

MASSACHUSETTS' RISING ECONOMIC RISK FROM CLIMATE CHANGE

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Massachusetts, along with the rest of New England, has been experiencing rapid climate change over recent decades. Just since 1970, average annual temperatures have risen by about two degrees F, and winter temperatures have risen even faster, by 1.3 degrees F per decade.¹ Long-term records from the Hubbard Brook Experimental Forest across the border in New Hampshire confirm these findings, showing that average temperatures rose 2.3 degrees F over the 20th century.²

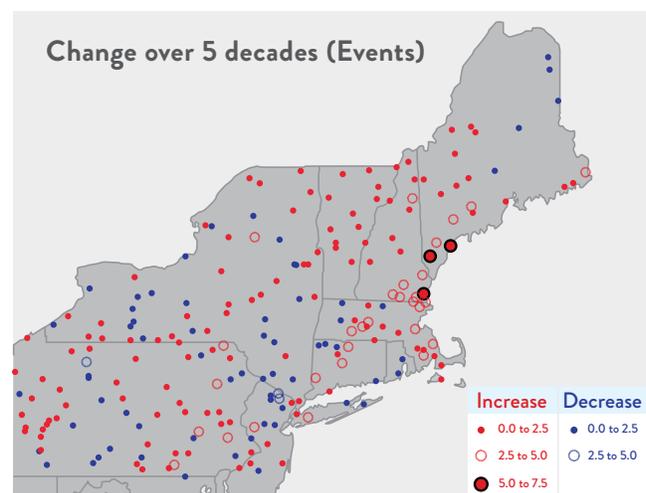
The warming trend is evidenced through an earlier spring, earlier plant leafing and blooming, and earlier melting of ice and snow, which is leading to earlier peak runoff in New England's rivers. In addition, the summer, fall and annual growing seasons are lasting longer, by about 2.5 days per decade and sea surface temperatures are rising.³

Precipitation patterns have also changed. More of the precipitation in winter is falling as rain rather than snow. Storms releasing two inches or more of precipitation are more frequent, and all across Massachusetts, the most intense storms are becoming even more intense,⁴ as the following figure shows.⁵

CLIMATE CHANGE'S IMPACT ON TEMPERATURE AND PRECIPITATION

Scientists predict that these trends will continue and may well accelerate if greenhouse gas concentrations in the atmosphere continue to rise. By 2050, average annual temperatures in Massachusetts may rise another four to five degrees F. Winter precipitation will rise another six to 16 percent, although there will be fewer days of snow and snow cover, and peak river flood levels will come a week earlier in the spring. Summer rainfall will decline while evaporation rates

TRENDS IN 4 INCHES IN 48 HOUR PRECIPITATION EVENTS 1984-2007



From Spierre and Wake (2010) Trends in Extreme Precipitation For The Northeast United States, 1984-2007

rise in the higher temperatures, causing drought to be an annual event.⁶ Sea surface temperatures will continue to increase, rising six to eight degrees F over the century.⁷

Although milder and shorter winters would seem to be beneficial, the price paid would be high. The number of days with temperatures over 90 degrees would likely rise three to six-fold over this century, with a potential two to four weeks of temperatures over 100 degrees by its end.⁸ These temperature increases and higher humidity from a more intense hydrological cycle would markedly raise the “heat index,” making high temperatures feel even more uncomfortable.

There would be three or four times as many days when the heat index reaches the public health level of “extreme caution.”⁹ Rain storms will also continue to become more intense, especially in the spring, when downpours will fall nearly twice as often, raising the likelihood of flooding. The extent of these future changes depends on global emissions trends that will determine how fast atmospheric greenhouse gas concentrations rise.

CLIMATE CHANGE AND INCREASED HURRICANE INTENSITY

The effects of climate change on hurricane frequencies and intensities have been the subject of considerable scientific research. As they generate power from warm, moist air over warm ocean waters, hurricanes are becoming more intense as climate change continues to increase ocean temperatures. The current scientific understanding is that sustained warming will result in the more intense hurricanes becoming more frequent in New England’s latitudes and the less intense hurricanes growing less frequent.¹⁰ With global warming driven by increasing emissions, the frequency of the most intense Category 4 and 5 storms would be expected to increase by 80 percent by 2080, or by roughly one percent per year.

In New England, where such storms typically weaken to Category 2-3 hurricanes while passing over cooler waters before making landfall, one can expect Category 3 storms to become more frequent, while over the same period, the frequency of the less intense Category 1-2 hurricanes is projected to diminish by 38 percent. These changes are unlikely to be steady trends, since the most intense hurricanes strike New England only rarely.

No Category 4 or Category 5 hurricane has yet struck Massachusetts, but climate change and rising ocean temperatures are making it more likely that one will eventually do so. The implication is that overall hurricane risks are increasing because historically Category 4 hurricanes caused 86 percent of recorded hurricane damages, even though they represented only 24 percent of hurricane landfalls. Category 5 hurricanes caused 48 percent of recorded hurricane damages, even though they represented only six percent of hurricane landfalls in the United States.¹¹ Higher winds cause more devastation, persist longer at damaging levels and generally affect a wider area. As in other Massachusetts coastal communities, the population on Cape Cod has quadrupled in the past half-century, and real estate development has proceeded rapidly.¹² With higher temperatures and a higher heat index, more people are likely to seek relief by going to the seashore. Studies have estimated that because of rising population, property values and new construction, the overall value at risk will continue to double in each decade through the next half-century.¹³

Rising sea levels and storm surges, intensifying hurricanes, and increasing values at risk together imply that the economic risks of climate change are rising dramatically.¹⁴ One recent simulation of future storm patterns concluded that hurricane damages in New England would increase by 72-150 percent over this century due to climate change alone.¹⁵ When all the contributing factors are brought together in an integrated analysis, using numbers that represent the best current scientific estimates, the findings are even more ominous. The results of such an integrated analysis for Massachusetts are presented below.¹⁶

Increased Risk of Economic Damage from Hurricanes

The National Hurricane Center, part of NOAA, estimates hurricane probabilities in each vulnerable region by fitting probability curves to historical data. Until now, the Center has neither estimated the effects of past climate change on hurricane frequencies nor predicted future effects. Nonetheless, the following table accepts the Center's estimates of hurricane return periods¹⁷ for 2010 and uses the scientific predictions discussed above to show the changing return periods from 2010 through 2060 of Category 1 through 5 hurricanes striking the state.

As the following table shows, although the probabilities of less intense hurricanes decline, the probabilities of major hurricane strikes increase by 50 percent over the period. Today, the 100-year event would be a Category 3 hurricane with maximum wind speeds of 111 to 129 mph,¹⁸ like the great 1938 hurricane, which would cause \$20 to \$30 billion in insured losses and at least twice that amount in total damages if it struck today.^{19, 20} By 2030, as the following table shows, the 100-year storm would be a much more damaging Category 4 hurricane with wind speeds of 130 to 156 mph.

STORM RETURN PERIODS, IN YEARS

Year	Category 1	Category 2	Category 3	Category 4	Category 5
2010	12.7	30.7	54	120	325
2020	13.2	31.8	48.8	108.5	294
2030	13.6	33.1	44.2	98.1	266
2040	14.2	34.4	39.9	88.8	240
2050	14.7	35.7	36.1	80.3	217
2060	15.3	37.1	32.7	72.6	196

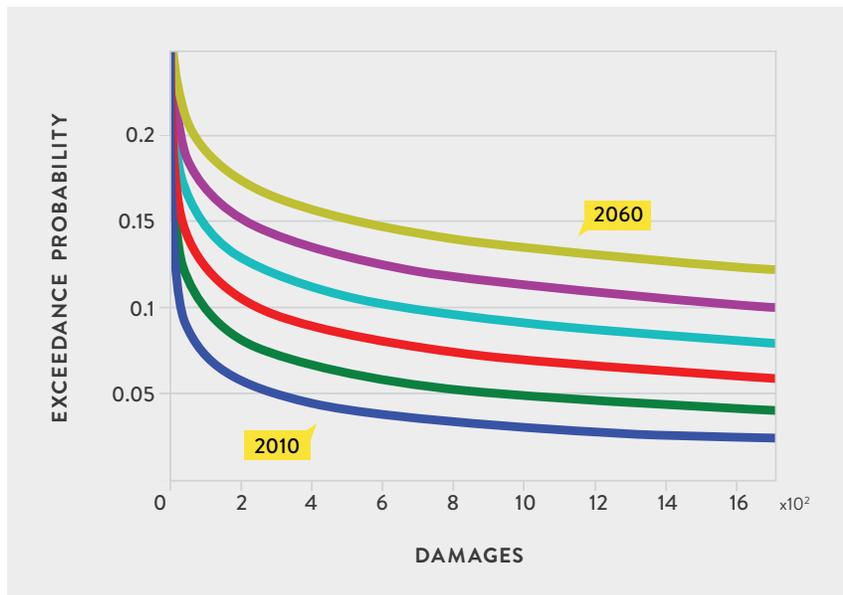
A study by Yale Economics Professor William Nordhaus, based on all recorded previous hurricanes striking the United States, found that damages increase as the 8th power of the maximum wind speed.²¹ In order to construct an overall risk analysis, these return periods, expressed as annual probabilities, were combined with the damage function estimated by Nordhaus and the estimate of a \$7.4 billion loss from a Category 1 hurricane, such as the 1991 Hurricane Bob. Damage estimates also factored in the effects of rising sea levels²² and the increase in coastal population and value at risk.²³ Consequently, the damages to be expected from hurricanes striking the region increase rapidly over time, as the following table shows. Expected losses are the damages that would be suffered from a storm of each intensity, multiplied by the probability of such a storm occurring, and then added up for all possible storms.

Expected losses represent the actuarially fair value of hurricane damages to the region – the amount that insurers would have to collect in premiums (without overhead) to break even over time. Expected losses rise dramatically, more than doubling in each decade, because of the combined effects of global warming on hurricane intensities and sea level, along with the increase in value at risk. This rapid rise in losses will put the insurance sector in Massachusetts under great pressure. Private and public insurers will have to raise rates dramatically, or insurers will withdraw from the market.

EXPECTED ANNUAL LOSSES FROM HURRICANES AND TROPICAL STORMS (\$BILLIONS)

Year	2010	2020	2030	2040	2050	2060
Expected Annual Loss	1.75	5.3	14.8	39.1	99.6	247

HURRICANE LOSS EXCEEDANCE CURVES FOR MASSACHUSETTS, 2010-2060



increase in damages, so the probabilities of loss – combining the two – barely fall. By 2040, there will be a one in 10 chance of a hurricane loss in coastal Massachusetts exceeding \$10 billion. Second, the loss exceedances rise rapidly over time. For example, the probability of a hurricane causing damages exceeding \$50 billion rises from about 1 in 40 in the year 2010 to about 1 in 12 by the year 2050.

The implication of these estimates is that climate change is sharply increasing the risks to the Massachusetts economy and its citizens by raising the likelihood of a natural disaster. Only an effective effort to reduce the accumulation of greenhouse gases in the atmosphere can mitigate this growing threat.

IMPACT OF SEA LEVEL RISES AND HIGHER STORM SURGES

For Massachusetts, one of the most threatening aspects of climate change is the continuing rise in sea levels because of thermal expansion of the oceans and the melting of continental ice bodies. Coastal Massachusetts is already sinking from long-term geologic processes. During the last century, for example, Boston sunk by six to eight inches, and it will sink another five to six inches in this century.²⁴ Consequently, the change in relative sea levels in Massachusetts is among the most rapid in the nation. By 2050, the sea level rise could be another three feet in Boston and along Cape Cod,²⁵ with even these projections perhaps too low.²⁶

The implications are disturbing. When waves are driven ashore by storms and tides, higher sea levels mean far more coastal flooding and damage to shorelines. A storm event with a surge height of 10 feet, which now has a probability of happening only once every 100 years, could happen once every eight years by mid-century and once every two years by 2100. By mid-century, the height of the surge in the 100-year storm event is predicted to be a foot higher, leading to much more extensive damage. In Boston, more than 10 percent of the city's land area would be threatened with inundation. The city is one of the most vulnerable in the nation.²⁷

In the future, the entire waterfront would be under water, and flooding would extend to Faneuil Hall, Quincy Market, the Boston Garden, North Station, the Aquarium and other iconic locations. Water would pour into the

Another way to measure the economic risks is to make use of loss exceedance curves, which are widely used in the insurance and other financial industries to measure risk exposure. A loss exceedance curve is the probability that a loss will be incurred that is equal to or greater than some specified amount. Loss exceedance curves for each decade from 2010 through 2060 for Massachusetts are plotted in the following graph.

Two things are immediately evident. First, the curves “flatten out” as loss amounts rise. Though probabilities of occurrence decline as maximum wind speeds rise, this is offset by the exponential

MBTA tunnels from the Haymarket and Aquarium stations. The Back Bay would be completely inundated as water surged into the mouth of the Charles River. Beacon Street, Commonwealth Avenue, Newberry Street, Charles Street, the Public Gardens and even Copley Square would be flooded.²⁸

Economic Damage from Heavy Storm Surge

A storm surge of the magnitude shown above would cripple Boston's transportation system. Logan Airport, which extends out into Boston Harbor, and the subway system would be shut down. Water would pour into the Big Dig, blocking access to the city and to Mass Pike. Storrow Drive and many other key transportation arteries would be under water.²⁹

The costs would be enormous. When the subways flooded in 1996, the repair costs alone exceeded \$70 million. Over this century, with another three feet of sea level rise, the cumulative costs are estimated to exceed \$90 billion, more than 10 times the costs if the climate were not continuing to change.³⁰ And, these estimates are conservative because they are based only on forecasts of rising sea levels and do not take into account the increasing frequency of more intense hurricanes and coastal storms. Including these impacts, the damage to Boston and other coastal communities will be greater.

In addition to Boston, the entire Massachusetts shore line is under increasing threat. Except for areas where the coast is rocky, beach and shore line erosion will accelerate, saltwater and brackish marshes will be lost,³¹ salt water will penetrate further into estuaries and coastal aquifers, and coastal properties and infrastructure will flood more severely and more frequently.³²

Cape Cod is also at great risk. Storm surge will cause the loss of beaches and wetlands beyond that caused by sea level rise alone.³³ Rates of beach erosion, now about 33 acres per year, would increase three to six times by 2050.³⁴ The headlands and cliffs that line the shore will be pounded by higher and closer waves. Particularly vulnerable areas include the shores of Nantucket and Martha's Vineyard, as well as areas on the south Cape and the south shore. The south shore of Nantucket is losing 15 feet of cliff per year, and that figure is bound to increase.³⁵

In 2007 the value of insured coastal property in Massachusetts at risk from climate change was \$772 billion, more than half of the statewide total of property exposed to these risks, and these amounts are increasing by roughly seven percent per year, almost doubling every decade.³⁶ The effects are already being felt. Property and casualty insurers are withholding policies from properties, not only on the coasts but at increasing distances from the coast, and/or raising insurance rates. Therefore, more owners increasingly need to rely on the state government for insurance, which is also raising rates and deductibles.

CLIMATE CHANGE'S IMPACT ON OTHER EXTREME WEATHER EVENTS

Nor'easters

Nor'easters now strike Massachusetts once or twice a year, on average, and can cause considerable damage because of high winds and intense precipitation that can last over several tidal cycles and cause extensive flooding and shoreline erosion. With higher sea levels, these storms will be more damaging.³⁷ Climate change and warming sea temperatures may be making these storms more frequent along the New England coast.³⁸ Moreover, rising sea and atmospheric temperatures and a more energetic hydrological cycle could cause Nor'easters to become more intense.

Inland Flooding

Climate change is increasing flood risks across the state. Flooding on the state's 265 (named) rivers is capable of significant damage. The 2006 Mother's Day flood cost more than \$70 million just in federal and state assistance, and flooding in 2010 resulted in more than 37,000 applications for FEMA assistance, with a total bill exceeding \$90 million.³⁹

Twenty-two of twenty-three major New England rivers examined in one study show increased peak flows in a comparison of periods before and after 1970.⁴⁰ Another study also found a statistically significant upward trend in peak flood levels in Massachusetts and other New England rivers in 1971-2006 when compared to the levels in 1931-1970.⁴¹ This is the expected result of increased winter precipitation falling as rain, combined with diminished snow cover, warmer spring temperatures and earlier melting. Further climate change will only exacerbate these risks, leading to more extensive flood damages. For example, a recent study found that more than a quarter of all bridges in Massachusetts and the rest of New England are vulnerable to flood damages, mostly from scouring near their bases and abutments.⁴²

Heat Waves

The large majority of weather-related deaths in most years are the result of extreme heat, particularly in cities due to concentrations of vulnerable people and urban heat-island effects. By 2050, the number of days over 90 degrees F in Boston will have risen to 25 under a low-emissions scenario and 38 under high-emissions scenarios, a significant increase from nine in 1990. As mentioned above, these increases will be exacerbated by higher humidity. Almost one quarter of the state's adult population is obese; one in ten is poverty-stricken; one in seven is elderly, and of these more than one in three has some disability.⁴³ Moreover, the proportion of residential buildings in Massachusetts with air conditioning is below the national average.⁴⁴

Three of the leading causes of death, which together account for well over a third of all mortality in Massachusetts will be directly exacerbated by global warming: heart disease, stroke, and respiratory disease.⁴⁵ Episodes of extreme heat lead to increases in both illness and death.⁴⁶ Heat waves result in more heart attacks, strokes, and asthma attacks. A recent study found that "heat wave mortality risk increased 2.49 percent for every 1°F increase in heat wave intensity and 0.38 percent for every one-day increase in heat wave duration. Mortality increased 5.04 percent the first heat wave of the summer versus 2.65 percent in later heat waves, compared with non-heat wave days."⁴⁷ In cities, heat island effects will be intensified by higher nighttime temperatures.

CLIMATE CHANGE'S IMPACT ON MASSACHUSETTS' ECOLOGY

Fisheries

Fisheries have long been a core industry in Massachusetts. Today, the value of commercial fish and shellfish landings in Massachusetts is about \$700 million per year, primarily in New Bedford and Gloucester, but also in Boston and on Cape Cod. In addition, recreational fishing makes a very significant economic contribution. For example, according to a recent study by, the direct economic impact of striped bass fishing in Massachusetts in 2005 was \$650 million, of which more than 95 percent was related to recreational fishing.⁴⁸ The multiplier effects raise these numbers almost two-fold in terms of total economic impacts.

Many of these fisheries are threatened by climate change. The waters south of Cape Cod may become too warm to support a lobster population. Warmer waters also promote shell diseases, parasites, and algal blooms that damage that important resource.⁴⁹ The cod fishery on George's Bank is already near the southern end of its range, and further warming may make recovery of this traditional fishery more difficult. Moreover, the disappearance of estuaries and

marshes as the sea level rises will affect many species that depend in some way on those habitats, including clams, scallops, flounder, alewife, bluefish, and striped bass.

Forests

Climate change will significantly affect the forests and woodlands that cover much of Massachusetts. Traditional species such as spruce, maple, beech, and birch will become rarer as their range shifts northward, and oak, pine, and hickory will replace them.⁵⁰ The traditional fall “foliage tour” will very likely shift more toward northern New England. The longer growing season and the fertilization effect of higher CO₂ concentrations are likely to be counteracted by a proliferation of forest pests and pathogens, such as the wooly adelgid, spruce budworm, gypsy moth, pine bark beetle, and several others, creating challenges for foresters and landowners.

THE IMPACT OF CLIMATE CHANGE ON HEALTH COSTS

Health costs already account for more than 10 percent of total domestic product in Massachusetts, and that percentage is rising because the long-term rate of increase in health costs has been about double that of the overall state economy. Climate change will not only compromise the health of the population but will also impose an even heavier burden of health expenditures on the state.

Increased Air Pollution

The earlier spring and higher summer and fall temperatures are expected to affect air quality adversely. More pollen and other airborne allergens will be present with the changing seasons. Ozone and smog formation is likely to increase because higher temperatures heighten the underlying chemical reactions in the atmosphere and also increase volatile organic compounds released from trees and vegetation.^{51,52} Atmospheric ozone exacerbates bronchitis, asthma and other lower respiratory tract diseases, which are among the leading causes of death in Massachusetts. Concentrations of fine particulates, which are even more damaging to health, will also increase due to climate change.⁵³ The aggravated air pollution that typically accompanies heat waves especially harms children, who have a higher risk of developing asthma because their lungs are still developing and growing, and they are prone to higher exposure because they breathe at a higher rate than adults and often play outdoors.⁵⁴ Each year, asthma attacks strike more than 100,000 children in Massachusetts and near half a million adults.⁵⁵

Massachusetts has also had difficulty in reaching national standards of air quality, particularly for ozone, and has been in non-attainment status for most of the past decade. Climate change will make it more difficult to reach and maintain existing air quality standards. A recent EPA assessment concluded that allowable levels for fine particulates should be significantly lowered,⁵⁶ which will mean tighter regulations and higher pollution control costs in the state.

West Nile virus and Lyme disease

Climate change is also likely to aggravate vector-borne diseases such as West Nile virus and Lyme disease.⁵⁷ In the past decade more than 21,000 cases of Lyme disease were reported. Lyme disease can be extremely debilitating, affecting every tissue and every major organ system in the body. Lyme disease can even be fatal in severe cases. Studies have found that almost two-thirds of Lyme disease patients still experience significant symptom months or years after the infection was treated, including persistent, severe fatigue and pain. The burden on the medical system from increased incidences of Lyme disease could be great.

A survey of over 2,000 people who had tested positive found that roughly 26 percent had been on disability or public support, with a majority receiving support for more than two years and 37 percent for more than five years.⁵⁸ More

than half had visited an emergency room as a result of their illness, 15 percent had done so three to five times, and nine percent had done so six or more times. More than half of patients saw seven or more physicians to obtain a diagnosis; over a third saw 10 or more physicians.

THE WAY FORWARD

The best scientific information indicates that the Massachusetts economy and its people face rapidly rising risks of catastrophic damages from global warming. Recognizing this, the Commonwealth has developed programs and policies to mitigate and adapt to those risks. The state's leaders, whether in politics and government or in the private sector, have compelling reasons to continue strong support for immediate action at the state, national and international level to reduce greenhouse gas emissions and mitigate the growing risks of global warming. The people of Massachusetts, who ultimately bear those risks and will suffer the damages, should ensure that all their leaders do so.

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