

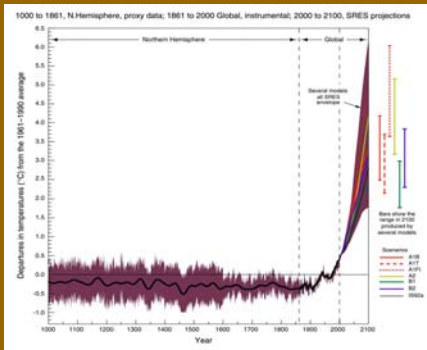
Long-Term Climate Change and Water Resources; Global and Local Issues

- Paul Kirshen, Director, Tufts University Water: Systems, Science, and Society (WSSS) Interdisciplinary Research and Graduate Education Program
- Impacts
- Adaptation

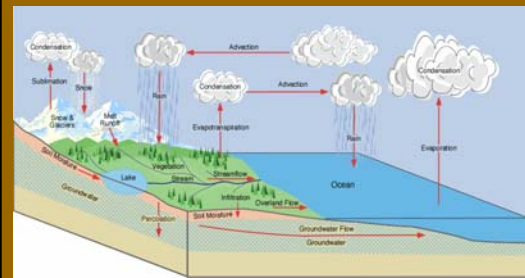
Topics

- Hydrologic Cycle
- Some Global Impacts
- Metro Boston
 - River Flooding
 - Water Supply
 - Water Quality
 - Coastal Flooding

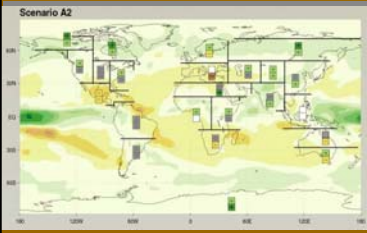
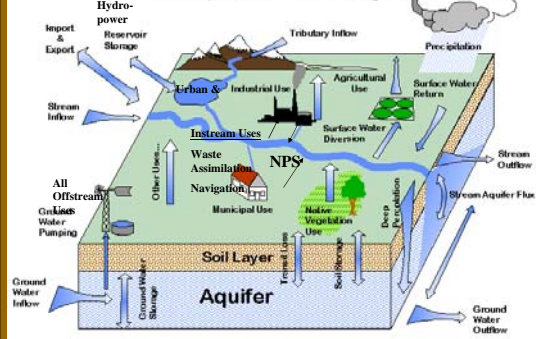
Variations of the Earth's surface temperature; 1000 to 2100



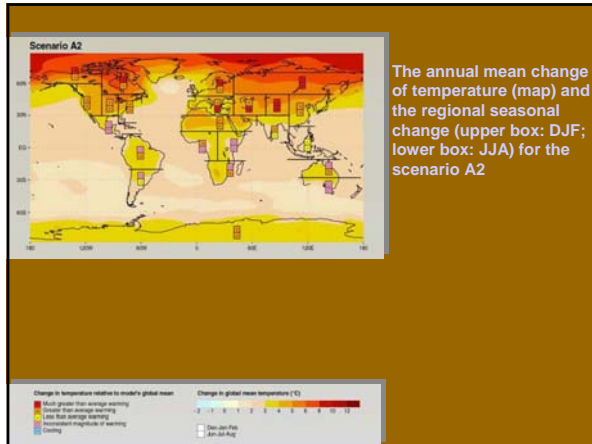
Hydrologic Cycle



Conceptual Water Budget



The annual mean change of precipitation (map) and the regional seasonal change (upper box: DJF; lower box: JJA) for the scenario A2




Streamflows Changes

- Streamflow = Precipitation – Evapotranspiration
- Evapotranspiration = function (temperature)
- Runoff may increase, decrease, no change

Eg. Figure 4-1, IPCC WG II, 2001,
By 2100, Mid Atl USE runoff: -12.5% to + 37.5 %

Changes in extreme hydrological events



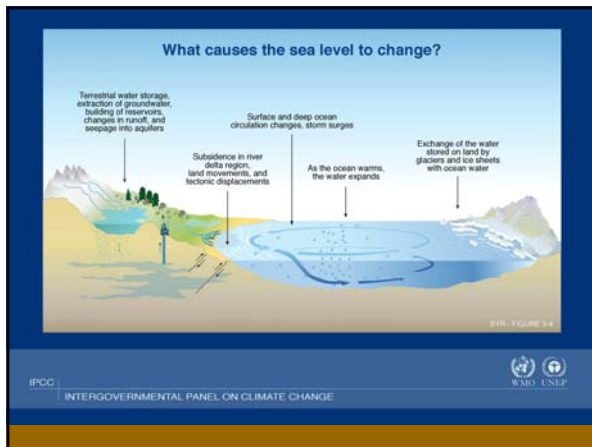
Increased summer drying over most mid-latitude continental interiors and associated risk of drought (*Likely*)

- Decreased crop yields
- Decreased water resource quantity and quality
- Increased risk of forest fire

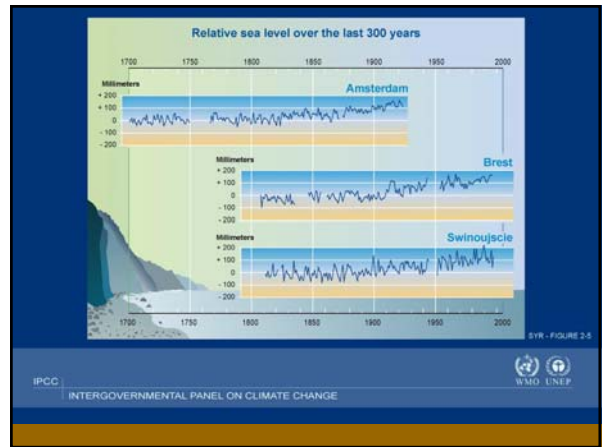
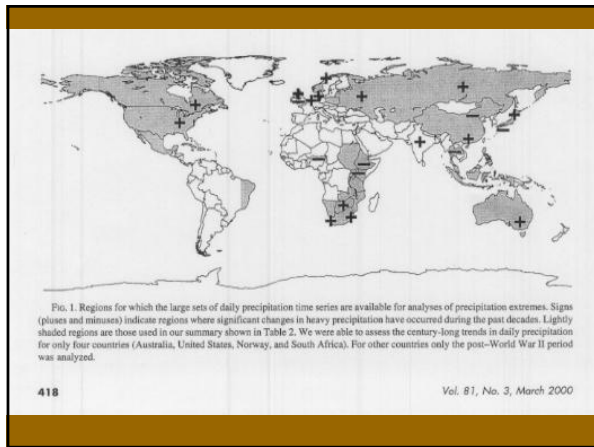
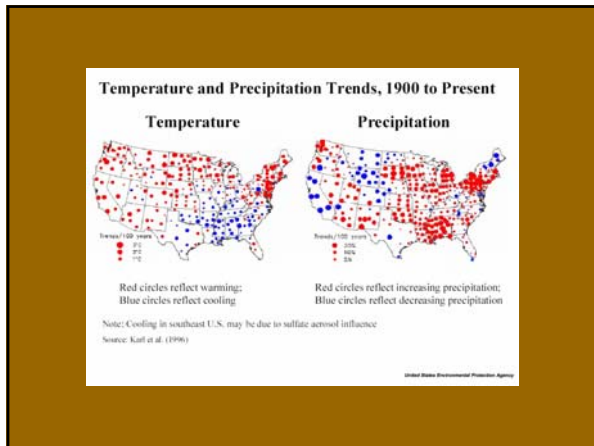
More intense precipitation events (*Very likely*, over many areas)

- Increased flood, landslide, avalanche, and mudslide damage
- Increased soil erosion

- Eustatic sea level rise of 0.09 m – 0.88 m from 1990 to 2100, central value of 0.48 m depends on scenario and models
- More coastal flooding and erosion



Already seeing some hydrologic changes

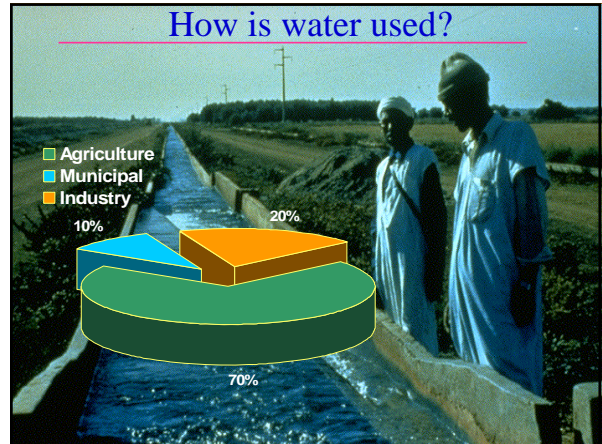
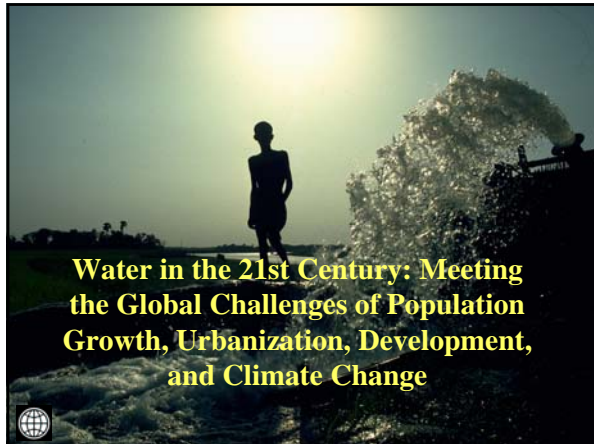


“Risks of large scale, (abrupt), and possibly irreversible impacts are yet to be reliably quantified”

Sea level rise from disintegration of Greenland and West Antarctic Ice Sheets

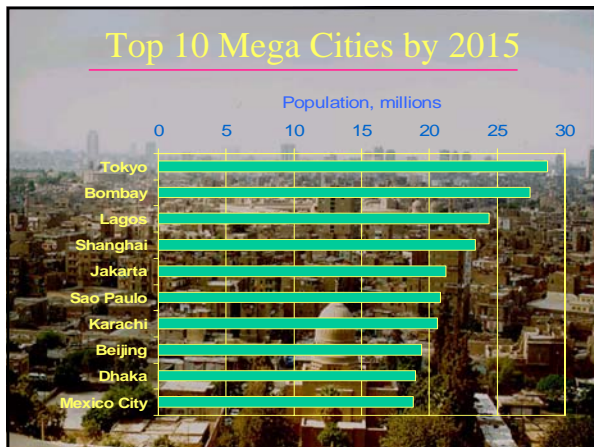
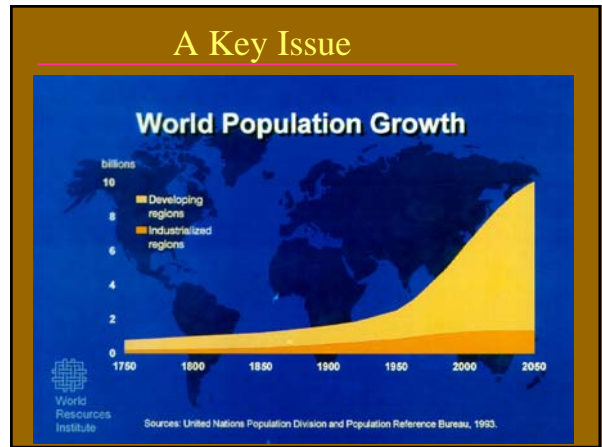
Substantial slowing or collapse of ocean circulation that transports heat to North Atlantic

Very low likelihood in 21st century but increases with rate, magnitude and duration of climate change



Present Stresses

- 1.1 billion lack access to improved water services
- 2.0 billion live without sound wastewater disposal
- 3.0 million children die from waterborne diseases each year
- At any one time, 50% of people in developing world suffering from water and food related diseases
- Women in the developing world spend ~10 million person-years each year to bring household water from distant source
- 300 major river basins cross international borders and require extra management (e.g., West Bank, Indus, Mekong, Rio Grande, Aral, Nile, Volta...)



Burkina Faso

Bonam village

Life expectancy at birth:
male 45.6
female 47.6

Total fertility rate x woman: 6.9

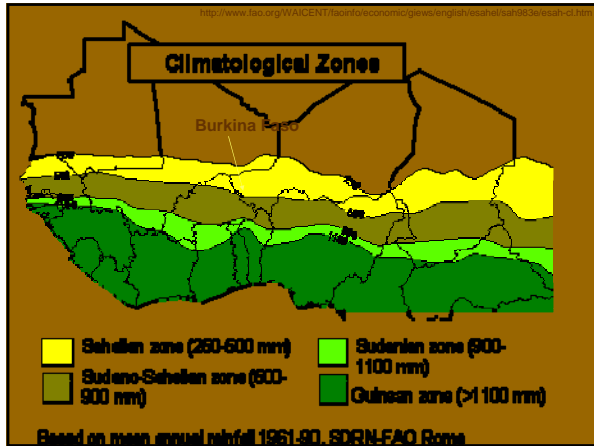
Infant mortality rate (x 1000): 105
Child (<5) mortality rate (x 1000): 198

Literacy rate (% age 15+):
male 33.9
female 14.1

Annual Population growth rate: 2.6 %
Human Development Index rank: 169 (of 173)
Gender development Index rank: 143 (of 173)

90 percent of population supported by agriculture, 80 % subsistence.

10 - 15 % of food imported



Seasonal livelihoods



Dry season:
November to May



Rainy (farming) season
May to October


CFAR Sites

BONAM, Central Plateau (met station at Boulsa)

Annual rainfall: 600-700 mm

Inhabitants mostly Mossi, some settled Fulbe
Rainfed farming: sorghum, millet, maize, groundnuts, B.gnuts, cowpea, rice

30% of hh have plows



Planting maize
Bonam, July 1999


IPCC WGII Third Assessment Report – Regional Issues with Emphasis on Developing Countries of Africa

Paul V. Desanker (Malawi)
Coordinating Lead Author
Chapter 10 (Africa)

Desertification would be exacerbated by reductions in average annual rainfall, runoff, and soil moisture, especially in southern, North, and West Africa (*medium confidence*).

Overall Vulnerability High

Vulnerability of human systems high as a **result of heavy reliance on rain-fed agriculture; frequent droughts and floods; and poverty.**



Overall Adaptive Capacity

Adaptive capacity of human systems in Africa is **very low** due to **lack of economic resources and technology.**

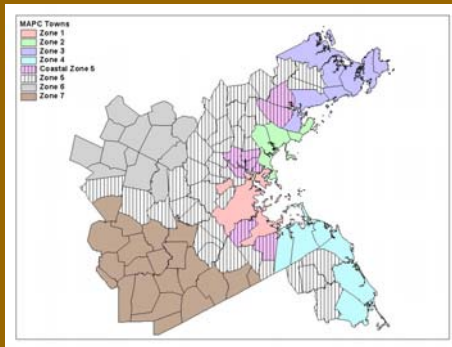


CLIMB Project

Climate's Long-Term Impacts on Metro Boston

- Tufts University, University of Maryland, Boston University
Paul Kirshen, Project Manager, Co-PI, paul.kirshen@tufts.edu
Matthias Ruth, Co-PI, mruth1@umd.edu
William Anderson, bander@bu.edu, T.R. Lakshmanan, laksh@bu.edu
- MAPC
Justin Alland, jalland@mapc.org
Martin Pillsbury, mpillsbury.org

The MAPC Area



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Results (STAR) Program
Grant #

Why Urban Area ?

- Few past studies on urban areas
- Urban infrastructure designed for socio-economic conditions as well as climate conditions
- World is urbanizing; in a few decades, more in urban than rural areas

2100 Climate Change in New England

- 3 to 5 degree C increase in temperature (temperature of Richmond, VA or Atlanta, GA)
- Up to 25% increase in precipitation
- Increase in the the frequency and intensity of extreme precipitation events and droughts
- Uncertain change in frequency and intensity of hurricanes and nor'easters
- Increase in relative sea level elevation of 0.3m to 1 m (historic rise has been ~ 0.3 m)

2100 GCM Climate Scenarios

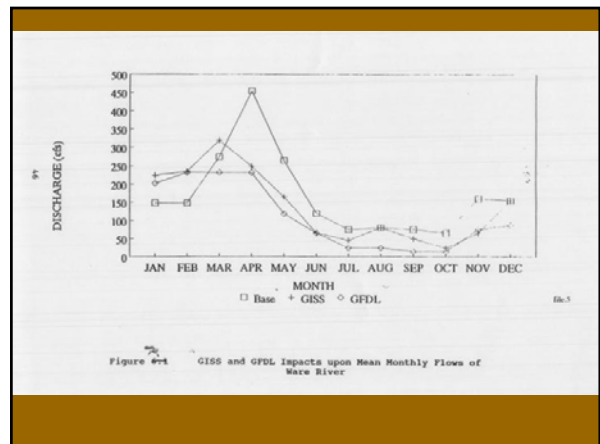
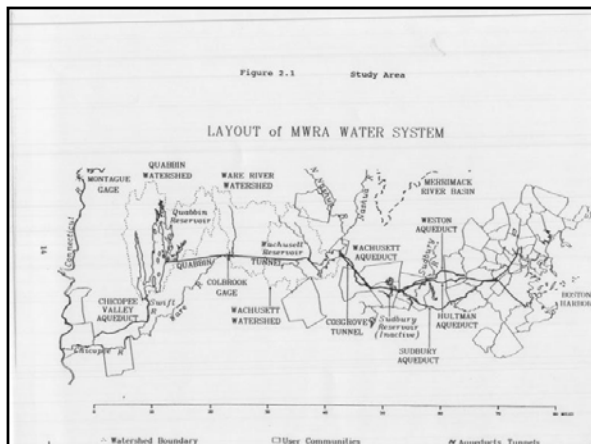
Present	CC	Had
Prec 2100/Prec 2000	1.059	1.23
PET 2100/Prec 2000	1.145	1.078
Runoff 2100/2000	1.010	1.333
Temp	4.8 C	2.95 C

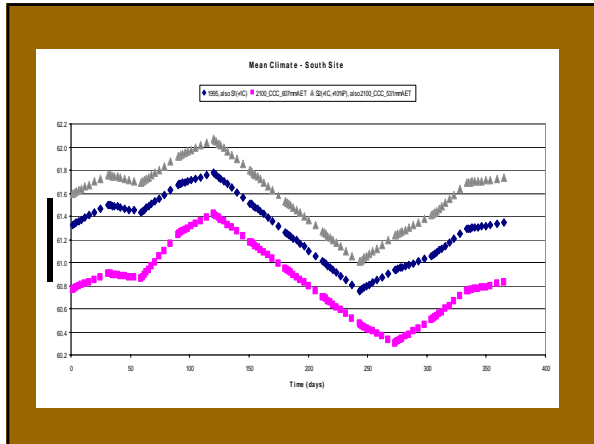
Zone		2000 Pop(1000)	Percent	2050 Pop (1000)	Percent
ZONE 1	Coastal Urban S.	682	21.2	820	20.7
ZONE 2	Coastal Urban N.	213	6.6	256	6.5
ZONE 3	Coastal Sub. N.	138	4.3	172	4.3
ZONE 4	Coastal Sub. S.	141	4.4	179	4.5
ZONE 5	Developed Sub.	1,613	50.2	1,941	48.9
ZONE 6	Developing, Sub. S.	289	9.0	411	10.4
ZONE 7	Developing Sub. N.	139	4.3	189	4.8
TOTAL		3,215	100	3,967	100.0

CLIMB Research

- Water Supply
- Water Quality
- Coastal and River Flooding
- Health
- Energy Demand
- Research Methods – Computer Modeling, Scenarios, Uncertainty Analysis, Stakeholder Inclusion

Water Supply





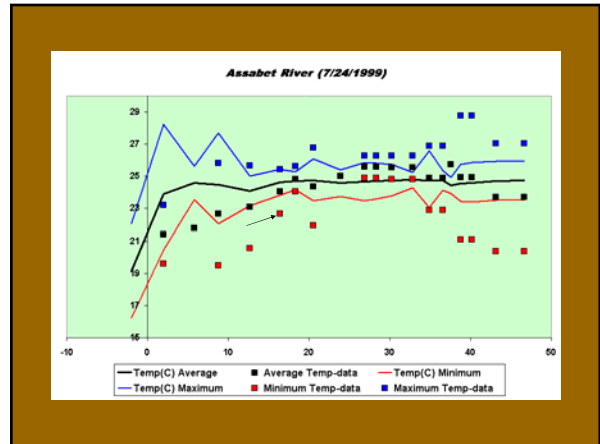
Summary of Water Supply - Cumulative, 2000-2100

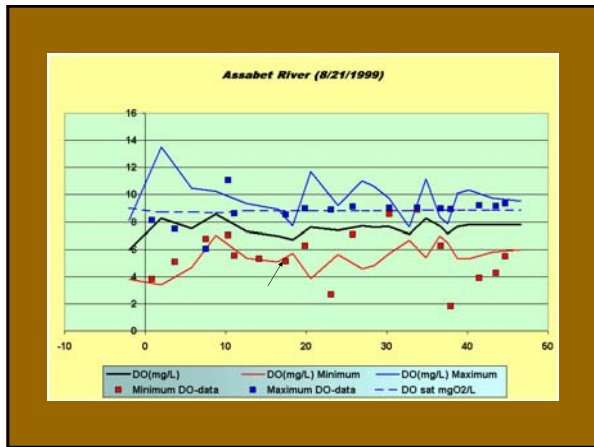
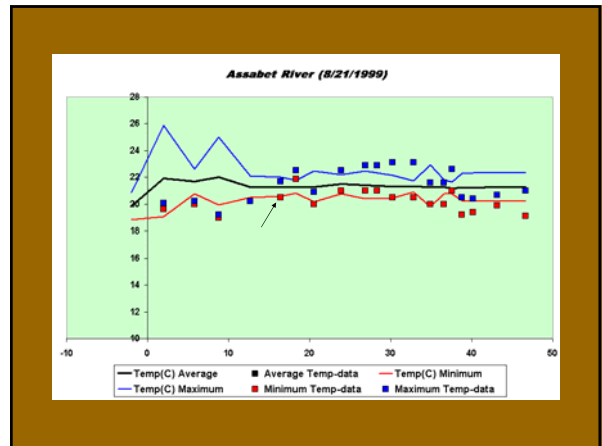
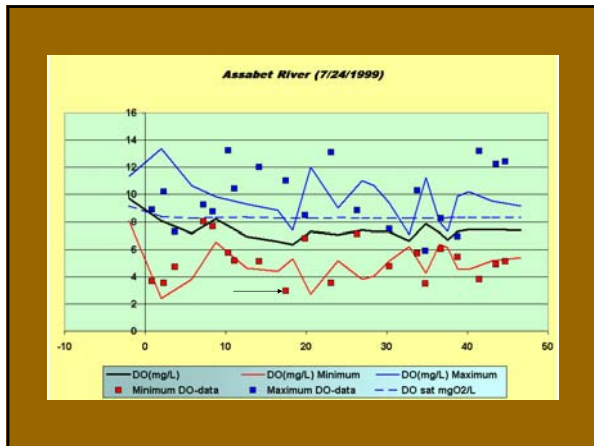
Scenario	MWRA Reliability (%)	MWRA Deficit (% demand)	All Local Reliability (%)	All Local Deficit (% demand)
BASE	100	0	93	78
RIO	99.6	5	84	86
BYWO	97	56	---	---
GREEN	100	0	83	84

Water Quality



- ## Loads
- Point Source Nutrients – Eutrophication
 - NPS BOD
 - SOD



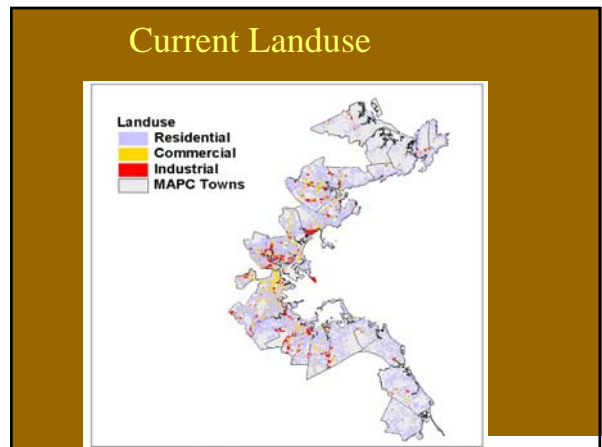


Integrated Impacts of Climate Change in the Coastal Zone of Metro Boston

Kelly Knee, Paul Kirshen, Pablo Suarez, Matthias Ruth
 Tufts University – Boston University – University of Maryland
 CLIMB Project

Study Area Overview

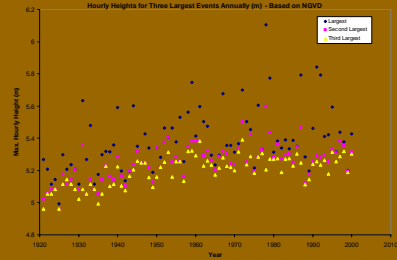
- 32 coastal municipalities in 5 zones
 - 1.2 million people
 - 110,000 hectares
 - Residential area = 40,000 hectares
 - Commercial area = 5,000 hectares
 - Industrial area = 3,000 hectares



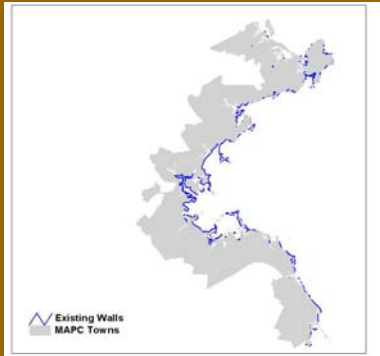
Sea Level Rise

- Eustatic sea level rise = thermal expansion and ice melt
- Subsidence = local rate of settling
- Relative sea level rise = eustatic sea level rise & subsidence
- Historic relative sea level rise in Boston = 1 foot per century

NOS Gage Data - Boston



Current Coastal Protection



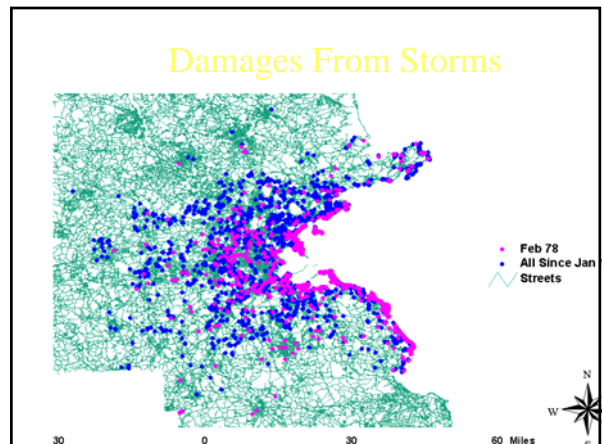
Current Coastal Protection



Present Flood Vulnerability

- February Blizzard of 1978, 100 Year Coastal Flooding, caused \$550 million in damages and \$95 million emergency costs (2000 dollars) in coastal MA.

Damages From Storms





Sea Level Rise

Projections:

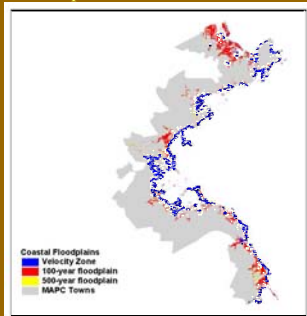
- Canadian Climate Center (CCC)
 - 0.41 meter increase by 2100
 - Accounts for thermal expansion alone, not ice melt or subsidence
- The Hadley Center
 - 0.3 to 0.5 meter increase by 2100
 - Accounts for thermal expansion and ice melt, not subsidence
- Subsidence
 - 0.20 meter by 2100

Storm Surge Flooding

- Tropical cyclones (hurricanes)
 - Formed in the tropics
 - Usually make landfall in the southeast US
 - Protection provided by Cape Cod
- Extra-tropical cyclones (nor'easters)
 - Formed off southeast US
 - Predominant winds from the northeast
 - More severe impacts for Metro Boston
 - Blizzard of 1978, "Perfect Storm"

Storm Surge Flooding

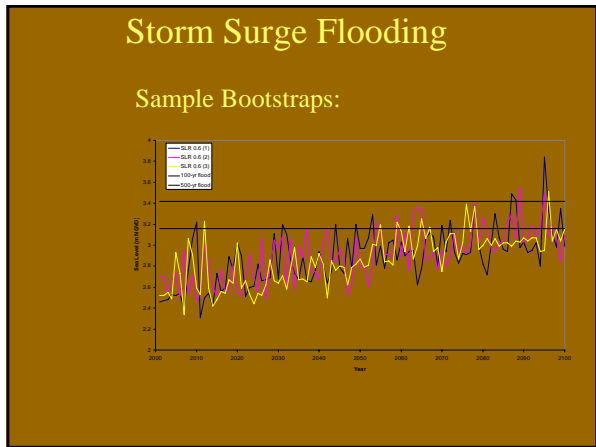
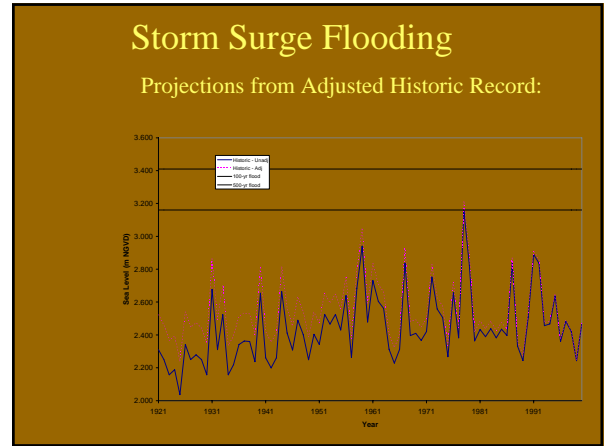
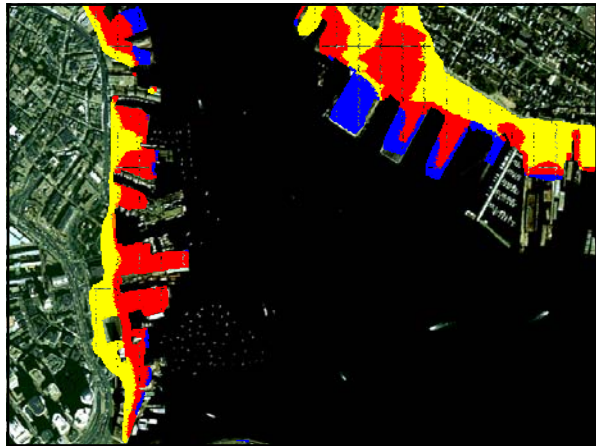
100-year floodplain = 11,000 hectares,
500-year floodplain = 1,000 additional hectares



Storm Surge Flooding

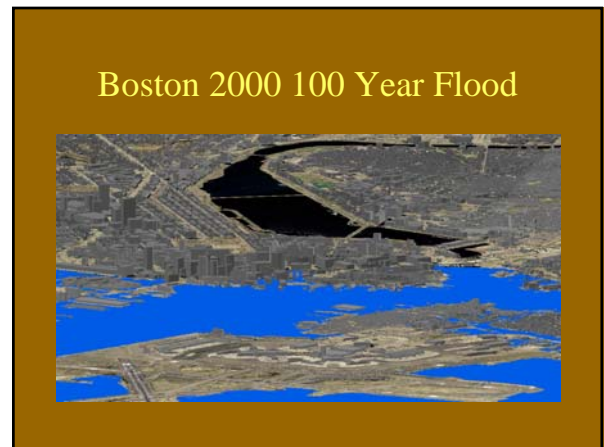
Current recurrence intervals (in Boston):

- 10-year storm = 2.82m
- 100-year storm = 3.16m
- 500-year storm = 3.41m

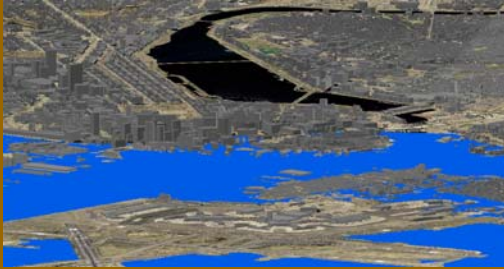


Model Run	Res	Cm/ln	Emgny	Adpt	Total
3 Baseline - Growth, One Event	1205	4305	337	0	6447
4 Baseline - Growth, Three Events	1616	5735	1250	0	8601
5 Ride-It-Out* - Moderate SLR, One Event	3563	13525	2905	0	19993
6 Build-Your-Way-Out* - Moderate SLR, 1 Event	1091	3984	863	3462	9400
7 Green* - Moderate SLR, One Event	756	2697	587	1766	5806
14 Ride-It-Out* - One meter SLR, Three Events	16140	64250	13666	0	94056
15 Build-Your-Way-Out* - One meter SLR, 3 Events	1820	6703	1449	3462	13434
16 Green* - One meter SLR, Three Events	3272	12760	2726	6798	25556

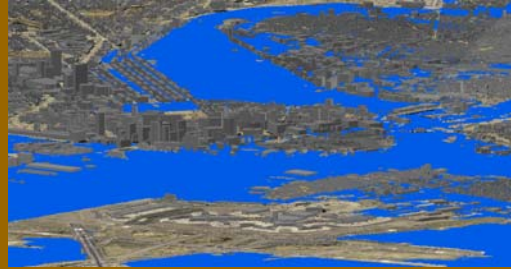
Table 6: Costs of SLR Scenarios (\$million). Res= residential costs, Cm/ln = commercial/industrial costs, Emgny = Emergency Costs, Adpt = adaptation costs



Boston 2050 100 Year Flood



Boston 2100 100 Year Flood

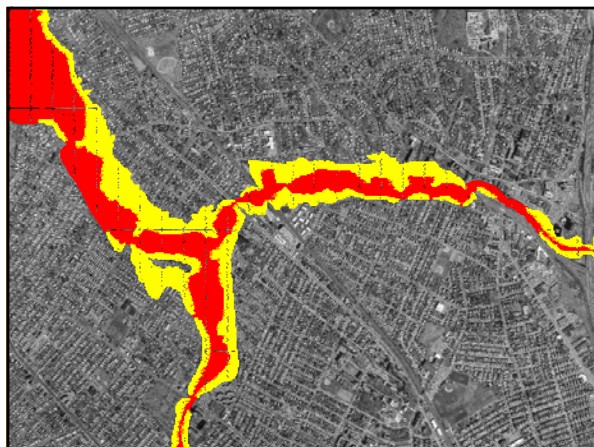


Riverine Flooding Scenarios

Pablo Suarez and Bill Anderson
Boston University

Possible Change in Recurrence Intervals of MA Flood Plains (Khairin and Zwiers, 2000)
(based upon adjusted changes in 24 hr precipitation)

Present Flood Plain Area	Present Climate	2050	2100
100 year	100	46	24
500 year	500	110	38



Estimated Aggregate Riverine Flood Damage, 2000-2100 (\$million, 2000)

(Draft – do not cite)

	Commercial	Industrial	Residential	Total
Ride-it-Out				
No climate change	6,226	22,741	1,789	31,155
Climate change	12,121	41,096	3,964	57,182
<i>increment</i>	5,895	18,355	2,175	26,027
Build Your Way Out				
No climate change	5,834	19,724	1,629	27,187
Climate change	12,573	42,301	4,056	58,930
<i>increment</i>	6,739	22,577	2,427	31,743
Green				
No climate change	2,903	6,832	693	10,428
Climate change	5,322	13,097	1,126	19,546
<i>increment</i>	2,419	6,265	433	9,118

Summary of CLIMB Quantified Impacts

Energy	Summer: More electricity Demand Winter: Less gas demand
Health	Summer: Increased rate of heat-related mortality Winter: Less cold related mortality
Vehicle Transportation (due to flooding)	Increased travel time, Loss of trips, More travel miles
River Flooding	Temporary loss of land and land activity
SLR	Permanent loss of some coastal land, Temporary loss of land and land activities
Water Supply	Less reliable local supply
Water Quality	Less Dissolve Oxygen, More Non-point source pollution, Warmer Water
Tall Buildings	Wind induced sways can cause human discomfort, and costly architectural and fire protection damage

Integrated RIO Impacts

Energy	Health	Transport	R. Flood	Sea level Rise	Water Supply	Water Quality	Environment	Economy and Society
More electricity Demand More gas demand More brown out More local emissions More demand	Decrease in air quality Higher mortality Less heat related mortality	Loss of rail service ? Loss of traffic signals Loss of draw bridges Disruption of air traffic?	NA	NA	Increased cooling water needs Potential water quality issues in Canada if expansion of Canadian hydropower	Increased cooling water will impact water quality Heat and blowdown	More emissions	Disproportional impact on elderly and poor Increased energy expenditures Loss of productivity and quality of life
NA	NA	NA	NA	NA	NA	NA	NA	Stress on health care system Loss of productivity Loss of quality of life
Increased energy demand	Reduced public safety	Increased travel time Loss of trips More miles More hours	NA	NA	NA	NA	More emissions	More impacts on poor Loss of productivity Disruption of production chains

Integrated RIO Impacts

R. Flooding	Energy	Health	Transport	R. Flood	Sea level Rise	Water Supply	Water Quality	Environment	Economy and Society
Possible disruption in local deliveries	Increased pathogen in water supply	Decrease transportation sector	Temporary loss of land and land activity	Will increase flooding impacts	Could flood water treatment plants and wells	Could flood water treatment plants More non-point source pollution	Wetland loss Erosion	Property, productivity and quality of life losses Poor less able to respond (see Transportation) Infrastructure damage	
NA	NA	Decrease transportation sector	Could increase river flood losses	Permanent loss of some coastal land Temporary loss of land and land activities	Salt water intrusion	Times with lower streamflows and water tables	Property, productivity and quality of life losses Poor less able to respond (see Transportation) Infrastructure damage		
Possible loss of local energy supply because of lack of cooling water	Less reliable local supply	NA	NA	NA	Less reliable local supply	Less DO More Non-point source pollution Warmer Water	Environment stress Less biodiversity	Poor less able to respond Productivity, property values, and quality of life losses	
Warmer waters could result in loss of local energy production	Increased illness due to exposure to waterborne diseases	NA	NA	NA	More treatment necessary	NA	NA	Poor less able to respond Productivity, property values, and quality of life losses	

Conclusions

- Climate Change has occurred
- It will continue
- It will impact human and natural systems
- Time to take action to mitigate GHG emissions
- Time to consider taking adaptation actions; in many cases, less expensive to take actions now to protect systems.

Possible Adaptation Policies

- 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.” [ii] 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. [ii]

[ii] See the findings of Hertz and J. Smith, *Working with Global Climate Change: The Role of Adaptation in the United States*, Pew Center on Global Climate Change, Washington, DC, 2004.

[iii] Working Group III of IPCC, *Climate Change 2007: The Scientific Basis, Third Assessment Report, Summary for Policy Makers*, Cambridge University Press, Cambridge, 2001.

Massachusetts

- Commonwealth of Massachusetts released its Climate Protection Plan in spring 2004. While the plan focused upon controlling GHG emissions and opportunities for sequestering 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.” [iii] The new Massachusetts Water Policy released on November 9, 2004, did not mention climate change considerations though it stressed more proactive planning.

[iii] Department Policy 2004

[iv] Office of Environmental Development, Department of Environmental Affairs, 2004, Page 10/10.

Local

- 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. ^[i] 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. ^[ii] www.iclei.org/co2/index.htm
- ^[iii] Pew Center On Global Climate Change, (Innovative Policy Solutions to Global Climate Change, In Brief, Number 8, no date). Report paper?

Integrated Adaptation Impacts

	Energy	Health	Transport	River Flood	Sea Level Rise	Water Supply	Water Quality	Environment	Economy and Society	Mitigation
Energy	Both expand capacity and conserve	In different locations, either reduce or improve air quality	More reliable public transport and traffic signals	NA	NA	NA	In different locations, either more or less cooling water demand	In different locations, either increase or decrease emissions	Rate changes ? Growth and loss of some energy management subsectors	Energy conservation and use of renewables for replacement and new capacity will reduce GHG emissions
Health	Increased energy demand in summer	Install air conditioning Improve and expand health services Implement at early warning systems	NA	NA	NA	NA	NA	More urban heat effects unless energy conservation	AC expansion Better health care system ?	AC expansion may require more energy use (see Energy)

	Energy	Health	Transport	River Flood	Sea level Rise	Water Supply	Water Quality	Environment	Economy and Society	Mitigation
Transport	Reliable heating oil delivery Lowers energy demand	Reduce emissions Fewer road deaths	Expand public transport Increase road network redundancy	Perhaps less runoff	NA	NA	Perhaps less runoff	Reduce emissions and congestion If coastal roads minimized, might allow landward migration of coastal wetlands under SLR	More reliable transport network	Public transportation will reduce GHG, more roads may increase GHG
Riverine Flooding	NA	If less flooding, less spread of water borne and related diseases	If retreat, less benefits transport	Flood proofing Retreat Increase recharge	If increased recharge, less reduced coastal flooding	If increased recharge, less increased water supply	If increased recharge, less improved fish and coastal water quality Retreat will result in improved NPS runoff	Retreat and increased recharge have positive environmental benefits	Less flood damages and overall less homeowner expenses More recharge will lead to more water supply	If greenways part of flood adaptation, then possible benefits such as carbon sequestration, less urban heat island, more shade. If denser development, then more efficient energy and other resource uses

	Energy	Health	Transport	River Flood	Sea level Rise	Water Supply	Water Quality	Environment	Society and Economy	Mitigation
Sea level Rise	NA	NA	If retreat, then yes	Note	Flood proofing Protection in high density, developed areas Retreat	NA	NA	Less coastal use is positive for environment	Less flood damages and overall less homeowner expenses	If wetlands can be re-established, similar to river flooding
Water Supply	NA	NA	NA	NA	NA	Demand Management Joint regional system	If less water demand, improved water quality	If less water demand, improved water quality	More reliable water supply	Less energy use in water supply
Water Quality	NA	Less water pollution related diseases	NA	NA	NA	Reduced need for water treatment	Manage non-point source pollution and other loads, increase discharge	Improved water quality	Rate changes ?	If vegetation part of BMPs, then possible benefits such as carbon sequestration, less urban heat island, more shade. If denser development, then more efficient energy and other resource uses

CLIMB Adaptation 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 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 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. 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
- impact fees
- precautionary principle
- designing for future climate (similar to designing for uncertain socio-economic conditions)
- Allow insurers to set premiums based upon expected future losses
- Encourage projects with co-benefits
- more

END