Massachusetts

CLIMATE CHANGE ADAPTATION REPORT

September 2011

Submitted by the
Executive Office of Energy and Environmental Affairs
and the
Adaptation Advisory Committee

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Dear Fellow Massachusetts Citizens,

I am pleased to present to you the first Climate Change Adaptation Report for Massachusetts. The product of many months of research, discussion and analysis by a broad array of practitioners, scientists, non-governmental organizations, and federal, state and local governments, this report fulfills an important mandate of the Global Warming Solutions Act of 2008.

Developed by the Climate Change Adaptation Advisory Committee, the report provides a framework for assessing a suite of strategic, long-term solutions designed to enable our neighborhoods and natural resources to adapt to climate change at the same time that we strive to mitigate the greenhouse gas emissions that are contributing to it. Indeed, this report makes clear that climate change mitigation and adaptation are two sides of the same coin. While we do our part in reducing and stabilizing greenhouse gas emissions in our state, we must also think seriously about how Massachusetts as a state will be impacted by climate change and how to prepare for and respond to it.

The Climate Change Adaptation Report describes the process, principles, findings, and recommendations of the Advisory Committee, and presents a first step toward the identification, development, and implementation of strategies to advance Massachusetts' ability to better adapt to a changing climate. Like other coastal states, Massachusetts is faced with increasing sea level rise and storm surges, higher temperatures, and changes in precipitation over the course of this century – all of which could contribute to profound impacts on our coastal infrastructure and businesses, public health, and natural ecosystems in coming years.

Using this report as a solid jumping off point, my staff and our agencies will begin evaluating potential strategies contained in the report and work with stakeholders to prioritize them and assess feasibility of implementation. In addition, we plan to form a stakeholder group that will explore mechanisms for addressing the potential impacts of climate change (such as sea level rise) as part of EEA's Massachusetts Environmental Policy Act (MEPA) review process.

In closing, I would like to acknowledge the significant undertaking that this report represents, and extend the Administration's gratitude to Committee members and all those who participated in the various subcommittee discussions that informed this report for their time and valued input.

Regards,

Richard K. Sullivan, Jr.
Secretary

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Acknowledgements

The Executive Office of Energy and Environmental Affairs (EEA) would like to extend its gratitude to members of the Climate Change Adaptation Advisory Committee for providing their time, expertise, and vision to create this report.

This effort was able to draw on input from a large cross-section of stakeholders. We would also like to thank members of the public who provided input at various meetings and during the informational sessions held during the spring of 2009.

A special thanks to all the subcommittee chairs— Andrew Finton, Jack Buckley, Ronald Killian, Edward Kunce, Michael Celona, Ann Lowery, John Clarkeson, and Bruce Carlisle—for facilitating and gathering input from subcommittee members and coordinating meetings. We are grateful to members of each of the subcommittees who invested time and effort to provide subject-matter expertise to supplement existing data resources in each sector, assess resource vulnerabilities, and develop potential strategies to adapt to climate change.

We would also like to acknowledge Bruce Carlisle and Julia Knisel from the Office of Coastal Zone Management for their work on Part I of the report; to Ron Killian from the Massachusetts Department of Transportation (MassDOT) for his detailed reviews of drafts, and; to John O'Leary from the Department of Fish and Game (DFG) for his technical input and reviews of various chapters.

The report greatly benefited from the work of all our interns who helped with meetings, and supported various subcommittees.

Finally, EEA's team that managed the Advisory Committee process, Kathleen Baskin, Vandana Rao, and John Clarkeson and Jane Pfister, who designed this report, deserve special recognition.

Authorizing Statute

Global Warming Solutions Act of 2008

SECTION 9. Notwithstanding any general or special law to the contrary, the secretary shall convene an advisory committee to analyze strategies for adapting to the predicted impacts of climate change in the commonwealth. The advisory committee shall be chaired by the secretary, or his designee, and comprised of representatives with expertise in the following areas: transportation and built infrastructure; commercial, industrial and manufacturing activities; low income consumers; energy generation and distribution; land conservation; water supply and quality; recreation; ecosystems dynamics; coastal zone and oceans; rivers and wetlands; and local government.

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Executive Summary

Climate change is the greatest environmental challenge of this generation, with potentially profound effects on the economy, public health, water resources, infrastructure, coastal resources, energy demand, natural features, and recreation. The Commonwealth of Massachusetts is committed to doing its part to mitigate and adapt to this challenge, recognizing the necessity of engaging in adaptation planning today by taking a close look at strategies that could help the state become more resilient and ready to adapt to climate change as it occurs.

The Global Warming Solutions Act, passed by the Massachusetts Legislature and signed by Governor Deval Patrick in 2008, directed the Secretary of Energy and Environmental Affairs (EEA) to convene an advisory committee to develop a report, analyzing strategies for adapting to the predicted changes in climate. This report by the Massachusetts Climate Change Adaptation Advisory Committee is organized into two parts. Part I includes an overview of the observed and predicted changes to Massachusetts' climate and their anticipated impacts, key findings, a set of guiding principles to follow, and key adaptation strategies that cut across multiple sectors. Part II is organized into five broad areas, describing for each area the vulnerabilities to climate change and outlining adaptation strategies that could help increase resilience and preparedness.

Key Predictions and Impacts

Massachusetts' climate is already changing and will continue to do so over the course of this century—ambient temperature has increased by approximately 1°C (1.8°F) since 1970 and sea surface temperature by 1.3°C (2.3°F) between 1970 and 2002. These warming trends have been associated with other observed changes, including a rise in sea level of 22 centimeters (cms) between 1921 and 2006, more frequent days with temperatures above 32°C (90°F), reduced snowpack, and earlier snow melt and spring peak flows (Frumhoff et al., 2006, 2007; Hayhoe et al., 2006). By the end of the century, under the high emissions scenario of the Intergovernmental Panel on Climate Change (IPCC), Massachusetts is set to experience a 3° to 5°C (5° to 10°F) increase in average ambient temperature, with several more days of extreme heat during the summer months. Days with temperatures greater than 32°C (90°F) are predicted to increase from 5 to 20 days annually that Massachusetts experiences today to between 30 to 60 days annually; while up to 28 days annually are predicted to reach above 38°C (100°F), compared to up to two days annually today (Frumhoff et al., 2006, 2007). Sea surface temperatures are also predicted to increase by 4°C (8°F) (Dutil and Brander, 2003; Frumhoff et al., 2007; Nixon et al., 2004), while winter precipitation—mostly in the form of rain—is expected to increase by 12 to 30 percent. The number of snow events is predicted to decrease from five each

month to one to three each month (Hayhoe et al., 2006).

Massachusetts' vast coastline makes it particularly vulnerable to climate change. Assuming that sea level continues to increase at its current rate, because land in Massachusetts is naturally subsiding, by the end of the century, it is expected to rise by another one foot (IPCC, 2007). In addition, the magnitude of sea level rise is predicted to be compounded by thermal expansion of the oceans, the melting of ice on land (such as Greenland) and the collapse of the West Antarctic Ice Sheet. By the end of this century, under the IPCC high emissions scenario with ice melt, it has been suggested that sea level rise resulting from all these factors could reach six feet (Pfeffer et al., 2008). Since a large percentage of the state's population, development, and infrastructure is located along the coast, the impact of this change will be significant, putting the Massachusetts economy, health, natural resources, and way of life at risk.

Higher temperatures, especially the higher incidence of extreme heat days, will have a negative impact on air quality and human health. In general, impacts from climate change on human health can include respiratory illnesses, exacerbation of allergies and asthma, an increase in vector borne diseases, and degraded water quality. Floods from surges of coastal waters and high intensity precipitation events also threaten the state. If these events occur with greater intensity and frequency, as is predicted by many climate change models, the damage could be more severe and cumulative, straining local and state resources and the ability of government agencies to adequately respond.

The Scale and Scope of the Challenge

The issue of climate change, and in particular climate change adaptation, is multi-sectoral and complex. As it plays out in coming years, it will span geographical scales, with greater impacts predicted in areas along the coast and in floodplains. Climate change will also vary temporally—some of the impacts may not be felt for another 30 years or further in the future, while others are already upon us. It may also come in bursts and manifest itself as extreme weather events, with the frequency of such events predicted to increase over time. Massachusetts may experience large-scale catastrophic events, similar to Hurricane Katrina in New Orleans (2005) and the ice storm in Massachusetts (2008), or may see smaller but incremental changes that could have long-term impacts on freshwater resources, fisheries, food crops, coastal properties, and the economy.

The Costs and Risks Associated with Climate Change

While the costs of making changes and actively managing the built and natural environments to buffer the impacts of climate change may be substantial, the cost of inaction may be far higher. A sea level rise of 0.65 meters (26 inches) in Boston by 2050 could damage assets worth an estimated $463 billion (Lenton et al., 2009). Evacuation costs alone in the Northeast region resulting from sea level rise and storms during a single event could range between $2 billion and $6.5 billion (Ruth et al., 2007).

Common Strategies Across All Sectors

Several themes and climate change adaptation strategies that resonate across multiple sectors became evident during meetings of the Advisory Committee and through the development of this report. These strategies represent broad approaches that can shape and inform many climate change adaptation efforts in Massachusetts.

Some solutions to address climate change adaptation can also be considered mitigation strategies because, in addition to contributing to increased resilience and preparedness to climate change, they concurrently achieve reductions in greenhouse gas emissions that contribute to the problem.

The need to perform risk and vulnerability assessments was widely recognized across all sectors. These assessments determine levels of susceptibility and exposure to and impacts of climate change among people, physical structures and assets, natural resources and the environment, economic conditions, and other resources and interests. Areas needing thorough risk and vulnerability assessments include existing critical infrastructure and facilities, vulnerable natural habitats and ecosystems, vulnerable groups or populations, community- or region-specific hazards and threats, water supplies, businesses, homes and other structures, and social and cultural resources. Strongly connected to these assessments is the need for accurate and robust data, because better data collection leads to more accurate risk assessments and more informed decision-making.

Although the state already has data and information to initiate many of the adaptation strategies outlined in this report, more up-to-date and accurate information, models, and decision-support tools representing future climate change predictions and estimates are necessary. These include increased monitoring and observations of key climate parameters, creation or use of models and climate assessments down-scaled to be Massachusetts-specific, collection and use of high-resolution land elevation topography and near shore seafloor bathymetry, collection of improved and expanded socio-economic, epidemiological and demographic information, and development of key decision-support tools.

Once the risks and vulnerabilities are properly assessed through the use of this information, their impacts must be minimized through effective planning and management. For example, future risks and costs can be reduced for new development and redevelopment through the careful siting and inclusion of design, engineering, construction and maintenance standards that account for higher sea levels, increased temperatures, more intense coastal storms, and inland flooding. Also, sound land use decisions—guided by regulation and standards, incentives, and technical support—will help local communities adapt to and withstand climate change impacts.

Another important set of cross-cutting strategies identified during the development of this report include measures that preserve, protect, and restore natural habitats and the hydrology of watersheds. These strategies not only benefit natural resources and habitat, but can also play a critical role in protecting and increasing resilience of key infrastructure sectors, human health, and the local economy.

Finally, effective emergency response systems will be critical in preparing for climate change impacts and extreme weather events. These will especially be needed at the local level, where the first responses typically originate. Government officials and emergency response crews at all levels should assess and enhance emergency management tools and capabilities such as the State Risk Assessment Inventory, the State Comprehensive Emergency Management Plan, the State Hazard Mitigation Plan, and mapping and information systems in order to respond to climate change.

Regarding infrastructure, the most significant vulnerability of existing structures stems from the fact that they were built based on historic weather patterns, not taking into account future predicted changes to sea level, precipitation, or flooding. This puts the infrastructure at increased risk of future damage and economic costs. Therefore, having more accurate maps and surveys—such as LiDAR (Light Detection and Ranging) elevation surveys—will help update current conditions, identify vulnerable facilities, and improve predictive capability. Incorporating these changes into the repair and upgrade of existing infrastructure, as well as into the improved siting and design of future infrastructure, will help minimize the anticipated impact of climate change effects on the infrastructure network. Key strategies include bolstering infrastructure resources by increased conservation, efficiencies, reuse of resources, and timely maintenance; building system redundancies; updating land use, siting, design, and building standards to include climate change projections; using natural systems for enhanced protection; and increasing resilience of infrastructure and the built environment.

Sector-Specific Strategies

Various adaptation alternatives, opportunities, and measures are available to address vulnerabilities arising from climate change. Strategies vary by type, scale, scope, and institutional responsibility.

An analysis of natural resources and habitat identifies potential strategies to enable the four broad ecosystem types in Massachusetts—forested, aquatic, coastal, and wetland—to adapt to climate change. These include protecting ecosystems of sufficient size and across a range of environmental settings, maintaining large-scale ecosystem processes and preventing isolation, limiting ecosystem stressors, and maintaining ecosystem health and diversity. These also include using nature-based adaptation solutions, embracing adaptive management, and developing a unified vision for conservation of natural resources, which can be carried out on a collaborative basis.

Predicted impacts of climate change on human health include the potential for increased heat stress; increased respiratory and heart diseases; elevated levels of ozone and particulate matter; higher pollen counts; increased vector-borne diseases; more outbreaks of water-borne diseases; and degraded surface water quality and increased shellfish pathogens. Extreme weather events can disrupt power, sanitary and health care services, and access to safe and nutritious food, while damaging homes and property. The public and private healthcare systems can address climate change-related demands by going through a network-wide climate change needs assessment that examines enhancing regionalization efforts to address non-emergency situations, developing and increasing responsive capacity through collaboration and improved coordination, and potentially relocating vulnerable health care facilities. In addition, there is a need to improve capacity to adequately detect and treat against pests and diseases, achieve and maintain ambient air quality standards, increase outreach to and support for vulnerable populations, and improve indoor air quality.

Climate change is also expected to affect many aspects of Massachusetts' economy and all levels of government. Climate change impacts will put greater stress on governments by increasing demand for emergency and other services. Among industries expected to be affected are weather-dependent activities such as agriculture, forestry and fisheries, and other industries such as manufacturing (which includes computers, electronic equipment, fabricated metal, and machinery) and service industries, such as real estate management, tourism and recreation, and health care. Examples of impacts include increased flooding, which can affect all sectors of the economy; less winter precipitation in the form of snow, which could adversely affect recreation; and higher temperatures adversely affecting outdoor workers, agricultural


AP Photo/Michael Dwyer

output, the maple syrup industry, and fisheries populations.

Strategies to prepare and enable these industries to become more resilient to climate change include establishing redundant supply routes and sources; developing local and renewable sources of energy; examining possible changes in insurance markets that better capture future climate-related risks; assessing, and protecting facilities and cultural sites that are particularly vulnerable to flooding and sea level rise; and revising bank finance formulas to reflect risk over the duration of mortgages. Strategies for local, state, and federal governments—such as enhancing essential services, engaging in long-range local and regional planning, and developing guidelines, regulations, and standards—can help society better cope with predicted changes in climate.

Coastal resources, including residential and commercial development, ports, and infrastructure; coastal engineering for shoreline stabilization and flood protection; and coastal, estuarine, and marine habitats, resources, and ecosystem services are especially susceptible to increasing sea level rise, flooding, storm damage, and erosion. The ability to address changes in the coastal environment is reliant upon access to strong planning, management, and collaboration among various public and private entities. By incorporating climate change projections into existing strategic, management, and fiscal plans, resiliency in the face of climate change can be enhanced.

Conclusion

The time to address climate change is now. It is clear that while some climate change adaptation strategies are new, many are simply extensions or modifications of existing programs and efforts to practice good environmental stewardship, protect public health, and preserve public safety. The ability to adapt to climate change will be improved through robust science, data collection and analysis; inclusion of climate change in the criteria and evaluation of programs; application of a climate change lens to current planning efforts; examination of regulations, as needed, to take climate change into account, and; continuation of current efforts to increase resilience and decrease vulnerabilities in a wide variety of public and private assets.

Planning for and managing impacts of climate change before they occur are preferable to reactive decision-making after an impact takes place. This approach has the potential to reduce costs, minimize or prevent impacts to public health and safety, and minimize damage to crucial natural resources and built infrastructure. Both management and planning should be flexible, dynamic, and adaptive, and strategies must be continuously revisited and revised.

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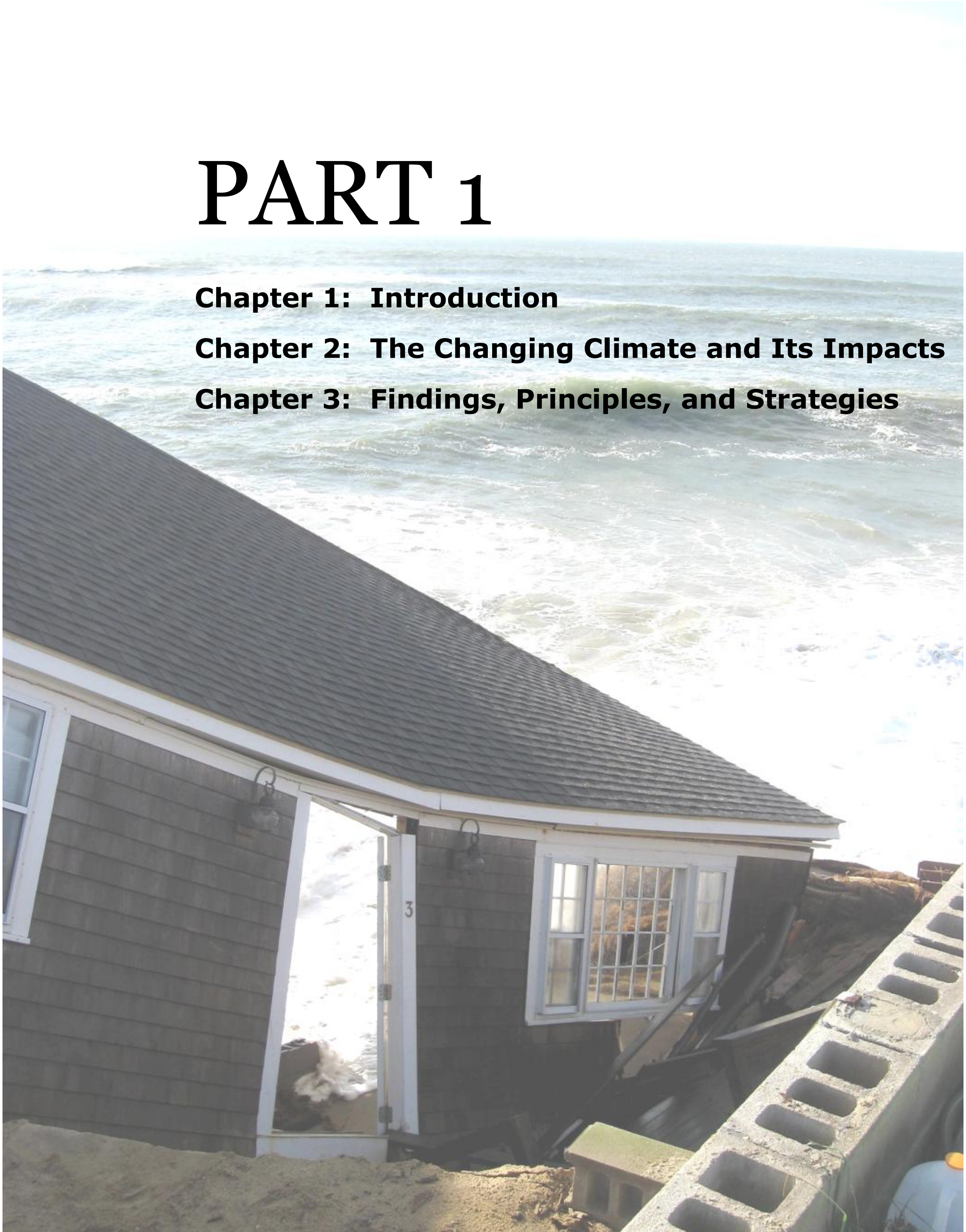
PART 1



1 Climate Change Adaptation in Massachusetts

The Commonwealth of Massachusetts is already experiencing the effects of climate change in the form of hotter summers, rising sea levels, more frequent flooding, and warmer waters — leading to a growing concern about how the impacts of these changes will affect the state's future. The "Perfect Storm" of October 1991, which was once considered a one in greater than 1,000-year event, is now a one in 200- to 500-year event (Kirshen at al., 2008). Storms such as the Hurricane of 1938, which caused widespread coastal flooding and resulted in losses such as loss of life, property, and infrastructure, are now considered one in two-year events in Massachusetts. Extensive areas of beachfront are lost to coastal erosion and some groundwater supplies near the coast are rendered undrinkable by saltwater intrusion. Every summer, 5 to 20 days now reach over 32°C (90°F), nearly double of what it was 45 years ago. This results in poor air quality and causes significant respiratory and cardiovascular health problems, especially for children and the elderly.

Over the last 40 years, fish stocks have shifted north to remain within their preferred temperature range (Nye et al., 2009). Summer heat stress reduces Massachusetts dairy milk production by 5 to 10 percent and weed problems escalate for local farmers. River and stream flooding from increased extreme rain events results in combined sewer overflows and the increased stormwater can cause outbreaks of water-borne diseases from pathogens such as Giardia and Cryptosporidium. Migratory songbirds decline as their habitat is reduced and degraded, while stands of hemlock fall prey to the woolly adelgid, an invasive insect.

Over the next several decades, temperatures are expected to continue to increase. As winters get warmer and receive less snow, Massachusetts ski areas and other winter recreation businesses will be adversely affected. By 2100, the Northeast region can expect a decrease of 10 to 20 percent in skiing days, resulting in a loss of $405 million to $810 million per year (Ruth et al., 2007). With warmer marine waters, lobster, cod, and other commercially important seafood species will become harder to find in state waters and nearby fishing grounds.

Other industries are also vulnerable to climate change. By the end of the century, the $31 million maple sugar industry is projected to lose 17 to 39 percent in annual revenue due to decreased sap flow. With increasing temperatures, electricity demand in Massachusetts could increase by 40 percent in 2030, most of which would occur in the summer months and require significant investment in peak load capacity and energy efficiency measures (Ruth et al., 2007). Also this increase in energy demand for cooling triggers the electric grid to fire up fossil-fuel powered "peaking" plants—among the most expensive of the region's energy generation portfolio to operate—resulting in the production of additional climate change-causing greenhouse gas emissions.

Taken as a whole, these impacts can have significant economic consequences to Massachusetts. Studies quantifying climate change impacts on the U.S. Gross Domestic Product (GDP) estimate that, by the year 2100, under a business-as-usual emissions scenario, damages from climate change are projected to cost up to 2.6 percent of the U.S. GDP (Ackerman et al., 2009). There are no studies that have downscaled economic impacts of climate change to the state level, but it seems logical and likely that a coastal state like Massachusetts will see significant impacts to its economy from sea level rise, precipitation shifts, and temperature changes.

At the same time, it is important to recognize that, even with these potential negative economic impacts, climate change may create new economic opportunities. From new fish stocks to longer growing seasons, new natural resource-related opportunities might emerge. With a variety of sectors that develop and deploy technologies to address water quality, sewerage and stormwater, these businesses might be able to take advantage of new markets as precipitation patterns change. With an integrated policy to reduce greenhouse gas emissions, build a clean energy economy, and gain energy independence, Massachusetts has already seized state, national, and global economic opportunities in clean energy research and development, manufacturing, delivery and services.

Recognizing these concerns and the potential opportunities, Massachusetts enacted the Global Warming Solutions Act of 2008. Along with mandating immediate action to reduce

Massachusetts' contribution to global warming, the Act established the Climate Change Adaptation Advisory Committee to investigate the potential impacts of climate change in Massachusetts and propose strategies to adapt to these impacts. This report presents the work and recommendations of the committee. This introductory chapter summarizes the Global Warming Solutions Act, describes the committee and its work, and provides an overview of the remainder of the report.

The Global Warming Solutions Act

In recognition of the scope and magnitude of the threat and opportunities posed by global climate change, Governor Deval Patrick signed the Global Warming Solutions Act on August 13, 2008. Enacted by the state Legislature under the leadership of Senate President Therese Murray, Senate Committee on Global Warming and Climate Change Chairman Marc Pacheco, and House Speaker Salvatore DiMasi, the Act affirms Massachusetts' leadership in clean energy and environmental stewardship by requiring reductions in greenhouse gas emissions from 1990 levels by between 10 and 25 percent by 2020, and by 80 percent by 2050. In December 2010, in compliance with the new law, the Secretary of Energy and Environmental Affairs set the 2020 reduction limit at 25 percent, and unveiled the *Massachusetts Clean Energy and Climate Change Plan for 2020*, which lays out a strategy to achieve that goal.

Among other components, the Global Warming Solutions Act contains a section focused on meeting the threats and challenges posed by climate change. Section 9 of the Act requires the Secretary of Energy and Environmental Affairs (EEA) to convene and chair an advisory committee "to analyze strategies for adapting to the predicted impacts of climate change in the Commonwealth". To ensure expansive and diverse input, the Act called for broad advisory committee membership, with experts from a range of sectors facing climate change impacts. The Act also required the advisory committee to submit to the Legislature a report of its findings and recommendations on strategies for adapting to climate change.

The Climate Change Adaptation Advisory Committee

In June 2009, the EEA Secretary named the Climate Change Adaptation Advisory Committee to advise the State on strategies for adapting to sea level rise, warming temperatures, increased incidence of floods and droughts, and other predicted effects of climate change. As mandated by the Act, the committee includes members representing the following sectors: transportation and built infrastructure; commercial, industrial, and manufacturing activities; low-income consumers; energy generation and distribution; land conservation; water supply and quality; recreation; ecosystem dynamics; coastal zone and ocean; rivers and wetlands; and local government. The committee also included experts in public health, insurance, forestry, agriculture, and public safety.

Five technical subcommittees provided forums for in-depth examination of specific topic areas:

- Natural Resources and Habitat
- Key Infrastructure
- Human Health and Welfare
- Local Economy and Government
- Coastal Zone and Oceans

In addition, a sixth subcommittee, under the local economy and government subcommittee focused on land use issues. The subcommittees comprised of members of the full committee, as well as additional experts and representatives. (See sector chapters for the subcommittee membership list.) In all, more than 200 individual experts, professionals, and stakeholders participated in the advisory committee process.

To develop the report, the committee followed a deliberate process to gain public input, evaluate data and information, develop recommendations, and inform the Legislature.

Public Engagement

To provide wide public input into the report development process, public comment was taken at a series of public information and input sessions. Eight public information sessions were held across the state in June and July of 2009. Presentations at these sessions provided an overview of the Global Warming Solutions Act, a review of current global trends on climate change and predicted climate change impacts in the Northeast (such as temperature change, sea level rise, and precipitation), and examples of how these impacts may affect Massachusetts. After an open forum for public input and questions-and-answers, contact information was solicited to ensure that stakeholders received updates on the committee's progress.

In addition. EEA established a website to publish information about climate change adaptation and post documents, presentations, references, and advisory committee and subcommittee meeting notices. Every meeting was open to the public and time was specifically allocated at each meeting for members of the public to speak. EEA also publicized the meetings widely via its website, email, newsletters, and The Environmental Monitor, published bi-weekly by EEA's Massachusetts Environmental Policy Act office.

Meetings

The advisory committee met three times between June and October of 2009. At the first meeting, the committee reviewed and discussed predicted climate changes in Massachusetts and approved a general course of action and timeline. The focus of the committee's second meeting was on the progress and general themes emerging from the work of the individual subcommittees and from the public information sessions. Among the common topics identified were shared data and information needs, the preliminary identification of Massachusetts' potential vulnerabilities to climate change impacts, and the recognition of the "cross-cutting" nature of many expected impacts. The six subcommittees met frequently over the summer and fall of 2009, reviewing climate change effects, discerning risks and vulnerabilities, and identifying possible strategies to reduce these threats and ensure that Massachusetts is better positioned to address and adapt to a changing climate. In October 2009, at its third meeting, each subcommittee presented the highlights of its recommendations to the whole committee. These presentations were followed by questions and deliberations, and a discussion on the final steps of the process.

Legislative Briefings

Over a two-month period between October and December of 2009, the advisory committee made presentations on its efforts and progress to the House Committee on Global Warming and Climate Change, chaired by Representative Frank Smizik. These presentations included: briefings on Climate Change Science provided by Rob Thieler of the U.S. Geological Survey and on Coastal Zone and Ocean topics by Bud Ris of the New England Aquarium; briefings on Key Infrastructure by Alexander Taft of National Grid and Ray Jack of the Town of Falmouth; on Local Economy and Government by Karen O'Reilly of AIU Holdings, Inc. and Missy Stults from ICLEI—Local Governments for Sustainability, and on Land Use by Marc Draisen of the Metropolitan Area Planning Council; and briefings on Natural Resources and Habitat by Andrew Finton of The Nature Conservancy and on Human Health and Welfare by Paul Epstein of Harvard University. The briefings were open to the public and well attended.

Overview of the Climate Change Adaptation Advisory Committee Report

This report to the Legislature presents the work and recommendations of the committee in two parts. Part I, which is comprised of three chapters, contains the over-arching conclusions and recommendations of the committee. Chapter 2 presents a summary of the observed and forecasted changes in climate parameters and the known and expected impacts in Massachusetts. Chapter 3 contains several key findings that emerged from the committee process and describes a set of principles that guided the committee process and should serve as guidelines for future development and implementation of climate change adaptation strategies. Chapter 3 also presents cross-cutting strategies, which were informed by and developed directly from the information and ideas generated by the individual sector-specific subcommittees.

Part II contains individual sector-specific chapters. These chapters contain analysis and policy suggestions for specific topics (or "sectors"): Natural Resources and Habitat, Key Infrastructure, Human Health and Welfare, Local Economy and Government, and Coastal Zone and Oceans. Each chapter provides a general overview of the sector and its general vulnerabilities, followed by a description of sub-sectors with specific vulnerabilities and impacts that could result from predicted climate change (as described in Chapter 2), and strategies to help increase resilience, decrease vulnerabilities, and better prepare the sector for a changing climate.

Each strategy is associated with one of two implementation timelines—short-term and long-term. Short-term strategies are those strategies that can be implemented over the next five years—a time frame that is considered to be a typical planning horizon. Long-term strategies are those that may take many years to implement, or would not be expected to be initiated for at least five years, such as larger infrastructure projects or strategies dependent on data collection and monitoring. In addition, no regret strategies are also identified for each sector, i.e., strategies that are easily implemented, help to make systems more resilient, and would offer substantive benefits beyond climate change adaptation.

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2 The Changing Climate and Its Impacts

It is widely accepted by the scientific community that the increased amount of emissions from anthropogenically generated greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are contributing to changing climatic conditions. Generation of these gases has increased dramatically in the last century from industrial processes, fossil fuel combustion, and changes in land use (e.g., deforestation). In its 2007 report, the Intergovernmental Panel on Climate Change (IPCC) found that the "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (IPCC, 2007).

Global climate change is already causing and will continue to result in significant local impacts.

Since the start of the Industrial Revolution, emissions of greenhouse gases from human activity have resulted in accumulation in the atmosphere, trapping more heat and enhancing the "greenhouse effect". Without the natural heat-trapping function of these gases, the earth's atmosphere would be too cold to support life. CO_2 concentrations, however, are higher today than they have ever been during human history. There is broad agreement and high confidence this increase in greenhouse gas concentrations is changing the earth's climate—not only raising average global temperatures, but more importantly, altering regional and local climatic and weather patterns (IPCC, 2007). Observed effects of climate change include increased atmospheric and ocean temperatures, heat waves, increased evapotranspiration and precipitation, and a greater intensity of storms, floods, and droughts. Thermal expansion of a warmer ocean and the melting of glaciers are contributing to a rise in sea level. These changes are expected to continue for a minimum of several decades even if greenhouse gas emissions are reduced.

This chapter summarizes the observed and forecasted changes in climate conditions and the expected impacts in Massachusetts.

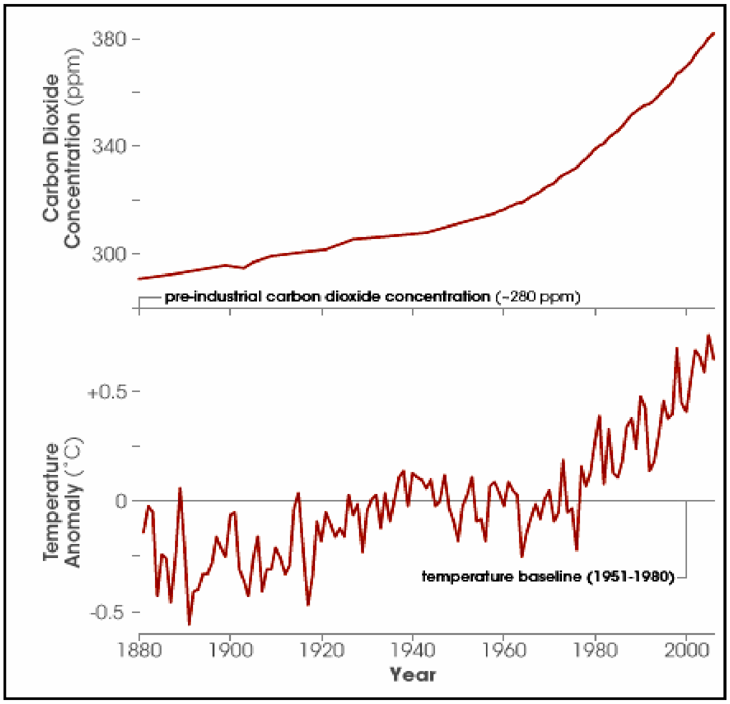


Figure 1: ***Global Temperature and CO_2 Trends***
Source: NASA graphs by Robert Simmon, based on carbon dioxide data (Dr. Pieter Tans, NOAA/ESRL) and temperature data (NASA Goddard Institute for Space Studies).

The Global Scale

Globally, CO_2 concentrations have reached 385 parts per million (ppm)—about 105 ppm greater than during pre-industrial times (see Figure 1). The increasing atmospheric CO_2 and other heat trapping greenhouse gases are causing an increase in the earth's air temperatures. Over the last 100 years, global average temperature has increased by about 0.74°C (1.3°F) (IPCC, 2007). A recent study by NOAA (2010) indicates that the summer of 2010 tied with 1998 as having the warmest global temperature on record. For the period between January–September in 2010, the global combined land and ocean surface temperature was 0.65°C (1.17°F) above the 20th century average of 14.1°C (57.5°F). Also, each year in the 2000s was hotter than average conditions in the 1990s, which, in turn, were hotter than average conditions in the 1980s. This trend could continue until the end of the century. According to climate models, global temperatures could increase by an additional 1.8° to 4°C (3.2° to 7.2°F) by the end of this century.

The ongoing debate in the scientific community is not about whether climate change will occur, but the rate at and extent to which it will occur and the adjustments needed to address its impacts. Much of the uncertainty about the predicted rate and extent of climate change results from the difficulty of projecting whether and how rapidly greenhouse gas emissions will be stabilized or reduced.

In general, relatively modest changes in temperature are predicted to have major impacts on already stressed coastal ecosystems, thus threatening biodiversity and ecosystem-based economies such as fisheries, tourism, and recreation (NOAA, 2009). The amount of water available on a global scale is projected to increase in the higher latitudes by 10 to 40 percent and decrease in already dry regions by 10 to 30 percent. Scientists predict an increase in precipitation in the form of heavy rain events, as well as vast desertification of the African continent. Sea level is projected to rise and cause increased coastal inundation, and scientists predict many low lying areas around the world—such as the Nile River Delta, the Ganges-Brahmaputra Delta, and small Pacific Ocean islands—will be submerged.

> Annual temperatures across the Northeast have warmed about 1°C (almost 2°F) since 1970.

Global warming is also likely to cause melting of the ice caps. The Arctic is expected to experience ice-free summers within a few years. Overall, the biodiversity of plants and animal species is projected to decrease—20 to 30 percent of the assessed plant and animal species in the world face an elevated risk of extinction.

Climate change is projected to impact food production and cause an increase in the number of people affected by malnutrition. There is also predicted to be an elevation in public health concerns given the expectation of a greater incidence and range of vector-borne diseases and longer disease transmission seasons.

Climate Change Predictions and Impacts in Massachusetts

Peer-reviewed scientific projections and existing data and observations were examined and compiled to help define current conditions and the range of predicted climate changes in Massachusetts. This information was used in the development and analysis of strategies to adapt to these predicted changes. Where available, Massachusetts-specific data were used for this report, but, for the most part, assessments and projected impacts developed for the northeast United States were used as a surrogate for impacts in Massachusetts.

To determine how the climate will change, the Climate Change Adaptation Advisory Committee examined current conditions—for this report, defined as the average of observed data over a 30-year period from 1961–1990, and two future time periods: i) a mid-century view which, unless indicated otherwise, is defined as an average of the

Parameter	Current Conditions (1961–1990)	Predicted Range of Change by 2050	Predicted Range of Change by 2100
Annual temperature[1] (°C/°F)	8/46	2 to 3 / 4 to 5	3 to 5/5 to 10**
Winter temperature[1] (°C/°F)	-5/23	1 to 3 / 2 to 5	2 to 5 / 4 to 10**
Summer temperature[1] (°C/°F)	20/68	2 to 3 / 4 to 5	2 to 6 / 4 to 10**
Over 90 °F (32.2 °C) temperature[2] (days/yr)	5 to 20	—	30 to 60
Over 100 °F (37.7° C) temperature[2] (days/yr)	0 to 2	—	3 to 28
Ocean pH[3,4]	7 to 8	—	-0.1 to -0.3*
Annual sea surface temperature (°C/°F)	12/53[5]	2/3 (in 2050)[5]	4/8
Annual precipitation[1]	103 cm/41 in.	5% to 8%	7% to 14%**
Winter precipitation[1]	21 cm/8 in.	6% to 16%	12% to 30%**
Summer precipitation[1]	28 cm/11 in.	-1% to –3%	-1% to 0%**
Streamflow—timing of spring peak flow[1] (number of calendar days following January 1)	85	-5 to -8	-11 to -13**
Droughts lasting 1–3 months[1] (#/30 yrs)	13	5 to 7	3 to 10**
Snow days (number of days/month)[1]	5	-2	-2 to –4**
Length of growing season[1] (days/year)	184	12 to 27	29 to 43

Table 1: ***Changes in Massachusetts' Climate***

Sources: 1-Hayhoe et al., 2006; 2-Frumhoff et al., 2007; 3-IPCC, 2007; 4-MWRA, unpublished; 5-Nixon et al., 2004

Note: All numbers have been rounded to the nearest whole number. Unless otherwise indicated, the predictions for the year listed as 2050 are for the period between 2035–2064. * *Global data;* ***Predictions for period between 2070-2099*

2035–2064 predictions, and ii) an end-of-the-century prediction (2100).

Each of the two future scenarios has a predicted range of change—the lower number is based on the lowest prediction of the low emissions scenario ("B1" scenario with CO_2 concentration of 550 ppm or above) as outlined by the IPCC (Nakicenovic et al., 2000), and the higher number is based on the highest prediction of the higher emissions scenario ("A1FI" scenario with CO_2 concentration of 970 ppm) as outlined by the IPCC (Nakicenovic et al., 2000). Table 1 provides an overview of the observed and expected changes in Massachusetts' climate over a 140-year period.

Inherent in scientific predictions of climate change is a measure of uncertainty. Due to the variety of influencing factors, it is difficult to know what the levels of future greenhouse gases emissions will be. The further the projections are made into the future, the higher the level of uncertainty associated with projected emission levels, demographics, economic development, and technological advances that could drive greenhouse gas emissions.

However, the risk to Massachusetts is clear. As a coastal state, Massachusetts is expected to experience significant impacts to its coastline due to sea level rise. All of the scenarios of partial or complete melting of ice caps in Greenland and Antarctica threaten to raise sea level and inundate the highly populated coastal areas of Massachusetts by the end of the century. Scientists also predict that, by mid-century, Massachusetts will experience longer growing seasons, more short-term droughts, and increased precipitation rates especially during the winter months (Hayhoe et al., 2006). The duration of the winter snow season could be reduced by 50 percent, with impacts on industries from skiing to water supplies.

Ambient Temperature

As with global climate change, the climate of the Northeast United States and Massachusetts has already been changing. Over the last century, annual air temperatures from Maine to New Jersey have increased. Weather station records of the United States Historical Climatology Network indicate that the Northeast has been warming at an average rate of nearly 0.26°C (0.5°F) per decade since 1970, and winter temperatures have been rising even faster at a rate of over 0.7°C (1.3°F) per decade (Frumhoff et al., 2006, 2007; Hayhoe et al., 2006). By mid-century, the projected increase is 2.1° to 2.9°C (3.8° to 5.2° F), and 2.9° to 5.3°C (5.2° to 9.5°F) by the end of the century. According to Frumhoff et al (2006), temperatures over the next few decades are projected to increase more in winter than in summer.

Extreme heat in summer is becoming more frequent.

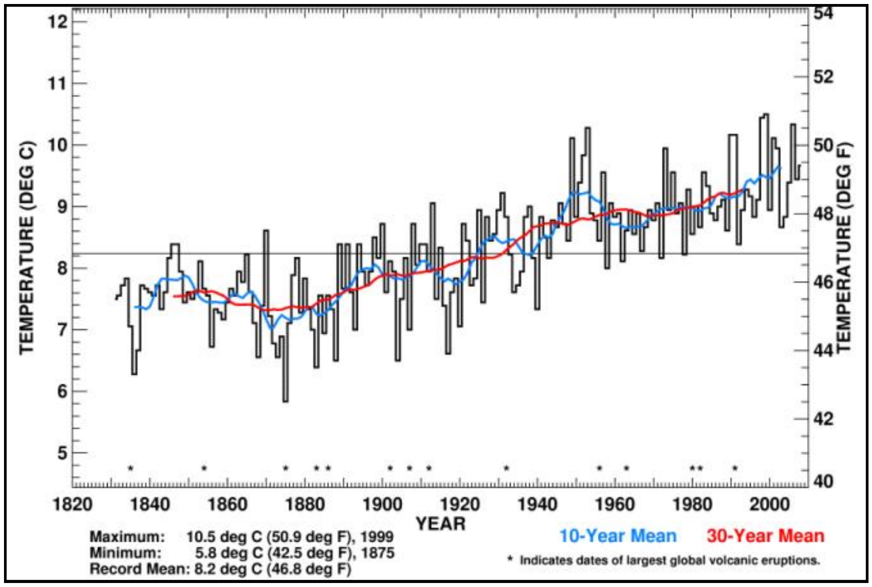


Figure 2: *Blue Hill Observatory Annual Temperature, 1831–2008*
Source: Michael J. Iacono, Atmospheric and Environmental Research, Inc./Blue Hill Observatory, MA
Note: Plot includes temperature data for 1831–1884 from Milton and Canton that were adjusted to the Blue Hill summit location.

These warming trends are associated with other observed changes including, more frequent days with temperatures above 32°C (90°F), rising sea surface temperatures and sea levels, changes in precipitation patterns and amounts, and alterations in hydrological patterns. Heat waves are expected to increase in duration each year as greenhouse gas emissions increase. By late-century, many North-eastern cities can expect 60 or more days per year over 32°C (90°F) under the higher-emissions scenario or at least 30 such days if conservation and renewable energy efforts are successful. (There are now approximately 12 such days each year.) The number of days over 38°C (100°F) in the summer of 2100 could range from 3 to 9 under the lower-emissions scenario to between 14 and 28 under the higher-emissions scenario (Frumhoff et al., 2006, 2007).

Winters are warming at 0.72°C (1.3°F) per decade since 1970.

Projected increases in temperature could result in a decline in air quality, aggravate asthma, and cause other human health effects in Massachusetts, which already has one of the highest rates of adult asthma in the United States (Massachusetts Department of Public Health—State Health Facts). Periods of extreme heat—or heat waves—are already significant health threats, especially to children, the elderly, and lower income communities. The extreme heat is most dangerous in urban areas because of a combination of large concentrations of vulnerable populations and a large extent of heat-absorbing pavement and buildings, which cause daytime and nighttime temperatures to be markedly higher than in suburban or rural areas. Heat waves are of particular concern and could have broad implications for public health, infrastructure, government capacities, plants, and crops. The state's susceptibility to these extreme heat events is high, since 36 percent of its land area is urban and more than half of the 100 most populated cities in New England are located in Massachusetts. Higher temperatures can also affect the agricultural section. While a longer growing season due to increased temperatures may support new crops and fruits, agricultural activities could experience compounded impacts due to changes in precipitation and runoff, and increasing weed and pest problems.

Sea Surface Temperature

Data collected at Woods Hole in Massachusetts show that annual mean sea surface temperature increased at a rate of 0.04°C (0.07°F) per year from 1970-2002, a total of 1.3°C (2.3°F) during that period (Nixon et al., 2004). By mid-century, sea surface temperature could increase by 1.7°C (3°F) and, by the end of this century, it could increase 2.2° to 2.8°C (4° to 5°F) under the lower emissions scenario, or 3.3° to 4.4°C (6° to 8°F) under the higher emissions scenario (Dutil and Brander, 2003; Frumhoff et al., 2007; Nixon et al., 2004).

The anticipated effects of sea temperature increases on many coastal and marine animals are not certain , but it is likely that habitat boundaries of some species may shift. Certain native populations will likely move northward toward cooler waters, and the occurrence of species that are typically found in southern latitudes is predicted to increase in Massachusetts and nearby waters. While the increased temperatures will have broad effects across estuarine and marine habitats and the ecosystem services they support, impacts to commercially important species will influence the state's fishing industry—both recreational and commercial. For example, cod require habitat with a mean annual bottom temperature below 12°C (54°F). This species will likely disappear from the waters south of Cape Cod by late-century under the higher emissions scenario (Drinkwater, 2005; Dutil and Brander, 2003; Frumhoff et al., 2007). Bottom waters of the Georges Bank fishery, one of the most productive fishing grounds in the eastern Atlantic, may also approach the maximum temperature threshold for cod, reducing recruitment and productivity, and further taxing the sustainability of the region's significant cod fishery (Frumhoff et al., 2007).

In shallower nearshore waters south of Cape Cod, lobster fisheries may be lost by mid-century. Already, declining populations of lobster south of Cape Cod are indicative of possible climate impacts. Increased surface temperatures and more high-latitude freshwater input (from precipitation and ice-melt) may disrupt large-scale circulation patterns in the western North Atlantic, leading to profound cascading effects on marine ecosystems and weather patterns.

Recent scientific literature suggests that climate warming may double the frequency of Category 4 and 5 storms by the end of century, but may decrease the frequency of less severe hurricanes (Bender et al., 2010). Although broad consensus on this issue has not been achieved, several researchers, as part of a World Meteorological Organization panel, recently agreed that there will likely be stronger, but fewer, hurricanes as a result of global warming (Knutson, 2010). Douglas and Fairbanks (2010) suggest that the magnitude of long duration storms, such as a two-day storm, may be increasing. This can have particular impact on the built infrastructure.

Sea Level Rise and Coastal Flooding

Sea-level projections for the 21st century are evolving rapidly. There are several factors that contribute to sea level rise—expansion of the water as its temperature rises, changing water currents, and melting of ice on land (such as Greenland). In Massachusetts, these factors are further amplified by local subsidence of land. Relative sea level rise in Massachusetts from 1921 to 2006 was 2.6 millimeters annually (0.10 inches/year)—an increase of approximately 26 centimeters or 10.2 inches per century (NOAA, 2009) (See Figure 3). Over that same time period, the global rate of sea level rise was about 1.7 mm/year (0.07 inches/year) (IPCC, 2007). Thus, there is about 1 mm/year (0.04 inches/

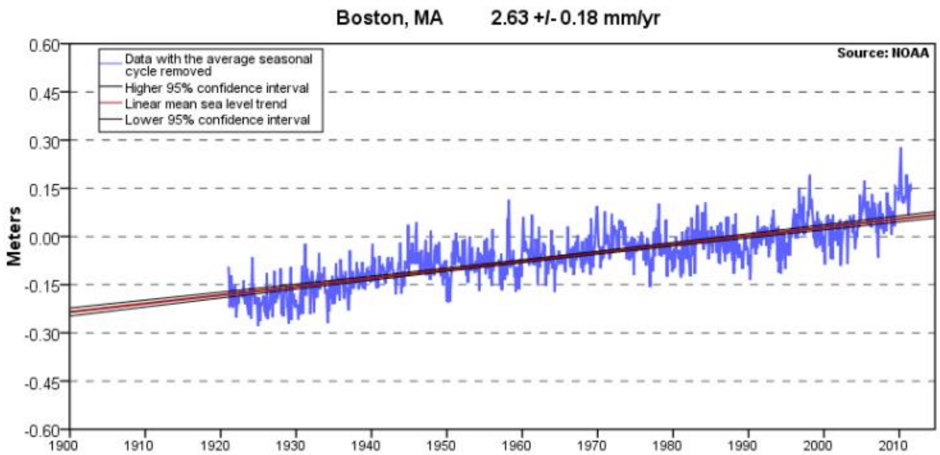


Figure 3: Mean Sea Level Trend measured at the Boston tide gauge.
Source: NOAA. http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8443970

year) local land subsidence in the relative sea level record (Bamber et al., 2009).

The Massachusetts Climate Change Adaptation Advisory Committee relied on three sources of projections for sea level rise by 2100 (Table 2 and Figure 4). First, the 2007 IPCC projections are widely viewed as conservative (Rahmstorf, 2007; Rahmstorf et al., 2007; Jevrejeva, 2008) but are highly credible and internationally recognized. Second, the Rahmstorf et al. (2007) approach uses a relationship between global mean surface temperature and sea level and then projects future changes using the IPCC Third Assessment Report (2001) temperature scenarios. Third, Pfeffer et al. (2008) use the IPCC (2007) steric projection, and add ice melt to it. Pfeffer et al. (2008) base this on physically plausible melt or deterioration rates for Greenland, Antarctica, and other glaciers and ice caps related to different rates of melting and discharge that are known from ice sheet and glacier behavior.

Sea currents also play a role in sea level rise along the Massachusetts coast. The northeastern U.S. may experience additional sea level rise above the global mean due to changes in the strength of the Atlantic Meridional Overturning Circulation, of which the Gulf Stream is a part (Yin et al., 2009; Hu et al., 2009). As the Atlantic Meridional Overturning Circulation slows, the dynamic topography of the sea surface changes and sea-level rises along the coast. Yin et al. (2009) suggest that there is the potential for an additional 15 to 27 cm (5.9 to 10.6 in.) sea level rise in Boston by 2100, while Hu et al. (2009) suggest that a sea level rise of 10 to 30 cm (3.9 to 11.8 in.) will occur in the northeastern U.S. by 2100.

Finally, Bamber et al. (2009) found that the collapse of the West Antarctic Ice Sheet would not only add to sea level rise but, as it shrinks, would also cause a redistribution of ocean mass due to the reduced gravitational attraction of the smaller West Antarctic Ice Sheet. This would be a global effect, most pronounced in a band at ~40° north latitude where the sea level rise is projected to be about 25 percent more than elsewhere around the globe. Coastal Massachusetts extends from roughly 41°10'N to 42° 53'N and would experience the full brunt of this impact. There is presently high uncertainty regarding the potential for full West Antarctic Ice Sheet collapse, but this effect also applies to a partial collapse. Overall, by 2100 sea level rise in Massachusetts could range from 29 to 201 cm.

Current rates of sea level rise and projections for accelerated trends are all significant threats to the coastal communities of the state. Sea level rise would increase the height of storm surges and associated coastal flooding frequencies, permanently inundate low-lying coastal areas, and amplify shore-

Source	Projections by 2050		Projections by 2100		
	Low Emissions	High Emissions	Low Emissions	Mid Emissions	High Emissions
Pfeffer et al 2008	—	—	78/31	83/33	201/79
Rahmstorf 2007	20/8	40/16	50/20	80/32	140/55
IPCC 2007	—	—	18/7	48/19	59/23
Current sea-level trend (A1F1 scenario)	16/6		29/11		

Table 2: *Projected Sea Level Rise (centimeters/inches)*
Note: All numbers have been rounded to the nearest whole number.

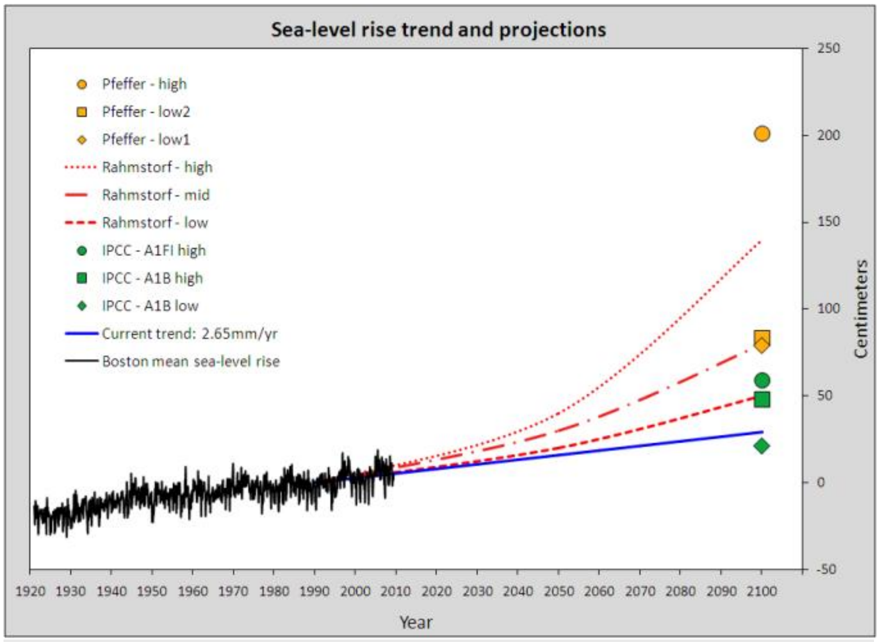


Figure 4: *Global sea level rise trend and projections*

line erosion. Extensive development and infrastructure, both public and private, would be affected in these expanding vulnerable areas. Analysis of five coastal sites in the Northeast, including Boston and Woods Hole, indicates that future sea level rise would create significant increases in the frequency of today's 100-year flood events (Kirshen et al., 2008).

Increased sea level, combined with increased erosion rates, is also predicted to threaten Massachusetts' barrier beach and dune systems. Development on the beaches themselves, as in the case of Plum Island, will continue to face challenges associated with erosion and storm damage. Barrier beaches will be more susceptible to erosion and overwash, and in some cases breaching. Such breaching will put at risk extensive areas of developed shoreline located behind these barrier spits and islands, such as the shorelines of Plymouth, Duxbury, and Kingston. Engineered structures, such as seawalls designed to stabilize shorelines, could be overtopped. Large areas of critical coastal and estuarine habitat, including the North Shore's Great Marsh—the largest continuous stretch of salt marsh in New England, extending from Cape Ann to New Hampshire—are at risk as they will be unable to adapt and migrate as sea level rises and local land subsides. The National Marine Fisheries Service estimates that 32 percent of the commercial fish and shellfish collected in New England are directly dependent on estuaries and salt marshes for various life stages, including spawning and early stage development (Stedman and Hanson, 1997). Higher sea levels will also intrude on productive aquifers situated in permeable sands and gravels, while drinking water options for more and more communities and private homeowners will become limited due to saltwater intrusion.

Precipitation

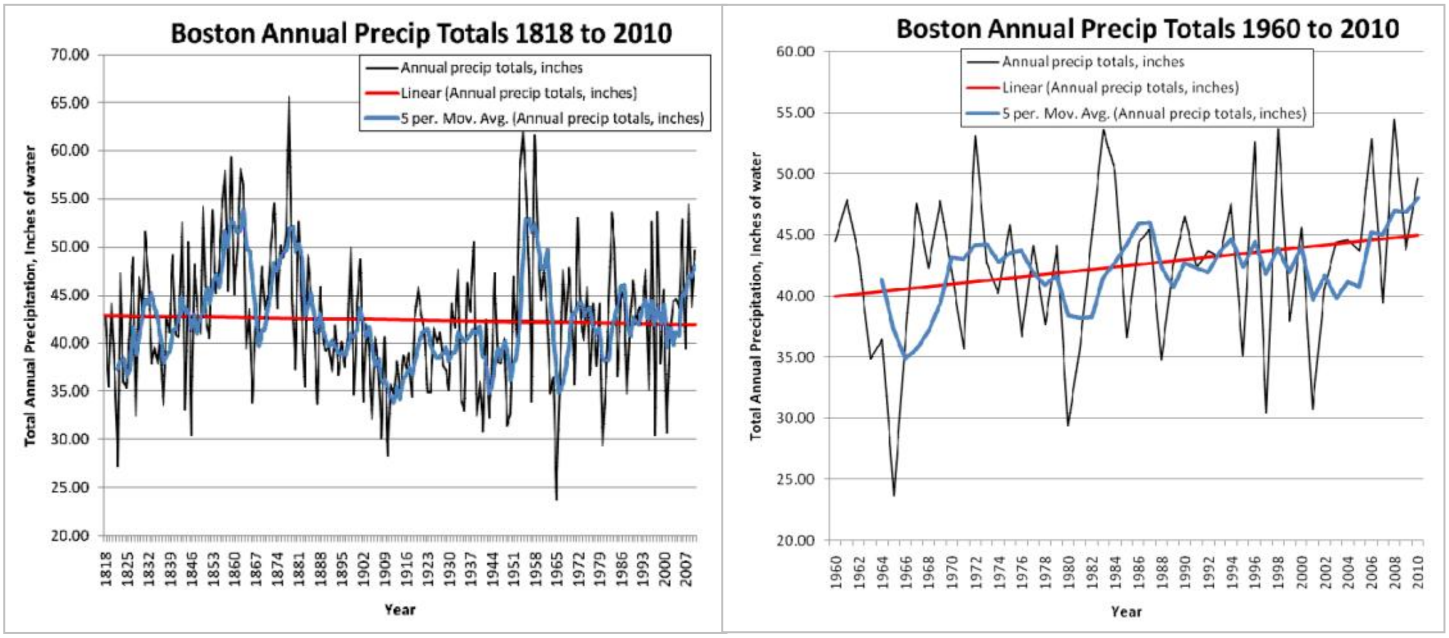
New England is expected to experience changes in the amount, frequency, and timing of precipitation. Although Massachusetts is a water-rich part of the country, the predicted changes could add pressure to the state's water resources. Since 1900, precipitation recorded at United States Historical Climatology Network weather stations across the Northeast has increased on average by 5 to 10 percent.

While precipitation data that goes back nearly 200 years (Figures 5) illustrates a slight decrease in annual precipitation. However, a more recent 50-year view shows an increase in total precipitation by approximately 10 percent (2.12 mm/year). Also, except in the Cape Cod region, the most recent 30-year normal precipitation for Massachusetts is the highest it has been since records started to be taken (Massachusetts Water Resources Commission, 2008). In the past few decades, more of this precipitation has been falling during winter as rain (Frumhoff et al., 2006, 2007; Hayhoe et al., 2006; Keim et al., 2005).There is also evidence of a strong increase in extreme precipitation (defined as the annual maximum daily precipitation depth) since the 1970s (Douglas and Fairbank, 2010) in northern coastal New England.

By the end of the century, under the high-emissions scenario, annual precipitation is expected to increase by 14 percent, with a slight decrease in the summer—a time when river flows are already low—and a 30 percent increase in the winter (Hayhoe et al., 2006). It is predicted that most of the winter precipitation will be in the form of rain rather than snow. This change in precipitation type will have significant effects on the amount of snow cover, winter recreation, spring snow melt and peak stream flows, water supply, aquifer recharge, and water quality. Large areas of the Northeast are projected to lose more than one-quarter and up to one-half of their snow-covered days toward the end of the century in the high-emissions scenario as a result of increased ambient temperature in February and March.

> March 2010 was the wettest month on record in Massachusetts with 18.8 inches of precipitation!

Massachusetts is situated in the central part of the



Figures 5: ***Annual precipitation in Boston from January 1818 to December 2010. The blue line represents a five-year moving average and the red line a least squares regression.***

Source: Data from 1818 through 1870 is from the Smithsonian Miscellaneous Collections Volume 79, (reprinted in 1944), Henry Helm Clayton, pages 815-816. Data from 1871 onwards taken from the National Weather Service. Both data sets assembled and arranged by Harlow A. Hyde, DeLand, FL, 2011; graphs provided by the Massachusetts Office of Water Resources at the Massachusetts Department of Conservation and Recreation.

region where thresholds between snow and rain are sensitive and reductions in snow would be the largest (Frumhoff et al., 2006, 2007). Snow is also predicted to fall later in the winter and cease falling earlier in spring. Observed hydrologic changes due to this include the early occurrence of spring "ice-out" on lakes (i.e., the complete thawing of surface ice) by between 9 and 16 days (Frumhoff et al., 2006, 2007; Hodgkins et al., 2002, 2003). These trends are predicted to continue at an increasing rate in future decades, and the impacts caused by these changes are predicted to become more severe (Karl et al., 2009). Furthermore, predictions indicate that the days of peak flow in the spring time—a reflection of the amount of winter snowpack and the timing of melting which currently typically occurs 84.5 days from January 1—will decrease each year by five to eight days by mid-century, and by 11 to 13 days by the end of the century (Hayhoe et al., 2006).

Winter snowpack is decreasing.

The predicted changes in the amount, frequency, and timing of precipitation, and the shift toward more rainy and icy winters would have significant implications. Damaging ice storms similar to the storm in mid-December 2008—which left over a million people in New England without power, caused widespread property and tree damage, and resulted in national emergency declarations in Massachusetts, New Hampshire, and Maine—could increase (IPCC, 2007). As winter temperatures continue to rise and snow cover declines, opportunities for winter recreation such as skiing and snowmobiling will decrease, and the associated billion-dollar industries will suffer. More winter rain is expected to drive more high-flow and flooding events during the winter, earlier peak flows in the spring, and extended low-flow periods in the summer months. These changes in hydrologic cycles would have profound impacts on water resources, including increased flooding and polluted overflows from stormwater and wastewater systems during high periods of flow, and increased stress on surface and ground drinking water sources during periods of drought and low flow. Already today, during dry periods, existing water withdrawals from groundwater aquifers in some parts of the state have caused extensive segments of rivers to go dry and because of the shortage of adequate and uncontaminated water supplies, towns like Brockton, Hull, and Swansea are looking to expensive, energy-intensive desalination solutions. Climate change threatens to exacerbate and replicate situations like these.

Altered timing and amount of streamflow due to reduced snowpack.

Floods

It is forecast that the Northeast will experience a greater frequency of high precipitation events. Past observations show that extreme precipitation events (>50 mm / 2.0 in. of rain) have increased during the period between 1949 and 2002 in eastern Massachusetts (Wake et al., 2006). In 2010, heavy spring rains (three intense rainstorms in March alone) caused flooding throughout the state. A number of rivers were at their highest flows since record keeping began (see Table 3). Scientists predict an 8 percent increase in extreme precipitation events in the northeastern U.S. by mid-century, and up to a 13 percent rise by 2100. Rainfall during the wettest five-day period each year is projected to increase by 10 percent by mid-century and by 20 percent by the end of the century (Frumhoff et al., 2006, 2007).

During the Mothers' Day floods of 2006, communities along the northeastern Massachusetts received 38.1 cm (15 in.) of rain in a 100-hour period.

By 2050, Boston could experience the current 100-year riverine flood every two to three years on average and, by 2100, the current 100-year riverine flood is expected to occur every one to two years under both the low- and high-emissions scenarios. In the case of coastal storms, the frequency and timing of winter storms or nor'easters could change. Under the low-emissions scenario, little change is predicted in the number of nor'easters striking the Northeast, but it could experience approximately 5 to 15 percent more late-winter storms under the high-emissions scenario (Frumhoff et al., 2007).

Streamflow and Drought

Changes in temperature, as well as changes in the amount, timing, and type of precipitation, affect streamflows and drought characteristics. With more winter precipitation in the form of rain and less as snow, there is likely to be more runoff during the winter and less during the spring. This phenomenon along with the increased temperatures would cause streamflow to peak earlier in the year and to be lower in the spring, which is typically when flows are highest. Changes in precipitation and runoff can have a significant impact on fisheries, agriculture, and other natural systems.

Drought is related to soil moisture, which, in turn, is related to evapotranspiration, rainfall, temperature, drainage, and climatic changes. By the end of the century, under the high emissions scenario, the occurrence of droughts lasting one to three months could go up by as much as 75% over existing conditions (Hayhoe et al., 2006). Streamflows would be lower in the summer months, especially under the high emissions scenario, as a result of higher evapotranspiration. Low flows and higher ambient air temperatures would increase water temperatures, which would affect coldwater fisheries, water-dependent industries, growth, habitat, and salmon and other anadromous fish migrations. Observations indicate that the timing of the migration of anadromous fish species, such as the Atlantic salmon and alewives, has advanced in the last few decades and they are migrating earlier in the season (Huntington et al., 2003; Juanes and Beland, 2004).

Station Name	March-April 2010 Peak Flows		Historic Peak Flow		Start of Analysis Period
	Date	Gage Height (m/ft)	Date	Gage Height (m/ft)	
Charles River at Waltham	3/15/2010	2.3 / 7.56	2/3/1976	1.99 / 6.54	1932
Indian Head River at Hanover	3/15/2010	2.23 / 7.32	3/18/1968	2.17 / 7.13	1967
Taunton River near Bridgewater	4/1/2010	4.56 / 14.97	3/20/1968	4.41 / 14.48	1930
Segreganset River near Dighton	3/15/2010	2.64 / 8.66	3/18/1968	2.34 / 7.69	1967

Table 3: ***Recent record High Spring flows in Massachusetts Rivers***
Source: U.S. Geological Survey Massachusetts-Rhode Island Water Science Center
http://pubs.usgs.gov/of/2010/1315/

Toward Adaptation

Changes in the climate can cause both subtle as well as devastating effects to humans, human infrastructure, and natural systems. An increase in temperature can cause increased virulence of viruses, insects and pests; decimation of sensitive crops and plants; increased asthma and other human health effects; and can impact the built environment. Increased intensity of precipitation can cause increased flooding, put humans and their property at risk, ruin crops, and create public health concerns from sewage and hazardous waste leaks. Also, if the timing of the precipitation changes, it could compromise water supplies and water availability for fish and various habitats. Increases in sea level rise can have severe consequences for both natural and manmade systems.

There is a clear and compelling need for actions to advance climate change adaptation in Massachusetts. Scientific consensus affirms that adaptation is necessary despite efforts to reduce greenhouse gas emissions and its impacts. The 2007 IPCC report found that:

Societies across the world have a long record of adapting and reducing their vulnerability to the impacts of weather- and climate-related events such as floods, droughts and storms. Nevertheless, additional adaptation measures will be required at regional and local levels to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades.

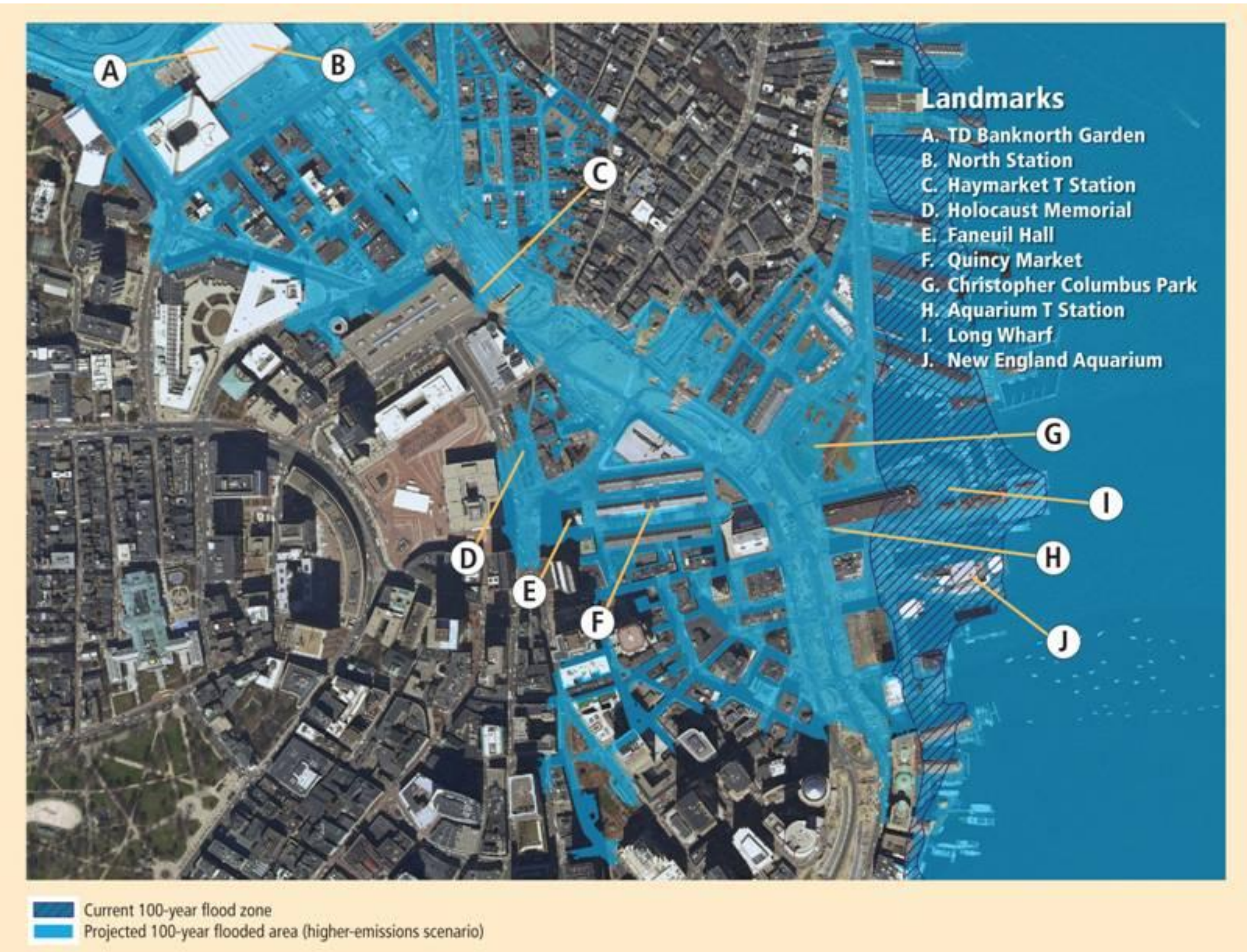


Figure 6: ***Projected Inundation of Boston Landmarks in 100 Year Flood under Higher Emissions Scenario***

Source: Kirshen et al., 2008. Coastal Flooding in the Northeastern United States due to Climate Change

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3 Findings, Principles and Strategies

Recognizing the risks posed by climate change, the Commonwealth of Massachusetts has and will continue to identify and implement measures to protect its social, economic, cultural, and natural resources. There is broad consensus that, even with ambitious global reduction of greenhouse gas emissions, some level of climate change is inevitable (IPCC, 2007). Therefore, in addition to providing strong leadership and action on mitigation, it is important for Massachusetts to continue a similar commitment on climate change adaptation.

The formation of the Climate Change Adaptation Advisory Committee by the Global Warming Solutions Act served as an important impetus and a forum for informed and broad-based dialogue on this issue. Based on the Committee's work, this chapter presents: (1) several key findings that articulate the central themes and challenges of adaptation in Massachusetts; (2) a set of principles that have guided and should continue to guide Massachusetts' approach to adapting to climate change; and (3) a series of common strategies that cut across several, if not all, sectors.

1. FINDINGS

The following findings—based on the common themes, challenges, opportunities, and needs identified through the Committee process—inform all strategies, including the cross-cutting strategies presented later in this chapter, and can continue to shape future climate change adaptation efforts in Massachusetts.

Climate Change Is Already Happening and Will Continue

Climate change is already having demonstrable effects in Massachusetts and the region. As described in Chapter 2, the Northeast has been warming at a rate of nearly 0.27°C (0.5 °F) per decade, and winter temperatures are rising at an even faster rate of 0.72°C (1.3°F) per decade (Frumhoff et al., 2007). These long-term warming trends are associated with other observed changes, including rising sea-surface temperatures and sea levels, more frequent days with temperatures above 32°C (90°F), reduced snowpack, and earlier spring snowmelt resulting in earlier peak streamflows.

While projected climate trends indicate that the situation will worsen, the range in scope and magnitude of these changes, as well as the impacts that they will cause, will be influenced by current and future levels of greenhouse gas emissions. Even with aggressive policies to reduce greenhouse gas emissions, however, efforts will be required to adapt to climate change impacts already in play due to past emissions.

Climate Change Impacts Are Wide Ranging and Affect Many Sectors of Society

From greater frequency of excessively hot days to increased flooding and habitat disruption, the impacts of climate change have broad implications. As an example, predicted sea level rise and the associated increases in flooding, erosion, and salt water intrusion into freshwater aquifers will have adverse effects on residential and commercial development, infrastructure and critical facilities, and natural resources and ecosystems. These impacts, in turn, will affect residents, landowners, private business, industry, government, and many others. Developing effective and efficient responses to climate change will require high levels of communication, coordination, collaboration, and integration across and within all levels of government, in close connection with private businesses and industries, non-governmental organizations, academic institutions, and stakeholder groups.

The Cost of Impacts Will Be High

Impacts from climate change will be very costly. Under the high emission scenario described by the Intergovernmental Panel on Climate Change (IPCC, 2007), the average annual cost of climate change impacts to the U.S. could reach 2.6 percent of the gross domestic product by 2100 (Ackerman et al., 2009). Lenton et al. (2009) estimate that a global sea level rise of 20 inches (0.5 meters) by 2050 would expose $25 trillion to $28 trillion in assets to a 100-year storm event in 136 port megacities worldwide—over $7 trillion in assets in 17 port cities in the United States alone. Boston ranks fourth among U.S. cities with the greatest predicted risk of asset exposure due to sea level rise, with predicted asset exposure from a mid-century 100-year storm event estimated to exceed $400 billion and current asset exposure to a 100-year storm estimated at $77 billion (Lenton et al., 2009). Adding to that, evacuation costs alone from sea level rise and storms in Massachusetts may range between

$2 billion and $6.5 billion, depending on the severity of the storm event (Ruth et al., 2007).

Responding to these impacts with solutions such as large-scale engineering would require significant capital investments, which would be costly to residents, businesses, and governments alike. Difficult decisions and trade-offs will potentially need to be made, therefore, about abandonment, relocation, and fortification of the state's natural and manmade systems. The construction of seawalls, which is one way to counter the effects of sea level rise (Lenton, 2009), could cost $5 to $21 million per linear mile (Union of Concerned Scientists, 2009)—and would come at the cost of other important natural processes. A physical barrier such as a sea wall can deprive beaches of necessary sediment that flows in with the tide, and many recreational beaches can be lost. Other structural solutions would also be expensive. For example, elevating a single family home by two feet could cost $22 to $62 per square foot (Union of Concerned Scientists, 2009) depending on a building's foundation type (Jones et al., 2006). Another option—managed retreat (allowing the coastline to move inland in specified locations as a response to sea level rise)—would affect property values as land and structures are subsumed by the rising sea.

The 1938 Category 3 hurricane that hit the Northeast raised high tide by 10 feet above normal, washed over most barrier beaches in the Narragansett and Buzzards Bays, killed over 600 people, and damaged property worth about $400 million in New York, Connecticut, Massachusetts and Vermont (Ashton et al., 2006). It was estimated that the same hurricane in 1998 would cost $20 billion in insured property damage. (Pielke and Landsea, 1998).

Climate change will continue to impact the future price, affordability, and availability of insurance coverage (Dailey et al., 2009). In many areas of Massachusetts—especially Cape Cod and the Southeast—home and business owners are already facing significant rate increases or denial of coverage as private insurance companies reassess their risk (and reinsurance rates) in the face of an increase in extreme weather events (causing greater risk of wind damage) and the effects of climate change (Breslau, 2007).

Given the uncertainty of future climate conditions and impacts, and the costs associated with certain alternatives to address these impacts, some strategies (or components thereof) are not presently practical or economical. Added to this scenario is the recognition that, over time, the cost of inaction may be even higher and more disastrous than the cost of implementing appropriate adaptation strategies. There is broad consensus that some viable adaptation options for certain sectors would result in lower costs or have low cost-benefit ratios and achieve significant cost savings if implemented sooner rather than later.

Even under current conditions, climate impacts are costly. Flooding of the Boston subway system in 1996 cost over $92 million in damages (Ruth et al., 2007).

Current and Accurate Information Improves Decision-Making

Effective planning and management at the regional and local levels is enhanced by current and accurate information. Although there is enough information to begin implementing many of the strategies outlined in this report, information gaps limit more focused assessments and decision-making. Also, while sector-specific information is necessary, there are certain types of data—such as the acquisition of high-resolution topography as generated by LiDAR (see Strategy #2 under cross-cutting strategies for description) technology—that could support multiple sectors concurrently. Compiling and synthesizing existing information and conducting region-specific analysis will help support the development of more specific strategies to adapt to climate change impacts. Through improvements in the science and methods of "downscaling" global climate models—and by expanding mapping, monitoring, and assessing specific parameters and ecosystem processes—more robust and precise information can be advanced to support the development of strategies targeted to changing conditions in both the built environment and natural resource areas.

Integrating Mitigation and Adaptation Strategies Provides Double Benefits

According to the IPCC (2007), "there is high confidence that neither adaptation nor mitigation alone can avoid all climate change impacts; however, they can complement each other and together can significantly reduce the risks of climate change". Massachusetts is actively striving to reduce greenhouse gas emissions and address adaptation because of its particular vulnerabilities to climate change. Massachusetts can set an example to others and do its part to minimize the degree to which climate change adaptation will be necessary in the future. Some climate adaptation strategies or responses to reduce risk and vulnerability also serve to reduce greenhouse gas emissions (and vice versa). Identifying these areas of mutual benefit was a core theme throughout the development of this report. There are also areas of potential conflict between climate change adaptation and mitigation strategies that must be reconciled. As an example, an increase in ambient air temperature can lead to an increase in the use of air conditioning to provide relief during high heat days. This in turn increases the demand for electricity, which in Massachusetts is mainly generated through the burning of natural gas and coal.

Adaptive Management and Forward-Thinking Goals Should Be Built into Current Actions

The science of climate change is constantly improving, as predictions are refined with new data, research, and modeling. Addressing the challenges posed by a changing climate can seem daunting. Incorporating climate change into existing strategic, management, and fiscal plans and building upon existing efforts can, however, readily increase adaptation capacity. The concept of "adaptive management" is particularly suited to climate change response, where planning and decisions are made within a context of incomplete and imperfect knowledge. Adaptive management seeks to reduce risk and uncertainty over time through the deliberate development of iterative and flexible approaches. It relies on monitoring and evaluation to adjust these approaches based on what has been learned.

Long-term choices about climate responses can be segmented into shorter-term, more manageable steps and decisions. By ranking and prioritizing, leveraging resources and shared goals, and enhancing communication, collaboration, and partnerships, forward-thinking climate change responses can be built into current land-use and resource management plans, financial budgets and capital investments, regulatory processes, and similar implementation mechanisms.

Actions Addressing Climate Change May Present Opportunities

The need to adapt to climate change and mitigate the emissions of greenhouse gases could create economic opportunities in Massachusetts. These could include the expansion of sectors such as clean energy, restoration and management services, the construction industry, research and development in an array of high tech sectors, and development of drought- and pest-resistant crops.

2. PRINCIPLES

Each adaptation strategy will have specific elements and considerations. However, the development and implementation of climate change adaptation strategies should be guided by the following core principles.

Broad-Based Participation

The effects of climate change will be felt throughout Massachusetts. To address these challenges effectively, engagement of a wide array of stakeholders is necessary. The development of this report was informed by the active participation of more than 200 experts, representatives, and stakeholders, as well as input from the general public. As efforts to increase Massachusetts' capacity to adapt to climate change advance, diverse and broad participation will continue to be essential.

Best Available Science & Technology

Significant progress has occurred over the past decades in the scientific understanding of the earth's changing climate, its causes, and its impacts. The science and models that inform the understanding of global and regional climate change issues are evolving rapidly. Recognizing the value of this work, the options and strategies being considered in Massachusetts to adapt to climate change impacts should be grounded in the most current and established science and technology.

Strong Leadership

In order to prioritize and implement adaptation strategies, strong leadership will be necessary at the local, state, and federal levels. A national leader on clean energy, climate and environmental issues, Massachusetts is poised to be a pacesetter on climate change adaptation.

Coordination of Efforts

Climate change impacts occur across a range of issue areas. Consequently, developing effective and efficient responses will require strong coordinated efforts among various entities with different mandates and interests— from the private sector, to the state and federal agencies, cities and towns, non-government organizations, and academic institutions. In moving forward, current partnerships should be fostered and new ones developed.

Assisting Vulnerable Populations

Vulnerable populations are broadly defined as those who are more susceptible to the effects of climate change, and for whom adaptive change will be more difficult. Whether by virtue of economic status, social capacity and resources, health, age, or geography, adaptation efforts should be mindful of, and include, planning to meet the unique needs and conditions of people who are most vulnerable, protecting them during sudden extreme events, and helping them adapt to health issues, energy costs, and other chronic impacts.

Cost-Effective and Risk-Based Approaches

With the potential for large impacts from climate change, the current and future benefits and costs of various adaptation alternatives deserve careful consideration. There is explicit recognition that, given the uncertainty of future climate conditions, costs of impacts, and the costs associated with alternative responses, there may be particular strategies (or components thereof) that are not presently practical or economical. Investments of resources need to be made strategically, focusing on: climate-related impacts and their relative risks, timing of occurrence, and uncertainties as well as costs and cost-effectiveness of responses. Priority should be given to strategies that have clear, robust, and long-term benefits and significance, including those that,

- address known risks and vulnerabilities;
- support large portions of the public over special interests;
- promote public health, safety, security, and well-being;
- protect particularly vulnerable populations or those with unequal access to resources;
- build upon current programs and successes;
- protect critical habitats and key ecosystem services; and
- provide economic growth potential.

3. CROSS-CUTTING STRATEGIES

The technical subcommittees of the Climate Change Adaptation Advisory Committee—which were organized by general issue areas or "sectors"—made significant progress in their review of climate change impacts, general risks and vulnerabilities, and possible strategies. As is evidenced by the wide-ranging assembly of strategies for each sector in Part II of this report, there are numerous options and prospective pathways for improving capacity in Massachusetts to adapt to climate change. The following set of recommended strategies was informed by and developed directly from the information and ideas contained in the individual sector-specific chapters. These cross-cutting strategies emerged as common themes in several, if not all, sectors and were discussed extensively at the subcommittee and the advisory committee meetings. Guided by the principles and informed by the findings presented earlier in this chapter, these strategies represent a synthesis to direct and inform climate change adaptation efforts in Massachusetts.

Strategy #1 — Combine Mitigation and Adaptation Strategies

The committee discussed the connection between the state working to reduce its share of greenhouse gas emissions as part of a global effort, and the influence that will have on reductions in climate change impacts. The Committee found many strategies that would have the dual benefit of helping a sector adapt to a changing climate while also helping to reduce or mitigate greenhouse gas emissions. One such strategy is the acquisition or conservation of large forest blocks that would minimize stressors, and provide ecosystem resilience, while also serving as a carbon sink.

Another strategy is deploying measures such as the implementation of Smart Growth, including "low impact development" (LID) and Leadership in Energy and Environmental Design (LEED) building methods. LID and LEED techniques reduce the environmental and energy footprint of conventional residential and commercial buildings and provide for better site-design. With less energy, water resource, and material demands for both construction and operation, harmful emissions can be reduced. These strategies will reduce operation and maintenance costs over time, while conserving natural habitats, providing for better localized water recharge, and minimizing anthropogenic stress on ecosystems. Other examples of specific strategies that address both climate change adaptation and mitigation are reductions in allergens and asthmogens from decreased emissions, using tree plantings to reduce heat island effect and reduce heating and cooling costs, and increasing adaptive building techniques, such as white roofs, to reduce cooling requirements (and therefore emissions).

Strategy #2 — Identify and Fill Critical Information Gaps

Effective adaptation efforts require up-to-date and accurate information, models, and decision-support tools. Addressing the key knowledge and technological gaps to identify and predict vulnerability of both the built environment and natural resource areas is a high priority. Much of the information and products currently used for land-use and infrastructure planning, lending and investment decisions, and resource management reflect climate conditions from the last several decades and do not accurately reflect current risks of inundation, temperature change, and other climate-related impacts. Therefore, assessing future risk and developing strategies for adaptation poses significant challenges. Through improvements in the science and methods of "downscaling" global climate models so that they reflect Massachusetts-specific conditions—and by expanding mapping, monitoring, and assessments of specific parameters and ecosystem processes—more robust and specific information can be advanced to support the development of strategies targeted to changing conditions.

The use of monitoring and modeling—including expansion, acceleration, and leveraging of existing efforts—is essential in following climate trends and simulating climate change scenarios. Other types of monitoring and models will be needed to address vulnerabilities of inland and coastal wetland resource areas; cultural, archaeological, and historic resources at risk; important infrastructure; and water quality and quantity. For all kinds of monitoring, it is important to have consistent methods, frequent sampling and long study durations since many climate-related phenomena are inherently variable and more data points over longer periods will provide a higher degree of confidence in discerning the effects of climate change. Consideration should also be given to providing a single entity or clearinghouse to better support, integrate, standardize, and disseminate these resources within each sector, or across multiple sectors.

A common strategy among all sectors was to collect or update information to better predict impacts from storm-related flooding and sea level rise, such as:

- LiDAR (Light Detection and Ranging) — LiDAR is an airborne laser sensor technology for collecting extremely accurate elevation data. It can be used to help predict the impact of flooding and sea level rise on estuarine marshes and to identify neighborhoods, businesses, and infrastructure at risk from coastal storms and sea level rise.

- Floodplain mapping — Maps of areas that have a 1 percent chance of flooding during a given year (i.e., the 100-year flood) should be updated. Massachusetts' regional equations used for estimating floods of various frequencies, which are derived from available U.S. Geological Survey streamgage data and basin characteristics, have not been updated in over 35 years and do not reflect current conditions (rainfall patterns and impervious surfaces)—much less what would likely occur given future climate change. These shortcomings are illustrated by the fact that many flood damaged areas lie outside the mapped areas at risk of a 100-year flood. In fact, according to the Federal Emergency Management Agency (FEMA), as many as 30 percent of flood damage claims lie outside these areas. It is recommended that various funding sources be pursued vigorously and more flexible and relevant formats for floodplain mapping be discussed with FEMA. Updating the flood maps to reflect current conditions is a first step toward developing maps that can also incorporate predictions of future conditions.
- Rainfall Intensity — It is recommended that the "design storms" (i.e., what qualifies as a 100-year storm or a 50-year storm) for Massachusetts be updated to reflect current conditions and those precipitation conditions predicted for the future. Transportation and environmental agencies and many local planning boards rely on the precipitation return frequencies derived by the National Weather Service in 1961, 1964, and 1977. Precipitation return frequencies are used in designing stormwater controls to attenuate the peak rate of runoff from land development and in sizing culverts. Local culverts are likely undersized, which can potentially cause culvert failure and damage due to flooding. This could get worse over time as rainfall intensity increases with climate change.

Strategy #3 — Advance Risk and Vulnerability Assessments

Risk and vulnerability assessments are used to determine the susceptibility and exposure of groups or communities of people, physical structures and assets, natural resources and the environment, economic conditions, and other resources and interests to changing climate conditions and associated impacts. These assessments can be conducted for various purposes, at different scales, for a range of subjects, and with a range of techniques. While the areas of interest and approaches may vary, these assessments all share the primary goal of quantifying and qualifying levels of risk and vulnerability.

This report provides an initial outline of some of the risks and vulnerabilities for general sectors. These overviews of vulnerability are useful starting points, but in some cases, more complete and detailed assessments are required to generate the necessary materials, information, and tools to support the development, prioritization, and implementation of targeted and robust—yet flexible—climate change adaptation plans and strategies.

Risk and vulnerability assessments can be conducted within the context of the uncertainties and complexities posed by climate change, and through the employment of scenarios, assignment of probabilities, and ranking of impacts. The utility of these assessment outputs, however, is greatly influenced by the quality and accuracy of the information available to drive the analysis. This recommendation is thus closely tied to the previous one. By identifying and filling critical information gaps, the process and products of risk and vulnerability assessments will be enhanced, and lead to better and more cost-effective adaptation plans, actions, and decisions.

Given limited available resources, undertaking a systematic, comprehensive risk and vulnerability assessment for each component of every sector examined in the report is not practical. Consequently, strategic choices must be made to determine the vulnerability assessments to be conducted. As derived from the sector chapters, thorough risk and vulnerability assessments are needed for the following:

- Existing critical infrastructure, including energy generation, transmission, and distribution; communication networks; drinking and wastewater facilities; roads and highways; railways and subways; shipping, transportation, and cruise terminals; ferry and water transportation terminals and facilities; dams, levees, flood barriers, jetties, and breakwaters; and health care facilities
- Economic sectors, including agriculture and aquaculture, fishing, health care and life sciences, technology, financial services, manufacturing, education, government, and tourism
- Vulnerable groups or populations, including economically disadvantaged communities; densely-populated areas (i.e., urban areas); the elderly, infirmed, and young; and non-English speaking or English-as-second language groups
- Natural habitats and ecosystems, including forested, freshwater aquatic, coastal, and marine ecosystems
- Community-specific analyses, including local hazards and threats; critical local facilities; local public and private water supplies; businesses; homes and the built environment; cultural and historical sites; and crucial local natural resources

Strategy #4 — Evaluate and Prioritize Adaptation Strategies for Implementation

Challenging decisions lie ahead regarding the options and alternatives for reducing risk to public infrastructure, private property, and human safety and welfare as a result of climate change. As evidenced from the collection of strategies identified in the individual sector chapters, a broad range of adaptation alternatives, opportunities, and measures exist for the vulnerabilities considered. The strategies vary by type, including monitoring and assessments, policies and regulations, and technical assistance and education; scale, including region, state, community, and neighborhood; scope, including specific economic sectors, elements of the built environment, various aspects of public health and safety, and ecosystem components and processes; and responsibilities, including government agencies, private business and industry, non-government organizations, academic institutions, and individual homeowners.

Given this array of options, there is a strong need to prioritize specific adaptation responses determined to be the most effective and efficient. Evaluation and prioritization of adaptation alternatives should consider many factors including, but not limited to, the probability and magnitude of potential impacts, the vulnerability of the groups or individuals affected, the range and feasibility of alternatives available, broad-based stakeholder input, and the opportunity to build upon current programs and successes. Careful consideration is warranted for examining the current and future benefits and costs—including capital and recurring, primary and secondary—of different adaptation alternatives.

While strategic prioritization is required, there are a number of approaches which—in light of established trends of certain climate conditions, the high probability of risk, and the potential for significant impact and adverse consequences—are clearly priority candidates for implementation. One example is the early implementation of adaptation strategies that could be encouraged through incentives and incorporated into existing programs. These are termed as “no regrets” strategies—strategies that are beneficial regardless of climate change that should be encouraged where cost-effective. Innovative efforts, such as the state’s StormSmart Coasts Program’s work to provide coastal communities with expertise in planning for storms, floods, sea level rise, and climate change, can be improved and expanded along the coast and inland before climate change impacts are fully realized.

Strategy #5 — Support Local Communities

Many of the State’s communities are already grappling with flooding, pollution, erosion, repeated storm damage, heat impacts, and other problems likely to be exacerbated by climate change. As a home-rule state, many of the land-use decisions in Massachusetts are made by cities and towns. Managers of key assets such as water supply infrastructure or local public safety resources may not have the technical capacity or the resources to plan for climate change. Consequently, to be successful, adaptation strategies must be connected with and directly support vulnerable communities. Addressing some of these challenges at the local level will require assistance—both, technical and financial—from state and federal governments, regional planning agencies, professional trade organizations, and non-profit partners. This assistance can help to ensure that revised operating procedures, best practices for analyzing risk, guidance for implementing adaptation measures, and updated design standards for new facilities are readily accessible to local government and businesses.

Communities can also learn from one another, as some already have experiences with climate change adaptation strategies to share. Adaptation support must also extend to key businesses and industries such as local employers and vital, but vulnerable, trades such as fishing and agriculture. Building upon current programs that have demonstrated successes and efficiencies, such as the Massachusetts Office of Coastal Zone Management's StormSmart Coasts Program (see Chapter 8 for more details) and the ICLEI (International Council for Local Environmental Initiatives)—Local Government for Sustainability network, will be important. In addition to technical and planning support, financial assistance to aid communities in their efforts to implement sound climate change adaptation strategies will be critical.

ICLEI—Local Government for Sustainability

Since the early 1990s, ICLEI has led an international member network to advance climate protection and sustainability. Member communities bring experience, leadership, and the ability to create solutions to a global problem while advancing measures at the local level. The ICLEI network includes 38 Massachusetts communities who represent coastal regions from Boston Harbor and Nantucket to areas inland, such as Amherst and Pittsfield, and communities in between. This expanding network of local governments from across the state can share successes and challenges and create resilient communities together with the larger ICLEI network.

Strategy #6 — Improve Planning and Land Use Practices

With increasing climate change impacts, particularly those related to coastal and riverine flooding, society will be faced with difficult decisions regarding risk to public infrastructure, private property, natural resources, and human safety and welfare. Criteria, priorities, and policies are needed to help better inform where protection of infrastructure and other investments are necessary. In order to help fortify existing structures and minimize and prevent exposure, sound land use decisions should be promoted through technical support to local communities on consistent and effective land-use standards and guidelines, model bylaws, and state permitting processes. (See Chapter 7 for more details on land use and planning.) The Department of Fish and Game's BioMap2, provides a proactive decision support tool to inform both conservation of resilient ecosystems and areas better suited for development.

Strategy #7 — Enhance Emergency Preparedness

Hazard mitigation, evacuation, and emergency response plans should be evaluated and updated to reflect changing climate conditions and new development. In general, emergency preparedness resources have evolved in response to past emergencies and storm events. The scope, magnitude, and frequency of historic emergencies have served as the basis for the design and development of the existing emergency preparedness infrastructure. As storms become more frequent and intense and sea level rises, new and increased levels of exposure may arise, and many areas that previously escaped storm impacts will likely be vulnerable.

Managers should assess and enhance emergency management tools and capabilities in order to respond to the predicted increased frequency and intensity of extreme weather events. These tools include the State Risk Assessment Inventory, the State Comprehensive Emergency Management Plan, the State Hazard Mitigation Plan, mapping and information systems, and other emergency management tools. (See Chapter 7 for more details.)

Strategy #8 — Encourage Ecosystem-Based Adaptation

Natural ecosystems provide resilience and reduce the vulnerability of the natural and built environments. Protecting resilient ecosystems also increases their ability to thrive, and strengthens the services they support. Using natural habitats as "green" infrastructure can help impede and potentially eliminate the risk posed by some climate change impacts while supporting crucial biota, enhancing quality of life, and serving as a carbon sink.

Strategy #9 — Continue to Seek Expert Advice and Stakeholder Input

Continued efforts should also be made to ensure broad-based expert and stakeholder input. Means to engage representatives, stakeholders, and the general public should include enhanced communication efforts, formal and informal public hearings, issue-based meetings with broad partners and interests, enhanced state agency presence in local communities, and advisory groups convened for deliberation on specific research topics and policy change proposals.

Strategy #10 — Ensure Agency and Regional Coordination

There is a need for strong communication, coordination, and integration across various state agencies. Massachusetts should explore options for policy and implementation coordination across executive agencies, state and local authorities.

Climate change adaptation also needs to be addressed nationally and regionally in the Northeast. Collaboration on adaptation within and across state and federal boundaries is essential to ensure coordinated data collection and modeling activities, thereby reducing costs and minimizing duplication. Collaboration is also essential to performing multi-state assessments, planning for shared natural and infrastructure resources, and to allowing climate adaptation planners to learn and build from each other's successes and challenges.

Massachusetts is actively participating in multi-state and regional coordination and collaboration efforts on climate change adaptation. The 2008 New England Governor's Conference Resolution 32-5 entitled 'Resolution Concerning Climate Change and Adaptation' recognized the importance of needing to adapt to climate change, and committed the New England Governors and Eastern Canadian Premiers to share data and information on vulnerable areas, and coordinate decision-making and planning processes to optimize regional adaptation and mitigation strategies. The Northeast States for Coordinated Air Use Management (NESCAUM) is actively facilitating a multi-agency coordination effort to discuss adaptation efforts occurring at state and federal agencies in the Northeast and assess the need for regional collaboration between these efforts. The goal of this group is to provide a mechanism for coordination, communication, and work across sectors and states, and to develop a framework for the Northeast to address adaptation to climate change.

Going forward, Massachusetts should continue to actively participate in on-going regional collaboration efforts, share this report with regional partners, collaboratively pursue federal funding for adaptation efforts in all the New England and northeastern states, participate in regional efforts to create an online clearinghouse for climate change adaptation information, work with other states to address specific issues that cross political boundaries, foster academic collaboration, and reach out to other organizations for inclusion in future information sharing and collaborative planning for the Northeast.

Strategy #11 — Promote Communication and Outreach

Because climate change adaptation is complex, it is imperative that targeted communication efforts are in place to inform local officials, the private sector, and citizens of the potential risks and consequences of a changing climate. An ongoing strategy should be the training and skill-building of decision-makers and environmental planners to promote fluency on climate change adaptation sufficient to initiate and perpetuate action. For this, an assessment of the current knowledge, perceptions, skills, and intentions of these constituents should be conducted so that communication is appropriately focused.

Strategy #12 — Start Now, Be Bold

Enough is known about climate change science and its impacts to start to address it now. Earlier action is often cheaper and could help prevent predicted future impacts to key infrastructure resources, public health, natural systems, and the economy.

4. MOVING FORWARD

This report presents a first step toward the identification, development, and implementation of strategies that will advance the State's ability to adapt more effectively and efficiently to a changing climate. Significant challenges remain, and there is much work to be done. Under the leadership of the legislative and executive branches, and with the assistance and collaboration afforded by a broad range of partners—cities and towns, non-government organizations, academic institutions, private businesses, and stakeholder groups and individuals, Massachusetts can strategically position itself to maximize opportunities and address threats. With the submittal of this report to the Legislature, the statutory obligations of the Committee are complete. The Committee now urges the Secretary of Energy and Environmental Affairs to consider the committee's recommendations and find opportunities for action—immediately, in the short run, and the long-term—and to consider how to maintain public, expert, and stakeholder input into the ongoing challenge of adapting to climate change in Massachusetts.

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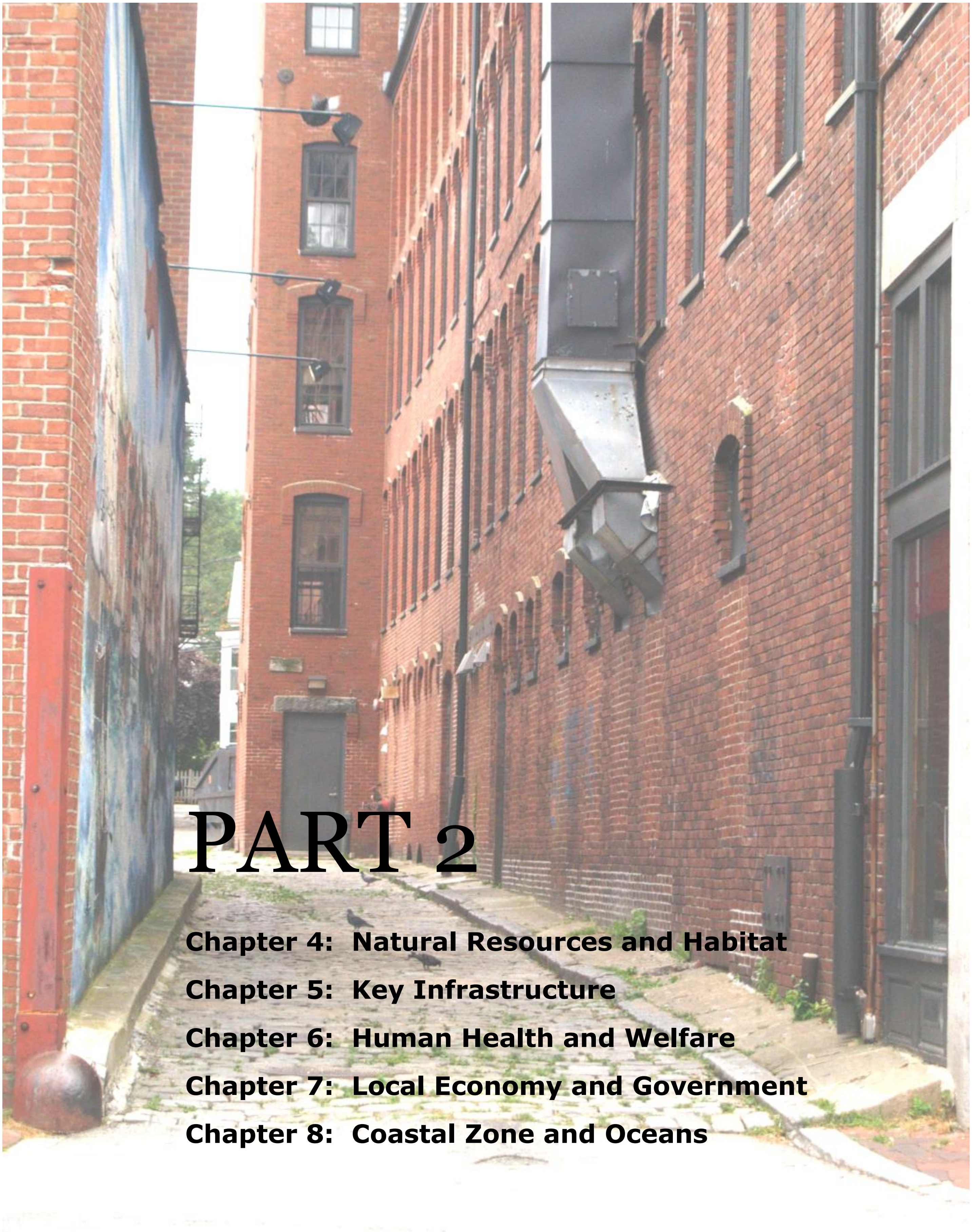


PART 2

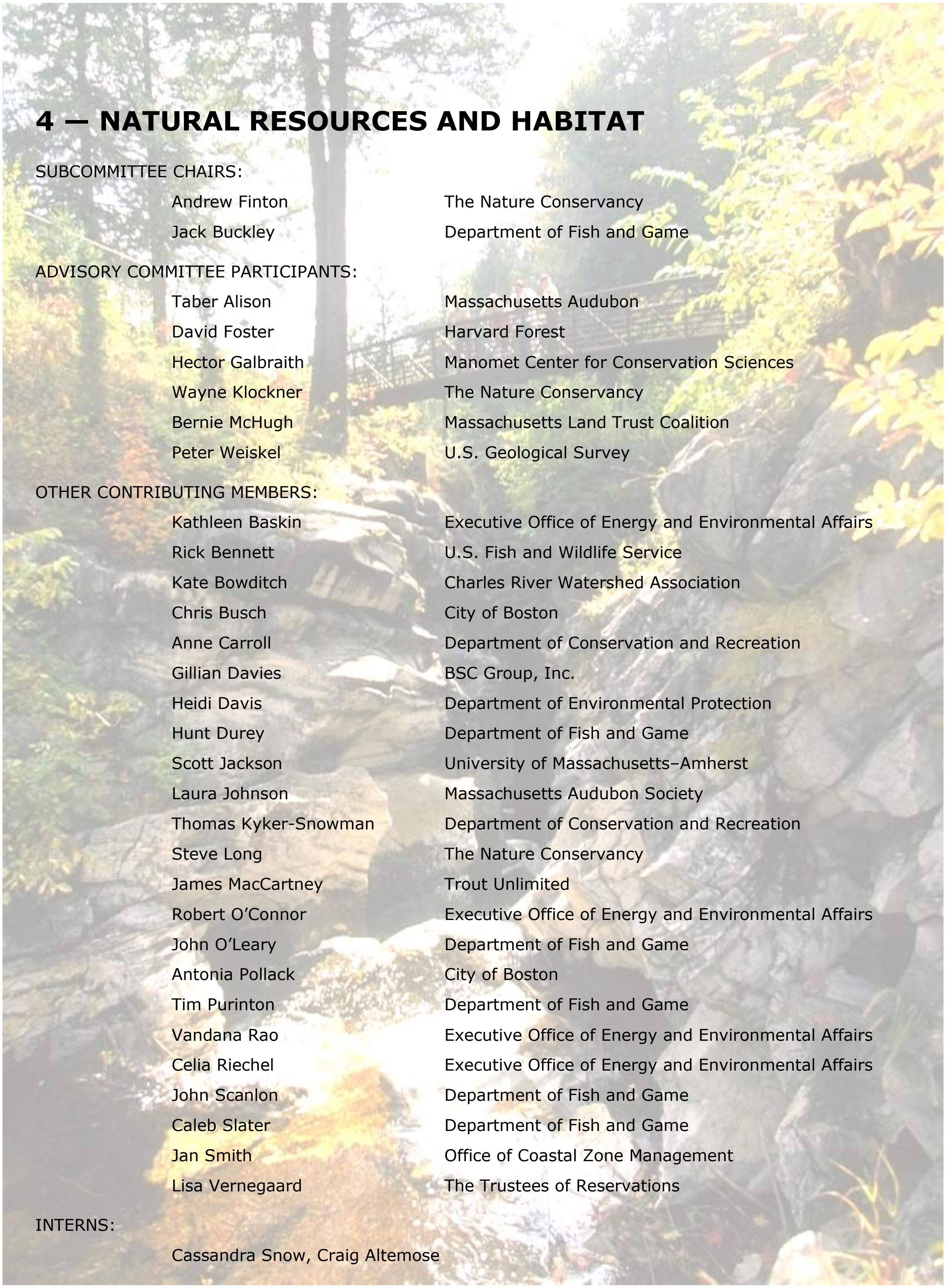
Chapter 4: Natural Resources and Habitat

Chapter 5: Key Infrastructure

Chapter 6: Human Health and Welfare

Chapter 7: Local Economy and Government

Chapter 8: Coastal Zone and Oceans



4 — NATURAL RESOURCES AND HABITAT

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4 Natural Resources and Habitat

Introduction

Since climate is a major determinant of ecosystem function and the distribution, abundance, and behavior of organisms, climate change is likely to trigger fundamental responses in and alterations to Massachusetts ecosystems. Climate change will have a significant impact on the biological diversity of Massachusetts and the Northeast as northern, cold-adapted, niche species are lost or replaced by more southern generalist species. Ecological relationships and processes will be undermined by climate change, and there remain many uncertainties in our understanding of ecological response.

Ecological changes in response to climatic change have been observed in the northeastern United States, as plants leaf out and bloom earlier (Wolfe et al., 2005), amphibian breeding seasons start earlier (Gibbs and Breisch, 2001), and Atlantic salmon spring migrations begin sooner (Juanes et al., 2004). In addition to these direct impacts, species and ecosystems face a broad range of indirect climate-related threats. Two examples are the way temperature changes cause decoupling of bird migration and food source timing and provide a competitive advantage to non-native insects and plants.

It is also important to recognize that the observed ecological changes in North America and elsewhere have occurred under a relatively modest average global temperature increase of only 0.74°C (1.3°F); the additional increase of 3° to 5°C (5° to 10°F) predicted for the Northeast is likely to have increased impacts on ecosystems.

This chapter addresses vulnerabilities and adaptation strategies for four ecosystem types: forest, coastal, aquatic, and wetland. The chapter examines these broad ecosystem types to provide a better understanding of how climate change will affect fish, wildlife, plants, and natural resource functions and ecosystem services over time, across the state, and within regions. Strategies that enhance the functions of these ecosystems can also significantly benefit the economy, infrastructure, public health and safety, coastal resources, and other sectors.

Current Stressors

Evaluation and assessment of the impacts of climate change to natural systems, and strategies to abate these threats, should be conducted in the context of current stressors on ecosystems and populations such as: the loss of habitat and ecosystem function caused by development, fragmentation, invasive species, or other threats. These stressors will continue to be a persistent factor affecting the viability of natural systems. In fact, even without the additional threat of climate change, many elements of the state's biodiversity face an uncertain future. Climate change is occurring at such a rapid rate that changes to species and ecosystem function may occur in a disruptive way resulting in loss of species and ecological values.

Economic Benefits of Natural Resources

Healthy and functional ecosystems support several important sectors of the economy and provide valuable social benefits (TEEB, 2009). Having resilient ecosystems can buffer these ecosystem services against the significant impacts that are occurring or are projected to occur due to climate change.

Intact forested watersheds, wetlands, and rivers support clean drinking water and help water suppliers avoid the need for billions of dollars of water purification infrastructure and operations. Protecting functional floodplains and other wetlands prevents the need for additional flood control infrastructure and flood damage repairs. Coastal wetlands act as important natural buffers that prevent storm and flood damage to expensive inland infrastructure. Estuaries are the breeding ground and nurseries for many species of marine organisms that play important ecological and economic roles.

An added benefit of healthy and properly functioning ecosystems is improved resistance to invasive plants, animals, insects, and diseases. As a result, fewer resources are needed for control of these ecologically and economically costly threats. Forests and other naturally vegetated landscapes sequester atmospheric carbon, equivalent to approximately 10 percent of Massachusetts' carbon emissions. Conservation of wetland soils with significant carbon stores (i.e., peat) also prevents the release of additional carbon to the atmosphere.

It is estimated that each acre of forest in Massachusetts provides $1,500 annually in economic value from forest products, water filtration, flood control, and tourism. For the state's 3.1 million acres of forest, this equals $4.6 billion annually (Campbell, 2000).

About 40 percent of Massachusetts residents who are 16 years or older engage in wildlife-related recreation, contributing slightly more than $1.6 billion to the Massachusetts economy. The multiplier effect on the Massachusetts economy of the direct expenditure of $1.6 billion dollars is approximately $2.6 billion. This supports about 27,000 jobs, providing $975 million in wages, $213 million in state income and state tax revenue, and $243 million in federal revenue.

Forest harvesting directly supports 3,700 jobs for foresters, loggers, sawmill workers, and wood processing plant workers in Massachusetts; the wood products industry produces over $385 million of goods annually (American Forest and Paper Association, 2011).

Overall Vulnerabilities

There are similar vulnerabilities across ecosystems based on projected changes in temperature, precipitation (timing and amount), increased storm intensity, drought and the number of extreme heat days, sea level rise, and increased coastal storm surge. Many of these parameters affect ecosystem processes (e.g., stream flow), individual species and populations.

What forms will these changes take? Until recently, our dominant model of change was for habitats to slowly replace each other as their optimum climatic conditions shifted. Thus, we might expect to see the highly vulnerable spruce-fir forests at upper elevations replaced by northern hardwood forest as it moves upslope to track its optimum climatic conditions. This model of entire communities shifting is important in evaluations of what may occur to habitats under climate change. However, this model may not fully represent what actually could occur.

Different organisms have different intrinsic rates of response to climate change. For example, a northeastern warbler such as the American redstart can potentially shift its breeding range northward by several hundred kilometers in only a few days. Yet, the majority of the plants that make up the breeding habitat of this species are far less able to respond as rapidly. Rather than entire ecosystems or communities shifting their distributions across the landscape, we may see them dissociating and separating, then reconfiguring into potentially novel combinations upslope or further north or not reconfiguring at all. This dissociation and reconfiguring has become the dominant model of how ecological communities may be affected by climate change.

The overall approach to assessing the potential vulnerabilities of natural resources to climate change and development of adaptation strategies is presented in the Figure 7.

This chapter assesses the relative vulnerabilities of the state's various habitat types. Each ecosystem category is reviewed for specific associated functions (e.g. biodiversity, flood attenuation) and assessed for the impact to and vulnerabilities of individual functions. These results are used to develop potential adaptation strategies which, if implemented, could help ecosystems resist climate effects, make vulnerable ecosystems more resilient, and assist ecosystems likely to be lost to move into new structures and functions. This analysis represents a generalized assessment that can be informed and refined by other assessments being conducted by the Manomet Center for Conservation Sciences, The Nature Conservancy, the Division of Fisheries and Wildlife, and others.

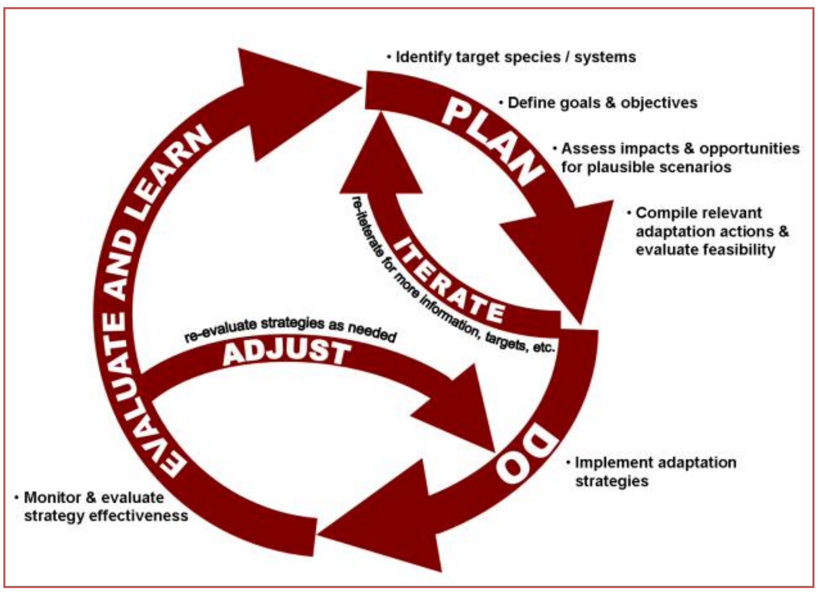


Figure 7: ***Climate change adaptive management framework***
Source: Adapted from Glick et al. (2009); Heller and Zavaleta (2009)

This analysis does not look at direct potential impact to specific fisheries, wildlife and plant species and populations. The assumption is that health and diversity of ecosystems serve as a surrogate for maintaining biological diversity. Nevertheless, significant changes in natural communities and populations will occur as a consequence of climate change and these changes may have significant impacts on diversity and status of populations, societal perception of wildlife, and public health.

Adaptation Strategies

In general, adaptation strategies for natural resources and habitats include land and water protection (such as acquisition and easements), land and water management, regulation changes, targeted public funding, increased agency cooperation and coordination, and enhanced and focused monitoring.

All of these adaptation strategies should be used in an adaptive management framework (Figure 7). These adaptation strategies may be used to resist climate change impacts on important habitats to increase habitat resilience or, when habitat vulnerability to climate change impacts is great, to facilitate change from one habitat type to another. Many of these strategies will also serve to mitigate the effects of climate change by sequestering carbon.

It is anticipated these adaptation strategies will be implemented by a broad array of partners including federal, state, and local governments, non-governmental organizations, and others. Significant progress is already being made toward coordinated action through entities such as the Massachusetts Climate Change and Wildlife Alliance (www.climateandwildlife.org).

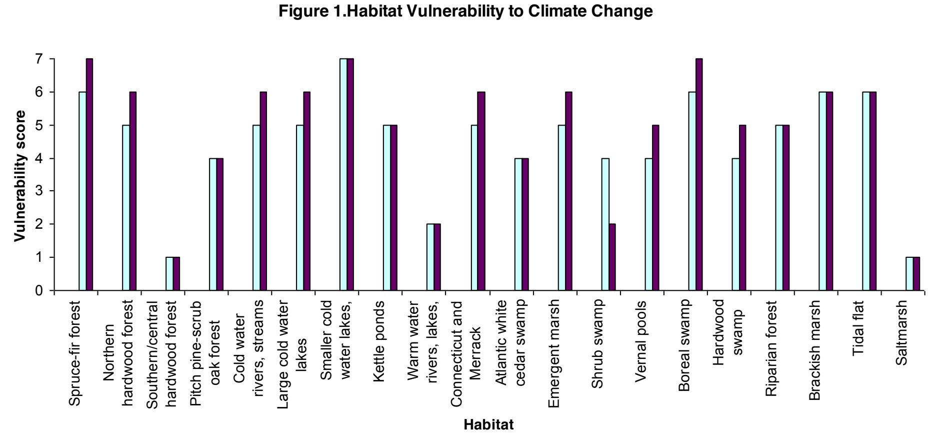
Climate Change Habitat Vulnerability Rankings: Climate Change & Wildlife Management

Massachusetts agencies are taking steps to develop stronger science-based information so that their climate change related decisions will be better informed. Funded by a grant from the Wildlife Conservation Society, the Manomet Center for Conservation Sciences began working in early 2008 with the Massachusetts Department of Fish and Game's (DFG) Division of Fisheries and Wildlife (MassWildlife) and other partners, including The Nature Conservancy, to improve "climate-smart" criteria in the existing State Wildlife Action Plan (SWAP). The SWAP is MassWildlife's "blueprint" for future conservation in Massachusetts.

A panel of experts drawn from MassWildlife, the Manomet Center, and The Nature Conservancy conducted assessments of 20 key Massachusetts habitats with the following questions in mind:

- How do the fish and wildlife habitats rank in terms of their likely comparative vulnerabilities to climate change?
- How will the representation of these habitats in Massachusetts be altered by a changing climate?
- What degree of confidence can be assigned to the above predictions?
- Which vertebrate species in greatest need of conservation are likely to be most vulnerable to climate change?

Figure 1.Habitat Vulnerability to Climate Change



Note*: The left bar in each pair represents a doubling of CO_2, while the right bar is a tripling of CO_2.*

The comparative vulnerabilities of the habitats were evaluated under two emissions scenarios and scored on a vulnerability scale. The study also identified likely future ecological trajectories, assigned confidence scores, and identified other non-climate stressors that could interact with and exacerbate the effects of climate change. The analyses show that different ecological systems are more or less vulnerable to climate change and, consequently, that we can expect to see major changes in their distributions across the Massachusetts landscape.

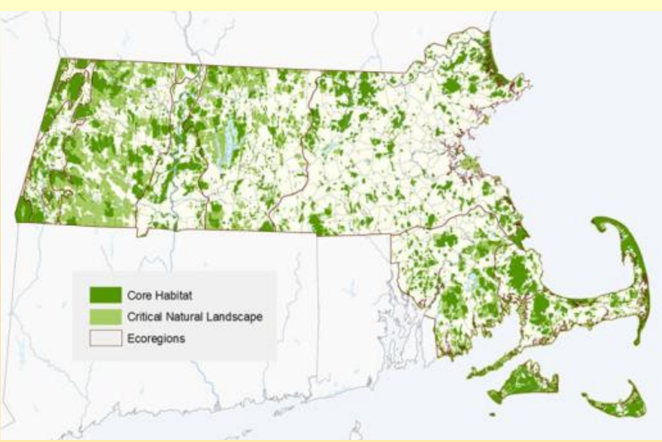
The results of this project are presented in a series of reports. This first report, "Climate Change and Massachusetts Fish and Wildlife: Introduction and Background," provides background to the project by describing how biodiversity conservation is currently carried out by MassWildlife; the history, objectives, and methods of the SWAP; and how the climate in Massachusetts has been changing and is expected to change over the remainder of this century. The subsequent reports, "Climate Change and Massachusetts Fish and Wildlife: Habitat and Species Vulnerability" and "Climate Change and Massachusetts Fish and Wildlife: Habitat Management," address habitat and species vulnerabilities, likely ecological shifts under climate change, and potential management/conservation options. A detailed review of the findings is found on the DFG website at: http://www.mass.gov/dfwele/climatechange.htm

Guiding Principles

While many strategies are unique to specific ecosystems (e.g. allowing inland migration of coastal wetlands in the face of rising sea levels) and are detailed in the following sections, many no-regrets climate adaptation approaches apply to all ecosystem types that help protect and restore ecological resilience. Several principles rooted in ecology, conservation biology, and ecosystem management, and well-supported in current climate adaptation literature (Heller and Zavaleta, 2009; Mawdsley et al., 2009; Beier and Brost, 2010) serve as core climate adaptation strategies:

- Protect ecosystems of sufficient size—Anchor conservation in sites of sufficient size and quality to remain resilient over centuries, recover from disturbances, maintain space for the breeding requirements of component species, allow space for dynamics, and protect internal gradients and topographic variation.
- Protect ecosystems across a range of environmental settings—Represent key geophysical settings across gradients reflecting combinations of topography, geology, and elevation. Focus conservation efforts on places that are critical to biodiversity in the present and are likely to be critical in the future.
- Protect multiple example ecosystems to capture redundancy—It is unlikely that conservation will succeed at every site, as future climate is complex and local—and regional-scale impacts are unpredictable. Protecting replicate sites in many independent places ensures that at least some examples will persist through centuries.
- Maintain large-scale ecosystem processes and prevent isolation—Ecosystems and species are dependent on regional scale processes such as hydrologic cycles and disturbance regimes. It is important to maintain high quality source breeding habitats and connectivity across habitats to facilitate species dispersal, migration, and maintenance; protect local connectivity for individuals, as well as regional movements of populations to facilitate climate change adaptation; protect land and water; and identify compatible land uses in areas critical to connectivity. Intact landscapes that capture the most robust examples of ecosystems represent the best opportunities to protect and enhance ecosystem function and biodiversity.
- Limit ecosystem stressors—Strategies that focus on reducing threats, such as habitat conversion and fragmentation (i.e., development), invasive species, and airborne and waterborne pollutants, can maintain ecosystem resilience and allow ecosystems to provide a full range of functions and services.
- Maintain ecosystem diversity—Preserve as many options as possible for natural adaptation in response to climate change. Expect and plan for species losses and possible gains from other regions.
- Use nature-based adaptation solutions—Allowing intact forest, wetland, river, and coastal ecosystems to function as "green infrastructure" that protects ecological, economic, and social values is an economical climate adaptation approach. These "soft engineering" should be considered wherever possible as alternatives to "hard engineering" solutions. As an example, where appropriate, protection of coastal wetlands can be an alternative to coastal armoring for reducing the impacts of sea level rise and storm surge.

BioMap2



The Massachusetts Department of Fish & Game's Division of Fisheries and Wildlife and Natural Heritage and Endangered Species Program (NHESP), in partnership with The Nature Conservancy's Massachusetts Program, developed BioMap2 to protect the state's biodiversity in the context of projected effects of climate change.

BioMap2 combines NHESP's 30 years of rigorously documented rare species and natural community data with spatial data identifying wildlife species and habitats that were the focus of the Division of Fisheries and Wildlife's 2005 State Wildlife Action Plan (SWAP). BioMap2 also integrates The Nature Conservancy's assessment of large, well-connected, and intact ecosystems and landscapes across the Commonwealth, incorporating concepts of ecosystem resilience to address anticipated climate change impacts.

Protection and stewardship of BioMap2 Core Habitat and Critical Natural Landscape are essential to safeguard the diversity of species and their habitats, and intact and resilient ecosystems, across Massachusetts. A summary report and interactive web viewer can be found at: http://www.mass.gov/dfwele/dfw/nhesp/land_protection/biomap/biomap_home.htm.

- Embrace adaptive management—Ecosystem managers should develop flexible concepts for understanding natural systems. The effectiveness of protection and management should be verified through monitoring, and long-term ecological monitoring projects that inform climate adaptation decisions should be supported.
- Develop a unified vision for collaborative conservation of natural resources—Analyses such as the State Wildlife Action Plan and BioMap2 (2010) serve as blueprints for ecosystem protection and restoration and galvanize the conservation community to engender long-term ecological resilience. Public funding and progressive, flexible, and climate-responsive regulations will be crucial to abate the threats of climate change on natural resources and provide long-term protection of green infrastructure.

Forested Ecosystems

Existing Resources

Forests covered the great majority of Massachusetts prior to European settlement. Then, in the 18th and 19th centuries, there was dramatic alteration of the forest landscape due to logging practices and the conversion of forest to agriculture (Foster et al., 1997). Today, about 62 percent (three million acres) of the approximately five million acres of Massachusetts is forested (Alerich 2000) and over 90 percent of that is upland forest (MassGIS).

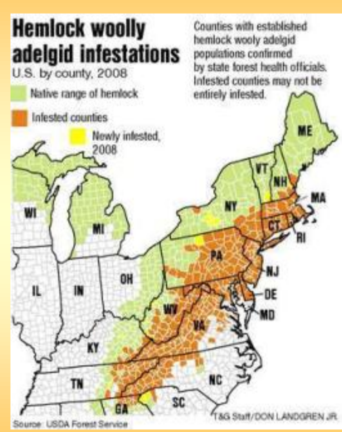
There are many forest types in Massachusetts, including spruce/fir and pitch pine/scrub oak. Two general types of upland forest occur in Massachusetts—namely northern hardwood (beech, birch, maple) forest in western and north-central Massachusetts, and central hardwood (oak, hickory) forest in eastern and south-central Massachusetts. Within the northern hardwood region, the northern hardwood-hemlock-white pine type is most common, with the spruce-northern hardwood type occurring only in the higher elevations. Within the central hardwood region of Massachusetts, oak-hickory-white pine-hemlock is most common, with pitch pine-oak occurring on the relatively infertile, sandy soils associated with coastal areas of eastern Massachusetts and portions of the Connecticut River valley in central Massachusetts.

Upland forests provide important functions including support for a variety of habitats and wide-ranging biological diversity, purification of air and water, moderation of subsurface and overland water flow, and the sequestration of carbon in both the above-ground growing vegetation and in the organic components of forest soils. In addition, forests provide scenic, recreational, and tourism benefits and a rural quality of life for many citizens.

Upland forests also provide energy to streams in the form of organic material. Small streams rely on this energy almost exclusively to initiate their trophic interactions and food webs. These forests provide important filters along wetlands, rivers, and streams. Upland forests stabilize soils and sediments in often high-gradient streams, thus minimizing erosion; help to moderate temperature by providing shade to small streams; provide important habitat for wildlife species that occupy vernal pools; and provide either direct or indirect habitat benefits to wildlife species including forest-dependent species, such as warblers and thrushes, and forest dwelling salamanders, such as marbled and Jefferson salamanders.

Terrestrial Invasive Species—The Hemlock Woolly Adelgid

One pest that appears to be expanding its habitat as a result of climate change is the Hemlock Woolly Adelgid. This small, almost microscopic creature from Japan feeds on and destroys hemlock trees. Here in the U.S., it has no natural predator, and has been severely thinning hemlock populations. Some believe it will eliminate the entire hemlock population in the Southern Appalachians within the next decade. Colder temperatures have limited the agelgid's northern spread, but as winters become milder in New England, experts expect the agelgid to continue its march north.



The insect has already found its way into Massachusetts. In 2001, the state authorized $60,000 to introduce 10,000 Japanese lady bugs to eat the adelgid. While the numbers of adelgid decreased after a particularly cold winter, the lady bug population seems to have largely vanished, and it is making a comeback. The town of Weston, MA spent $5,000 in the fall of 2008 to treat 100 trees, and has authorized further expenditures of $25,000. While treatments on individual and wide scale levels can help keep the numbers of adelgid in check, there is no permanent solution or preventive defense. Continued vigilance will be required to maintain the existing Hemlock populations.

Impacts and Vulnerabilities

Climate change will cause changes in species composition and forest structure. While common species such as maples may decline in abundance and oaks may increase under climate change, more vulnerable species such as spruce may be extirpated from portions of the state or their distribution may be significantly reduced. Climate change, in conjunction with other stressors, will alter forest function and its ability to provide wildlife habitat, and could reduce the ability of forests to provide ecological services such as air and water cleansing.

Massachusetts can experience a greater intensity and frequency of forest-disturbing weather events, including ice storms, localized or regional wind events such as microbursts or hurricanes, and more frequent and longer droughts and associated wildfire. All of these conditions can suddenly kill or alter the vigor of native trees, thereby opening the forest to new species. The same climate change phenomena that affect trees could also impact forest-dependent species such as song birds, forest floor plants, and invertebrates, as well as disrupt predator-prey relationships, and alter phenological patterns and other, often complex, ecological processes. Some changes may be slow while others may proceed quickly once critical thresholds are met (e.g., forest pests).

Predicted change in species composition from increased ambient temperatures is generally a function of the extension of northern limits of species that have limited cold tolerance and a change in the habitat suitability. Range shifts in tree distribution (historically, forest types have shifted at the range of 12 to 15 miles every 100 years) will change the relative proportions of forest tree species. The migration of tree species in response to habitat changes, however, is likely to be much slower than the predicted changes in habitat due to climate change. It is also important to note that movement is likely to occur at the individual species level and not by groups of species. The speed at which these impacts take place may come either quickly or over decades. Northern forest types such as spruce-fir will likely disappear from Massachusetts. Red spruce and balsam fir will likely have decreasing reproductive success, northern hardwoods will recede to higher elevations within the state and northward out of the state, and southern forest types such as central, transitional, southern hardwoods will likely increase in abundance. Changing climate factors and forest types will also likely alter the composition and role of myriad other species defining forests including vertebrates, invertebrates, shrubs, herbs, non-vascular plants, fungi, and bacteria.

Invasive insects and diseases will also respond to climate change; hemlock woolly adelgid is likely to expand northward while the response of others, such as the emerald ash borer, the Asian longhorned beetle (currently attacking hardwoods in Worcester), or the widespread beech bark disease, is uncertain. Overall, the negative impacts of invasive species may increase as native forests are increasingly stressed and become more vulnerable to changes in mean and maximum air temperatures and subsequent changes in the water cycle.

The following strategies could be considered for implementation to mitigate potential climate change impacts on forest resources.

Potential Strategies

For a forest ecosystem to maintain its biodiversity, it should be able to absorb small perturbations, prevent them from amplifying into large disturbances (resistance), and return to the original level of productivity, function, structure and, in some cases, species composition following a disturbance (resilience). The resistance and resilience of ecosystems are dependent on their sizes, conditions and landscape contexts.

1. Land Protection—Secure Large Unfragmented Forest Blocks

Forest ecosystem functions can be greatly impaired by forest fragmentation caused by roads, development, and infrastructure. To maintain these functions, an important climate adaptation strategy is to identify and protect resilient forest ecosystems—both forest reserves and actively managed forests—based on the principles outlined in the guiding principles section of this chapter.

2. Policy, Flexible Regulation, Planning, and Funding

Consider establishing landowner incentives for forest ecosystems. Because nearly 80 percent of forests in Massachusetts are privately owned, incentives for private land owners to keep their forest lands as forest and manage them for compatible natural resource values will be crucial for both climate adaptation and mitigation (i.e. carbon sequestration) strategies, as such incentives are less costly than purchasing these parcels as conservation land. These potential strategies are,

a. Establish mechanisms to pursue a goal of "no net loss of forests," such as funding for technical assistance to implement smart growth and reduce development footprint on forests, mitigation requirements for forest conversions, and to increase tree planting in

Government Takes the Initiative

Over the last four years, the Massachusetts Executive Office of Energy and Environmental Affairs and its agencies have invested an unprecedented $218 million to permanently protect more than 85,000 acres of land and create or restore 114 urban parks.

urban/suburban open land. This could add to permanent forest conservation of key wildlife corridors for climate adaptation and of exceptionally productive forests for sequestration.

b. Add state tax incentives to "keep forests as forests," including a state tax credit for the cost of professionally prepared forest management plans (the main impediment to adding acreage to the state Forest Tax Law).

c. Establish an initiative to promote the buying of local forest produce.

3. Management and Restoration

For greatest resilience and adaptability, Massachusetts forests should exhibit a balance of forest structure, composition, and age classes across the state and across ownership, as well as a mix of approaches to forest management, with forest reserves controlled by natural processes, as well as actively managed forests that provide forest products in addition to carbon sequestration and other functions and services. This goal may be achieved through the following strategies.

a. Reserve Management. Encourage forest reserve management to allow natural processes to determine the long-term structure, composition, function, and dynamics of the forest to the maximum extent possible. Use the general approach and the Forest Reserve Management Guidelines developed as a result of the Department of Conservation and Recreation's (DCR) Forest Futures Visioning process and informed by EEA's Forest Reserve policy developed in the early 2000's.

Forest Reserve Management in Massachusetts

The Massachusetts Department of Conservation and Recreation (DCR) is implementing the Forest Reserve Management Guideline recommendations and will designate over 100,000 acres of DCR lands as Reserves within eleven "Ecological Land Units" that capture the forested settings of the Commonwealth. In addition, "Parklands" which will make up approximately 75,000 acres of DCR lands, will be managed primarily for recreation, human experiences and cultural values. Reserves and Parklands will be set aside from active forest management. DCR will designate approximately 120,000 acres of "Woodlands" to be managed as demonstration forests, focusing on restoring late successional conditions and sustainable production of timber.

b. Reserve Selection and Designation. For forest reserves to maintain their ecological function over long periods, forests managed as reserves should be large (The Nature Conservancy recommends >15,000 acres each), minimally fragmented, and representative of varied ecological settings that define Massachusetts' forest biodiversity. The Forest Futures Visioning process recommended that DCR designate the approximately 310,000 acres of land within the forest and parks system as Reserves, Parklands, and Woodlands to prioritize the ecosystem services these lands provide.

c. Manage invasive species. Launch an initiative to remove invasives from large unfragmented forest blocks on state land in collaboration with non-profit partners. Invasive exotic plants homogenize a forest, reduce the diversity of species composition, and weaken resistance to change. Established procedures can reduce the impact of forestry practices on the spread of invasive species (e.g., cleaning of machines to remove seed or root cuttings before moving to a new site), monitoring for their presence and controlling them early.

d. Protect regeneration. Delays in regeneration reduce the ability of the forest ecosystem to function consistently over time. Manage activities that limit the ability of native trees, wildflowers and herbs to regenerate, such as over-browsing by white-tailed deer and damage from all terrain vehicle (ATV) activity.

e. Practice prudent fire management. In fire adapted and fire dependent forest types (e.g. pitch pine-scrub oak), utilize current fire management practices to maintain the ecosystem processes and breadth of biodiversity of these systems. Consider establishing a fire management council to facilitate prescribed fire management in fire-adapted pitch pine/scrub ecosystems on a landscape scale. More frequent and pronounced droughts are expected to couple with an overall increase in forest growth, and this combination would mean that fire-adapted systems could see increased frequency and/or intensity of fire and associated risk to human life and property.

f. In some cases, enhance sequestration through planting. Planting native seed stock of local genetic origin in these stands can return the forest to full stocking. This increases capacity to sequester carbon while also increasing resilience. In the absence of browsing pressure or dense invasive species, forests will naturally regenerate to fill gaps produced by disturbances.

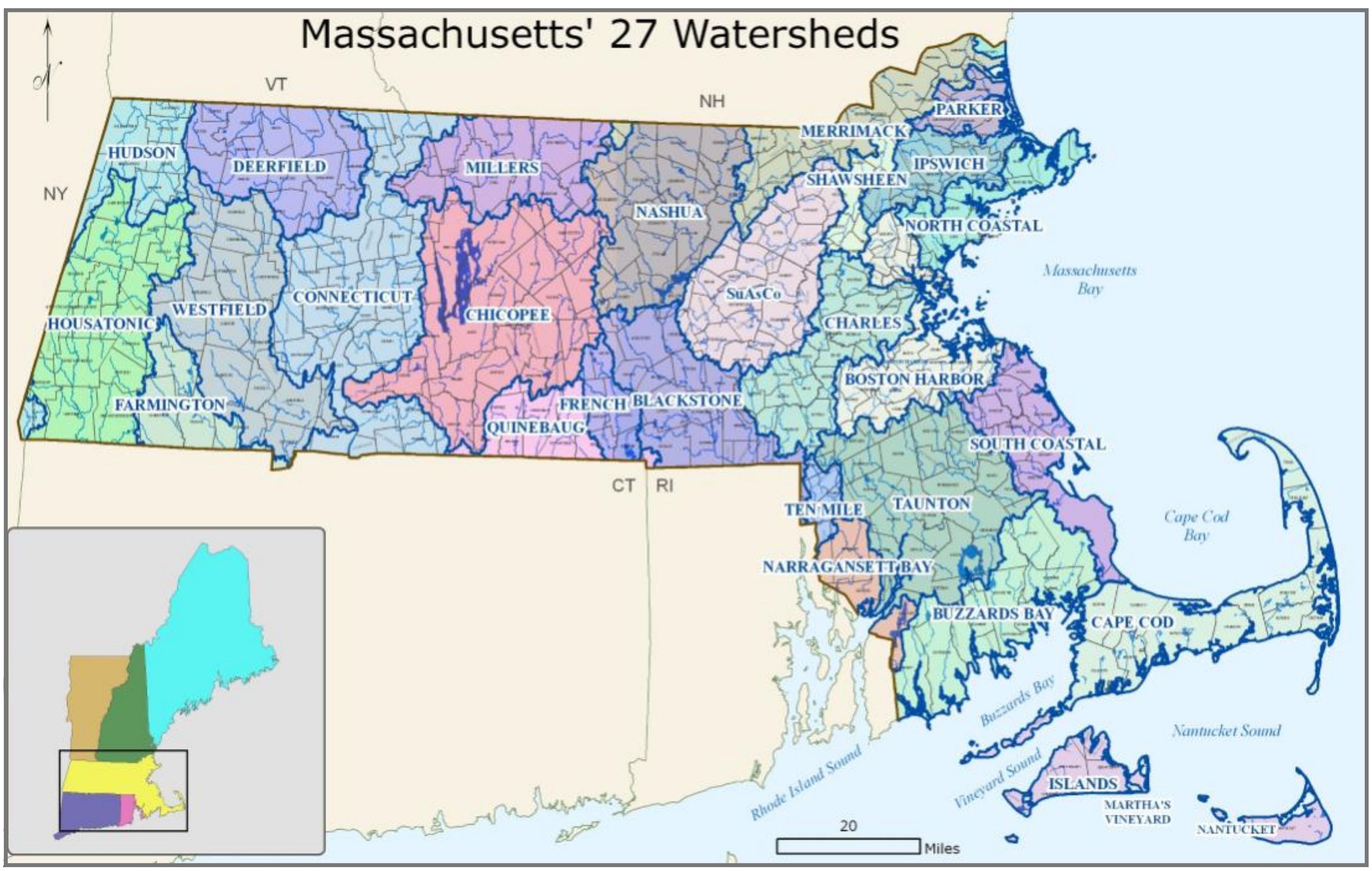
4. Monitoring, Research, and Adaptive Management. Support long-term ecological monitoring programs such as the DCR's Continuous Forest Inventory, a data set collected over 50 years which provides invaluable information on the status and trends of the state's forest resources), and the joint DCR/MassWildlife/University of Massachusetts program for long-term monitoring of plant community dynamics on paired forest reserves and actively managed state lands.

Aquatic Ecosystems

Aquatic ecosystems refer to rivers, streams, lakes, and ponds. Although many ecologists consider wetlands and salt marshes under this category, these systems are addressed in separate sections in this report.

There are 27 major river basins in Massachusetts. Mainstem rivers such as the Connecticut and Merrimack are characterized by wide, low gradient streambeds meandering through broad river valleys with extensive flood plains. Large and mid-sized mainstem rivers and their larger tributaries vary considerably, but have some common features. Moving from their headwaters to their mouths, gradient in these rivers typically declines and sediment sizes decrease. Organically enriched soils become more widespread as floodplains widen, due to deposition of organic material in slower moving waters. These rich floodplains are the foundation for productive floodplain forests, shrub swamps, and other habitats. However, floodplain forest is already one of the most uncommon and degraded ecosystems in Massachusetts (Swain and Kearsley, 2001), and faces further threat from a combination of earlier spring runoff, more frequent low flow conditions (during spring runoff and summer droughts), and more frequent high flow conditions (during winter flood events). This combination would fundamentally alter the hydrologic periodicity of these dwindling riparian ecosystems, likely favoring invasive, exotic plant species, which are already a major threat to these unique areas.

Small streams in the upper reaches of a watershed originate where rainfall, runoff, and groundwater first come together to form defined stream channels, typically with year-round flow. These streams account for the majority of the linear stream miles in



Massachusetts. They accumulate and assimilate all upstream inputs, perturbations, and degradations and transmit them to reaches downstream. In most cases, small streams rely on groundwater for a high percentage of their annual flow and have food webs that are highly dependent on additions of nutrients from the surrounding vegetation. These streams often have naturally low fish diversity, low productivity and relatively high gradients. The substrates may be dominated by boulder and cobble in high-gradient watersheds like the Westfield River, or gravel and sand in lower gradient watersheds like the Taunton River. It has long been realized that healthy small streams contribute to the integrity of a watershed by maintaining the soil, increasing infiltration, reducing the impacts of flooding, and maintaining summer base flow. These functions not only support biodiversity, wildlife, and river processes, but also provide crucial flood control services and drinking water protection.

Massachusetts has nearly 3,000 named lakes and ponds, totaling over 150,000 surface acres. Some lakes, such as the kettlehole ponds on Cape Cod, were naturally formed over 10,000 years ago during the retreat of the last Ice Age. While many of the state's lakes and ponds were created or enhanced by dams and are thus positioned at the headwaters to streams and rivers, they are a crucial link in the overall aquatic community. Many of these lakes and ponds support drinking water and recreational needs in addition to providing habitat for a wide variety of fish and wildlife.

Impacts and Vulnerabilities

Aquatic ecosystems are vulnerable to climate change. Predicted changes in timing, frequency, and duration of precipitation events, more intense storms, a shift from winter snow to rain, more frequent and longer summer droughts, and increases in temperature trends and extreme high temperatures will affect both lotic (flowing water) and lentic (still water) habitats.

Water quality and quantity are expected to be adversely affected by predicted increased temperature, drought, an increase in the number of extreme heat days, and a decrease in summer precipitation. Higher temperatures, along with changes in stream flow, will degrade water quality. Warmer, drier conditions will lead to deeper and stronger thermal stratification in lakes which will decrease the volume of the deeper, cooler, well oxygenated water that is critical summer habitat to a number of species. As a result, this habitat may be eliminated from many shallower lakes and ponds. In addition, non-native species will likely become a bigger problem for lake and stream ecosystems under warmer conditions (Ramsar, 2002). In general, climate change can influence the establishment and spread of invasive species and can reduce resilience of native habitats to these species (U.S. EPA, 2008). Increased mobilization of non-point source nutrients, and suspended solids from more intense winter rain storms, followed by higher summer temperatures, will result in more algal blooms (e.g., blue-green algae) and vigorous growth of aquatic vegetation leading to eutrophication in lakes and impounded rivers.

A projected increase in average winter temperatures will decrease the amount of snowpack and ice and negatively impact aquatic ecosystems. Reduced ice cover on lakes and ponds will result in more winter sunlight and more abundant aquatic vegetation, while less melting snowpack will reduce spring groundwater recharge. A shift to winter rains will potentially lead to more runoff, flooding, greater storm damage, scour, and erosion during a time when there is reduced vegetative cover and low evapotranspiration (the combination of evaporation from the ground and transpiration from plants) during the winter months. Peak river flows are predicted to occur earlier as higher average temperatures and a shift from winter snow to rain accelerate the spring melt. Flooding, and an accompanying loss of vegetative cover, could reduce many ecological functions, causing effects such as reduced primary productivity and loss of carbon storage; degradation of wildlife habitat, in-stream aquatic habitat, and water quality; and increased incidence of water-borne disease, sedimentation, pollutant loading of waterways, and surface runoff (Ramsar, 2002). In waterways and waterbodies, increased temperatures are likely to cause loss of thermal refuges for coldwater species, decreases in dissolved oxygen, changes to hydrologic mixing regimes, and changes in biogeochemical cycling (Ramsar, 2002).

Higher summer temperatures, less summer precipitation, and an increase in drought frequency and duration will affect both water quantity and quality. Some intermittent streams may cease flowing earlier in the season and more frequently and some perennial streams may become intermittent. In some rivers and streams, coldwater habitat will be replaced by warm water habitat. This will likely be accompanied by marked changes in the species that live in these habitats.

Climate change can affect fisheries through changes in abundance, distribution, and species composition. Fisheries in small rivers and lakes are believed to be more susceptible to changes in temperature and precipitation than those in larger rivers and lakes (Ramsar, 2002). As coldwater habitats warm, coldwater fisheries, which are already stressed by reduced habitats and population losses, will be especially affected. Though some adult fish may tolerate higher stream temperatures, in certain circumstances they will not reproduce. Climate change may affect stream flow by increased flooding incidences from extreme precipitation events, and low flow occurrences in late fall. Flooding, in turn, can scour stream bottoms where fish eggs are lodged. The earlier seasonal growth of plants could result in lower stream base flows earlier in the spring and negatively affect primary productivity.

The predicted changes in precipitation patterns can also increase stormwater discharge, which can affect both water quantity and quality. Hydrologic changes from increased flooding can amplify erosion and scour in streams and initiate channel incision. Problems associated with channel incision include undermining of structures, downstream sedimentation, severe bank erosion and widening, and degradation of aquatic and riparian habitats. Overbank floods that once spilled across the floodplain can become confined within the channel, and the river can get disconnected from the floodplain, leading to a loss in the ability of the floodplain to provide flood storage, storm damage prevention, groundwater recharge, pollution attenuation, sediment transport/storage, and protection of water quality. Under these conditions, flora and fauna that are adapted to a floodplain environment may experience a loss of habitat and range. Without periodic inundation, there would be a loss of wetlands and fisheries-related hatching and nursery areas.

As rivers incise, their banks fail and the channels become over-wide in proportion to depth. Sediment transport decreases, and there is greater deposition of sediments, especially mid-channel. Flows can become discontinuous, creating barriers to fish movement. Shallower flows can lead to increased temperatures and lower dissolved oxygen levels. Increased erosion in rivers can result in scour at restrictions such as culverts, often perching or undermining these structures so that they present barriers to aquatic organism movement and pose a threat to public safety.

Potential Strategies

Adaptation strategies should strive to integrate the protection of rivers, streams, lakes, riparian areas, floodplains, and wetlands with comprehensive land-use, watershed, and floodplain/buffer management, and targeted land acquisition. Strategies to be considered include:

1. Land Protection. Use land acquisition and conservation restrictions to target protection of vulnerable intermittent headwater streams and their buffer areas. Acquisition could be supplemented by stream easements. Well-protected headwater streams and lakes that provide high quality, cold-water flows will be integral to maintaining suitable downstream conditions during periods of warming.
2. Policy, Flexible Regulation, Planning, and Funding
   a. Facilitate streamlined permitting of aquatic habitat management projects.
   b. Develop streamflow criteria and regulations to encourage re-establishment of natural flow regimes in rivers and streams.
   c. Provide greater protections to vulnerable intermittent streams through legislation, or by encouraging local bylaws.
3. Management and Restoration
   a. Identify vulnerable river reaches, establish and protect belt-width-based river corridors, restore floodplains, and increase use of bioengineering techniques for bank stabilization.
   b. Identify and protect remaining critical coldwater fish habitat areas and seek to reconnect high quality habitats by removing in-stream barriers and re-establishing in-stream flows.
   c. Identify and implement strategies for early detection, rapid response, and prevention of invasive exotic plants and animals that out-compete native species and gradually reduce the diversity of species composition.
4. Monitoring, Research, and Adaptive Management. For aquatic system resilience, standardize monitoring protocols, improve communication with existing long-term ecological research monitoring sites, monitor pilot adaptation

strategies, and support existing monitoring networks that have a nexus with adaptation strategies.

a. Through geomorphic assessment, identify vulnerable river reaches and monitor rivers for disconnection from floodplains.

b. Update Federal Emergency Management Agency (FEMA) floodplain maps to reflect current conditions and predictions of future conditions.

Coastal Ecosystems

Seaward of the sandy beaches and rocky coastlines, beyond the salt bays and estuaries, Massachusetts' territorial waters extend three nautical miles out into the Gulf of Maine. The land under this area of open ocean is the relatively shallow continental shelf, which supports coastal ecosystems. Depths of seawater can range from 100 feet to a little more than 1,000 feet, but there are no deep trenches in Massachusetts waters.

Almost all of Massachusetts' salt waters are in estuaries and bays; very little is open ocean. Massachusetts has three great bays: Massachusetts Bay, which includes the area between Gloucester and Brant Rock, north of Plymouth; Cape Cod Bay, which includes the area from Plymouth to the tip of Cape Cod; and Buzzards Bay, extending from the Westport River near the Rhode Island border, east to the Cape Cod Canal and south to the last of the Elizabeth Islands (see "Massachusetts' Coastal Zone" map). Within the great bays are smaller bays such as Nahant Bay north of Boston, and Hull, Hingham, and Quincy bays south of Boston—all within the Massachusetts Bay.

Estuaries are affected by tidal flows and are considered brackish water, although the degree of salinity varies. Estuaries often have associated salt marsh habitat and are rich in nutrients, providing a valuable nursery for finfish, shellfish, and other macro- and micro-invertebrates, and supporting a wide range of vertebrate wildlife. These habitats are vital links in the life histories of diadromous fishes (those that spend part of their lifecycle in salt water and part in fresh water), which rely on these

complex ecosystems to provide food and protection. There are estuaries all along coastal Massachusetts, but the most extensive system lies just west of Plum Island, feeding into Plum Island sound and the marshes of Essex County. A second extensive estuary system is in the Nauset Marsh/Pleasant Bay area on outer Cape Cod. Numerous shorter estuaries are along the south side of Cape Cod. The East Branch of the Westport River is one of the longest estuaries in Massachusetts.

Located between the high spring tide and mean tide levels of protected coastal shores, salt marshes and the adjacent tidal flats comprise one of the most productive ecosystems on earth. In spite of the stresses of wide variations in temperature, salinity, and degrees of inundation, the salt-tolerant vegetation of the salt marsh community provides the basis of complex food chains in both estuarine and marine environments. It also provides habitat for various species of wildlife, including migrating and overwintering waterfowl and shorebirds, and the young of many species of marine organisms. In the northeastern United States, salt marsh communities are dominated by two species of perennial, emergent grasses adapted to growth in salty soils—Saltmarsh Cordgrass and Saltmeadow Cordgrass. While these dominant species give the community a deceptively simple, grassland-like appearance, salt marsh systems are heterogeneous and provide a variety of habitats. For example, pans—the open areas in a marsh—are important to migrating waterfowl.

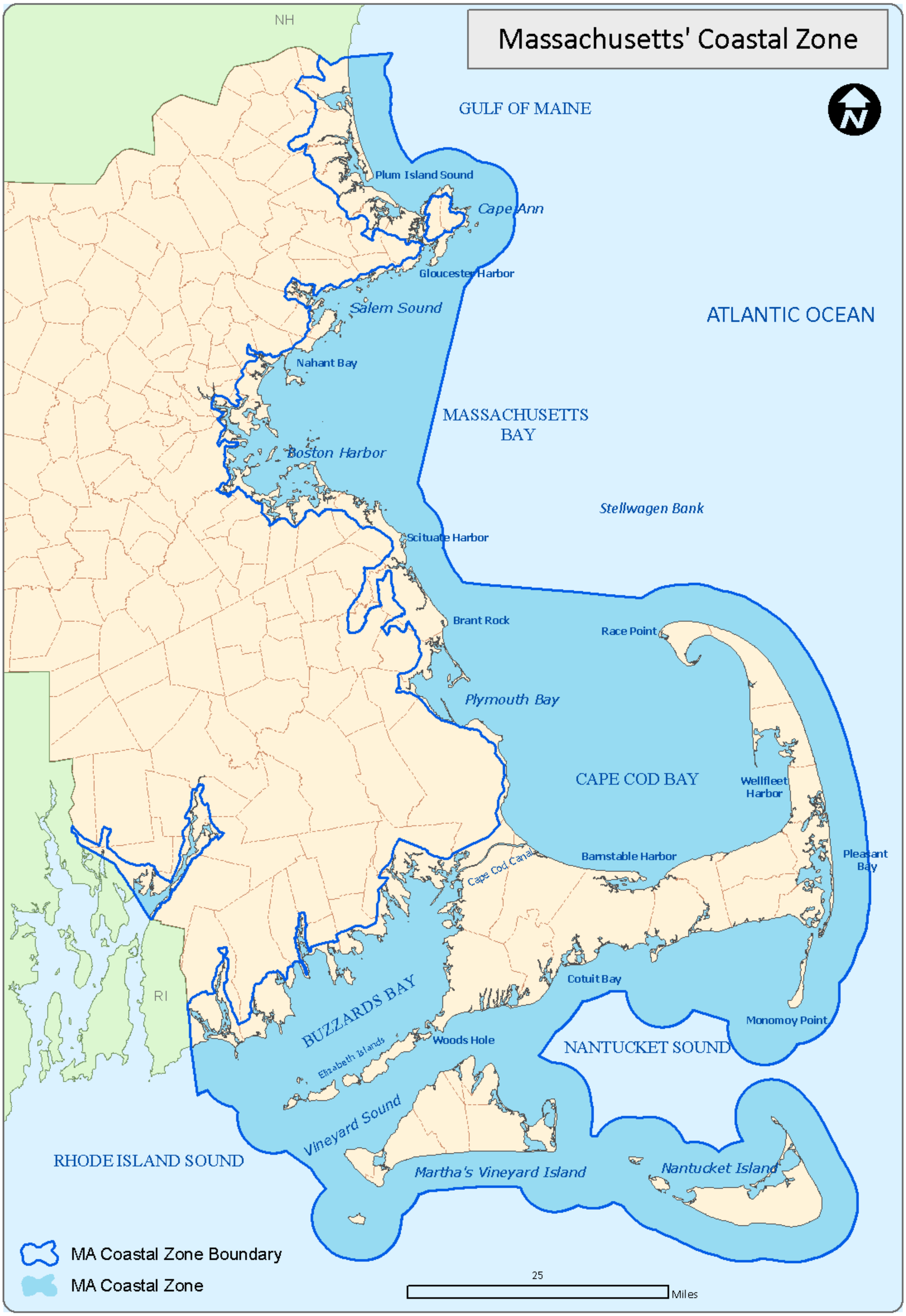
Impacts and Vulnerabilities

Coastal ecosystems will be particularly vulnerable to the impact of climate change due to the nature of their locations. In addition to responding to increased temperature, variable precipitation, and extreme weather events, sea level rise—a major climate change-related threat to Massachusetts—will expose these critical habitats to increased loss and decimation. It is anticipated that important coastal habitats will be lost and reduction of sediment load to beaches and other coastal habitats will limit the ability of these areas to maintain accretion at a rate that could match sea level rise.

Potential Strategies

A number of adaptation strategies should be explored to identify ways to mitigate potential climate change impacts to coastal ecosystems.

1. Land Protection
   a. Identify and protect undeveloped areas that are upgradient from coastal wetlands to allow wetland migration and buffer intact ecosystems; and


Massachusetts' Coastal Zone
NH
GULF OF MAINE
Plum Island Sound
Cape Ann
Gloucester Harbor
Salem Sound
ATLANTIC OCEAN
Nahant Bay
MASSACHUSETTS BAY
Boston Harbor
Stellwagen Bank
Scituate Harbor
Brant Rock
Race Point
Plymouth Bay
CAPE COD BAY
Wellfleet Harbor
Barnstable Harbor
Cape Cod Canal
Pleasant Bay
RI
BUZZARDS BAY
Cotuit Bay
Monomoy Point
Woods Hole
Elizabeth Islands
NANTUCKET SOUND
Vineyard Sound
RHODE ISLAND SOUND
Martha's Vineyard Island
Nantucket Island
MA Coastal Zone Boundary
MA Coastal Zone
25
Miles

Projected change in intertidal habitats at Parker River

The vulnerability of selected intertidal habitats in Massachusetts to climate change has been evaluated by the U.S. Fish and Wildlife Service through simulation of sea level rise at coastal Massachusetts National Wildlife Refuge sites, including the Parker River. The investigators modeled the fates of intertidal habitats using four global sea level rise scenarios. Predicted sea level rises of 0.39m (1.3 ft), 0.69m (2.3 ft), 1.0m (3.28 ft), and 1.5m (4.9 ft) by the year 2100 were superimposed on current rates of sea level rise.

At the Parker River, the extents of the intertidal habitats appear to be highly sensitive to even relatively modest sea level rise changes, with marked losses and gains occurring under the 0.39m (1.3 ft) sea level rise scenario. The habitat types that suffer greatest reductions in extent under most sea level rise scenarios are brackish marsh and tidal flats, with reductions of 50 to 99 percent. As sea level rises, intertidal land will become subtidal (hence, the increase in open water and loss of tidal flats), while saltmarsh will extend further upgradient as the inundation and salinity changes—at the expense of the brackish marshes it will replace. It is important to note, however, that the ability to move upgradient may be highly restricted by the lack of open undeveloped upland.

Projected change in intertidal habitats at Parker River

Intertidal Habitat	Current area (acres)	0.39 meter		0.69 meter		1.0 meter		1.5 meter	
		Area Change	% Change	Area Change	% Change	Area Change	% Change	Area Change	% Change
Brackish marsh	2,306	1,955	-15	1,114	-52	458	-80	3.9	-99
Salt marsh	150	423	182	1,206	704	1,715	1043	818	445
Tidal flat	803	327	-59	303	-62	382	-52	1,605	99
Estuarine open water	1,500	2,104	40	2,218	48	2,379	59	2,579	72
Ocean beach	226	264	17	266	18	261	15	22.3	-90

   b. Develop high-resolution elevation models (based on LiDAR data) to identify and prioritize protection of areas that may become wetlands in the future as sea level rises.

2. Policy, Flexible Regulation, Planning, and Funding
   a. Expand use of ecological solutions to sea level rise. Hurricane Katrina dramatically illustrated the adverse consequences of removing natural ecological wetland buffers to coastal storms and relying entirely on engineered solutions. Investigate the benefits of shifting from engineering-based and infrastructure-focused solutions toward a union of engineering and ecological planning;
   b. Consider developing more flexible conservation regulations that take into account potential sea level rise and changing floodplains; and
   c. Encourage integrated community planning. Coastal habitats in Massachusetts are often areas with competing interests, stakeholders, and multiple jurisdictions. Extend planning of coastal areas beyond the state and federal agencies and involve other stakeholders to ensure representation of varied interests. (See Chapter 8 on details about assistance provided by Massachusetts Coastal Zone Management through their StormSmart Coasts program.)

3. Management and Restoration
   a. Identify, assess and mitigate existing impediments to inland migration of coastal wetlands. As sea levels continue to rise, the whole system of coastal wetlands and subtidal habitats will move inland. This cannot occur in areas where the topography does not permit it, or where barriers, such as roads, seawalls, or settlements, prevent it;
   b. Identify and assess potential restoration of coastal wetlands. Sea level rise destroys habitats since the rate of rise exceeds the rate at which wetland soils are replenished by sediments. It may be possible at some sites to mitigate this and preserve the wetlands;

c. Manage the spread of invasive species. Support efforts to reduce nutrient loading of waterways and waterbodies.

4. Monitoring, Research, and Adaptive Management. Track the movement of tidal resources as they respond to sea level rise using on-the-ground sensing (e.g., more tide gauges), and remote sensing (e.g., increased regular photo coverage of vulnerable areas). Integrate this information into management plans so that decision-makers are alerted when management thresholds that trigger new policies are reached.

Wetland Ecosystems

Wetlands have always been an important feature of the Massachusetts landscape. Common wetland types include wooded deciduous swamps, emergent wetlands, wet meadows, bogs, and vernal pools. As Massachusetts is a coastal state and one of the most densely populated states in the country, development pressures, and accompanying wetland losses, are a reality. It has been estimated that, by the mid-1980s, Massachusetts had lost approximately 28 percent of its estimated original wetland base. More recent data suggest that about 1700 acres (approximately 0.2 percent) changed during the period from the mid 1990s to present (MassDEP, 2011). Activities causing the most loss are residential development, commercial development, sand and gravel operations, and agriculture. Of these losses, wooded deciduous swamps are the most highly impacted.

Existing Resources

For purposes of this document, wetlands in this chapter refer to freshwater wetlands such as shrub and forested swamps, emergent marshes, bogs and fens, vernal pools, and related ecosystems. Shrub swamps are shrub-dominated wetlands occurring on mineral or mucky mineral soils that are seasonally or temporarily flooded or saturated. They often occur as successional areas between freshwater marsh and forested swamp (Mitsch & Gosselink, 2007) and occur in association with other wetland types in wetland complexes.

Forested swamps, the most abundant type of all wetlands in the northeastern United States (Golet et al., 1993), are wetlands where trees dominate the vegetation and there is generally little buildup of peat. They usually occur as patches within the surrounding upland matrix forest. In the warmer southern and eastern sections of the state and in the central hardwood area, forested swamps are dominated by red maple or Atlantic white cedar.

Bogs are among the best-known peatlands and generally have the thickest peat deposits. Bog communities receive little or no streamflow and they are isolated from the water table, making them the most acidic and nutrient-poor of peatland communities. Several of the state's listed rare animal species are found in bogs. Marshes and wet meadows are some of the most important inland habitats for many species of animals, both rare and common.

Vernal pools are relatively common, with some 30,000 statewide. These are ephemeral wetlands that fill annually, mainly in the spring, from precipitation, runoff, and rising groundwater. In most years, they become completely dry later in the season, losing their water to evaporation and transpiration over the summer. This wet-dry cycle prevents fish from becoming established permanently and presents an important fish-free, if temporary, breeding habitat for many species.

Impacts and Vulnerabilities

Changes in the timing, frequency, and duration of precipitation and increases in flooding will cause changes in water depths, hydroperiods, and flow dynamics. Loss of snow and ice will result in a loss of ice-related structural changes to banks and floodplains. If reduced precipitation and increased drought occur during the season when animals breed and develop in vernal pools, then the length of time that vernal pools hold water could be reduced, potentially leading to a reduction in vernal pool populations.

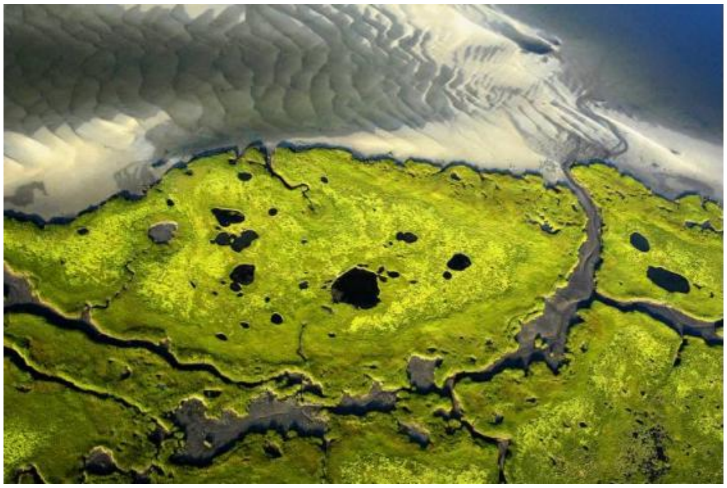
With increased temperatures, species and wetland types that are more typical of cooler and/or higher northern areas (such as northern bogs, spruce-fir boreal swamps, hemlocks) may be reduced or disappear. Wetlands dominated by conifers usually found in cool conditions may become more deciduous, changing their biogeochemistry and potentially the entire wetland habitat. Southern species, including invasives and pests, could move northward or expand their presence in locations that are currently at the northern edge of their range and could stress some native species. Native New England species and populations may become less competitive relative to southern species/populations when the growing season lengthens and temperatures warm.

Increased temperatures can also dry the peat wetland soils, resulting in oxidation and release of stored organic carbon to the atmosphere and changes in pH. Wetland soils may lose saturation. The surface can become less absorptive and more prone to scour, erosion, and runoff, thus reducing groundwater recharge and storage function. Higher temperatures may also cause reduction or loss of isolated vegetated wetlands and drier or transitional fringes of bordering vegetated wetlands. Reductions in regulated wetland size might be temporary or permanent, depending on overall climatic changes. In some cases, former wetlands would no longer be regulated and would be treated as uplands, but would have the potential to return to wetland status and function during wetter times and, therefore, continue to provide crucial buffering capability to upland developed areas.

Potential Strategies

Various adaptation strategies should be investigated as ways to mitigate potential climate change impacts to wetland ecosystems.

1. Land Protection
   a. Identify and protect resilient wetland ecosystems. Focus land protection on areas with high ecological integrity and resiliency over time. Priority areas include large undeveloped blocks of habitat that contain diverse wetland complexes, large wetland systems, and intact riverine systems with abundant associated wetlands.
   b. Identify and prioritize protection of migration corridors between wetland areas and between wetlands and the associated upland habitat including large resilient parcels connected by migration corridors. Planning should include both aquatic and terrestrial connectivity.
   c. Preserve and acquire buffer zones. Buffer zone protection should incorporate predictions for wetland resource and ecological migration resulting from climate changes.
   d. Use LiDAR and other data to identify important wetlands and ensure that a variety of wetland types is represented in land protection planning.
   e. Protect the natural hydrologic function of wetlands with large peat deposits. When peat deposits are exposed to oxygen, they release stored carbon. Preventing the release of carbon stored in peat provides climate change mitigation.
2. Policy, Flexible Regulation, Planning, and Funding
   a. Develop flexible and climate-responsive regulations to support ecological adaptation and resilience.
   b. Survey wetlands across the state to identify vulnerable reaches.
   c. Encourage the passage of bylaws and use of other tools to strengthen protection of isolated vegetated wetlands that are most vulnerable to climate change. Consider revising the Massachusetts Department of Environmental Protection (DEP) "Handbook for Delineating Bordering Vegetated Wetlands Under the Massachusetts Wetlands Protection Act" to include flexible wetland delineation criteria for use when drought and below-normal precipitation conditions are observed in the field. Review U.S. Army Corps of Engineers Draft Interim Wetland Delineation Manual for applicability in Massachusetts.
   d. Explore strategies to improve protection of buffer zones around vulnerable wetlands and vernal pools.
   e. Promote restoration of floodplains.
   f. Consider climate change when evaluating development in vulnerable wetland and floodplain areas.
   g. Consider changes to the 401 Water Quality Certification Regulations to address vulnerable isolated vegetated wetlands.



3. Management and Restoration
   a. Develop flexible and climate-responsive management strategies to support ecological adaptation and resilience.
   b. Coordinate and share information with other states in the Northeast, and maximize coordination between state agencies and between state and local government and federal agencies.
   c. Promote riparian zone and floodplain management, restoration and preservation by removing restrictions between rivers and floodplains, daylighting streams, removing dams, and integrating brownfields remediation projects with floodplain restoration.
   d. Encourage application of geotextiles and bioengineering techniques for erosion control and stream stability. Discourage traditional engineering solutions to flood control such as berms, channelization, channel widening, and armoring of banks.
4. Monitoring, Research, and Adaptive Management
   a. Monitor different types of wetlands. Establish long-term research and monitoring sites.
   b. Support research on adaptive strategies and pilot projects.
   c. Prepare and distribute a wetlands, waterways/ waterbodies and climate change adaptation best management practices handbook.
   d. Consolidate existing MassGIS and Natural Resources Conservation Services soils mapping that identify peat deposits in Massachusetts, and utilize as a planning tool for management of soil carbon stores.

Conclusion

Analysis across habitat categories yielded several similar broad principles for potential adaptation strategies. These were grouped in four categories: Land and Water Protection; Land and Water Management and Restoration; Policy, Flexible Regulation, Planning and Funding; and Monitoring, Research, and the Effective Use of Adaptive Management Techniques. Although strategies are specific to habitat categories, the commonalities across habitats were striking. Many recommended strategies reflect ongoing initiatives that require refocusing and enhancements to incorporate climate change as a factor in decision-making. For example, the land acquisition process at DFG, which already considers habitat connectivity and occurrence of unfragmented interior forest blocks, was recently re-adjusted to also consider climate change as a factor. Land acquisition at EEA and its other agencies is also undergoing a similar effort. Results from the Climate Change and Massachusetts Fish and Wildlife reports will be used to inform implementation strategies of the State Wildlife Action Plan—the major guidance document for decision-making relative to wildlife and habitat management.

This chapter identifies forests, wetlands, rivers, and streams as critical habitats with an array of functions that may be affected by climate change. Protecting these ecosystems, and their functions, will be a crucial step in helping natural systems and human communities cope with climate change. It will be important to develop a flexible regulatory approach that will allow time-sensitive responses to threats, and development of flexible wetland definitions that reflect on-the-ground realities. One of the greatest challenges identified in this chapter is the need to develop an efficient monitoring program that informs an adaptive management decision framework.

The symbol signifies adaptation strategies that are also climate change mitigation actions.

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5 — Key Infrastructure

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5 Key Infrastructure

Introduction

A society cannot function without well-maintained infrastructure that provides critical services for its citizens. These services include providing habitable residential and workspace, transportation, energy sources, telecommunications, clean water, health, and safety, as well as systems to control such infrastructure threats as flooding, and improper release or disposal of wastewater, solid waste, and hazardous materials.

Since the Industrial Revolution, significant infrastructure development in Massachusetts has occurred along the coastline, major rivers, and in floodplains. This trend, along with other urban growth patterns, placed much of Massachusetts' key infrastructure resources in areas that are predicted to experience adverse effects from climate change.

A compounding factor is that most, if not all, of the key infrastructure resources were sited and designed based on historic weather, sea level, and flooding patterns. Climate change impacts are predicted to result in significant changes to these variables, making many infrastructure assets in Massachusetts vulnerable to future damage. It is expected that increased frequency of extreme weather events, combined with sea level rise, will considerably raise the risk of damage to transportation systems, energy-related facilities, communication systems, a wide range of structures and buildings, solid and hazardous waste facilities, and water supply and wastewater management systems. Consequential changes in precipitation patterns, particularly from extreme weather events, will threaten key infrastructure assets with flood and water damage.

The seven main infrastructure sectors analyzed in this chapter are listed in Table 4.

Overview of Vulnerabilities

Predicted climate change impacts have the potential to damage or destroy key infrastructure throughout Massachusetts. A problem common to infrastructure design is that planners, engineers, and designers traditionally have used historic weather characteristics to determine the weather conditions that infrastructure assets can withstand. Since future climate patterns are expected to be different, designs based on historic weather patterns could leave infrastructure at risk.

Predicted climate change impacts—in particular, sea level rise and more numerous extreme storm events—have the potential to impair public and private services and business operations. A substantial rise in sea level, even during calm weather, will cause flooding of buildings, roadways, tunnels, water and wastewater treatment facilities, and equipment and instruments associated with power stations and telecommunication facilities. Solid waste landfills and hazardous waste sites located in low lying coastal areas also will be vulnerable. In addition, saltwater intrusion into freshwater aquifers located near the

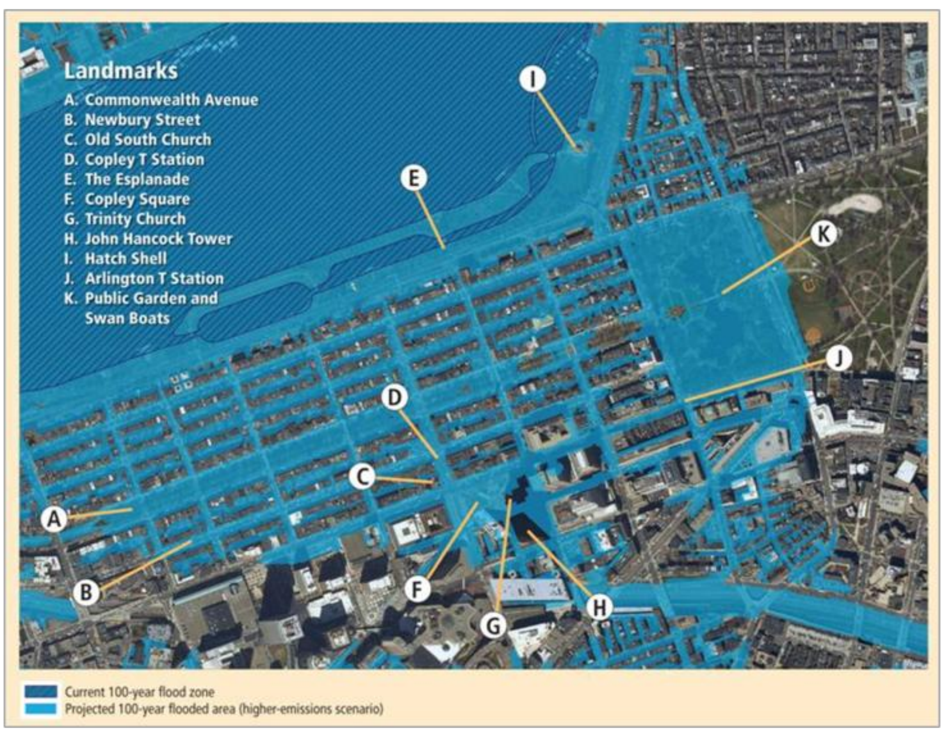
SECTOR	INFRASTRUCTURE INVOLVED
Energy (electric, gas, petroleum)	Production, transmission, storage, and distribution including power plants, substations, electric lines, natural gas systems, and fuel systems
Transportation (land, sea, air)	Roads, highways, bridges, tunnels, subway, commuter and commercial rail, ferries, buses, airports, and ports
Water (supply, wastewater, stormwater)	Water sources, pump stations, storage tanks or reservoirs, distribution systems, drinking water treatment, municipal separate storm sewer systems, combined wastewater and stormwater systems, decentralized stormwater management systems, and septic systems
Dam Safety and Flood Control	Dams, dikes, and land levees
Solid and Hazardous Waste	Solid waste facilities and hazardous waste storage and management facilities
Built Infrastructure and Buildings	Commercial, residential, industrial, institutional, and governmental buildings
Telecommunications	Phone, internet, and cable

Table 4. ***Key infrastructure sectors vulnerable to climate change impacts***

coastline will compromise coastal drinking water sources.

Sea level rise will expose infrastructure to storm surges and shift the current 100-year coastal storm floodplain and velocity zone landward to cover much of the Back Bay and Boston waterfront areas, for example. Some of the state's most significant infrastructure—including the Massachusetts Port Authority's Logan International Airport and port/ maritime facilities, the Massachusetts Water Resources Authority's (MWRA) Deer Island Sewage Treatment Plant, and highway and public transit tunnels—are located in these areas.

The expected increases in intensity and frequency of extreme storm events could severely impact infrastructure, damage public and private services, and negatively impact business operations throughout the state. High winds and flooding along rivers and streams have incapacitated both inland and coastal communities during large storm events such as the Blizzard of '78, the Mother's Day Storm of 2006, the Ice Storm of December 2008, and to some extent the recent Tropical Storm Irene (2011). In the past, such storms have been relatively infrequent and services have been restored relatively quickly. Occasionally much larger storms, such as the Hurricane of 1938, Hurricane Carol (1953), and Hurricane Donna (1960), have caused extensive devastation throughout Massachusetts. With more frequent large storm events, damage to key infrastructure could become more frequent, take longer to repair, and entail more costly repairs and economic disruption.



General Strategies

Preparing for future climate change impacts will take a coordinated effort of private and public sectors, non-profit organizations, and managers and users of infrastructure resources. Primary strategies should promote actions that will bolster infrastructure resources to defend them against these impacts while simultaneously supporting other sectors' strategies,and promoting due diligence and sound management decision-making. These include:

1. Accurate Mapping and Surveys: Update floodplain mapping using new LiDAR elevation surveys and climate models to identify at-risk facilities and natural features, and establish action priorities with cost estimates. Conduct comprehensive LiDAR mapping of the Massachusetts coast, shoreline waterways, and other flood-prone land areas and facilities, complemented by a detailed three-dimensional survey of individual at-risk facilities to determine vulnerabilities, most cost-effective strategies (defend or retreat), and action time frames.

2. No Regrets Actions: These measures will bolster infrastructure resources for future climate change impacts and improve other related efforts. They could also be actions that reduce greenhouse gas emissions and save future investments and valuable resources. Examples include:

•conservation, efficiencies, and reuse of key resources, such as drinking water conservation and improved stormwater management,

which will provide capacity and resilience for many key infrastructures to withstand climate change impacts;
- cost-effective and simple improvements, such as flood-proofing structures, which can be made during routine maintenance and upgrading.

3. Explore Possible Changes in Land Use, Design, Site Selection, and Building Standards: Investigate amendments to existing land use planning and zoning laws and regulations and building codes to account for expected climate change impacts when designing and constructing new infrastructure, repairing and upgrading existing infrastructure, and evaluating sites and areas suitable for infrastructure development. Bolster ongoing efforts by state agencies to factor climate change into future design, permitting, and building requirements. These land use, siting, design, and building standards should be reviewed on a routine basis to integrate new knowledge on predicted climate change impacts.
4. Enhance Natural Systems: Provide protection and resilience of infrastructure to climate change impacts by enhancing natural systems such as restoring wetlands, coastal features, and flood storage capacity. Restore the natural hydraulic features of watersheds to increase resiliency and capacity redundancy in wastewater systems, water supplies, and stormwater management resources.
5. Identify Lead Times for Adaptive Construction: Since different types of facilities have varying life spans, translate those timeframes into lead times for infrastructure replacement and rehabilitation. Energy infrastructure that has a lifespan of 30 years will have a different adaptation strategy than a power plant that may have a 50- to 60-year lifespan. The amount of time needed to permit, repair, improve, or build infrastructure will vary and should be identified.

The remainder of this chapter examines the vulnerability of various infrastructure sectors to climate change impacts and outlines no regret, short -term, and long-term strategies that will continue to be reviewed and considered for implementation regionally or statewide.

Energy

Without reliable energy services, the basic needs of residents, visitors, businesses, and governments cannot be met. Lost or damaged energy supplies would cause loss of power to homes, schools, government buildings, hospitals, industries, and businesses, as well as to various types of infrastructure, such as communications systems, which depend on energy to function.

Existing Resources

The electric power infrastructure is an interconnected system of power plants, substations, and hundreds of miles of high voltage transmission lines and local distribution wires. There are approximately 170 electric generating facilities throughout Massachusetts, ranging in size from less than one to hundreds of megawatts (MW). Several of the largest plants are located along the coast. The fuel used by generators to create electricity is diverse—natural gas, coal, oil, nuclear, and renewable sources such as solar, wind, hydro, and biomass. Massachusetts annually consumes about 56 million megawatt-hours (MWh) of electricity representing 46 percent of New England’s total consumption (U.S. Department of Energy, 2008). ISO New England reports that, in 2008, the Greater Boston area consumed about 40 percent of the state’s electricity. A large share of the electricity is generated in-state, but Massachusetts also relies on electricity from neighboring states.

Massachusetts is the largest consumer of natural gas in New England. The US Census Bureau reported that gas is the state’s largest energy source for home fuel (about 44 percent), and ISO New England notes that natural gas is also the leading energy source for electricity generation in New England as a whole (38 percent). Massachusetts receives its gas supplies via three interstate pipeline systems and via liquefied natural gas (LNG) tanker ships. Massachusetts has three liquefied natural gas import terminals. One is located on land in Boston Harbor and the other two are located 11 to 13 miles offshore. Ships connect to buoys at the offshore terminals, the LNG is gasified, and then it is transported via undersea pipelines. Gas is delivered to customers through 1,000 miles of underground transmission pipes and 21,000 miles of local distribution pipes.

Massachusetts is dependent on petroleum product imports from domestic and foreign sources. There are five major petroleum terminals along Boston

Harbor waterways and smaller terminals in other coastal communities. Almost 90 percent of the petroleum products are imported into the state by ship or barge. To reach inland regions such as western Massachusetts, petroleum is transported via trucks from in-state and out-of-state terminals. The oil terminals in Springfield receive petroleum via local underground pipelines fed from ships in New Haven, CT, and Providence, RI.

Impacts and Vulnerabilities

To assess climate-induced changes and impacts for this sector, assets were identified and organized into three broad subcategories: 1) facilities, including electric generation plants (nuclear, natural gas, oil, and coal), LNG terminals, propane plants, petroleum product terminals and storage facilities, and electric substations; 2) above-ground wires and pipes; and 3) below-ground wires and pipes.

The energy sector's three primary climate change concerns are flooding (due to increased precipitation and storm surge), extreme events (such as hurricanes and snow and ice storms), and increased temperature. These events can affect almost all infrastructure assets. In addition, climate change impacts that affect energy producing regions beyond Massachusetts' borders, such as the Gulf Coast, could cause greater frequency and severity of energy supply interruptions for Massachusetts.

The following are the predicted impacts on energy infrastructure:

- Extreme and more frequent weather events, including flooding, may damage energy production and delivery equipment such as generation plants (e.g. the Pilgrim nuclear power station), terminals, storage facilities and above- and below-ground wires and pipes. Damaged infrastructure will lead to interrupted service, degraded energy reliability, increased equipment maintenance or replacement costs, and adverse impacts to public safety.
- Sea level rise and storm-related flooding may require relocating coastal infrastructure, which would require new real estate acquisitions for replacement sites.
- Extreme temperature changes could result in an increased demand for cooling in summer and a decreased demand for heating in winter. One 2005 study of changes in Boston's heating and cooling demand indicates that, "depending on the climate scenario, household electricity consumption in peak summer months may be nearly three times that of the 1960-2000 average, with over 25 percent of the increase directly attributable to climate change" (Amato et al., 2005). Such changes also can shift energy production and use. For example, high temperatures reduce thermal efficiency of electric generation. This could challenge the ability of the electric system operators to meet peak electricity demands.
- There may be lengthened repair times and delays. Repair crews will find it more difficult to work in protective gear for extended periods in high temperatures, during prolonged rain or in extreme cold.

Potential Strategies

No Regrets Strategies

1. Encourage Energy Efficiency. Energy efficiency is both a mitigation and an adaptation strategy. Decreased energy demand defers the need for additional infrastructure and helps to avoid peak load outages.

Impacts of the Ice Storm of December 2008

From December 11 through December 18, 2008, central, western, and northern Massachusetts experienced a severe ice storm, which caused devastation over almost 7,000 square miles. The storm damage affected the energy and transportation infrastructure, homes and schools, and even the Appalachian Trail. Over one million customers were impacted by power outages with over 550,000 customers losing their electricity at the peak of the storm, and some for up to two weeks. This also caused additional damage, such as frozen water pipes in commercial and residential properties, as well as lost revenue. Countless trees were damaged, with downed trees and tree limbs blocking roads, damaging property and bringing down power lines.

The storm was very costly—the Federal Emergency Management Agency (FEMA) obligated over $32 million for reimbursement to seven Massachusetts counties for eligible costs; state costs exceeded $7 million and municipalities expended over $5 million. National Grid, one of the primary electrical suppliers in the area, claimed over $30 million in storm-related costs.

2. Educate Asset Owners and Regulators. Regulators, energy asset owners, and privately- and municipally-owned utilities should understand the future impacts of climate change on infrastructure and the benefits and costs associated with preparing for and responding to climate change.
3. Diversify Energy Supplies. To avoid reliance on supply from one geographical region that may be more vulnerable to climate change, utilities and other energy suppliers should continue to assess the diversification of their energy supply portfolios and factor in future climate change predictions.
4. Track Trends in Energy Demand, taking into account climate change forecasts. Regulators, energy asset owners, and privately- and municipally-owned utilities should carefully track changes in energy demand resulting from climate change and factor such changes into future planning and procurement strategies.
5. Plan for Changes in Consumers' Expectations Regarding Energy Types. Consumers have altered their perceptions about climate change. As a result, more consumers are requesting energy supplies from cleaner energy sources. Closely monitor consumer trends to anticipate the types of energy supplies that will be in demand, such as renewable energy and emerging biofuels, and the potential impacts that climate change will have on these new sources.

Short-Term Strategies

1. Utilize and Accelerate Deployment of New Energy Efficiency Technologies. Smart Grid technology may stabilize load requirements during high demand periods, thus ensuring supply and system integrity as well as increasing power reliability during storms, flooding, or high peak load.

A **Smart Grid** is a network for electricity transmission and distribution systems that uses two-way, state-of-the-art communications, advanced sensors and specialized computers to improve the efficiency, reliability, and safety of electricity delivery and use.

2. Encourage Research and Development of Renewable Energy Technologies. Renewable energy technologies such as solar, wind, tidal and wave power, and other emerging renewable applications are new and growing sources of electricity supply and jobs. They will diversify our electricity generation portfolio and reduce pollution.
   - Wind: Climate change (temperature, precipitation, humidity, solar) may lead to changing wind patterns. Design wind turbines to meet low-medium-high wind speeds. Monitor onshore, nearshore, and offshore wind patterns to determine optimal siting locations.
   - Solar: With enhanced monitoring and preparation, Massachusetts can rapidly protect its growing solar electric capacity from severe weather impacts, including panel degradation. Careful monitoring of the Massachusetts climate and better predictions will be necessary to determine the proper specifications of future photovoltaic investments.
3. Consider Undertaking a Regional Analysis of New England's Integrated Energy Infrastructure. Analyze climate change effects on interstate energy infrastructure. The New England states, along with the electric Independent System Operator of New England (ISO New England), and gas and oil industry representatives, should work together to develop a comprehensive regional analysis of climate change impacts on supply and demand as well as storm response.

Long-Term Strategies

1. Collaborate with other states and utilities to ensure the best-integrated strategies are deployed, particularly given the size of capital and operational investments in utilities infrastructure, and support facilities with long life-spans.
2. Utilities should work with land use planners at the state environmental and regulatory levels to secure necessary parcels to meet the need for energy infrastructure that is threatened by flooding, extreme storm events, and increased temperature.

Transportation

The Massachusetts transportation system is vitally important to the daily functioning and economic future of the state. The transportation sectors outlined in Table 5 and their respective infrastructure ensure economic vitality and quality of life by safely and efficiently moving people, goods, and services throughout the state.

Existing Resources

To appreciate the breadth and depth of our reliance on a diverse transportation network, Table 5 outlines the basic elements of the state's road and rail network and other transportation infrastructure.

Impacts and Vulnerabilities

The impact to the various forms of transportation, particularly along the coast, could dramatically affect the ability to sustain normal levels of commerce, public health, safety, welfare, and security, and to respond to natural or human-induced severe events. Coastal transportation infrastructure is most vulnerable to sea level rise and extreme weather events including high winds, waves, and storm surge. High temperatures and dense air conditions could increase runway length requirements to accommodate typically diminished aircraft performance in such weather situations.

Inland infrastructure also may be affected by changing precipitation patterns, extreme weather events, and increased temperatures. Massachusetts may not have sufficient alternative transportation modes and routes available in particularly sensitive locations to provide backup and continuity of service in responding to climate change effects.

Potential Strategies

No Regrets Strategies

1. Continue Maintenance of Existing Infrastructure. Maintain existing transportation infrastructure to minimize the chances of flooding or other damage that might occur before final or more permanent adaptation plans can be implemented.

TRANSPORTATION RESOURCE HIGHLIGHTS*	
ROADS	71,887 lane miles (60,970 local lane miles at 85 percent, 10,917 state lane miles at 15 percent) 5,116 inventoried bridges (3,550 state, 1,566 municipal) Vast majority of total freight in Massachusetts moves by truck ($307 billion commodity value, 196 million tons)
RAIL	438 million Massachusetts Bay Transportation Authority (MBTA) passengers per year, or 1.2 million passengers per day (5th highest transit ridership in U.S.) 175 cities and towns, with a total population of 4.7 million people, serviced by the MBTA 2,500 vehicles, 258 stations, 885 miles of track, 500 bridges, 20 miles of tunnels, 19 maintenance shops 2.65 million Amtrak riders per year (Boston's South Station is Amtrak's 6th busiest station in U.S.) Commercial rail traffic: 14 carriers carry about 500,000 rail carloads per year over 1,000 miles of track
AIR	The 39 public-use airports handled about 2.1 million operations (takeoffs & landings) and 26.0 million passengers in 2009. Of those totals, Logan Airport accommodated 345,300 operations and over 25.5 million passengers The other 38 public-use airports accounted for 1.75 million operations and 476,000 passengers Logan Airport managed 191.1 million pounds of cargo, 28.8 million pounds of mail, and 326.5 million pounds of express/small packages in 2009 198 private landing areas: 112 helipads, 47 landing strips/airfields, 38 seaplane bases, and one military landing strip
BUS	29 million passengers per year use 1,372 buses and vans provided by 15 Regional Transit Authorities MBTA operates 1,055 buses on 186 routes over 761 route-miles; THE RIDE, a paratransit service, operates 568 vehicles in 62 municipalities and averages over 1.58 million trips per year Boston's South Station provided about 190,000 bus trips for an estimated 5.7 million passengers in 2009; these figures do not include charter, tour, school, and non-South Station bus trips throughout the state
WATER-BORNE TRANSIT	2.7 million passengers and 590,000 vehicles per year on island ferries 1.22 million commuter ferry passengers per year 105 cruise ships from 15 cruise lines carry 300,000 passengers per year Port of Boston handles the majority of the state's bulk and containerized cargo; 11 ocean freight ports total
WALK/BIKE	12 percent Massachusetts residents and 24 percent Cambridge residents walk to work 48 percent of all downtown Boston trips are made by walking 13.3 percent walk and 1 percent bike to work in Boston (1st and 15th respectively of major US cities, and 1st in combined

Table 5: ***Massachusetts' Transportation Resources***

** References listed at the end of the chapter*

2. Expand the use of the statewide GIS-based system asset maps by combining them with updated floodplain mapping and revised peak flood flow calculations.
3. Formulate risk-based methods to evaluate service life of infrastructure assets against adverse climate change.
4. Update hydrologic and hydraulic analyses statewide, including engineering methods used in the calculation of peak flood flow rates, to reflect influence of climate change-induced events (e.g., the U.S. Geological Survey's Regionalized Peak Flow Equations for Massachusetts and the 50-year old National Weather Service's Precipitation Frequency Atlas, TP-40).
5. Research and Develop Engineering Solutions. The Massachusetts Department of Transportation and Massachusetts Port Authority should work with regional and municipal agencies to identify, develop and implement solutions—including reconstruction, removal, or relocation of vulnerable infrastructure—to protect existing assets from climate change impacts in the long- and short-term.
6. Protect Existing Infrastructure. Modifications include elevating, armoring, modifying, or relocating critical infrastructure. Airport, mass transit, port, and highway agencies should consider sizing stormwater management structures (e.g., pipes, culverts, outfalls) for future storm events and balancing upfront costs of incrementally larger structures today with the future costs of replacing an entire drainage system.

Short-Term Strategies

1. Public and private transportation entities should adjust standard maintenance and inspection procedures to take into account climate changes impacts, including increasing the frequency of routine inspections of coastal zone and inland bridges and drainage structures and initiating comprehensive regional asset damage inventories after major storm events.
2. Develop New Design Standards. Revise standards to be consistent with guidelines reflecting climate considerations issued by such entities as the American Association of State Highway and Transportation Officials, Federal Highway Administration, American Public Transit Association, Federal Transit Administration, U.S. Department of Transportation Maritime Administration, and the Federal Aviation Administration.

Long-Term Strategies

1. Encourage innovation across transportation sectors. Encourage use of new technologies at airports for navigation aids and airfield lighting systems that function better during storm events. New aircraft technologies could also improve landing and takeoff performance, potentially minimizing adverse impacts of more consistently high temperatures.
2. Enhance water-based transit options in affected coastal and riverine areas as a long-range transport alternative and as an interim back-up to damaged infrastructure.
3. Develop financing mechanisms. Evaluate and implement as necessary new ways to fund the anticipated expenses, including construction and long-term maintenance and operation costs, to address climate change impacts at the state and local levels.

Water Resources

Water-related infrastructure includes multi-component systems involved in procuring, treating, and distributing drinking water; collecting, treating, and discharging wastewater; managing stormwater; and using dams, levees, seawalls, and other structures to control surface hydrology. Most of the facilities that support these infrastructure resources are publicly owned by municipalities.

Existing Resources

Maintaining infrastructure associated with potable water is critical to the public health and safety of Massachusetts residents. Approximately 95 percent of the 6.5 million residents living in Massachusetts obtain their drinking water from one of the state's 531 community public water supply systems. The remaining 5 percent of Massachusetts residents obtain water from one of the estimated 550,000 private wells. Raw water from approximately 82 percent of the water sources is treated prior to being distributed for public consumption.

Approximately 79 percent of Massachusetts' 6.5 million residents discharge 785 million gallons of treated sewage into the state's waters each day through over 20,000 miles of pipe and 126 treatment facilities. According to the Massachusetts Water Resources Authority (MWRA), the Deer Island Sewage Treatment Plant alone treats an average of 350 million gallons of sewage per day from about 2.1 million people in 43 metro Boston communities (MWRA, 2010). Another 21 percent of the homes, municipal buildings, and businesses (Massachusetts Infrastructure Investment Coalition, 2007) are not connected to a sanitary sewer system and discharge sewage to an on-site subsurface sewage disposal or to an approved treatment facility with a state groundwater discharge permit. There are 280 municipal and private facilities that discharge wastewater to groundwater (Felix, 2009).

Stormwater infrastructure is comprised of municipal separate storm sewer systems and combined wastewater and stormwater systems. Historically, stormwater management systems consisted of pipes, culverts, dams, detention basins, and storage reservoirs and were designed to convey stormwater, control peak flows, and prevent flooding. More recently, stormwater control measures have been designed to treat and infiltrate stormwater.

There are hundreds of dams and levees controlling water flow in rivers and streams throughout the state. Many of these are large structures that hold back significant volumes of water. Seawalls, groins, and other coastal flood control structures are common along the 1,500 miles of Massachusetts coastline.

Impacts and Vulnerabilities

Sea level rise could potentially inundate numerous municipal collection systems and some wastewater treatment plants along the Massachusetts coast and inland to a point where it could make economical sense to abandon them after their current useful lives. At other locations, it may make sense to use larger regional facilities (or expand existing upland facilities) for the treatment of wastewater and then use decentralized systems to discharge the treated water back in its original watershed. In general, to preserve water management operations (such as wastewater treatment, stormwater systems), it is important to take measures to reduce stress on river and coastal infrastructure such as dams, levees, and seawalls.

Another challenge is that existing Massachusetts Stormwater Management Standards apply only to sites undergoing development or redevelopment which are subject to review under the Wetlands Protection Act, Rivers Protection Act, or the Water Quality Certification Program, and do not apply to other upland areas that generate stormwater.

Potential Strategies

No Regrets Strategies

1. Continue to Facilitate Enhancement of Natural Systems. Redirect inflow from traditional stormwater collection systems into systems using low-impact design technology and restored natural hydrology to keep stormwater on site and increase available capacity and groundwater recharge. Increased use of groundwater recharge would also assist in reducing polluted runoff to surface waters, decrease flooding, and enable existing dams, levees, and other flood control structures to operate during more extreme storm events.
2. Continue to Promote and Expand Conservation and Reuse Efforts. Enhance ongoing efforts to conserve potable drinking water, reduce wastewater discharge, and decrease stormwater runoff. Implement the Massachusetts Water Conservation Standards and advance the use of treated wastewater, especially in commercial and industrial settings.
3. Coordinate Information Gathering. Coordinate efforts of land use planners, facility designers, and regulators in the collection and analysis of basic geographical, geologic, and engineering information needed to characterize vulnerabilities of water-related infrastructure systems.

Short-Term Strategies

1. Offset Impacts to Water Supplies. Consider revising the Massachusetts State Plumbing Code

Mother’s Day Storm—Infrastructure Overwhelmed!

The 2006 Mother’s Day storm began Friday, May 12 and, for the next 100 hours, dumped up to 15 inches of rain on many North Shore communities in Massachusetts. A U. S. Geological Survey flood gauge at Lowell showed that the flood level in the Merrimack River reached 59 feet, making it a 40-year occurrence event. On May 13, two days before flood levels in the Merrimack River peaked, a force main to the Haverhill Wastewater Treatment Plant gave way, spilling 35 million gallons per day of untreated sewage into the Merrimack River. The break occurred when the rapidly moving river in a tributary washed out a culvert that ran beneath a section of a power easement roadway and the force main. As the storm continued, waters flowed over bridges and into the streets and basements throughout the region. It took almost a week to repair the break.

The Department of Environmental Protection estimates that, had the water level in the Merrimack risen another two to three feet, wastewater treatment plants in the Greater Lawrence Sewer District would have lost their pumping stations and power to their treatment plants, resulting in major additional discharge of untreated sewage to the Merrimack River. It is also likely the drinking water treatment facilities in Tewksbury, Lowell, and Lawrence would have also become incapacitated.

to encourage and (in some cases) require water conservation. Assess the potential to increase water supplies through the reuse of non-potable water and use of greywater technologies.

2. Make Near-Term Changes to Publicly Owned Treatment Works. Evaluate flood-proofing vulnerable drinking water and wastewater facilities by raising the elevation of structures above predicted flood stages, installing watertight doors and windows, replacing wet/dry well pumps with submersible pumps, increasing emergency back-up provisions to keep all key equipment operational, and relocating vulnerable equipment. Ensure emergency and contingency plans include the use of backups, such as emergency generators for power generation.
3. Address Stormwater Flows
    a. For new development and redevelopment projects in upland areas, DEP should investigate developing requirements similar to those currently contained in DEP's Wetlands/ Water Quality Certification Regulations, which promote stormwater infiltration into the ground (i.e., at its site of origin where feasible), rather than direct run-off toward central stormwater drainage systems that discharge to surface waters. This will help decrease flooding, improve aquatic baseflow, recharge aquifers, and improve the quality of surface waters;
    b. Expand implementation of low-impact development as a stormwater mitigation mechanism;
    c. Periodically evaluate the long-term control plans for Combined Sewer Overflows (CSO) developed by the 24 Massachusetts CSO communities to determine if additional efforts are needed to protect the environment and public health from more frequent CSO activations. Free-up wastewater treatment and conveyance capacity by continuing to identify and remove infiltration and inflow from wastewater collection systems; and
    d. Expand public outreach and education efforts concerning the negative impacts of stormwater on flooding, the quality of rivers and streams, and the quantity of water in aquifers.
4. Enhance the SRF Program. Review and potentially modify the State Revolving Fund (SRF) Program —which provides $100 million of low-interest loans for water and wastewater projects—to encourage communities to address climate change impacts and avoid investments in highly vulnerable areas.

Early Experiences in Climate Change Adaptation at MWRA

During the 1980's and 1990's, the Massachusetts Water Resources Authority (MWRA) designed and constructed the massive Deer Island Wastewater Treatment Plant to meet federal regulations and provide environmentally sound treatment of wastewater from two million people in the metropolitan Boston area. A key component of the facility was construction of a 9.5 mile long, 24-foot diameter outfall tunnel into Massachusetts Bay, bored in solid rock 100 feet under the bay. Anticipating that the outfall would be in service for 50 to 100 years, MWRA engineers accommodated for changes in sea level in its design. As the sea level rises, water leaving the tunnel will push against a higher head, reducing the capacity of the tunnel and the treatment plant. In 1989, the designers reviewed the most current projections in climate modeling and decided to raise the entire plant about 1.9 feet higher to accommodate potential sea level change for at least the first 50 or 60 years of the facility's service.

5. Compile critical information on water and wastewater treatment facilities, including elevation data, location of pump stations and other affiliated structures; identify the location and capacity of stormwater conveyance waterways and structures.
6. Analyze how current flooding conditions and U.S. Federal Emergency Management Agency (FEMA) flood maps will change under certain climate change scenarios.
7. If appropriate, revise the Wetlands Protection Act Regulations and other regulatory tools that cite FEMA maps (which are required to reflect current and not future conditions) to reflect forecasted flood boundary alterations that may be linked to climate change.
8. Implement a program to educate water resource utility owners and operators on the vulnerabilities of their assets to climate change impacts.

Long-Term Strategy

Use Adaptive Management Techniques to Develop Long-term Infrastructure Sustainability Plans. Develop long-term sustainable solutions that include a mix of both decentralized resources and regional approaches. Some solutions may involve centralized or decentralized physical assets.

Dam Safety and Flood Control

As the major flood control structures used in Massachusetts, dams have been constructed for agricultural, industrial, and energy generation purposes. Many hydropower dams were constructed in the 17th century. The Department of Conservation and Recreation (DCR) Office of Dam Safety is responsible for the oversight of dam safety. Under current laws, responsibility for periodic inspections, inspection report preparation, and mandated preparation of emergency action plans for "high hazard potential" structures falls to the dam's owner.

Among the predicted climate changes for the Northeast U.S., extreme storm events, sea level rise, and increased intensity of precipitation pose the greatest threats to flood control structures (for more on flood control structures along the coast, such as sea walls, see section on 'Coastal Engineering for Shoreline Stabilization and Flood Protection' in Chapter 8) in Massachusetts, which, for the most part, were originally designed to control floodwater volumes and velocities based on historic weather patterns.

Existing Resources

There are more than 2,800 known dams in the state, most privately owned and operated. Of the known dams, at least 1,349 are not subject to the state dam safety regulations, due to their size, design, and ownership status. Of those subject to regulation (1545 dams):

- 304 are classified by the DCR as having a "high hazard" potential (dams located where failure will likely cause loss of life and serious damage to key infrastructure and the built environment);
- 727 are classified as having a "significant hazard" potential (dams located where failure may cause loss of life and may damage key infrastructure and built environment or cause temporary loss of use of services and key facilities); and
- 514 are classified as having a "low hazard" potential (dams located where failure may cause minimal property damage, and no loss of life is expected).

Unlike the case in many western and mid-western states, dikes and levees are not common in Massachusetts and other eastern states. A few highly specialized flood control structures are located in the state, including a hurricane storm surge barrier in New Bedford, flood diversion canals in North Adams, and levees located along the Connecticut River in Springfield, Holyoke, and Chicopee.

Many dams no longer serve the original purpose of their designs. Additionally, many contribute to major water quality problems—they can create a reservoir of contaminated sediments and severely limit the ability of waterways to use natural systems to help maintain clean water.

Potential Strategies

No Regret Strategies

1. Update modeling protocols and precipitation data. Use the Northeast Regional Climate Center data from 1993 (or most recent) in future safety analyses and design work until more up-to-date climate change data becomes available.
2. Prepare or revisit emergency action plans. Use approaches and assumptions in the preparation of emergency action plans that consider the most updated estimates of likely levels of precipitation, flooding, and extreme storm events, particularly when preparing or revising emergency actions that address "high hazard" dams.
3. Encourage cooperative efforts with federal and regional agencies to improve dam safety. Cooperate closely with federal agencies, the Association of State Dam Safety Officials, and various state agencies as new analytical data are developed and made available to the planning, engineering, and regulatory communities, including DCR data on dam locations and risk status for the entire state.

Short-Term Strategies

1. Develop Dam Planning within State Agencies. State agencies, with the Massachusetts Emergency Management Agency (MEMA) taking a lead role, should coordinate risk assessment planning for high hazard potential dams, using the worst-case assumptions of climate change impacts.
2. Mandated Insurance Program. Evaluate the value of establishing insurance requirements for dam owners and insurance companies to acknowledge and financially cover liabilities, anticipate future threats, address potential vulnerabilities, and reduce the state's expense in emergency response and cleanup.

Long-Term Strategies

1. Continue support for the Division of Ecological Restoration's river restoration program. The program helps facilitate dam removal with the

goals of preserving river continuity, maintaining the natural cleansing capability of waterways, and preventing water quality degradation associated with contaminated sediments build-up behind a dam.

2. Creative financing via federal and state opportunities. Explore various state and federal funding opportunities and evaluate expanding their eligibility criteria to provide low-interest loans for beneficial dam removal projects.
3. Continue to encourage the establishment of public, non-profit, and private partnerships to enhance efforts to target the removal of dams that either are deemed high hazard under DCR's rankings or which cause water quality or habitat impairments.
4. Seek to remove potential institutional barriers and evaluate the benefits of a streamlined dam maintenance and removal review and approval processes.

Solid and Hazardous Waste

Solid and hazardous waste infrastructure comprise solid waste landfills, combustion facilities, transfer stations, and hazardous waste treatment, storage, and disposal facilities. Other entities that have the potential to generate hazardous waste in the event of a natural disaster include waste generators such as retailers with hazardous materials (e.g., pharmacies and chain retail stores), certain chemical handling businesses, fuel tank farms, waste transporters, and residences equipped with heating oil tanks and containing hazardous household products.

Existing Resources

Massachusetts hosts 25 active solid waste landfills, seven solid waste combustion facilities, 230 active handling facilities (e.g., transfer stations), several large recycling facilities (e.g., the Springfield Materials Recycling Facility), and over 700 inactive landfills, many of which are located near environmentally sensitive wetland areas.

Most of the 12 hazardous waste treatment, storage, and disposal facilities (TSDFs) are not located in floodplains or coastal areas. One exception is Clean Harbors Braintree, New England's largest hazardous waste TSDF, which is located on the Fore River in Weymouth. Most facilities store their hazardous waste in containers that can be moved easily. Tank areas are above-ground and are diked to protect them from heavy stormwater run-off. In an emergency, hazardous waste in drums and tanks can be removed and shipped to a less vulnerable facility quickly, provided that roadways are passable.

Industries with hazardous waste and hazardous materials, however, are concentrated in coastal cities. There are approximately 680 large quantity hazardous waste generators and several thousand very small quantity generators in Massachusetts. Smaller generators may lack resources for emergency planning, which may increase the risk of abandoned hazardous materials during a flooding or storm event.

Impacts and Vulnerabilities

Climate change impacts could cause flooding of low-lying solid waste landfills, generation of large volumes of solid waste following a major storm event, and release of large amounts of fuel and hazardous materials (such as paints, solvents, and pesticides) from flooding of private homes and businesses.

More rainstorms and associated runoff could cause structural damage, increased release of leachate, or even exposure of waste at landfills located in historic wetlands and other sensitive locations. Erosion could increase because culverts and detention basins associated with solid waste facilities may not be able to handle increased runoff. More leachate could lead to a need for larger storage tanks or could cause increased discharge of leachate into the sewer system. If flooding conditions persist, contaminants from within the landfill could be carried away by floodwaters. Waste management services could be disrupted if facilities are closed due to damage or if capacity is exceeded due to an unexpected surge in solid waste production.

Potential Strategies

No Regrets Strategies

1. Enhance Geographic Information Systems (GIS) data for solid and hazardous waste management facilities.
2. Ensure that contingency plans for hazardous waste treatment, storage, and disposal facilities and large quantity generators include a description of procedures, structures, or equipment used at the facilities to prevent flooding and run-off from hazardous waste handling areas.

Short-Term Strategies

1. Develop better mapping data to identify solid and hazardous waste facilities that would be vulnerable to rising sea level and new, more frequent, or more severe flooding.
2. Consider requiring all solid and hazardous waste facilities operating in areas prone to coastal or inland flooding to prepare adaptation plans. This could be addressed through the permit renewal process.

3. Encourage local government agencies that oversee the operation or building of industrial facilities with hazardous waste and hazardous materials in areas prone to flooding to develop outreach materials on flood adaptation measures.
4. New retail gasoline fueling stations should be sited and designed using most recently available FEMA flood study and map information, incorporate additional provisions to address sea level rise over design life when located in a coastal flood zone, and contain appropriate containment systems, while older and abandoned gas stations should be identified and evaluated for their vulnerability under various climate change scenarios.
5. Enhance state and local efforts to regularly collect household hazardous waste.
6. Solid and hazardous waste infrastructure and emergency planning efforts should contemplate the need for possible temporary, large-scale storage of hazardous waste and materials generated from flooded properties.
7. Implement the Massachusetts Disaster Debris Management Plan as approved by the Federal Emergency Management Agency (FEMA). Implementing the recommendations of this plan will significantly enhance the abilities of local and state governments to respond to the challenges of managing disaster debris.

Long-Term Strategies

1. Develop a regional contingency plan for household hazardous waste collection during flood events.
2. Develop a detailed inventory of existing and potential hazardous waste generators and calculate the total hazardous waste facility storage capacity for Massachusetts.
3. Evaluate modification of the siting and design requirements for new and expanded waste management facilities to account for predicted site-specific climate change impacts that could be expected during the life of the facility.

Built Infrastructure and Buildings

Existing Resources

The built infrastructure and buildings sector encompasses the design, building, and operation of publicly- and privately-owned buildings. Many of them are situated in areas along the coast or major waterways and floodplains that may be particularly vulnerable to climate change impacts like storms and flooding.

Impacts and Vulnerabilities

Building design standards are based on historic climatic patterns. As climate patterns are likely to be very different in the future, the existing built infrastructure in the state could be adversely affected. Thermal stresses on building materials will be greater, cooling demands will be higher, existing flood-proofing may be inadequate, floodplains may extend to areas with unprotected structures, heat island effects may increase, corrosion of building materials may accelerate due to salt water intrusion, and building-related illnesses, primarily caused by mold build-up, may increase.

Potential Strategies

Strategies designed to protect existing and future buildings from predicted climate change impacts should consider the location of the existing/proposed building, the timing of when a projected climate change impact is expected to occur, the life-span of the structure, historical significance of the existing structure, and the cost and engineering involved with moving, demolishing-recycling, or protecting the structure.

The Spaulding Rehabilitation Hospital and Projected Sea Level Rise

Emergency facilities must do more than respond to natural disasters, they must also be planned and developed with these potential threats in mind. When planning its new eight story, 132-bed facility in the Charlestown Navy Yard, the Spaulding Rehabilitation Network considered both the current FEMA floodplain maps and sea level rise projections of between 0.27 m & 1.4 m (0.9 & 4.6 ft) over the next 75 to 100 years.

Designers concluded that a rise in sea level of two feet over 75 years was a reasonable projection, resulting in a shifting of the 100-year floodline. Taking into account height restrictions and the relationship of the building to the surrounding topography, the finished floor of the building has been established at 0.41 m (1.35 ft) higher than the new 100-year flood elevation and 0.11 m (0.35 ft) higher than the new 500-year flood elevation (as projected for 2085). Additional precautions include mechanical and electrical installations located on the roof, no patient facilities located on the ground floor or below, patient rooms having key-operable windows for emergency ventilation, and basement parking protected by establishing the top of ramp elevations set at the same level as the ground floor.

No Regrets Strategies

1. Require analysis of new construction and major renovation projects to include provisions to address predicted climate change impacts.
2. Use permitting and environmental review processes to recommend that new construction and renovation projects consider the use and protection of basement and first-floor levels, the installation of enclosures for roof-top equipment to protect them from more severe weather exposure, use of green roofs to absorb additional precipitation and decrease cooling needs, enhancement of site work to include bio-swales, the use of permeable pavement, construction of wetlands to handle surface water run-off, and raising the height of damp-proofing of foundations to accommodate increased flooding.
3. Consider climate change impacts in developing universal (accessible) design guidelines for all future projects.

Short-Term Strategies

1. Consider allocation of additional space in new building design and existing building retrofits to house the necessary mechanical equipment to handle increased heating, ventilation, air conditioning, pumping, or generator capacity.
2. Consider purchasing appropriately-sized generators and pumps to handle increased flooding and properly-sizing building structural components to carry additional precipitation and wind loads, and improve drainage around buildings.
3. Assess when and where to fortify existing buildings and when to move, demolish-recycle, or abandon vulnerable structures.
4. Plant shade trees to decrease solar/thermal load on buildings.

Long-Term Strategies

1. Evaluate modification of review and approval processes and building codes to require consideration of climate change impacts and life-cycle costs in public and private developments and construction activities.
2. Take steps to ensure that the life span of a building is in line with anticipated climate changes (i.e., a 50-year building will not be located in an area where flooding is projected in 30 years' time).

Information and Communications Technology

Information and communication technology stability and security in the face of climate change should be considered a high priority because of the pervasive influence of and reliance on this sector in daily life.

Existing Resources

Telecommunication networks are classified as either fixed (e.g., telephone and cable services using copper wire, coaxial cable, or fiber optics) or mobile (e.g., cellular and satellite connections). Information and communication technology services can be broken down into telecommunication services (broadband, mobile voice and data, and fixed voice) and broadcast services (television and radio). In Massachusetts, there is one primary local exchange carrier (Verizon). There are ten cable TV providers serving over two million subscribers in 308 of the state's 351 cities and towns (MassDTC, 2009). Massachusetts also benefits from 35 licensed full- and low-power TV stations (FCC, 2011a), 120 community TV stations (MassHome, 2010); 272 Federal Communications Commission-licensed radio stations (FCC, 2011b), and 745 licensed telecommunications operators (Mass DTC, 2011).

Impacts and Vulnerabilities

Information and communications infrastructure that could be affected by climate change effects include mobile and fixed radio, TV and cellular towers, satellite dishes, central office facilities, switching and base stations and foundations, manholes, underground pits, and thousands of miles of surface and subsurface wires, cables, and conduits.

The primary climate change impacts on this infrastructure would be extreme weather events, including flooding, erosion, heavy rainfall, coastal storm surges, and hurricanes. Additionally, high wind, lightning, and ice storm events could damage or destroy utility lines, poles, and towers. Increased temperatures and solar radiation could lead to a greater demand on certain equipment for cooling capacity and more rapid deterioration of aerial transmission cables. Salt spray from coastal storms and saltwater intrusion may increase corrosion of telecommunication towers and other equipment in coastal areas. While New England is forecasted to have an overall increase in annual precipitation, the region also may experience more seasonal drought periods, which could lead to forest fires and resulting infrastructure damage.

These varied events could adversely affect public safety, emergency, and transportation-related communications, as well as personal and business activities. The implications of these effects include increased capital and operating expenditures to repair, replace, redesign, or relocate telecommunications infrastructure at a faster rate. Other implica-

tions include a need to increase customer rates to cover infrastructure damage or replacement costs, to offset decreased productivity and maintain overall economic activity when systems are disrupted, and to re-establish compromised public health, safety, and security operations.

Some elements of the information and communication technology infrastructure have relatively long life spans and long lead times for design, approvals, and construction. They also may require high capital costs to implement.

Early in 2009, Governor Deval Patrick initiated an IT Collaborative to "organize the voice of the Information Technology industry through the creation of a sustainable, cross-cluster dialogue of stakeholders in business, government, and academia". This approach should include an emphasis on adapting the industry quickly to predicted climate change effects, such as increasing use of wireless technologies, achieving higher resilience standards (e.g., in mobile and fixed communication towers and transmission equipment), and reducing vulnerability and remediation costs.

The trend toward more wireless technology and the continued rapid evolution of information and communication technology should help the industry, as well as other impacted sectors dependent on this technology to adapt more successfully to extreme weather events and other predicted climate changes.

Potential Strategies

No Regrets Strategies

1. Inventory facilities, including transmission lines, towers, and satellite dishes; underground and underwater structures; computer terminals and peripheral equipment; broadcasting stations; and emergency communication systems for vulnerability to coastal and inland elements of climate change.
2. Support rapid updating of topographic and floodplain mapping.
3. Continue regular maintenance of existing infrastructure. Undertake a regional and national analysis of information and communication technology adaptation in the face of climate change, taking into account the lifecycle costs of these systems.

Short-Term Strategies

1. Identify lead times for climate change impacts and for redesigning, revamping, repairing, replacing, or relocating infrastructure elements. Adaptive planning should help accelerate the overall planning process, realizing that the technology itself is undergoing rapid change.
2. Incorporate climate change concerns into design standards and site selection while accelerating new sustainable technologies.

Long-Term Strategy

Assess the vulnerabilities of competing technologies to climate change risks, and ensure decision-makers involved in network upgrades or realignments are properly informed by this information. (Maunsell, 2008)

Commonalities Among Sectors and Strategies

Although the chapters in this report are organized into specific sectors, there are several interconnections among and within them. This section attempts to address those overlaps and interconnections between the Key Infrastructure sectors and the other chapters, and between the state's climate change mitigation efforts.

Key Infrastructure Interconnections

1. Energy and Transportation Sectors: Impacts to the energy and transportation sectors will influence the state's ability to adapt to climate change impacts affecting other forms of infrastructure, as well as in other sectors such as public health and economy, and will influence the state's ability to mitigate climate change. Losses of energy production and distribution and access to modes of transportation are identified as major climate change vulnerabilities in all sections of this report. Without a resilient and reliable source of energy and effective means of transporting people, goods, and services, it will be difficult for Massachusetts to adapt to climate change, prepare for or recover from emergency situations, and maintain state and national security objectives. As such, those strategies identified in the energy and transportation sectors should be considered not only as ways of protecting those individual sectors, but also as ways of protecting the other sectors throughout the state and region from the effects of climate change.
2. Water Resource Sectors: Many adaptation strategies identified to address potential climate change impacts are very similar among the three major water-based infrastructure resources: water supply, wastewater, and stormwater management. Examples from two broad categories, "design and operational features" and

"enhanced natural hydrology," demonstrate the interconnectivity of some key strategies among the water-based infrastructure sub-sectors.

a. Design and operational features: Strategies involving water conservation measures are common to both water supply and wastewater management. Reduced demand for water through measures such as water conservation, grey water reuse, and reduction in unaccounted-for water losses (e.g., leaking pipes), not only reduce the demand on public water supplies, but also reduce the amount of wastewater that needs to be managed. Reduced water use can protect against concerns about insufficient water supplies, especially during predicted periods of extended summer drought. Wastewater should be considered a commodity having considerable value in reuse, rather than just a waste flow that has no value. Additionally, less stress on these infrastructure systems generally results in greater resiliency to handle emergencies that may be caused and/or aggravated by climate change impacts. This will also result in reduced operational, management, and replacement costs. Low-impact design strategies also provide synergy of benefits to multiple water resource sectors.

b. Enhanced natural hydrology: Nature is effective in providing clean drinking water and managing wastewater and stormwater. Water resource managers are more often adopting watershed-based strategies that take a holistic view of water resource issues in a manner that considers the natural hydrology of a geographic area. Future decisions on water supply, wastewater, and stormwater management that mimic and reinforce the natural hydrology of a geographic area (e.g., a watershed) will enable natural systems to help manage future climate change impacts.

Lessons from the Dutch—Use of Natural Systems

The Dutch are well-known for their prowess in engineering structures designed to keep floodwaters out. In a country where about half the population lives below sea level, over 10,000 miles of flood defense contributes to the $2.5 trillion worth of existing infrastructure upon which the Dutch are highly dependent. In recent years, the Dutch have increasingly supported the use of natural barriers, such as sand dunes and marshes, to ease the force of storms and retain floodwaters and now ban drainage of existing marshes in further support of natural ecosystems over artificial systems.

Furthermore, the Dutch are adopting approaches aimed at carefully accommodating, rather than resisting, flood waters where possible. The essence of this principle (of integrated coastal policy) is: flexible integration of land in sea and of water in land, making use of materials and forces present in nature. The Dutch plan to return 222,000 acres of land to floodplain buffers for use as marshland or natural forest land. They have placed a moratorium on new flood-prevention infrastructure in some towns and are lowering, repositioning, or removing some dikes. This marks a significant change in the way they think of water by embracing land uses or construction types that tolerate soggy conditions.

Natural hydrologic systems have evolved to be flexible and adaptable to the extremes of weather phenomena, so strategies that reinforce and use natural systems can be very successful and cost-effective. These watershed-based approaches could be integrated more fully in the development of MassDEP's Comprehensive Water Resources Management Plans, which are required for certain water resources permitting and considered in funding assistance decisions.

3. Increased Conservation Measures and "Green" Designs

The State's vulnerabilities to climate change may be reduced if it decreases its reliance on and use of certain services. Additionally, natural ecosystems provide a number of services which support built infrastructure resources. By diminishing or eliminating non-climate stressors to infrastructure, that infrastructure may have more capacity to be resilient to climate changes. Here are a few examples to help illustrate this benefit:

a. Energy—Energy efficiency improvements and lowered demand will reduce loads on stressed electrical infrastructure while mitigating climate change through a reduction in greenhouse gas emissions.
b. Transportation—Reducing vehicle miles traveled reduces physical and capacity stresses on roads, bridges, and tunnels, increasing their resiliency to climate and weather-related impacts. When the population diversifies its travel patterns, individuals have greater flexibility in their transportation options. Reducing vehicle miles travelled also has implications for lower greenhouse gas emissions, providing climate change mitigation and reducing the need for adaptation.
c. Urban forests—Urban forests can perform a variety of vital infrastructure services. Trees are very effective in filtering pollutants from the air, as well as reducing volumes and pollutant loads from stormwater runoff. Increased urban vegetation and tree canopy, as well as innovative strategies such as green roofs, are also very effective in reducing the heat island effect in urban areas, which can reduce the demand and stress on energy infrastructure.

Charles River Natural Valley Storage Project

In 1910, the Charles River was dammed, creating the "Charles River Basin." In subsequent years, however, residents feared that the dam would significantly increase flooding during major storms. Brought in to study the precipitation data, the US Army Corps of Engineers noted a surprising lack of flooding in the towns north of Newton. It attributed this to a series of isolated wetlands that naturally store and gradually release water to the Charles River, buffering the effects of particularly rainy seasons on the river's water levels. In light of this information, Congress authorized the purchase of 17 wetlands (8103 acres) for $8.3 million, creating the "Charles River Natural Valley Storage Area." At the time, the Army Corps of Engineers was also considering a $100 million dam construction project to serve the same purpose, but decided in favor of the wetland solution.

Since 1974, when the purchase was authorized, the decision is believed to have created benefits of over $7.5 million to the local economy and has prevented flood damage estimated at $3.2 million. Additionally, property values bordering these wetlands sell at a 1.5 percent premium. Use of this natural solution over a significantly more expensive engineered solution has already paid for itself in a way the second dam never could. The Charles River Natural Storage Area is a living example of an economical, environmentally conscious solution.

The symbol signifies adaptation strategies that are also climate change mitigation actions.

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6 — Human Health and Welfare

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6 Human Health and Welfare

Introduction

Changes in climate will undoubtedly affect human health and welfare in Massachusetts—both directly via extreme heat events and indirectly through increases in vector-borne diseases. Climate change will affect the quality of the air we breathe, the shelter we rely on, the quality and quantity of the water we consume, the food we grow and transport, and the nature and level of demands for health care services.

Some residents will be more susceptible to the effects of climate change, and adaptive change will be more difficult for them. Whether by virtue of economic status, social capacity and resources, health, age, or geography, adaptation efforts should include planning to meet the unique needs and conditions of the state's most vulnerable populations—including those with limited resources to take protective and adaptive measures and to recover after losses, and those coping with existing chronic illnesses that could be aggravated by the expected climatic changes. Children, the elderly, the disabled, and low-income groups, in particular, should be considered in any adaptive plan. A focus on vulnerable populations requires an understanding of community or population characteristics, conditions that could contribute to a disproportionate risk, and obstacles to resiliency. (Note that in this chapter, strategies that are especially applicable to vulnerable populations are denoted by "VP".)

The maintenance, support, and improvement of existing public health and health care infrastructure are critical to the overall preparedness for the effects of climate change. To support and promote a strong, healthy, and resilient population, and responsive local health systems, adaptation efforts for human health should build on conventional and existing medical and public health standards, using a variety of approaches. These approaches may include using health surveillance systems to track disease occurrence and identifying locations and population groups at greatest risk for specific health threats. These efforts may also include assessing infrastructure capacity and emergency response preparedness, developing preparedness and response plans, and creating treatment plans to reduce health risks. Effective adaptation and mitigation strategies should seek to reduce exposure and increase resilience. These efforts can be executed at scales ranging from large-scale regional initiatives to delivery of personalized health services. This chapter examines topics within the following categories outlined in Table 6.

General Overview of Vulnerabilities

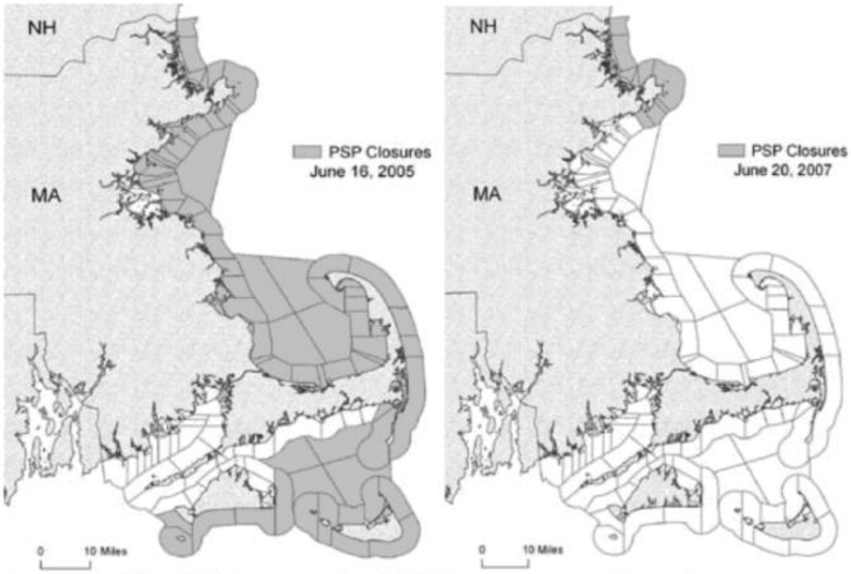
Vulnerabilities of each of the above categories are closely interconnected. As an example, an increase in precipitation will lead to increased runoff of nutrients and chemicals into water bodies, potentially compromising surface water quality and possibly affecting drinking water quality. Water laden with nutrients promotes the emergence of algal blooms, which release into the air and water toxins harmful to humans and animals, and which can contaminate shellfish stocks.

In general, climate change impacts on human health may include:

- higher temperatures contributing to complications or exacerbation of conditions

CATEGORY	TOPICS
Public Health	Public health infrastructure, vector-borne diseases, heat stress, allergens, respiratory and cardiovascular diseases, extreme and anomalous weather events
Air Quality	Ambient and indoor air quality
Water Quality/Sanitation	Drinking water, algae blooms, wastewater, water-borne diseases
Agriculture and Food Systems	Crops and livestock, water demand, pesticide use, new or invasive pests, food transmitted illnesses, security and safety
Vulnerable Populations	Food security, pesticides, allergens, air and water quality, vector-borne diseases, recovering from extreme weather events

Table 6. ***Public Health topics examined in this chapter***



A record Red Tide event in 2005 led to extensive closures throughout state waters (left) while 2007 saw shorter closures confined mainly to the North Shore (right).

- among those with respiratory illnesses and cardiovascular disease;
- increased ozone and particulate matter production, coupled with higher temperatures, which result in poor air quality, and increased risk to those with existing respiratory diseases;
- increased plant pollen production and more allergenic pollen content, which may aggravate and exacerbate allergies, asthma and other respiratory illnesses;
- changes in disease patterns and a possible increase of vector-borne diseases (including Lyme disease, Eastern Equine Encephalitis and West Nile virus) as ticks and mosquitoes adapt to changing conditions;
- increased potential for water-borne disease outbreaks during and after flooding events;
- degraded surface water quality from sediments, pathogens, nutrients, and pesticides in stormwater and agricultural runoff;
- shifts in shellfish pathogens, with possible increasing contamination and closed shellfish beds;
- extreme weather events such as ice storms, heat waves, and more powerful storms that disrupt power and sanitary services, health care services, and access to safe and nutritious food, and which cause damage to homes and property; and
- increased mental and physical health burdens from the need to cope with more extreme weather, disaster response, and uncertainty.

Advancing Adaptation and Mitigation from a Public Health Perspective

While some greenhouse gas reduction (climate mitigation) measures will improve public health and welfare (such as reducing carbon emissions from cars), others may have significant adverse health and environmental consequences (such as potential increased national reliance on nuclear power without nuclear waste management improvements or proper consideration of potentially harmful public health consequences resulting from climate change impacts to nuclear reactors, particularly those sited along the coast). Likewise, adaptation strategies, such as increased use of air conditioning, may contribute to further climate change. A life cycle analysis that examines the health, environmental, and economic costs of proposed technologies and practices is a useful method for projecting potential co-benefits and potential costs of implementing them (Epstein et al., 2008).

The following are complementary mitigation and adaptation strategies that have multiple public health and environmental benefits.

- A Healthy Cities Initiative: Promote green buildings, rooftop gardens, walking paths, biking lanes, tree-lined streets, open space, access to locally grown healthy food, flood control systems that mimic natural processes, low impact development techniques, motor vehicle transit / congestion control, smart growth, and improved clean public transport. These strategies will reduce the heat island effect, decrease vehicular miles traveled, promote exercise, save money, support local agriculture and healthy nutritious diets, create jobs, and advance climate-stabilizing technologies. The State's June 2009 landmark transportation reform legislation created "The Healthy Transportation Compact" which supports this strategy. The compact involves the transportation, public health, and environmental agencies "work[ing] cooperatively to adopt best practices to increase efficiency to achieve positive health outcomes through the coordination of land use, transportation and public health policy" (www.massdot.state.ma.us, click on Healthy Transportation Compact link).
- Alternative fuel vehicles: Hybrid and electric vehicles can minimize fossil fuel combustion, reduce emissions of particulates (such as black carbon), ozone precursors, and CO_2, which will

The Chicago Heat Waves of 1995 and 1999

Heat waves are responsible for approximately ten times as many fatalities per year as hurricanes, rainstorms, lightning, floods, and tornadoes combined. Lessons learned in other parts of the country can help guide Massachusetts' response to heat waves.

In the summer of 1995, the city of Chicago experienced a heat wave that killed 739 residents. The temperatures reached a peak of 106°F (41°C) during the day, while night time lows were still in the high 70s and low 80s. Temperatures stayed in the 90s and 100s for over a week. As air-conditioner usage soared, area utilities could not cope with the record-breaking energy demand and 49,000 households lost electricity—leaving them even more vulnerable to the overbearing heat. Fatalities were highest among those who lived alone, had little access to transportation, did not leave the house on a daily basis, and lacked an air conditioner.

In 1999, when Chicago was hit by another heat wave, it was better prepared with a more responsive municipal effort. Chicago officials responded faster to the weather, alerting the press and the public, providing free transportation to rapidly opened cooling centers around the city, and checking in on elderly people through phones and in-person visits by police officers. Fatalities attributed to the heat wave numbered 110 that year.

Today the city is taking additional steps to prepare it for a warmer summer—water and heat trapping alleyways are being replaced by permeable materials, heat hot-spots are being targeted for pavement removal, plants are being added to roofs, and trees that are more resistant to higher temperatures are being planted citywide.

ultimately decrease unhealthy emissions, and benefit urban areas in particular.

- Improving the electricity grid infrastructure: A more efficient distribution grid can reduce air emissions from existing power plants, which in turn can mitigate expected increases in ground level ozone and particulate matter that result from higher ambient air temperatures.

The rest of this chapter covers key aspects of public health and offers no regret, short-term, and long-term adaptation strategies for each sub-category in response to potential climate change impacts. The following narrative outlines strategies that will continue to be reviewed and considered for implementation.

Public Health Infrastructure

Massachusetts has a comprehensive and sophisticated public health infrastructure with a variety of resources—material and human, local and statewide, governmental and private—that support disease prevention, surveillance, and management.

At the municipal level, boards of health are responsible for public health issues and enforcing public health regulations. Local and state public health officials share enforcement responsibility for state sanitary and housing codes. In addition, several regional boards or health department associations (e.g., Franklin Regional Council of Government, Nashoba Valley Association of Boards of Health) exist to provide additional services to member communities. There are 15 regional health coalitions in place to strengthen public health preparedness and capacity.

At the state level, the Massachusetts Department of Public Health (DPH) provides services to residents, enforces regulations, and operates several hospitals and a state public health laboratory. DPH provides technical assistance to local boards of health, and manages a range of programs focused on disease surveillance, communicable disease control, and environmental health.

The public and private health care system provides acute and chronic care to residents through hospitals, community health centers, nursing homes, and private practice offices. These entities are the primary sources of data for disease tracking and surveillance. The public and private health care system employs over 100,000 professionals at more than 125 hospitals and rehabilitation facilities, 600 clinics and community health centers, 500 nursing homes and hospices, 65 psychiatric and mental health facilities, 300 Emergency Medical Services units, 35 Medical Reserve Corps, and 5 Veterans Affairs Hospitals. A large number of medical care facilities are located near the coastline around the Greater Boston area where the population concentration is highest.

Vulnerabilities

The effects of climate change will potentially stress each component of the public health infrastructure. Public and private health care systems will need to respond to increased occurrences and demand for

treatment of acute and chronic diseases and ailments such as heat stress, exacerbation of pre-existing asthma, new diseases, mental health effects such as anxiety resulting from displacement under emergency circumstances, and physical trauma from flooding.

DPH Assists Communities Understand and Plan for Climate Change

The Massachusetts Department of Public Health (DPH) is one of five entities (four states and one city) to be awarded a $345,000 three-year cooperative agreement under the Centers for Disease Control and Prevention (CDC) Climate Change Ready States and Cities Initiative to conduct needs and capacity assessments and to help create plans for cities and towns to address the human health consequences of climate change. Under this program, DPH will work primarily with Massachusetts local health officials, but will also coordinate such efforts with the Massachusetts Climate Change Adaptation Advisory Committee. The project proposal uses information developed in this chapter and references many of the goals and strategies presented in this chapter. This important award will allow the DPH to assist Massachusetts communities with understanding and planning for the potential health effects associated with climate change.

Boards of health will need to respond to increasing burdens in the areas of housing, sanitation, disease, and other public health issues arising from sea level rise, higher summer temperatures, and extreme weather events. Other impacts will result from the potential interruption of transportation and energy generation and transmission critical to providing health care, and interruption of services at hospitals and health care centers.

The greatest vulnerability to the local health infrastructure is likely to be the lack of resources. Boards of health have broad responsibilities and face difficulties in enforcing a wide variety of existing public health regulations and responding to local, small-scale emergencies. Public health goals, and the extent to which they are met by boards of health, vary greatly depending on staff resources and experience, access to testing and tools, and the community's overall capacity for emergency response. In the event of an increased number of emergencies, state or regional boards and other entities may need to divert resources—sometimes all available resources—to the emergencies at the expense of executing core public health programs.

Vulnerabilities in the private health care system include ongoing challenges in the capacity to handle an increasing number of patients with chronic illnesses, such as asthma, and surges of patients after climatic events. The possibility of migration into Massachusetts from other states and countries, so called "climate refugees," could add to the demand for emergency response and public health services.

Facilities and supporting infrastructure near the coastline and in floodplains are particularly vulnerable to rising sea level and increased flooding. Hospitals are an energy-intensive commercial sector, and are consequently vulnerable to power disruptions from weather events, as well as to increasingly higher energy costs.

Potential Strategies

Existing public health infrastructure may be able to meet the challenges expected from climatic changes. Still, planning at all levels of health infrastructure could begin to evaluate and identify climate-related vulnerabilities in order to adjust priorities and plan for improving our response capabilities.

The current public health infrastructure could undergo a system-wide climate change needs assessment. Planning documents already contain much of the information needed for such an assessment, although they do not organize the information to assist adaptation planning. Changes in the current local public health program model, such as enhancing regionalization efforts to address non-emergency situations, can allow for more efficient mutual aid and increased coverage across the state. The need for enhanced capacity in core public health activities could be met by a regional system that supports the critical skills necessary to prevent disease and injury in communities.

The public and private healthcare system may need to plan for physically modifying or relocating vulnerable health care facilities located along the coastline or in floodplains. In addition, a more detailed evaluation of current provider capacity to meet the needs of more patients suffering from climate change-related ailments is needed.

Short-Term Strategies

1. State, regional, and local public health officials may begin to incorporate climate vulnerabilities into existing plans.
2. State, regional, and local public health officials could begin to conduct public health climate change planning to identify the most vulnerable facilities and response capacity from the state to the facility level.
3. Consider promoting an education campaign targeted to vulnerable populations, which could include support for a network of notification procedures for vulnerable communities, cooling

Operation Helping Hands

"Operation Helping Hands," the Massachusetts response to assisting evacuees from Hurricane Katrina, was a broad and comprehensive program to coordinate the efforts of federal, state and non-profit organizations to assist approximately 250 Katrina area evacuees who were transported to Massachusetts within a few days of the event.

The Massachusetts Department of Public Health (DPH) is the primary support agency responsible for coordination of "state public health, mental health, medical, and health care resources during activation of the State Emergency Operations Center". The response included:

- administration and management tasks, such as making sure evacuees had identification;
- medical assistance, including acute care, management of prescription medications, and assistance in obtaining replacement eyewear;
- mental health evaluation and care for both existing chronic illness and post-traumatic stress;
- public health measures such as assuring access to applicable vaccinations and the collection and sharing of standardized information with other responding states; and
- social support, such as assisting with food, clothing and housing; assistance regarding pets; school registration, and assistance with finding other family members and developing plans for the future.

Approximately 60 staff and volunteers were coordinated as a part of this effort, along with about 100 National Guardsmen. Additional efforts were required to assure that volunteers had proper credentials.

Many lessons were learned from this experience in Massachusetts, including the need for immediate structured, yet flexible, responses to emergencies, and the usefulness of the Massachusetts Medical Society, the regional Center for Public Health Preparedness and the Medical Reserve Corps. Having access to a fallow military base for immediate housing and other

centers (gathering places for people to get relief during heat waves), and "check on your neighbor" programs (VP).

4. Consider assessing the capacity of providers to address anticipated increased patient volumes and changing health demands, including capacity to address heat waves and anomalous winter weather events.
5. Seek to implement the DPH asthma action plan to improve the ability to adequately treat chronic asthma with effective care plans.
6. Promote participation in energy efficiency programs for the health care sector such as the U. S. Department of Energy's Hospital Energy Alliance and Energy Smart Hospitals and the U. S. Environmental Protection Agency's Energy Star for Healthcare.

Long-Term Strategies

1. Facilitate and enhance regionalization efforts among local boards of health.
2. Encourage distributed sources of energy generation (such as community-scale solar and wind power) to increase preparedness and resiliency of the network of health care providers, and to decrease emissions.
3. Promote workforce development to train public health staff to respond to climate change-related health threats.
4. Identify facilities and strategize how to modify or relocate vulnerable health care facilities away from the coastline, improve flood control protection, or stabilize facilities in flood prone areas.
5. Support efforts to reduce greenhouse gas emissions, which in turn, would reduce long-term health effects of climate change.

Vector-Borne Diseases

Vector-borne diseases are transmitted by carriers such as insects and arthropods. In Massachusetts, Lyme disease, babesiosis, human granulocytic anaplasmosis, tularemia, and Rocky Mountain spotted fever are spread by ticks. West Nile virus and Eastern Equine Encephalitis virus are spread by mosquitoes. Several of these diseases can cause serious illness or even death. Others could become established in Massachusetts as a result of changing climatic patterns.

Warming Temperature and Vector-Borne Diseases

Eastern equine encephalitis is Massachusetts' most severe vector-borne disease. With the general trend of warmer temperatures leading to higher mosquito numbers and greater activity, the possibility of more human disease will apply to all mosquito-borne diseases, including West Nile virus and St. Louis encephalitis virus. A similar trend is probable with tick-borne diseases as well, resulting in the prospect of more human cases of Lyme disease, babesiosis (a malaria-like parasitic disease), and anaplasmosis (a bacteria which infects white blood cells).

Vector life cycles, particularly of the mosquito, are dependent on temperature and moisture, making impacts from climate change likely. Populations particularly vulnerable to vector-borne diseases include people who are elderly, very young, un- or under-insured, outdoor laborers (i.e., farm and construction workers), those geographically isolated from health care services, and those with low levels of education, low-income, or compromised immune systems.

Existing Resources

Health care providers and veterinarians are required to report the occurrence of certain vector-borne diseases (e.g., West Nile virus, Eastern Equine Encephalitis, and Lyme disease) to the appropriate state agencies. Mosquito control districts assist with mosquito surveillance and control, while DPH conducts mosquito surveillance and virus testing on mosquito, animal, and human samples. DPH also routinely tests samples to detect the emergence of new mosquito-borne diseases. Limited tick and tick-borne pathogen surveillance occurs through academic institutions and cooperative extensions. The environmental control of ticks occurs mainly through individual use of fee-for-service pesticide application companies. DPH records and analyzes data collected on human cases of some vector-borne diseases. In addition, DPH creates educational materials for the public to encourage personal prevention practices, and for health care providers to promote prompt recognition of certain vector-borne diseases and appropriate treatment.

Vulnerabilities

With climate change, the general public will likely be subject to greater exposure to disease vectors and related pesticide application. The likely effects of predicted climate change are prolonged transmission seasons for all vector-borne diseases, extending the risk of transmission outside of the traditional late spring through early fall timeframe. In addition, mosquito populations are likely to increase as rising temperatures shorten reproductive cycles and result in more generations per season. There will be a greater demand for monitoring, treatment, and health services. Increased suspected human cases may tax laboratory resources and potentially limit their capacities to perform other work needed to detect the emergence of new pathogens.

Although warming temperatures will not increase the speed at which tick vectors reproduce, warmer winters may decrease tick mortality and would likely support an abundant tick population. Unless populations of preferred tick host species such as white-tail deer and small rodents diminish, an increased risk of transmission to humans can be expected. Substantial increases in the number of the more serious tick-borne diseases, such as human granulocytic anaplasmosis, babesiosis, and Rocky Mountain spotted fever, could result in rising use of medical resources. In addition, babesiosis could pose a threat to blood supply since many carriers who could be potential blood donors are asymptomatic, and most blood recipients are immuno-suppressed and more vulnerable to developing severe diseases. Because surveillance of tick populations and pathogens is not as systematic or centralized as surveillance of mosquitoes, detection of new tick species and/or identification of emerging pathogens spread by ticks could be delayed.

Potential Strategies

Short-Term Strategies

1. Continue requiring reporting of human cases and positive laboratory results of vector-borne diseases including diseases that are not currently endemic to Massachusetts.
2. Work to improve capacity to respond to vector-borne diseases, streamline and automate reporting mechanisms, and stockpile supplies for prevention (e.g., insect repellent, repellent impregnated work clothing).
3. Continue to develop and enhance electronic reporting procedures for laboratories.
4. Maintain mosquito surveillance at multiple sites throughout Massachusetts.
5. Continue testing to identify other, currently non-endemic, viral agents.
6. Educate the public, particularly high-risk groups, about personal prevention practices, and encourage their adoption.
7. Educate the public about mosquito breeding habitats and opportunities to eliminate them (such as reducing areas of standing water).

Long-Term Strategies

1. Consider developing a systematic tick surveillance program statewide to monitor vector densities and infection rates.
2. Evaluate the benefits of implementing a web-based disease reporting procedure for health care providers.
3. Evaluate and support service providers in expanding institutional capacity to meet the needs associated with climate change induced increases in vector-borne diseases.
4. Consider using community-based groups and trade organizations to do outreach and education about risks and prevention, and to connect individuals and families to appropriate services (VP).

5. Examine developing occupational health and safety regulations to protect outdoor workers (VP).
6. Facilitate monitoring of current non-endemic diseases for trends (VP).
7. Develop strategies for large-scale use of integrated pest management control to reduce pesticide use (VP).
8. Improve capacities to conduct vector and human surveillance in order to identify high-risk groups and places to better target outreach, education, and prevention efforts (VP).

Ambient Air Quality

Climate change alters local weather patterns, such as temperature and wind speed, which, in turn, affect the distribution of air pollution. Anthropogenic sources of air pollution promote climate change through the emission of CO_2, volatile organic compounds and oxides of nitrogen. Volatile organic compounds, oxides of nitrogen and sunlight combine to form ozone and smog, which are harmful to public health, ecology, and public welfare. Byproducts of combustion, such as, ozone and fine particulate matter, contribute to air pollution and associated respiratory and cardiovascular disease.

Massachusetts Environmental Public Health Tracking Network

The Massachusetts Department of Public Health (DPH) recently launched a web-based Massachusetts Environmental Public Health Tracking network, which contains data on ambient air quality, hospitalizations due to asthma and myocardial infarction, and pediatric asthma for all Massachusetts communities. Using information from this tracking network, federal, state, and local public health agencies, the medical community and advocacy groups will be better prepared to develop and evaluate effective public health actions to prevent or control these diseases.

Principal public health concerns are allergy symptoms related to increased allergen production, and increased respiratory and cardiovascular disease related to worsening air pollution and higher temperatures. Particularly vulnerable populations include the elderly; the very young; low-income groups; immigrants; the homeless; un- or under-insured people; residents with increased exposure to ambient asthmagens; residents of older or substandard housing; people who are geographically isolated from health care services; people with certain pre-existing conditions, especially asthma or lung dysfunction or compromised immune systems; and outdoor laborers such as farm and construction workers.

Existing Resources

The Massachusetts Department of Environmental Protection (DEP) is responsible for monitoring outdoor air quality and developing regulatory programs to reduce emissions of pollutants that adversely affect public health, welfare, and the environment. DEP provides data on criteria pollutants (sulfur dioxide, ozone, carbon monoxide, nitrogen dioxide, lead, particulate matter ≤10 microns and ≤ 2.5 microns), controls many other pollutants emitted from facilities (e.g., power plants, incinerators, vehicles), and administers the Massachusetts regulatory portion of the Regional Greenhouse Gas Initiative. The DPH Bureau of Environmental Health evaluates environmental and health data to determine the likelihood of health effects associated with environmental factors.

Vulnerabilities

Warming conditions may increase ground-level ozone and particulate matter levels, allergens, and extreme heat events which, in turn, can exacerbate existing cardiovascular and respiratory conditions and other health effects. Meteorological changes can impact local and regional pollution distribution, with a number of modeling studies (Tagaris et al., 2007; Murazaki and Hess, 2006) predicting accumulation and concentration of pollutants (e.g., ozone) in the Northeast. An increase in ambient temperature is likely to stimulate earlier flowering, increased growth and prolonged pollen production in plants, which can increase and prolong asthma and allergy incidents. Also, the potency/strength of pollen can increase as a result of higher temperatures and carbon dioxide levels. The increases in allergenicity of plant materials can lead to more severe respiratory responses. In addition, synergistic effects can be expected from entrainment of respirable-sized particles that attach to pollen are delivered deep into the lungs and contribute to, or worsen lung dysfunction. Increased plant growth correlates to increases in decomposition—suggesting heightened fungal abundance. Such increases may result in greater amounts of airborne spores which are linked with exacerbation of asthma.

Individuals with pre-existing respiratory and cardiovascular conditions will be the most susceptible to decreased air quality, especially those who do not have access to quality health care. People who work outdoors most of the day will be disproportionately impacted. The heat island effect in urban areas will exacerbate air quality deterioration and disproportionately impact lower-income individuals who do not have ready access to air conditioning or health care, as well as people who work outside in urban environments. An increase in pollen production and its allergenicity will impact individuals statewide. The increasing need for health care will likely stress the existing health care and public health infrastructure if certain adaptation strategies are not implemented.

Potential Strategies

Training of and coordination between physicians, other health practitioners, local health officials, and other components of the health care industry will help mitigate health impacts resulting from decreased air quality through improved primary health care for affected populations. Determining how each health and environmental agency manages adaptation and data tracking as a whole will assist in coordinating care. Some of this work may be integrated into existing programs or centralized through agency coordination. In order to understand local impacts of climate change risks, it is important to identify sensitive populations, develop targeted preparedness and response plans, and develop the capability to conduct health impact assessments that evaluate health outcome data and relevant air quality indicators associated with climate change.

To minimize future air quality impacts, more aggressive emissions controls (both in the U.S. and elsewhere) will be needed to make progress toward reducing emissions of particulates and key ozone precursors (especially NO_x so that ozone concentrations are below health-based standards). The primary strategy for responding to health impacts from climate change is preventing the occurrence of illness and injury by reducing risk factors, early detection and treatment of disease, and effective preparedness and emergency response plans. To accomplish the goal of preventing illness and injury due to climate change, more specific efforts could include:

Short-Term Strategies

1. Achieve and maintain air quality standards. Attain air quality standards for ozone; continue to attain current federal particulate matter standards. Continue to control direct particulate emissions and precursors of particulates such as sulfur and oxides of nitrogen and other asthmagens.
2. Enhance clean energy generation programs. Control emissions from sources such as industrial and wood burning facilities and diesel engines.
3. Build on the existing public health practice of surveillance and health outcome tracking in order to identify and monitor health impacts related to climate change.
4. Promote telecommuting to avoid exposure during air quality alerts.
5. Promote heat island effect reduction strategies: cool roofs, green roofs, green spaces, and designs that minimize heat magnification.
6. Encourage opportunities for public transit use, walking, and bicycling, and evaluate expanding facilities that promote these transportation options.
7. Seek to increase use and installation of green infrastructure such as trees and other vegetative cover, with preference for hypoallergenic species.
8. Create mechanisms to provide technical advice and communicate the health-related aspects of climate change, including risks and risk reduction. Disseminate air quality ratings to the public, decision makers, local health departments, and healthcare providers, and ensure that the information is accessible to all residents (i.e., translated from English to relevant native languages and distributed broadly in affected communities).
9. Enhance scientific understanding of the relationship between climate change, air quality, and health outcomes by conducting health impact assessments at the state and local levels.
10. Use existing DPH and census data to identify and physically locate vulnerable populations (VP).
11. Expand capacity for modeling and forecasting health effects using standardized health impact assessment methods to incorporate climate change.

Long-Term Strategies

1. Explore and develop multi-pollutant strategies to reduce greenhouse gas emissions, criteria air pollutant emissions, and air toxics emissions.
2. Continue monitoring and meeting regional haze requirements by decreasing haze-forming pollutant emissions, with a goal of restoring natural visibility conditions in our state and national parks and wilderness areas.
3. Encourage and invest in expansion of scientific and technological research to identify novel means to reduce air pollution.
4. Facilitate improved access to health insurance and medical care, medical support equipment and medications (VP).
5. Support expansion of strategic planning efforts to assist both health-related service providers and health care recipients in meeting anticipated needs associated with climate change impacts.
6. Prioritize planting of hypoallergenic trees in communities with high rates of asthma and lung dysfunction (VP).

7. Consider providing technical and financial support to companies to reduce their ambient air emissions (specifically ozone precursors and particulate matter) (VP).
8. Examine the feasibility of reducing or removing subsidies for activities and projects that result in reduced ambient air quality (VP).

Indoor Air Quality

Climate change impacts on both outdoor air quality and the built environment have the potential to negatively impact indoor air quality. If there are increasing numbers of "bad air days" due to poor outdoor air quality, people may spend more time indoors. Buildings as shelter are the first line of defense against a sub-optimal outdoor environment, but they can also be severely impacted by the effects of climate change. Increased temperature and precipitation, as well as extreme weather events, can degrade the building envelope, allowing moisture and pest penetration, mold growth, and off-gassing from building materials in the indoor environment. The natural solution is dilution with outdoor air. However, when ambient air quality is poor, using it to dilute indoor pollutants may not be recommended. Strategies are needed to decrease exposure to indoor air pollutants, particularly during poor air quality days.

Existing Resources

To understand the effects of climate change on indoor air quality, a number of indicator data can be used, including environmental data sets, building history, weather/meteorology, and floodplain forecasts. As discussed in the previous section, DEP is responsible for monitoring outdoor air quality and developing regulatory programs to reduce the emission of pollutants that impact human and environmental health and welfare. The Massachusetts School Building Authority and the Division of Capital Asset Management are beginning to examine the age and needs of existing government-owned buildings, so that the highest priority risks and building needs of the most vulnerable properties can be identified and addressed. Further, the DPH Indoor Air Quality program has conducted assessments of hundreds of schools and other public buildings in Massachusetts, generating data to further identify vulnerable areas. There is a need for similar examination by private property owners. Where flood damage may be severe, building modification or even relocation may need to be considered. Both forecasting and floodplain information are important for identifying geographic risks related to climate change, pinpointing buildings most at risk, and predicting the extent of damage that may occur.

Vulnerabilities

Flooding can have severe impacts on buildings, properties and their occupants. When water penetrates a structure, it can compromise its integrity, promote mold growth, and cause aggravated health responses in compromised populations (asthmatics and those with pre-existing respiratory conditions). Mold can induce irritant symptoms, particularly among those with pre-existing respiratory conditions who may experience more aggravated effects (i.e. asthma attacks). Responding to water damage issues can be very costly and especially burdensome for those without health or homeowners insurance, and financial considerations add to the stress or trauma of adequately responding.

Saturated soils can cause damage to building structures (i.e., cracking, collapse) and buried components can provide further points for moisture penetration. If water-damaged porous materials such as gypsum wallboard are not dried within 24 to 48 hours, the damaged materials should be removed and replaced. Appropriate containment practices should be used during remediation to prevent exposure. Those with pre-existing conditions, such as asthma, or who are immuno-compromised may be displaced during the remediation process. This displacement can cause short- and medium-term stress and trauma.

Conversely, prolonged periods of water shortage (i.e., droughts) can cause soils to dry out and settle. This can damage building foundations and create pathways for later moisture penetration. Droughts are associated with increases in airborne particulates, particularly if there are wildfires. Increased dust loads can cause irritant symptoms, and exacerbate conditions of those with pre-existing respiratory conditions.

Increased temperature (with high humidity levels) can directly degrade building components, promoting indoor condensation and mold growth (cracks in roofs allow more water entry, for example). Increases in temperature/UV index can also result in off-gassing from building materials. Overall increases in temperature can magnify the effects of the urban heat island effect and accelerate building deterioration.

There may not be enough cooling center capacity to manage the expected increases in heat stress and illness, particularly in urban areas. Heat stress can be a trigger for respiratory, cardiovascular, and cerebrovascular episodes, such as heart attacks and strokes. An increase in temperature is often coupled with an increase in ambient ozone levels, which is a respiratory irritant. This can also cause increased indoor ozone levels (from penetration through open windows or increased ventilation rates) which can result in the production of more toxic compounds as ozone interacts with household products.

An extended growing season could result in increased numbers of pests including flies, mosquitoes, and cockroaches. Window screens are required by the state sanitary code to be used in homes to prevent pest intrusion through open windows. With increased degradation rates in homes, breaches in the building envelope can also allow pests to enter. In turn, this may result in increased exposure to toxic compounds as a result of increased use of pesticides.

Potential Strategies

Strategies for emissions reductions are particularly important in this area. Improvements in building materials can help prevent off-gassing, improve energy efficiency and recovery, improve air filtration, and make buildings mold resistant. Buildings are also high energy users, with energy expended in producing building components, building construction, and operating costs. Reducing the embedded energy and operational costs related to buildings can reduce adverse impacts and air pollution from energy generation.

Information such as building surveys and histories can help building owners anticipate water damage, and meteorological data and associated indexes can help building owners anticipate and prepare for heat-related incidents. Building renovations, efficiency improvements to buildings, and the energy supply network provide an opportunity to improve capacity to manage extreme heat events.

Short-Term Strategies

1. Educate property owners about existing and future floodplains to encourage implementation of methods to reduce damage.
2. Seek to increase cooling center capacity, particularly in urban areas.
3. Encourage or mandate use of reflective paints and materials, and white roofs to decrease heat stress on buildings.
4. Consider targeted surveying of buildings (residential, commercial and public) to identify structural needs and vulnerabilities.
5. Promote installation of drainage improvements, insulation, and vapor barriers or retarders, and provide instruction on appropriate drying and salvage efforts.
6. Compile a database of areas expected to experience localized street flooding throughout the state and share this information with interested parties.
7. Consider enhancing construction standards for buildings to be resilient to climatic impacts, including flood, and hurricane resistance.
8. Improve overall drainage around buildings and on thruways. Consider installing building drainage that infiltrates stormwater into the ground or storage for use during droughts.
9. Promote the increased use and installation of natural systems for control of stormwater and flooding.
10. Expand use of porous pavement to improve drainage on roadways and prevent run-off into buildings or into ground surrounding buildings with basements or crawlspaces.

Long-Term Strategies

1. Continue to support research and development in heating, ventilation, and air-conditioning and the clean energy fields to ensure that reduced energy consumption and improved indoor air quality are achieved.
2. Continue to support research and development of building components that resist microbial growth, reduce emissions of volatile organic compounds, and have low environmental impact.
3. Encourage the planting of shade trees, use reflective, light colored paints and use alternate cooling practices (i.e. more ceiling fans, green roofs, and urban open space and garden areas) to reduce the impacts of heat stress on buildings and the general population.
4. Seek to implement the Governor's Zero Net Energy Buildings Task Force recommendations.
5. Continue using the State Sanitary Code (105 CMR 410.000: Minimum Standards of Fitness for Human Habitation, State Sanitary Code, Chapter II) to protect tenants, and require property owners take action to remediate water-damaged building materials, including mold contaminated materials. Resources to assist the DPH and local boards of health to enhance this activity should be considered (VP).
6. Continue to have the DPH Indoor Air Quality Program provide technical service to building/ home owners and local boards of health concerning remediation of water damage in

buildings.

7. Initiate and implement efforts to educate health care providers regarding health risks related to mold exposure and encourage health care providers to contact appropriate persons (e.g., local or state health department) to investigate potential exposures (VP).
8. Evaluate opportunities to provide technical and financial support to property owners to remediate mold (VP).

Water Quality

Different patterns of precipitation, drought, flooding, and extreme events will all have an impact on the quality of water and its use for drinking, food processing, recreation, commercial and industrial production, and energy generation.

Vulnerabilities

Sea level rise, higher storm surges, and more extreme precipitation patterns can affect the quality and quantity of water supplies. Saltwater intrusion in coastal water supplies could affect drinking water quality and lead to increased corrosion of pipes and related infrastructure. Extreme precipitation patterns may also result in higher and faster streamflows which, in turn, can lead to over-bank flooding, stream channel erosion and sedimentation, and impacts to surface water bodies (see Chapter 5 on impacts to infrastructure, and Chapter 4 on impacts to natural resources). Surface and groundwater may become contaminated as extreme precipitation and floods release toxic material, nutrients, and pathogenic microorganisms and parasites from land surfaces. Flooding can cause sewage systems to fail and overflow, increasing hazards from sewage-related pathogens and toxic materials. High turbidity levels in ground or surface waters contribute to an increase in disinfection by-products with a greater potential for bacterial regrowth within drinking water distribution systems. Increased precipitation and water levels may provide breeding grounds and harborage for pests, resulting in an increased potential for water-borne diseases.

Increased nutrient enrichment of salt and freshwater systems from increased runoff can lead to an increase in algae blooms and shellfish pathogens. These issues carry high societal costs, which potentially include the loss of drinking water supplies; increased water treatment costs; increased frequency of water-borne disease incidents, food recalls, and shellfish bed closings; and decreases in trade, tourism, and allied industries.

Finally, periods of reduced rainfall resulting in drought could reduce stream flows, snow pack, aquifer recharge, contaminant dilution, and dissolved oxygen. Intense droughts may also put more pressure on local water supplies and agricultural irrigation needs. Populations vulnerable to the effects of drought include people with heightened sensitivity to water quality (the elderly, some low-income groups with higher exposure to poor water quality, and people with compromised immune systems), households dependent on private wells, and individuals and families lacking access to clean water recreational resources. Large and small businesses that rely on large amounts of water (such as power plants, manufacturing facilities, laundries and farms) are also particularly vulnerable.

Potential Strategies

Short-Term Strategies

1. Continue to monitor water quality reports, toxicology reports, epidemiologic reports, and the impacts of storms and hurricanes on water-borne diseases.
2. Create a forum for gathering information on exposures and diseases related to extreme weather events and flooding, and the potential impact of climate change on morbidity and mortality.
3. Educate the public about ecologically-sound landscaping practices, which reduce reliance on chemical fertilizers that can enrich freshwater systems with ecosystem-disrupting nutrients.
4. Work with communities and provide local authorities with information about the impacts of weather on water supply and increased inland and coastal flooding.
5. Seek to redirect and reduce flooding through improved stormwater management techniques including reducing impervious surfaces and using best management practices, and potentially relocating problematic pollutant sources from flood plains.
6. Identify water and sewer facilities susceptible to saltwater intrusion and coastal inundation.
7. Evaluate and prioritize implementation of improved controls of agricultural, urban, and stormwater runoff to prevent ocean and freshwater contamination, as well as enrichment of nutrients in aquatic areas that offer ideal growth medium for harmful algal blooms.
8. Assess and plan for impacts on regulatory and incident response resources. This will require an expansion of the emergency response workforce at all levels to enforce regulations, address water shortages, provide pest control measures, and respond to disease outbreaks.

9. Support local mutual aid collaboration to develop contingency plans to respond to water supplies impacted by climate change.

Long-Term Strategies

1. Consider re-evaluating standards for the design and maintenance of septic systems and implement changes as necessary to offset climate change related impacts.
2. Conduct outreach and education on water conservation practices, and reducing the use of pesticides and fertilizers.
3. Identify means to improve and implement water management, including improving and enforcing water quality protections.
4. Seek to implement and enforce legal and design standards to reduce agricultural, urban, and stormwater runoff.

Agriculture and Food Systems

The primary impacts of climate change, including increased air temperature, more frequent and severe drought, and more high-intensity precipitation events, could directly influence the productivity and resilience of agricultural systems in Massachusetts. Plant and animal species used in agriculture respond to these factors individually and interactively; plants respond directly to the principal cause of climate change i.e., increased atmospheric CO_2 concentration. There are a number of secondary impacts as well such as changes in crop species (including opportunities for new crops or varieties and loss of existing crops); increasing pressure from existing plant and animal pests that respond to temperature; and emergence of new or invasive pests as warmer climate ranges shift northward. There are additional impacts on agriculture and the food system that will be realized principally as public health and welfare effects, rather than direct agricultural effects.

Vulnerabilities

While there is some potential for benefit to certain crops (mostly cool-season crops) from the direct effects of increased carbon dioxide (CO_2 fertilization) and from a longer growing season, the negative impacts of higher temperatures and more erratic and severe weather far outweigh any benefits. The ability to produce food is susceptible to increased pest pressure from insects, diseases, and weeds that is likely to result from higher annual temperatures. New and organic farmers, who may be less experienced, have fewer options in terms of agricultural chemicals, have potentially less access to capital for infrastructure improvements, and are vulnerable to increased pest and disease pressure.

Many farms, particularly those with less access to working capital for infrastructure improvements, are vulnerable to erosion from an increase in heavy rains, and to crop loss from longer and more frequent droughts. An increase in heat stress days (maximum temperature of more than 90°F) will have a strong negative impact on farming and livestock, especially milk production in dairy cows. Increased use of pesticides against increased plant pests and diseases will potentially create risks to pesticide applicators, farm workers, the public, the environment, immigrants, low-income residents, pregnant women, young children, and those who rely on subsistence fishing. Warming trends have been linked to increases in marine and freshwater algal blooms, as well as seafood-borne toxins. Uncooked seafood, particularly shellfish, may pose new health threats through increases in infectious or toxic organisms.

Also, extreme weather events may contribute to movement of toxins into different environments from run-off, which may then affect food supply. Ocean acidification through CO_2 settling may impact seafood supplies with adverse effects on organisms' abilities to form shells, and could result in ecosystem ripple effects. With respect to outdoor recreational activities provided by agriculture, impacts on crops such as apples, berries, and maple syrup may reduce the opportunities for certain popular and emblematic New England outdoor activities such as apple and berry picking and maple sugaring.

Populations vulnerable to climate change impacts on food systems include the elderly, low-income communities, immigrants, people who rely on subsistence fishing, those living in areas with limited or no access to affordable nutritious food ("food deserts"), and people with low health status, particularly those with illnesses most severely impacted by diet (i.e., diabetes, heart disease, and cerebrovascular disease).

Potential Strategies

Local agriculture has been expanding in Massachusetts for the last few years, keeping pace with a growing awareness of the benefits and importance of locally grown food. Beyond the issues of food quality and a desire to preserve the infrastructure necessary to ensure food security, agriculture plays a role in the state's cultural heritage and helps to preserve dwindling open spaces. Farmers face enormous challenges in adapting to the changes that are likely to result from climate change. Resources that could mitigate these challenges include ongoing programs to monitor food supply and pest/disease outbreaks, an existing inventory of land suitable for agricultural use, public communication on food safety and food security issues, and a regulatory system for registration and use of pesticides.

Short-Term Strategies

1. Continue to monitor food supplies for potential disease outbreaks.
2. Consider providing funding and personnel to monitor for new insects, weeds, and pathogens that are likely to expand their ranges into Massachusetts.
3. Revisit integrated pest management thresholds and strategies in light of changing pest population dynamics.
4. Encourage adoption of best practices to control runoff of pesticides, nutrients, or fertilizers, and soil, which contribute to poor water quality.
5. Consider providing low- or no-cost loans for infrastructure adaptations such as irrigation, drainage, and livestock facilities.
6. Expand educational efforts for pesticide risk management, crop adaptation and management, and conservation practices.
7. Increase efforts to monitor the use and occurrence of pesticides in the environment.
8. Continue to track food-borne illnesses to determine if new patterns or agents are emerging.
9. Provide technical assistance and outreach in partnership with existing federal programs (such as U.S. Department of Agriculture's Natural Resources Conservation Service) that deliver programs at the state or county level.

Long-Term Strategies

1. Facilitate research on crop adaptation and diversity.
2. Seek to identify and understand specific impacts of climate change on food supplies, food quality, and disease transmission to develop appropriate policies and regulations.
3. Consider increasing food subsidies for lower income residents, and modify eligibility requirements to ensure access to healthy food (VP).
4. Evaluate the benefits of modifying development/ zoning priorities to increase access to places to purchase fresh food (VP).
5. Investigate providing technical and financial support to assist small farms to bring produce to new markets, particularly in urban areas. This may include support for participation in community-supported agriculture by low-income families (VP).
6. Promote and provide/increase technical and financial support for small-scale farming (VP).
7. Evaluate the opportunity to provide disaster assistance or insurance for small farms for crop losses (VP).
8. Strive to improve and enforce water quality protections for water bodies that are used for subsistence fishing (VP).
9. Examine providing technical and financial support to farmers for transitioning to new crops and infrastructure (VP).
10. Increase and improve support for and enforcement of federal and state OSHA and workplace safety laws relating to pesticide/ herbicide exposure prevention (VP).
11. Conduct outreach and education targeting vulnerable population groups and their employers about health and safety precautions (VP).
12. Study potential improvements to state health and safety laws relating to pesticide/herbicide exposure prevention (VP).



The symbol signifies adaptation strategies that are also climate change mitigation actions.

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7 — Local Economy and Government

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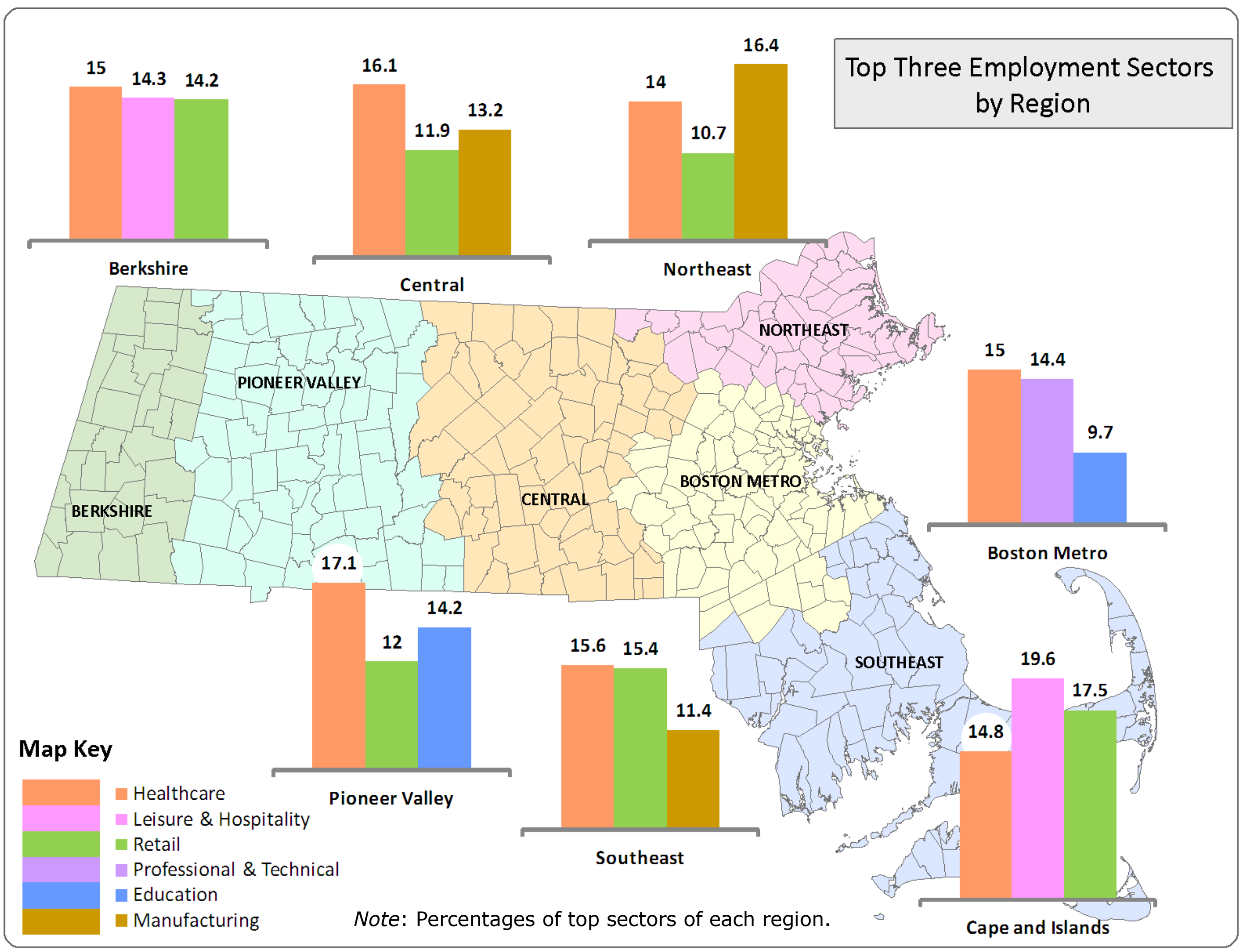
7 Local Economy and Government

Introduction

As climate change occurs, it will affect many of the features that make Massachusetts attractive—its cities and towns, job opportunities, historic sites and natural beauty. This chapter reviews how predicted climate change may affect key sectors of the Massachusetts economy and government. Some may be near-term impacts while others may create longer -range challenges. The sectors addressed in this chapter include weather-dependent industries such as agriculture, forestry, and fisheries; manufacturing such as computers, electronic equipment, fabricated metal, and machinery; and service industries such as real estate management, tourism and recreation, health care, and higher education. This chapter also provides an overview of the potential impacts on government and the services it provides, helping citizens to seek "safety, prosperity, and happiness" (Constitution of the Commonwealth of Massachusetts, 1780), and the importance of proper planning, development and siting in the land use section.

The Massachusetts Executive Office of Housing and Economic Development tracks economic activity in Massachusetts, dividing the Commonwealth into seven economic regions: Berkshire, Boston Metro, Cape and Islands, Central, Northeast, Pioneer Valley, and Southeast (See "Top Three Employment Sectors by Region" map below). In each of the seven regions, the health care industry is consistently among the top three employers. Retail ranks among the top three employers in six regions, manufacturing in three regions, and leisure and hospitality rank among top employers in two regions—the Cape and Islands, and the Berkshires.



Note: Percentages of top sectors of each region.

Education, among the top employers in Massachusetts, is concentrated in two regions, the Boston Metro and the Pioneer Valley (Nakajima, 2009).

Of the more than 6.4 million people living in Massachusetts, 5.18 million are considered to be of working age and 3.42 million are active in the workforce, either employed or seeking employment (Massachusetts Dept of Labor, 2009). The state ranks fifth in population density among the country's states and territories (U.S. Department of Commerce, 2000). In 2007, approximately 21.2 million travelers visited Massachusetts and spent over $15.1 billion (United States Travel Industry Association, 2008).

Overall Vulnerabilities

As discussed in Chapter 2, scientific research indicates that the state's climate will be warmer, the coastline will alter due to sea level rise, and fluctuations in weather extremes will bring more intense rain and ice storms, and greater heat intensity. Although all sectors will be affected by climate change, the impacts will be dependent on geography and the specific characteristic of a sector. For example, variable timing of precipitation events, as well as increased periods of heat and drought, are concerns for the agricultural sector and industrial processes that depend on water.

Should the water shortages predicted for the southwestern states intensify, Massachusetts may become an attractive place for water-dependent operations, including agriculture and manufacturing, resulting in an influx of new residents from the Southwest to New England—reversing a trend prevalent in the 1980s and 1990s. The business-as-usual scenario for 2035, as developed by NOAA, predicts that migration to the northern states will increase by 20 percent from 2020-2035 (NOAA, 2009). This will likely result in mounting pressure on water supply management strategies as the competition for water grows between human needs and ecosystem needs.

Economic Opportunities

Massachusetts is well poised to take advantage of the opportunities that climate change presents by developing new technologies for energy production and use, irrigation techniques, engineering design, and curriculum development. As an emerging economic sector, clean energy is expected to play an increasingly important role in the state's economic growth. In fact, according to a recent study (Clean Edge, Inc., 2010), Massachusetts has already become the leading state on the East Coast for clean energy innovation, investment, deployment, and jobs.

A Massachusetts Clean Energy Center survey of 471 local companies showed that more than 11,000 people were employed in clean energy at the end of 2010, up 65 percent since 2007. Some 3,500 people are employed in manufacturing of energy efficiency products, a growth of 20 percent since 2007, and the fastest growth (67 percent) is in energy storage. Employment in energy efficiency services has nearly doubled, from 1,000 in 2007 to 1,972 in 2010 in just the 69 firms surveyed, which represent only a fifth of energy efficiency services companies in the state. Jobs in solar manufacturing, installation, and services, meanwhile, have more than doubled during this same period.

In terms of future job potential, the clean energy sector will soon be the tenth largest employment group in the state. Renewable energy companies are the fastest growing firms in the state with an expected 30 percent job growth while energy efficiency firms are expected to grow by 25 percent, over three times greater than the next fastest

Wind Turbines at Ski Resorts: Energy Self-Sufficiency and Good Economic Sense

Ski resorts are constantly upgrading snowmaking capacity and efficiency in order to convert tremendous amounts of water into snow to supplement what nature provides. This effort is ongoing and will increase with predicted climate change of higher temperatures and reduced winter snow cover.

At Jiminy Peak in northwest Massachusetts, a 1.5 MW wind turbine installed in 2007 provides approximately 33 percent of the electrical demands of the resort annually. Winds blow strongest at the site during the winter when power needs are greatest for snowmaking, lifts, and night lighting. During these months, the turbine may provide as much as half of the electrical demand. Wind resource studies conducted by Jiminy Peak showed that the investment pay back was reachable within seven years and it would supply lower cost power for the long-term. The resort is currently investigating the installation of a second turbine.

Early in 2011, Berkshire East completed its wind energy project, making it the first ski resort in the world to be powered entirely by on-site wind generation.

December 2008 Ice Storm Affects Business

A dangerous combination of low pressure, moist air, and cold, powerful winds produced a violent ice storm over the Northeastern states in December 2008. Upstate New York, New Hampshire and northern Massachusetts were most severely affected. Thousands of local businesses were forced to close due to a lack of electricity, heat, sewage, and transportation of necessary supplies. Airports were closed and travel was shut down throughout New England. Delivery trucks could not reach their destinations, slowing commerce dramatically. The loss of sales in combination with property damage from falling branches and ice buildup caused small businesses to lose tens of millions of dollars.

emerging growth sector (Global Insight, Inc., 2007). The Advanced Biofuels Task Force estimated that development of non-food-crop-based alternatives to petroleum fuels could yield 2,500 permanent Massachusetts jobs within the industry by the year 2025, with another 3,700 jobs through indirect spending effects (Commonwealth of Massachusetts, 2008). Policies in the recently released Massachusetts Clean Energy and Climate Plan for 2020 (Commonwealth of Massachusetts, 2010) will help create 36,000 jobs in the State in 2020, including about 13,000 via transportation policies and 23,000 via policies to improve efficiency of energy use in buildings. The estimate for employment from in-state demand for renewable energy in Massachusetts in 2020 is 6,000 to 12,000 full-time jobs.

The potential integration of renewable energy and agriculture could result in the protection of farmland, while reducing or eliminating energy costs to farm operations and reducing the overall demand for fossil fuels. In agriculture, opportunities abound in the research and development of improved pest controls by private companies and academic research laboratories. The development of hybrid crops better able to withstand new pests emerging as a result of climate change could help increase crop resilience and protect farm income. Extended spring and summer growing seasons may improve crop yield and provide opportunities to expand crop varieties. They could also create an economic boon to warmer weather, tourist-based businesses.

In the health sector, climate change will affect human health worldwide. Massachusetts hospitals and universities could address these health effects in their research and teaching. In higher education, continuing research on climate change and adaptive strategies, improved engineering and design, and clean energy alternatives all provide additional opportunities for Massachusetts' economy.

Adaptation Strategies

In response to the vulnerabilities described above, the following pages outline key economy and government sectors and adaptation strategies that will continue to be evaluated and examined in response to potential climate change impacts.

Local Economy—Agriculture

Since colonial days, Massachusetts has maintained an agricultural economy through farming and forestry. Today, farming and agritourism remain central to the economy of many communities. While Massachusetts ranks 43rd among all U.S. states in agricultural production, it ranks 14th in net farm income per farm operation and fourth in net farm income per acre (USDA, 2007). Six of the state's counties are in the top two percent in the United States for direct sales to consumers.

There are approximately 6,000 farms in Massachusetts, with farmland covering approximately 14 percent of the land mass, or approximately 590,000 acres (USDA, www.agclassroom.org). Although many farms and much of the agricultural land base are devoted to major food crops such as apples, cranberries, vegetables, livestock and dairy products, greenhouse and nursery products such as flowers and ornamental plants are the leading sources of income for Massachusetts farmers. Specialty crops include apples, beans, butternut squash, cabbage, cranberries, corn, dairy products, potatoes, and pumpkins. Many of these are sold directly to consumers through farmers' markets, pick-your-own farms, agritourism, and farm stands.

Impacts and Vulnerabilities

Relatively small fluctuations in temperature, groundwater, seasons, and pest population dynamics can have dramatic short- and long-term effects on crops.

Increasing temperatures can extend growing seasons, bringing more income opportunities as well as increased operational expenses, including labor, irrigation, and other fixed costs. As higher temperatures and variable precipitation strain water resources, many agricultural enterprises may be challenged to reduce water use by altering irrigation practices. Irrigation demands, and their associated energy costs, may continue to rise as these climatic changes become less predictable. Agricultural water management will also be affected by potential competition from non-agricultural users such as expanding suburban development. With an increase in the potential for flood as well as drought, increased capture and storage of water may be needed to provide a reliable and continuing source of water for irrigation-dependent crops.

Cranberries generate the largest gross revenue as an individual crop in the Massachusetts agricultural industry (USDA, 2007). With rising temperatures predicted, cranberry farmers are looking to bog management practices in New Jersey for lessons on maintaining successful operations in milder climates (Wick, 2009). With the cranberry production area primarily along the coasts, concerns are growing that sea level rise could cause saltwater intrusion into the groundwater and disrupt bog drainage in low slope streambeds.

Extreme and unpredictable weather patterns will also affect agritourism, a major growth sector. The number one impact on most Massachusetts retail farm sales is weekend weather because it affects the volume of customers coming both to the farm and to regional farmers markets. Climate change may also disrupt the balance between crop pests and diseases and the natural enemies or barriers that control them. Warmer climates enable more insect reproduction cycles in a season, resulting in potentially devastating effects such as the migration and spread of the Hemlock Woolly Adelgid into Massachusetts from neighboring states.

Lastly, a potential threat to Massachusetts agriculture is the sale of productive farmland for other development purposes. This is especially true in a climate change scenario where rising sea level can spur displaced populations from the New England coast and other "climate refugees" to migrate to undeveloped inland areas, such as agricultural lands.

Potential Strategies

General Agriculture Strategies

No Regrets Strategies

1. Assess vulnerable crops. Identify major crops and livestock likely to be affected by climate change, and practices that may mitigate these effects.
2. Establish technical assistance programs. Develop programs to keep the agricultural community informed about the impacts of climate change, how to adapt to the changing conditions, and alternative agricultural products.

Long-Term Strategies

1. Shift to alternate varieties or products. Evaluate means to alter farming practices and shift crop preferences to products better suited to greenhouse cultivation or new climate conditions.
2. Promote the concept of "Buy Local". Approximately 15 percent of the foods consumed in the state are Massachusetts grown. Increasing the consumption of locally grown products reduces the negative effects of shipping agricultural produce. For example, shortening the distance from production to consumption minimizes potential supply disruptions due to storm events, decreases shipping costs, and reduces greenhouse gas emissions from long-distance transportation.
3. Promote urban/community gardening efforts. Urban gardening may help to reduce the heat island effect in larger developed communities, increase consumption of locally grown products, and further reduce the negative effects of shipping agricultural produce.
4. Encourage expansion of improved storage facilities to hold and protect local produce during the growing season and after harvest.

Pest Control

1. Escalate pest monitoring efforts. Consider instituting monitoring and farmer education programs to identify and report harmful pests.
2. Conduct research and investigate use of pest controls for changing conditions. Integrated pest management, and the use of herbicides, fungicides, and insecticides will likely be needed to address pests not presently common in Massachusetts. Research by educational institutions and trade groups on organic strategies, as well as training in new pest controls may be needed to improve familiarity of best practices and alternative solutions to emerging pests.

Figure 8: ***Buy Local Groups*.**
Regional Buy Local Groups connect farmers to their surrounding communities and vice versa.
http://www.mass.gov/agr/massgrown/buy-locals.htm

Crops and Soils

No Regrets Strategies

Research soils, crop alterations. Enhance analysis of current soils and identify crops better able to accommodate shifting climate conditions.

Long-Term Strategies

Development of agricultural hybrids. Consider working to develop hardier hybrid crops to help protect crop resilience and, therefore, farm income. More attention may need to be paid to developing disease- and drought-resistant varieties. Research and development of hybrids can be ventures of private growers as well as educational institutions such as the University of Massachusetts Amherst. Private investors may fund research of commercially popular crops.

Agricultural Operations

No Regrets Strategy

Develop local alternative energy. Coordinate efforts between state agricultural and energy resources departments to enhance programs encouraging the development of local renewable energy on agricultural lands.

Long-Term Strategies

1. Adjust seasonal labor pools. Consider the need to shift from seasonal employment (college and high school students, migratory harvest workers) to alternate labor pools should longer warm seasons preclude labor pools dependent on academic calendars or shifting harvest seasons.
2. Expand crop planting to accommodate extended growing seasons, as feasible.

Water Use

No Regrets Strategies

Seek implementation of alternative irrigation practices and install water conservation practices to reduce vulnerability to water supply fluctuations. The U. S. Department of Agriculture's Natural Resources Conservation Services (NRCS) is a leader in helping Massachusetts irrigated farmland benefit from new lower water use technologies.

Long-Term Strategies

Increase use of storage. With the potential for extreme storm events and reduced summer precipitation, consider increased capture and storage of water to help increase crop reliability. Explore the option of providing farmers with financial incentives to invest in storage capacity.

Sea level rise impacts

Long-Term Strategies

Use improved LiDAR elevation data and information on sea level rise to guide cranberry growers who are considering relocation of vulnerable bogs.

Land Use Impacts on Agriculture

No Regrets Strategies

1. Continue efforts to minimize conversion of protected farmlands to non-agricultural uses.
2. Continue farm protection programs. Continue the Department of Agricultural Resources' Agricultural Preservation Restriction Program to preserve and protect farmland in collaboration with local land trusts and with matching funds from USDA (NRCS).

Local Economy—Forestry

More than 63 percent (nearly 3.3 million) of the state's total land area is forested (USDA, 2006). Timberland makes up 2.6 million acres much, of which is under private ownership (Butler, 2006). Concentrated in the central and western counties of Worcester, Berkshire, Franklin, Hampshire, and Hampden, Massachusetts timberland is capable of producing 20 cubic feet of wood per acre per year. In recent years, up to $845 million in economic activity has been generated annually from the Massachusetts forest products industry, which employs more than 24,000 workers. A total of 92 million board feet are harvested from Massachusetts forests each year, some of which are exported to other states. Massachusetts has 49 sawmills that produce approximately 49 million board feet of lumber each year (Reichel, 2009).

Most of the privately owned forests in Massachusetts are not managed for commodity use. It is estimated that Massachusetts forests support $15 billion in tourism annually. Forest-oriented wildlife recreation contributes about $1 billion to the state's economy, of which over a third is attributed to private forests. Active forest management helps to protect more than 350,000 acres of private forested open space, 50 percent more land than the state owns. If tree planting activities are increased to ameliorate the heat island effect in cities, mitigate urban

stormwater, and to sequester additional carbon, the increased need for saplings and trees will benefit the state's $2.6 billion nursery industry, the largest component of the Massachusetts agricultural sector (Riechel, 2009). Forests and trees, in addition to their ecological value, provide climate and nutrient regulation, soil retention, stormwater mitigation, heat island reduction in cities, and natural filtration of drinking water supplies.

Impacts and Vulnerabilities

Shorter and milder winters can disrupt seasonal schedules foresters rely upon to harvest timber and other forest products on tracts of land where frozen ground is preferable for operating harvesting equipment. Overall productivity may be reduced since operating harvesting equipment in mud is costlier. Warmer temperatures will also impact the time frame during which certain timber harvesting can be conducted—to take into account other ecological considerations such as wildlife species migration and nesting. Warmer temperatures can directly alter the value of forest products by causing an increase of stain in the wood from its sap. This stain, or discoloration, affects the grade of wood and may diminish its market value. More intense rainstorms will increase the costs of erosion control, requiring larger culverts on harvest sites.

Higher temperatures will disturb certain tree species, including spruce, hemlock and sugar maple, and alter the reproduction season of some rare species. Mortality may be much higher in young trees since they are less prone to survive heat and water stress, insect and fungal pests. Warming and the unpredictability of weather patterns may change the window during which certain timber harvesting can be conducted without harming rare species. Increased temperatures and the shorter duration of cold and chilling periods may increase invasive pests and plant diseases, such as the hemlock woolly adelgid (Adelges tsugae), which is far more virulent in southern forests (see case study in Chapter 4). Warmer weather may decrease the ability of certain species to survive and lead to an overall reduction in forest growth in this region. Many southern tree species (including species such as oak and hickory found in the upland central hardwoods forest, the predominant forest type in Massachusetts) could potentially move northward in a warming climate.

Although a relatively small industry in Massachusetts, sap collection for maple sugar products totals about 50,000 gallons with an approximate current value of $2 million. This significant niche industry relies on a sustained springtime freeze and thaw cycles. Such cycles are expected to become less common, and any sustained warming trend will be troubling for maple sugar producers.

Finally, increased temperatures and a longer growing season can increase aeroallergens, potentially affecting foresters with respiratory conditions and allergies.

Potential Strategies

No Regrets Strategies

1. Assess vulnerable species. Identify forest types likely to be vulnerable to climate change, and practices that may mitigate these effects.
2. Provide technical assistance. Provide foresters with information and support services about how climate change may disturb forests, and impart skills and strategies for keeping forests viable.
3. Enhance carbon sequestration. As forests are a very significant carbon sink in Massachusetts, explore strategies that maximize sequestration. Strengthen and develop markets and industries that use harvested wood in long-term products that store the carbon removed.

Short-Term Strategy

Reevaluate current harvest and natural regeneration practices. Research, educate, and develop incentives to encourage forestry practices that foster regeneration of vulnerable species (such as northern hardwoods) to perpetuate their many benefits. By regenerating species now, the growth of more mature trees will extend into periods when climate change impacts may increase in severity.

Local Economy—Fishing and Aquaculture

Massachusetts is one of the leading commercial fishing states in the U.S. In 2006, gross sales by the Massachusetts commercial fishing industry was $4.4 billion (U. S. Dept of Commerce, 2006), supporting 83,000 jobs in the state. This revenue includes not only products brought to the pier (landings) but also related sales and employment through processing and transport operations. The industry delivers a broad range of products including scallops, cod, flounder, haddock, lobster, goosefish, whiting, clams, crabs, hake, herring, pollock, squid, swordfish, and tuna.

The inland and shoreside industry is found mostly in New Bedford, Boston, Cape Ann, and Cape Cod, and produces hybrid striped bass, tilapia, trout, summer flounder, and other finfish. The marine aquaculture industry, found mostly on Cape Cod and the Islands, produces quahogs (hard-shell clams) and oysters, and small quantities of scallops, soft shell clams, and mussels.

Reported sales of marine shellfish topped $11.2 million in 2007. Altogether, inshore and intertidal shellfish such as soft shell clams, northern quahogs, blue mussels and oysters approximated 29 million pounds and exceeded $20 million (Murphy et al., 2009). In addition, the surf clam and quahog dredge fishing vessels landed $1.5 million and $1.4 million worth of surf clams and northern quahogs, respectively (Massachusetts Division of Marine Fisheries, 2008).

Total landings in 2008, not including dredge fisheries and large pelagic species (such as bluefin tuna), amounted to 530 million pounds, with a value of $383 million. Just over 10 million lbs of American lobster were landed in 2008 for a value of $44 million.

Of the New England states, Massachusetts enjoys the highest number of jobs sustained and total sales supported by recreational fishing, with over 6,080 jobs and $803 million in sales in 2006 (U. S. Department of Commerce, 2008). Recreational saltwater anglers took 4.5 million fishing trips and landed 15 million fish including striped bass, mackerel, summer flounder, cod, haddock, black sea bass, and scup. Saltwater anglers spend $800 million annually pursuing their sport, including $200 million from out-of-state participants. For freshwater fishing enthusiasts, more than 500 of Massachusetts' lakes, ponds, rivers and streams are stocked annually with trout, bass, herring, salmon and many other varieties.

Impacts and Vulnerabilities

As the ocean absorbs carbon dioxide, its pH level drops and it becomes more acidic. This could reduce calcification, a process by which sea creatures create their shells and exoskeletons (Green et al., 2009). These changes would affect mollusks, crustaceans, and some plankton species important to the ocean food chain and to human consumption, leading to a significant impact on the multi-million dollar clam, scallop, finfish, and lobster industries. The species distribution will likely change with warming ocean temperatures and this will alter the abundance and availability of those species vital to commerce and the marine ecosystem. Many commercial fishermen and lobstermen may need to harvest from other waters or change their target of harvest (Jansen and Hesslein, 2004). A change in the target harvest may then require a change of gear, incurring a considerable expense.

A recorded warming trend in the coastal waters of Southern New England since 1999 has been cited as one reason for the lobster stock in Buzzard's Bay and Long Island Sound to seek deeper waters. As a result, southern New England and New York face a recommendation under consideration by the Atlantic States Marine Fisheries Commission for a substantial cut in landings to protect the remaining population, including a potential five-year ban on lobstering to help restore depleted stocks. Lobster experts have concluded that continued elevated temperatures in the nearshore southern New England and Mid-Atlantic waters will result in a near abandonment of these historically productive areas by lobsters, resulting in a stock that is far smaller than seen in the late 20th century (See http://www.asmfc.org/).

Shellfish aquaculture takes place mainly in the tidal margins. Farmed beds need shallow tidal effects. Some species, notably oysters, require a mix of salt and fresh water for their full life cycles. However, climate change can cause low-lying coastal zones to flood as the sea rises. The resulting new beach or tidal flat areas may not be suitable for aquaculture, or they may not be available at all as the presence of seawalls, roads and other structures may prevent the creation of new shallow water habitats. A shift in the low-lying coastal zones may also threaten the nursery and feeding habitat of other valued fish species. As a result, stocks of bluefish, tuna, cod, haddock, and sea bass typically available for commercial and recreational anglers may be diminished.

Although aquaculture harvesters will incur less gear damage with less ice, overall yield could be affected with changes in food availability and harmful algal blooms (HAB's) such as "red tide". In New England, red tide is the term used to describe a population explosion or bloom of the toxic phytoplankton Alexandrium fundyense. Red tide is an annual occurrence in the Gulf of Maine with distribution and concentration dominated by nutrient availability and weather patterns, both subject to climate change. Shellfish concentrate the toxin, creating a public health risk if consumed, forcing the closure of productive shellfish areas and affecting harvesters and wholesale and retail shellfish sales.

For freshwater fishing, temperature changes may threaten these fish species, with warmer water temperatures resulting in a reduction of dissolved oxygen in surface waters, which can stress fish habitat (Jansen and Hesslein, 2004).

Potential Strategies

No Regrets Strategies

1. Assess vulnerable species. Identify species likely to be affected by climate change and practices that may mitigate these effects. This could be done by state and federal agencies, in collaboration with academic researchers and trade groups.
2. Provide technical assistance.
   a. Provide the fisheries and aquaculture sector with information about how each sector might be affected by climate change, and with skills and strategies for keeping fisheries and aquaculture viable pursuits; and
   b. Provide research assistance to the fishery industry to assist with changes in harvesting processes and targeted fish stocks.
3. Conduct research to predict which species of fish might thrive in a changed ocean environment.

Long-Term Strategy

Invest in good science to understand changes in fish abundance, ensuring that fisheries management evolves over time to address changing conditions.

Local Economy—Manufacturing (Computers, Electronic Equipment, Fabricated Metal, and Machinery)

Massachusetts is home to many manufacturing companies, employing approximately 9 percent of the state's workforce, or about 300,000 workers. The biggest sectors, comprising 85 percent of total manufacturing jobs, include computers and electronics, fabricated metal, food processing, machinery, chemical, printing, plastics and rubber, transportation equipment, paper, and electrical equipment. The remaining smaller sectors include textile mills, furniture, and petroleum and coal.

Ninety percent of Massachusetts' businesses have fewer than 100 employees and 85 percent are classified as small businesses with 20 employees or fewer. Small businesses employ more than one quarter of the statewide workforce. Although small businesses typically make decisions with a three- to five-year outlook, many employers make decisions that affect their businesses over a longer term on matters such as the selection of facility locations. Larger investor-owned businesses use longer-term time frames when making decisions related to market and product development, particularly research and development.

According to the 2008 Milken Institute State Technology and Science Index (DeVol et al., 2008), Massachusetts was ranked as the top science and technology economy in the U.S. Expanding research of new energy sciences, building design, and infrastructure engineering in Massachusetts will help the manufacturing industry develop an increased resilience to climate change.

Impacts and Vulnerability

Heavier, harsher storms causing floods will likely have an impact on buildings, energy delivery and transmission, and transportation systems. Manufacturing operations in low lying areas may be exposed to increased inundation. More frequent and extreme weather events may disrupt the supply chain of businesses dependent on raw materials for production. Similar impacts may affect product delivery as firms rely more on speedy transportation of goods rather than stockpiling of large inventories, and they may also affect workers' abilities to get to their job sites. Rising temperatures will increase the need for climate control in the workplace. If water availability is affected by an increased variability in precipitation, water-dependent manufacturing industries will likely be strained.

Potential Strategies

No Regrets Strategies

1. Protect water as an asset.
   a. Continue to use market-based solutions to preserve water resources and conserve water;
   b. Encourage water storage, taking advantage of high rain periods to offset drought periods;
   c. Expand/promote opportunities for water recycling, including grey water;
   d. Explore opportunities to coordinate water treatment and energy generation. Locating power plants adjacent to wastewater treatment facilities could partially displace freshwater needs for cooling purposes; and

e. Seek to reduce water use in energy production by considering alternative technologies, since peak water use in energy production often coincides with periods of high heat and low water availability.

2. Encourage or incentivize conversion to more energy-efficient processes or local renewable energy sources to alleviate dependence on the grid and to protect from power disruptions that can occur during extreme weather events.
3. Support improvements to on-site stormwater management to mitigate heavier rains, especially at facilities in low lying areas.

Short-Term Strategy

Examine advantages of increasing inventory supplies and identify alternative materials and inventory suppliers to avoid delivery interruptions.

Long-Term Strategies

1. Encourage businesses to incorporate climate change impacts, particularly as data are refined to a sub-state level, into risk assessments and risk minimization strategies.
2. Consider long-term location alternatives that avoid or address the impacts of climate change.
3. Support building design modifications, such as electrical and HVAC systems, that withstand more frequent flooding and heat waves.
4. Consider altering operation schedules to cooler times of day.
5. Investigate alternate transportation routes, energy supplies, and communication systems for suppliers, customers, and workers to respond to evolving climate change impacts.
6. Establish partnerships with industry and government to facilitate technical assistance to businesses that are adapting to climate change.

Local Economy—Service Industries

This sector includes the insurance, financial services, real estate management, health care, higher education, and tourism and recreation sectors.

Health care and social services are the largest employers, with over 470,000 jobs provided statewide, contributing in excess of $30 billion toward the state's gross domestic product (GDP) annually. Massachusetts is renowned worldwide for quality health care and attracts an equally global clientele, with two hospitals ranking in the top ten facilities in the nation (Comarow, 2009). A number of hospitals statewide have been designated sole community provider status, offering area residents ready access to many state and federal health programs.

Approximately 200,000 employees in the insurance and financial management industries generate more than $33 billion annually for Massachusetts' GDP. At $47.1 billion, real estate management generates the most toward the GDP of any economic sector in Massachusetts and provides jobs for approximately 446,000 people.

Massachusetts is also known for the quality and variety of its educational institutions, attracting students throughout the year, creating approximately 310,000 jobs, and producing just over $8 billion in GDP.

Massachusetts is home to 20 national parks and historic sites; over 450,000 acres of state-owned forests, parks, greenways, historic sites, lakes, ponds, and reservoirs; and innumerable local parks and recreational venues, scenic seashores, harbor islands, riverfront areas, convention centers and resorts. Tourism is a significant economic driver that generated over $15 billion in direct spending in Massachusetts in 2007 (United States Travel Industry Association, 2008). Massachusetts residents account for one-third of the visits calculated in tourism industry reports, while travelers from out-of-state offer a larger overall contribution to the state's economic health, visiting longer and spending more. The state is a destination for domestic and international travelers throughout the year.

Impacts and Vulnerabilities

Due to the impacts of climate change, buildings in low-lying and flood-prone areas will become more vulnerable to flooding, and facilities may need increased cooling systems. The insurance industry's income is also dependent on sales and activities in other parts of the country, and not solely on Massachusetts, so climate change impacts in distant areas can have an economic impact on insurance companies headquartered in Massachusetts. Damage resulting from more extreme storm events will initially be borne by the insurance industry, but will ultimately be passed on to policy holders. Insurance payments could increase for flooded property, damaged crops, livestock, spoiled perishable food due to electricity outages, and heat wave-related health insurance losses.

Those working outdoors, in sectors such as construction, public works, and parks, may see a reduction in productivity during high heat days. Increases in overall summer temperatures and frequency of heat waves are expected to reduce or slow construction projects due to health and safety concerns for workers.

The SEC and Climate Change

According to the Securities and Exchange Commission's (SEC) interpretative guidance, companies should evaluate, for disclosure purposes, the actual and potential material impacts of environmental matters, including the physical impacts of climate change on their businesses.

Oceanfront and riverbank resorts may face inundation from rising seas and flooding. Changes in global ocean currents may contribute to stronger hurricanes, putting additional pressure on Massachusetts coastal areas, especially Cape Cod. Real estate values in low-lying areas may drop as the risk of flooding and associated insurance premiums increase. Insurance firms will likely seek higher premiums. The insurance industry can play a particularly critical role in providing disincentives to build or remain in high risk areas, such as coastlines that experience increased storm surges and sea level rise.

Others firms may leave the market, seeking better returns elsewhere. With the Security and Exchange Commission's rules requiring a company to identify the impact of climate change on business or legal developments, insurance companies are likely to pay particular attention to the level of impact risk in both their coverage and investment portfolios.

Should storm events increase, political pressure may mount to encourage additional public financing of these risks in an effort to keep insurance costs low, through government programs such as the National Flood Insurance Program (NFIP). These programs work to reduce flood damage through hazard identification and mapping, effective community floodplain management, and insurance protection for property owners through subsidized insurance premiums (Federal Emergency Management Agency). The result could be taxpayer funds expended to underwrite risky investments and activities in vulnerable areas and indirectly encourage development in flood prone areas.

In Massachusetts, the Fair Access to Insurance Requirements (FAIR) Plan provides insurance to property owners the private market does not cover. Funded by the 400 property and casualty insurance companies operating in Massachusetts, FAIR provides a safety-net of coverage and has become the leading underwriter on Cape Cod, with over 23 percent of the market. Increasing risk in coastal and inland low-lying areas from more frequent and harsher storm events may not only lead to diminishing coverage by traditional insurance companies, but also a burden on FAIR and NFIP beyond their capacity to provide adequate coverage or to remain solvent in the face of a catastrophic event.

The health care industry is likely to see an influx of patients as well as impacts on operations (e.g., increased flooding risks or increased demand for interior cooling). Massachusetts will continue to be a destination for patients, making overall capacity a potential issue. However, beyond the capacity of the health care infrastructure, additional strain will be placed upon health care insurers. Should reliance upon health care facilities rise due to increases in vector borne and other diseases, the pressure on health care costs may further complicate cost containment measures and put even more pressure on insurance premiums. As many of Massachusetts' hospitals and universities promote research and teaching, they are poised to take on research and treatment of climate-related health impacts.

The tourist industry will potentially face a decline in water availability. Many hotels have already adopted conservation measures to reduce water use and associated costs.

The need to seek relief from heat may increase popularity of recreational activities, such as beach and waterfront activities. Climate change may result in a longer warm weather tourist season, but the associated increases in operation budgets will have to be sufficient to make the extended season economically viable. With a longer tourism season, employers may need to shift from their traditional seasonal labor pool comprising students and migratory workers to more permanent employees.

Warmer temperatures may limit traditional outdoor winter activities such as skiing, snowmobiling, and ice fishing. Less ice cover on lakes reduces the number of days available for ice fishing and increases the risk of accidents. To maintain a full ski and snowboard season, ski areas will need to increase snowmaking operations, thus increasing their operational costs and requiring more demand on water and power. While the fall foliage season attracts many visitors, rising temperatures will also put the colorful sugar maple at risk (Case, 2005).

Potential Strategies

No Regrets Strategies

1. Improve elevation data. To better predict and delineate areas of risk, use elevation assessment tools such as LiDAR to help inform decisions on siting.
2. Provide outreach and educate public and private employers about Occupational Safety and Health Administration requirements regarding employee protections in times of high heat.
3. Increase emergency preparedness for cold weather accidents.
4. Evaluate the impacts of the true cost of risk over time, and consider revising mortgage banking formulas to better reflect the risk. The mortgage qualification process currently takes only the first year of insurance premium into account, rather than the likely rise in a premium due to an increasing risk scenario over time. Alternate pricing strategies, such as a three-year rolling average of insurance costs to forecast future premiums, may produce better lending evaluation criteria when reviewing mortgage applications for both commercial and residential borrowers.

Short-Term Strategies

1. Continue to promote and enhance water conservation efforts to reduce occurrences of water shortages.
2. Increase and expand the focus on emergency preparedness, particularly in areas predicted to experience the greatest impacts.
3. Assess the ability to address health care capacity needs in potential areas of flooding, extreme heat, or poor air quality. Establish alternatives to avert temporarily overwhelming local health care facilities.

Long-Term Strategies

1. Improve science and research on prevention and cures of vector borne diseases that are predicted to increase with climate change (See Chapter 5 on Health and Human Welfare for more information).
2. To address potential changes in seasonal labor pools due to longer warm weather climate,
   a. develop new labor pools for tourist attractions through broadened training opportunities and outreach; and
   b. consider altering staff deployment and staff funding to tourist sites of consistent high use.
3. Encourage employers of outdoor workers to shift work schedules to cooler times of day whenever possible, including possibly extending break periods at midday to avoid times of highest heat.
4. Evaluate benefits and consequences of altering snowmaking strategies at enterprises dependent on snow cover, by making more snow during colder weather and stockpiling snow for later use.
5. Reevaluate the Federal Emergency Management Agency's (FEMA) role in providing insurance in vulnerable areas to improve alignment of potential risks of development with climate change impacts.

Local Economy—Cultural Resources

Massachusetts cultural resources are an important part of the state's, New England's and the nation's unique cultural heritage. A variety of cultural repositories exist across the state, such as

- libraries, archives, historical societies, museums, and city and town halls, which house culturally significant objects such as literary collections, special and rare collections, manuscripts, historical archives, municipal records, and artifacts;
- historic sites or areas, such as Local, State, and National Historic Districts and archaeological sites yet to be studied;
- ethnographic resources, areas and objects with unique cultural meaning for specific ethnicities or population groups, such as Native American Sacred Grounds; and
- public recreational areas such as parks and beaches, which may also contain outdoor sculptures as well as historic artifacts.

Existing Resources

These resources are managed by a variety of governmental, private, and nonprofit organizations, such as the Board of Library Commissioners, the Massachusetts Archives, the Massachusetts Historical Commission, the Department of Conservation and Recreation, municipal governments, historical societies, museums, private boards, Native American Tribes, and other ethnic groups.

Impacts and Vulnerabilities

Many cultural resources are vulnerable to climate change because of their location and fragility. There are many specific climate change impacts on these resources:

- Sea level rise may flood sites in coastal floodplains;
- Rising temperatures may make it too hot to visit sites without climate control capabilities;
- Rising humidity may damage archives and library, museum, historical society, and

municipal collections and place increased burden on climate control systems;

- Increased precipitation and floods may completely inundate sites or damage the structural integrity of historic buildings, archives, libraries, museums, and historical society collections;
- Increased extreme weather events may damage fragile historic buildings, archaeologically and ethnographically significant sites, libraries, museums, archives and their contents;
- Changing growing seasons and rising ocean temperatures may affect culturally significant species—such as lobsters, cod, blueberries, cranberries, and sugar maples; and
- Ocean acidification may damage underwater archaeological sites along the continental shelf, including shipwrecks and Native American sites.

Potential Strategies

No Regrets Strategies

1. Structural reinforcement. Consider improvements to the structural stability, water drainage systems, and weatherproofing of culturally significant sites as part of capital improvement projects.
2. Incorporate climate change vulnerabilities and adaptation strategies into the decision-making process related to maintenance, structural reinforcement, studies and funding, relocation of threatened objects, and landscaping of cultural sites.
3. Investigate installation of year-round climate control capabilities, including natural site climate control capabilities such as tree cover and vegetation, and re-examine the thermal properties of buildings to increase resilience and reduce greenhouse gas production.
4. Prepare historic landscapes for drought by planting drought-resistant native plants to reduce water needs.
5. Cultural resource property managers may coordinate among themselves and with emergency management organizations such as Massachusetts Emergency Management Agency (MEMA), FEMA, and COSTEP-Massachusetts (Coordinated Statewide Emergency Preparedness) to assess resource vulnerability and develop plans for resilience.

Short-Term Strategies

1. Prioritize sites for study. Identify and focus research efforts on historical, archaeological, and ethnographically significant sites that are most vulnerable to sea level rise and climate change.
2. Maintain and develop emergency management plans in conjunction with MEMA and FEMA. Re-examine and strengthen existing or create new emergency management plans for cultural resources based on identified new potential impacts.

Long-Term Strategies

1. Consider enhancing monitoring and record-keeping of the type and extent of existing vegetation at cultural resource sites to monitor any effects of climate change.
2. Investigate developing and implementing a plan to digitally record as many artifacts, collections, and sites as possible, prioritizing by level of risk to damage or destruction.

Government

Government at local, state, and federal levels face many of the same challenges as other sectors, such as facility siting, energy use for worker comfort, health risks to employees, sea water infiltration into groundwater supplies, and transportation mobility issues. Collaboration between government, education, and business is vital to effective climate change adaptation.

General Impacts and Vulnerabilities

Harsher weather events can include flooding from rains or coastal storms, extended heat periods, and saltwater infiltration of water supplies. As greater exposure to such vulnerabilities is likely to increase, emergency preparedness will take on added importance.

Structures such as buildings, roads, bridges, and dams that exist along rivers, the seashore, and in other vulnerable areas are more likely to be impacted from sea level rise and storms. Low income and vulnerable populations will disproportionately suffer the effects of extreme events, be least-equipped to adapt, and likely rely more heavily on government for support and relief. Of great risk to local government is its fiscal vulnerability, as damage to private property due to climate extremes may result in a reduction of the municipal tax base, while at the same time call for an increase in services for vulnerable populations, emergency response, and public and private infrastructure maintenance upgrades or replacement.

Government often provides a vision and planning effort that precedes action (Heilbroner, 1992). The need to be ready for an uncertain future requires leadership and decision-making about infrastructure, land, emergency response procedures, and many other components of modern social interaction.

Government, however, cannot provide such leadership in a vacuum. By enhancing existing alliances with trade associations, the insurance industry, worker unions, and institutes of higher education, government can foster improved climate change readiness in its own service to constituents as well as to each economic sector.

Potential Strategies

No Regrets Strategies

1. Consider vulnerable populations during emergency planning efforts, including potential relocation options. This may include the following strategies:
   a. In the wake of extreme weather events, assist employees with alternate transportation to job sites;
   b. During temperature swings, plan to accommodate an increased demand for health and safety services; and
   c. Encourage good neighbor advisories and institute cooling centers during heat waves.
2. Continue, and enhance as necessary, maintenance efforts on roadways and bridges to avoid washouts and increase vegetation along roadways and bridge embankments to hold soils on sloping areas.

Short-Term Strategies

1. Continue sponsoring climate change data collection and research as budgetary constraints allow.
2. Research and develop new products and engineering strategies to build climate change resilience.
3. Evaluate and implement changes in procurement, grant criteria, engineering standards, building codes, and zoning, as precautionary measures to reduce vulnerability to climate change impacts.
4. Collaborate with trade associations and the insurance industry to develop specification improvements that ensure building and infrastructure designs are more resilient to climate change. Examine development of a building-and-design education curriculum that incorporates planning for climate change.

5. Consider possibly amending Chapter 41, Section 81D of the Massachusetts General Laws to require inclusion of a climate change impact assessment and establishment of mitigation strategies in community master (comprehensive) plans.
6. Incorporate evaluation of climate change impacts into Massachusetts Environmental Policy Act (MEPA) (required by the Massachusetts Global Warming Protection Act of 2008) and other permitting processes, as these could facilitate consideration of climate change impacts in the development/redevelopment process.

Long-Term Strategy

Target infrastructure funding to assist in redirecting development toward less vulnerable areas.

Government—Enhance Emergency Preparedness

Emergency preparedness resources have evolved over time based on the demands of past emergencies and storm events. The scope, magnitude, and frequency of historic emergencies have served as the basis for the design and development of our current emergency preparedness infrastructure. As noted, storm-related emergency situations are expected to become more frequent and intense, and, with changes such as sea level rise, many areas that previously escaped storm impacts will now be vulnerable.

For the purposes of this assessment, the public safety sector has been viewed through the lens of emergency management. Emergency management is divided into four phases: preparedness, response, recovery, and mitigation.

Existing Resources

The overall emergency management strategy involves all levels of government, with an overarching concept of one level of government supporting another, e.g., federal government supporting the states, and states supporting regional and local entities. Typically, when the emergency management capacity of a lower level of government is exceeded, support is requested and provided by the next higher level of government. This planning and implementation model has generally worked well and has been enhanced with the requirements established by the National Incident Management System.

Impacts and Vulnerabilities

Since September 11, 2001 and the major storm events that hit the Gulf Coast region in the last decade, emergency management professionals have recognized how easily and quickly response and recovery capacity can be exceeded at all levels of government. These lessons can serve as the starting point for enhancing future emergency management capabilities in order to respond to the increased frequency and intensity of extreme weather events expected from climate change.

Potential Strategies

1. Update MEMA databases and maps. During emergency response and recovery phases, MEMA serves as the state's emergency operations center (SEOC). The SEOC is the focal point for all agencies and organizations that provide response and recovery activities, as well as the information source for the Governor's Office during emergency situations. Recent storm events and exercises have revealed areas in mapping and information systems that need to be updated and enhanced. As these efforts move forward, the potential impacts from climate change should be factored into the scopes of work for enhancing these systems, which will include getting support from state agencies such as the Massachusetts Department of Transportation (MassDOT) and DEP.
2. Update the State Risk Assessment Inventory. Based on predicted increases in areas subject to flooding and coastal storm flowage (e.g., expanded "A" and "V" zones), the State Risk Assessment Inventory should include an accurate list of at-risk government facilities and resources.
3. Update the State Comprehensive Emergency Management Plan to recognize the potential for climate change to influence the severity and frequency of a range of natural and technological hazards (flood, severe weather, drought, water contamination, etc.). Update and revise hazard-specific annexes and plans, referencing mapping and technical data with regard to climate change research.
4. Expand the scope of the State Hazard Mitigation Plan. This plan is routinely updated and submitted to the federal government to support funding requests for various mitigation projects that enhance the preparedness of government/public facilities to withstand future storm events and reduce damage potential based on historic experiences. Future plans should consider factoring in expected vulnerabilities from climate change impacts. This may require federal approval to allow flexibility in Hazard Mitigation programs, since federal requirements are prescriptive and could limit hazard mitigation projects designed to address climate change impacts.
5. Design and implement coordinated education and outreach efforts to increase awareness of the cost savings and public safety benefits of hazard mitigation, enhanced preparedness planning, and other projects that will assist communities and state agencies with climate change adaptation. Assistance programs to help municipalities develop debris management plans comprise one of several areas where local officials need both education and technical assistance.
6. Continue assessment of emergency responses. Since extreme weather events are predicted to occur more frequently, it is important to ensure that various sectors (such as the energy sector) have the capacity to respond to these events. Emergency management plans should be updated to account for predicted climate change and impact on delivery systems should be evaluated. Maintaining a database of available equipment parts to facilitate sharing during an emergency, and increasing replacement budgets and material stock should be considered.
7. Increase capacity to address emergencies by facilitating greater cooperation and sharing of resources and expertise with the business community, forestry sector, and the tourism industry at a regional scale.
8. Continue assessment of emergency equipment, supplies, and evacuation facilities.
9. Practice the execution of communities' emergency action plans, involving local non-governmental organizations for support, staffing, and building constituent support.
10. Establish support mechanisms to ensure overall preparedness to meet increased demand on local public works and emergency response staffs due to more extreme weather events.

Government—Improve Planning and Land Use Practices

Difficult societal decisions lie ahead regarding options and alternatives for reducing risk to public infrastructure, private property, natural resources, and human safety and welfare. Public discussions and deliberations can be initiated now to develop criteria, set priorities, and establish or modify policies to determine where protection should be advanced and where managed retreat may be more prudent. Future risk and costs can be minimized for new development and redevelopment through the careful siting and inclusion of design standards that account for higher sea levels and more intense storms and precipitation events.

Numerous planning and land use tools will be critical to addressing climate change. These tools should be used to engage the public, analyze and present data to guide policy making, and inform conservation and development plans. New or revised policies and regulations can assist in guiding infrastructure or other investments to desirable outcomes given anticipated climate change impacts. The intent of this section is to synthesize and summarize means of employing land use tools and techniques to address the many challenges of adapting to a changing climate. Strategies have been divided into three sections: those that a.) apply predominantly to new development, b.) address existing development, and c.) concern planning regulations and assistance. These strategies will continue to be investigated for feasibility.

Potential Strategies

New Development Strategies

1. Consider sizing infrastructure (such as pipes, culverts, rain gardens) to handle predicted storm events. Consider modifying existing standards within the Massachusetts Stormwater Handbook to better handle stormwater volumes reasonably expected as the climate changes with an emphasis on green infrastructure.
2. Seek to ensure that state investments in infrastructure and development projects (direct or indirect via grants, loans, tax incentives or other funding mechanisms) reflect potential climate change impacts, especially future risk projections. Consider incorporating future risk projections into program-level project selection criteria and in capital budget review by the Executive Office of Administration and Finance in order to properly assess impacts.
3. Examine utilization of state statutes and regulations to ensure that new buildings are sited and built in a manner that reduces their vulnerabilities to impacts of climate change, especially those in inland and coastal floodplains and other current and future threatened areas. Consider applying one or more of the following land use tools.
    a. Provide incentives and tools including funding, a robust technical assistance program, and complementary state policies to aid in the implementation of "no adverse impact" policies.
    b. Guide development of structures and infrastructure to areas unlikely to be eroded or flooded by more intense and frequent storms and/or predicted sea level rise.
    c. Apply a "no adverse impact" approach (see case study on StormSmart Coasts in Chapter 8) via statewide regulation.
    d. Explore mechanisms that proactively address migrating wetlands. Consider utilizing "rolling regulations" that facilitate wetlands or beaches to migrate inland as sea level rises. Rolling regulations provide an alternative to prohibiting all development in coastal areas, preclude coastal armoring, and facilitate sediment transfer.
4. Site and design development to preserve/restore natural hydrology. Facilitate restoration or creation of flood storage where feasible.
    a. Investigate applicability of low impact development (LID) strategies via potential state stormwater regulations;

    b. Provide incentives and tools including funding, technical assistance, and complementary state policies to aid in the implementation of LID site design and stormwater management regulations;
    c. Develop regulations and incentives to encourage development projects to restore or create flood storage;
    d. Develop incentives for landowners to return impervious surface to permeable surface, especially once the impervious surfaces are no longer needed (for example, parking for an abandoned mall); and
    e. Consider establishing a public revolving loan fund or tax credits to support and encourage retrofitting—brownfield cleanup fund may be a model.

Land uses that absorb more water

A school in Manchester, Massachusetts invested $1.2 million on artificial turf for its athletic fields. After receiving four inches over rain during 12 hours on a Thursday evening and Friday morning, the newly constructed rubber turf field was dry enough to play on Saturday. The field substance used allows water to absorb into the ground rather than running off as stormwater. The field's design helps to recharge groundwater naturally while keeping the field dry and ready to use. With an increasing number of high-intensity storms anticipated with climate change, investments that increase pervious surfaces could have the dual benefit of reducing flooding and replenishing aquifers.

Existing Development Strategies

1. Explore options for ensuring that, as sea level rises, vulnerable buildings and infrastructure are structurally prepared for storm events. Means to achieve these goals may include enhancement of the building code to the extent feasible. "Index" the code to scientifically-derived standards, consider applying flood hazard area regulations to "A" zones, and consider updating policies/ regulations/safety standards applicable to vulnerable structures not covered by the building code.
2. Evaluate the potential benefits of classifying coastal areas by "tier" based on degree of risk, extent of existing development and corresponding investment, sensitivity of natural resources, and other factors. Indicate for each tier the degree to which areas so designated could be addressed, including options such as:
    a. Protect from sea level rise, in which:
        i. coastal armoring/shoreline stabilization will be allowed in the form of traditional "hard" engineered barriers (with careful consideration of their impact on surrounding property and habitats); physical barriers where appropriate and feasible, particularly in areas where land and existing development is too important to lose (for example, the hurricane barrier in New Bedford); or "soft" measures—landscape flood mitigation such as extensive LID and preservation or creation of wetlands or coastal dunes to mitigate storms impacts;
        ii. infill development will be permitted;
        iii. structures/infrastructure will be rebuilt if damaged; and
        iv. flood resistant building and infrastructure measures will be employed.

    b. Left for "nature to run its course," in which:
        i. coastal armoring/shoreline stabilization is strictly limited or not allowed;
        ii. new buildings and infrastructure are limited or not allowed;
        iii. managed retreat and relocation policies/ programs are pursued;
        iv. buildings are to be removed if threatened or "substantially" (for example, 50 percent) damaged;
        v. expansion of existing development is tightly constrained; and
        vi. existing infrastructure is maintained, but not repaired/replaced if substantially damaged.
3. Develop and implement a protocol for each proposed tier that applies appropriate state and local planning, regulatory, infrastructure, investment, and other tools. Begin with a factual inventory that characterizes coastal locations by degree of risk, existing extent of development, environmental sensitivity, and other factors. Then

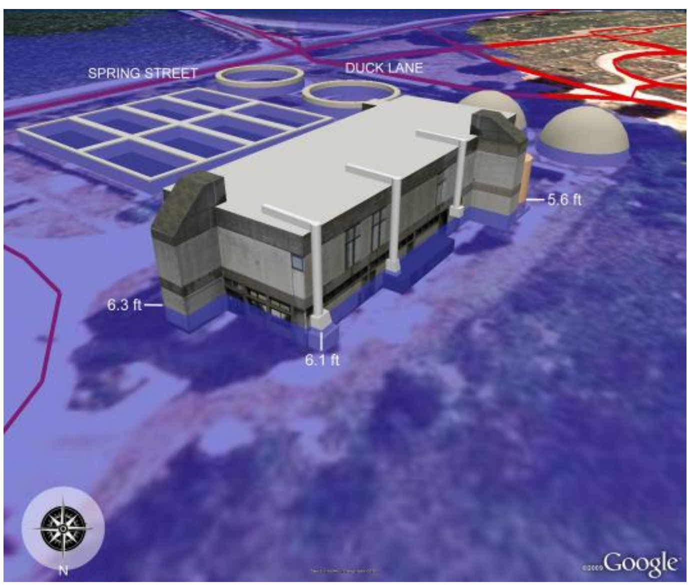


Figure 9: ***WasteWater Treatment Plant in Hull, MA: Simulated flooding around a critical facility from base flood plus 3.3 feet of sea level rise.***
Base flood (i.e., a 100-year flood) elevations taken from FEMA Preliminary Digital Flood Insurance Rate Map for Plymouth County (11-7-2008). Labels represent flood water depths measured from building foundation at ground level.
Source: http://www.mass.gov/czm/stormsmart/resources/hull_inundation_report.pdf

Massachusetts precedence for 'no-build' in dangerous coastal areas

When a landowner sued the town of Chatham for its refusal to permit construction of a new home in the town's mapped floodplain, Chatham defended its floodplain zoning bylaw intended to protect local people, property and resources. In 2005, the Massachusetts Supreme Judicial Court issued a landmark ruling that upheld the bylaw, citing reasonable public interest, stating that its enforcement was not tantamount to a taking and did not require direct compensation from the town. Further, the land retained more than a token value. Even though residential units could not be built on the land, various other uses including fishing and agricultural uses were allowed on the site. The town's right to enact regulations that ensure the safety of its citizens in the face of a hazardous landscape was upheld.

utilize this information as the basis to:

a. Engage in a classic planning exercise to engage stakeholders and produce a plan that designates tiers and selects appropriate land use outcomes for each tier. Implement the resulting plan through statute, regulations, policies, and programs as appropriate;

b. Perform a scenario-based risk assessment in which the probable impact of various adaptation actions are determined for various climate change and socio-economic scenarios. For each location, the most robust adaptation option will generally be the one that performs best in the majority of scenarios. As part of the analysis, gather stakeholder input on costs of various socio-economic scenarios and acceptable degree of risk; and

c. Undertake some other process to produce a plan that addresses coastal impacts of climate change.

Planning, Regulation, and Assistance Strategies

1. Consider assigning an agency the responsibility to gather and provide data, offer policy guidance, facilitate inter-agency coordination, and otherwise serve as an information provider on climate change and adaptation strategies in order to coordinate actions and guide plans, regulations, and investments.
2. Promote state, local, and other land conservation and development plans that reflect future climate change risk projections and that post-storm emergency response and decision-making plans are in place. Investigate the Statewide Hazard Mitigation Plan and local mitigation plans prepared for MEMA/FEMA to determine if emergency planning is adequately addressed and respond as needed. Assist regional planning agencies in the production of regional climate action plans that comprehensively assess risks, costs, and potential solutions for adapting to climate change. Work with and provide incentives for municipalities to integrate the appropriate regional climate action plan into master, open space, and other local plans in order to ensure that they address climate change preparedness, resiliency, and adaptation over a long-term horizon.
3. Incorporate evaluation of climate change impacts in MEPA and environmental permitting processes. Review (and revise accordingly) state permitting procedures and regulations for ways to consider climate change concerns such as requiring alternatives and impact analyses for development of current and future threatened properties.
4. Use climate change impacts information to help identify high-value land acquisition:

   a. preserving large unfragmented blocks of open space and connecting corridors to allow species to migrate with their habitat;

   b. protecting unregulated but vulnerable areas for conservation uses;

   c. conserving parcels just inland to allow coastal ecosystems to retreat as seas rise; and

   d. preserve agricultural soils and lands, especially near urban markets.
5. Investigate opportunities where local regulations (general, environmental, zoning, etc.) can minimize the impact of climate change. Provide robust financial and technical assistance and enhanced planning and land use tools in order to encourage and assist communities in the potential use of local regulations to, among other things:

   a. preserve large unfragmented open spaces and connecting corridors;

   b. consider potential future floodplain expansion in land use planning and direct growth away from floodplains and other vulnerable areas—this may include the use of some form of overlay zoning (either through the potential hybrid of existing floodplain designations or expansion of regulated flood zones to encompass the 500-year flood zone) to preserve high water "climate impact zones";

   c. concentrate development on portions of a parcel that are least vulnerable; and

   d. transfer development rights from areas at risk and properties that have been damaged by storms.
6. Investigate opportunities where local land use regulations and building codes can address the "heat island" effect. Encourage the implementation of local land use regulations (zoning, subdivision, etc.) and the adoption of state building code provisions that address heat concentration including:

   a. land use regulations governing impervious surface, tree, shading, street/building orientation, etc.;

   b. building code provisions on roofing materials, insulation, fenestration, etc.; and

   c. incentivizing white, if not green, roofs.

The symbol signifies adaptation strategies that are also climate change mitigation actions.

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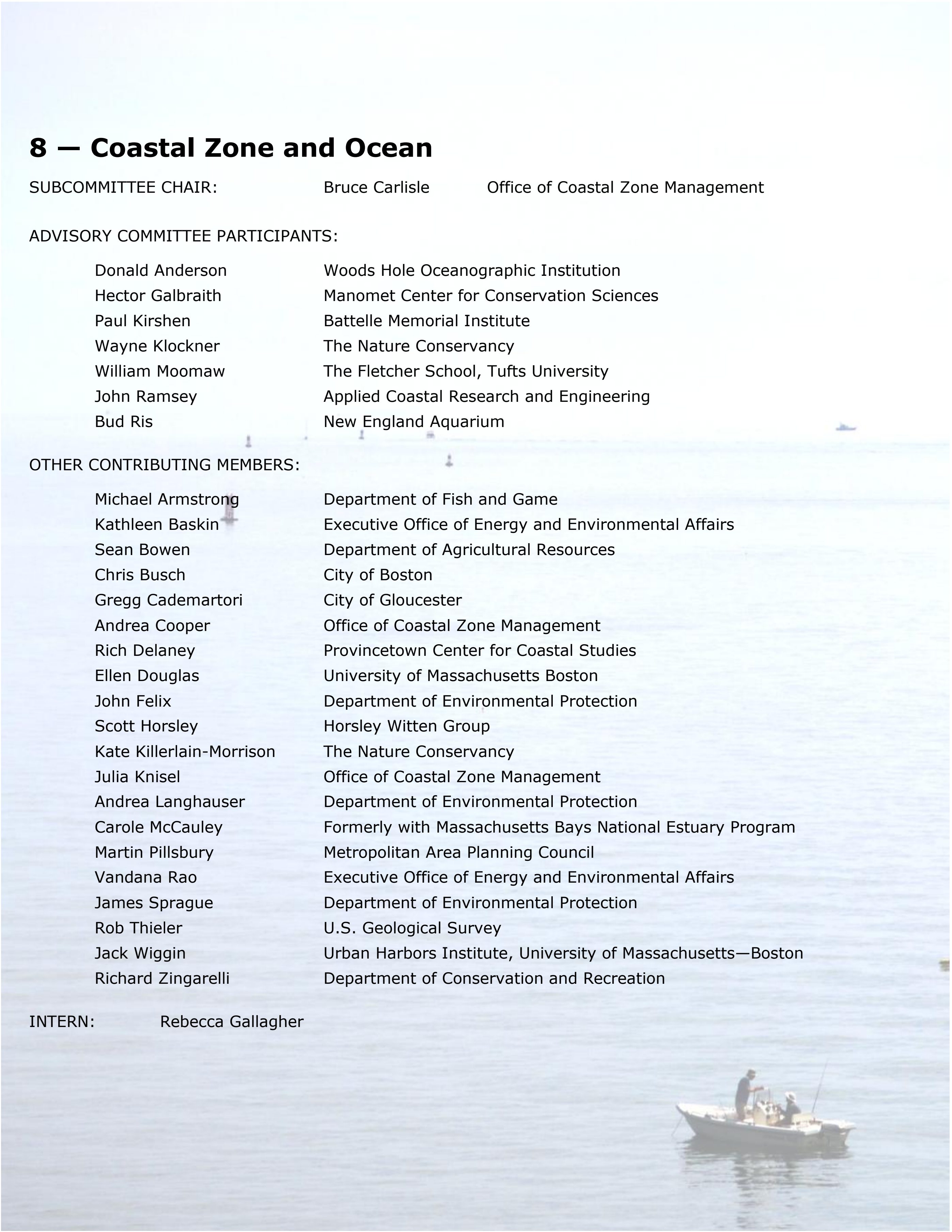

8 — Coastal Zone and Ocean

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8 Coastal Zone and Ocean

Introduction

Massachusetts' coastline and ocean are tremendous resources that have shaped the state's economy, history, and way of life. Today, unfortunately, these resources are threatened by a host of issues, including erosion of public beaches, costly storm damage of homes and businesses, habitat loss, pollution of waterways from land runoff, and the spread of invasive species. While work is underway to address these challenges, the focus is often based on a historic view of coastal and ocean environments. Climate change—with its resulting acceleration of sea level rise, potential increased frequency and intensity of storms, and shifts in ocean temperature, currents and chemistry—is altering these already dynamic environments, exacerbating coastal management challenges.

Through efforts in coastal hazards management, ocean planning, habitat restoration, fisheries assessment and management, and land protection, Massachusetts has taken many important steps and is poised to become a national leader in coastal climate change adaptation. To reduce and mitigate severe climate change threats to public safety, local and regional economies, marine and terrestrial habitats, and public and private infrastructure, a new focus is needed.

This chapter provides a general overview of the climate change vulnerabilities within the coastal zone and ocean "sector" in Massachusetts. It then focuses on three categories: (1) residential and commercial development, ports, and infrastructure; (2) coastal engineering for shoreline stabilization and flood protection, and; (3) coastal, estuarine, and marine habitats, resources, and ecosystem services. For each of these three categories, the chapter summarizes the existing resources and climate change adaptation efforts currently underway; discusses the vulnerabilities of these resources to climate change; and offers potential strategies for reducing risk and vulnerability and improving resilience to the evolving impacts of a changing climate.

Overview of Vulnerabilities

Unaddressed, climate change will result in significant impacts to Massachusetts' coast and ocean waters. On the coast, modest changes in temperature can have major impacts on sensitive ecosystems, threatening biodiversity and ecosystem-based economies, such as fisheries, tourism, and recreation. Sea level rise will exacerbate impacts to development, infrastructure, and natural systems from erosion and storm damage. Impacts could include loss of life; extensive property damage; destruction of public infrastructure; release of sewage, oil, debris, and other contaminants; and loss of commercial and marine-related businesses critical to local, regional, and state economies.

Coastal salt marshes, barrier beaches, and floodplains are particularly vulnerable to rising sea levels because they are generally within a few feet of existing sea elevations. These areas also provide extensive recreational opportunities and significant environmental services, including providing habitat for many species, playing a key role in nutrient uptake, and protecting inland areas from flooding. In the ocean, temperature changes can influence ocean current strength, stratification of the water column, temperature and salinity levels, and nutrient and mineral transport—affecting the ecosystems and economically important species that depend on them. In addition, increased marine acidity levels will impact shell formation for certain species. The overall result of these changes for ecosystem and fisheries health will be significant.

Adaptation Strategies

Today, Massachusetts is already facing and endeavoring to manage the impacts of sea level rise, including increased erosion and storm damage. The resiliency of Massachusetts coastal and ocean ecosystems and economies—that is, their ability to accommodate impacts from both existing natural hazards and future climate change—requires planning, collaboration, and action. With the many economic and environmental issues facing the state, addressing the additional challenges posed by climate change can seem a daunting, complicated, and expensive endeavor. However, by incorporating climate change projections into existing strategic, management, and fiscal plans, resiliency can improve. The result will be forward-thinking climate change strategies that could be built into land use plans, financial budgets and capital investments, regulatory processes, and similar implementation mechanisms. The following section contains possible strategies aimed at improving resiliency of Massachusetts' coasts and oceans. To more effectively convey a wide range of issues and suggestions, recommendations are organized under three categories within the Coastal Zone and Ocean sector. Strategies with similar elements have been consolidated.

Residential and Commercial Development, Ports, and Infrastructure

The coastal zone is densely developed with homes, businesses, roadways, docks, ports, and other infrastructure and facilities critical to local, regional, and state economies, but also highly vulnerable to storm damage and other impacts of climate change such as sea level rise. The built environment in the coastal zone, which constantly changes due to new development and redevelopment, presents a significant challenge for climate change adaptation.

Existing Resources

Massachusetts' coastal cities and towns are home to one third of the State's population and its coastal counties have more than three-quarters of the state's population. According to a U. S. Census Bureau estimate in 2007, coastal cities and towns with significant populations (>45,000 people) include Boston, New Bedford, Quincy, Fall River, Lynn, Revere, Plymouth, Weymouth, Peabody, and Barnstable. Within these and other coastal communities are an extensive number of residences, businesses, shopping centers and malls, industrial operations and the critical public and private infrastructure that supports this development.

A significant economic sector is coastal and marine tourism and recreation—which includes recreational fishing and boating—with an annual output of $8.7 billion in 2004. Another important sector to the marine economy is the commercial seafood sector—comprised of fishing and fishing supplies, marine aquaculture, seafood processing and wholesaling, and retail and food service seafood sales—whose value in 2004 was $1.6 billion (Donahue Institute, 2006).

Massachusetts Coastal Economy

The total output of the Massachusetts coastal economy is approximately $117 billion, or 37 percent of annual gross state product. The coastal zone economy directly employs over 1 million people, representing close to 37 percent of employment in the state.

Many resources already exist to reduce risks to development in the coastal zone. Massachusetts has statutory and regulatory programs that govern the siting and design of new construction and redevelopment, including the Massachusetts Environmental Policy Act (MEPA), The Public Waterfront Act (MGL chapter 91) and the Wetlands Protection Act. Environmental variation driven by a changing climate may necessitate modifications to these policy tools. Certain Massachusetts General Laws (e.g., Zoning Enabling Act, Wetlands Protection Act, Subdivision Control Law, and the Septic System Regulation-Title V) grant powers to municipalities to guide siting and design for growth. Local officials rely on Flood Insurance Rate Maps, the state Smart Growth/Smart Energy Toolkit, and funding via the Community Preservation Act to help guide siting and development.

Vulnerabilities

Development in the coastal zone is highly vulnerable to current and future impacts of climate change. Without adaptation, one can expect more extensive damage and loss of development associated with infrastructure and critical facilities due to severe erosion of coastal shorelines, overwash and

The Cost of Coastal Storms

The Massachusetts Hazard Mitigation Plan (2007) illustrates two significant coastal storms that hit Massachusetts in 1991, Hurricane Bob and the October nor'easter. These two events caused $49 million in damages to uninsured property and infrastructure (e.g., roads, bridges, public facilities, and public utilities). An additional $125 million was paid out by the National Flood Insurance Program (NFIP) in flood insurance claims. The following year saw another coastal storm that caused more than $12.6 million in damages to public infrastructure and 1,874 NFIP claims at a cost of nearly $12.7 million.

breeching of barrier beaches, inundation of coastal floodplains from sea level rise, increased storm surge, and flooding. Coastal communities that have been densely developed for decades already experience frequent and expensive flood damages. From 1978 to 2009, Scituate property owners received more than $49.6 million in National Flood Insurance Program (NFIP) claims. Scituate ranks number one in terms of flood damages and accounts for 17.6 percent of NFIP payments to policyholders in Massachusetts. The town of Scituate and other communities, including the city of Quincy, are actively working to help property owners elevate utilities and entire homes to reduce flood damages (Massachusetts Office of Coastal Zone Management, 2009). Other vulnerabilities include:

- Widespread damage of public and private development with limited or no relocation options;
- Impassable roadways and constrained access for emergency vehicles and personnel resulting in significant risk to public safety; and
- Inoperable wastewater and stormwater systems and associated public health concerns.

The funding and other incentives outlined in the previous section, while effective for short-term planning purposes, may not adequately consider longer-term of sea level rise or an increase in the intensity and frequency of storm events. Recent revisions to the State Building Code (780 CMR 120.G) strengthened existing standards for construction in floodplains and coastal dunes. Since many designs still do not address future inundation or migration of resource areas such as wetlands, however, new construction and redevelopment are likely occurring in areas that will erode and flood within the lifespan of these projects.

Potential Strategies

Adaptation strategies are necessary to reduce risk along Massachusetts' highly populated coast. An important and highly effective way to minimize threats to human health and safety, damage to public and private property, and preventable expenditure of scarce resources is to site new development and major redevelopment away from current and future vulnerable areas, including floodplains, zones subject to storm surges and wind-driven waves, and areas with high erosion rates. Additionally, by planning development to account for the future migration of important resource areas such as salt marshes, dunes, and areas subject to storm flow, the ability of natural systems to respond to changing conditions can be maintained. A proposed project located in an area that might be considered buildable today, may be undevelopable after weighing the projected costs against projected risk, factors such as increased sea level and flood frequency.

Climate change will result in greater storm damages to existing development and an increase in recurring storm damage to individual properties (referred to as "repetitive losses"). Difficult choices face Massachusetts regarding options for protecting the built environment and their potential conflict with existing property rights. Now is the time to start a public dialogue about the benefits, costs, risks, and resources needed to make informed decisions about where to target major investments to protect existing development. The analysis and assessment of risk management needs to be done at several scales and within different socioeconomic contexts, including state, regional, and local levels. In urban areas with large populations—especially those that are environmental justice communities—implementation of highly engineered structural protection measures will likely be a high priority for extensive public infrastructure and private development. Other areas may be able to reduce risk through approaches involving less engineered

Coastal Zone Management's StormSmart Coasts

Like other New England states with "home rule" government, many land-use decisions in Massachusetts are made at the local level. For coastal communities, this means grappling with the impacts and effects of erosion, storm surge, and flooding problems, which are being exacerbated and accelerated by global climate change. To help communities address these challenges, the Massachusetts Office of Coastal Zone Management (CZM) launched its StormSmart Coasts program in 2008. CZM developed user-friendly tools such as fact sheets, case studies, smart growth planning strategies, legal and regulatory tools, and extensive technical materials. CZM also held a series of regional workshops to connect local officials directly with the program.

Then, in 2009, CZM began five StormSmart Coasts pilot projects with seven communities—Boston, Falmouth, Hull, Oak Bluffs, and the three-town team of Duxbury, Kingston, and Plymouth—to test drive local, proactive implementation of StormSmart Coasts tools. The results are successful, transferable coast-wide models and enhanced partnerships with regional, state, and federal agencies; conservation organizations; academia; and the private sector to better serve coastal communities in Massachusetts. For more information, see the StormSmart Coasts website (www.mass.gov/czm/stormsmart).

structural measures, such as Low Impact Development, or some combination thereof.

1. Analyze strategies for siting new development and redevelopment outside of projected vulnerable and future resource areas. Design new development and redevelopment projects according to risk projected over the project lifespan. This may be achieved by the following means:
   a. Continue to discourage and avoid siting in current and future vulnerable areas, such as floodplains, velocity zones, and areas with high erosion rates. Additionally, by planning development to account for the future locations of important resource areas such as salt marshes, dunes, and areas subject to storm flowage, the ability of natural systems to respond to changing conditions can be protected;
   b. Consider building on Executive Orders 149 and 181 (intended to reduce vulnerability and damage costs in floodplains and on barrier beaches); explore issuing an Executive Order that specifically directs state development and significant redevelopment, as well as state-funded projects, out of vulnerable coastal areas;
   c. Strengthen the alternatives analysis for

Figure 10: ***Projected Inundation at High Tide, East Boston—2100***

Shading indicates current areas of East Boston, Massachusetts, inundated at high tide in the year 2100 under low and high sea level rise (SLR) scenarios. The future elevation of high tide is based on the current elevation of Mean Higher High Water (MHHW) plus projected SLR. The low SLR scenario at 2 m (A) includes both regional SLR due to land subsidence and the low end of the range of eustatic (global) SLR projected by Rahmstorf (2007). The high SLR scenario at 3 m (B) includes both subsidence and the high end of the range of eustatic SLR projected by Rahmstorf (2007). On the right, the top inset shows areas near Constitution Beach and the bottom inset shows areas near Central Square, under the high scenario. Highest confidence in the delineation of the elevation exists for blue-shaded areas. Areas shaded with red and orange contain minor uncertainty (5%) due to the vertical resolution of the topography

Source: Map developed by Chris Watson and Ellen Douglas, UMass-Boston; Paul Kirshen, Battelle development siting and design standards to identify, characterize, and avoid project risk and adverse effects associated with climate change impacts;

d. Develop Chapter 91 policy guidance to fully implement 310 CMR 9.37(2)(b)(2), which states "[In the case of a project within a flood zone]…new buildings for non-water-dependent use intended for human occupancy shall be designed and constructed to…incorporate projected sea level rise during the design life of buildings", in a manner consistent with predicted sea level rise stated in this report. Consider a change to the regulation to include all new development and any redevelopment considered significantly vulnerable;

e. Examine Wetlands Protection Act rules and/or policies for potential revisions that address predicted changes in spatial extent of coastal wetlands;

f. Promote the nationally recognized "No Adverse Impact" approach—advanced by the Association of State Floodplain Managers (2007) and underlying the Massachusetts Office of Coastal Zone Management's StormSmart Coasts program—that calls for the design and construction of projects to have no adverse or cumulative impacts on surrounding properties;

g. Consider expanding recent revisions to the State Building Code, with provisions that strengthen requirements for storm-resistant building designs, materials, and features;

h. Update coastal erosion and flood-hazard zones delineations, especially in areas that experience high velocity floodwaters and breaking waves, so that they incorporate projected rather than historic rates of sea level rise; and

i. Consider whether a rise in water table levels warrants changes to the Massachusetts Septic System regulations (known as Title V) to provide for additional protective separation distances for septic systems.

2. Decrease risk and repetitive losses to existing development by implementing the following strategies:

a. Consider additional revisions to the State Building Code to expand the requirement for elevating new and substantially improved buildings above the base flood elevation in hazard areas beyond the "V" zone (velocity flood zone with wave heights >3 feet) in order to accommodate sea level rise. Examine expansion of this standard to Federal Emergency Management Agency designated "A" zones (wave heights <3 feet) in coastal areas.

b. Consider incentives such as insurance cost reduction and hazard mitigation grants for communities that embrace climate change adaptation measures.

c. Seek to reduce the number of vulnerable coastal properties through land acquisition from willing sellers in fee, or by conservation restrictions. Evaluate the use of Transfer of Development Rights, a smart growth technique that is currently in use, to direct coastal redevelopment inland. A potential scenario may include several components for further consideration such as:

   i. to promote the transfer, existing homeowners who agree to sell their rights and abandon a storm-damaged property could receive state and local tax breaks for rebuilding in an upland area, or could purchase municipally owned land appropriate for development at a below-market rate;

   ii. additional funding could be realized by encouraging coastal communities to adopt the Community Preservation Act and use the Community Preservation Fund for acquisition of properties at risk of storm events and sea level rise (high risk for development) that also have preservation or recreation value; and

   iii. pool resources of the state and other partners, such as non-profit land trusts, to acquire land and conservation restrictions in perpetuity within vulnerable coastal areas.

Freeboard is the height of watertight surface between a body of water and the lowest point of entry. The expense of incorporating increased freeboard into new structures is low, generally adding only about 0.25 to 1.5 percent to the total construction costs for each foot of added height.

d. Consider a statewide rolling easements policy for existing development along the shoreline. These rolling easements are typically coupled with policies that prevent armoring of the coast. Similarly, require that reconstruction of buildings significantly damaged by storm events comply with new standards and delineations of erosion and flood-hazard zones.

e. Evaluate and update hazard mitigation, evacuation, and emergency response plans to address the changing conditions associated with new development and climate change, especially related to sea level rise and increased storm intensity and frequency. Make updates to these plans as refinements are made to climate change projections and development patterns change within a community, or at a minimum of every five years.

Hull Freeboard Incentive

The Town of Hull offers a freeboard incentive to protect the health and safety of its citizens, prevent property damage, and reduce the need for costly emergency services during storm events. For residential and commercial building elevation, or new construction projects, building department permit fees will be reduced by $500 (or by the cost of the permit, if lower than $500) if an elevation certificate is provided to verify the building is elevated a minimum of two feet above the highest federal or state requirement for the flood zone. If the base-flood elevation on the FEMA November 2008 draft map is higher than the current map, eligibility for the permit fee reduction will be based on the draft map.

Coastal Engineering for Shoreline Stabilization and Flood Protection

Public and private coastal engineering structures are designed to protect buildings, infrastructure, and other uses in the coastal zone by controlling shifts in shoreline positions and blocking floodwaters. Engineered beaches and dunes that introduce sediment into starved beach systems are also considered in this section. Future permitting of coastal engineering projects could include consideration of local and regional processes and conditions to better eliminate or reduce impacts from erosion, flooding, and long-term inundation.

Existing Resources

A variety of structures exists along the coast of Massachusetts to stabilize the shoreline and protect buildings and infrastructure from erosion and flooding. Coastal structures include bulkheads, seawalls, revetments, groins, jetties, and breakwaters, as well as hurricane barriers, and flood and tide gates. The State conducted a comprehensive inventory of publicly owned or managed coastal structures along the shoreline (Massachusetts Coastal Hazards Commission, 2007). Visual inspections by civil engineers resulted in the rating of bulkheads, seawalls, revetments, groins, jetties, and breakwaters according to their condition using a letter system, from excellent (A) to critical (F). Structures with critical levels of deterioration exhibit conditions such as section loss, cracking and undermining. These structures provide little or no protection from major coastal storms and require complete reconstruction to regain functionality. Each structure was also assigned a priority rating based on its condition and ability to protect buildings from erosion and flooding. Structures with a high priority rating may warrant emergency stabilization due to the presence of high-density residential dwellings or other critical structures and the potential for loss of life or property. The inventory provides critical information required to better manage these structures. Similar assessments will need to be conducted for coastal structures that are in private ownership.

Vulnerabilities

Impacts of climate change will affect the ability of coastal structures to resist major storm events and prevent damage due to erosion and flooding. Structures placed along the shoreline, largely in the 1940s and 1950s and prior to enactment of coastal management policies and regulations, have interrupted the natural process of sediment transfer. Many of these structures, which were not designed for projected future conditions, remain standing landward of narrow beaches and other sediment starved resource areas. Potential overtopping, undermining, and collapse of coastal structures by storm surge combined with higher sea levels are serious concerns. Because of limited functionality and these potential impacts, residential and commercial development, ports, and infrastructure will likely be more vulnerable in the future. Maintenance and future plans for coastal structures challenge the state, municipalities, and residents of the coastal zone and require new strategies.

Coastal shorelines shift continuously in response to a variety of factors. Wind, waves, tides, seasonal variations, human alterations, and sea level rise influence the movement of sand and gravel within shoreline systems. Developed coastlines that face east or northeast are particularly vulnerable to nor'easters, which are common winter storms in Massachusetts. These coastlines are typically dominated by erosion and flooding. Erosion rates often increase as a result of coastal structures such as seawalls and revetments, which cut off the supply of sediment to adjacent beaches and decrease their widths and volumes. Barrier islands in Massachusetts actively erode because of decreased sediment supply as well as inlet dynamics, changes in nearshore shoaling patterns, location and size of coastal structures, and other human alterations. Climate change will exacerbate these issues—higher sea levels and future storm events will result in greater erosion and flooding impacts over time.

Potential Strategies

The assessment of vulnerable coastal areas will require a better understanding of sediment resources and transport. By incorporating current shoreline change rates and trends as well as additional wave run-up analyses, the delineation of flood and erosion -hazard areas can be strengthened. The armoring of the coast has interrupted natural processes that build and maintain beaches, and has contributed to sand deficits that exist on many Massachusetts' beaches today. There are limits to the effectiveness and availability of beach nourishment and there are difficult decisions to make regarding holding the line or retreating. Protection of individual properties will need to be balanced against other local concerns such as effects to abutting properties, safety of emergency responders, and community resource values. In some cases, large-scale approaches may be considered to preserve uses (such as water-dependent and marine industrial) that cannot be relocated or protected using traditional structures. Overall, it is important to evaluate the application, design, and placement of coastal engineering approaches. Strategies for consideration include:

1. Institute policies and regulations to improve assessment of local erosion and flooding, and evaluate design and placement of engineered approaches to manage these coastal hazards. New or revised state policies and regulations that address coastal erosion and flooding, particularly related to coastal engineering practices, would improve assessment and management of these hazards.
   a. Strengthen the delineation of erosion and flood-hazard areas by incorporating current rates and trends of shoreline change as well as additional analyses of the maximum vertical extent of wave run-up on beaches or structures. With additional resources, state agencies could acquire and update this information every five to ten years for effective management of risk, especially in a changing climate.
   b. Continue to advance use of soft engineering approaches that supply sediment to resource areas such as beaches and dunes in order to manage the risk to existing coastal development. Periodic nourishment with sand is essential to maintaining dry recreational beaches along many developed coasts.
   c. Adhering to provisions of the Massachusetts Ocean Management Plan, examine issuing a state policy regarding the mining of sediment from the seafloor to guide the use of sand and gravel resources from Massachusetts' tidelands, especially for nourishment of private beaches.
   d. Consider prioritizing placement of sediment on public beaches over offshore disposal. Management of sediment resources is a necessary component of the overall resiliency approach that will allow competing interests to adapt and coexist in the dynamic coastal zone.
   e. Conduct an alternatives analysis when replacing failing public structures that pose an imminent danger, and ensure review of the analysis by local and state environmental agencies. Assessment of the analysis should consider cumulative impacts and the No Adverse Impact approach.
2. Plans to replace or construct new coastal engineered structures could better incorporate local conditions and higher sea levels. Analyses of benefits and costs may support large-scale engineered, structural protection of areas that are highly-developed urban centers or have significant water-dependent and marine industry that cannot be relocated.

Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services

Massachusetts coastal, estuarine, and marine habitats—such as beaches, salt marshes, and bays—provide valuable environmental, social, and economic benefits. Such benefits or "ecosystem services" are the wide range of conditions and processes through which natural systems help sustain and fulfill human life (Daily et al., 1997). These include maintenance of habitat for fish and shellfish, storm surge and flood protection, nutrient cycling and pollution prevention, atmospheric and climate regulation, renewable energy sources (wind, waves, and tides), and recreational opportunities.

While it is impossible to put an accurate dollar figure on the value of coastal and ocean systems, targeted economic analyses point to the tremendous value of this sector. For example, the National Marine

RESOURCE	AREA (ACRES)
Coastal bank	2,112
Barrier beach	11,840
Coastal beach	5,376
Coastal dunes	11,712
Rocky intertidal shore	1,024
Tidal flat	18,944
Salt marsh	45,376
Submerged aquatic vegetation	19,392

Table 7. ***Extent of coastal and estuarine habitats in MA***

Fisheries Service indicates that 32 percent of the commercial fish and shellfish collected in New England are directly dependent on estuaries and salt marshes (Stedman and Hanson, 1997). For New Bedford and Gloucester alone, value of the commercial fish and shellfish caught in 2010 was more than $346 million (MA DMF, 2011). In addition, the U.S. Army Corps of Engineers concluded that the flood control benefits of wetlands in the Charles River basin alone were estimated to be nearly $40 million per year in 2003 dollars (Schuyt and Brander, 2004).

Existing Resources

Massachusetts has over 4669 km. (2,900 miles) of varied coastline and over 5180 km^2 (2,000 $miles^2$) of estuarine and marine waters that include a vast array of habitats, flora, and fauna. Using digital wetland resource maps developed by the Department of Environmental Protection's Wetland Conservancy Program and distributed by MassGIS, an inventory of these resources was obtained, as shown in Table 7.

The State also has abundant bays, sounds, and other ocean habitats with various geologic settings, bottom types, depths, tide and current regimes, and biological interdependencies. For a comprehensive overview of the marine habitats in state waters, see the Baseline Assessment of the Massachusetts Ocean Management Plan (Massachusetts Executive Office of Energy and Environmental Affairs, 2009), which contains synopses of primary and secondary producers, benthic communities, fisheries resources, avifauna, marine mammals, and invasive species. Table 8 , taken from the plan's Baseline Assessment, lists some habitat features and their biological links.

Existing state regulatory programs have strong provisions to avoid, minimize, and—if necessary—mitigate the current, but not future, adverse effects of anthropogenic stressors. Recent advancements in protection include updates to the Massachusetts Wetlands Protection Act regulations and the state's Title V Sanitary Code, development of nitrogen loading standards through the Massachusetts Estuaries Project, and siting and performance standards that protect sensitive and unique habitats in the Massachusetts Ocean Management Plan (Massachusetts Executive Office of Energy and Environmental Affairs, 2009). State funding programs, including Coastal Pollution Remediation, Section 319 Nonpoint Source Pollution Competitive Grants, and the State Revolving Fund, provide significant state resources that leverage local funds to implement specific capital projects to address pollution from wastewater, stormwater, and nonpoint source runoff.

Vulnerabilities

Changes in air and sea temperature, precipitation, ocean circulation and flow dynamics, sea level, and storm patterns will have cascading effects on coastal, estuarine, and marine habitats and resources—affecting the ecosystem services they provide. The list below summarizes significant vulnerabilities that could have cascading effects throughout ocean and coastal habitats:

- increases in stratification (the separation in the water column into distinct layers by salinity and/ or temperature);
- changes in nutrient availability, and shifts in primary and secondary production due to changes in temperatures, precipitation, fresh water inputs, and currents/circulation;
- changes in, and potential loss of, suitable habitat and critical life-stage support for ecologically important marine and estuarine species;
- shifts in location and productivity of important marine and estuarine species, with a potential decrease and loss of significant commercial and recreational fisheries due to shifts in suitable habitat;
- loss of commercial fishing and aquaculture revenue due to shellfish impacts from reduced shell formation and reproduction and growth rates, and increased shellfish diseases, pathogens, and harmful algal blooms;
- loss of inter-tidal estuarine marsh habitat caused

Habitat Features	Characteristics
Non-living Structures (Cobble/rocky/boulder/ledge bottom [not shell] often called "rock piles")	Many species use these bottoms due to their 3-dimensional structures, which provide shelter. Some species' life histories require this type of habitat (e.g., juvenile cod and lobster)
Living Structures (Submerged Aquatic Vegetation, kelp, and structure-forming invertebrates)	Many species use these types of bottom due to their three-dimensional structure, which provide shelter. Some species' life histories require this type of habitat.
Areas of Upwelling	Important to driving productivity by bringing in nutrients; may not be a major feature in Massachusetts but could be important on a local scale
Deeper waters (channels, depressions)	Protected from the direct effects of storm-induced waves and warming waters
Estuaries, river mouths	Turbidity front at freshwater-saltwater interface can influence productivity.
Shell habitat	Settling habitat for invertebrates, may provide shelter
Shallow waters (<5 feet/1.5 meters) Mud flats, Salt marshes	Critical nursery areas; mud flats are of high value to marine animals that live and feed in this substrate
Frontal boundaries	Represent important "edge" habitat for a wide variety of resident and migratory pelagic species
Tide rips	Smaller frontal boundary features; sport fishing species; variety of species utilize these features and are popular fishing spots
Mud bottom	Has potential to provide abundant forage; lower resiliency to recurrent impacts in cold/deep mud bottom

Table 8. ***Marine habitat features and some important characteristics***

by an inability of marsh accretion and soil formation to keep pace with rapid sea level rise, further compounded by limitation of opportunities for landward migration;

- degradation and loss of freshwater drinking water supplies through increased saltwater intrusion into groundwater aquifers;
- increase in adverse human health effects and degraded estuarine water quality due to increases in polluted run-off and combined sewer overflow events; and
- shell thinning due to increased ocean acidity in organisms with calcium carbonate shells (e.g., snails, clams, mussels, crabs, and lobsters), impacting both the ecosystem and economy.

Potential Strategies

The protection of land from future development through direct acquisition or conservation restrictions is one of the most straightforward and effective tools for climate change resiliency. To maximize the climate resiliency benefits from land conservation efforts by state agencies, evaluation and prioritization criteria for potential acquisition or restriction could include factors that examine the predicted future changes to the project area in terms of landscape, community, and habitat changes.

"Green" infrastructure—where habitat enhancements and natural systems are used instead of hard engineering for storm-damage prevention and other purposes—also promotes resiliency. The green infrastructure concept has strong connections to stormwater management and nonpoint pollution source control, where natural systems (such as vegetated swales, bio-retention cells, and green roofs) perform the water management functions of traditional engineered curbs, gutters, and pipes, but with significant natural benefits and less cost. Habitat enhancement projects that would serve as green infrastructure include: oyster or mussel reefs for storm surge attenuation, constructed wetlands for floodwater control and storm surge attenuation, planted coir fiber sills for erosion control and storm surge protection, and beach or dune nourishment for erosion control and storm surge protection. Shellfish aquaculture also provides ancillary benefits including nutrient (especially nitrogen) reduction when the cultured product is harvested.

As the marine and estuarine waters of the U.S. East Coast increase in temperature in response to global climate change, coldwater species are expected to move farther northward and species whose ranges have historically been farther south of Massachusetts will shift into Massachusetts waters and north of

Cape Cod. Fisheries managers will need the ability, tools, and information to change management measures in response to the redistribution of species. This will need to be accomplished at the interstate level involving the Atlantic States Marine Fisheries Commission, New England and Mid-Atlantic Fisheries Management Councils, and the National Oceanic and Atmospheric Administration. Future productivity of individual stocks may be significantly increased or decreased in response to climate change, habitat, secondary productivity, or ecosystems.

Historic harmful algal blooms, along with emerging data, suggest decadal cycles of occurrence. Climate change has the potential to alter abundance and distribution, disrupting natural, established cycles. At present, models focus on offshore waters. Higher model resolution in the nearshore will aid in the management of highly productive coastal and estuarine shellfish growing areas. As described above, while the general vulnerabilities of the coastal zone and ocean can be identified, the specific impacts and effects of changing estuarine and marine conditions are not well-known at this time.

Effective management requires sufficient and accurate information. Through this recommended strategy, the scope and focus of current monitoring, assessment and modeling efforts could be expanded to ensure that adequate ocean monitoring and observation capabilities exist in Massachusetts. This would provide sustained, high-resolution information at key locations for sea level, storm frequency and magnitude, salinity, pH, temperature, nutrients, biological community structure and size, currents, chlorophyll, and other parameters that will inform management of climate change impacts and trends. Strategies to be considered for implementation include the following:

1. Bolster land conservation efforts and account for changing landscape and natural communities, protect valuable ecological resources, and provide zones for migration:
   a. Protect land from future development through direct acquisition or conservation restrictions.
   b. Include factors that examine the predicted future changes to the project area in terms of landscape, community, and habitat changes in the evaluation and prioritization criteria for potential acquisition or restriction. Also, include tracts/habitat complexes at varying scales and geographic distribution in preservation targets. The ability of prospective areas to accommodate shifting natural communities and features like floodplains and seasonal wetlands will enhance natural resiliency.
   c. Identify the location of future habitats (and resource areas) through the implementation of predictive mapping and modeling, as a necessary step in the protection of these evolving ecosystems.
2. Improve resiliency of natural habitats, communities, and populations to climate change through habitat restoration, green infrastructure, and invasive species management efforts; design projects for future conditions. Healthier natural systems are better able to absorb and rebound from the impacts from weather extremes and climate variability.
   a. Ensure that projects account for future changes in the ecosystem, investments are justified given those predicted changes, and the project is designed and engineered for sea level rise and changes in hydrology.
   b. Promote resiliency through use of habitat enhancements such as constructed wetlands, oyster or mussel reefs (or other types of shellfish aquaculture), and for storm-damage prevention and floodwater control in lieu hard engineering solutions, where feasible.
3. Increase natural resiliency and reduce anthropogenic stressors through directed improvements in estuarine and marine water quality that minimize unavoidable impacts to habitat. This could be achieved via the following methods:
   a. Consider retreating and migrating wetlands, expanding floodplains, rising sea level and water tables, and increased inundation and flooding through program specific criteria, guidance, policies, or performance standards.
   b. Strengthen consideration of cumulative impacts as influenced by climate change at project planning levels, whether through MEPA review or the State Revolving Fund Loan Program Project Intended Use Plans.

Low Impact Development at Caldwell Farm—Building Smarter to Protect Natural Areas

Low Impact Development (LID) projects are designed to maintain natural drainage flow paths, minimize land clearance, and reduce impervious surfaces—all of which reduce stress on habitats and promote natural resiliency. The Caldwell Farm development in Newbury is an excellent example of how the interests of developers, realtors, and local officials can be brought together to create a "low impact development" that benefits all—including the homeowner.

A 66-unit housing project on a 125-acre site, Caldwell Farm was developed by C.P. Berry Construction Company, which incorporated LID techniques and the protection of open space to maintain 100 acres of the site as fields, forest, freshwater, and saltwater wetlands adjacent to the Parker River National Wildlife Refuge and an Area of Critical Environmental Concern (ACEC). LID techniques used in Caldwell Farm were cluster buildings, reduced road pavement width, and natural buffers to resource areas and grass swales for drainage. Caldwell Farms has received several national awards, including "the Best Overall Community" by the National Association of Home Builders in May 2007.

c. Consider use of the No Adverse Impact approach, which calls for the design and completion of projects so that they will not have adverse or cumulative impacts.

d. Consider development of No Net Increase approaches such as the nitrogen cap policy implemented by the Cape Cod Commission, which requires an offset of each increment of additional nitrogen load with some means of nitrogen removal for other nitrogen loads in the watershed.

e. Maximize incentives, training opportunities, and requirements for Low Impact Development natural design and stormwater best management practices in local planning and regulatory processes to enable routine implementation of these proven smart growth tools, improving water quality and stormwater absorption and reducing flooding impacts.

4. Evaluate incorporating flexibility into fisheries management systems to accommodate species shifts. Expand biological surveys into estuaries, which is where climate change effects are anticipated to be especially pronounced. To avoid unnecessary burdens on recreational and commercial fisheries, fisheries managers could consider a move to a management system that incorporates more contemporary estimates of productivity and ecosystem processes, ensuring that targets are realistic and achievable. Ecosystem-based approaches that address cumulative impacts, establish cross-jurisdictional management mechanisms, and incorporate triggers and methods for adjustments based on evolving knowledge and information will provide significant institutional resilience to climate change.

5. Improve shellfish management and aquaculture by incorporating predictions of harmful algal blooms, marine pathogens, and rainfall. Obtain higher model resolution in the nearshore to aid in managing highly productive coastal and estuarine shellfish growing areas.

6. Increase monitoring, observations, and assessments to better manage resources and respond to critical shifts in conditions. Expand the scope and focus of current monitoring, assessment and modeling efforts including:

   a. Use acoustic mapping to provide base information necessary for determining bathymetry and seafloor hardness and roughness.

   b. Develop a better understanding of the spatial and temporal distribution and habitat needs of marine animals and plants.

   c. Track other important biotic components, especially endangered sea turtles, seabirds, major avifauna and bat migratory pathways, benthic communities of flora and fauna, certain pelagic fish, and areas of high trophic support (primary and secondary productivity and forage fish).

   d. Contribute to and support the development and operation of regional and local 'ocean observing system' infrastructure. Support and augment the few existing efforts that routinely collect such data, including the ocean observation system, whose buoys provide a range of information essential for navigation, safety, and oceanographic modeling and forecasting.

   e. Develop models of coastal hydrodynamics and inundation (coupled with biological and chemical models) to support scenario analyses of future conditions and to test hypotheses.

   f. Continue and augment other high priority baseline datasets, such as seafloor and water column temperature and salinity measurements, which can be used to track decadal, annual, and seasonal trends in salinity, temperature, and water column stratification. Improved measurements of waves and chlorophyll are also important for providing baseline information for modeling.

The symbol signifies adaptation strategies that are also climate change mitigation actions.

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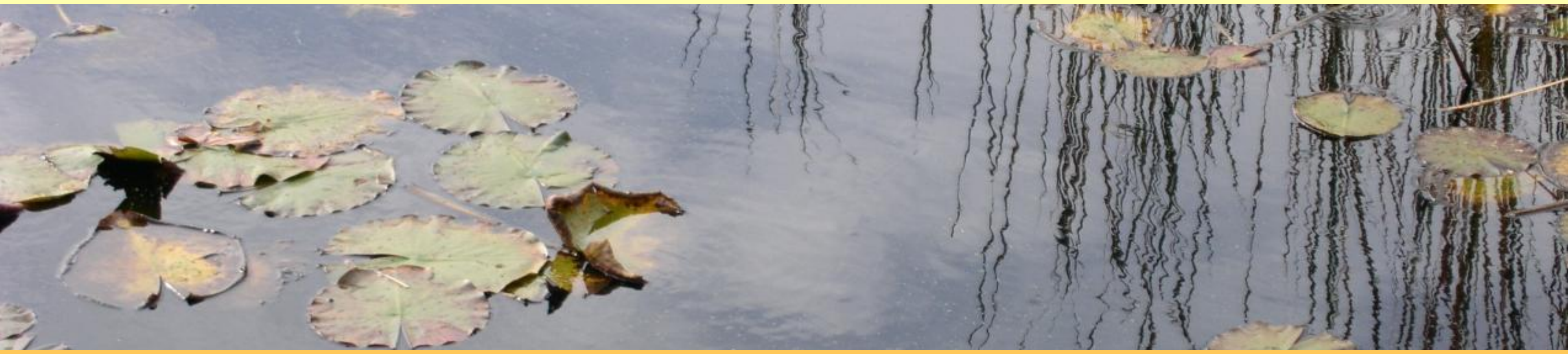

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