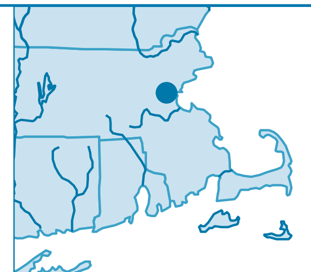
Climate's Long-term Impacts on Metro Boston (CLIMB)



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Major Impacts by 2100 of Climate Change on Metropolitan Boston

- During the 21st century, sea level along metropolitan Boston's coastline could rise at least 24 inches (0.61 meters)

- Higher sea levels of just 12 inches or more could give a typical 10-year storm the intensity of the present 100-year storm; similarly, a 100-year storm would hit with the intensity of the present 500-year storm

- Property damage from coastal flooding, plus the cost of emergency services, could total $94 billion during this century

- Homeowners in metropolitan Boston's 100- and 500-year floodplain could sustain flood damage averaging between $7,000 and $18,000 per home

- Boston could face at least 30 days of temperatures above 90∞F, more than double the current number. Mortality rates tend to rise in Boston when temperatures exceed 90° F.

- By 2030, the average number of days in July requiring air conditioning could increase by over 24% with a corresponding rise in energy use.

- Global warming will reduce water quality in rivers and streams making parts of them uninhabitable for fish and aquatic plants.

- During and immediately after extreme weather events, motorists could spend an estimated 80% more hours on the road due to traffic delays; likewise, 82% more trips could be cancelled because of road flooding.

- River flooding related to global warming is expected to impact twice as many properties and double the overall cost of damage during this century.

- Water systems relying totally upon local supplies may need to draw on the Massachusetts Water Resources Authority system to supplement their supplies to maintain acceptable local water service affected by climate and demographic changes.

Overview

After more than 20 years of research and analysis, scientists now agree on the fundamental causes of greenhouse gas emissions and their effect on the Earth's atmosphere. Increased releases of carbon dioxide and methane, among other global warming gases from fossil fuels burned to generate energy, are accumulating in the lower atmosphere, trapping the sun's heat, and raising surface temperatures on earth. In the last century, scientists detected a distinct warming trend of 0.8° Fahrenheit. Based on the rate of increase and other calculations, the climate models used by the CLIMB study predict a rise in average temperatures for metropolitan Boston of between 3° C and 5° C (6–10° F) by the end of this century. Higher temperatures will produce a number of related effects:

- Higher sea levels in 2100 of between 24 inches and 39 inches due to the combined effects of increases in ocean volume, melting land ice, and land subsidence
- More coastal flooding from higher sea levels and continuing land subsidence
- More inland flooding from rainfalls
- Loss of wetlands and estuaries
- Greater energy demand, primarily for summertime cooling
- Higher concentrations of air pollution
- Increased public health problems from unprecedented high temperatures

Not all regions of the world face the same impacts from climate change, but regardless of their geographical and climatological situation, some type of effect from moderate to extreme will be felt.

As an immediate step toward solving this problem, governments, businesses, and individuals must reduce releases of greenhouse gases. Many entities and institutions are already lowering energy use by switching to renewable or less polluting alternative sources and by becoming more energy efficient. These mitigation initiatives have both immediate and long-range benefits, making them attractive, "no-regrets" options.

Joe Pelczarski/Massachusetts Costal Zone Management

Flooding in Rockport's Bearskin Neck from the storm of 1978.

Until fairly recently the debate has focused on determining (a) the causes and rate of climate change, (b) the extent and degree of potential impacts, and (c) the best strategies to mitigate greenhouse gas emissions. Now researchers, assuming the likelihood of climate change, have begun to consider a variety of adaptation strategies. Even within highly industrialized countries, possible impacts and responses vary widely. While there are generalized predictions of the likely consequences of global warming to specific regions of the U.S., until now no jurisdiction has yet developed a plan for adapting to these impacts.

The CLIMB Project

For the first time, a group of experts has compiled a comprehensive analysis of adaptive actions by a major metropolitan area to pre-empt some of the worst effects of climate change. *Climate's Long-Term Impacts on Metropolitan Boston (CLIMB)* describes how global warming could impact a major U.S. coastal city, what those impacts are likely to cost, and what adaptive measures can be taken to protect the region from the worst of these effects. This study culminates a four-year, one million dollar research effort, funded by the United States Environmental Protection Agency (EPA), and conducted by 10 experts at Tufts University, the University of Maryland, and Boston University in consultation with officials from the EPA, the State of Massachusetts, the Metropolitan Area Planning Council, and local government officials throughout the Boston metropolitan region.

What Is CLIMB?

CLIMB is a multi-sector analysis of how global warming will affect some of the key socio-economic activities typical in major urban centers. CLIMB demonstrates how global warming could fundamentally affect the Boston region over the next century, requiring tens of billions of dollars to adapt to changes and to repair climate-related damages.

The study tests overall monetary and environmental costs for three adaptive strategies:

- "Ride-It-Out" assumes no adaptive steps will be taken to ameliorate the effects of global warming except rebuilding residential and commercial property and public infrastructures after they are damaged by climate-related flooding and other weather-related events. Of the three options, this is the most expensive [p. 58].*

- "Build-Your-Way-Out" assumes limited pre-emptive actions, such as coastal protection by "hardening" shorelines with sea walls, bulkheads, etc., to limit the effects of global warming. In most locations, this is the second most costly scenario [p. 58].

- The "Green" scenario assumes fairly aggressive pre-emptive actions to blunt the effects of global warming. This includes new building codes for greater energy efficiency, early warning systems in anticipation of extreme high temperatures, and, above all, steps to minimize the effects of flooding in metro Boston's coastal plain. In addition, the Green scenario assumes that all new structures in the

* Page numbers in brackets refer to the corresponding page in the full CLIMB study.

100- and 500-year floodplains are completely flood proofed when they are built and that existing buildings are flood proofed at the time of sale. In the majority of locations the cost of this scenario is the lowest of the three, while its environmental benefits are the highest [p. 59].

Doing nothing to prepare for climate change will result in the greatest amount of damage and the highest possible costs to governments and residents in the Boston region. In contrast, investing now in measures to adapt to and protect against the changing climate will significantly reduce the amount of damage from global warming and lower the costs of adaptation. Above all, CLIMB provides a blueprint for elected officials and policy makers to understand and evaluate their options for protecting key assets from the consequences of global warming.

What's New about CLIMB?

To date, the bulk of climate change research has concentrated on the causes of global warming and strategies to mitigate climate change by reducing of greenhouse gas emissions. CLIMB is the first study to take this research to the next level by analyzing how a major urban area can adapt to fundamental and far-reaching changes that will inevitably occur due to global warming. For the purpose of this study, metropolitan Boston comprises over 100 municipalities in six counties [p. 22, Table 7.1]. Unlike many other global warming studies, however, CLIMB is more than simply a report; it is a dynamic tool that can be used by government officials, business leaders and others to develop and deploy the most cost effective measures for protecting critical economic and social assets from disruptive climate change.

Joe Pelczarski/Massachusetts Costal Zone Management

1978 storm damage to Rockport Harbor.

Why Is CLIMB Important?

The quality of life and long-term economic success of metropolitan regions such as Boston depend heavily on the reliability of their infrastructures. Transportation and communication networks, for example, provide mobility of people, goods, and information; power plants and energy distribution systems provide energy essential for homes, businesses, and industries; and water supply, drainage, flood management, and waste water treatment systems provide water to consumers, protect homes and businesses from flooding, and ensure treatment of effluents to minimize adverse environmental and health effects from pollution.

The higher the levels of economic activity, the more important are the quality and reliability of infrastructure systems. These links are especially critical in urban areas. Disruptions to infrastructures can have far-reaching implications both for the public welfare and for the regional economy. Flooding in the fall of 1996, for example, inflicted heavy damage on parts of metro Boston. According to the *Boston Globe*, the storm "flooded powerful institutions such as the Museum of Fine Arts and Northeastern University, wreaked havoc on the Green Line's Kenmore Square station, and caused $70 million in property damage." In the summer of 1999, New England's power grid nearly collapsed because of unprecedented demand on electricity in response to record high temperatures [Carlos Monji, Jr., "Region Swelters in Record Heat," The *Boston Globe*, June 8, 1999].

Boston's Vulnerability to Global Warming

Recent research on the effects of global warming in metro Boston shows that sea level will rise, peak summer temperatures will be higher, seasonal energy demand will shift, and the frequency and intensity of severe winter and summer storms will increase. Infrastructures are designed according to the prevailing socioeconomic and environmental conditions at the time of planning and construction, and thus are very sensitive to climate. Sustained changes in climate and weather may affect the ability of existing infrastructure to provide reliable services and may require costly adjustments or repairs to remain viable.

Most infrastructures have a lifetime of many decades–parts of the Boston subway and sewer system are more than 100 years old. Upgrading or substituting infrastructures can also take many years, as the "Big Dig" illustrates after more than a decade of work and a cost of $14.6 billion. Being able to anticipate today what the climate-induced impacts may be on existing and future infrastructure is therefore vital for planning and investment decisions.

Getting policy-makers to focus on long-range planning, however, presents a challenge. In response, CLIMB provides the pathways for public officials to make decisions that employ the most efficient and effective choices in dealing with the long-term consequences of climate change.

Key Findings

CLIMB presents key findings in seven areas of public welfare and infrastructure: sea level rise, river flooding, public health, water quality, energy, transportation, and water supply.

COASTAL AND RIVER FLOODING

Flooding relates directly to all aspects of metro Boston's infrastructure. It can seriously damage the built environment, paralyze transportation, interrupt energy distribution, and impair wastewater treatment, posing threats to the economy of the region and the health of its inhabitants. Metro Boston faces an especially high risk of coastal and river flooding because of its long coastline, numerous rivers and streams, concentrated coastal development, and high exposure to heavy rainstorms, hurricanes and nor'easters.

Sea Level Rise

The Problem

Sea level rise in the Boston coastal zone, encompassing 32 municipalities with a combined population of 1.2 million, will lead to more severe and frequent flooding events [p. 54]. During the past century, land subsidence and sea level rise resulted in a 0.3 meter (slightly less than 1 foot) relative increase in sea level [p. 55]. During the 21st century, according to projections of the Canadian Climate Center, continued

"Current mean sea level in Boston (2000). This computer graphic shows current conditions with Boston harbor in the foreground and the Charles River in the background.

Kelly Knee, Applied Science Associates, Inc.

"Effects of a 100-year coastal storm surge in Boston with sea level rise by 2075. This computer graphic shows the floodplain in 2075 with Boston harbor in the foreground and the Charles River in the background."

Kelly Knee, Applied Science Associates, Inc.

coastal subsidence and sea level rise will result in a net increase of 0.60 meters (approximately 2 feet) [p. 55]. Higher relative sea level will add to the base elevation of any storm surge, giving it more power to overtop both natural and constructed protection.

A continued trend in the rate of sea level rise could give the typical 10-year storm the intensity of a 100-year storm. Similarly, higher sea levels could make a 100-year storm as powerful as an epic 500-year storm. The potential devastation from these events is easy to imagine and can be quantified.

- By 2050, 1.4 million people in the Boston metro area will live along the coast.

- The total property and contents damages, together with emergency services, from storms coupled with rising sea levels over the next 100 years could reach $94 billion, if no adaptive steps are taken except to rebuild after each flood [p 56].

Joe Pelczarski/Massachusetts Costal Zone Management

Destruction in Rockport from the storm of 1978.

- According to CLIMB's analysis, damage to residential property located in the 100- and 500-year floodplain is expected to average between $7,000 and $18,000 per structure depending on location [p. 57].

How to Adapt

In many cases, some of the expected $94 billion in damages from coastal flooding could be cost-effectively avoided through proactive adaptation strategies. These include limiting development in flood-prone areas, flood-proofing buildings, or installing protective structures.

Thus, while it may be necessary to use expensive structural protection in areas that are highly developed, a less structural approach appears warranted in areas not as densely developed or those considered environmentally sensitive. Our adaptation scenarios were based upon taking action well before 2050. Besides being more cost effective, the less structural Green approach (a) offers no-regrets or co-benefit advantages, (b) is environmentally benign, and (c) allows more flexibility to respond to future unpredictable changes. While uncertainty in the expected rate of sea level rise and damages makes planning difficult, the results also show that no matter what the climate change scenario or the location, not taking action is the worst response.

River Flooding

The Problem

CLIMB developed a method to calculate and compare damage from river flooding related to global warming with flooding likely to occur in the absence of climate change. Accordingly, flooding related to global warming is expected to impact twice as many properties and double the overall cost of damage during this century.

Total losses throughout metropolitan Boston from river flooding will exceed $57 billion by 2100 assuming no adaptive steps are taken. CLIMB estimated this to be $26 billion more damage than would occur without climate change [p. 81, Table 10.2].

Areas at the fringe of present floodplains have a disproportionately high representation of low value houses that are likely to be uninsured. If, as expected under climate change, these fringe areas are flooded by severe events, households that can least afford to cope with the costs of flooding will become more vulnerable [p. 83, Figure 10.6].

How to Adapt

- Extensive flood-proofing under the Green scenario could reduce river flood damage due to global warming from $26 billion to an estimated $9 billion by 2100 [p. 81, Table 10.2].

- In addition, adopting regulations and incentives that require flood-proofing of all buildings in 100- and 500-year floodplains will further help reduce damage.

- The most costly option would be to take no action at all and simply to repair and rebuild structures damaged by increased flooding from climate change.

PUBLIC HEALTH

The Problem

The CLIMB study examined only health problems related to temperature extremes. Boston normally experiences fewer than 13 days per year when temperatures exceed 90° F, whereas climate change scenarios indicate that by 2030 the region could see 23 or more such days, and by the end of the century there could be 30 days with temperatures over 90° F, more than twice the current number.

The increase in hot days will result in a higher incidence of cardiovascular problems such as heatstroke, heat cramps, heat exhaustion, and heat-related deaths [p. 116]. For example, in August 1975, the day after the temperature reached an all-time high of 102° F, Boston reported 66 deaths per million residents, compared to a mean daily mortality rate of 23.5 per million [p. 121]. Further analysis of morbidity and mortality by the CLIMB study shows that mortality rates rise when temperatures go above 90° F.

How to Adapt

The historical record indicates that over time humans adjust physiologically to temperature extremes. In the future, therefore, rapid drops or sudden rises in temperature may affect only the most vulnerable [p. 117]. Meanwhile, to combat the effects of higher temperatures, adaptive measures will be necessary.

- The most obvious of these are an increase in the use of air conditioning, improvements in health care, and the use of early warning systems for individuals most prone to suffer from excessive heat or cold.

Joe Pelczarski/Massachusetts Costal Zone Management

Coastal damage from the storm in 1978.

- Less evident "Green" strategies include a city-wide program to plant shade trees and the adoption of building codes that require energy-efficient construction materials and designs to reduce heat build-up in dense urban areas. All of these steps will help mitigate the already common "heat-island" effect, which could be exacerbated by climate change [pp. 129-30].

- For these measures to be effective, however, officials must start making aggressive investments now, particularly in improvements to the energy infrastructure to handle the increased summer demand for air conditioning. (See "Energy" below.)

WATER QUALITY

The Problem

The effect of deteriorating water quality due to global warming will primarily harm the environment. Adequate dissolved oxygen (greater than 5 milligrams per liter) is essential for a body of water to support healthy aquatic plants and fish. To determine the effect of climate change on dissolved oxygen, CLIMB studied a typical river, the Assabet, flowing between Westborough and Concord in the western suburbs of metro Boston.

Because of the current low levels of dissolved oxygen, the Massachusetts Department of Environmental Protection (DEP) lists all sections of the Assabet River as unsuitable "for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation" (*i.e.*, swimming, boating, and fishing). Extensive eutrophication is apparent from excessive algae and plant growth attached to the river bottom, particularly behind the five major dams.

Several stretches of the river are already unable to fully support many fish species and plants due to low levels of dissolved oxygen. Even if the population in the Assabet's watershed remained constant and waste water discharges into it were unchanged, increased air temperatures from global warming would lower dissolved oxygen levels by 0.5 milligrams per liter. This represents a significant decrease in dissolved oxygen levels already considered low by federal standards. As oxygen levels continued to decline, many fish species and plants could die. To remedy this, expanded treatment of both direct discharges into the river and polluted run-off would be required at a cost of millions of dollars for the Assabet River alone.

How to Adapt

The additional expense to adapt to climate change is significant because of the high cost of extra nonpoint source pollution management. This underscores the need to consider the integrated impacts of temperature, streamflow, precipitation, land use, population, and water and wastewater management in evaluating the potential impacts of climate change on water quality [p. 142].

ENERGY

The Problem

In the U.S., 58 percent of energy consumption by households and 46 percent of energy use by the commercial sector goes to heating and cooling indoor spaces. More extremely hot days in metropolitan Boston will likely result in an appreciable increase in days of high electricity use for air conditioning. For instance, by 2030 the average number of days in July that require cooling will increase electricity demand by over 24% [p. 36]. This in turn will drive up the need for additional power plants, leading to higher emissions from fossil fuel combustion. In contrast, the number of extremely cold days in winter will decline. While the implications of changing summer and winter energy use may not be significant in overall physical energy terms, there could be significant consequences from the large capital costs to expand the electric energy system for cooling and the contraction of the historical heating oil market [p. 37].

How to Adapt to Increased Energy Use

The Boston region must start planning now to meet future energy demand caused by global warming. Among the "no regrets" options of the Green scenario are construction of thermal shells around buildings to insulate them from extreme temperatures, installation of high efficiency air-conditioners and furnaces to reduce energy demand, and investments in new, less polluting energy resources [p. 154].

Some changes such as energy-efficient building codes for metropolitan Boston and elsewhere will need to be implemented in the near term, or the building stock will become increasingly inadequate for handling the demands of climate change.

CLIMB's analysis of energy use throughout the Boston area reveals several lessons for research, planning, and policy:

- The impact of climate change on heating and cooling energy requirements must be regionalized. Boston residents, for example, are less sensitive to cold temperatures and their "balance point" for heat use is lower than that for, say, Floridians. Similarly, the balance point for air conditioning use in Boston is lower than for other parts of the U.S.

- The analysis of temperature and energy demand should be calibrated to capture daily or even hourly variations in maximum peak requirements during the summer.

- Energy use should be "disaggregated" by energy type and sector (residential and commercial) to accurately reflect the responses of each type to temperature extremes. The commercial sector, for example, is considerably less sensitive to temperature fluctuations than the residential sector.

- A methodological innovation of the CLIMB study is the inclusion of "degree-days" to track annual trend variables. This captures the dynamic fluctuations of energy use rather than relying on an average response for the historical period of analysis. [pp. 51-52]

- By 2030, climate change will be responsible for 25-40% of increased energy demand in the region. If those increases are not taken into account in planning, policy, and investment decisions, then the region may experience shortfalls in energy supply that disrupt the local economy.

TRANSPORTATION

The Problem

More frequent extreme weather events will result in major increases in delays and lost trips during storm periods due to road flooding over the course of the 21st century.

The magnitude of hours and trips lost as the result of extreme rainfall events in the metropolitan Boston area will be much higher under a scenario of climate change: aggregate traffic delays during storm periods due to flooded roads could increase by about 80%, and lost trips over the same period are projected to increase by 82% compared to the delays and cancelled trips that would occur without climate change [p. 97].

How to Adapt

It is unlikely that infrastructure improvements such as realignment of roadways, many of which run through river valleys, can be justified on a cost-benefit basis. Thus, increased delays during large storms resulting from global warming are a nuisance that motorists will have to endure as the frequency of extreme rain events increases. Nonetheless, the CLIMB study found that during this century commercial and private motorists could spend an estimated 80% more hours on the road in stormy periods due to traffic delays caused by road flooding from extreme weather events (100- and 500-year storms). The same analysis projected an 82% increase in lost road trips because of flooding attributable to global warming [p. 97].

WATER SUPPLY

The Problem

According to CLIMB's analysis, water supply in the inner core of metropolitan Boston that is served fully or partially by the Massachusetts Water Resources Authority (MWRA) is the least vulnerable element in the region's infrastructure. This is because of the low demand on this system at present. Under the climate change model predicting lowest streamflows in the region, local water systems relying totally upon local supplies will need to draw on the MWRA regional water authority system to supplement their supplies to maintain acceptable local water service under climate and demographic changes. Yet despite these higher demands on the MWRA under this "Build-Your-Way-Out" option, the reliability of the MWRA regional water system will remain manageable in the future under climate and demographic changes.

How to Adapt

Presently the MWRA is not obligated to serve all locally supplied systems in event of temporary or permanent shortages. This could become necessary, however, by the end of this century. Therefore, local systems should consider anticipating climate and demographic changes by using adaptation actions such as demand management and other measures outside the scope of this study. Suggestions include:

- improving in-stream flows through better storm water management,
- increasing system storage capacity with reservoirs or aquifer use, and

- considering using such water supply sources as reclaimed wastewater and desalination.

Implementation of such actions has historically involved long lead-times [p. 155].

OVERALL CONCLUSIONS

CLIMB's research provides the following major conclusions.

Anticipatory Actions.–A common finding of CLIMB's analyses is that failure to take any adaptation action is the most ineffective and expensive response. The full dynamic analyses showed, and localized case studies implied, that early actions well before 2100 result in less total adaptation and impact costs to the region. Some examples include:

- implementing both structural and nonstructural coastal flood-management strategies before 2050 to reduce the total costs of flood mitigation and impacts
- maintaining policies to improve health care
- enacting regulations to encourage more energy efficient housing stock
- integrating water quality management to include land use, drainage, and waste water treatment, and
- continuing to maintain redundancy in road networks.

Co-Benefits.–Because of the integration of sector impacts and adaptation actions, CLIMB demonstrates that proactive steps in one sector will benefit other sectors, particularly in the case of flood management, and in most cases are beneficial even if climate change is less severe than CLIMB's scenarios assume. For example, land use policies that limit development in flood-prone areas, thus reducing the impacts of flooding and storm damage, also improve water quality and overall environmental quality. Because early action mitigates future impacts, and because improvements to infrastructure systems require long lead times, the CLIMB study recommends against taking action or responding only after major disasters are incurred.

Land Use.–Another common theme is that, as expected, present and future land use greatly affects the magnitude of climate change impacts. This is because the distribution of the population affects the location of infrastructure and hence the impacts of climate change on it. Moreover, land use affects flood magnitudes and losses, water quality, water availability, and local heat island effects. Prohibition of new development–and where possible, flood proofing or retreat of existing development–in flood zones is an example of land use regulation that can both decrease potential damages to property and improve hydrological conditions, thereby decreasing the severity of flooding. In general, the threat of climate change reinforces the importance of good land use planning.

Environmental Impacts.–Since the emphasis of the research was upon impacts on infrastructure, impacts upon the environment were not directly considered. Potentially significant environmental impacts such as poorer air and water quality and wetland loss could accompany direct impacts on infrastructure. Generally, adaptation measures that lessen an infrastructure impact also reduce environmental impacts. Furthermore, such steps may mitigate greenhouse gas emissions. One clear exception is expansion of air conditioning to manage heat stress mortality.

Socio-Economic Impacts.–CLIMB's impact and adaptation analyses, using a variety of indicators, measured some of the socio-economic impacts of climate change on the region's infrastructure. The incremental damage to properties in river flood and coastal zones under an increased frequency of extreme weather events is the most profound of the measurable economic impacts. The analyses, however, did not capture how impacts and the possible benefits of adaptation might be distributed throughout the region by economic sector or household groups (differing in age structure, ethnic mix, economic prosperity and other factors which may influence an individual's ability to adapt). Although disproportional impacts on various socio-economic groups may clearly exist, CLIMB did not attempt to evaluate them.

Other and Hybrid Adaptation Actions.–In most cases, the CLIMB study standardized and simplified its analyses by examining three adaptation responses. These options, however, were never intended to include all possible adaptation strategies. There are many actions that were not considered, such as offshore protection structures or shoreline retreat, as well as possible combinations of actions by location or hybrid adaptation such as Ride-It-Out in one area and GREEN in another. As shown, however, in the discussion of coastal flooding, and as should be expected, hybrid adaptation strategies are anticipated to be more beneficial than a single type of response.

Adaptive Actors and Institutions.–The adaptation responses considered in this research will require actions by many participants ranging from private citizens to the federal government. Our analysis, as well as related outreach activities, indicates that local levels of government (municipalities and counties) will play an especially critical role in adaptation. Due to the complementarities of effective adaptation actions, a coordinated response strategy will be necessary.

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