CLIMATE RESILIENT DESIGN STANDARDS & GUIDELINES
FOR PROTECTION OF PUBLIC RIGHTS-OF-WAY

APPENDIX A. OVERVIEW OF FLOOD BARRIER TYPES

BOSTON PUBLIC WORKS DEPARTMENT

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

Technical Advisory Group (TAG) Kick-off Meeting
February 6, 2018

ADDITIONAL MATERIALS FOR GENERAL REFERENCE

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.
Raised Roadways	●	●		●	●					●	Norfolk, VA
Raised Curbs & Sidewalks	●	●		●	●					●	Sacramento, CA
Passive Barriers	●		●	●			●	●	●	●	New York City, NY
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. (2015, February). Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions. *A Better City.*; FEMA 259 Ch. 5F.; Burden, Amanda M, et al. (2013, June) Urban Waterfront Adaptive Strategies. *Department of City Planning City of New York.*

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

Source: Indolences (2007). *Sacramento River Levee.* Wikipedia. Retrieved From https://commons.wikimedia.org/wiki/File:Sacramento_River_Levee.jpg

HORIZONTAL LEVEES

Benefits

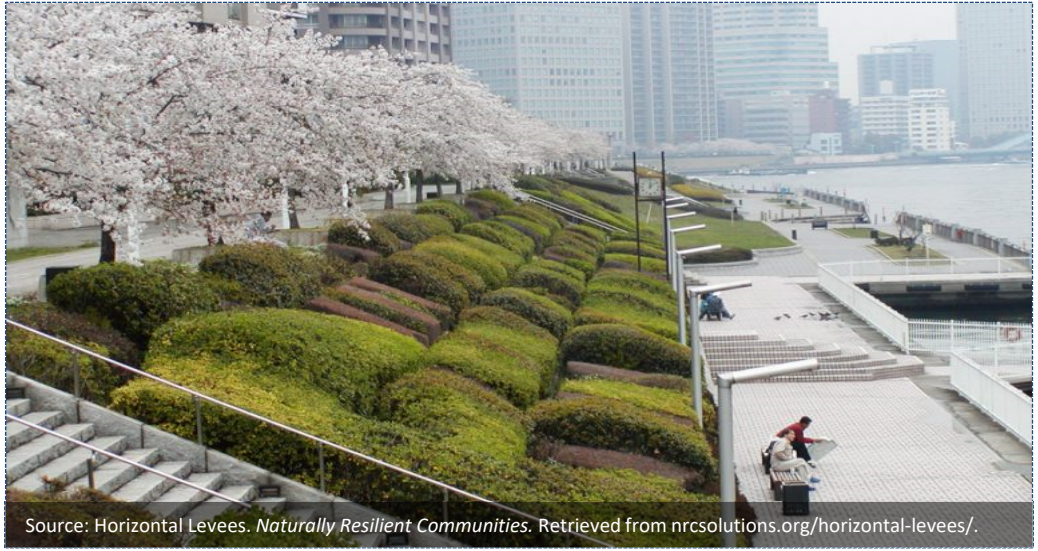
- Less cost of traditional levees
- Can be designed with a pathway along the top
- Quick recovery after storm events
- Mitigate impacts of flooding by buffering, elevating, and accommodating flood waters
- Provides public access to waterfront
- Ecological enhancement opportunities

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.* Retrieved from www.climateapp.nl/; Burden, Amanda M, et al. (2013, June). Urban Waterfront Adaptive Strategies. *Department of City Planning City of New York.*; Deltares; Sweco; Witteveen & Bos; KNMI ; Horizontal Levees. *Naturally Resilient Communities.* Retrieved from http://nrcsolutions.org/wp-content/uploads/2017/03/NRC_Solutions_Levees.pdf

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.* Retrieved from nrcsolutions.org/horizontal-levees/.

REVETMENTS

Benefits

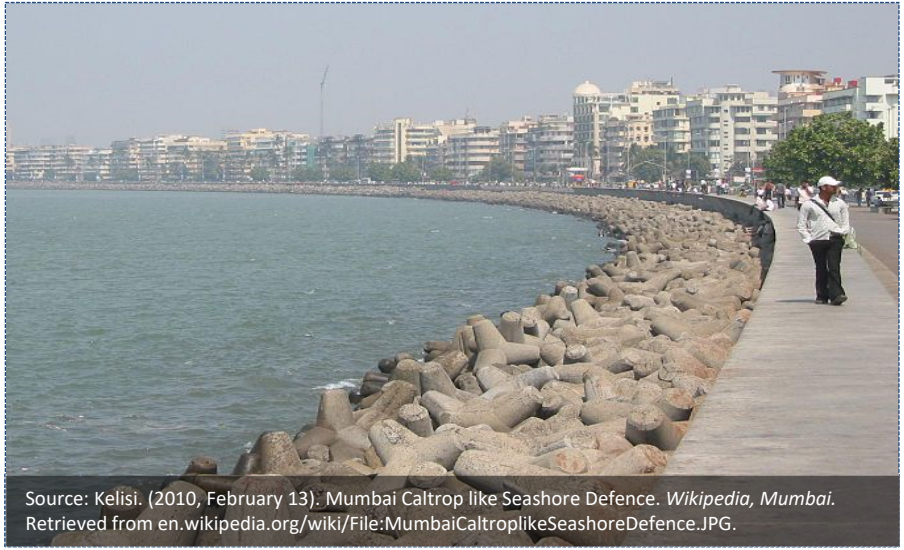
- Dissipates wave energy during storm events
- Can be designed with a pathway along the top
- Easier to maintain than soft protection measures
- Well-suited to mitigate wave action
- Suitable for areas with less space for ecological shoreline treatments
- Generally less expensive than bulkheads
- Less erosion and scour impact
- More flexible based on diversity of building materials

Drawbacks

- Requires space between levee and waterfront
- Less aesthetic than vegetation
- May result in increased wave action down current

Sources: Burden, Amanda M, et al. (2013, June). Urban Waterfront Adaptive Strategies. *Department of City Planning City of New York.*; StormSmart Properties Fact Sheet 7: Repair and Reconstruction of Seawalls and Revetments. *Massachusetts Office of Energy and Environmental Affairs.* Retrieved from https://www.mass.gov/files/documents/2018/05/29/ssp-factsheet-7-revetments-new.pdf.

Revetments are onshore structures designed to protect the shoreline from erosion.



Source: Kelisi. (2010, February 13). Mumbai Caltrop like Seashore Defence. *Wikipedia, Mumbai.* Retrieved from en.wikipedia.org/wiki/File:MumbaiCaltroplikeSeashoreDefence.JPG.

SUPER LEVEES/RAISED LAND

Source: Valin, I. (2009, November 24). Levee-Town (Super!). *Smart Cities DIVE.* Retrieved from 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.

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. (2013, June) Urban Waterfront Adaptive Strategies. *Department of City Planning City of New York.*.; Valin, I. (2009, November 24). Levee-Town (Super!). *Smart Cities DIVE.* Retrieved from 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 flooding for neighboring sites
- Disruptive to sediment transport
- Toe erosion and scour problematic
- Possible less aesthetically pleasing than vegetation or soft solutions

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

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

Source: WRT Design. Georgetown Waterfront Park. Retrieved from www.wrtdesign.com/work/georgetown-waterfront-park.

FLOODWALLS

Source: Jakec. (2015, August 25). Floodwall in Sudbury, Pennsylvania. *Wikipedia.* Retrieved from https://en.wikipedia.org/wiki/Flood_wall#/media/File:Floodwall_in_Sunbury,_Pennsylvania.JPG

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

Benefits

- Ease of construction
- 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. (2013, June). Urban Waterfront Adaptive Strategies. *Department of City Planning City of New York.*; Wright, Kathryn, et al. (2015, February). Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions. *A Better City.*

RAISED ROADWAYS

Benefits

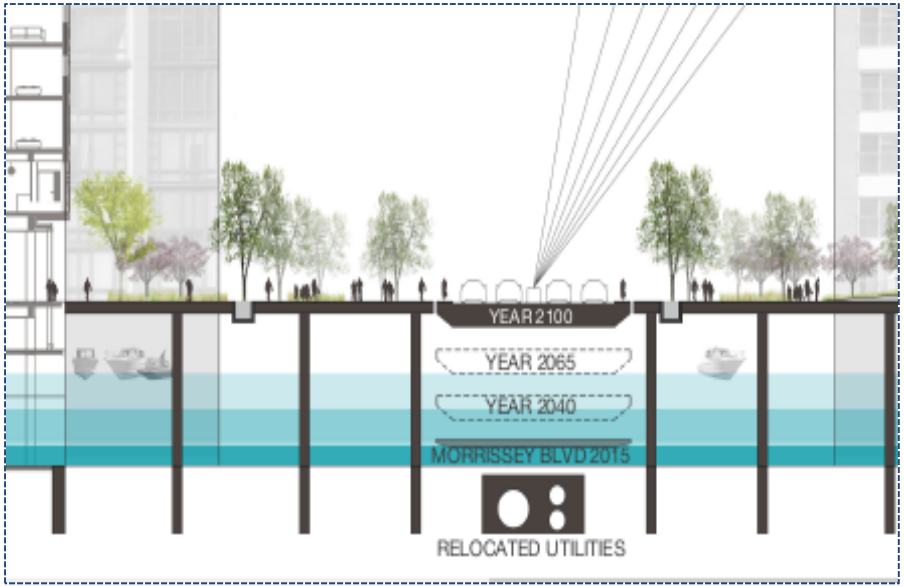
- Roadway out of flood zone
- Provides safe evacuation routes

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
- Costs

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

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



RAISED CURBS & SIDEWALKS

Benefits

- Less difficult than raising whole road
- Prevents water from entering adjacent buildings

Drawbacks

- Limits handicap accessibility to street
- Pedestrian safety
- Retains water in the street (possible benefit for stormwater storage)
- Drainage considerations necessary for where to direct water
- Roadway intersections
- Loading/access impacts to adjacent buildings/structures

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

Raised curbs and sidewalks can act as flood walls and don't require full roadway elevation.

Source: Conradi, Bob. (2016, December 9). Council Weighs Traffic Safety, Business Access After Raised Sidewalk Installed. *The Saline Post.* Retrieved from www.thesalinepost.com/government/council-weighs-traffic-safety-business-access-after-raised-sidewalk-installed.

PASSIVE BARRIERS

Benefits

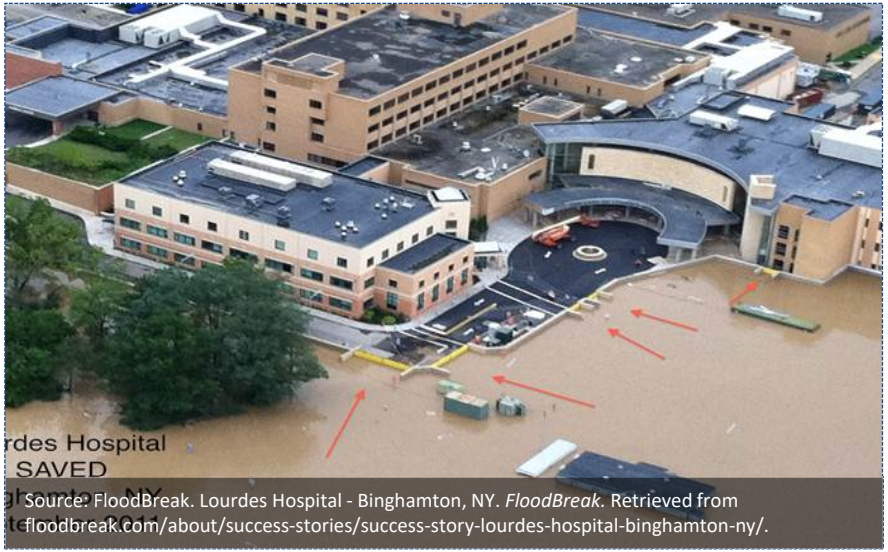
- Does not require human deployment
- Does not use electricity
- Deployed based on water height
- Installed to be custom-sized
- Minimize disruption to fair weather function

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
- May not deploy if ground is frozen

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

INFLATABLE FLOOD BARRIERS

Source: Flood Control International. NOAQ Tubewall Flood Barrier. *FloodControl International.* Retrieved from http://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: Sustainable Buildings Initiative. Climate Resilience Toolkit. *Sustainable Buildings Initiative.* Retrieved from https://sustainablebuildingsinitiative.org/toolkits/climate-resilience-toolkits/flooding-and-sea-level-rise/flood-barriers?toolkit=204/; Wright, Kathryn, et al. (2015, February) Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions. *A Better City.*

INFLATABLE FLOOD BARRIERS

BEFORE

Source: Chia, Jessica. (2016, June 12). 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. Retrieved from www.dailymail.co.uk/news/article-3637271/Texas-man-uses-dam-filled-WATER-house-dry-27-inch-flood.html.

AFTER

Source: Chia, Jessica. (2016, June 12). 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.* Retrieved from www.dailymail.co.uk/news/article-3637271/Texas-man-uses-dam-filled-WATER-house-dry-27-inch-flood.html.

MEMBRANE FLOOD BARRIERS

Benefits

- Reusable, easier to deploy and clean up, and are often cheaper than sandbags
- Do not require building or site modifications
- Can be anchored to impermeable structures for watertight seal
- Can be used on various surfaces
- Flexible length and shape options

Drawbacks

- Not appropriate for frequent tidal events
- 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

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

Membrane flood barriers use floodwater to seal and stabilize the groundsheet and backwall.

Source: Aquobex. Rapidam. *Aquobex.* Retrieved from aquobex.com/products-list/rapidam/.

MEMBRANE FLOOD BARRIERS

Source: Aquobex. Rapidam. Aquobex. Retrieved from aquobex.com/products-list/rapidam/.

Source: BLUEMONT. (2016, February 1). Bluemont and Newcastle City Council Mobile Flood Barrier Tests. *BLUEMONT*. Retrieved from http://www.bluemont.com.au/bluemont-and-newcastle-city-council-mobile-flood-barrier-tests/

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

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

Source: Dalheim, R. (2017, March 3). Seven-foot plywood flood barrier prepares mall for storm. *Woodworking Network.* Retrieved from https://www.woodworkingnetwork.com/wood/panel-supply/seven-foot-plywood-flood-barrier-prepares-mall-storm

MODULAR FLOOD BARRIERS

BEFORE

Source: Alibaba.com. Aqua Fence Freestanding Barriers - Buy Flood Protection Product on Alibaba.Com. Alibaba.com. Retrieved from www.alibaba.com/product-detail/Aqua-Fence-Freestanding-Barriers_138734799.html.

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Source: Alibaba.com. Aqua Fence Freestanding Barriers - Buy Flood Protection Product on Alibaba.Com. *Alibaba.com.* Retrieved from www.alibaba.com/product-detail/Aqua-Fence-Freestanding-Barriers_138734799.html.

FLOOD PLANK BARRIERS

Benefits

- Does not permanently block access/view to waterfront
- Does not require additional land (like floodwalls or levees)

Drawbacks

- Not appropriate for gradual and tidal flooding protection
- Deployment requires human intervention
- Sufficient installation time for larger projects
- May not be appropriate for high-velocity flows and wave action
- Susceptible to corrosion and rust

Sources: Flood Barriers. Flood Barriers: Flood Protection Products and Information Resources. *Flood Panel.* Retrieved from www.flood-barriers.com/; Wright, Kathryn, et al. (2015, February). Enhancing Resilience in Boston - A Guide for Large Buildings and Institutions. *A Better City*.

Flood plank barriers are temporary, watertight barriers placed prior to flood events.

Source: Williams, F. Who's Afraid of Floods? The Mobile Flood Walls in Austria Keep Everyone Safe!. *EliteReaders.* Retrieved from https://www.elitereaders.com/mobile-flood-walls-austria-machlanddamm/?cn-reloaded=1

FLOOD PLANK BARRIERS

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Source: Williams, F. Who's Afraid of Floods? The Mobile Flood Walls in Austria Keep Everyone Safe!. *EliteReaders.* Retrieved from https://www.elitereaders.com/mobile-flood-walls-austria-machlanddamm/?cn-reloaded=1

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Discussion on Flood Protection Options Selected

How do we get to 4 ft. protection by 2070, with the option to add an additional 2 ft. in the future.

- Harborwalk Barrier
- Raised Roadway
- Vegetated Berm
- Deployable Flood Barrier

OTHER OPTIONS TO DEVELOP SAMPLE DESIGN DOCUMENTS?

Flood Protection Solutions Considered for Design Guidance	HARBORWALK BARRIER	RAISED ROADWAYS	VEGETATED BERM	DEPLOYABLE BARRIER
Static Options (Shoreline and Upland)				
Levees	●	●	●	
Horizontal Levees	●	●	●	
Revetments	●	●		
Super Levees/Raised Land		●	●	
Floodwalls	●	●		
Seawalls/Bulkheads	●			
Raised Roadways		●		
Raised Curbs & Sidewalks		●		
Passive Barriers	●	●		
Dynamic Options				
Inflatable Flood Barriers				●
Membrane Flood Barriers				●
Modular Flood Barriers				●
Flood Plank Barriers	●			●

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