are summarized in New York State Environmental Facilities Corporation, 1998, pp. B-51, B-52.)

Several droughts of recent years have brought the system to the third of these four stages, which includes serious water restrictions encompassing bans on outdoor water use and the prohibition of air conditioning using public water supplies unless room temperatures are kept at 78°F or above (New York City Department of Environmental Protection, 1991, 1999). A listing of recent droughts in both the New York City and Delaware River Basin Commission areas is reported by New York City Department of Environmental Protection (1999).

In addition, the City has an emergency water supply available from the Chelsea Pumping Station, located on the east bank of the Hudson River in Dutchess County. This station can pump up to 100 million gallons per day from the Hudson River into the Delaware Aqueduct. It was used in the summer and fall of 1985 and for two weeks in May, 1989, under emergency approval from the New York State Department of Health.

The City has long used reservoir simulation models to operate and evaluate the system; these including the principal model, the Reservoir Systems Analysis simulation model (RSA model). A version of this model, based on a model originally developed by the New York State Department of Environmental Conservation, is described in Laedlein and Mayer (1985). The RSA model is a monthly simulation model designed to analyze the entire New York City water supply system. In addition to the RSA model, the City maintains its Daily Simulation Model of the Delaware System for the purpose of evaluating specific system functions, in particular the impacts of conservation release requirements on hydroelectric operations. In addition, the Delaware River Basin Commission's Daily Flow Reservoir Operation Model, developed originally for the U.S. Army Corps of Engineers (1980), is used to evaluate the effects of proposed operation policies and projects on the Delaware River. These and other available models can be used to evaluate changing stream flow patterns resulting from climate change impacts.

The Delaware reservoirs of the New York City system are managed in conjunction with the Delaware River as a whole, but not with all of the elements of water supply in the Delaware River basin (see below). This joint management is pursuant to decrees of the United States Supreme Court, and is under the jurisdiction of the Delaware River Basin Commission, a Congressionally chartered compact, with a river master, generally a United States Geological Survey employee.

The water systems of New York City, the Delaware Basin, and other adjacent systems to the west in New Jersey and to the east on Long Island are generally mature infrastructure systems with well-developed institutions that include city, state, and county agencies and the Delaware Basin River Commission, and an intergovernmental group formed as a result of the work of the New York City Mayor's Intergovernmental Task Force on New York City Water Supply, the Southeastern New York Intergovernmental Water Supply Advisory Council (SENYIWSAC).

The systems are operated by agencies already used to dealing with substantial, albeit short term, natural variation in weather. These characteristics make the implementation of institutional and infrastructure adjustments to increase resilience more feasible. System descriptions are in Delaware River Basin Commission (1983); Major (1992); New York City Mayor's Intergovernmental Task Force on New York City Water Supply Needs (1992); U.S. Geological Survey (1997); New York State Environmental Facilities Corporation (1998); and New York City Municipal Water Finance Authority (1999).

Changes in the system from 1950 to 2000 have involved massive infrastructure expansion; a downward impact on estimates of system yield due to the drought of the 1960s; demand management; and more recently, active watershed management for water quality protection (see Platt *et al.*, 2000).

After World War II, the system was substantially expanded to include the Delaware reservoirs, which now supply 50% of the system's water. These include the largest storage reservoir in the system, Pepacton (in service date 1954), as well as Cannonsville, Rondout, and Neversink. This expansion brought not only the reservoirs, but also the regulation of the Delaware according to Supreme

Court decrees, and the formation of the Delaware River Basin Commission.

Water systems are often characterized by the concept of "safe yield," which is the estimated yield of the system that could be maintained during the drought of record. This has declined substantially for the New York City system in the last half century, as a result of the 1960s drought. Previously, safe yield had been calculated at 1,800 mgd; after the 1960s drought, this dropped to 1,290 mgd. (It is now at 1,323 mgd as a result of the acquisition of the Jamaica Water Company.) A new drought of record would affect this further.

The ultimate impact of conservation measures, principally metering and low-flow fixtures, in offsetting demand growth is still unknown, but many observers feel that the effects so far have been significant (see, for example, New York City Department of Environmental Protection, 1998, 1). The most important of these measures are the Universal Metering Program and the associated move from flat rate pricing to metered per-unit pricing. Under the metering program, all connections in the city will soon be metered; about 23%, mostly industrial and commercial connections, were metered prior to the start of the program. Other important conservation programs include New York City's low-flow fixtures law and retrofit programs and its aggressive leak detection program.

Looking further into the future, there are a variety of factors that might change total demands on the system in addition to the global warming impacts considered below. These include demand growth in existing use areas, the addition of new user communities both upstate and on Long Island, and additional conservation flow demands (to maintain fisheries, for example) by the State. A wide range of planning issues is presented in the reports of the Mayor's Task Force (New York City Mayor's Intergovernmental Task Force on New York City Water Supply Needs, 1986, 1987a,b, 1992). The Southeastern New York Intergovernmental Water Supply Advisory Council, a stakeholder in the present study, is continuing much of this work.

Role of Climate

Climate is an important determinant of the design and operation of water supply systems; every system is affected by variation in hydrologic conditions, droughts, floods, and temperature (including its impacts on evapotranspiration and demands). Global climate change is now likely, and will be accompanied by temperature increases, changes in precipitation, and a rise in sea levels (Intergovernmental Panel on Climate Change, 1996a,b,c). On the other hand, it is accepted that there are many uncertainties, both at the global and regional levels. At regional scales relevant to the New York City water system, for example, current global climate change models cannot forecast rainfall patterns with sufficient accuracy to indicate what will happen to precipitation in the New York City system watersheds. Thus, although there are potential impacts of global warming both on demand and on supply in the New York City system, planning must be a matter of considering what elements of the system might be impacted by global warming, what information will be needed to make decisions, and what the timing of such decisions should be. Urban water supply systems have large infrastructures, substantial customer bases, and long lead times for planning. For these reasons, it is important to evaluate the potential effects of global environmental change.

The climate changes most likely to affect water demand and supply include temperature changes, precipitation changes, and sea-level rise. In most cases, both institutional and infrastructure responses will be required. These can be small to substantial (although it should be remembered that with respect to the New York City water system, relatively small changes can be large in absolute terms). The changes may also be both within an individual system, such as the New York City water system, and between systems, as for example possible water exchanges between the New York City system and Long Island groundwater systems. In addition, the different impacts of climate change can interact, which will affect the mix and size of the adaptive measures required.

Temperature Changes. Increases in mean regional temperatures can be expected to affect demands for air-conditioning and recreational demands for water, such as increased releases to maintain fishing habitat. On the supply side, there will be increases in evaporation that will reduce available flows. It is the effect of temperature change on evapotranspiration that is the key relationship between temperature change and water supply.

Precipitation Changes. A principal effect on demands would be for outdoor sprinkling, a substantial water use in areas of one and two family homes. This could fall or rise depending on the direction of precipitation change. A drop in precipitation and runoff would affect average reservoir storage and thus would also affect operating rules; a severe drop in precipitation would be a serious problem in terms of water supply. The frequency of droughts would increase, the safe yield of the system would be substantially reduced, and there could be the need for both institutional changes and new infrastructure investments.

A substantial increase in precipitation would cause local flooding problems, but on the other hand increased flows may help with some ecosystem and recreation problems associated with sea-level rise. Modeling results indicate that precipitation changes can be either positive or negative; the spatial and temporal resolution of the models does not permit a more secure forecast within current modeling and computational techniques.

Sea-Level Rise. Sea-level rise can affect coastal water systems such as the New York City system in several ways. A rising sea will push salt intrusion further up the Hudson (and the Delaware) estuaries. The Hudson River salt front (defined as 100 mg/L chloride) is gauged by the United States Geological Survey. Normally, the salt front ranges between the area from about river mile 35 (Haverstraw Bay, with the southern tip of Manhattan = river mile 0) and upper Newburgh Bay, at about river mile 60, but extreme high freshwater stream flows can push the salt front all the way out of the river and extreme drought conditions can send the salt front above the water intake for the city of Poughkeepsie. In addition, rising sea levels can result in salt-water intrusion into aquifers, such as those on Long Island, resulting in the degradation of water supplies from groundwater. Finally, rising sea levels can be expected to impact ecosystems serviced by the freshwater system.

Sector Stressors Other Than Climate

There are a variety of factors in addition to climate change that might change total future demands on the system. As mentioned, these include demand growth in existing use areas due to population and income growth, the addition of new user communities both upstate and on Long Island, and additional conservation flow demands by the State. In addition, income and population growth also have affects on water quality; this occurs particularly through the development of second homes in watershed areas, and the construction of larger primary residences in the closer-in watershed areas. These effects will continue to be relevant even with demand management measures.

POTENTIAL IMPACTS OF CLIMATE CHANGE

Research Questions

The research questions relevant to this sectoral study are based on the nature of the systems involved, the role of climate, and the possibilities of adaptation. The New York City and adjacent water systems have rarely been studied as related elements of a larger system, except for the joint management inherent in the Supreme Court Delaware decrees. The research questions essentially deal with the examination of the shared ability of these mature infrastructure systems, built for specified purposes and conditions, to be coordinated and dynamically adapted to new conditions of climate change. The questions include:

- What are the likely effects in direction and amount of climate change on demand and supply in the region's systems?
- What feasible *infrastructure* adaptations to climate change can be undertaken to exploit currently unused joint operation opportunities in these interregional systems, taking into account current and future hydrologic and demand conditions?
- What feasible *institutional* adaptations to climate change can be undertaken to exploit currently unused joint operation opportunities in these interregional systems, taking into account current and future hydrologic and demand conditions?
- What are the benefits, costs and optimal timing of available adaptations?

A broad long-term research approach for considering the impacts of climate change on water supply systems and developing an adaptation strategy includes the following elements:

1. Forecasts and estimates of the effects of climate change on flow, including estimates of extreme events.
2. Forecasts and estimates of demand on the system, incorporating a range of economic, demographic, and technological elements.
3. Combined assessment of the first two, in order to examine the potential range of variation of demand/supply combinations in future years.
4. Examination of the elements of the system in order to identify those that are likely to be impacted by the above variation.
5. Development of a strategy of adaptation, including infrastructure and institutional changes, staged over time, and intended to be cost-effective in coping with the variability imposed by climate change (in addition to natural variability).

This study begins the investigation of many of these questions, potential impacts, and adaptation strategies.

Previous Studies

There has been relatively little work on climate change and the New York City water system. The Mayor's Task Force noted the need to be aware of climate change impacts on the system a decade ago (Mayor's Intergovernmental Task Force on New York City Water Supply Needs, 1987a, 17), a point taken note of in Schneider (1990), although there has not been as yet an extensive effort to consider these impacts in any systematic way; this project fills a part of this gap. A short review of relevant considerations is in Alpern (1996).

On the other hand, the system does have one of the few concrete adaptations to global warming in any large water supply system, an outflow pipe for the Third City Tunnel on Roosevelt Island built higher than originally planned explicitly to take into account the possibility of rising sea levels (Hurwitz, 1987; Schwarz and Dillard, 1990, 348).

(The redesign was not total, however; the designers raised the outlet to the extent possible within existing design constraints, rather than redesigning completely.)

There has been some work on the impacts of climate change on the Delaware system, and in other urban areas on water demands and climate change. A review focusing on the uncertainty of effects in the Delaware Basin is in Lins *et al.*, 1997. Boland (1997) studied the effects of climate on water demands in the Washington, DC, area, concluding that foreseeable effects could be offset by conservation measures (p. 175).

The most comprehensive recent demand forecasts for the New York City system (Hazen and Sawyer, 1989) showed large increases in demand under some assumptions, using a model based on population and income forecasts, but with substantial reductions forecast due to the implementation of potential conservation measures (Table 6-1). For 1995, for example, total demand without conservation was projected at 1,631.3 million gallons per day, and with assumed additional conservation measures such as metering and plumbing fixture replacement, 1,445.0 mgd. For 2015, the same study projected daily demands of 1,845.1 mgd without conservation, and 1,461.6 mgd with conservation (Hazen and Sawyer, 1989, p. 1–16). Since that study, effective demand management programs have been put into place, offsetting upward demand pressures from population and income (see the assessment in New York City Department of Environmental Protection, 1998). However, for the reasons given above, demands may once again increase.

TABLE 6-1
Estimated effects of conservation measures on demand in New York City (mgd)

	NYC Demand—Met by NYC Sources				
	1995	2005	2015	2025	2035
Projected demand without conservation	1611.3	1739.1	1845.1	1952.6	2061.4
Savings due to conservation measures					
Reduced use due to initial conversion of flat rate accounts	35.0	35.0	35.0	35.0	35.0
Reduced use due to price increases	48.5	76.6	104.6	133.4	163.0
Reduced use due to replacing plumbing fixtures	33.6	69.8	106.5	143.6	181.1
Reduced use due to multi-family residential conservation	23.4	50.2	78.9	109.2	141.0
Savings due to improved programs dealing with leakage, abandoned buildings and vacant lots	45.8	53.7	58.5	63.4	68.3
Savings sub-total	186.3	285.3	383.5	484.6	588.4
Projected demand with conservation	1425.0	1453.8	1461.6	1468.0	1473.0

(In 1995, total New York City demand without conservation is projected to be 1631.3 mgd of which 20.0 mgd is assumed to be met by Jamaica Water Supply Company wells. Total projected demand with conservation is 1445.0 mgd.

Source: Hazen & Sawyer 1989

Data and Methods

The aspects of climate change most relevant to water supply planning are temperature increases, changes in precipitation, associated increases in extreme events, and rise in sea levels. These changes may have a wide range of impacts on both the demands for and the supplies of water from the region's systems. The estimates of physical parameters (below) show something of the range of uncertainty involved, as does a consideration of future demands, which could increase or decrease depending on expansion of users of system water, climate change impacts, and conservation.

The data used in the study, except for the GCM forecasts and the Palmer Drought Severity Index (PDSI) forecasts below, were taken from available studies of the New York City and adjacent water systems. It should be noted that these studies, while numerous and useful, were in general not originally undertaken with a view to examining climate change impacts, and therefore do not provide the full information required for detailed assessment of adaptation alternatives. The procedure therefore has been to identify the main elements of climate change that impact water demand and supply, and to identify likely infrastructure and institutional changes that might be made to adapt to these effects. The analysis is framed by the basic understanding that, at least for water systems and barring (possible) surprises, the effects of climate change can best be seen as an additional source of uncertainty imposed upon the substantial hydrologic and demand uncertainties with which water systems must regularly deal (Stakhiv, 1993).

Climate Change and Socio-economic Scenarios

Several future physical parameters of climate that can be expected to affect regional water systems were projected for the MEC region to provide an indication of the potential range of climate variability. These parameters include temperature and precipitation. (For a study of the socioeconomic impacts of climate change on water in the United States, see Frederick and Schwarz, 2000). While such projections cannot be expected to provide credible estimates for specific locations, the use of a scenario approach with GCM outputs can be used to demonstrate the effects that climate change might bring to the system (Boland, 1997, 171, 174).

The GCM scenarios described in Chapter 2 *Regional Climate and Potential Change* were used to consider climate change impacts on water supply with the Palmer Drought Severity Index for the region. The PDSI calculations for the region are done not only for the four GCM run results, but also for a range of sensitivity on the temperature and precipitation parameters; this provides a wider look at the range of possible outcomes than using the GCM outputs alone. It should be noted that the concept of drought in the PDSI is a purely physical concept; by contrast, in speaking of a Drought Management Plan, water supply managers refer to the intersection of physical drought and the use of water in a specified time period.

PALMER DROUGHT SEVERITY INDEX (PDSI)

The Palmer Drought Severity Index compares anomalous dry and wet years to normal years; it is used to identify relative droughts and floods at particular places (Palmer, 1965). It uses a simple overall water balance approach. Runoff occurs whenever the soil profile is full, and there is evaporation at the potential rate whenever there is enough water present. Higher temperatures result in increased drought through increases in potential evapotranspiration (PET) and evapotranspiration (ET). Increased precipitation causes increased flooding. Inputs into the PDSI model are monthly mean temperatures and precipitation (interpolated for the MEC region from GCM results) . In addition, other inputs are the soil water capacities and the Thornthwaite (1948) parameters, which are a function of the mean temperature and latitude. The program used for calculations is Karl (n.d.). Outputs are the monthly PDSI and other climatic variables. The PDSI classes for wet and dry periods are:

> 4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to –0.49	Near normal
–0.50 to –0.99	Incipient drought
–1.00 to –1.99	Mild drought
–2.00 to –2.99	Moderate drought
–3.00 to –3.99	Severe drought
< –4.00	Extreme drought

It should be noted that this model is particularly sensitive to temperature changes, as the results below indicate.

The Palmer Drought Severity Index was calculated for the Metro East Coast Region as a whole, using historic data and an interpolation from GCM outputs. Over the period of record (1900–1997), daily data for each of 23 sites used in the study were downloaded from the National Climatic Data Center at: http//www.ncdc.noaa.gov/ol/climate/research/ushcn/daily.html. (This page also presents the data inventory and format.) The data set is the United States Historical Climate Network (USHCN) set; more information on the data can be found at: http://www.ncdc.noaa.gov/ol/climate/research/ushcn/ushcn.html. The 23 sites of daily data were combined using all available data; there were somewhat fewer sites available during the beginning years of the assessment than in the later years. A discussion of the PDSI can be found in Rind et al., 1990.

Results

The Palmer Drought Severity Index results (Figure 6-3) generally suggest more droughts in the region; this is because of rising temperatures as well as, in the Canadian Centre model, less precipitation. In the Hadley Centre model, more precipitation modifies this effect, with conditions becoming generally wetter throughout the new century. These results, by emphasizing both variability and uncertainty, suggest that the adaptations described in this work are important elements for study. Drought and flood probabilities for future years are also shown (Figures 6-4 and 6-5). These indicate the key role of precipitation, the most difficult parameter to forecast at the regional level: depending on the GCM model, both floods and droughts can increase or decrease. Sensitivity results, showing drought and flood probabilities for stepwise changes in temperature and precipitation are shown in Figures 6-6 and 6-7 and also Table 6-2, which gives flood and drought probabilities for numerous temperature and precipitation changes.

To check on the regionalization used for this assessment, the PDSI was calculated directly from historical data and the relevant GCM output at three points: Mohonk Lake, in the Catskills; Setauket, on Long Island, and Flemington, NJ, which is close to the boundary of the Delaware watershed. The results are shown in Figures 6-8, 6-9, and 6-10. The results are close in each case, which suggests that the regional calculation is appropriate for policy at this level.

ADAPTATION (SPECIFIC)

The overall results of the study indicate that there are substantial opportunities for adaptation in the New York City and adjacent systems. These adaptations are likely to be valuable both for natural variability in the current climate, and for anthropogenic climate change. There will almost certainly be effects on Metro East Coast water systems of climate change, through precipitation, temperature and its effects on evapotranspiration, and sea-level rise,

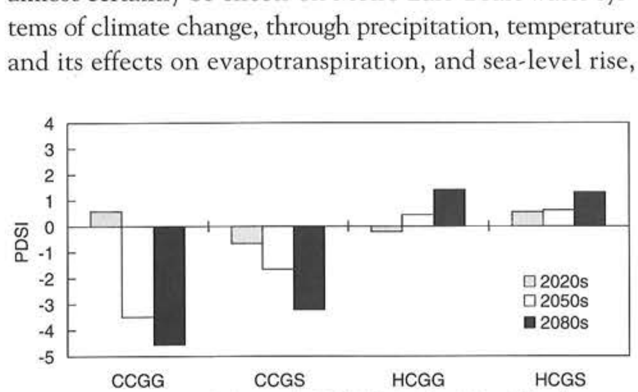

FIGURE 6-3 Projected change in PDSI, Metro East Coast Region.

and these changes have to be monitored and appropriate adaptations undertaken over time. Moreover, the water sector interacts with the other sectors of the MEC study, and these interactions must be taken into account in adaptations. Possible adaptations and their locations are identified below.

In the MEC Region's water supply systems, some adaptations to climate change, both small and large, can be made within individual systems, which makes them simpler in institutional terms. As noted earlier, a well-known instance is the raising of an outlet pipe for City Tunnel #3 at Roosevelt Island in New York City above its original design level, explicitly in response to potential sea-level rise.

A larger example of a within-system adaptation that might be undertaken in response to climate change impacts is the possible expansion of New York City's Chelsea pump station on the east bank of the Hudson River south of Poughkeepsie. This is described in more detail in the Integration Across Sectors section below.

Many adaptations to climate change in the region's water systems relate to new institutional, operational and infrastructure relationships among systems that are now connected, but need to be more closely integrated, and among systems that are not now connected. Some of these changes may be worthwhile from the standpoint of climate change adaptation, and some from the standpoint of operating efficiency even absent climate change. Something of the geographic range of potential changes can be seen by considering Figure 6-2, which shows the counties that were part of the Mayor's Task Force; in addition to these, there are also systems in New Jersey, and systems along the Delaware River (see Figure 6-11).

Climate change impacts may require a still more integrated operation of the New York City reservoirs on the

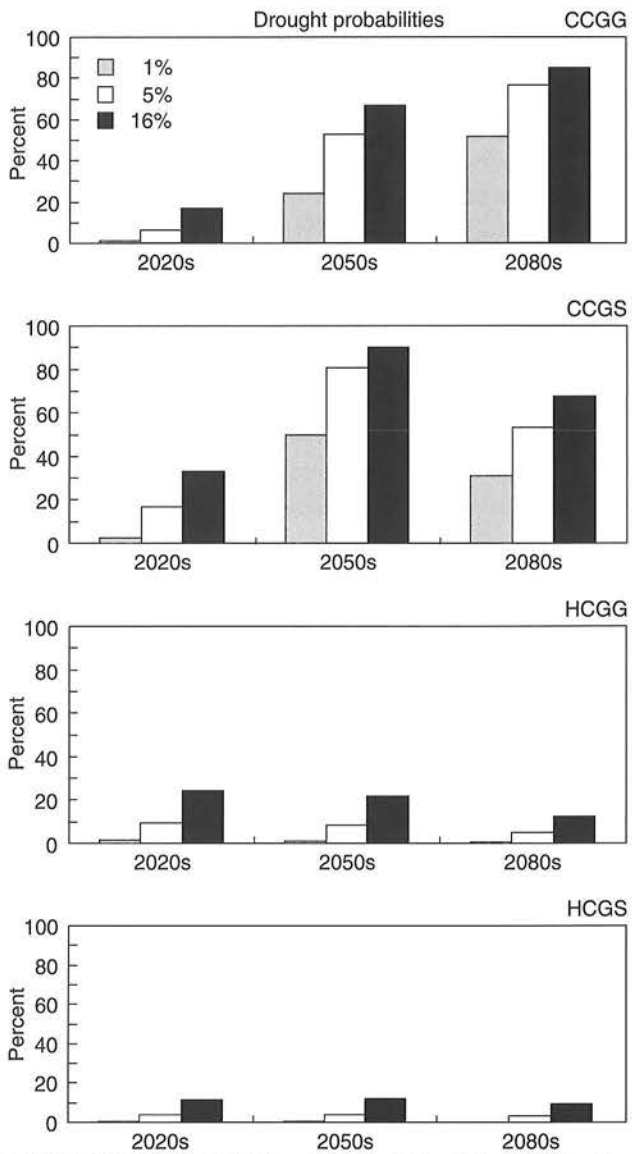

FIGURE 6-4 Projected GCM drought probabilities, Metro East Coast Region.

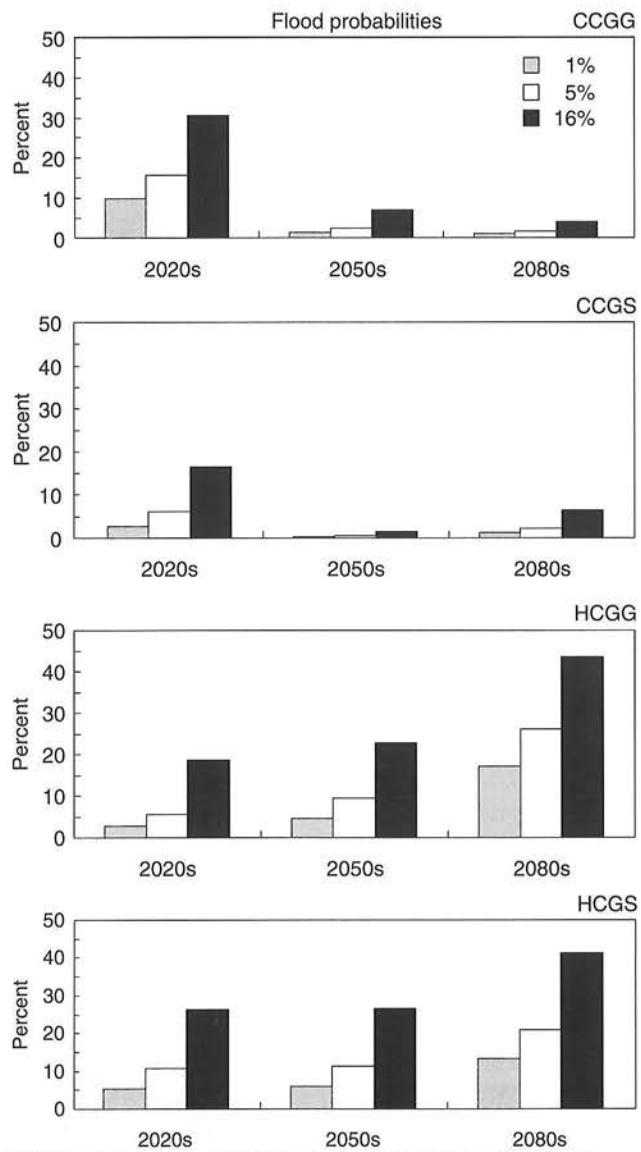

FIGURE 6-5 Projected GCM flood probabilities, Metro East Coast Region.

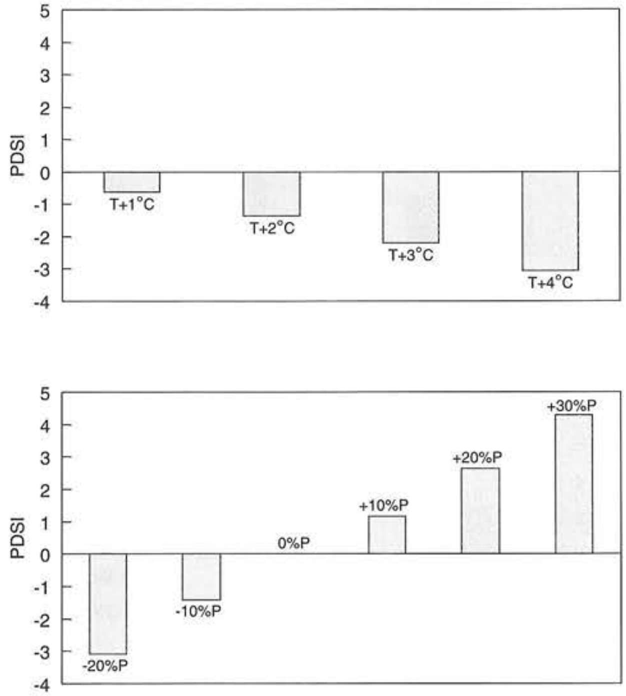

FIGURE 6-6 PDSI sensitivities, Metro East Coast Region.

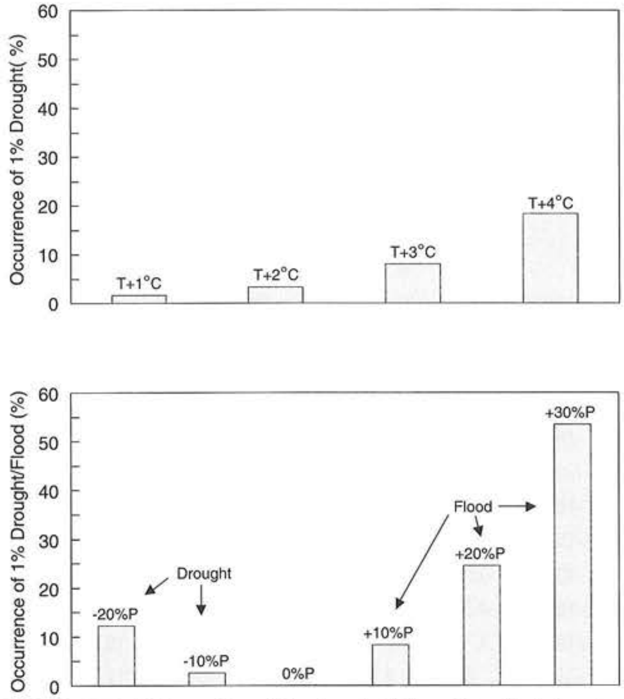

FIGURE 6-7 1% Drought and flood probabilities, Metro East Coast Region.

Delaware and other Delaware Basin systems (Hansler and Major, 1999). To the west of the City, the Delaware River and the New York City system are already linked operationally through a strong institution, the Delaware River Basin Commission (see, for example, Delaware River Basin Commission, 1983). The main surface water systems of interest in the Delaware Basin downstream of the New York City reservoirs include the F.E. Walter Reservoir in the Lehigh Basin west of the Delaware, operated by the U.S. Army Corps of Engineers; the Merrill Creek Reservoir in New Jersey, operated by a consortium of electric utilities; the Philadelphia intake pipe at Torresdale, which provides an average 200 million gallons per day to Philadelphia; and the intake of the Delaware and Raritan Canal at Bull Island, operated by the New Jersey Water Supply Authority, which draws 100 million gallons per day for areas in central and northern New Jersey.

The ecological systems of the Delaware River and the estuary are directly affected by releases from the Delaware River reservoirs of the New York City System and other reservoirs in the Delaware Basin. For example, lower basin well fields near Camden, New Jersey and New Castle, Delaware draw water from the Potomac/Raritan/Magothy aquifer, which is sensitive to salinity in the estuary as affected by releases to the river. In addition, recreation and fishing demands in the Delaware can be competitive for reservoir storage with water supply demands, and during drought and hot weather, this competition is at its keenest.

Infrastructure changes appropriate to climate change may include the rehabilitation of the Delaware Canal in Pennsylvania, modification of dams, and interconnections among Delaware systems. Institutional implications of such changes may include water banking, reservoir and canal cost-sharing, intake modification cost-sharing, and interconnection cost-sharing.

Also to the west of New York City, useful links among systems may include water sharing between the New York City system and northern New Jersey. During the 1981 drought, a pipe to transfer 20 million gallons per day was laid across the George Washington Bridge (Delaware River Basin Commission, 1981), and the maintenance of such a link is certainly feasible.

On the eastern side of the New York City System, infrastructure and institutional change may be needed to link the New York City System with Long Island groundwater systems. Given sea-level rise and the differing hydro-geologic characteristics of the systems, there may be scope both for a water exchange and for some net water supply to Long Island. If sea-level rise results in salt-water intrusion into the Long Island aquifers, a serious problem of water supply could occur, because Nassau and Suffolk counties on Long Island currently depend completely on groundwater supply.

One solution, which would require substantial institutional and infrastructure investments, would be to supply some of the Island's water through the New York City system. To do this, there would have to be immediate attention to a design issue in City Tunnel #3. City Tunnel #3, when completed, will reach to eastern Queens, and so could be used as a conduit for water destined for Long

TABLE 6-2
PDSI sensitivities and probabilities, Metro East Coast Region.

Clim. Chg. Mean		Drought			Flood		
(C,%)	PDSI	1%	5%	16%	1%	5%	16%
T+1	−.61	1.6	10.5	22.0	.0	.8	10.5
T+2	−1.37	3.3	21.3	41.2	.0	.3	7.5
T+3	−2.19	8.0	36.9	60.8	.0	.0	4.2
T+4	−3.07	18.3	57.6	74.8	.0	.0	1.9
−20% P	−3.09	12.2	62.8	78.6	.0	.0	.0
T+1, −20% P	−3.92	28.5	76.3	88.8	.0	.0	.0
T+2, −20% P	−4.83	51.7	87.3	95.1	.0	.0	.0
T+3, −20% P	−5.72	72.3	93.4	98.6	.0	.0	.0
T+4, −20% P	−6.67	86.5	98.4	99.2	.0	.0	.0
−10% P	−1.43	2.6	21.8	44.2	.0	.0	1.9
T+1, −10% P	−2.21	6.1	36.8	64.9	.0	.0	1.6
T+2, −10% P	−2.99	13.4	57.9	76.4	.0	.0	1.4
T+3, −10% P	−3.85	30.8	74.4	83.0	.0	.0	.0
T+4, −10% P	−4.88	53.4	86.5	92.2	.0	.0	.0
+10% P	1.17	.0	2.5	6.3	8.4	15.9	35.5
T+1, +10% P	.57	.3	3.9	10.0	5.2	11.6	25.7
T+2, +10% P	.02	1.3	8.4	17.7	3.2	5.2	21.8
T+3, +10% P	−.61	2.3	12.0	23.6	.4	3.3	13.6
T+4, +10% P	−1.42	5.2	24.3	42.1	.0	.7	9.1
+20% P	2.65	.0	.3	4.0	24.5	36.5	62.0
T+1, +20% P	2.01	.0	1.5	4.8	16.6	29.0	53.8
T+2, +20% P	1.31	.1	3.5	7.5	12.7	20.5	46.7
T+3, +20% P	.61	.9	5.2	10.1	6.0	14.7	30.6
T+4, +20% P	−.05	1.9	9.3	19.0	4.5	9.4	24.4
+30% P	4.28	.0	.0	.2	53.4	68.2	88.4
T+1, +30% P	3.54	.0	.0	3.1	39.1	56.6	79.1
T+2, +30% P	2.79	.0	1.1	4.4	29.1	43.5	63.5
T+3, +30% P	2.00	.1	3.1	6.2	20.7	29.1	54.6
T+4, +30% P	1.22	.8	4.1	8.5	14.9	24.3	46.2

Island users. The third stage will go from Kensico Reservoir to the interconnecting chamber of Stage 1 just south of Hillview Reservoir, and the fourth stage will go from the northern terminus of Stage 1 directly to Queens. However, as currently planned, the third and fourth stages are designed to meet New York City needs alone. They would have to be reconfigured in terms of physical design and operating rules in order to permit supply to Long Island at some future time. Such infrastructure changes will have to be accompanied by the development of institutional relationships that are still embryonic.

To the north of the City system, operational integration of several reservoirs in the Adirondacks in the case of extreme droughts might be contemplated, although the location of these reservoirs in the Adirondack Park, protected as wilderness in the New York State Constitution, would doubtless make integration institutionally complex.

Institutional changes have been significant in the development of the New York City water supply system.

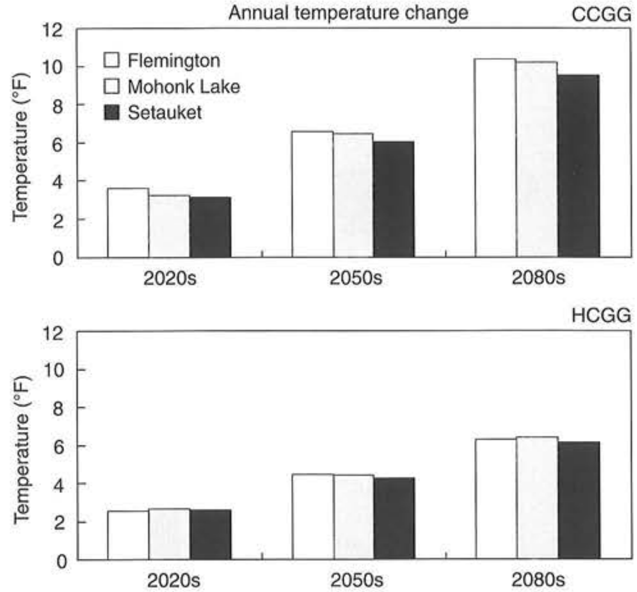

FIGURE 6-8 CCGG and HCGG projected annual temperature change.

Perhaps the most notable example since World War II is the creation of the Delaware River Basin Commission. More recently, the intergovernmental group formed as a result of the work of the New York City Mayor's Intergovernmental Task Force on New York City Water Supply, the Southeastern New York Intergovernmental Water Supply Advisory Council, has played a useful role in maintaining relationships, fostering cooperation, and studying key problems.

In the United States as a whole, important new developments in water institutions include the increasing use of markets and privatization. These methods have not been as common in the relatively water-rich east as in the west, but they may become more common as climate change and demand pressures increase uncertainty. With respect to markets, for example, the Metropolitan Water District of Southern California (MWD) has announced its willingness to buy additional supplies of water on the free market; the MWD already operates water banks with groundwater operations in Kern County and Ventura County, California (Metropolitan Water District of Southern California, 1999).

The Delaware River Basin Commission has undertaken one example of this type of institutional innovation, purchasing water supply storage in the U.S. Army Corps of Engineer's F.E. Walter Reservoir used for flood control in the Lehigh Valley. There has been some privatization of public water supply operations (although not generally of ownership) in the MEC area, for example the operation of the Jersey City system by the United Water Company. These types of institutional changes, while not directly related to climate change, can be expected to increase institutional flexibility in adapting to climate change in the future.

Many adaptations can be made that do not require great detail for planning purposes. However, this is not true for

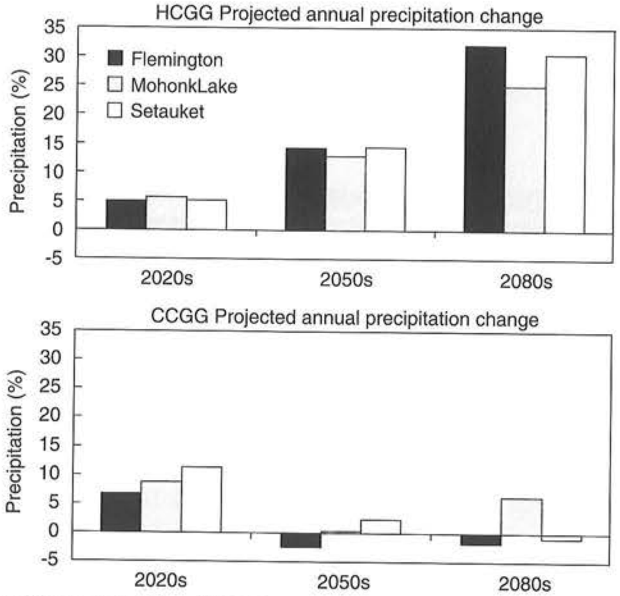

FIGURE 6-9 CCGG and HCGG projected annual precipitation change.

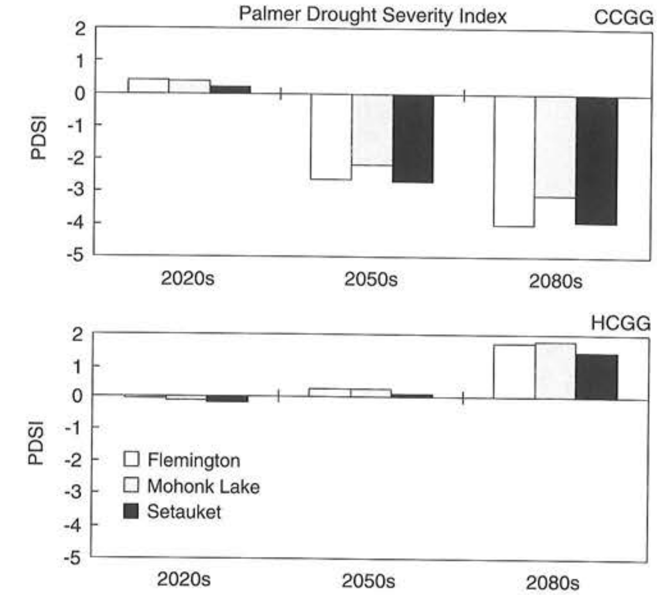

FIGURE 6-10 CCGG and HCGG projected PDSI.

every change in the system, especially for some operating system changes. An example of the complexity of detailed operational changes from climate change is provided by fish habitat maintenance in the Esopus Creek. (See Rosenzweig et al., 1999, Water Sector pp. 10–11.) Esopus Creek, which is the water link between the Schoharie and the Ashokan Reservoirs via the Shandaken tunnel, is a multi-purpose stream. It is used, among other purposes, for float tubing (which may be quite important as measured by user-days/year), kayaking and canoeing. However, one of the most important of the Creek's uses is for trout fishing; it is a celebrated Northeastern trout fishery. It supports the natural reproduction and growth of rainbow trout (*Salmo gairdenerii*); brown trout (*Salmo trutta*); and brook trout (*Salvelinius fontinalis*), the breeding populations of which occur principally in small tributaries.

The greatest dangers to the trout are low levels of dissolved oxygen, slow stream velocity, low depth of flow, high water temperature, and high levels of turbidity. The spawning and growth of trout eggs are enhanced by the proper bed load and material. In fact, the female trout often uses the bed material to cover and protect her eggs. However, if the stream flow and stream depth are low, fine sediments build up and settle in the stream bed. This condition inhibits the supply of dissolved oxygen from the atmosphere to the developing embryos and is exacerbated if turbidity levels in the stream are high. The net result is the formation of anoxic conditions that suffocate the embryos.

If the Esopus Creek's stream flow and stream depth are reduced in a warmer climate with low precipitation, additional water would have to be supplied to the Ashokan reservoir through the Shandaken tunnel to support the trout fishery. However, since the turbidity levels increase when flow enters it from the tunnel, the trout fishery of the Esopus Creek may be jeopardized. This scenario illustrates the complexity of adaptations to climate change at the operational level, and of the need for detailed studies of operating rules in such cases.

ADAPTATION (GENERAL)

Adaptation measures for climate change in water resources are discussed in Chapter 14, "Water Resources Management," of IPCC 1996b; an excellent survey of evaluation methods is in Carter et al., 1994. Major (1998; see also Stakhiv and Schilling, 1998 and Frederick, 1998) provides a list of adaptive measures in water resources, including:

- Interconnection of systems to provide additional backup for changing regional conditions.
- Incremental construction where possible and economically feasible (e.g., a number of small systems rather than one large one) to allow for adaptation to changing circumstances.
- Choice of robust designs, in which the chosen design will be moderately effective under a wide range of outcomes, rather than optimal under one outcome.
- Postponement of irreversible (or very costly to reverse) decisions.
- Use of a range of formal decision techniques, including scenario analysis, sensitivity analysis, Monte Carlo methods, and others.
- Design for extreme conditions. Using historical or synthesized flows, the water resource planner can suggest approaches that explicitly deal with extreme events (floods and droughts), rather than simply maximizing the expected value of net benefits.
- Reallocation of storage. After projects are constructed, and circumstances change, storage can be reallocated to

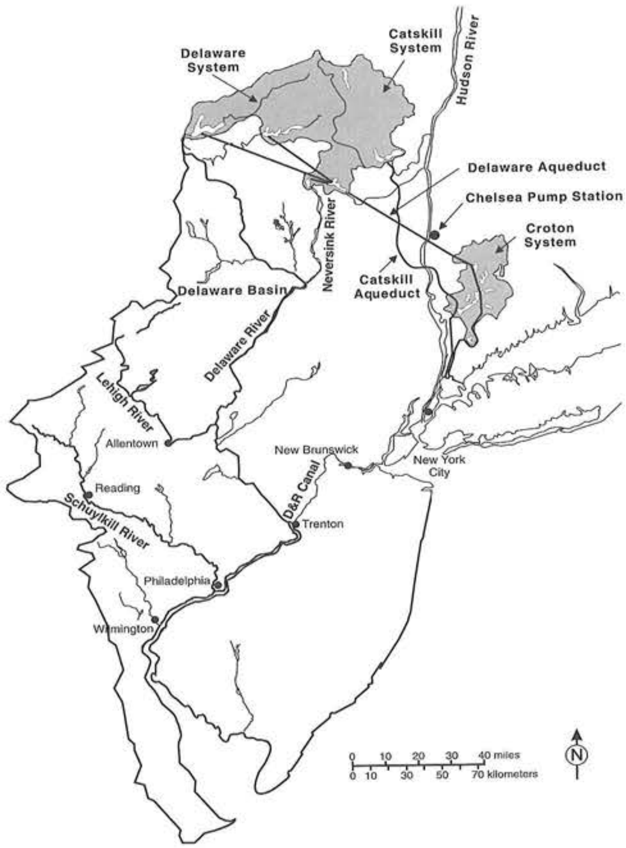

FIGURE 6-11 Opportunities for adaptation: New York City Water Supply System and the Delaware River Basin.

improve project performance under changed climatic conditions. In a dryer climate, for example, storage can be shifted from flood control to water supply.

- Reallocation of supply through the development of water markets.
- Development of non-structural measures such as warning systems. Flood and storm warning systems (inland and coastal) can be used to adjust to the risks and uncertainties of flooding.
- Demand management measures. These measures, such as implementing pricing schemes, requiring low-flow toilets or formulating drought contingency plans, can be used to control demand and thus provide in effect a measure of additional capacity in existing supplies.
- Shoreline planning schemes to provide adaptability to rising sea levels.
- Physical project changes to account for sea-level changes (e.g. raising outflow levels).
- Preservation of ecosystems. As an adjustment to uncertainty, areas can be reserved to protect against the uncertain effects of climate change on ecosystems.

Many of these adaptation strategies are relevant to, and some have been used for, the New York City water system. The assessment of the suitability of these and other adjustments should be undertaken in the context not only of their benefits with respect to climate change impacts, but also in terms of their effects on general system efficiency.

CHALLENGES AND OPPORTUNITIES

The challenge of adaptation in the New York City water supply system and adjacent systems is to undertake the preparatory work for the required institutional and infrastructure changes. This should be begun and completed within the next decade, in order to stay ahead of possible climate impacts. The work should include studies of adaptation opportunities, assessment of benefits and costs, and optimal scheduling. All of this should be done to the level at which agencies can undertake detailed implementation studies as required. Further, periodic monitoring and analysis of possible climate-related changes in precipitation, temperature, and sea-level rise should be undertaken by the agencies.

INTEGRATION ACROSS SECTORS

The water sector relates to many of the other impact sectors, including health, institutions, and sea-level rise. In particular, it relates to sea-level intrusion, through effects on wetlands (for a survey of wetlands in the New York City watersheds, see Tiner, 1997), aquifers, and water intakes located on rivers. An example of the last is the Chelsea Pump Station.

The pump station is located on the east bank of the Hudson River at Chelsea, south of Poughkeepsie, and has a present capacity of 100 mgd. River water is taken via an intake into the pump station, and after treatment is forced into the nearby Shaft 6 of the Delaware Aqueduct, where it mixes with water from the Delaware system. Studies have been made to increase its capacity, and further studies of the Hudson River system are underway for New York City. Detailed diagrams of the current station and possible expansion options are provided in Malcolm Pirnie (1986).

Increased sea-level rise, bringing increased salinity, could affect the operation of the station. This would exacerbate a fundamental conflict, which is that the station is needed most in drought, which is precisely the time when the salt front moves upstream. Adaptations to this could include moving the intake upstream and changing the seasonal use of the station. For this purpose, careful assessments would have to be done of sea-level rise and the salinity front. Hence, regular monitoring of these physical parameters will continue to be essential.

A study of the Chelsea Pump Station system (Malcolm Pirnie, 1986) indicated that an additional 100 mgd of withdrawal would cost $28 million, and an additional 200 mgd of withdrawal would cost $86 million; the corresponding costs with filtration would be $223.5 million and $327.9 million. These costs, when updated by the ENR 20-city construction cost index from the 1986 average to the 1998 construction cost average would amount to $38.6, $118.7, $308.4, and $452.5 million, respectively. The updated costs given here are illustrative; the actual costs would take into account impacts of climate change and other factors relating to ongoing study of the Hudson River.

INFORMATION AND RESEARCH NEEDS

Research needs include detailed assessments of the adaptation possibilities that have been identified, with engineering, economic and environmental details relevant to assessing the benefits and costs of adaptations and their optimal scheduling over time. In examining the ability of these mature water supply infrastructure systems to be dynamically adapted to new conditions of climate change, the first step is a comprehensive identification of infrastructure and institutional adaptations that are available both within each system and between and among systems.

Many of the most promising adaptations become feasible if the New York City and Delaware River Basin water supply systems, as well as some additional neighboring systems such as those on Long Island, are jointly operated in a more completely integrated way. Potential adaptations include water banking, drought and other joint operating system revisions, physical system interconnections and emergency pumping.

The effectiveness of potential adaptations to climate change should be comparatively evaluated with current hydrologic and demand conditions and a range of future scenarios based on GCM results and demand forecasts. The costs of adaptations and appropriate timing for them should be evaluated and the potential overall success of system adaptation to climate change assessed. A new demand forecasting study for the New York City system that takes climate change into account would be helpful. Undertaking the research summarized here should provide early, vitally needed and well-founded results and recommendations.

POLICY RECOMMENDATIONS

The water supply system of New York City, and those of neighboring areas, face new sources of uncertainty from climate change, especially as it is manifested through temperature, precipitation, and sea-level changes. Because of the uncertainty associated with climate change itself and the level of its manifestations, as well as the dearth of detailed studies of the relationships of these changes to specific demands and supply sources, it is difficult at this stage to make effective forecasts. However, what is known is that there are substantial opportunities for increasing the resilience of the area's water supply systems, and these should be carefully examined and related to increasingly good forecasts of climate change effects.

A useful next step would be for SENYIWSAC to undertake a study of possible adaptations, at first with the existing membership, and then in conjunction with experts from the Delaware Basin and New Jersey. (Beyond that, it may be appropriate for the National Academy of Sciences to undertake a study of adaptation to climate change for these key urban water systems.) The discussions should cover the information and research needs, and the challenges and opportunities described in this report. The principal elements for examination should include:

- The likely effects in direction and amount of climate change on each element of demand and supply in the region's systems.
- Feasible *infrastructure* adaptations to climate change that can be undertaken to exploit currently unused joint operation opportunities in these interregional systems, taking into account current and future hydrologic and demand conditions.
- Feasible *institutional* adaptations to climate change that can be undertaken to exploit currently unused joint operation opportunities in these interregional systems, taking into account current and future hydrologic and demand conditions.
- The benefits, costs and optimal timing of each available adaptation.
- Development of a strategy of adaptation, including infrastructure and institutional changes, staged over time, and cost-effective in coping with the variability associated with climate change (in addition to natural variability).

Barring very substantial surprises, the region's water supply systems should be able to cope with climate uncertainty over the very near term, but an effective planning process needs to be put in place soon in order to consider the adaptations that may be required in the future, especially because the implementation of institutional and infrastructure measures is likely to require long-term institutional commitments. The long time scales and planning horizons, engineering and environmental challenges and political complexity of these issues argue strongly for moving ahead now with planning.

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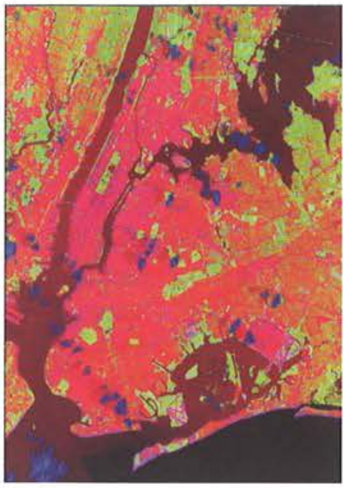

CHAPTER 7

PUBLIC HEALTH

The Metro East Coast Region (MEC) includes 20 million people in 31 counties in the tri-state area of New York, New Jersey, and Connecticut. The socio-economic, ethnic, racial, and genetic diversity of this area engenders an equally complex set of health issues unique to this part of the world. Among the distinguishing demographic features of the region's health profile are the number of inner city persons living in poverty, the number of immunocompromised persons, and the number of immigrants. The goal of this public health sector assessment is to evaluate the potential impacts of climate change on summer-season heat-stress mortality, water- and vector-borne diseases, and air pollution-related morbidity and mortality in the MEC Region. In addition, we present preliminary results of a modeling analysis of the future burden of respiratory morbidity in the region based on combining regional photochemical air pollutant projections and health impact coefficients from previous studies relating pollutant levels to respiratory hospitalizations.

BACKGROUND

With 20 million people, the cultural, ethnic, racial, and socio-economic diversity of the MEC Region makes it unique among world metropolitan areas (Tables 7-1 and 7-2). This is mirrored in a complex set of public health vulnerabilities. These include extensive areas of extreme poverty, particularly in the inner city; high population density; the constant influx of immigrants and transients; an unfiltered municipal water supply; and a sizeable population of immunocompromised persons (Hamburg, 1998).

Table 7-3 displays estimated mortality rates for counties comprising the MEC Region, for the region as a whole, and for the entire United States. Heart disease is the leading cause of death in both the MEC and United States, with rates over 10% higher in the MEC Region. The mortality rate for HIV is over twice as high in the MEC as in the United States. Asthma mortality is similar in the MEC Region as a whole to the United States; however, large variations exist across counties within the MEC Region.

Trends over time (1981–1996) in cause-specific mortality rates are given in Table 7-4. Heart disease rates have been declining, with a much steeper decline from 1986 to 1991 in the MEC as compared with the total United States. From 1981 to 1991, cancer mortality rose in both the region and the country but seem to be leveling off in the most recent years for which data are available. Although mortality due to cerebrovascular disease has been declining for much of the past 20 years, there has been an increase in the trend from 1991 to 1996. Pneumonia and influenza mortality rates seem to be leveling off in both regions, with the MEC trend showing a little more instability than that for the total United States.

Chronic obstructive pulmonary disease and asthma mortality have been on the rise in both the MEC and the United States. By comparison to the national asthma mortality rate of 1.9 deaths per 100,000 persons, higher rates are seen in the MEC counties with the highest poverty rates (see Table 7-3), including the Bronx (6.3/100,000), Brooklyn (3.9/100,000), New York (Manhattan) (4.4/100,000), and Essex, NJ (2.7/100,000). For the rest of the MEC, asthma mortality rates are near or below the national average.

Asthma hospitalization rates have increased nationwide over the past two decades, particularly in the northeast (Mannino et al., 1998). In boys and girls under age 15,

Patrick L. Kinney, Columbia University School of Public Health; Drew Shindell, Center for Climate Systems Research, Columbia University; Eunpa Chae and Brion Winston, Columbia University School of Public Health

TABLE 7-1
Population of MEC Region by county and race, 1996

COUNTY	White	Black	Other	% Non-white
Connecticut				
Fairfield	716,988	88,845	26,380	13.8%
Litchfield	175,443	1,857	2,505	2.4%
N. Haven	688,123	88,004	16,510	13.2%
New Jersey				
Bergen	720,323	45,230	81,456	15.0%
Essex	401,636	323,507	30,582	46.9%
Hudson	413,371	85,828	50,836	24.8%
Hunterdon	113,667	2,524	2,507	4.2%
Mercer	246,504	67,814	15,201	25.2%
Middlesex	570,606	62,868	68,151	18.7%
Monmouth	510,081	55,687	24,479	13.6%
Morris	408,039	14,660	26,478	9.2%
Ocean	451,611	14,924	7,119	4.7%
Passaic	372,083	89,785	19,591	22.7%
Somerset	234,105	18,597	17,668	13.4%
Sussex	137,149	1,494	2,174	2.6%
Union	376,336	100,835	20,562	24.4%
Warren	94,414	1,667	1,350	3.1%
New York				
Bronx	627,554	508,703	52,610	47.2%
Dutchess	230,536	23,567	8,597	12.2%
Kings	1,174,762	928,081	150,714	47.9%
Nassau	1,119,948	126,252	57,298	14.1%
New York	967,055	407,461	153,899	36.7%
Orange	291,575	25,912	6,257	9.9%
Putnam	88,663	907	1,309	2.4%
Queens	1,199,615	459,234	315,359	39.2%
Richmond	336,943	35,913	25,296	15.4%
Rockland	231,131	30,817	16,359	17.0%
Suffolk	1,224,119	95,891	36,175	9.7%
Sullivan	62,904	6,387	1,048	10.6%
Ulster	154,440	8,987	3,229	7.3%
Westchster	712,042	134,512	46,465	20.3%
Total	14,963,103	3,855,843	1,286,855	25.6%

From Centers for Disease Control and Prevention, 1999.

asthma ranks second and third, respectively, for causes of hospitalization among Connecticut residents (CT DPH, 1998) and ranks first in New York City, where the childhood rates are three times the national average (NYC DOH, 1998). Hospitalization rates for asthma and total respiratory causes (including asthma, bronchitis, pneumonia, and emphysema) for selected MEC counties in 1996 are displayed in Table 7-5. These data demonstrate widely varying rates across counties similar to those observed for asthma mortality. In 1996, Bronx County, NY, had over four times the national rate and parts of Manhattan (e.g., in East Harlem) led the nation with seven times the national average. Within the city, asthma hospitalization rates for children in poor minority neighborhoods were over four times greater than for children in high-income neighborhoods. Per capita income and asthma hospital admissions (total numbers for 1997) for all ages are mapped in Figures 7-1 and 7-2.

TABLE 7-2
Estimated percentage of population living in poverty, by county, MEC Region, and U.S., 1996

CONNECTICUT		NEW JERSEY		NEW YORK	
County	% Poverty	County	% Poverty	County	% Poverty
Fairfield	6.9	Bergen	4.6	Bronx	31.4
Litchfield	5.0	Essex	16.7	Dutchess	7.9
N. Haven	10.0	Hudson	17.3	Kings	29.3
		Hunterdon	2.9	Nassau	5.1
		Mercer	8.2	New York	22.7
		Middlesex	5.8	Orange	10.5
		Monmouth	6.3	Putnam	4.0
		Morris	3.3	Queens	16.3
		Ocean	7.3	Richmond	9.2
		Passaic	12.3	Rockland	9.0
		Somerset	3.4	Suffolk	7.4
		Sussex	3.9	Sullivan	15.1
		Union	7.8	Ulster	11.3
		Warren	6.2	Westchester	9.1
REGION					
MEC	10.2				
US	13.8				

Source: Bureau of the Census, 1999.

Table 7-6 shows that, across the United States, hospitalizations due to malignant neoplasms have been declining over the past 20 years while pneumonia has been on the rise. Nationwide asthma rates rose in the mid 1980's, but appear to have declined by 1996. Contrary to the national trend, evidence suggests that New York City's asthma hospitalization rates, already among the highest in the nation, were still on the rise through 1996.

Trends in New York City case reports for three important vector-borne diseases are displayed in Table 7-7. Recent increases have been observed for both Lyme disease and malaria. Too few years are available for cryptosporidiosis to detect any trends.

CURRENT PUBLIC HEALTH STRESSORS

Chief among the current public health vulnerabilities in the MEC region is poverty, which is endemic to pockets of many counties (see Table 7-2 and Figure 7-1). Diabetes, HIV, and asthma are three of the many diseases that have been associated with poverty in the MEC (Wallace and Wallace, 1999). Obesity and a high-sugar, high-fat diet may explain much of the association of poverty with diabetes. Drug abuse and drug-related behavior, e.g., sex for money, probably accounts for much of the association with HIV. Over the MEC region, HIV mortality is right skewed (median = 14.3), varying by more than 25-fold from the lowest HIV

TABLE 7-3
Selected age-adjusted mortality rates, by MEC county, for the entire MEC Region, and for the U.S., 1996. (deaths/100,000 persons/year)

	Heart Disease	Malignant Neoplasms	Cerebrovsc. Disease	Pneumonia/ Influenza	COPD*	HIV	Asthma
Connecticut							
Fairfield	271.2	190.6	51.1	28.7	26.4	11.1	1.4
Litchfield	245.4	189.4	44.4	28.4	33.1		
N. Haven	260.4	205.0	49.1	28.8	28.7	14.6	1.7
New Jersey							
Bergen	257.0	204.9	49.0	23.0	24.3	7.2	1.2
Essex	278.3	223.8	58.2	32.6	29.9	76.6	2.7
Hudson	277.5	214.8	49.6	34.4	32.4	48.0	2.0
Hunterdon	241.3	186.0	50.0	40.3	33.1		
Mercer	287.2	221.3	44.7	41.1	35.1	17.5	1.9
Middlesex	293.5	226.5	51.7	30.0	30.8	13.4	1.2
Monmouth	280.9	209.0	49.0	26.6	31.5	15.7	1.3
Morris	273.5	203.8	50.0	28.2	30.3	4.0	1.2
Ocean	307.7	219.1	43.6	20.7	30.2	11.0	.7
Passaic	272.4	211.6	47.9	23.4	27.4	26.9	1.8
Somerset	229.1	184.5	52.9	27.8	27.2	6.5	1.5
Sussex	263.1	216.0	49.2	34.6	47.0		
Union	254.4	202.6	51.8	27.1	27.6	27.5	2.2
Warren	302.3	198.5	47.7	31.7	38.2		
New York							
Bronx	371.2	196.1	41.1	40.2	26.2	108.7	6.3
Dutchess	328.1	223.9	51.9	38.8	42.0	11.2	1.2
Kings	406.4	195.5	29.6	34.7	22.4	66.0	3.9
Nassau	331.7	199.1	35.7	34.5	25.5	7.7	1.4
New York	264.8	180.4	29.6	33.8	22.9	85.4	4.4
Orange	325.0	225.1	52.0	34.0	41.7	9.4	1.8
Putnam	276.0	226.6	40.1	36.1	31.9		
Queens	369.5	172.6	24.9	26.6	19.4	29.7	2.1
Richmond	450.3	227.0	23.3	49.9	31.6	25.4	1.8
Rockland	322.9	204.0	37.3	42.5	35.3	5.8	1.1
Suffolk	344.3	228.6	50.4	33.1	40.9	8.8	1.8
Sullivan	349.2	224.0	46.0	38.7	46.1	18.6	
Ulster	314.4	238.8	45.8	35.8	49.3	12.7	2.0
Westchester	273.4	199.7	43.8	31.9	28.7	14.0	1.5
MEC Region	300.7	208.0	44.9	32.8	32.2	26.3	2.0
USA	276.4	203.3	60.0	31.4	39.8	11.6	1.9

*Chronic Obstructive Pulmonary Disease

Source: CDC, 1999

area (Morris, NJ, 4.0; 3.3% poverty) to the highest (Bronx, NY, 108.7; 31.4% poverty) with a regional rate more than twice that of the national average.

The large number of immuno-compromised persons in the MEC, mainly persons with HIV, are susceptible to a wide variety of co-morbidities and opportunistic infections (CDC, 1998). The municipal water supply is one potentially significant source of pathogen exposure for these people. As noted earlier, Cryptosporidiosis is a self-limiting enteric disease in individuals with normal immune function caused by an aquatic protozoan that is resistant to chlorination. In persons with HIV and in the very young and old, the disease may be life threatening (Meinhardt et al., 1996). A 1993 outbreak of cryptosporidiosis in Milwaukee, WI, caused over 400,000 cases of acute diarrhea and several deaths (MacKenzie et al., 1995).

TABLE 7-4
Trends in five year intervals from 1981 to 1996 in age-adjusted mortality rates for selected causes: a) MEC Region and b) U.S. (deaths/100,000 persons/year)

MEC Region

	Heart Disease	Malignant Neoplasms	Cerebrovascular Disease	Pneumonia/ Influenza	COPD	Asthma
1981	361.1	191.2	58.3	24.8	21.9	1.3
1986	349.3	207.2	50.0	31.3	28.9	1.5
1991	303.3	210.9	41.9	31.1	30.7	1.9
1996	300.7	208.0	44.9	32.8	32.2	2.0

United States

	Heart Disease	Malignant Neoplasms	Cerebrovascular Disease	Pneumonia/ Influenza	COPD	Asthma
1981	328.3	184.0	68.2	23.4	25.4	1.4
1986	318.8	195.2	59.4	28.9	31.4	1.5
1991	285.6	203.8	54.1	30.9	35.5	2.0
1996	276.4	203.3	60	31.4	39.8	1.9

A similar mass exposure in the New York metropolitan area could result in substantial mortality among the HIV positive population.

Housing characteristics and indoor air quality also affect the health status of the MEC population. Indoor environmental factors that have been linked to adverse health outcomes include lead paint, asbestos fibers, environmental tobacco smoke (ETS), emissions from gas stoves and space heaters, various volatile organic compounds including formaldehyde and organochlorine pesticides, fungi, and a wide range of allergenic particles associated with pets, house dust mites, cockroaches, and rodents (Samet et al., 1987; Gold, 1992). Levels and impacts of these factors are likely to vary across the MEC as functions of housing type, socioeconomic status (SES), age, and other factors. Several indoor agents, including ETS and biogenic allergens, have been linked with either the causation or exacerbation of asthma (NAS, 2000).

While considerable progress has been achieved over the past 30 years in reducing levels of some outdoor air pollutants (e.g., sulfur dioxide and carbon monoxide) in the MEC, other pollutants, especially ozone and particulate matter, continue to reach unhealthful levels on a regular basis (U.S. EPA, Air Quality Trends Report, 1998). The human-health based National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter are often exceeded in the MEC Region, placing several counties out of compliance. Human health effects that have been associated with these two pollutants include mortality and hospitalizations for cardiovascular and respiratory diseases, increases in respiratory symptoms such as cough and wheeze, diminished lung function, and others (Kinney, 1999). Effects are greatest among the elderly, the young, and persons with compromised health status such as asthmatics.

TABLE 7-5
Hospitalization rates for total respiratory conditions and asthma, selected MEC counties and the United States, 1996. (hospitalizations/100,000 persons/year)

	Total Respiratory	Asthma
Connecticut		
Fairfield	748.3	130.9
Litchfield	874.5	85.6
N. Haven	982.9	167.5
New York		
Bronx	1964.7	846.9
Dutchess	873.2	105.1
Kings	1544.5	511.8
Nassau	877.6	160.7
New York	1256.8	420.7
Orange	1133.6	198.3
Queens	1083.4	281.9
Richmond	1270.4	246.6
Rockland	644.3	98.8
Suffolk	769.1	144.7
Sullivan	1194.2	133.6
Ulster	985.9	104.4
Westchester	814.8	124.1
USA	1226.5	179.5

Source: NY and CT State Departments of Public Health.

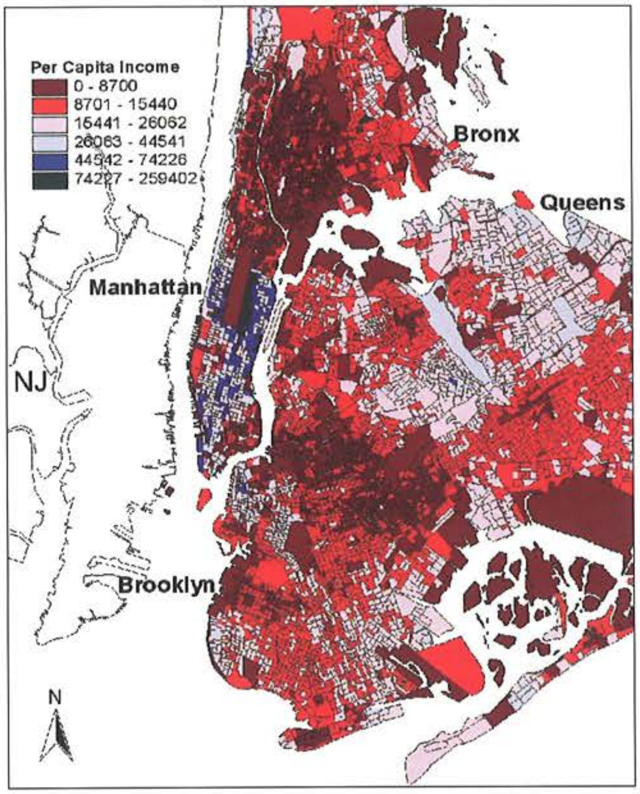

FIGURE 7-1 Geographic distribution of income per capita across New York City in 1990. Data aggregated at the census block group level.
Source: Bureau of the Census, 1999

Another outdoor pollutant of concern, but for which no outdoor air regulations exist, is diesel exhaust particles (DEP), emitted in large quantities by trucks and buses throughout much of the MEC region. Diesel particles consist of tiny carbonaceous nuclei upon which are adsorbed a wide variety of organic compounds, including the carcinogenic polycyclic aromatic hydrocarbons (Kinney et al., 2000). Because of their small size, DEP can be inhaled and deposit deeply in the human respiratory tract. Occupational epidemiology studies have linked DEP exposures with lung cancer. Environmental epidemiology studies have linked exposure to traffic-related pollution—e.g., based on residential proximity to major roadways—with increased respiratory symptom rates and diminished lung function (e.g., see review in Kinney et al., 2000). Within the MEC, DEP exposure is often viewed as an environmental justice issue with respect to the siting of bus depots and other diesel-related sources. For example, seven of eight bus depots and stations in Manhattan are located north of 100th Street in the underpriviledged and largely minority communities of Harlem and Washington Heights.

An important demographic feature of the MEC population that influences regional public health is its status as an intra- and international travel and immigration destination. The MEC continues to be a major port of entry to the United States for visitors, refugees, and immigrants. The high population density of the MEC region, and the constant flux of large numbers of people through it, favors the spread of communicable diseases within and beyond the area. Population movement through the inner city has been important for the intra-regional increased incidence, and the extra-regional dispersion, of tuberculosis and AIDS in recent decades (Cantwell et al., 1994; Bifani et al., 1996). Also, the number of imported malaria cases among people returning or arriving from endemic countries has increased in New York City in recent years to over 100 cases annually (McNeeley et al., 1998).

CLIMATE-RELATED PUBLIC HEALTH STRESSORS

The most direct health effect likely to be associated with a warming and more variable climate is an increase in summer-season heat stress morbidity and mortality[1], particularly among the poor elderly. Though winter-season morbidity and mortality due to infectious diseases might decline if climate change results in shorter and less severe winters, this benefit would likely be offset by a rise in heat-wave associated illness and death as the number of days >90°F(32°C) increases. If hydrological regimes become more variable as predicted (IPCC, 1996), morbidity and mortality associated with extreme weather events, especially flooding, may also rise.

Indirectly, climate change in the MEC region could contribute to at least three classes of adverse health out-

[1]Morbidity includes various measures of illness (e.g., doctor visits; hospitalizations) whereas mortality represents deaths.

TABLE 7-6
Trends from 1981-1996 in hospitalization rates for selected causes: U.S. and New York City (Hospitalizations/100,000 persons/year).

Year	Heart Disease	Malignant Neoplasms	Cerebrovascular Disease	Pneumonia	Asthma	NYC Asthma
1981	1466.7	856.1	354.0	337.8	183.6	unavailable
1986	1558.8	777.1	371.4	394.0	199.3	unavailable
1991	1478.3	636.2	333.2	434.2	195.6	434.4
1996	1605.7	520.5	361.7	455.3	179.5	480.8

Source: CDC, NHDS 1981, 1986, 1991, 1996

comes. The incidence of certain vector-borne diseases might rise as spring and fall warming extend the season in which disease reservoirs, vectors, and parasites are active and as wintertime survival increases. Secondly, water-borne disease organisms may become more prevalent depending on how rising temperatures affect wild animal populations in the watershed area, the viability of aquatic pathogens, and water availability. Finally, climate warming is likely to foster the formation of photochemical air pollutants such as O_3 and certain fine particles that have been associated with adverse human health effects including mortality (Davis et al., 1997). Complex feedback mechanisms, such as increasing pollen levels at higher CO_2 concentrations, and interactions between pollen and diesel particles, may exacerbate these impacts.

Climate change impacts on public health have undergone considerable research and debate for the past decade (IPCC, 1996; Epstein and Leaf, 1998). On the global scale, this has included examination of climate change impacts on risk of hunger (Rosenzweig and Hillel, 1998), vector-, water-, and food-borne disease (Martens, 1995; Patz et al., 1996; Lindsay and Martens, 1998), and direct effects of heat and cold on mortality (Martens, 1998). Much of the work on smaller geographic areas has focused on changes in the distribution of vector-borne disease for a particular country (Loevinsohn, 1994; Bryan et al., 1996) and the impact of heat-stress mortality on individual cities (Kalkstein and Smoyer, 1993; Katsouyanni et al., 1993).

Two reports have assessed climate change impacts in the MEC Region. A recent qualitative analysis by the Environmental Defense Fund (1999) discussed impacts of climate on heat-stress mortality, mosquito-borne disease,

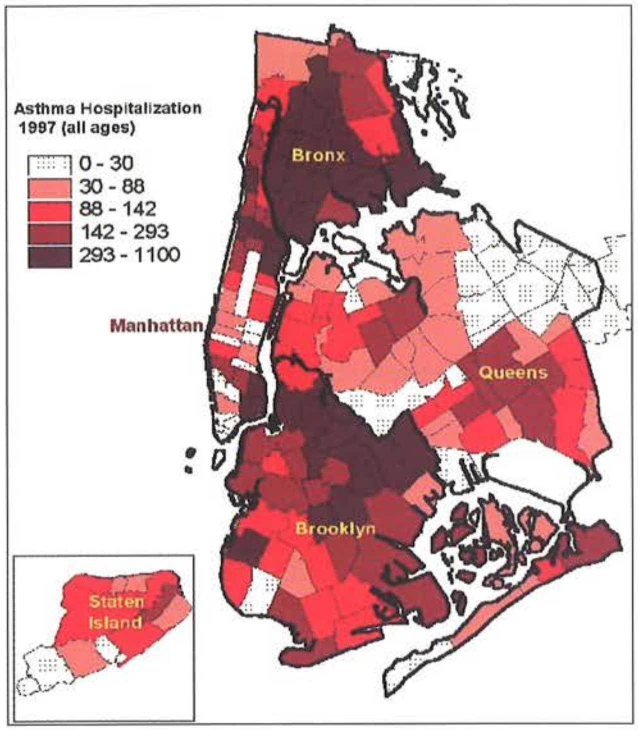

FIGURE 7-2 NYC asthma hospital admissions in 1997 by zip code.

and asthma. Based on a review of previous studies, it was concluded that all three outcomes had the potential to increase as a result of climate warming. Previously, Kleinman and Lipfert (1996) examined the potential effects of higher temperatures and air pollutant levels on mortality and respiratory hospital admissions in New York City. For a 2°C increase in annual mean temperature, the authors estimated that annual mortality would rise 0.67% and summertime respiratory hospital admissions by 1.3% in New York City. These annual estimates reflect the averaging of very large impacts on a few summer days with negligible impacts during the remainder of the year. Most of the projected increase in mortality was attributed to higher temperature, whereas ozone accounted for the bulk of the rise in hospitalizations.

Here we briefly review the literature on three potential health impacts that could result from climate change in the MEC Region: heat stress, vector-borne and water-borne diseases, and respiratory effects of photochemical air pollution.

TABLE 7-7
Trends in cryptosporidiosis, Lyme disease, and malaria, New York City.

Rates per 100,000 population

Year	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Cryptosporidiosis																		3.9	6.4	4.5
Lyme disease										0.3	1.5	2.2	1.5	1.3	1.9	1.4	2.9	1.3	6.2	5.7
Malaria	0.8	0.9	0.6	0.9	0.9	1.0	0.6	0.6	0.9	0.4	0.4	1.3	1.4	1.6	1.8	2.3	2.0	1.4	3.0	3.7

From NYC DOH, 1998.

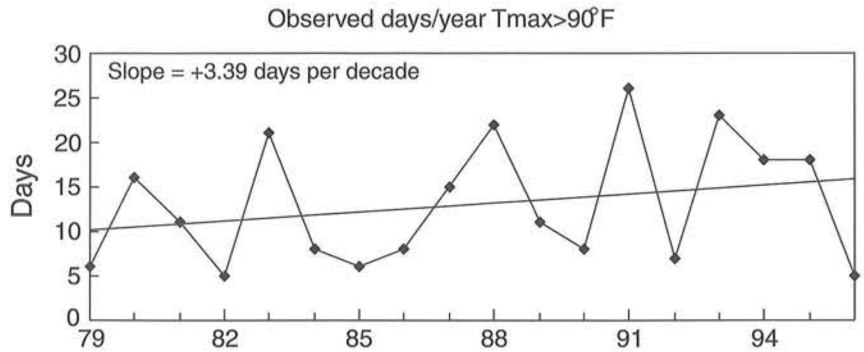

FIGURE 7-3 Average number of observed days per year with Tmax >90°F, New York City (1979 to 1996).

Heat Stress

Increased morbidity and mortality due to heat stress is one potential direct impact of climate change in the MEC (Marmor 1975; Kalkstein, 1991; IPCC, 1996). Heat-induced illnesses and deaths in large cities have been noted at least since the early part of this century (Gover, 1938). In 1993, New York City led the nation in heat stress mortality with over 300 deaths (Kalkstein, 1993). It has been estimated that this toll could increase by two to seven times over the next century as the number of days with temperatures >90°F(32°C) increases through the 2090s (Kalkstein and Greene, 1997; EDF, 1999). Figure 7-3 shows the trend in observed days/year above 90°F from 1979 through 1996 in New York City, indicating a steady increase from an average of about 10 per year to over 15 per year (Rich Goldberg, personal communication). Note the substantial interannual fluctuations around the trend line. Figure 7-4 plots projected average numbers of days/year above 90°F for decades starting from 2000 to 2090 for the four alternative GCM scenarios, as well as for an extrapolation of the current trend. These models show increases from about 20 days per year in the decade starting 2000, to between 27 and 80 days/year in the final decade of this century.

Heat stress interacts with pre-existing disease states to precipitate acute morbidity and mortality. Kilbourne (1997) found that persons with cardiovascular disease, respiratory ailments, and a history of stroke have greater risk of mortality during heat waves. Because certification due to excess heat is rare, it has been difficult to get an accurate estimate of the total mortality impact of heat stress (Oechsli, 1970). Many heat-related deaths are not a clear result of heatstroke or other heat-related illnesses, and thus are not reported as such in medical records. The use of different criteria and definitions for heat-related mortality in different studies has led to some confusion regarding which diseases contribute most. Other difficulties in heat-related mortality studies are the incorporation of the time delay between exposure to heat and onset of fatal illness, collinearity among variables generated over common time periods, non-linear time trends, and inconsistent criteria for temperature and mortality determination.

Some of these difficulties have been resolved by the use of time-series analysis. This method is particularly appropriate in studying heat-related mortality data because it optimally evaluates short-term effects of time-varying exposure. Using total daily mortality as the outcome variable enables an assessment of the total impact of heat-stress across causes of death. Time-series analysis also allows researchers to evaluate multiple weather and other environmental variables, and can elucidate the lag time between exposure and manifestation of effect, which has typically been observed to be 1–2 days (Pope, 1996).

The relationship between ambient temperature and risk of death is a complex one. Populations appear to adapt to prevailing meteorological conditions, both through physical and physiological mechanism. It is when temperatures exceed normal limits, especially early in the summer, that risk of heat-related mortality is greatest. In a 1938 study of U.S. mortality in the summer months, Gover noted that positive deviations from normal temperatures during summer predicted mortality in 86 large cities. This was confirmed by Rogot and Padgett in a 1976 study of temperature and stroke mortality in the United States, as well as by MacFarlane in a 1978 study of daily mortality during three summer hot spells in London. Another common observation is a super-linear relationship between mortality risk and temperature as temperature rises above normal levels (e.g., Sartor et al., 1997).

The observation by Kalkstein (1991) that minimum temperature was a key predictor of mortality has led to the hypothesis that high over-night tem-

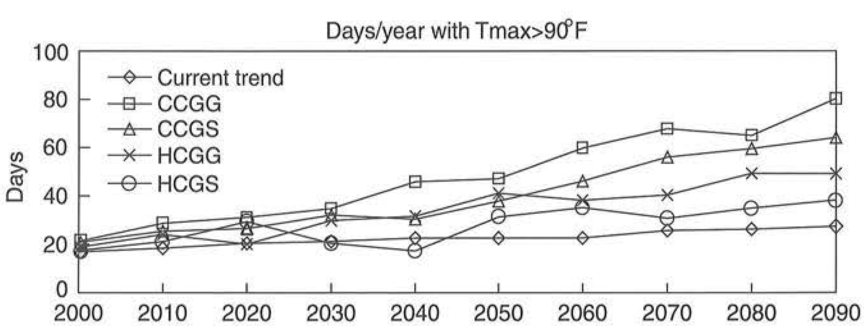

FIGURE 7-4 Change in the average number of days per year with Tmax >90°F for projected changes in climate, relative to 1961–1990. Scenarios depicted include extrapolation of current trend, and outputs from the four GCM scenarios: CCGG, CCGS, HCGG, and HCGS.

peratures play a key role in heat-related mortality risk. Specifically, excessively hot nights exacerbate the stress of extremely hot days, since the cooler nighttime temperatures usually serve to mitigate the adverse effects of hot daytime conditions. It is also thought that high winds decrease the adverse effects of hot weather by increasing body cooling (Kunst, 1993).

The elderly appear to be the most vulnerable population subgroup. MacFarlane (1978) found that the increase in mortality during hot spells in London were largely restricted to individuals older than 60 years. More recently, Whitman reported that during the Chicago heat waves of 1994 and 1995, individuals over the age of 65 accounted for 63% and 72% of all deaths, respectively. With the general aging of the MEC population, the proportion of persons in the older age groups will increase in coming years.

Urban living increases the risk of heat-related mortality. Higher temperature in cities as compared with surrounding suburban areas, combined with the higher proportion of socioeconomically disadvantaged, are factors that contribute to excess deaths. The temperature disparity between cities and surrounding suburbs is attributed to the fact that a large proportion of urban surface area is covered by man-made materials that absorb daytime radiant heat and radiate this heat during the night. This "urban heat island" leads to higher minimum temperature in the cities which, as discussed earlier, appears to exacerbate heat stress. The high concentration of disadvantaged populations living in urban core neighborhoods interacts with this phenomenon to enhance vulnerability.

The distribution of heat-stress impacts across the MEC will likely vary both as a function of local surface temperatures as well as by the residential distribution of the disadvantaged elderly. In addition to the urban heat island effect, strong gradients in local surface temperatures also occur within urban areas due to variations in vegetation cover as well as reflectivity of man-made surfaces, as shown in Figure 7-5 (Small, 2000). In addition, the residential distribution of disadvantaged persons is very heterogeneous in the MEC (Figure 7-1).

Factors associated with poverty include deteriorating and poorly maintained housing, and inadequate interior climate control due to the expense of owning and operating air conditioners (Semenza et al., 1996). Reduced mobility of the elderly poor, due in part to fear of crime, leads to greater time spent indoors. Anecdotal evidence suggests that vegetation may increase with affluence in some urban areas, enhancing protective shading from heat effects. Thus, locally elevated surface temperatures may interact with poverty over small geographic scales to create even greater heat-stress impacts in the disadvantaged neighborhoods of the MEC. Future work by our group will analyze the small-scale geographic distribution of heat-stress impacts in the MEC using remote sensing in conjunction with available demographic and health data.

The extent to which heat stress will impact public health in the MEC as a whole over the next century is not known, but will depend on individual adaptability, the prevalence of publicly and privately accessible air-conditioned environments, and the ability of weather services and local health agencies to warn the population of upcoming heat waves (Kalkstein, 1991). The distribution of impacts by age and socioeconomic status are likely to be marked. The effects of summer heat stress may be partially offset by reductions in wintertime mortality due to cardiovascular disease and respiratory infections as warming reduces the duration and severity of winters (Langford and Bentham, 1995; Martens, 1995).

While the direct effects of climate change on human health in the MEC due to increased heat stress have the potential to be significant, adaptive responses involving increasing access to air conditioning and improved early

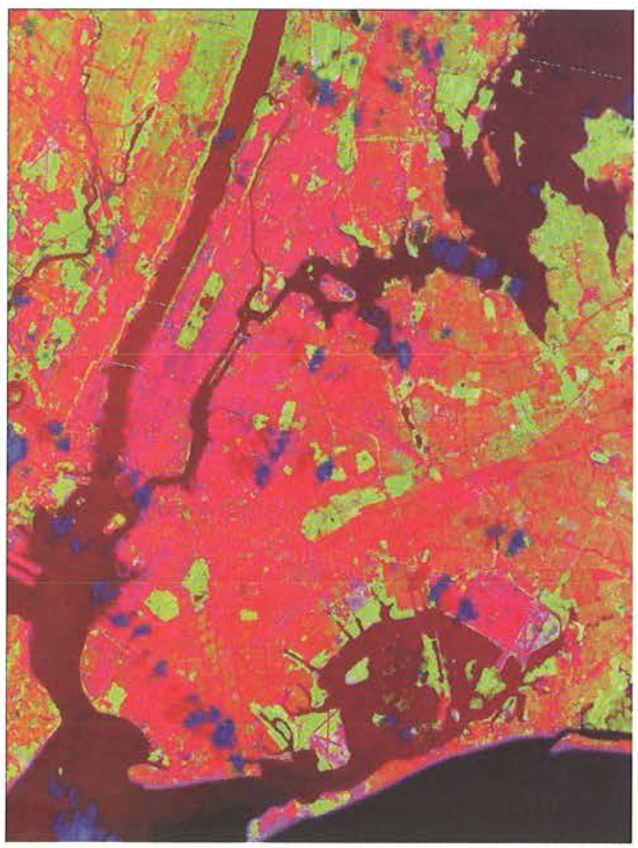

FIGURE 7-5 New York City surface temperature and vegetation fraction. The image is a reduced resolution false color composite combining surface temperature and vegetation abundance information derived from Landsat TM data acquired 2 June, 1996. Red indicates surface temperature, green indicates vegetation abundance and blue indicates uncertainty in the vegetation fraction estimate. Red and pink areas are characterized by higher surface temperatures and lower vegetation abundances. Green and yellow areas are characterized by higher vegetation abundances and lower surface temperatures. Blue and black areas have lower surface temperatures and little or no vegetation. Source: Christopher Small, Lamont-Doherty Earth Observatory

warning mechanisms are relatively straightforward, given sufficient political will and economic resources. The impacts of increased peak energy demand during summer heat waves will need to be addressed via new supplies however.

The more complex set of indirect effects of climate change, including vector- and water-borne diseases and air-quality impact on respiratory diseases, may have an even greater cumulative impact on health in the MEC region over the coming century. In addition, due the their complexity, the indirect impacts will be more difficult to forecast, prevent, and effectively adapt to.

Vector-Borne Diseases

The distribution, dispersion, and transmission potential of many important disease vectors and reservoirs are largely determined by climatic factors. Warming of sub-tropical and temperate regions supports the poleward movement of arthropods, arachnids, and mammals from the lower latitudes and increases the wintertime survival rate of endemic vectors (Rodriguez-Tan and Weir, 1998; Kovats et al., 1998; Gratz, 1999). Here we briefly discuss three vector-borne diseases: malaria, West Nile Encephalitis, and Lyme disease.

An increased incidence of locally acquired malaria may be one adverse outcome of climate warming in the MEC. Competent vectors of malaria exist in the MEC (Zucker, 1996) but do not presently support sustained transmission of the disease for two main reasons. First, most aspects of *Anopheles* population dynamics and behavior are limited by an intolerance of temperatures below 9°C (48.2°F); this threshold is even higher for the *Plasmodium* parasite, which cannot reproduce below 14.5°C (58.1°F) (Lindsay and Birley, 1996). Second, on average, the U.S. population spends less than two hours a day outside (Godish, 1997), minimizing the opportunity for exposure. Both of these protective factors may be undermined as the climate of the MEC warms.

Prior to 1991, local malaria transmission had not occurred in the region since 1966 (Zucker, 1996). Both 1991 cases, which occurred in southern New Jersey at the MEC-Mid Atlantic Region (MAR) border, were *attributed to unusually warm, humid weather;* the first case was also linked to the proximity of documented and undocumented immigrant workers. In 1993, three more cases of locally acquired malaria occurred in Queens, NY (Layton et al., 1995). It was concluded that a recent immigrant living in northern Queens, possibly of Latin American or Caribbean origin, had served as the source of mosquito inoculation; and that the mosquito population had been favorably affected by *warmer, more humid temperatures*.

Several climate models suggest that the annual mean temperature will increase largely as a result of higher winter and spring temperatures. These trends may expand the mosquito season into the spring and improve the survival of the parasite, increasing the possibility of exposure. While public health, environmental, and residential infrastructure in the MEC probably preclude the possibility of a large-scale outbreak, the frequency of isolated cases may rise as climatic conditions and the increasing incidence of imported cases (associated with immigration to the MEC region) continue to favor local transmission.

The West Nile Encephalitis epidemic of 1999, also mosquito-borne, provides an alarming illustration. Seven confirmed fatalities occurred during a very wet August that followed an unusually mild winter and dry July. It appears that this pattern of temperature and precipitation selectively favored the prevalence of two mosquito species, *Culix pipiens* and *Aedes vexans*, that can carry and spread the West Nile virus. This epidemic highlights the magnitude of both public health and societal impacts that changing patterns of vector-borne diseases may have as the climate changes and becomes more variable over the next century.

The incidence of Lyme Disease may also change with the climate (McMichael and Haines, 1997). In a study of black-legged tick (*Ixodes*) populations in New Jersey, Vail and Smith (1998) found that temperature and humidity accounted for most of the variation in behavior. Two recent papers have noted a northward movement of ticks in Europe coincident with warmer winters (Lindgren et al., 2000; Tälleklint et al., 1998).

Water-Borne Disease: Cryptosporidiosis

In 1993, an outbreak of cryptosporidiosis in Milwaukee, WI, caused over 400,000 cases of acute diarrhea and several deaths (MacKenzie et al., 1995). Though it is uncertain how the municipal water supply became contaminated with C. *parvum*, it has been suggested that heavy spring rains carried large quantities of wild and domestic animal manure into the watershed area (Nadakavukaren, 1995; Scott et al., 1994). As the ranges the mammal hosts of the parasite (e.g., deer and mouse) overlap with the watersheds of the MEC, and as the chief means of municipal water purification (chlorination) is relatively ineffective against C. *parvum*, the elements for significant outbreaks currently exist in the MEC region. With a relatively high number of immuno-compromised persons in the MEC region, a mass exposure similar to the Milwaukee episode could have serious consequences in the MEC region.

As the climate in the MEC warms, the conditions for C. *parvum* outbreaks will become more favorable if some combination of the following three conditions are met. First, if warming substantially increases evapo-transpiration rates, concentrations of C. *parvum* in municipal water supplies would rise as the watermark falls. Second, warming of the aquatic environment may improve parasite viability (Colwell, 1996). Finally, if warmer winters facilitate the survival of deer and other significant wild sources of contamination, human infection rates may similarly rise. Again, precipitation patterns may ultimately determine if and how the epidemiology of this disease is impacted. If, as some GCMs project, the frequency of severe storm events increases over the next century, we would expect the probability of cryptosporidiosis outbreaks to similarly rise.

Air Quality and Respiratory Diseases

In 1971, the U.S. EPA established National Ambient Air Quality Standards (NAAQS) for "criteria pollutants," a small set of ubiquitous outdoor air pollutants with well-established human health effects. The criteria pollutants include ozone (O_3), $PM_{2.5}$, PM_{10}, lead, carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). The current NAAQS are summarized in Table 7-8.

TABLE 7-8
Current primary National Ambient Air Quality Standards for criteria pollutants

Pollutant	Standard	Averaging Time	Year Last Revised
Ozone	80 ppb	3-year average of the annual 4th-highest 8-hour concentration	1997
$PM_{2.5}$	15 µg/m^3 65 µg/m^3	annual 24-hour	1997
PM_{10}	50 µg/m^3 150 µg/m^3	annual 24-hour	1987
Lead	1.5 µg/m^3	quarterly	1978
Carbon Monoxide	9 ppm 35 ppm	8-hour 1-hour	1994
Nitrogen Dioxide	53 ppb	annual	1995
Sulfur Dioxide	30 ppb 140 ppb	annual 24-hour	1996

Over the past three decades, considerable progress has been made in controlling levels of several of the criteria pollutants (e.g., sulfur dioxide, carbon monoxide, and lead). However, concern remains about the human health impacts of O_3 and particulate matter (i.e., $PM_{2.5}$ and PM_{10}), for which concentrations remain elevated in many parts of the country, including the New York metropolitan area. The atmospheric reactions that produce O_3 and $PM_{2.5}$ from combustion precursors are strongly dependent on temperature. Thus, climate change is likely to foster increasing concentrations of these pollutants if precursor emissions are held constant, and will make it more difficult to reduce concentrations even with reductions in precursor emissions.

O_3 is a strong oxidant gas that occurs naturally in the stratosphere (i.e., 30–50 km altitude) but which is an unwelcome pollutant in the troposphere (the lowest 10 km of the atmosphere). Tropospheric O_3 is a secondary pollutant (i.e., not directly emitted to a substantial degree) that is produced via complex chemical reactions involving nitrogen oxides, reactive hydrocarbons, and sunlight (U.S. EPA 1996a). In populated areas, the primary sources of O_3 precursor pollutant emissions are motor vehicles and the fuel supply system that supports them. Vegetation can be another important source of reactive hydrocarbons. Because of the importance of solar radiation and temperature in O_3 photochemistry, significant concentrations of O_3 appear only in the warmer months, i.e., May through October. Further, O_3 production occurs only during daylight hours, resulting in a characteristic mid-day concentration peak in urban areas. However, O_3 concentrations often remain elevated late into the evening, especially in regions downwind of major urban areas. As a result, residents of downwind regions, such as the Connecticut coastline and Long Island, typically experience longer periods of elevated O_3 levels than do urban dwellers, such as those living in New York City. Because of its reactive nature, O_3 only partially penetrates indoors, with indoor/outdoor ratios ranging from 0.1 to 0.8, depending on the degree of natural ventilation (penetration is greatest when open windows are used for ventilation).

$PM_{2.5}$ represents the mass concentration of airborne particles with aerodynamic diameters smaller than 2.5 micrometers (µm). $PM_{2.5}$ particles vary widely in size, composition, and origin (U.S. EPA, 1996b). Some are emitted directly by fossil fuel combustion, such as fly ash and soot from coal and diesel fuel combustion. Others form as secondary pollutants by chemical reactions in the atmosphere that convert gases emitted by fossil fuel combustion, such as sulfur dioxide, to particles, such as acid sulfates. Important chemical components of $PM_{2.5}$ include sulfates, nitrates, elemental carbon, organic molecules, and a variety of trace elements (Spengler and Wilson, 1996). Outdoor $PM_{2.5}$ particles penetrate readily to the indoor environment (Ozkaynak and Spengler, 1996). Unlike O_3, significant indoor sources of $PM_{2.5}$ exist, the most prominent being smoking and cooking.

HUMAN HEALTH EFFECTS OF OZONE

O_3 is a strong oxidant gas which upon inhalation deposits throughout the respiratory system. Epithelial cells in the deep lung are especially vulnerable to oxidant damage, both because the delivered dose of O_3 is greatest there and because these cells lack a protective mucous layer. Acute O_3-induced lung injury is characterized by epithelial cell destruction, pulmonary edema, and inflammation (U.S. EPA, 1996a).

Human chamber studies have shown that brief O_3 exposures at or above 80 ppb cause reversible drops in lung volumes, increases in non-specific bronchial responsiveness, and pulmonary inflammation (U.S. EPA, 1996a;

Horstman et al., 1990; Devlin et al., 1991). There is a broad distribution of responsiveness across human subjects for all of these effects, with some individuals exhibiting responses several fold higher than the population mean response, and others showing no response. Epidemiology studies involving repeated measures across days have also demonstrated the acute effects of low-level O_3 exposures on lung function in children and adults (Hoek et al., 1993; Kinney et al., 1989; 1996a; Spektor et al., 1991).

Epidemiology studies also have reported acute associations between O_3 and daily asthma exacerbations, emergency room visits, hospital admissions, and deaths (Burnett et al., 1994; Kinney and Ozkaynak, 1991; Thurston et al., 1992). These studies suggest that asthmatics may be especially vulnerable to O_3-induced pulmonary effects. The known effects of O_3 on acute pulmonary inflammation suggest a plausible role in exacerbation of asthma.

Summer-season hospital admissions for asthma and for total respiratory causes have been significantly associated with ambient ozone levels (Thurston et al., 1992; Burnett et al., 1994). In a multiple regression analysis of daily data from three New York state metropolitan areas, including New York City, Thurston et al. (1992) reported that mean ozone levels accounted for 12–24% of asthma admissions and 5–18% of total respiratory admissions in the New York state metropolitan areas studied. Analyzing similar data from southern Ontario, Burnett and colleagues (1994) reported that mean O_3 levels were associated with 5% of asthma, COPD, and infectious disease hospital admissions for persons of all ages, and with 15% of the admissions among children. Thurston et al. (1994) reported that 21% of total respiratory admissions in Toronto, Ontario were associated with mean O_3 levels and that the relationship persisted after high O_3 days (>120 ppb) were excluded from the analysis. Table 7-9 summarizes the risk coefficients (admissions per 100 ppb ozone per day per 1,000,000 persons) for respiratory and asthma hospitalizations from these three key studies, as summarized in U.S. EPA 1996a.

HUMAN HEALTH EFFECTS OF PARTICULATE MATTER

A large number of recent time series observational studies have reported small, statistically significant associations between particulate matter (i.e., TSP, PM_{10}) and daily mortality, suggesting that the mortality effects seen in episodes earlier this century persist at lower contemporary levels of particle exposure, at least among the most vulnerable members of society, such as the elderly and those with pre-existing cardiopulmonary disease (Katsouyani et al, 1997; Kinney et al., 1995; Pope et al., 1992; Schwartz, 1993). Cause-specific analyses usually have observed larger relative effects for deaths attributed to respiratory, and to a lesser extent cardiovascular, causes than for other causes of death. Quantitative results from studies of this kind have been remarkably consistent, suggesting a 5–10% increase in total daily deaths associated with increases of 100 μg/m^3 in daily average PM_{10} concentration (U.S. EPA, 1996b).

A more limited body of epidemiologic evidence is available showing acute morbidity effects of daily PM exposures (Dockery and Pope, 1994). Observational time series studies similar to those addressing acute mortality have reported acutely increased hospitalizations or emergency room visits for respiratory complaints in association with $PM_{2.5}$ and/or sulfate particles (Burnett et al., 1994; Thurston et al., 1992; Schwartz, 1994). Repeated measures studies in small cohorts of subjects have reported small but statistically significant declines in lung function and increases in lower respiratory symptoms associated with ambient PM_{10} and sulfate concentrations (Hoek and Brunekreef, 1993; Pope and Kanner, 1993). As a group, findings from these studies of pulmonary effects reinforce the plausibility of the acute mortality results noted earlier, and suggest a possible role of acute pulmonary irritation in the mechanistic pathway leading to mortality in susceptible individuals.

Epidemiology studies correlating mortality rates and PM concentrations across metropolitan areas represent the oldest and most extensive evidence for chronic PM effects (Lave and Seskin, 1970; Evans et al., 1984). However, interpretation of early cross-sectional observational studies was seriously hindered by uncertainties regarding potential confounding by cigarette smoking, occupational exposures, and other factors (Evans et al., 1984). Confirmatory results have emerged recently from two large prospective cohort studies which, based on individual questionnaire data on smoking and other risk factors, were able to control for

TABLE 7-9
Effect estimates of daily admissions for asthma and total respiratory causes as a function of ambient ozone concentration. (Adm/100ppb/day/1,000,000 persons)

Reference	Location	Admission Cause	Effect Estimate
Thurston et al., 1992	New York City, New York	Total respiratory	1.4 (+/– 0.5)
Thurston et al., 1992	Buffalo, New York	Total respiratory	3.1 (+/– 1.6)
Burnett et al., 1994	Ontario, Canada	Total respiratory	1.4 (+/– 0.3)
Thurston et al., 1994	Toronto, Canada	Total respiratory	2.1 (+/– 0.8)
Thurston et al., 1992	New York City, New York	Asthma	1.2 (+/– 0.5)
Thurston et al., 1992	Buffalo, New York	Asthma	1.2 (+/– 0.5)
Thurston et al., 1994	Toronto, Canada	Asthma	1.4 (+/– 0.8)
Thurston et al., 1994	Buffalo, New York	Asthma	1.2 (+/– 0.4)

From EPA, 1996a.

major potential confounders at the individual level in the analyses (Dockery et al., 1993; Pope et al., 1994). These two recent studies are also important because they analyzed multiple, alternative PM measures, including $PM_{2.5}$. In a cohort of 8,111 white adults, Dockery and colleagues reported a linear exposure response of mortality risk vs. average $PM_{2.5}$ concentrations across six U.S. cities, controlling for smoking and other risk factors (Dockery et al., 1993). The risk of death was increased by 26% for an exposure difference of 18.6 $\mu g/m^3$ across cities. This mortality risk was similar to that associated with 25 pack-years of cigarette smoking. Pope and colleagues reported similar findings from a prospective follow-up of 552,138 adults from 151 metropolitan areas (Pope et al., 1994). For a subset of 50 locations where $PM_{2.5}$ data were available, the risk of death was increased by 17% for an exposure difference of 24.5 $\mu g/m^3$ across metropolitan areas.

CLIMATE CHANGE AND AIR QUALITY

As climate changes and becomes more variable, episodes of elevated O_3 and $PM_{2.5}$ are likely to become more frequent and more severe (NRC, 1991; IPCC, 1996). There is a strong positive relationship between O_3 concentration and temperature. Relating daily maximum O_3 and temperature for three sites in Connecticut, Wackter and Bayly (1988) found that daily maximum ozone increased linearly with daily maximum temperature above 70°–80°F, and that mean maximum ozone levels may exceed the EPA standard of 120 ppb (1 hr daily avg) for temperatures over 90°F (32°C). Similar results were found for New York City (U.S. EPA, 1993). With GCMs predicting significant increases in the number of days per year >90°F (see above), the frequency of high ozone days is also likely to increase. Secondary $PM_{2.5}$ formation also is likely to be enhanced under these conditions. Other factors that are likely to influence pollution levels in the coming century include urbanization and its influence on temperature (i.e., the urban heat island effect), changes in precursor emissions in the MEC and regions to the south and west, changes in horizontal global circulation (e.g., greater stagnation of summer time air masses), and changes in tropospheric injection rates of stratospheric ozone (NRC, 1991; Wang et al., 1998).

A comprehensive assessment of air pollution-related human health risks that might result from climate change would include all of the health effects of O_3 and PM noted in the above sections. A logical strategy would be to take meteorological outputs from alternative climate change scenarios, drive atmospheric chemistry models with these meteorological inputs along with assumptions regarding changes in precursor emissions, and thereby estimate future ground-level O_3 and $PM_{2.5}$ concentrations at future time points. These pollution estimates would then be combined with exposure/response functions for each health effect, derived from the available liturature, to estimate the human health impacts of changing air quality. Estimates of future population numbers would also be needed as inputs to this calculation. Indices of vulnerability, based on age or socioeconomic status, might also be included.

As part of the initial year of the MEC climate change impact analysis, we began preliminary work on an air quality risk assessment of the kind outlined above. Our initial work examined O_3 and its effects on asthma and other respiratory hospital admissions. In the section that follows, we describe the methods and results of our preliminary work for this case study. Note that this is not intended to represent a comprehensive analysis of the human health impacts of climate and air quality. A full analysis would include both O_3 and $PM_{2.5}$, and would examine all significant health effects of these two pollutants, especially effects on mortality.

IMPACTS OF CLIMATE CHANGE ON GROUND-LEVEL OZONE AND RESPIRATORY HOSPITALIZATIONS

Research Questions

The aim of this research study is to analyze the potential impacts of climate change on respiratory hospitalizations due to ground-level O_3 in the MEC region in the 21st century. The rationale for this approach includes: 1) the documented impacts of current-day O_3 concentrations on respiratory hospitalizations, 2) the possibility that ground-level O_3 concentations may increase over time in the MEC region as climate warms and precursor emissions increase, and 3) the potentially high degree of vulnerability of the MEC population, due to the current high rates of asthma in portions of the MEC region. To accomplish this aim, we combine regional photochemical air pollutant projections under scenarios of climate change with risk coefficients from previous O_3 epidemiology studies to estimate the change in O_3-attributed hospitalizations in the MEC region from 1996 to 2030 and 2100.

Data and Methods

Projections of future climate and O_3 precursor emissions are used as inputs to a global photochestry model run at GISS. Because it is computationally very expensive to model the full range of chemical reactions in the troposphere in a GCM suitable for climate studies, we have chosen to use a subset of molecules, and include only the photochemical reactions that involve those chosen species. It is now accepted that the abundance of O_3 is most often limited by the availability of NO_x, rather than the hydrocarbons, which are also O_3 precursors (e.g. Tranier et al, 1993; National Academy of Sciences panel on Air Quality Standards, 1996). Therefore, we have not included an explicit representation of non-methane hydrocarbons (NMHCs) in our reduced chemistry scheme. We do, however, include equivalent carbon monoxide emissions from isoprene, which is thought to be the most important contribution of NMHCs (Wang et al., 1998c; Horowitz et al., 1998).

The simplified chemistry scheme is based on CH_4, CO, NO_x (NO + NO_2 + NO_3 +HONO), HO_x (OH, HO_2), and O_x (O+O(1D)+O_3) chemistry. A contribution to carbon monoxide from isoprene has also been included, but otherwise hydrocarbons other than methane have been neglected. Methane is set to fixed values in the troposphere. Ten chemical species are transported in the model: O_x , NO_x , H_2O_2, H_2O, CO, HNO_3, N_2O_5, HO_2NO_2, CH_3OOH, and HCHO. After combining the short-lived radicals into equilibrated families, we find that all the species have long enough lifetimes (except for HO_x, whose very short lifetime keeps it in equilibrium at all times) that we can use an extremely simple explicit scheme to calculate chemical changes, using a chemical time step of one hour.

The chemical scheme includes 52 reactions. Heterogeneous hydrolysis of N_2O_5 into HNO_3 takes place on sulfate aerosols, using the reaction rate coefficients given in Dentener and Crutzen (1993). Sulfate surface areas are taken from an online calculation performed with the same GISS GCM (Koch et al., 1999), assuming a monodispersed size distibution. Photolysis rates are calculated with Fast-J, a scheme which uses only seven wavelength intervals, yet deviates only slightly from a full line-by-line calculation (M. Prather, personal communication, 1999) and compares well with other photolysis schemes (Olson et al., 1997). The model includes 14 photolysis reactions. Photolysis calculations are performed every two hours, giving us a fairly realistic diurnal simulation.

Emission inventories of NO_x and CO have been compiled for the 4^0 x 5^0 grid used in this version (see below) of the GISS model. The use of detailed NO_x and CO emissions is critical since emissions vary widely with location. Nitrogen oxide sources are quite similar to those specified for the NASA Subsonic Assessment (SASS) aircraft project, consisting of annual emissions from fossil fuel burning, and monthly emissions from biomass burning, soils, and aircraft. CO emissions from energy use and from biomass burning are included. An additional CO source is the conversion of isoprene emissions.

To model nitrogen oxides produced by lightning, the GISS convection scheme is first used to calculate both the total lightning, and the cloud-to-ground lightning frequencies interactively in each grid box and at each time step. Then the production rate of NO_x from lightning (Price et al, 1997) is used to derive the NO_x produced, including the vertical distribution of the lightning produced NO_x (K. Pickering, personal communication, 1997). Phase transformation and removal of soluble species is calculated using a wet deposition scheme as in Koch et al. (1999).

Surface dry deposition is calculated using a resistance-in-series model (Wesley and Hicks, 1977) coupled to a global, seasonally varying vegetation data set as in Chin et al. (1996). Note that the leaf area indices are therefore not connected with the GCM's land-surface component. Aerodynamic resistances are based on the model's surface heat and momentum fluxes, as in Koch et al. (1999).

The above chemistry scheme has been installed directly into the latest version of the GISS climate model, II'. This is a primitive equation model, run here with nine vertical sigma layers, centered at 959, 894, 786, 634, 468, 321, 201, 103, and 26.5 mbars, and horizontal resolution of 4 x 5 degrees (latitude x longitude). The GCM's physics time step is one hour, so that changes to tracer masses from transport and chemistry are both applied every hour.

The capability of the GISS GCM to accurately model the transport of trace species has been greatly improved recently. All the chemical tracers, along with heat and moisture, are advected with a quadratic upstream scheme (Prather, 1986). (Momentum advection uses a fourth-order scheme.) Improvements to transport both within the boundary layer and across the boundary layer edge, along with convection, are especially important, since trace gas emissions at the Earth's surface come from discrete, spatially inhomogeneous sources. A primary example of the improvements can be seen in the interhemispheric exchange times of CFC-11 and 85Kr. In the earlier version of the model, the exchange times were roughly a factor of two too long, whereas in the new version, the values are within 15–25% of observations (Rind and Lerner, 1996). Improvements in the interhemispheric exchange time occurred because the alterations in both the boundary layer and convection schemes improved the tropical precipitation and wind fields. Interestingly, neither change by itself was overly effective, a result which illustrates the highly non-linear nature of GCM interactions. The GISS GCM II' has been used previously for ozone (Mickley et al., 1999) and sulfate (Koch et al., 1999) simulations.

The use of water vapor as an online, chemically active tracer is another important feature of this model. Most chemical models assume that water vapor is constant since they do not have a detailed model of the hydrological cycle, while most climate models do not have any chemistry. Thus the interaction between water vapor and climate has seldom been examined, although it is thought to be one of the key issues in climate modeling (IPCC, 1995).

Calculated O_3 and NO_2 fields are used in the GCM's computation of radiative heating and fluxes, which is performed every five hours. These fully interactive chemical constituent changes are therefore able to affect the meteorology in the GCM. To explore the influence of this feedback, we have also performed simulations where this feedback was not allowed, in which case the model used climatological O_3 and NO_2 distributions in its radiation calculations. In addition to O_3, the GCM calculates radiative absorption and emission from water, CO_2, N_2O, chlorofluorocarbons and methane in the longwave, and CO_2, NO_2 and O_2 in the shortwave (Hansen et al., 1983). Change in tropospheric O_3 plays an important role in the radiative heating that drives tropospheric meteorology, through their absorption in the Huggins bands in the ultraviolet, the Chappius bands in the visible, the 9.6 micron and especially the 14 micron bands in the infrared (Shine et al., 1995; van Dorland et al., 1997).

A key output from the O_3 photochemistry model is a one-year time series of estimated hourly ground-level O_3 concentrations in the $4^0 \times 5^0$ grid covering the MEC region. (Note that this large grid size, covering most of New York State, is a limitation of the model used in the current application. In future developments, a regional-scale air quality model, nested within the GCM, should enable finer geographic analyses.) The model was run for the years 1999, 2030, and 2100. From the hourly data, we computed the one-hour and eight-hour maxima for each day. The daily maxima were then averaged over each year to obtain a summary measure of O_3 levels for each target year. The difference between the means for 2030 and 1999 and for 2100 and 1999 were computed. These differences characterized changes in total O_3 exposure between the base year (1999) and the projected years (2030 and 2100).

Results

The impacts of a given change in ambient O_3 concentrations on asthma and total respiratory hospital admissions have been characterized in several recent studies, as noted above (Thurston et al., 1992, 1994; Burnett et al., 1994). Table 7-9 summarizes the risk coefficients derived from these studies. The coefficients represent estimates of the average population risk of being admitted to the hospital when O_3 concentrations increase by 100 parts per billion (ppb). Note that typical daily maximum one-hour O_3 concentrations in the MEC summer range from 60 to 100 ppb, with occasional peaks extending up to 150 ppb or higher. In the initial work presented here, we calculated a weighted average risk coefficient for total respiratory admissions using the inverse squared errors of the individual coefficients as weights, yielding a mean risk coefficient of 1.5 admissions per 100 ppb ozone per day per 1,000,000 persons. Similarly for asthma, a mean risk coefficient of 1.2 was calculated. These coefficients are assumed to represent the average daily risk faced by a group of 1,000,000 persons in the MEC region per 100 ppb increase in O_3. Note that these risk coefficients have been used as point estimates in the present analysis. An alternative method for combining risk estimates using a random effects model would incorporate variability in risk between studies. Such an approach, along with uncertainty estimates on the O_3 estimates, would enable an explicit consideration of uncertainties.

To calculate increases in hospitalizations under climate change scenarios, we multiplied the mean risk coefficient by the changes in annual mean ozone concentrations (using the 8-hour daily maxima) from 1999 to 2030 and to 2100 (in units of 100 ppb) obtained from the ozone chemistry model. Our use of 8-hour average ozone estimates along with risk coefficients based on 1-hour average regressions may lead to an underestimate of the magnitude of the projected ozone impacts. The result was then multiplied by 365 to cumulate over the year, and then multiplied by the projected MEC population in millions. For the present analysis, we have assumed that the MEC population remains constant over time. This can be considered a conservative assumption, since increases in total population, and/or shifting to the right of the age distribution, would lead to larger impacts. Underestimates may be especially great in suburban regions where rapid growth is anticipated.

The calculations described above yielded estimates, for the MEC region as a whole, and for the New York state MEC counties, of the numbers of additional total respiratory and asthma hospital admissions that might occur in 2030 and 2100 as a result of increasing ozone exposures. For the New York state counties, we further divided the total admissions by the numbers of hospitalizations in 1996 to calculate the percent increase in annual hospitalizations at the two time points.

Results are displayed in Table 7-10. In 2030, we estimate an increase in annual average 8-hour daily maximum ozone concentrations of about 12 ppb. For the MEC region as a whole, this corresponds to an increase of 995 and 819 annual hospital admissions for total respiratory causes and asthma, respectively. About 80% of these increased admissions occur in the 14-county part of the MEC region in New York State (804 and 643 for total and asthma, respectively), directly proportional to the fractional population residing there. These increases represent only a 0.6% rise in annual hospital admissions for total respiratory causes, but a somewhat larger 1.6% rise in asthma admissions. In 2100, a much larger annual average ozone increase of about 51 ppb is projected. For the MEC region as a whole, increases of 4,149 and 3,319 are projected for total respiratory and asthma admissions, respectively. For the New York state MEC region, increases of 3,552 and 2,682 are calculated for these two admissions categories. These increases represent a 2.5% rise in annual hospital admissions for total respiratory causes, and a 6.5% rise in asthma admissions.

CHALLENGES AND OPPORTUNITIES

These results suggest that in the short term (i.e., up to the year 2030), impacts of climate change on ground-level ozone concentrations are not likely have a large impact on asthma and other respiratory hospitalizations in the MEC region. Impacts of the size we calculated (0.6% and 1.6% increases in hospital admissions) are not likely to be discernable given the interannual variability in hospital usage. By the year 2100, the impacts become more significant, especially for asthma. These preliminary results illustrate a general point, i.e., that it becomes more important for climate change impacts to be factored into policy decisions regarding ozone mitigation strategies as the planning horizon becomes more long-term. This comment is reinforced by the fact that our analysis has ignored demographic shifts that might result in even larger ozone-related public health impacts in a growing and aging MEC population.

It is important to emphasize the limited scope of the preliminary analyses presented here. Because we did not have access to an appropriate aerosol model, we have ignored possible effects of climate changes on fine particle concentrations and the wide-ranging health impacts that could result from such effects. We have restricted attention to only two of the known health effects of O_3, hospitalizations for asthma and total respiratory causes. Mortality effects could be readily incorporated into future extensions of these analyses. Also, potential interactions between air pollution and heat stress effects have been ignored. Finally, the economic costs of air pollution-related health impacts have not been assessed in the present work.

Although equity issues have been ignored in the impact analysis presented here, it is important to recall that current health status varies tremendously across the MEC region (see e.g., Figure 7-2). Given these disparities in health status, it appears likely that the public health impacts of air pollution in the MEC region will disproportionately affect those who are most vulnerable, including the very old, the very young, and those with pre-existing health impairment such as asthma.

INTEGRATION ACROSS SECTORS

There are several areas of potential integration between the health sector and other MEC analysis sectors. One key area is that of peak energy demand during summer hot spells. The hot humid conditions that are most likely to adversely impact human health are the same conditions that place the largest stress on the energy supply infrastructure of the MEC region. Recent examples of capacity problems in the MEC include a three-day power outage in the summer of 1999 that impacted a wide are in northern Manhattan. Among other impacts, significant freezer sample losses were experienced in biomedical laboratories of the Columbia Presbyterian Medical Center. The additional capacity that will be needed to supply peak energy demands under a warming and more variable climate will likely result in increased emissions of air pollution in the MEC regions, including ozone precursors.

Another area of integration is between wetlands and vector-borne diseases. As alluded to in the earlier discussion, mosquito-borne diseases have assumed an increasingly prominent stature among potential public health threats in the MEC region. Attitudes and policies directed towards wetlands are likely to have important effects on vector population dynamics. Conversely, policies adopted in response to outbreaks of mosquito-borne diseases like West Nile virus have the potential, unless managed carefully, to cause significant harm to regional wetlands.

INFORMATION AND RESEARCH NEEDS

Further research is warranted in several areas. First, additional scenarios of ozone health impacts could be developed that include alternative assumptions about 1) the demo-

TABLE 7-10
Projected increases in hospital admissions resulting from increased ground-level O_3 concentrations in 2030 and 2100 associated with climate change

Region	Hospital Admissions Category	2030			2100		
		O_3 Increase	New Hospital Admissions	Percent Change in Admissions	O_3 Increase	New Hospital Admissions	Percent Change in Admissions
MEC	Total Respiratory	12.15 ppb	995	*	50.65 ppb	4,149	*
	Asthma		819	*		3,319	*
NY State Counties	Total Respiratory		804	+0.6%		3,552	+2.5%
	Asthma		643	+1.6%		2,682	+6.5%

*Unable to calculate due to the unavailability of hospital admissions statistics for NJ.

graphic makeup of the MEC region in future years, and 2) differential risk coefficients for different demographic groups. Uncertainties about these factors may represent the largest sources of uncertainty in predicting future health impacts of ozone. The analysis should be extended to PM and to other health outcomes. Another promising research direction is to analyze the independent and interactive health impacts of heat stress in conjunction with air pollution should be considered. The availability of spatially detailed surface temperature maps obtained from satellite imagery offers the potential to carry out epidemiologic studies, and risk assessments, using small geographic units. Research that seeks to model interactions across sectors, such as those discussed above, is a final area that warrants further work.

POLICY RECOMMENDATIONS

The wide range of possible impacts of climate change and variability on human health in the MEC region provide a strong rationale for incorporating climate change models into future policy decisions regarding mitigation of heat stress, vector- and water-borne diseases, and air pollution in the MEC region. We developed a model for analyzing climate change impacts on air pollution-related health effects—using O_3 effects on hospitalizations as a case study. This analytical framework can be extended to include additional pollutants and health outcomes, potentially providing a comprehensive assessment of such effects. Our analysis suggests that climate change impacts should be included as one of the considerations in developing long-range strategies directed towards ground-level ozone mitigation in the MEC region.

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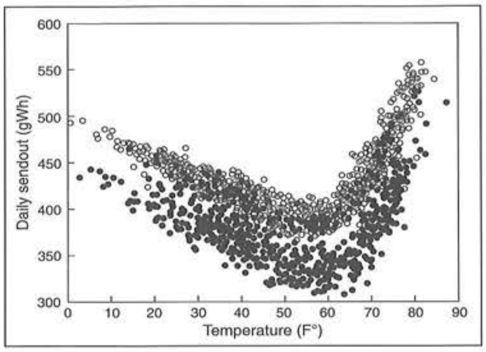

CHAPTER 8

ENERGY DEMAND

The premise of this chapter is that climate change will affect the need for energy in the Metropolitan East Coast Region. The questions addressed in the chapter include:

1. What are the potential *impacts* of climate change on the energy system?
2. What *adaptation* strategies may be effective as potential responses?

This chapter presents information on current trends in energy supply and demand, particularly electricity, and projections of electric-peak demand is presented. The potential impacts of climate change on electricity demand are examined, primarily through the use of forecasting models. Measures by which the energy system can adapt to climate change are described.[1] Finally, the interaction of energy adaptation measures and the effect of summer heat waves on public health are examined.

The largest part of energy consumed in the Metropolitan East Coast Region is divided about equally between transportation and three other uses and (residential, commercial and public use). Only a small fraction is for industrial use. In this assessment, we concentrate on energy use of the built environment, specifically residential and commercial buildings. The main concern therefore is electricity.

The *impacts* of climate change on the region's built environment are likely to be: (a) reduced demand for winter heating, and (b) increased demand for summer cooling, especially for electricity.

An assessment of the future of the energy sector in the Metropolitan East Coast Region confronts two major uncertainties: uncertainty in the extent of future climate change, and uncertainty in future energy prices because of steps that may be taken to reduce the use of fossil fuel. These uncertainties are compounded by the present fluid nature of the energy industry itself. Following the deregulation of the natural gas industry, the electric power industry is now being deregulated. State by state, companies that formerly had a regulated monopoly in their service areas are now becoming subject to competition from other electricity suppliers. This is encouraging decentralized electric generators operated by independent power producers, and a convergence of the electric and gas industries. In the energy sector, climate is not the only thing that is changing.

Prior Studies

Linder et al (1987) estimated the potential impacts of climate change on electric utilities in New York State. They distinguished between downstate and upstate New York, and compared them with a utility in the Southeast United States. Their results are summarized as follows.

For an increase in summer temperature of 1.46°F in 2015, the downstate peak demand due to the temperature increase would grow by 591 to 1,080 megawatts. This is primarily due to air conditioning loads.

The market saturation of weather-sensitive electrical end-uses is a critical component of the distribution of electricity among residential, commercial, and industrial customers in New York State. There were two assumptions of future residential air conditioning market saturation. One was that air conditioning would maintain its then current share of 2% of total annual electricity consumption across the total of all end-uses and classes. The second was that the air conditioning share would increase by almost half, to 2.9%, by 2015. If the market saturation of air conditioning equipment were to increase over time, the capacity requirements in New York State would increase by 90%.

[1] In keeping with the mandate of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, this chapter is not primarily aimed at mitigation, i.e., reduction of greenhouse gas emissions. However, some of the principal measures needed to adapt to climate warming—namely, greater energy efficiency and energy conservation—are the preeminent means of reducing these emissions.

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Because of the nature and patterns of weather-sensitive loads, the response to climate change is likely to have a greater impact on peak demand (capacity requirement) than on energy consumption (generation requirements). Therefore, the system peak demand in New York State is forecast to grow slightly faster than system energy consumption. Follow-on research was suggested to include more detailed and complete analyses of the weather-sensitivity of customer demand for electricity.

The sensitivity of electricity demand and supply was estimated using two approaches: a statistical approach, using regression analysis on historical data, and a structural approach. In the structural approach, the saturation and utilization of individual types of appliances and other end-uses were analyzed and then aggregated, with adjustments for losses in transmission and distribution made explicit. The structural approach was applied to hourly electric loads on each New York utility, using a utility planning model. Compared to the statistical approach, the structural approach shows an overall higher sensitivity of demand to temperature changes, about 50% higher for peak demand.

Climate conditions can alter the effective capacity and operating efficiency of gas turbines (used primarily for generating power during periods of peak requirements) and fossil-fuel–fired and nuclear steam generators (used to serve base load and intermediate load requirements). The largest relative impact of climate conditions is the relationship between gas turbine efficiency and ambient air temperatures. The efficiency of steam generators is sensitive to air and water temperatures used for cooling during the condensing stage of the steam cycle.

Because it is very dependent on hydroelectricity, New York State is vulnerable to possible reductions in stream flow due to climate change. A rough estimate indicates that the reduction in stream flow could reduce hydro generation in New York 6.2–8.5% by 2015.

The case studies reflect significant uncertainties in modeling the weather-sensitivity of demand. Further development of data and methods to estimate the sensitivity of demand to climate change over time would be valuable. The lack of a detailed assessment of the potential change in climate variability was seen as an important limitation of the scenario approach used.

Linder and Inglis (1990) expanded on their New York study with an estimate of the national impacts of climate change on electric utilities. They found that global warming would increase electricity demand, generating capacity requirements, annual generation, and fuel costs. The impacts could be significant within a few decades, and would increase substantially over time if global warming continued.

They estimated that climate change could increase new capacity additions 14–23% between 2010 and 2055 above what would be needed in the absence of climate change. Annual increases in electricity generation were estimated to increase 4–6% by 2055. However, regional impacts differed substantially for the scenarios studied.

On a weighted average basis (weighted by electricity sales), utility peak demands were estimated to increase by about 5.6% per change in degree Fahrenheit (ranging from –2.4 to +9.7% across utility areas), and annual energy demands were estimated to increase by about 1.8% per change in degree Fahrenheit (ranging from –1 to +5%). These estimates did not take into account probable increases in the market saturation of air-conditioning equipment as temperature rises over time.

Linder and Inglis recommended areas for further research. These included (1) estimates of variables in addition to temperature that are relevant to impact assessment, and (2) estimates of climate change at a more disaggregated regional or local level.

Scott, Wrench, and Hadley (1994) note several studies which indicate that global warming would produce about a 1.1% increase in heating requirements per 1°F rise in annual average temperature and comparable increases in cooling requirements. Almost all rely on general circulation model forecasts of average monthly temperatures. An exception is a German study by Gertis and Steimle (1989), which used building energy models and found that increases in energy consumption for air conditioning depended strongly on changes in humidity, increasing between 7% and 21% per 1°F increase. Scott et al. note that there is some question whether existing utility planning models that ignore the nonlinear effects of relative humidity can adequately capture the effects of global warming on electric energy demand.

Accordingly, Scott et al. identify the critical variables that would affect the demand for electricity and other sources of energy by sector if climate were to change. They use the DOE2 building model with weather conditions in four cities that represent extremes in temperature and humidity. They conclude that energy use for cooling is nonlinearly related to temperature because of the physics of latent and sensible heat, and is strongly influenced by humidity. For the typically commercial building, energy consumption is not especially sensitive to average wind speed and solar insulation ("cloudiness"). Scott et al. find that a model based simply on cooling degree-days will generally underpredict cooling energy use, although it will overpredict cooling energy use in a warm, dry climate.

In a follow-on study, Belzer, Scott, and Sands (1996) develop national estimates of the potential impacts of climate change on energy consumption in commercial buildings in the United States. They use a degree-day model applied to a sample of commercial buildings. For a 7°F increase in temperature in 2030—a temperature increase that they describe as an extreme upper bound—they find that the change in cooling demand would increase more than 50%. The model did not take into account humidity change.

Rosenthal, Gruenspecht, and Moran (1995) estimate the impact of global warming on U.S. energy expenditures for space heating and cooling in residential and commercial buildings. In contrast to earlier studies, they find that a 1.8°F global warming would reduce rather than increase national expenditures on space conditioning. They use a modified degree-day approach in which the reference point for calculating degree-days varies from the usual 65°F. For heating and cooling commercial buildings, it is taken as 50°F; for residential heating, it is 60°F.

For utilities meeting summer peak demands, Rosenthal et al. note that increased capacity requirements arise only when the daily maximum temperature exceeds the maximum summer temperature without global warming. Moreover, the 40-year trend towards a warmer climate observed in ground-based measurements has been exclusively a nighttime phenomenon, according to the Intergovernmental Panel on Climate Change (IPCC, 1990). Estimates that ignore this diurnal pattern will overstate the impact of warming on capacity requirements.

Rosenthal et al. note that utilities have studied extensively the relationship between weather and energy consumption, and that these studies could provide a rich empirical base to build from. These as well as related foreign studies are reported by the IPCC (1996b).

BACKGROUND

The pattern of electricity use is quite consistent among the three states in which the Metropolitan East Coast Region is located. About three-quarters of electrical energy are consumed in the residential and commercial sectors, with the larger share in the latter. (Table 8-1).

Fossil fuel is supplied to the Metropolitan East Coast Region in the form of petroleum arriving by sea and pipelines, natural gas arriving by pipelines, and coal arriving by train. In addition, a substantial portion of the electricity generated for the region is based on nuclear power. The metropolitan region has virtually no indigenous fossil fuel resources. Locally, there is a small amount of renewable energy supplied by landfill gas, and negligible amounts of solar and wind power.

TABLE 8-1
Electric utility retail sales by state and sector (millions of megawatt-hours), 1998

	New York	New Jersey	Connecticut	Total	Percentage
Commercial	53.2	31.1	11.7	96.0	42%
Residential	40.2	23.2	10.9	74.3	33%
Industrial	25.1	13.3	5.8	44.2	19%
Other	12.7	0.5	0.5	13.7	6%
Total	**131.2**	**68.2**	**29.0**	**228.2**	**100%**

Source: K. Wade, 2000

Northern New Jersey is the site of six petroleum-refining plants that receive crude oil from overseas and distribute refined products to the northeastern states. Oil products also arrive from the Gulf Coast and southwestern United States by two pipelines. In addition, there are several oil depots along the East River and at ports on Long Island Sound, which receive refined products for local distribution. Oil-fired electric generating plants along waterways in New York receive light distillate and residual oil shipped by barge. Residual oil originates at both domestic and overseas refineries.

Natural gas arrives in pipelines from the Gulf Coast, the southwestern United States, and western Canada. Because of its competitive price and preferable environmental characteristics, there is a growing appetite for natural gas, which is limited by the capacity of existing pipelines. Under federal legislation, states may provide consumers with the opportunity to buy natural gas from sources other than the local distribution company, a process called "unbundling." New York and New Jersey now provide this option, but Connecticut as yet does not.

Electricity supply in the Metropolitan East Coast region is controlled by three different power networks. The 14 counties in the New York portion are served by utilities supported by the New York Independent System Operator (NYISO—formerly the New York Power Pool), which has a summer peak capacity of 34,650 megawatts. The 14 counties in New Jersey are served by utilities that are part of the PJM Interconnection, L.L.C. with a peak capacity of 56,000 megawatts. The three counties in Connecticut are served by utilities that are part of ISO New England, which has a peak capacity of 27,117 megawatts (ISO New England, 2000a).

For the three states that the region overlaps, the energy sources used for electricity generation are shown in Table 8-2. The largest share of utility generation is from nuclear power. However, a significant amount of power now comes from nonutility sources; these are independent power producers other than the traditional franchised utilities. As most nonutility power is gas-fired, the major fuel used to generate electricity in the three states is natural gas.

The dominant fossil fuel for electric generation has changed from oil to natural gas in the past decade, but there are short-term switches between the two (as in 1998) as the relative prices fluctuate; many power plants can burn either. About two-thirds of the natural gas is consumed by independent power producers who produce one-quarter of the power generated in the states (New York State Energy Research and Development Authority, 1999).

TABLE 8-2
Electricity generation by state and primary energy source (billions of kilowatt-hours), 1998

	New York	New Jersey	Connecticut	Total	Percentage
Nuclear	31.3	27.0	3.2	61.5	28%
Coal	23.5	5.6	1.5	30.6	14%
Hydro	26.6	−0.1	0.4	26.9	12%
Gas	19.9	2.9	1.0	23.8	11%
Oil	14.5	0.5	8.6	23.6	11%
Other	—	—	0.4	0.4	—
Total Utility	115.8	35.9	15.1	166.8	77%
Nonutility	28.7	17.7	4.5	50.9	23%
Total generation	**144.5**	**53.6**	**19.6**	**217.7**	**100%**

Note: "Nonutility" consists of independent power producers' sources other than the traditional franchised utilities. Source: K. Wade, 2000

Since 1990, there has been rapid growth in the share generated by independent power producers.

NEW YORK ELECTRICITY

Electricity in the New York Metropolitan Region is now supplied by three franchised utilities—Consolidated Edison, Orange & Rockland Utilities, and Long Island Power Authority—as well as by the New York Power Authority. In this region, the New York Power Authority provides electricity primarily for the Metropolitan Transportation Authority, New York City public buildings, New York City Housing Authority, Port Authority of New York and New Jersey, New York State Office of General Services, Westchester County, and the governments of various towns and villages. In 1999, Con Edison merged with Orange & Rockland Utilities. The Long Island Power Authority (LIPA) is a recently established New York State entity that owns the distribution system of the former Long Island Lighting Company (LILCO). For the next five to ten years, it is committed to purchase most of its electricity from the former LILCO generating plants on Long Island, now owned by KeySpan Energy. KeySpan was formed by the consolidation of the Brooklyn Union Gas Company and LILCO.

About one-fifth of the state's electric power is generated by nuclear reactors at four plants: James A. Fitzpatrick, Ginna, Nine Mile Point 1 and 2, and, in the Metropolitan East Coast Region, Indian Point 1 and 2.

New York Power Authority has major hydroelectric plants on the Niagara and St. Lawrence Rivers. This renewable energy constitutes almost one-quarter of the state's utility-generated power. However, only about 3% of this inexpensive public power reaches the metropolitan region (Figure 8-1).

The supply of electric power to New York City and Long Island is severely constrained by the capacity of transmission lines into the region. Transmission lines from outside the region represent only about one-quarter of the region's capacity to deliver electricity. This limits the ability to import power at times of peak demand, particularly for Long Island. Long Island is more isolated from the national grid than any other part of the country (Perez-Pena, 1999).

Long Island Power Authority has proposed to install an additional major transmission line across Long Island Sound to connect it more strongly with the New England grid. Con Edison is limited in its transmission ties with upstate New York by the width of its right-of-way through Westchester County, although conceivably new technology such as superconducting cable could increase the capacity of this corridor.

Con Edison has two 345-kilovolt (kv) transmission lines across the Hudson River, from Brooklyn to Hudson County, New Jersey, and one 345 kv line across The Narrows by way of Staten Island to Linden, New Jersey (Northeast Power Coordinating Council, 1989). These provide a link with the PJM Interconnection, a system with 60% more generating capacity than New York's. The NYISO requires that 80% of the power supplied to New York City be generated locally, and Con Edison is not considering building new transmission lines to import more power from outside the region.

For the first time since the late 1980s, however, a substantial number of companies are presently seeking to build new power plants in the Metro East Coast Region, as shown in Table 8-3. Five of these in New York City, and another six in adjoining New York counties have applied for licenses in New York State. Another 10, in nearby counties in Connecticut, have completed applications for interconnections with ISO New England. The total power of these 21 plants is 11,000 megawatts. An additional 11 plants in the metropolitan region, amounting to 4,000 megawatts, have not

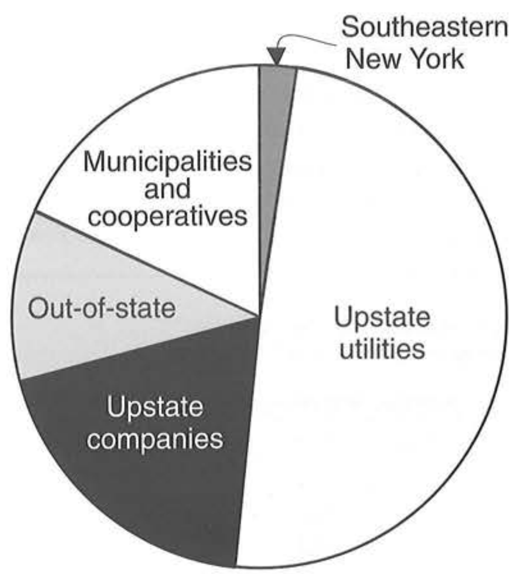


FIGURE 8-1 Distribution of New York Power Authority hydroelectricity.
Source: NYPA Annual Report, 1994.

TABLE 8-3
Applications for electric power plants in the Metropolitan East Coast Region, May 2000

Project	Power (megawatts)	Developer	Location	Estimated In-Service Date
North of New York City—3,767 megawatts				
Bowline Unit 3	750	Southern Company	Haverstraw, Rockland	2002
Ramapo Energy Project	1100	Ramapo Energy, LP	Ramapo, Rockland	2002–03
Torne Valley Station	827	Sithe Torne Valley, LLC	Ramapo, Rockland	2002–03
Grassy Point	550	Haverstraw Bay, LLC	Haverstraw, Rockland	2003
Wawayanda*	540	Calpine Corporation	Wawayanda, Orange	2004
New York City—2,630 megawatts				
Astoria Energy, LLC	1000	SCS Energy	Astoria, Queens	2003
East River Repowering	360	Con Edison	Lower Manhattan	2002
Poletti Station Expansion	500	New York Power Authority	Astoria, Queens	2002
Ravenswood Cogeneration Project	250	KeySpan Energy	Long Island City, Queens	2002
Sunset Energy Fleet, LLC	520	SEF	Brooklyn	2002
Long Island—580 megawatts				
Brookhaven	580	Brookhaven Energy, LP	Brookhaven, Suffolk	2003
Nearby Connecticut—4,044 megawatts**				
Wallingford Power	550	Wallingford Department of Utilities	Wallingford	2000/2001
Meriden Power	544	PDC Meriden Power Co.	Meriden	2001
Towantic Energy	540	Arena Capital L.T.D.	Oxford	2001/2002
Rocky River Power	530	Sempra Energy Resources	New Milford	2001
Milford Power+	40	PDC Power Development Co.	Milford	2001
Bridgeport Harbor Station	520	Wisvest Corp.	Bridgeport	2003
New Haven Harbor	520	Wisvest Corp.	New Haven	2003
Devon A	300	NRG Energy Inc.	Devon	2003
Norwalk Harbor A	100	NRG Energy Inc.	South Norwalk	2003
Norwalk Harbor B	400	NRG Energy Inc.	South Norwalk	2004

*Publicly announced project, application expected. **New Haven and Fairfield Counties +Power output increased

Sources: New York State Public Service Commission, 2000; ISO New England, 2000b.

yet applied for licensing but are being evaluated in system reliability impact studies by the New York Independent System Operator, as listed in Table 8-4. The total new capacity of this 15,000 megawatts is half again larger than Con Edison's in 1999, and the almost half of the present installed power in the entire state of New York.

In addition, there is a trend toward decentralized electric power generation where commercial and industrial establishments generate their own power on site. New and emerging technology, such as microturbines and fuel cells, are small units that lend themselves to these applications. This distributed generation, discussed below, will add to the power generated within New York City and in the metropolitan region.

Electricity prices of Con Edison and Long Island Power Authority are among the highest in the country (New

TABLE 8-4
Proposed electric generating plants being evaluated in reliability studies

Project Name	Owner/Developer	Size (mw)	Interconnection Point	Utility
(Unnamed)	Millenium Power	160	Hell Gate/Bruckner	Con Edison
(Unnamed)	Millenium Power	320	Hell Gate/Bruckner	Con Edison
Cogen Tech Linden	Cogen Tech Linden Venture	20	Goethals	Con Edison
Cogen Tech Linden	Cogen Tech Linden Venture	70	Goethals	Con Edison
Cogen Tech Linden	Cogen Tech Linden Venture	160	Goethals	Con Edison
Cogen Tech Linden	Cogen Tech Linden Venture	160	Goethals	Con Edison
(Unnamed)	ABB Development	1075	Dunwoodie-Rainey 71,72	Con Edison
SEFCO	NYC Energy	80	Kent Avenue	Con Edison
(Unnamed)	Astoria Generating	499	Astoria	Con Edison
Astoria Energy	SCS Energy	1000	Astoria	Con Edison
Besicorp/Empire State	Besicorp/Empire State	475	Saugerties	Central Hudson Gas & Electric

Source: New York Independent System Operator, 1999.

York City Office of the Comptroller, 1999). Electricity prices have recently declined in the New York metropolitan area, but not as much as the national average, so that the price gap is widening (New York Academy of Sciences, 1999).

Judged by energy consumption per capita or per unit of Gross State Product (GSP), New York is the most energy-efficient state in the continental United States. This is due principally to the efficiency of moving people by mass transit in the metropolitan area, and the fact that very little of the GSP is due to heavy manufacturing.

NEW JERSEY ELECTRICITY

Northern New Jersey is supplied by Public Service Electric & Gas Company (PSE&G) and GPU Energy (formerly Jersey Central Power & Light Company). Electricity generation within New Jersey has been characterized by rapid growth in nonutility sources, amounting to 33% (in 1998). However, in 1996 almost half of its electrical power was imported from out of the state (U.S. Energy Information Administration, 2000a).

New Jersey has nuclear plants located at Oyster Creek, Hope Creek, and Salem 1 and 2. None of them in the Metropolitan East Coast region. When all units are operating. New Jersey has the highest percentage (75.0%) of electricity generated from nuclear power utilities of any U.S. state. The share dropped however to 29% when PSE&G took its Salem plants in southern New Jersey out of service in 1995 (U.S. Energy Information Administration, 2000a).

Electricity prices in New Jersey are the fifth highest in the nation. These high prices were one of the forces leading to New Jersey taking an aggressive approach to electrical industry restructuring (U.S. Energy Information Administration, 2000a).

CONNECTICUT ELECTRICITY

The three nearby counties in Connecticut that are within the metropolitan region are supplied with electricity by Connecticut Light and Power Company, and United Illuminating Company. In 1986, more than half of the electricity generated in the state was from nuclear power. By 1996, however, the share of nuclear had been reduced to 31%, and in 1997 by 100%, as a result of the permanent shutdown for safety reasons of the Connecticut Yankee plant and the shutdown of the Millstone plants, one of the three units permanently. There is also a nuclear plant at Haddam Creek. Connecticut is normally a net exporter of electricity, principally to the rest of New England, but in 1996 almost 30% of its power was imported due to the nuclear shutdowns.

Connecticut, like New York, has one of the highest levels (23% in 1998) of nonutility generation in the country.

Connecticut has been one of the leaders in the move toward deregulation. Utilities are required to sell non-nuclear generation plants by January 2000 and nuclear plants by January 2004.

ENERGY-RELATED POLLUTION

All three states are in the Ozone Transport Region, which covers 11 northeastern states, as well as Washington, DC and northern Virginia. In this region, the electric utilities are affected by the federal requirement that requires the states to enact regulations to achieve region-wide reductions in nitrogen oxides (NO_X) from May through September. Ozone is formed in the atmosphere by the reaction of nitrogen oxides with volatile organic compounds in the presence of sunlight. Due to the movement of air masses, this is a regional problem. To address it, an emissions trading program has been established to encourage the reduction of nitrogen oxide emissions from sources where it is most economical to do so. However, New York Governor George Pataki recently announced even more stringent regulations for New York State, requiring that the same Clean Air Act targets for NO_X be met year round.

Sulfur dioxide restrictions more stringent than those required by the Clean Air Act are also being imposed in New York State (*New York Times*, October 14, 1999). Sulfur aerosols in the atmosphere have been found to have an important effect in screening the earth's surface, thus lowering the surface temperature (IPCC, 1996).

Current Trends in Electric Energy Demand

During the decade from 1988 to 1998, the combined electric energy demand in New York, New Jersey, and Connecticut grew at the low rate of 0.6% per year, as shown in Table 8-5. The commercial sector, which comprised 42% of total electricity demand in 1998, was the fastest growing, at 1.6% growth per year. The residential sector, accounting for 32% of electricity demand in 1998, grew at a rate of about 0.8% per year. Industrial energy use declined in all three states.

Current Trends in Energy Supply

The energy supply structure is changing because of new technology, the availability of inexpensive natural gas,

TABLE 8-5
Growth in utility retail sales in New York, New Jersey and Connecticut by sector (millions of megawatt-hours), 1988, 1993, and 1998

Sector	1988	1993	1998	Growth rate*
Commercial	81.7	86.9	96.0	1.6
Residential	68.5	72.5	74.3	0.8
Industrial	52.3	50.4	44.2	–1.7
Other	12.2	13.3	13.7	1.2
Total	**214.6**	**223.0**	**228.2**	**0.6**

*Growth rate in percent per year, 1988–1998

Source: K. Wade, 2000.

changing demand, but most of all due to the deregulation of the industry.

Until recently, electric power throughout the country was generated and delivered by local companies with a franchised monopoly overseen by state public utility commissions. By the early 1990s, a number of developments had begun to make local competition among several different electricity suppliers possible.

- The notion that ever larger power plants running constantly to meet the minimum daily electric load (base load) would necessarily provide the cheapest electricity had been dispelled, resulting in large part by the experience with nuclear power plants.
- New efficient technologies were small enough to be manufactured in units ("modules") in a factory, thereby gaining economies of large-scale production, and ease of transport to the generation site.
- Deregulated natural gas prices were low.
- New information and control technologies were emerging.
- Changing regulatory policies facilitated competition among electricity suppliers.

By the end of 1992, competitive bidding for new power supplies was approved in 20 states The Federal Regulatory Commission (FERC) approved "market-based" pricing for some wholesale power sales, and Congress broadened the scope of wholesale competition with the passage of the Energy Policy Act of 1992. In 1992, for the first time, generating capacity added by independent power producers exceeded that added by traditional electric utilities (U.S. Energy Information Administration, 2000b).

As a result of deregulation, the traditional vertical structure of franchised public utilities is disappearing. For example, Con Edison has sold the bulk of its generating plants, some 5,500 megawatts, and become a "wires" company primarily providing local distribution of electricity (Con Edison, 1999a).

The electricity and gas industries are converging. In metropolitan New York, Brooklyn Union Gas and Long Island Lighting have combined as KeySpan Energy. As gas becomes the dominant fuel for both power generation and domestic heat and cooking, there is an overlap between the supply and retail functions of electricity and gas suppliers, and it becomes advantageous for the two to combine.

Deregulation does not guarantee that the price of electricity will go down. With competition, the price will respond rapidly to changes in supply and demand, as oil prices do now. When supply is short, for example, to meet peak demands during summer hot spells, the unregulated cost of electricity may increase sharply. During the past two summers, prices have spiked as high as $7,000 per megawatt-hour, compared to a typical price of $35 to $45 per megawatt-hour (Lynch, 2000). In New England, the wholesale cost of power reached more than 100 times its usual level for a few hours during an unexpected heat wave in May 2000 (Berenson, 2000).

Whether such price spikes will persist is a matter of debate. In California, which has led the country in electricity deregulation, the governor has asked the federal government to impose controls on the wholesale price of electricity across the West. However, power companies and some economists argue that price controls are a misguided and shortsighted measure that will only increase the risk of blackouts in both the short and long run. Nationally, and in the metropolitan region, independent power generators are moving quickly to add new plants to bring supply and demand back into line (Berenson, 2000).

Finally, except for hydroelectricity in New York State, renewable energy is a very minor source of electric power and is unlikely to be a major local source of energy for decades to come (Morris et al., 1996).

Aside from these trends in new directions, one must also consider the fact of constantly aging infrastructure. Failures may become more frequent, particularly with ever-increasing summer peak loading.

Determinants of Energy Demand

On the national level, the two primary determinants of energy demand are population and the level of economic activity usually measured as Gross National Product (GNP). The relationship is illustrated in Figure 8-2, which shows

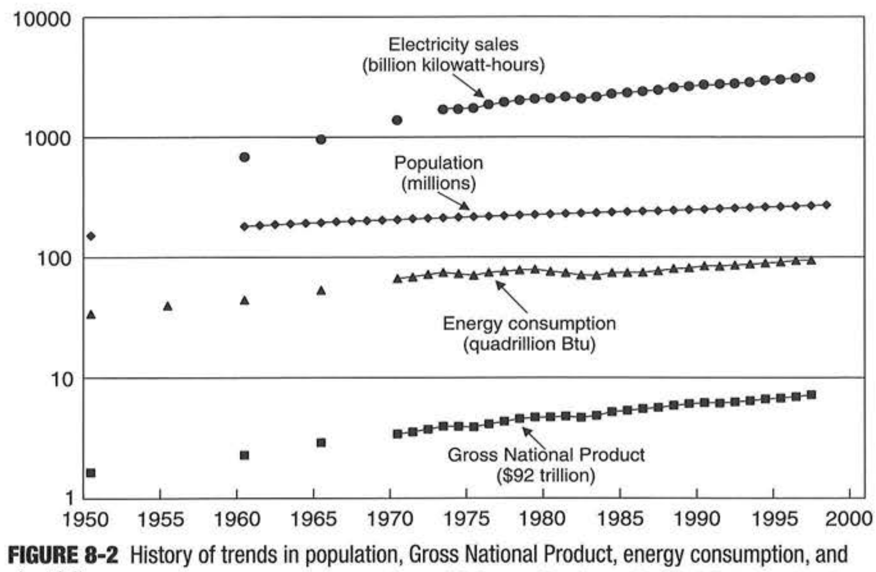


FIGURE 8-2 History of trends in population, Gross National Product, energy consumption, and electricity.
Source: U.S. Bureau of the Census, Statistical Abstract, various dates.

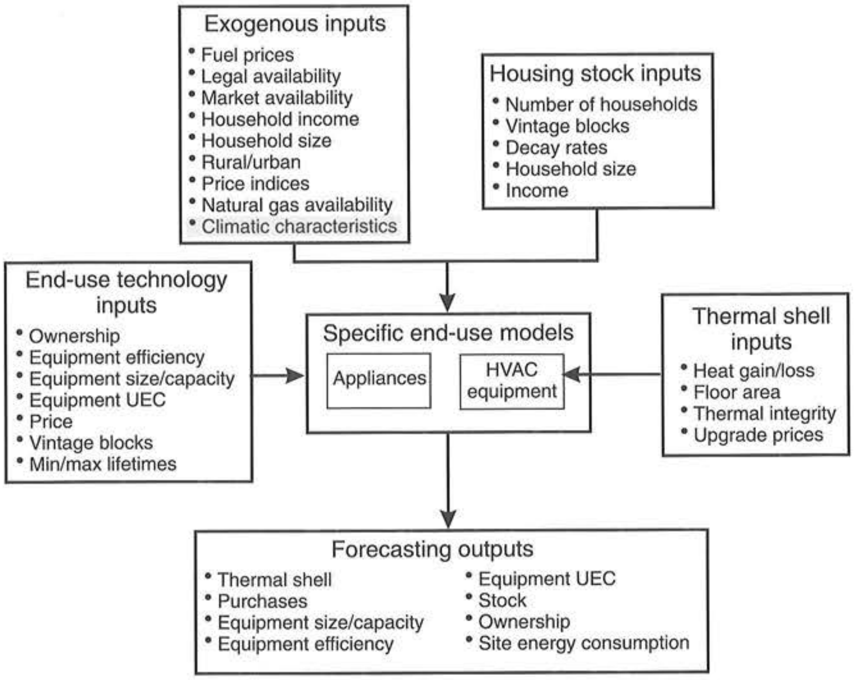


FIGURE 8-3 Factors affecting energy consumption at a residence. Source: Koomey et al., 1995.

the annual growth in population, GNP, energy consumption, and electric power sales over the past few decades. The data are shown on a logarithmic grid so that proportional changes over time appear as parallel lines. (The relative position of the curves vertically has no significance.)

Between 1973 and 1997 growth in energy consumption has generally paralleled population growth, a rate of 1% per year. Electricity sales have generally paralleled the higher rate of growth of GNP 2.5% per year during that period. On the other hand, between 1973 and 1986, conservation and efficiency measures helped to keep U.S. energy consumption at nearly constant levels while the country's GNP grew by 35%. This demonstrates the significant potential for reducing the use of energy without hurting the economy.

Final end-use energy consumption is usually classified by economic sector—principally commercial, residential, industrial, transportation. On this level, electricity demand in the residential and commercial sectors may be estimated by the number of households, the amount of manufacturing and non-manufacturing employment, or the number of buildings with electric cooling and heating, and the energy-efficiency of those buildings.

At the end-use level, energy demand forecasting models have been developed by Lawrence Berkeley National Laboratory (LBL) for commercial buildings and by the Electric Power Research Institute (EPRI) for the residential sector. The numerous factors that influence energy demand in a residential building are shown in Figure 8-3.

An example of the direction and extent of changes in energy demand due to various residential end-uses is shown in Figure 8-4. The forecasts of the LBL REEPS (Residential End-Use Energy Planning System) model offer a picture of how much energy will be used for what purposes in the residential sector over time.

The figure compares forecasted growth in primary energy by end use from 1995 to 2010 for both the REEPS forecast and that of the *1995 Annual Energy Outlook* prepared by the Energy Information Administration. The end uses are ranked according to the REEPS forecast with highest growth at the top and the lowest at the bottom. The largest growth in primary energy use is due to space heating with electricity and natural gas, followed by the use of electricity for "miscellaneous," space cooling, and lighting. Energy for water heating, refrigerator, and freezers is expected to decline primarily because of efficiency standards now in place for these end uses.

Sanchez et al. (1998) have examined the high growth miscellaneous category in detail. Miscellaneous product types can be classified into four broad categories: consumer electronics, electric resistance heaters, lighting, and small motors. From 1976 to 1995, growth in consumer electronics accounted for nearly half the miscellaneous growth. In 1995, nearly half of all consumer electronics energy was consumed in the standby mode. The largest

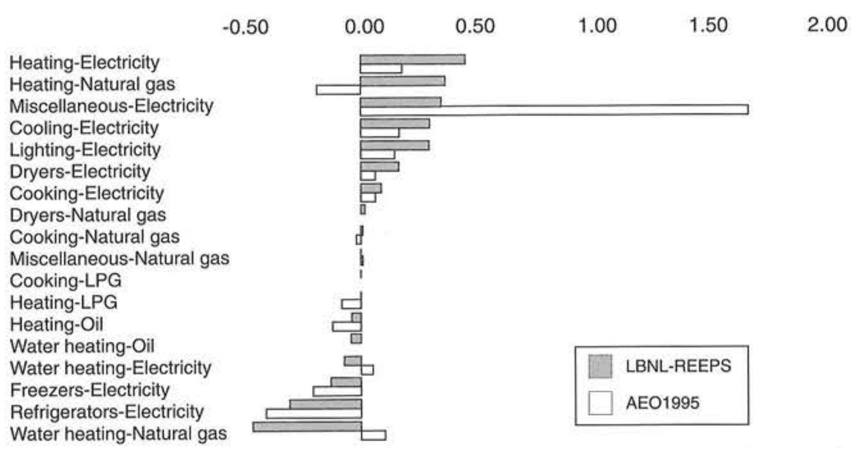


FIGURE 8-4 Projected changes in U.S. primary energy use (ES) due to various residential end-uses, 1995-2010. 1 Exajoule (EJ) = 10^{18} joules. REEPS total net projected growth 1995–2010 = 1.0 EJ (total use in 1995 = 17 EJ; AE095 total net projected growth 1995–2010 = 1.4 EJ (total use in 1995 = 19 EJ). Source: Koomey et al., 1995.

TABLE 8-6
Miscellaneous consumers of residential electricity, in order of U.S. consumption

1995 estimate	1996–2010 forecast
Color television	Torchiere lamp
Furnace fan	Color television
Waterbed heater	Dehumidifier
Torchiere lamp	Security system
Microwave oven	Compact audio system
Auto drip coffee maker	Microwave oven
Clothes washer motor	Projection television
Dishwasher motor	Satellite system
Ceiling fan	Pool pump
Video cassette recorder	Home computer

Source: Sanchez et al., 1998

leakers include audio systems, televisions, cable boxes, and video cassette recorders.

From 1996 to 2010, Sanchez et al. project that consumer electronics and halogen torchiere lamps will account for 70% of forecasted miscellaneous growth. Of 97 product types investigated, only ten were responsible for over half of current and forecast miscellaneous growth (Table 8-6.)

Projections of Electric Energy Demand

The New York Independent System Operator, PJM Interconnection, and New England Independent System Operator forecast demand for future electric generating capacity for individual utilities or service areas 20 years ahead. Peak load projections for the major utilities in the Metro East Coast region are compared with recent history in Figure 8-5. The NYISO projection for Con Edison applies to Con Ed customers. The peak load in the Con Edison service area is larger because the company delivers power in the region for the New York Power Authority and other sources.

The growth rates in peak load represented in the figure are compared in Table 8-7. The growth rates anticipated for the three major suburban utilities are all higher than those for Con Edison customers. Probably this is because of higher projected population growth in the suburbs. However, the actual growth rate in the Con Edison service area from 1989 through 1999, shown by the trend arrow, is almost double that projected for future growth in Con Edison customers.

New York State forecasts growth in electricity "sendout"—total energy—of 0.6% to 1.2% for the state as a whole during the next 20 years (New York State Energy Planning Board, 1998). The New York Power Pool (now the New York Independent System Operator) forecasts growth of about 1.1% for the utilities within the Metro East Coast region (New York Power Pool, 1999b).

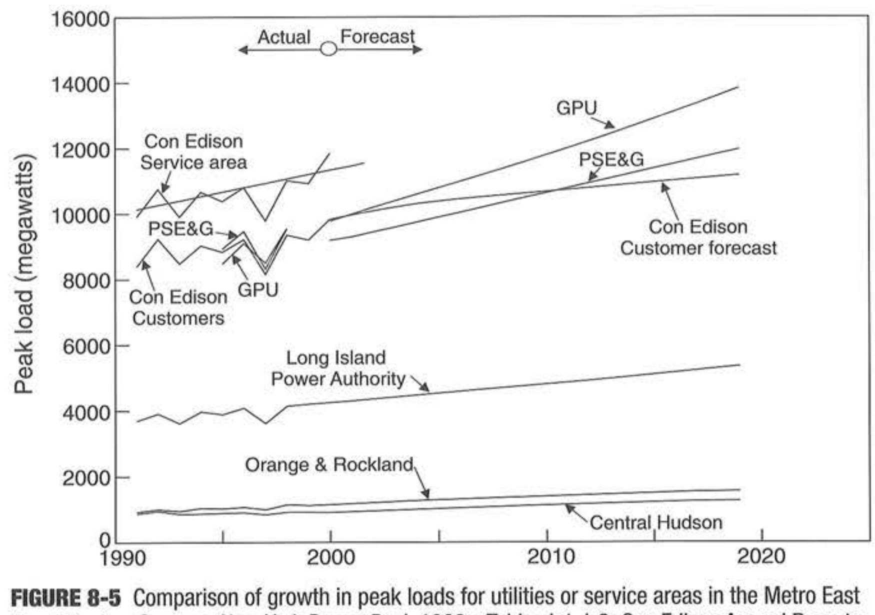


FIGURE 8-5 Comparison of growth in peak loads for utilities or service areas in the Metro East Coast Region. Sources: New York Power Pool, 1999a, Tables I-1, I-2; Con Edison Annual Reports, 1995, 1999; PJM Interconnection, L.L.C., www.pjm.com

TABLE 8-7
Comparison of growth rates in peak loads among Metro East Coast utilities

	Time interval	Growth rate per year
GPU forecast	1999–2018	1.84%
PSE&G forecast	1999–2018	1.40%
Con Edison service area trend	1989–1999	1.26%
LIPA forecast	1999–2018	1.22%
Con Edison customer forecast	1999–2018	0.67%

The variation in monthly peak loads projected for the PSE&G area is shown in Figure 8-6. The summer peak load remains 40% higher than the winter peak two decades hence. No relative worsening of summer cooling requirements due to climate change seems to be anticipated by the utility in this time period.

CLIMATE IMPACTS ON ENERGY DEMAND

Although the major drivers of energy demand in the United States are population and economic activity, climate makes itself felt at the margins. In particular, a warming climate is likely to increase summer peak electricity loads, straining the generation, transmission and distribution systems to their limits (see Box 8-1). This section describes analyses designed to quantify and project the impact of climate on energy demand, especially under peak conditions.

The 20-year projections made by the utilities may not take into account expected changes in climate, but their *short-term* demand forecasts—for the next few days—do take into account expected changes in the weather. These short-term forecasting methods provide a basis for estimating the effect of long-term climate change, because they relate demand to climatic factors.

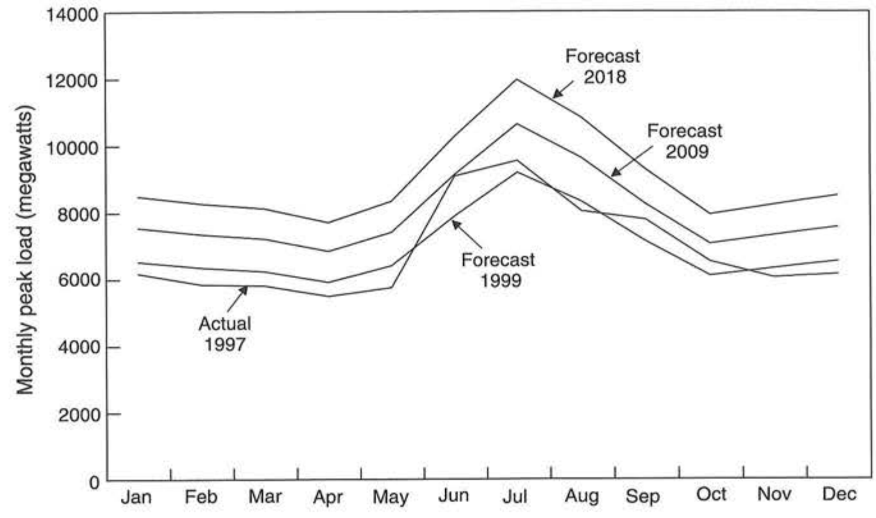


FIGURE 8-6 Actual and forecast monthly peak loads in the PSE&G service area for 1997, 1999, 2009, and 2018.
Source: PJM Interconnection, www.pjm.com.

The impact of climate on energy demand is determined by changes in winter heating and, more importantly for electricity demand, summer cooling. Energy peak demand increases with extremes of cold and heat. Total energy demand is roughly proportional to heating and cooling degree-days. A degree-day is the difference between a reference temperature, usually 60 or 65°F, and the average temperature for the day.

Heating degree-days in New York City are less than those in New York State as a whole, and since 1980–1985 they have declined by double the amount for the state, as seen in Figure 8-7. On the other hand, cooling degree-days in New York City are more than in New York State as a whole, and in the same time period they have increased by six times as much.

These trends are expected to continue or become more pronounced. The declining number of heating degree-days and the rising number of cooling degree-days in the metropolitan region are shown projected using two general circulation models in Figure 8-8. Compared to the base time period of 1979–1996, heating degree-days may decline 20–40% by the 2080s. Cooling degree-days may increase by 45 to 135 percent, that is, by almost half to more than double the recent values.

A decline in heating degree-days reduces the impact on the energy system, whereas growth in cooling degree-days greatly increases the impact. Relatively little electricity is used to provide heating, whereas air cooling is principally provided by electricity. Thus, it is the effect of a rising requirement for electricity-based air cooling that is the principal climate change impact of concern in the energy sector.

Response of Electric Energy Demand to Change in Temperature

The response of electric energy demand to a change in temperature can be measured by its elasticity. For example, the elasticity of residential electricity demand to cooling and heating degree-days in California was calculated by month from 1977 through 1995 (McMenamin, 1997). Electricity consumption was compared with cooling and heating degree-days, measured by the difference between the daily average temperature and 65°F.

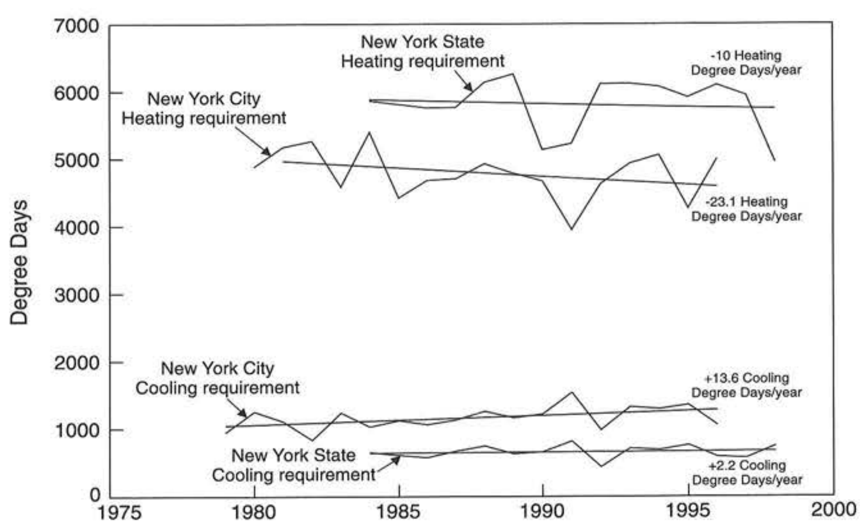


FIGURE 8-7 Cooling and heating degree-days in New York City and New York State.
Sources: National Weather Service and NYSERDA.

The elasticities of electricity demand with respect to cooling degree-days was most evident in summer months, as indicated by the peaks in Figure 8-9. In these months, the "typical value" was found to be 0.2, indicating that a 10% increase in cooling degree-days will cause a 2% increase in monthly electricity use. The summer

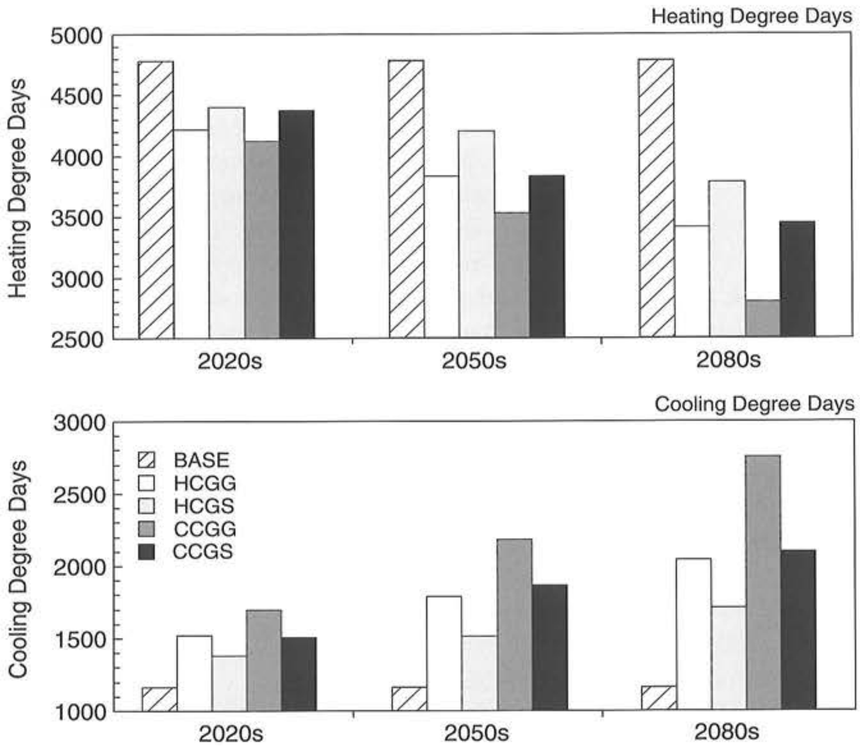


FIGURE 8-8 Projected heating and cooling degree-days in the Metropolitan East Coast Region.
Notes: Base time period is 1979–1996. Degree-days are calculated from a base value of 65°F. Bars represent high and low range of two global climate models, the Canadian Centre (CC) and the Hadley Centre (HC) (models).

peak values for elasticity ranged from about 0.05 to 0.45. The elasticity builds up from zero in winter months to its summer peak. Thus, the elasticity of electricity demand is a function of the average monthly temperature, rising with higher temperatures. The hotter it gets, the greater is the increase in electricity demand with an additional degree of temperature.

In contrast, the elasticity of electric energy demand with heating degree-days in the California sample, shown in Figure 8-10, switches sign. In winter months, cold weather increases heating loads. However, since most heating systems are not electric, the elasticity is modest, at about 0.1. In the summer months, the elasticity is negative, indicating that cool weather reduces electricity loads.

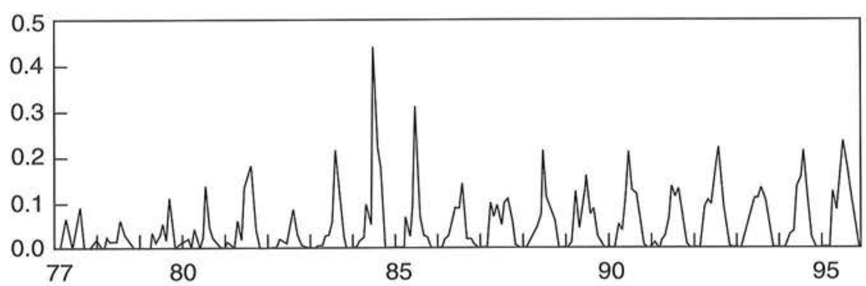


FIGURE 8-9 Elasticity of residential electric energy demand with respect to cooling degree-days, calculated by month from 1977 to 1996. Source: J.S. McMenamin, 1997.

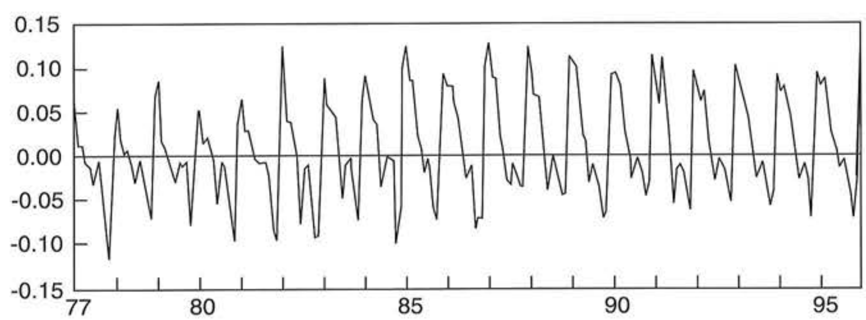


FIGURE 8-10 Elasticity of residential electric energy demand with respect to heating degree-days. Source: J.S. McMenamin, 1997.

Energy Demand Models

Cooling and heating degree-days provide only a rough indication of energy demand. Weather conditions other than temperature, for example humidity, wind speed, cloud cover, and the previous day's weather, have been found to be important in influencing energy demand on a given day (Consolidated Natural Gas Company, 2000). For more precise projections of energy demand, therefore, models have been constructed that take into account these other factors.

On the local scale, for example, the COMMEND model used by the Electric Power Research Institute to characterize heating and air conditioning in commercial buildings requires users to enter service demand data (Sezgen et al., 1995). Service demand is characterized by the annual heating and cooling loads in a base year, peak-heating and peak-cooling requirements in the base year, the sensitivity of heating and cooling loads to changes in efficiency of other end uses, building occupancy, and environmental factors such as weather conditions and the average heating and/or cooling degree-days.

New York Power Pool Zone Forecasting Models

The New York Power Pool Zone Forecasting Modeling system consists of a set of advanced neural network and regression models to forecast hourly loads, daily peaks, monthly peaks, and energy demand for the New York State electric system.

Three types of data are used: load, weather, and calendar (New York Power Pool, 1999b). The weather data include:

- Dry bulb temperature
- Wet bulb temperature
- Wind speed
- Cloud cover

Calendar data include individual days of the week, all major U.S. holidays, sunrise-sunset tables, and seasonal variables.

To account for regional differences, the models were developed individually for 11 regions of the state, shown in Table 8-8 with the weather stations used for data. The New York metropolitan region consists of regions G through K: mid-Hudson, Millwood, SPR Dunwoodie, New York City and Long Island. In total, these correspond generally with the service areas of Con Edison, Long Island Power Authority, Orange & Rockland, Central Hudson Gas & Electric, and the retail customers of New York Power Authority. Once the weather data were obtained, the relationship between energy loads and weather was examined.

BOX 8-1. JULY 6, 1999 POWER FAILURE

The summer of 1999 brought unusually high temperatures and humidity to much of the eastern half of the United States. Many electrical systems set records for energy output during several extended heat waves. On July 6, the PJM Interconnection, which serves New Jersey and much of the Eastern seaboard, experienced a voltage drop by as much as 5% which lasted several hours. A blackout occurred in the Washington Heights section of Manhattan and parts of the Lower East Side and Long Island.

The low voltage in the PJM system occurred because demand exceeded supply. Demand was exceedingly high due to record usage of electricity resulting from high temperatures, high humidity, a strong economy, and from increased transmission losses created by high transfer levels across the system. Electricity was supplied into PJM from sources as far away as Florida, the Midwest, and Canada. Nevertheless, supply was insufficient to meet the demand because some generators were unavailable or unable to meet their rated capability due to ambient conditions, and some capacitors were not in service (PJM Interconnection, 2000). By using a number of emergency procedures, however, PJM did not have to resort to system-wide rolling blackouts, and was able to supply emergency energy to the New York Power Pool (PJM Interconnection, 1999).

The New York Independent System Operator, a consortium of the state's electric utilities, requires that each of its members be able to deliver at least 18% more power than customers use at peak periods. On July 6, Con Edison for the first time fell below that standard, to 17%. The Long Island Power Authority had just a 10% cushion, and Public Service Electric and Gas in New Jersey came within 5% of its capacity (Perez-Pena, 1999).

Con Edison, with its power distribution system underground, has one of the lowest rates of power failure in the industry, and by far the lowest of any New York State utility, according to the New York State Public Service Commission. Nevertheless, blackouts have occurred in 1993 in Brooklyn and 1996 in Queens because "feeder cables" that supply communities become overheated as more energy is pushed through them and as the ground becomes hotter. In many cases, the cables were installed decades ago. Con Edison is installing new cables with greater capacity and better insulation, but company officials say that it will take years to replace them all (Perez-Pena, 1999).

Con Edison's decision to shut down the Washington Heights network resulted from a combination of factors stemming from record high electrical loads and heat, according to The New York Times. These caused a concentration of an unusually high number of component failures in the network, resulting in the outage of 8 of the 14 feeders in the Washington Heights network just prior to the shutdown. This culminated in a fire in the Sherman Creek substation, which serves the Washington Heights network. The fire caused two additional feeders to be removed from service, which resulted in the decision to shut down the network (Con Edison, 1999c).

With the shutdown, power was cut off to two of Columbia University's four laboratory buildings in Washington Heights when the university's backup generators were either not in place or failed. According to Columbia researchers, hundreds of experiments were destroyed or set back by months, and hundreds of thousands of dollar's worth of enzymes and other chemicals were ruined when refrigerators lost power (Kennedy, 1999).

On April 10, 2000 a group of 100 small businessmen filed suit against Con Edison, joining 60 bodega owners and the City of New York in suing. To date, Con Edison has compensated 1,266 businesses up to $2,000 each for losses during the blackout, but the businessmen say that they have not been adequately compensated (Barnes, 2000).

Investigations by the New York State attorney general and the Public Service Commission found that the Washington Heights network was maintained no differently than any other network (Barnes, 2000). Nevertheless, the perception persists among part of the public that the region was neglected because, except for Columbia, it is a low-income neighborhood.

TABLE 8-8
Zones in New York Power Pool Zone Forecasting Models, determined by local power grids. Zones in the Metropolitan East Coast Region are G, H, I, J, and K.

Zone	Weather Stations	Weight
A: Frontier	Buffalo	91%
	Elmira	5%
	Syracuse	54%
B. Genessee	Elmira	5%
	Rochester	85%
	Syracuse	10%
C. Syracuse	Binghampton	23%
	Elmira	14%
	Syracuse	55%
	Watertown	9%
D: Adirondack	Plattsburg	100%
E: Utica	Binghampton	20%
	Massena	17%
	Monticello	13%
	Utica	35%
	Watertown	15%
F: Capital	Albany	76%
	Binghampton	3%
	Plattsburg	5%
	Poughkeepsie	6%
	Utica	10%
G: Mid-Hudson	Newburgh	68%
	Poughkeepsie	27%
	White Plains	4%
	Albany	2%
H: Millwood	White Plains	100%
I: SPR Dunwoodie	White Plains	100%
J: New York City	JFK	21%
	La Guardia	79%
K. Long Island	Islip	100%

Source: New York Power Pool, 1999b

The model was developed in a series of steps:

- Load and weather data were examined for consistency and quality
- Weather stations were mapped to zones and combined to produce aggregate weather variables for each zone
- Economic trends for the state and eleven zones were developed to forecast both energy and peak demand for the state
- Neural network and regression models were developed to forecast both energy and peak demand for each of the 11 zones.

Three economic drivers/indices were developed to capture long-term changes in energy demand: residential energy consumption, manufacturing segment growth, and non-manufacturing segment growth. For the residential index, the energy consumption in each zone was developed from the 1998 *Annual Energy Outlook* of the Energy Information Administration. Space heating and cooling shares were developed from the 1996 Gas Research Institute *Baseline Projection Data Book* for the New England region.

The long-term forecast using the models projected a state electric system with peaks growing at 1.15% annually and total energy consumption growing at 1.4% annually. For the state, summer peaks grow at 1.15% annually, faster than the 1.0% annual growth in winter peaks. By 2010, summer peaks are estimated to be 20% higher than winter peaks, compared to 5% in 1996.

The eleven zone models are forecast with a combination of the individual zone models and the system load model. These models were combined using a "share-out" approach to produce the load forecast by load zone. In this approach, the model result for each zone is used to develop the zone's percentage of the entire load for New York State. This percentage is then applied to the result from the New York State system model to estimate the final forecast for each zone.

Climate Impacts on Downstate New York Electricity

For this study, the New York Power Pool Zone Forecasting Model was used to estimate the effect of future extreme weather conditions on electricity demand in the five downstate zones that are part of the Metropolitan East Coast region.

To put these estimates in context, the daily electric energy load in New York State as a whole is shown in Figure 8-11 for the years 1996 and 1997. Each point represents the daily energy sendout (gigawatt-hours) and the average dry bulb temperature for the day. The distribution of points for both years bottoms out in the range 50–65°F. As the average daily temperature *decreases* from this range, it is evident that the daily sendout increases at a slightly increasing rate. As the temperature *increases*, the daily sendout increases more sharply, again at a slightly

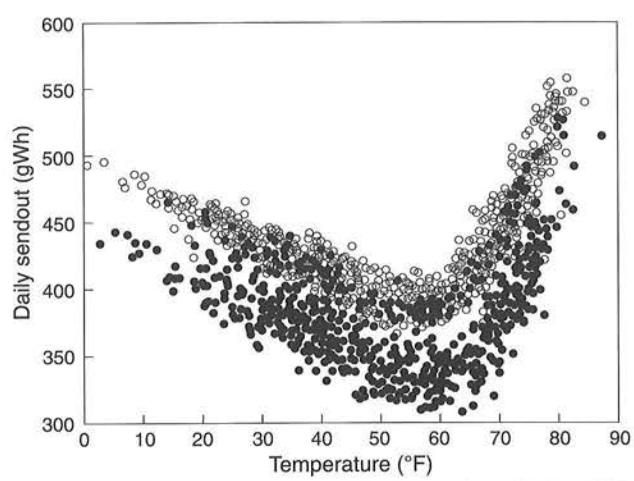


FIGURE 8-11 Daily electric energy load (gigawatt-hours) in New York State vs. average dry bulb temperature (°F). Solid points are 1996, open points are 1997. Source: New York Power Pool, 1999b.

TABLE 8-9

Calculated midweek electricity demand in July for the New York State portion of the Metropolitan East Coast Region for assumed values of temperature and humidity, with other conditions those of July 1999.

		Daily Peak (MW)			
Relative Humidity		***40%***	***60%***	***80%***	***100%***
Temperature (°F)	85	15,655	16,717	17,489	18,089
	90	17,140	18,168	18,872	19,409
	95	18,655	19,565	20,158	20,604
	100	20,296	20,997	21,457	21,799
	101	20,490	21,143	21,596	21,923
		Daily Sendout (GWH)			
Relative Humidity		***40%***	***60%***	***80%***	***100%***
Temperature (°F)	85	308	333	351	364
	90	339	365	381	392
	95	372	395	409	417
	100	404	423	432	438
	101	410	427	436	441

Source: John Pade, New York Independent System Operator, 2000

increasing rate. For the lower boundary of the distribution of points to appear convex, there must be an increasing rate of change in both directions.

At extremely high temperatures, however, the daily sendout would increase at a *decreasing* rate as the point is approached where there are no more air conditioners to turn on. There is therefore a transition zone where the rate of increase in the daily sendout goes from increasing to decreasing. With summer peak cooling loads expected to increase in the future, the question is how to extrapolate electricity demand under these peak conditions.

To answer this question, the New York Power Pool Zone Forecasting Model was used to calculate what the electricity demand would be under a set of assumed extreme conditions for temperature and humidity. The results for daily peak (megawatts) and daily sendout (gigawatt-hours) are shown in Table 8-9.

To represent extreme conditions, the peaks and sendouts in the table are average values for a Tuesday through Thursday in July. The non-weather data was the same as that for 1999. These results for daily sendout are plotted in Figure 8-12 and for daily peak in Figure 8-13.

In both cases, the increase in electricity demand with increasing temperature at constant relative humidity is virtually linear. In the case of daily sendout, the curve is slightly concave at humidities above 40%. In the case of daily peak, some concavity appears above 100°F. This may be explained in both cases by a saturation of the capacity for air conditioning. For the case of daily peak, however, the points are so close to perfectly linear that they can be represented by a linear equation calculated by regression analysis with a correlation coefficient of 0.99.

This does not mean, however, that the transition zone between 85°F and 101°F is necessarily linear. If there were a systematic increase in relative humidity with temperature, for example, the energy demand curves would be convex, that is, increasing at an increasing rate. If there were a systematic decrease, they would be concave. In either case, it is consistent with the necessity for a transition zone at some point on the energy-temperature curve for them to be close to linear.

For future daily peaks, it therefore appears valid to use the linear regression equation to extrapolate beyond 101°F. This assumption is used to estimate the future daily peaks shown in Figure 8-14 for the 2020s, 2050s and 2080s. These estimates are determined by the future values of temperature and relative humidity calculated in the two global climate models (see Appendix Energy 1). The percentage increase in the daily peak load from that calculated for 1999 ranges from 7% to 12% in the 2020s, 8% to 15% percent in the 2050s, and 11% to 17% in the 2080s.

It should be noted that Figure 8-14 does *not* show the projected increase in peak demands from 1999 to the decades shown. The normal growth in electricity would probably exceed the change shown for the 2020s, for example. These are the *increases* in the peak demand that

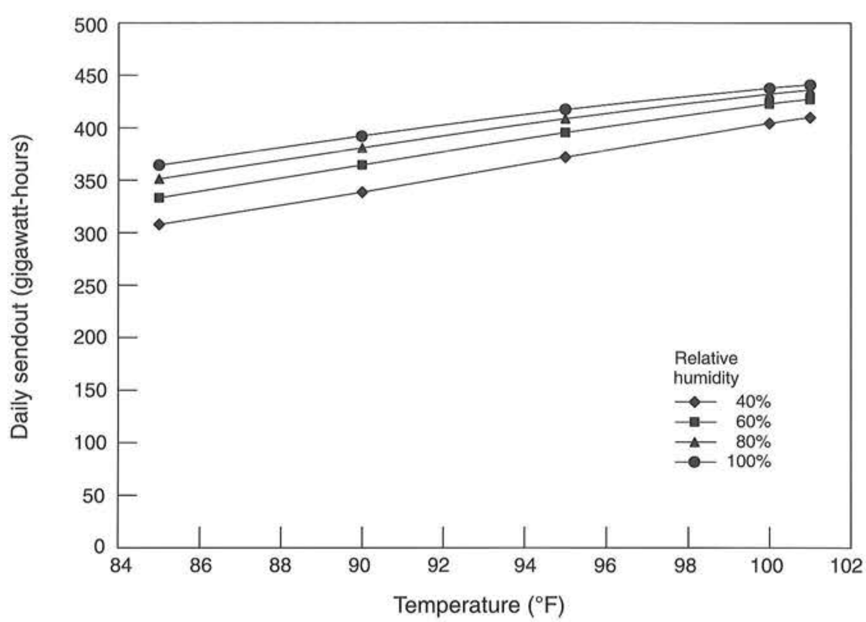


FIGURE 8-12 Parametric relationship of daily sendout with temperature and relative humidity in the New York portion of the Metropolitan East Coast Region calculated with the New York Power Pool Zone Forecasting Model.

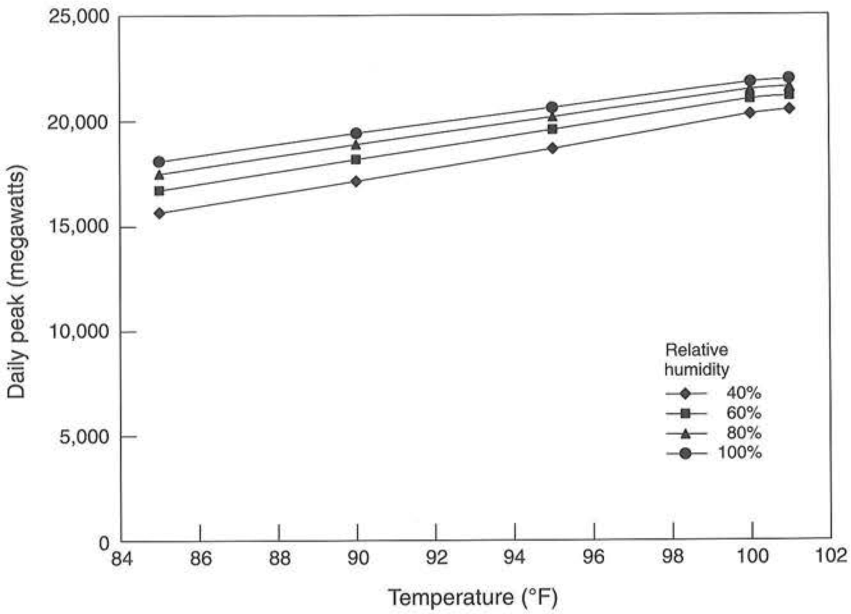


FIGURE 8-13 Parametric relationship of daily peak with temperature and relative humidity in the New York portion of the Metropolitan East Coast Region calculated with the New York Power Pool Zone Forecasting Model.

would have occurred in 1999 if the temperature and humidity had been as projected for future decades by the two general circulation models. As such, they may be interpreted as the approximate difference that would exist in peak demands in those decades strictly due to expected changes in temperature and humidity.

For the fixed levels of humidity, the New York Power Pool model indicates that a 1°F increase in temperature leads to an increase in the downstate daily peak load of 240 to 309 megawatts. By comparison, Linder et al. (1987) estimated an increase in the downstate peak load of 591 to 1,080 megawatts for a 1.46°F temperature rise in 2015, or 404 to 740 megawatts per degree Fahrenheit.

Impacts on Peak Loads

On strictly theoretical grounds, higher air temperatures would be expected to increase the energy required for air conditioning at an increasing rate. Air conditioning removes two sources: sensible heat due to the drop in temperature and latent heat that is released by the condensation of water vapor. At higher temperatures, the air can hold more water vapor. The increase in this "absolute humidity" of the air is greater for the same increment of relative humidity at higher temperatures. Therefore, under these conditions the proportion of latent heat increases, and the total heat removal resulting from the same temperature drop increases. Thus, the higher the temperature with a given relative humidity, the greater the energy required to reduce the air temperature by one degree.

Moreover, the electric power required to provide this energy increases disproportionately with higher temperature for a number of reasons. For example, air conditioning units become less efficient at higher air temperatures. The resistance of copper wires increases at higher temperatures and with greater electric current passing through them.

This is the opposite of our results in two respects. At a given temperature, for example, our results indicate a smaller and smaller increase in daily peak as relative humidity increases. Furthermore, at successively higher temperatures, these increments in daily peaks for equal steps in relative humidity generally become smaller and smaller.

The explanation for this is that the model represents a finite system: the New York State electric power system. At high temperatures, the incremental system demand is determined by the additional air conditioning load. Air conditioners, which cycle on and off, come closer to being all on. In other words, the system is approaching load saturation.

Another condition is that the parametric results for daily peak and daily sendout apply to 1999. They represent what the situation would have been with the assumed combinations of temperature and relative humidity rather than what actually occurred. Projecting these results to the 2020s, therefore, implies that the electric power system at that time is faced with comparable saturation of the air conditioning units.

For these projections, we note the following caveats:

- The New York Power Pool Zone Forecasting Model was not developed for long-term climate projections, but for forecasting electric loads in the next few days. It includes many more variables than the two—temperature and relative humidity—that were varied parametrically for our purposes. This required that many

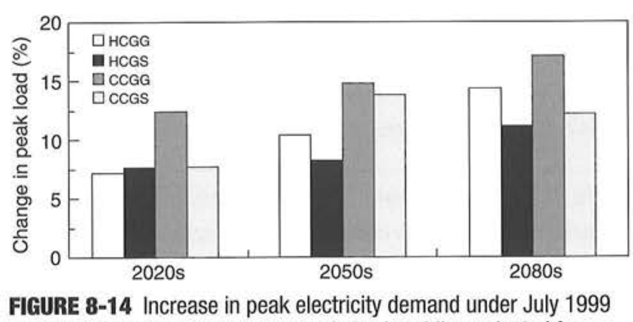


FIGURE 8-14 Increase in peak electricity demand under July 1999 conditions with temperatures and relative humidity projected for future decades.

Note: Bars represent low and high range of two global climate models, the Hadley Centre (HC) and the Canadian Centre (CC) models.

assumptions be made as to what constitutes "everything else being equal."

- The 20 combinations of temperature and relative humidity were selected to map the region at the boundary of present day experience for the purpose of extrapolating trends into the higher temperatures that are expected. Although the choice of these combinations was arbitrary, the projected electricity peaks calculated by the model for these 20 points bracket the 18,662 mw calculated by the model for actual 1999 conditions. Notwithstanding, some of the 20 combinations of temperature and humidity are extremely unlikely to occur.
- To calculate the estimated changes shown in Figure 8-14, the results of the two general circulation models are searched for the combination of temperature and humidity that maximizes daily electricity peak in future summer months. Thus, whatever uncertainties result from the use of the Zone Forecasting Model are compounded by those inherent in the application of the general circulation models.

ADAPTATION TO CLIMATE CHANGE

The most important adaptation of the energy sector to climate change-related demand shifts are measures to reduce energy consumption, particularly space cooling in summer, through energy conservation and increased energy efficiency. Aggregate energy consumption is the product of millions of individual decisions on the type and level of energy services required, the type of equipment and fuel to use, the types of buildings in which we live and work, and the kinds of commercial services and manufactured products that we buy.

Many measures to reduce energy consumption were part of the demand-side management programs instituted by state public service commissions through the electric utilities in the early 1990s. In the future, the promotion of such measures will depend in part on how the system benefit charges now collected from utilities by New York, New Jersey and Connecticut will be allocated.

In this section, adaptive responses are identified, in particular technical approaches and policy options for improving energy efficiency and reducing energy use. Such adaptive responses include:

- *The "Cool Communities" program.* This federal program, initiated by the Environmental Protection Agency and now administered by the Department of Energy, promotes the idea of reducing the "heat island effect" in cities through the use of high-albedo surfaces on roofs and pavements and by extensive tree planting. (Akbari et al., 1992). Mesoscale meteorological modeling results indicate that New York City may reach 3.6°F to 5.4°F higher temperatures than the suburbs on a summer afternoon. With high-albedo surfaces and urban forest strategies, the model suggests that the temperature could be reduced by up to 3.6°F. The 20% decline in New York City's trees in the past decade should be reversed (U.S. Department of Energy, 2000). Simulations of buildings indicate that energy savings of 3–35% are attainable. Wintertime penalties in heating energy use are very small or negligible in most cases (Taha et al., 1995).
- *Natural ventilation in new buildings.* A revolutionary design for a commercial building in London uses an external, corkscrew like bracing structure rather than the conventional steel core. The design uses natural air pressure differences around the building's face to circulate air efficiently once it is taken in through vents or open windows. This will minimize the energy needed to run air-conditioning units (American Society of Civil Engineers, 1999).
- *"Weatherization" of low-income housing.* With federal support, states weatherproof, insulate, and upgrade the energy efficiency of low-income housing to reduce winter heating bills. The regulation does not now authorize other measures that provide summer cooling in New York, New Jersey and Connecticut. In the Chicago heat wave of 1995, most fatalities were old people living without air conditioning on the top floors of old, uninsulated buildings, probably with dark roofs. (See "Integration Across Sectors" below.)
- *Tax incentives to reduce energy demands.* New York State has taken the lead in making commercial and residential buildings more efficient by adopting a "green building credit" against state income taxes. The tax credit, which was signed into law on May 15, 2000, is intended to encourage building owners to use advanced technologies like fuel cells and photovoltaic panels to generate electricity on site. The tax credits would pay 30% of the cost of buying fuel cells, less federal and state grants, and 100% of the cost of solar panels, minus the cost of building materials that would have been used otherwise (Holusha, 2000).
- *Low-energy cooling in structures.* In residences, ceiling fans offer an important complement to air-conditioning by raising the critical temperature at which air conditioning is needed and by pre-cooling homes prior to the use of an air conditioner (Meier and Pon, 1993). Gas air conditioning, with approximately 88% efficiency, is a viable alternative to electricity, when net efficiency of electric generation is accounted for (Lynch, 2000). As alternatives to electric air conditioning, the following technologies have been identified as the most promising for cooling commercial buildings: absorption chillers, dessicant cooling, evaporative cooling, cooled ceiling,

and night and slab cooling (Huang, 1993). A brief description and comparison of these technologies, taken from Behne (1997), follows.

Night ventilation: Night ventilation takes advantage of the cooling potential of the outside air at night and the thermal storage capacity of the building. If the outdoor temperature is lower than the indoor temperature at night, cooling air can enter the building either through natural ventilation or with fans. The building must have sufficient thermal storage capacity to remain relatively cool as the outside temperature rises during the day. Night ventilation can be used to reduce the load on conventional air conditioning, especially if the peak load normally occurs early in the day.

Evaporative cooling: Direct evaporative coolers cool the incoming air by evaporating water directly into it. These are suited to residences in a dry climate. An indirect evaporative cooler is a combination of a direct evaporative cooler and an air-to-air heat exchanger.

Dessicant cooling: In conventional air conditioning, the incoming air is dehumidified by cooling it below the dew point. The latent heat released by the condensation of the water must then be removed as well as the sensible heat due to lowering the air temperature. However, the incoming air can be dehumidified with sorptive materials, called dessicants, such as silica gel. Dessicant cooling systems are combinations of an adsorptive or absorption dehumidifier and an evaporative cooler. The dessicants are recycled continuously in a regenerative process. Dessicant cooling is particularly useful in climates with high humidity.

Absorption chiller: An absorption chiller works in the same way as a conventional compression chiller. The difference is in the energy source used to compress the refrigerant. Compression chillers use mechanical energy—supplied by electricity—while absorption chillers use heat instead, supplied by steam or hot water. As a result, a greater amount of heat must be vented to the atmosphere at the site. However, the absorption chiller uses only about 10% as much electricity. Absorption chillers are the only alternative to completely substitute for a conventional compression chiller for air and water-cooling.

Cooled ceiling: Interior spaces can be cooled both by convection and radiation by circulating cooled water through pipes in the ceiling slab or just below it. Energy consumption and peak power demand can be reduced in all-air systems if cooled ceilings are used to remove the sensible cooling load.

In modeling studies for climates similar to that of the metropolitan New York region, absorption chillers and dessicant cooling were found by Behne (1997) to reduce peak power demands in buildings by 70% to almost 90%.

Demand-Side Measures

Between 1973 and 1986, conservation and efficiency measures helped to keep U.S. energy consumption at nearly constant levels while the country's gross national product grew by 35%, as previously noted. Many believe that opportunities for further demand reduction are still available using existing and newly developed conservation and efficiency measures.

Demand-side management (DSM) is the term for programs that focus on getting consumers to consume less energy or to consume less in peak periods. Basic types include: building or business audits to identify potential energy savings; performance-based rebates; technology-based rebates; reduced interest payments to finance energy-efficient investments; direct installation of energy-efficient equipment; energy load management programs; educational and advertising campaigns; and end-use fuel substitution.

From 1989 through 1993, there was a steady increase in utility DSM spending and in energy and demand savings. Since then, however, DSM has declined with the deregulation of the electric power industry. Even at their peak, however, demand-side management programs were often slow to take hold. According to the EPA, the problem is rooted in a set of common institutional and political barriers. These include: perceived high initial cost and delayed return on investment in energy-efficient technology; lack of information; low priority given to energy consumption; low energy costs; limited availability; popular attitude and consumer habits; and inaccurate price signals. In the future, state promotion of demand-side measures will be determined by their allocation of system benefit charges paid by the utilities (Kushler and Witte, 2000).

Technical Approaches for Improving Energy Efficiency and Reducing Energy Use

Technical measures to reduce the use of energy may simultaneously reduce both conventional air pollution and greenhouse gases using what are sometimes called "harmonized strategies." (STAPPA and ALAPCO, 1999). Technical approaches to achieve energy-efficiency improvements can be divided along three lines: building measures (e.g., building shell measures to reduce heating/cooling requirements), equipment improvements, and process changes (U.S. Environmental Protection Agency, 1998).[2]

BUILDING SHELL MEASURES

Approaches to improve the efficiency of building shells include a wide variety of building design, construction, landscaping, and retrofit actions. Major decreases in ener-

[2] In residential and commercial buildings, energy use for heating and cooling accounts for about 57% of carbon dioxide emissions, appliances account for about 20%, lighting for about 14%, and hot water about 9% (OTA, 1991).

gy use can be achieved by increasing insulation levels, installing improved window technologies, orienting the building to take advantage of the sun for heating, using thermal mass for storing energy, and minimizing north-facing window area. Interior design can emphasize minimizing of ventilation energy requirements. While many building shell approaches are practical only during the design and construction of buildings, significant energy savings are available through shell retrofit measures designed to reduce infiltration and heat loss. Renewable sources of energy such as photovoltaic panels, solar hot water technology, and geothermal heat pump technologies can also play a role in reducing energy demand in buildings (New York City Department of Design and Construction, 1999). *Four Times Square*, the new office tower in New York City, provides an example of "green" building practices that include lighting, energy efficiency, indoor air quality, and waste management.

- *Device or equipment measures*. These measures replace existing energy-using equipment with more efficient technologies, and are available for every kind of energy end use at efficiencies substantially above current levels. Examples are given in Table 8-10. The applicability of energy-efficient equipment, however, can be limited by technical, operational or economic barriers.
- *Process measures*. Substantial energy-efficient gains can be achieved through changes in the processes used to produce goods and services. Processes can range from substituting an energy-efficient fax machine or electronic mail system to the adoption of electric arc systems to make use of waste heat in industrial and other facilities.
- *Load shifting*. Load shifting changes energy consumption patterns to different times of the day to reduce energy demand at peak hours. Load shifting does not directly increase energy consumption efficiency, but it can lead to more efficient operation. Electric utilities make significant use of programs to electronically cycle air conditioners during peak periods, and peak load pricing programs to shift consumption to off-peak hours.
- *Cogeneration and district heating*. Making use of the waste heat from electricity generation—cogeneration of heat and power—raises the overall efficiency of the process. Many independent power plants serving local building complexes provide cogeneration, in some cases also providing cooling. Con Edison's steam-electric generation system in Manhattan—the largest, and recently judged the best, in the world—is another and older example on a much larger scale (Con Edison, 2000). The steam district heating system extends from the lower tip of Manhattan to 96th Street on the west side of Central Park and to 89th Street on the east side. About 60% of Con Edison's steam sales are for both heating and air conditioning. The company's plans for expansion of the steam system at the margins requires customers to use the steam for air conditioning as well as heating, specifically to reduce summer electricity peak loads (Consolidated Edison, 1990).
- *Fuel switching*. Substitution of one energy source for another is an effective way to reduce greenhouse gas emissions. This can occur not only at sites that provide power, such as large electricity generating stations, but on a much smaller scale such as a home. Substituting gas for electricity, for example, can lead to a reduction in power plant fuel consumption and emissions. Alternatively, replacing current gas technologies with very efficient electric technologies can produce net system reductions in energy use and emissions, even after accounting for the losses in the generation and transmission of electricity. As with load shifting, the energy and emissions reductions realized by fuel switching depend heavily on the specific situation.

TABLE 8-10
Projected annual savings of residential energy efficiency upgrades*

Energy Efficiency Upgrades	Purchase Price[a]	Amount Bill Savings[b]	Simple Payback (years)	Annual Rate of Return
Fluorescent Lamps and Fixtures	$200	$80	2.5	41%
Duct Sealing	$250	$95	2.6	41%
Energy Star Clothes Washer	$194	$66	2.9	37%
Energy Star Programmable Thermostat	$107	$29	3.7	30%
Water Heater Tank Wrap (R-12)	$85	$23	4.2	27%
Energy Star Refrigerator	$97	$23	4.2	27%
Energy Star Heat Pump	$692	$126	5.5	19%
Energy Star Dishwasher	$29	$5	5.5	18%
Air Sealing	$522	$38	13.7	9%
Increase Wall and Attic Insulation	$1,784	$111	16.1	8%
Total	$3,960	$597	6.6	16%
Total Bill Savings as % of Baseline Bill[c]		36%		

* Assumes typical house with air-source heat pump, electric water heating, clothes washer, clothes dryer, and dishwasher. Purchase prices and annual bill savings for efficiency measures are nominal 1997 dollars. The rate of return assumes 3% annual inflation in residential energy prices. After-tax rates of return assume a 28% marginal income tax rate.

[a] Purchase price of clothes washer, dishwasher, thermostat, and heat pump measures its incremental to the price of existing NAECA appliance standards. All other prices reflect the full cost of the measure, including installation.

[b] Bill savings assume average electricity cost of $0.088 per kWh. Bill savings of equipment measures are relative to NAECA standard unit.

[c] Heating andcooling consumption values are from LBNL, energy modeling using DOE-2, other end-use consumption's are from the U.S. DOE's Residential Energy Consumption Survey (RECS).

Source: DOE, Lawrence Berkeley Laboratory.

Two general factors influence whether a given technical approach is feasible. The first concern is whether an approach can be implemented in new, retrofit, and/or replacement situations. Some approaches are feasible only when a building is being constructed since they are key elements of a structure's design. Other measures are feasible when existing equipment is replaced due to failure, while still other options can be retrofitted at any time. Energy used in heating buildings, for example, is determined in large part by the type of building, the quality of its construction, and level of thermal integrity. Although building thermal integrity can be improved by retrofitting it with better insulation, once built, the building's basic heating and cooling requirements can seldom be changed. They therefore apply for the building's remaining life which is measured in decades.

Most primary heating and cooling systems, residential or commercial, undergo major maintenance every 20 to 30 years. Upgrading boilers/furnaces and/or air-conditioning can generally be undertaken without significant structural change. Targeting of pre-1970s buildings would be appropriate (Lynch, 2000).

The second factor affecting the feasibility of the technical approaches listed above is that some energy-efficiency options are not compatible with existing equipment or energy service needs. Replacing electric resistance heating in a home with an efficient heat pump, for example, would be impractical if the home does not contain any duct work. Certain commercial HVAC (heating, ventilating, and air-conditioning) systems are suited only to certain applications and/or climate zones, or the lighting needs of a retail store may not be compatible with the most efficient type of lighting systems available. The key to successful implementation of energy-efficient options, therefore, is to target the selected approaches to those segments of the market in which the specific approaches are practical, feasible, and economic.

In New York City, there have been several obstacles to improving energy efficiency in buildings. Codes and regulations have had limited success in promoting energy efficiency in buildings because they do not promote use of cutting-edge technology, and in fact do not apply to most renovations. At present price levels, energy costs are not a large enough fraction of a building manager's operating costs to be concerned. Landlords pass through energy costs to renters; renters often do not control the heating. Fundamentally, there is no incentive for builders to pay more to make a building more energy efficient (Audin, 1996).

Policy Options for Improving Energy Efficiency and Reducing Energy Use

Policy options are instruments through which one or more technical approaches can be promoted. Policy options recommended by the Environmental Protection Agency to states preparing action plans for improving energy efficiency and reducing energy use are as follows (U.S. Environmental Protection Agency, 1998):

- *Provide financial incentives for efficiency improvements.* States can provide financial incentives for accelerating equipment replacement rates through tax credits or low-interest loans on efficiency improvements. They can tax inefficient appliances and equipment, or work with utilities to sponsor rebate programs that induce customers to buy efficient products.
- *Develop institutional planning and support structures*. State agencies established to deal with energy issues may conduct planning and analysis, administer programs, and provide support for utilities, industry, and consumers. Many such agencies are instrumental in facilitating energy-efficiency measures. The New York State Energy Office, considered by many to be a model of such activities, was terminated by Governor Patacki. However, many of its most effective functions continue to be performed by the New York State Energy Research and Development Authority.
- *Institute long-range planning.* Many states, including New York but not New Jersey or Connecticut, mandate an energy agency to provide assessments of state energy consumption as well as potential ways to increase efficiency and reduce energy use. These plans provide valuable focal points for policy development through time and across the economic sectors that affect energy consumption.
- *Facilitate interaction between Demand Side Management program sponsors and potential customers*. States, for example, are in a good position to act as a liaison between federal energy-efficiency programs and local industries and governments, or between utilities and potential commercial or industrial energy-efficient clients.
- *Rationalize state tax policy.* Although practice varies from state to state, tax policies often favor energy consumption over energy efficiency. For example, purchases of gas and electricity may be exempted from state tax, while energy-efficiency instruments (more efficient equipment, insulation, etc.) are not. These policies could be revisited and revised.
- *Provide information and education*. States and local governments can gather and disseminate information, often working with utilities, on the energy and financial implications of energy-efficiency projects in certain types of buildings and facilities, and promote research, development and demonstration projects. Through their university systems, states may also promote energy-efficiency training in professional planning and urban design programs.

- *Take direct action to reduce energy consumption in government facilities*. States and local governments can reduce energy consumption on their own properties, including schools and low-income housing projects. Such programs may involve retrofitting existing buildings, changing building and procurement practices to require energy-efficiency investments, and modifying building design requirements.
- *Establish and enforce efficiency standards and codes*. More integrated and aggressive approaches to promoting energy efficiency in buildings may be encouraged by strengthening outdated building codes. There must also be enforcement of the codes they adopt. The Energy Policy Act of 1992 encourages states to adopt energy-efficient provisions at least equal to ASHRAE (American Society of Heating, Refrigeration, and Air-conditioning Engineers) standards for commercial buildings, and the 1992 model Energy Code from the Council of American Building Officials for residential structures.
- *Demonstrate building efficiency measures and facilitate energy-efficient programs*. States and local governments are well situated to initiate energy-efficiency demonstration projects in buildings, often using their own facilities, and to publicize resulting information on energy and cost savings. Similarly, they are often well situated to coordinate interactions between landlords and tenants, especially in the commercial sector, in order to facilitate improvements in existing buildings. Programs to include these goals can include innovative approaches such as setting minimum efficiency standards for rental properties, or developing shared savings programs where landlords and tenants both benefit from energy-efficient investments.

A modeling study to evaluate measures to reduce carbon dioxide emissions in New York found that energy efficiency measures, together with fuel switching to natural gas, led to the largest share of carbon dioxide emission reductions (Morris et al., 1996). Although energy conservation and efficiency improvements are described here as the principal steps to adapt to climate change, they are also preeminently the steps needed to reduce greenhouse gas emissions.

Distributed Generation

With ever higher peak summer electric loads, local distribution systems are subject to greater stress, particularly in New York City, exemplified by the Washington Heights blackout in July 1999. In June 1999, Con Edison had announced that it planned to spend $414 million that year to upgrade its transmission and distribution infrastructure (Con Edison, 1999b). An important way relieve the loads on local distribution systems is distributed generation.

Distributed generation means self-generation or localized, on-site or customer-sited generation, often connected to the local utility's distribution system. Distributed generation may be designed to meet particular customer needs for peaking or backup power, base load, reliability or power quality. It may also be designed for the local utility to meet distribution peak loads at the substation level or to avoid upgrading or building additional local distribution lines.

Distributed generation has the potential to provide site-specific reliability and transmission and distribution (T&D) benefits including: increased reliability, shorter and less extensive outages, lower reserve margin requirements, improved power quality, reduced line losses, reactive power control, mitigation of transmission and distribution T&D congestion, and increased system capacity with reduced T&D investment.

The technologies that can be used for distributed generation depend upon size, economics, and state of development. The New Jersey Climate Change Action Plan (2000) recommends microturbines, fuel cells, photovoltaics, and geothermal heat pump systems. Microturbines and fuel cells in particular may provide economic advantages to larger systems because they are modular. They can be obtained with short lead times, and they are flexible as to location. Since they are small they also can provide redundant sources of supply. There may be economic benefits due to peak shaving, combined heat and power (cogeneration) applications, and standby power applications. Finally, there may be environmental benefits due to reduced land impacts, reduced environmental emissions, and lower environmental compliance costs.

Unfortunately, electricity restructuring, zoning and permitting processes, and regulatory and business practices developed for centralized electric generation and ownership have created potential barriers to the development of distributed generation in competitive markets. These barriers include lack of standardized interconnection requirements, high standby charges for backup power, charges for utility stranded cost recovery, and low utility buy-back rates. To overcome these barriers, the Connecticut Energy Advisory Board (2000) proposes a number of actions:

- Review existing interconnection standards and explore development of statewide interconnection standards.
- Develop a statewide policy regarding standby rates and related utility rates that balance the importance of removing barriers to distributed generation and the importance of maintaining fair and reasonable rates for customers that do not generate their own electricity.
- Coordinate the activities of state agencies to identify and address barriers that impede development of new energy technology.

- Support pilot programs to improve planning and operational methods to address grid stability and reliability.
- Support development of systems for demand-side bidding by the Independent System Operator
- Review implementation and scope of net metering regulations for possible expansion.
- Maintain solar contractor licensing and training.
- Encourage efficient production and distribution technologies and infrastructure.
- Encourage retrofit programs in areas where transmission and distribution are constrained, incorporating the value of the benefits of distributed generation with the development of cost avoidance measures.
- Encourage high-efficiency cogeneration and combined heat and power where appropriate and consistent with other policy goals.

INTEGRATION ACROSS SECTORS: ENERGY AND PUBLIC HEALTH

The factors that determine summer energy demand are much the same as those that cause heat stress: temperature, humidity, wind speed, cloud cover, and antecedent weather conditions (see Box 8-2). When it gets hot, people turn on their air conditioners, which demand electricity. The hotter it gets, the more the air conditioners work, demanding more electricity.

Heat stress is projected to increase with climate warming during the next century as shown in Figure 8-15. Compared to the base period of 1997–98, days with a heat index of Category IV will tend to decline toward the end of the century as there are more days in the higher categories. From an average of twelve days in the reference period, days with a heat index of Category III will increase to twenty or thirty in the 2020s, twenty-five to nearly fifty in the 2050s, and even more in the 2080s. Days with a heat index of Category II, none of which were recorded in the reference period, will rise from a few in the 2020s to as much as 10 or 12 in the 2050s, and more later.

A number of studies have compared ambient climate conditions to mortality during a heat wave. The duration, high humidity, high minimum temperatures, and low wind speeds all contribute to increased mortality, and a time lag exists between the peaks in the heat index and deaths, as illustrated for the 1995 Chicago heat wave in Figure 8-16 (Huang, 1996). Many health researchers have found that deviation from the mean temperature is a better predictor of heat stress mortality than absolute temperature (Kinney et al., 2000), just as cooling degree-days—a common predictor of summer energy demand—are measured by the difference in daily temperature from 60°F or 65°F.

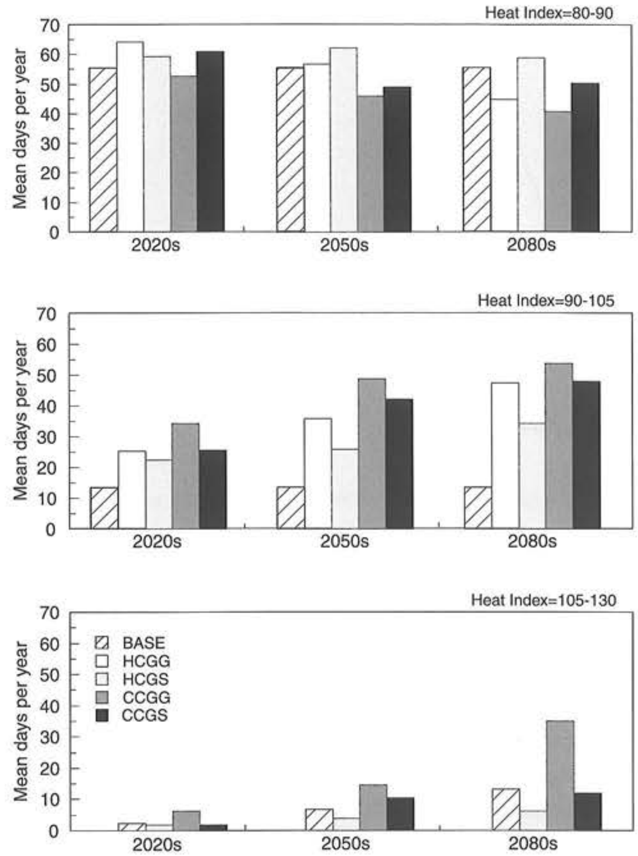


FIGURE 8-15 Heat indices projected for La Guardia Airport, New York City, by global climate models.

Extremely high temperature and humidity over successive nights is a crucial factor in heat-related deaths. Over the last half-century, these conditions have become more frequent (Stevens, 1998).

Epidemiological studies of heat-wave deaths have given little attention, however, to the role of the building and its interior conditions. Simulations of these conditions in the Chicago heat wave of 1995 indicate that some of the structural measures that would save lives are the same as those that would reduce energy demand. An exception is the use of electric air conditioners, which are estimated to have prevented probably 3,600 deaths in New York City from 1965 to1988 (Kalkstein, 1995). Unfortunately, when electric air conditioners are used, they add to the electricity peak load and contribute to worsened global warming by causing more carbon dioxide to be emitted. As recently as 1995, 20% of residences in the Con Edison service area lacked air conditioners.

The number of deaths from heat stress has been higher over a period of time in New York City than in Chicago or any other American city, as shown in Table 8-11. With a doubling of the concentration of carbon dioxide in the atmosphere—a common measure of the climate change in the next century—the annual toll would increase fivefold (Kalkstein, 1995).

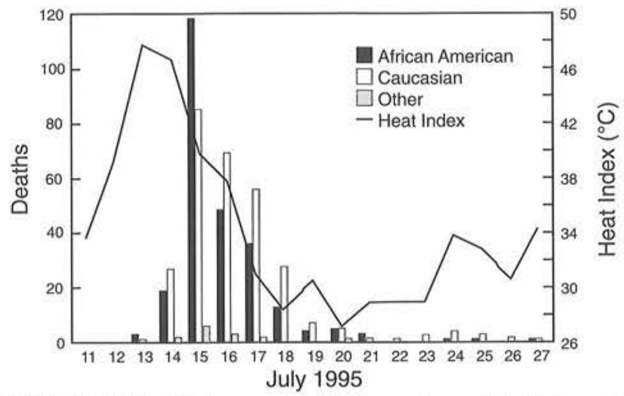


FIGURE 8-16 Heat index compared to the numbers of deaths by race each day of the July 1995 heat wave in Chicago.

Source: J. Huang, 1996.

In these heat waves, worsened air pollution exacerbates the unhealthy conditions. For reasons of electric system reliability, the New York Independent System Operator requires that at least 80% of New York City's electric power be generated locally, a higher percentage than most other cities. All electric generating plants will be operating at peak power, adding nitrogen oxides, sulfur dioxide, particulates, and other pollutants as well as heat to the atmosphere.[3] The higher air temperatures accelerate the formation of ozone which causes asthmatic attacks and worsens other respiratory diseases. At night, the pollution lying over the city inhibits heat loss and contributes to the heat island effect. On these hot days, the association between mortality and airborne particulates also increases dramatically.

An estimate of the increase in mortality and respiratory hospital admissions is shown in Table 8-12 (Kleinman and Lipfert, 1996). The causes of respiratory hospital admissions are divided about evenly among ozone, airborne particulates, and temperature. Temperature, however, is by far the leading cause of death.

These 1996 results must be accompanied by a number of caveats, all relating to uncertainties. The rate of increase in mortality with temperature varies among cities and over time. There are large differences between actual pollution exposure and outdoor air quality. Ozone is greatly attenuated indoors, while particulate matter may increase. Thus, if climate change forces people to spend more time in air-conditioned spaces, outdoor air quality becomes less important than indoor air quality, except for the unfortunate few who can't afford air conditioning. It can be argued that the change in daily temperature is more important than the absolute level, which says that at least some portion of the population will adapt to higher temperatures (Lipfert, 2000).

[3] Because of their low efficiency, the combustion turbines turned on by Con Edison and KeySpan that burn distillate oil under peak load conditions produce more carbon dioxide per kilowatt-hour of energy than does coal in New York State.

TABLE 8-11
Death toll from heat stress in some major cities

	Annual toll (1964–1985)	Annual toll with atmospheric CO_2 doubled
Shanghai	418	3,587
New York	**320**	**1,743**
Philadelphia	288	938
Cairo	281	1125
Chicago	173	412
St. Louis	113	744
Los Angeles	84	1,654
Montreal	69	430

Source: Kalkstein, 1995

In the Chicago heat wave, more deaths occurred in inner-city areas and disproportionately among older, infirm residents on the top floors of apartments without air conditioning. The mortality pattern appears to correlate with the thermal response of different building types to a heat wave, as well as current conditions in the housing stock (Huang, 1996).

A building simulation program was used by Lawrence Berkeley Laboratory to simulate indoor conditions without air conditioning in four prototypical multifamily buildings of different vintages during the 1995 Chicago heat wave. The buildings were simulated first with windows closed, and then with windows opened for ventilation whenever the outdoor temperatures were lower than inside. To study the benefits of potential energy conservation strategies, the simulations were repeated with additional ceiling insulation, light-colored roofs, and lowered window-shading coefficients.

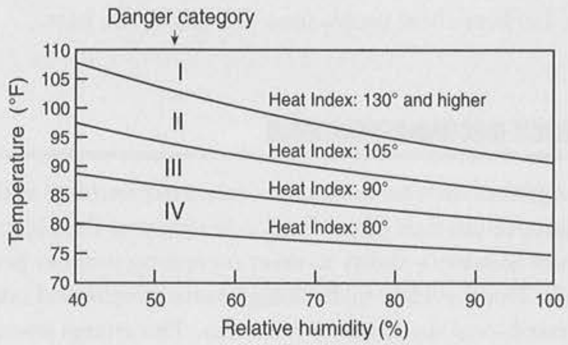
If the buildings were unventilated, as was reported often to be the case, the simulation indicated that indoor temperatures could reach 108°F (42°C) on the top floors of buildings built in the 1940s. They were hotter than the human body temperature for 80% of the hours during the peak three days. Conditions in the 1970s apartment buildings were even worse, with temperatures averaging 108°F (42°C) over the three-day period. Because of their greater

TABLE 8-12
Health effects of a temperature increase in New York City of 2°C (percent change)

	Mortality	Respiratory hospital admissions
From temperature alone	0.61%	0.45%
From ozone	0.02%	0.58%
From airborne particles	0.04%	0.32%
Total effect	0.67%	1.3%

Source: Kleinman and Lipfert, 1996

BOX 8-2. HEAT INDEX



The National Weather Service combines temperature and humidity to find the heat index—an "apparent temperature" measuring the discomfort of people during a heat wave. However, other factors—sunlight, wind and even body type—also affect the way one feels the heat.

Category I Heatstroke (caused when the body loses its ability to cool itself during excessive exposure to high temperatures) and sunstroke (a form of heatstroke caused by excessive exposure to sun) highly likely with continued exposure.

Category II Sunstroke, heat cramps, or heat exhaustion likely, and heatstroke possible with prolonged exposure and/or physical activity.

Category III Sunstroke, heat cramps and heat exhaustion possible with prolonged exposure and/or physical activity.

Category IV Fatigue possible with prolonged exposure and/or physical activity.

mass and moderate insulation, these buildings would remain hot for days after the peak temperature had passed. The heat index reached 129°F (54°C) in the 1940s apartments and 134°F (57°C) in the 1970s apartments over the period.

The simulations showed that the single most important strategy to prevent excessive building overheating during a heat wave is ventilation. (The victims of the 1995 Chicago heat wave were reported to have been found in sealed apartments because they were afraid to go out to seek relief.) In older, uninsulated buildings, however, adding ceiling insulation and lightening the roof color will have an appreciable impact on conditions in top-floor apartments.

Most of these kinds of improvements in low-income housing are made under the Weatherization Assistance Program for Low-Income Persons (10 CFR 440 and U.S. Department of Energy, 1999) of the U.S. Department of Energy (USDOE). Most of the weatherization funding in New York State comes from this program and the Low-Income Home Energy Assistance Program (LIHEAP) administered by the U.S. Department of Health and Human Services (Campaign to Keep America Warm, undated).

The USDOE mission statement for the Weatherization Assistance Program is "to reduce heating *and cooling* costs for low-income families, particularly the elderly, people with disabilities, and children, by improving the energy efficiency of their homes and ensuring their health and safety." However, in northern states designated by the U.S. Department of Energy as "cold weather states," measures are aimed strictly at reducing winter heating bills. Cooling assistance, consisting of fans and air conditioners, is normally provided only in states designated as warm weather states (Sabree-Sylla, 2000).

More than 385,000 dwellings have been weatherized in New York State since 1977, but the backlog is 1.5 million and at the current reduced rate of funding only 10,326 units were to be weatherized in 1999 (New York State Division of Housing and Community Renewal, 1999). At the present rate, therefore, the great majority of these units will never be weatherized. The maximum average cost per unit was estimated to be $2,032. State funding is allocated to counties by a formula that takes into account both the number of income-eligible persons and climate, with climate measured only by *heating* degree-days. In New York, a portion of the public benefit charges administered by the Public Service Commission will be allocated to a low-income program that includes weatherization (Kushler and Witte, 2000).

While weatherization measures that provide insulation from the cold also insulate dwellings from the heat, the additional steps of providing fans, air conditioning, and light-colored roofs, which would provide summer cooling are not normally authorized under the New York Weatherization Assistance Program.

Immediately following the July 1999 heat wave, however, the federal government released $100 million in LIHEAP emergency funds to states on the Atlantic seaboard, including $3 million to Connecticut, $9 million to New Jersey, and $28 million to New York. The New Jersey Department of Community Affairs distributed more than 6,000 air conditioners and fans, and paid out $6 million in additional energy bill assistance (Sabree-Sylla, 2000). For New York, this after-the-fact funding compares to the $29.9 million in regular funds from USDOE and LIHEAP for the 1999 program (U.S. Department of Health and Human Services, 1999).

There would seem to be good reason to extend the weatherization program in northern urban areas to account for the growing threat of summer heat stress before these heat waves occur. Even if air conditioning is provided to at-risk populations under the weatherization program, however, the cost of running the air conditioning could inhibit its use by the poor and elderly, even though the unit is available to them. To address this problem the Connecticut Energy Advisory Board has proposed a number of measures:

- Develop and manage the statewide electricity procurement aggregation program for the benefit of low-income consumers.
- Re-establish the Connecticut Assistance Advisory Council to review methods to increase stable financial support for low-income assistance programs such as the Winter Energy Assistance Program, the Arrearage Forgiveness Program, Operation Fuel, and the Connecticut Energy Assistance Program.
- Work with utilities to promote and enhance universal service and current low-income programs including policies governing low-income discounts on regulated services. "Universal service" means electric service sufficient for basic needs (an evolving bundle of basic services) available to virtually all members of the population regardless of income.
- Upgrade energy efficiency standards and services for multi-family rental housing.
- Assure that low-income consumers are adequately served by competitive suppliers by providing credit enhancement through regulated utilities and other provisions as necessary.
- Assure that the Consumer Education Outreach Program adequately addresses the needs of low-income customers.
- Monitor the impact of electricity restructuring on low-income customers.

INFORMATION AND RESEARCH NEEDS

The major conclusion of this review is that worsening summer heat waves will stress both people and energy systems. The most direct solution for protecting people is to provide air conditioning for everybody. To provide the electricity that would be needed, the power industry is responding as it knows how: by building more generating units. A question for research is: how much will more local power under peak conditions increase the stress on electric distribution systems, contribute further to global warming, worsen local air pollution, and further raise the temperature of the urban heat island?

To break this cycle, the principal research need is how to promote means of cooling that can be widely used and that demand less or no energy; for example, passive cooling of buildings and the community.

In an unregulated market, electricity prices may skyrocket in these hot spells. Mechanisms need to be found to prevent these costs from further burdening the low-income residents of the inner cities who suffer most from heat waves: the castaways on the urban heat island. Even without such price increases, measures need to be strengthened to keep these people from dying from the heat.

POLICY RECOMMENDATIONS

The gradual increase in summer cooling requirements in the Metropolitan East Coast Region is straining the electric power industry's ability to meet increasing summer peak loads. This is evident in declining reserve margins and overstressed local distribution networks. The energy investments being made now will be with us for many decades to come. *The industry should take climate change into account now for better long-term solutions to providing electric power.*

As the climate warms, the industry can adapt through some combination of four solutions:

- Construction of local power plants to keep up with the rising demand
- Construction of additional transmission lines to bring more power into the metropolitan area
- Upgrading of local power lines that distribute electricity to customers
- More aggressive energy efficiency improvements, particularly to reduce summer peak electric loads.

The industry's present response to rising peak demand is to build additional power plants, especially within the metropolitan region. New high-efficiency plants will be used year-round, but the old inefficient plants may well be retained for service under these peak conditions.

This cannot be regarded as a satisfactory long-term solution for several reasons. With summer peak loads 40–50% higher than winter peaks, the system is inherently inefficient and therefore costly because much of its capacity is idle most of the year. The older plants brought into service during summer peaks add to local air pollution at the worst possible time, add heat to the urban heat island, and add disproportionately to carbon dioxide emissions. Moreover, additional power adds to the stress on local distribution systems. Finally, simply generating more and more power adds to carbon dioxide emissions.

A portion of additional power to New York City can be provided with increased transmission capacity. This can be through the New York system, trading seasonally with sources to the north that have winter peak loads, or with stronger interconnections with the adjoining systems in New Jersey and Connecticut. Indeed, the promise of a wider electric power market through deregulation requires greater access to more sources. *The adequacy of transmission interconnections in the metropolitan region therefore needs to be assured.*

However, the adverse impact of climate change on the energy sector is not simply a matter for the electric utilities. It is the public that must reduce the demand for energy, and public policy must respond.

The broadest solution must be to reduce the need for electricity through improved energy efficiency, primarily in commercial and residential buildings. The technologies for doing this are well established and continually improving. The policy options for improving energy efficiency and reducing energy use, identified earlier in this report, are well known. An important new element will be how the system benefit charges now collected from the electric distribution companies will be allocated by the states among research and development, low-income programs, and energy efficiency.

Measures to adapt to climate change by reducing energy use will at the same time reduce greenhouse gas emissions. In the past several years, companies participating in voluntary energy reduction programs sponsored by the U.S. Environmental Protection Agency have found that these measures also save money. However, *stronger incentives are needed to achieve broader participation*.

The crux of the energy problem is the need for summer cooling, virtually all of which is now provided by electric air conditioning. Gas-fired air conditioning is a practical and economic alternative that would reduce peak electricity loads, but it would not decrease emissions. *Priority should be given to promoting passive means of cooling in buildings and in the community.*

Summer heat in New York City is higher than the surrounding suburbs because of the heat island effect. This situation can be partially relieved with extensive tree planting and the use of light-colored surfaces on roofs and pavements. *These measures are specified in the Cool Communities program of the Federal government, which should be aggressively promoted.*

As the climate in the Metropolitan East Coast Region warms, access to cool air will become more necessary for some to survive summer heat waves. The victims of heat waves in the city are mainly older, infirm, poor people living on the top floors of old buildings without air conditioning. For those with air conditioning, deregulated electric rates are likely to increase sharply during heat waves, putting poor people at a further disadvantage. *The "weatherization" program that exists to save energy costs in housing for low-income people should be extended to provide summer cooling in urban areas as well as winter heating, and should be much more generously funded.* This would save lives as well as energy.

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CHAPTER 9
INSTITUTIONAL DECISION-MAKING

The international scientific community has begun to focus upon the reality of global climate change and sophisticated research techniques provide increasingly accurate models of the potential impacts of associated weather extremes, disease outbreaks, and global and local environmental destruction. Yet decision-making institutions have not, for the most part, incorporated global climate change in their policies and planning efforts. This report presents the implications of climate change, thus far considered largely in a global context, in very local terms. As research and discussion of climate change begin to focus on anticipated regional impacts, decision-makers in the Metropolitan East Coast (MEC) Region and elsewhere should begin to consider and implement practical adaptation policies affecting land use, infrastructure, natural resource management, public health, and emergency and disaster response.

During 1999, the MEC Region experienced a series of events of the kind anticipated to accompany climate change and increased climate variability. In August 1999, a sudden and severe rainstorm brought New York City's transit system and many of its streets to a standstill for hours.[1] In September 1999, Tropical Storm Floyd flooded parts of upstate New York and Northern New Jersey, causing substantial property damage. An outbreak of the West Nile virus in New York City in the fall of 1999 caused seven deaths and 62 reported cases of the disease[2] and provoked an unprecedented public response. Prolonged summer heat waves caused power outages and necessitated drought-related water restrictions. Although these events are difficult to attribute to global climate change, they generated widespread public awareness of more frequent severe climate-related incidents that are also potential effects of global climate change. As such, these events and public reactions to them should provide an incentive for decision-makers to more actively consider policies for adaptation that reflect the potential for future climate change and variability.

The scientific findings presented in the MEC Assessment project climate change impacts that escalate by the end of the 21st century. Ongoing and future research is likely to produce more conclusive results and more targeted guidance for decision-makers. The region's institutions can begin, however, to expand their capacity to anticipate and respond to potential impacts and to minimize associated vulnerabilities by leveraging existing planning and operations and new investments to accommodate changes in climate and the environment. Actions that increase the resiliency of the built environment and strengthen institutional collaboration will serve current and future generations and decrease the long-term costs of adaptation.

Adaptations for Institutional Decision-Making

A large and varied group of institutions throughout the region plans and manages activities associated with the vulnerability of populations, the environment, and land-based structures, and is responsible for a high level of investment in the region's resources. The three main effects of global climate change—increasing temperatures, precipitation extremes, and sea-level rise—that are expected to impact the region in different ways by the end of the next century pose new challenges to these institutions. Their decisions and efforts are likely to determine the region's ability to cope with or adapt to the changes.

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[1] R.D. McFadden, "Water Everywhere: the Overview; Surprise Deluge Cripples Morning Rush in New York," *New York Times* (August 27, 1999).

[2] L.K. Altman, "Officials Working to Contain West Nile Virus," *New York Times* (April 26, 2000), Edition L, p. B6.

For purposes of this report, an adaptation (or coping) action is defined as one that reduces or avoids the adverse impacts or consequences of global climate change. Potential adaptive measures are extensive and can be applied long before, just before, or after the effects of global climate change have been realized. Some examples of adaptations, oriented primarily toward the effects of sea-level rise, are given below.

ADAPTATIONS ASSOCIATED WITH PLANNING AND CONSTRUCTION

- land use and environmental planning and capital programming to ensure the location of new structures and relocation of existing structures outside of impact areas associated with sea-level rise
- acquiring property to prevent or guide development in hazard areas
- redesigning structures to avoid impacts, including the removal of traditional flood retaining structures
- retrofitting existing and redesigning new structures with barriers, higher elevations, and other forms of protection against water inundation and the extremes associated with heat and wind
- using operational procedures and controls for infrastructure services and facilities to reduce or avoid population exposure during hazard events

ADAPTATIONS DIRECTLY TARGETED TO VULNERABLE POPULATIONS

- educating the public about global climate change and adaptations and behaviors, including infrastructure and land usage patterns, that will reduce vulnerability
- improving communication mechanisms such as warning systems
- moving people and businesses away from vulnerable areas through incentives, relocations, and in extreme cases, evacuations
- providing emergency response and disaster assistance for reconstruction

The choice among these adaptations and the ability to respond in these different ways will depend upon criteria that often vary from place to place and institution to institution within the region. Such criteria pertain to cost, reliability and effectiveness, equity, environmental compatibility, uncertainty, etc.[3]

[3] Titus has proposed the following set of criteria specifically for adapting to global climate change: economic efficiency, performance under uncertainty, urgency, low cost, equity, institutional feasibility, threat to unique or critical resources, health and safety, consistency with other societal goals, private versus public sector strength (J.G. Titus, "Strategies for Adapting to the Greenhouse Effect," *APA J* (Summer 1990), p. 313).

Many of these options could be drastic if isolated from ongoing activities and undertaken simply as add-ons to existing activities. They become more feasible when they are coordinated with ongoing planning, design, construction and operational programs as Zimmerman (1996) and others have pointed out. Titus puts this approach in the following way: "Constructing a project *because* of the greenhouse effect will rarely if ever be an easy solution: it will require more certainty than incorporating climate change into a project that would be undertaken anyway."[4]

Scope

This report targets key authorities and responsibilities of public sector agencies that are pertinent to adaptation to global climate change in the MEC Region. The MEC Region is comprised of 31 counties in Connecticut, New Jersey, and New York.[5] Preventive actions, such as those that reduce greenhouse gas emissions, are beyond the scope of this study. It is important to note, however, that the same institutions that may implement adaptation mechanisms often have an interest in or authority over preventive actions.

Approach and Organization of the Report

This report consists of five parts that reflect the overall approach taken to analyze the institutional decision-making sector, the results of that analysis, and a synthesis or conclusion.

The *first* part, this introduction, sets forth the scope, purpose, approach, and organization of the report.

The *second* part briefly discusses how organizations make decisions in the MEC Region with reference to the other sectors covered in the MEC Assessment: Coasts, Wetlands, Infrastructure, Water Supply, Public Health and Energy Demand.

The *third* part identifies those global climate change conditions most likely to affect land use, populations, and infrastructure. This information, drawn from the MEC global climate change project, comprises the basis or reference point for adaptation by organizations and institutions likely to respond in the course of their decision-making authority in the MEC Region.

The *fourth* and most extensive part is organized in terms of the vulnerabilities and adaptive measures relevant to specific sectors. In addition to identifying these vulnerabilities and potential adaptation strategies, this section identifies the institutions likely to be responsible for making decisions about and implementing adapta-

[4] Titus (1990), p. 316.

[5] This is identical to the Tri-State Metropolitan Region adopted by the Regional Plan Association covering 13,000 square miles (R.D. Yaro and T. Hiss, *A Region at Risk*, Washington, DC: Island Press, 1996, pp. 19–20).

tions, and to some extent assesses their ability to do so (in terms of organizational characteristics and jurisdictional authorities and capacities). The agencies covered are primarily public sector or quasi-public agencies that directly influence adaptations for the built environment. Future organizational forms and responsibilities are not forecasted, and it is assumed that responses through the 21st century will be directed by organizations that currently exist.

The *fifth* part offers key conclusions and directions for further research.

HOW ORGANIZATIONS MAKE DECISIONS IN THE METROPOLITAN EAST COAST REGION

Organizations make decisions about activities potentially applicable to adaptation to global climate change from many different perspectives and under many authorities. Some are engaged in policy identification and formulation (including regulatory policy) and planning. Others concentrate on implementation (design, construction, operations and maintenance). Still others focus on the ownership and financing of the built environment.

Organizations covered in this inventory are primarily involved in land use, infrastructure, and other support facility and service decisions. Within these broad categories the focus is on organizations whose jurisdictions extend to the activities and facilities predicted to become the most vulnerable to sea-level rise and more frequent and extreme temperatures and weather events.

The inventory of public agencies and quasi-public organizations (such as authorities) summarized in Appendix Decision-Making 1 is organized according to the institutional functions, ranging from policy and planning through operation and maintenance, within each sector category.[6] In reality, however, there is an implicit if not a formal dynamism among these functions, and they often become indistinguishable.

The major drivers of land use and infrastructure investment in areas that are vulnerable to global climate change related sea-level rise, for example, include the traditional forces related to the economy, programmatic elements and investments, and regulation, as well as interactions of these forces with one another. *Market mechanisms* in the form of real estate investments and economic development have largely shaped the coastal areas given the fact that a large portion of the coasts is privately owned. *Programmatic investments* for capital construction and rehabilitation in transportation, wastewater collection and treatment, water supply, and waterfront parkland have created and transformed infrastructure that occupies or transgresses coastal locations to connect the region's activities. *Regulation* has also had a substantial impact, in the form of permitting and environmental review procedures, on the siting and operation of public and private structures in environmentally sensitive and/or coastal areas.

Given the enormity of and pervasiveness of these in-place programs, it makes sense for adaptation measures for global climate change to link to these firmly entrenched institutions and mechanisms. For example, while planning the rehabilitation of transportation infrastructure under the Intermodal Surface Transportation Efficiency Act (ISTEA) and its successor, the Transportation Equity Act for the 21st Century (TEA-21), it makes sense to incorporate global climate change requirements into the design, siting, and planning of new or updated facilities. The application of flood plain regulations under the National Flood Insurance Program (NFIP) also provides a critical opportunity. Because these regulations already govern the elevation of structures, changing their specifications and adding elevation restrictions that reflect global climate change scenarios, will likely provide a useful adaptation approach.

Magnitude and Nature of Institutional Capacity in the MEC Region

The magnitude and complexity of the governmental and quasi-governmental jurisdictions within the 31-county MEC Region is reflected in the very large investment in the built environment within the region and the number and variety of agencies and governments with direct and indirect authority over the built environment.

First, the level of financial investment and income generated in the MEC Region is large. For governmental functions in 1993 alone in the MEC region, governmental revenues were estimated at $85.9 billion and governmental expenditures were $90.7 billion (in 1993 dollars).[7] Assets within the region are estimated at about $1 trillion.[8] Moreover, the region is currently undertaking a number of major capital investment projects, such as the construction of the Third Water Tunnel and Route 9A along the west side of Manhattan.

[6] Other organizations indirectly involved in the effects of global climate change on the built environment are too numerous to account for here. These include the many research organizations at academic institutions, national laboratories, and companies and professional associations that set standards and guidelines for the built environment, for example, governmental associations like the Environmental Council of States (ECOS), the New England States for Coordinated Air Use Management (NESCAUM), mayors and governors associations, the american associations of state officials for wetlands, transportation, air quality, etc.

[7] R.D. Yaro and T. Hiss, *A Region at Risk* (Washington, DC: Island Press, 1996, p. 204), Figure 95.

[8] See Chapter 4 Infrastructure, citing HAZUS, "FEMA Tool for Estimating Earthquake Losses (NIBS/FEMA, Washington, DC: NIBS/FEMA,1999).

TABLE 9-1

Number of Governments and Agencies Engaged in Global Climate Change Activities

Level of Government	Estimated # of Governments engaged in global climate change functions[b]	# of Agencies engaged in global climate change functions
Federal[a]	1	12
Interstate	—	4
State	3	18[c]
Substate Regional	—	2
Local	928 approx.[d]	Est. 2000[e]

NOTES

[a] Includes departments, cabinet level agencies, and foundations and institutes only, not regulatory commissions or subunits of any of the above.

[b] The tabulation of agencies does not include the very large number of non-governmental or quasi-governmental entities in the form of authorities, commissions and special districts that operate and manage the various land uses potentially subject to the effects of sea level rise.

[c] This number is based on the assumption that there are six different kinds of agencies per state: Environmental; Coasts and Wetlands; Water Supply and Health; Transportation and Waste Management Infrastructure; Energy; Recreation. The number is based on governmental agencies only and does not include state corporations.

[d] This includes incorporated places, census designated places and minor civil divisions with populations over 2,500 in the 31-county MEC region. The data are tabulated from U.S. Bureau of the Census, *County and City Data Book*, 1994, Table D (Washington, DC: U.S. GPO, 1994).

[e] This estimate assumes two relevant agencies per local government unit—a planning/buildings department or official and a public works department or official. While many small governments are not likely to delegate authority beyond the Town or County level, many of the region's larger cities and especially New York City will have as many as a dozen or more applicable agencies. This approach is similar to the one used by Marr (1979) in a historical study for the Marine EcoSystems Analysis (MESA) Program, New York Bight Project.

Second, the total number and variety of governing entities within the 31-county region is remarkable. By mid-1995, the total number of such entities was estimated at over 2,000.[9] The number of incorporated places and census designated places and minor civil divisions with populations over 2,500 totaled close to 1,000. If one assumes that approximately two agencies per government entity will have some global climate related functions,[10] the number of local agencies grows to a couple of thousand. Estimates of the number of entities in the MEC Region by level of government are shown in Table 9-1. Some specific examples of these agencies are given in Table 9-2.

Third, while a number of institutional mechanisms in the MEC Region promote some level of integration and coordination among this very large number of entities, most of these efforts tend to be highly specialized by function and by area of the region. For example, at the present time, region-wide planning is not the formal responsibility of any given governmental agency. Some organizations have undertaken this responsibility, however. For example, the Regional Plan Association has traditionally undertaken this function. Development planning, coastal zone planning, and infrastructure planning occur within states and localities but by separate entities. When these activities are undertaken at a regional scale, it is usually under the auspices of a state or federal program, and the boundaries of such efforts rarely encompass the entire region.

[9] R.D. Yaro and T. Hiss, *A Region at Risk* (Washington, DC: Island Press, 1996), p. 197. This number includes "local governments, commissions, special districts, and authorities."

[10] This approach is similar to the one used by Paul D. Marr in a historical study for the Marine EcoSystems Analysis (MESA) Program, New York Bight Project, entitled "Jurisdictional Zones and Governmental Responsibilities" (Albany, NY: NYS Sea Grant, October 1979), p. 26. Marr multiplied by 3 rather than 2.

TABLE 9-2

Selected Governments and Agencies Engaged in Global Climate Change Activities

Level of Government	Type or Name of Agency
Federal	U.S. Department of Defense; U.S. Army Corps of Engineers; U.S. Environmental Protection Agency; U.S. Department of the Interior Fish and Wildlife Service and National Park Service; Federal Emergency Management Agency; U.S. Department of Commerce, National Oceanic and Atmospheric Administration; U.S. Department of Transportation; U.S. Department of Energy; U.S. Department of Agriculture, Soil and Water Conservation Service; U.S. Department of Health and Human Services, Public Health Service—Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry; National Institutes of Health; U.S. National Science Foundation
Regional Interstate	Interstate Environmental Commission (tri-state); Port Authority of NY and NJ; Delaware River Basin Commission; Palisades Interstate Park Commission
State	Agencies dealing with: Environmental Protection; Coasts and Wetlands; Water Supply; Health; Transportation and Waste Management; Energy; Recreation
Substate Regional	Hackensack Meadowlands Development Commission; New York Metropolitan Transportation Council; North Jersey Transportation Planning Authority
Local	County and municipal agencies dealing with: Planning and Zoning; Buildings; Public Works; Parks and Recreation

Note: See Appendix Decision-Making 1 for more detailed examples and descriptions of these organizations in terms of their potential roles in global climate change adaptation.

Selected Factors Affecting Institutional Adaptability

The ability of any organization to take on adaptive measures will depend on the extent to which it sees the immediacy and importance of the need to act in the context of its other interests and responsibilities. The following factors guide that vision and the ability of the organization to act:

- Knowledge and understanding of and experience with global climate change and its effects
- Mission, and its compatibility with global climate change issues
- Jurisdiction or domain, including mechanisms for inter-agency coordination
- Capacity (human, financial)
- Capability (politics, organizational culture)

The guiding concept is that organizations and institutional decision-making are more likely to promote adaptations to global climate change if they have:

- Missions that are compatible with and reflect commitment to managing global climate change hazards or can be convinced to alter their missions in a manner consistent with needs for global climate change management,
- Flexible or unallocated resources and discretion to use those resources for such activities,
- Knowledge and understanding of and experience with these issues (e.g., membership in hazard consortiums, skilled human resources in risk and safety), and
- Ongoing activities that are closely associated with actions necessary to adapt to global climate change so that global climate change adaptation can be seen as a part of or reinforce what they are doing or have to do for other purposes.

Although an extensive analysis of these factors as they apply to MEC region institutions is beyond the scope of this report, these factors will be referenced in the sections below where information is readily available from secondary sources.

THE ROLE OF CLIMATE FACTORS

An understanding of institutional decision-making systems should be framed by attributes of global climate change to which organizations are likely to react. Other sector reports identify many of these attributes. The pertinent ones for institutional decision-making are summarized here for reference.

The most commonly cited attributes or environmental conditions of global climate change are temperature increases, changes in precipitation, and sea-level rise. Although this report focuses largely on adaptations to sea-level rise, these three attributes are interrelated and changes in temperature and precipitation patterns are discussed briefly.

As indicated above, institutional decision-making is likely to be driven by public concern, anticipated costs, the perception that actions will minimize or reverse the predicted consequences, and the perception that such actions are within an institution's jurisdiction or mission.

Institutions are most likely to respond to the physical or statistical attributes of the consequences or effects of global climate change rather than to global climate change phenomena directly. For example, institutions are not likely to react to a rise in sea level or temperature per se, but rather to the suddenness or severity of the events precipitated by sea-level rise and temperature changes, such as flooding from storm surges.

Each of the global climate change attributes can be measured or characterized in terms of:

- Timing
- Duration
- Frequency
- Magnitude
- Severity (extent of effect, express as area affected and cost of damage; type of damage, the most serious of which is the loss of human life)
- Suddenness/predictability
- Location of the effect relative to vulnerable structures and settlements and large populations
- Synergism with other events

Several examples of past events in the MEC Region and elsewhere help to illustrate these measures. *Timing* was a significant factor in the enhanced effects of the December 1992 nor'easter that coincided with and was reinforced by the high tide. A March 1962 nor'easter which persisted through five tidal cycles illustrated the effects of *duration* (see Chapter 3 *Sea-Level Rise and Coasts*). More recently, the severe and unpredicted rainstorms of August 27, 1999 underscored the consequences of *suddenness* when flash flooding halted transportation systems throughout the MEC region in a virtually unprecedented manner.

The most relevant metrics for the measurement and expression of data for each of these factors are averages, extreme values (existence of outliers), variability, and rate of change. The choice of metrics for measuring attributes of events affects what future forecasts will look like. For example, the persistent use of averages may underestimate future events if, as global climate change forecasts/models predict, extremes become more frequent. Thus, given the significance of both average and extreme values both metrics are used below where the data are available.

The MEC region global climate change scenarios and the global climate models upon which they are based are described in detail in the Executive Summary of the MEC Assessment. The results for temperature, precipitation, and sea-level rise are summarized below and are shown in Tables 9-3, 9-4, and 9-5 for four different global climate models[11] for 2020, 2050 and 2080. They are summarized here since they are an important reference for identifying activities that are at risk and hence, which are areas for potential adaptation.

[11] The four scenarios are the Canadian Centre Greenhouse Gas (CCGG), the Canadian Centre Greenhouse gas and Sulfate aerosols (CCGS), the Hadley Centre Greenhouse Gas (HCGG), and the Hadley Centre Greenhouse gas and Sulfate aerosols (HCGS). This information is drawn from Chapter 2 *Regional Climate and Potential Change*.

Direct Heat Effects

Table 9-3 shows the results for temperature change in the MEC Region (see Chapter 2 *Regional Climate and Potential Change*). It is critical to recognize, however, that heat stress is a product of both temperature and relative humidity (see Chapter 8 *Energy Demand*). Table 9-3 contains both average and extreme values for temperature. Extremes are significant because many of the effects of global climate change on structures and materials are related to extremes rather than to averages. Also significant, but less readily available, is data on frequency distributions portraying how temperature and weather extremes may cluster, since many materials and structures may withstand a short period of extreme weather but not sustained periods. Information on extremes of cooling (expressed as number of days at temperatures less than 32°F) is not included since all scenarios show cooling declining often dramatically over the next century.

Some of the direct consequences of temperature change are stresses imposed upon the materials used in the construction of our built environment and increased energy demand.

TABLE 9-3

Selected Data on Temperature Change for Institutional Decision-making, MEC Region*

			SCENARIO		
	Current Trend[a]	CCGG	CCGS	HCGG	HCGS
		Year Incremental Increases in Ave. Temperature (F)			
2020	0.98	3.45	2.10	2.58	1.68
2050	1.57	6.52	4.80	4.37	2.63
2080	2.16	10.15	6.47	6.25	4.35
		Year Extreme Temperatures (Ave. No. of Days Per Year >90 degrees F.)[b]			
Base	13.0	13.0	13.0	13.0	13.0
2020	20.0	31.6	28.0	24.7	23.6
2050	22.6	50.9	38.1	37.0	27.9
2080	26.4	71.0	59.9	46.2	34.6

Notes

[a] Temperature is measured in degrees Fahrenheit. The current trends of the temperature were obtained by fitting a straight line through a monthly dataset for Central Park for 1901–1998, and extrapolating outward. All changes are measured with respect to 1961–1990 means.

[b] These numbers are based on daily data for La Guardia Airport in Queens, NY from 1979–1996.

Source: Chapter 2 *Regional Climate and Potential Change*

MATERIALS STRESS

The heat tolerances of materials depend upon the type of material, the duration of the condition, and the loading upon the material. Increased vulnerability of materials under increasing temperatures may be particularly critical for transportation when the size of loads, pattern of load release, and usage of the materials is combined with the effects of increased temperature.

Thermodynamic concepts largely govern the extent to which materials stress occurs. Resistance to heat changes is a function of the strength of weaker molecular bonds in the materials. Small temperature changes affect asphalt and coatings since smaller temperature changes (that occur around room temperature) can break weaker bonds in organic materials that are typical of some of these materials. Steel and concrete are generally more resistant to small changes in temperature. There are also kinetic causes to materials stress, such as corrosion, that are exacerbated in hot humid environments and contribute to materials stress.

ENERGY DEMAND

Energy demand is projected to increase with a warmer climate, but in particular ways. According to Chapter 8 *Energy Demand*, it is the combination of increasing temperature and humidity, rather than a higher temperature alone that is likely to produce heat stress and raise peak demand.

Changes In Hydrologic Regimes

Changes in hydrologic regimes result from a combination of changes in temperature, precipitation patterns, and other factors. More detailed descriptions of this concept appear in other sector reports for this study. Some of the most significant results from these other reports are presented below as specific reference points for institutional decision-making.

DROUGHT

Causes. Drought conditions occur when evaporation rates exceed precipitation rates and consequently produce changes in the safe yield of the region's system. It is uncertain how the balance between losses due to evaporation and gains due to precipitation will change in the region (see Chapter 6 *Water Supply*).

Consequences. Accordingly, it is difficult to predict how a drought will affect the region's water supply and distribution systems. The flexibility of the region's systems has so far prevented any severe scarcity of supply.

FLOODING

Causes. Temperature increases are associated with many changes in water systems, including several which result in sea-level rise and related flooding, such as thermal expansion, glacial melting, seasonal snow melt, increased precipitation, and ice jams. These would occur in addition to or exacerbate further some of the human-related causes of flooding, such as the increase in impervious surfaces from watershed development, reduction in water retention ability of soil from land clearance for development, obstruction of channels, and straightening of channels. The extent and impact of flooding depends on a number of environmental factors such as soil and land

TABLE 9-4
Selected Data on Precipitation for Institutional Decision-making, MEC Region

			SCENARIO		
	Current Trend[a]	CCGG	CCGS	HCGG	HCGS
Year			Precipitation (% change)		
2020	1.1	9.0	1.4	5.0	8.6
2050	1.6	0.1	−15.6	13.9	10.4
2080	2.3	0.1	−2.1	29.9	21.6

[a] See footnotes to Table 9-3.

mass types as well as on the intensity and duration of precipitation.

Consequences. Floods often have vast impacts on human settlements depending on the magnitude of the flooding and the extent of exposure of human populations. Immediate impacts are numerous. The key impact of flooding and the one that is the most quantifiable is loss of life, income and property. A second potential effect is an increase in waterborne pathogens as increases in water masses and standing water combine with increased pollutants washing into the waterways to provide new breeding grounds for bacteria. A third consequence is the cumulative loss of community and culture. Individual losses are also aggregated into societal losses in the form of erosion of revenue and tax bases. The fact that the MEC Region accounts for among the largest number of claims under the National Flood Insurance Program,[12] is a clear indication that the region is already vulnerable to such hazards.

INSTITUTIONAL AND DECISION-MAKING ADAPTATIONS BY SECTOR

Adaptive responses to climate change affect a range of decision-making authorities, from siting, design, and construction of activities and facilities to detailed operations. The applicability of responses depends upon the type and degree of threat and the location of the activity or structure at risk.

The adaptive responses introduced earlier in the report can be consolidated into the following categories of adaptations for structures and activities. The categories are similar to and align with agency functions.

- Planning
- Regulation

[12] As of June 30, 1995, New Jersey and New York ranked 5th and 7th respectively in the number of policies in force under the National Flood Insurance Program; the two states ranked 3rd and 4th among states in the Nation in terms of the number of policies issued directly by FEMA, excluding "Write Your Own" policies (FEMA Mitigation Division, January 2000).

TABLE 9-5
Selected Data on Flood Levels (including sea level rise effects), MEC Region (only values for NYC—at the Battery—are shown)[a]

			SCENARIO		
	Current Trend	CCGG	CCGS	HCGG	HCGS
			Year Flood Levels (in feet)		
2020	10.2	10.5	10.4	10.2	10.2
2050	10.4	11.4	11.3	10.8	10.6
2080	10.7	12.8	12.2	11.5	11.1
			Year Return Frequency (in years)		
2020	63	43	49	58	62
2050	48	19	20	34	41
2080	36	4	8	16	24

Notes
[a] These are conversions to feet from Chapter 3 *Sea-Level Rise and Coasts*, and reflect values for the 100-year flood levels for combined extratropical and tropical cyclones, MEC (in feet), including projected global sea level rise, local subsidence, mean high water, and combined extratropical and tropical storm surge. This scenario is consistent with but not identical to that used for the Infrastructure Sector report. For explanations of the scenarios see Chapter 3 *Sea-Level Rise and Coasts*.

- Construction, including initial construction, retrofit, and redesign
- Operation
- Emergency preparedness, response, and assistance

The sectors vary in the extent to which these functions are applicable to adaptations.

This section highlights the vulnerabilities, decision-making authorities, and proposed adaptations relevant to climate change for each MEC sector.[13] Appendix Decision-Making 1 lists in summary form many of the relevant agencies and organizations by type and function. Appendix Decision-Making 2 identifies a selected number of examples of existing planning programs that are applicable to adaptation to global climate change impacts.

Coasts and Wetlands

The MEC Region's coastal geography has been one of its most valuable assets for global trade and economic growth, and its abundance of prized waterfront real estate make its coastal areas among the most densely populated in the nation. Ironically, these same geographical advantages and patterns of development are likely to incur the largest costs in adaptation to global climate change impacts.

The coastal zone as delineated on coastal zone management plan maps generally encompasses an area that is larger than floodplains. Within New York City's coastal area alone there are an estimated 3,000 acres of freshwater wetlands (of which 2,000 acres are on Staten Island)[14] and 4,000 acres of tidal wetland (Jamaica Bay). Additional

[13] Information presented is as of April 2000.
[14] City of New York Department of City Planning. *NYC Comprehensive Waterfront Plan* (NY, NY: DCP, 1992).

tidal wetlands are located on Staten Island (Prince's Bay), the Bronx (Pelham Bay), and Queens (Alley Pond Park). The number, size and diversity of the region's wetlands has declined over the past three centuries, while the population and density of the coastal areas has increased.[15]

VULNERABILITIES

Chapter 3 *Sea-Level Rise and Coasts* and Chapter 5 *Wetlands* forecast impacts of climate change related sea-level rise on the region's coasts and wetlands, some of which were summarized in the earlier section. These impacts, predicted from climate change models are:

- a rise in sea level from 4.3–11.7 in by 2020, 6.9–23.7 in by the 2050s, and 9.5–42.5 in by the 2080s (Chapter 3 *Sea-Level Rise and Coasts*; these ranges combine variations across stations and scenarios). It is emphasized in Chapter 3 that the rise is non-linear and should accelerate significantly after about 2050.
- an increase in the frequency and severity of high impact coastal storms.
- a possible increase in beach erosion rates of 3 to 6 times by the 2050s and 4 to 10 times by the 2080s; sand volumes needed for beach replenishment could increase by 10% by 2020 and by another 5–20% by 2050.

Ultimately, impacts from increasing rates of sea-level rise in the region include: permanent inundation of low-lying areas and wetlands; higher rates of beach and salt-marsh erosion; more frequent and severe flooding; and northward migration of the salt front along the Hudson River.

Chapter 5 *Wetlands* notes that the region's loss of 75% of the region's wetlands is largely due to human activities like dredging and development. Sea-level rise is expected to exacerbate and accelerate future loss.

ADAPTATIONS AND DECISION-MAKING AUTHORITIES

Recommended adaptations in Chapter 3 *Sea-Level Rise and Coasts* in the near-term (over the next 20 years) are:

- factoring sea-level rise and higher erosion rates into coastal planning decisions and setting new construction set back lines
- strengthening existing hard structures to protect vital coastal infrastructure and highly populated areas
- changing zoning and land-use policies to provide for systematic and equitable retreat from vulnerable areas and to allow for landward migration of beaches; this could include easements and acquisition of coastal property, especially for remaining open space, for recreation
- removing or abandoning structures in imminent danger
- increasing investment in stabilizing dunes and beach nourishment

Adaptations identified in Chapter 5 *Wetlands* include:

- strengthening existing environmental and land use regulations to offer greater protection for existing wetlands
- transferring undeveloped wetlands and adjacent landward properties to agencies that oversee parks and open space to avoid further loss
- restoring wetlands and providing for inland migration of marshes through measures such as the removal of sea walls and debris in certain locations

Short-term interventions to avoid consequences include immediate evacuations and diking to redirect flood waters. Long-term interventions involve a complex system of land use controls and design modifications to avoid exposure to flooding. One of the more common and traditional types of intervention under the jurisdiction of the U.S. Army Corps of Engineers is structural controls, such as levees and sea walls.

Planning for the Location of Structures and Activities. Planning potentially guides development away from areas that are projected to be inundated in the future. These planning authorities also afford the opportunity for the purchase of land for protection from threats and human exposure. Some of these mechanisms already exist under the National Flood Insurance Program (NFIP). State and local programs and financial institutions usually require flood insurance for properties in flood-prone lands as a condition for obtaining a mortgage, and as such, these requirements are also important interventions to reduce human exposures to floodwaters. Agencies engaged in this kind of planning are shown in Figure 9-1 and their functions are briefly described in Appendix Decision-Making 1.

Land Use and Economic Development Planning. Many planning activities throughout the MEC Region affect the disposition of coastal and wetland areas. Municipal planning departments are largely responsible for basic land use plans and needs assessments. The organization of these departments and the extent of their planning activities vary within the region.

County and municipal planning agencies throughout the MEC Region should recognize opportunities to adapt current and future plans and zoning ordinances to cope with and minimize forecasted global climate change impacts. For example, land use agencies can propose more restrictive zoning along the coasts, promote uses that are less vulnerable to flooding associated with sea-level rise,

[15] City of New York Department of City Planning. *NYC Comprehensive Waterfront Plan* (NY, NY: DCP, 1992), pp. 18, 20.

and/or impose design conditions that provide better flood protection.

A critical function of the NYC Department of City Planning (DCP) is identifying capital facility and land-use related program needs. Under the New York City Charter, the Department prepares for the Mayor the annual Citywide Statement of Needs (SON) for presentation to and approval by the City Council. The City Office of Management and Budget, Borough Presidents, and community boards also play important roles in the review process. This needs assessment process identifies many projects that ultimately become vulnerable to sea-level rise if not adequately designed and sited in the land use review process.

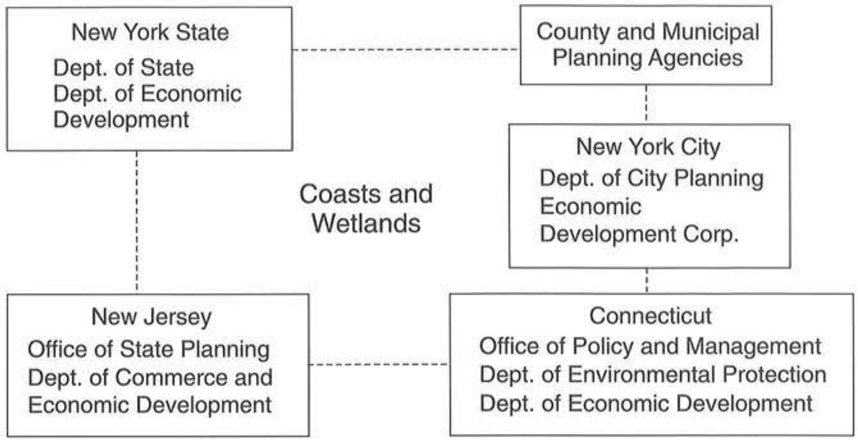

FIGURE 9-1 Agencies engaged in planning for coasts and wetlands.

Within New York City, quasi-governmental economic development authorities play a significant role in determining land use and coastal development. The NYC Economic Development Corporation (EDC) influences the location of built structures through planning and market analysis as a quasi-governmental agency for the purpose of promoting long-term economic growth.[16] The Empire State Development (ESD), a state authority whose mission is business development, also influences waterfront development. One example of a project assisted by the ESD in the MEC Region that reflects the enormity of investment in coastal property is the Queens West Waterfront Development—a 75 acre mixed-use waterfront development project estimated at $2.3 billion. The Queens West Development Corporation, a subsidiary of New York State's ESD Corp., initiated the project.[17]

Coastal, Waterfront and Harbor Planning. Coastal zone management planning provides a potentially strong mechanism for controlling land use along the coasts. The potential significance of these plans for global climate change is that they identify, set development policies for, and restrict as well as suggest uses in areas within zones and boundaries threatened by flooding. The federal Coastal Zone Management Act (CZMA, Public Law 92-583) first called for state implementation of coastal zone management plans in 1972. It provides the backbone for state and local planning and regulatory action in coastal areas, and essentially delegates authority to states and localities. The 1990 amendments explicitly referenced potential sea-level rise from global climate change as a factor that should be "anticipated and addressed" in the state plans prepared for coastal zones.[18] In Connecticut, the CT Department of Environmental Protection administers Municipal Coastal Programs. In New Jersey this function is carried out by the NJ Department of Environmental Protection. In New York State, the Department of State oversees the plan and implements it by means of the Local Waterfront Revitalization Program (LWRP). In New York City, the DCP is responsible for the local coastal management planning process. The City's latest plan dates from 1992 with a revision currently under review.[19] In the three states, coastal planning provides the foundation for a number of regulatory programs for the control of tidal, coastal and wetland areas.

In many areas of the region, the record with respect to plan development and/or plan implementation has been limited. By the mid-1990s, New York City and about 80% of the municipalities in Connecticut and Westchester had completed a coastal management plan. However, only about a third of the municipalities in Suffolk County and none in Nassau had plans, according to a report by the Citizens Campaign for the Environment and Citizens Environmental Research Institute.

The U.S. Army Corps of Engineers' substantial harbor planning and management activities in the MEC region focus on coastline alterations, restorations, and channel deepening. To the extent that these activities influence landside land uses they constitute a potential adaptive measure to guard against sea-level rise effects. This work is

[16] NYCEDC, www.ci.nyc.us/html/edc/home.html and www. newyorkbiz.com

[17] www. empire.state.ny.us

[18] U.S. Congress, Office of Technology Assessment, Preparing for an Uncertain Climate-Volume I, OTA-O-567 (Washington, DC: U.S. Government Printing Office, October 1993), p. 37 and Chapter 4.

[19] The NYC Department of City Planning conducts coastal planning through its authority under the NYS Coastal Zone Management Program (under the NYS Waterfront Revitalization and Coastal Resources Act originally enacted in 1981) which in turn is mandated under the Federal Coastal Zone Management Act (originally enacted in 1972). The City produced its major plan, "Reclaiming the City's Edge" in 1992, and its latest proposed plan was issued in September 1999, entitled "The New Waterfront Revitalization Program: A Proposed 197a Plan."

coordinated with other agencies, such as the Port Authority of New York and NewJersey (PANYNJ), economic development agencies, and federal and state environmental agencies. The Corps' most recent study, the National Economic Development (NED) Plan (September 1999), sets forth a plan for the deepening of seven harbor channels in the New York harbor area to a depth of 50 feet or more. The dredging is promoted as an important need for maintaining and increasing the competitiveness of the Port of New York and New Jersey, the largest port complex on the East Coast of North America. Over the course of the 20th century, the dredging has deepened these channels from depths of 30 feet to about 45 feet. The environmental consequences of dredging are an actively debated public policy issue in the MEC Region. PANYNJ's extensive port investment plans, amounting to $5–7 billion in construction and expansion, also provide a potential area for adaptations to anticipated climate change impacts.[20] The standing of the PANYNJ in 1998 relative to other ports is shown in Table 9-6 according to several different measures of port activity:[21]

TABLE 9-6
Rankings for Activity in the Port of NY and NJ, 1998[a]

Indicator of Activity	Metric	Competitors	Rank
Container Traffic	TEUs (20-ft equivalent units)	Long Beach and Los Angeles	3[b]
Cargo Value	U.S. dollars for exports	—	1
	U.S. dollars for imports	Long Beach and Los Angeles[a]	3
	Total trade	—	3
Cargo Volume	Metric tons:		
	Cargo volume for exports	12 other ports	13
	Cargo volume for imports	Houston	2
	Total cargo volume	Houston, New Orleans, and South Louisiana	4

[a] Source of data is the American Association of Port Authorities (www. AAPA-PORTS.org)
[b] This rank also applies to North America and the Western Hemisphere in addition to the United States.

Parkland, Park, and Open Space Planning. A large proportion of coasts and wetlands is parkland or open space. Thus, the manner in which parkland is sited, developed and used is an adaptation measure. New York City's waterfront plan of 1992 pointed out that: "Fully 42 percent of the waterfront is city, state or federal parkland which includes hundreds of acres of natural or undeveloped land, active recreation areas and narrow strips along highways and rail lines."[22] The region's largest coastal parkland areas, some of which encompass substantial wetlands, are Gateway National Recreation Area, Palisades Interstate Park, the Hackensack Meadowlands, Liberty State Park in New Jersey, and the Long Island parks including Robert Moses State Park and the Fire Island National Seashore. These and other parks are managed by many different kinds of agencies such as state commissions (e.g., the Hackensack Meadowlands Development Commission and the Palisades Interstate Park Commission—a bistate entity), various authorities, and local, state, and national park agencies (e.g., the National Park Service, the Department of City Planning and the NYC Department of Parks). Responsibilities are often divided among state and local agencies depending on who owns the parkland.

Development pressures in and around parklands and open spaces have persisted in recent years. For example, Gateway Estates in Brooklyn, NY, and the Trump development on the west side of Manhattan were built on wetlands. The efforts of public and nonprofit organizations to counter such development have successfully protected some lands and in some cases have supported land purchases and wildlife designations. In the Hackensack Meadowlands, the Hackensack Meadowlands Preservation Alliance, representing eighty environmental groups, municipalities, foundations, businesses and civic organizations, is actively preventing further development of the Hackensack wetlands.[23]

Given that parkland is particularly suitable as a buffer zone against natural hazards, yet must also be protected, opportunities exist to align parkland development more strongly with those objectives. For example, much of the land and structures on the five mile strip of the Hudson River Park in Manhattan that is intended for redevelopment lie below a 10-12–foot elevation and are likely to be at risk of inundation over the next century.

Property Acquisition. Property acquisition throughout the MEC Region is used to protect coastal, wetland, floodplain, watershed lands and open space, and many of the areas acquired are vulnerable to the effects of sea-level rise. An expansion of this strategy could provide an effective adaptive mechanism to reduce vulnerability to sea-level rise.

New York State has prepared open space conservation plans since 1990. Its 1998 plan identifies the purchase of land or easements for purposes such as greenways, habitat protection, and the consolidation of coastal properties for

[20] PANYNJ, "Background Paper on Investment Options: the Port Authority of NY and NJ," c. 1999.
[21] American Association of Port Authorities (www. AAPA-PORTS.org).
[22] NYC Department of City Planning, Waterfront Revitalization Plan (NY, NY: NYCDCP, 1992).

[23] Hackensack Meadowlands Preservation Alliance, Meadowlands Preservation Update, Little Ferry, NJ: HMDC, April 13, 2000.

conservation, and includes the State's purchase of 15,280 acres in Sterling Forest (the largest land purchase in the MEC Region).[24] New York State created the NYS Environmental Protection Fund in 1993 for purpose of preserving open space and land acquisition. In New Jersey, 886,000 acres has been acquired under the Green Acres program since 1961.[25] Within the MEC Region, both New York and New Jersey are purchasing land for the purpose of establishing walkways under the New York-New Jersey Harbor Estuary Program. Although many of the purchases have not been in areas projected to be vulnerable to sea-level rise, they nevertheless provide models for future purchases as adaptations in areas vulnerable to global climate change.

Regulation. Agencies throughout the MEC Region exercise regulatory authority over coasts and wetlands under the jurisdiction of numerous environmental and land use laws.

Zoning ordinances provide broad conditions for building and site use and layout. NYC DCP regulates through its zoning ordinance, for example, the siting and design of activities that involve new construction or projects that require variants from the zoning ordinance. Once in the process, projects have also been eligible to be reviewed under the Uniform Land Use Review Procedure (ULURP) and also undergo an environmental review. Those that are in conformance with the zoning ordinance are considered "as of right" and do not undergo the same level of review. Proposed changes to the City's zoning, called the Unified Bulk Program, primarily focus on height limitations, site design, and transfer of development rights. Because they can constrain building heights and increase lot coverages, the zoning changes could potentially affect the vulnerability of structures in coastal areas to flooding from sea-level rise. More direct protection against natural hazards is incorporated into building codes.

Environmental review procedures are a common, quasi-regulatory land use tool applicable to certain projects. They are practiced in the MEC Region within New York City, by the States, and by federal agencies under the National Environmental Policy Act. Within New York City, the City Environmental Quality Review (CEQR) process provides the major control over the environmental impacts associated with projects of a certain magnitude and in certain locations.

Permits are a traditional mechanism for regulating all aspects of project development from planning and siting through operation and maintenance. Environmental criteria, which provide a foundation for adaptations to climate change, are incorporated primarily into state-issued permits for construction, structural modification, and waste discharges in coastal areas, floodplains, wetlands, and other environmentally sensitive areas (see Appendix Decision-Making 1 for a listing of some of the planning-related programs). Adapting permit criteria to reflect anticipated climate change impacts could significantly decrease the vulnerability of activities already requiring such permits.

Emergency Response. The responsibility for anticipating and responding to flood-related emergencies in coastal areas, such as those that might arise as a result of sea-level rise, rests with federal, state and local emergency management agencies. The Federal Emergency Management Agency (FEMA) provides financial support, design and construction technical expertise to municipalities, and generally works with state and other federal agencies to adapt to disasters similar to those anticipated from global climate change. Through its administration of the National Flood Insurance Program (NFIP), the agency provides regulatory oversight for floodplain development for communities in the program that agree to adopt and enforce floodplain management ordinances. Most of the municipalities within the MEC Region are in the NFIP.

Once a disaster occurs, FEMA provides disaster relief during a natural hazard under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (PL 93-288, as amended) and E.O. 12148.[26] FEMA also manages Project Impact, a nationwide initiative to help communities prepare and protect themselves. Participation in Project Impact has helped a number of communities improve their disaster-resistance and bounce back with much less loss of property.

Water Supply

A reliable and abundant supply of fresh water is critical to the growth and sustainability of any major urban center. In New York City and throughout much of the region, a complex network of infrastructure institutions has evolved to provide high-quality drinking water. Increasing temperatures and changing hydrological regimes are likely to affect water supplies in the MEC Region over the next century. While the frequency or severity of droughts is difficult to forecast, institutional anticipation of and response to increasing variability in water supply and demand could achieve more resilient and efficient sys-

[24] NYS Department of Environmental Conservation & the Office of Parks, Recreation and Historic Preservation, *Conserving Open Space in New York State 1998. State Open Space Conservation Plan* (Albany, NY: NYS DEC and NYS Office of Parks, Recreation and Historic Preservation, 1998).

[25] New Jersey Office of State Planning, *2000 State Development and Redevelopment Plan: Interim Plan* (Trenton, NJ: NJ OSP, 2000).

[26] USACE, FEMA, National Weather Service, NY/NJ/CT State Emergency Management, *Metro NY Hurricane Transportation Study*, Interim Technical Data Report (New York, NY: USACE, November 1995), p. 5.

tems. These adaptations would have long-term value for the region, regardless of future climate change.

VULNERABILITIES

Climate change related stressors on the MEC Region's water supply, as identified in Chapter 6 *Water Supply* include:

- potential pressure on water supplies due to increased water demand and evaporation from temperature increases and decreased precipitation. This could increase the frequency and/or severity of droughts and compromise safe yields. These pressures will not be felt equally across the region. To some extent this effect will be countered by increases in the supply from increased precipitation and runoff.
- increased stress on existing fresh-water supplies from the movement of the salt front in estuaries as a consequence of sea-level rise and increased salt water infiltration into aquifers on Long Island.

ADAPTATIONS AND DECISION-MAKING AUTHORITIES

The water supply systems of the New York region are managed by a complex set of organizations. The mix of organizations differs by function (from ownership through operation and maintenance), system component (from the sources of the supply through distribution and ultimate use), and geographic location within the region. Moreover, the combination of function and system component for a given geographic area within the region represents yet another layer of complexity. This is the context in which any adaptations for water supply will occur. Interagency coordination within and across the functions of planning, regulation, operations, and emergency management will be key here.

Water Supply Planning and Facility Design. Water supply planning addresses the balance between water supply and demand, the deployment of water sources, and the development of water conservation strategies. Institutionally, water supply planning was initiated originally at the federal level under various federal Water Resources Planning Acts and under areawide water quality management planning provisions of the Clean Water Act and its amendments. Water supply planning has a long history in the MEC Region: New York and Newark both tapped watersheds beyond their borders by the turn of the 20th century.[27] The amount of water or its quality has rarely been a limiting factor to human activity and settlements in the MEC region.

Within the past two or three decades, water resources demand and supply forecasting and planning for the MEC Region has been undertaken on an intermittent basis by special task forces and study groups usually under the auspices of federal, state or local governments. Planning studies within the past decade or two have included the Corps of Engineers' Northeast Water Supply Study, the Mayor's Intergovernmental Task Force on New York City Water Supply Needs (1987; 1992), and the Water Resources Management Strategy for the Delaware/Lower Hudson Sub-State Region by the NYS Department of Environmental Conservation and conducted by Hazen & Sawyer Engineers (1987).

Water supply decision-makers, especially those in already water scarce regions, are increasingly conscious of the effects of climate change, even though it may not be an explicit component of the planning process. In the MEC Region, in fact, the Mayor's Task Force on Water Supply recognized the value in an awareness of climate change and potential impacts over a decade ago (see Chapter 6 *Water Supply*). As pointed out in Chapter 6, New York City's system incorporates one of the few existing tangible adaptations to climate change among the nation's large water supply systems: an outflow pipe for the new Third Water Tunnel on Roosevelt Island was built higher than had been originally specified in order to accommodate sea-level rise associated with climate change.

A key planning function for water supply planning is the ability to forecast demand accurately. Water demand is currently projected by the City of New York through the NYC DEP and the New York City Mayor's Intergovernmental Task Force on NYC Water Supply Needs, the Regional Plan Association, and in previous years by the NYS DEC. Wide discrepancies often exist in water demand projections by organization and by projection scenario.

Variations in water supply forecasts translate into projections of both declines and increases in the occurrence of droughts. Drought management planning is a key water supply planning activity as well as an essential vehicle for emergency preparedness.[28]

Regulation. Numerous state regulations are relevant to potential water demand adaptations. These include water conservation measures invoked during drought periods, in coordination with drought management plans, and day-to-day or more routine conservation measures such as flow restrictive devices on plumbing and restrictions on the timing and use of water, such as lawn watering restrictions.

Operations. Water supply operation does not reflect the same level of integration and coordination that occurs in water supply planning. Agencies involved in water operations are shown in Figure 9-2. Within the region, water supply operations vary by geographical and organizational

[27] New York City drew its water from the Catskill and Delaware systems which are about 125 miles from the City at the farthest point, and Newark drew its water from the Pequannock Watershed.

[28] New York State Environmental Facilities Corporation. *State Clean Water and Drinking Water Revolving Funds Revenue Bonds, Series 1998 C*, (New York, NY: NYS EFC, March 25, 1998), pp. B-51, 52

scope. Jurisdictional units rarely, if ever, exchange supplies. New York City's public system services the entire municipality and a number of others located outside of its borders. Withdrawals are subject to an arrangement with the Delaware River Basin Commission. Northeastern New Jersey is served by United Water NJ and southeastern New York is serviced by United Water NY as well as by private well systems. The parent company of both of these companies is United Water Resources (acquired by Suez Lyonnaise des Eaux and as of 2001, under the subsidiary Ondeo). This service area has been characterized by a patchwork of arrangements for maintaining and operating water and for the ownership and management of water supplies, some of which are from groundwater and others from surface water supplies.

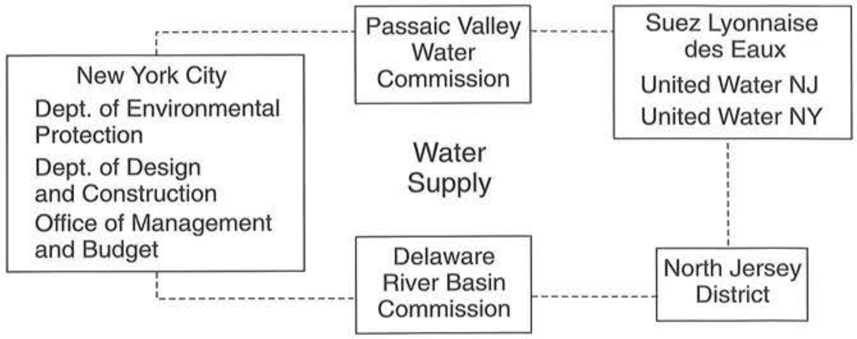

FIGURE 9-2 Water supply operations organizations in the MEC Region.

Depletion of water supplies due to more severe or frequent droughts or salt-water intrusion effects would likely necessitate improved mechanisms for exchange among the water supply systems to equalize water availability. Alternative responses include tapping new supplies and desalination. Past periods of water shortage in the region provide lessons in drought response capabilities. Although New York City has never experienced a complete shutdown of its water supply system, it came close to often extremely serious shortages during severe droughts in 1950, 1965, the early 1980s, 1985, the late 1980s, 1995, and in 1999. Drought periods appear to have become more frequent. The safe yield in the driest year is estimated at 1.29 bgd from upstate sources, with an additional 33 mgd from groundwater sources in southeastern Queens. The City has increased the security and reliability of its water system and expanded its flexibility to distribute water within the City as well as to Long Island with the construction of the Third Water Tunnel. In the early 1980s, a temporary pipe was constructed across the George Washington Bridge to transfer up to 20 mgd from the Delaware system through New York City and then to what used to be the Hackensack Water Company (now United Water NJ). The $5 million investment was facilitated by interagency coordination between the U.S. EPA, the water companies, and PANYNJ that owned the bridge. The pipe was tested, but was never operational. It was ultimately dismantled.[29]

Infrastructure: Transportation and Wastewater

The MEC Region's infrastructure ranks among the largest and most heavily used in the nation.[30] The ranges of the size and condition of facilities, interdependencies among different modes, and types of technologies are equally dramatic.

The scale of the region's infrastructure needs, investments, and revenues exceeds that of most other areas of the country. The Metropolitan Transportation Authority's (MTA) Capital Program for 2000–2004, for example, calls for $16.5 billion in investment and the PANYNJ) has a $3.9 billion budget for 2000 alone.[31] A 1998 study by the NYC Office of the Comptroller estimated that infrastructure costs (encompassing education, health, transportation, environmental facilities, recreation, human resources and safety services) would require an investment of $92 billion of which $52 billion was in the City's 10-Year Capital Strategy for FY 1998–2007, leaving a shortfall of $40 billion.[32] Together transportation and environmental services (including sanitation) account for $50 billion or 53% of the $92 billion in estimated needs and about the same proportion of the shortfall. This situation reveals the relatively low priority given to infrastructure maintenance and investment and the resultant enormous amount of resources required simply to achieve the engineering criteria for a "State of Good Repair" (SOGR). On the other hand, this creates important opportunities to integrate into SOGR investments changes that will reduce the vulnerabilities of infrastructure to climate change impacts.

VULNERABILITIES

According to Chapter 4 *Infrastructure*, sea-level rise and an increase in the severity and frequency of storms threaten to flood or otherwise damage much of the region's transportation infrastructure by the end of this century. As the

[29] D. Weissman, "Big pipeline project dries up after rains," *Newark Star Ledger* (September 20, 1981).

[30] The MTA carries 2 billion passengers a year (MTA Capital Program 2001-2004). PANYNJ reported that PATH ridership was at a level of 67.3 million passengers in 1999, the highest level in half a century (PANYNJ, "Port Authority Revenues at All Time High," News Release, April 4, 2000).

[31] MTA *Capital Program 2001-2004* (http:// www. mta.nyc.ny.us/mta/cap2000–2004.html) and PANYNJ News Release, "Port Authority Approves $3.9 Billion Budget for 2000-Record Net Revenues Help Fuel Record Capital Program," May 25, 2000 (http:// www. panynj.gov/pr/87-00.html).

[32] City of New York, Office of the Comptroller. *Dilemma in the Millennium*. Capital Needs of the World's Capital City (NY, NY: NYC Office of the Comptroller, August 1998), p. ES-8.

report reveals, based on the findings of a USACE/FEMA/NWS report (1995), many of the transportation systems, including the nation's largest public transit system, are at critical elevations between 6 and 20 feet above sea level (NGVD), and will become vulnerable to the rising sea levels, increased storm surge heights, and shorter storm recurrence periods predicted by climate change models. Tables 9-6 and 9-7 show the large number of vital transportation corridors and facilities, from the Holland Tunnel to the World Trade Center PATH station to La Guardia Airport that would be at risk from storm surges of 10-12–foot, levels expected to become probable within the next century according to sea-level projections.[33] The December 1992 nor'easter and the severe rainstorm of August 1999 both flooded parts of New York City's transit system and, though the impacts were short-lived, the crippling of the system caused delays and disruptions for millions throughout the transit-dependent city.

Non-transportation infrastructure facilities such as water treatment plants, power generation plants, and storm sewers are also located at low elevations along coasts and rivers making them vulnerable to sea-level rise and flooding. In New York City, for example, 70% of the sewers are combined sewers which discharge when the tide is low and tide gates are open.[34] Under climate-related sea-level rise projections, they could become permanently submerged and cause backups.

ADAPTATIONS AND DECISION-MAKING AUTHORITIES

Infrastructure planning and management authorities, distinguished by ownership, location, type and function, largely determine how potential climate change effects will impact structures and systems. These authorities potentially can integrate changes in siting, materials and structural criteria aimed at adapting to sea-level rise into the design, construction, operation, and maintenance of infrastructure facilities ultimately affecting vulnerabilities to sea-level rise and flooding. Infrastructure planning in the MEC Region is widely diffused across many types of infrastructure agencies and levels of government, whose authorities often overlap with land use and coastal planning. In order for many of the changes necessary for adaptation to occur, coordination among these entities will be needed.

[33] The database for facility elevations is drawn largely from the 1995 multi-agency report on the flooding and wind effects of various categories of hurricanes (USACE, FEMA, National Weather Service, NY/NJ/CT State Emergency Management, *Metro NY Hurricane Transportation Study*, Interim Technical Data Report, November 1995). The scope of the study is the 5 boroughs; Morris, Passaic, Somerset, Bergen, Essex, Hudson, Union, Monmouth, Middlesex Counties (NJ); Westchester, Rockland, Nassau, Suffolk Counties (NY); Fairfield County (CT).

[34] NYS Environmental Facilities Corporation, 1998, p. B-56.

The region's past experience with storm-related impacts on its transportation infrastructure system as well as other factors unrelated to climate change provide a strong basis for understanding and responding to the vulnerability of its infrastructure to extreme weather events. First, even without future climate change or sea-level rise, there is an increasing potential for storm-related losses to occur due to growth in the region's population and assets alone. Second, the region is currently in the midst of a major capital investment period as it seeks to repair overused and aging infrastructure and to build new facilities to accommodate current and future demands. This provides many opportunities to incorporate environmental and storm-related factors into the planning, engineering and management of infrastructure investments. Third, as stated in Chapter 4 *Infrastructure*, FEMA's Q3 Flood Zone Maps, which show 100-year flood zones, are upgraded periodically but have not systematically accounted for changes in land use and the widespread loss of greenlands and wetlands that serve as buffers between water bodies and developed areas. FEMA could adjust its Q3 maps to document this increase of land in flood zones and thus guide future land use and technical standards for infrastructure siting and operation.

Chapter 4 *Infrastructure* further recommends the following adaptation strategies that address the potential for significant loss of life and assets to climate change impacts on the built environment over the next century:

- an agency-by-agency, systematic and thorough inventory of infrastructure assets, vulnerabilities, potential hazards, and loss potential that reflects climate change impact scenarios
- short-term protective engineered solutions that elevate or block individual systems or system components, when feasible and cost-effective
- land use changes which move critical infrastructure landward and maintain waterfront as open space and recreational areas
- engineering code changes that require the location of critical infrastructure at sufficient elevations.

Transportation. Efforts to reduce the vulnerabilities of the region's transportation infrastructure to potential sea-level rise and more frequent and severe storms should reflect the infrastructure's value to the region's day to day operations and to evacuation plans which are dependent on reliable transport systems. Current and future responses to maintenance requirements and expansion needs could incorporate engineering and land-use decisions that safeguard transportation structures from sea level and flood scenarios.

State and regional authorities that plan and/or manage bridges, roads and transit systems in the MEC Region potentially play a key role in adapting design, construc-

TABLE 9-6
Transportation Facilities Potentially Most Vulnerable to Inundation from Global Climate Change (at NGVD < or = to 10 ft.)

Facility and Owner/Operator	Elevation (NGVD)
Metropolitan Transportation Authority (MTA)	
AMTRAK/LIRR East River Tunnel, Long Island Shaft	9
LIRR Long Beach Branch Line, Oceanside Tunnel	6.2
LIRR Port Washington Branch Line, Flushing Tunnel	9.2
LIRR Far Rockaway Station	9.2
LIRR Oyster Bay Station	9.5
Metro-North Hudson Line tracks, South of Croton River	6.3-6.5
Metro-North Hudson Line tracks, Croton River Bridge	7.0-7.5
Metro-North Hudson Line, Spuyten Duyvil Station	7.7
Metro-North New Haven Line at Sherwood Millpond	9.8
Metro-North New Haven Line at Grasmere Brook	9.6
14th St. Tunnel at Avenue D vent (L line)	7.2
Canal Street Grate (1, 2, 3, 9 lines)	9.8
Canal Street Station (A, C, E lines)	8.7
Clark Street Tunnel at Front Street Vent (2, 3 lines)	9.1
Cranberry Street Tunnel at Front Street Vent (A, C lines)	7
Greenpoint-Jackson Ave. (Newtown Center) Vent (G line)	8.1
Joralemon Tunnel at State St. Grate (4 and 5 lines)	9.8
Lexington Ave. Tunnel at 135th St. Bronx Vent (4, 5, 6 lines)	9.9
Montague St. Tunnel at Broad St. Vent (M, N, R lines)	7.5
South Ferry Station (1, 9 lines)	9.1
Whitehall St. Station (M, N, R lines)	9.1
Christopher St. Station	-14.6
9th St. Station	-15
12th St. Station	0
Brooklyn-Battery Tunnel, Morris St. Entrance	8.6
Brooklyn-Battery, West St. Entrance	8.6
Cross Bay Parkway (Bridge), Queens	8
Marine Parkway/Gil Hodges Memorial Bridge	8
Verrazano-Narrows Bridge	8
Port Authority of New York and New Jersey (PANYNJ)	
PATH Stations at Exchange Place, Grove St., Hoboken, Pavonia	7, 9.8, 7.4, 10
PATH shafts at Morton St., Railroad Ave., Washington St.	7.3, 9.7, 7.6
Port Authority of New York and New Jersey (PANYNJ) **CONTINUED**	
PATH/TA Station (Ramp D) at World Trade Center	8.1
Holland Tunnel, New Jersey Entrance	7.6
Holland Tunnel, New Jersey Land Vent Shaft	7.6
Holland Tunnel, New York Entrance	9.5
Holland Tunnel, New York River Vent Shaft	8.6
Holland Tunnel, New York Land Vent Shaft	8.6
Autoport Marine Terminal in Essex County, NJ	9.5
Howland Hook Marine Terminal in Staten Island	9.9
Port Newark & Elizabeth	9.6
Red Hook Marine Terminal in Brooklyn	9.8
Passenger Ship Terminal	8.9
Pier 40	8.9
LaGuardia Airport	6.8
Teterboro Airport	5
NYC DOT	
Battery Park Tunnel	9
West Street	9
FDR Drive, above 59th St. and vicinity of Williamsburg Bridge	6
NJ DOT	
U.S. Highway 1 at Rahway and Elizabeth in Union County	9.4 and 9.6
U.S. Highways 1 and 9 at Jersey City and Newark in Hudson County, and North Bergen Township in Bergen County	2, 6.8, 8
I-95 in Bergen County	5.8
N.J. Route 17 in Bergen County	3.9
U.S. Highway 46 at Little Ferry in Bergen County	5.6
N.J. Route 3 at Secaucus in Hudson County	8
NYS Department of Parks and Recreation	
Meadowbrook Parkway	7.3
Wantaugh Parkway	6.3

Source: USACE, FEMA, NWS (1995) and reported in Chapter 4 *Infrastructure*.

tion, operation, and maintenance. Current planning for the rehabilitation and reconstruction of many of the region's transportation arteries provides the opportunity to incorporate adaptation needs in a relatively unobtrusive way.[35] Some of the major transportation agencies in the region engaged in transportation planning alone or planning and operations include state, county, and city departments of transportation, the New York Metropolitan Transportation Council (NYMTC), the PANYNJ, the Metropolitan Transportation Authority (MTA), NJ Transit, and AMTRAK. Infrastructure agencies are listed in Appendix Decision-Making 1 by function and jurisdiction and in Appendix Decision-Making 2 by planning function. Figure 9-3 portrays some of the major public transportation planning agencies in the region. Any given corridor or transportation system in the region is often jurisdictionally divided among a number of these agencies. Planning initiatives are primarily guided by federal transportation policy and air quality legislation, current needs and conditions, and capital budgeting concerns.

[35] For example, New York State condition rating systems reveal that three quarters of New York City's bridges connecting the five boroughs, are in "fair" or "poor" condition (NYC DOT, *1998 NYC Bridges and Tunnels Annual Condition Report*, p. 65).

TABLE 9-7
Transportation Facilities Potentially with More Modest Vulnerability of Inundation from Global Climate Change (at NGVD 10 ft < NGVD <= 12 ft)

Facility and Owner/Operator	Elevation (NGVD)
MTA	
AMTRAK/LIRR East River Tunnel, Top of ramp	12
AMTRAK/LIRR West Side Storage Yard	10
LIRR Far Rockaway Branch Line, Valley Stream Station	11.4
Metro-North Grand Central Terminal, Steinway Tube, Queens Vent (#7 line)	11.0
53rd St. Tunnel at Nott Ave. Vent	10
Rutgers St. Tunnel at South St. Vent (F line)	10.6
Metro-North/TA Steinway Tunnel at 50th Ave. Vent (7 line)	11
Brooklyn-Battery Tunnel, Brooklyn Entrance	11.6
Queens Midtown Tunnel, Queens Entrance	10.6
Bronx-Whitestone Bridge	12
Throgs Neck Bridge	10
PANYNJ	
Holland Tunnel, New Jersey River Vent Shaft	10.6
Holland Tunnel, New Jersey Vent Shaft	10.6
Lincoln Tunnel, New York River Vent Shaft	11.6
Lincoln Tunnel, New York Third Tube Vent Shaft	10.6
JFK International Airport	11.7
Newark International Airport	10.3
NJDOT	
U.S. Highway 1 at Linden, Union County	11

Source: USACE, FEMA, NWS (1995) and reported in (Jacob, Edelblum, and Arnold, April 2000)

The large number of such agencies as well as spatial and functional divisions underscore the need for coordination and integration, especially given the new concerns brought about by global climate change.

Operationally, a number of adaptations can and already have been invoked whenever climate change related phenomena threaten transportation infrastructure. With the exception of NYMTC, many of the same agencies that undertake planning functions are also responsible for operations along with other agencies that specialize in operations alone. Some of the conventional operational methods for adaptation include having equipment and materials available to reduce the impacts of these events, as well as procedures for reducing risks to people and property should such events occur. For example, for flooding, these methods include pumping and barricading using diking and sealing.

Wastewater Treatment. The primary form of adaptation to sea-level rise for wastewater treatment and collection systems will be reconstruction and retrofit of existing facilities and construction of new facilities at higher elevations. Stormwater water discharges occur via a complex system of regulators and tide gates.[36] In the case of a shut-down of New York City's combined sewer overflows due to short-term inundation, wastewater would have to be pumped out on an emergency basis. A more long-term solution would require raising drainage fields or providing for permanent pumping arrangements. In certain parts of the region with smaller volumes of wastewater flow, natural drainage systems could replace traditional outflow systems. For example, efforts are currently underway to use wetlands for stormwater discharge and treatment in the Staten Island Bluebelt.

Wastewater treatment system planning throughout the region was completed a couple of decades ago under guidelines of the Clean Water Act with the exception of several new plants and upgrades in the New York City watershed. The construction of wastewater treatment and collection systems is largely dictated by financial and regulatory programs. The key regulatory program is the authority over wastewater discharge permits under the federal National Pollutant Discharge Elimination System (NPDES). In New York, the Environmental Facilities Corporation coordinates financing programs for construction and modification of wastewater treatment facilities, and these programs include the Clean Water State Revolving Fund for new wastewater treatment plants and modifications of existing ones and other special programs for the watershed.

Any organizational responses to climate change impacts on wastewater treatment systems will occur in the context of a variety of kinds of arrangements that currently exist for system operation. New York City's system of 14 wastewater treatment plants with a dry weather flow of 1.77 bgd through a 6,000-mile distribution system, is operated by a single municipal agency, the NYC Department of Environmental Protection (DEP).[37] In New Jersey, public authorities or private companies manage wastewater treatment systems. United Water of NJ operates a number of wastewater collection and treatment facilities in northeastern New Jersey. Authorities like the Passaic Valley Sewerage Authority also direct operations. Connecticut has a mix of municipally and privately operated facilities.

Electric Energy Demand

Energy demand issues and the availability of supplies to meet demand have been at the forefront of public concern and public policy in the MEC Region and throughout the nation for quite some time. These concerns have been associated with industry deregulation, aging infrastructure, and

[36] The city currently has 490 sewer regulators and 552 tide gates (NYS Environmental Facilities Corporation, 1998, p. B-59).
[37] NYS Environmental Facilities Corporation, 1998, p. B-58.

rising average and peak demands that highlight problems of reliability, cost, environmental impacts, and the way we use and supply energy. Some energy experts underscore the current transitional and competitive environment as an impetus for the industry to shift to cleaner fossil fuels, alternative energy sources, and more aggressive energy efficiency initiatives. In the MEC Region, energy policy is being discussed and power infrastructure investments are being made, yet these are inextricably bound to areas well beyond the region.

Institutional and decision-making aspects of climate change scenarios projecting more frequent and prolonged periods of high temperatures in the MEC Region need to be viewed against this backdrop.

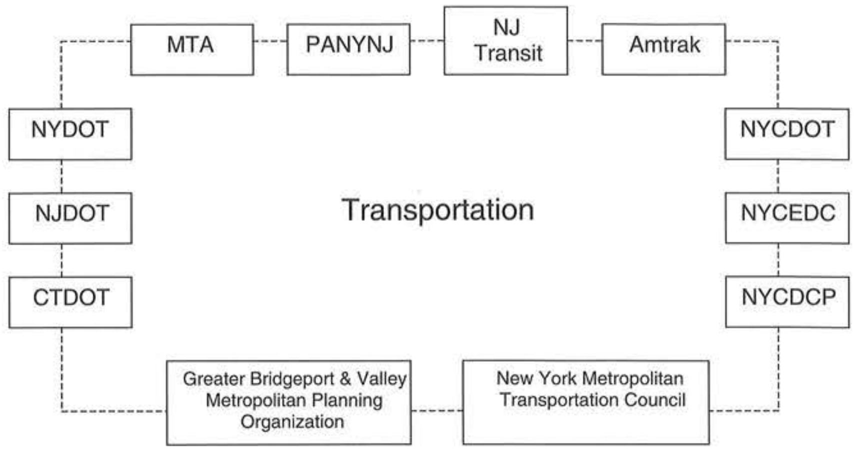

FIGURE 9-3 Transportation planning agencies in the MEC Region. Note: See Appendix Decision-Making 1 for abbreviations.

VULNERABILITIES

As a result of global climate change, demand for cooling during the summer is expected to increase over the next century while demand for winter heating is expected to decrease. The factors associated with energy demand during the summer months are related to heat stress, which is a combination of both temperature and relative humidity (see Chapter 8 *Energy Demand*).

Electric power generation, fuel and energy storage, and transmission facilities in the MEC Region are likely to be impacted by climate change in the following ways:

- First, prolonged heat or cold can increase energy demand while reducing the ability of energy supply systems to produce, transmit, and distribute energy for cooling and heating respectively. The potential outcome is more frequent outages or periods of reduced service (e.g., brownouts).
- Second, to meet the need for cooling water and navigational waters for fuel transport, energy production and fuel storage facilities typically have coastal locations. To the extent that these facilities occupy such locations, they face threats from flooding as a consequence of sea-level rise.

ADAPTATIONS AND DECISION-MAKING AUTHORITIES

The adaptations that have been identified in Chapter 8 *Energy Demand*, include:

Increasing supply by increasing capacity by means of:
- constructing new power plants
- constructing new transmission lines
- upgrading local lines for electricity distribution

Reducing demand by means of:
- increasing energy conservation
- employing technologies that reduce demand, such as passive cooling and weatherization
- increasing shading through tree planting and high-albedo surfaces
- educating the public to encourage energy efficiency

INCREASING ENERGY CAPACITY AND SUPPLY

Adaptation measures that increase the capacity of existing plants, and/or provide for new plants, and/or the redistribution of power via transmission systems involve a constellation of policy, planning, investment, and regulatory authorities that occur at the state level in the MEC Region. Local action and intervention are also common. Coordination of planning areas within the region and between the region and entities external to the region, as well as vertical coordination from planning through operations will be needed to expand capacity and supply and to meet environmental requirements to reduce emissions. At the operational level, electric power producers and distributors will play key roles.

Planning and Policy. State energy plans and policies are potentially important determinants of the distribution and generation of energy within the region. In New York State, the State Energy Planning Board issues the State Energy Plan and its accompanying environmental impact assessment forecasts energy supply and demand as a basis for changes in capacity. The New York State Energy Research and Development Authority (NYSERDA), established by state statute in 1975 as a public benefit corporation, focuses on energy efficiency, the environment, and economic development through research and development activities, financial and technical support, and partnerships. It has virtually no direct authority over the operations or siting of electric utility plants, but can influence investment through some of its public finance authority.

Within New York City, the Economic Development Corporation's Energy Division assumed the jurisdiction of the NYC Energy Policy Office and currently develops policies for electricity and natural gas (not transportation). The Energy Division influences policy with respect to the development of new plants in the City. Since the infamous 1977 blackout in New York City, the NYS Independent Power Operator has required that 80% of the City's electricity be supplied by plants located within the City or directly linked by transmission lines to the City. The one New Jersey plant that is directly connected to the City is considered "in-City generation".[38] Expansion of power plant capacity within New York City is highly controversial. The East River repowering project involving the closure of the Waterside plant and the expansion of the 14th Street plant in Manhattan is just one example.

While no new plant has been built in the MEC Region since the late 1980s, plans are currently underway for expansion in capacity through both the construction of new plants and the redistribution of power production among existing plants. In the mid-Hudson Region of New York State, for example, Pacific Gas & Electric Corp. has proposed a new 1,080-megawatt, $500 million plant in Athens, Green County with new technology for emissions and water usage, that could account for 4–5% of statewide demand. The proposal has received final approval for its state environmental requirements.[39]

Transmission lines provide the MEC Region with the ability to obtain power from other parts of the country. Some of these systems, described in the Energy Sector report, have limitations on expansion due to rights-of-way requirements necessitating new cable technologies. Transmission capacity, particularly to New York City and Long Island, is considered a limiting factor to the provision of extra power in certain parts of the region.[40] In Connecticut, the construction of a new transmission line, the Long Island Sound 24-mile line, is intended to enhance exchanges between Connecticut and Long Island. Other enhancement projects are also underway to expand transmission capacity in Connecticut portions of the MEC Region.[41]

A critical factor in electricity outages is considered to be a "failure of distribution feeders leaving high voltage substations and distribution transformed near end use customers." These failures result from old equipment.[42] Upgrading and renewal of distribution infrastructure is thus crucial to maintaining system reliability. A recent trend in alliances between utilities and telecommunication companies seeking rights-of-way for installing fiber optic lines has proven to be one cost-effective means of accelerating the upgrading of underground lines.

Regulation. Energy supply regulations, centralized primarily at the state level, offer potential leverage for introducing adaptations into energy provision and supply and demand management.

These controls exist at least with respect to siting, capacity, operations, and pricing. Siting regulation is typically done at the state level. In Connecticut, for example, the Connecticut Siting Council approves electric power infrastructure siting. In New York State, a multi-agency siting review process is required after applications are filed under Article X of the NYS Public Service Law. The state public service commissions, e.g., the CT Department of Public Utility Control, the NJ Board of Public Utilities Energy Division, and the NYS Public Service Commission regulate prices.

Operational Controls. Electric power within the New York area is managed by utilities that provide generating and distribution functions throughout the region. The region's system is interconnected to a power grid that extends well beyond the New York area. The key service providers/distributors or suppliers and their jurisdictions are summarized in Appendix Decision-Making 1, and more detailed descriptions are provided in Chapter 8 *Energy Demand*.[43]

The institutional arrangements for energy production are becoming radically transformed as a result of deregulation. Companies that were typically vertically integrated from production to distribution to the customer are now selling production units and focusing primarily on distribution. The result is more geographically complex arrangements for obtaining and supplying energy. In the MEC Region, for example, the United Illuminating Company, serving the Greater New Haven and Greater Bridgeport areas sold its New Haven and Bridgeport Harbor generating plants to Wisconsin Electric Cor-

[38] Richard Miller, SVP, NYC EDC, Energy Division. This reliability requirement was established by a non-profit corporation, the New York Independent System Operator (formerly the NY Power Pool), that is one of three power networks supplying power to the MEC region, and governs New York State's transmission system and establishes reliability rules.

[39] Perez-Pena, R., "Big Power Plant on the Hudson Wins Approval," *New York Times* (June 3, 2000), p. B4.

[40] Perez-Pena, R., op cit., p. B4.

[41] Connecticut Siting Council, "Review of the Connecticut Electric Utilities' 1999 Twenty-Year Forecasts of Loads and Resources," 1999, p. 9.

[42] Connecticut Siting Council, "Review of the Connecticut Electric Utilities' 1999 Twenty-Year Forecasts of Loads and Resources," 1999, p. 10.

[43] Chen, D.W., "Agency Votes to Accept Bid for 2 A-Plants," *New York Times*, March 29, 2000, L, p. B1.

poration in April 1999. Con Edison's sale of its nuclear plants (Indian Point 3 in Westchester County and another plant outside of the region) to Entergy Nuclear of Jackson, MI was approved by the NY Power Authority in March 2000. The transaction was described as "the largest sale of a public asset in New York State history" and one which amounted to "at least four times as much as any previous sale of a nuclear plant, based on dollars per generating capacity."[43]

It is uncertain how this trend toward physically and institutionally separating energy production and distribution will impact the energy sector's ability to adapt to climate change and associated higher demands. Paralleling the separation of production and distribution are increases in the size and geographic reach of conglomerates that control the network. Such conglomeration enlarges the resources that can be tapped. However, areas of demand increase also and place new constraints on the distribution of power. As noted above, some areas, such as New York City, are required to generate a large portion of their power from local plants.

Utilities respond to unplanned, unanticipated extremes of heat or cold and concomitant increases in demand with many different kinds of operational controls. The Connecticut Siting Council lists, for example, the following resource management approaches for periods of high demand as well as for normal demand during system downtime: "additional power purchases; full operation of all available generation units; power factor correction through transmission and distribution capacitors; reinforcement of electric substations; reconductoring of transmission lines; continued temporary reactivation of units in Norwalk and Wallingford; transfer of load to be served by facilities outside of Connecticut; and voluntary interruption of service to customers who agree to such interruption."[44]

REDUCING ENERGY DEMAND

Energy consumption is relatively high in the MEC Region, and peak demand has been rising (see Chapter 8 *Energy Demand*). Much of the consumption is in the buildings and transportation sectors. NYSERDA's 1999 Three-Year Plan, citing the NYS Energy Plan, identified the following statewide trends in energy usage:

- New York State ranks fourth among the states in energy consumption.
- About two-thirds of energy expenditures are in the buildings sector and almost a third are in the transportation sector.
- Energy use in the State has risen 5% between 1990 and 1997, primarily attributed to a rise in the buildings and energy generation sectors.

These patterns of relatively high overall energy consumption and the dominance of the buildings and transportation sectors in usage, and the dominance of the buildings and energy generation sectors in growth have considerable implications for strategies to reduce demand or change facility design or operation to withstand the effects of global climate change.

While a number of programs exist at the federal and state level to promote energy conservation and efficiency, most are voluntary or incentive-based and have not been adopted by the majority of energy users in the residential and commercial sectors. A renewed interest in reducing energy demand and costs has been associated with recent changes in power industry structure and with increasing energy bills. Chapter 8 *Energy Demand* provides examples of existing programs for energy conservation that could be enforced or expanded to significantly reduce energy demands. These include:

- demand-side management measures such as rebates for energy-efficient lighting, appliances, and other building features
- updated efficiency standards and codes for commercial buildings and more assertive enforcement
- passive cooling programs like the U.S. EPA's "Cool Communities" initiative that promotes tree planting and high-albedo roofs and pavements in urban areas to reduce the heat island effect
- weatherization assistance programs that provide funding for measures that increase the efficiency of both winter heating and summer cooling in homes

VULNERABILITIES OF ENERGY PRODUCTION AND DISTRIBUTION FACILITIES

Key vulnerabilities of energy production systems occur by virtue of the traditional location of power plants at waterfront locations because of the need for cooling water and shipments of fossil fuel via waterborne transport. Distribution systems are also vulnerable. Overhead power lines are extremely vulnerable to high winds and icing associated with storm events. Underground lines are vulnerable to flooding. Adaptations involve a wide range of design measures similar to those for other infrastructure, such as dikes to shield plants from flooding. Operational adaptations in the form of shifts in power distribution are common among the region's five New York State plants, New Jersey's four plants, and the plants in Connecticut.

[44] Connecticut Siting Council, "Review of the Connecticut Electric Utilities' 1999 Twenty-Year Forecasts of Loads and Resources," 1999.

Utilities also have jurisdiction over the location of distribution lines, including their elevations, to protect them against flooding. However, utility rights-of-way and acquisition of those rights are governed by complex arrangements among utilities, that depends on location.

Public Health

The health effects of global climate change are likely to be new and unpredictable. The capability of public health institutions to effectively anticipate and respond to these effects will depend on their capacity to adapt to a more dynamic and demanding environment. In the MEC Region, resources for adaptation to health trends and crises are provided by a network of public and private organizations through research, detection and surveillance, eradication, evacuation, health services, education and training, and actions that reduce the sensitivity of individuals and populations to disease. This network includes government, academic, and for profit institutions, and encompasses state and local health departments and hospital and health service networks. Because of the critical linkages between health outcomes and environmental and ecological factors, environmental agencies also play an important role in the public health sector.

VULNERABILITIES

According to Chapter 7 *Public Health*, impacts of climate change on public health in the MEC region will likely fall under three categories:

- heat stress[45]
- water and vector-borne diseases[46]
- respiratory diseases, including asthma, aggravated by ground-level ozone, particulates, and other pollutants.

According to the findings in Chapter 7 *Public Health*, heat stress mortality in New York City could increase by 2–7 times over the next century as the number of days over 90° Fahrenheit increases from about 20 days/year in 2000 to 27–80 days/year during the 2090s. The effects of heat stress on the poor, elderly and infirm will be most extreme and should invoke decisions about more equitable provision of air conditioning. The increasing number of hot days and increasing duration of extreme temperatures will also cause higher ground-level ozone concentration and likely aggravate an already high rate of asthma and other respiratory disease in the MEC Region, especially among sensitive populations. This potential impact has implications for both healthcare institutions and agencies that monitor and regulate air quality.

Another key potential impact of global climate change on public health in the MEC Region and around the world is an increase in vector-borne diseases. Potential manifestations include unpredictable expansions in known diseases and the emergence of new diseases from excessive and sustained heat and humidity, excess precipitation and flooding which can increase and redistribute areas of hibernation of disease vectors, and alterations in the chemical composition of the atmosphere.

Extreme weather conditions that increase the potential for flooding, electrocution, and mold problems also have public health implications.

ADAPTATIONS AND DECISION-MAKING AUTHORITIES

Chapter 7 *Public Health* recommends the following adaptive responses to these potential public health impacts:

- increasing access to air conditioning, especially among the poor and elderly
- improved early warning mechanisms and outreach regarding heat, vector-borne disease, and ozone levels
- coordinated responses to vector-borne disease and wetland management

State health departments maintain primary responsibilities for health policy and management and for addressing new and emerging threats. These state departments delegate many of their functions to local health departments. The NYC Department of Health (DOH) and county health departments are thus also relevant entities for regulation and planning, while a constellation of health service organizations manage the service delivery process.

Several federal agencies also assume critical functions in the surveillance and response to disease outbreaks. The U.S. Department of Health and Human Services houses the Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR). A major responsibility of the CDC is the tracking and detection of new diseases or outbreaks of known diseases and direction of rapid responses to reduce the incidence of disease. The CDC also provides testing protocols, training and other resources to local governments,

[45] Chapter 7 Public Health sector report indicates that heat stress mortality in New York City could increase by 2–7 times over the next century as the number of days over 90 degrees F increases from about 20 days/year in 2000 to 27-80 days/year during the 2090s. The most vulnerable populations are elderly and poor city-dwellers. P.L. Kinney, E. Chae, and B. Winston, "Metro East Coast Climate Change Impact Assessment: Public Health Sector Report," April 26, 2000.

[46] Chapter 7 Public Health indicates that the incidence of vector-borne diseases such as malaria, West Nile Encephalitis, and Lyme disease is likely to increase with an increase in warm and humid weather in the MEC region. Recent years have witnessed an increase in the incidence of malaria and Lyme disease in the region that correlates with increasing summer temperatures. The West Nile Encephalitis outbreak in New York City during the Fall of 1999 followed a wet and humid August, a dry July, and a mild winter. The mosquito-borne disease killed seven and infected over 60 others before the City's insecticide campaign and cooler temperatures ended the epidemic.

for example. In the New York City region, the CDC gave grants of $2.7 million to 19 state and local health agencies specifically for West Nile virus programs to reduce the time between disease onset and diagnosis.[47] The National Institutes of Health also provide research support for disease identification.

Health institutions are most likely to actively respond to the following climate change related trends and events:

- emergence of new disease-related vectors
- increased lifetime/survival time of disease-related vectors
- redistribution of species in a manner that reduces the natural predators of disease-related vectors
- increased aerosol production and ozone production leads to increased respiratory illness
- increased mortality and morbidity, particularly among sensitive populations (such as the elderly, a group that is growing as a proportion of the region's population)
- increased northward and altitude migration of species, whose effects on the food chain can have repercussions on disease, economic and recreational activity

The institutional response to the emergence of the West Nile virus is an example of the ability of health institutions to create the capacity to meet the needs of a new health threat.[48] In the course of developing the West Nile Virus Response Plan, the NYS DOH collaborated with the CDC, the U.S. EPA, and the NYC Mayor's Office of Emergency Management.[49] The plan outlines prevention, response and control systems, specific surveillance systems for mosquitoes, animals, and humans, improved data collection and dissemination systems, and a public awareness and education campaign. The NYS DOH and local health agencies have increased staff and fiscal resources to implement the plan.

In April 2000, New York City announced its own comprehensive West Nile virus prevention and control plan which includes larvicide efforts, mosquito, bird and human surveillance activities, and a public education campaign.[50] According to its web site, the New Jersey Department of Health also has been in direct communication with New York City and State health officials and has enhanced its intergovernmental coordination in implementing its mandated county-based mosquito surveillance and control programs.[51]

[47] L.K. Altman, "Officials Working to Contain West Nile Virus," *New York Times* (April 26, 2000), L, p. B6.

[48] This material is drawn from published documents and web sites of the NYS DOH and NYC DOH and news articles. NYS DOH Press Release: "State Plan for West Nile Virus Response Prepared: Public Comment is Solicited on Draft Plan." 2/18/00. New York State West Nile Virus Response Plan. NYS DOH, May 2000.
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[50] http://www.ci.nyc.ny.us/html/doh/html/public/press00/mr132-00.html

[51] http://www.state.nj.us/dep/mosquito/depfs.htm

SUMMARY, CONCLUSIONS AND SYNTHESIS

This report has covered the manner in which institutional decision-making can respond to the vulnerability of populations, land use, and land-based structures in the MEC Region to the three kinds of effects anticipated from global climate change: increases in temperatures, increased variability of rainfall, and sea-level rise and associated flooding. This approach has focused on those institutions, primarily public agencies, whose authorities are most relevant to adaptations to global climate change based on their prominence in planning or management of the affected facilities or activities.

This assessment reveals that many of the region's most influential decision-making institutions already possess missions and authorities compatible with the kinds of actions and policies that could facilitate adaptation to climate change impacts. The region's current capital planning efforts and revisions of land-use and environmental policies offer prime opportunities to incorporate measures to increase resiliency in the face of climate change. Such a broadening of the scope of traditional decision-making criteria to include potential climate change impacts, however, requires more targeted education of institutions about climate change, specifically in terms of the kinds of regional impacts presented in this MEC Assessment. The extent to which institutions integrate climate change considerations into their policies and actions, and the potential for such actions to be effective, will also depend on a process to increase the level of agency interaction and collaboration within the region.

The most challenging adaptations will involve operational improvements in the in-place built environment, particularly in the region's most densely populated areas along the coasts. Significant opportunities for pre-disaster adaptation do exist. The nature of adaptations is likely to depend on the magnitude of both the anticipated impacts and the costs of adaptation. For large, immovable structures, for example, temporary barricades against sea-level rise might in some cases be the best precautionary measure. Other more flexible structures such as ferry docking stations could be elevated or moved to provide more permanent protection against sea level rise and storm inundation.

Opportunities exist to promote the introduction of adaptations in the course of planning, capital investment, and policy development in the MEC region. Transportation investments, for example, are underway for new roadway design, airport modifications, and transit systems under the Transportation Equity Act for the 21st Century (TEA-21). Where such changes already incorporate flood protection, modifications can be considered to incorporate new vulnerabilities posed by projected sea-level rise scenarios.

The region also has in place many planning and regulatory mechanisms for protecting coastal zones, wetlands and floodplains, such as coastal zone plans, the National Flood Insurance Program, and wetland restoration programs. The key to adaptation is to promote implementation and enforcement of these existing policies and regulations as well as to add requirements that reflect anticipated climate change impacts.

Existing facilities pose greater challenges for planning and regulation. Relevant adaptations include structural additions such as temporary barricades and operational controls. Operational controls can and have been innovative. In the water supply area, as mentioned earlier and in Chapter 6 *Water Supply*, the Third Water Tunnel was able to elevate one of its structures in response to global climate change. A pipe was constructed between New York and New Jersey during the 1980 drought to redistribute water. The Chelsea Pump Station along the Hudson River continues to be a possible alternative water supply for the City in an emergency.

Non-structural adaptations include both short-term improvements and long-term changes that alter population exposure to anticipated impacts through relocation and alter usage patterns through behavioral changes. In areas where land uses are marginal, programs such as property acquisition can gradually restore areas to non-developed uses and thus reduce population exposure during extreme events.

INSTITUTIONAL FACTORS

Institutional factors mentioned at the outset as influencing adaptability include: knowledge and understanding of and experience with global climate change and its effects; consistency of an organization's mission with global change issues; jurisdiction or domain, including mechanisms for interagency coordination; capacity (human, financial); and capability (politics, organizational culture). Among these factors, jurisdictional and capacity issues are noteworthy.

Jurisdiction or Domain and Interagency Coordination. Few agencies, especially at the local level, currently consider global climate change as part of their authority. Climate change policies generally reside with environmental and energy agencies and are often limited to response rather than adaptation concerns. In the MEC Region, however, a number of agencies have begun to adapt their functional jurisdictions and related policies in ways that accommodate the kinds of impacts associated with global climate change. As more severe weather events have affected a larger population, emergency management has gradually diffused throughout agencies, often in subtle ways. Rising temperatures and longer periods of high temperatures have also mobilized agencies to anticipate and address the consequences of waterborne pathogens in drinking water supplies and vector-borne diseases.

More systematic and effective adaptations to climate change will require improved interagency coordination. While current planning and regulations tend to guide certain land use activities away from coasts, wetlands, and floodplains, the mechanisms determining land use vary by sector and across the region, necessitating coordinated action in many instances. Natural resource management across the region is similarly fragmented. While a number of water and energy agencies, for example, recognize to some extent the challenges associated with climate change impacts, a lack of coordination currently restricts their capacity to respond and plan for the future. The region's tradition of highly specialized organizations, divided by function and geography, limits the kind of interagency collaboration required to tackle the regional threats to physical and socioeconomic stability associated with climate change. Instances of collaboration and coordinated action among them have thus far been mostly ad hoc.

Capacity. Availability of and accurate information is a key caapacity factor. Agencies identified as having global climate change related functions are information rich in some areas and information poor in others. Information about flooding, a key impact associated with sea-level rise and increasing storm frequency and severity, is highly centralized. Regardless of their authorities or jurisdictions, infrastructure agencies seem to rely on just a few sources of information on flood risks as they take action in coastal areas, namely the location of floodplains on FEMA maps that may be outdated (see Chapter 4 *Infrastructure*). Engineering design and practice agencies continue to use these maps as reference points. Capital investments are another key capacity factor. The past few decades have witnessed considerable growth in land development and revitalization in the MEC Region as well as increased attention to issues of environmental quality. This has been accompanied by new capital investment, both public and private, for support systems. Climate change adaptations could reinforce these investments, given necessary institutional recognition and coordination. An increasing trend in investment in property acquisitions for environmental purposes also offers a ready context and mechanism for adaptation to sea-level rise.

FURTHER RESEARCH

Several areas of research emerge from this evaluation of institutional decision-making in the MEC Region with respect to its capability to guide adaptation to global climate change.

First, in addition to research on the impacts of climate change in the region in terms of timing and severity, research is needed to establish the costs of various adaptive measures. Such research should consider a range of scenarios of impact and adaptation and distinguish between actions that are undertaken de novo and those that are an integral part of the operations of the built environment. In addition, an understanding of the forces that shape coastal development is key to an adaptive strategy that includes incentive systems for guiding growth away from areas vulnerable to sea-level rise. The results of such research would provide the foundation for the kind of cost-benefit analysis that can guide decision-making in many institutions.

Second, research should focus on achieving a clearer understanding of the capacity of individual agencies to deal with global climate change issues either in the context of existing responsibilities or as additional responsibilities. This effort should identify linkages between various adaptation needs and the actions and activities already underway in the region as Zimmerman (1996) and others have pointed out.

Third, research is needed on best practices for applying managerial concepts of coordination, collaboration, and negotiation for global climate change issues faced by institutions in the MEC Region. These applications should be feasible within existing agency jurisdictions and capacities.

Finally, the heart of effecting change and sensitivity to a new issue is education. There is clearly a growing base of concern in the MEC Region regarding global climate change and its potential short-term and long-term impacts. Future research should determine effective means with which to further educate decision-makers and the general public about climate change and adaptation issues. Such efforts should ultimately mobilize well-informed institutional responses.

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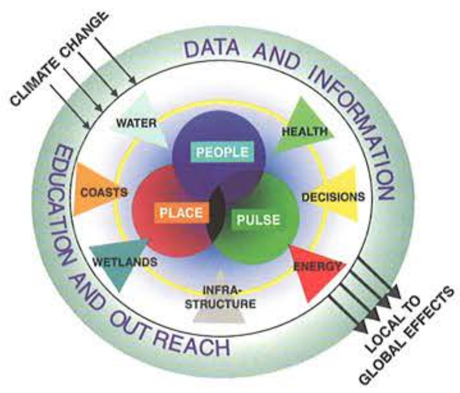
PART 3

CONCLUSIONS



CHAPTER 10

ADAPTATIONS AND POLICY RECOMMENDATIONS

Climate is changing in the New York Metropolitan Region. Over the past 100 years, temperature in the region has warmed nearly 2°F; however, it is very difficult to determine the causes of the observed climate trends.

The rate and amount of temperature rise is projected to increase over the 21st century due to anthropogenic greenhouse warming. Substantial uncertainties about climate change remain, including the rate and magnitude of projected regional changes. Gradual changes may be punctuated by changes in climate extremes.

The use of a range of plausible scenarios enabled the Metro East Coast Assessment researchers to project possible impacts created by climate variability and change as well as to evaluate the MEC Region's responses. An assessment exercise such as the Metro East Coast study is useful in developing preparedness for extreme climate events in the present as well as readiness for a changing climate.

PEOPLE, PLACE, AND PULSE

Climate change will fundamentally affect the people, place, and pulse of the Metro East Coast Region. Coastal areas and communities appear to be among the most vulnerable sites in the region, due to the potential for changing sea levels and more frequent flooding from storm surges. Although it is impossible to know if and when the area will experience a catastrophic storm and flooding event, projections show that severe storm recurrence periods are likely to shorten (Chapter 3 *Sea-Level Rise and Coasts*). Shoreline homes, airports, railway tunnels and roads, operating and derelict industrial facilities (including hazardous waste sites), and ecosystems are at risk of flooding ever more repeatedly (Chapter 4 *Infrastructure*). Coastal wetlands, such as the Jamaica Bay salt marshes, may show the earliest and most manifest evidence of loss associated with sea-level rise (Chapter 5 *Wetlands*). Given limited potential for retreat inland, the remaining fringe of coastal wetlands may decline, causing a ripple of other ecological effects, including the loss of critical bird and aquatic habitats.

The Metro East Coast Assessment found that the New York City water supply system—the largest in the study region and one of the largest in the world—should be able to respond to the expected increases in annual temperature and their effects on the water supply via evaporative demand as well as greater variability in rainfall, at least in the near term (Chapter 6 *Water Supply*). Responses to projected salt-water intrusion and the longer term need further study. The direction of change in the total amount of precipitation remains an uncertainty. The MEC Water Supply Sector team has called for the evaluation of enhanced intra- and inter-regional water distribution protocols, which could potentially include mutual aid agreements with the Delaware River water system.

Inequity and spatial and demographic unevenness of climate change impacts are found among the region's public health risks (Chapter 7 *Public Health*). There is likely to be increased exposure to heat stress conditions, greater potential for water-borne or vector-related disease outbreaks, and higher concentrations of secondary air pollutants, resulting in higher frequency of respiratory ailments and attacks. Populations currently at risk, including the poor, immuno-compromised, elderly, and very young, will be the most vulnerable.

Electric energy demand and health effects will interact under conditions of climate change because of the connections between climate warming, increased energy demand, electricity blackouts or brownouts, and resulting heat stress (Chapter 8 *Energy Demand*). Heat stress may become especially problematic for the elderly urban poor if electricity outages, exacerbated by heightened demand for air conditioning in hotter conditions, occur more frequently in the future.

Although climate change will dampen the winter demand for energy, this will be offset by an estimated increase in summer electricity demand. Summer demand could be especially strong during summer heat waves as illustrated in the set of four successive heat waves that hit the region from late June through early August, 1999. The temperature rose to more than 90°F for 27 days during the period. The climate change scenarios project that the average number of days exceeding 90°F (13 days in the current climate) will increase by 2-3 times by the 2050s. The peak electrical demand recorded in the region occurred on July 6, 1999. Brownouts and an extended blackout occurred in the primarily minority neighborhoods of upper Manhattan and the South Bronx. These events might foreshadow future extreme events.

The Metro East Coast Assessment found that climate change impacts in the region will be simultaneous, multidimensional, and interactive. Heightened frequencies of storm-surges will damage major infrastructure juxtaposed to already threatened coastal wetlands; health impacts cannot be separated from the impacts of augmented heat waves on energy demand. Drinking water supplies during droughts may be negatively affected by saltwater intrusion in the Hudson River estuary.

Finally, the Assessment concluded that climate change impacts will not be limited by the region's boundaries. Global cities, such as New York, are important hubs for international capital and labor flows. A major climate-related disruption of New York Stock Exchange activities, for example, would have reverberating impacts on financial markets around the world.

ADAPTATIONS TO CLIMATE CHANGE

Adaptations and adjustments may include physical modifications to infrastructure (e.g., higher seawalls and raised airport runways); changes in decision-making practices (e.g., increased use of management strategies with overlapping jurisdictions and longer timeframes); and far-reaching societal shifts (e.g., disinvestments in highly vulnerable coastal sites and increased support for at-risk populations of the poor and elderly). These new responses, in turn, will interact with the ongoing processes of ecological and societal transition in the region.

Management institutions and agencies with responsibility for the coastal zone in the Metro East Coast Region need to incorporate the potential for changing climate conditions in their current decision-making. Options for reducing the increased coastal storm-surge hazards and risks to regional infrastructure include short and medium-term protective engineering and insurance measures and longer-term land-use planning. Adaptation strategies to protect the region's coastal wetlands include facilitating the inward migration of shore marshes by establishment of buffer zones.

Projections of sea-level rise and increasing storm-surge hazards brought forward in this Assessment are relevant to decisions regarding clean-up of toxic waste sites, wetland restoration projects, wastewater treatment plants, and transportation corridors. These projections also need to be taken into account in appropriate and realistic ways during current and future preparation of new flood maps and frequency estimates, response protocols, coastal building code regulations, beach renourishment time-tables, and insurance policy mandates. Such activities will be necessary to protect the region's human, physical, and ecological assets.

For energy demand, the emphasis in adapting to climate change should be on improved energy efficiency, particularly to reduce summer peak electricity loads, and enhanced passive cooling in buildings and communities. Local lines that distribute electricity to customers need to be upgraded, and the adequacy of transmission lines to bring more power into the metropolitan area should be assured.

POLICY RECOMMENDATIONS

How can environmental managers in the region respond to the potential challenges and opportunities of climate change, and how can they bring the issue into their everyday decision-making processes? Decision-makers are being challenged to be pro-active with respect to potential climate change and variability, responsive to potential environmental changes on longer time horizons, and flexible in the face of increased uncertainty (Chapter 9 *Institutional Decision-Making*).

Policy recommendations were made in each of the sector studies of the Metro East Coast Assessment. The Sea-Level Rise and Coasts, Infrastructure, and Wetlands sectors recommend that the implications of sea-level rise associated with climate change be taken into account in the designation of coastal hazard zones, adaptation of setback requirements, rolling easements, and limits to development in coastal zones. The Water Supply Sector recommends that a study be conducted of possible climate change adaptations first with specialists from the relevant agencies within the Metro East Coast Region and then with experts from the Delaware Basin and New Jersey. For the Public Health Sector, climate change projections should be incorporated into future policy decisions regarding public health issues. Policies are needed that incorporate climate change impacts into ground-level ozone mitigation. The "weatherization" program that exists to save energy costs in housing for low-income people could be extended to provide summer cooling in urban areas as well as winter heating.

At the regional level, climate variability and change could be associated with several initiatives. These include education and outreach programs, enhanced methods for defining and entraining potential climate change impacts into planning decisions, and increased inter-agency communication and cooperation. Current major capital reinvestment activities and structural shifts in management regimes in the Metro East Coast Region provide excellent pathways for integration of climate change adaptation into stakeholders' decision-making practices.

Climate Awareness Program

As an education and outreach component, a regional Climate Awareness Program would be effective to inform both decision-makers and the general public about the nature of current climate processes, lessons learned in responding to climate extremes, and future climate change. Enhanced training of weather forecasters in the region about the climate change issue along with climate awareness websites or other easily accessible sources of updated information would facilitate this process. In conjunction with the Metro East Coast Regional Assessment, CIESIN (Center for International Earth Science Information Network) is developing a Climate Awareness website for the region with the Columbia Earth Institute of Columbia University. (See http://metroeast_climate.ciesin.columbia.edu for the Assessment website).

Climate Impact Indicators

Through our communication with stakeholders in the course of the Metropolitan East Coast Regional Assessment, we learned that the impact of potential climate change has to be put into the discourse of everyday decision-making processes. Rates of possible sea-level rise, and temperature and precipitation shifts are relatively remote to the average decision-maker and region resident. Impacts must be put into contexts that are meaningful. The development of a set of cost-based, urban-focused climate change impact indicators would make a significant contribution. For example, what will sea-level rise mean in terms of increased costs of beach renourishment and what will temperature increases mean to acute asthma sufferers.

Inter-Agency Climate Task Force

Increased intra-sectoral and inter-sectoral communication among agencies and institutions also would greatly increase the response capacity of local decision-makers to potential climate change impacts. This kind of enhanced communication would allow decision-makers to identify potential problems and define common solutions. Examples of the general utility of within-sector interactions already are present in the MEC Region. SENYIWSAC (Southeastern New York Intergovernmental Water Supply Advisory Council) is a volunteer, non-regulatory group of water supply managers that communicate on common problems and planning initiatives. Regional air traffic control protocols for the region's three major airports and numerous smaller airports are another example.

Inter-sectoral working groups are fewer. Such groups are critical for addressing the multidimensional impacts that cut across sector lines. In the Metro East Coast Region, this type of interaction is especially important given the highly integrative nature of the urban environment problems such as the links between public health and energy demand, and the links between the ecological and infrastructural components of the coastal environment. Interagency task forces developed as part of regional environmental management activities, such as the Florida Everglades and Chesapeake Bay, can serve as valuable examples of how to develop climate change-related groups in the MEC Region.

RESEARCH NEEDS

Each of the sector studies of the Metro East Coast Assessment identified specific gaps in knowledge and the research needed to fill those gaps. Research needs identified for the Sea-Level Rise and Coasts Sector include improving the resolution of topographic data in order to better assess risks of higher storm surges and refining the calculation of potential changes in saltwater intrusion in the Hudson River. Data needs of the Infrastructure Sector are a detailed catalog of historic storm damages, accurate inventories of major infrastructure systems and components, and evaluation of infrastructure and network fragility. Future research in the Wetlands Sector focuses on determining the dynamic processes that are contributing to current marsh losses. This involves the study of marsh geomorphology, structure, and ecology, as well as continuing research on the influence of current rates of sea-level rise on the region's coastal wetlands. The role of other anthropogenic influences such as dredging and sediment transfer, and water pollution needs to be defined. Research is needed on marsh accretion rates, on how storm-wave action and freezes influence salt-marsh geomorphology and on biogeophysical interactions between salt-marsh flora and geologic and climatic conditions.

Research needs for the Water Supply Sector include detailed assessments of adaptation options, with engineering, economic and environmental factors relevant to the benefits and costs of adaptations and their optimum scheduling over time. Also needed is a better understanding of the likely effects in direction and amount of climate change on each element of demand and supply in the region's systems, especially calculations of potential changes in water demand in urban and suburban areas. For the Public Health Sector, additional scenarios of ozone health impacts are needed that include alternative assumptions about the demographic make-up of the MEC

Region in future years and differential risk coefficients for different demographic groups. Another important research direction for the Public Health Sector is the study of the independent and interactive impacts of heat stress in conjunction with air pollution. The Energy Demand Sector should expand to include potential impacts on supply as well as demand.

THE CLIMATE CHANGE CHALLENGE

The complex nature of potential climate change impacts in urban regions poses tremendous challenges to urban environment managers to respond cooperatively, flexibly, and with far longer decision-making timeframes than currently practiced. Given the already fragmented nature of urban environments and jurisdictions, the political and social responses to the global climate issue in cities should begin at once. Transforming the urban management paradigm to better prepare for climate change will safeguard against negative feedbacks in the Metro East Coast Region and around the world.

In summary, the Assessment illustrates that the future environmental conditions of the Metro East Coast Region will be much more dynamic than in the recent past. The highly sophisticated environmental management and response strategies that evolved during the 20th century in the region were based largely on the idea that the ecological and environmental baselines were static, although ranging within the conditions of dynamic equilibrium. Under this premise, local environmental change was seen as being brought about largely through direct human action.

Global climate change forces a fundamental reassessment of these assumptions. In the 21st century, the baselines will change and local decision-makers will have limited ability to control the pace of this transformation. The gases already emitted into the global atmosphere are projected to cause some degree of warming and environmental change regardless of the implementation of any comprehensive policy designed to reduce greenhouse gas emissions (the root cause of projected climate change). For the citizens and stakeholders of the Metro East Coast Region, the challenge will be to adapt to and mitigate climate change simultaneously and equitably.

PART 4

APPENDICES

Geographic Information Systems (GIS) is a combination of computer hardware, software, and data that let us store, create, and analyze spatial data. Any information that is referenced to a location is spatial data. For example, addresses, latitude and longitude, or another coordinate system correlates specific data values to a place on Earth or in space. Any physical and cultural geographic features and their attributes can be displayed on a GIS system if they have this geo-referencing. GIS systems let us layer many different kinds of information together and examine their relationships. In a GIS we can create a digital map of an area using layers describing political boundaries, roads, streets, wetlands, soil types, building footprints and more. Once the map is created we can use the GIS to ask questions such as, "how many wetlands are within 100 feet of the roads"? The ability to create and update geographic information and interact with different elements of a map is what makes GIS such a powerful tool for many different applications. GIS is used in land use planning, transportation planning environmental management, business marketing and health and social services program planning and management and education.

GIS IN THE METROPOLITAN EAST COAST ASSESSMENT

Columbia University Center for International Earth Science Information Network, (CIESIN) has developed and managed a Geographic Information System (GIS) as a component of its partnership in the Metropolitan East Coast (MEC) Climate Change Assessment study. GIS was used in the MEC project in four capacities:

1. To assist researchers in mapping the results of their studies.
2. To create a visual description of the study region as a tool for researchers, stakeholders.
3. To communicate findings to the general public on the Metro East Coast website.[1]
4. As part of an on-line resource for students and educators wishing to use the MEC Assessment data in their classroom studies.

The Metropolitan East Coast GIS has played a valuable role in assisting research participants to analyze and visualize their results. Fundamentally, the GIS provides a detailed description of the physical and social geography of the study region. More importantly, the GIS helps to map the magnitude and spatial distribution of potential threats to the region's infrastructure, public health, water supplies, coastal zones and wetland areas resulting from climate change. Publishing the maps that illustrating these potential threats on the Metropolitan East Coast web site contributes to the project's goal of increasing public awareness about global climate change issues. One of the most interesting applications of the MEC GIS is a special Educator's Package that delivers GIS data layers and a free GIS software program along with a series of lesson plans for teachers and students to use in classroom projects.

Data Set Inventory

The Metropolitan East Coast study region is a 31-county area that constitutes the New York City metropolitan area. We have complied the following data layers for use in the MEC GIS:

- Tiger Files, 1997 US Census Bureau:
  Political Boundaries, Roads, Landmarks, Water Bodies, Streams, and Demographic Information by Census Tract & Block
  Climate Models from the CCS and Hadley Centers on Climate Change
- New York City Department of Environmental Protection, Watershed Layers:
  Watershed Bounds
  Reservoirs
  Streams
  Farms
  Monitoring Sites
  20-foot Contours
  Political Divisions
- Landsat Thematic Mapper image of the New York region
- USGS Digital Elevation Models
- USGS 1:250,000 Land Use Land-Cover Data
- National Wetland Inventory
- New Jersey Department of Environmental Protection, 1:58,000 Land Use Classifications
- Digital Ortho-Photo Quadrangles for New Jersey & Long Island
- NPA Data, Growth Projection Data

General Description Maps

In order to provide an easy way for researchers and stakeholders in the project to express the study area's physical and cultural geographic features, we developed a GIS that

[1] URL for the MEC website is: http://metroeast_climate.ciesin.columbia.edu

would layer census and other data over digital maps of the states and counties of the MEC region. This affords the ability to illustrate layers such as census geography, road and transportation networks, cultural landmarks, major cities, water bodies and streams over the base map.

We have incorporated into the GIS a series of satellite images that depict the vegetation, urban development and landforms that are part of the study region's urban center and the suburban and rural areas that surround it. A unique set of images using satellite data created by Christopher Small of Lamont-Doherty Earth Observatory show thermal patterns in the Metropolitan East Coast area.

Global Climate Model Maps

A fundamental tool in the Metropolitan East Coast Assessment is scenario analysis based on global climate models (GCMs). These computer models project possible changes in global temperature and precipitation. The two models used in the reports that contribute to the National Assessment are from the Hadley Centre for Climate Prediction and Research[2] and the Canadian Centre for Climate Modeling and Analysis.[3]

Datasets from these centers contain point data with an x and y location and variables for temperature and precipitation for specific years in the future. We compiled these data into values to express projections for the time-slices 2020s, 2050s, and 2080s. To view these data as maps we have layered grid cells of the sizes in the climate models (3.75 degrees (long) x 2.5 degrees (lat) in the Hadley Model, 3.75 (long) x 3.71 (lat) in the Canadian Centre model) with thematic maps that express the variable-based climate scenarios for the time-slices. Temperature values are in degrees centigrade and precipitation is defined as percent change.

A series of maps created using these data include:

- Hadley Global Temperature
- Hadley Global Precipitation
- Canadian Global Temperature
- Canadian Global Precipitation
- Hadley v. Canadian Temperature 2020s, 2050s, 2080s
- Hadley v. Canadian Precipitation 2020s, 2050s, 2080s

Demographic Mapping

The US Census Bureau Provides a series of digital geographic information layers known as the Topographically Integrated Geographic Encoded and Referencing (TIGER) files. These files include layers for roads, streams, political boundaries, landmarks and census geography boundaries such as blocks, tracks and metropolitan statistical areas (MSA's). We have compiled the Census tracts for the 31-county area of the Metropolitan East Coast study with the associated demographic variables to create a series of thematic maps to illustrate social patterns throughout the region.

Using these data we created the following demographics thematic maps:

- Population Density
- Average Income
- Poverty: percent of population living below the poverty line
- Average Housing Value
- Buildings built before 1940

On-line creation of thematic maps for any of other the over 220 variables from the 1990 U.S. Census is possible using either CIESIN's DDViewer (demographic data viewer) program at http://www.ciesin.org/interapps.html, or through the Metropolitan East Coast Assessment Educators' Pack, downloadable at http://metroeast_climate.ciesin.columbia.edu/.

Digital Elevation Models

To understand the potential effects of sea level rise we have employed USGS Digital Elevation Models (DEMs). These models, which depict the average elevation over a 30-square meter (323 square feet) grid cell, allow us to see which coastal areas are most susceptible to increases in mean sea-level elevation. The horizontal accuracy of the data sets is between 1.5 and 3 meters (5 and 10 feet). Using ESRI's ArcView Spatial Analyst software we derived an estimated 5-foot (1.5 meter) contour set for the area and through a projection, we are able to overlay this contour with our other data layers.

This DEM along with detailed information on transportation features (roads, bridges, tunnels, shipping ports, and airports), and buildings were compiled to study the potential impacts of climate change on the region's infrastructure. Using this analysis we have developed a series of maps that indicate the areas with 0 to 3 feet (0 to 0.9 meters), which highlights those areas that are vulnerable to flooding. The potential impacts to the area major airports, highways, and other infrastructure elements can easily been seen.

Land Use Coverage Data

Land use data derived from satellites and arial photography contributes to the GIS by adding an improved temporal dimension. We study the historic change in land use and land cover in the region and incorporate these trends into our analysis of the possible impacts of climate change. We compare the change of land use classification

[2] http://www.meto.govt.uk/sec5/sec5pg1.html
[3] http://www.cccma.bc.ec.gc.ca/

percentages by census tract over the past twenty years. For the New Jersey sections of the Metropolitan East Coast region we have studied the changes in land use and land cover over the past ten years using land use classification layers at a scale of 1:58,000 for the years 1986 and 1997 provided by the New Jersey Department of Environmental Protection.

GIS PROJECTS FOR INDIVIDUAL SECTORS

Coastal Sector Maps

For the Coastal Sector, we have developed a series of maps that define the demographic make-up of populations that are at risk to impacts of sea-level rise. Six study areas were chosen to review: Coney Island, Rockaway, the Battery, and Westhampton in New York and Asbury Park and Sea Bright in New Jersey.

To create the maps we layered five-foot contour intervals from 7.5-minute quadrangle Digital Elevation Models with the Census tracts. The Census tract boundaries are not very accurate; for example, tracts that depict coastal areas very often extend well into the ocean. The zero elevation contours were assumed to be the base shoreline. We edited the census tracts in order to bring the tracts into conformity with the shorelines. Three thematic maps were then generated for each of the six sites using the demographic variables from the 1990 Census: Population Per Square Mile, Average Household Income, and Average Housing Values. Contours lines for the 5-, 10- and 15-foot elevations were placed over the classified census tracts. The resulting maps give a sense of the social composition of populations living near the coasts, those most likely to be subjected to sea-level rise and increased frequency and severity of coastal storm events.

Health Sector Maps

For the Public Health sector, we have employed GIS technology to compile data sets on several diseases and map their spatial distribution. Maps for all the following have been created:

- Heart Disease
- Malignant Neoplasms
- Cerebro-Vascular Disease
- Pneumonia/Influenza
- COPD
- HIV
- Asthma

We also use the GIS to map the spatial and temporal correspondence between ground level ozone and asthma rates, a relationship that is of significant concern in terms of climate impacts. Maps will be created to show the potential increases in these diseases based of environmental change as predicted by internationally recognized Global Climate Models.

MEC EDUCATION MODULE

As part of the outreach and education efforts of the Metropolitan East Coast Assessment, we have developed an education module. The modules use the research of the Assessment as a foundation for students to look at climate change at a local level.

The module is composed of three parts: background, skills, and application. In the background section of the module, we use lectures and readings to introduce students to main concepts of the Metropolitan East Coast Assessment:

- Science of Climate Change
- Climate Change Research: Globally to Locally (IPCC, National Assessment, Metropolitan East Coast Assessment)
- The Metropolitan East Coast Region: People, Place and Pulse
- Climate Impacts, Examples from the MEC Assessment
- Adaptation and Mitigation: Social Responses to Climate Change

During the course of the module, the students are taught to use GIS software and data from the Metropolitan East Coast Assessment to develop maps that combine demographic and physical data of the region to express relationships such as vulnerabilities to climate impacts. (See MEC Educator's Pack for examples of the GIS activities).

In preparation for the final component of the module, a public-hearing role-play, the students learn interviewing skills. The students pick or are assigned roles that represent a variety of interests and perspectives in the Metropolitan Region. Some of the roles have been:

STAKEHOLDERS

The Port Authority of New York and New Jersey
New York City Department of Health
Federal Emergency Management Agency (FEMA)
Regional water planners
Environmental Protection Agency, Region 2
New York Power Authority

TECHNICAL SPECIALISTS

Climate Scientist
Ecologist

Hazards Specialist
Energy Specialist
Social Scientist

NON-GOVERNMENTAL ORGANIZATIONS, PROFESSIONAL ORGANIZATIONS, AND OTHER INTERESTS

Regional Plan Association
Environmental Defense
Climate Change Learning and Information Center
American Petroleum Industry
Emissions Trading Firm
General Public

LOCAL AND STATE GOVERNMENT

Office of the Mayor of New York City
New York Congressional Representatives

Because the Metropolitan East Coast Assessment has done extensive outreach within the region, the students are able to contact the representatives of the various "roles" with whom we have worked and thus have direct access to decision- and policy-makers in the region. The students conduct and write-up the interviews in preparation for the culminating activity of the module: the mock public hearing.

In the mock public hearing, the students are expected to present the views and opinions of the particular "role" that they researched and interviewed. Before the day of the hearing, the students are presented with an invitation to the public hearing, which outlines the issue that is up for discussion. The question can be broad, such as "Should New York State develop a Climate Change Action Plan?" or very specific, for example "Should New York City tax money be spent on building a storm wall in Lower Manhattan?" The students discuss the issues that contribute to the decision according to their rules and finally, vote on the given question.

Through the module, several themes emerge:

- Local impacts of global environmental change
- Overlapping impacts that exist within a city with complex systems
- Scientific uncertainty and decision-making
- The role of mitigation versus adaptation in global climate change
- Short-term and long-term thinking

MEC EDUCATOR'S PACK

The GIS-based MEC Educator's Pack is a package of GIS software, datasets and lesson plans designed for educators who are interested in using GIS technology to explore global climate change issues. The package includes a free GIS software program called ArcExplorer created by ESRI, a leading GIS software developer. The datasets available include climate models and the US Census Bureau's TIGER Files, as well as several other datasets from the MEC Assessment. We also provide two lesson plans that use ArcExplorer to view the MEC data and produce a series of maps that illustrate climate change scenarios in the MEC region. The MEC Educator's Pack is available for free from the MEC web page at http://metroeast_climate.ciesin.columbia.edu or on a CD-ROM upon request. For additional information please contact:

Center for International Earth Science Information Network (CIESIN)
Columbia Earth Institute
Lamont-Doherty Earth Observatory
61 Route 9W
Palisades, NY 10964
845-365-8988
http://www.ciesin/org

Contents

The MEC Educator's Pack contains a series of programs and datasets under the flowing directory structure:

ArcExplorer

- aeclient—This is the free GIS software program from Environmental Research Institute (ESRI). Click on this icon on the website to start the install program.
- arcexplorer_user_guide—An introduction to and a tutorial on using ArcExplorer

More information on ArcExplorer and all of ESRI's GIS products and services may be found on their website at http://www.esri.com.

GIS_Data

CLIMATE MODELS

- Canadian—ccs258.xxx—These five files are the shape file of the Canadian Center Model
- Hadley—hsc258.xxx—These five files are the shape file of the Hadley Center Model

GEO_DATA

This directory contains a number of geographic data layers for use in project, including:

File Name	Description
31 County Metro Area.shp	Counties in the MEC Region
5_foot_metro_contours.shp	5 Foot Contours from DEMs for NYC area
airports.shp	Airports

county.shp	US Counties
ghospital.shp	US Government Hospitals
lalndmrk.shp	Landmarks
cities.shp	US Cities

TIGER

This directory contains a file called MEC *tracts.shp* that contains all the census tract boundaries for all the census tracts with in the MEC region with the associated demographic variables.

Lesson_Plans

This directory holds two sample lesson plans that provide step-by-step instructions for using the GIS program and data sets in the classroom. The first lesson gives instructions for creating maps using the climate change scenarios from the Canadian and Hadley climate models. The second lesson entails creating thematic maps using the 1990 Census data for the MEC region.

System Requirements

ArcExplorer will only run on a PC-based platform. Recommended system requirements are a Pentium Chip and at least 16 MB RAM. The entire Educator's Package uncompressed is approximately 60 Megabytes in size.

Lesson Plan for Middle School Science Class

1.) LESSON PLAN ONE—MAPPING CLIMATE CHANGE SCENARIOS WITH ARCEXPLORER

In this lesson, we use the data layers from the Hadley and Canadian climate centers to create thematic maps illustrating temperature and precipitation predictions for the 2020s, 2050s, and 2080s. We will make maps at the global scale and maps that focus on the Metro East Coast region. After completion the maps may be printed out and used in a comparison exercise that looks at the differences between the projections of the two models. This exercise can also be used as a reference for further explorations that investigate the scientific basis that provides the foundation of the models and their resulting projections.

Step One: Setting Up

Create a directory on your hard drive to install the MEC Educator's Pack. Download the MEC Educators Pack into the new directory. Install ArcExplorer by going to the directory *Mec_Educators_Pack/ArcExplorer/* and click on the *aeclient.exe* file. This will start the installation process. Accept all the default values in the installation process.

After the installation is complete, it is necessary to restart the computer. Once the computer is running again, there will be an ArcExplorer icon on the desktop. To start the program, click on the icon.

Step Two: Start a Project

Start a project by moving your cursor to the *File* menu and click on *File/New ArcExplorer*.

Step Three: Adding Data Layers to the Project:

Click on the *Theme* menu and the *add theme* option (or click on the *plus sign icon* at the top of the window) and navigate to where the *country.shp* file is stored (C:/MEC GIS Viewer/GIS_Data/Geo_Data/country.shp). Select the following layers: *hcs.shp*, *ccs.shp*, *country.shp*, *31cnty_geoshp.shp* and click on the *add theme* button.

Step Four: Creating a Thematic Map of the Hadley Climate Model Showing Temperature Predictions for the Year 2020.

1. Make the *hcs258.shp* visible
2. Double click on the layer name *hsc258.shp* to open up the *Theme Properties Dialogue Box*.
3. Under the *Classification Options* on the left side of the box; choose *Class Breaks*.
4. Choose the *classify* option.
5. Next under the *Numeric Field* drop down list choose *T20S*.
6. Set the number of classes to 6.
7. Create a new color ramp by double clicking on the *Start Color*.

From the new color pallet window select a light color blue for your start color and click the *OK* button. Click on the *End color* and choose a bright red color and click *OK*. Then click on the *OK* button on the lower right of the dialogue box.

We now have a layer of cells colored by the one of the values in the database. In this case, the values of the cells are predicted change in temperature in degrees centigrade for the 2020s.

8. To make the country boundaries layers visible, left click on the check box next to the country file to make the theme visible. This enables a better understanding of the cells' locations.
9. Change the fill pattern to transparent so that only the country borders will be seen: Double click on the *Country file* name on the left side of the ArcExplorer window to open the *Theme Dialogue* box. At the center of the box you will see the option to change the color, style, and the size of the symbols. From the style option click on the drop down box and choose the *Transparent* option. If you wish to change the color of the outline select *Other* symbol properties and from the new window that appears change the line color. Click the *OK* button at the button of the *Theme Properties Dialogue* box.
10. Use the pan and zoom tools to explore different regions.
11. When you are ready to print out the map go to the *File* option on the menu bar and choose the *Print* option.

12. Make maps showing temperature changes for the 2050s and 2080s. To do this, reclassify the grid using the T50S and the T80S variables. Print out each of these maps. Next make a series of maps showing predicted precipitation change using the variables P20S, P50S and P80S.
13. Save your project by going to *File/Save Project*.

Step Five: Adding the 31-County Region Boundaries
To get a close look at the projected climate scenarios in the Metropolitan East Coast Region, we add the geoshape file that layers on the county boundaries for the region.
1. Make the theme *31cnty_geoshp.shp* visible.
2. Change the fill pattern to *Transparent*.
3. Classify the theme *hsc258.shp* to the temperature variables T20S.
4. Zoom into the new *31cnty_geoshp.shp* theme.
5. How much does the model predict that the temperature will change?
6. Now classify the 2050s and 2080s, noting the projected changes.
7. Now do the same for the projected precipitation changes.
8. Save your project.
9. Print out some of your maps.

For the Teacher

This lesson is designed to get students familiar with using the ArcExplorer program and the various data sets. Once students are comfortable with using the program, you can expand your explorations. This lesson has students create and compare maps using Hadley and Canadian data sets. Students can do research on the methods and assumptions that serve as foundation for the development of the models; they can begin to explain the reasons for the models' differing scenarios. The students may discuss some of the potential flaws in the models; it is especially relevant to discuss the challenges of applying a global model to a relatively small area such as the 31-county Metropolitan East Coast region. A follow-on exercise involves discussion of and search for additional data layers that would be useful to bring into the project. Many data are available on the internet and can be imported into the projects to create alternative exercises.

LESSON PLAN TWO—DEMOGRAPHIC THEMATIC MAPPING

In this lesson, we use demographic information created by the U.S. Census Bureau and GIS files describing the census tracts for the MEC region. Included in the MEC Educators Pack is a GIS file called MEC *Tracts.shp* that contains all of the census tracts for the MEC region with an attached database containing over 200 demographic variables on age, ethnicity, income, employment and other categories. In this lesson, this file is used to create color-coded maps that display the spatial distribution of these variables. For more information on census geography visit the bureau's web site at (http://www.census.gov/).

Step One: Setting Up
Create a directory on your hard drive to install the MEC Educator's Package. Download the MEC Educators Pack into the new directory. Install ArcExplorer by going to the directory *Mec_Educators_Pack/ArcExplorer/* and click on the *aeclient.exe* file. This will start the installation process. Accept all the default values in the installation process. After the installation is complete, it will be necessary to restart the computer. Once the computer is running again, a new ArcExplorer icon will be on the desktop. Click on the Icon to start the program.

Step Two: Starting the Project
Start a project by moving your cursor to the *File* menu and click on *File/New ArcExplorer.*

Step Three: Adding Layers to the Project
Click on the *Theme* menu and the *add theme* option (or click on the plus sign icon at the top of the window) and navigate to where the MEC *Tracts.shp* file is stored (C:/MEC GIS Viewer/GIS_Data/Geo_Data/TIGER/Mec Tracts.shp). Select the layer and click on the *add theme* button.

Step Four: Mapping Demographic Variables
1. Double click on the layer name MEC *Tracts.shp* to open up the *Theme Properties* dialogue box.
2. Under the *Classification Options* on the left side of the box choose *Class Breaks*.
3. Choose the *classify* option.
4. Under the drop down list you will see the 200+ demographic variables that you can use for your mapping. Choose the variable *AVGHHINC* to map the average house hold income for the MEC region.
5. Set the number of classes to 6. This creates six classifications in which the data will be divided.
6. Create a new color ramp by double-clicking on the *start color.*
7. From the new color pallet window, select a light yellow for your start color and click the *OK* button. Click on the *end color* and choose a bright red color and click *OK*. Then click on the *OK* button on the lower right of the dialogue box. We now have a layer of cells colored by one of the values in the database
8. Add some of the other layers that are available under the *Geo Data Folder* such as airports, hospitals, landmarks, and cities.
9. Print out your maps using the *print option* from the *File* menu.

For the Teacher

Demographic maps can supplement a great many lessons from social studies to mathematics. Try combining the demographic information with the climate change scenarios. The students can discuss possible hypotheses regarding impacts of climate change in the region. Math teachers can use the data to discuss different ways to classify and display large datasets. The maps that students generate in these exercises can provide a springboard for group discussions on politics, economics, land use planning, and science and public policy.

APPENDIX CLIMATE 1 Metro East Coast Climate Sites

City	State	Latitude	Longitude	Years	Mean Annual Temp (°F)	Mean Annual Precipitation (inches)
Falls Village	CT	41.95	–73.37	1916–1997	46.75	42.65
Groton	CT	41.35	–72.05	1900–1997	49.22	46.71
Stamford	CT	41.13	–73.55	1919–1997	50.14	52.83
Atlantic City	NJ	39.38	–74.43	1900–1997	54.17	39.66
Belvedere	NJ	40.83	–75.08	1900–1997	49.40	43.53
Boonton	NJ	40.90	–74.40	1900–1997	50.03	46.84
Charlotteburg	NJ	41.03	–74.43	1900–1997	48.25	50.08
Flemington	NJ	40.57	–74.88	1900–1997	50.14	46.57
Hightstown	NJ	40.27	–74.57	1900–1997	51.95	47.35
Longbranch Oakhurst	NJ	40.27	–74.00	1913–1997	51.22	46.25
New Brunswick	NJ	40.47	–74.43	1900–1997	51.43	46.92
Plainfield	NJ	40.60	–74.40	1900–1997	51.86	48.23
Tuckerton	NJ	39.60	–74.35	1900–1997	52.77	47.45
Bridgehampton	NY	40.95	–72.30	1930–1997	50.12	48.16
Glenham	NY	41.52	–73.93	1932–1997	50.92	43.68
Mohonk Lake	NY	41.77	–74.15	1900–1997	46.82	47.46
Port Jervis	NY	41.38	–74.68	1900–1997	48.50	42.72
Poughkeepsie	NY	41.63	–73.92	1900–1997	47.60	40.01
Scarsdale	NY	40.98	–73.80	1904–1997	50.55	43.30
Setauket Strong	NY	40.97	–73.10	1900–1997	51.83	44.39
Walden	NY	41.55	–74.17	1925–1997	48.58	44.03
West Point	NY	41.38	–73.97	1900–1997	50.80	48.94
Yorktown Heights	NY	41.27	–73.80	1900–1997	49.03	47.91

Note: Central Park, NYC meteorological station was omitted from the urban heat island correction done for the Metro East Coast Assessment due to poor data quality.

APPENDIX COAST 1 Sea-Level Trends in Eastern North America

Station	**RSLR (1)** *(mm/yr)*	**SEOT (2)** *(mm/yr)*	**AVER. (3)** *(mm/yr)*	**COR. SLR (4)** *(mm/yr)*
Yarmouth, N.S.	2.26	0.81	2.0	0.26
Charlottetown, PEI	2.69	0.20	1.14	1.55
Halifax, N.S.	3,52	0.13	2.83	0.69
St. John, N.B.	2.72	0.23	1.19	1.53
Eastport, ME	1.54	0.42	1.19	0.35
Bar Harbor, ME	2.21	0.27	1.19	1.02
Portland, ME	1.94	0.13	0.92	1.02
Portsmouth, NH	1.80	0.22	1.49	0.31
Boston, MA	2.68	0.15	1.49	0.31
Cape Cod Canal, MA	2.01	1.03	1.75	0.26
Wood's Hole, MA	2.47	0.18	1.75	0.72
Providence, RI	1.73	0.24	1.35	0.38
Newport, RI	2.44	0.16	1.35	1.09
New London, CT	2.10	0.21	1.35	0.75
Bridgeport, CT	**2.57**	**0.67**	**1.35**	**1.22**
New Rochelle, NY	**2.05**	**1.48**	**1.35**	**0.70**
Montauk, NY	**2.27**	**0.33**	**1.78**	**0.49**
Pt. Jefferson, NY	**2.20**	**0.56**	**1.78**	**0.42**
Willets Point, NY	**2.30**	**0.22**	**1.78**	**0.52**
New York City, NY	**2.73**	**0.07**	**2.17**	**0.56**
Sandy Hook, NJ	**3.85**	**0.21**	**1.87**	**1.98**
Atlantic City, NJ	3.97	0.15	1.87	2.10
Lewes, DE	3.09	0.7	2.35	0.74
Baltimore, MD	3.14	0.11	1.81	1.33
Annapolis, MD	3.46	0.18	1.81	1.24
Washington, DC	3.05	0.26	1.81	1.24
Solomons Is., VA	3.36	0.22	1.81	1.55
Gloucester Pt., VA	3.64	0.38	1.20	2.44
Kitopeake B., VA	3.35	0.36	1.20	2.15
Hampton Roads, VA	4.26	0.20	1.20	3.06
Portsmouth, VA	3.74	0.29	1.20	2.54
Wilmongton, NC	2.04	0.27	1.23	0.81
Charleston, SC	3.27	0.18	1.01	2.26
Savannah, GA	3.01	0.23	0.43	2.58
Fernandina, FL	1.97	0.14	0.57	1.40
Mayport, FL	2.23	0.21	0.57	1.40
Daytona Beach, FL	2.01	0.66	0.57	1.44
Miami Beach, FL	2.29	0.26	0.69	1.60
Key West, FL	2.23	0.11	0.69	1.54
Average (N=39)	2.67 ±0.70	0.32±0.53	1.41	1.26±0.73

(1) **RSLR:** raw tide-gauge data (PSMSL, 1998); (2) **SEOT:** standard error of trend; (3) **Aver.:** average trend ≤ 6000 yrs BP, C14 data (Gornitz, 1995b); (4) **COR. SLR:** corrected sea level trend, i.e., (1)–(3); (5) Because the rate of sea-level rise has decreased over the last several thousand years, a linear regression fit to the geologic data tends to overestimate the correction, thus lowering the modern sea-level trend; Gornitz, 1995a..

APPENDIX COAST 2 Tidal Data

Site	MTL-NGVD		MSL-NGVD	
	feet	*cm*	*feet*	*cm*
Battery Park	0.62	18.9	0.70	21.3
Coney Island	0.58	17.7	0.65	19.8
Rockaway Beach	0.57	17.4	0.63	19.2
Long Beach	0.53	16.2	0.58	17.7
Westhampton Beach	0.52	15.8	0.56	17.1
Montauk	0.48	14.6	0.51	15.5
Sandy Hook	0.76	23.2	0.79	24.1

Note: To convert surge or flood levels based on NGVD to MTL, subtract (MTL–NGVD) from the surge (flood) height. Similarly for NGVD to MSL.

A datum is an arbitrary elevation level used as a reference from which heights or depths are measured. A tidal datum is defined in terms of a particular phase of the tide. Commonly used datums are as follows:

MEAN HIGHER HIGH WATER (MHHW)

The arithmetic mean of the higher of two high tides in a tidal day averaged over a specific 19-year Metonic (lunar nodal) cycle (The National Tidal Datum Epoch).

MEAN HIGH WATER (MHW)

The arithmetic mean of of the high water levels taken over a specific 19-year cycle.

MEAN SEA LEVEL (MSL)

The arithmetic mean of hourly water levels measured over a specific 19-year cycle.

MEAN TIDE LEVEL (MTL)

The arithmetic mean of MHW and MLW. This value is very close to, but not identical with mean sea level.

MEAN LOW WATER (MLW)

The arithmetic mean of the low water levels over a specific 19-year cycle.

MEAN LOWER LOW WATER (MLLW)

The arithmetic mean of the lower of two low tides in a tidal day, observed over a specific 19-year cycle.

NATIONAL GEODETIC VERTICAL DATUM (NGVD)

Formerly known as the mean sea level (MSL) of 1929.

APPENDIX COAST 3 Characteristics of Study Sites

	Coney Island	Rockaway Beach	Long Beach	Westhampton Beach	Sea Bright Ocean Town	Asbury Park Manasquan
Length						
mi	2.95	6.4	7.77	4.0	11.8	9.0
km	4.75	10.3	12.5	6.4	19.0	14.5
Initial date	1994–1995	1975–1997	2002–2003	1997	1994–1998	1997–1999
Duration, yr	50	25	50	30	50	50
Renourish cycle, yr	10	3	6	3	6	6
SLR						
in/yr	0.11	0.11	0.10	0.10	0.15	0.15
mm/yr	2.73	2.73	2.58	2.45	3.85	3.85
Berm ht.[a]						
ft	13.0	10.0	10.0	9.5	10.4	10.4
m	3.96	3.05	3.05	2.9	3.17	3.17
Depth of closure[a]						
ft	–17.0	–17.0	–20.0	–22.0	–21.0	–20.0
m	–5.18	–5.18	–6.10	–6.70	–6.40	–6.10

[a] Referenced to NGVD (see Appendix Coast 2)

APPENDIX COAST 4 Projected Sea-Level Rise Scenarios and Subsidence

METRO EAST COAST REGION (cm)

Site	Decade	Current Trend	CCGG	CCGS	HCGG	HCGS	SUBS
NYC	2000	8.2	9.5	9.5	8.6	7.6	4.3
	2010	10.9	15.9	16.4	12.7	11.1	5.7
	2020	13.7	24.1	21.7	16.1	13.9	7.1
	2030	16.4	31.4	25.3	22.1	18.0	8.6
	2040	19.1	44.7	36.7	27.1	23.6	10.0
	2050	21.8	51.1	47.5	32.5	25.8	11.4
	2060	24.6	64.8	54.1	38.9	30.7	12.9
	2070	27.3	82.3	65.4	46.3	36.9	14.3
	2080	30.0	95.5	75.9	54.4	42.6	15.7
	2090	32.8	114.5	98.6	60.0	49.5	17.2
WP	2000	6.9	8.2	8.2	7.3	6.4	3.0
	2010	9.2	14.2	12.2	11.0	9.3	4.0
	2020	11.5	21.9	19.5	14.0	11.7	5.0
	2030	13.8	28.8	22.7	19.5	15.4	6.0
	2040	16.1	41.7	33.7	24.1	20.6	7.0
	2050	18.4	47.7	44.1	29.1	22.4	8.0
	2060	20.7	60.9	50.2	35.0	26.8	9.0
	2070	23.0	78.0	61.1	42.0	32.6	10.0
	2080	25.3	90.8	71.2	49.7	37.9	11.0
	2090	27.6	109.3	93.4	55.5	44.3	12.0
PJ	2000	6.6	7.9	7.9	7.0	6.1	2.7
	2010	8.8	13.8	11.8	10.6	8.9	3.6
	2020	11.0	21.4	19.0	13.5	11.2	4.5
	2030	13.2	28.2	22.1	18.9	14.8	5.4
	2040	15.4	41.0	33.0	23.4	19.9	6.3
	2050	17.6	46.9	43.3	28.3	21.6	7.2
	2060	19.8	60.0	49.3	34.1	25.9	8.1
	2070	22.0	77.0	60.1	41.0	31.6	9.0
	2080	24.2	89.9	70.1	48.6	36.8	9.9
	2090	26.4	108.1	92.2	54.3	43.1	10.8
M	2000	6.8	8.1	8.1	7.2	6.3	2.9
	2010	9.1	14.1	12.1	10.8	9.2	3.9
	2020	11.4	21.8	19.4	13.8	11.6	4.9
	2030	13.6	28.6	22.6	19.3	15.2	5.8
	2040	15.9	41.5	33.5	23.9	30.4	6.8
	2050	19.2	47.5	43.8	28.9	22.1	7.8
	2060	20.4	60.7	50.0	34.7	26.6	8.7
	2070	22.7	77.7	60.8	41.7	32.3	9.7
	2080	25.0	90.5	70.9	49.4	37.6	10.7
	2090	27.2	108.9	93.0	55.1	44.0	11.6

Site	Decade	Current Trend	CCGG	CCGS	HCGG	HCGS	SUBS
SH	2000	11.6	12.9	12.8	11.9	11.0	7.7
	2010	15.4	20.4	18.4	17.2	15.5	10.2
	2020	19.3	29.7	27.3	21.7	19.5	12.8
	2030	23.1	38.1	32.0	28.8	24.7	15.3
	2040	27.0	52.6	44.6	35.0	31.4	17.9
	2050	30.8	60.1	56.5	41.5	34.8	20.4
	2060	34.7	76.7	66.0	50.8	42.6	24.8
	2070	38.5	93.5	76.6	57.5	48.1	25.5
	2080	42.4	107.9	88.3	66.7	55.0	28.1
	2090	46.2	127.9	112.0	74.1	62.9	30.6
LB	2000	8.0	9.3	9.3	8.4	7.4	
	2010	10.6	15.7	15.6	12.4	10.8	
	2020	13.3	23.8	21.4	15.8	13.5	
	2030	16.0	31.1	25.0	21.7	17.6	
	2040	18.6	44.4	36.3	26.7	23.1	
	2050	21.4	50.8	47.1	32.0	25.2	
	2060	23.9	64.5	53.7	38.4	30.1	
	2070	26.6	82.0	65.0	45.7	36.3	
	2080	29.2	95.3	75.5	53.9	41.9	
	2090	31.0	114.3	98.3	60.0	48.8	
WH	2000	7.3	8.6	8.6	7.7	6.8	
	2010	9.7	14.7	13.6	11.5	9.9	
	2020	12.2	22.6	20.2	14.6	12.4	
	2030	14.6	29.6	23.5	20.3	16.2	
	2040	17.0	42.6	34.6	25.0	21.5	
	2050	20.1	48.8	45.1	30.2	23.4	
	2060	29.2	110.9	95.0	57.0	45.9	
	2070	24.3	79.3	62.4	43.3	33.9	
	2080	26.8	92.3	72.7	51.2	39.4	
	2090	29.2	110.9	95.0	57.0	45.9	

Note: All changes are with respect to the 1961–1990 mean.

Tide-gauge stations: **NYC** New York City (the Battery), **WP** Willets Point, **PJ** Port Jefferson, **M** Montauk, **SH** Sandy Hook. Other sites: LB Long Beach, WH Westhampton.

APPENDIX COAST 5 100-Year Flood Levels for Combined Extratropical and Tropical Cyclones

METRO EAST COAST REGION (feet; meters)

SCENARIO	LOCALITY					
	2020s					
	NYC	**CI**	**RB**	**LB**	**WH**	**SB**
Current	10.2 (3.10)	11.2 (3.4)	10.1 (3.08)	10.4 (3.17)	9.9 (3.02)	10.6 (3.23)
CCGG	10.5 (3.20)	11.5 (3.5)	10.4 (3.17)	10.8 (3.29)	10.1 (3.08)	11.0 (3.35)
CCGS	10.4 (3.17)	11.4 (3.5)	10.4 (3.17)	10.7 (3.26)	10.1 (3.08)	10.9 (3.32)
HCGG	10.2 (3.11)	11.2 (3.4)	10.2 (3.11)	10.5 (3.20)	9.9 (3.02)	10.7 (3.26)
HCGS	10.2 (3.11)	11.2 (3.4)	10.1 (3.08)	10.4 (3.17)	9.8 (2.99)	10.6 (3.23)
	2050s					
	NYC	**CI**	**RB**	**LB**	**WH**	**SB**
Current	10.4 (3.17)	11.4 (3.5)	10.4 (3.17)	10.7 (3.26)	10.1 (3.08)	11.0 (3.35)
CCGG	11.4 (3.47)	12.4 (3.8)	11.3 (3.44)	11.7 (3.57)	11.0 (3.35)	12.0 (3.66)
CCGS	11.3 (3.44)	12.3 (3.7)	11.2 (3.41)	11.6 (3.54)	10.9 (3.32)	11.9 (3.63)
HCGG	10.8 (3.29)	11.8 (3.6)	10.7 (3.26)	11.0 (3.35)	10.4 (3.17)	11.4 (3.47)
HCGS	10.6 (3.23)	11.6 (3.5)	10.5 (3.20)	10.8 (3.29)	10.2 (3.11)	11.1 (3.38)
	2080s					
	NYC	**CI**	**RB**	**LB**	**WH**	**SB**
Current	10.7 (3.26)	11.7 (3.6)	10.6 (3.23)	11.0 (3.35)	10.4 (3.17)	11.4 (3.47)
CCGG	12.8 (3.90)	13.8 (4.2)	12.8 (3.90)	13.1 (3.99)	12.4 (3.78)	13.5 (4.11)
CCGS	12.2 (3.72)	13.2 (4.0)	12.1 (3.69)	12.5 (3.81)	11.8 (3.60)	12.9 (3.93)
HCGG	11.5 (3.50)	12.5 (3.8)	11.4 (3.47)	11.8 (3.60)	11.1 (3.38)	12.2 (3.72)
HCGS	11.1 (3.38)	12.1 (3.7)	11.0 (3.35)	11.4 (3.47)	10.7 (3.26)	11.8 (3.60)

The 100-year flood level includes projected global sea level rise, local subsidence, mean high water, and combined extratropical and tropical storm surge.

NYC New York City (the Battery), **CI** Coney Island, **RB** Rockaway Beach, **LB** Long Beach, WH Westhampton Beach, **SB** Sea Bright/Asbury Park.

APPENDIX COAST 6 Shoreline Erosion

METRO EAST COAST REGION (feet/year; meters/year)

SCENARIO	LOCALITY				
			2020s		
	Coney Island	Rockaway Beach	Long Beach	Westhampton Beach	Seabright/Asbury Park
Current	1.27 (0.39)	1.69 (0.51)	1.35 (0.41)	1.53 (0.47)	1.61; 1.88 (0.49; 0.57)
CCGG	2.24 (0.68)	2.97 (0.90)	2.42 (0.74)	2.53 (0.77)	2.48; 2.89 (0.76; 0.88)
CCGS	2.02 (0.62)	2.67 (0.81)	2.18 (0.66)	2.26 (0.69)	2.28; 2.65 (0.70; 0.81)
HCGG	1.50 (0.46)	1.98 (0.60)	1.61 (0.49)	1.63 (0.50)	1.81; 2.11 (0.55; 0.64)
HCGS	1.29 (0.39)	1.71 (0.52)	1.38 (0.42)	1.39 (0.42)	1.63; 1.89 (0.50; 0.58)
			2050s		
	Coney Island	Rockaway Beach	Long Beach	Westhampton Beach	Seabright/Asbury Park
Current	2.03 (0.62)	2.68 (0.82)	2.18 (0.66)	2.44 (0.74)	2.58; 2.99 (0.79; 0.91)
CCGG	4.75 (1.45)	6.29 (1.92)	5.17 (1.58)	5.46 (1.66)	5.02; 5.84 (1.53; 1.78)
CCGS	4.42 (1.35)	5.84 (1.78)	4.80 (1.46)	5.04 (1.54)	4.72; 5.49 (1.44; 1.67)
HCGG	3.02 (0.92)	4.00 (1.22)	3.26 (0.99)	3.38 (1.03)	3.47; 4.03 (1.06; 1.23)
HCGS	2.40 (0.73)	3.17 (0.97)	2.57 (0.78)	2.62 (0.80)	2.91; 3.38 (0.89; 1.03)
			2080s		
	Coney Island	Rockaway Beach	Long Beach	Westhampton Beach	Seabright/Asbury Park
Current	2.79 (0.85)	3.69 (1.13)	2.97 (0.91)	3.36 (1.02)	3.54; 4.12 (1.08; 1.26)
CCGG	8.88 (2.71)	11.75 (3.58)	9.70 (2.96)	10.32 (3.15)	9.01; 10.48 (2.75; 3.19)
CCGS	7.06 (2.15)	9.34 (2.85)	7.69 (2.34)	8.13 (2.48)	7.38; 8.58 (2.25; 2.61)
HCGG	5.06 (1.54)	6.69 (2.04)	5.49 (1.67)	5.73 (1.75)	5.58; 6.48 (1.70; 1.97)
HCGS	3.96 (1.21)	5.24 (1.60)	4.27 (1.30)	4.41 (1.34)	4.60; 5.34 (1.40; 1.63)

APPENDIX INFRASTRUCTURE 1 Basic Elements of Probabilistic Hazard and Risk Assessment

A probabilistic hazard can be expressed in one of several forms, one of which is known as a *Hazard Curve*, expressed as P = P(h*). It typically shows, on the vertical axis, the (logarithm of) annual probability $P(h \geq h^*)$ that the hazard parameter in question (in this case storm surge height *h*) is equal to or larger than a pre-set value *h** ; and on the horizontal axis it shows (the logarithm of) h*, the hazard parameter in question, i.e. the storm surge height (in ft or m) above a reference sea level or other vertical reference datum (in our examples above NGVD = National Geodetic Vertical Datum of 1929).

For small probabilities (P<<1), or large recurrence periods T, the inverse of the annual probability P is the average recurrence period T associated with surge height h*, i.e.:

$$T(h^*) \approx 1 / P(h^*) \qquad (1)$$

If the storm surges can be assumed to be part of a Poisson process, i.e. an ensemble of independent random events, then an exact relation between probability of occurrence P, average recurrence period T, and exposure time t applies as follows:

$$P = 1 - \exp^{(-t/T)} = 1 - e^{(-t/T)} \qquad (2)$$

Equation (2) can be used to obtain the probability of occurrence P during exposure time t for a random Poisson process with average recurrence period T, with t and T measured in the same time units (years). Note that equation (2) approaches equation (1) for T>>(t=1y). Another interesting special case is P = 1 – 1/e = 0.63 (or 63%) when exposure time t and average recurrence period T are the same, i.e. t/T = 1. In many practical cases where the recurrence period T is long compared to the exposure period t of interest, we can use equation (1). But we may encounter cases during this study where the recurrence periods T become so short that exposure time t and recurrence periods T are comparable; or where exposure time t (of a structure "waiting" to be flooded) may be longer than the average recurrence period T of the flood with height h*. In that case we must use equation (2) to obtain a meaningful probability of occurrence of any single flood, which never can be larger than 100%, i.e. P is always ≤1.

ASSETS In this study the value of the infrastructure assets is generally taken to be their current replacement value. This definition limits the resulting risk only to direct losses associated with the physical damage, its repair or replacement, but not the indirect losses associated with loss of operations, revenues and secondary economic losses, which in the case of networked transportation structures can be enormous.

FRAGILITY The storm surge fragility of the transportation infrastructure is poorly or at best incompletely known because during the systems' lifetime only few of the severest events have occurred. Hence fragility is empirically constrained only for low coastal flooding levels, and only for the structures at locations with the lowest elevations. This limitation constraints much of our assessments later on to largely qualitative statements about which facilities may be flooded under what hazard conditions without being able to quantify the expected direct losses, nor the losses resulting from limited or ceased operations. Moreover, in rigorous studies one must consider network fragility that is different from system component fragility. The operational losses from a failed network are much larger then the sum of the point-losses or local damages in the network.

PUTTING IT ALL TOGETHER: RISK Risk is the area-integrated product of hazard, assets, and asset-specific fragility, given the asset-specific hazard. Once the storm surge hazard is quantified probabilistically at any given site, say by a hazard curve P(h*), one normally proceeds to quantify the risk for a given asset or facility by using the following principles: Find the probability P that is associated with a certain surge height h* at the site of a facility with the asset value A. Let us assume that we know the fragility F(h*) of the structure when subjected to the surge height h*, whereby the condition $0<F(h^*)<1$ applies. That is, the fragility is the fractional loss F=L/A. If total loss occurs, L=A and hence F=1. If no loss occurs, L=0 and hence F=0. The expected risk can be expressed as the probability P(h*) for the loss L = AF(h*) to occur. Repeating this procedure for many different surge heights h* will yield an entire Risk Curve of the form

$$P = P(L) = P(L \mid h^*) \qquad (3)$$

where $P(L \mid h^*)$ reads: the probability for an expected loss L, given a surge height h*. Risk curves show on the vertical axis the probability P (of damage L occurring), and on the horizontal axis the damage L. Ignoring for the moment that lifelines are in reality mostly networks of interacting facilities, we assume here that there is one risk curve per facility.

What are the total regional (direct) losses that can be expected from a given storm j with a given probability Pj?

In that case we need to know the surge heights h_{ij} that storm j is expected to produce at all locations i at which the assets Ai are located, each of which has a fragility $F_{ij}(h_{ij})$ producing individual asset losses L_{ij}.

The total estimated loss which storm j produces will then be T_j = Sum Of L_{ij} where the sum Sum Of is over losses L_{ij} at all asset locations i.

Repeating many different storm tracks and different storm strengths (e.g. for hurricanes as measured by the Saffir-Simpson scale), each storm being associated with a probability P_j, yields an entire array of probabilities P_j vs. total losses T_j values. Plotting the P_j vs. T_j values will give a scatter-graph of the probability of losses vs. the magnitude of losses. From this graph one can derive for any chosen probability P* a distribution of expected total losses T* for which one may choose the mean, median or any other percentile level of confidence, assuming either normal or log-normal distributions, which ever fits the "data" best. This "Risk (or Loss) Distribution Curve" can then be used to determine the "probable maximum loss" (PML) in the area at any desired exceedance probability P and for any desired level of confidence. This generalized, probabilistic definition of PML varies from that used ordinarily in deterministic risk assessments where PML simply means the largest loss amongst all scenarios considered possible, but without quantifying the rate of occurrence or annual probability, i.e. some measure of likelihood.

Another option is to "deaggregate" the risk results further into their contributing factors by, for instance, taking the Saffir-Simpson scale, SS, for hurricanes into account. In that case one would plot the probabilities P on the vertical axis over a SS—T plane to search for the combinations of SS (storm category) and T (total loss in $) that-say—exceed a certain probability level (i.e. emerge as mountainous probability islands above a threshold probability sea). Such plots may allow one to choose the probability "mode" of the data set (the most likely occurrence). Or, by rearranging the variables and plotting loss T over the SS—P plane it would allow one to search for the most expensive storms (see PML, above) and at the same time know their probability and the SS category they would be associated with. Such insights can be important for insurance portfolio decisions, emergency relief planning, mitigation cost/benefit planning, and disaster planning whether by large facility or real estate holders or by public decision-makers setting regulatory policies.

To carry out such comprehensive computations and analyses requires extensive computer programs and storm track probability input data, which the Federal Emergency Management Agency (FEMA) has commissioned to be developed for standardized loss assessments on a national scale. They do already exist as HAZUS (1999) programs for computing earthquake losses; however, the wind, flood and storm surge versions, although partly in development, will take still several years to be fully developed and released. In the interim, we must instead choose a simple heuristic approximation to obtain at least some very rough estimates for expected storm losses. The results of this approximate heuristic approach are presented in the main text of this sector report.

APPENDIX INFRASTRUCTURE 2 Storm Surge Heights

Locations at which MNYHTS (1995) provides storm surge heights (ft) for Saffir-Simpson Category 1-4 storms. Latitudes and longitudes are geocoded and approximate.

ID	Location	Area/County/State	Long	Lat	Cat 1	Cat 2	Cat 3	Cat 4
1	Amityville	Great South Bay	−73.4175	40.6789	2.5	8.7	19.7	26.8
2	Asharoken N. Shore	Suffolk	−73.3603	40.9278	5.2	9.3	13.6	18.0
3	Atlantique	Fire Island	−73.1736	40.6394	6.8	11.4	15.4	19.8
4	Battery	Manhattan	−74.0154	40.7026	10.5	16.6	23.9	28.7
5	Bayonne	NJ	−74.1147	40.6686	9.2	12.5	19.3	27.9
6	Bridgeport	Connecticut	−73.2053	41.1669	7.2	7.2	11.1	13.9
7	Center Orches	Moriches Bay	−72.7842	40.7728	5.5	9.7	13.2	19.7
8	Centre Island	Oyster Bay	−73.5208	40.9000	5.7	10.3	15.2	19.8
9	City Island	Bronx	−73.7869	40.8472	6.3	11.5	17.3	22.2
10	Cold Spring Harbor	Oyster Bay	−73.5170	40.8500	5.7	10.3	15.2	19.8
11	Davis Park	Fire Island	−73.0053	40.6839	6.5	11.3	15.9	19.6
12	East Rockaway Inlet	Kings	−73.7506	40.5914	9.0	14.8	20.0	25.2
13	East Rockaway	Hewlett Bay	−73.7506	40.5914	6.1	17.0	22.1	26.9
14	Elizabeth	NJ	−74.2111	40.6639	8.4	10.3	13.6	17.2
15	Floyd Bennett Naval Air Station	Brooklyn	−73.8996	40.6001	6.7	14.0	21.7	28.5
16	Flushing Bay	Flushing, Queens	−73.8500	40.7670	6.6	11.6	16.3	20.9
17	Fort Hamilton	Brooklyn	−74.0336	40.6186	9.3	15.2	20.9	27.0
18	Freeport, South Shore	Nassau	−73.5836	40.6575	7.7	14.9	23.2	29.4
19	Fresh Kills Landfill	Staten Island	−74.1830	40.5500	8.6	10.5	12.8	17.3
20	George Washington Bridge	NYC	−73.9500	40.8500	6.9	14.1	16.8	26.7
21	Gilgo Beach	Suffolk County	−73.3830	40.6170	8.0	13.6	17.3	23.5
22	Glen Cove	Long Is. Sound	−73.6342	40.8622	6.0	10.9	16.0	21.0
23	Goethals Bridge	Arthur Kill	−74.1737	40.6230	8.9	10.7	14.4	17.8
24	Gravesend Bay	Brooklyn	−74.0097	40.5897	9.2	15.2	20.8	27.2
25	Great Kill	Staten Island	−74.1519	40.5550	10.1	15.9	21.2	27.1
26	Greenwich Cove	CT	−73.5750	41.0175	8.4	8.4	11.1	15.1
27	Hell Gate	Wards Island	−73.9139	40.7986	7.9	11.7	14.9	18.1
28	Huguenot	Staten Island	−74.1950	40.5372	10.2	16.6	22.1	27.4
29	Island Park	Long Beach	−73.6558	40.6042	8.3	16.0	21.0	25.7
30	Jamesport	Great Peconic Bay	−72.5819	40.9494	3.8	6.8	10.2	13.8
31	Jones Beach State Park	LI	−73.5153	40.5975	8.4	13.8	19.1	24.1
32	Keansburg	NJ	−74.1303	40.4417	9.7	15.6	20.8	26.2
33	Kennedy International Airport	Queens	−73.7789	40.6398	6.6	15.6	24.5	31.2
34	Keyport Harbor	NJ	−74.1997	40.4444	10.3	16.6	22.4	27.4
35	La Gaurdia Airport	Queens	−73.8725	40.7772	6.4	11.2	15.7	20.8
36	Lawrence	Nassau Co.	−73.7170	40.6000	6.7	15.7	20.4	25.4
37	Liberty Island	NJ	−74.0456	40.6900	10.3	15.7	22.8	28.0
38	Lincoln Tunnel	NYC	−73.9953	40.7692	7.5	17.2	20.5	30.8
39	Linden	NJ	−74.2450	40.6219	9.0	10.6	14.3	17.7
40	Long Beach	Nassau Co.	−73.6664	40.5833	8.7	15.5	20.1	24.8
41	Mamaroneck Harbor	L.I. Sound	−73.7000	40.9330	6.0	11.0	15.9	21.0
42	Manhattan Bridge	NYC	−73.9935	40.7102	10.1	15.8	22.4	25.6
43	Manorhaven	Manhasset Bay	−73.7153	40.8431	6.5	11.7	17.8	22.7
44	Mattituck	North Shore	−72.5347	40.9911	4.3	7.6	11.0	14.6
45	Mecox Bay	South Shore	−72.3170	40.8830	5.7	9.9	14.0	17.9
46	Midland Beach	Staten Island	−74.0830	40.5670	9.4	15.3	20.7	26.8
47	Mill Neck Bayville	Nassau Co.	−73.5558	40.8897	5.7	10.3	15.2	19.8
48	Monmouth Beach	NJ	−73.9670	40.3170	6.2	10.2	13.8	17.4
49	Montauk Point	South Fork	−71.8578	41.0719	4.9	7.9	10.7	13.5

ID	Location	Area/County/State	Long	Lat	Cat 1	Cat 2	Cat 3	Cat 4
50	N.J. Turnpike	Kearny, NJ	–74.1458	40.7683	6.9	7.4	8.5	12.2
51	Napeague Beach	South Shore	–72.0494	40.9931	5.2	8.9	12.6	16.2
52	New Rochelle	Westchester Co.	–73.7670	40.9000	6.1	11.2	16.4	21.5
53	Newark Bay Bridge	Bayonne	–74.1189	40.6953	7.1	9.1	11.8	15.0
54	Newtown Creek	Queens/Kings	–73.9633	40.7361	9.6	14.4	21.0	23.6
55	Northport Bay	Suffolk	–73.3725	40.9217	5.4	9.8	13.7	18.1
56	Norwalk	CT	–73.4083	41.1175	7.1	7.1	10.0	13.3
57	Oakwood Beach	Staten Island	–74.1122	40.5489	9.7	15.7	21.0	27.0
58	Oceanside	Middle Bay	–73.6222	40.6469	6.1	16.7	23.0	28.3
59	Orient	North Fork	–72.3000	41.1330	4.5	7.4	10.4	13.4
60	Ossining	NY	–73.8619	41.1628	2.9	7.6	8.7	14.6
61	Palisades Park	Overpeck CR	–73.9981	40.8481	Dry	Dry	Dry	9.2
62	Passaic River	Harrison N.J.	–74.1186	40.7122	8.5	10.0	13.4	15.9
63	Patchogue	Great South Bay	–73.0000	40.7500	2.4	4.8	9.2	15.1
64	Peekskill/Indian Point	NY	–73.9170	41.2830	2.0	6.6	7.8	13.7
65	Pelham Bay	Bronx	–73.7900	40.8661	6.4	11.6	17.5	22.4
66	Perth Amboy	NJ	–74.2500	40.5000	10.8	18.7	23.8	26.9
67	Port Chester	N.Y. State Line	–73.6661	41.0017	5.8	10.6	15.6	20.5
68	Port Jefferson	North Shore	–73.0697	40.9464	5.0	9.0	13.1	17.3
69	Ridgefield Park	Hackensack R.	–74.0170	40.8500	Dry	Dry	Dry	9.9
70	Rockaway Beach	Queens	–73.8519	40.5714	9.1	14.0	20.4	26.6
71	Hempstead Harbor	Roslyn	–73.6514	40.7997	6.2	11.3	16.5	21.8
72	Sands Point	Long Island Sound	–73.7170	40.8500	6.1	11.1	16.3	21.5
73	Sandy Hook	NJ	–73.9903	40.4431	7.7	12.3	16.5	21.7
74	Sayreville	NJ	–74.3614	40.4592	8.2	11.6	17.1	27.8
75	Seagate	Coney Island	–74.0097	40.5758	9.1	15.0	20.5	26.4
76	Sheepshead Bay	Brooklyn	–73.9400	40.5819	7.8	15.1	21.0	27.4
77	Shelter Island	Gardiners Bay	–72.3333	41.0644	5.1	8.5	12.0	15.5
78	Shippan Point	CT	–73.5242	41.0278	8.1	8.1	10.6	14.9
79	Shoreham	Long Island Sound	–72.9081	40.9572	4.6	8.1	11.8	15.5
80	Smith Pt./Moriches	Great South Bay	–72.8747	40.7372	6.2	10.6	14.8	18.2
81	South Beach	Staten Island	–74.0653	40.5892	9.1	15.0	20.4	26.4
82	St. George	Staten Island	–74.0670	40.6330	10.0	16.0	22.0	26.7
83	Stapleton	Staten Island	–74.0786	40.6239	9.9	15.4	21.1	26.0
84	Stramford	CT	–73.5330	41.0500	8.0	8.0	10.2	14.4
85	Stratford	CT	–73.1336	41.1844	7.6	7.6	11.6	14.3
86	Tappan Z. Bridge	NY	–73.9000	41.0170	4.6	9.5	10.5	17.5
87	Tottenville	Staten Island	–74.2497	40.5111	10.4	20.0	23.2	26.9
88	Travis	Staten Island	–74.1883	40.5931	9.0	10.5	14.3	17.7
89	US 1 at Passiac River	Newark	–74.1728	40.7356	7.4	9.2	11.9	14.0
90	Victory Bridge	Raritan R.	–74.2919	40.5078	10.7	18.0	19.7	24.9
91	Ward Point	Staten Island	–74.2500	40.4830	10.7	17.5	23.2	27.6
92	West 96th Street	Manhattan	–73.9706	40.7940	8.2	15.0	17.7	28.1
93	West Hampton	Moriches Bay	–72.7158	40.7758	6.0	10.4	14.1	18.1
94	West Islip	Great South Bay	–73.3067	40.7061	3.2	8.4	15.9	22.6
95	WestPoint	NY	–73.9500	41.3830	6.9	6.9	10.0	13.2
96	Whitestone	Bronx	–73.8303	40.8017	6.5	11.3	16.6	22.2
97	Willets Point	Queens	–73.7670	40.7830	6.3	11.4	18.3	23.0
98	Wood Bridge	NJ	–74.2830	40.5500	10.0	12.5	19.3	21.9

APPENDIX ENERGY 1 Estimate of Future Growth in Daily Peak Electricity Demand

The results calculated with the New York Power Pool Zone Forecasting Model exhibit a nearly linear relationship between daily electricity peak and temperature for a given level of relative humidity. This makes it possible to extrapolate beyond the 101°F limit of the model to estimate future daily peaks when temperatures are expected to be higher. The scenarios of the Hadley Centre and Canadian Centre global climate models provide the basis for this extrapolation. The rise in daily peak at a given level of relative humidity increases very nearly linearly with temperature. With equal increments in relative humidity, the increase in daily peak decreases at higher humidity. At higher temperatures, these increments become smaller.

These same twenty points can be represented using multiple linear regression analysis by the equation

Peak load (mw) = 31.75*(Relative humidity %) + 271.32*(Temperature °F) – 8269.5

with a correlation coefficient of 0.99. For the same levels of relative humidity, the daily peaks are parallel and equally spaced for successive increments in relative humidity. For the purpose of extrapolating to higher temperature levels, however, they appear satisfactory, particularly in the middle range of relative humidity of 60 to 80%.

Future changes in temperature and humidity due to increased carbon dioxide in the atmosphere are represented in the results of the Hadley Centre and Canadian Centre global climate models as anomalies, i.e., differences from the temperature and humidity in the 1961–1990 time period appearing in the same model scenario. For daily peaks, it was assumed that the same differences in temperature and humidity existed with respect to the 1999 daily peak calculated by the NYPP model.

The change in peak load is calculated using only the first two terms in the equation for daily peak; the constant drops out in comparing two sets of conditions. The percent change is calculated by dividing the change in peak load by the peak load calculated with the NYPP model for the year 1999: 18,622 mw.

In the Canadian Centre GCM, the values for relative humidity are not given. Therefore they are not included in the calculation. For numerical values of temperature and relative humidity that are comparable in size, the contribution of relative humidity is about one-tenth the total calculated for the two by the regression equation. For temperatures in the 90s and relative humidity in the 60s, the contribution of relative humidity would be less. Since this is a small value, the Canadian Centre results are shown despite the absence of relative humidity in the calculation.

CALCULATION OF MAXIMUM PERCENT INCREASE IN DAILY PEAK ELECTRICITY DEMAND

	Relative humidity	Temperature	Peak load	% increase
Change in 2020s				
HCGG	0.16	1.78	19,999	7.2
HCGS	1.09	2.02	20,085	7.6
CCGG	0	5.38	20,971	12.4
CCGS	0	2.16	20,097	7.7
Change in 2050s				
HCGG	−1.13	4.14	20,599	10.4
HCGS	2.27	2.29	20,187	8.2
CCGG	0	7.02	21,416	14.8
CCGS	0	6.35	21,234	13.8
Change in 2080s				
HCGG	0.69	6.64	21,329	14.3
HCGS	2.23	4.32	20,736	11.1
CCGG	0	8.62	21,850	17.1
CCGS	0	5.27	20,941	12.2

APPENDIX DECISION-MAKING 1 Key Institutions and Organizations

COASTS AND WETLANDS

Management/Planning/Economic Development

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Land Use	Statewide planning agencies	Statewide	Provide population, economic and land use forecasts; occasional development of statewide development or growth plans; provide planning assistance to local governments.
	NJ OSP, Plan Development and Implementation Committee, State Planning Commission	NJ	NJ State Development and Redevelopment Plan (1992), under revision (expected adoption 2000).
	NYS DOS	NY	
	CT OPM, Policy Development and Planning Div.	CT	Conservation and Development Policies Plan for CT, 1998-2003.
	NYC DCP	NYC	Prepares annual capital program plans at the community board level; zoning; prepares the coastal zone management plan.
	County and Municipal Planning Agencies	CT, NJ, NY	
	Regional Plan Association (RPA)	31-county tri-state region	Produce the regional land use, economic development, and transportation plan and associated studies for the 31-county region.
Economic Development	NYC EDC	NYC	Influence state and local economic development under state statute.
	CT Dept. of Economic Development	CT	
	NJ DECD	NJ	
	NYS Department of Economic Development/Empire State Development	NY	
Coastal Zone Planning	NYS DOS Division of Coastal Resources	NY	Prepare coastal zone management plans.
	NJ OSP, NJ DCA	NJ	In addition to state agency responsibilities, the federal government is involved in The Long Island Sound Study and Plan and its Comprehensive Conservation and Management Plan (CCMP). It specifies coastal land use and environmental objectives for the protection of the waters of the Sound and encompasses Long Island Sound, the southern coast of CT, and portions of NYC bordering the Upper East River.
	CT DEP, LI Sound office, Planning & Standards Section	CT	

COASTS AND WETLANDS
Regulation Oversight

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Land Use; Environment	NYC Office of Environmental Review	NYC	Has authority over the environmental review of facilities regulated under SEQRA/CEQR, including large housing developments and infrastructure facilities.
	NYC DCP	NYC	Approves development plans for housing, commercial, and institutional structures and infrastructure under the Uniform Land Use Review Procedure (ULURP).
Coastal Zone Regulation	CT DEP, Office of Long Island Sound	CT	Responsible for issuance of permits for regulation of development in environmentally sensitive areas, such as wetlands, coastal areas and floodplains.
	NJ DEP, Environmental Protection & Energy, Land Use Mgmt. & Compliance Divisions, Land Use Regulation	NJ	CT: Coastal Management Act, Tidal Wetlands, Structures, Dredging and Fill. NJ: Waterfront Development Law, the Coastal Area Facility Review Act or the Wetlands Act of 1970, Flood Hazard Area Control Act, and the Tidelands Act.
	NYS DEC	NY	NY: Environmental Conservation Law Permits-Protection of Waters, Tidal Wetlands, State Water Quality Certification.
	USACE—NY District State environmental agencies	NY and NJ*	Directly regulates wetlands development through permits; Issues dredge and fill permits (Rivers and Harbors Act) and wetlands permits (Clean Water Act).

INFRASTRUCTURE: TRANSPORTATION
Planning (includes needs assessment)

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Transportation Planning (including Transportation Improvement Programs under Clean Air and federal transportation legislation)	CT DOT	CT	CT Master Transportation Plan (General Statutes, Sec. 13b-15). CT Transportation Improvement Program.
	Greater Bridgeport and Valley Metropolitan Planning Organization	Ansonia, Bridgeport, Derby, Easton, Fairfield, Monroe, Seymour, Shelton, Stratford, Trumbull	CT TIP for Bridgeport Region prepared in conjunction with the CT DOT, regional planning agencies and transit districts.
	NJ DOT	NJ	NJ State Transportation Improvement Program.
	North Jersey Transportation Planning Authority, Inc.	13 counties (bounded by Hunterdon, Somerset, Middlesex, Monmouth); Jersey City and Newark	Northern NJ Transportation Improvement Program.
	NYS DOT	NY	NYS Transportation Improvement Program.
	NYMTC	NYC, Putnam, Nassau, Suffolk, Westchester, Rockland	NY TIP for the downstate area.
	NYC DCP, Transportation Division	NYC	NYC DCP conducts studies and creates transportation plans.
Port and Harbor Planning	NYC EDC	NYC	Strategic Plan for the Redevelopment of the Port of NY (forecasts and investments for the port).

INFRASTRUCTURE: TRANSPORTATION

Operations and Development (as well as planning)

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Harbor	USACE, NY District	NY and NJ*	Maintains/deepens harbor ship channels through dredging; Prepares dredged material management plans.
Trains, Ports, Bridges, Airports	PANYNJ	Portions of NY and NJ	Develops, operates and maintains Port Authority bridges, tunnels, the PATH system, port facilities, ferries and airports.
Roads, Bridges	NYC DOT NYC DDC NYC OMB NYS DOT	NYC NYS	Operates and maintains city-owned roads and bridges. Construction of large facilities and design-related decisions. Value engineering reviews of capital projects; Determines City's operating budget. Operates and maintains state-owned roads and bridges.
Subways, Buses, Rail	MTA	NYS (with NYC focus, some holdings in other states, e.g., New Haven RR)	Owns, manages, operates and maintains the NYC subway system, selected rail facilities, and maintenance yards.
Buses, Rail	NJ Transit	Portions of NJ	Owns, manages, operates and maintains buses and rail in NE NJ with routes between NJ and NY.
Transportation, Water Infrastructure	NJ OSP	NJ	Infrastructure Needs Assessment: 2000-2020.

INFRASTRUCTURE: WASTEWATER TREATMENT

Planning

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Water Quality Planning	State environmental agencies; designated localities	Statewide	Water quality planning occurs at areawide and facility levels and has been ongoing at least since the federal Clean Water Act of 1972.

INFRASTRUCTURE: WASTEWATER TREATMENT

Operations and Construction

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Wastewater Treatment and Collection	NYC DEP NYC DDC, NYC OMB State and municipal agencies and authorities	Five boroughs of NYC and upstate watershed areas State and municipal watersheds	Owns, manages, operates and maintains wastewater treatment plants, sewers and associated facilities (pumps, regulators), etc. in both surface and subsurface locations, under state and federal statutes.

INFRASTRUCTURE: WASTEWATER TREATMENT

Regulation/Oversight

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Environment; Environmental facilities	NYS DEC	NYS	Regulatory authority over the design and operation (permits/compliance) for wastewater treatment facilities, air emissions, and solid and hazardous waste transport, storage and disposal facilities and for construction in waterfront, coastal and environmentally sensitive areas such as wetlands and floodplains.
	NJ DEP	NJ	
	CT DEP	CT	
	U.S. EPA—Region 2	NY and NJ*	Exercises oversight authority over the design and operation (permits/compliance) for wastewater treatment facilities, air emissions, and solid and hazardous waste transport, storage and disposal facilities; NY/NJ Harbor Estuary Project; REMAP.
	Interstate Environmental Commission (IEC)	Portions of NY, NJ, CT	Exercises oversight of sources of air and water discharges, including infrastructure.

WATER SUPPLY

Planning

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Water Resources Planning	State and local environmental agencies	NYS, NJ, CT	Plan development for the disposition of wastewater outfalls and land use development for the specification of wastewater discharge capacity; regulates wastewater treatment facility permit conditions.
	Federal, state, and local agencies	Long Island Sound NY-NJ Harbor Estuary Program	Estuary plans for estuaries under the National Estuary Program specifying sources and restrictions on pollutants into regions waterways; CCMP.

WATER SUPPLY

Operations

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Water Supply	NYC DEP NYC DDC NYC OMB	NYC, selected upstate towns	Owns, manages, operates and maintains water supplies, transmission, storage and distribution.
	Suez Lyonnaise des Eaux: United Water NY United Water NJ; PVWC, Jersey City, Newark, North Jersey District	Rockland county, NY NE NJ, portions of NYS west of Hudson	Manages, operates and maintains water systems under contract to municipalities.
	Delaware River Basin Commission (DRBC)	Delaware River Basin	Manages, operates and maintains water systems.

PUBLIC HEALTH

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Funding; Research/ Surveillance	U.S. Department of Health and Human Services (DHHS)—Region II; CDC	NYS and NJ* and national	Financial support for health programs, monitoring and assessment of health patterns and trends, mortality, morbidity statistics.
Service Provision	Hospital and health service organizations	Various	Manage and carry out health support services.
	NYC Health and Hospitals Corp. (HHC)	NYC	Manages and operates NYC hospitals.
Health Oversight	NYC DOH NYS DOH NJDOH	NYC NYS NJ	Responsible for health of populations, enforcing the public health code, overseeing water supply systems; monitoring of health condition; and related functions.

ENERGY DEMAND
Planning

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Energy Planning and Policy	CT Energy Advisory Board	CT	State Energy Policy Report.
	NJ OSP, NJ BPU, Bureau of Planning & Research	NJ	Energy Master Plan—a portion of the NJ State Development and Redevelopment Plan.
	NYS Energy Planning Board	NYS	NYS Energy Plan and Final EIS; research and development.
	NYSERDA		
	NYC EDC, Energy Division	NYC	Research and development.

ENERGY DEMAND
Operations

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change)
Electric Utilities	Con Edison	NYC	Own, manage, operate and maintain electrical production and distribution systems.
	Orange & Rockland Utilities	Orange and Rockland counties	
	NYS Electric & Gas Corp.	Westchester and Putnam (part)	
	Central Hudson Gas and Electric Co.	Parts of Putnam, Orange, Dutchess, Ulster, Greene NY	
	Rockland Electric Company	NE NJ at the NY/NJ border	
	Long Island Power Authority (LIPA)	Nassau and Suffolk counties, NY	
	NY Power Authority		
	General Public Utilities	S. NJ—Monmouth County, NJ south and NW NJ; NE NJ	
	Public Service Electric and Gas (PSE&G)	CT	
	The Connecticut Light and Power Company (subsidiary of Northeast Utilities)		
	The United Illuminating company		
	The Connecticut Municipal Energy Electric Cooperative		

ENERGY DEMAND
Regulation

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change
Rate-setting, etc.	CT DPUC	CT	Regulatory authority over distribution companies and licensing authority for suppliers; rate management functions.
	NJ BPU Energy Division	NJ	
	NYS PSC	NY	

CROSS-CUTTING RESPONSIBILITIES
Emergency Response

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change
Disaster Assistance and Analysis	FEMA, Region II	NYS and NJ*	Research and response capabilities for natural and manmade disasters; National Flood Insurance Program (NFIP)
Response	NYC OEM county offices	NYC, applicable counties	Response capabilities for natural and manmade disasters.
	NYS EMO	Statewide	
	NJ OEM	NJ	
	CT OEM	CT	

CROSS-CUTTING RESPONSIBILITIES
Finance

Function/ Authority	Key organizations	Jurisdiction in MEC region only*	Existing mandate (applicable to global climate change
Utility Rate-setting	CT DPUC	CT	Approve electric power rates.
	NJ BPU, Energy Division	NH	
	NYS PSC	NY	
	NYS EFC		Set water supply rates for City and adjacent county users, where applicable.
	Water Finance Authority		Rate bonds for city and county facilities (including infrastructure) based on economic condition and other criteria.
	NYC Water Board	NYC	
Bond Rating	Moody's	National	
	Standard & Poor	National	
Investment	Investment Banks (numerous)		Provide capital for public and private development.

Notes:

There are numerous professional organizations that provide the standards for planning, designing, operating, maintaining and constructing the built environment in the region, such as American Society for Civil Engineering (ASCE), American Society for Testing and Materials (ASTM), American Water Works Association (AWWA), American Public Works Association (APWA), Institute of Electrical and Electronics Engineers (IEEE), American Institute of Architects (AIA), Water Environment Federation (WEF), etc. In addition, while the academic institutions and consortia and public and private organizations in the region and elsewhere that can provide a research base for climate change decision-making have not been documented here, their input will be a key part of the institutional analysis.

*Some jurisdictions extend beyond the region. For example, U.S. EPA Region II's jurisdiction extends to Puerto Rico and the Virgin Islands.

Selected Abbreviations: BPU—Board of Public Utilities (NJ), CCMP-Comprehensive Conservation and Management Plan, CDC—Centers for Disease Control (U.S.), DCA—Department of Community Affairs, DCED-Department of Commerce and Economic Development (NJ), DCP—Department of City Planning (NYC), DDC—Department of Design and Construction (NYC), DEC—Department of Environmental Conservation (NYS), DECD—Department of Economic and Community Development (CT), DEP—Department of Environmental Protection (NJ), DHHS—Department of Health and Human Services (U.S.), DOH—Department of Health, DOS—Department of Sanitation/Department of State, DOT—Department of Transportation, DPUC—Department of Public Utility Control (CT), DRBC—Delaware River Basin Commission, EDC—Economic Development Corporation (NYC), EDF—Environmental Defense Fund, EFC—Environmental Facilities Corporation (NYS), EMO—Emergency Management Office, ESD—Empire State Development (NYS), FEMA—Federal Emergency Management Agency, HHC—Health and Hospitals Corporation (NYC), IEC—Interstate Environmental Commission (formerly the Interstate Sanitation Commission), MTA—Metropolitan Transportation Authority, NRDC—National Resources Defense Council, NYMTC—New York Metropolitan Transportation Council, NYSERDA—NYS Energy Research and Development Administration, OEM—Office of Emergency Management, OMB—Office of Management and Budget, OPM—Office of Policy and Management (CT), OSP—Office of State Planning (NJ), PANYNJ—Port Authority of New York and New Jersey, PSC—Public Service Commission, PVWC—Passaic Valley Water Commission, REMAP—Regional Environmental Monitoring and Assessment Program, RPA—Regional Plan Association, USACE—U.S. Army Corps of Engineers, USEPA—U.S. Environmental Protection Agency.

APPENDIX DECISION-MAKING 2 Planning Programs

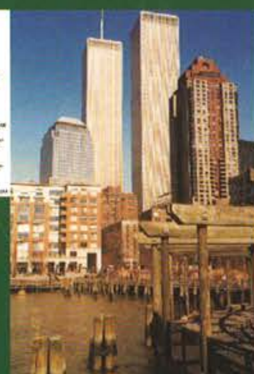
Program	Organization
Coasts and Wetlands	
Coastal Zone Management Act—CZMA Plans	NYS Department of State, NYC DCP
Statewide Comprehensive Outdoor Recreation Plans (SCORP)	State environmental and parks agencies
The New Waterfront Revitalization Program—a Proposed 197a Plan (11/99)	NYC DCP
Economic development planning	
Strategic Plan for the Redevelopment of the Port of NY (2/99)	NYC EDC
Bight Restoration Plan, as part of the National Estuary Program, NY-NJ Harbor Estuary Program, Comprehensive Conservation & Management Plan (3/96)	U.S. EPA, NYS DEC, NJDEP, Hudson River Foundation
National Economic Development (NED) Plan—Jurisdiction is the USACE "Principles and Guidelines"	U.S. Army Corps of Engineers (USACE)
NY & NJ Harbor Navigation Study (9/99); Dredged Material Management Plan for the Port of NY/NJ (9/14/98)	
Emergency Management Plans	FEMA; CT, NJ, NY emergency management offices
New Jersey State Development and Redevelopment Plan (1999 Interim Plan)	NJ OSP
Conserving Open Space in New York State 1998, State Open Space Conservation Plan.	NYS DEC & the Office of Parks, Recreation and Historic Preservation
New Jersey Common Ground—1994–1999 New Jersey Open Space and Outdoor Recreation Plan.	NJ DEP, Green Acres Bureau of Recreation and Open Space Planning
Conservation and Development Policies Plan for Connecticut, 1998–2003	CT Office of Policy and Management, Policy Development and Planning Division
Long Island Sound Study (LISS) and Plan and Comprehensive Conservation and Management Plan	CT DEP, Long Island Sound Office
Infrastructure	
NYC Solid Waste Management Plan - Enclosed Barge Unloading Facilities (EBUFs)	NYC DOS
Clean Air Act State Implementation Plan (SIP) - Transportation Element	U.S. EPA, NYS DEC, NYC DEP; similar agencies in NJ and CT
ISTEA/TEA2/NEXTEA Transportation Improvement Program	U.S. DOT, NYS DOT, NYMTC
Statewide transportation master plans	CT, NJ, NY DOTs
Five Year Capital Plan for Transit	MTA
New Jersey Infrastructure Needs Assessment 2000-2020	NJ OSP
Water Supply	
Regional and statewide plans for water supply	CT, NJ, NY environmental agencies
Energy	
NYS Energy Plan - Action Plan for Global Warming	NYSERDA; NYS Energy Planning Board
Public Health	
West Nile Virus Response Plan (5/00)	NYS DOH, NYC DOH

GLOSSARY

ACOE Army Corps of Engineers
AIA American Institute of Architects
APWA American Public Works Association
ASC American Society for Civil Engineers
ASTM American Society for Testing and Materials
AWWA American Water Works Association
BAL Bronchoalveolar lavage
BFE Base Flood Elevation
BIDS Business Improvement Districts
BMP Best Management Practice
BOC Bureau of Census
CAA Clean Air Act
CBRA Coastal Barriers Resource Act
CCCMA Canadian Centre for Climate Modeling and Analysis
CCMP Comprehensive Conservation and Management
CDC Centers for Disease Control and Prevention
CEQR City Environmental Quality Review
CIESIN Center for International Earth Science Information Systems
CNG Consolidated Natural Gas
COPD Chronic Obstructive Pulmonary Disease
CZMA Coastal Zone Management Act
CZM Coastal Zone Management
CZMP Coastal Zone Management Plan
DEC Department of Environmental Conservation
DEP Department of Environmental Protection
DEP Diesel Exhaust Particles
DHHS Department of Health and Human Services
DOH Department of Health
DOI Department of the Interior
DPH Department of Public Health
DRBC Delaware River Basin Commission
DSM Demand-Side Management
EBUFs Enclosed Barge Unloading Facilities
ECL Environmental Conservation Law
EDC Economic Development Corporation
EDF Environmental Defense Fund
EFC Environmental Facilities Corporation
EIS Environmental Impact Statement
EMO Emergency Management Office
ENR Engineering News Record
ENSO El Niño-Southern Oscillation
EPA Environmental Protection Agency
EPRI Electric Power Research Institute
ESD Empire State Development
FEMA Federal Emergency Management Agency
FERC Federal Regulatory Commission
FHWA Federal Highway Administration
GCC Global Climate Change
GCM Global Climate Model
GDP Gross Domestic Product
GHG Greenhouse gas
GIS Geographic Information System
GISS Goddard Institute for Space Studies
GNRA Gateway National Recreation Area
GRI Gas Research Institute
GRP Gross Regional Product
HAZNY HAZOS New York
HAZUS Federal Emergency Management Agency natural hazard loss estimation method
HIV Human Immunodeficiency Virus
HMGP Hazard Mitigation Grant Program
HVAC Heating, Ventilating, and Air Conditioning
IBA Important Bird Area
IEEE Institute of Electrical and Electronics Engineers
IPCC Intergovernmental Panel on Climate Change
ISC Interstate Sanitation Commission
ISTEA Intermodal Surface Transportation Efficiency Act
KWH Kilowatt-hour
LBL Lawrence Berkeley National Laboratory
LIPA Long Island Power Authority
LWRP Local Waterfront Revitalization Program
MAR Mid-Atlantic Region
MEC Metropolitan East Coast
MHW Mean High Water
MNYHTS Metro New York Hurricane Transportation Study, produced jointly by the U.S. Army Corps of Engineers, Federal Emergency Management Agency, the National Weather Service, and other state and local agencies in 1995
MPO Metropolitan Planning Organization
MTA Metropolitan Transportation Authority
NAAQS National Ambient Air Quality Standards
NAO North Atlantic Oscillation
NAS National Academy of Sciences
NCDC National Climatic Data Center
NED National Economic Development
NEMS National Energy Modeling System
NEPA ACTS National Environmental Policy Act
NEXTEA, NEXTEA2 National Economic Crossroads Transportation Efficiency Acts
NFIP National Flood Insurance Program
NGVD National Geodetic Vertical Datum
NICE National Industrial Competitiveness for Energy, Environment and Economy
NJDEP New Jersey Department of Environmental Protection
NOAA National Oceanic and Atmospheric Administration

NO_x Nitrogen oxides
NPDES National Pollutant Discharge Elimination System
NPS National Park Service
NRC National Research Council
NRDC Natural Resources Defense Council
NSPS New Source Performance Standards
NWP Nationwide Permit
NWS National Weather Service
NYC CPD New York City City Planning Department
NYC DOH New York City Department of Health
NYC New York City
NYISO New York Independent System Operator
NYMTC New York Metropolitan Transportation Council
NYSDEC New York State Department of Environmental Conservation
NYSDOS New York State Department of State
NYSDOT New York State Department of Transportation
NYSERDA New York State Energy Research and Development Authority
OEM Office of Emergency Management
PANYNJ Port Authority of New York and New Jersey
PATH TRAINS Port Authority Trans-Hudson (rapid transit trains)
PDSI Palmer Drought Severity Index
PERT Pilot Emission Reduction Trading
PET Potential Evapotransipration
PML Probable Maximum Loss
PSC Public Service Commission
PSE&G Public Service Electric and Gas
PURPA Public Utilities Regulatory Act of 1978
PVSC Passaic Valley Sewerage Commission
PVWC Passaic Valley Water Company
REEPs Residential End-Use Energy Planning System
REMAP Regional Environmental Monitoring and Assessment Program
RPA Regional Plan Association
RSA MODEL Reservoir System Analysis simulation model
RSLR Relative Sea-Level Rise
SENYIWSAC Southeastern New York Intergovernmental Water Supply Advisory Council
SEQRA State Environmental Quality Review Act
SES Socio-economic status
SIP State Implementation Plan
SLR Sea-Level Rise
SON Statement of Needs
SPDES State Pollutant Discharge Elimination System
SS Safir Simpson; the scale on which hurricane severity is measured
TIP Transportation Improvement Plan
TWS Tidal Wetlands Boundary
TWTA Tidal Wetlands Trends Analysis
ULURP Uniform Land Use Review Procedure
USACE United States Army Corps of Engineers
USHCN United States Historical Climate Network
WEF Water Environment Federation
WES Waterways Experiment Station
WIFM Waterways Implicit Flood Model
WPA Work Projects Administration
WRI World Resources Institute

Metro East Coast Contribution to the National Assessment of the Potential Consequences of Climate Variability and Change for the United States



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