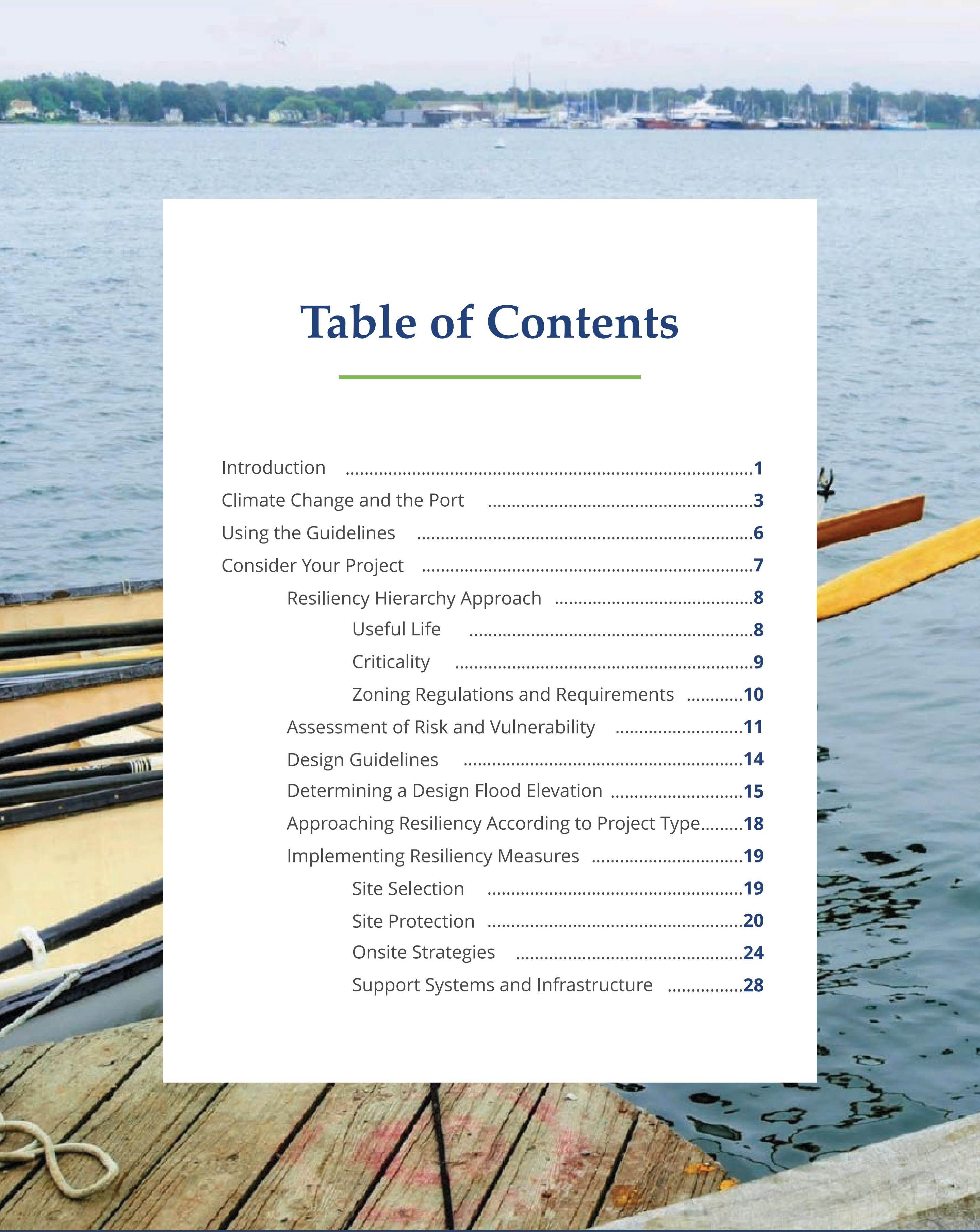
Resilient Design Guidelines

NEW BEDFORD HARBOR

A guide for the Port of New Bedford to bolster building and infrastructure resilience in the face of sea level rise and storm surge

JUNE 2020



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Port of New Bedford

Positioned on the northwestern corner of Buzzard's Bay and flanked by the City of New Bedford and the Town of Fairhaven, the Port of New Bedford has been the top-valued fishing port in America for 19 years straight. More than 6,800 people are directly employed by New Bedford's commercial port and it generates economic activity in excess of $11 billion. Its importance reaches far beyond its immediate surroundings—the Port is the center of the commercial fishing industry on the east coast.

The port defines the resilient, hard-working identity of the surrounding communities. A diverse population makes up the workforce and keeps its daily operations running. From commercial fishing and fish processing and packing to cargo transport and offshore wind development, the port supports a unique blend of industrial, commercial, and recreational activities that contribute to the vibrant culture of New Bedford and Fairhaven.

Because the port serves such a vital role in the economy and culture of the area, it is essential to plan for its continued ability to adapt and thrive. As climate change brings an increasing threat of sea level rise and intense storms, the City of New Bedford and the Town of Fairhaven have come together to develop an action and adaptation strategy for the Port. Using the state-of-the-art modeling and input from experts and information from frontline workers, the team created this set of resilient design guidelines to encourage sustainable future development and proactive retrofits of existing infrastructure to maximize the useful life of key public and private assets.

What's Here?

With over 350 years of maritime history, the Port is largely made up of business and services supporting the fishing industry. However, many other buildings and various types of infrastructure round out the working waterfront. Here are some highlights of the assets found in the Port.

- 200 maritime businesses
- Commercial fleet of 500 fishing vessels
- Ferry services to Cuttyhunk Island and Martha's Vineyard
- Cargo shipping facilities
- Bulk and break-bulk cargo facilities
- Shipyards
- Vessel repair facilities
- Launch, water taxi, and charter boat services
- Launch, water taxi, and charter boat services
- Road and rail connections
- 150-foot hurricane barrier
- Fueling stations
- Numerous other businesses including restaurants, marinas, and manufacturing plants
- Open space
- Private residences

Climate Change & the Port

The climate in Massachusetts and New Bedford is already changing. Burning fossil fuels to power our homes and vehicles and keep our economy running emits greenhouse gases. We have increased greenhouse gases in our atmosphere to a level that has led to disruptions to the Earth's climate. As a result, we are experiencing hotter days, more extreme storms, and rising seas bringing high tides further inland. These impacts are only projected to intensify in the future.

Of particular importance to the Port of New Bedford are the effects of sea level rise (SLR) and storm surge on the resilience of infrastructure and business operations.

Sea Level Rise

Resilient MA—a State resource that compiles the latest climate data—has modeled SLR under four emission scenarios.

Intermediate	Intermediate High	High	Extreme

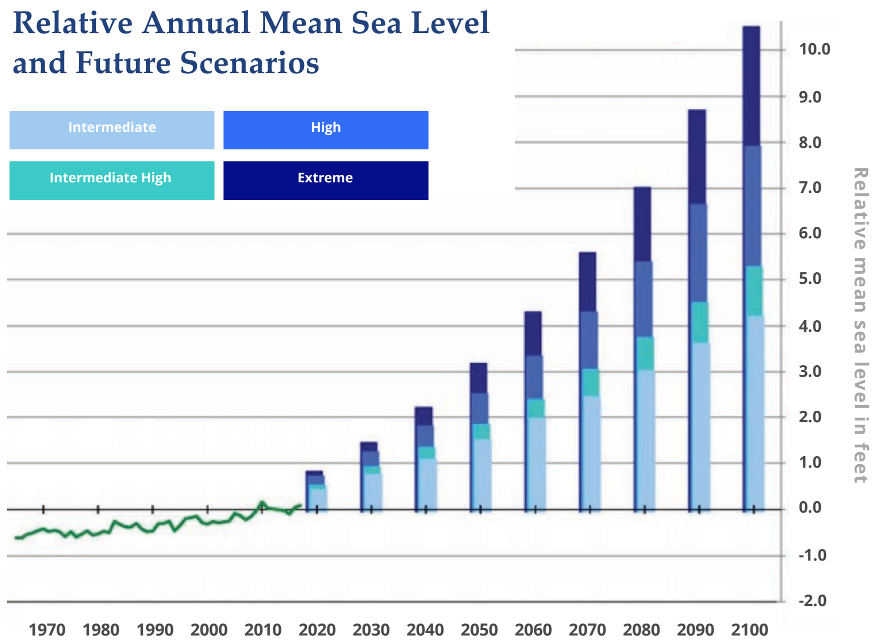
While the extent and rate of SLR depends on reducing greenhouse gas, the State recommends planning for sea level rise under a **high emission** scenario under which we would experience the following increases in sea level from a 2010 baseline:

1.2 feet by 2030

2.5 feet by 2050

4.3 feet by 2070

7.8 feet by 2100



Mean Higher High Water *(Preliminary Projections)*

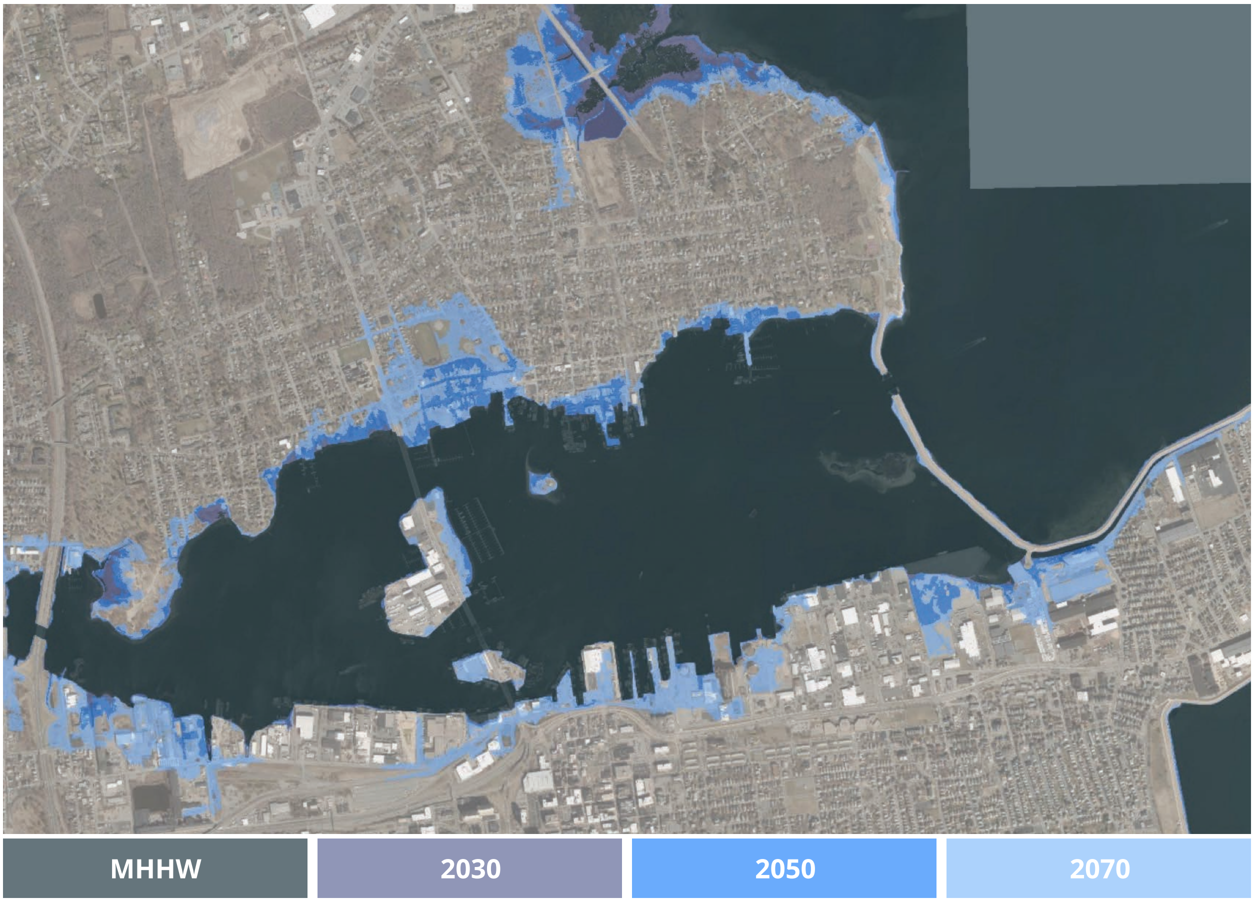


Figure 1. Created using the Massachusetts Coast Flood Risk Modeling (MC-FRM) tool, this map shows land area in the Port of New Bedford that will be underwater in a given year based on the mean higher high water (MHHW) level.

Flood risk modeling based on these projections indicate an increased risk of flooding along the shore of the New Bedford Harbor. While the Port of New Bedford is fortunate to be protected from routine storm surge by a hurricane barrier, SLR projections present a daily threat and make it essential to take steps to protect the harbor's infrastructure. Of particular importance to the Port of New Bedford are the effects of SLR and storm surge on the resilience of infrastructure and business operations.

Storm Surge

While SLR projections are important for long-term planning for daily coastal inundation, sea level rise coupled with storm events, such as hurricanes and Nor'easters, create greater flooding risks and damage potential for coastal communities. With the frequency and intensity of storms rising, it is essential to plan for the impacts of storm surge. Even with the hurricane barrier, damage from storm surge is possible. The modeling used for this project incorporates data from thousands of storms to be able to model the effect of factors such as waves, wind, tides, and storm surges.

MC-FRM Coastal Flood Exceedance Probability

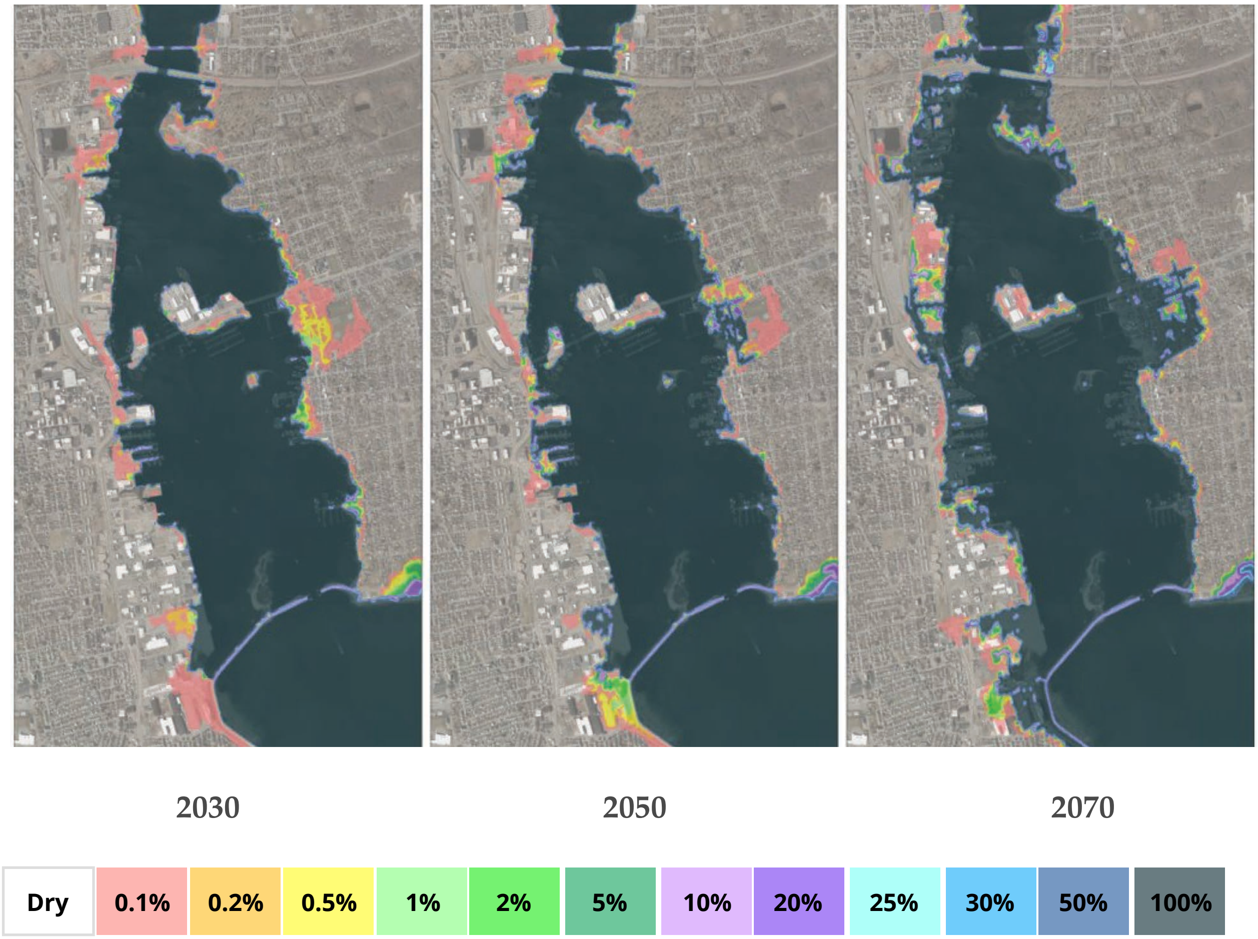


Figure 2. The probability of flooding in the years 2030, 2050, and 2070. 1% corresponds to a 100-year flood risk area, whereas 50% corresponds to a 2-year flood risk area. By 2070—and even 2050—there is significant land area that falls under the 1-year flood risk area.

Using the Guidelines

These guidelines are intended for developers, businesses, residents, and City/Town staff members that are living or working in and around the Port of New Bedford. Whether for a public planning project, developing or redeveloping in the area, or looking to upgrade an existing structure, these guidelines are here to provide resources and strategies on how to increase the resilience of the Port's many assets. These guidelines are meant to enhance existing base zoning codes and standards to proactively prepare for the impacts of sea level rise. Be sure to always consider the timelines for and building code requirements that may already apply to your project site.

Consider Your Project

Whether considering how to protect a large new development or your own home from climate change impacts, there are dozens of approaches you can take.

To begin using this guide, you should determine the following as this will help to determine which of the following sets of guidelines will be most valuable to you in your design process.

Are you trying to make an **existing** property, structure, or asset more resilient?

OR

Are you considering a **new** development, redeveloping a property, or constructing new infrastructure?

Resiliency Hierarchy Approach

Resiliency strategies vary in terms of the types of risk they serve to manage or avoid. The guidelines that follow offer strategies along a hierarchy that emphasizes risk avoidance when possible, protection from risk when it is not possible to avoid it, and ways to recovery quickly from impacts when assets cannot be completely protected. To help narrow down the best solution for your purpose, it can be helpful to consider the extent to which you are able to enhance resiliency within this hierarchy approach.

A — **AVOIDANCE** - taking steps to eliminate a risk or hazard

P — **PROTECTION** - taking steps to minimize the vulnerability of an asset from predicted hazards

R — **RECOVERY** - designing for quick recovery from predicted hazards

Additional factors for considering the best design approach for a project are the criticality of the project or its various assets, as well as the expected useful life of the asset(s).

Useful Life

New buildings or infrastructure that are intended to last for decades will require different resiliency measures than an upgrade to an existing structure that will be replaced in the next ten years. Sea levels are projected to continue rising, so a design based on 2030 projections may no longer be effective in 2050 or beyond. Considering your project's useful life will inform what level of protection is required and at what point in time. Useful life is generally longer than design life —it represents the extended service life of most infrastructure[2]. A project's useful life should be assessed using professional knowledge, prior useful life timeframes, and projected future conditions. See the **Determining a Safe Elevation** section for the implications of a project's useful life on recommended design elevations.

[2] City of Boston. 2018. Climate Resilient Design Standards & Guidelines for Protection of Public Rights-of-Way. https://www.boston.gov/sites/default/files/imce-uploads/2018-10/climate_resilient_design_standards_and_guidelines_for_protection_of_public_rights-of-way_no_appendices.pdf.

Criticality

Whether or not your project is "critical" will inform the extent of recommended mitigation measures. The American Society of Civil Engineers' *Flood Resistant Design and Construction* (ASCE 24) prescribes the minimum requirements and expected performance for the siting and design and construction of buildings and structures in flood hazard areas that are subject to building code requirements. The table below describes the types of buildings and structures, according to ASCE 24. Flood Design Classes 3 and 4 are considered critical, which has implications for recommended design elevations (See the **Determining a Safe Elevation** section).

		CRITICAL	
Flood Design Class 1	**Flood Design Class 2**	**Flood Design Class 3**	**Flood Design Class 4**
Buildings and structures that normally are unoccupied and pose minimal risk to the public or minimal disruption to the community should they be damaged or fail due to flooding.	Buildings and structures that pose a moderate risk to the public or moderate disruption to the community should they be damaged or fail due to flooding, except those listed as Flood Design Class 1, 3, and 4.	Buildings and structures that pose high risk to the public or significant disruption to the community should they be damaged, be unable to perform their intended functions after flooding, or fail due to flooding.	Buildings and structures that contain essential facilities and services necessary for emergency response and recovery, or that pose substantial risk to the community at large in the event of failure, disruption of function, or damage by flooding.
Includes temporary structures; minor storage facilities; small parking structures.	Includes the majority of residential, commercial, and industrial buildings.	Includes large gathering spaces; museums; community and recreation facilities; schools and childcare centers; healthcare facilities; nursing homes; fish processing plants; structures associated with power generation, water and sewer plants, telecommunication, and other utilities; facilities that handle hazardous waste.	Includes hospitals; fire, rescue, ambulance, and police stations and garages; emergency shelters; power generation stations; communication tower; electrical substations; fuel of water storage tanks; facilities that handle hazardous waste over a certain threshold.
For more details on the ASCE Flood Design Class of Buildings and Structures, visit the ***highlights***.			

If your project falls into Flood Design Class 3 or 4, strategies that seek **Avoidance** will be most effective. On the other hand, depending on the specifics of the project, structures in the Flood Design Class 1 or 2 may be sufficiently protected by strategies that emphasize **Recovery**.

[3] FEMA. 2013. "Windows, Doors, and Opening Protection." https://www.fema.gov/media-library-data/20130726-1707-25045-9020/chapter10.pdf.
[4] Ibid.

Zoning Regulations and Requirements

These guidelines are not meant to replace existing codes and standards, but rather to augment them to proactively prepare for the impacts of sea level rise. Be sure to always consider the zoning regulations, permitting, and building code requirements that may already apply to your project site.

Massachusetts:

- *Massachusetts State Building Code*
- *Massachusetts State Energy Efficiency Stretch Code*
- *Wetlands Protection*

New Bedford:

- *Construction Standards and Specifications*
- *Full Zoning Ordinance*
- *Guidelines for the Bedford Landing-Waterfront Historic District*
- *New Bedford Wetlands Ordinance*
- *Stormwater Management Rules and Regulations*

Fairhaven:

- *Fairhaven Wetlands Bylaw*
- *Full Zoning Bylaws*
- *Living with Wetlands*

Assessment of Risk and Vulnerability

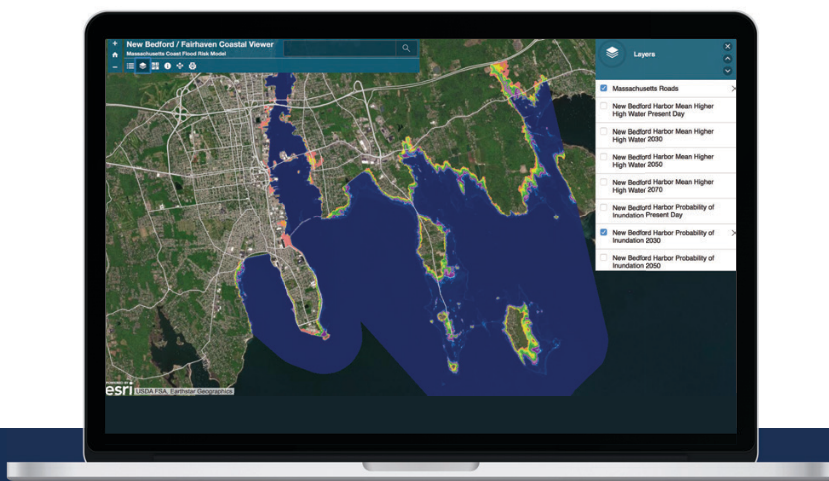
These guidelines seek to enhance the resilience of infrastructure to the threats of sea level rise (SLR), extreme storms, and storm surge. In order to fortify your project against the hazards posed by these conditions, it is essential to understand the risks and your project's associated vulnerabilities.

Massachusetts Coast Flood Risk Model (MC-FRM)

Traditional flood maps are backwards looking (e.g., FEMA FIRMs), meaning they are based on historic trends and do not take into account SLR predictions. Many maps that do take into consideration SLR tend to use a "bathtub" approach that does not reflect the dynamic nature of coastal flooding that occurs during storm events. Recognizing the limitations of traditional flood risk models, the Woods Hole Group—in collaboration with MassDOT and UMASS Boston—created the Massachusetts Coast Flood Risk Model (MC-FRM) which models the physics-based flow of water during coastal storms.

MC-FRM is a dynamic, probabilistic SLR and storm surge model that takes into account tropical and extra-tropical storms, SLR, landscape, elevations, and a changing climate. MC-FRM can predict flood probabilities, flood duration, inundation depths, winds, waves, flood pathways, flood volumes, and currents. It also provides accurate site-specific information, creating the ability to offer individualized project recommendations. The model has been peer-reviewed by a Technical Advisory Committee made up of the Woods Hole Oceanographic Institute (WHOI), the United States Geological Survey (USGS), the National Oceanic and Atmospheric Association (NOAA), the United States Army Corps of Engineers (USACE), and the United States Environmental Protection Agency (USEPA).

Because of the impressive capabilities of MC-FRM, these guidelines encourage the use of the MC-FRM projections and modeling tools to help you assess your exposure to risks posed by sea level rise and storm surge. MC-FRM is free and publicly available and also being used as the state standard for projecting flood risk associated with coastal climate change.



Access the MC-FRM data through the ***New Bedford/Fairhaven Coastal Viewer***. This interactive tool, provided by Woods Hole Group, allows you to explore the mean higher high water tidal benchmark, probability of inundation, and the 1% depth of inundation for present day, 2030, 2050, and 2070.

Case Study: Putting MC-FRM Technology to Use

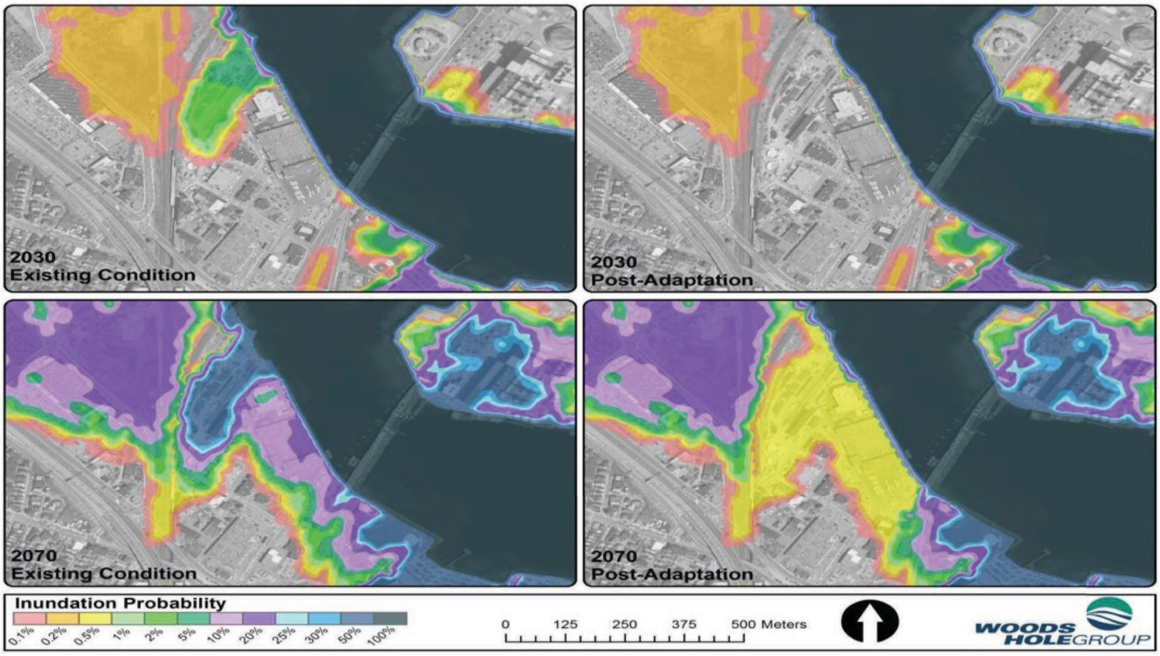
MC-FRM is already being used to protect infrastructure in Massachusetts. Below is an example of how the modeling was used to protect the long-term resilience of a critical transportation asset.

Charlestown MBTA Bus Depot

Before

After

The Charlestown Bus Garage is the MBTA's largest bus depot, housing 208 buses. SLR projections using MC-FRM showed increasing flooding at the site in the coming decades. Using these data, the MBTA made plans to replace a rusting sea wall with a living shoreline, a bike path, and a sea wall with a slightly higher elevation, leading to greatly reduced flood risk.



Design Guidelines

The following guidelines strive to enhance the resilience of your property or facility by introducing key considerations for measures along the Resilience Risk Hierarchy. The guidelines suggest that projects first determine a safe elevation (or Design Flood Elevation (DFE)), then establish a resilience approach based on the project type (retrofit or new construction, criticality and useful life), and finally, implement resilience measures accordingly.

Determining a Design Flood Elevation (DFE)

Whether you are retrofitting an existing building, upgrading infrastructure, or working on new development, determining a design flood elevation will help inform what strategies you pursue.

Currently, DFEs are typically determined by identifying the FEMA base flood elevation (BFE) for the project site and then adding some additional elevation to that level as a safety factor (usually called freeboard). This current approach does not account for the compounding effects of sea level rise (SLR) and storm surge, and as such, it does not adequately hold up to the changing design guidance for today. Therefore, utilizing the projections from MC-FRM, which are being applied across the Commonwealth for developing DFEs, these guidelines suggest that you take the following steps to calculate DFEs:

1. **Assess the useful life of your project.** Understanding the extended service life of your project will determine what tools you use to assess vulnerability. See previous section for guidance.

2. **Determine the MC-FRM projections for your project.** Consult the ***New Bedford Harbor-specific flood depth map*** that corresponds to the useful life of your project. For example, a project constructed in 2020 with a useful life of 50 years should consult maps with projections for the year 2070. Additionally, projects that have proposed service lives extending equal to or greater than 50 years should also consider flexible design approaches that can be adjusted over time due to the uncertainty in climate projections over longer time frames. So while projects should always attempt to reach the design target at the end of the useful service life, longer use projects may be able to establish intermediate goals along the way that ultimately allow them to reach the target level if SLR occurs slower or faster than expected. For example, a 2020 project with a 50-year service life would have a target DFE associated with a 2070 1% return period flood; however, it may be reasonable to create a flexible design for a 2050 1% return period flood DFE with a plan and design adaptation in place to reach the 2070 1% level at a later date.

3. **Identify the depth at the project site.** Using the ***New Bedford Harbor-specific 100-year (or 1% annual chance) MC-FRM flood depth map*** or the appropriate year(s), determine the flood depth information for your project site. Add this number to the site-specific ground elevation at your project site.

4. **Add a freeboard.** A freeboard is a factor of safety, or a buffer between projected flood levels and a building's lowest occupiable floor or infrastructure's lowest point. In this case a freeboard is used as an extra precaution, especially for critical structures. To determine if your structure is considered critical or not, refer back to the Consider Your Project section. Below are the standard freeboard heights.

Criticality	Sea Level Rise Adjustment
Non-critical	+ 12"
Critical	+ 24"

The steps presented above provide a simplified version of the State design standards and guidelines currently under development by the Resilient Massachusetts Action Team (RMAT). The New Bedford Harbor guidelines, as well as the State design standards and guidelines, are both based on the MC-FRM data sets. As such, the basis for the DFE level will be the same. As the state toolkits, design standards, and climate change guidelines are released, the approach detailed herein can be modified and refined with the more accurate and detailed information provided by RMAT.

The Importance of Freeboard

Adding a Freeboard can be a beneficial step to design or renovation. The following are some of the benefits, summarized by ***Storm Smart Coasts***.

Homeowners - Whether or not you live in the house year-round, having it elevated increases the chances that it will weather storms safely, decreasing your worry and protecting your investment. If you're building a new home, or doing a renovation, ask your builder/designer about incorporating freeboard.

Builders/Contractors – Incorporating freeboard provides a competitive edge over other builders, allowing you to market the benefits of reduced flood insurance and flood risk to potential buyers. When planning for retrofits (especially those requiring bringing structures up to current NFIP standards), explain the benefits of freeboard to your clients.

Municipalities - Encourage the use of freeboard in appropriate private and public construction throughout your community's floodplain. (NOTE: The Massachusetts Attorney General's office has recently rejected bylaws requiring freeboard, but municipalities may promote its use.)

Businesses - Protect your buildings, important records, and inventory from flooding; drastically decrease your recovery/clean-up time after storm; and potentially save your business. The Institute for Business and Home Safety reports that more than 25 percent of businesses that close due to storm damage never reopen.

Adding a Freeboard may also ***decrease your flood insurance payments***.

Determining Design Flood Elevation

Once you have determined the project's useful life, flood exposure, flooding depth, and criticality, you can calculate the DFE. The DFE will help inform implementation of adaptation strategies.

Developing a Basic Design Flood Elevation*

Depth data from MC-FRM for site specific location and based on useful life		Freeboard	Design Flood Elevation
		For non-critical structures	
2030	1% depth at location	+12"	Ground elevation at site + 1% depth at site (from MC-FRM) + Freeboard.
2050	1% depth at location	+12"	
2070	1% depth at location	+12"	
		For critical structures	
2030	1% depth at location	+24"	Ground elevation at site + 1% depth at site (from MC-FRM) + Freeboard.
2050	1% depth at location	+24"	
2070	1% depth at location	+24"	

* For critical assets and structures, project managers may want to contact Woods Hole Group for a more accurate design flood elevation determination for the specific site.

Approaching Resilience According to Project Type

In many cases, resilience strategies can be applicable both to existing properties and new construction. Importantly, however, in keeping with the Resiliency Hierarchy approach, avoidance and protection strategies should always be considered over recovery strategies, where possible. The ability to follow this hierarchy will likely differ if your project is an existing property or asset versus a new property or asset:

Are you looking to make an existing property or asset more resilient?

When it comes to existing properties, your options for increased resilience may be more limited with regard to the hierarchical approach of avoidance, protection, and recovery. Existing properties may already be sited and constructed with exposure to climate risks and, therefore, avoidance is no longer possible. However, the strategies that follow may help to protect and minimize impacts, or at least facilitate repair and recovery after an event. Whenever possible, elevating structures or critical equipment above the DFE per guidance in the previous section should be considered. When that is not feasible, wet and dry floodproofing strategies should be considered.

Are you developing a new property or constructing new infrastructure?

When developing a new property or infrastructure, avoidance strategies that strive to eliminate the risk to projects entirely should be considered, wherever possible. Less constrained by existing infrastructure or facilities, new properties may have more flexibility to incorporate hazard elimination and mitigation from the earliest stages of conceptual design and construction, for example, by integrating questions of siting and design. New projects should prioritize strategies including the selection of sites with minimal risk and elevation of structures and critical infrastructure, before implementing stop-gap measures such as floodproofing and other forms of structural reinforcement.

Implementing Resiliency Measures

The following strategies aim to support project managers in making the smartest decisions for their properties. Icons identify where along the Resiliency Hierarchy particular strategies fall, by labeling them as primarily opportunities for avoidance (A), protection (P), or recovery (R), or a combination thereof. Importantly, within specific strategies, opportunities may exist to implement a combination of avoidance, protection, and recovery measures. Project managers should always look for opportunities to avoid, then protect from, hazards, where possible.

A = Avoidance **P** = Protection **R** = Recovery

Site Selection

When considering the development of a new building or infrastructure, smart location selection is the single best way to ensure your project is protected from SLR and storm surge.

A **Siting Considerations:** Consider the following when selecting a site for construction.

- **Floodplain:** Based on the project service life, consult the appropriate *MC-FRM probability map* associated with the end of service life. If the service life extends beyond 2070, use the 2070 probability map. This will provide the expected future flood risk at a given site. If flood risk is high, consider whether a different site might make more sense in the long term.
- **Proximity to services:** Consider what services are most critical to have immediate access to. Make sure access will not be impacted if surrounding routes become impassible. Are there other ways to facilitate access to services if proximity will expose your property to SLR or storm surge?
- **Access to evacuation routes:** If a storm were to threaten the property, consider whether there are sufficient, safe means by which individuals can evacuate or emergency vehicles can get to the site, if necessary.

Conducting alternative site analyses will help you weigh your options in selecting a safe, functional site.

Site Protections

If development on a site exposed to sea level rise or storm surge is necessary, several strategies implemented alone or in concert can work to minimize impacts to a property. The following strategies, unless otherwise noted, are adapted from the ***Urban Waterfront Adaptive Strategies*** guide developed by the City of New York. Additional resources include the ***Landscaping to Protect Your Coastal Property from Storm Damage and Flooding guide***, developed by The Massachusetts Office of Coastal Zone Management's (CZM's) StormSmart Coasts program and featured as a resource on both the City of New Bedford's ***Conservation Commission resources page*** and the Town of Fairhaven's ***Conservation Commission resources page***.

P

Shoreline Enhancements: A fortified shoreline goes a long way in protecting a waterfront property from the impacts of SLR. If your property gives you control over a portion of the shoreline, consider the following strategies to help reduce erosion and protect the shore from flooding and storm surges.

Nature-Based Solutions:

- Living shorelines: Bank stabilization technique that use plants, sand/soil, and limited use of hard structures to provide shoreline protection and maintain valuable habitat.
- Beaches and dunes: Natural protective features that provide a sandy buffer to protect from waves and flooding, and are sometimes reinforced with vegetation, geotextile tubes, or a rocky core.
- Tidal wetlands: Constructed or restored tidal wetland that use plants and soils to retain and filter water while creating wildlife habitat.

Man-Made Infrastructure:

- Groins: structures that extend perpendicularly outward from the shore to trap sand, prevent beach erosion, and break waves.
- Breakwaters: Offshore structures typically made of rock or stone intended to break waves, reducing the force of wave action.
- Artificial reefs: Submerged, or partially submerged, structures made of rock, concrete, or other materials, that are designed to provide marine habitat for plants, invertebrates, fish, and birds, while also attenuating waves.
- Bulkheads: Vertical retaining walls intended to hold soil in place and allow for a stable shoreline.
- Revetments: Shoreline structures typically made of stone rubble or concrete blocks placed on a sloped surface to protect the underlying soil from erosion and reduce the forces of wave action.

Revetments along Brooklyn Bridge Park (Photo Credit: MusikAnimal)

P

Flood Barriers: In cases where shoreline enhancements may be insufficient or unfeasible, projects may want to consider installing or deploying structures to prevent or minimize flooding.

- **Floodwalls:** Permanent or deployable walls used at the shoreline or upland to prevent flooding.
- **Seawalls:** Massive stone, rock, or concrete structures built parallel to the shoreline that are designed to resist the forces of heavy storm waves and prevent coastal flooding of upland areas.
- **Levees:** Earthen embankments located at the shoreline that provide protection from flooding.
- **Surge barriers:** Fixed dam structures and operable gates that can be closed to stop water in order to prevent storm surge from flooding coastal areas.

R

P

Green Infrastructures: Structures that leverage or mimic natural features to filter, store, or harvest rainwater and stormwater can play an important role in minimizing damage to a property from an extreme storm or flood. These green infrastructure techniques can also minimize or prevent pollutants from entering water bodies and systems during these events.

- **Waterfront parks**: Open spaces designed with landscape features such as floodable areas, elevated land masses and other adaptive park design features that can quickly recover following storm events and help protect upland areas from coastal flooding.
- **Pervious surfaces:** Maintaining or expanding the amount of pervious surface around your site will increase the rate of water infiltration, reducing flooding risk.
- **Bioswales:** Low-lying, vegetated areas that capture and filter stormwater and slow runoff during a storm event.[3]

[3] National Association of Transportation Officials. Urban Street Design Guide: Bioswales. https://nacto.org/publication/urban-street-design-guide/street-design-elements/stormwater-management/bioswales/.

- **Green roofs:** Buildings partially or entirely covered in vegetation that provide stormwater capture and reduced stormwater flow, cooling and energy reduction, and urban habitat for plants and animals. [4]
- **Storage basins:** Structure designed to temporarily or permanently retain quantities of stormwater or runoff, minimizing flooding onsite and downstream by reducing flow. [5]
- **Rain garden:** Depressed landscapes with deep-rooted plant species specifically designed to collect water and facilitate ground infiltration rather than contribute to stormwater flows and runoff. [6]

P

Roadway Modifications: While potentially resource-intensive, strategies that propose major modifications to roadways nevertheless can provide important district-wide and property-specific benefits. These strategies focus on maintaining access and circulation around and to-and-from properties in the case of a major storm or flooding event.

- **Elevation of streets:** All streets, especially those on key evacuation routes, should be elevated above the expected storm level to protect from flooding.
- **Watertight Manhole Covers:** Sealing manhole covers will prevent backflow into the sewer system.

[4] Green Roofs. "About Green Roofs." https://greenroofs.org/about-green-roofs.

[5] Naturally Resilient Communities. "Floodwater Detention and Retention Basins." http://nrcsolutions.org/floodwater-detention/.

[6] Naturally Resilient Communities. "Rain Gardens." http://nrcsolutions.org/rain-gardens/.

Raised Roadways in Sunset Harbor, Miami Beach, FL

Miami Beach has begun raising roadways by two feet to reduce flood risks. The City is employing creative space management techniques to accommodate this elevation, such as low seating spaces that can safely handle flooding.

Photo credit: Miami Beach Times

Onsite Strategies

The following strategies offer protection to structures or enable their recovery in the case of exposure to hazards. Accordingly, these strategies are particularly appropriate for existing buildings or retrofits. Some of these strategies could also be applicable for new buildings, however, particularly for properties where the risk of hazard exposure increases toward the end of design life.

P

Dry floodproofing: Dry floodproofing makes a structure watertight to floods of a certain duration and depth. It reduces the potential for flood damage by reducing the chance of interior inundation. Dry floodproofing is most appropriate when relocating or elevating the structure is not cost-effective or technically feasible.[7] Consider the following strategies to dry floodproof your building.

- **Seal openings**
    - Use flood-resistant doors
    - Install watertight shields
    - Permanently seal windows and other openings below the Design Flood Elevation
    - Use aquarium glass or other specialized glazed storefront systems
- **Prevent water infiltration**
    - Use of deployable (e.g., stop logs, flood doors/gates, inflatable barriers) or permanent floodwalls or a berm on the exterior of building or around the site's perimeter to prevent water infiltration

[7] "Dry Floodproofing Measures." FEMA. Retrieved from: https://www.fema.gov/media-library-data/06dabddadc3887f91906172d863749ab/P-936_sec3_508.pdf

- Use waterproof membranes, permanent sealants or coatings to reduce seepage through walls, slabs and foundations

- **Seal electrical conduits and other utilities**
- **Reinforce structure**
  - Reinforce walls to resist hydrodynamic loads caused by flooding
  - Install pressure relief valves in floor system to avoid damage due to buoyancy forces
- **Install backup systems**
  - Install pumps to prevent build-up of incidental leakage
  - Install early warning devices to monitor water levels in dry floodproofed spaces
  - Install devices to prevent surge intrusion through storm or sanitary sewers

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P

Wet floodproofing: Wet floodproofing provides resistance to flood damage while allowing floodwaters to enter the structure. These strategies are most appropriate for enclosures found under a building, such as a limited-use basement or parking structure.[8]

- **Use flood damage-resistant materials**
  - Choose materials that are resistant to saltwater intrusion and corrosion
- **Prepare for flooding**
  - Ensure only non-critical and non-vulnerable components are located below the DFE
  - Install flood openings to equalize the hydrostatic pressure exerted by floodwaters to prevent structural damage to walls and floors
  - Secure components and equipment (i.e., fuel tanks) to avoid buoyant movement during flooding
  - Install pumps to gradually remove floodwater from basements and non-draining areas

[8] "Wet Floodproofing." FEMA. https://www.fema.gov/wet-floodproofing

P

A

Elevate Fueling and Mechanical Equipment: Regardless of whether you are going to dry or wet floodproof your building, a critical step in preparing a building for flooding is to elevate essential mechanical equipment. Take stock of essential equipment located below the Design Flood Elevation and consider relocating to a higher floor or elevating in place (i.e., placing on a concrete slab or water-resistant stand). Some equipment can be protected by dry floodproofing using flood barriers, but sump pumps are required to eliminate risk of seeping water damaging equipment. See FEMA's advice for protecting building fuel systems from flood damage.

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Wind and Storm Resistance: In addition to SLR, climate change is bringing an increase in the frequency and intensity of storms. Consider incorporating the following materials and landscaping strategies to reduce the chance of storm damage to your building from wind, rain, or hail.

- Use high wind rated roofs and windows
- Use laminated glass or polycarbonate glazing systems to protect windows from windborne debris
- Use salt-resistant plantings to increase plant survival and decrease flood risk

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Flood Damage-Resistant Materials: Especially if a building has areas of regular flooding, choosing materials that are resistant to damage will increase the resilience of the building. Consult FEMA's ***Coastal Building Materials*** for recommended flood damage-resistant materials.

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Outward Swinging Doors: Constructing or introducing outward swinging doors can provide additional protection in the case of a storm event. Materials used for weather stripping are generally located on the interior side of outward swinging doors, minimizing exposure to the elements. Furthermore, products are available to enhance the performance of outward-swinging doors that may not be available for inward-swinging doors.[9]

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Vestibules: Vestibules can also offer added protection for entrances to buildings, providing a buffer from flooding. For example, vestibules could be designed to accommodate or capture water with water-resistant materials and drainage.[10]

[9] FEMA. 2013. "Windows, Doors, and Opening Protection." https://www.fema.gov/media-library-data/20130726-1707-25045-9020/chapter10.pdf.

[10] Ibid.

Support Systems and Infrastructure

Protecting the infrastructure and systems that support a property is also crucial to its continued function and safety in the case of an extreme event. The following strategies provide specific guidance for systems including energy, utilities, and lighting.

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Redundant Energy Systems: In case a building's power system is compromised from a flooding or extreme storm event, having a backup system can help avoid disruption to operations.

- Install a backup generator
- Configure electrical, mechanical, and telecommunication systems for easy isolation of system components below the Design Flood Elevation to facilitate repairs and to minimize disruption due to flood damage
- Install redundant electrical, mechanical, and telecommunication systems if primary systems may need to be temporarily shut down

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Managing Hazardous Materials: Both for new construction and retrofits, project managers and designers should pay close attention to resilience considerations for the transport and storage of hazardous materials. Facilities that should receive this special consideration include fueling stations, fuel storage tanks, and facilities handling or storing chemical supplies or waste oil.[11]

- Avoid siting hazardous material containers in vulnerable locations, and ensure that these containers and facilities in which they may be housed are structurally secured.
- Secure other large objects that could mobilize in the case of an event and compromise the integrity or safety of hazardous material storage.[12]

[11] Massport. 2015. Massport Floodproofing Design Guide. https://www.massport.com/media/1149/massport-floodproofing-design-guide-revised-april-2015.pdf.

[12] City of Boston. 2019. Coastal Flood Resilience Design Guidelines. http://www.bostonplans.org/getattachment/d1114318-1b95-487c-bc36-682f8594e8b2.

Utilities, telecom, shore to ship power, exterior lighting systems:

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- **Stormwater infrastructure:** Flooding events can overwhelm stormwater drainage systems. Consider the following strategies to reduce the risk of overflow:
    - Utilize green infrastructure to increase stormwater infiltration
    - Assess local volume capacity and expand drainage capacity to accommodate higher volumes where needed
    - Assess CSOs and storm outfalls; implement tide gates at vulnerable locations
    - Establish inspection, debris and sediment removal, and maintenance processes

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- **Underground utilities:**
    - Protect underground utility and telecommunication infrastructure from water damage through dry floodproofing and resilient materials selection
    - Encase underground utilities and watermains in resilient materials

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- **Shore power** (cold ironing or shore to ship power) protection:
    - Check shore power cords frequently for damage to ensure their continued safe use. Utilize salt-water resistant conduit.

Climate Risk Enhanced Cost-Benefit Analysis

Because all projects are confined by factors such as finite resources, limited budgets, and location constraints, having a process to compare the cost implementing a certain resiliency measure with the cost of not implementing it will help you arrive at a workable, cost-effective solution.

Knowing that you may not be able to design your way out of all potential flood damage, a cost-benefit analysis can inform a best path forward. A Climate Risk Enhanced Cost-Benefit Analysis considers the incremental capital or operating costs of designing for resilience in balance with the projected avoided losses over time due to flood-related failures. Both the criticality and useful life span of the project will be important factors in this analysis. For more information on Climate Risk Enhance Cost-Benefit Analysis, consult the Section D of the ***Climate Resiliency Design Guidelines***.

Design Guidelines Summary

Type	Strategy	Retrofit	New Development	Resiliency Hierarchy Ranking
Site Selection	Siting Considerations		✓	Avoidance
Site Protection	Shoreline Enhancements	✓	✓	Protection
	Flood Barriers	✓	✓	Protection
	Green Infrastructure	✓	✓	Protection/ Recovery
	Roadway Modifications	✓	✓	Protection
Onsite Strategies	Dry Floodproofing	✓	✓	Protection
	Wet Floodproofing	✓	✓	Protection
	Elevate Fueling and Mechanical Equipment	✓	✓	Avoidance/ Protection
	Wind and Storm-Resistance	✓	✓	Protection
	Flood Damage-Resistant Materials	✓	✓	Protection/ Recovery
	Outward Swinging Doors	✓	✓	Recovery
	Vestibules	✓	✓	Recovery
Support Systems and Infrastructure	Redundant Energy Systems	✓	✓	Recovery
	Managing Hazardous Materials	✓	✓	Protection
	Utilities, telecom, shore to ship power, exterior lighting systems	✓	✓	Avoidance/ Prevention/ Recovery

Thank You

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