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.

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.

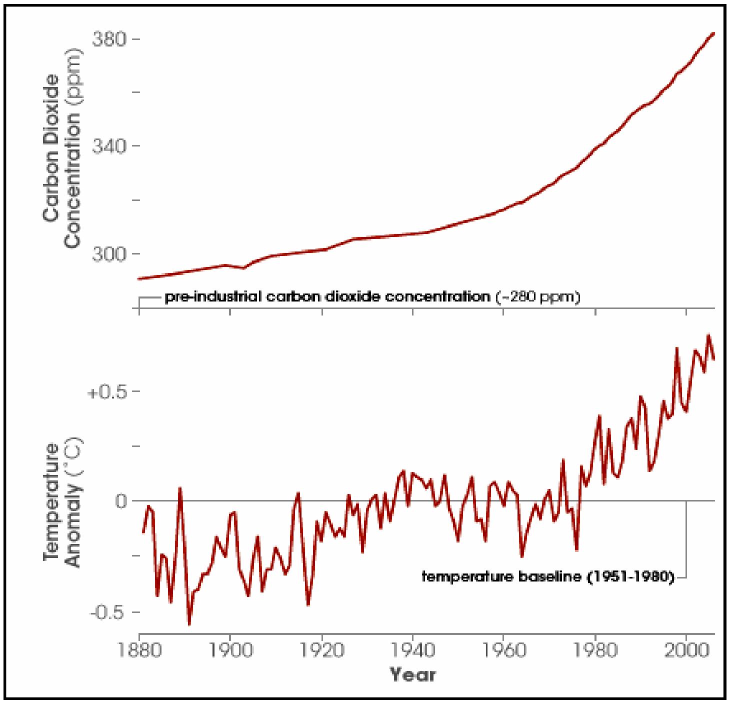


Figure 1: ***Global Temperature and CO_2 Trends***
Source: NASA graphs by Robert Simmon, based on carbon dioxide data (Dr. Pieter Tans, NOAA/ESRL) and temperature data (NASA Goddard Institute for Space Studies).

The 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.

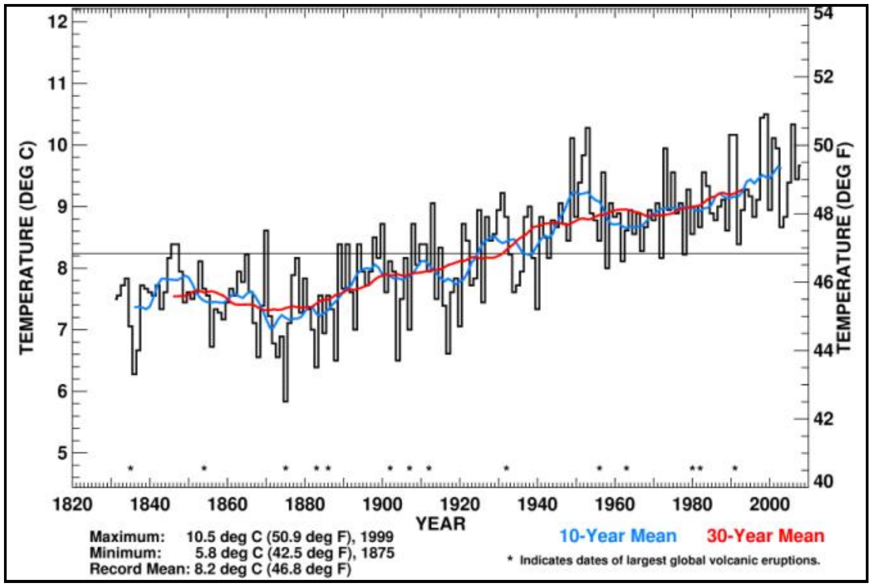


Figure 2: *Blue Hill Observatory Annual Temperature, 1831–2008*
Source: Michael J. Iacono, Atmospheric and Environmental Research, Inc./Blue Hill Observatory, MA
Note: Plot includes temperature data for 1831–1884 from Milton and Canton that were adjusted to the Blue Hill summit location.

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.

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/

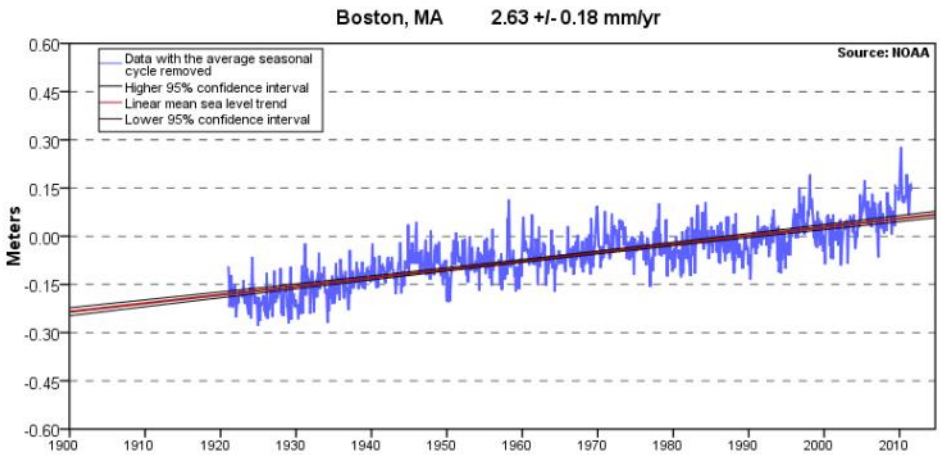


Figure 3: Mean Sea Level Trend measured at the Boston tide gauge.
Source: NOAA. http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8443970

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.

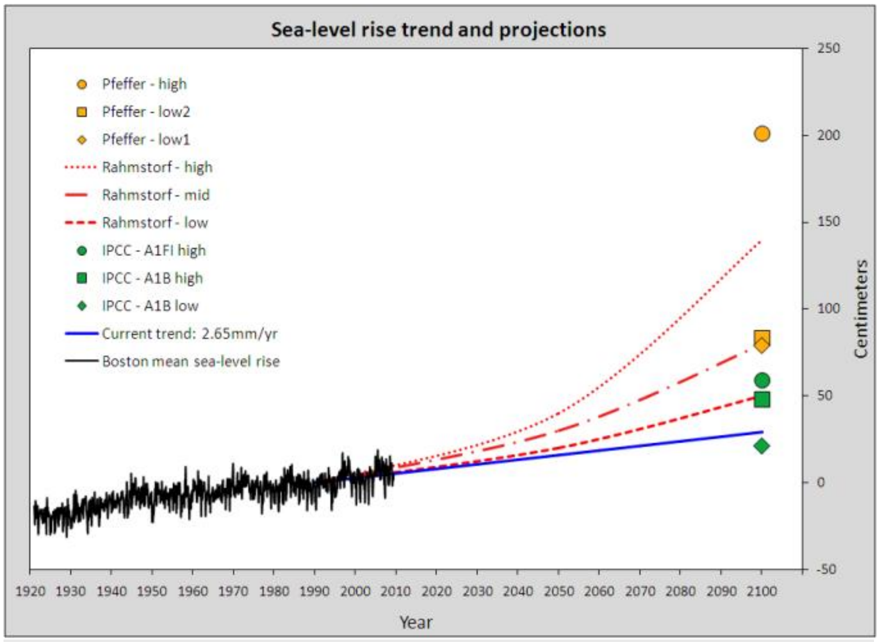


Figure 4: *Global sea level rise trend and projections*

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

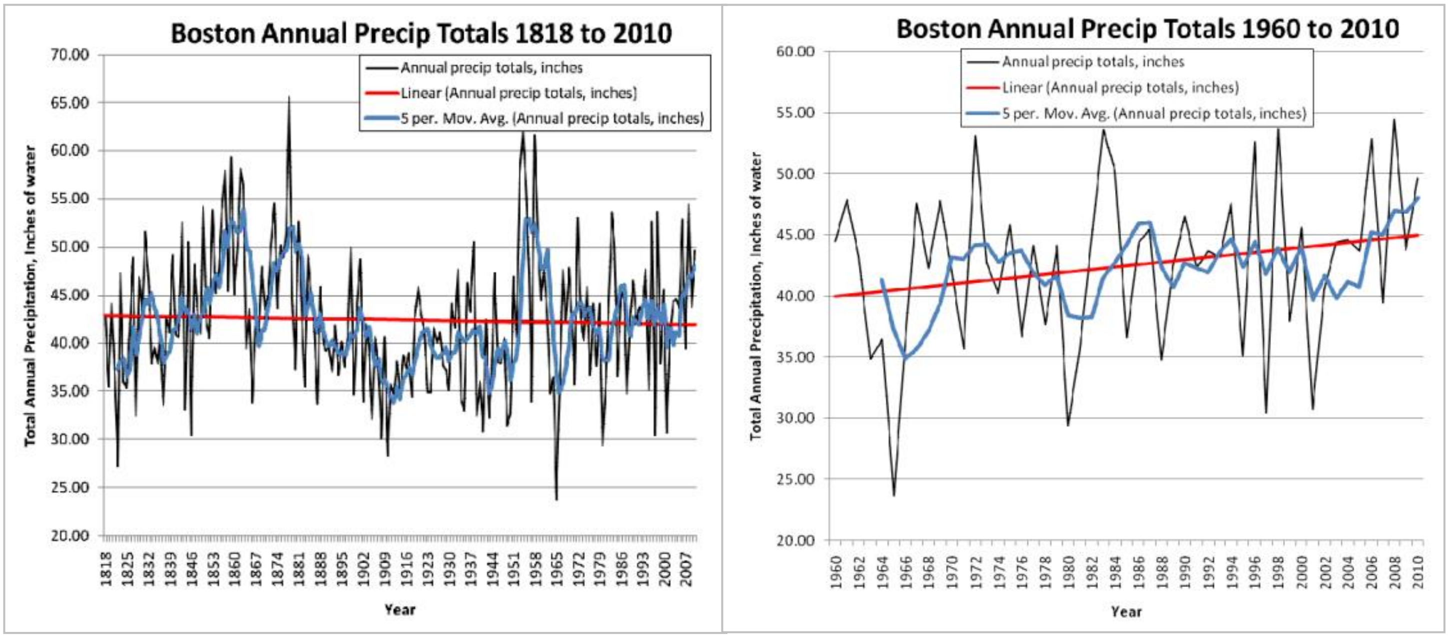
New England is expected to experience changes in the amount, frequency, and timing of precipitation. Although Massachusetts is a water-rich part of the country, the predicted changes could add pressure to the state's water resources. Since 1900, precipitation recorded at United States Historical Climatology 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.

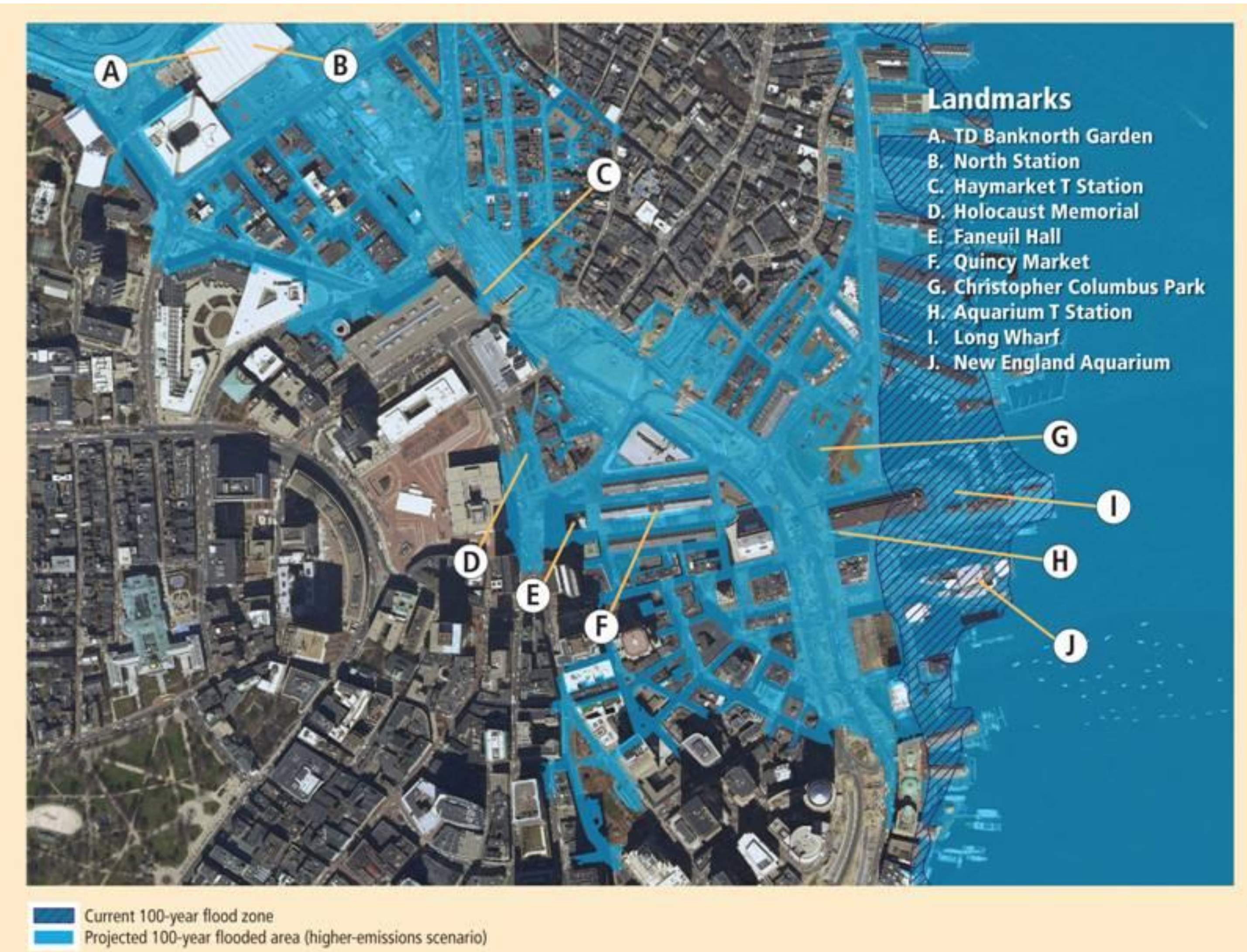


Figure 6: ***Projected Inundation of Boston Landmarks in 100 Year Flood under Higher Emissions Scenario***

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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