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transform your environment

Resilient Design of Water & Wastewater Infrastructure

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NEWEA Annual Conference

January 29, 2020

Boston, Massachusetts

SHMCAP Key Risk Assessment Findings and Actions

14 hazards

- Inland flooding
- Drought
- Landslide
- Coastal flooding
- Coastal erosion
- Tsunami
- Extreme temperatures
- Wildfire
- Invasive species
- Hurricanes/Tropical storms
- Severe winter storms / Nor'easters
- Tornadoes
- Other severe weather
- Earthquakes

Inland flooding: Over $9.1M in damages/year, 2007-2014

Coastal flooding: On average, 6 events/ year, 2009-2018

Tornadoes: 200+ critical facilities in tornado hazard zones

108 actions,

including:

- Develop climate change design standards
- Maintain and enhance climate change projections
- Incorporate climate effects into capital planning functions
- Create MA Coastal Flood Risk Model

MA Climate Projections

By end of century:

Changes in precipitation

- 18% increase in consecutive dry days
- 57% increase in days with > 1 in. rainfall
- 7.3 inches additional annual rainfall

Rising temperatures

- 10.8°F increase in average annual temperature
- 42% decrease in days/year with min. temperatures < 32* F
- 1,280% increase in 90-degree days/year

Sea level rise

- 4-10.5 feet along the MA coast

Extreme weather

- Increase in frequency and magnitude

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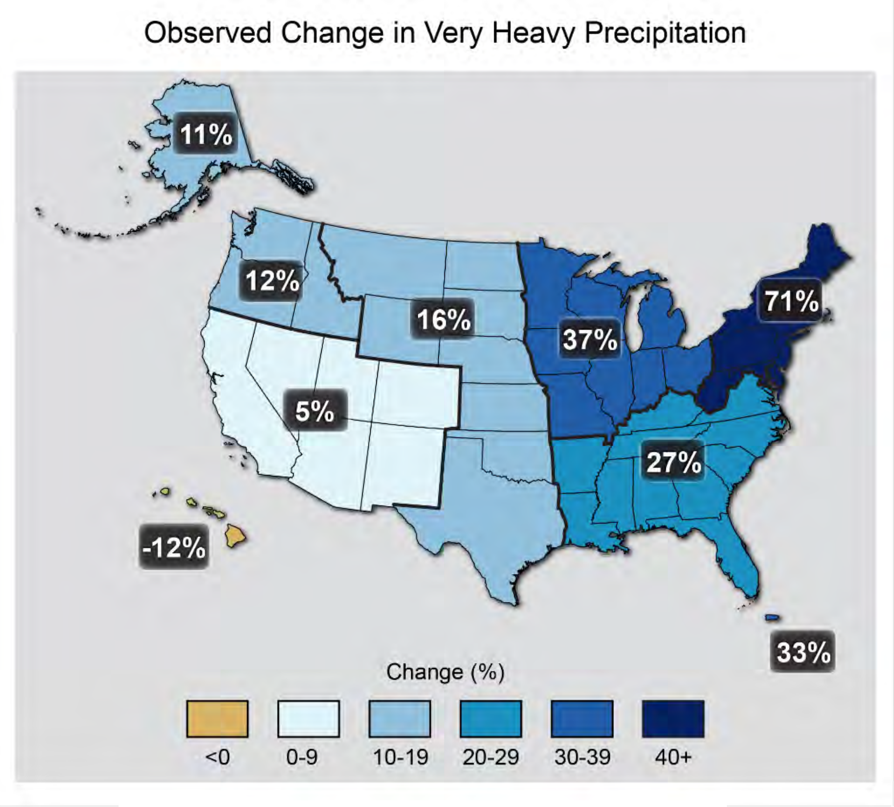
Climate Change - Increase in extreme precipitation events

FM Global – Coping With Extremes, 2016

"Increasing frequency of extreme precipitation events is a major risk facing US businesses"



Source:

Climate Change Impacts in the US: The Third National Climate Assessment, 2014

EXTREME PRECIPITATION

8%

Increase in extreme precipitation events by midcentury

13%

Increase in extreme precipitation events by 2100

FLOODING

ZONE	ANNUAL CHANCE	FLOODPLAIN
A, AE, A1-A30	1% ANNUAL CHANCE	100-YEAR FLOODPLAIN
X	0.2% ANNUAL CHANCE	500-YEAR FLOODPLAIN

"By 2050, Boston could experience the current 100-year riverine flood every two to three years on average"

WINTER STORMS

The blizzard of 2013 left nearly **400,000 Massachusetts residents without power**

"Heavy blizzards are among the **most costly and disruptive** weather events for Massachusetts communities."

HURRICANES AND EARTHQUAKES

HURRICANE

Sandy

and nor'easters

cause downed trees and power lines

Upward trend in North Atlantic hurricane activity since 1970

Nor'easters along the Atlantic coast are increasing in frequency and intensity

EARTHQUAKE

30-40

Earthquakes occur in New England each year, although most are not felt.

Source: Climate Science Special Report, Fourth National Climate Assessment (NCA4), Volume prepared by the U.S. Global Change Research Program (USGCRP)Northern Middlesex Council of Governments. 2015. "Hazard Mitigation Plan for the Northern Middlesex Region," 159-160.

As an FYI: Boston Sea Level Rise Projections (ft)

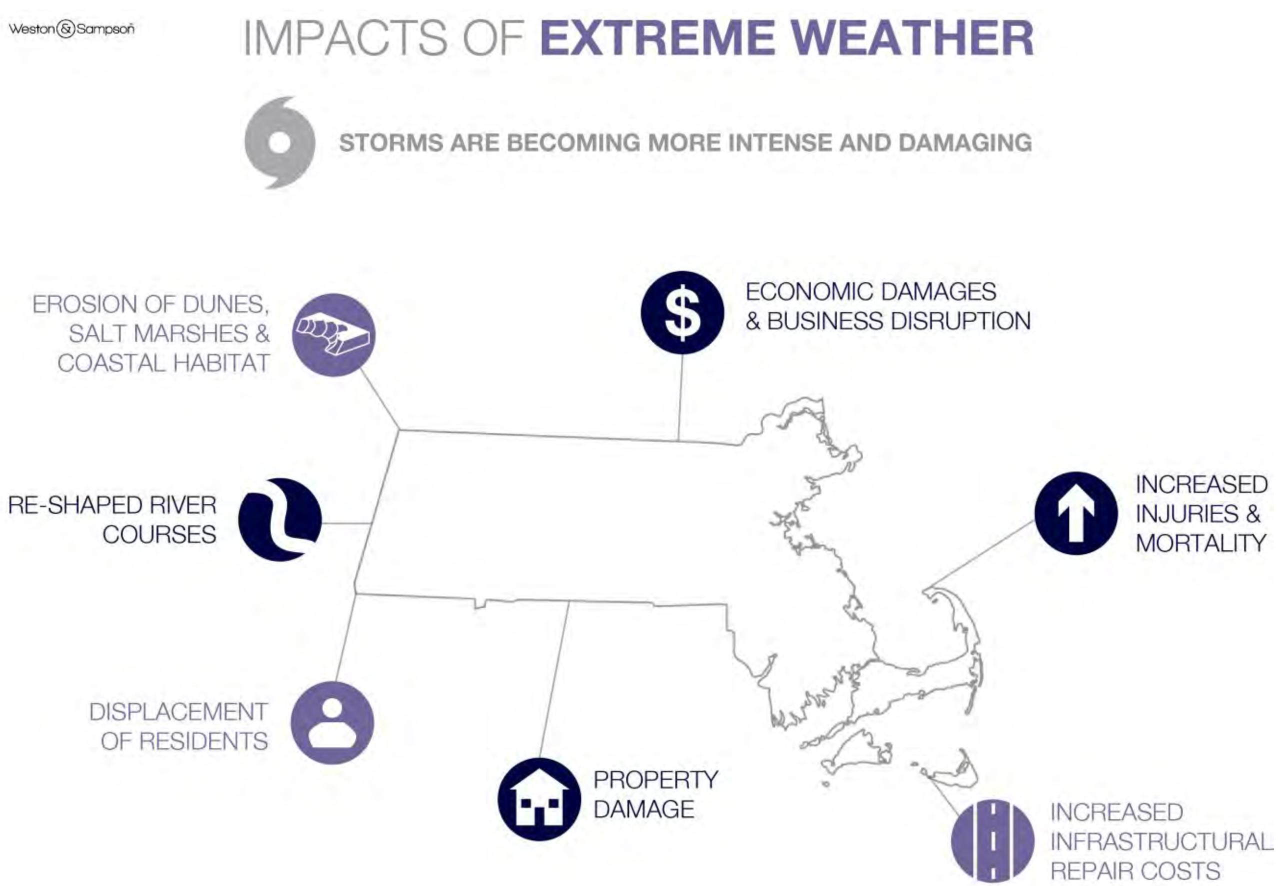
Increased coastal flooding

Permanently inundated low-lying coastal areas

Increased shoreline erosion

Emission Scenario	2030	2050	2070	2100
Intermediate	0.7	1.4	2.3	4.0
Intermediate-High	0.8	1.7	2.9	5.0
High	1.2	2.4	4.2	7.6
Extreme	1.4	3.1	5.4	10.2

(Source: Northeast Climate Adaption Science Center)



Massachusetts Executive Office of Energy & Environmental Affairs. 2019. "Extreme Weather." Massachusetts Climate Change Clearinghouse. http://www.resilientma.org/changes/extreme-weather

EXTREME TEMPERATURES

WARMER ANNUAL AIR TEMPERATURES

UP 0.5°F PER DECADE SINCE 1970, ON AVERAGE

WARMER WINTERS

UP 1.3°F PER DECADE SINCE 1970, ON AVERAGE

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EXTREME TEMPERATURES
IN MASSACHUSETTS

6	24	35
2005 OBSERVED ANNUAL AVERAGE	MID-CENTURY PROJECTED ANNUAL AVERAGE	END-OF-CENTURY PROJECTED ANNUAL AVERAGE

DAYS WITH TEMPERATURES ABOVE 90°F

145	114	101
2005 OBSERVED ANNUAL AVERAGE	MID-CENTURY PROJECTED ANNUAL AVERAGE	END-OF-CENTURY PROJECTED ANNUAL AVERAGE

DAYS WITH TEMPERATURES BELOW 32°F

Massachusetts Executive Office of Energy & Environmental Affairs. 2019. "ResilientMA Datagrapher." Massachusetts Climate Change Clearinghouse. Resilientma.org/datagrapher/?c=Temp/state/tx90/ANN/MA/
Notes: Mid-century projected annual averages use a 2040-2069 time range. End-of-century project annual averages use a 2080-2097 time range.

INFRASTRUCTURAL FEATURES

Police Department

Photo by Hopkinton Police Department

Fire Department

Photo by Hopkinton Fire Department

Wastewater Treatment & Collection

Dams

Echo Lake Dam. Photo from Tata and Howard

Roadways

Photo by ACOE

Water Supply

BUILDING CLIMATE RESILIENCE IN THE COMMONWEALTH

RESILIENCE = **MITIGATION** + **ADAPTATION**

RESILIENCE
The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner.

MITIGATION
aims to reduce the causes of climate change

ADAPTATION
involves modifying our decisions, activities and ways of thinking to adjust to a changing climate

Definitions taken from the Massachusetts 2018 State Hazard Mitigation and Climate Adaptation Plan and Canada in a Changing Climate report (Adaptation.NRCan.gc.ca)

Climate Resilience Concepts

Retreat

- Relocation out of flood plain (current and future), elevating critical assets

Protect

- Permanent Barriers, Temporary Barriers, Dry Floodproofing

Accommodate

- "Room for the river", green infrastructure, wet floodproofing, stormwater storage

Flood Protection Solutions	Coastal & Fluvial Flooding (Storm Event)	Coastal & Fluvial Flooding (Gradual)	Pluvial Flooding	Protect	Retreat/Elevating	Accommodation	Deployable	Flexible/Adjustable	Short-Term	Long-Term	Implementation Examples
Static Options (Shoreline and Upland)											
Levees	●	●		●		●				●	New Orleans, LA
Horizontal Levees	●	●	●	●		●				●	Tokyo, Japan
Revetments	●	●		●						●	Manchester by the Sea, MA
Super Levees/Raised Land	●	●		●	●					●	Osaka, Japan
Floodwalls	●	●		●						●	New Orleans, LA
Seawalls/Bulkheads	●	●		●						●	Georgetown, D.C.
Passive Barriers	●		●	●			●	●	●	●	New York City, NY
Raised Roadways	●	●		●	●					●	Norfolk, VA
Raised Curbs & Sidewalks	●	●		●	●					●	Sacramento, CA
Dynamic Options											
Inflatable Flood Barriers	●		●	●			●	●	●		Houston, TX
Membrane Flood Barriers	●		●	●			●	●	●		Newcastle, Australia
Modular Flood Barriers	●		●	●			●	●	●		New York City, NY
Flood Plank Barriers	●		●	●			●	●	●	●	Grein, Austria

LEVEES

Benefits

- Can be designed with harborwalk path
- Drainage systems within levee can aid in stormwater impact

Drawbacks

- Extensive amount of space required to construct
- Susceptible to scour/erosion
- Seepage through embankment
- Overtopping may lead to catastrophic damages

Source: Wright, Kathryn, et al. "Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions." A Better City, Feb. 2015.; FEMA 259 Ch. 5F.; Burden, Amanda M, et al. "Urban Waterfront Adaptive Strategies." Department of City Planning City of New York, June 2013.

Earthen embankment designed and constructed to prevent flood waters from reaching downstream areas.

Source: "Dutch lessons on levee design and prioritization for California." California WaterBlog, UC Davis Center for Watershed Sciences, 26 Feb. 2015, californiawaterblog.com/2015/02/26/21st-century-delta-dutch-lessons-on-levee-design-prioritization/.

HORIZONTAL LEVEES

Benefits

- Less cost of traditional levees
- Can be designed with a pathway along the top
- Quick recovery after storm events
- Mitigate impacts of flooding by buffering, elevating, and accommodating flood waters
- Provides public access to waterfront
- Ecological enhancement opportunities

Drawbacks

- Natural habitat requires maintenance & repair after storm events
- Requires space between levee and waterfront for vegetation

Sources: Bosch Slabbers, et al. "Adaptation Solutions." *ClimateApp*, Bosch Slabbers; Burden, Amanda M, et al. "Urban Waterfront Adaptive Strategies." Department of City Planning City of New York, June 2013.; Deltares; Sweco; Witteveen & Bos; KNMI, www.climateapp.nl/; "Horizontal Levees." *Naturally Resilient Communities*, Naturally Resilient Communities, nrcsolutions.org/horizontal-levees/

Horizontal levees are an extension to a hardened levee or floodwall, and provide a natural habitat between the water and the levee for moderate surge levels, wave action, erosion, and flood events.

Source: "Horizontal Levees." Naturally Resilient Communities, Naturally Resilient Communities, nrcsolutions.org/horizontal-levees/.

SUPER LEVEES/RAISED LAND

Benefits

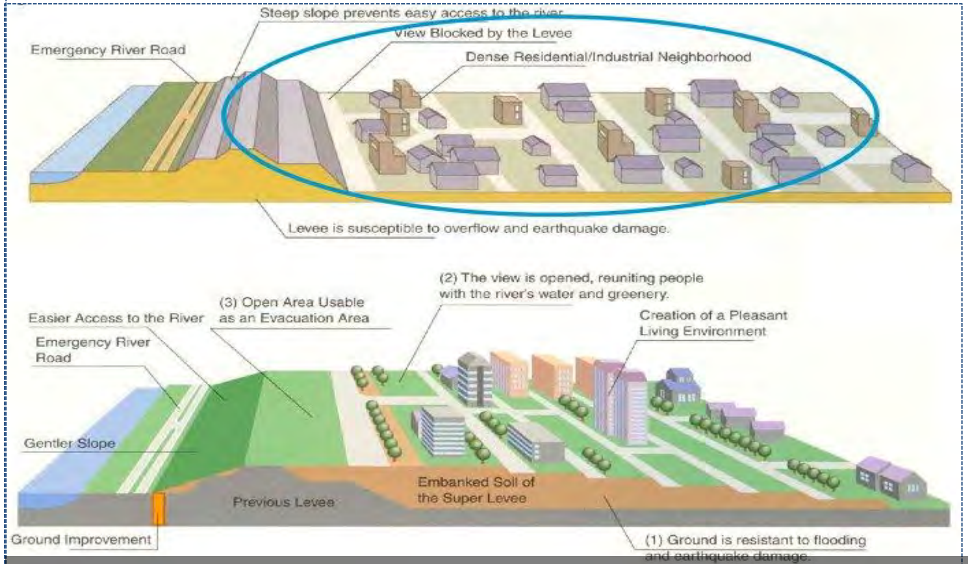
- Area out of flood zone
- Once constructed, raised land requires virtually no unusual ongoing capital or maintenance costs
- Seepage less problematic than traditional levees
- Less threat of breach or slope failure
- Levee does not block access or view of waterfront
- More resistant to flooding and earthquake damage
- Stormwater drainage design opportunities can be similar to that of normal levees

Drawbacks

- Very expensive, requires massive grade change and rebuilding infrastructure and buildings
- Numerous engineering and design issues
- Redesign & construction of dense, developed urban environment

Sources: Burden, Amanda M, et al. "Urban Waterfront Adaptive Strategies." Department of City Planning City of New York, June 2013.; The Polis Blog. "Levee-Town (Super!)." Smart Cities DIVE, www.smartcitiesdive.com/ex/sustainablecitiescollective/levee-town-super/9331/.

Super levees are wider than a normal levee, and include raising grades on the downstream side to a negligible slope.



Source: The Polis Blog. "Levee-Town (Super!)." Smart Cities DIVE, www.smartcitiesdive.com/ex/sustainablecitiescollective/levee-town-super/9331/.

SEAWALL/BULKHEAD

Benefits

- Well established solution
- Abundant design information available
- Space efficient
- Can be built with boardwalk or roadway
- Reinforcement and repair is fairly simple
- Drainage holes can aid in stormwater management

Drawbacks

- Significant upfront costs and O&M costs
- May worsen down current flooding
- Disruptive to sediment transport
- Toe erosion and scour problematic
- Less aesthetic than vegetation or soft solutions

Source: Bosch Slabbers, et al. "Adaptation Solutions." *ClimateApp*, Bosch Slabbers; Burden, Amanda M, et al. "Urban Waterfront Adaptive Strategies." Department of City Planning City of New York, June 2013.; Deltares; Sweco; Witteveen & Bos; KNMI, www.climateapp.nl/

Seawalls are designed to resist wave forces to protect upland areas from flooding during major surge events.

Source: "WRT Design | Georgetown Waterfront Park." WRT Design | Wallace Roberts and Todd, www.wrtdesign.com/work/georgetown-waterfront-park.

FLOODWALLS

Source: "Flood wall." Wikipedia, Wikimedia Foundation, 11 Jan. 2018, en.wikipedia.org/wiki/Flood_wall.

Floodwalls are generally reinforced concrete structures designed to resist hydrostatic pressure in high and low surge events.

Benefits

- Less space required than earthen structures
- Can be combined with other measures

Drawbacks

- More expensive than levees to construct
- Physical and visual separation from waterfront
- Scour, seepage and uplift problematic
- May affect drainage in the area
- Proper drainage considerations necessary to prevent stormwater back ups

Source: Burden, Amanda M, et al. "Urban Waterfront Adaptive Strategies." Department of City Planning City of New York, June 2013.; Wright, Kathryn, et al. "Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions." A Better City, Feb. 2015

PASSIVE BARRIERS

Benefits

- Does not require human deployment
- Does not use electricity
- Deployed based on water height
- Installed to be custom-sized
- Minimize disruption to fair weather function

Drawbacks

- Upfront costs significantly higher than temporary barriers
- Effectiveness limited to adjacent structures
- Does not address gradual sea level rise tidal changes
- Drainage designs would be necessary to relocate flood waters

Sources: Burden, Amanda M, et al. "Urban Waterfront Adaptive Strategies." Department of City Planning City of New York, June 2013.; "Climate Resilience Toolkit." *Sustainable Buildings Initiative*, Sustainable Buildings Initiative, sustainablebuildingsinitiative.org/toolkits/climate-resilience-toolkits/; Wright, Kathryn, et al. "Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions." A Better City, Feb. 2015; http://floodbreak.com/about/success-stories/success-story-lourdes-hospital-binghamton-ny/

Passive, retractable flood barriers require no deployment measures and are usually recessed into sites.

Source: "Lourdes Hospital - Binghampton, NY." FloodBreak, FloodBreak, floodbreak.com/about/success-stories/success-story-lourdes-hospital-binghamton-ny/.

RAISED ROADWAYS

Benefits

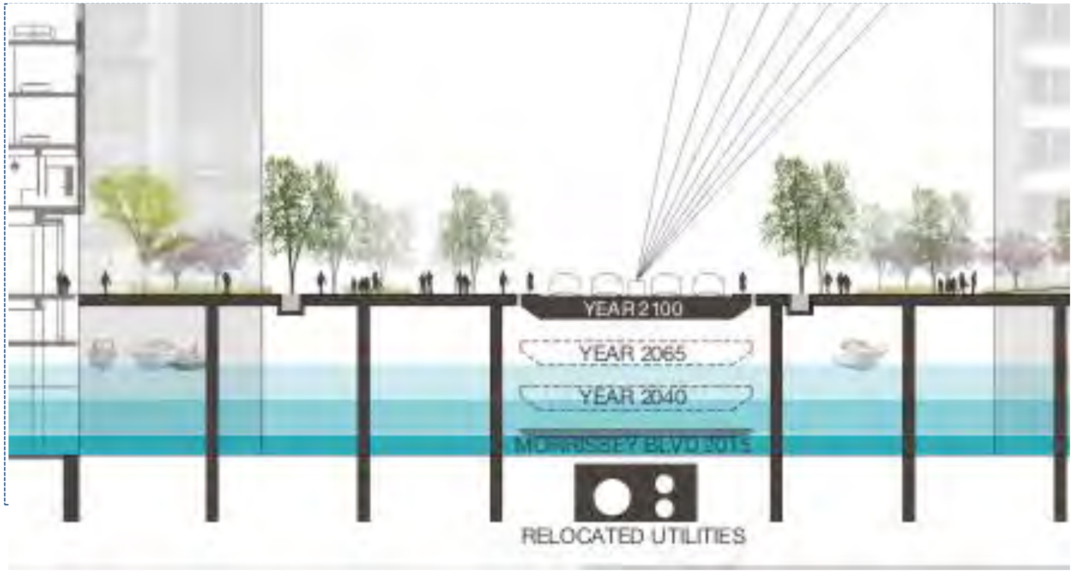
- Out of flood zone
- Safe Evacuation Routes

Drawbacks

- Difficult in developed/urban environment
- Connections to existing structures and infrastructure may also need to be raised
- Sidewalks and access routes need to be raised
- Utility access
- Widened roadway to manage sloped embankments
- Settlement associated with increased grades
- Infeasible for roadway portions that pass through tunnels

Sources: Bosch Slabbers, et al. "Adaptation Solutions." *ClimateApp*, Bosch Slabbers; Deltares; Sweco; Witteveen & Bos; KNMI, www.climateapp.nl/

Raised roadways elevate streets to above expected flood levels to act as flood barrier



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INFLATABLE FLOOD BARRIERS

BEFORE

Source: Chia, Jessica. "Texas man uses 400ft plastic dam he found on the Internet to protect his house from record 27-Inch floods - and it worked!" Daily Mail Online, Associated Newspapers, 12 June 2016, www.dailymail.co.uk/news/article-3637271/Texas-man-uses-dam-filled-WATER-house-dry-27-inch-flood.html.

AFTER

Source: Chia, Jessica. "Texas man uses 400ft plastic dam he found on the Internet to protect his house from record 27-Inch floods - and it worked!" Daily Mail Online, Associated Newspapers, 12 June 2016, www.dailymail.co.uk/news/article-3637271/Texas-man-uses-dam-filled-WATER-house-dry-27-inch-flood.html.

INFLATABLE FLOOD BARRIERS

Source: "NOAQ Tubewall Flood Barrier." Inflatable Flood Barrier - NOAQ Tubewall, FloodControl International, www.floodcontrolinternational.com/PRODUCTS/FLOOD-BARRIERS/noaq-tubewall.html.

Inflatable barriers are set up prior to a potential flood event and use incoming flood waters to inflate automatically and create a barrier to divert water.

Benefits

- Reusable, easier to deploy and clean up, and are often cheaper than sandbags
- Do not require building or site modifications
- Can be used and maintained by individual sites
- Flexible to accommodate bends and site restrictions

Drawbacks

- Not appropriate for frequent tidal events
- Models range in deployment time
- Puncture risk due to ice/sharp items
- Deployment requires human intervention and sufficient installation time
- Most temporary barriers do not protect from high-velocity flooding and wave action
- Can obstruct building access and sidewalks when deployed
- No drainage capabilities

Sources: "Climate Resilience Toolkit." *Sustainable Buildings Initiative*, Sustainable Buildings Initiative, sustainablebuildingsinitiative.org/toolkits/climate-resilience-toolkits/; Wright, Kathryn, et al. "Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions." A Better City, Feb. 2015

MODULAR FLOOD BARRIERS

Benefits

- Reusable, easier to deploy and clean up, and are often cheaper than sandbags
- Do not require building or site modifications

Drawbacks

- Not appropriate for frequent tidal events
- Deployment requires human intervention and sufficient installation time
- Most temporary barriers to not protect from high-velocity flooding and wave action
- Can obstruct building access or sidewalks when deployed
- Structural materials may prevent flexibility in site setups

Sources: "Climate Resilience Toolkit." *Sustainable Buildings Initiative*, Sustainable Buildings Initiative, sustainablebuildingsinitiative.org/toolkits/climate-resilience-toolkits/; Wright, Kathryn, et al. "Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions." A Better City, Feb. 2015

Modular flood barriers can be constructed of a wide range of materials and use floodwaters to deploy.

Source: "Temporary Flood Barriers - Unique Flexible Design ." AquaFence, aquafence.com/products-2/.

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ADAPTATION STRATEGY ACTIONS

- Vulnerability and Risk Assessment
- Community Outreach and Education
- Local Bylaws, Ordinances, Plans, and Other Management Measures
- Redesigns and Retrofits
- Ecological Restoration and Habitat Management
- Energy Resilience
- Chemical Safety
- Land Acquisition
- Subsidized Low-Income Housing Resilience
- Mosquito Control Districts
- Nature-Based Solutions for:
  - Flood Protection
  - Drought Mitigation
  - Water Quality / Infiltration
  - Infrastructure and Technology
  - Cooling
  - Air Quality

Design Criteria Selection

Precipitation Values

- Peak hourly intensity (in/hr)
  - 10-year
  - 50-year*
  - 100-year*
- Total Storm Volume (in/24 hr)
  - 10-year
  - 50-year*
  - 100-year*

* Based on available data

Coastal Flood Elevation

- Base Flood Elevation (BFE)
- Sea Level Rise - BFE
- Minimum Design Flood Elevation
- Additional factors for critical infrastructure/facilities

Extreme Heat

- Number of days over 90 degrees F
- Annual average maximum daily temperatures

Precipitation

	Peak Hourly Intensity Rainfall (in/hr)		
End of useful life	10-year design storm (in/hr) (BWSC 2015 (A1FI))	50-year design storm (in/hr)	100-year design storm (in/hr)
Baseline	1.66	2.33	2.62
2035	1.78	No data available	No data available
2060	1.91	No data available	No data available
2100	2.11	No data available	No data available
	Total Storm Volume (inches over 24 hour)		
End of useful life	10-year design storm (in) (BWSC 2015 (A1FI))	50-year design storm (in)	100-year design storm (in) (City of Cambridge 2015)
Baseline	5.25	7.18	8.08
2035	5.60	No data available	10.2
2060	6.03	No data available	No data available
2100	6.65	No data available	11.7

Baseline: NOAA Atlas 14

Boston Water and Sewer Commission (BWSC) uses **NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES** for design.

These projections should be considered for stormwater impacts. Flexibility/adaptation pathways more difficult in below grade drainage systems, so we recommend using precautionary (A1F1) projections.

Sea Level Rise

	Critical* Facilities Sea Level Rise (2 ft. Freeboard Min.)			
End of useful life	Base Flood Elevation (BFE)	Sea Level Rise Adjustment	Sea Level Rise Base Flood Elevation (SLR-BFE)	Minimum Design Flood Elevation (DFE)
Baseline	FEMA 1% (PFIRMS)	N/A	FEMA 1% (PFIRMS)	BFE + 24"
2030	FEMA 1% (PFIRMS)	+9"	BFE + 9"	BFE + 33"
2050	FEMA 1% (PFIRMS)	+21"	BFE + 21"	BFE + 45"
2070	FEMA 1% (PFIRMS)	+40"	BFE + 40"	BFE + 64"
	Non-Critical Facilities Sea Level Rise (1 ft. Freeboard Min.)			
End of useful life	Base Flood Elevation (BFE)	Sea Level Rise Adjustment	Sea Level Rise Base Flood Elevation (SLR-BFE)	Minimum Design Flood Elevation (DFE)
Baseline	FEMA 1% (PFIRMS)	N/A	FEMA 1% (PFIRMS)	BFE + 12"
2030	FEMA 1% (PFIRMS)	+9"	BFE + 9"	BFE + 21"
2050	FEMA 1% (PFIRMS)	+21"	BFE + 21"	BFE + 33"
2070	FEMA 1% (PFIRMS)	+40"	BFE + 40"	BFE + 52"

2030: Through 2040
2050: 2041 to 2060
2070: 2061 to 2080

The Boston Harbor Flood Risk Model (BH-FRM) for 2070 1% design flood should be used wherever available.

New construction projects should aim for 2070 DFE at a minimum.

If 2070 DFE is infeasible to achieve at this point, use intermediary DFE with plan to reach 2070 DFE.

Critical infrastructure and/or projects over $100 million (design and construction) should undergo a full climate risk assessment.

Extreme Heat

Included in "flood protection" for potential impacts on systems and materials:

- Thermal expansion
- Material degradation from excessive heat
- Pavement softening
- Increased failure/reduced efficiency of electrical/mechanical systems (power outages and pumps)
- Health and safety impacts

2030: Through 2040
2070: 2061 to 2080

	Extreme Heat Events (BRAG Report)		
End of useful life	# days above 90°F (Rossi et. al 2015)	Annual Average Temperature (°F) (City of Cambridge, 2015)	# heat waves (days with max temperatures at or above 90°F) (City of Cambridge, 2015)
Baseline	11	50	11
2030	29-31	53-53.5	~20-40
2070	47-68	55.8-58.7	~25-90

CLIMATE RESILIENT DESIGN STANDARDS & GUIDELINES
CITY OF BOSTON PUBLIC WORKS DEPARTMENT (BPWD)

ASCE AWARD WINNING PROJECT!

DESIGN CONSIDERATIONS FOR WATER & WASTEWATER INFRASTRUCTURE

Refer to AWWA J100 Risk & Resilience Assessment Process

- Ref. "Risk Analysis and Management for Critical Asset Protection for Water & Wastewater Systems", AWWA J100
- Ref. "Emergency Planning for Water & Wastewater Utilities", Manual M19, AWWA
- America's Water Infrastructure Act (AWIA) of 2018

  - IDENTIFY CRITICAL ASSETS
  - ANALYZE POTENTIAL THREATS
  - ANALYZE CONSEQUENCES
  - EVALUATE RESILIENCE STRATEGIES
  - INCORPORATE RESILIENCE ANALYSIS IN EVERY PROJECT DESIGN

DESIGN CONSIDERATIONS FOR WATER & WASTEWATER INFRASTRUCTURE

CONSIDER THE CONSEQUENCES OF FAILURE TO CONSIDER CLIMATE CHANGE IMPACTS ON WATER AND WASTEWATER INFRASTRUCTURE COMPONENTS!

- Loss of services
- Loss of access to critical system components
- Loss of customer trust
- Loss of revenue
- Loss of control to restore service
- Loss of bond financing capacity
- What's in your future?

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transform your environment

thank you

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