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U.S. Department of Transportation
Federal Highway Administration

FHWA Climate Resilience Pilot Program:

Massachusetts Department of Transportation

The Federal Highway Administration's (FHWA)'s Climate Resilience Pilot Program seeks to assist state Departments of Transportation (DOTs), Metropolitan Planning Organizations (MPOs), and Federal Land Management Agencies (FLMAs) in enhancing resilience of transportation systems to extreme weather events and climate change. In 2013-2015, nineteen pilot teams from across the country partnered with FHWA to assess transportation vulnerability to extreme weather events and climate change and evaluate options for improving resilience. For more information about the pilot programs, visit: **http://www.fhwa.dot.gov/environment/climate_change/adaptation/**.

massDOT
Massachusetts Department of Transportation

Although the strongest impacts of Superstorm Sandy were experienced further south, that event was a wake-up call for Massachusetts about the risk of climate change impacts. The Massachusetts Department of Transportation (MassDOT) sought to better understand the vulnerability of the I-93 Central Artery/Tunnel (CA/T) in Boston to sea level rise and extreme storm events. MassDOT combined a state-of-the-art hydrodynamic flood model with agency-driven knowledge and priorities to assess vulnerabilities and develop adaptation strategies for this valuable component of transportation infrastructure.

Scope

MassDOT worked closely with project stakeholders and a technical advisory team to assess the impacts of climate change on the I-93 CA/T system. I-93 is a major North-South transportation corridor that traverses Boston through a network of more than 160 lane-miles, more than half of them in tunnels, six interchanges, and 200 bridges.

Objectives

- Develop an inventory of all assets in the CA/T network.
- Assess vulnerability of the CA/T to sea level rise and extreme storm events.
- Investigate adaptation options to reduce identified vulnerabilities.

Approach

Define geographical scope and develop GIS dataset of assets. The project team acquired and reviewed existing asset management data (housed in the Maximo® Asset Management software), conducted field visits, and held meetings with knowledgeable MassDOT staff to collect institutional knowledge on the location and existing condition of CA/T assets. Based on this information, the project team defined the geographic scope of the study as the entire CA/T system to capture the numerous interdependent systems, and because the "potentially critical areas of the CA/T" are all encompassing.

Tip O'Neill Tunnel northernmost portal. Photo credit: MassDOT

Tip O'Neill Tunnel exit ramp. Photo credit: MassDOT

Vent building number 1 with many flood entry points. Photo credit: MassDOT

Survey critical areas and develop asset definition. The project team conducted field visits and elevation surveys to ground truth existing elevation information (e.g., LIDAR). The team conducted these surveys in geographically complex areas flagged as critical flood pathway locations. Additionally, the team grouped assets into a relational database/hierarchy. The hierarchy encompasses individual assets (e.g., pumps, electrical controls) as well as the structures and facilities that are used to house them.

Conduct hydrodynamic analysis. The project team utilized a hydrodynamic modeling process based on mathematical representations of the processes that affect coastal water levels such as riverine flows, tides, waves, winds, storm surge, sea level rise, and wave set-up, at a fine enough resolution to identify site-specific locations that may require adaptation alternatives.

Of 10 available models, the project team selected the Advanced Circulation (ADCIRC) model because of its ability to accommodate complex geometries and bathymetries and heterogeneous parameter values. The team coupled ADCIRC with the Simulating Waves Nearshore (SWAN) Model to simulate storm-induced waves in concert with the hydrodynamics. The coupled model is called the Boston Harbor Flood Risk Model (BH-FRM). Through model calibration and validation, the project team demonstrated that BH-FRM is very good at simulating important coastal storm processes and impacts.

The project team selected four time periods for study (2013, 2030, 2070, and 2100 with 2070 and 2100 being represented by the same model run), and developed scenarios simulating sea level rise along with the impact of hurricanes and Nor'easters. For hurricanes, the impact of the event varies significantly depending on where in the tidal cycle it hits.

The project team used a Monte Carlo statistical approach to develop:

- Depth of flooding information at tens of thousands of locations
- Detailed time-varying inundation maps
- Flood pathways and sources
- Probability of flooding in future years

Assess vulnerability. The project team modified the vulnerability assessment (originally designed to encompass exposure, sensitivity, and adaptive capacity) to consider exposure only. The team defined an asset as exposed if the depth of flooding in the model runs exceeded the storm-designed standards that governed the original design of the CA/T. For the CA/T system to perform, it is critical that all components of the system operate properly; therefore, the project team rated the sensitivity of all CA/T components as very high and the adaptive capacity of all components as very low since there is little redundancy in the system.

Develop adaptation strategies. The project team evaluated local adaptation options for assets and land owned and managed by MassDOT, as well as some regional adaptation solutions. Whereas local adaptation options focus on protecting individual structures, regional adaptation focuses on flood pathways, where a larger upland area is flooded by water arriving from a vulnerable section of the coastline. Regional solutions can be more cost effective than local adaptation solutions but often require coordination between and investment by multiple stakeholders.

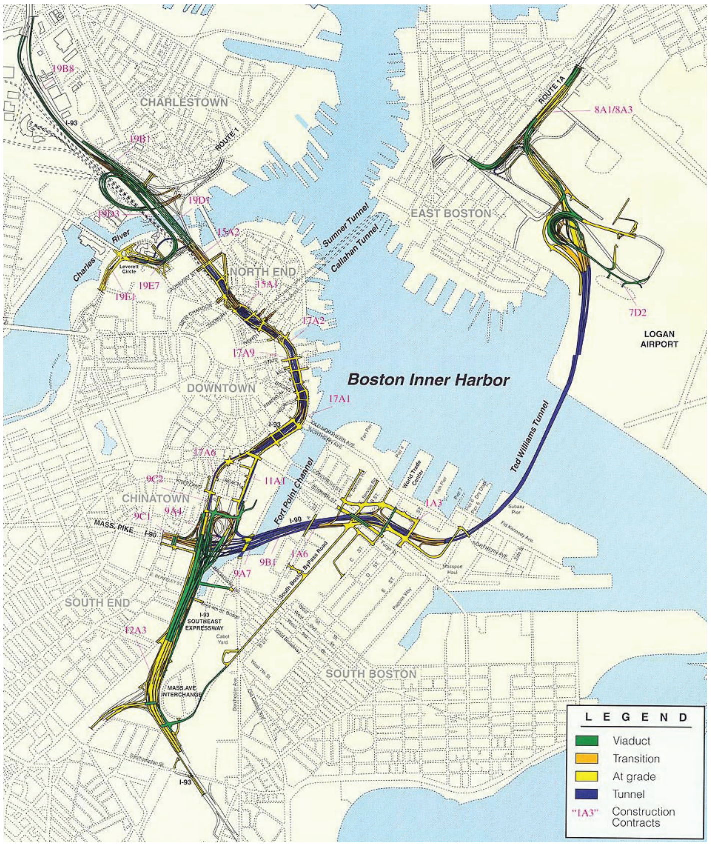

Figure 1. Schematic of the CA/T system. Source: MassDOT

Key Results & Findings

Modeling outputs. Over time, both the extent and probability of flooding is projected to increase across metro Boston and the surrounding communities. The project team used the BH-FRM-generated maps to identify potentially flooded locations and to assess flood entry points and pathways (and thereby identify potential locations for regional adaptation strategies). In many cases, large upland areas are flooded by a relatively small and distinct entry point (e.g., a low elevation area along the coastline).

Vulnerability assessment and adaptation strategies. The extent of flooding under current climatic conditions is fairly limited with low exceedance probabilities. This allows MassDOT to focus its near-term efforts on reducing the vulnerability of individual structures and on local adaptation strategies. However, the number of vulnerable structures requiring major adaptation (including tunnel portals) more than triples by 2070.

Because all elements of the CA/T system are critical for operations, the project team determined that rather than prioritizing structures for adaptation based on differing sensitivities, all structures have an equal priority for adaptation.

Cost of adaptation. The team estimated that total materials and installation costs for protecting non-tunnel structures through 2100 would be nearly $47 million, and the materials and installation costs for watertight gates at tunnel portals would be approximately $27 million under current (2013) flood conditions, with an additional $19 million needed for protection through 2030. The team estimated that additional costs to protect the tunnels through the late 21st century would be nearly $150 million.

Sample Adaptation Strategies

- All structures should be inspected for possible flood pathways at grade.
- All outfalls discharging in the Boston Harbors should be equipped with tide gates.
- All doorways exposed to possible flooding should be water tight.
- Where projected flood depths are less than 2 feet, relatively inexpensive temporary flood barriers could be used (e.g., sandbags, inflatable dams). Through 2030, none of the flood depths around the structures exceeded 2 feet, suggesting that no major adaptation actions are immediately needed.
- Where projected flood depths exceeded 2 feet, a wall should be constructed around the flooded perimeter area. Walls constructed as a local adaptation strategy should be designed to be adjustable above the initial height for protection beyond 2030.

"Although the focus is on the CA/T system, its vulnerabilities are tied to other systems (e.g., the Massachusetts Bay Transportation Authority subway lines, dam operations) and their respective resiliency in ways never anticipated."

– MassDOT Pilot Team

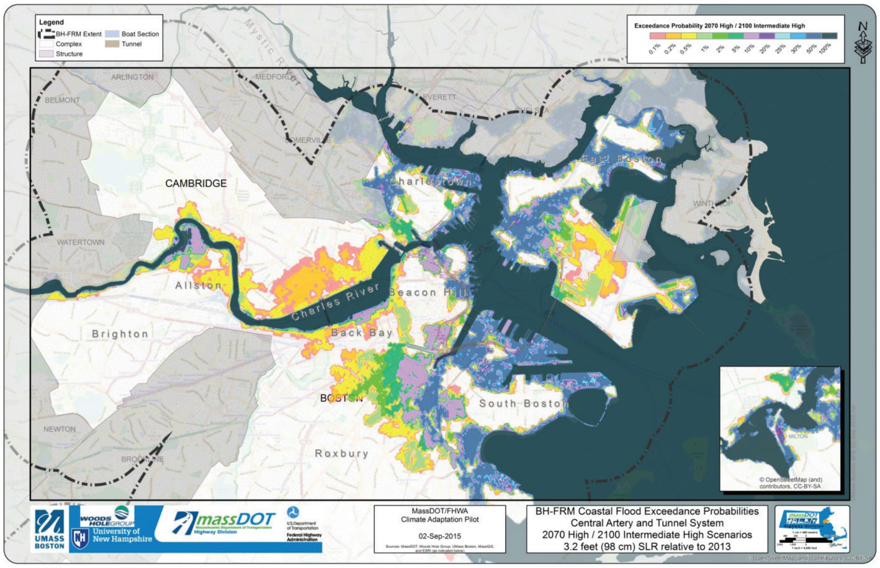

Figure 2. BH-FRM results showing probability of flooding in 2070/2100. The darkest blue represents a 100% probability while the red represents a 0.1% probability. Source: MassDOT

Lessons Learned

Select the appropriate model for the location. In heavily populated areas with critical transportation infrastructure such as the CA/T, high-resolution hydrodynamic modeling is warranted due to the importance of transportation and human impacts, as well as the spatial complexity of terrain and bathymetry.

GIS is a powerful tool. The use of GIS was essential to the success of this project; however, there were many challenges, including incompatible datasets; conversion of data from CAD to GIS; the complexity and interconnectedness of the CA/T system; and a lack of staff with sufficient GIS expertise.

Consider a range of storm scenarios. In addition to storm intensity and direction, the timing of a storm relative to the tidal cycle is an important consideration. The project team found that the timing of the peak hurricane surge is very important since it is a shorter duration event while the timing of the peak Nor'easter surge has little effect on maximum water levels because the surge is spread over a much longer time period.

Do not rely solely on digital databases. Interaction with a range of MassDOT staff not only resulted in vastly improved data discovery but also increased their interest and support of the project. Also, information collected during site visits was essential for assessing vulnerability and developing adaptation options, because local conditions cannot always be captured in automated digital data (e.g., LIDAR).

Integrate findings with existing process/systems. The use of unique asset identifiers consistent with MassDOT databases will support the interaction of the CA/T geodatabase with the MassDOT asset management database, making the information readily accessible during future investment decision making.

Next Steps

Share the results. MassDOT will meet with District 6 staff to review the findings in detail and to begin discussing when and where local adaptation strategies need to be implemented. Additionally, MassDOT will meet with the City of Boston to evaluate the plausibility of the identified regional flood entry points.

Determine engineering feasibility. Before advancing with implementation of adaptation strategies, MassDOT will need to conduct an engineering feasibility study to determine if the proposed adaptation strategies for the portal entrances (gates) are structurally feasible.

Update the emergency response plan. The results of this vulnerability assessment will support an evaluation and update of the emergency response procedures for the CA/T to ensure the safety of the traveling public.

Regularly update modeling and assessment. To accommodate both changes in the coastline and improvements in the understanding of climate change and its impacts, the project team recommends updating and re-running the hydrodynamic model and revisiting the vulnerability assessment and adaptation strategies every seven to ten years.

For More Information

Final report available at:
www.fhwa.dot.gov/environment/climate/adaptation/2015pilots/

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