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*Even though urban infrastructure systems are important and are designed according to socioeconomic and environmental conditions that are very sensitive to climate, there have been few major integrated assessments of the impacts of climate change on metropolitan infrastructure systems and services and possible adaptations. An analysis of the Boston metro area found that adaptation actions taken before full climate-change impacts occur will result in fewer expected negative impacts to the region than waiting for major impacts to occur. Adaptation of infrastructure to climate change must also consider land use management, environmental and socio-economic impacts, equity, and adaptation actors and institutions. There are existing and additional policy instruments to encourage action.*

In their review of issues related to adaptation to climate change in the United States, Easterling and others state that "Consideration of actions — e.g., mitigation policy — that can reduce this likelihood [of adverse climate change induced impacts] is reasonable and prudent. . . . However, recognition is increasing that the continued combination of increases in emissions and the inertia of the climate system means that some degree of climate change is inevitable. . . [even] if extreme measures could be instantly taken to curtail global emissions. . . . [Thus] adaptation actions . . . present a complementary approach to mitigation. Adaptation can be viewed as reducing the severity of many impacts if adverse conditions prevail."[1] They also find in their review that "proactive adaptation can reduce US vulnerability to climate change" and policies can be implemented to improve adaptive capacity. Proactive adaptation comprises actions that take place before impacts of climate change are observed. Reactive adaptation comprises actions taken after impacts have been observed.[2]

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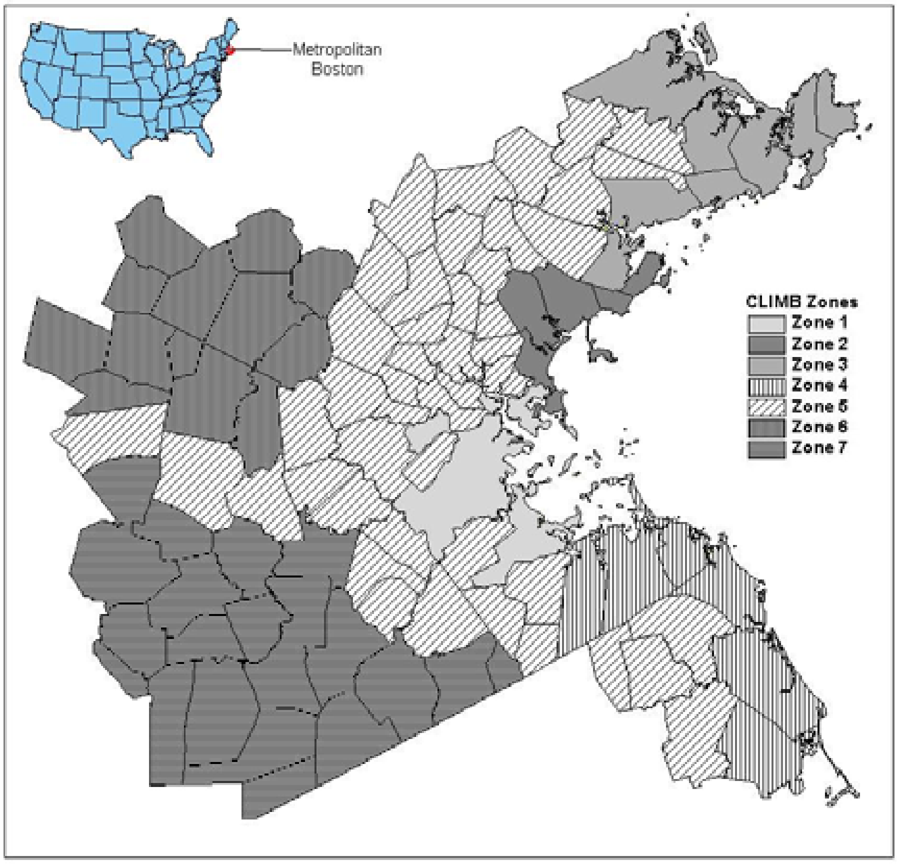
Here we present the results of a study of the possible impacts of climate change on infrastructure in metro Boston and then suggest some policies to encourage cost-effective, environmentally sensitive, and socially equitable adaptation. Infrastructure provides human, environmental, and economic services and directly contributes to the quality of life. Services typically include flood control, water supply, drainage, waste water management, solid and hazardous waste management, energy, transportation, constructed facilities for residential, commercial, and industrial activities, communication, and recreation. Without infrastructure, economies could not function and many human and environmental systems would collapse. Yet even though urban infrastructure systems are important and are designed according to socioeconomic and environmental conditions that are very sensitive to climate, there have been few major integrated assessments of the impacts of climate change on metropolitan infrastructure systems and services. Since infrastructure systems last considerably longer than decades (some a century or more) and provide the footprint and direction for future development, it is important that decision-makers understand the short- and long-term consequences of climate change on infrastructure.

The Climate's Long-term Impacts on Metro Boston (CLIMB) project was conducted from 1999 to 2004 by a research team from Tufts University, University of Maryland, and Boston University with assistance from the Metropolitan Area Planning Council (MAPC) and a Stakeholder Advisory Committee.[3] As shown in Figure 1, Metro Boston includes the major cities of Boston and Cambridge and the other ninety-nine municipalities within approximately twenty miles of Boston. The area is bordered on the east by Boston Harbor (the confluence of three major rivers) and on the south, west, and north approximately by the circumferential Route 495, covering an area of 1,422 square miles. The population of Metro Boston is approximately 3.2 million. Land use varies from densely populated urban areas in the east, suburbs in the center, to undeveloped farmland and some urban "sprawl" on the fringes. It is the heart of the New England economy and provides its major airport and seaport facilities. The region is currently experiencing pressure on most of its infrastructure systems and severe development pressure in the municipalities just outside of the core urban areas. It is characterized by a climate with four distinct seasons with annual precipitation of 1000 mm relatively evenly distributed throughout the year; some as snow in the winter. The average monthly temperature is approximately 10 degrees Celsius.

## Climate Change in Metro Boston

Since 1900, the global average temperature has increased approximately 0.6 degrees Celsius.[4] Part of this increase is associated with natural variations in global temperature but, as stated in the Intergovernmental Panel on

*Figure 1*




7 CLIMB Zones: Zone 1 = South Coastal Urban, Zone 2 = North Coastal Urban, Zone 3 = North Coastal Suburban, Zone 4 = South Coastal Suburban, Zone 5 = Developed Suburbs, Zone 6 = Developing Suburbs South, Zone 7 = Developing Suburbs North

Climate Change (IPCC), "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities"[5] that result in the emission of extra amounts of greenhouse gases (GHG) such as carbon dioxide, methane, and nitrous oxide. These gases trap additional heat radiated from Earth, thus causing additional warming of the atmosphere. For example, the concentration of $CO_2$, the major GHG, has increased approximately 30 percent since 1750 to its present level of 370 parts per million (ppm). The present concentration is not likely to have been exceeded during the past 20 million years.[6] Seventy-five percent of $CO_2$ is from burning fossil fuels. The United States emits approximately one-fourth of the global total of $CO_2$.[7] In New England, temperatures have increased approximately 0.4 C since 1895, slightly less than the U. S. average increase.[8] Besides warming, climate change will also result in, for example, higher sea levels due to melting of ice on land and thermal expansion of the ocean, storms with greater precipitation, higher maximum temperatures, and more frequent droughts. This has resulted in "regional changes in climate [that] . . . have already affected a diverse set of physical and biological systems in many parts of the world."[9] Review of historical meteorological and sea level records in New England indicate that there is already evidence of some of these changes here.[10] For example, sea level in Boston has increased approximately 0.30 meters since 1900; half due to climate change and half due to natural land subsidence.

Future climatic changes depend upon emission scenarios and the response of the climate to the emissions, both of which are uncertain. Because of the long lifetime of some GHGs and the inertia of the climate system, even if there were significant decreases in emissions, the climate would continue to change. GHG emissions are expected to increase over the next century. For example, $CO_2$ may increase to 500 to 1000 ppm. The 2001 IPCC reports that these increases could raise global temperatures an additional 1.4 to 5.8 degrees Celsius by 2100.[11] J. B. Smith observes that "Substantial increases in global mean temperature can set off large-scale changes in the Earth's climate system such as shutdown of the thermohaline circulation [i.e. Gulf Stream] or melting of the West Antarctic ice sheet. The thresholds are uncertain (and for some of these events may be quite high). . . . However, it is possible that warming in the 21st century could trigger such events."[12]

Climate-change scenarios for various times in the future are generated from complex dynamic models of the interactions of the atmosphere, land surface, and the oceans known as General Circulation Models or GCMs. The climate-change scenarios used in the CLIMB study were the same Canadian Climate Centre and Hadley Center GCM results that were used in New England during the recent U.S. national assessment of climate change.[13] In particular, the Canadian CGCM1 and the Hadley HadCM2 GCMs with a greenhouse gas emission scenario of a one percent annual increase in equivalent $CO_2$ and the direct effects of sulphate aerosols in the atmosphere (IS92a scenario), which decrease the amount of energy reaching Earth from the Sun. Scenario data from the GCMs were obtained for the inland grid cell closest to our study area for the years 2030 and 2100. A summary of scenario impacts in our study area is below. One scenario is humid and warm, the other more humid and less warm. As points of reference, presently the average annual temperature of Richmond, Virginia, is approximately equal to the low temperature possible for the region in 2100, while that of Atlanta, Georgia, is equal to the high temperature projection. The total sea level rise due to climate change and subsidence for both scenarios is approximately 0.6 meters.

*Table 1*

**2100 Annual Climate Change Scenarios for Metro Boston**

| | Temp. Increase (Degrees Celsius) | Precipitation (%) |
|---|---|---|
| CGCM1 | 4.80 | 5.90 |
| HadCM2 | 2.95 | 23.00 |

These are considered to be low and mid-range scenarios compared to the most recent available climate-change scenarios for the region.[14]

## Climate-Change Policy in the Region

Generally the emphasis in the United States has been on mitigation policies. The official U. S. Global Climate Change Policy is "to reduce domestic greenhouse gas (GHG) emissions relative to the size of the American economy. The United States will achieve this goal by cutting its GHG intensity — how much it emits per unit of economic activity — by 18 percent over the next 10 years."[15]

Massachusetts is a member of the Regional Greenhouse Gas Initiative (RGGI). This is "a cooperative effort by nine Northeast and Mid-Atlantic states to design a regional cap-and-trade program to cover carbon dioxide emissions from power plants in the region. In the future, RGGI may be extended to include other sources of greenhouse gas emissions, and greenhouse gases other than $CO_2$."[16] Acknowledging the potential impacts of climate change on Massachusetts and the contribution of Massachusetts's GHG emissions, the Commonwealth of Massachusetts released its Climate Protection Plan in spring 2004. While the plan focused upon controlling GHG emissions and opportunities for sequestrating carbon, one part of the plan explicitly responds to the challenges of adaptation; in Section 10 the plan states that the Office of Coastal Zone Management "will integrate climate change considerations, their policy-making and management of state-owned coastal resources . . . will encourage coastal municipalities to institute adaptation measures to reduce climate impacts, assist state open space preservation programs in the identification of coastal areas in need of protection."[17] The new Massachusetts Water Policy released on November 9, 2004, did not mention climate change considerations though it stressed more proactive planning.

Several municipalities in metro Boston participate or have participated in the Cities for Climate Protection Program of the International Council for Local Environmental Initiatives (ICLEI). The goal of this program is to provide technical assistance to municipalities to inventory and reduce their emissions of GHGs and air pollutants.[18] Generally, the state and regional actions are in line with the findings of a recent Pew Center report on state and regional action plans; all examples discussed mitigation plans with no mention of adaptation plans.[19]

## Methodology

Potential changes in infrastructure performance play themselves out across space and time, owing to differences in infrastructure densities and use, differences in environmental conditions, and the long-term nature of climate change as well as the long-lived nature of the various infrastructure systems. To capture spatial variations in climate-change impacts on Metro Boston, seven sub regions or zones are distinguished (Figure 1) such that:

- coastal regions are treated separately from regions inland;
- areas north of the City of Boston, which have different coastal properties and socioeconomic features, are delineated from southern parts of the MAPC region;
- highly urbanized areas are dealt with separately from suburbs; and
- rapidly growing suburbs are distinguished from already highly developed and densely populated ones.

The CLIMB study conducted analyses of many of the critical infrastructure systems in Metro Boston. For each of these systems a dynamic model based on mathematical and statistical analysis was constructed and used to make simulations over the period 2000 to 2100.[20] Emphasis was placed upon consistent, transparent analyses, ground-truthed by the Stakeholder Advisory Group. In most cases, simulations were run under one set of demographic projections, two climate change scenarios in addition to the present climate, and three possible adaptation responses to climate change. This allowed us to compare our best estimates of the future impacts of climate change on infrastructure systems under different climate and policy scenarios.

Population projections to 2050 were developed based upon data provided by MAPC and the NPA Data Services, Inc.[21] After 2050, it was assumed there were no changes in population. The regional projection is in Table 2. As stated above, climate-change scenarios were the same as those used for the region by the U.S. national assessment of climate change.

*Table 2*

**CLIMB Population Projections**

| Zone | 2000 Pop.* | % | 2050 Pop.* | % |
|---|---|---|---|---|
| 1 South Coastal Urban | 682 | 21.1 | 820 | 20.7 |
| 2 North Coastal Urban | 213 | 6.6 | 256 | 6.5 |
| 3 North Coastal Suburbs | 138 | 4.3 | 172 | 4.3 |
| 4 South Coastal Suburbs | 141 | 4.4 | 179 | 4.5 |
| 5 Developed Suburbs | 1,613 | 50.2 | 1,941 | 48.8 |
| 6 Developing Suburbs North | 139 | 4.3 | 189 | 4.8 |
| 7 Developing Suburbs South | 289 | 9.0 | 411 | 10.4 |
| Total | 3,215 | 100.0 | 3,968 | 100.0 |

*(1000)

The adaption scenarios included:

- The "Ride it Out" (RIO) scenario that, in essence, assumes that no adaptation to climate change occurs and that damages and benefits continue to occur with no attempts by society to minimize damages or maximize benefits.

- The "Green" scenario assumes conscious, sustainable responses to observed trends, as well as proactive or anticipatory implementation of policies and technologies in an effort to counteract, and prepare for, adverse climate impacts. Some of the practices might be put in place before impacts are felt (for example, moving occupants out of flood plains), after impacts occur, or at the end of lifecycles of infrastructure systems.

- The "Build Your Way Out" (BYWO) scenario assumes that replacement of failed systems is undertaken and susceptible systems are protected by structural measures.

Generally we did not examine mixed, locally specific adaptation scenarios for each sector. That is, for one adaptation scenario, we assumed that all infrastructure systems of one type would use the same adaptation approach. For example, we evaluated the consequences of the entire region adapting to river flooding by a structural approach, and then a nonstructural approach. In some cases though, say coastal flooding, we made some adjustments in the analysis for different local impacts.

Superimposed upon long-term climate-change trends are normal variations in weather and seasonal climate. These introduce another set of uncertainties into the analyses that must be considered. This was done by using Monte Carlo simulation of the impacts over the period 2000 to 2100 with multiple possible time series of future weather conditions with long-term climate-change trends included in them.[22]

Regional systems analyzed included energy use, sea level rise, river flooding, surface vehicle transportation, water supply, and public health (heat-stress mortality). Localized case studies were carried out for water quality, tall buildings, and bridge scour (that is, possible damage to bridge foundation from high water. Only the regional results are reported upon here.

## Summary of Results by Sector

*Energy Use* Warmer winters will result in less energy use but there will be summer electricity demand increases. Depending upon the climate-change scenario, by 2030, monthly residential per capita energy demand during the peak demand month of August could be as much as 20 to 40 percent greater than without climate change and, per employee, commercial energy use may be 6 to 10 percent greater. This has major implications for the regional electricity system, which is designed to meet current peak demands. Anticipatory adaptation could alter the region's energy demand to more effectively correspond with future climatic conditions via planned adjustments in the attributes of temperature-sensitive infrastructure and energy technologies (e.g., building thermal shells, air-conditioners, furnaces, more efficient energy generation and distribution, and diversification of energy sources). Identifying potential impacts for the region now is important because the energy industry is extremely capital intensive and as a consequence the flexibility of policy-induced changes in energy generation and demand trajectories over the short and medium run is limited. In the long run, as the capital stock naturally turns over, building codes may be changed to calibrate the thermal attributes of the building stock to expected future climates. Such changes need to be implemented in the relatively near term or the building stock will become increasingly maladapted to climate. In the near term, planting urban shade trees and installing high albedo roofs can begin to modify the thermal characteristics of the Massachusetts energy infrastructure in order to reduce space-conditioning energy use.

*Sea Level Rise* The total damage to residential and commercial and industrial buildings and contents and emergency costs over the next 100 years, if there is no climate change but only land subsidence and land use management policies remain the same, is approximately $7 billion. Under various sea level rise scenarios and rebuilding strategies, the costs of the RIO scenarios range from approximately $20 billion to $94 billion (all costs are in 2000 dollars). Possible adaptations to sea level fit into two categories: structural adaptations including sea walls or non-structural adaptations including flood proofing of existing structures or retreat from vulnerable coastal areas. If structural or nonstructural adaptation actions are taken well before 2050, the total damage and adaptation costs over this period could range from approximately $6 billion to $25 billion. Our findings on adaptation to increased storm surge impacts support those of others; it may be advantageous to use expensive structural protection in areas that are highly developed and take a less structural approach in less developed areas and/or environmentally sensitive areas. Besides being more cost effective, the less structural approaches are no-regrets or co-benefit policies, are environmentally benign, and allow more flexibility to respond to future uncertain 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* If present land use policies are maintained and there were no climate change, the overall cost of river flood damage to buildings and contents would total approximately $31 billion through 2100. With present policies and the climate-change scenario of the Canadian Climate Centre, damages could total $57 billion. While taking a structural approach to adaptation does not significantly change the costs, taking a nonstructural approach through floodproofing (Green Scenario) can reduce the total damage costs (not considering adaptation costs) to approximately $20 billion. The most severe incremental impacts will occur in the fast growing western suburbs. The likely economic magnitude of these damages is sufficiently high to justify large expenditures on adaptation strategies such as universal flood proofing in all flood plains by, for example, elevating flood-prone buildings. In addition, damages under the Green Scenario with climate change are substantially lower than might be expected in the absence of climate change but with no adaptation strategies.

*Transportation* Increases in the intensity of extreme weather events will result in a major increase in delays and lost trips due to road flooding over the course of the 21st century. Lost trips occur when origins and destinations are flooded. Delays occur when road links are flooded, causing traffic to be redirected to other links, which then become congested. Our simulations indicate that such lost trips and delays can be expected to roughly double over the next century. The economic impact of these delays and lost trips, however, is relatively small compared with those of flood damage to residential, commercial, and industrial properties or traffic delays during dry weather. It is unlikely that infrastructure improvements such as moving roadways in river valleys can be justified on a cost-benefit basis. Thus, the increase in weather-induced delays is a nuisance that motorists will have to endure as the frequency of extreme rain events increases.

While our simulations did not address public transportation explicitly, a review of recent flooding in the Massachusetts Bay Transportation Association's underground lines showed the vulnerability of transit systems to extreme weather events and high costs associated with both infrastructure repairs and travel disruption. This problem is likely to increase under a climate change scenario. Boston's Central Artery Tunnel — The Big Dig — is also an area of concern. The Big Dig's tunnel entrances, however, are less vulnerable to flooding than most underground facilities in the region because of their relative height.

*Water Supply* Most of the region is served by the regional surface water system consisting of the Quabbin and Wachusett Reservoirs. It has a large storage capacity and a demand presently less than safe yield (the amount of water a reservoir system can reliably release each day). It is operated by the Massachusetts Water Resources Authority (MWRA). Some municipalities depend upon local surface and ground water systems without large storage capacities. Under the climate change scenario with the least future precipitation, the reliability of the MWRA system will not change but the reliability of some local systems could decrease by 7 percent by 2050 and 10 percent by 2100. Only by the local systems using the regional MWRA system to supplement their supplies (the BYWO scenario) is it possible to maintain acceptable local water supplies under climate and demographic changes. Even with the higher demands on it under BYWO, the reliability of the MWRA regional system remains manageable in the future. Since presently the regional system is not obligated to serve all locally supplied systems in event of temporary or permanent shortages, local systems should anticipate climate and demographic changes and take adaptive actions such as demand management, which includes many approaches including increase rates, increasing instream flows through better storm water management, increasing system storage capacity though reservoirs or aquifer use, and considering using such water supply sources as reclaimed wastewater and desalination. Implementation of these actions has historically taken long lead-times.

*Public Health* Impacts related to heat-stress mortality were analyzed. There will be slightly higher average heat-stress mortality until about 2010 under climate change compared to the base case. From 2010 onward, mortality declines more rapidly under climate change than without it and from approximately 2012 onward, the number of deaths actually declines as the number of heat events increases. One explanation behind this possible reversal lies in the effects that repeated events may have on a population's adaptive behavior — with more frequent events, the population becomes better prepared to deal with the problems. These findings, however, assume that current trends in the region continue such as increases in the use of air conditioning, and improvements in health care and the use of early warning systems for individuals most vulnerable to changes in temperature. Besides maintaining these trends, additional adaptations to climate change may be needed. For example, the region has seen few efforts to increase the use of shade trees to decrease albedo, increase moisture retention, and thus contribute to local cooling. Similarly, little new construction uses materials or designs that reduce a building's albedo, its heating and cooling needs, and thus energy consumption and impacts on local air quality. Such engineering approaches to prepare the local building stock for a changing climate, together with appropriate zoning and transportation planning could go a long way in reducing, for example, urban heat island effects, which may be exacerbated by climate change. For these results to be achievable requires aggressive investment in all areas ranging from health care to space cooling to smart land use, as well as potentially drastic behavioral adjustments of the local population. On the one hand, such adjustments will need to be large yet, given past experience, seem doable. On the other hand, they may entail major changes in lifestyles in the region.

Several general themes emerge from these analyses. (1) Either structural (BYWO scenario) or less structural (Green scenario) actions taken before full climate-change impacts occur will result in lower expected negative impacts to the region's infrastructure systems. (2) Under many scenarios, an effective adaptation action taken soon will result in lower total future negative impacts even if climate change does not occur; for example, this was found to be the case in river and coastal flooding impacts and adaptation. (3) Climate change will significantly add to the negative impacts of demographic change upon infrastructure services in the region because the region is already close to buildout. (4) Another analysis that was conducted, but is not described here, found that with the exception of the energy and the health (as represented by heat stress mortality) sectors, effective adaptation actions in the CLIMB region taken by one sector have the potential to improve the services of other sectors as well as environment, social, and economic conditions and mitigation. For example, adaptations to better manage river flooding include moving structures from flood plains, and increasing runoff recharge rates. Retreat from flood plains will be beneficial to transportation in the sense that fewer trips will begin and end in flooded areas, so the impact of floods on system performance will be less. If land use restrictions lead to denser development, there will also be a benefit in terms of less residential energy use, which may in part offset the need for more air conditioning. Retreat from flood plains will also have the environmental benefits of less displacement of natural flora and fauna in these ecologically rich areas. These same areas may also serve as greenways, which benefit mitigation efforts. Increased recharge rates, which reduce the extent of flooding, have very widespread benefits in terms of improved water supply and water quality. (5) Finally, 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, an adaptation action that best lessens an infrastructure impact also lessens environment impacts and it also mitigates greenhouse gas emissions.

## Policy Implications

While starting to limit GHG emissions is a policy that most industrialized nations of the world endorse, some amount of climate change is inevitable even if emissions were substantially decreased below 1990 levels. Therefore, policy makers must turn to the issues of how to guide adaptation to a changed climate. In our research, we examined three choices that cover a wide range of actions. Reviewing the impacts that may occur under the various broad classes of policy actions result in the following policy recommendations.

- **Anticipatory Actions** A common result of the analyses is that not taking any adaptation actions over our analysis period of 2000 to 2100 is the most ineffective response. We showed in our full dynamic analyses (and it is implied from our localized case studies) that taking action well before 2100 results in fewer adaptation and impact costs to the region. Some examples from above include implementing both structural and nonstructural flood management strategies before 2050 to reduce the total costs of flood mitigation and impacts, maintaining policies to continue to improve health care, implementing policies to encourage more energy efficient housing stock, integrating water quality management to include land use, drainage, and treatment, and continuing to maintain redundancy in road networks. Because of the integration of sectoral impacts and adaptation actions, taking action in one sector will benefit other sectors, particularly in the case of flood management. Because taking action earlier mitigates future impacts and in the case of infrastructure systems requires long lead times, our conclusion recommends adaptive action planning and responses taken before major impacts are incurred.

- **Land Use** Another common theme is that, as expected, present and future land uses greatly affect the magnitude of the impacts. This is because the distribution of the population affects the location of infrastructure and hence the impacts, but also the way that the land is developed affects flood magnitudes and losses, water quality, water availability, and formation of local heat islands. 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.

- **Equity** The impact and adaptation analyses through the use of various indicators measured some of the socioeconomic impacts of climate change on the region's infrastructure. The analyses, however, did not capture how impacts and the possible benefits of adaptation might be distributed throughout the region by age distribution, ethnic mix, economic prosperity, and other factors that may influence an individual's ability to adapt. Issues of equity must be part of all policy initiatives.

- **Adaptive Management** In most cases, we standardized and simplified our analyses by examining three adaptation responses. We never intended these to include all possible adaptation actions. There are many actions that were not considered such as beach nourishment or shoreline retreat as well as possible combinations of actions by location or hybrid adaptation such as RIO in one area and GREEN in another. As found, however, in the coastal flooding part of the SLR anaylsis, and as should be expected, hybrid adaptation strategies are expected to be more beneficial than just a single type of response. The research has also shown that impacts are sensitive to the uncertainties of climate change and response actions. Therefore, policies should be pursued that are a combination of flexible, monitored actions capable of adjustment as more knowledge is gained about impacts.

- **Adaptation Actors and Institutions** The adaptation responses considered in this research will require actions by many institutions ranging from private citizens to the federal government. Our analysis as well as outreach activities indicate 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.

- **Policy Instruments**. There are several policy instruments that may be useful in implementing the policies. These include zoning regulations such as cluster zoning and conservation districts, updating building and design codes to include the present and possible future climate, adding climate change impacts to Environmental Impact Statements, using State Revolving Funds to finance the incremental costs of climate change adaptation, changing floodplain regulations to discourage rebuilding after any amount of flood damage, more community education about climate change impacts, permitting for use of natural resources, drought management plans, early warning systems, and impact fees.

## Conclusions

Scientific evidence indicates that anthropogenic climate change in metro Boston region has occurred and will continue in the future due to the long lifetime of some greenhouse gases. The magnitude of future impacts to the services provided by infrastructure depend upon future efforts to control emissions of the gases as well as the manner in which society chooses to respond to the climate changes, the process of adaptation. The research of others has shown that proactive adaptation actions will usually be more effective than reactive actions. Our research has reinforced this for metro Boston. Policies must be implemented that encourage such actions.

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