ResilientCoasts

FINAL PLAN

APPENDIX II

Near-Term Adaptation Areas Technical Documentation

Executive Office of Energy and Environmental Affairs

CZM

ResilientMass

ResilientCoasts

November 2025

Massachusetts ResilientCoasts Plan

Technical Documentation for Near-Term Adaptation Areas

November 2025

INDUSTRIAL ECONOMICS, INCORPORATED

Prepared for:

Massachusetts Office of Coastal Zone Management
100 Cambridge St #900
Boston, MA 02114

Prepared by:

Industrial Economics, Incorporated
2067 Massachusetts Avenue
Cambridge, MA 02140

Table of Contents

Acknowledgements

This Appendix provides technical documentation for certain data used in the 2025 Massachusetts ResilientCoasts Plan. The methods and data addressed in this report are used to develop sector-level and overall vulnerability scores for initial Near-Term Adaptation Areas based on currently available data on the vulnerability and exposure of people and housing, built infrastructure, and economy to coastal flood risk. The work represents a collaboration between the Massachusetts Office of Coastal Zone Management (CZM) and contractors Woods Hole Group and Industrial Economics, Incorporated (IEc), a consulting firm with expertise in assessing the multisectoral impacts of climate change. Direction from CZM was provided by Chief Coastal Resilience Officer Deanna Moran. The primary project team at IEc included James Neumann, Isabel Holland, Charles Fant, Emily Evenden, and Jacqueline Willwerth.

The project team is grateful for the sharing of data and other assistance from multiple Massachusetts state agencies and other organizations, with particular thanks to Housing Navigator for providing access to data on affordable housing units.

1 | Introduction

This Appendix provides documentation of data used to identify the Near-Term Adaptation Areas included in the Massachusetts ResilientCoasts Plan (Chapter 6). The approach for identifying Near-Term Adaptation Areas, in general, was to focus on areas included in the 1% annual chance flood extent for the 2030s period (based on a sea level rise scenario of 1.2 feet above 2008 baseline), using modeling runs of the Massachusetts Coast Flood Risk Model (MC-FRM), and intersect those areas of near-term coastal flood risk with current high concentrations of people and housing, infrastructure, and economic resources. Note that within the ResilientCoasts Plan, the Near-Term Adaptation Areas differ from the Coastal Resilience Districts. The districts are designed to depict the areas with near- and long-term coastal flooding and erosion (based on the 0.1% annual chance flood extent for the 2070s period), while the Near-Term Adaptation Areas focus on near-term coastal flood risks.

The MC-FRM data has been used by the Commonwealth for a broad range of analyses, including the 2022 Massachusetts Climate Change Assessment and 2023 ResilientMass Plan. Massachusetts Office of Coastal Zone Management (CZM) provides a web-accessible viewer for the MC-FRM results which includes a representation of the 2030 1% annual chance flood extent. Detailed descriptions of the MC-FRM, the sea-level rise and storm surge representations, and other information on MC-FRM can be found in Appendix B of the 2022 Massachusetts Climate Change Assessment.

As stated in the ResilientCoast Plan, the purpose of these Near-Term Adaptation Areas is as follows:

- Identify coastwide where there is a confluence of people and housing, infrastructure, and economic resources **exposed to near-term (2030s) coastal flood hazard risk**
- Help inform **district-level prioritization** for public and private resources and intervention
- Help educate communities and other stakeholders about coastwide risk and **how their vulnerability compares** to the larger Coastal Resilience District and region

The remainder of this Appendix consists of five sections. Section 2 provides information on the overall methodology applied for the analysis, including inter-sectoral and cross-sectoral ranking procedures to arrive at an aggregate ranking of areas for adaptation focus. Sections 3 through 5 provide detailed information on the data sources, methods, and metrics used for a total of 15 indicators of concentration of people and housing (four indicators); built infrastructure (six indicators); and economic resources (five indicators). Each of these three sections addresses indicator construction in one of the three sectors. Section 6 provides a short summary of recommendations for future work to improve these indicators in subsequent updates to the ResilientCoasts Plan.

2 | Overall Methodology

The overall purpose of the approach to Near-Term Adaptation Areas is to identify the intersection of near-term coastal flood risk and concentrations of people and housing, built infrastructure, and economic resources. The approach seeks to be evidence-based, consistent with priority climate change and natural hazard impacts aligned with those from the 2022 Massachusetts Climate Change Assessment and the 2023 ResilientMass Plan, and wherever possible based on transparent and publicly available data sources.

Key elements of this approach therefore include the following dimensions:

- Each sector incorporates multiple indicators (four to six per sector) which contribute to an overall sectoral ranking.
- The indicators are constructed by assessing either coastal flood risk (e.g., average annual flood damage, or the frequency of extreme high-tide traffic delays) or exposure for each indicator using GIS analysis and other methods. Exposure-based indicators do not consider coastal flood frequency, but risk-based indicators do consider estimated flood frequency.
- As noted, all indicators estimate risk or exposure within the 2030 1% annual chance flood extent within US Census Block Groups, within the limits of available data. Some indicators (such as point locations of some categories of built infrastructure) can be more reliably located within the coastal flood extent. Buildings can be located within the coastal flood extent using MassGIS building footprint data, but the exact purpose of buildings in the flood extent (e.g., residence, industrial, employment center) is more difficult to determine and is sometimes based on the best available attribution at the Census Block Group scale.
- There are a total of 894 Census Block Groups with some portion of their area within the 1% annual chance flood extent. Each Census Block Group is assigned a rank, from highest to lowest vulnerability, based on the methods described in Sections 3 through 5. The indicator-level ranks are

Highlights of the Methodology

- Focused on identifying the intersection of near-term coastal flood risk and concentrations of people and housing, built infrastructure, and economic resources.
- The spatial unit of analysis is the Census Block Group – 894 block groups in the Commonwealth have some portion of their area within the 2030 1% annual chance flood extent.
- All Census Block Groups are ranked for all 15 indicators – the rankings are used within sectors and across sectors to estimate which Block Groups have the greatest overall projected vulnerability to coastal flooding.
- Many of the indicators align with priority impacts of climate change, identified by stakeholders and experts engaged in the 2022 Massachusetts Climate Change Assessment and the 2023 ResilientMass Plan. As a result, many indicators also draw on data developed in those efforts.
- Indicators in the people and housing sector in particular measure the potential vulnerability of lower income and other EJ populations while also recognizing the importance of all residential structures in the Commonwealth in guiding near-term adaptation.
- Built infrastructure indicators focus on the direct risks of coastal flooding to physical infrastructure. Indirect risks (such as effects of damaged transit infrastructure for riders that live outside the near-term coastal flood extent) are also important, but adaptation actions that focus on preventing the direct impacts will, by extension, also prevent most or all of the consequent indirect effects.
- Indicators of concentrated economic activity present unique challenges, because economic resources can be difficult to reliably locate with the coastal flood extent. As a result, more of the indicators rely on "proxy" data, such as impacts to roads important to economic activity.

then combined into a sectoral score using an indicator weighting scheme also described in the subsequent chapters.

- We used the *Calculate Composite Index* tool in ArcGIS Pro to generate standardized indices by combining multiple input variables within the three sectors (People and Housing, Built Infrastructure, and Economy) into a single index variable. Index variables were scaled and ranked, with the smallest value assigned a rank of 1, the next value assigned a rank of 2, and so on. Ties received the average of their ranks. We combined the scaled variables using an average ranking to produce the final composite index score. This feature in ArcGIS Pro also applies the indicator weights mentioned in the previous bullet – the specific weights applied to each indicator for the People and Housing, Built Infrastructure, and Economy sectors are described in Sections 3, 4, and 5, respectively.[1]

- An overall composite cross-sectoral ranking *across* the three sectors is generated based on the sectoral composite scores. Census Block Groups in the top 15 percent of sectoral ranking (the 85th percentile, constituting the 134 highest ranked Census Block Groups) are identified, and the cross-sectoral Census Block Groups with 85th percentile rankings in one, two, or three sectors are identified as having the highest cross-sectoral rank.

- All results presented in the ResilientCoasts Plan are mapped by Census Block Group. While a more accurate visual representation would be to clip the mapped area to the 1% annual chance flood extent, the entire Census Block Group is shown for visual clarity. At the coastwide scale, many of the areas within the 1% annual chance flood extent are a thin strip along the coast making it difficult to see the data visualizations. The data underlying the rankings, however, considers only areas within the near-term flood extent. More detailed mapping can be found in Appendix III where the data has been clipped to the MC-FRM 1% annual chance flood extent and is shown by Coastal Resilience District rather than coastwide scale.

- There are several important limitations in the methods and data used to identify Near-Term Adaptation Areas. Most of these limitations involve imprecision in the location of resources in each Census Block Group to the space within the near-term flood extent – for example, as noted above, while structure location can be located with reasonable accuracy using the MassGIS building footprint layer, the use of the building, such as for residential or commercial use, must be inferred from Census Block Group level information.[2] It was not possible to exhaustively ground-truth locations, or to independently verify the more than one dozen datasets used in this work. The results are appropriate for planning scale decision making but are not of a resolution or level of detail appropriate for project-specific work.

---

[1] The function used is the ArcGIS Composite Index tool. Specific function settings applied are as follows: 1. Preset Method to Scale and Combine Variables: Custom; 2. Method to Scale Input Variables: Rank; 3. Method to Combine Scaled Variables: Average; 4. Variable Weights (example given is for People and Housing sector): 1_annDamRes = 0.25; 3_haa = 0.25; 5_popD1_r = 0.25; 6_ej_v2_r = 0.25; 5. Additional Classified Outputs: Quantile (Output Index Number of Classes = 10).

[2] For determining whether structures were residential or commercial, for example, the analysis differentiates damage to residential structures from commercial structures using the ratio of total structure value in each category data at the CBG level.

3 | People and Housing Sector

Indicators in the People and Housing sector focus on two metrics of housing vulnerability (damage to residential buildings of all types and affordable housing units at risk of flooding), and two metrics of population vulnerability to flooding (overall residential population potentially exposed to flooding and the Environmental Justice (EJ)-designated residential population potentially exposed to flooding). This section provides a summary of methods and data used to characterize vulnerability of people and housing to coastal flood risk. Table 1 below provides a summary of the four indicators, gives a brief description of the indicator, data sources, spatial resolution of the data, and the units of the indicator used to rank Census Block Groups (CBGs).

TABLE 1. Indicators used in the People and Housing Sector for Near-Term Adaptation Areas

Indicator	Description	Data Sources	Data Type	Indicator Units
• **Projected Residential Building Damage**	Annual Expected Damage (AED) for residential buildings in 2030 1% annual chance flood extent	2022 Massachusetts Climate Assessment and Neumann et al. (2021) Building Structures (2-D), Nov 2024 from MassGIS	Damage and total value at 150 m grid Share of residential value at CBG level	Percent damage (of total residential structure value), scaled to be a value between 0 and 1.
• **Affordable Housing Units**	Number of (income-restricted) units in 2030 1% annual chance flood extent	Housing Navigator Massachusetts	Point data (from address)	Number of units (subject to data use agreement, proprietary)
• **Residential Population Exposed**	Estimated residential population exposed to flooding	2020 Census data Residential and building footprint from indicator 1	CBG level, but scaled by portion of residential building area in floodplain	Population count
• **Environmental Justice Population Exposed in EJ CBGs**	Estimated EJ-designated residential population exposed	EEA Office of EJ & Equity derived from Census American Community Survey (ACS) data	CBG level, scaled by residential building area in floodplain and EJ share of population	EJ population count (summed for all three EJ categories)

To develop an overall ranking of CBGs for this sector, the rankings for each of the four indicators are equally weighted.

3.1 People and Housing Indicator 1: Residential Building Value Vulnerability

Description:

This indicator attempts to estimate the magnitude of residential buildings vulnerable to coastal flooding. The metric applied is the annual percent damage of total residential structure value for buildings in the MC-FRM 2030 1 % annual chance flood extent. All residential buildings are considered, with any height, ownership, or occupancy, but commercial, industrial, or other types of structures are excluded. These residential buildings could be exposed to coastal flooding, whether the occupants rent or own the structure.

Data Sources:

This indicator is derived from data used in the Massachusetts Climate Change Assessment and ResilientMass Plan, using methods and some data sources from the National Coastal Property Model (NCPM), which was developed by U.S. Environmental Protection Agency and IEc to estimate coastal structure (buildings) damage and the potential for land to be permanently inundated because of sea-level rise and periodic storm surge. For this metric, only the estimates of the value of structures are used, resolved to 150-meter grid cell scale and updated to 2017 assessed values, corrected to market values using site-specific equalization ratios. The assessed value data is subject to a data use agreement and cannot be shared directly. Note that the Project Team could not use MassGIS data on structure values for two reasons: (1) It was not possible to re-run the NCPM with MassGIS data for this purpose owing to time and resource constraints; and (2) The codes used for assigning structure value to a residential purpose are not fully consistent across municipalities within Massachusetts at this time. Data on percent residential value (as a portion of total structure value) by CBG is also derived from the NCPM data. The NCPM model and data are described in more detail in Neumann et al. (2021).

The analysis differentiates damage to residential structures from damage to commercial structures using a ratio of total structure value in each category data at the CBG level. Data from MassGIS on building footprint locations are used to ensure that building footprints intersect with the 1 % annual chance flood extent. In CBGs where no structure footprints intersect with the near-term flood extent, damage is set to zero.

Depth-damage functions that provide an estimate of the percent of residential structure value damaged for a given depth of stillwater flooding (no wave action) are derived from documentation of FEMA's HAZUS flood hazard model and assigned to the predominant residential structure type prevalent to CBGs (e.g., two-story residential buildings with basements).

Summary of Method:

Damages to residential buildings incorporate the MC-FRM 2030 flood data for areas within the 1% annual chance flood extent. The damages reflect an average annual percent damage calculated from a flood depth exceedance curve, which is converted to a damage exceedance curve using the HAZUS depth-damage relationships. The curve is constructed from the probability and depth of flooding for the six return period flood depths generated by MC-FRM for 2030 – the 5%, 2%, 1%, 0.5%, 0.2%, and 0.1% annual chance. The average annual damage percentage is the sum of all estimated damage percentages multiplied by their respective probabilities – or effectively the area under the damage exceedance curve.

Note that the percentage damage value used in this indicator is calculated as the total estimated average annual damage for all properties in the CBG's 1% annual flood extent divided by the total structure value of all properties in the CBG's 1% annual flood extent.

Data Type:

Percent damage and total value from the original data are at 150 m grid spacing; the share of residential structure value is at the CBG level. Data used to rank CBGs is provided at the CBG level.

Indicator Units:

Annual average percent damage from coastal flood hazard, scaled to be a value between 0 and 1. Numerator is total average annual loss to structures in 2030 within the 1% annual chance flood extent area of the CBG; denominator is total residential structure value within 1% annual chance flood extent area of the CBG. This metric is designed to characterize the potential for physical damage from flooding, rather than differences in residential market value that might affect the expected annual dollar damages from flooding. This percentage approach is the same indicator used in the Massachusetts Climate Change Assessment and the ResilientMass Plan. The reasoning is that a percentage metric guards against focusing on areas with high market value – and instead provides more of a flood damage intensity indicator.

3.2 People and Housing Indicator 2: Affordable Housing Vulnerability

Description:

This indicator measures the number of units of permanent, affordable (income-restricted) housing located in the near-term coastal flood area (i.e., the MC-FRM 2030 1 % annual chance coastal flood extent).

Data Sources:

Number and locations of units are provided by an agreement with Housing Navigator Massachusetts. The number and locations of affordable housing units cannot be provided publicly as it is subject to a data use agreement which restricts data sharing for privacy reasons.

Summary of Method:

CBGs are ranked by the total number of affordable housing units located within the 1% annual chance flood extent. Forty-eight of the 894 CBGs included in this analysis have affordable housing units in the flood extent area; all other CBGs are assigned a value of zero and are equally ranked in the 49th position. These 48 are ranked by the number of units within flood extent. The data that can be shared publicly includes the identification of the 48 CBGs with nonzero units in the flood extent.

Data Type:

CBG, scaled to the 1% annual chance flood extent within the CBG.

Indicator Units:

Affordable housing unit count. As noted above, however, the actual counts of units cannot be shared publicly, only the presence or absence of units for each CBG can be shared.

3.3 People and Housing Indicator 3: Total Population at Risk of Coastal Flooding

Description:

This indicator estimates the magnitude of residential population that resides in the coastal flood area (i.e., the MC-FRM 2030 1% annual chance coastal flood extent). These populations could be exposed to coastal flooding of their residence, whether rented or owned.

Data Sources:

Total population data by CBG from the U.S. Census Bureau's American Community Survey (ACS) for the years 2016 to 2020.

Summary of Method:

CBG level populations are adjusted to estimate the number of people in each CBG who reside within the 1% annual chance flood extent. Starting with Census population data at the CBG level, IEc scaled these data by the portion of the residential building area of that CBG that is present in the 1% annual chance flood extent. This percentage varies by CBG. In other words, if 2,500 people live in a CBG, and we calculate that 10% of the residential building area in the CBG lies in the flood extent, then we attribute 250 people reside in the flood area.

The data are adjusted for intensity of flood risk using a "distance to shore" adjustment. The indicator for each CBG is adjusted using the inverse of the distance from the shoreline as a weighting factor to reflect the intensity of the flood risk. For all CBGs that are directly on the coast, a weight of 1 is assigned. For CBGs inland of that line, a weight corresponding to the inverse of the distance to the shore (that is, a number less than one) adjusts the indicator downward relative to those CBGs directly on the shoreline.

Data Type:

CBG, scaled to the 1% annual chance flood extent within the CBG.

Indicator Units:

Population count.

3.4 People and Housing Indicator 4: Environmental Justice Populations Exposed to Coastal Flood Risk

Description:

This indicator attempts to estimate the proportion of state-designated Environmental Justice (EJ) populations that reside in the coastal flood area used for all indicators (i.e., the MC-FRM 2030 1% annual chance coastal flood extent). These EJ populations could be exposed to coastal flooding of their residence, whether rented or owned.

Data Sources:

EJ population data by CBG were provided to the project team by the EEA Office of Environmental Justice and Equity. These population count data support the official designations of CBGs in the EEA EJ Map Viewer based on demographic data from the U.S. Census Bureau's American Community Survey (ACS) for the years 2016 to 2020. The data include total CBG populations and the percentage of the population in two categories: minority and English language isolated.[3] Both of these categories and the counts of population are defined based on self-reported ACS responses to the ACS and using Census definitions for both terms.

IEc used data from the Massachusetts Climate Change Assessment to develop estimates of low-income populations in each MA EJ CBG. These data define individuals in a low-income household as having household income at or below two times the federal poverty level – or approximately $40,000 to $50,000 in 2024.[4] This is a slightly lower threshold than defined at the CBG level in the MA EJ statute, which uses a CBG wide threshold of 65 percent of the median Massachusetts statewide household income (Census reports the median household income for Massachusetts as $101,341 for 2019-2023 – 65 percent of this is just over $65,000). ACS data provides the percentage of population at or below two times the federal poverty level in each CBG, but do not report populations at or below higher income levels.

Summary of Method:

IEc first identified all Massachusetts CBGs that meet any type of EJ designation, from the EEA EJ Map Viewer data source.

CBG level populations are then adjusted to estimate the number of people in each CBG who reside within the 1% annual chance flood extent. Starting with Census population data at the CBG level, IEc scaled these data by the portion of the residential building area of each CBG present in the 1% annual chance flood extent. This percentage varies by CBG.

IEc then adds population counts in multiple categories if the CBG is designated as EJ for multiple categories. In other words, if a CBG is designated as low income only, then the indicator reflects only the estimated low-income population exposed to flooding. If, instead, the CBG is designated as both low income and language isolated, the indicator sums the low income and language isolated population estimates. All three population estimates are summed in those CBGs designated in the EJ Map Viewer as low income, minority, and language isolated.

In some and perhaps many cases this summation may result in double-counting – that is, some of the same people may be low income, minority, and/or language isolated.[5] There is no reliable way to resolve this potential double-counting using publicly available ACS data – even if ACS data provided cross-tabulation data, the calculation would be compromised by the scaled data used to estimate populations in the area of the 1% annual chance coastal flood extent. As a result, this indicator can be considered more of an index of total EJ population flood vulnerability than a strict EJ population count, providing additional weight to CBGs where the population meets more than one of the EJ thresholds.

[3] EEA did not provide data on the low-income population in each CBG, so IEc estimated as described in the next paragraph.

[4] Measures are from federal poverty level data, which are a measure of income updated yearly by the Department of Health and Human Services (HHS) and that is used to determine eligibility for certain programs and benefits such as Medicaid and the Children's Health Insurance Program (CHIP) coverage.

[5] Note that there is also a fourth state-defined EJ category for low-income and minority status combined, with lower thresholds for both. CBGs which qualify for this fourth category are also include in the EEA CBG data and online map used here and provided at https://mass-eoeea.maps.arcgis.com/apps/MapSeries/index.html?appid=535e4419dc0545be980545a0eeaf9b53 .

Finally, IEc uses the same "distance to shore" adjustment as was described for indicator 3 above. The indicator for each CBG is adjusted using the inverse of the distance from the shoreline as a weighting factor to reflect the intensity of the flood risk. For all CBGs that are directly on the coast, a weight of 1 is assigned. For CBGs inland of that line, a weight corresponding to the inverse of the distance to the shore (that is, a number less than one) adjusts the indicator downward relative to those CBGs directly on the shoreline.

Data Type:

CBG, scaled[6] to the 1 % annual chance flood extent within the CBG.

Indicator Units:

Population count. As noted, however, the population count will reflect some level of double counting of individuals who meet the definition of multiple EJ categories (low income, minority, language isolated).

[6] In general, "scaled" in this context means that, as with the overall population indicator, the EJ population at CBG level is allocated to the 2030 1% annual floodplain proportionate to the CBG-level ratio of residential building footprint area in the floodplain versus in the CBG as a whole. There are some nuances about how this applied specifically to individual EJ category populations (low income, minority, language isolated).

4 | Built Infrastructure Sector

Indicators in the Built Infrastructure sector focus on the vulnerability of roads (with two metrics, one for roads affected by high-tide flooding and one for more intense episodic storm flooding), rail transit (with two metrics, one for the passenger rail network and one for critical supporting infrastructure), municipal and health sector structures, and utility infrastructure. This section provides a summary of methods and data used to characterize vulnerability of each of these categories of built infrastructure to near-term coastal flood risk. Table 2 below provides a summary of the six indicators, gives a brief description of the indicator, data sources, the spatial resolution of the data, and the units of the indicator used to rank CBGs.

TABLE 2. Indicators used in the Built Infrastructure Sector for Near-Term Adaptation Areas

Indicator	Description	Data Sources	Data Type	Indicator Units
• **Roads – High-tide Flood Vehicle Delays**	Estimated hours of traffic delays from high-tide flooding in 2030s	2022 Massachusetts Climate Change Assessment and Fant et al. (2021)	Road segments (often areas between intersections, as defined by U.S. DOT)	Lost value of time (in dollars) from annual vehicle hours of delay (in NOAA high tide areas)
• **Roads – Flood Vulnerability**	Total average annual daily traffic (AADT) located within the floodplain, summed across all segments	MassDOT network and traffic volume: https://gis.data.mass.gov/datasets/massgis::massgis-massdot-roads/explore	Road segments (often areas between intersections, as defined by U.S. DOT)	Total daily vehicle trips vulnerable to flood (excludes bridge traffic)
• **Transit Rail Exposure**	Total passenger track length within coastal flood extent	Rail Inventory | MassGIS Data Hub MassGIS Data: MBTA Rapid Transit | Mass.gov	Transit line data	Feet of passenger track (excludes Silver Line)
• **Transit Critical Infrastructure Exposure**	MBTA-designated critical transit maintenance areas within flood extent	MBTA-supplied GIS data	Polygon locations	Area (square meters) within flood extent

• **Public and Health Services Infrastructure**	Municipal services and public facilities (police, fire, schools, libraries, child care centers, town and city halls.) Hospitals and health centers (hospitals, community health centers, long-term care centers	ResilientMass Climate Hub (arcgis.com), MassGIS Data Layers | Mass.gov	Point locations	Number of locations
• **Utility Exposure**	Wastewater treatment plants, major electrical substations, fuel terminals, large hazardous waste quantity generators in	EPA Facility Registry Service (FRS) Wastewater Treatment Plants | HIFLD (arcgis.com); Power Plants | U.S. Energy Atlas (eia.gov); Substations [and others as indicated in main text]	Point locations	Number of locations

To develop an overall ranking of CBGs for this sector, the rankings for the four main categories of resource - roads, transit, public and health services infrastructure, and utility infrastructure - are each assigned an equal 25 percent weight. Since two indicators are used for each of the road and transit categories, each of the two indicators in those categories is in turn given equal (50 percent) weight within the category, resulting in a 12.5 percent overall sector weight for each of the four road and transit indicators.

4.1 Built Infrastructure Indicator 1: Roads – High-tide flood vehicle delays

Description:

This indicator estimates the extent to which Massachusetts coastal roads are temporarily flooded as the result of extreme high tide, as defined in NOAA's Sea Level Rise Viewer. The length and extent of such extreme high-tide flooding on roads leads to traffic delays – the higher the level of travel typically using the road, and the longer the extent of the flooding period, the more traffic delays result. Traffic delays are expressed as the value of lost time to travel – which equals traveler hours (hours of delay multiplied by average vehicle occupancy) multiplied by a U.S. Department of Transportation (DOT) estimate of the economic value of lost time, as used in Fant et al. 2021.

Data Sources:

This indicator is derived from data used in the Massachusetts Climate Change Assessment and ResilientMass Plan, using methods and some data sources from a published national-scale analysis of current and projected daily tidal flooding of roads and the resulting traffic delays (see Fant et al. 2021). The study used road network and average annual daily traffic (AADT) from U.S. DOT; road elevation data from Jacobs et al. (2018); and estimated the traffic delay impacts in all of the NOAA high tide areas located in the Commonwealth.

Summary of Method:

Data on road delays are resolved from road segments to CBGs using GIS analysis and a spatial allocation algorithm that apportions road segments spanning multiple CBGs using the length of road segment within each CBG. In the underlying modeling, the ability of drivers to change routes to avoid temporary high-tide flood events is accounted for by an adjustment procedure for time lost that incorporates an index of road density and route redundancy developed and applied at the CBG level. All flood events lead to some delays, but in areas with a high degree of route redundancy those delays are less than in areas with fewer routing options. This is a simplified measure of trip disruption – actual trip routes and trip disruption algorithms are not used in the underlying study.

This metric is the product of the hours of high-tide flood delay, AADT by passenger and freight type for the relevant road segment, U.S. DOT average vehicle occupancy rates for passenger vehicles, and U.S. DOT recommended valuation rates per hour of delay for passenger and freight vehicles.[7]

[7] Average vehicle occupancy rates from FHWA. 2013. Highway functional classification concepts, criteria and procedures. 2013 ed. Washington, DC: US DOT, FHWA. To quantify the unit cost of delay for passenger vehicle-hours, the value of travel time savings (VTTS) estimates from the US Department of Transportation's 2016 guidance—$20.40 ($2,015 per person-hour)—are used. The National Cooperative Highway Research Program (NCHRP) inputs to their truck freight reliability valuation model (NCHRP 2016) are used to quantify the hourly cost of delay for freight vehicles. These costs include $65 per delay hour for operating and maintenance costs (including fuel, truck/trailer lease or purchase payments, repair and maintenance, and driver wages and benefits) and $35 for cargo-related supply chain costs, for a total of $100 per delay hour per truck (NCHRP - National Cooperative Highway Research Program – Transportation Research Board; National Academies of Sciences, Engineering, and Medicine. 2016. Methodology for estimating the value of travel time reliability for truck freight system users. Washington, DC: National Academies Press.

Data Type:

Road segments (typically road lengths between intersections) within CBGs.

Indicator Units:

Lost value of time in 2030 from the annual vehicle occupant hours of delay.

4.2 Built Infrastructure Indicator 2: Roads – flood vulnerability

Description:

This indicator estimates the total average annual daily traffic (AADT) for the full length of the road network for the 2030 1 % annual chance flood extent in each CBG. The metric includes AADT for all primary, secondary, and tertiary roads.

Data Sources:

MassDOT road network and traffic volume from publicly available sources – see https://gis.data.mass.gov/datasets/massgis::massgis-massdot-roads/explore

Summary of Method:

Total AADT for all roads identified in the MassDOT road network within each CBG is summed. A single trip across multiple road segments may register as multiple trips, one within each road segment – as such this metric provides an estimate of both the number of trips and their length within the flood-affected area. The criticality of the road segment or the ability of passengers to change routes is not accounted for in this metric.

Data Type:

Road segments within CBGs.

Indicator Units:

Total daily vehicle trips vulnerable to any type of flood considered in 2030 1% annual MC-FRM flood extent. The count excludes bridge traffic.

4.3 Built Infrastructure Indicator 3: Transit rail exposure

Description:

This indicator estimates the linear extent of passenger transit rail (both rapid transit and commuter and long-distance rail) which lies within the 2030 1% annual chance flood extent.

Data Sources:

This indicator relies on data from two sources:

- The locations of passenger rail lines are from the MassGIS data hub: Rail Inventory | MassGIS Data Hub. For this indicator, all lines with a primary purpose of carrying passengers, including Amtrak lines and Massachusetts Bay Transportation Authority (MBTA) commuter rail, are used.

- The location of surface mass transit lines, also from MassGIS: MassGIS Data: MBTA Rapid Transit | Mass.gov. Only surface lines are counted, below-ground lines traveling through tunnels are excluded. We also excluded the Silver Line, which is a bus line which travels on some of its route on surface roads, to avoid potential double counting with the roads indicators.

Summary of Method:

The total linear extent of rail lines within each CBG and also within the flood extent is counted. Rail lines on bridges over water are manually excluded.[8]

Data Type:

Line data are used, allocated to CBG and the flood extent.

Indicator Units:

Feet of passenger track (excludes the Silver Line).

4.4 Built Infrastructure Indicator 4: Transit Critical Infrastructure Exposure

Description:

This indicator estimates the areal extent of MBTA critical support infrastructure facilities within the MC-FRM 2030 1% annual chance flood extent. The critical facilities include maintenance yards, layover areas, and certain stations – all of which were explicitly identified by MBTA personnel as critical to the continuing operation of rapid transit and bus systems; transit track was not incorporated. All area within the property boundaries identified by MBTA personnel for this project are counted equally.

Data Sources:

This indicator is derived from GIS data in polygon format provided by representatives of the MBTA.

Summary of Method:

The variable rank is based on the total area of the polygon in the floodplain of all critical facilities polygons.

Data Type:

The original polygon data are allocated to the near-term flood extent within CBGs. Data used to rank CBGs are based on the total area for all critical facilities.

---

[8] We exclude rail impacts from the following CBGs where train tracks are on bridges intersecting the 2030 1% flood extent in the Charles and Merrimack Rivers. List of CBGs: 250092501001, 250092515001, 250092516004, 250092601002, 250092608002, 250092610002, 250092610003, 250092611022, 250173521021, 250173523003, 250173531021, 250173531023, 250173532002, 250173533003, 250250008071, 25025981501.

Indicator Units:

Area of critical facilities properties (in square meters) within the flood extent.

4.5 Built Infrastructure Indicator 5: Local facilities and health infrastructure

Description:

This indicator measures the number of municipally owned facilities and other select public services and the number of health infrastructure facilities within the 2030 1% annual chance flood extent. All structures meeting the definitions used below are included, with any height, ownership, or occupancy. These buildings may be exposed to coastal flooding.

Data Sources:

This indicator is derived from location data available from MassGIS or related data sources. The specific data files used for six municipal or public service types of facilities and three types of health care facilities (of any ownership) are as follows. The descriptions below include the data label used in the shape files developed for this work.

1. **Police** (Police stations): https://gis.data.mass.gov/datasets/massgis::police-stations-feature-service/about
2. **Fire** (Fire stations): https://gis.data.mass.gov/maps/massgis::massachusetts-fire-stations/about
3. **Schools**: https://gis.data.mass.gov/maps/a7ccf184af704f5fbd17d69f935554d6/about
4. **Libraries**: https://gis.data.mass.gov/datasets/massgis::massachusetts-public-libraries-feature-service/about
5. **TownHalls** (Town/city halls): https://gis.data.mass.gov/datasets/massgis::town-and-city-halls-feature-service/about
6. **CCCs** (Childcare centers): https://hifld-geoplatform.hub.arcgis.com/datasets/geoplatform::child-care-centers/about
7. **AHosp and NAHosp** (Hospitals (both acute and nonacute)): https://www.mass.gov/info-details/massgis-data-acute-care-hospitals AND https://www.mass.gov/info-details/massgis-data-non-acute-care-hospitals
8. **CHCs** (Community Health Centers): https://www.mass.gov/info-details/massgis-data-community-health-centers
9. **LTCCs** (Long-term care centers): https://gis.data.mass.gov/datasets/massgis::long-term-care-residences-feature-service/about

Summary of Method:

Municipal/public service and health care facility locations within the 2030 1% flood extent are identified and the number of locations summed across both types (municipal/public service and health care) for each CBG.

Data Type

Point location data converted to counts within each CBG.

Indicator Units:

Number of municipal buildings or public service locations plus the number of health care facility locations within the flood extent in each CBG.

4.6 Built Infrastructure Indicator 6: Utility exposure

Description:

This indicator measures the number of utility facilities of various types within the 2030 MC-FRM 1% annual chance flood extent. All locations in the underlying dataset are points, rather than building footprints, so it is possible that some larger facilities that are not shown within the 2030 1% annual chance flood extent may have a portion of their overall facility footprint within the flood extent, even though the point location data does not indicate as such. These facilities may be exposed to coastal flooding.

Data Sources:

This indicator is derived from location data available from MassGIS, national government data sources, or was provided to CZM by specific state agencies engaged in the ResilientCoasts planning process. The specific data files used for six types of utility facilities (of any ownership) are as follows. The descriptions below include the data label used in the shape files developed for this work.

1. **WWTP** (Wastewater treatment plants): https://hifld-geoplatform.hub.arcgis.com/maps/4b9bac25263047c19e617d7bd7b30701/about
2. **Subs** (Major Electrical Substations): https://www.fisheries.noaa.gov/inport/item/66139
3. **MBTASubs** (MBTA Substations): Provided by MBTA to CZM, and shared with the consultant team via email on 2/10/25
4. **Powerplants**: https://atlas.eia.gov/datasets/eia::power-plants/about
5. **FuelT** (Fuel Terminals): Identified by CZM and provided to the consultant team via email on 2/24/2025
6. **LQG** (Large Quantity [Hazardous Waste] Generators): https://gis.data.mass.gov/datasets/massgis::massdep-major-facilities/about
    - This data set was queried as follows: **LQG_MA** (Large Quantity Generators of MA-regulated Hazardous Waste) = **Y OR LQG_RCRA** (Large Quantity Generators of EPA/RCRA-regulated Hazardous Waste) = **Y**

Note that for items 2 and 3 above, one MBTA substation was also included in the Major Electrical Substations dataset (GEOID 250235091024 Substation ID UNKNOWN133451). That location was counted once to avoid double counting an identical facility location.

Summary of Method:

Utility locations within the 2030 1% flood extent are identified and the number of locations summed for each CBG.

Data Type:

Point location data converted to location within each CBG.

Indicator Units:

Number of relevant resources within the CBG. Count is the number of utility locations within the flood extent in each CBG.

5 | Economy Sector

Indicators in the Economy sector focus on the vulnerability of commercial and industrial building; employment; Massachusetts Designated Port Areas (DPA) and working waterfronts; freight rail lines; and the high-tide flooding of roads indicator described in Section 4.1 of the Built Infrastructure sector. The last of these is an exact duplication of the metric from the Built Infrastructure sector, but in the Economy sector is designed as a proxy for limitation to mobility that could affect the tourism and associated coastal recreation businesses. This section provides a summary of methods and data used to characterize vulnerability of each of these categories of economic resources to near-term coastal flood risk. Table 3 below provides a summary of the five indicators, gives a brief description of the indicator, data sources, the spatial resolution of the data, and the units of the indicator used to rank CBGs.

TABLE 3. Indicators used in the Economy Sector for Near-Term Adaptation Areas

Indicator	Description	Data Sources	Data Type	Indicator Units
• **Commercial and Industrial Building Value at Risk**	Annual Expected Damage (AED) for commercial and industrial buildings in flood extent	2022 Massachusetts Climate Change Assessment and Neumann et al. (2021)	Damage and total value at 150 m grid Share of commercial/ industrial value at CBG level	Estimated dollar value of average annual loss in 2030s.
• **Jobs Exposure**	Estimated total jobs in CBG but allocated to commercial and industrial buildings in flood extent	US Census, LEHD Origin-Destination Employment Statistics (LODES)	Jobs data at CBG level, scaled by commercial/ industrial building area within floodplain	Total number of jobs
• **DPA and Working Waterfront Exposure**	State Designated Port Areas and Working Waterfronts within coastal flood extent	Designated Port Areas and Working Waterfronts as identified by the location of Seaports from MassDOT and Marinas from MORIS	Polygon (DPA) and location data Polygon data converted to location within each included CBG	DPA designation plus number of working waterfront locations
• **Freight Rail Line Exposure**	Total active freight track length within coastal flood extent	Rail Inventory | MassGIS Data Hub	Line data – that is, lines representing the center of the rail bed	Feet of freight track

• **Roads – High-tide Flood Vehicle Delays**	Estimated lost value of time to traffic delays from high-tide flooding in 2030s	2022 Massachusetts Climate Change Assessment and Fant et al. (2021)	Road segments as identified in U.S. DOT data used in Fant et al. (2021). See below for additional details.	Annual economic value of time lost to delay (in NOAA high tide areas) (see NOAA SLR Viewer)

To develop an overall ranking of CBGs for this sector, each of the five indicators is equally weighted.

5.1 Economy Indicator 1: Commercial and Industrial Building Value at Risk

Description:

This indicator estimates the magnitude of commercial and industrial building vulnerability. The metric applied is the total average annual coastal flood damages for commercial and residential buildings in the 2030 1% annual chance flood extent. All commercial and residential structures are considered, with any height or ownership, but residential and other types of structures are excluded. These commercial and residential buildings could be exposed to coastal flooding, and the value lost could represent damage to structure or contents. Compensation for losses from insurance are not considered. Indirect losses, such as lost productivity, business interruption, lost sales or revenue, or temporary or permanent employment losses are also not considered in this metric.

Data Sources:

This indicator is derived from data used in the 2022 Massachusetts Climate Change Assessment and 2023 ResilientMass Plan, using methods and some data sources from the National Coastal Property Model (NCPM), which was developed by U.S. Environmental Protection Agency and IEc to estimate coastal structure damage and the potential for land to be permanently inundated as a result of sea-level rise and periodic storm surge. For this metric, only the estimates of the value of structures are used, resolved to 150-meter grid cell scale and updated to 2017 assessed values, corrected to market values using site-specific equalization ratios. The fine scale assessed value data is subject to a data use agreement and cannot be shared directly.

Note that the Project Team could not use MassGIS data on structure values for two reasons: (1) It was not possible to re-run the NCPM with MassGIS data for this purpose owing to time and resource constraints; and (2) The codes used for assigning structure value to a commercial or industrial purpose are not fully consistent across municipalities within Massachusetts at this time. Data on percent commercial and industrial value (as a portion of total structure value) by CBG is also derived from the NCPM data. The NCPM model and data are described in more detail in Neumann et al. (2021).

Data from MassGIS on building footprint locations is used to ensure that building footprints intersect with the 1% annual flood extent. In CBGs where no structure footprints intersect with the near-term flood extent, damage is set to zero.[9]

Depth-damage functions that provide an estimate of the percent of commercial or industrial structure value damaged for a given depth of stillwater (no wave action) flooding are derived from documentation of FEMA's HAZUS flood hazard model and assigned to the predominant structure type prevalent to CBGs.

Summary of Method:

Damages to commercial and industrial structures incorporate the MC-FRM 2030 flood data for areas within the 1% flood extent. The damages reflect an average annual percent damage calculated from a flood depth exceedance curve, which is converted to a damage exceedance curve using the HAZUS depth-damage relationships. The curve is constructed from the probability and depth of flooding for the six return period flood depths generated by MC-FRM for 2030 – the 5%, 2%, 1%, 0.5%, 0.2%, and 0.1% annual chance. The average annual damage is estimated damage from a given return period event, times their respective probabilities – or effectively the area under the damage exceedance curve.

Data Type:

Percent damage and total value from the original data are at 150 m grid scale; the share of commercial and residential structure value is at the CBG level. Data used to rank CBGs is provided at the CBG level.

Indicator Units:

Annual average damage from coastal flood hazard, in dollars per year. Unlike the metric for residential structure, which characterizes the potential for physical damage from flooding, this metric for commercial and industrial flood risk does reflect differences in residential market value that might affect the expected annual dollar damages from flooding. The reasoning is that the total value of commercial and industrial damages in monetary terms is the best indicator of the loss of economic resources to flooding.

5.2 Economy Indicator 2: Jobs Exposure

Description:

This indicator attempts to estimate the job density at risk within the coastal flood extent used for all indicators (i.e., the MC-FRM 2030 1% annual chance coastal flood extent). Employment data are combined with building footprint and other data on commercial/residential buildings in the flood extent to generate an estimate of jobs at risk (or more accurately, employment centers at risk, since we are unable to assess how flood exposure might affect job accessibility, or whether affected jobs might continue in remote or alternative settings). Unlike the annual expected damage to places of employment (Economy Indicator 1) which focuses on the cost to repair structures from flood damage, this indicator provides a distinct measurement of potential disruption to the employed population as a result of flood exposure, a different type of economic disruption, with potentially

[9] Note that the MassGIS file includes all structures of at least 150 square feet in size, which includes many small outbuildings. Time and resource constraints prevented the team from excluding small structures from the total building footprint data.

different density of impact as well (for example, warehouse work typically has a low density of employment per unit of building space, while office, food service, or retail work typically has a higher density of employment).

Data Sources:

Employment data is from US Census, LEHD Origin-Destination Employment Statistics (LODES). Data are accessed by CBG for all industries.

Summary of Method:

CBG level employment was adjusted to reflect the portion of commercial and industrial property within the 1% annual chance flood extent. Using the same procedure as was used for the commercial and industrial total flood (expected annual damage), IEc scaled the job count data by the portion of the commercial and industrial building area of that CBG that is present in the 1% annual chance flood extent. This percentage varies by CBG. The result scales the total number of jobs in the CBG by the portion of the most likely employment locations that is in the flood extent.

Data Type:

CBG, scaled by commercial/industrial building area within the 1% annual chance flood extent within the CBG.

Indicator Units:

Count of total number of jobs, using full-time equivalent (FTE) units.

5.3 Economy Indicator 3: DPA and Working Waterfront Exposure

Description:

This indicator combines the presence of a Designated Port Area (DPA) within a CBG with the number of locations of working waterfronts, as identified by the location of seaports and marinas, within the 2030 1% annual chance flood extent. The metric is a count of the number of these types of facilities within each CBG.

Data Sources:

Designated Port Areas and Working Waterfronts, as identified using data on the location of Seaports from MassDOT and Marinas from MORIS

Summary of Method:

Port and working waterfront facility locations within the 2030 1% flood extent are identified and summed across both types.

Data Type:

Polygon (DPA) and location data (working waterfront). The polygon data is converted to a location within each CBG.

Indicator Units:

Number of relevant resources within the CBG. Count is the number of DPAs plus the number of working waterfront locations within the flood extent in each CBG.

5.4 Economy Indicator 4: Freight rail exposure

Description:

This indicator estimates the linear extent of freight rail which lies within the 2030 1% annual chance flood extent.

Data Sources:

This indicator relies on data from the MassGIS data hub: Rail Inventory | MassGIS Data Hub For this indicator, all lines with a primary purpose of freight carriage are used. Lines traveling through tunnels are excluded.

Summary of Method:

The total linear extent of freight rail lines within each CBG and also within the flood extent is counted. Rail lines on bridges over water are manually excluded.[10]

Data Type:

Line data are used, allocated to CBG and the flood extent.

Indicator Units:

Miles of freight track.

5.5 Economy Indicator 5: Roads – High-tide flood vehicle delays

Description:

This indicator estimates the extent to which Massachusetts coastal roads are temporarily flooded as the result of extreme high tides, as defined in NOAA's Sea Level Rise Viewer. The length and extent of such high-tide flooding on roads leads to traffic delays – the higher the level of travel typically using the road, and the longer the extent of the flooding period, the more traffic delays result. Traffic delays are expressed as the lost value of time traveler hours spent in delay (hours of delay multiplied by average vehicle occupancy multiplied by the value of lost time from U.S. DOT sources – see Section 4.1 for details).

NOTE: This indicator is an exact duplicate of Built Infrastructure Indicator 1. In the Economy sector it is meant to provide a metric for reduced mobility associated with tourism and coastal recreation opportunities. Because it

[10] We exclude rail impacts from the following CBGs where train tracks are on bridges intersecting the 2030 1% flood extent in the Charles and Merrimack Rivers. List of CBGS: 250092501001, 250092515001, 250092516004, 250092601002, 250092608002, 250092610002, 250092610003, 250092611022, 250173521021, 250173523003, 250173531021, 250173531023, 250173532002, 250173533003, 250250008071, 250259815011.

is identical in construction to Built Infrastructure Indicator 1, the reader is directed to Section 4.1 for a summary of data sources, methods, data type, and indicator units.

6 | Areas for Future Research and Improvement of Indicators

For this first iteration of the ResilientCoasts Plan, identification of Near-Term Adaptation Areas relied on existing and readily available data and methods. In addition, draft versions of the results were shared for comment with internal, external, and public groups for comment and review. Nonetheless, several limitations remain which may be addressed in future versions of the plan. The Project Team has identified five areas where improvements in the ability of indicators to measure vulnerability of people and housing, built infrastructure, and economic resources to coastal flood risk:

- ***Additional verification of site locations.*** Data on locations of municipal resources, health care facilities, and utilities are provided as points, but the facility locations may include larger or smaller areas within the 2030 1% annual chance flood extent. Additional effort to verify site locations could improve these indicators. In a few cases the Project Team relied on local government staff familiar with the particulars of specific CBGs to manually adjust data, but more comprehensive verification could improve the precision of these indicators.
- ***Improve the resolution of estimated building and other asset damages.*** Estimates of residential, commercial, and industrial building damages are based on attributed information on building usage and type, and generic depth damage functions. More precise estimates of damage could be obtained with building specific information on type, perhaps obtained by additional analysis of the MassGIS aggregated assessors data (which could not be used in this analysis owing to inconsistencies in the coding of building types). Additional information on multi-story buildings and on specifics of existing flood-proofing and structure elevation above flood heights could also improve the precision of these estimates. In addition, more precise estimates of damage to rails might be made with the addition of railbed elevation data.
- ***Update building value.*** Particularly for the damages for commercial and industrial buildings, where building value is the basis for estimation of structure damage from floods, updated information (more recent than 2017) would be useful. In addition, more information on structure vulnerability for these facilities, including whether critical building contents such as utility infrastructure or valuable machinery are located in lower floors more vulnerable to flooding would improve estimates of flood damage.
- ***Add information on location asset magnitude.*** In this initial analysis, all locations (municipal, health care, utility, and working waterfront) are considered equally. Each of these facilities, however, is of differing size, age, and replacement cost, and each has differing magnitudes of service (e.g., schools serve differing numbers of students). Additional information on these locations could provide better measures of the relative value of supporting adaptive measures at each location.
- ***Add indicators of ecosystem/natural resources vulnerability***. This initial effort to develop indicators omits consideration of ecosystem and natural resources vulnerability. Data to characterize these resources, which have a highly context-specific value for ecosystem service provision and vulnerability to flooding or other types of compromise, were judged to be incomplete at this time. Future efforts should reconsider whether sufficient information exists to add these types of indicators.

ResilientCoasts Initiative

mass.gov