Preparing for Coastal Climate Change: How Do We Assess Vulnerability and Plan to Adapt

Paul Kirshen, PhD
Research Professor, UNH

National Park Service and Salem Sound Coastwatch Climate Change Lecture Series, Salem MA

December 10, 2013
Topics

- Uncertainty
- Adaptation
- Portsmouth Coastal Resiliency Initiative
All human and natural systems are sensitive to climate: thus as climate changes, their services will change. Therefore we must consider how we will adjust to the changes, the process of adaptation.
NOAA Digital Coast Viewer – High Tide plus 6 feet
Forms of Adaptation

- Reactive
- Proactive
- Spontaneous

Research shows that ‘proactive’ is generally most effective
Ecological adaptation

• “Resistance options” that forestall impacts and protect highly valued resources

• “Resilience options” that improve the capacity of ecosystems to return to desired conditions after disturbance,

• “Response options” that facilitate transition of ecosystems from current to new conditions.

Millar, Constance I., Stephenson, Nathan L., Stephens, Scott L., 2007. Climate change and forests of the future Managing in the face
Built Environment Adaptation

- No Action
- Accommodate
- Protect
- Retreat
- Prepare for Recovery

“A mix of actions taken over space and time by public and private organizations...”
Figure SPM.5. Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. [Figures 10.4 and 10.25]
Figure 13.27: Compilation of paleo sea level data, tide gauge data, altimeter data (from Figure 13.3), and central estimates and likely ranges for projections of global-mean sea level rise for RCP2.6 (blue) and RCP8.5 (red) scenarios (Section 13.5.1), all relative to pre-industrial values.

(US NCA, 2013)
Can we assign probabilities to these climate projections?
Address Uncertainty with Strategies that:

- Consider a range of future conditions
- Are robust, and/or flexible and adjustable
- Include no-regrets and co-benefit solutions
- Are integrated with mitigation, regional and sustainability planning
- Recognizes Adaptive Capacity (economic, social, and natural resources, institutions, technology)
- Evaluated with Multiple Criteria
- Are stakeholder driven
- Combine “here and now” and “prepare and monitor” actions
Mechanical, electrical and emergency services on roof out of harm's way

Key floors above 2085 High Estimate 100 Year Flood

Operable windows keyed open in event of systems failure

Critical patient programs above ground floor

Spaulding Rehabilitation Hospital, Charlestown Navy Yard, Boston

Architect: Perkins + Will

Analytical diagrams P+W / Partners HealthCare
“Prepare and Monitor”

- Process results in a series of adaptation actions planned to be implemented in the future with:
  - the approximate future time periods of their implementation
  - the amount of climate change and other changes within the approximate periods when actions should be taken – *trigger points*
- Establishment of climate, biophysical and socio-economic monitoring system to determine when trigger points have been reached
- Options are preserved for implementation of future actions
Example of “Prepare and Monitor”

_Thames Estuary, United Kingdom_

Thames Estuary 2100
Chapter 5: The Thames Estuary 2100 Plan

Three time horizons – three themes for flood risk management

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Theme</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first 25 years</td>
<td>“Maintaining confidence and planning together”</td>
<td>Continuing maintenance, operation and essential improvements.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safeguarding the spaces for future flood management.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TE2100 will have a real influence in the preparation of, and updating of regional and local strategic and spatial plans.</td>
</tr>
<tr>
<td>The middle 35 years</td>
<td>“Renewal and reshaping the riverside”</td>
<td>Many of the existing walls, embankments and smaller barriers will need raising and major refurbishment or replacement in this period.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>These major projects provide an opportunity to reshape our riverside environment through working with spatial planners, designers, environmental groups and those who live and work in the Estuary area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Towards the end of this period, a decision will be made on the century option to be adopted.</td>
</tr>
<tr>
<td>To the end of the century</td>
<td>“Preparing for, and moving into the 22nd century”</td>
<td>From 2070 (based on government’s current climate change guidance) a major change will be needed and one of our “end of the century” options will be implemented.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This is a long time in the future but your views are important as they will set the basis from which future changes in attitudes are measured.</td>
</tr>
</tbody>
</table>
Trigger Points

- Mean Sea Level
- Peak Surge Level
- Peak River Flood
- Erosion
- Habitat
- Land Use
- Public/Institutional Attitudes to Flood Risk
Flexibility

• Timing of Actions
• Changing Actions
• Adjustable Infrastructure
• Safeguarding Land for Future Options
• Coordination with Other Infrastructure Projects
Corollaries

• Design with Nature

• Safe to Fail, not Fail Safe
Infrastructure design has often had demand flexibility, now must have climate flexibility built in!
Figure 3. Conceptual modular concrete seawall at Umana School/Harborside Community Center.
Floodwall with Gates, Houston
Articulating Floodwall
Enhanced Natural Dunes and Vegetation

**Figure 6-5.** Electrical utilities elevated for protection against flooding

**Figure 7-2.** Photograph of membrane providing flood protection
Figure 7.4. Low wall construction

Figure 7.5. Small patio gate

**Figure 2-1**
This house near Atlanta was flooded several times. During the largest flood, the water reached as high as 2 feet above the first floor.

**Figure 2-2**
The house was elevated in a way that added to both its appearance and its value.
Phase 1
Local Solution - Aquarium MTBA Station,
February, 11, 2103
City of Boston
Evacuation Routes
& Emergency Neighborhood Centers
12/2005
The Netherlands

“Living with Water”

However, public debate after the 1993 and 1995 floods focused on the potentially negative consequences to the landscape of further raising the dykes. A new ‘living with water’ strategy was developed, which argues that extreme-climate events should be accommodated rather than fought with heavy infrastructure. The idea is that instead of always reinforcing and heightening the dykes along rivers, occasional flooding will be accommodated and carefully managed in specific designated areas. This new approach, designed to deal with the medium...
Another idea being developed is that of a "water plaza", which can be used as a playground during normal weather conditions...  

... while in times of heavy rainfall the sunken square can be filled with water to take the pressure off the sewerage system.

http://news.bbc.co.uk/2/hi/in_pictures/8362183.stm
This multi-storey car park being built near the city’s academic hospital will cater for 1,200 cars and 10,000 cubic metres of water which will be stored in a reservoir at the base of the structure.

City authorities are subsidising the development of green roofs, which are already in place on buildings like the municipal library, above.
Add Bridge Piers as Scour Increases

APPLICABLE BRIDGE TYPES

Concrete Beams on Hammerhead Piers

Addressing Water Quality Impacts

Microbial Risks
- Improved Filtration Systems
  - MF and UF Membranes
- Advanced Disinfection
  - Ozone
  - Ultraviolet
  - Advanced Oxidation

Chemical Risks
- Improved Pretreatment
- GAC and Ion Exchange Sorption
- NF and RO Membranes
- Advanced Oxidation
Multiple Options for Municipal and Commercial Freshwater Adaptation

Fig. 1. Schematic of the integrated watershed management optimization model. Note: BMPs = best management practices; SW = surface water; GW = groundwater; WTP = water treatment plant; P use = potable water use; NP use = nonpotable water use; ASR = aquifer storage and recharge; and WWTP = wastewater treatment plant.
Example of Staged Strategy

Present to 2050 – Local Solutions

2050 to 2100 – Regional Solutions

Retreat

Figure 15. Example of parapet wall
What is Climate Adaptation about?

"Climate change adaptation can be broadly defined as the process of

1) *evaluating* the changes in climate that are occurring and that are expected to occur,
2) linking those climatic changes to impacts on the *things we value* *(Vulnerability!)*,
3) identifying ways to *address those impacts*,
4) and ultimately updating and implementing strategies to *reduce future risks*."
SLR Scenario Planning for Portsmouth NH
Buildings
11.5 ft
Buildings
13.5 Ft
Infrastructure
13.5 Ft
Stormwater
Wetlands
13.5 Ft
Figure 4: Four Subareas Comprising the Area of Coastal Flood Impact

North Subarea
Areas north of Islington Street and State Street

Central Subarea
Bounded on the north by Islington and State Streets and south to South Street and encompassing South Mill Pond and Peirce Island

South Subarea
Areas north and south of New Castle Avenue; and Little Harbor west to South Street

Sagamore Subarea
Areas within the Sagamore Creek drainage area inland westward to Peverly Hill Road and south to Elwyn Road and east of the Town of Rye border
Displaying Impacts

elevation increases the number of buildings impacted increases.

Table 4: Summary of flood impacts based on assessed value per building.

<table>
<thead>
<tr>
<th>Subarea</th>
<th>7.5 feet</th>
<th>11.5 feet</th>
<th>13.5 feet</th>
<th>18.0 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>$22,667,533</td>
<td>$162,790,228</td>
<td>$180,273,596</td>
<td>$307,903,360</td>
</tr>
<tr>
<td>Central</td>
<td>$3,175,938</td>
<td>$61,599,338</td>
<td>$84,880,151</td>
<td>$178,798,579</td>
</tr>
<tr>
<td>South</td>
<td>$5,907,856</td>
<td>$26,393,580</td>
<td>$36,711,040</td>
<td>$58,196,538</td>
</tr>
<tr>
<td>Sagamore</td>
<td>$484,939</td>
<td>$5,134,649</td>
<td>$7,615,214</td>
<td>$54,830,986</td>
</tr>
<tr>
<td>Total</td>
<td>$32,236,266</td>
<td>$255,917,795</td>
<td>$309,480,001</td>
<td>$599,729,464</td>
</tr>
</tbody>
</table>
Table 5: Critical facilities impacted under the four flood scenarios.

<table>
<thead>
<tr>
<th>Impact by Flood Scenario</th>
<th>Map ID#</th>
<th>Critical Facility</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 feet</td>
<td>n/1</td>
<td>WH EB Radio</td>
<td>815 Lafayette Road</td>
</tr>
<tr>
<td>11.5 feet</td>
<td>n/1</td>
<td>Clough Drive Pump Station</td>
<td>210 Clough Road</td>
</tr>
<tr>
<td>15.5 feet</td>
<td>X</td>
<td>Deer Street Pump Station</td>
<td>2 Deer Street</td>
</tr>
<tr>
<td>18.0 feet</td>
<td>n/1</td>
<td>Margeson Apartments</td>
<td>245 Middle Street</td>
</tr>
<tr>
<td></td>
<td>n/1</td>
<td>Jackson Hill Sub-Staion</td>
<td>Jackson Hill Street</td>
</tr>
<tr>
<td></td>
<td>n/1</td>
<td>Lafayette Road Pump Station</td>
<td>630 Lafayette Road</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Leslie Drive Pump Station</td>
<td>590 Market Street</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Marcy Street Pump Station</td>
<td>535 Marcy Street</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Strawberry Banke Museum</td>
<td>14 Hancock Street</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Mechanic Street Pump Station</td>
<td>133 Mechanic Street</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Mill Pond Way Pump Station</td>
<td>131 Mill Pond Way</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>New Hampshire Port Authority</td>
<td>535 Market Street</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>PGSH Schiller Station Power Plant</td>
<td>Gosling Road</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Northwest Street Pump Station</td>
<td>221 Northwest Street</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Portsmouth Middle School</td>
<td>155 Parrott Avenue</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Portsmouth Library</td>
<td>175 Parrott Avenue</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Exit Yard</td>
<td>Brewer Street</td>
</tr>
</tbody>
</table>

n/1 = No impact identified. X = Land and/or structures impacted

Revised April 2, 2013

Table 6: Bridges impacted under the four flood scenarios.

<table>
<thead>
<tr>
<th>Impact by Flood Scenario</th>
<th>Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 feet</td>
<td>L95 at Piscataqua River</td>
</tr>
<tr>
<td></td>
<td>Market Street Extension at North Mill Pond</td>
</tr>
<tr>
<td></td>
<td>Sarah Mildred Long Bridge at Piscataqua River</td>
</tr>
<tr>
<td></td>
<td>Memorial Bridge at Piscataqua River (approaches of former structure only)</td>
</tr>
<tr>
<td></td>
<td>Maplewood Avenue bridge at North Mill Pond</td>
</tr>
<tr>
<td></td>
<td>Peave Island Bridge</td>
</tr>
<tr>
<td></td>
<td>Mary Street Bridge at South Mill Pond</td>
</tr>
<tr>
<td></td>
<td>Junkins Avenue bridge (culverts) over South Mill Pond</td>
</tr>
<tr>
<td></td>
<td>New Castle Avenue Bridge to Shapleigh Island</td>
</tr>
<tr>
<td></td>
<td>Bella Isle Road Bridge at Little Harbor (approaches only)</td>
</tr>
<tr>
<td></td>
<td>Route 1A at Sagamore Creek (approaches only)</td>
</tr>
<tr>
<td></td>
<td>Route 1 Lafayette Road at Sagamore Creek</td>
</tr>
</tbody>
</table>

n/1 = No impact identified. X = Land and/or structures impacted

Table 7: Culverts and combined sewer overflows (CSOs) impacted under the four flood scenarios.

<table>
<thead>
<tr>
<th>Impact by Flood Scenario</th>
<th>Drainage Infrastructure</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>X X X X</td>
<td>CSO (1)</td>
<td>Upper North Mill Pond</td>
</tr>
<tr>
<td>X X X X</td>
<td>CSO (2)</td>
<td>South Mill Pond</td>
</tr>
</tbody>
</table>
Figure 2. High marsh dieback observed in Portsmouth marshes. (A) Marsh hay develops hummocks and dies off, to be replaced by green algae and glasswort (B) on Pleasant Point in 2011. (C) Hummocks developing in marsh hay in marsh on Peirce Island, May 2012 (photos: D. Burdick).
Portsmouth Flooding Adaptation
## Sample of Portsmouth NH Plan

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Time Period</th>
<th>Adaptation Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.5 feet</td>
<td>2012</td>
<td>- Need a tide gate/tide barrier at US 1 Bypass plan for 18 feet elevation eventually</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ensure stormwater drains have flap gates plan for 18 feet elevation eventually</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Small watersheds, may need to investigate the need for pumping water to estuary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Consider filling ground or elevating buildings at lower ground, or their abandonment</td>
</tr>
<tr>
<td>13.5 feet</td>
<td>2050-2100</td>
<td>- Expand a tide gate/tide barrier at US 1 Bypass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ensure stormwater drains have flap gates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Small watersheds, but may need to investigate the need for pumping water to estuary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Abandon structures at lower elevations</td>
</tr>
<tr>
<td>18.0 feet</td>
<td>2100 and Beyond</td>
<td>- Expand a tide gate/tide barrier at US 1 Bypass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ensure stormwater drains have flap gates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Small watersheds, may need to investigate the need for pumping water to estuary</td>
</tr>
</tbody>
</table>
Wetlands

Recommendations

1. If saltmarsh preservation is a priority, the City should chart a path for providing upland migration of tidal marsh. The City or Conservation Commission should examine public and private lands and work with landowners and managers to establish migration areas for tidal marsh. Losses in ecosystem services from submerged tidal wetlands can be mitigated by allowing the high marsh to migrate into adjacent uplands and non-tidal wetlands.

2. The City should continue to recognize 100 feet as the minimum buffer width along all tidal wetlands and enforce a strict no-build policy in this buffer. In addition, 100 foot buffers should remain in place for all non-tidal wetlands that are subject to flooding by present day storm surges as shown on Map WE-1.2.

3. Municipal and private construction should include provisions for allowing tidal flow should also be designed to carry as much suspended sediment as possible to promote the accretion of tidal marshes. Barriers will need to be removed and provision for tidal waters and suspended sediments to nourish the marshes will be needed, specifically for large culverts and bridges where transportation paths cross wetlands.

Revised April 2, 2013

CRI Appendices

4. City and State highway departments need to be contacted about the flooding risk from storms and provided with specific information about intentions to protect existing wetlands and the expected expansion of wetlands, especially at low-lying elevations.

5. Over the long term, a bridge is needed for Greenleaf Avenue and a tidal culvert designed for two-way flow is needed for Peverly Hill Road.

6. Pathways for marsh migration onto low-lying uplands and freshwater waters should be planned for Currier Cove Road, Belle Isle Road, the South Cemetery, Clough Drive, and Brackett Road.

7. Decisions will need to be made regarding the drainage that passes through the athletic fields at the High School and empties into Sagamore Creek.

8. Peirce Island will need to be fortified if the State Fishing Pier and swimming pool are to be maintained. A compromise might allow tidal marshes to migrate and occupy the remainder of the low-lying portions of the Island.

9. Discussion with managers of the Urban Forestry Center, South Cemetery, and Creek Farm as well as other protected lands managed by the City (e.g. Peirce Island) should seek to promote marsh migration over uplands.

10. To extend the lifetime of existing saltmarshes, sediment amendments (called nourishment) could be made to the surface of the marsh to maintain elevations as sea level rises.
PART 6. POLICY, PLANNING AND REGULATORY RECOMMENDATIONS .......... 39

A. Zoning Ordinances and Land Development Regulations ........................................... 39
   1. Zoning Districts and Overlays ............................................................................. 39
   2. Floodplain Standards ......................................................................................... 40
   3. Setbacks and Buffers ......................................................................................... 41
   4. Redevelopment Standards .................................................................................. 42
   5. Resilient Design and Construction of Buildings and Infrastructure ..................... 42
   6. Shoreland Protection Options ............................................................................ 43

Revised April 2, 2013

Portsmouth Coastal Resilience Initiative Report

B. Master Plan ........................................................................................................... 43
C. Coastal Wetlands ................................................................................................... 46
D. Public Health .......................................................................................................... 47
E. Emergency Management and Hazard Mitigation Planning ........................................ 47
Possible Enhancements
## 1) Benefit:Cost Analysis

Accommodation Results, Protect for High Sea Level Rise - **Hampton (1)**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Action</th>
<th>2050 Expected Value, Cumulative, Discounted Damage Costs ($M)</th>
<th>Adaptation Costs Discounted ($M)</th>
<th>Net Benefits (Benefit is damage avoided) ($M)</th>
<th>Benefit: Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>High SLR</td>
<td>No Adaptation</td>
<td>$318.8</td>
<td>0</td>
<td>-$318.8</td>
<td></td>
</tr>
<tr>
<td>Low SLR</td>
<td>No Adaptation</td>
<td>$287.7</td>
<td>0</td>
<td>-$287.7</td>
<td></td>
</tr>
<tr>
<td>High SLR</td>
<td>Protect to High SLR 2100 100 Y Flood and Beyond by Regulation</td>
<td>$0</td>
<td>$40.5</td>
<td>$278.3</td>
<td>8:1</td>
</tr>
<tr>
<td>Low SLR</td>
<td>Protect to High SLR 2100 100 Y Flood and Beyond by Regulation</td>
<td>$0</td>
<td>$40.5</td>
<td>247.2</td>
<td>7:1</td>
</tr>
</tbody>
</table>
2. Vulnerability: Social & Human Capital

Median household income (US$)
- 12891 - 20000
- 20001 - 30000
- 30001 - 40000
- 40001 - 50000
- 50001 - 80000

Census 2010 Blocks
Community Mapping
Impt Community Function
3. Participatory Planning

How will we work with Exeter?

- *Listen*
  - Broad Community Outreach
  - Neighborhood and place-based conversations
- *Model and Collaborate*
  - Everyday residents of Exeter in an ongoing advisory role to scientists
- *Recommend and Discuss*
  - Draft climate adaptation plan
Risk-Based Trend Detection with Rich Vogel, Tufts University

Cost of Regret of Over-Investing = Total Cost of Adaptation + Expected Damages without increase with adaptation - Expected Damages without increase without adaptation

Cost of Regret of Under-Preparing = Expected Damages with increase without adaptation - Expected Damages with increase with adaptation - Total cost of adaptation
Conclusions

-Mitigation must continue
- Adaptation is Possible
-Time is running out for planning
Thank you