Infrastructure Systems, Services and Climate Change: Integrated Impacts and Response Strategies for the Boston Metropolitan Area

EPA Grant Number: R.827450-01

also known as

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

Executive Summary

Period Covered by the Report: September 1999 to June 2004
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Title: Infrastructure Systems, Services and Climate Change: Integrated Impacts and Response Strategies for the Boston Metropolitan Area
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Research Category: Integrated Assessment of the Consequences of Climate Change Grant Program
Project Period: September 1999 to June 2004
Objective(s) of the Research Project: The services provided by infrastructure systems include flood control, water supply, drainage, wastewater management, solid and hazardous waste management, energy, transportation, providing constructed facilities for residential, commercial, and industrial activities, communication, public health and recreation.

Even though infrastructure systems and services are designed according to socioeconomic and environmental conditions that are very sensitive to climate (for examples; energy and water demands, wind and water loads) and have interrelated impacts upon each other, there have been no major integrated assessments of the impacts of climate change on metropolitan infrastructure in the US. Infrastructure systems last considerably longer than decades (some a century or more) and provide the footprint and direction for future infrastructure and related future socioeconomic activities and environmental quality. Hence it is important that decision-makers understand the short- and long-term consequences of climate change on infrastructure. This includes both local and regional decision-makers because they make most infrastructure-related decisions and state and national decision-makers because they provide policy guidance.

The objectives of the research include:

- Documentation and analysis of the state of present infrastructure systems and the socioeconomic and environmental services provided by them in the Boston Metropolitan Area (includes the major cities of Boston and Cambridge and 99 other municipalities within approximately 20 miles of Boston - land use varies from urban to farms and open space) using various indicators to indicate their contribution to the quality of life in the region;

- Determination of the integrated direct and indirect impacts of climate change, socioeconomic, and technology scenarios on the future evolution of infrastructure and the regional quality of life over time;
- Identification and importance of policies and short- and long-term research needs for the provision of infrastructure services that will meet stakeholder needs over time given the uncertainties of climate and other changes; and
- Collaboration with the Metropolitan Area Planning Council (MAPC), our local partner, to ensure that stakeholders are involved, their concerns are addressed, and the project results are effectively communicated to them and the public at large and to begin to engage stakeholders in the process of preparing for potential climate change.

Summary of Findings:

The CLIMB study conducted analyses of many of the critical infrastructure systems in Metro Boston with the major analysis tool being dynamic modeling of the period 2000 to 2100 with spatial disaggregation to seven subregions (referred to as zones) of metro Boston. In most cases, impacts were examined under one set of demographic projections, two climate change scenarios in addition to the present climate, and three possible adaptations responses to climate change. The adaptation scenarios included:

- The “Ride it Out” scenario 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 pro-active or anticipatory implementation of policies and technologies in efforts 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” scenario assumes that replacement of failed systems is undertaken and susceptible systems are protected by structural measures.

Systems analyzed included:

- Energy Use
- Sea Level Rise
- River Flooding
- Transportation
- Water Supply
- Public Health (heat-stress mortality)
- Localized Case Studies (Water Quality, Tall Buildings, Bridge Scour)

The conclusions of each sector are summarized below.

Energy Use. The summer electricity demand increases will cause negative impacts in the region. Anticipatory adaptation could alter the region’s energy demand response function to more effectively correspond with future climatic conditions via planned adjustments in the attributes of temperature-sensitive infrastructure and energy technologies (i.e. building thermal shells, air-conditioners, furnaces). 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. However, 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, polices such as urban shade tree planting and installation of 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. 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. Our adaptation scenarios were based upon taking action well before 2050 or even earlier. 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. Our analysis of climate change impacts on river flooding indicate that the number of properties damaged and the overall cost of flood damage will both double relative to what might be expected with no climate change. 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. The most extensive adaptation strategy – as incorporated in the "green" scenario – greatly reduces the incremental flood damage due to climate change. In fact, damages under the green strategy 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 frequency 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. The economic impact of these delays and lost trips, however, are relatively small compared with those of flood damages to residential, commercial and industrial properties. It is unlikely that infrastructure improvements such as realignment of roadways in river valleys can be justified on a cost-benefit basis. Thus, increased weather induced delays are a nuisance that motorists will have to endure as the frequency of extreme rain events increases.

Water Supply. Under the climate change scenario with the least future precipitation and the adaptation actions considered in the report, only by the local systems using the regional MWRA system to supplement their supplies 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 regional MWRA systems remains manageable in the future under climate and demographic changes. Since presently the MWRA is not obligated to serve all locally supplied systems in event of temporary or permanent shortages, local systems should consider anticipating climate and demographic changes by using adaptation actions such as demand management and others not analyzed in this study such as 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. Only 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 observed reversal lies in the effects that repeated events may have on a population's adaptive behavior – the more frequent the number of events, the more may the population be prepared to dealing with it. These findings, however, assume that current adaptation 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 prone to changes in temperature. Besides maintaining these trends, additional adaptations to climate change may be needed. For example, the region has seen only 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 to 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 investments 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.

Water Quality. The localized case study found that the additional costs to adapt to climate change with or without population growth are significant because of the high costs of extra nonpoint source pollution management. These results point to 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 upon water quality.

Tall Buildings. The localized case study of a typical tall building in metro Boston found that if design wind velocities increased by 30 percent over the present Massachusetts Building Code, large wind induced sways potentially could cause human discomfort and costly architectural damage. They could also cause cracking and spalling of fire protection materials from the surface of steel structural members leading to reduced safety against fire protection. The structure may also experience increased cracking of non-structural architectural finishes, leading to increased maintenance costs. In sum, the serviceability of the building will be reduced. It is unknown what the expected wind speed may be under climate changes. Some researchers only predict 3 to 5 percent by 2095, but the research does suggest some of the additional analyses that may be necessary in the future.

Bridge Scour. The localized case study found that with increased flood discharges in rivers, bridge foundation scour could become a problem. One solution is retrofitting existing bridge footings with riprap.

Generally, three themes emerge from these analyses. Either structural (BYWO scenario) or less structural (Green scenario) actions taken before full climate change impacts occur will result in less expected infrastructure negative impacts to the region. The second is that under many scenarios, an effective adaptation action taken soon will result in less total future negative impacts in a sector even if climate change does not occur. For examples, this was found in the analyses of river and coastal flooding impacts and adaptation. The third theme is that climate change will significantly add to the negative impacts of demographic changes upon infrastructure services in the region. This is because the region is already close to buildout.

Summary by Integration of Impacts and Adaptation Actions

Impacts. The emphasis of the research was on the integration of climate and demographic changes upon an infrastructure and on examining these impacts with a common framework. Based upon the results of this research, it is also possible to examine how impacts in one sector will impact another sector. Ride It Out negatively impacts of one infrastructure system in most cases will also negatively impact the performances of other infrastructure systems. River flooding most negatively impacts the other sectors followed by sea level rise and energy supply – these are the sectors with the largest numbers of impacts cutting across sectors. Water supply and water quality are next with transportation and health following. Health (not only including heat-stress mortality) followed by water supply and water quality are the sectors must impacted by other sectors. These interactions are important because they have the potential to magnify any negative impacts caused by climate change alone in a sector.

Adaptation. It was found that generally anticipatory adaptations were most effective in lessening the impacts of climate change. Since the sectors are interrelated, adaptations to address problems in one sector will have effects on other sectors. In some cases the effects will be complementary, but in others they may work against each other. All of the adaptations will also have environmental impacts other than on climate change and will have broader economic and social implications. Furthermore, all of these adaptations may have impacts on our efforts to mitigate climate change by reducing greenhouse gas emissions.

In most cases, it was found that an effective adaptation action in one sector also lessens climate change impacts in another sector. For example, actions to improve water quality also have the potential to improve water supply, the environment, and greenhouse gas emissions. Water quality adaptations, however, may result in increased water management rates.

The interactions of adaptations with other sectors are most widespread in the case of management of future river flooding. Adaptations include increased use of flood proofing, retreat from flood plains, and increased recharge rates. Retreat from flood plains will be beneficial to transport 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 (and coastal areas) 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 actually serve to reduce the extent of flooding, have very widespread benefits in terms of improved water supply and water quality.

With the exception of the Energy and Health (as represented by heat-stress mortality) sectors, in the CLIMB region effective adaptations actions taken by one sector have the potential to improve the service of other sectors as well as the environment, social and economic conditions and mitigation. In order to capture these complementarities, a high level of cooperation by different infrastructure agencies in decision-making and implementation will be needed.

Overall Conclusions

CLIMB research provides the following major conclusions.

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 less total 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 against adaptative action planning and responses taken only after major impacts are incurred.

Land Use

Another common theme is that, as expected, present and future land use greatly effects the magnitude of the impacts. This is because the distribution of the population affects the location of infrastructure and hence the impacts, but also how the land is developed effects 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, an adaptation action that best lessens an infrastructure impact also lessens environment impacts. It also mitigates greenhouse gas emissions. One clear exception is expansion of air conditioning to manage heat stress mortality.

Socio-Economic Impacts

The impact and adaptation analyses through the use of various 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 houshold groups (differening in age structure, ethnic mix, economic prosperity and other factors which may influence an individual's ability to adapt), though distributional impacts clearly may exist.

Other and Hybrid Adaptation Actions

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 offshore protection structures 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 shown, however, in the coastal flooding part of the SLR section, and as should be expected, hybrid adaptation strategies are expected to be more beneficial than just a single type of response.

Some other adaptation actions not considered include:

Updating all building and design codes to the present (or even potential future), not past, climate

Adding climate changes to the Environmental Impact Assessment Process

Major Technology and Lifestyle Changes such as telecommuting, and high efficiency resource (e.g. energy, water) using devices

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.

Contribution to Understanding of and Solutions for Environmental Problems

The CLIMB study is based upon the hypothesis that the operation and services provided by urban infrastructure will be impacted by climate change as they are sensitive to climate. Using various indicators, our research has shown that compared to conditions of just population growth, climate change impacts are significant in many infrastructure sectors. We have also identified some specific actions and policies that can be taken in the near-term future to lessen some of the negative impacts. These actions are not intended to be optimal in terms of timing, location, or even action, but they do show that taking <u>anticipatory</u> action wells before 2100 results in less total adaptation and impact costs to the region than taking no action. We have also shown that considering the joint or integrated effects of sectoral impacts and adaptation actions is beneficial.

Through our outreach activities, we have also provided information about the research to many stakeholders at all institutional levels and have been, in turn, informed by them about issues of concern.

Publications/Presentations:

This is the status of material prepared to date. Several other publications are in preparation.

Publications

Amato, A., Ruth, M., Kirshen, P., Gute, D., Magliano, N., and Horwitz, J., Potential Effects of Climate Change on Temperature-Related Mortality in Metropolitan Boston, in preparation.

Knee, K., Kirshen, P., Vogel, R., and Ruth, M., Optimization of Adaptation Strategies to Sea Level Rise in Metro Boston, in preparation for Journal of Water Resources Planning and Management.

Ruth, M., Kirshen, P.H., and Donaghy, K., (co-editors), Climate Change and Variability: Consequences and Responses, (on research conducted as part of the 1999 and 2000 EPA STAR grant program), in preparation.

Kirshen, P.H., Wilson, C., Chudyk, W., and Ruth, M., Long-Term Climate and Socio-Economic Change and Water Quality in the Boston Metropolitan Area: the Assabet River, submitted to the Journal of Water Resources Planning and Management, 2004.

Knee, K., Kirshen, P.H., Vogel, R., Ruth, M., Adaptation to Sea Level Rise in Metro Boston, submitted to Climatic Change, 2004.

Luftig, J., Agyeman, J., and Kirshen, P., Incentives to Urban Adaptation to Climate Change; A Case Study of Cambridge, Massachusetts, submitted to New England Journal of Public Policy, October 2003.

Amato, A., Ruth, M., Kirshen, P., and Horwtiz, J., Regional Energy Demand Responses to Climate Change: Methodology and Application to the Commonwealth of Massachusetts, Climatic Change, in press.

Sanayei, M., Edgers, L., Alonge, J., and Kirshen, P., Effects of Increased Wind Loads On a Tall Building, Civil Engineering Practice, Fall/Winter, 2003.

Ruth, M, and Kirshen, P., Integrated Impacts of Climate Change upon Infrastructure Systems and Services in the Boston Metropolitan Area, World Resource Review 13(1), pgs 106-122, 2001.

Proceedings and Presentations

M. Ruth "Anticipatory Management", The Gordon Research Conferences, Oxford, England, August 9, 2004.

M. Ruth "Anticipatory Management of Urban Infrastructure Systems for Adaptation to Climate Variability and Change", Joint Global Change Research Institute, College Park, Maryland, May 18, 2004.

M. Ruth, A. Amato and P.H. Kirshen, "Potential Effects of Climate Variability and Change on Temperature-related Mortality in Metropolitan Boston", Centennial Meeting of the Association of American Geographers, Philadelphia, Pennsylvania, March 14-19, 2004.

M. Ruth and P.H. Kirshen, "Climate Impacts on Urban Infrastructure: Regional Costs and Adaptation Strategies", Annual Meeting of the Western Regional Science Association, Maui, Hawaii, February 23-28, 2004.

M. Ruth and P.H. Kirshen, "Preparing Urban Infrastructure for Impacts of Climate Change", University of Puerto Rico, San Juan, Puerto Rico, February 13, 2004.

M. Ruth and P.H. Kirshen, "Vulnerabilities and Adaptation of Urban Infrastructure in a Variable and Changing Climate" Faculty of Earth and Life Sciences, IVM, Vrije Universiteit Amserdam, Amsterdam, The Netherlands, January 30, 2004.

M. Ruth and P.H. Kirshen, “Perspectives and Plans for Environmental Research” Institute for Environmental Studies, IVM, Vrije Universiteit Amserdam, Amsterdam, The Netherlands, January 29, 2004.

Kirshen, P., Adaptation of Urban Water Infrastructure to Long-Term Climate Change: A Case Study of Metro Boston, Invited talk at the Smart Growth and the Environment Lecture Series, University of Maryland, 2 December, 2003.

M. Ruth, “Modeling Urban Infrastructure Vulnerabilities to Climate Change: Methodologies and Applications”, University of Maryland Department of Geography Seminar Series, College Park, Maryland, November 20, 2003.

M. Ruth and P.H. Kirshen, “Urban Infrastructure Vulnerabilities and Dynamics in a Changing and Variable Climate”, Department of Geography, University of Southern California, and Center for Sustainable Cities, November 7, 2003.

M. Ruth and P.H. Kirshen, “Public Policy Water Issues”, Confrence on Maryland Water Policy Issues – What does the Future Hold?, Water Resources Research Center, University of Maryland, College Park, Maryland, October 24, 2003.

Kirshen, P., Long-Term Climate Change; Global and Local Issues, Weather Observers Conference, Boston Museum of Science, Keynote address, October 18, 2003.

M. Ruth and P.H. Kirshen, “Modeling Infrastructure Vulnerabilities and Adaptation to Climate Change in Urban Systems: Methodology and Application to Metropolitan Boston“, European Regional Science Association, Annual Meeting, Jyväskylä, Finland, August 27 – 30, 2003.

Ruth, M., and Kirshen, P., Urban Infrastructure and Sustainability in a Changing Environment, paper presented at the Second International Society for Industrial Ecology Conference, Ann Arbor MI, 29 June -2 July 2003.

William P. Anderson, Pablo Suarez and T.R. Lakshmanan, Assessing the Potential Impacts of Climate Change on Transportation Infrastructure Performace in the Boston Metropolitcan Area, Kyoto Special Seminar Series, Kyoto Universitiy, Japan. June, 2003.

Kirshen, P., Wilson, C., Knee, K., Suarez, P., Ruth, M., Anderson, W., and Lakshmanan, T.R., Integrated Impacts of Long-Term Climate Change on the Water Resources Systems in the Boston Metropolitan Area and Adaptation Responses, Proceedings of ASCE World Water and Environmental Resources Congress, Philadelphia, PA, June 23-26, 2003.

M. Ruth, “The Joys and Perils of Large-Scale Interdiscisplinary Research“, Ecological Economics Student Group Seminar Series, University of Maryland, College Park, Maryland, May 9, 2003.

M. Ruth, A. Amato and P.H. Kirshen, “Potential Effects of Climate Change on Temperature-related Mortality in Metro Boston“, Western Regional Science Association, Annual Meeting, Tucson, Arizona, February 26 - March 1, 2003.

Kirshen, P.H., Knee, K., Ruth, M., and Suarez, P., Infrastructure Impacts of Climate Change on Coastal Metro Boston, AAAS Special Symposium on "Cities in Transition: Climate Change

Impacts, Adaptation, and Mitigation", AAAS Annual Meeting and Science Innovation Exposition, Denver CO, 13-18 February 2003.

Ruth, M., Kirshen, P.H., Anderson, W., Lakshmanan, T.R., Amato, A., Suarez, P., Knee, K., Gute, D., and Horowitz, J., Synergies between Mitigation and Adaptation to Climate Change in Cities, AAAS Special Symposium on "Cities in Transition: Climate Change Impacts, Adaptation, and Mitigation", AAAS Annual Meeting and Science Innovation Exposition, Denver CO, 13-18 February 2003.

Ruth, M. and Kirshen, P., Climate's Long-term Impacts on Metro Boston, U.S. Environmental Protection Agency, 5th State and Local Climate Change Partner's Conference, Annapolis, Maryland, November 20 - 22, 2002.

Kirshen, P., Edgers, L. , Edelmann, J., Percher, M., Bettencourt, B., Lewandowski, E., and Limbrunner, J., A Case study of the Possible Effects of Climate Change on Bridge Scour, Proceedings of First International Conference on Scour of Foundations, Texas A&M University, College Station TX, 17-20 November, 2002.

M. Ruth, A. Amato and P.H. Kirshen, "Regional Energy Demand Responses to Climate Change: Methodology and Applications to Massachusetts", North American Meeting, Regional Science Association International, San Juan, Puerto Rico, November 14 - 18, 2002.

Kirshen, P.H., Integrated Impacts of Climate Change on the Infrastructure Services of Metro Boston and Policy Options for Adaptation, invited paper at US EPA Region 1 Environmental Research Seminar, Boston MA November 14, 2002.

William P. Anderson, Pablo Suarez and T.R. Lakshmanan, Assessing the Potential Impacts of Climate Change on Transportation Infrastructure Systems, MIT-Harvard Seminar Series on Environmental Management, November 2002

Kirshen, P., Ruth, M., Knee. K., Wilson, C., and Amato. A., Preliminary Findings of Climate Impacts on Metro Boston, invited paper at Energy Modeling Forum, Snowmass, CO, August 1-2 2002.

Kirshen, P.H., Coastal Impacts of Climate Change on Metro Boston, presentation to Meet the Scientists Program, Tufts University, March 19, 2002.

Kirshen, P.H., The Impacts and Costs of Climate Change to the Boston Region, presentation to the Boston Area Solar Energy Association, March 14, 2002.

Kirshen, P.H., Impact of Global Warming-Induced Climate Change on the Hydrology of Massachusetts, invited paper at 2002 Annual Meeting of the Association of Massachusetts Wetland Scientists (AMWS), Boxboro MA, March 23, 2002, also presented the Waste Water Advisory Committee of the Massachusetts Water Resources Authority, March 1, 2002.

Ruth, M. and Kirshen, P.H., Dynamic Investigations into Climate Change Impacts on Urban Infrastructure: Background, Examples, and Lessons, Proceedings of Western Regional Science Association Annual Meeting, Monterey, California, Feb. 18 - 20, 2002.

Kirshen, P.H., and Ruth, M., Integrated Impacts of Climate Change on the Infrastructure Systems and Services of the Boston Metro Area, invited for Proceedings of ASCE World Water Resources and Environmental Congress, 20-24 May 2001, Orlando, FL.

Ruth, M., and Kirshen, P., Integrated Impacts of Climate Change upon Infrastructure Systems and Services in the Boston Metropolitan Area, presented at XIth Global Warming International Conference and Expo (GWXI), Boston, MA, 25-28 April 2000.

Supplemental Keywords: From list; water, watersheds, global climat,e human health, indicators, integrated assessment, sustainable development, public policy, decision making, community-based, engineering, social science, hydrology, geology, epidemiology, modeling, analytical, general circulation models, northeast, Atlantic coast, Massachusetts (MA), EPA Region 1, transportation, industry.

Other; Infrastructure, climate change, urban, suburban, metropolitan, energy demand, flooding, sea level rise, water supply, wastewater treatment, public health, scenario analysis, buildings, bridges, Boston.

Relevant Web Sites: www.tufts.edu/tie/climb