RESILIENTMASS ACTION TEAM (RMAT)

CLIMATE RESILIENCE DESIGN STANDARDS & GUIDANCE

COMPILED DESIGN CRITERIA GUIDANCE LANGUAGE

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GUIDANCE LANGUAGE FOR SEA LEVEL RISE / STORM SURGE DESIGN CRITERIA

Projected Tidal Datums

Definition

A tidal datum is a standard vertical elevation reference defined by certain phases of the tide. Tidal datums are often the reference for shoreline or coastal property boundaries where an elevation related to local sea level is needed. Projected tidal datums can be used to identify the elevation of tide levels along a shoreline in the future based on sea level rise. The following are some of the most common tidal datums (https://tidesandcurrents.noaa.gov/datum_options.html) that are extracted from the Massachusetts Coast Flood Risk Model (MC-FRM):

- Mean Higher High Water (MHHW)
- Mean High Water (MHW)
- Mean Tide Level (MTL)
- Mean Low Water (MLW)
- Mean Lower Low Water (MLLW)

Projected Tidal Datum Values

The projected Tidal Datum Elevations vary across the coastline based on a variety of factors and may vary at a given site.

Asset Name	Recommended Planning Horizon	Projected Tidal Datum Elevation (ft-NAVD88)				
		MHHW	MHW	MTL	MLW	MLLW
Test	Standards and/or Projected Values will be presented here, if available					

How Tidal Datums may inform Planning

Identify if the asset (function, access, operability, etc.) may be impacted considering the range of projected Tidal Datums (from MLLW to MHHW) over the useful life of the asset. Based on those projected values, consider if there are opportunities on the site to establish a migration zone for the shoreline and associated coastal resources to move inland to higher ground as sea levels rise. Buildings and infrastructure assets that are not intended to be exposed to tidal fluctuations (like seawalls, dams, and tide gates) should consider relocation or elevation at a minimum above the future target MHHW as planning advances to early design.

How Tidal Datum may inform Early Design

Additional site investigations are recommended to evaluate and inform design of assets that are affected by projected Tidal Datums (e.g., shoreline restoration projects). Consider current, intermediate, and target Tidal Datums and how the asset may respond to different projected Tidal Datums given actual site conditions. Note: there may be assets that are not directly exposed to the future shoreline that are affected by projected Tidal Datums (e.g., stormwater infrastructure could be impacted by rising tidal levels).

How Tidal Datums may inform Project Evaluation

Consider how the project's design narrative and drawings address current, intermediate, and/or target projected Tidal Datums for the overall site and individual assets. Projects should identify if opportunities for living shorelines, natural resource restoration, and/or a migration zone for tidal datums were considered in plans and design. Current and projected Tidal Datums should be indicated on project drawings.

Limitations for Projected Tidal Datums, Standards, and Guidance

The recommended Standards for Tidal Datums are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected Tidal Datum values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence. The geographic extents of projected Tidal Datums are based on the MC-FRM outputs as of 9/13/21, and Tidal Datums are recommended to be evaluated if a project location is exposed to coastal flooding, even if no projected values are available through the Tool.

Projected Water Surface Elevation

Definition

Projected Water Surface Elevation is the projected elevation for a specific future flood event, considering storm surge, tides, and wave setup. Wave setup, as included in water surface elevation, is defined by FEMA as “an increase in the total stillwater elevation against a barrier (dunes, bluffs, or structures) caused by breaking waves.” (https://www.fema.gov/sites/default/files/2020-02/Coastal_Wave_Setup_Guidance_Nov_2015.pdf).

Projected Water Surface Elevation Values:

The projected modeled elevations may vary across large sites due to variations in the site’s physical features (e.g., topography), so the elevations are presented as a maximum, minimum, and area weighted average values in the table below. The area weighted average represents the most typical value corresponding to the projected Water Surface Elevation of the project site.

Asset Name	Recommended Planning Horizon	Recommended Return Period	Projected Water Surface Elevation (ft-NAVD88)		
			Minimum	Maximum	Area Weighted Average [I]
Test	Standards and/or Projected Values will be presented here, if available				

How Water Surface Elevation may inform Planning

Consider the range of the projected Water Surface Elevation within the project area by clicking the “Projected Water Surface Elevation Maps” tab, which will appear for the asset with the least frequent return period recommended through the Tool. Three maps are provided that illustrate the projected Water Surface Elevation and extent of flooding for the planning horizon and return period indicated. If the range (or variability) is greater than one foot for an individual map, a project site survey or assessment of the most recent LiDAR elevation dataset may help users understand variations in existing site grading that may impact the projected values. If there are significant variations in existing site grading, the size of the project polygon drawn in the Tool may need to be reduced to evaluate the projected Water Surface Elevation of a specific asset location. Users may draw multiple project polygons to evaluate the variability in projected Water Surface Elevation at the site.

Identify if the asset is planned within and below the projected Water Surface Elevation for the target planning horizon. Buildings and infrastructure assets that are not intended to be exposed to coastal flooding (e.g., assets other than flood control dams, tide gates, or culverts) should consider relocation or elevation above the target maximum projected Water Surface Elevation. The area weighted average and maximum values are appropriate for planning purposes before formal design studies.

Review the existing site topography and identify areas that are above the maximum water surface elevation value. Consider the regional context of the site as well. If the project site is located along the waterfront and relocation is not feasible, identify if there are opportunities to provide local and/or regional flood protection with strategies such as berms or living shorelines that limit exposure of the asset. Identify if there are adjacent sites that would benefit or be impacted by these strategies.

If use of flood control measures is necessary where waves are interacting with the shoreline, ensure project is not reflecting waves on neighboring properties.

How Water Surface Elevation may inform Early Design:

Additional site investigations and engineering analyses are recommended to evaluate the ability to elevate the existing asset above the projected Water Surface Elevation or relocate the asset outside the extent of projected flooding. If elevation and/or relocation are not feasible, the design should consider ways that coastal flooding will not significantly impact the asset's ability to function as intended, followed by identifying measures to protect the asset from coastal flooding. Consider if the design strategy may provide additional on-and off-site benefits (regional protection benefits, community benefits, and/or ecosystem service benefits), as well as reduce the potential for negative impacts on- and off-site. The design should consider current, intermediate, and target projected Water Surface Elevations, and how the asset and site may adapt over time in conjunction with projected Wave Heights and projected Wave Action Water Elevation. Wet and dry floodproofing measures should be considered for building assets and follow existing FEMA guidance for design and materials below the target maximum Water Surface Elevation.

How Water Surface Elevation may inform Project Evaluation:

Consider how the project's design narrative and drawings or plans address current, intermediate, and/or target projected Water Surface Elevations for the asset and overall site. Projected Water Surface Elevations should be referenced in plans and designs.

Consider how the project addressed the existing site topography (including range in elevation) with the projected Water Surface Elevation for individual assets and the overall site. Were opportunities to relocate or elevate assets identified? Consider the positive benefits or negative impacts on-site or off-site because of the existing and proposed elevations planned or designed, including stormwater runoff.

Projects should provide justification if planning/designing assets below the recommended maximum projected Water Surface Elevation (both intermediate and target). For buildings, justification should be provided for design of occupiable spaces (such as first floor elevations) and critical systems (such as mechanical equipment) below the minimum projected Water Surface Elevation.

Limitations for Projected Water Surface Elevation Values, Standards, and Guidance:

The recommended Standards for Water Surface Elevation are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected Water Surface Elevation values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six annual exceedance probabilities/return periods (0.1% (1,000-yr), 0.2% (500-yr), 0.5% (200-yr), 1% (100-yr), 2% (50-yr), 5% (20-yr)). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to conduct their own due diligence.

Projected Wave Heights

Definition

Wave height is measured in feet, and the value represents the vertical distance between the highest point (crest or peak) and the lowest point (trough) of the wave (per the figure shown below). The stillwater level or "calm sea" state lies between the crest and trough.

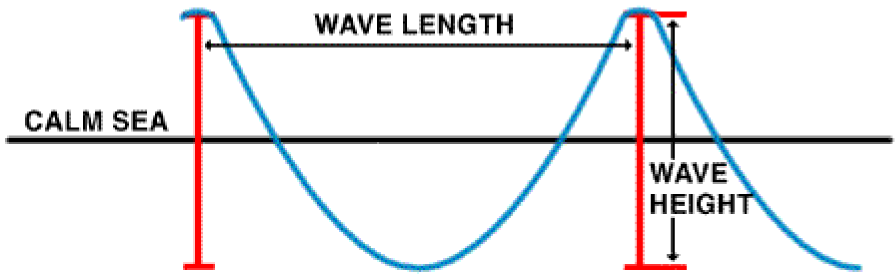

Figure of How Wave Heights are Measured
(https://www.ndbc.noaa.gov/educate/waves.shtml)

The projected Wave Height is statistically calculated using the significant wave height outputs from the Massachusetts Coast Flood Risk Model (MC-FRM). The projected Wave Height represents the wave height statistic that is slightly higher than the average of the highest 1% of wave heights and is the design maximum wave height as recommended by the Hydraulic Engineering Circular No. 25 (HEC-25) Highways in the coastal environment (USDOT, FHWA, 2020). These values are used to inform the projected Wave Action Water Elevation, in conjunction with the projected Water Surface Elevation. *Wave heights should not be directly added to the Water Surface Elevation to estimate Wave Action Water Elevations.*

Projected Wave Heights Values:

The projected Wave Heights may vary across sites, so the heights are presented as a maximum, minimum, and area weighted average values in the table below. The area weighted average represents the most typical value corresponding to the projected Wave Height of the project site.

Asset Name	Recommended Planning Horizon	Recommended Return Period	Projected Wave Height (ft.)		
			Minimum	Maximum	Area Weighted Average [I]
Test	Standards and/or Projected Values will be presented here, if available				

How Wave Heights may inform Planning:

Consider the range of the projected Wave Heights within the project area and the regional context of the site. If it is located along the waterfront, identify if there are opportunities to reduce wave heights through nature-based solutions, on-site and/or off-site. For restoration efforts, consider whether reducing wave heights is needed to meet project goals.

If the site is not along the coast and in more inland areas or outside of existing FEMA Zone AE (https://msc.fema.gov/portal/home), site-specific analysis is recommended to interpret projected Wave Heights, including identifying off-site opportunities to reduce wave heights.

The area weighted average may be appropriate for planning purposes before formal design studies, but users should consider the design intent and geographic variability of the project, including proximity to coast.

How Wave Heights may inform Early Design:

FEMA designates existing areas with expected wave heights greater than three feet as "Zone VE, a Coastal High Hazard Area, where waves and fast-moving water can cause extensive damage during the 1-percent-annual chance flood." If the area weighted average projected Wave Height is greater than three feet, design strategies appropriate in FEMA VE zones (https://www.fema.gov/sites/default/files/documents/fema_using-limit-oderate-wave-action_fact-sheet_5-24-2021.pdf), as well as nature-based strategies that mitigate wave height and impact, should be considered.

"FEMA has documented storm damage for decades. Post-storm damage shows that even 1.5-foot waves can cause significant damage to buildings that were not built to withstand them" (https://www.fema.gov/sites/default/files/documents/fema_using-limit-oderate-wave-action_fact-sheet_5-24-2021.pdf). The range of projected Wave Heights should be used to estimate wave forces for intermediate and target planning horizons. Wave forces are directly proportional to wave heights, and may be calculated using existing standards (e.g., Goda 1974).

How Wave Heights may inform Project Evaluation:

Consider how the project's design narrative and drawings address current, intermediate, and/or target projected Wave Heights for the overall site and individual assets. Projects should provide justification for not incorporating projected Wave Heights in planning/design efforts, which may include proximity to the coast (the site is not along the coast and in more inland areas or outside of existing FEMA Zone AE) and supporting analyses.

If the area weighted average projected Wave Height exceeds three feet, what design elements are included on site to protect the asset from the wave forces? Does the design reference building standards used in FEMA Zone VE floodplain management? These may include, but are not limited to:

- Buildings elevated on pile, post, pier, or column foundations, and anchored to the foundation.
- No structural fill is proposed.
- The bottom of the lowest horizontal structural member is at or above projected Water Surface Elevation.

Limitations for Projected Wave Heights, Standards, and Guidance

The recommended Standards for Wave Heights are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six annual exceedance probabilities/ return periods (0.1% (1,000-yr), 0.2% (500-yr), 0.5% (200-yr), 1% (100-yr), 2% (50-yr), 5% (20-yr)). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to conduct their own due diligence.

Projected Wave Action Water Elevation

Definition

The Wave Action Water Elevation represents the flood elevation that incorporates the projected Water Surface Elevation and Wave Heights associated with the recommended return period and planning horizons. This accounts for anticipated sea level rise, tidal datums, storm surge, and storm climatology through the Massachusetts Coast Flood Risk Model (MC-FRM), which is a hydrodynamic, probabilistic model that considers hundreds of thousands of historic and simulated storms. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

Projected Wave Action Water Elevation Values:

The projected Wave Action Water Elevation may vary across any given site, so the elevations are presented as a maximum, minimum, and area weighted average values in the table below. The area weighted average represents the most typical value corresponding to the projected Wave Action Water Elevation of the project site.

Asset Name	Recommended Planning Horizon	Recommended Return Period	Projected Wave Action Water Elevation (ft-NAVD88)		
			Minimum	Maximum	Area Weighted Average [I]
Test	Standards and/or Projected Values will be presented here, if available				

How Wave Action Water Elevation may inform Planning:

Consider the range of the projected Water Surface Elevation and the range of the projected Wave Heights within the project area in conjunction with the values provided above. The projected Wave Heights directly affect wave action, so reducing wave energy through on-site or off-site design strategies may allow projects to reduce the overall projected Wave Action Water Elevation.

The area weighted average and maximum values are appropriate for planning purposes before formal design studies. Refer to additional guidance provided in projected Water Surface Elevation and Wave Heights.

How Wave Action Water Elevation may inform Early Design:

Additional site investigations should be conducted to evaluate the ability to relocate the asset above the target maximum value. If elevation and/or relocation are not feasible, the design should consider ways that coastal flooding will not significantly impact the asset's ability to maintain functionality, followed by identifying measures to protect the asset from coastal flooding and wave forces. The design should consider current, intermediate, and target elevations, and how the asset and site may adapt over time in conjunction with projected Wave Heights and projected Water Surface Elevations.

Wet and dry floodproofing measures should be considered for building assets and follow existing FEMA guidance for design and materials below the target maximum Wave Action Water Elevation.

Natural resource assets that are located below the target maximum Wave Action Water Elevation should consider design strategies that incorporate native vegetation tolerant of existing and future conditions. This includes vegetation that can tolerate periodic exposure to saltwater and can help reduce wave action, to the extent practicable.

How Wave Action Water Elevation may inform Project Evaluation:

Consider how the project's design narrative and drawings address current, intermediate, and/or target Wave Action Water Elevation for the overall site and individual assets. Projects should reference projected Wave Heights and projected Water Surface Elevations with projected Wave Action Water Elevation and how they were considered together in plans and designs.

Consider how the project addressed the existing site topography (including range in elevation) with the projected Wave Action Water Elevation for individual assets and the overall site. Were there opportunities to relocate or elevate assets above the maximum target projected Wave Action Water Elevation? If a Building/Facility asset, does the design incorporate wet and dry floodproofing measures? Consider the positive benefits or negative impacts on-site or off-site because of the existing and proposed elevations planned or designed, including stormwater runoff.

Limitations of Projected Wave Action Water Elevation, Standards, and Guidance

The recommended Standards for Wave Action Water Elevation are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected Wave Action Water Elevation values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six annual exceedance probabilities/return periods (0.1% (1,000-yr), 0.2% (500-yr), 0.5% (200-yr), 1% (100-yr), 2% (50-yr), 5% (20-yr)).These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to conduct their own due diligence.

Projected Duration of Flooding

Definition

Duration of Flooding is the length of time an area remains flooded during a storm event. Duration of Flooding is important because it correlates with disruption in services and the level of impact of the flood (e.g., the amount of damage done, the amount of time power is out, etc.). *

How to Estimate Projected Duration of Flooding Values:

Asset Name	Recommended Planning Horizon	Recommended Return Period
Test	Standards will be presented here, if available	

*Note: Duration of Flooding is not a standard output of the Massachusetts Coast Flood Risk Model (MC-FRM), so projected values are currently not available through this Tool. Consult a professional coastal engineer or scientist/modeler to estimate projected Duration of Flooding based on the recommended Standards and outputs provided through this Tool.

How Duration of Flooding may inform Planning:

Evaluate how projected Duration of Flooding may impact the asset, including access and operability. Flood duration impacts the length of time occupants may need to evacuate, shelter in place, or are unable to access a building. Duration of Flooding may impact infrastructure, including inaccessible transportation routes and discharges through outfalls. Identify the duration for which these impacts are tolerable, and opportunities to increase that length of time (such as considering back-up power generation). If the projected Duration of Flooding is greater than the acceptable time for the asset to be inoperable, then that is an issue that should be considered as part of the planning phase of the project.

Coastal natural resource assets are generally adapted to being flooded for periods of time, but if there are non-coastal natural resource assets exposed to coastal flooding (e.g., emergent wetlands, open recreation space, etc.), Duration of Flooding and/or salinity may impact species and asset health.

How Duration of Flooding may inform Early Design:

Establish the projected Duration of Flooding by consulting with a professional coastal engineer or modeler and using the recommended Standards and outputs provided through this Tool.

The projected Duration of Flooding may inform emergency operations and management and recovery plans; corresponding operating procedures should be considered during the design process as they are informed by the location and design of assets.

Duration of Flooding may not be a significant design consideration if assets are designed above the maximum projected Water Surface Elevation or relocated so that the asset location is not exposed to coastal flooding. Duration of Flooding may impact assets not located within the future flood extents. For example, sluice gates at flood control structures outside of the project area that may need to be closed during the duration of coastal flooding to mitigate flooding at the project site.

How Duration of Flooding may inform Project Evaluation:

Consider if the project addresses Duration of Flooding in their design narrative and/or operations plans, if any. Has a professional coastal engineer or scientist/modeler been engaged to estimate the projected Duration of Flooding based on the recommended planning horizon, return period, and projected Tidal Datums and Water Surface Elevation? If Duration of Flooding is unknown at planning or early design level, did the project identify plans and/or design measures to maintain functionality and access for the asset for at least 48 hours? This could be through design features (e.g., elevating and/or relocating assets or protecting them by barriers or dry/wet flood proofing) or operational features (e.g., deployable pumps and emergency response plans).

Limitations for Duration of Flooding Standards and Guidance

The recommended Standards for Duration of Flooding are based on the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Projected Flood Velocity

Definition

Flood Velocity describes the magnitude and direction of floodwaters in terms of distance/time (e.g., feet per second or miles per hour). Flood Velocity is important for assessing the flood-induced forces on different structures (i.e., low flow/static flooding will place different stressors on a structure than high speed flows). The projected Flood Velocity is the estimated velocity associated with the recommended return period and planning horizon. *

How to Estimate Projected Flood Velocity Values

Asset Name	Recommended Planning Horizon	Recommended Return Period
Test	Standards will be presented here, if available	

*Note: Flood Velocity is currently not a standard output of the Massachusetts Coast Flood Risk Model (MC-FRM), so projected values are not available through this Tool at the time of production. Consult a professional coastal engineer or scientist/modeler to estimate projected Flood Velocity based on the recommended Standards and outputs provided through this Tool.

How Flood Velocity may inform Planning:

"The direction and velocity of floodwaters can vary significantly throughout a coastal flood event. Floodwaters can approach a site from one direction as a storm approach, then shift to another direction (or through several directions) as the storm moves through the area. Projects should consider the topography, the distance from the source of flooding, and the proximity to other buildings and obstructions; those factors can direct and confine floodwaters, with a resulting acceleration of velocities."(https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf)

Materials considered as part of the project should be able to withstand the projected Flood Velocity, especially for the materials that could be mobilized by high speed flows for assets that are planned below the maximum projected Wave Action Water Elevation.

How Flood Velocity may inform Early Design:

Establish the projected Flood Velocity by consulting with a professional coastal engineer or scientist/modeler and using the recommended Standards and outputs provided through this Tool. If this is not feasible during early design, consider existing best practices to estimate coastal Flood Velocity. For critical facilities, see Section 2.1.2.3 of FEMA Design Guide 543: https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf.

The projected Flood Velocity may inform adaptive management of existing revetments and sizing/positioning of inlets. The projected Flood Velocity may also inform the capacity of channels, culverts, catch basins, and storm pipes for flooding events.

"In structural design, velocity is a factor in determining the hydrodynamic loads and impact loads. Even shallow, high-velocity water can threaten the lives of pedestrians and motorists" (https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf). For buildings and other above ground structural assets, identify if the asset is currently protected by flooding and if/how it is secured in place (i.e., foundation type). Shallow foundations are more vulnerable than deep foundations.

How Flood Velocity may inform Project Evaluation:

Consider if the project addresses Flood Velocity in their design narrative and/or operations plans, if any. Has a professional coastal engineer or scientist/modeler been engaged to estimate the projected Flood Velocity based on the recommended planning horizon, return period, and other projected values (Tidal Datums and Water Surface Elevation) provided through the Tool? If preliminary estimates for projected Flood Velocity were developed using FEMA Design Guide 543, was the projected Water Surface Elevation used in that assessment? How do plans and designs reflect Flood Velocity considerations; for example, for stream restoration projects, has the flood velocity been considered as part of the design and have appropriate measures, such as riprap or grade control, been adopted if projected Flood Velocity is greater than allowable velocity of the natural channel?

Limitations for Flood Velocity Standards and Guidance

The recommended Standards for Flood Velocity are based on the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to conduct their own due diligence.

Projected Scour & Erosion

Definition

Coastal erosion is the loss of sediments along the coast due to sea level rise, waves, and coastal storm events. This process lowers the elevation of beaches and other landforms and shifts shorelines landward. Scour refers to a "localized lowering of the ground surface due to the interaction of currents and/or waves with structural elements, such as pilings [and seawalls]. Soil [and sediment] characteristics influence an area's susceptibility to scour. Erosion and scour may affect the stability of foundations and filled areas, and may cause extensive site damage" (https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf). *

How to Estimate Scour & Erosion Values

Asset Name	Recommended Planning Horizon	Recommended Return Period
Test	Standards will be presented here, if available	

*Note: Information related to Scour and Erosion is not a standard output of the Massachusetts Coast Flood Risk Model (MC-FRM), so projected values are not available through this Tool. Consult a professional coastal engineer or scientist/modeler to estimate projected extent of Scour and Erosion based on the recommended Standards and outputs provided through this Tool.

How Scour & Erosion may inform Planning:

Projects should consider the effects of scour and erosion in areas with erodible soils and sediments. Erosion affects most coastal landforms and may threaten dunes and other natural protective features, lowers ground elevations, undermines shallow foundations and below ground utilities, and reduces penetration depth of deep foundations (https://www.fema.gov/sites/default/files/2020-08/fema55_voli_combined.pdf). Therefore, understanding the extent of potential scour or erosion is valuable for assessing development setbacks, the depth to bury utilities behind dunes and seawalls, and the depth of foundations and pilings.

Erosion during storms occurs despite the presence of erosion control devices such as seawalls, revetments, and toe protection (https://www.fema.gov/sites/default/files/2020-08/fema55_voli_combined.pdf). Long-term erosion can also shift flood hazard zones landward. Refer to Limitations below. Flood depth, which is estimated by the difference between projected Water Surface Elevation and existing site topography, has direct correlations to damages. In areas susceptible to Erosion, changes in ground surface conditions during a flood event may increase the estimated flood depth. Additionally, the proposed construction materials may need to consider a plan to reduce or avoid Scour and Erosion.

How Scour & Erosion may inform Early Design:

Natural and human-caused shoreline changes (https://www.arcgis.com/apps/MapSeries/index.html?appid=80fc0c7ef5e443a8a5bc58096d2b3dc0) and Erosion and Scour potential should be considered. Shore protection structures may have unintended on-site and off-site impacts related to Erosion. Seawalls, bulkheads, and revetments may exacerbate Erosion of adjacent coastal resources and landforms. Early designs should explore opportunities to restore sediments and natural buffering capacity.

The potential effects of localized coastal Scour when planning foundation size, depth, or embedment requirements should be considered. Refer to existing FEMA guidelines (Coastal Construction Manual) for additional guidance on designs considering Scour & Erosion.

Projected Scour may be calculated using existing best practices, such as the methodologies provided in "TRB's National Cooperative Highway Research Program (NCHRP) Web-Only Document 181: Evaluation of Bridge-Scour Research: Abutment and Contraction Scour Processes and Prediction examines bridge-abutment scour and the effectiveness of the leading methods used for estimating design scour depth."

How Scour & Erosion may inform Project Evaluation:

Consider if the project's design narrative and drawings address Erosion and Scour potential for the overall site and individual assets. Is the project located in an area that has low-lying beaches, coastal dunes, coastal bluffs, coastal banks, and/or cliffs? If flood and erosion control structures are proposed (e.g., seawalls, bulkheads, revetments, etc.), does the project provide documentation for sediment modeling and reference projected Water Surface Elevations, projected Wave Heights, and estimated projected Flood Velocity? Were nature-based solutions considered instead of or in addition to 'gray' infrastructure to avoid or limit Scour and Erosion potential?

Limitations for Scour & Erosion Standards and Guidance

The recommended Standards for Scour & Erosion are based on the user drawn polygon and relationships as defined in the Supporting Documents. Scour & Erosion is recommended as design criteria for consideration based on asset type and if the site is located within the extents of the Massachusetts Coast Flood Risk Model (MC-FRM) as of 9/13/2021 for the associated planning horizon (2030, 2050, or 2070). The flood extents as defined in the current version of the MC-FRM do not reflect future extents as a result of erosion and/or scour; sites located outside of the modeled extents may be subject to Scour & Erosion as a result of long-term erosion that shifts flood hazard zones landward. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to conduct their own due diligence, including but not limited to evaluating current and future erosion potential.

Conditional Text that appears with Projected Sea Level Rise / Storm Surge Values

If the design criteria is Future Tidal Datums…	If the project polygon intersects an area with "Hatch = 1" WITH underlying values, provide dynamic table output, and provide the following note below the table output: "**This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale."** If the project polygon intersects an area with "Hatch = 1" with NO underlying value, don't provide any table output instead provide following text: "**This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale."** For projects that receive any Exposure Score for SLR/SS (other than "Not Exposed"), but project polygon does NOT intersect with the extents of Future Tidal Datums for the corresponding planning horizon, the Tool should output the following text for Future Tidal Datums design criteria: **"Note: The site is exposed to Sea Level Rise/Storm Surge, but projected Tidal Datums are not available within the site. Additional site-specific analyses are recommended to identify projected Tidal Datums for the recommended planning horizon. Consult a professional coastal engineer or modeler to estimate projected Tidal Datums based on the recommended Standards and additional outputs provided through this Tool."**
If the project polygon intersects the "9997" hatch zone…	Display the following text for the SLR/SS climate parameter: **ATTENTION: This project intersects areas influenced by wave overtopping based flooding These areas are where flooding is caused by intermittent pulses that come from wave run-up and overtopping at a coastal structure. Additional site analyses are recommended to establish design values associated with design criteria**.
If the project polygon intersects the "9997" & "9998" hatch zones…	Display the following text for the SLR/SS climate parameter: **ATTENTION: This project intersects areas influenced by combined effect of direct flooding and wave overtopping based flooding. These areas are where flooding is caused by surge, tides, and wave setup as well as intermittent pulses that come from wave run-up and overtopping at a coastal structure. Additional site analyses are recommended to establish design values associated with design criteria.**
If the project polygon intersects the "9998" hatch zone…	Display the following text for the SLR/SS climate parameter: **ATTENTION: This project intersects dynamic landform areas. These areas are where geomorphology is extremely dynamic and expected flooding can vary drastically. Additional site analyses are recommended to establish design values associated with design criteria.**
If the project polygon intersects "9999" hatch zones…	Display the following text for the SLR/SS climate parameter: **ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.**

GUIDANCE LANGUAGE FOR EXTREME PRECIPITATION DESIGN CRITERIA

Projected Total Precipitation Depth & Peak Intensity for 24-hour Design Storms

Definition

Total Precipitation Depth for 24-hour Design Storms is the total amount of rain in inches that falls over a period of 24-hours. It can be any 24-hour period, not just a traditional calendar day. This is given for a specific design storm (return period) such as the 100-year or 10-year storm (1% or 10%). Peak Intensity is the maximum rate of rainfall in inches per hour of a 24-hour design storm*.

Projected Total Precipitation Depth and Peak Intensity values can be used to assess potential flooding impacts and inform design of green and grey infrastructure solutions to mitigate flooding and manage stormwater.

Projected Total Precipitation Depth Values and Peak Intensity Methods

The Tool uses climate projections developed by Cornell University as part of the EEA's Massachusetts Climate and Hydrologic Risk Project (https://journals.ametsoc.org/view/journals/hydr/23/3/JHM-D-21-0183.1.xml). Assets receive a projected value for the 24-hour Total Precipitation Depth associated with a recommended return period (design storm) and planning horizon.

Asset Name	Recommended Planning Horizon	Recommended Return Period	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Instructions for Estimating Peak Intensity
Test	Standards and Projected Values will be presented here			Downloadable Instructions PDF

*Note: The projected Peak Intensity for 24-hour Design Storms is not provided through the Tool but can be calculated using methods referenced here.

---*DYNAMIC OUTPUT ONLY FOR TIER 3 DAMS AND FLOOD CONTROL STRUCTURE ASSETS* ---

ATTENTION: This is a Tier 3, Dams & Flood Control Structures project. Due to the criticality and useful life of this project, it is recommended that NCHRP15-61 method be used to calculate projected Total Precipitation Depth for 24-hour Design Storms, and those results be compared to the projected values provided in the Tool.

---*DYNAMIC OUTPUT ONLY FOR TIER 1 ASSETS* ---

ATTENTION: This is a Tier 1 project. Due to the criticality and useful life of this project, it is recommended that the NOAA+ method be used to calculate projected Total Precipitation Depth for 24-hour Design Storms, and those results be compared to the projected values provided in the Tool.

How Total Precipitation Depth may inform Planning

It may be helpful to develop a combined hydrologic/hydraulic (H/H) model for the site, which is typically conducted as part of an engineering analysis. This may inform the placement of green and grey stormwater infrastructure to manage stormwater flooding, as well as model effectiveness of stormwater solutions.

In addition to projected Total Precipitation Depth, consider the following:

- Are there onsite, offsite, and/or upstream local or watershed scale interventions (such as tree-planting, soil/habitat restoration, forest/other ecosystem conservation and restoration, floodplain restoration, pavement removal) that may mitigate stormwater flooding and provide opportunities for collaborative stormwater management, without negatively impacting ecosystem services?
- Are there notable elevation changes on-site that may expose the assets to additional risk (such as increased water flow or erosion)? Are there potential flood pathways as a result of on-site or off-site grade changes?
- Are there existing or proposed developments upgradient from the site that may result or increase on-site flooding?
- Will stormwater design cause impacts to Environmental Justice neighborhoods or climate vulnerable populations (e.g., due to off-site flooding)?

If other rainfall projections are readily available for the project site, consider comparing these data to the projected Total Precipitation Depth values as well as historic rainfall data.

How Total Precipitation Depth may inform Early Design

The projected Total Precipitation Depth may inform design of stormwater-specific assets, such as stormwater-utility infrastructure (for example stormwater drainage pipes, force mains, underground stormwater detention storage tanks, sub-surface infiltration chambers, etc.), flood control infrastructure (for example dams, sluice gates, etc.), and green infrastructure. The associated peak intensity and distribution of the projected Total Precipitation Depth may inform design and size stormwater management systems to address stormwater quantity issues.

Non-stormwater specific assets, such as building and natural resource assets, may use the projected Total Precipitation Depth to identify how rainfall depths and associated peak intensities may impact the asset, and design the asset accordingly to reduce damage potential.

In addition to projected Total Precipitation Depth values, consider the following:

- Is it spatially/physically feasible for stormwater utility infrastructure to be sized for the projected Total Precipitation Depth?
- Can design elements be modified over time to adjust to the change in future climate projections? An adaptive management approach may be a more feasible approach.
- If on-site mitigation is not possible due to site constraints, what opportunities exist for off-site mitigation?
- Do ecosystem service benefits (stormwater or otherwise) change over time due to climate change impacts? Consider climate change impacts in the design of nature-based solutions, beyond the asset's useful life.

How Total Precipitation Depth may inform Project Evaluation

Consider how the project narrative and drawings address the projected Total Precipitation Depth with respect to the overall site and an individual asset's design or planning. Justification should be provided if using a different method than the tiered estimation method recommended by the Tool.

In addition, consider the following:

- If the runoff generated for the projected Total Precipitation Depth cannot be accommodated on-site, how does the project propose to manage the additional stormwater? What are the ramifications of not managing stormwater on-site? Will resource areas be adversely affected if runoff is directed offsite?
- Does the proposed stormwater management system incorporate an adaptive approach such that modifications in the future can improve climate resilience?
- Does the project propose use of green infrastructure or nature-based solutions in conceptual design of the overall project site or assets within?
- What actions or plans are proposed to mitigate potential on-site and off-site impacts as a result of projected Total Precipitation Depth and Peak Intensity, including potential impacts to Environmental Justice neighborhoods or climate vulnerable populations?

Limitations for Projected Total Precipitation Depth & Peak Intensity, Standards, and Guidance

The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methods for producing of these precipitation outputs, see Steinschneider & Najibi 2022[1], Najibi et al. 2022[2], and the dataset technical documentation[3].

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

The projected values, standards, and guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without

[1] Steinschneider and Najibi (2022). Observed and Projected Scaling of Daily Extreme Precipitation with Dew Point Temperature at Annual and Seasonal Scales across Northeastern United States." *Journal of Hydrometeorology* Vol. 23(3), pp. 403-419. Doi: https://doi.org/10.1175/JHM-D-21-0183.1

[2] Najibi, Mukhopadhyay, and Steinschneider (2022). "Precipitation Scaling with Temperature in the Northeast US: Variations by Weather Regime, Season, and Precipitation Intensity." *Geophysical Research letters* Vol. 49(8), e2021GL097100. Doi: https://doi.org/10.1029/2021GL097100

[3] Steinschneider and Najibi (2022). "Future Projections of Extreme Precipitation across Massachusetts: A Theory-Based Approach Technical Documentation." *MA EOEEA Data Services* <https://eea-nescaum-dataservices-assets-prd.s3.amazonaws.com/cms/GUIDELINES/FinalTechnicalDocumentation_IDF_Curves_Dec2021.pdf>

supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Projected Riverine Peak Discharge & Peak Flood Elevation

Definition

Riverine Peak Flood Elevation is defined as the elevation of surface water resulting from, or anticipated to result from, the flooding of a river. Riverine Peak Discharge is defined as the highest discharge rate usually displayed as cubic feet per second (CFS). Riverine flooding examples include inundation of roads, infrastructure, or structures due to extreme precipitation resulting in overbank flooding or flash flooding. If the site is potentially exposed to riverine flooding based on preliminary exposure score, assets will receive riverine design standards recommendations.*

How to estimate Projected Riverine Peak Discharge & Peak Flood Elevation Values

Asset Name	Recommended Planning Horizon	Recommended Return Period	Tiered Estimation Method	Step-by-Step Instructions
Test	Standards will be presented here			Downloadable Instructions PDF

*Note: Projected Riverine Peak Discharge and Peak Flood Elevation are not currently available through this Tool. Users should follow the step-by-step instructions outlined in the downloadable instructions PDF to estimate the projected Riverine Peak Discharge and Peak Flood Elevation based on the recommended planning horizon, percentile, and tiered estimation method. The three tiers represent various anticipated levels of effort for calculating design criteria values, dependent upon the consequences of failure of an asset as a function of scope, time, and severity and useful life of the asset.

Ecological restoration projects may consider use of alternative hydrology design methods for riverine environments (per NOAA and USGS guidance) instead of methods provided through the Tool. Coordination with the appropriate State Agencies on design process and how future climate conditions are considered is recommended.

How Riverine Peak Discharge & Peak Flood Elevation may inform Planning

Consider riverine flood exposure and risk when planning for design and consider how risk may increase over time due to increases in rainfall. It can be helpful to develop a combined hydrologic/hydraulic (H/H) model for the site using the projected Total Precipitation Depth, which is typically conducted as part of an engineering analysis. This can inform a broader context to understand where flooding is projected to assess both upstream and downstream impacts at a regional/watershed scale. This may include considering the following:

- If possible, consider locations where the asset could be relocated away from riverine flooding exposure, particularly high exposure areas. Consider other on-site locations where critical assets can be relocated away from riverine flooding exposure and impact.
- Are there notable elevation changes on-site that may expose the assets to additional risk (such as increased water flow or erosion)? Are there flood pathways on-site or from off-site grade changes?
- Can the site provide the opportunity for flood protection beyond the site through increasing the floodplain or flood barriers? (i.e., local, neighborhood, or regional scale?)
- Are there other local or regional interventions that would reduce riverine flooding at the site?

How Riverine Peak Discharge & Peak Flood Elevation may inform Early Design

Evaluate how the projected Riverine Peak Discharge and Peak Flood Elevation may impact the asset and design the asset accordingly to reduce damage potential. It may be useful to consider adaptive management approaches, including improvements beyond the project area. Consider identifying how peak discharge flows, elevations, and flood pathways may change over time. If the climate risk changes through the asset's useful life, evaluate if the asset and/or site can be designed/constructed incrementally to mitigate riverine flood risk.

How Riverine Peak Discharge & Peak Flood Elevation may inform Project Evaluation

Consider how the project narrative and drawings address the projected Riverine Peak Discharge and Peak Flood Elevation with respect to the overall site and an individual asset's design or planning. Justification should be provided if using a different method than the tiered estimation method recommended by the Tool.

In addition, consider the following:

- Are green infrastructure or nature-based solutions being proposed for planning and conceptual design of the site and assets?
- Did the project consider relocation away from riverine flood exposure?
- Does the project incorporate an adaptive approach to riverine flood exposure and risk, such that modifications in the future can improve climate resilience?
- Does the project coordinate with, or plan to coordinate with, related regional or watershed efforts?

Limitations for Riverine Peak Discharge & Peak Flood Elevation Standards and Guidance

The recommended Standards for Riverine Peak Discharge and Peak Flood Elevation are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

GUIDANCE LANGUAGE FOR EXTREME HEAT DESIGN CRITERIA

Projected Annual/Summer/Winter Average Temperatures

Definition

Average Temperatures represent the daily average temperature over a period of time: Annual represents January through December, Summer represents June through August, and Winter represents December through February. Annual Temperatures are anticipated to increase with climate change, but the rate of change varies depending upon the season.

How to Estimate Projected Annual/Summer/Winter Average Temperatures Values

Asset Name	Recommended Planning Horizon	Recommended Percentile**	Projected Annual Average Temperature [˚F]	Projected Summer Average Temperature [˚F]	Projected Winter Average Temperature [˚F]
seawall	Standards and/or Projected Values will be presented here, if available				

How Annual/Summer/Winter Average Temperatures may inform Planning

Evaluate how the change in projected Average Temperatures may impact the initial planning and pre-design considerations associated with the asset and overall project. Average Temperatures represent a generalized trend, so it may be useful to identify locations along the East Coast with current conditions similar to the projected conditions. If there are other locations or zones that currently experience these climate patterns, they may inform adaptive plans and design strategies. Based on the region, will the asset use, function, or maintenance change as a result of increased projected Average Temperatures? For example: building assets may see changes in heating, cooling, and ventilation needs; infrastructure assets may see increased maintenance frequency; natural resources assets may see changes in flora and fauna with changes in Average Temperatures.

How Annual/Summer/Winter Average Temperatures may inform Early Design

Early design studies may include evaluating strategies from other locations along the East Coast that currently experience similar Average Temperatures to projected values. Are there design strategies that are applicable for today's climate conditions (or the climate conditions at the time of construction) and the projected Average Temperatures? Refer to additional applicable design criteria for more guidance related to Maximum Temperature, Heat Index, Cooling and Heating Degree Days, and Growing Degree Days that may support and inform early design and conceptual strategies.

How Annual/Summer/Winter Average Temperatures may inform Project Evaluation

Consider if the project and subsequent assets address changes in Average Temperatures as part of the design narrative and/or operations plans, if any. Have the projected changes in Average Temperatures been estimated following the recommended standards (planning horizon, percentile, and tiered estimation method) of this Tool? If not, justification should be provided for using a different method than the tiered estimation method recommended by the Tool. Some of the examples of strategies may include lighter color pavement materials with high SRI for roadways, flexible design of HVAC systems based on building usage to handle both present and future cooling loads, increasing tree canopy and shade structures for parks and open spaces.

Limitations for Average Annual/Summer/Winter Temperature Standards and Guidance

The recommended Standards for Projected Average Annual/Summer/Winter Temperature are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they are not comprehensive and do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Projected Number of Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F

Definition

Temperatures above 90°F and above 95°F are considered heat and extreme heat events in New England, respectively. Temperatures below 32°F are considered freezing events. An increase in Number of Days Per Year with Maximum Temperature above 90°F and 95°F may lead to an extended summer season. A decrease in Number of Days per Year with Minimum Temperatures below 32°F may lead to less snowfall and a shorter "traditional" New England winter season*

How to Estimate Projected Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F Values

Asset Name	Recommended Planning Horizon	Recommended Percentile**	Projected Days with Max Temp > 95˚F (days)	Projected Days with Max Temp > 90˚F (days)	Projected Days with Max Temp < 32˚F (days)
Test	Standards and/or Projected Values will be presented here, if available				

How Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F may inform Planning

Evaluate how the increase in projected Days Per Year with Maximum Temperature > 95°F and >90°F may impact the initial planning and pre-design considerations associated with the asset and overall project. It may be useful to compare the percent increase between current and estimated projected days per year values or create visuals that help communicate the increase in temperature expected, as well as the reduction in cold days. For example, with a 100% increase in days per year over >90°F between present and future, we can expect twice as many days per year as we experience now. With a 25% decrease in days per year <32°F, we can expect 1 out of 4 of our current days per year below 32°F to be above 32°F.

Identify how the asset's typical use and maintenance may be impacted by these changes in extreme temperatures. For example, planting selection (forests, parks, gardens, crops) may be affected by the extreme hot and reduced cold temperatures. Some plant species require a defined period of below freezing weather to thrive. Consider if there are other zones/locations that currently experience these climate patterns that may inform adaptive plans and design strategies.

Identify how these changes in extreme temperatures will impact public health and safety, especially populations that reside within Environmental Justice neighborhoods or climate vulnerable populations. Plans should consider how that impact may be mitigated through design.

How Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F F may inform Early Design

Consider the asset's useful life and possible operational and maintenance protocols that may need to change throughout the asset's useful life based on changes in extreme temperatures. The useful life of the asset may be less than expected due to changes in extreme temperatures. It may be helpful to examine an adaptive framework that considers increased maintenance needs and reduced useful life; identify tipping points or triggers as part of routine maintenance and inspection that would inform action for retrofits and/or replacement of assets to adapt to extreme temperatures over time.

Material selection may be impacted by changes in extreme temperatures, from pavement design to façade color choice. Integrating light colors with a high solar reflectance index (SRI), high density vegetation, increased tree canopy, and elements that provide shading can reduce the impacts of extreme heat by decreasing observed surface temperatures.

Extreme heat may also impact construction, including workplace safety considerations, and material selection, including potential deformation of heat sensitive materials (for example, steel or asphalt). Refer to additional applicable design criteria for more guidance related to Heat Index, Cooling and Heating Degree Days, and Growing Degree Days that may support and inform early design strategies.

How Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F may inform Project Evaluation

Consider if the project and subsequent assets address changes in extreme temperatures (increased extreme heat and reduced extreme cold) as part of the design narrative and/or operations plans, if any. Have the projected Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F been estimated following the recommended standards (planning horizon, percentile, and tiered estimation method) of this Tool. If not, justification should be provided for using a different method than the tiered estimation method recommended by the Tool. Have the impacts to public health and safety, in particular impacts to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations been identified with plans for mitigating those impacts as part of planning and design efforts? For examples of strategies, refer to Project Evaluation guidance under Projected Annual/Summer/Winter Average Temperatures above. Do they provide additional co-benefits for public space and/or the environment?

Limitations for Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F Standards and Guidance

The recommended Standards for Days Per Year with Maximum Temperature > 95°F, >90°F, <32°F are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Projected Heat Index

Definition

The National Weather Service (NWS) Heat Index or the "real feel" is based on temperature and relative humidity. The Heat Index is what the temperature feels like to the human body when relative humidity is combined with the air temperature and is measured in °F following the chart published by NWS.*

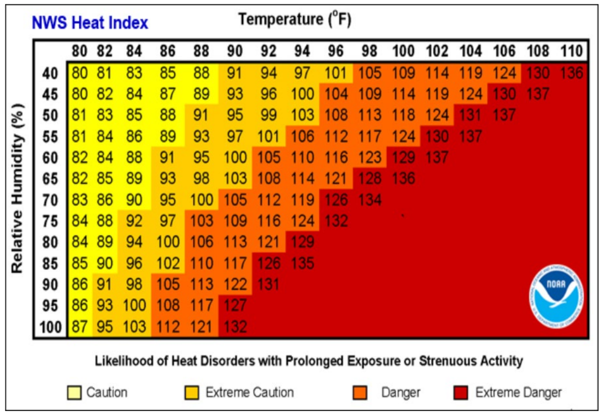

Figure of Heat Index Chart from NWS (https://www.weather.gov/ama/heatindex)

The NWS Heat Index considers shady and light wind conditions but does not account for strong winds or full sun exposure. Exposure to full sunshine can increase Heat Index values by up to 15°F and strong wind of very hot dry air can be detrimental to public health and safety. The NWS uses the Heat Index to issue warnings and advisories relevant to public health considerations when daytime heat indices is more than 100°F for two or more hours.

How to Estimate Projected Heat Index Values

Asset Name	Recommended Planning Horizon	Recommended Percentile**	Tiered Estimation Method	Step-by-Step Instructions
Test	Standards will be presented here			Downloadable Instructions PDF

***Note**: Projected Heat Index are not currently available through this Tool. Users should follow the step-by-step instructions outlined in the downloadable instructions PDF to estimate the projected Heat Index based on the recommended planning horizon, percentile, and tiered estimation methods. The three tiers represent various anticipated levels of effort for calculating design criteria values, dependent upon the consequences of failure of an asset as a function of scope, time, and severity and useful life of the asset.

How Heat Index may inform Planning

Evaluate how the increase in projected Heat Index may impact public health and safety, especially populations that reside within Environmental Justice neighborhoods or climate vulnerable populations, since Heat Index is a direct measure of feel-like temperatures. See the figure below for Heat Index effects on the human body.

Classification	Heat Index	Effect on the body
Caution	80°F - 90°F	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	90°F - 103°F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	103°F - 124°F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125°F or higher	Heat stroke highly likely

Figure of Heat Index Classification from NWS (https://www.weather.gov/ama/heatindex)

How Heat Index may inform Early Design

Consider the asset's useful life and possible design and/or operational and maintenance protocols that may need to change throughout the asset's useful life based on changes in Heat Index.

- For building assets, consider if the building materials can accommodate increased humidity and vapor impacts. Consider the potential increased need to reduce indoor air temperature and remove moisture. Will back-up power supply be needed for occupancy safety in the event of power shortages?
- For infrastructure assets, early design may need to consider seasonal implications and location considerations for regular maintenance activities. For example, will the asset need regularly scheduled maintenance during summer months in areas when the Heat Index is typically high? Consider if there will be an increased demand as a result of Heat Index? What are the implications on health and safety for people using or maintaining infrastructure assets?
- For open space assets, are there opportunities for increased vegetation and tree/constructed canopies that may reduce the temperature and relative humidity on site? Are there opportunities to add programming with water fountains, shaded structures, and/or cooling centers, especially for populations that reside within Environmental Justice neighborhoods or climate vulnerable populations?

How Heat Index may inform Project Evaluation

Consider if the project and subsequent assets address changes in Heat Index as part of the design narrative and/or operations plans, if any. Have the projected changes in Heat Index been estimated following the recommended standards (planning horizon, percentile, and tiered estimation methods) in this Tool? If not, justification should be provided for using a different method than the tiered estimation method recommended by the Tool. Have the impacts to public health and safety, in particular populations that reside within Environmental Justice neighborhoods or climate vulnerable populations, been identified with plans for mitigating those impacts as part of planning and design efforts? For examples of strategies, refer to Project Evaluation guidance under Projected Annual/Summer/Winter Average Temperatures above.

Limitations for Heat Index Standards and Guidance

The recommended Standards for Heat Index are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Projected Number of Heat Waves Per Year & Average Heat Wave Duration

Definition

A Heat Wave is defined as three or more consecutive days with maximum temperatures of 90°F or above. Number of Heat Waves represents number of events (with one event representing at least three consecutive days with maximum temperatures of 90°F), and Average Heat Wave Duration represents the number of days for the average duration of each event over the year.*

Heat Waves are a public health and safety threat that may result in heat-related deaths. According to World Health Organization (WHO), Heat Waves, "can burden health and emergency services and also increase strain on water, energy and transportation resulting in power shortages or even blackouts. Food and livelihood security may also be strained if people lose their crops or livestock due to extreme heat."

How to Estimate Projected Number of Heat Waves Per Year & Average Heat Wave Duration Values

Asset Name	Recommended Planning Horizon	Recommended Percentile**	Projected Number of Heat Waves per Year (events)	Projected Average Heat Wave Duration (days)
building	Standards and/or Projected Values will be presented here, if available			

How Number of Heat Waves Per Year & Average Heat Wave Duration may inform Planning

Evaluate how the increase in projected Heat Waves (number of events and duration) may impact public health and safety, especially populations that reside within Environmental Justice neighborhoods or climate vulnerable populations. Refer to Heat Index for additional considerations related to human health impacts.

Planning may consider early decisions related to asset orientation and location. For example, assets located in urban areas typically experience more Heat Waves than rural areas as a result of Urban Heat Island (UHI) effect (https://www.mapc.org/resource-library/extreme-heat/). Are there opportunities to relocate the asset to an area with less frequent Heat Waves per year? Are there opportunities to mitigate or adapt to the threats of Heat Waves in preliminary planning, through passive design or programming?

How Number of Heat Waves Per Year & Average Heat Wave Duration may inform Early Design

Consider the asset's useful life in conjunction with projected Number of Heat Waves Per Year & Average Heat Wave Duration. Evaluate if consecutive high heat days may shorten the useful life and/or operational ability of the asset. Identify if there are design and/or operational and maintenance protocols that may need to change throughout the asset's useful life.

Heat Waves may increase demand for emergency services and/or water and power supply that may result in strained resources, including water shortages and blackouts. Food and livelihood security may also be impacted as a result of frequent or prolonged Heat Waves due to loss of crops or livestock. Consider if the asset and/or site are impacted by these related threats, and if populations that reside within Environmental Justice neighborhoods or climate vulnerable populations are impacted as a result. Identify what may be needed to adapt or mitigate these impacts, including redundancies for critical systems and/or regional coordination efforts. Refer to additional applicable design criteria for more guidance related to Heat Index, Maximum Temperatures, Heating and Cooling Degree Days, and Growing Degree Days that may support and inform early design and early strategies.

How Number of Heat Waves Per Year & Average Heat Wave Duration may inform Project Evaluation

Consider if the project and subsequent assets address increased events of sustained extreme heat (number and duration of Heat Waves) as part of the design narrative and/or operations plans, if any. Have the projected changes in Number of Heat Waves Per Year & Average Heat Wave Duration been estimated following the recommended standards (planning horizon, percentile, and tiered estimation methods) of this Tool? If not, justification should be provided for using a different method than the tiered estimation method recommended by the Tool. Have the impacts to public health and safety, in particular populations that reside within Environmental Justice neighborhoods or climate vulnerable populations, been identified with plans for mitigating those impacts as part of planning and design efforts? For examples of strategies, refer to Project Evaluation guidance under Projected Annual/Summer/Winter Average Temperatures above.

Limitations for Number of Heat Waves Per Year & Average Heat Wave Duration Standards and Guidance

The recommended Standards for Number of Heat Waves Per Year & Average Heat Wave Duration are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Projected Cooling Degree Days & Heating Degree Days (base = 65°F)

Definition

Cooling Degree Days (CDD) is a metric used to inform the energy consumption needed to cool indoor spaces for occupancy comfort when outside temperatures exceed 65°F. CDD measures the difference between the average daily temperature and 65°F. For example, if the average temperature for the day is 95°F, the difference between 65°F results in 30 CDD for that day.

Heating Degree Days (HDD) is a metric used to inform the energy consumption needed to heat indoor spaces for occupancy comfort when outside temperatures are below 65°F. HDD measures the difference between the average daily temperature and 65°F. For example, if the average temperature for the day is 35°F, the difference between 65°F results in 30 HDD for that day.*

How to Estimate Projected Cooling Degree Days & Heating Degree Days Values

Asset Name	Recommended Planning Horizon	Recommended Percentile**	Projected Cooling Degree Days (base = 65˚F) (degree days)	Projected Heating Degree Days (base = 65˚F) (degree days)
building	Standards and/or Projected Values will be presented here, if available			

How Cooling Degree Days & Heating Degree Days may inform Planning

Massachusetts has historically had more HDD than CDD. Evaluate how the change in projected HDD and CDD may impact the initial planning and pre-design considerations associated with the asset and overall project. It may be useful to compare the percent increase between current and estimated projected HDD and CDD values. For example, there may be a 100% increase in CDD between present and future (twice as many CDD as we experience now), but only a 25% decrease in HDD. Planning and pre-design efforts should consider how the asset and overall project respond to current and future conditions through an asset's useful life.

It may be useful to compare the projected CDD and HDD with climate zones that have similar CDD and HDD under current conditions as a basis-for-discussion and reference. Evaluate how energy demands may need to change over time (annually or seasonally) and opportunities for sustainable and passive design strategies.

Identify potential impacts to public health and safety as a result of changes in projected CDD and HDD and identify what steps may be taken in planning and design to mitigate those impacts. Identify if are there additional impacts if the building serves populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.

How Cooling Degree Days & Heating Degree Days may inform Early Design

Consider the asset's useful life and possible operational and maintenance protocols that may need to change throughout the asset's useful life based on changes in projected CDD and HDD. The supporting mechanical, electrical, and plumbing components of the building may have a shorter useful life than the overall building due to changes in CDD and HDD. It may be helpful to examine an adaptive framework that considers increased maintenance needs and reduced component useful life; identify tipping points or triggers as part of routine maintenance and inspection that would inform action for retrofits and/or replacement of assets to adapt to changes in CDD and HDD over time. For example, are there opportunities for heating, ventilation, and air conditioning (HVAC) systems to be designed to efficiently perform under current and future conditions? Energy efficiency and sustainable design strategies are recommended to reduce overall energy consumption needs associated with CDD and HDD.

How Cooling Degree Days & Heating Degree Days may inform Project Evaluation

Consider if the design narrative (especially related to the mechanical, electrical, and plumbing components) and/or operations plans address changes in CDD and HDD. Have the projected changes in CDD and HDD been estimated following the recommended standards (planning horizon, percentile, and tiered estimation methods) of this Tool? If not, justification should be provided for using a different method than the tiered estimation method recommended by the Tool. Have the impacts been identified with plans for mitigating those impacts as part of planning and design efforts? Could this impact existing capital planning and/or regular maintenance schedules? Are there additional risks to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations that are addressed in plans and designs? For examples of strategies, refer to Project Evaluation guidance under Projected Annual/Summer/Winter Average Temperatures above.

Limitations for Cooling Degree Days & Heating Degree Days Standards and Guidance

The recommended Standards for Cooling Degree Days & Heating Degree Days are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Projected Growing Degree Days (base = 50°F)

Definition

According to the Climate Smart Farming program at Cornell University, Growing Degree Days (GDD) "measures heat accumulation to help agricultural producers predict when a crop will reach important developmental stages. It can also be used to help predict potential pest and disease threats."

Growing Degree Days (GDD) are a measure of heat accumulation that can be correlated to express crop maturity (plant development). GDD is calculated by subtracting a base temperature of 50°F from the average of the maximum and minimum temperatures for the day. Minimum temperatures less than 50°F are set to 50, and maximum temperatures greater than 86°F are set to 86. These substitutions indicate that no appreciable growth is detected with temperatures lower than 50° or greater than 86°. Increases in daily average temperatures over 50°F will result in an increase in GDD.*

GDD may inform planning and early design considerations for forested ecosystems, agricultural resources, and open spaces.

How to Estimate Projected Growing Degree Days Values

Asset Name	Recommended Planning Horizon	Recommended Percentile**	Projected Growing Degree Days (base = 50 ˚F, max = 86 ˚F) (degree days)
Test	Standards and/or Projected Values will be presented here, if available		

How Growing Degree Days may inform Planning

For planning purposes, GDD is often used to predict plant development and manage crop harvest. The projected GDD can help users assess how a particular season (current or historical) may compare to future seasons. For example, if an agricultural resource asset, consider if the asset or site is important for food security and how changes in GDD may impact food security. Evaluate if current species of plants/vegetation may be able to adapt to the increase in GDD. Identify if pollination may be affected as a result of changes to GDD. For example, if a forested ecosystem asset, evaluate if there may be impacts to forestry management or maple syrup production. Identify if there are populations that reside within Environmental Justice neighborhoods or climate vulnerable populations that rely on this asset and how changes in growing season length and timing affect them.

How Growing Degree Days may inform Early Design

Identify if the projected GDD may inform selection of crop varieties and planting and harvesting schedules. Analysis of GDD in relation to plant hardiness zones may be helpful in assessing species selection is for a site. https://www.fs.fed.us/nrs/pubs/rmap/rmap_nrs9.pdf. Identify if certain species may be appropriate for selection that are suitable to the changing climate and increased GDD; species selection may need to evolve over time to adapt to the changing climate. What alternatives should be considered that would increase resiliency of the ecosystem in growing season? Consider how increasing precipitation events (frequency and duration) as well as prolonged periods of drought may also inform planning and design.

How Growing Degree Days may inform Project Evaluation

Consider if the project and natural resource assets address increased GDD as part of the design narrative and/or planting plans for the growing season. Have the projected changes in GDD been estimated following the recommended standards (planning horizon, percentile, and tiered estimation method) of this Tool? If not, justification should be provided for using a different method than the tiered estimation method recommended by the Tool. Have the impacts to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations that may rely on this asset been identified with plans for mitigating those impacts as part of planning and design efforts? For examples of strategies, refer to Project Evaluation guidance under Projected Annual/Summer/Winter Average Temperatures above. Consider if the strategies response to other climate impacts (for example heavy rainfall or drought conditions).

Limitations for Growing Degree Days Standards and Guidance

The recommended Standards for Growing Degree Days are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for resilience. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.