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

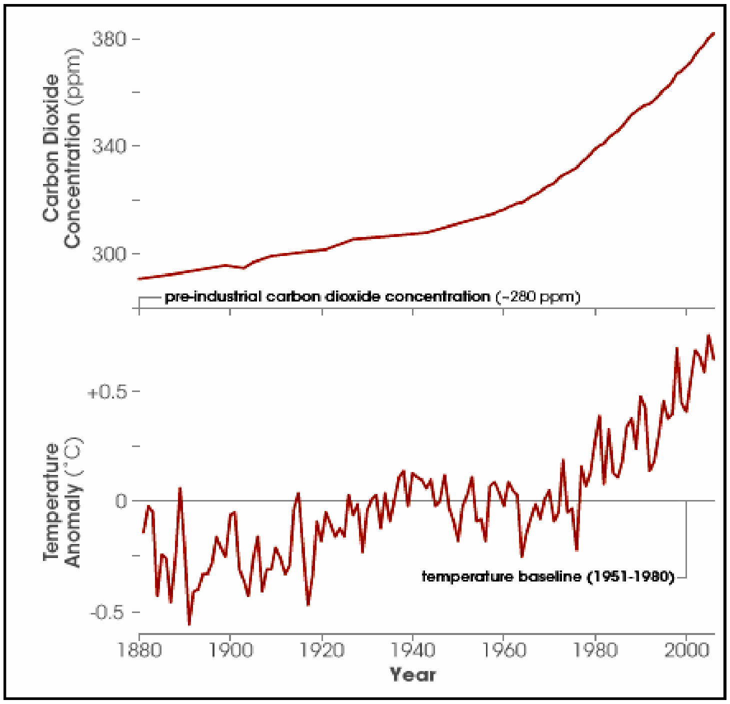


Figure 1: ***Global Temperature and CO_2 Trends***
Source: NASA graphs by Robert Simmon, based on carbon dioxide data (Dr. Pieter Tans, NOAA/ESRL) and temperature data (NASA Goddard Institute for Space Studies).

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.

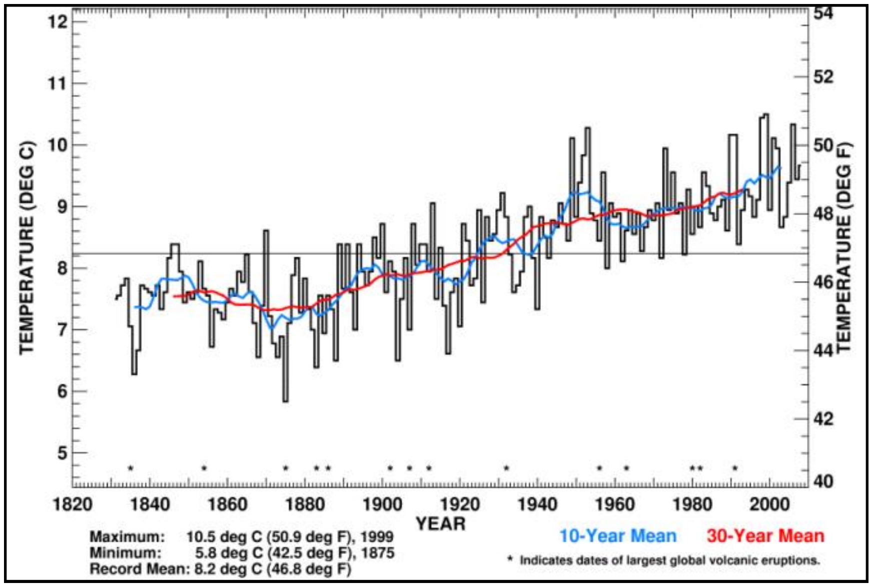


Figure 2: *Blue Hill Observatory Annual Temperature, 1831–2008*
Source: Michael J. Iacono, Atmospheric and Environmental Research, Inc./Blue Hill Observatory, MA
Note: Plot includes temperature data for 1831–1884 from Milton and Canton that were adjusted to the Blue Hill summit location.

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/

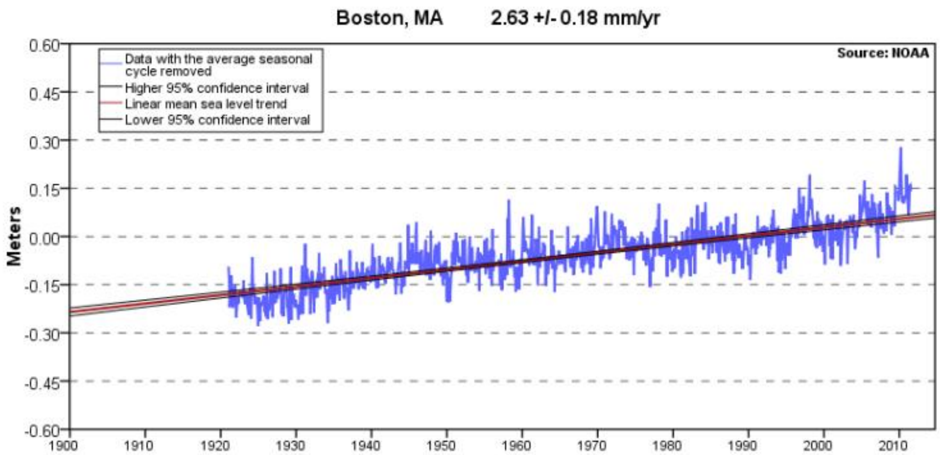


Figure 3: Mean Sea Level Trend measured at the Boston tide gauge.
Source: NOAA. http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8443970

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.

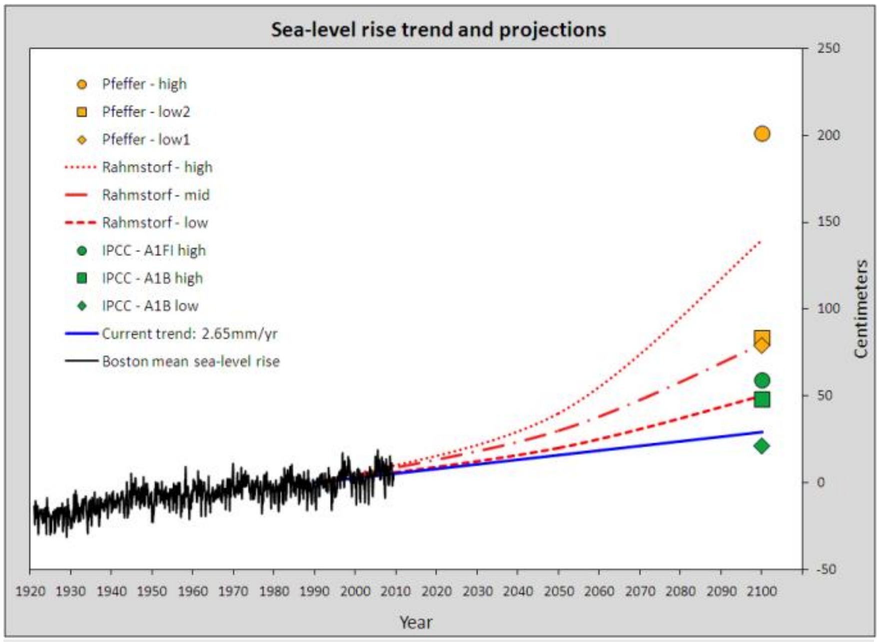


Figure 4: *Global sea level rise trend and projections*

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

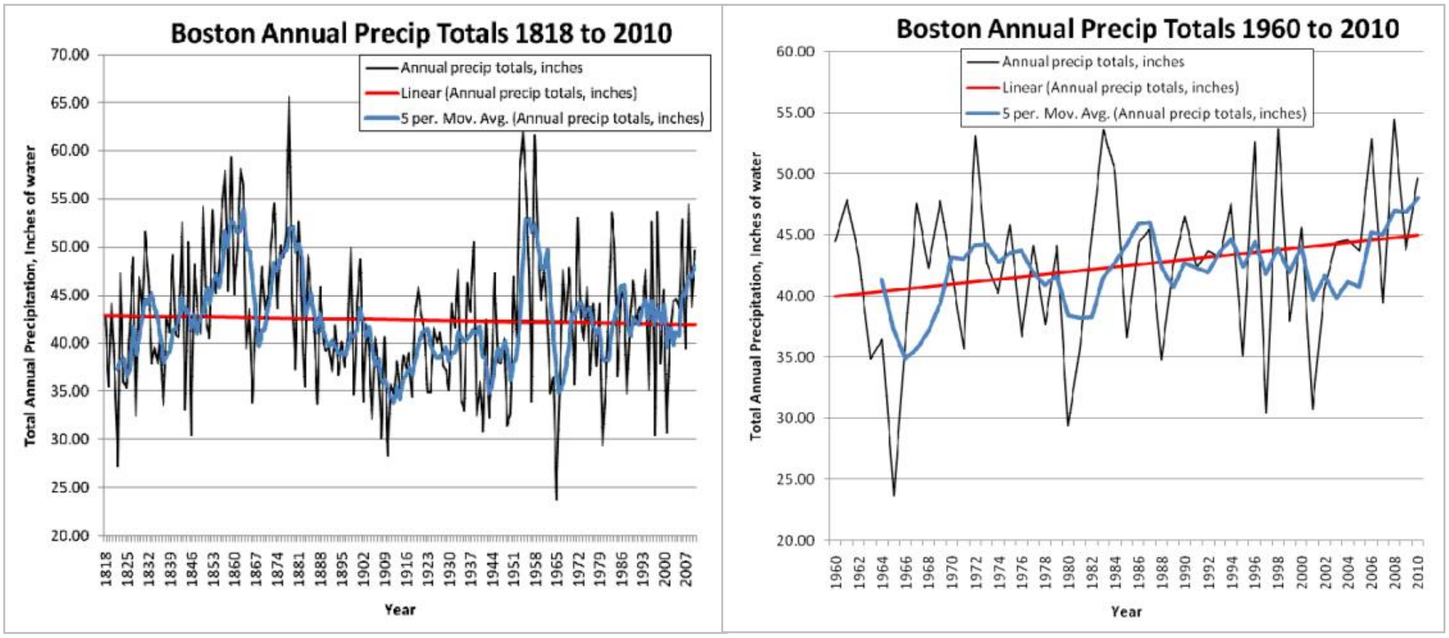
New England is expected to experience changes in the amount, frequency, and timing of precipitation. Although Massachusetts is a water-rich part of the country, the predicted changes could add pressure to the state's water resources. Since 1900, precipitation recorded at United States Historical Climatology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

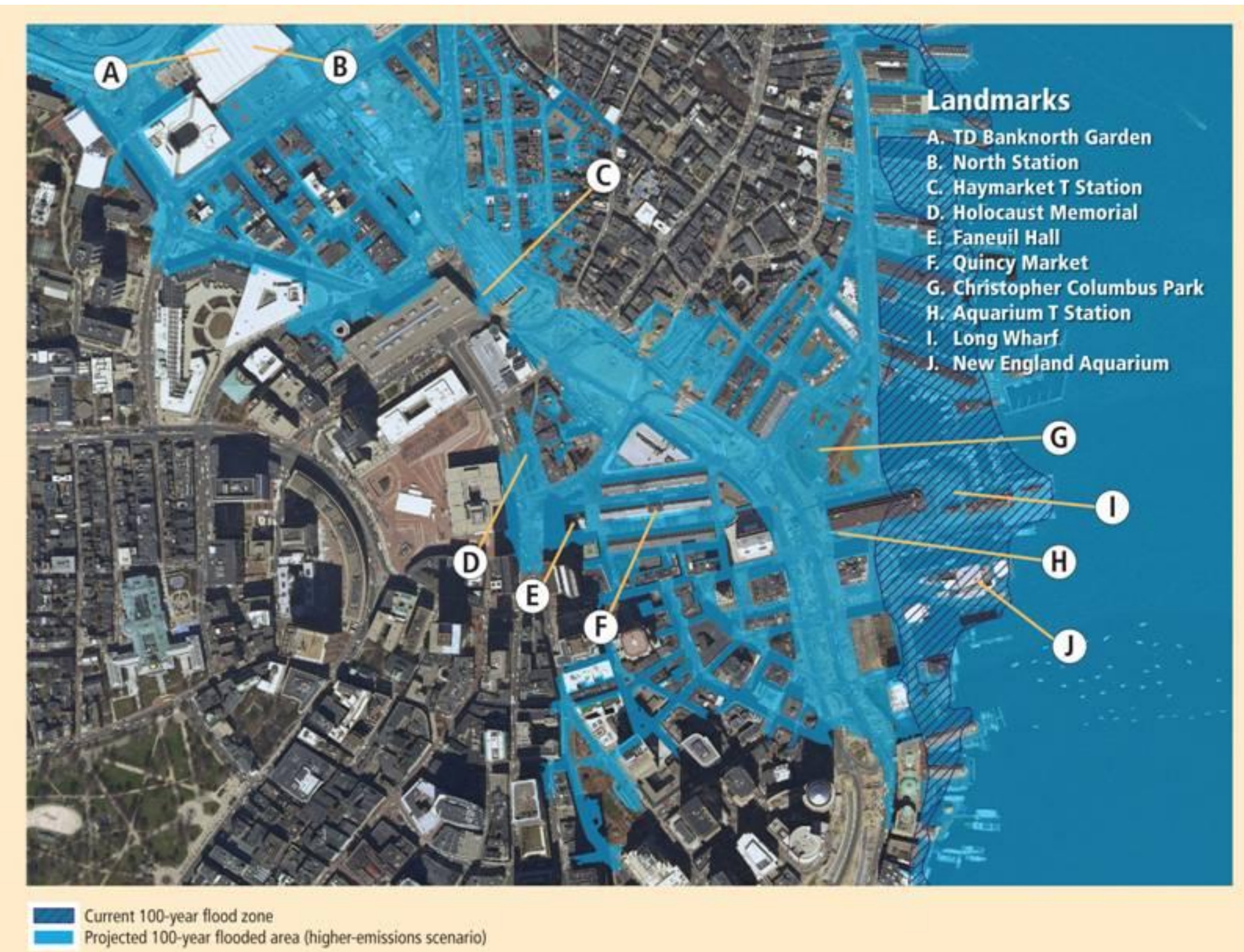


Figure 6: ***Projected Inundation of Boston Landmarks in 100 Year Flood under Higher Emissions Scenario***

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

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