MassDOT-FHWA Pilot Project: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options of the Central Artery
• Sea Level Rise (SLR)
  – Thermal expansion of ocean water
  – Increased input of water from land-based sources

• Northeast and Mid-Atlantic SLR is higher than global average
  – 1.75 mm/yr (Maine) to 6.05 mm/yr (Virginia)
  – Changes in ocean circulation (Yin et al., 2009, 2010)

• People live on the coast
  – 80% within 60 miles
  – ¾ of the cities
Importance of Storms

Water Surface Elevation (m-NAVD88)

Wind Velocity
30.00 m/s
0.00 m/s

Annual
High
1% Risk
NAVD88 (ft)

<table>
<thead>
<tr>
<th>MHHW</th>
<th>1% Risk</th>
<th>NAVD88 (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>2050</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>2100</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>2010</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>2050</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>2100</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>2010</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>2050</td>
<td>11.0</td>
<td>11.0</td>
</tr>
<tr>
<td>2100</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>2010</td>
<td>13.0</td>
<td>13.0</td>
</tr>
<tr>
<td>2050</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>2100</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>2010</td>
<td>16.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

MassDOT
Massachusetts Department of Transportation
Highway Division
Hurricane Sandy in Boston

If peaks were simultaneous...

9.4 feet
Sandy 7.4 feet
3.3 yr event

1988 New England Flood Tide Profiles (Boston Harbor)

$50 billion damages in NYC
Hydrodynamic Modeling

- Includes relevant physical processes (tides, storm surge, wind, waves, wave setup, river discharge, sea level rise, future climate scenarios)
- Covers a larger physical area to correctly represent the storm dynamics
Hydrodynamic Modules

- Advanced Circulation Model for Oceanic, Coastal, and Estuarine Waters (ADCIRC)

- Simulating WAVes Nearshore (SWAN)

Tightly Coupled

- Currents
- Storm Surge
- Tides
- Water Levels
- Winds
- SLR
- Discharge

- Waves
- Wave Setup
Why do we need a sophisticated approach?

- The risk is high
- There are a lot of factors that are important
  - Bathymetric effects
  - Storm types and parameters
  - Coastline geometry
  - Infrastructure
  - Frictional effects
  - Coastal processes (waves, tides, etc.)
- Flooding pathways can be significantly influenced by dynamic processes
- Achieve more detailed results to answer what is causing the flooding (e.g., increased river discharge, wave overtopping, storm surge, etc.)
- Test performance of engineering adaptations
<table>
<thead>
<tr>
<th>Data Need</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiDAR and topography</td>
<td>MassGIS, MassDOT, USGS, NOAA CSC, Site-specific surveys</td>
</tr>
<tr>
<td>Bathymetry</td>
<td>NOAA/NGDC, USGS, Site-specific surveys</td>
</tr>
<tr>
<td>Land cover</td>
<td>MassGIS, USGS</td>
</tr>
<tr>
<td>River flow and stage</td>
<td>BWSC, USGS, City of Cambridge</td>
</tr>
<tr>
<td>Historical high water marks</td>
<td>USGS, Gadoury (1979), NOAA Tides and Currents</td>
</tr>
<tr>
<td>Flow control structure info.</td>
<td>Massachusetts DCR, USACE, MCZM</td>
</tr>
<tr>
<td>Storm climatology</td>
<td>Emanuel et al. (2006), Cheung et al. (2007), Vickery et al. (2007)</td>
</tr>
</tbody>
</table>
Inundation maps based on standard “bathtub” model do not reflect dynamic nature of coastal flooding (e.g., bathymetry, coastal geometry, infrastructure, frictional effects, and processes)

FEMA is only backward looking

Simulation Scenarios

- Combined Surge and Sea Level Rise
- Present and future climate change scenarios
  - Simulate flooding associated with projections for 2030, 2070, 2100
- Robust tropical and extra-tropical storm sets
- Monte Carlo simulations, using a large statistically robust set of storms (Emanuel, et al., 2006)
Grid Development

Grid covers a large regional area (North Atlantic) to capture large-scale storm (hurricane, nor’easter) dynamics.
Grid Development

Unstructured grid = varying resolution with high resolution in areas of interest (Central Artery)
Challenges

- Urban model grid development
- Extra-tropical (Nor’easters) and tropical (hurricanes) storms
- Nor’easters have not been modeled in this manner previously
- Tidal influence
- Temporal alignment of peak discharge and peak storm surge
- Simulation time for Monte Carlo approach
- Tremendous stakeholder interest – required FAQ sheet generation
Storm Climatology

- Includes both tropical and extratropical storm sets

Tropical Storms

- Data set provided by WindRiskTech (Emanuel, et al., 2006)
- Optimized selection by integrated kinetic energy approach
- Select storms used to develop a surface response function
- Increased storm intensities for 21st century based on climate models

Extra-Tropical Storms

- Data set developed by examining Boston tidal residual water levels
- Re-analysis data used to feed a balanced wind model
- Probability determined based on Rudeva (2008)
• **Integration of Urban Dams**
  – Charles River Dam (Charles River)
  – Amelia Earhart Dam (Mystic River)

• **Implementation of new boundary condition in the ADCIRC model**
  – Includes pumping systems to maintain specific range of water levels in upstream basins

• **Allows evaluation of combined processes**
  – Discharge, SLR, and Storm Surge
  – Assess infrastructure adequacy under the combined influence under climate change conditions
  – Pumps can handle projected freshwater discharge, but combined discharge and overtopping needs to be considered
Hydrodynamic Model Results

- Detailed inundation maps
  - Risk Contours
  - Percent occurrence depth contours
  - Flooding pathways and sources
  - Specific storm events
- Cumulative distribution functions of water level (at 10s of thousands of locations)
- Visualizations of flooding
- Current and future vulnerabilities
- Input to develop preparedness plans over time and scale
- Ability to test potential performance of engineering adaptations and economic impacts
Hydrodynamic Model Results
Hydrodynamic Model Results