Appendix B: Investment Assessment Technical Appendix

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Attachments

1 Introduction and the Case for Resilience

1.1 Introduction

This technical appendix summarizes the methods the project team applied for the Investment Assessment for the ResilientMass Finance Strategy. The following is a summary of key parameters for the Investment Assessment:

- The Investment Assessment does not capture all resilience costs or resilience value. The information presented reflects estimates developed using a defined set of assumptions and inputs. The investment need analysis is intended to illustrate the potential scale of investment that may be required to progress the key resilience measures and does not represent final investment need or spending commitments.
- The Investment Assessment focuses on seven key resilience measures that are centered on resilience actions related to capital projects with physical assets. This does not include all statewide resilience action areas or needs, including important programs necessary to build community resilience.
- The Investment Assessment focuses primarily on resilience investments through 2050 for publicly owned assets, though the methodology varies by key resilience measure.
- The Investment Assessment relies on existing studies and data largely from state and local agency sources.
- The Investment Assessment is not a capital improvement plan and does not identify specific assets for prioritization or investment.
- The project team reviewed individual project costs to inform assumptions for an estimated statewide investment need estimate when feasible. The investment need analysis, however, typically does not represent the sum of individual project cost data reviewed.[1] Investment needs are presented as ranges to demonstrate the low to high end of analysis results based on input assumptions.
- Resilience value is summarized using case studies and existing literature on benefits of resilience investments. For a subset of strategies, quantitative resilience value analysis was conducted using benefit-cost analysis (BCA) for project prototypes. Notably, each individual project is unique. Costs and benefits presented in the BCA are based on the assumptions presented in this appendix and do not represent benefit-cost ratios for all projects related to these strategies.
- The investment need analysis focuses on upfront capital investment and does not include costs related to operations and maintenance (O&M) or financing.

For each key resilience measure, this appendix includes the following information:

1. **Background**: Information is summarized on the key resilience measure, relevant existing, ongoing or upcoming studies, and applicable funding programs available to pay for projects.
2. **Investment Need:**
    a. **Cost Data Review Summary:** A summary of projects, agency input, and relevant existing studies is provided. It is important to note that not all project data reviewed are summarized here. Additional project data are presented in Attachment 1: Sources Provided.
    b. **Investment Need Analysis:** Results and methodology for the estimated rough order of magnitude investment need are summarized. It is important to note that the investment need

[1] For example, the project team reviewed data for past and proposed dam removal projects. The project team then developed a range for dam removal projects and applied that range to a total statewide estimate of dams to be removed. Individual dam removal project costs were not added together to estimate the total dam removal cost.

analysis does not necessarily incorporate all of the data the project team reviewed, as some data did not represent typical costs.

c. **Investment Need Analysis Limitations and Other Considerations:** Information on limitations and other considerations related to the investment need analysis, such as key resilience measure overlap and methodology caveats, is discussed.

3. **Resilience Value:** Information on the benefits offered by investments related to the key resilience measure is summarized. For a subset of key resilience measures, the project team conducted primary BCA of prototypical projects. Results of this analysis are presented here, with more information on methods and assumptions provided in Attachment 3: Resilience Value Methodology for Project Prototypes.

This information is followed by a discussion of the overarching analysis key limitations. Technical appendices are provided that include information on the provided sources (Attachment 1), collected project information (Attachment 2) and resilience value quantitative analysis methodology (Attachment 3).

1.2 The Case for Resilience

Massachusetts is not unique in grappling with understanding the investment needed to advance climate resilience. In New York, Legislation S.2129-B/A.3351-B creates a 'Climate Superfund' and notes that the cost of statewide climate adaptation investments will easily exceed $150B through 2050. Earlier proposals for text for a Climate Change Superfund Act noted that the cost of statewide climate adaptation investments will "easily reach several hundred billion [B] dollars"[2] based on key known investment needs including $100B to upgrade New York City's sewer system to handle large rain events, an estimated $52B to protect New York City from storm-driven flooding from a United States (US) Army Corps of Engineers (USACE) study, and a study estimating $75B to $100B in costs to protect Long Island from extreme weather.[3,4] A study for Los Angeles County by the Center for Climate Integrity estimated it would cost municipal, county, state, and federal governments $12.5B to protect communities through 2040, of which $9B would be incurred by municipal agencies. The largest proportion of adaptation costs estimated relate to stormwater drainage, followed by cool pavements and urban tree canopy.[5] Analysis completed for this Investment Assessment estimates that benefits outweigh costs by a ratio of at least 2:1 for resilience investments to upgrade undersized culverts, install green stormwater infrastructure (GSI), and protect wastewater infrastructure.

Taking action now, however, provides the Commonwealth with quantifiable avoided economic losses. Depending on the level of response from the city, the total cost of storm damages in Boston alone has been estimated between $5B and $100B during this century.[6] Climate change has a direct impact on the cost of providing government services. The Federal Reserve Bank of Boston found that, based on the estimated historical relationship between temperature and local spending, municipal expenditures will increase considerably in the coming decades due to projected rising temperatures. In Boston, municipal general fund expenditures grew 3.2 percent (%) per capita for every increase of 1 degree Fahrenheit (°F) in average temperature from 1990 to 2019.[7]

In addition to increased costs of service provision, homeowners experience the costs of climate change. Between 2005 and 2017, coastal homes in Massachusetts lost over $273 million (M) in relative

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[2] All dollar amounts are in 2024 US dollars ($), unless specified otherwise.

[3] The Climate Change Superfund Act, S02129B, S02129B, New York Senate and Assembly 2023-2024 Regular Sessions (2023). https://nyassembly.gov/leg/?default_fld=&leg_video=&bn=S02129&term=2023&Summary=Y&Actions=Y&Committee%26nbspVotes=Y&Floor%26nbspVotes=Y&Memo=Y&Text=Y&LFIN=Y&Chamber%26nbspVideo%2FTranscript=Y.

[4] The Climate Change Superfund Act, S02129A, S02129A, New York Senate and Assembly 2023-2024 Regular Sessions (2023). https://legislation.nysenate.gov/pdf/bills/2023/S2129A.

[5] Center for Climate Integrity, *Los Angeles County's Climate Cost Challenge. A $12.5 Billion Bill to Protect Communities through 2040.* (2024), https://climateintegrity.org/uploads/media/LACounty-ClimateCosts-2024.pdf.

[6] Environmental Protection Agency, "What Climate Change Means for Massachusetts," August 2016, https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-ma.pdf.

[7] Federal Reserve Bank of Boston, "The Effects of Weather on Massachusetts Municipal Expenditures: Implications of Climate Change for Local Governments in New England," Federal Reserve Bank of Boston, December 19, 2022, https://www.bostonfed.org/publications/new-england-public-policy-center-research-report/2022/effects-of-weather-on-massachusetts-expenditures-implications-of-climate-change-in-new-england.aspx.

appreciation.[8] Additionally, climate change and disaster risk are driving increased premiums and reduced access to property and casualty insurance in several markets across the US.[9] Between 2020 and 2023, average insurance premiums in the US increased 13% (in real terms), with a high correlation between insurance premiums and local disaster risk.[10] These same communities, several in Massachusetts, experienced a spike in nonrenewal rates. The number of policies held by insurer-of-last-resort plans doubled in high-climate risk communities between 2018 and 2023, as homeowners increasingly struggle to insure their homes.[11,12]

The impact of climate resilience on property and casualty insurance markets poses a systemic risk to the Massachusetts economy. A 2025 report from Ceres notes that the potential withdrawal of insurers from certain market segments or geographic areas would impact individual homeowners and real estate markets, as access to home mortgages depends on the availability of insurance. Potential large financial losses borne by insurance companies would impact financial markets as well as the companies' ability to cover future events[13] The Massachusetts Property Insurance Underwriting Association (MPIUA), also known as the Massachusetts Fair Access to Insurance Requirements (FAIR) Plan, would also be impacted, as all member companies writing basic property insurance in the Commonwealth share losses on a premium volume basis. [14,15]

Across the US, 27 weather and climate disasters became $B events and generated $182.7B in damages, making 2024 the fourth-costliest year on record.[16] Globally, losses from damage to assets and capital from natural disasters in 2022 were valued at $313B, while the broader economic and social cost of failing to act on climate change now is estimated at $1,266 trillion.[17,18] Global projections of climate change damages estimate that as of 2023, even with significant action, the world economy is already committed to a 19% income reduction through 2050, due to losses in labor productivity, reduced agricultural yields, and damage to physical infrastructure. By 2050, the estimated annual cost of these damages will reach $38 trillion, which exceeds the cost to limit global warming to 2 degrees Celsius by a factor of 6:1.[19] Private investors are planning for a hotter world and responding to states' perceived climate risk. For unprepared businesses, the physical risks associated with climate places 5% to 25% of corporate profits at risk of erosion by 2050.[20]

The cost of climate impacts will not be distributed evenly, and certain populations will be disproportionately affected. For example, Massachusetts ranked second in the country for percentage of federally subsidized affordable housing units located in areas vulnerable to coastal flooding.[21] Extreme heat and storm events create public transit delays that disproportionately reduce economic opportunity for low-income residents and people of color, who are most dependent on reliable public transit for access to employment. [22] Historically redlined areas of Boston experience 7.5°F hotter days than the rest of the city

8 *Rising Seas Swallow $403 Million in New England Home Values* (First Street Foundation, 2019), https://assets.firststreet.org/uploads/2019/03/Rising-Seas-Swallow-403-Million-in-New-England-Home-Values.pdf.
9 *Climate Change, Disaster Risk, and Homeowner's Insurance*, n.d.
10 Benjamin J. Keys and Philip Mulder, *Property Insurance and Disaster Risk: New Evidence from Mortgage Escrow Data*, w32579 (National Bureau of Economic Research, 2024), https://doi.org/10.3386/w32579.
11 *Next to Fall: The Climate-Driven Insurance Crisis Is Here - And Getting Worse* (U.S. Senate Budget Committee, 2024).
12 Keys and Mulder, *Property Insurance and Disaster Risk*.
13 "The Changing Climate for the Insurance Industry," Ceres: Sustainability Is the Bottom Line, accessed July 11, 2025, https://www.ceres.org/resources/reports/changing-climate-insurance-industry.
14 "MPIUA | The Massachusetts Property Insurance Underwriting Association," accessed July 11, 2025, https://www.mpiua.com/.
15 MPIUA provides basic property insurance on eligible property for applicants who have been unable to gain insurance through the voluntary market.
16 "2024: An Active Year of U.S. Billion-Dollar Weather and Climate Disasters | NOAA Climate.Gov," January 10, 2025, https://www.climate.gov/news-features/blogs/beyond-data/2024-active-year-us-billion-dollar-weather-and-climate-disasters.
17 "2023 Weather, Climate and Catastrophe Insight | Aon," accessed April 23, 2025, https://www.aon.com/weather-climate-catastrophe/index.aspx.
18 Caroline Alberti, "The Cost of Inaction," CPI, January 4, 2024, https://www.climatepolicyinitiative.org/the-cost-of-inaction/.
19 Maximilian Kotz et al., "The Economic Commitment of Climate Change," *Nature* 628, no. 8008 (2024): 551–57, https://doi.org/10.1038/s41586-024-07219-0. Note: This study includes an outstanding editor's note that the reliability of data and methodology presented in the manuscript is currently in question as of November 6, 2024.
20 "Act on Climate Risk Today or Face the High Cost of Inaction," BCG Global, accessed May 1, 2025, https://www.bcg.com/press/11december2024-climate-risk-cost-of-inaction.
21 Massachusetts, *ResilientMass Plan: 2023 Massachusetts State Hazard Mitigation and Climate Adaptation Plan*, 2023.
22 Staci Rubin et al., *Riding Toward Opportunities: Communities Need Better MBTA Service to Access Jobs* (Conservation Law Foundation, 2021), https://www.clf.org/wp-content/uploads/2021/12/Transit-Access-Study_FINAL_Dec-2021_REVISED.pdf.

and have 20% less parklands and 40% less tree canopies than other areas of the city.[23,24] These conditions exist in communities throughout the Commonwealth and result in disproportionately negative impacts on vulnerable populations. This includes people experiencing homelessness, people with chronic health conditions, pregnant people, outdoor workers, low-income people, children and youth, older adults, and homebound individuals, who are all at an increased risk for health and mortality impacts from extreme heat events.[25]

Studies have found that the benefits of resilience investments can outweigh costs. Benefits can include avoided physical damages; reduced business interruptions and resident displacement; avoided transportation delays, public health impacts, and property insurance increases; fiscal impact benefits; and job creation, recreation, and environmental co-benefits. In the US, a retrospective study of mitigation activities funded by federal grants found that over a period of around 20 years, $1 in natural hazard mitigation investment resulted in $6 of savings in avoided damages.[26] A study from the US Chamber of Commerce of 25 modeled natural disaster scenarios adds to this finding, estimating $7 in reduced economic costs after an event (e.g., production and income losses from people leaving the labor force) from each $1 in resilience investment.[27] When adding the benefits from avoided damage and cleanup costs, benefits outweighed costs 13:1. For the Investment Assessment, the project team conducted benefit-cost analysis for prototypical projects within the key resilience measures. The benefits consistently outweigh costs on an order of at least 2:1. While benefits and costs vary by each project, these modeled benefits are likely to be higher given not all benefits are readily monetizable and the analysis focuses on direct benefits, rather than the cascading impacts to the regional economy.

2 Investment Need and Resilience Value of Key Resilience Measures

2.1 Significant and High Hazard Dams

Description: *Remove or, where not feasible, upgrade or repair significant and high hazard dams to respond to future climate conditions, protect communities' safety and security, and restore habitats for cool-water and warm-water fisheries.*

2.1.1 Background

Dams can help to maintain water supply, generate hydroelectric power, and reduce the risk of flooding through controlled storage and release.[28] However, if the dam is structurally compromised or extreme weather occurs, dam failure can lead to dangerous flooding conditions. Most dams in Massachusetts were constructed in the 1700s and 1800s to power small mills and have outlived their original purpose.[29] Repair or removal of dams can reduce the risk of dam failure events and can also restore natural waterways to improve habitat connectivity and water quality.

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[23] Redlining is a discriminatory practice of denying loans or services within a specific geographic area due to the race or ethnicity of its residents. The practice originated in the 1930s and was deemed illegal with the passage of the Fair Housing Act of 1968, but has had lasting ramifications. For additional detail see "Understanding Redlining and Its Impacts," American Planning Association, https://www.planning.org/blog/9231005/understanding-redlining-and-its-impacts/.

[24] *Boston Heat Resilience Plan* (City of Boston, 2022), https://www.boston.gov/sites/default/files/file/2022/04/04212022_Boston%20Heat%20Resilience%20Plan_highres-with%20Appendix%20%281%29.pdf.

[25] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022), 32–38, https://www.mass.gov/doc/2022-massachusetts-climate-change-assessment-december-2022-volume-ii-statewide-report/download.

[26] *Natural Hazard Mitigation Saves: 2019 Report* (Multi-Hazard Mitigation Council, 2019), https://www.nibs.org/files/pdfs/NIBS_MMC_MitigationSaves_2019.pdf.

[27] *The Preparedness Payoff: The Economic Benefits of Investing in Climate Resilience* (U.S. Chamber of Commerce, 2024).

[28] "Dams 101 | Association of State Dam Safety," accessed July 14, 2025, https://damsafety.org/dams101.

[29] Division of Ecological Restoration, "River Restoration: Dam Removal," Mass.Gov, https://www.mass.gov/river-restoration-dam-removal.

Massachusetts has approximately (~) 3,000 documented dams, including ~1,400 state-regulated jurisdictional dams and ~1,500 dams that are under federal jurisdiction or are non-jurisdictional, as categorized below.

- State-regulated jurisdictional dams are overseen by the Office of Dam Safety (ODS) and are owned by private entities, municipalities, or state entities. Jurisdictional dams are assigned hazard codes (low, significant, or high) and condition ratings (good, satisfactory, fair, poor, or unsafe). Hazard codes describe the risk of impact if the dam were to fail (e.g., to people, the environment, or the economy), while condition describes the physical condition of the dam. ODS has a dam safety goal seeking to ensure all dams reach compliance, in service of becoming safe and climate resilient. In an ODS dataset from April 2025, there are 908 state-regulated dams categorized as significant or high hazard.[30] Separately, 434 state-regulated dams are categorized as unsafe or in poor physical condition and of these dams, 207 are significant or high hazard. ODS prioritizes addressing significant and high hazard potential dams in unsafe and poor conditions and has identified 43 priority dams.

  Of the ~1,400 state-regulated jurisdictional dams, 99 were constructed for or are managed for flood control and 256 support water supply, based on data provided by Department of Conservation and Recreation (DCR). An unknown number create recreational impoundments with public boat launches and public beaches. The remaining dams may provide uses ranging from no use at all to local recreation.

- Other jurisdictional dams are regulated by federal agencies such as the Federal Energy Regulatory Commission (FERC) and USACE.

- Non-jurisdictional dams are not regulated by ODS and are typically under 6 ft in height and/or 15 acre-feet in storage.[31]

Various state agencies mitigate, operate, and maintain jurisdictional dam operations, primarily DCR and Massachusetts Department of Fish and Game (DFG). Agencies that provide funding for various dam projects include: DFG’s Division of Ecological Restoration (DER), DCR, Federal Emergency Management Agency (FEMA), Executive Office of Energy and Environmental Affairs (EEA), DFG, Massachusetts Emergency Management Agency (MEMA), as well as federal sources such as National Oceanic and Atmospheric Administration (NOAA), USACE, and US Fish and Wildlife Service (USFWS).[32] Most commonly, funding is available for dam removal projects with the primary purpose of habitat restoration and co-benefits of flood reduction and public safety.

The 2023 ResilientMass Plan identifies “Increased Risk of Dam Overtopping or Failure” as a priority impact in the infrastructure sector in Massachusetts.[33] The plan identifies several actions to reduce flooding and risks associated with dams, specifically recommending that state agencies evaluate and mitigate dam risks (including repairing and removing dams), strengthen dam response planning, and implement related flood risk reduction and resilience projects. DFG’s 2025-2030 Five-Year Strategic Plan specifically calls for actions to reconnect habitats, improve diadromous fish species, reduce public hazards, and increase climate resilience by, in part, removing dams that are no longer necessary.[34] DFG has developed Biodiversity Conservation Goals for the Commonwealth prompted by Governor Healey’s 2023 Executive Order Number 618 on Biodiversity Conservation in Massachusetts.[35]

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[30] Office of Dam Safety, “Dam Safety Database,” April 2025.

[31] It is also possible that there are dams that are non-jurisdictional because of agricultural exemption. Additional details on defining non-jurisdictional dams can be found in 302 Code of Massachusetts Regulations (CMR) Section 10.03.

[32] Some examples of Commonwealth programs that can support dam projects include EEA Dam and Seawall Repair or Removal Program, DER Priority Ecological Restoration Program: Dam Removal & River Restoration, and Municipal Vulnerability Preparedness (MVP) Program.

[33] Massachusetts, *ResilientMass Plan: 2023 Massachusetts State Hazard Mitigation and Climate Adaptation Plan*.

[34] *Connections: Working Together for Nature*, Five-Year Strategic Plan (Massachusetts Department of Fish & Game, 2024), https://www.mass.gov/doc/dfg-strategic-plan-1/download.

[35] “Executive Order No. 618: Biodiversity Conservation in Massachusetts,” Mass.Gov, September 21, 2023, https://www.mass.gov/executive-orders/no-618-biodiversity-conservation-in-massachusetts.

2.1.2 Investment Need

2.1.2.1 Cost Data Review Summary

DER works with interested dam owners to remove dams by providing technical assistance, contracted technical services, project management, and grants.[36] Since 2004, DER has worked in partnership with agencies, non-profit organizations, and dam owners to remove over 65 dams. DER provided baseline dam removal costs for DER's projects, noting that a typical dam removal project (which represents ~80% of their projects) costs $1.1M for project development and construction costs, while "extreme/challenging" dam removal projects (20% of their projects) cost $9.1M per project.[37] DER noted that this breakdown of typical and extreme/challenging, and the associated costs, is specific to DER's project portfolio, as the agency deliberately selects projects that are feasible and, therefore, may not accept exceptionally high-cost projects to their program.

In a 2023 dam safety presentation, ODS reported dam removal projects can range from $775,000 to over $20M.[38] The presentation notes an estimated cost of over $31M to address 34 DFG dams, and over $33M to abate high priority safety concerns for DCR dams (which excludes consideration of removal of many small dams). It also notes that mitigation for abandoned dams alone would cost over $51M. DFG also provided cost information for a list of significant hazard dams under their jurisdiction and costs for removal or repair for seven projects. These costs ranged from $119,000 (Town Farm Pond Dam repair) to $5.9M (White Island Pond Dam repair), with an average of $2.5M per dam.

Costs for the Mill Street Dam Removal Project in Pittsfield, Massachusetts (completed in 2020) were ~$3.8M in 2019 $ (close to $5M in 2024 $).[39] This project, which was funded in part by state sources including the EEA Dam and Seawall Repair or Removal Program and the MVP grant program, supported ecosystem health and climate resilience.

MEMA is currently managing three dam resilience projects with a combined total cost of $25M. In 2023, the Healey-Driscoll administration announced $25M for the removal of eight aging dams; $20M is for the removal of Bel Air Dam, and the remaining $5M is for the removal of the other seven dams.[40]

The US Geological Survey (USGS) Dam Removal Information Portal includes a database of cost estimates and cost drivers for 668 dam removal projects.[41] For 50 dams in Massachusetts, the mean dam removal cost was ~$810,000.

AECOM cost estimators noted costs of $1.1M for a typical dam removal with a higher end estimate of $6M for more complex projects that include sediment control/management and upgrading existing infrastructure based on present analysis in 2025. Recent large dam rehabilitation projects in nearby states cost $30M to $50M per dam.

2.1.2.2 Investment Need Analysis

In an ODS dataset from April 2025, there were 908 state-regulated jurisdictional dams categorized as significant or high hazard. Separately, 434 dams are categorized as unsafe or in poor physical condition; of these dams, 207 are significant or high hazard. DFG's 2024 presentation Vision 2050: Biodiversity Conservation Goals for the Commonwealth included an example goal of "restore rivers and streams" which included removal of over 300 dams by 2050 for purposes of fish passage, aquatic connectivity, and

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36 DER works with interested dam owners to remove dams by providing technical assistance, contracted technical services, project management, and grants. DER's projects are selected via a competitive process, with DER selecting projects that bring significant ecological and community benefits to the Commonwealth. Once selected, DER guides the project from start to finish. DER also provides a limited number of site reconnaissance and preliminary design studies to interested dam owners, also based on a competitive process. Since 2004, DER has removed over 65 dams.

37 Assumes that project development costs reflect design and permitting costs associated with dam removal projects.

38 "Dam Safety in the Commonwealth," November 2023.

39 "MVP Project Case Study - Pittsfield FY20," Mass.gov, 2022.

40 "Administration Announces $25M for Removal of 8 Unsafe Dams," *Massachusetts Municipal Association (MMA)*, December 12, 2023, https://www.mma.org/administration-announces-25m-for-removal-of-8-unsafe-dams/.

41 Jeff Duda et al., "Compilation of Cost Estimates for Dam Removal Projects in the United States," U.S. Geological Survey, 2023, csv,xml,zip, https://doi.org/10.5066/P9G8V371.

climate resilience; however, this goal was not included in the spring 2025 goals for the Commonwealth.[42,43]

The analysis estimates costs for the removal of 200 to 300 dams and is agnostic to which dams. The analysis applies an assumed distribution of costs. For the low end, in absence of known figures of cost distribution or specific project costs, the investment need analysis assumes 60% of dam removals cost the USGS state average (~$810,000 per dam), 30% cost $1.5M based on the AECOM cost estimators' typical dam removal cost estimate, 9% cost $9M based on DER's extremely/challenging unit cost, and 1% cost $30M based on the higher end of costs reviewed. The high-end cost estimate assumes those cost brackets but at a ratio of 40%, 45%, 14%, and 1% respectively. The rough order of magnitude estimated investment need for this key resilience measure is displayed in Table 1.

Table 1: Rough Order of Magnitude Investment Need Estimates for Significant and High Hazard Dams

Investment Need	Low Estimate	High Estimate
Remove 200 to 300 dams	$0.5B	$1.5B

Notes: Results are rounded.

2.1.2.3 Investment Need Analysis Limitations and Other Considerations

- The specific focus of this key resilience measure is on significant and high hazard dams. DER input noted that over 90% of Massachusetts's dams are no longer serving the purpose they were built for and are gradually or quickly deteriorating.
- The investment need analysis does not specify which dams are to be removed. ODS has prioritized 47 dams for removal. Dams are both publicly and privately owned. Of the ~1,400 state-regulated jurisdictional dams, state agencies own ~20%, while municipalities own ~40% and the remainder are privately owned. Public benefits can result from removal/repair of private dams (e.g., avoided casualties and property and business losses).
- Costs for dam removal and repair are highly variable. Each project is unique based on its setting and situation. Reviewers noted that the cost of a dam repair or removal is typically dictated by factors other than the structural element. Hazard class and size do not correlate to the price and complexity of the project. The cost drivers in each case are generally sediment quantity/quality, location/access, and potentially impacted infrastructure such as bridges, culverts, and buildings. DER noted that the biggest drivers of cost are contaminated sediment trapped by the dam that needs to be managed as part of the dam removal project and additional infrastructure that needs to be protected, upgraded, or removed as part of the project. Dams in urban environments can be more expensive due to all the infrastructure and buildings that are built around the dam. The USGS database uses 32 categories of cost drivers, including river habitat features, presence of water treatment or pumping plants, river erosion, need for mechanical sediment removal, and sediment contamination. The most common cost drivers listed for 17 of the Massachusetts dams in the USGS database are: revegetation, sediment mechanical removal, reshaping topography, pilot channel, structure removal safety, sediment contamination, river erosion, and rewatering.
- DFG flagged that some of the dam removal/repair projects in the Dam Safety Database provided by ODS have already been funded and/or commenced work.
- The investment need focuses on dam removal rather than repair. Dams with public purposes (e.g., drinking water supply and flood control) may be critical for repair rather than removal, but ongoing costs may not make sense if the dam is obsolete and no longer serves a public purpose. Numerous technical and state agency reviewers noted that there is no way to speculate which

[42] "Vision 2050: Biodiversity Conservation Goals for the Commonwealth," June 14, 2024, https://massland.org/sites/default/files/documents/tom_oshea_presentation_cp_meeting_2024_june_14.pdf.

[43] Jennifer Ryan and Schlüter, *Biodiversity Conservation Goals for the Commonwealth* (2025), https://massland.org/sites/default/files/documents/eea_biodiversity_goals_march_18.pdf.

dams would be repaired versus removed or what the cost differential would be between repair and removal. Dam repairs can vary greatly from project to project and include tasks such as: spillway repair, spillway enlargement, crest raise (concrete or earth), stability berms, stability anchors, intake repair, outlet repair, gate repair, foundation grouting, filter berms, mass concrete repair, and masonry repair. The specific project, dam type, issues, and size all impact the cost. Some studies have found that, while not always the case, dam removal typically costs less than dam repair.[44,45]

Based on agency input, it was noted that many dam owners would prefer to remove their dams but may lack the funding and/or technical expertise to do so. Dams can be a risk for their owners, who can be held liable for mismanagement. Dam owners are also held responsible for ongoing inspections and maintenance. ODS noted annual costs for inspection and updating emergency action plans can be ~$10,000, depending on the size of the dam. A 2011 State Auditor's report estimated the cost for development/update of an emergency action plan plus the cost for a phase one (safety) inspection could be nearly $30 thousand per year (in 2024 $).[46] These are required for significant hazard dams every 5 years and every 2 years for high hazard dams.

- Climate resilience in dam design is primarily based on 302 CMR Section 10.14(6) which guides spillway design for design floods and design storms. However, presently, for purposes of designing the spillway, the precipitation is backwards looking and does not project forward. Inadequate spillway capacity can cause a dam that is otherwise compliant based on physical condition to become noncompliant. Notably, given spillway capacity is based on backwards-looking precipitation and does not project forward, repairs relating to the spillway may not address increases in flood volume with climate change.
- This key resilience measure has overlap with others, namely Coastal and Riverine Floodplain Resilience.

2.1.3 Resilience Value

Avoided emergency response and flood damages. Dam overtopping or failure poses risk to safety and property. Flooding impacts from dam failure can cause business disruption and economic losses associated with temporary business closure or relocation.[47] The potential dam failure at Whittenton Pond Dam in 2005 was estimated to exceed $1.5M in emergency response costs and economic losses.[48] In 2023, flash flooding in Leominster caused over $30M in damages, including the collapse of the Brooks Pond Dam and the evacuation downstream of the Barrett Park Pond Dam.[49,50] Given that the frequency of intense precipitation events in New England has increased by 74% over the last century and is projected to increase by an additional 40% by the end of this century, the risk of dam failure is likely to increase.[51]

Avoided repair and maintenance costs. A case-study analysis by DER found that the cost of dam removal for three dams was on average 60% less expensive than repair and maintenance over 30 years.

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44 Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts* (2015), https://www.mass.gov/doc/phase-3-economic-community-benefits-from-stream-barrier-removal-projects-in-massachusetts/download.

45 Zbigniew J. Grabowski et al., "Fracturing Dams, Fractured Data: Empirical Trends and Characteristics of Existing and Removed Dams in the United States," *River Research and Applications* 34, no. 6 (2018): 526–37, https://doi.org/10.1002/rra.3283.

46 *Local Financial Impact Review: Massachusetts Dam Safety Law* (Commonwealth of Massachusetts, Aduitor of the Commonwealth, 2011), https://www.mass.gov/doc/local-financial-impact-of-massachusetts-dam-safety/download.

47 Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.

48 Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.

49 "Feared Collapse of Leominster Dam Highlights Hundreds More That Threaten Damage," GBH, September 14, 2023, https://www.wgbh.org/news/local/2023-09-14/feared-collapse-of-leominster-dam-highlights-hundreds-more-that-threaten-damage.

50 "Leominster Still Rebuilding One Year after Catastrophic Flooding - CBS Boston," September 11, 2024, https://www.cbsnews.com/boston/news/leominster-catastrophic-flooding-damage-recovery/.

51 *Water, Water, Everywhere: The Increasing Threat of Stormwater Flooding in Greater Boston* (Metropolitan Area Planning Council of Greater Boston, 2023), https://www.mapc.org/wp-content/uploads/2023/05/Stormwater-ReportFINAL.pdf.

Repair and maintenance costs for these dams ranged from 27% to 400% more than the cost for removal.[52] Several dams in Massachusetts are privately owned and can present cost liabilities that may impact business decisions. The Briggsville Dam removal project on the Cascade School Supplies company property preserved 150 jobs, as the cost to repair and maintain the dam would have caused the company to go out of business.[53]

Improved water quality and ecological health. Dam removal allows for habitat connectivity for fish and wildlife and improved habitat and water quality. The Ipswich and Parker Dam removals open nearly 140 miles of mainstem and tributary miles for migratory fish runs, which have direct positive potential impacts for the commercial fishing industry.[54] A University of Massachusetts-Amherst study found that impounded water had higher surface water temperatures downstream of the dams, and two-thirds of the dam impoundments studied had less dissolved oxygen in the water than upstream of the dams.[55] Contaminated sediment can also pool in stagnant water and pose risks to aquatic organisms. If a dam was to fail, this contaminated sediment could pose public health risks.[56]

2.2 Small Bridges and Culverts

Description: *Replace priority undersized small bridges and culverts to reduce flood hazards for communities and critical inland infrastructure and restore fish and wildlife movement.*

2.2.1 Background

Culverts and bridges play an integral role supporting Massachusetts's transportation network and reducing flooding. This key resilience measure specifically focuses on small bridges (defined as having spans between 10 and 20 feet in length) and culverts (structures measuring less than 10 feet in length).[57] There are ~25,000 documented culverts and 1,500 documented small bridges in Massachusetts, the majority of which are owned by Massachusetts' cities and towns.[58] Many have reached or are reaching the end of their designed service life and/or are undersized relative to the current stream flows.[59,60] Given that Massachusetts climate change predictions include increases in both the frequency of severe weather and the amount of precipitation, the risk of failing culverts and small bridges will likely be heightened under future conditions.[61,62]

There are numerous funding programs for culverts and small bridge projects in Massachusetts. The MVP Program provides support for communities to identify climate hazards, assess vulnerabilities, and develop action plans to improve resilience to climate change.[63] Massachusetts Department of Transport's

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[52] Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.

[53] Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.

[54] NOAA Fisheries, "Ipswich and Parker River Dam Removals in Massachusetts to Restore Fish and Protect Communities," NOAA, December 13, 2023, New England/Mid-Atlantic, https://www.fisheries.noaa.gov/feature-story/ipswich-and-parker-river-dam-removals-massachusetts-restore-fish-and-protect.

[55] Katherine Abbot et al., *Restoring Aquatic Habitats through Dam Removal* (n.d.), https://digitalmedia.fws.gov/digital/collection/document/id/2309/rec/1.

[56] "A Dam Removal Reunites A Mass. Neighborhood With The Housatonic River," September 30, 2020, https://www.wbur.org/news/2020/09/30/dam-removal-pittsfield-housatonic.

[57] Massachusetts Culverts and Small Bridges Working Group for Senator Hinds and the Massachusetts Legislature, *Recommendations for Improving the Efficiency of Culvert and Small Bridge Replacement Projects* (2020), https://www.mass.gov/doc/massachusetts-culverts-and-small-bridges-working-group-report/download.

[58] MassDOT owns 6,000 culverts and 440 small bridges, while MBTA owns ~1,380 culverts based on their preliminary inventory. Data from Culverts and Small Bridges Working Group Report, 2020 and MBTA agency input.

[59] Massachusetts Culverts and Small Bridges Working Group for Senator Hinds and the Massachusetts Legislature, *Recommendations for Improving the Efficiency of Culvert and Small Bridge Replacement Projects*.

[60] Massachusetts Culverts and Small Bridges Working Group for Senator Hinds and the Massachusetts Legislature, *Recommendations for Improving the Efficiency of Culvert and Small Bridge Replacement Projects*.

[61] Massachusetts Culverts and Small Bridges Working Group for Senator Hinds and the Massachusetts Legislature, *Recommendations for Improving the Efficiency of Culvert and Small Bridge Replacement Projects*.

[62] Written Jessica Levine and Keene Valley, *An Economic Analysis of Improved Road-Stream Crossings*, n.d.

[63] Eligible projects are on a public way, on the Bridges Web Application, and with a recorded span between 10 and 20 feet. The program utilizes phased grants to municipalities to separately fund the design ($100,000 funding limit) and construction ($500,000 funding limit) of bridge projects. Massachusetts, "Municipal Vulnerability Preparedness Program"

(MassDOT) Municipal Small Bridge Program provides funding to municipalities for the replacement, preservation and rehabilitation of eligible bridges.[64] DER's Stream Continuity Program has awarded grant funding to municipalities through the Culvert Replacement Municipal Assistance Grant Program and the Culvert Replacement Training Site Initiative to help municipalities replace outdated culverts with new, improved crossings and support training for road managers.[65] Additional Massachusetts funding comes from MassWorks, a program to support public infrastructure projects.[66] There is also some limited federal funding that can support culvert and small bridge projects. The FEMA Hazard Mitigation Assistance (HMA) grants, administered by MEMA, provides mitigation assistance grants for flood risk reduction projects, including bridge and culvert upgrades.

The Massachusetts Culverts and Small Bridges Working Group was established in 2018 to provide recommendations for policies and procedures to support replacement or repair of culverts and small bridges to improve storm resilience and natural resource connectivity.[67] Their 2020 report, Recommendations for Improving the Efficiency of Culvert and Small Bridge Replacement Projects, found that municipalities and MassDOT, as infrastructure owners, face challenges in design, permitting, and funding of these projects and require support in terms of technical assistance, training, financing, research, and execution. Massachusetts Department of Environmental Protection (MassDEP), USGS, and University of Massachusetts are currently developing a statewide hydraulic model that will help to facilitate planning and permitting for stream crossing improvements.[68,69] The model is currently in development and will be rolled out in phases over the next ~5 years. Another planned phase of the initiative will incorporate future stream flows.

2.2.2 Investment Need

2.2.2.1 Cost Data Review Summary

Based on field surveys conducted of ~8,500 culverts, DER estimates that at least half of all culverts and small bridges are undersized and need to be replaced to meet the road-stream crossing standards. DER estimated that the average cost to engineer, design, and permit a culvert upgrade is $150,000 and that the average cost to construct a larger, safer culvert that meets the road-stream crossing standards can be ~$1.2M.[70]

MassDOT's Resilience Improvement Plan (RIP) includes a Priority Resilience Project List (as of June 2024) that was developed with MassDOT's district offices and focuses on known vulnerabilities, particularly those related to drainage, flooding, erosion and past extreme weather events.[71] The list includes several culvert projects around the Commonwealth (in towns such as Otis, Petersham, Framingham, and Haverhill) to replace culverts. Based on a network-level study, 1,200 (or 20%) of

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64 MassDOT, "Municipal Small Bridge Program," https://madothway.my.site.com/GrantCentral/s/municipal-small-bridge-public-overview.

65 The majority of these grants will provide financial assistance for municipalities across the Commonwealth to complete field data collection and data and engineering work for their culvert/small bridge projects. However, the cost of design, permitting, construction and administration means project costs are much higher than the grant funding available. Julia E. Hopkins, "Healey-Driscoll Administration Awards $2.4 Million to Support Culvert Replacement and Restoration Projects," *MA Executive Office of Energy and Environmental Affairs*, October 28, 2024, https://www.mass.gov/news/healey-driscoll-administration-awards-24-million-to-support-culvert-replacement-and-restoration-projects.

66 In Fiscal Year (FY) 2025 (FY25), MVP funded around $5 million in culvert projects. MassDOT's Municipal Small Bridge Program awarded $17 million in FY 2024 (FY24). In 2024, DER awards amounted to nearly $4.2M for investments in culvert replacement, small bridge improvements, and technical assistance. MassWorks funded $5M in culvert projects in FY25.

67 "Budget Summary," MA Department of Transportation, FY2019, https://budget.digital.mass.gov/bb/gaa/fy2019/os_19/h102.htm.

68 Massachusetts Culverts and Small Bridges Working Group (2020). Recommendations for Improving the Efficiency of Culvert and Small Bridge Replacement Projects. Accessed at https://www.mass.gov/doc/massachusetts-culverts-and-small-bridges-working-group-report/download

69 New England Water Science Center, "Developing a Statewide Hydraulic Modeling Tool," October 2022, https://storymaps.arcgis.com/stories/09359fada3924c7a925402259ae5616f.

70 Massachusetts Department of Fish and Game (DFG) advised that culverts have been assessed by a variety of organizations, including municipalities, Regional Planning Agencies (RPA), watershed organizations, Trout Unlimited Chapters, and others. The results of these culvert assessments were entered into the Northeast Aquatic Connectivity database, where there are ~8,500 records in the database. Estimates for total culverts and small bridges are based on these records. The assessment methodology was developed by UMass Amherst.

71 MassDOT, *Resilience Improvement Plan* (2024), https://www.mass.gov/doc/highway-resilience-improvement-plan/download.

MassDOT's mapped 6,000 culverts, which does not include Massachusetts Bay Transportation Authority's (MBTA's) culverts, are vulnerable to extreme weather (based on stream characteristics in relation to culvert sizing). Importantly, this vulnerability relates to stream power and does not account for vulnerability to tidal inundation and also does not account for unmapped culverts.

As part of the agency review for this study, MassDOT estimated the cost to replace vulnerable culverts is around $2B, ~$2 to $2.5M per culvert (construction only).[72] MassDOT noted that the cost of the culvert replacement projects ranges based on the length of the proposed structures and complexity of the site. Current MassDOT's culvert replacement projects that are in development range from $2.5M to $10M. It was noted that these costs are construction cost estimates, and engineering, design, and permitting can have high variability on top of these costs.

Some recent projects are designed for future precipitation conditions, such as the Warren Wright Road in Belchertown project and the Pearl Street Culvert project in South Hadley. For the Warren Wright Road project, the town of Belchertown received $150,000 for design, engineering, and permitting work on a culvert replacement project designed to provide hydraulic connectivity for up to the 2070 50-year storm event.[73] For the Pearl Street Culvert, the 50-year storm was used for the design storm plus a 20% magnification for additional capacity to accommodate predicted climatic condition peak flows. The preliminary cost estimate for this was $900,000.[74]

MEMA has eight ongoing culvert resilience construction projects with a total combined cost of $24.1M. MassDEP estimated the range for planning, design, and construction of culvert and small bridge replacement to be between $75,000 and $800,000. The lower end costs related to replacement in kind and may not capture fully meeting standards.

The Nature Conservancy (TNC) noted the importance of accounting for size upgrades in the investment needs analysis. TNC estimated about half of current culverts could be assumed to require upsizing to small bridges, with a cost ~$1.5M per project. TNC also noted that small bridges may require upsizing to bridges which could cost an estimated $3 to $5M per project.

Additional estimates reviewed for culvert replacement include the North Jersey Transportation Planning Authority's (NJTPA's) Benefit-Cost Analysis for Asset Adaptation Strategies, where the cost to enlarge culverts to increase capacity was $1M per culvert in 2019 ($1.3M in 2024 $).[75] In a study by the Office of the New York State Comptroller, local governments were surveyed regarding their spending on projects to help them adapt to climate change.[76] Local governments were asked to estimate the total cost of culvert replacement/repair projects and the percentage of that cost that is due specifically to climate change hazards, e.g., where culvert replacement/repair is required due to increasing storm events or more frequent flooding, as opposed to upgrades due to general age or wear and tear. Survey respondents noted that 57.5% of the project costs were attributed to climate change.

2.2.2.2 Investment Need Analysis

The investment need analysis relies on assumptions for: how many culverts and small bridges require replacement/upgrade, which type of replacement/upgrade is required, and the cost of the replacement/upgrade. The low- and high-end analysis assume half of today's culverts and small bridges are undersized and need to be replaced to meet road-stream crossing standards based on DER's field surveys. However, a range was applied to estimate how many culverts require upsizing to an extent that

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[72] MassDOT noted their cost estimate is for larger scale projects and is based on functional classification that will require the agency to upgrade guardrails, utility relocation, and full depth, amongst other things.
[73] "State Awards $4.6M for Ecological Restoration and Climate Change Projects," June 16, 2025, https://www.iberkshires.com/story/68887/State-Awards-4.6M-for-Ecological-Restoration-and-Climate-Change-Projects-.html.
[74] "Pearl St - Elmer Brook Culvert Replacement | South Hadley, MA - Official Website," accessed June 16, 2025, https://www.southhadley.org/1346/Pearl-St---Elmer-Brook-Culvert-Replaceme.
[75] New Jersey Transportation Planning Authority, *Benefit Cost Analysis Costs for Asset Adaptation Strategies* (2019), https://www.njtpa.org/NJTPA/media/Documents/Planning/Regional-Programs/Studies/Passaic%20River%20Basin%20Climate%20Resilience%20Planning/Appendix-K.pdf?ext=.pdf.
[76] Office of New York State Comptroller, *New York's Local Governments Adapting to Climate Change: Challenges, Solutions and Costs* (2023), https://www.osc.ny.gov/files/local-government/publications/pdf/climate-change-2023.pdf.

they become small bridges and also how many small bridges would require upsizing to bridges, given the implications for project costing. For the low-end estimate, in absence of known figures for the breakdown, it is assumed that 15% of today's culverts must be upsized to small bridges and that 35% of those culverts not being upsized to small bridges (i.e., less than 10 feet in length) still need upsizing/replacement but stay as culverts (i.e. half of today's culverts do not require any investment). The same logic applies to small bridges; the low-end analysis assumes that 15% must be upsized to bridges (over 20 feet in length) and that 35% of the remaining small bridges require upsizing/replacement but stay as small bridges. For the high-end estimate, in absence of known figures for the breakdown, it is assumed that 35% of culverts and small bridges must be upsized to small bridges and bridges, respectively, and that 15% that remain as culverts/small bridges require upsizing/replacement (i.e. half of today's culverts and small bridges do not require any investment).

Multiple state agencies provided cost data for culvert replacement and upgrades. A range of these estimates was selected based on professional judgement and their frequency/applicability to determine the rough order of magnitude estimated investment need for this key resilience measure. For culverts that stay as culverts, a cost of $800,000 (low end) to $1.2M (high end) was applied. For culverts requiring upsizing to small bridges and for small bridges that require upgrades but stay as small bridges, a cost of $1.35M (low end) to $1.5M (high end) was used. For small bridges requiring upsizing to bridges, a cost of $3M (low end) to $5M (high end) was applied. Costs include assumed costs for engineering, design, and permitting. The rough order of magnitude estimated investment need for this key resilience measure is displayed in Table 2.

Table 2: Rough Order of Magnitude Investment Need Estimates for Small Bridges and Culverts

Investment Need	Low Estimate	High Estimate
Replace/upsize half of the existing culverts and small bridges	$13B	$20B

Notes: Results are rounded.

2.2.2.3 Investment Need Analysis Limitations and Other Considerations

- DER costs provided are replacement costs to meet Massachusetts' specified stream crossing standards and do not include designing/building a structure that also meets projected future storms. Culverts that meet stream crossing standards typically also protect against the present-day 50- or 100-year flood. The cost of meeting the projected future design flows will vary depending on the storm that it is being designed to withstand.
- It should be noted, on stream crossing standards, recognizing that road-stream crossings are relevant to several of the interests protected by the Massachusetts Wetlands Protection Act (WPA), MassDEP incorporated the Massachusetts Stream Crossing Standards (SCS) into the WPA regulations in 2014. The SCS require that all new, permanent crossings of freshwater rivers and streams consist of a span or embedded culvert in which, at a minimum, the bottom of a span structure or the upper surface of an embedded culvert is above the elevation of the top of the bank, and the structure must span the channel width by a minimum of 1.2 times the bankfull width (310 CMR Sections 10.54 and 10.56).[77] All replacement non-tidal crossings must meet the SCS "to the maximum extent practicable," and replacement of tidal stream crossings that restrict flow must demonstrate that the restriction is eliminated to the maximum extent practicable (310 CMR Section 10.53[8]). Projects that comply with the SCS for new or replacement crossings will provide improved passage for fish and wildlife that use stream corridors to access habitat. In addition, MassDEP, USGS, and the University of Massachusetts (UMass) are developing a

[77] Bankfull width is the width of the channel when it is full, just before it spills over into the floodplain.

statewide hydraulic model that will help to facilitate planning and permitting for stream crossing improvements. The model is currently in development and will be rolled out in phases over the next ~5 years. This tool will promote more resilient bridge designs. A future phase will incorporate future stream flows.[78]

- The focus of this key resilience measure is on replacing undersized culverts and small bridges. Costs to add new culverts to address future precipitation are not included here.
- Extrapolation to a statewide cost estimate requires assumptions relating to how many culverts and small bridges need replacement and what type of replacement is required. There is also no definition of "priority" crossings to apply to the statewide documented inventory. Costs also include all replacement costs, not only costs that may specifically relate to upgrades for climate change.
- This key resilience measure has overlap with others. Bridges longer than 20 feet in length are addressed in Strategic Transportation Infrastructure. There is also overlap with Coastal and Riverine Wetlands and Floodplains.

2.2.3 Resilience Value

Avoided physical damages maintenance costs: Storm-induced flooding at undersized culverts may result in physical damages to the culvert and road, as well as nearby infrastructure and properties. Damages can be costly, particularly if they are recurring and require temporary repair costs or if they impact nearby buildings. There are also significant ongoing costs for undersized culverts, such as frequently removing debris and costly recurring road and culvert repairs. A study in Maine estimated that the benefits of reduced repair and replacement costs of improved culverts would exceed lifetime project costs over a 50-year timeframe.[79] The frequency of extreme storms and level of precipitation will continue to increase as the climate changes, and it is critical that road-stream crossings are appropriately sized to handle increased stream flows.

Avoided traffic delays: Culverts and small bridges are an essential element of the transportation network in Massachusetts, and communities rely on functioning road networks and safe stream crossings. A retrospective study of road-stream crossing infrastructure in Vermont found that several recently improved culverts survived Tropical Storm Irene undamaged, whereas nearly 1,000 culverts without improvements were destroyed or damaged by the storm.[80] Failed culverts can lead to road closures, which can cause detours and delays. Preventing road closures results in avoided time and vehicle operating costs, as well as avoided lost income and disruption costs for businesses and employees located on inaccessible roads.

Avoided emergency services delays: In life-threatening situations, timely emergency care is a key factor that affects the chances of survival. If the route of an emergency medical services (EMS) provider is impacted by a road closure due to a failed culvert, there may be an increase in response time, with each minute increase having potentially catastrophic consequences. Similarly, fire and police response time can be delayed if there is road closure. Leaking culverts can also damage utility lines and cause utility disruption to residents and businesses.

Ecosystem services: Well-designed and adequately sized culverts that allow wildlife, sediment, and debris to pass naturally through a stream can provide water quality improvements, improved habitat, and biodiversity benefits. When culverts fail and there is road damage, sediment load can enter the stream which can degrade water quality and negatively impact the ecology of a stream.[81] Improved fish passage also increases populations of recreationally or commercially valuable wildlife species in the area.[82] The

[78] Information provided by MassDEP

[79] Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.

[80] Nathaniel Gillespie et al., "Flood Effects on Road–Stream Crossing Infrastructure: Economic and Ecological Benefits of Stream Simulation Designs," *Fisheries* 39, no. 2 (2014): 62–76, https://doi.org/10.1080/03632415.2013.874527.

[81] Levine and Valley, *An Economic Analysis of Improved Road-Stream Crossings*.

[82] Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.

fragmentation caused by undersized culverts can also lead to disconnected habitats and isolated subpopulations, ultimately contributing to biodiversity loss.[83] As the climate changes, resilient stream crossings will play an important role in preserving aquatic ecosystems as rising temperatures force fish to move throughout the watershed to cold water locations.[84]

Increase in property value: While the increase in property value specifically attributable to upgrading culverts is difficult to quantify, the reduced potential for flooding of the property and of roads used to access homes can make properties more attractive to buyers.[85] Upgrading culverts can also increase the value of developable residential and industrial properties due to the reduction in flood risk.[86] Importantly, however, some culvert projects could potentially increase the risk of flooding at nearby properties. As with all benefits noted, specific context is important for project level evaluation.

Improved safety: Poorly maintained and undersized culverts can erode stream banks and roads and become obstructed with debris, exacerbating flooding upstream. The storm flow from a culvert can also erode the sides of a paved channel or the bottom of a graded channel. When these water channels erode, they can create gullies on the side slopes that can trip the wheels of an errant vehicle or bicycle causing instability, loss of control or initiating a vehicle rollover.[87]

2.2.3.1 Resilience Value Project Prototype Spotlight: Suburban Culvert Replacement Prototype Project

A prototypical suburban culvert project was analyzed for benefits and costs. When floodwater exceeds the hydraulic capacity of a culvert, undersized culverts are more likely to fail and are more susceptible to debris buildup. Storm-induced flooding at undersized culverts may result in damage to the culvert, road, and surrounding properties. Upgrading the hydraulic capacity of undersized culverts is critical for improving resilience. It is important to note not all benefits were monetizable, so benefits may be understated. Benefits from avoided physical damages, traffic delays, EMS delays, avoided business disruption, and ecosystem services were estimated for a prototypical suburban culvert replacement project. For detailed methodology and assumptions, Attachment 3: Resilience Value Methodology for Project Prototypes.

A summary of the BCA results, accounting for the total estimated present value (2024 $) of project costs and project benefits, as well as the resulting benefit-cost ratios (BCRs), is presented in Table 3. The BCR is calculated by dividing the present value benefits by the present value costs.

Table 3: Suburban Culvert Replacement Prototype Project BCA Results (discounted)

Input	Higher-Cost Prototype	Lower-Cost Prototype
Capital cost	$1.2M	$776,000
Maintenance cost	$290,000	$194,000
Upfront capital and project lifetime maintenance costs	**$1.4M**	**$926,000**
Avoided physical damages	$1.3M	$860,000
Avoided traffic delays	$2M	$2M
Avoided critical services delays	$300,000	$300,000
Avoided business disruption	$40,000	$40,000

83 *Scientific Investigations Report*, Scientific Investigations Report, Scientific Investigations Report (2024).
84 Levine and Valley, *An Economic Analysis of Improved Road-Stream Crossings*.
85 Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.
86 *Hill Street Culvert Reconstruction, Raynham* (2022), https://srpedd.s3.amazonaws.com/wp-content/uploads/2022/10/11104354/RAYNHAMHILL-STREET-CASE-STUDY.pdf.
87 FHWA, "Correcting Unsafe Drainage Features," accessed June 16, 2025, https://highways.dot.gov/safety/local-rural/maintenance-drainage-features-safety/iv-correcting-unsafe-drainage-features.

Input	Higher-Cost Prototype	Lower-Cost Prototype
Ecosystem service benefits	$60,000	$60,000
Benefits over project lifetime	**$3.7M**	**$3.3M**
BCR	**2.7**	**3.5**

Notes: Analysis applies a 3.1% discount rate over 50-year project useful life. Benefits and costs are highly variable and unique to each project. BCRs shown here do not represent all projects of this type.

2.3 Coastal and Riverine Wetlands and Floodplains

Description: *Protect, enhance, and reconnect coastal and riverine wetlands and floodplains through*:

- *Restoration of coastal and riverine wetland and floodplain habitat*
- *Permanent conservation of undeveloped land*
- *Property buyout*
- *District-scale flood protections*

2.3.1 Background

Wetlands and floodplains allow flood waters to expand and lose velocity, reducing the risk of property damage and safety concerns. Wetlands and floodplains can be a natural sink for carbon in the soil and vegetation and are common breeding and feeding grounds for fish species and other wildlife.[88] There is an estimated over 700,000 acres of land in the FEMA 100-year floodplain in Massachusetts next to the ocean, rivers, lakes, streams, bogs, and other low-lying areas.[89,90] Massachusetts has over 1,500 linear miles of coastline and an estimated 590,000 acres of wetlands across coastal and freshwater areas.[91,92,93] A total of ~484,000 acres of these wetlands is freshwater.[94] These numbers reflect data values as 2025 and may not accurately reflect the actual number of acres of floodplain as these data are dynamic.

Inland and coastal flooding are expected to be exacerbated by climate change, causing widespread damage across the Commonwealth. According to the Massachusetts Climate Change Assessment, coastal property damage could exceed $1B per year by the 2070s, with more than 70% of these losses expected in the Boston Harbor Region. Residential structures affected by riverine flooding could face damages totaling $226M by 2090 (nearly double the estimated $116M in damages without climate change).[95]

The protection and restoration of wetlands and floodplain habitat could help to reduce these increased flood impacts. Building climate resilience through strategies such as permanent conservation of undeveloped lands (discussed in Section 2.4 Forest Conservation and Tree Planting), wetlands restoration, property buyouts, and district-scale flood protections can decrease risk. As noted at the

[88] Salt marshes can sequester almost 2,000 pounds of carbon per acre per year, from “Coastal ‘Blue Carbon.’”
[89] Based on AECOM geospatial analysis overlaying the FEMA National Flood Hazard Layer and FEMA Q3 Flood Zones from Paper Firms. FEMA, “National Flood Hazard Layer,” Map Service Center, March 28, 2024, https://www.fema.gov/flood-maps/national-flood-hazard-layer.
[90] MassGIS (Bureau of Geographic Information), *FEMA Q3 Flood Zones from Paper FIRMS Where NFHL Data Unavailable (Feature Service)*, n.d.
[91] Massachusetts, *ResilientMass Plan: 2023 Massachusetts State Hazard Mitigation and Climate Adaptation Plan*.
[92] Cape Cod Commission, *Climate Action Fact Sheet: Protect Preserve, and Restore Wetlands and Buffer Areas* (n.d.), https://capecodcommission.org/resource-library/file/?url=/dept/commission/team/Website_Resources/CAP/tool/Climate%20Action%20Fact%20Sheet-Supporting%20Coastal%20Wetlands.pdf.
[93] Massachusetts Department of Environmental Protection, *Inland and Coastal Wetlands of Massachusetts: Status and Trends* (2019), https://www.mass.gov/doc/inland-and-coastal-wetlands-of-massachusetts-status-and-trends/download.
[94] Cape Cod Commission, *Climate Action Fact Sheet: Protect Preserve, and Restore Wetlands and Buffer Areas*.
[95] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022), https://www.mass.gov/doc/2022-massachusetts-climate-change-assessment-december-2022-volume-ii-statewide-report/download.

beginning of this section in the key resilience measure description, the investment need assessment focuses on wetlands restoration, property buyouts, and district-scale flood protections.

There are many statewide initiatives focused on restoration and building climate resilience in coastal and riverine areas. Massachusetts is one of few states with strong wetlands laws, including WPA enacted in 1972 and Massachusetts Public Waterfront Act enacted in 1866, that regulates activity through permitting processes. Regulations promote nature-based solutions for enhanced resilience and aim to protect vulnerable wetland resource areas so that they can function to prevent storm damage and flooding; prevent pollution; and protect water supply, wildlife, fisheries, and shellfisheries habitat.[96] In May 2025, CZM released the 2025 ResilientCoasts Draft Plan, a 50-year comprehensive framework for statewide coastal resilience. This effort is led by Office of Coastal Zone Management (CZM), an agency within EEA, which focuses on policy, planning, and technical assistance for coastal and ocean issues. CZM provides Coastal Resilience Grants to support local and regional efforts that reduce the impacts of coastal storms, flooding, erosion, and sea level rise. The program has awarded nearly $50M since its implementation in 2014.[97]

The MVP Program, administered by EEA, supports many statewide projects including floodplain projects like restoration and district-scale protection. EEA's Resilient Lands Initiative preserves critical resources to improve the quality of life for residents and reduce vulnerability to climate impacts including flooding and sea level rise. This initiative includes a coastal subgroup focused on identifying and accelerating coastal land acquisition and restoration.[98] DER launched the Regional Restoration Partnerships Program in 2021 to provide financial and technical assistance for ecological restoration projects. Additionally, federal funding is available for flood risk reduction through FEMA's HMA grants, administered by MEMA. These grants support both localized and broader flood risk reduction projects, including funding for scoping and construction.

2.3.2 Investment Need

2.3.2.1 Cost Data Review Summary

2.3.2.1.1 Wetland Restoration

CZM supports a variety of wetland restoration projects. Reviewed projects include the Sawmill Brook Restoration Project, which was awarded $4.4M to complement funding from FEMA's Building Resilient Infrastructure and Communities (BRIC) program along with $1.5M from the NOAA CZM grant and $500 from MassDOT's Small Bridge Grant.[99] The project includes replacing a bridge and removing a tide gate, shoreline stabilization, and restoration of one acre of salt marsh.

DER currently supports 15 coastal wetlands projects, which it categorizes as either typical or extreme/challenging; ~85% of these projects fall in the typical category and primarily involve removing tidal restrictions caused by town-owned roads and culverts which cost ~$3.5M per project.[100] One such project is the Eagle Neck Creek Salt Marsh Restoration Project in Truro, restoring 15.4 acres of salt marsh by removing tidal restrictions at a cost of ~$3.6M including construction and pre-construction costs. In addition to culvert removal, other cost-effective techniques for salt marsh restoration include ditch

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[96] Edmund Coletta, "Healey-Driscoll Administration Proposes Regulations to Strengthen Resilience from Coastal and Inland Flooding," Mass.Gov, https://www.mass.gov/news/healey-driscoll-administration-proposes-regulations-to-strengthen-resilience-from-coastal-and-inland-flooding.

[97] Massachusetts Office of Coastal Zone Management, *ResilientCoasts Draft Plan* (2025), https://www.mass.gov/doc/resilient-coasts-draft-plan-online/download.

[98] Massachusetts Executive Office of Energy and Environmental Affairs, "Resilient Lands," 2024, https://www.mass.gov/info-details/resilient-lands.

[99] Note the Trump Administration has canceled many federal funding programs, including BRIC. The funding information noted above is based on the public facing webpage for this project accessed July 2025. "Central Street Culvert Replacement & Central Pond Restoration Project," Town of Manchester-by-the-Sea, MA, accessed July 9, 2025, https://www.manchester.ma.us/825/Central-Street-Culvert-Replacement-Centr.

[100] DER cost estimates include planning, implementation and/or maintenance costs of specific priority projects they have seen.

remediation, runnels, and marsh island creation. These nature-based solutions are recommended in the Great Marsh Coastal Adaptation Plan for their affordability and enhanced resilience benefits.[101]

For an "extreme/challenging" coastal wetland restoration project, which can involve complex infrastructure such as bridge crossings on MassDOT roads, DER estimates costs between $15M and $20M. The most significant effort to date, the Herring River Restoration Project, in the towns of Wellfleet and Truro, is estimated to cost $70M and is set to restore 1,100 acres of salt marsh over 20 years and multiple phases of development.[102]

DER currently supports five freshwater wetland restoration projects (excluding cranberry bog restoration projects, which are discussed below). Typical freshwater wetland projects cost between $500,000 and $3M, depending on project complexity, habitat stressors, and volume of fill removal. Although DER did not provide a specific cost estimate for "extreme/challenging" freshwater projects, *The Massachusetts Healthy Soils Action Plan* cites DER's estimate of ~$20,000 per acre ($26,000 in 2024 $).[103]

The Cape Cod Commission conducted its own analysis in 2021 and found that the cost of wetland restoration projects ranges from $716,000 to $2.9M per project (in 2024 $, including pre-construction, construction, and contingency).[104] For planning purposes, the Commission assumes an average cost of ~$2M per site. It also reports that salt marsh restoration project costs range from $3,300 to $15,550 per acre ($4,300 to $20,000 in 2024 $).

Many agencies and non-profits, including the Massachusetts Division of Fisheries and Wildlife (MassWildlife), Mass Audubon, and USFWS, are partnering with municipalities to protect dunes, beaches, salt marshes, and other natural features in the Great Marsh Area of Critical Environmental Concern (ACEC). The Great Marsh ACEC includes 25,000 acres of land and 10,000 acres of salt marsh. A 2022 project involving ditch removal and micro-tunneling to restore 85 acres cost $204,000. The second phase, covering 273 acres, was scoped to cost $334,000.

Cranberry Bogs Spotlight: There are ~13,500 acres of cranberry bogs in Massachusetts. Restoring cranberry bogs to functioning wetlands improves coastal resilience by allowing wetlands to absorb floodwater, recharge underground aquifers, and provide space for future marsh migration in tidally influenced areas. Massachusetts officials have set a goal to restore and protect 1,000 acres of dormant cranberry bog over the next decade.[105] A CZM-funded project for restoration of nearly 60 acres of former cranberry bog at the Upper Bass River was awarded $4.5M. Another proposed project, the Barnstable Clean Water Action Marstons Mills Cranberry Bog Restoration, seeks $3.2M to restore an additional 60 acres of retired cranberry bogs. According to DER, a typical cranberry bog restoration project for 40 acres of land, including land protection and restoration, costs ~$3.7M.[106] An "extreme/challenging" project involving 150 acres costs $5.5M. DER estimates that, if most cranberry bogs are eventually retired, the total statewide restoration cost could reach ~$900M.

Another example of large-scale collaboration for project success on wetland restoration is the Upper Coonamesset River Wetland Complex Restoration in Barnstable. This river wetlands project will reopen barriers to fish passage, restore 4,000 linear feet of stream channel, and restore 10 acres of native wetlands, among other benefits. NOAA's Office of Habitat Conservation is providing $1.7M, and USFWS

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[101] Ipswich River Watershed Association, *Great Marsh Coastal Adaptation Plan* (2017), https://www.mvcommission.org/sites/default/files/docs/Great%20Marsh%20Adaptation%20Plan%20part%201.pdf.
[102] "FAQs | Friends of Herring River," accessed June 12, 2025, https://herringriver.org/herring-river-ecosystem/faqs/.
[103] Executive Office of Energy and Environmental Affairs, *The Massachusetts Healthy Soils Action Plan* (2022), https://www.mass.gov/doc/healthy-soils-action-plan-2023/download.
[104] The Cape Cod Commission, *Economic Impacts of Climate Change on Cape Cod* (2021).
[105] Anna Phillips, "Why Cranberry Country Is Turning into Wetlands," Climate, *The Washington Post*, November 26, 2024.
[106] DER cost estimates include planning, implementation and/or maintenance costs of specific priority projects they have seen.

is providing over $1M through the National Fish Passage Program, with additional partners like DER and Mass Audubon.[107] [108] NOAA previously supported restoration on the lower Coonamesset River in 2020.

2.3.2.1.2 District-Scale Flood Protection (Coastal Focus)

Combining multiple strategies across and between districts can strengthen climate resilience and better protect communities. District-scale flood protection can include both gray infrastructure (e.g., levees, seawalls, bulkheads, revetments, culverts, pump stations, and roadway elevation) and hybrid green/gray infrastructure/nature-based solutions (e.g., natural stormwater detention features, beach nourishment, dune restoration, and vegetated berms).

The 2025 ResilientCoasts Draft Plan identifies key coastal hazards and identifies resilience measures tailored to different coastal typologies. The plan supports the development of Coastal Resilience Districts, where district-scale coastal resilience measures can be coordinated.[109] The plan presents a range of 23 high-level resilience concepts (e.g., waterfront parks and open spaces, restoring beaches and dunes, and retrofitting and redesigning seawalls) and ranks their suitability across various typologies. Cost ranges are provided for different measures but are not assigned to specific projects. One recommended near-term action includes the development and implementation of district-wide coastal resilience and capital infrastructure plans for each Coastal Resilience District to help inform and guide future project prioritization.

District-scale flood protection was a focus of the 2016 Climate Ready Boston initiative, a comprehensive citywide roadmap for mitigating climate impacts such as stormwater flooding, riverine and coastal flooding, and extreme heat.[110] This approach targets multiple assets (e.g., roads and structures), rather than individual sites or buildings. *Climate Ready Boston* proposed a variety of flood mitigation strategies, including deployable floodwalls, new open spaces, regulatory and planning measures, and other adaptations integrated into ongoing development projects.[111] For example, in East Boston, near-term (2030 to 2050) cost estimates are $43M to $86M, and long-term (beyond 2050) costs estimates are $130M to $216M. Similar plans are proposed for other neighborhoods, with the total cost of *Climate Ready Boston* initiatives estimated at over $4B.[112]

The Massachusetts Ocean Resource Information System (MORIS) hosts an inventory of public and private shoreline stabilization structures.[113] The inventory includes gray infrastructure (seawalls, bulkheads, revetments, groins and jetties) as well as beach and dune renourishment.[114] This inventory was developed in 2006 and updated in 2015 for the DCR and the CZM to assess current shoreline protection conditions and estimates the cost to maintain and upgrade these structures to withstand future sea level rise. The cost estimate for upgrading private shoreline stabilization structures is not included. As of 2015, structures protect ~16% of the Massachusetts coastline. The cost to restore all public and private shoreline structures to their original design condition was estimated at $3B, while upgrading public structures and restoring private ones to function under future sea level scenarios would cost $7.8B.[115]

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[107] NOAA Fisheries, "Cape Cod Cranberry Bog Project Restoring Wetlands and Fish Passage for River Herring | NOAA Fisheries," NOAA, April 15, 2025, https://www.fisheries.noaa.gov/feature-story/cape-cod-cranberry-bog-project-restoring-wetlands-and-fish-passage-river-herring.

[108] "Upper Coonamessett River Wetland Complex Restoration | U.S. Fish & Wildlife Service," accessed June 16, 2025, https://www.fws.gov/project/upper-coonamessett-river-wetland-complex-restoration.

[109] Massachusetts Office of Coastal Zone Management, *ResilientCoasts Draft Plan*.

[110] *Climate Ready Boston* (City of Boston and Green Ribbon Commission, 2016), https://www.boston.gov/sites/default/files/file/2023/03/2016_climate_ready_boston_report.pdf.

[111] *Coastal Resilience Solutions for East Boston and Charlestown* (City of Boston, 2017).

[112] Liz Rickley, *What Happened to Climate Ready Boston?*, April 24, 2024, https://www.clf.org/blog/what-happened-to-climate-ready-boston/.

[113] Massachusetts Office of Coastal Zone Management, "Massachusetts Shoreline Stabilization Structures," 2025, https://czm-moris-mass-eoeea.hub.arcgis.com/maps/14938ac47b43427f87a96231fc1eaec5/about.

[114] *Massachusetts Coastal Infrastructure Inventory and Assessment Report Update: Project No. P13-2814-D05 (3841S)* (Bourne Counsulting Engineering, 2015), https://archives.lib.state.ma.us/search?query=Massachusetts%20Coastal%20Infrastructure%20Inventory%20and%20Assessment%20Report.

[115] Massachusetts Office of Coastal Zone Management, "Massachusetts Shoreline Stabilization Structures."

Reviewers noted that addressing all the deficiencies is not feasible, and this estimate may overstate what could realistically be achieved.

The MVP Program funded the Island End River Flood Resilience Project, which included the design and permitting of a flood barrier system, an underground surge control structure, wetland enhancement, and public amenities along the Mystic River in the cities of Everett and Chelsea.[116] The project's total estimated cost was over $81M.[117] Additional relevant project examples are listed in Attachment 2: Collected Project Information. In addition to MVP funding, other grant applications have included large coastal protection projects such as the Chelsea Street Bridge Overlook, Riverside Park in New Bedford and Forest River Conservation Area Accessible and Equitable Greenspace in Salem, with total funding requests over $3M.

CZM has partnered with the Town of Barnstable on the Sandy Neck Beach Facility Coastal Resilience Project, a $6.6M initiative focused on restoring dunes and relocating infrastructure behind the primary dune. This project was awarded $2.8M in FY25/Fiscal Year 2026 (FY26) MVP funds and another $90,000 in FY25 CZM Coastal Resilience Grant funding and is expected to be completed in early 2026.[118]

Federal funding has historically been important for flood protection infrastructure projects. FEMA HMA grants support a variety of resilience projects in Massachusetts and typically cover about 75% of total project costs, though contributions range from less than 50% to 100%. In the current political climate, federal funding is more uncertain, but some HMA opportunities are still available.

USACE has completed multiple coastal storm damage reduction projects in Massachusetts, including Nantasket Beach in Hull. In a comparative alternatives analysis prior to construction in 2013, revetment construction was estimated at $6M, while beach nourishment was estimated to cost $50M (equivalent to $10M and $86M in 2024 $, respectively).[119]

In 2023, Massachusetts received $28M from the American Rescue Plan Act (ARPA) to redesign Amelia Earhart Dam and renovate Draw Seven Park to provide flood protection by eliminating flood pathways.[120] DCR's capital plan annual has $4.4M to support the Charles River Dam and Amelia Earhart Dam improvements. Additionally, the Mass Ready Act, filed in June 2025, includes $308M to address high-risk dams, flood control, and coastal infrastructure.[121] Resilient Mystic Collaborative scoped the entire project to cost $49M in 2022 (almost $53M in 2024 $), including storm hardening the dam, elevating the dam and adjacent areas, and adding an additional pump to the existing hydraulics system.[122]

2.3.2.1.3 Property Buyout & Land Acquisition

Property buyout programs target high-risk properties and lower damages over time by converting residential properties to parks or protected lands. MEMA is planning to conduct a feasibility study for a statewide voluntary flood buyout and elevation program in FY26 that will more thoroughly provide recommendations to inform the creation and implementation of such a program. The primary goal of the study is to determine the feasibility and optimal structure of a statewide voluntary flood buyout and

[116] FEMA, "Massachusetts: Cities of Chelsea and Everett – Island End River Coastal Flood Resilience Project | FEMA.Gov," August 28, 2023, https://www.fema.gov/case-study/massachusetts-cities-chelsea-and-everett-island-end-river-coastal-flood-resilience.

[117] Resilient Mystic Collaborative, *Coastal Flood Resilience: Island End River* (n.d.), https://static1.squarespace.com/static/5e3c156ca5f464358d25a06e/t/63a4aea321c4b266a9c2c276/1671736996541/Regional+Coastal+Food+Resilience+--+Island+End+River.pdf.

[118] Heather McCarron, "'In the Red Zone.' $6.6M Erosion Control Plan at Sandy Neck Nears Start in Barnstable," Cape Cod Times, accessed June 13, 2025, https://www.capecodtimes.com/story/news/environment/2024/12/05/barnstables-sandy-neck-beach-park-cape-cod-climate-change-erosion-resiliency/76616147007/.

[119] *Nantasket Beach Hull, Massachusetts Economic Analysis* (2013), https://www.nae.usace.army.mil/Portals/74/docs/topics/NantasketBeach/NantasketBeach-AppendixF.pdf.

[120] Ilyse Wolberg, "Healey-Driscoll Administration Announces $28 Million to Redesign Amelia Earhart Dam and Renovate Draw Seven Park, Improving Climate Resiliency," Mass.Gov, December 18, 2023, https://www.mass.gov/news/healey-driscoll-administration-announces-28-million-to-redesign-amelia-earhart-dam-and-renovate-draw-seven-park-improving-climate-resiliency.

[121] Executive Office of Energy and Environmental Affairs, "Mass Ready Act," Mass.Gov, June 2025, https://www.mass.gov/info-details/mass-ready-act.

[122] Resilient Mystic Collaborative, *Coastal Flood Resilience: Amelia Earhart Dam* (n.d.), https://static1.squarespace.com/static/5e3c156ca5f464358d25a06e/t/63a4ae934655f07a0fe4a371/1671736980194/Regional+Coastal+Food+Resilience+--+Amelia+Earhart+Dam.pdf.

elevation program that best suits Massachusetts' government structure. A vendor will be contracted to provide a comprehensive, multifaceted analysis that will determine the feasibility, effectiveness, and potential impacts. In addition, TNC received funding from a 2024 CZM Coastal Resilience Grant to proactively plan for collaborative and equitable retreat and relocation. The project includes launching a coastwide peer learning network, developing a resource database, and hosting public engagement events to identify best practices and barriers to proactive, community-led managed buyouts and relocation.

After a presidentially declared disaster, FEMA's flood buyout programs typically cover 75% of eligible costs with the remaining 25% paid by state or local governments. In some cases, the federal cost share can be as high as 100%.[123] In Massachusetts, MEMA administers the FEMA buyout program. Participation is voluntary and requires agreement from the local community. As of February 2024, FEMA reports that Massachusetts has 3,353 properties classified as "Repetitive Loss," defined as properties with two or more claims of at least $1,000 each under the National Flood Insurance Program (NFIP).[124]

In the 2025 ResilientCoasts Draft Plan, voluntary property acquisition can cost less than $2M or between $10M to $30M per project, depending on scale and location. It is important to note that a project includes multiple properties being acquired and not a single property. MEMA is currently managing three active property acquisitions in Massachusetts, with a combined total cost of $3.95M.

For comparison, the New Jersey Blue Acres flood buyout program has a maximum program award of ~$707,000 including both property buyout and incentive for future housing acquisition, although individual awards are capped based on several factors such as market value and location. [125,126,127]

The project team reviewed monthly housing market data from Redfin's data center portal, including median sales prices and number of residences sold per month, aggregated at the county level in Table 4.[128] The project team calculated a weighted sale price by factoring each county's acreage in the 100-year floodplain. This analysis resulted in an estimated sale price of nearly $675,000 per property.[129]

Table 4: Median Residential Sale Prices by County (2024)

Region	Single Family Residential	All Residential
Barnstable County	$682,000	$695,000
Berkshire County	$345,000	$324,000

123 FEMA, "Fact Sheet: Acquisition of Property After a Flood Event," November 13, 2018, https://www.fema.gov/press-release/20230502/fact-sheet-acquisition-property-after-flood-event.

124 To be classified a Repetitive Loss structure, a property must be located within a FEMA-designated flood zone, have a flood insurance policy, and have filed multiple documented claims. In addition, FEMA flood zones are based on historical flood probability data and do not account for projected future flood risks. As a result, this number underestimates the total number of vulnerable homes, particularly those not insured by FEMA or where damages are repaired using out-of-pocket payments by homeowners.
FEMA, "OpenFEMA Dataset: NFIP Multiple Loss Properties," version 1, February 29, 2024, https://www.fema.gov/openfema-data-page/nfip-multiple-loss-properties-v1.

125 *Blue Acres. CDBG-DR Requirements (New Jersey Department of Community Affairs Division of Disaster Recovery & Mitigation, 2024), https://www.nj.gov/dca/ddrm/pdf_docs/Blue%20Acres%20CDBG-DR%20Policy%20Manual%20V2_508.pdf.*

126 Program award or the award calculation is based on the buyout and housing incentive unmet need. The maximum Program award is updated annually based on the Federal Housing Administration's maximum award amount.

127 FEMA, "Property Acquisition for Open Space," March 28, 2024, https://www.fema.gov/grants/mitigation/guide/part-12/b/1#:~:text=B.-,1.2.,is%20provided%20in%20Table%2018.&text=The%20cost%20of%20the%20acquisition%20is%20less%20than%20or%20equal%20to%20$323%2C000.&text=The%20cost%20of%20the%20acquisition,%2D%20or%20first%2Dfloor%20units.&text=The%20cost%20of%20the%20acquisition,the%20structure%20must%20be%20occupiable.&text=The%20cost%20of%20the%20acquisition%20is%20less%20than%20or%20equal%20to%20$323%2C000.&text=The%20cost%20of%20the%20acquisition,%2D%20or%20first%2Dfloor%20units.&text=The%20cost%20of%20the%20acquisition,the%20structure%20must%20be%20occupiable.

128 "Data Center," Redfin Real Estate News, accessed July 14, 2025, https://www.redfin.com/news/data-center/.

129 Applies "All Residential" costs. Floodplain analysis based on AECOM geospatial analysis overlaying the FEMA National Flood Hazard Layer and FEMA Q3 Flood Zones from Paper Firms. FEMA, "National Flood Hazard Layer" (Map Service Center, March 28, 2024), https://www.fema.gov/flood-maps/national-flood-hazard-layer.

Region	Single Family Residential	All Residential
Bristol County	$513,000	$504,000
Dukes County	$1,586,000	$1,608,000
Essex County	$719,000	$657,000
Franklin County	$351,000	$340,000
Hampden County	$329,000	$327,000
Hampshire County	$456,000	$424,000
Middlesex County	$842,000	$790,000
Nantucket County	$3,886,000	$3,680,000
Norfolk County	$769,000	$724,000
Plymouth County	$632,000	$609,000
Suffolk County	$777,000	$786,000
Worcester County	$482,000	$472,000

Notes: Redfin data includes 2024 monthly data, annualized based on the number of sales and median sales price per month. All residential property includes condominiums, cooperatives (co-ops), multi-family (two- to four-unit), single-family residential, and townhouses.

In addition to property buyouts aimed at reducing future physical property damages, acquisition and restoration of undeveloped land can help protect critical properties that provide vital ecosystem services for the Commonwealth, providing habitat for wildlife, improving water quality, and mitigating flood risk. Section 2.4 Forest Conservation and Tree Planting below has more information on land acquisition and conservation.

2.3.2.1.4 Other Considerations

Most of the resources provided and reviewed focused on coastal flood protection; however, the central and western parts of Massachusetts also face increasing inland flood risk and require resilience investments at the community scale. Additional modeling and mapping of inland flood hazards is necessary to better inform the design and cost of inland strategies.

There are many different strategies that could be implemented to protect, enhance, and reconnect coastal and riverine wetlands and floodplains. The investment need analysis focuses largely on public infrastructure protection, but adaptation such as building-level floodproofing will be important for reducing flood risk. In addition to freshwater wetland restoration, inland floodplain restoration activities can include stream or river restoration through barrier removal, restoring riparian areas, and bank stabilization. Inland floodplain restoration can also encompass water quality improvement for habitats and/or drinking water improvements. The analysis does not include inland river corridor protection and restoration or floodplain reconnections due to data limitations, though it is noted that there would be additional costs associated with these investments.

There are several ongoing efforts in Massachusetts to advance inland floodplain and river corridor restoration. Nonprofit organizations such as TNC and Mass Audubon support projects that reduce inland flooding, such as through acquisition (discussed more in Section 2.4 Forest Conservation and Tree Planting below) and nature-based solutions. In partnership with federal and local entities, TNC led restoration efforts at the Fannie Stebbins Wildlife Refuge in Longmeadow for the removal of hydrologic barriers and planting of thousands of native floodplain trees to reestablish natural connectivity along the Connecticut River.[130] DER supports several river and stream restoration projects that improve hydrologic function, reconnect floodplains, and enhance aquatic habitats. These include dam and culvert removals,

[130] The Nature Conservancy, *Fannie Stebbins Wildlife Refuge Final Report of 2017-19 Floodplain Forest Restoration* (n.d.), https://www.nature.org/content/dam/tnc/nature/en/photos/s/t/Stebbins-Wildlife-Refuge-Restoration-Report-Final.pdf.

streamflow restoration, and urban river revitalization.[131] Section 2.2 Small Bridges and Culverts has more information on DER's Stream Continuity Program.[132]

2.3.2.2 Investment Need Analysis

Wetland restoration: Massachusetts has ~590,000 acres of wetlands, with 18% classified as coastal and 82% classified as freshwater (Section 2.4 Forest Conservation and Tree Planting below discusses wetland conservation). Massachusetts officials have set a goal to restore and protect 1,000 acres of dormant cranberry bog over the next decade, and DER estimated $900M for statewide cranberry bog restoration costs, however, research did not yield any statewide targets for wetland restoration overall.[133] Consequently, the investment need analysis required an acreage restoration target.

DER has restored over 1,800 aces to date though noted that its projects represent a very small piece of the total need. Other large-scale restoration efforts, such as in Chesapeake Bay in the Mid-Atlantic region, have ambitious targets. Chesapeake Bay has ~450,000 acres of wetlands; between 2010 and 2019, an average of 1,600 acres of wetlands was restored on agricultural lands per year.[134]

As such, the investment need analysis assumes that an area equal to 5% of existing wetlands would be restored under the low-end scenario and 15% under a high-end scenario. This equates to ~1,300 to 3,600 acres per year over 25 years, or 31,500 (~5,700 coastal and ~25,800 freshwater) to 90,000 acres total (16,200 coastal, 73,800 freshwater in the high end). The analysis applies a cost of $4,000 to $20,000 per acre for coastal wetlands and $26,000 per acre for freshwater wetlands. [135,136] The estimated cranberry bog restoration cost ($900M) was not added to this to avoid double counting.

District-scale flood protection (coastal focus): The low-end estimate for coastal flood protection uses the $4B estimate from *Climate Ready Boston.* The high-end cost estimate is based on the 2015 DCR/CZM coastal infrastructure inventory and assessment, which projected a cost of $7.8B to restore private shoreline structures and upgrade public structures to operate as intended under future sea level rise conditions.[137]

Property buyout: It is unclear which properties a state program would target and how many would be included. In FY26, MEMA will undertake an analysis that will scope options for a buyout program in Massachusetts. To estimate the investment need, a cursory analysis of existing programs was conducted to provide a preliminary cost estimate for property buyouts, acknowledging that this strategy will be further explored in upcoming studies, such as the MEMA's upcoming buyout study. The New Jersey Blue Acres flood buyout program averages around 40 properties annually; however, in the most recent year, there were 100 buyouts due to FEMA Hazard Mitigation Grant Program (HMGP) funding support. The investment need analysis assumes 50 to 100 properties annually, or 1,250 to 2,500 properties total over a 25-year period. The analysis applied a sales price of $675,000 per property, based on county-level sales data from Redfin weighted by land acreage in the 100-year flood zone.

The rough order of magnitude estimated investment need for this key resilience measure is displayed in Table 5.

[131] Division of Ecological Restoration, "The Division of Ecological Restoration Project Map," https://www.mass.gov/info-details/the-division-of-ecological-restoration-project-map.

[132] Division of Ecological Restoration, *DER's Stream Continuity Program* (n.d.), https://www.mass.gov/doc/ders-stream-continuity-program/download.

[133] Phillips, "Why Cranberry Country Is Turning into Wetlands."

[134] *Wetland and Forest Buffer Restoration Fact Sheet Relationship to Phase III Watershed Implementation Plan (WIP) Commitments* (n.d.), https://www.chesapeakebay.net/files/documents/wetland_buffer_wips__graphs_final.pdf.

[135] It is important to note that this is from Cape Cod Commission report noting costs for salt marsh restoration projects across the US. Given Massachusetts typically has higher costs than national averages, this may understate costs per acre. The Cape Cod Commission, *Economic Impacts of Climate Change on Cape Cod*.

[136] Executive Office of Energy and Environmental Affairs, *The Massachusetts Healthy Soils Action Plan*.

[137] MORIS hosts an inventory of public and private shoreline stabilization structures. The inventory includes gray infrastructure (seawalls, bulkheads, revetements, groins and jetties) as well as beach and dune renourishment. *Massachusetts Coastal Infrastructure Inventory and Assessment Report Update: Project No. P13-2814-D05 (3841S)*.

Table 5: Rough Order of Magnitude Investment Need Estimates for Coastal and Riverine Wetlands and Floodplains

Investment Need	Low Estimate	High Estimate
Restore coastal and freshwater wetlands	$1B	$2.5B
Install district-scale flood protection in coastal areas	$4B	$8B
Buyout 1,250 to 2,500 residential properties	$2.5B	$4.5B
Total (Rounded)	**$7B**	**$15B**

Notes: Results are rounded.

2.3.2.3 Investment Need Analysis Limitations and Other Considerations

- There are many different types of projects that could be captured in this key resilience measure, Coastal and Riverine Wetlands and Floodplains, with many unknowns related to both unit costs and statewide extrapolation. There are also multiple resilience options for protecting the same area. Understanding which strategy makes the most sense for a site is critical to developing more informed cost estimates.
- There is less information available on flood protection for non-coastal communities; however, there is still need for inland flooding adaptation, particularly in central and western Massachusetts. Additional modeling, mapping, and understanding of project need is necessary for a better understanding of the cost for district-scale inland flood protection projects.
- This key resilience measure has overlap with others, notably Forest Conservation and Tree Planting, Strategic Transportation Infrastructure, and Drinking Water and Wastewater Infrastructure. It also overlaps with Significant and High Hazard Dams and Small Bridges and Culverts.

2.3.3 Resilience Value

Avoided flood damage: Avoided flood damage can encompass physical damages to buildings as well as financial and systemic impacts to residents and businesses (e.g., public health impacts, fiscal impacts, business disruption, critical services disruptions, and transportation delays). As previously noted, according to the Massachusetts Climate Change Assessment, coastal property damage could cost over $1B per year by the 2070s, while damages to residential structures from riverine flooding are estimated to reach $226M by 2090 (nearly double the $116M estimated to occur without climate change).[138] In Cape Cod, sea level rise is projected to cost $20B in cumulative property damage between 2021 and 2100.[139]

A 2020 national study of US coastal counties found that wetlands provide substantial economic benefits by reducing storm damage. All coastal counties in Massachusetts showed marginal storm protection values well over $1M with the area around Boston alone valued at $117M for wetland-related storm protection (both in 2024 $).[140] The BCR for seawall, berm, or hybrid approaches on Cape Cod was estimated to be about 2.0 for protection against up to 12 feet of coastal flooding from 2021 to 2100.[141] For district-scale projects recommended for South Boston, such as seawall installation, raising infrastructure, and increasing beach and dune restoration, the estimated BCRs ranged from 8.7 to 44.9, demonstrating strong economic justification for investment in engineered coastal protection.[142]

[138] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022).
[139] The Cape Cod Commission, *Economic Impacts of Climate Change on Cape Cod*.
[140] Fanglin Sun and Richard T. Carson, "Coastal Wetlands Reduce Property Damage during Tropical Cyclones," *Proceedings of the National Academy of Sciences* 117, no. 11 (2020): 5719–25, https://doi.org/10.1073/pnas.1915169117.
[141] The Cape Cod Commission, *Economic Impacts of Climate Change on Cape Cod*.
[142] *Coastal Resilience Solutions for South Boston* (2018), https://www.boston.gov/sites/default/files/imce-uploads/2018-09/climatereadysouthboston_execsum_v9.1s_web.pdf.

Water, climate, and habitat quality improvements: Floodplains act as natural filters that allow sediment and harmful nutrients to settle. In the Chesapeake Bay watershed in the Mid-Atlantic, the subject of significant restoration efforts, the floodplain trapping value is $223M per year, with a streambank erosion cost of $123M per year, yielding a BCR of ~1.8.[143] Two wetland restoration projects in Barnstable County on the Parkers River (Yarmouth) and Pamet River (Truro) had BCRs of 5.2 to 8.3 and 4.2 to 7.2, respectively, when considering direct economic, carbon sequestration, nitrogen removal, and fisheries benefits against restoration costs from 2021 to 2050.[144] Separately, the BCR for the restoration of 410 acres of vulnerable cranberry bogs in Barnstable between 2021 to 2030, was between 1.1 and 2.0, based on the value of nitrogen removal and value of carbon sequestration.

Commercial and recreation economic benefits: Floodplain restoration yields commercial benefits through opportunities for commercial fisheries and recreational fishing and recreational or tourism activities such as swimming and boating. According to the 2025 ResilientCoasts Draft Plan, the Massachusetts marine economy is valued at $8.3B, with the fishing industry alone generating over $600M annually.[145] The Cape Cod Commission valued the potential loss of commercial fisheries through 2100 at $129M.[146] Cape Cod is estimated to lose between ~50 and 100 feet of beach width between 2040 and 2093, costing a cumulative $13B in lost value of beach recreation between 2021 and 2100.

2.4 Forest Conservation and Tree Planting

Description: *Expand forest conservation and tree planting, including urban forestry, to reduce urban heat island effect, increase carbon sequestration, improve stormwater management, and enhance cooling capacity.*

2.4.1 Background

Massachusetts has 62% forest cover, making it the eighth most forested state in the US despite it being the third most densely populated.[147,148] The forests and trees of Massachusetts provide a multitude of benefits, including improving air and water quality, providing habitat for wildlife, enhancing climate resilience, and supporting recreation opportunities.[149] As intense rainfall events become more frequent, the water-absorbing and filtration capacity of forests and urban trees is also important, as they reduce the impacts on stormwater infrastructure and transportation corridors through enhanced infiltration of rainfall and prevention of erosion. Urban forest ecosystems, including urban parks, street trees, and greenways, in developed areas improve air quality and increase aesthetic values of neighborhoods. Shade trees also provide a range of benefits related to microclimatic effects. A minimum level of tree cover in cities can lower ambient air temperatures and mitigate the impacts of wind events, resulting in improved quality of life and energy savings.[150,151] Strategies related to this key resilience measure have many benefits that intersect with all the other key resilience measures.

143 "Floodplains Provide Millions of Dollars in Benefits Every Year to People in the Chesapeake Bay and Delaware River Watersheds | U.S. Geological Survey," August 21, 2023, https://www.usgs.gov/centers/chesapeake-bay-activities/science/floodplains-provide-millions-dollars-benefits-every-year.

144 Cape Cod Commission, *Climate Action Fact Sheet: Protect Preserve, and Restore Wetlands and Buffer Areas*.

145 Massachusetts Office of Coastal Zone Management, *ResilientCoasts Draft Plan*.

146 The Cape Cod Commission, *Economic Impacts of Climate Change on Cape Cod*.

147 "Massachusetts Forests | UMass Amherst MassWoods," accessed June 10, 2025, https://masswoods.org/massachusetts-forests.

148 United States Environmental Protection Agency, *2022 Clean Watershed Needs Survey, Report to Congress* (United States Environmental Protection Agency, 2024), https://www.epa.gov/system/files/documents/2024-05/2022-cwns-report-to-congress.pdf.

149 Mary Cardwell et al., *Massachusetts State Forest Action Plan* (Massachusetts Department of Conservation and Recreation, 2020), https://www.mass.gov/doc/massachusetts-forest-action-plan/download.

150 Cardwell et al., *Massachusetts State Forest Action Plan*.

151 Department of Energy, "Landscaping for Shade," accessed June 12, 2025, https://www.energy.gov/energysaver/landscaping-shade.

The 2023 ResilientMass Plan has actions to protect 30% of land and ocean by 2030 and expand DCR's Greening the Gateway Program.[152] The Massachusetts Clean Energy and Climate Plans (CECP) for 2030 and 2050 outline the goals listed below, related to land conservation and tree planting:[153,154]

- Massachusetts will increase efforts to permanently conserve at least 30% of undeveloped land and water (including wetlands) by 2030 ("30x30") and 40% by 2050 ("40x50"). It is important to note that this goal to permanently conserve undeveloped land and water has been used in absence of specific forest conservation goals.
- Massachusetts will plant at least 16,000 acres of new urban and riparian trees by 2030 and 64,000 acres or more by 2050.

It is important to note that there are two additional goals in the 2030 CECP to incentivize at least 20% of privately owned forests and farms to adopt climate smart management practices and achieve no net loss of stored carbon in wetlands by 2030.[155] The cost for achieving these goals has not been estimated, as they are not capital intensive. The 2030 and 2050 CECPs provides a range of strategies, actions, and proposed policy changes to facilitate the achievement of these goals. While these strategies are comprehensive, this analysis quantifies the costs for the higher order goals, rather than individual strategies. It is noted that the 2030 and 2050 CECP goals are driven by carbon sequestration targets, however, in absence of defined and quantified goals for resilience to 2050, achieving the CECP goals will provide resilience benefits alongside carbon sequestration benefits.

There are various initiatives to support Massachusetts' conservation goals, with support from both state agencies and conservation partners. Mass Audubon is publishing costs of example conservation projects and will soon be publishing information on the estimated cost to achieve the '30x30' and '40x50' goals. The DCR Division of Water Supply Protection has an active land acquisition program to protect watersheds that provide drinking water for Massachusetts Water Resources Authority (MWRA). The program aims to protect the land from the impacts of climate change and urban stormwater runoff to protect drinking water sources. The Land Protection Program, a joint effort of DFG and MassWildlife, seeks to expand existing wildlife lands, enhance public access to lands and waters for wildlife-related recreation, and protect key fish and wildlife habitats through land acquisition. Most funding for land acquisition is from bond capital, with the remaining portion provided by the Wildlands Stamp Fund, a $5 fee added to each purchase of a hunting, fishing, or trapping license.[156] Additional land acquisition projects (detailed in Attachment 2: Collected Project Information) aim to protect habitats while simultaneously avoiding impacts of flooding and climate change.

2.4.2 Investment Need

2.4.2.1 Cost Data Review Summary

2.4.2.1.1 Undeveloped Land and Water Conservation

As noted in the 2030 CECP, the permanent conservation goals require ~167,000 additional acres to be protected to reach 30% by 2030 and 685,000 total by 2050.[157] As of 2022 reporting, nearly 30% of Massachusetts was permanently protected.[158] Based on data from MassGIS for Protected and

[152] Commonwealth of Massachusetts, *ResilientMass Plan* (2023), https://www.mass.gov/doc/resilientmass-plan-2023/download.
[153] *Massachusetts Clean Energy and Climate Plan for 2050*, n.d.
[154] *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (MA Executive Office of Energy and Environmental Affairs, 2022), https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download.
[155] *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*.
[156] "MassWildlife Land Acquisitions | Mass.Gov," accessed July 7, 2025, https://www.mass.gov/info-details/masswildlife-land-acquisitions.
[157] *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*.
[158] Massachusetts Office of Climate Innovation and Resilience, "Massachusetts Climate Report Card," Massachusetts Climate Report Card - Natural and Working Lands, 2024, https://www.mass.gov/info-details/massachusetts-climate-report-card-natural-working-lands. In 2022, this amounted to 1.395 million acres.

Recreational Open Space, the majority (65%) was under state or municipality ownership (August 2024).[159] There are two main paths to permanently protect land in Massachusetts:

- Acquire the land (fee simple acquisition): purchasing or accepting the donation of the entire interest in a piece of property.
- Conservation Restriction (CR) Acquisition/Agricultural Preservation Restriction (APR) Acquisition: a CR, also known as a conservation easement in other states, is a legal agreement between a landowner and a government agency or land trust that permanently protects open space by limiting future uses of the land but continues to leave the land in private ownership. An APR is a type of CR that preserves the land for agricultural purposes.

A combination of these two options will be needed to achieve the Commonwealth's conservation goals.

Acquisition

Review of the land purchase price per acre from AcreValue for agricultural and undeveloped land indicated $11,800 to $23,800.[160] LandWatch data for the average sale price for undeveloped land per acre indicated $15,400.[161] From 1985 through 2022, DCR's Division of Water Supply Protection (DWSP) program acquired nearly 27,500 acres (28% of the watershed area) at an average cost of $5,235 per acre.[162] DCR's Land Protection Program (State Parks) spends an average of $3,000 to $3,500 per acre statewide to acquire or protect undeveloped land (average of both developable and undevelopable land), with higher values per acre in the eastern part of the state, particularly on the North Shore and Cape Cod.

The Buzzards Bay Coalition (BBC), a nonprofit organization, focuses on flood reduction by preparing land for salt marsh migration; this preparation includes activities such as removing structures from acquired lands and replanting native species to restore natural habitats and improve drainage during coastal flooding.[163] BBC along with its partners has acquired over 10,000 acres of land in increments, including a 2023 purchase of 22 acres of Wainer Family Farm for $3M in 2024 $ ($136,000 per acre).[164]

PLACES Lab, a research group based at Boston University, estimated land values at the property level throughout the US using fair market value data to inform publicly funded land acquisitions for conservation. PLACES Lab noted that costs are often underestimated for conservation planning. The acquisition cost per acre for all vacant land from PLACES Lab is summarized by county in Table 6. The information is presented along with information on the county land cover data (from 2016) and protected area.

Table 6: PLACES Lab Fair Market Value for Vacant Land by County with County Land Information

County	Fair Market Value of Vacant Land Cost per Acre	Total Acreage	Impervious Cover	Open Space Protected in Perpetuity	Grassland/ Forest/Wetland
Suffolk County	N/A	37,000	55%	15%	25%
Nantucket County	$368,000	30,000	10%	50%	55%
Dukes County	$192,000	64,000	5%	35%	70%

159 "Mass GIS Data: Protected and Recreational Open Space," Mass GIS (Bureau of Geographic Information), August 2024, https://www.mass.gov/info-details/massgis-data-protected-and-recreational-openspace#overview-.
160 AcreValue – agricultural land valuation and data platform, average sale price/acre in MA (standard and soil adjusted). AcreValue, "AcreValue Market Explorer," https://www.acrevalue.com/market/massachusetts/.
161 "Massachusetts Undeveloped Land for Sale," LandWatch, https://www.landwatch.com/massachusetts-land-for-sale/undeveloped-land.
162 "DCR Watershed Land Acquisition | Mass.Gov," accessed July 14, 2025, https://www.mass.gov/info-details/dcr-watershed-land-acquisition.
163 Buzzards Bay Coalition, *BBC and Neighbors Convert Coastal Eyesore into Native Landscape to Absorb Flooding*, n.d., https://www.savebuzzardsbay.org/news/bbc-removes-coastal-eyesore/.
164 Faith Harrington, "A Conservation Group Bought the Farm That Supplied Sid Wainer Produce. What They Plan Next," New Bedford Standard-Times, accessed June 10, 2025, https://www.southcoasttoday.com/story/news/2023/04/18/sid-wainer-and-sons-family-farm-was-sold-to-buzzards-bay-coalitions-heres-what-we-know/70088602007/.

County	Fair Market Value of Vacant Land Cost per Acre	Total Acreage	Impervious Cover	Open Space Protected in Perpetuity	Grassland/ Forest/Wetland
Barnstable County	$118,000	261,000	10%	35%	65%
Norfolk County	$111,000	256,000	15%	20%	65%
Middlesex County	$105,000	527,000	15%	20%	65%
Essex County	$72,000	316,000	15%	25%	70%
Plymouth County	$43,000	409,000	10%	25%	70%
Bristol County	$39,000	357,000	10%	20%	70%
Worcester County	$17,000	967,000	5%	30%	75%
Hampden County	$13,000	399,000	10%	25%	75%
Hampshire County	$9,000	338,000	5%	30%	80%
Berkshire County	$8,000	599,000	5%	40%	85%
Franklin County	$5,000	448,000	0%	35%	85%

Notes: PLACES Lab data were used for fair market value of vacant land per acre; Total acreage, impervious cover, and grassland/forest/wetland acreage data exclude open water. Data sourced from MassGIS Data: 2016 Land Cover/Land Use[165,166] Acreage protected in perpetuity data sourced from MassGIS Data: Protected and Recreation Open Space.[167,168] Acreage and fair market value costs are rounded to the nearest 1,000. Impervious cover, open space protected, and grassland/forest/wetland percentages are rounded to the nearest 5%. Costs are shown in 2024 $.

The statewide weighted average fair market value for vacant land based on total acreage is $45,000 per acre. Excluding the top half most expensive counties with fair market value vacant land cost per acre data, the weighted average is closer to $18,000 per acre (representing around 70% of state acreage excluding open water). The weighted average for the five lowest cost counties (representing around 55% of acreage) is ~$11,500 per acre.

Conservation Restrictions

The purpose and terms of each CR are tailored to the specific characteristics of each property and are designed to meet multiple conservation objectives. The cost or value of the CR or APR is also directly related to the development potential or value of the land as these are the rights that are generally purchased. As such, the cost of a CR or APR is highly variable and typically also includes project costs such as costs of legal counsel/financial advisory, an appraisal for tax purposes, environmental reports and surveys (e.g., ecological and forestry surveys or wetland delineation costs), an endowment (sometimes annual) to an organization for monitoring, and maintenance and defense of the CR.

A 2009 Trust for Public Land report estimated the average cost of a CR in Massachusetts as $9,621 per acre, adjusted to 2024 $.[169] Recent information posted by Mass Audubon for projects ranged between $1,900 per acre for a 2,500-acre site in Monson to $15,600 per acre for protection of a 1,000-acre site in

165 "MassGIS Data: 2016 Land Cover/Land Use | Mass.Gov," accessed July 14, 2025, https://www.mass.gov/info-details/massgis-data-2016-land-coverland-use.

166 Information from the 2016 Land Cover/Land Use database: "This 2016 land cover information was initially developed as a 1-meter, 6-category draft raster derived from 2016 US Department of Agriculture (USDA) National Agricultural Imagery Program (NAIP) aerial multispectral imagery. Classes were impervious, bare, grass, shrub, tree, and water. Additional reference data were used to create this 19-class version, including: 2016 WorldView multispectral satellite imagery, lidar-based terrain elevation data, 2016-era 2D structures data, and other ancillary data such as MassDOT Roads, and MassDEP Wetlands. The wetlands in the final land cover product are exclusively from the C-CAP program and will differ from the MassDEP Wetlands data. The land cover information in this product is consistent with C-CAP's High-Resolution Land Cover Classification Scheme (PDF."

167 "MassGIS Data: Protected and Recreational OpenSpace | Mass.Gov," accessed July 14, 2025, https://www.mass.gov/info-details/massgis-data-protected-and-recreational-openspace.

168 Definition of In Perpetuity from database: "**In Perpetuity (P)**- Legally protected in perpetuity and recorded as such in a deed or other official document. Land is considered protected in perpetuity if it is owned by the town's conservation commission or, sometimes, by the water department; if a town has a CR on the property in perpetuity; if it is owned by one of the state's conservation agencies (thereby covered by article 97); if it is owned by a non-profit land trust; or if the town received federal or state assistance for the purchase or improvement of the property. Private land is considered protected if it has a deed restriction in perpetuity, if an Agriculture Preservation Restriction has been placed on it, or a CR has been placed on it."

169 MaryBruce Alford et al., *DEFENDERS OF WILDLIFE TRUST FOR PUBLIC LAND*, n.d.

the Housatonic River Valley.[170] Conversations with Massachusetts agency representatives noted CRs could be $5,000 to $9,000 per acre.

While efforts are underway to prioritize and protect land, such as Mass Audubon's 30x30 Catalyst Fund and DCR's Division of Water Supply Protection program to acquire land to protect drainage areas in watersheds that provide drinking water (detailed in the Coastal and Riverine Wetlands and Floodplains key resilience measure), the specific proportion of land that will be purchased and conserved versus conserved using a CR/APR is not fully known, particularly out to 2050. Factors that drive these decisions include availability and price of undeveloped land for sale, existing use of the land, and strategic considerations (e.g., prioritizing land in floodplains and connection of wildlife corridors).

2.4.2.1.2 Urban and Riparian Tree Canopy Expansion

The CECP identifies a goal to plant 16,000 acres of new urban and riparian trees by 2030 and 64,000 additional acres by 2050. The investment need analysis has utilized the assumptions and cost estimate excerpt from EEA Urban Forestry (and Reforestation) Strategic Plan Study[171] which also aimed to estimate the cost to achieve the CECP goal. Notably, the EEA model excerpt used provides only the results to 2030. Using the assumptions outlined in the study, the results were extrapolated to 2050.[172] Table 7 displays the estimated costs for tree planting to meet the 2030 and 2050 goals.

Table 7: Urban and Riparian Tree Canopy Expansion, 2030 and 2050

Metric	2030	2050
Number of urban trees planted (cumulative)	92,310	400,010
Number of riparian trees planted (cumulative)	205,128	888,888
Total trees planted (cumulative)	**297,438**	**1,288,898**
Total urban acres	18,462	80,002
Total riparian acres	4,103	17,778
Total acres planted	22,565	97,780
Total costs (cumulative)	**$55M**	**$300M**

Source: EEA Urban Forestry (and Reforestation) Strategic Plan Study

EEA's trees per acre assumes higher tree density for riparian areas. They assume five trees per acre for urban and 50 trees per acre for riparian.

The EEA assumptions include costs for tree maintenance in tree planting cost estimates.

2.4.2.2 Investment Need Analysis

Forest conservation: Agency reviewers noted that a reasonable assumption of 20% of land would be protected through a CR (which is typically cheaper than acquisition). The low end assumes 30% of the 685,000 acres will be protected through a CR at a cost of $7,000 per acre and that the remaining acreage will be acquired at a cost of around $11,500 per acre based on the PLACES Lab data (described above).

The high end assumes 20% of the 685,000 acres will be protected through a CR also at a cost of $9,000 per acre. It assumes the remaining 80% will be acquired at a cost of $18,000 per acre based on the PLACES Lab data (described above).

Tree planting: The costs for tree planting are the same for the low- and high-end scenarios, as these costs were extrapolated from the EEA study which did not include a range.

170 MassAudubon, "30x30 Catalyst Fund Projects," https://www.massaudubon.org/our-work/resilient-lands/land-conservation/30x30-catalyst-fund/30x30-catalyst-fund-projects.
171 "EEA Urban Forestry (and Reforestation) Strategic Plan Study," n.d.
172 It is important to note that AECOM values differ from EEA due to exclusion of inflation.

The rough order of magnitude estimated investment need for this key resilience measure is displayed in Table 8.

Table 8: Rough Order of Magnitude Investment Need Estimates for Forest Conservation and Tree Planting

Investment Need	Low Estimate	High Estimate
Conserve 685,000 acres of forest	$6.5B	$11B
Plant 64,000 acres of urban and riparian trees	$300M	$300M
Total (Rounded)	**$7B**	**$11B**

Notes: Results are rounded.

2.4.2.3 Investment Need Analysis Limitations and Other Considerations

- In the sources reviewed, there was a great degree of variability in the cost of CRs. There is a large range both between and in the sources reviewed.
- The estimate of per acre costs used does not include stewardship or endowment costs, which can significantly increase the cost (upwards of $50,000 by some sources).
- Massachusetts Equalized Valuation[173] data were considered but as the valuation uses both land and improvements, it cannot be used as a standalone source for estimating undeveloped land costs.
- Tree costs, sourced from EEA, include the cost of the tree (including transport), planting/maintenance labor costs, and fence/tree cost. Cost does not include overhead (e.g., Information Technology [IT]/office/management) or initial capital costs (e.g., equipment/machinery).
- This key resilience measure has overlap with Coastal and Riverine Floodplains (particularly land acquisition) and Heat Preparedness and Relief, and the benefits of this measure may reduce costs and risks in other key resilience measures.

2.4.3 Resilience Value

Reduction in urban heat island and other cooling benefits: Tree canopies provide shade and transpiration benefits that can lower pedestrian-level temperatures by up to 21°F.[174] This cooling benefit is particularly important for urban areas, where urban heat island effects can increase daytime temperatures between 1°F and 7°F higher on average than outlying areas.[175] An analysis of heat impacts in Phoenix, Arizona found that increasing urban tree canopies to 25% could deliver nearly $1B in mortality and morbidity reduction benefits due to a reduction in heat related illness and death. Across the heat reduction benefits considered (i.e., mortality, morbidity, road pavement, energy use, and labor productivity), $1 invested generated $3.70 in benefits.[176]

Tree canopies are not distributed evenly across Massachusetts communities, and those communities with less coverage may experience disproportionately positive impacts from tree canopy investment. Boston's tree canopy assessment found that tree coverage ranged from less than 10% in some areas of the city,

[173] Equalized Valuation is the determination of an estimate of the full and fair cash value of all property in the Commonwealth as of a certain taxable date.
[174] Haiwei Li et al., "Cooling Efficacy of Trees across Cities Is Determined by Background Climate, Urban Morphology, and Tree Trait," *Communications Earth & Environment* 5, no. 1 (2024): 1–14, https://doi.org/10.1038/s43247-024-01908-4.
[175] OAR US Environmental Protection Agency (EPA), "Learn About Heat Island Effects," Overviews and Factsheets, August 2, 2024, https://www.epa.gov/heatislands/learn-about-heat-island-effects.
[176] Anne deBoer et al., *Economic Assessment of Heat in the Phoenix Metro Area* (The Nature Conservancy, 2021), https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_EcoHeatAssement_AZ_Report.pdf.

compared to more than 95% in others.[177] Historically, redlined areas of Boston have 20% less parklands and 40% less tree canopy than other areas of the city and experience 7.5°F hotter days than the rest of the city.[178] An analysis of over 5,700 municipalities across the US found that, on average, low-income census blocks have 15% less tree cover and are 2.7°F hotter than high-income blocks.[179] Average reduction in national residential energy use due to urban trees is estimated to be 7.2%, which could result in significant energy cost savings for low-income and energy burdened communities.[180] When energy savings is considered alone, every $1 invested in a modeled tree planting program in California resulted in $1.42 in annual cooling savings.[181]

Property values and economic benefits: Urban trees provide aesthetic and amenity benefits that improve property values and livability. Across the Commonwealth, tree cover has been estimated to generate ~$21.4B in property value and over $1.9B in annual quality-of-life benefits.[182] A meta-analysis completed in 2022 by Kovacs et al., investigated tree cover and the impacts on property value. The analysis found that a 1% increase in tree cover in a residential area increases the property value by $277 per acre of land.[183]

Additionally, the urban forestry industry generates significant economic activity. Economic output per capita generated by urban forestry-related activities was $327 per capita in Massachusetts in 2017, or $2.2B annually (2017 $).[184] The positive economic impacts of forests apply to land conservation more broadly. A panel study of land conservation in all major New England cities and towns between 1990 and 2015 found a statistically significant and positive relationship between employment and land protection, with an outsized impact on rural areas.[185]

Ecosystem services and carbon sequestration: The Commonwealth's ecosystems are productive assets, or "natural capital" which provide significant ecosystem services to its residents.[186] A review of the costs and benefits of urban tree planting finds that every $1 invested in urban tree projects yields an average of $5.43 in benefits across benefit categories including aesthetic/amenities, shading, water regulation, carbon reduction, and air quality.[187] An analysis completed by the Trust for Public Land finds that every $1 invested in land conservation in Massachusetts generates $4 of economic value from ecosystem services such as water quality protection, stormwater management, and air pollution removal.[188] These findings align with other conservation studies in the US. A multi-decade analysis of public land acquisitions in Minnesota estimated the annual return on investment by 2052 between $0.21 and $5.28 per acre in the areas of carbon sequestration, water quality, and recreation benefits.[189]

The Massachusetts Forest Carbon Study found that Massachusetts' forests serve as a long-term net-sinks for atmospheric carbon, with the ability to remove 3 to 4.5 years of Massachusetts' current

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[177] "Tree Canopy Assessment, Boston MA," n.d., accessed June 16, 2025, https://www.boston.gov/sites/default/files/file/2020/09/Change-assessment_w_MJW-letter.pdf.
[178] *Boston Heat Resilience Plan*.
[179] Robert I. McDonald et al., "The Tree Cover and Temperature Disparity in US Urbanized Areas: Quantifying the Association with Income across 5,723 Communities," *PLOS ONE* 16, no. 4 (2021): e0249715, https://doi.org/10.1371/journal.pone.0249715.
[180] David Nowak et al., "Residential Building Energy Conservation and Avoided Power Plant Emissions by Urban and Community Trees in the United States," *United States Department of Agriculture, Forest Service / University of Nebraska-Lincoln: Faculty Publications*, January 1, 2017, https://digitalcommons.unl.edu/usdafsfacpub/318.
[181] E. G. McPherson and J. R. Simpson, "Potential Energy Savings in Buildings by an Urban Tree Planting Programme in California," *Urban Forestry & Urban Greening. 2: 73-86* 2 (2003): 73–86, https://doi.org/10.1078/1618-8667-00025.
[182] "Tree City USA Bulletin (Nov/Dec 2021), Arbor Day Foundation," n.d.
[183] Kent Kovacs et al., "Tree Cover and Property Values in the United States: A National Meta-Analysis," *Ecological Economics* 197 (July 2022): 107424, https://doi.org/10.1016/j.ecolecon.2022.107424.
[184] "Tree City USA Bulletin (Nov/Dec 2021), Arbor Day Foundation."
[185] Katharine R. E. Sims et al., "Assessing the Local Economic Impacts of Land Protection," *Conservation Biology: The Journal of the Society for Conservation Biology* 33, no. 5 (2019): 1035–44, https://doi.org/10.1111/cobi.13318.
[186] Raimundo Atal et al., *Accounting for Nature's Value* (2024), https://policyintegrity.org/files/publications/NCA_Report_vF.pdf.
[187] Xiao Ping Song et al., "The Economic Benefits and Costs of Trees in Urban Forest Stewardship: A Systematic Review," *Urban Forestry & Urban Greening*, Wild urban ecosystems: challenges and opportunities for urban development, vol. 29 (January 2018): 162–70, https://doi.org/10.1016/j.ufug.2017.11.017.
[188] The Trust for Public Land, *The Return on Investment in Parks and Open Space in Massachusetts* (2013), https://www.tpl.org/wp-content/uploads/2013/10/benefits-ma-roi-report.pdf.
[189] Kent Kovacs et al., "Evaluating the Return in Ecosystem Services from Investment in Public Land Acquisitions," *PLOS ONE* 8, no. 6 (2013): e62202, https://doi.org/10.1371/journal.pone.0062202.

statewide gross greenhouse gas emissions over the next 80 years.[190] Around 15% of Massachusetts' forests are classified as Forest Core, which plays a critical role in the resilience of the biodiversity of Massachusetts, specifically for species sensitive to forest fragmentation. Of the nearly 440,000 acres of Forest Core, over 80% is classified as "above average" for resilience, making them ideal locations for climate resilient forest conservation.[191]

2.5 Strategic Transportation Infrastructure

Description: *Reduce impacts from flood waters and erosion on strategic transportation infrastructure through protection or relocation of roadways, railway, tunnels, bridges and transit facilities and infrastructure.*

2.5.1 Background

Massachusetts has over 36,000 centerline miles of road,[192] 1,400 miles of rail right-of-way (ROW),[193] and additional supporting infrastructure as part of robust municipal and state transportation networks.[194,195,196] Extreme weather events exacerbated by climate change, such as extreme heat, coastal flooding, and heavy precipitation, can cause consequential damage to transportation infrastructure as well as gradual degradation of the network over time. The 2023 ResilientMass Plan notes that over 1,800 miles of road are in coastal hazard areas for a Category 1 Storm and over 3,000 miles of road vulnerable to a Category 3 Storm.[197]

There is significant ongoing work in Massachusetts to better understand and prioritize transportation resilience projects. The Massachusetts Transportation Funding Task Force was established in January 2024 to generate a long-term funding plan that will, among other goals, move transportation infrastructure towards resilience and ensure infrastructure can be maintained in a state of good repair and resilience.[198] The Task Force plan aligns with ResilientMass, MassDOT, and MBTA vulnerability assessments. In *ResilientMass*, MassDOT was identified as the lead agency to develop a Highway RIP and Resilience Improvement Prioritization. The Highway RIP was completed in June 2024 and estimates that, by 2090, maintenance costs will increase over baseline by $140M due to climate impacts on road surface conditions.[199,200] Additionally, in alignment with the 2023 ResilientMass Plan, DCR's 2025 Parkways Climate Change Vulnerability Assessment identifies current and future flooding risks across the historical parkways network.[201] In this report, DCR evaluated over 200 miles of parkway and will integrate the findings from this study into future planning and investment strategies.

In MassDOT's 2024 Beyond Mobility plan, a statewide long-range transportation plan, resilience is one of the six Priority Areas.[202] The 2024 Beyond Mobility Plan calls for development of resilience performance measures, including the number of Capital Investment Plan (CIP) projects addressing the locations of

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[190] Executive Office of Energy and Environmental Affairs, *Forest Carbon Study: The Impact of Alternative Land-Use Scenarios on Terrestrial Carbon Storage and Sequestration in Massachusetts* (2025), https://www.mass.gov/doc/forest-carbon-study-report-2025/download.

[191] "Forest Core," accessed June 10, 2025, https://biomap-mass-eoeea.hub.arcgis.com/pages/forest-core.

[192] Centerline miles of road refers to the length of a road measured along its center line and does not take into account the number of miles.

[193] Miles of rail ROW refers to the length of land area that rail tracks occupy and not the length of tracks, as multiple tracks can be in the same ROW.

[194] "State of the System. Focus on Today's MBTA," Focus 40. The 2040 Investment Plan for the MBTA., https://www.mbtafocus40.com/mbta-today.

[195] *Massachusetts Road Inventory Year End Report* (Massachusetts Department of Transportation Office of Transportation Planning, 2017), https://www.mass.gov/files/documents/2017/09/13/2016_ri_ye_rpt.pdf.

[196] Mass GIS (Bureau of Geographic Information), "MassGIS Data: Trains," November 2023, https://www.mass.gov/info-details/massgis-data-trains.

[197] Commonwealth of Massachusetts, *ResilientMass Plan*.

[198] Transportation Funding Task Force, *Massachusetts Transportation Funding Task Force* (2025).

[199] MassDOT, *Resilience Improvement Plan*.

[200] Commonwealth of Massachusetts, "ResillientMass Plan Action Tracker," https://resilient.mass.gov/actiontracker.

[201] Department of Conservation & Recreation, "DCR's Parkways Climate Change Vulnerability Assessment," Mass.Gov, May 2025, https://www.mass.gov/info-details/dcrs-parkways-climate-change-vulnerability-assessment.

[202] MassDOT, *Beyond Mobility: Massachusetts 2050 Transportation Plan* (2024), https://www.mass.gov/doc/massdot-beyond-mobility-full-plan/download.

vulnerable or at high risk to flooding and other natural hazards.[203] The CIP for FY 2025 through FY 2029 (FY29) includes $16.7B in capital improvement projects to be completed by MassDOT over the course of the 5-year period; ~60% of those investments focus on resilience and reliability of the existing system.[204] Separately, the MBTA's FY26 through FY 2030 CIP includes $9.8B in capital improvement projects.

MassDOT is currently conducting a statewide Flood Risk Assessment that identifies transportation assets that are exposed to flooding or associated erosion under various climate scenarios, quantifies the "do nothing" cost of future flooding related damage at the asset level, and provides qualitative consequences assuming no intervention.[205] Assessment results can inform capital planning to prioritize investments across transportation assets to reduce flood impacts due to climate change.[206]

The 2025 ResilientCoasts Draft Plan by CZM defines a resilience measure for road infrastructure and proposes completing a coastwide evacuation pilot study to increase road resilience.[207] In the May 2025 draft, the plan supports two measures for road infrastructure: elevate and right size infrastructure, and relocate or reroute; though these measures may be updated in future drafts, protecting road infrastructure is of high importance. MBTA has published multiple Vulnerability Assessments, including System Wide, Rapid Transit, Bus, and Commuter Rail Assessments, which are all publicly available.[208] These assessments have informed various completed resilience projects, including the elevated and reconstructed Charlestown Seawall and Aquarium Station Flood Proofing Project, as well as identified future priority projects in the 5-year CIP.[209] MBTA's 2024 Climate Assessment identifies next steps based on previous assessments and workshops to develop a systemwide resilience plan.[210] Additionally, a 2023 Massachusetts Institute of Technology thesis report Climate Change Adaptation Planning and Decision Making for Transit Infrastructure, undertaken in partnership with MBTA, investigates coastal flood vulnerabilities, specifically in MBTA's tunnel system, and considers adaptation pathways to address the identified vulnerabilities.[211]

2.5.2 Investment Need

2.5.2.1 Cost Data Review Summary

The cost data provided and reviewed largely related to five asset categories: 1) roads, 2) bridges, 3) tunnels, 4) rail, and 5) transit facilities/infrastructure. Other assets, such as ports, airports, and pedestrian and cycling paths, were not included.

2.5.2.1.1 Roads

There is significant ongoing work in Massachusetts to better identify and prioritize transportation resilience projects. However, at the time of this investment analysis, there is no statewide estimate of road resilience projects. Road resilience projects can include a variety of strategies such as road elevation to protect against flooding and application of heat-resistant materials to protect against heat-related degradation. The MassDOT FY25 to FY29 CIP includes $16.7B in capital projects to be completed by

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203 MassDOT, *Resilience Improvement Plan*.
204 MassDOT, *Final FY 2025-2029 Capital Investment Plan* (2024), https://www.mass.gov/doc/2025-2029-capital-investment-plan-final/download.
205 The scope of the assessment includes: the National Highway System (NHS) Roads (excluding tunnels), NHS bridges and large culverts, MassDOT-owned and MBTA commuter railroads (excluding light rail and subway), MassDOT facilities, and public-use airports (excluding Massport-owned properties).
206 MassDOT, "MassDOT Flood Risk Assessment Objectives," Mass.Gov, https://www.mass.gov/info-details/massdot-flood-risk-assessment-objectives.
207 Massachusetts Office of Coastal Zone Management, *ResilientCoasts Draft Plan*.
208 MBTA, *MBTA Climate Assessment* (2024), https://cdn.mbta.com/sites/default/files/2024-09/2024-9-26-mbta-climate-assessment-accessible_0.pdf.
209 MBTA, *Massachusetts Bay Transportation Authority FY26-30 Capital Investment Plan (CIP)* (2025), https://cdn.mbta.com/sites/default/files/2025-05/2025-05-20-fy26-30-cip-final.pdf.
210 MBTA, *MBTA Climate Assessment*.
211 Michael Vincent Martello, "Climate Change Adaptation Planning and Decision Making for Transit Infrastructure" (Thesis, Massachusetts Institute of Technology, 2023), https://dspace.mit.edu/handle/1721.1/151212.

MBTA and MassDOT over the 5-year period. An estimated 60% of those investments focus on resilience and reliability of the existing system.[212]

Cape Cod's Low-Lying Roads Project is a regional project to address roadways that will be flooded under sunny-day high tides in 2070.[213] Project cost estimates for 43 different adaptation strategies across one to two priority road segments per town amount to over $20M using gray infrastructure improvements (see Attachment 2: Collected Project Information). The study includes cost ranges for different road protection project types. Road elevation was estimated at $4M to $10M per mile, dune restoration at $3M to $4M, deployable barriers at $2M to $3M, and levee construction (for a 5-foot-high levee) at $200,000 to $3M.[214,215]

Morrisey Boulevard Reconstruction, supported by DCR, MassDOT, and other city and state authorities, is scoped to cost between $273M and $352M at the time of construction in 2036 ($182M to $234M in 2024 $) for climate resilient upgrades along ~2.5 miles of the six-lane road.[216,217] The costed resilience projects consider the addition of a tide gate, altering the harborside slope, and adding berms or other living shoreline elements. Another planned flood relief project on Route 20 in Worcester is currently estimated to cost around $7M to upgrade the existing drainage system and construction is scoped to begin Fall of 2025.[218] The Dorchester Resilient Waterfront Project at Tenean Beach and Conley Street, supported by DCR, MassDOT, MBTA, and others, plans to elevate Conley Street up to 14 feet to prevent flooding. The entire project is scoped to cost ~$12M, with the roadway building portion costing ~$1M.[219] It is important to note that the total project cost does not include the elevation of Tenan Yard, a critical MBTA Red Line access point, which would be required to maintain operability at the new street elevation.

Road elevation project costs can vary widely, based on factors such as number of lanes, mileage of road, extent of elevation, and presence of utilities. MassDOT noted that it does not have an inventory of low-lying facilities prone to flooding. As part of the data collection process for the Investment Assessment, MassDOT noted that road projects could cost $15M to $20M per centerline mile for modernization alone. Reviewed costs from the road elevation projects elsewhere (e.g., Virginia and Washington State) range from close to $2M per centerline mile to between $20M and $25M.

NJTPA developed a matrix of costs for asset adaptation strategies for bridges, culverts, facilities, rail tracks, road, and transit (bus line) assets.[220] For heat-resistant materials for roads, NJTPA estimates $40 per linear foot. Alternatively, using rut-resistant asphalt or concrete would cost $245,000 per lane mile for new roads or $331,000 per lane mile for road repair.[221]

The 2025 ResilientCoasts Draft Plan estimates that the cost per project to elevate and right-size road infrastructure can range from $10M to over $30M. The cost to relocate or reroute road infrastructure is

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[212] MassDOT, *Final FY 2025-2029 Capital Investment Plan*.

[213] The study identifies roads that would be prioritized for protection against coastal flooding The scoring framework is based on the type of road and average daily traffic, vulnerable populations, emergency or community services access, and the business activity density. Cape Cod Commission, "Low Lying Roads Project," 2024, https://www.capecodcommission.org/our-work/low-lying-roads-project/#:~:text=The%20results%20of%20the%20model,risk%20(e.g.%2C%20flooding).

[214] The study identifies roads that would be prioritized for protection against coastal flooding The scoring framework is based on the type of road and average daily traffic, vulnerable populations, emergency or community services access, and the business activity density. Cape Cod Commission, "Low Lying Roads Project."

[215] *Summary of Costs Associated with Levee-Related Activities* (National Levee Safety Program, 2023), https://mmc.sec.usace.army.mil/NLSP_website/NLSP_LeveeCostBrochure_FINAL_NOV2023.pdf.

[216] "Morrissey Re-Build Cost Put at $350m at High End; Some Ask More Plan Time," Dorchester Reporter, accessed June 16, 2025, https://www.dotnews.com/2024/morrissey-re-build-cost-put-350m-high-end-some-ask-more-plan-time.

[217] *Climate Resilience Solutions for Dorchester* (City of Boston, 2020), https://www.boston.gov/sites/default/files/file/2020/10/Climate%20Ready%20Dorchester-Final%20Report%20%28Spreads%20for%20web%29.pdf.

[218] "MassDOT Project Information," Mass.Gov, accessed July 10, 2025, https://hwy.massdot.state.ma.us/projectinfo/projectinfo.asp?num=612608.

[219] *Technical Analysis and Development Options for Dorchester's Waterfront: Executive Summary* (2023), https://www.bostonplans.org/getattachment/273db71a-8085-4924-b5cb-3f10ae1c093a.

[220] New Jersey Transportation Planning Authority, *Benefit Cost Analysis Costs for Asset Adaptation Strategies*.

[221] Lane mile represents the length of roadway including the number of lanes. Lane mile length is the product of centerline miles by the number of lanes.

estimated to be over $30M for a typical project, though the actual cost depends on the scale of the road segment to be relocated or rerouted.

2.5.2.1.2 Bridges

Bridge resilience upgrade costs are highly variable, driven by factors such as existing condition, bridge length, and hazard exposure. Bridge improvements to address resilience may relate to upsizing (such as converting culverts into small bridges (as discussed in Section 2.2 Small Bridges and Culverts), upgrades or retrofits to manage increased water pressure, protection of piers and abutments, and installation of flood barriers.

EPA's 2017 Climate Change Impacts and Risk Analysis (CIRA) estimated proactive and rehabilitative costs for bridges from projected changes in peak flows from 100-year, 24-hour precipitation events considering: 1) the application of riprap for bridge stabilization and 2) bridge pier strengthening and abutments with additional concrete. The analysis estimated the cost for Northeast bridges would be $285M annually under Representative Concentration Pathway (RCP) 4.5 and $350M annually in 2050 under RCP 8.5. [222,223]

NJPTA's bridge resilience costing includes heat adaptation strategies, such as increasing seat lengths of expansion joints at an estimated cost of 10% of the bridge replacement cost if implemented proactively (18% if the strategy was part of a repair/rebuild). For protection of bridge piers and abutments with riprap, NJPTA estimates 10% of the bridge replacement cost for proactive implementation and 75% for reactive. For alterations, upgrades, or bridge movement system retrofits to decrease excessive lateral or vertical displacement from buoyancy forces or water pressure, NJPTA estimates 8% of the bridge replacement cost for proactive implementation and 38% for reactive.[224]

Amtrak rail bridge projects with resilience improvement components in the Northeast Corridor (NEC) passenger rail line for FY22-23 include a $800M project in Maryland and $1.3B project in Connecticut (inflated to 2024 $).[225]

2.5.2.1.3 Tunnels

As summarized in the MassDOT Highway RIP, and originally included in MassDOT's 2015 FHWA Pilot Project Report, protecting tunnel portals in the Central Artery/Tunnel system in Boston through 2100 would cost $309M (2024 $) based on cost assumptions not specific design needs. [226,227]

MBTA's Tunnel Flood Mitigation program, which began in 2021, focuses on minimizing flooding in MBTA's tunnels through pump-room upgrades, flood protection for tunnel portals and head houses, and other upgrades. MBTA provided cost estimates for pump-room upgrades ($140M) and flood protection for tunnel portals ($30 million per portal).[228] MBTA noted that there are two additional portal locations, Silver Line and Community College, that require upgrades after completion of the 2025 projects.

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[222] Northeast in this report references Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

[223] EPA, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment* (2017), https://www.epa.gov/sites/default/files/2021-03/documents/ciraii_technicalreportfornca4_final_with_updates_11062018.pdf.

[224] New Jersey Transportation Planning Authority, *Benefit Cost Analysis Costs for Asset Adaptation Strategies*.

[225] U.S. Department of Transportation Federal Railroad Administration, *FY22-23 Federal-State Partnership (NEC) Grant Program Selections* (2023), https://railroads.dot.gov/sites/fra.dot.gov/files/2023-11/NECSelection%20Fact%20Sheets_Revised%2011-27-23_PDFa.pdf.

[226] Kirk Bosma et al., *MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery* (2015), https://www.cakex.org/sites/default/files/documents/MassDOT_FHWA_Climate_Change_Vulnerability_1.pdf.

[227] MassDOT, "Highway Resilience Improvement Plan and Resiliency Improvement Capital Program," May 15, 2024, https://www.mass.gov/doc/highway-resilience-improvement-plan-report-presented-at-the-massdot-board-meeting-on-may-15-2024/download. MassDOT, "Highway Resilience Improvement Plan and Resiliency Improvement Capital Program."

[228] MBTA has already costed Fenway Portal and Airport Portal and has identified an additional two portal locations at Silver Line and Community College. They provided guidance to estimate $25M per portal.

2.5.2.1.4 Rail & Transit Facilities and Infrastructure

As of August 2024, MBTA's FY25-29 CIP Project Requests and Sustainability and Resilience Criteria for 2025-2029 is ~$1.3B, with nearly $500M for very high priority projects. It is important to note that this list of unfunded or partially funded projects includes funding requests, not necessarily the full cost of projects. The 2023 thesis Climate Change Adaptation Planning and Decision Making for Transit Infrastructure estimates the replacement cost for heavy rail track to be $13M per mile and light rail track to be almost $5M per mile.[229] These values can be used to inform damage assessments.

The total cost of Phase 1 of the South Coast Rail expansion project was $1B for 36.2 miles, or nearly $28M per mile.[230] Internal analysis completed to cost resilience measures for sample heavy-rail scenarios found that elevating rail by 3 feet would cost $140M per mile (2025 $), to raise the rail 5 to 6 feet would cost $451M per mile (2026 $), and to elevate the rail 10 to 12 feet would cost $560M per mile (2027 $). Costs vary significantly depending on many factors such as the design flood elevation (DFE). Building to a lower DFE (e.g., raising tracks on existing fill) may be less expensive and could be done to withstand short exposure to flooding. Higher DFE track elevation options (e.g., raised rail with retaining wall or viaduct-based rail) likely require more extensive subsurface engineering that significantly increases costs. Costs will also vary based on constraints along the ROW, such as bridges carrying general traffic that pass over rail tracks and may need to be elevated to maintain minimum bridge clearances. While some options may provide broader community resilience benefits, they may provide protection beyond what is strictly necessary for the continuity of transit operations or be difficult to permit and construct, particularly where rail infrastructure is located in wetland resource areas. There are also specific engineering certifications that need to be sought if an elevated roadway or railway is proposed to serve a dual purpose as a levee; USACE often recommends against utilizing transportation infrastructure as levees or flood barriers.[231]

Maintenance and layover facilities, passenger facilities, rail and vehicle yards, and utility infrastructure are necessary to support rail services. The MBTA FY26 to FY30 CIP has ~$1B in spending planned for maintenance and administrative facilities, ~$1.3B for passenger facilities, and $2B for guideway, signal, and power projects.[232] However, this covers all projects, not just resilience improvement projects. While CIP projects may help improve the sensitive or adaptive capacity of MBTA assets, the majority of projects will not change the asset's underlying exposure due to the nature of the transit system and its spatial constraints. For example, signal infrastructure must be co-located with rail tracks and switches and there are limitations as to where the equipment can be mounted in a tunnel or along an at-grade right-of-way. Equipment replacement and upgrades may improve their ability to withstand exposure and minimize transit disruptions, but the inherent location of the infrastructure makes it impossible to elevate all critical assets out of harm's way.

In the 2023 thesis Change Adaptation Planning and Decision Making for Transit Infrastructure, almost 170 locations on MBTA property were identified as potential flooding ingress points and should be considered for resilience projects.[233] The analysis costed many asset resilience measures; station headhouse floodproofing such as the intervention at Aquarium Station is estimated to cost $3M, and floodwall installation is estimated to cost ~$18,000 per cubic meter of wall (2022 $).

Geographic Information System (GIS) analysis estimates about 50 structures, or 14%, of MBTA's support facilities are in the 100-year floodplain, including maintenance facilities, yards, bus garages, administrative facilities, and other critical support assets. It is important to note that this list of unfunded or partially funded projects includes funding requests, not necessarily the full cost of projects. While projects will be designed according to the MBTA's flood resilience design directive, as noted above, many improvements to existing infrastructure will not change the inherent exposure of assets to flooding. MBTA

[229] Martello, "Climate Change Adaptation Planning and Decision Making for Transit Infrastructure."
[230] MassDOT, "About the South Coast Rail Project," 2024, https://www.mass.gov/info-details/about-the-south-coast-rail-project#:~:text=Benefits%20of%20Phase%201:%20*%20Reconstructs%2012.1,riders%20once%20the%20Full%20Build%20is%20operating.
[231] Provided in discussions with MBTA.
[232] MBTA, *Massachusetts Bay Transportation Authority FY26-30 Capital Investment Plan (CIP)*.
[233] Martello, "Climate Change Adaptation Planning and Decision Making for Transit Infrastructure."

assets function as a system, so improvement projects cannot address exposure by elevating individual assets, rather they must elevate a system of assets on a site scale to withstand flooding.

Unit and traction power substations will require resilience investments. MBTA's Power Master Plan provides investment recommendations for many need areas including a South Boston Power Complex overhaul (the site feasibility study is costed at $3M separately in the MBTA FY26 to FY30 CIP) to evaluate future needs, including the cost of upgrades to address climate hazards like coastal flood risk.[234] The MBTA 2023 Capital Needs Assessment and Inventory requires over $5B to bring power assets into a state of good repair.[235]

Amtrak's 2017 Phase III Amtrak NEC Climate Change Pilot Study Adaptation Plan investigated several adaptation strategies (i.e., floodproofing, elevating, and relocating) for its rail, equipment, utilities, and buildings.[236] For a subset of strategies, cost estimates were provided but not for any projects in Massachusetts. Example projects elsewhere that may be applicable to Massachusetts included a deployable flood barrier at Wilmington Station, estimated at $2,600 per linear-foot to protect from a 100-year storm. NJTPA estimated the cost to build new or repair rail to withstand higher maximum temperatures is $250 per linear foot of track.

Additionally, in response to Hurricane Sandy, many Northeastern states completed resilience projects to bolster their rail and transit facilities and infrastructure.[237] Connecticut, for example, received $15M (2024 $) to complete a rail yard power upgrade. New Jersey received $61M for facility floodproofing, $31M for rail yard extension, and over $24M to install an automatic flood barrier at a maintenance facility.

2.5.2.2 Investment Need Analysis

The investment need analysis was dependent on cost information provided with additional supplementary geospatial analysis. Given the limitations of the existing transportation vulnerability assessment information, the Massachusetts transportation asset data were analyzed alongside available FEMA 100-year floodplain data (National Flood Hazard and historical Q3 flood boundary data originating in 1997 and updated most recently in 2023) (Table 9).

Table 9: Transportation Infrastructure GIS Analysis Sources

GIS Data File Name	Notes/Source
MassGIS Data: MassGIS-MassDOT Roads	Road classes 1 to 4: • Class 1: Limited access highway • Class 2: Multi-lane highway, not limited access • Class 3: Other numbered route • Class 4: Major road arterials and collectors *Source: MassGIS Data: MassGIS--MassDOT Roads*[238]
MassGIS Data: Trains	Rail includes all active passenger, freight, Amtrak, and MBTA Commuter rail lines *Source: TRAINS_ARC (all active rail lines) MassGIS Data: Trains*[239]*and MBTA*
MassGIS Data: FEMA National Flood Hazard Layer	Merged with the Mass Q3 data to get a 100-year floodplain (note there remains gaps; this merged dataset covers about 90% of the state) *Source: Mass GIS Data: FEMA National Flood Hazard Layer*[240]

[234] MBTA, "Power Master Plan - DRAFT," 2024.
[235] MBTA, *2023 Capital Needs Assessment and Inventory* (2024), https://cdn.mbta.com/sites/default/files/2024-04-05-mbta-cnai-report-final.pdf.
[236] Amtrak, "Phase III Amtrak NEC Climate Change Pilot Study Adaptation Plan," April 2017, https://www.amtrak.com/content/dam/projects/dotcom/english/public/documents/corporate/foia/phase-iii-amtrak-nec-climate-change-pilot-study-adaptation-plan-0417.pdf.
[237] "Resilience Projects in Response to Hurricane Sandy," Federal Transit Administration, September 22, 2014, https://www.transit.dot.gov/funding/grant-programs/emergency-relief-program/resilience-projects-response-hurricane-sandy.
[238] MassGIS (Bureau of Geographic Information), "MassGIS Data: MassGIS-MassDOT Roads," October 2024, https://www.mass.gov/info-details/massgis-data-massgis-massdot-roads.
[239] Mass GIS (Bureau of Geographic Information), "MassGIS Data: Trains."
[240] FEMA, "National Flood Hazard Layer."

GIS Data File Name	Notes/Source
MassGIS Data: FEMA Q3 Flood Zones from Paper FIRMS	Merged with the National Flood Hazard data to produce a 100-year floodplain (note there remains gaps; this merged dataset covers about 90% of the state) *Source: Mass GIS Data: FEMA Q3 Flood Zones from Paper FIRMs where NFHL Data Unavailable (Feature Service)*[241]

Table 10 includes centerline mileage of roads (classes 1 to 4), rail mileage, and MBTA-owned commuter rail in the FEMA 100-year floodplain. It is noted that this approach is cursory to understanding transportation vulnerability to climate change. It focuses on only one climate hazard (flooding); the analysis does not account for individual asset elevation, and the FEMA 100-year floodplain captures only a very simplified and narrow understanding of flood exposure. FEMA flood maps typically capture fluvial (riverine) but not pluvial (rain) or combined impacts, and there are unmapped regions. Additionally, change in precipitation and sea level rise are not accounted for with this approach.

Table 10: FEMA 100-Year Floodplain Exposure Analysis for MBTA Commuter Rail, Road (Classes 1 to 4)

MBTA Commuter Rail (Miles)	Road (Miles)
35	**609**

Note: Rail miles are considered ROW miles, and road miles are centerline.

Roads: In absence of additional detail, the analysis applies a cursory approach for road adaptation. An estimate of $15M to $20M per road centerline mile is used.[242] The value is multiplied by 50% of the 609 miles of road classes 1 to 4 in the 100-year floodplain for the low end, and 75% for the high end. This does not account for where and how specific roads may be vulnerable or what the adaptation strategy should be. More limitations are below. It also does not include costs for minor streets or roads (analysis focused on classes 1 to 4).

Bridges: For bridges, the EPA CIRA study (2017) estimates $280M to $350M per year for proactive mitigation costs under RCP 4.5 and RCP 8.5 conditions in 2050 for the Northeast; ~10% of bridges in the Northeast are in Massachusetts. While the count may not be representative of the bridge area or vulnerability, this proportion was used to downscale the Northeast results to Massachusetts, resulting in an estimated $20M to $25M annually in the 2050 period (2035 to 2064), or $520M to $630M over 25 years. [243] This range of costs ($520M to $630M) is used for the investment need analysis.

Tunnels: Tunnel costs for the low-end estimate include $309M to protect tunnel portals for roads in the Central Artery/Tunnel system to 2100,[244] $140M for pump room upgrades estimated by MBTA, and $60M for two MBTA projects to install flood protection for tunnel portals. The high-end estimate assumes these costs plus two additional MBTA flood protection for tunnel portal costs.

Rail and Transit Facilities and Infrastructure: MBTA suggested an approach for cost estimation that assumes all miles in land subject to coastal storm flowage, noting that for every foot of elevation, the grade must be changed by 1,500 feet before and after that elevation point due to maximum grade change

[241] MassGIS (Bureau of Geographic Information), *FEMA Q3 Flood Zones from Paper FIRMS Where NFHL Data Unavailable (Feature Service)*.

[242] This cost is highly variable based on a number of factors, including the type and level of adaptation required, the size of the road, the presence of other existing assets, and other factors. Smaller roads like those captured in the Cape Cod Low-Lying Roads Project have costs of $4 million to $10 million per mile or deployable barriers at $2 million to $3 million but the roads in that study are typically not class 1 through 4. Costs can also range significantly higher, such as those proposed for Morrissey Boulevard. Elsewhere in the country, such as in Washington State, a project to elevate and reconstruct 2.5 miles of roadway had a cost estimated at over $4 billion.

[243] The Northeast region, for the purposes of the CIRA report, includes Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, New Jersey, New York, Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia, which correspond to EPA Regions 1, 2 and 3.

[244] Note that this project is from 2015 and is based upon cost assumptions not specific design needs.

limits (which is typically 1.5% to 2%). Based on available data, the approach instead looks at MBTA-owned commuter rail mileage in the 100-year floodplain. There is an estimated 35 miles of MBTA-owned commuter rail in the 100-year floodplain.

As previously noted, light-rail and heavy-rail replacements incur different costs ($5M per mile and $13M per mile, respectively); however, these costs are typically used to inform damages rather than costs.[245] Instead, MBTA internal analysis completed for costs associated with elevating a segment of heavy rail are utilized for high- and low-end estimates. Heavy-rail costs of $140M per mile and $330M per mile have been used as the low- and high-end estimates, respectively, and were applied to only MBTA commuter rail ROW miles in the FEMA 100-year floodplain. For this analysis, MBTA light rail and heavy rail (i.e. subway and Green Line) are assumed to be made resilient with pump-room upgrades and flood protection for subway tunnel portals, as well as shore-based perimeter protection measures. Additional rail mileage owned by other public and private entities are not included in this analysis due to lack of data and existing studies, but it is important to note that further investment may be needed across the network to support system functionality.

For transit facilities and infrastructure, the analysis is based on the MBTA's requested $4.4B in its FY26 to FY30 CIP for projects in the categories that impact infrastructure such as Guideway, Signal, and Power, Passenger Facilities, and Maintenance and Administrative Facilities. The low-end estimate assumes that this cost is applied five times by 2050 to reach $22B and does not include all costs associated with changing the inherent exposure of these assets to flood risk. A high-end estimate is not included in this analysis, as more studies are required before determining what a high-end estimate could be. Additionally, cost estimates do not include anticipated repeated damages from increasing flood risk to these assets, which may further increase the cost of resilience and recovery investments between 2025 and 10, 20, or 50 years into the future. Therefore, a high-end cost recommendation would require further analysis and is not presented here.

The rough order of magnitude estimated investment need for this key resilience measure is displayed in Table 11.

Table 11: Rough Order of Magnitude Investment Need Estimates for Strategic Transportation Infrastructure

Investment Need	Low Estimate	High Estimate
Elevate/protect a portion of exposed miles of road classes 1 to 4 (highways and major roads) in the 100-year floodplain	$4.5B	$9B
Protect bridges with riprap and strengthen bridge piers and abutments to withstand future conditions	$500M	$500M
Install flood protection at tunnel portals and complete pump-room upgrades to protect tunnels	$500M	$500M
Elevate commuter rail that is MBTA-owned in the 100-year floodplain and upgrade/protect transit facilities and infrastructure	$27B	$33.5B
Total (Rounded)	**$33B**	**$44B**

Notes: Results are rounded.

2.5.2.3 Investment Need Analysis Limitations and Other Considerations

- Only a subset of transportation assets is discussed in the Strategic Transportation Infrastructure investment need analysis. Ports, airports, and roads outside of classes 1 to 4 were not included in the investment need analysis. Additionally, other modes of transportation, such as travel by

245 Martello, "Climate Change Adaptation Planning and Decision Making for Transit Infrastructure."

bicycle or ferry and related infrastructure, are likely to be impacted by climate change, but are not included in this report.

- Roadway expansion can result in additional runoff. Considering how to minimize impervious surface expansion can help to decrease additional flooding concerns.
- The investment need analysis does not include costs for resilience investments for the 15 Regional Transit Authorities.
- The investment need analysis primarily focuses on flooding. Heat has significant impacts on rail and other transportation infrastructure but currently has limited cost information available for adaptation measures. Heavy winds can also have major impacts on transit infrastructure but are not considered at this time. MassDOT is investigating pavement research and evaluating potential treatments to reduce heat island effects.
- The analysis does not account for individual asset elevation, and the FEMA 100-year floodplain captures only a very simplified and narrow understanding of flood exposure. FEMA flood maps typically capture fluvial (riverine) but not pluvial (rain) or combined impacts, and there are unmapped regions. The investment need analysis combines studies from different areas of the state that may not operate under the same conditions or assumptions. Change in precipitation and sea level rise are not accounted for with this approach.
- A complete vulnerability assessment was not completed as part of this approach, nor was any primary analysis completed to assess the likelihood of assets being damaged or their sensitivity to damage. The damage costs to assets are likely to increase over time due to stronger and more unpredictable weather events, exacerbated by climate change.
- There is no assessment of whether investment costs are justified based on expected resilience benefits for the roads, bridges, and tunnels approach. There is no overarching definition of “strategic transportation infrastructure” in Massachusetts, though there are many criteria that could be used to determine which assets are considered to be strategic (e.g., alternate route availability, average daily traffic, and evacuation routes). Project prioritization should be incorporated to determine where to invest in transportation resilience projects. MassDOT is currently working on road criticality assessments. MBTA is developing a climate resilience roadmap and incorporating climate vulnerability data into infrastructure planning initiatives to prioritize near-term investments for key asset types (e.g., power, facilities, signals, and track).
- MBTA assets function as a system, so improvement projects cannot address exposure by elevating individual assets, rather they must elevate a system of assets on a site scale to withstand flooding.
- A significant portion of the existing transportation infrastructure requires investment to address deferred maintenance. The analysis separates these costs from resilience investments.
- There is limited information about which resilience investments would be made for transportation infrastructure at the statewide level. As such, there are significant ranges in costs presented here depending on potential interventions, many of which may not be captured.
- Elevating roads and railroads will in many instances require filling adjacent wetlands and floodplain areas to accommodate the grade differences between the infrastructure and its surrounding (i.e., elevating a ROW may require widening its footprint). If roads or railroads run underneath bridges carrying general traffic, those bridges and approaches may also need to be elevated to maintain minimum clearances. Similarly, replacing a bridge over a navigable waterway subject to sea level rise would require elevating the bridge to ensure the waterway remains navigable (i.e., a shipping lane’s overhead clearance must be maintained throughout the lifetime of the bridge, especially as the water levels in the shipping lane rise). The extent, costs, and mitigation for these indirect effects of resilience interventions have not been analyzed.
- This key resilience measure overlaps with others including Small Bridges and Culverts, Coastal and Riverine Floodplain Resilience, and Drinking Water and Wastewater Infrastructure Protection

Investments. Investments in district-scale flood protection would particularly influence which actions are taken to protect transportation assets.

2.5.3 Resilience Value

Avoided physical damages and repair costs: A national study of hazard mitigation finds that investment in resilient transportation infrastructure generates $4 of benefits for every $1 spent. Monetized benefits include reduced casualties/post-traumatic stress, avoided property loss and insurance savings, and avoided business interruption and loss of service.[246] A separate analysis of the physical and economic costs of climate impacts on US rail and road infrastructure in 2050 relative to a 1986 to 2005 baseline reveal significant benefits for proactive investment in resilience. In the rail sector, the costs under a no-adaptation scenario are between 12 and 15 times higher in 2050 compared to a proactive scenario where infrastructure is fortified in advance of impacts. In the road sector, the cost of inaction is between 12 and 17 times higher in 2050 compared to the proactive scenario.[247]

For rail infrastructure, a 2023 MIT thesis estimates that losses solely for the MBTA rapid transit system due to sea level rise are projected to be $58M annually by 2030 without adaptation and resilience measures, while rail damages associated with extreme heat will require an additional $35M in annual repair costs; these estimates do not include damages for the remainder of the transit system.[248,249] For road infrastructure, a cost-benefit analysis completed for a complex road-elevation project to address flood-risk for Morrisey Boulevard, a significant transportation corridor along the Dorchester Shoreway, finds that the benefit of avoided damages to buildings alone generates between $1.40 to $4.00 in benefits for every $1 in project costs.[250] Additional benefits that were not monetized in the analysis, such as avoided damages to infrastructure, increased waterfront access, and ecological co-benefits further increase the return on the resilience investment.

Avoided transit disruption and travel time delays: Travel time delays created by flooding or heat events lead to productivity losses and freight movement disruptions which dampen economic activity in the Commonwealth. In Massachusetts, road delays from high-tide flooding could result in over 4M vehicle hours of delay by 2030 and 40M hours of delay by 2050.[251] Applying the US Department of Transportation (US DOT)-recommended value of travel-time savings ($21.10 per person-hour),[252] the economic value of the travel-time delay from high-tide flooding is conservatively $128M annually in 2030 and $1.3B annually by 2050.[253]

In the transit sector, named storms between 2006 and 2019 cost Amtrak $127M in lost ridership and revenue, with estimations of $220M by the year 2030.[254] During extreme heat events and in “slow zones”, trains operate at reduced speeds to compensate for heat-related stress or wear and tear on tracks—increasing travel times for riders and operating costs. Public transit delays disproportionately reduce economic opportunity for low-income residents and people of color, who are most dependent on reliable public transit for access to employment.[255] Investment in the MBTA Track Improvement Program has removed more than 220 slow zones (areas where trains reduce speeds to compensate for heat-related

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[246] *Natural Hazard Mitigation Saves: 2019 Report*.
[247] James E. Neumann et al., “Climate Effects on US Infrastructure: The Economics of Adaptation for Rail, Roads, and Coastal Development,” *Climatic Change* 167, no. 3 (2021): 1–23, https://doi.org/10.1007/s10584-021-03179-w.
[248] Michael V. Martello and Andrew J. Whittle, “Estimating Coastal Flood Damage Costs to Transit Infrastructure under Future Sea Level Rise,” *Communications Earth & Environment* 4, no. 1 (2023): 137, https://doi.org/10.1038/s43247-023-00804-7.
[249] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022).
[250] *Climate Resilience Solutions for Dorchester*.
[251] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022), 134.
[252] Person-hour refers to the amount of work one person can complete in one hour.
[253] Assumes average occupancy of 1.52 persons for passenger vehicles (all-travel) and general-purpose travel-time savings for “all-purposes” of $21.10 per person-hour. The value of travel-time savings estimate can be considered conservative, as it does not include the impact of business or commercial vehicle travel. See, , “Benefit-Cost Analysis Guidance for Discretionary Grant Programs,” May 2025, https://www.transportation.gov/sites/dot.gov/files/2025-05/Benefit%20Cost%20Analysis%20Guidance%202025%20Update%20II%20%28Final%29.pdf#:~:text=This%20document%20is%20intended%20to%20provide%20applicants%20to,%28BCA%29%20for%20submittal%20as%20part%20of%20their%20application.
[254] *2022 Amtrak Climate Resilience Strategic Plan*, 2021.
[255] Rubin et al., *Riding Toward Opportunities: Communities Need Better MBTA Service to Access Jobs*.

stress or wear on tracks) generating nearly $1M in economic benefit per day from saving riders over 40,000 hours in daily travel-time delays across the state.[256]

Reduced public safety and security risks: Resilient transportation infrastructure provides access to essential businesses, such as grocery stores and hospitals and access to critical evacuation routes during an emergency event. An analysis completed for Austin, Texas found that flood events can make nearly 60% of required destinations inaccessible.[257] Road closures due to flooding create detours and traffic that delay emergency services such as EMS, police, and fire responders. The economic impacts to human health and property losses related to emergency services delays from flooding events in Massachusetts is projected to be $1.4M annually by 2070.[258] Unprotected transportation infrastructure is vulnerable to washout in a flood or hurricane event, landslides, fire, and other disasters that place pedestrians and motorists at risk. According to the National Weather Service, on average each year over half of flooding deaths result from driving in flood waters.[259] Major flooding events in August 2023 led to multiple stranded motorists in Lawrence, Massachusetts, requiring emergency response.[260]

2.6 Drinking Water, Wastewater and Stormwater Infrastructure

Description: *Protect and upgrade critical drinking water, wastewater and stormwater infrastructure to reduce impacts from coastal and inland flooding and extreme precipitation.*

2.6.1 Background

Infrastructure that is critical to the health and safety of citizens of Massachusetts must be sufficiently protected from coastal and inland flooding and extreme precipitation to avoid fatal consequences. According to the 2022 Massachusetts Climate Change Assessment, inland flooding poses the greatest risks for damage to inland buildings, electricity and utility distribution systems, and transit services.[261] MWRA evaluated the potential impacts of sea level rise on 30 coastal or near coastal wastewater and administrative/operational facilities. 13 facilities are within FEMA's 100-year flood elevation or to be conservative, within 1 foot above the 100-year elevation.[262] In a national study analyzing flood risk over the next 30 years, critical infrastructure facilities with operational risk in Suffolk County has increased by 20%.[263] There is a wide range of critical infrastructure that will require investment for resilience purposes. Based on data and methodology available, the focus for this key resilience measure is drinking water, wastewater and stormwater infrastructure.

Drinkwater and Wastewater Infrastructure

Drinking water in Massachusetts is derived from various sources, with most water infrastructure owned by municipalities and state entities owning the remainder. Residential wastewater for homes connected to the sewer system is piped from homes to wastewater treatment plants (WWTP). Drinking water and wastewater treatment plants, and sewer system infrastructure, are usually maintained by municipal or regional sewer departments; however, some sewer infrastructure is owned by state entities.[264] Climate

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256 Governor Healey and Lt. Governor Driscoll, "Governor Healey, Lieutenant Governor Driscoll, GM Eng Celebrate Removal of Slow Zones for the First Time in 20 Years," Mass.Gov, accessed May 28, 2025, https://www.mass.gov/news/governor-healey-lieutenant-governor-driscoll-gm-eng-celebrate-removal-of-slow-zones-for-the-first-time-in-20-years.

257 Matthew Preisser et al., "A Network-Based Analysis of Critical Resource Accessibility during Floods," *Frontiers in Water* 5 (October 2023), https://doi.org/10.3389/frwa.2023.1278205.

258 *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022), 45–49.

259 NOAA US Department of Commerce, "NWS Boston - Flood Safety Awareness Week," NOAA's National Weather Service, accessed May 28, 2025, https://www.weather.gov/box/flood_safety.

260 Frank O'Laughlin and Boston 25 News Staff, "Cars Stranded on Flooded Roads, Yards Turned into Lakes as Storms Bring Torrential Rain to Mass.," Boston 25 News, August 9, 2023, https://www.boston25news.com/news/local/cars-stranded-flooded-roads-yards-turned-into-lakes-storms-bring-torrential-rain-mass/ZJZWOXR7FVHCTIG6E4JDGRBQ3U/.

261 Commonwealth of Massachusetts, *2022 Massachusetts Climate Change Assessment: Volume II - Statewide Report* (2022), https://www.mass.gov/doc/2022-massachusetts-climate-change-assessment-december-2022-volume-ii-statewide-report/download.

262 Massachusetts Water Resources Authority, "Climate Change," https://www.mwra.com/our-environment/climate-change.

263 J.R. Porter et al., "Community Flood Impacts and Infrastructure: Examining National Flood Impacts Using a High Precision Assessment Tool in the United States," *Water* 13, no. 3125 (2021), https://doi.org/10.3390/w13213125.

264 Melissa Chalek, "Maintenance of Water and Sewer Infrastructure in Response to Sea Level Rise in Massachusetts," 2020, https://docs.rwu.edu/cgi/viewcontent.cgi?article=1004&context=law_ma_sp.

change can threaten the quality of source water through increased runoff of pollutants and sediment, decreased water availability from drought and saltwater intrusion, as well as adversely affecting overall efforts to maintain water quality.[265] Heavy rainfall can overwhelm the capacity of WWTPs, leading to the release of untreated sewage into water bodies. Additionally, coastal flooding and storm surges can cause damage to wastewater systems.[266] The 2025 ResilientCoasts Draft Plan notes that potential damages to drinking water and wastewater infrastructure would have far-reaching consequences across multiple communities. Recommendations for adaptation include elevating infrastructure above the DFE, relocating, or hardening infrastructure to be more resilient, depending on the project feasibility and the coastal typologies located nearby.

While aging infrastructure has resulted in a substantial investment gap, and future federal funding is at risk, there are state and federal funding sources to support drinking water and wastewater projects. In 2024, the State Revolving Fund (SRF) granted more than $1.4B in low-interest-rate loans and grants were awarded to 168 projects across Massachusetts designed to improve water quality, upgrade, or replace aging drinking water and wastewater infrastructure and promote energy efficiency measures at water treatment facilities. [267] Another $1.2B has been allocated to 67 projects for 2025.[268] Projects were selected through the SRF process administered by the Massachusetts Clean Water Trust.[269] The latest round of funding from the Clean Water and Drinking Water SRFs supports 49 clean water construction projects totaling ~$932M and 50 drinking water construction projects totaling ~$503M. An additional $8M will be offered as grants for 69 Asset Management Planning projects.[270] The Water Utility Resilience Program supports local drinking water and wastewater utilities in their efforts to prepare for climate change. The program is a collaborative effort across MassDEP Bureaus to improve the availability of map products from water utilities. The utility-level critical infrastructure maps and statewide service area maps are designed by MassDEP to enhance critical infrastructure resilience planning, asset management planning, and climate change adaptation.[271] The MVP grants award funding for wastewater projects as part of their climate change resilience grant program.[272] The MassWorks Infrastructure Program (MWIP) provides funding to public infrastructure projects that go to municipalities and other eligible public entities, including for sewer upgrades and potable water services.[273] The FEMA HMA Grant is also currently funding stormwater and water projects in Massachusetts.[274]

Stormwater Infrastructure

Stormwater infrastructure includes both traditional ‘gray’ systems, such as concrete pipes, catch basins, and storm drains, as well as ‘green’ infrastructure, including tree trenches, rain gardens, bioswales, constructed wetlands, porous pavements, and green roofs. In Massachusetts, there are communities with combined sewer systems (CSS), which collect stormwater and wastewater in the same pipes, and communities with separate systems for sanitary and stormwater flows. Municipal separate storm sewer

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265 US Environmental Protection Agency, “Climate Adaptation and Source Water Impacts,” Overviews and Factsheets, May 2, 2016, https://www.epa.gov/arc-x/climate-adaptation-and-source-water-impacts.

266 Green.org, *Climate Change and Its Impact on Wastewater Management*, n.d., https://green.org/2024/01/30/climate-change-and-its-impact-on-wastewater-management/#:~:text=Heavy%20rainfall%20can%20overwhelm%20the,which%20can%20damage%20wastewater%20systems.

267 Fabienne Alexis, “Healey-Driscoll Administration Awards $1.4 Billion in Loans and Grants to Fund Wastewater and Drinking Water Infrastructure Projects,” March 26, 2024, https://www.mass.gov/news/healey-driscoll-administration-awards-14-billion-in-loans-and-grants-to-fund-wastewater-and-drinking-water-infrastructure-projects#:~:text=BOSTON%20%E2%80%94%20The%20Healey%2DDriscoll%20Administration,promote%20energy%20efficiency%20measures%20at.

268 Alexis, “Healey-Driscoll Administration Awards $1.4 Billion in Loans and Grants to Fund Wastewater and Drinking Water Infrastructure Projects.”

269 “The Massachusetts Clean Water Trust,” Mass.Gov, https://www.mass.gov/orgs/the-massachusetts-clean-water-trust.

270 Mass.Gov, “The Massachusetts Clean Water Trust.”

271 Massachusetts Department of Environmental Protection, “Water Utility Resilience Program,” https://www.mass.gov/guides/water-utility-resilience-program.

272 “Municipal Vulnerability Preparedness (MVP) Program | Mass.Gov,” accessed July 14, 2025, https://www.mass.gov/municipal-vulnerability-preparedness-mvp-program.

273 Executive Office of Economic Development, “MassWorks Infrastructure Program,” Mass.Gov, https://www.mass.gov/info-details/massworks-infrastructure-program.

274 MEMA provided a list of current HMA projects as of May 2025.

system (MS4) communities are required to obtain a permit and implement a Stormwater Management Program (SWMP).[275]

Climate change is expected to increase stormwater runoff due to more extreme flood events and an expected total annual precipitation increase of 2% to 13% by 2050.[276] Runoff picks up pollutants such as trash, chemicals, bacteria, oils, nutrients, and dirt/sediment that can harm rivers, streams, lakes, and coastal waters. Population growth and the development of urban areas are major contributors to the amount of pollutants in the runoff, as well as the volume and rate of runoff from impervious surfaces due to increases in precipitation. Together, they can cause changes in hydrology and water quality that result in habitat modification and loss, increased flooding, decreased aquatic biological diversity, and increased sedimentation and erosion.[277]

Many stormwater systems are in poor condition and are undersized to meet future needs. CSS communities are likely to experience an increase in combined sewer overflow (CSO) occurrences. CSOs happen when heavy rainfall or other flooding causes combined sewer systems to discharge untreated water into bodies of water, polluting them with contaminants. CSO discharges are regulated by MassDEP and US EPA in accordance with state and federal CSO policies and the State Water Quality Standards. Massachusetts has 19 CSO permittees that have National Pollutant Discharge (NPDES) permits. The CSO permittees include mostly older urbanized communities across the Commonwealth, such as Boston, New Bedford, Worcester, and Springfield.[278] MWRA is continuously working on CSO control; between 1995 and 2005, MWRA eliminated CSO discharges from 34 of 84 outfalls around Boston and reduced CSO volumes by over 2.8B gallons per year.[279] One approach to addressing CSO occurrences is installing new stormwater and sewer infrastructure to separate the combined system. When municipalities perform sewer separation projects, they typically size new storm drainpipes and structures to accommodate future design storms. A best practice for promoting resilience is to use projected precipitation data and consider larger design storms when sizing pipes.

GSI includes tree trenches, rain gardens, bioswales, constructed wetlands, porous pavements, green roofs, and other measures that are designed to passively capture and treat stormwater using natural processes. GSI measures are decentralized and distributed, meaning that they capture, slow, and infiltrate rain where it falls.[280] These types of interventions reduce the volume of stormwater runoff and CSO events and improve the health of receiving waterways. GSI is an important element for climate resilience. For example, the City of Boston Office of Green Infrastructure includes climate projections and resilience planning in its forthcoming comprehensive Green Infrastructure plan.

There are several grant and loan programs available for stormwater projects in Massachusetts. MassDEP manages multiple grant opportunities for BMP design and construction, stormwater infrastructure, water quality assessment, and watershed management planning. Funds are distributed through various grant programs such as the Statewide Water Management Act Grant, Water Quality Management Planning Grant, Stormwater MS4 Municipal Assistance Grant Program, and the Clean Water SRF, among others. CZM distributes Coastal Habitat and Water Quality Grants and Coastal Pollutant Remediation (CPR) Grants for stormwater BMP design and construction, water quality monitoring/assessment, education and outreach, and water quality monitoring/assessment. Hazard Mitigation Grants from MEMA and DCR are available for BMP design and construction, including for green infrastructure to reduce flooding hazards. EEA's MVP Action Grant Program supports nature-based design and construction projects targeting water

[275] REG 06 US EPA, "Municipal Separate Storm Sewer System (MS4) Storm Water Management Program (SWMP)," Other Policies and Guidance, July 8, 2016, Texas, https://www.epa.gov/tx/municipal-separate-storm-sewer-system-ms4-storm-water-management-program-swmp.
[276] *Massachusetts Climate Projections*, n.d.
[277] OW US EPA, "NPDES Stormwater Program," Overviews and Factsheets, October 22, 2015, https://www.epa.gov/npdes/npdes-stormwater-program.
[278] "Sanitary Sewer Systems & Combined Sewer Overflows | Mass.Gov," accessed August 5, 2025, https://www.mass.gov/guides/sanitary-sewer-systems-combined-sewer-overflows.
[279] "Combined Sewer Overflows (CSOs)," MWRA, accessed June 16, 2025, https://www.mwra.com/your-sewer-system/combined-sewer-overflows-csos.
[280] Green Infrastructure Leadership Exchange, *Climate Resilience Resources Guide* (2023), https://www.flowstobay.org/wp-content/uploads/2023/12/CRRG-Report_2023_FINAL-1.pdf.

quality in the context of climate change vulnerability. Federal funding is also available through various EPA grant programs.[281]

Other Critical Facilities and Infrastructure

There is a range of other critical facilities and infrastructure that require resilience upgrades. This includes structural facilities such as hospitals, fire stations, solid waste facilities, power plants, electrical substations, and underground utilities. In Oak Bluffs, the results of a risk assessment show that, by 2030, many important roads to access the hospital will be unpassable for ambulances when there are coastal flooding events.[282] Without additional information, costs for these facilities and infrastructure have not been extrapolated to date. MEMA staff noted that MEMA has 15 ongoing generator and microgrid projects totaling $6.4M. These facility types include hospitals, fire stations, emergency operations centers, police stations, pump stations, and shelters.

Critical public infrastructure will also be impacted by other hazards besides coastal and inland flooding and extreme precipitation, such as wildfire, drought, and extreme heat; however, that is not the focus of this key resilience measure. Relevant actions from the 2023 ResilientMass Plan include: divert solid waste by increasing local capacity and infrastructure to reduce emissions and vulnerability and promote increased resilience; and address impacts of flooding to infrastructure, natural resources, and groundwater through better understanding of climate change drivers.[283]

2.6.2 Investment Need

2.6.2.1 Cost Data Review Summary

2.6.2.1.1 Drinking Water and Wastewater Infrastructure

In 2022, Massachusetts reported $7.7 billion in grey and green stormwater infrastructure needs to continue meeting federal Clean Water Act requirements over the next 20 years.[284] In addition, the Commonwealth reported $1.4 billion in capital needs for CSO correction, and $1.8 billion for sewer replacement/rehabilitation, including combined sewer separation.[285]

US EPA conducts a drinking water infrastructure needs survey and assessment with state-level information every 4 years. The 7th Report to Congress (2023) identified a statewide need over $18B for water systems to continue to provide safe drinking water over the next 20 years.[286, 287] These costs are for purposes such as distribution, treatment, and storage rather than resilience needs specifically. A 2017 study based on a survey of 146 cities and towns throughout the Commonwealth (42% of Massachusetts' municipalities) found that communities have an estimated $10.5B in need for clean water delivery and $13B for wastewater treatment and handling (2024 $).[288]

MassDEP has proposed a possible new program to provide funding for drinking water and wastewater utilities to conduct climate change vulnerability assessments; possible threats to the existing water systems include saltwater inundation and intrusion that causes contamination of water supply related to sea level rise and coastal surge. MassDEP estimated the cost of developing a vulnerability assessment to

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[281] "Available Funding for Stormwater Projects in Massachusetts | Mass.Gov," accessed August 5, 2025, https://www.mass.gov/info-details/available-funding-for-stormwater-projects-in-massachusetts.

[282] "The Martha's Vineyard Hospital Resilience Project," June 2024, https://experience.arcgis.com/experience/edb495a9c406466d99c112323470cde7/page/ABOUT/.

[283] Commonwealth of Massachusetts, "ResillientMass Plan Action Tracker."

[284] United States Environmental Protection Agency, *2022 Clean Watershed Needs Survey, Report to Congress*.

[285] United States Environmental Protection Agency, *2022 Clean Watershed Needs Survey, Report to Congress*.

[286] US Environmental Protection Agency, *Drinking Water Infrastructure Needs Survey and Assessment. 7th Report to Congress.*, EPA 810R23001 (2023), https://www.epa.gov/system/files/documents/2023-09/Seventh%20DWINSA_September2023_Final.pdf.

[287] "Costs, Regulation, and Financing of Massachusetts Water Infrastructure: Implications for Municipal Budgets," *InfrastructureUSA: Citizen Dialogue About Civil Infrastructure*, 2017, https://infrastructureusa.org/costs-regulation-and-financing-of-massachusetts-water-infrastructure-implications-for-municipal-budgets/.

[288] "Costs, Regulation, and Financing of Massachusetts Water Infrastructure: Implications for Municipal Budgets," *InfrastructureUSA: Citizen Dialogue About Civil Infrastructure*, 2017, https://infrastructureusa.org/costs-regulation-and-financing-of-massachusetts-water-infrastructure-implications-for-municipal-budgets/.

be between $50,000 and $300,000 per facility. MassDEP noted that costs of resilience measures vary but could range between $500,000 and $5M per treatment plant.

MassDEP also proposed funding emergency power (i.e., generators) at publicly owned treatment works to ensure continued operation in the event of a flood or other weather-related event resulting in a loss of power. The justification for this funding follows that failure to have a functional emergency power source that is protected from flood events can result in the discharge of untreated or partially treated sewage to waterways. This work may require relocating electrical panels from the basement or floor below the flood elevation and upgrading electrical systems. Other potential project components that are uncosted include raising walls, installing flood doors, or increasing the height of a levee. MassDEP estimated the cost of providing an emergency power source plus associated electrical work is likely to range from $1M to $3M per treatment plant and assumes 25% of the facilities would participate in the project. Subject matter experts from state agencies considered this to be a low-cost estimate for generators, and a general guide is that a 1 megawatt (MW) generator can cost ~$1M for delivery to the site alone.

The City of Everett's Second Street Resiliency Upgrades, with funding from MWIP, is expected to cost $2.6M to upgrade watermain systems to enhance water system resilience and limit service interruptions for domestic water use and fire-fighting capabilities. A project in Whately is estimated to cost $370,000 (in 2024 $) to construct 900 linear feet of water main to complete a water distribution network.

A planning study for South Essex Sewage District in Salem found that it would cost ~$6.5M to build a flood wall to protect a pumping station. Another pumping station was recommended for relocation, as a more cost-effective solution to protect from flooding. Newburyport was awarded ~$2M in MVP grants over several years to improve the resilience of the WWTP; this funding supported planning, design, and construction of the rebuilding of a revetment and elevated berm to protect against sea level rise and storm surge. Provincetown was awarded $1M in FY25 to upgrade its central vacuum station and pump stations to increase resilience of their sewer service against extreme weather events.

The National Association of Clean Water Agencies (NACWA) and Association of Metropolitan Water Agencies conducted a cost assessment of adaptations to address the likely impacts of climate change on the nation's drinking water and wastewater facilities to 2050. While the study was conducted in 2009, it is the most comprehensive and relevant regarding this key resilience measure and has recently been cited by NACWA with escalated figures.[289] For the Northeast region[290], the NACWA assessment found that costs to upgrade drinking water and wastewater utilities sufficiently range between $188B and $281B (2024 $) including capital costs, O&M, and financing.[291] Adaptation strategies included investment in new water sources (e.g., desalination and wastewater recycling), increasing storage, increasing treatment, better use of green and gray infrastructure in wet weather, increasing effluent treatment, and raising and relocating vulnerable infrastructure.

2.6.2.1.2 Stormwater Infrastructure

There is no statewide investment need estimate for stormwater infrastructure resilience upgrades. The 2022 Clean Watershed Needs Survey (CWNS) Report to Congress assessed the capital investment necessary for states to meet the US EPA's Clean Water Act (CWA) water quality goals over the next 20 years. The CWNS estimated $7.7B is needed for Massachusetts stormwater infrastructure, the fourth highest nationally.[292] While the report notes that increased needs are due to an increase in the frequency and intensity of heavy precipitation events due to climate change, it does not attribute any portion of the cost estimate to resilience upgrades specifically, nor does it specifically assess flood resilience needs.

In a 2017 study based on a survey of 146 cities and towns throughout the Commonwealth (42% of Massachusetts municipalities), it was estimated that municipalities will pay $2.3B (2024 $) over the next

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[289] *Resiliency in the Balance: Funding Challenges for Clean Water Utilities in Addressing Climate Adaptation* (NACWA, 2023), https://www.nacwa.org/docs/default-source/resources---public/nacwa-climate-resiliency-report.pdf?sfvrsn=4c75c361_2.

[290] The northeast region includes Massachusetts, Connecticut, Delaware, Washington DC, Maine, Maryland, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia.

[291] *Resiliency in the Balance: Funding Challenges for Clean Water Utilities in Addressing Climate Adaptation*.

[292] United States Environmental Protection Agency, *2022 Clean Watershed Needs Survey, Report to Congress*.

20 years in stormwater management to keep up with federal regulations.[293] Many municipalities and towns (and those municipalities and towns with MS4 Permit requirements) have their own Stormwater Management Plans that identify stormwater assets, vulnerability, and possibly future stormwater projects.

The City of Easthampton, for example, created a Green Infrastructure Master Plan in 2021 using funding from the MVP Action Grant Program that details 21 priority projects that would accrue benefits in terms of flooding, climate resilience, and improved water quality after green infrastructure upgrades.[294] Along with project pricing, which ranges from $31,000 to $1.8M (2024 $), the plan also captures the long-term pollutant load reductions for each constructed project. The MVP Action Grant Program supports many other stormwater improvement plans and projects across the Commonwealth, including a $709,720 grant for Great Barrington to create a vegetated buffer zone to cool and filter stormwater and almost $2M for the Town of Plymouth's Barlett Road Culvert and Stormwater Management Improvement Program.[295]

The commissioner of Public Utilities in Pittsfield has identified the need for stormwater infrastructure upgrades that would cost the city between $2M and $3M annually for preliminary studies and construction.[296] Separately, in the City of Melrose, the FEMA HMA Grant is funding the Burnett and Lauren Streets Stormwater Management Project and the Lebanon and Sylvan Street Stormwater Management System Project. The FEMA Grant covers $1M of the total $1.3M project cost. Additional projects that are seeking funding include a $2.3M project in Medford to design and construct drainage infrastructure improvements.

Boston is spending approximately $410,000 per acre (2024 $) from 2024 to 2029 to separate portions of its combined sewer system.[297] Presently, 630 acres of combined sewer area are planned for separation in East and South Boston (~$258.3M). Boston's sewer system serves 20,500 acres of both combined and separate sewer piping. The Boston Water and Sewer Commission's (BWSC) wastewater collection system currently consists of 155 miles of combined sewer and 3 miles of combined sewer overflow pipe out of the total 1,538 linear miles. In its 2015 progress report, MWRA reported $906.6M ($1.4B in 2024 $) for planning, design, and construction of projects to reduce CSO discharge. Several of these projects include sewer separation.[298]

BWSC Coastal Stormwater Discharge Analysis in 2023 provides concept cost estimates for resilience improvements at 11 locations to protect from sea level rise and storm surge.[299] These upgrades align with Climate Ready Boston initiatives to increase shoreline protection. In total, the 11 project concept cost estimates (without the inclusion of storm surge barriers) are scoped at over $580M (2024 $), and the addition of storm surge barriers at two of the locations is scoped at over $2B.

BWSC's Stormwater Best Management Practices Recommendations Report includes cost recommendations for GSI in and around Boston.[300] For all watersheds discussed, infiltration and bioretention are the most common best management practices (BMPs) suggested, but drywell, porous pavement and wetland are also recommended for some areas in the Charles River watersheds. Total BMP program cost over the lifecycle of the identified projects to achieve water quality goals is $652M in

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[293] "Costs, Regulation, and Financing of Massachusetts Water Infrastructure."

[294] City of Easthampton, *Green Infrastructure Master Plan* (City of Easthampton, 2021), https://easthamptonma.gov/635/Green-Infrastructure-Master-Plan-2021.

[295] Executive Office of Energy and Environmental Affairs, *MVP Action Grant Funded Project Descriptions: FY25 MVP Action Grant Projects* (2025), https://www.mass.gov/doc/mvp-action-grant-project-descriptions/download.

[296] Erin Douglas, "In the Berkshires, an Effort to Corral Climate Change, One Stream at a Time.," *The Boston Globe*, July 2, 2024, https://www.bostonglobe.com/2024/07/02/science/massachusetts-berkshires-culverts-bridges-stormwater-climate-change/.

[297] Angelica Ang, "Climate Change Is Messing with City Sewers - and the Solutions Are Even Messier," *Grist*, August 21, 2024, https://grist.org/cities/climate-change-is-messing-with-city-sewers-and-the-solutions-are-even-messier/.

[298] *Massachusetts Water Resources Authority Combined Sewer Overflow Control Plan Annual Progress Report 2015* (2016), https://www.mwra.com/sites/default/files/2023-11/cso-cost-control-receiving-water.pdf

[299] BWSC, *Coastal Stormwater Discharge Analysis* (2023), https://www.bwsc.org/sites/default/files/2023-02/BWSC%20Coastal%20Stormwater%20Discharge%20Analysis%20-%20Final%20Report.pdf.

[300] CH2MHILL, *Stormwater Best Management Practices Recommendations Report* (2016), https://n25y3ydugmwewgka8na4uu9i.blob.core.windows.net/d8a9oa5wmg7ggk5jahv5wnqv/BWSC_BMP_Recommendations_Report.pdf.

2016 $ ($991M in 2024 $), which includes the entire MS4. Unit costs include cover design, construction, and permitting.

CZM provided some general cost estimates for GSI based on their Coastal Habitat and Water Quality (CHWQ) grant projects that support the design and construction of stormwater BMPs, displayed in Table 12. Reviewers noted that these numbers may be on the low end and more suitable for rural communities.

Table 12: General Cost Estimates for Green Stormwater Infrastructure from CZM

Phase	Cost Estimate	Source	Note
Assessment	$60,000	CHWQ grant projects	Cost estimate for a municipal or sub-watershed scale
Design	$90,000	CHWQ grant projects	Cost estimate for one site
Permitting	$10,000	CHWQ grant projects	Cost estimate for one site, as applicable
Bidding and construction	$490,000	CHWQ grant projects	Cost estimate for one site

2.6.2.2 Investment Need Analysis

Drinking Water and Wastewater Infrastructure: In absence of a statewide needs assessment, the analysis relies on the NACWA study Resiliency in the Balance: Funding Challenges for Clean Water Utilities in Addressing Climate Adaptation.[301] To estimate the costs specific to Massachusetts, a scaling factor of 11% was applied to the NACWA study estimates for the Northeast region.[302] This factor was calculated using EPA data on the proportion of total wastewater flow in the Northeast that is managed by Massachusetts systems, reflecting the state's relative scale and service demand in the region. The same EPA data source was also used in the original NACWA assessment. Additional calculations were made by the project team to exclude O&M costs and financing costs, which are included in the NACWA assessment. Applying these adjustments, the projected cost to adapt Massachusetts' drinking water and wastewater infrastructure is ~$8.5B (2024 $).[303]

Stormwater Infrastructure: The analysis focuses on the cost of separating combined sewers and expanding GSI to address an anticipated change in wet weather events. The analysis does not include the cost of additional stormwater pipe upsizing for most Massachusetts communities that have separate stormwater systems. Additionally, the estimate does not include costs for stormwater pumping, treatment, or peak flow attenuation, which may be required depending on the receiving water and topography of the area. These are limitations within the current estimate which require additional research.

- **Combined Sewer Separation:** There are 19 CSO permittee jurisdictions across Massachusetts, which are comprised of primarily urban areas with older stormwater infrastructure that was installed before communities began using separate pipe systems for wastewater and stormwater.[304] The cost to separate these systems is highly variable depending on a number of factors, including the surrounding infrastructure. The analysis included a review of recent sewer separation projects in the Commonwealth, which allowed for the identification of a cost range. This review identified BWSC and the City of Lynn as recent sewer separation projects with

[301] *Resiliency in the Balance: Funding Challenges for Clean Water Utilities in Addressing Climate Adaptation*.

[302] The northeast region includes Massachusetts, Connecticut, Delaware, Washington DC, Maine, Maryland, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia.

[303] NACWA presents values in present value terms with O&M costs and financing incorporated. AECOM backed out these figures to be consistent with the other values presented in this report. NACWA financing assumptions include: nominal discount rate of 4.5%, annual O&M costs of 10% of capital cost, O&M escalation of 2%, financing interest rate and period of 4.5% over 30 years, and a model period of 41 years.

[304] Massachusetts Department of Environmental Protection, *Annual Sewage Notification Report 2024* (2025), https://www.mass.gov/doc/2024-sewage-notification-annual-report/download.

published cost estimates per acre of sewer separation. According to the BWSC, the average cost of the city's sewer separation projects was $340,000 per acre in 2021.[305] Sewer separation in the City of Lynn had an estimated project cost of $200 million to separate 300 acres of combined sewer area, or an average cost of $660,000 per acre of combined sewer area.[306] These capital cost estimates were adjusted to 2024 $ and inform the low- and high- ranges of the cost to separate combined sewer systems in Massachusetts.

The average cost per acre of sewer separation is applied to the estimated acres of combined sewer area in the 19 CSO permittee communities across Massachusetts. These estimates are informed by a review of the sewer systems of each of the 19 CSO permittee communities and adjusts for previously completed sewer separation projects. For communities where an estimate of the acreage served by combined sewers was not available, linear miles of combined sewer piping was converted to acres of combined sewer area using an average of 13.4 acres served per mile of sewer piping.[307] Across the Commonwealth, the project team identified an estimated 28,700 acres of combined sewer system area.

- **Green Stormwater Infrastructure:** To estimate the GSI resilience need, this analysis applies a methodology developed to estimate climate adaptation costs in Los Angeles County, California. This methodology assumes an increase in the acres of impervious area controlled (e.g., via green infrastructure) that is proportional to the increase in wet weather events.[308]

  According to the ResilientMass Climate & Hazards Viewer, Massachusetts is projected to experience a 7.9% to 12.2% increase in annual precipitation depth for an extreme rain event (99th percentile storm) in 2050.[309,310] The analysis assumes that an additional 7.9% of the state's 320,400 developed impervious acres (excluding rights-of-way) will need to be managed by GSI through 2050. [311,312] After adjusting for 80,000 acres of urban tree planting included in the Forest Conservation and Tree Planting key resilience measure, the analysis assumes that 7.9% of the remaining impervious acreage, approximately 19,000 acres of impervious surface area, will need to be managed by additional GSI.

  The investment need is estimated using the capital cost per impervious acre controlled. The high-end cost per impervious acre controlled estimate is sourced from Allegheny County Sanitary Authority's (ALCOSAN) Clean Water Plan, which undertook a comprehensive review of publicly reported GSI capital costs from jurisdictions across the U.S. The Clean Water Plan establishes median capital cost of $453,000 (2024 $) per acre of impervious area controlled.[313,314] The low-end cost is sourced from the Water Environment Federation's Stormwater Report, which cites a

[305] Ang, "Climate Change Is Messing with City Sewers - and the Solutions Are Even Messier."
[306] Anthony Cammalleri, "Lynn Pours $200 Million into Water-Sewer Project," *Itemlive*, January 20, 2023.
[307] This acreage was developed using estimates of average acres of combined sewer area served per mile for the BWSC system. Boston Water and Sewer Commission, *2025-2027 Proposed Capital Improvment Program* (2024), https://www.bwsc.org/sites/default/files/2024-11/2025-2027%20Proposed%20CIP.pdf.
[308] Center for Climate Integrity, *Los Angeles County's Climate Cost Challenge*.
[309] "ResilientMass Climate & Hazards Viewer," accessed July 29, 2025, https://eeaonline.eea.state.ma.us/ResilientMAMapViewer/.
[310] Precipitation projections are downscaled for Massachusetts at the HUC8 watershed scale using Global Climate Models and a Stochastic Weather Generator and reflect a warming scenario linked to the Representation Concentration Pathway (RCP) 8.5, a comparatively high greenhouse gas emissions scenario - *ResilientMass Climate & Hazards Viewer*
[311] Overlaying MassGIS 2016 LandCover data and ResilientMass Climate Hazards data for percentage change in precipitation depth found that 70% of impervious land cover in Massachusetts is within an area (eastern Massachusetts) expected to experience a 7.9%-9.5% change in precipitation depth for the 99th percentile storm. To remain conservative, 7.9% was used as the input to estimate the impervious area controlled.
[312] "MassGIS Data: 2016 Land Cover/Land Use | Mass.Gov," accessed July 29, 2025, https://www.mass.gov/info-details/massgis-data-2016-land-coverland-use.
[313] "Appendix_c-5_gsiplanninglevelcostestimating.Pdf," n.d., accessed July 29, 2025, https://www.alcosan.org/docs/default-source/clean-water-plan-documents/controlling-the-source/appendix_c-5_gsiplanninglevelcostestimating.pdf?sfvrsn=3d980163_2.
[314] The high-end unit cost uses the same source cited in the LA County Study, It is adjusted from Pittsburgh to Massachusetts using an RSMeans location multiplier (average of Massachusetts cities) and adjusted to 2024 $.

cost of $305,000 (2024 $) per impervious acre controlled, based on a review of nine GSI programs in New York State.[315,316]

The rough order of magnitude estimated investment need for this key resilience measure is displayed in Table 13.

Table 13: Rough Order of Magnitude Investment Need Estimates for Drinking Water, Wastewater and Stormwater Infrastructure

Investment Need	Low Estimate	High Estimate
Drinking Water and Wastewater		
Increase storage, add effluent treatment, protect or relocate facilities, and expand green and gray infrastructure to handle higher flows	$6B	$9B
Stormwater		
Separate combined sewer systems to modernize stormwater infrastructure and correct CSO events	$9B	$15B
Decrease impervious surface through expansion of GSI	$5B	$9B
Total (Rounded)	**$20B**	**$32B**

Notes: Results are rounded.

2.6.2.3 Investment Need Analysis Limitations and Other Considerations

- This analysis focuses on the main categories of drinking water, wastewater, and stormwater infrastructure for which there was information to develop cost estimates for the statewide resilience investment need. There are many other critical infrastructure assets that will also require resilience investments. Investment needs for power infrastructure (including transmission and distribution), communication networks, solid waste and other critical public facilities (e.g., hospitals) are not costed due to data limitations. This critical infrastructure along with other public infrastructure such as educational institutions, state capitols, city halls, post offices, and brownfield sites will require investments related to increasing drainage capacity, infrastructure burying and hardening, and facility relocation and floodproofing, among others.
- There is a gap in understanding statewide investment need for drinking water, wastewater, and stormwater resilience. Additional studies with a resilience focus would allow for an increased understanding of investment need.
- The NACWA assessment notes that water and wastewater systems will require different adaptation strategies and that technologies are constantly evolving; original cost estimates are based on 2009 technologies and climate change assumptions. A broad stroke approach was taken to estimate costs to drinking water and wastewater infrastructure using an existing study. There are limitations to this estimate, including developing a statewide cost from a figure for the Northeast. In absence of state-reported information, the investment need analysis used the ratio of water flow handled by Massachusetts relative to the northeast to determine the proportion of cost from the NACWA study attributable to Massachusetts.
- Other climate hazards will impact drinking water and wastewater infrastructure, such as extreme heat; however, they are not the focus of this key resilience measure.

[315] Water Environment Federation, "The Real Cost of Green Infrastructure," *Stormwater Report*, December 2, 2015, https://stormwater.wef.org/2015/12/real-cost-green-infrastructure/.
[316] The low-end unit cost is adjusted from Syracuse to Massachusetts using an RSMeans location multiplier (average of Massachusetts cities) and adjusted to 2024 $.

- The investment need is highly dependent on the capacity and existing infrastructure, with wide variability in costs depending on the specifics of existing infrastructure, including supporting infrastructure.
- Separating combined sewer areas is already an ongoing strategy in Massachusetts for numerous reasons, not just resilience.
- Estimates for separating combined sewer areas are reliant on cost data from past projects and information publicly available related to existing infrastructure. Furthermore, in absence of a specific target, the analysis assumes 100% separation which may not be cost-effective or feasible.
- Cost estimates for sewer separation do not include costs for stormwater pumping, treatment, or peak flow attenuation which may be required depending on the receiving water and topography of the area.
- The investment need focuses on upfront capital investment and does not include operations and maintenance costs to property operate infrastructure and treat drinking water, stormwater, and wastewater due to a lack of statewide data availability.
- There are many communities in Massachusetts that are not combined sewer communities but have MS4 requirements and stormwater focused commitments that are and will continue to be costly. GSI estimates presented for the investment need analysis are statewide but specific resilience stormwater investment needs at the community-level for non-CSO communities are not included. Additional study should be completed to better understand the investment need associated with stormwater pipe upsizing.
- While residential systems such as privately owned wells and septic tanks are also susceptible to flooding, they are excluded from this stormwater discussion.
- The NACWA assessment includes costs for inflow and infiltration programs to account for changes in precipitation, which are strategies used to reduce the amount of groundwater and stormwater entering the sanitary sewer system. As such, there may be double counting between the drinking water/wastewater and stormwater GSI investment need estimates.
- This key resilience measure overlaps with others, notably Strategic Transportation Infrastructure and Coastal and Riverine Wetlands and Floodplains. It is important to note that the NACWA assessment includes levee construction as an adaptation cost.

2.6.3 Resilience Value

Avoided property damage: Storm-induced flooding to drinking water and wastewater infrastructure may result in physical damages both to the asset and to nearby properties. Resilience against rising sea levels, extreme storms, and ocean tide events are a key concern for critical infrastructure close to the ocean. Facilities are prone to failure from structural, electrical, and process disruptions from high water-level events. Inaction can require costly emergency repairs and higher maintenance costs, eroding the long-term financial sustainability of local utilities and increasing burdens on ratepayers.

Avoided service disruptions: USACE found that proactive flood adaptation investment for infrastructure yields $2 to $6 in avoided costs per $1 invested over a 50-year project lifetime, with benefits including reduced flood damage, emergency response costs, service interruptions, and regulatory fines.[317] Inaction will require emergency repairs that can cost more and occur more frequently, eroding the long-term financial sustainability of local utilities and increasing burdens on ratepayers. Without critical utilities such as water, businesses might need to temporarily close, and residents may need to relocate during the repair time.

Public health and safety protections: Flooding or excess rain can lead to runoff or sewer overflow that contaminates well water and other drinking water sources with harmful pollutants or bacteria that could

[317] Justin Humphrey et al., *Federal Spending for Flood Adaptations* (Congressional Budget Office, 2024).

cause illness if consumed. Without resilience upgrades, these disruptions would endanger source water quality and public health. In Boston, stormwater pump stations protect evacuation routes and low-lying neighborhoods already facing multiple stressors. When these systems fail, consequences can cause road flooding and delay emergency response.

When water exceeds a certain depth against a WWTP building, it can flow over or breach protective barriers and flood the building, equalizing the pressure inside and out. This can interfere with discharges and untreated effluent, damaging the surrounding environment and contaminating nearby waterbodies. This can result in closure of surrounding beaches which, during heat waves, are essential cooling infrastructure.

Ecosystem service co-benefits and avoided environmental impacts: Stormwater runoff containing pollutants, like debris or oil, or nutrients, from fertilizer or other sources, into natural bodies of water can cause detrimental impacts to the existing aquatic ecosystems. CSO and other sewage runoff also contribute to increased algae blooms in bodies of water that create loss of oxygen and have damaging effects on the natural ecosystem.[318] When a WWTP floods, discharges and untreated effluent can enter surrounding waterways and groundwater, damaging the environment and contaminating nearby waterbodies. Reducing flooding, runoff, and volume of water that enters the stormwater system through interventions such as GSI can offer multiple co-benefits, including property value benefits, heat mitigation, air quality improvement, carbon sequestration, biodiversity, pollinator habitat, and water filtration.

2.6.3.1 Resilience Value Project Prototype Spotlight: Green/Gray Stormwater Infrastructure Prototype

To understand the resilience benefits of improved stormwater infrastructure, a prototype hybrid green/gray stormwater project for a suburban area of Massachusetts was developed. Green and gray stormwater infrastructure are often used in tandem, as GSI helps to address stormwater issues at the source, while drainage improvements can manage the excess water that GSI does not capture. This combined approach offers a more sustainable and effective way to manage stormwater in urban environments. Alongside traditional drainage upgrades, utilizing urban trees, rain gardens, and increasing open greenspace provides a range of benefits including avoided property damages and ecosystem benefits. GSI elements can also improve property values and reduce energy costs.

The project involves upgrading a drainage pipe to increase capacity, removing an area of impervious surface (such as a parking lot or vacant lot in a residential area) and replacing this area with GSI and nature-based solutions to reduce stormwater runoff. Typical project costs were estimated and co-benefits quantified primarily using FEMA methodology for the different components of the hybrid GSI project. Detailed methodology and assumptions are in Attachment 2: Collected Project Information.

A summary of the BCA results, accounting for the total estimated present value (i.e. 2024 $) of project costs and project benefits, as well as the resulting BCR, is presented in Table 14. The BCR is calculated by dividing the present value benefits by the present value costs.

[318] "Human Wastewater Is Feeding Harmful Algae Blooms off of Southern California's Coast," University of California, Los Angeles (UCLA accessed June 16, 2025, https://newsroom.ucla.edu/releases/treated-sewage-algae-blooms-southern-california-coast.

Table 14: GSI BCA Results (discounted)

Input	Value
Capital costs	$719,000
Operating cost	$76,000
Upfront capital and project lifetime maintenance costs	**$795,000**
Ecosystem Service Benefits	
Urban trees	$390,000
Rain garden	$89,000
Open space	$89,000
Avoided Economic Costs	
Avoided property damage	$1,000,000
Benefits over project lifetime	**$1,600,000**
BCR	**2.0**

Notes: Analysis applies a 3.1% discount rate over 30-year project useful life. Benefits and costs are highly variable and unique to each project. BCRs shown here do not represent all projects of this type.

2.6.3.2 Resilience Value Project Prototype Spotlight: Wastewater Treatment Plant Berm Prototype

A prototype WWTP resilience project in Massachusetts was developed to demonstrate resilience value of protecting critical infrastructure; a vegetated earthen berm was built around the perimeter of a small, coastal WWTP. A berm can provide protection from ocean flood events and wave action and can provide protection to the biological treatment processes at a WWTP. Typical project costs were estimated and benefits quantified primarily using FEMA/Hazus methodology for the WWTP. Benefits from avoided physical damages, impacts to residents, impacts to businesses and the economy, and avoided environmental damages were estimated.

A summary of the BCA results, accounting for the total estimated present value (2024 $) of project costs and project benefits, as well as the resulting BCR, is presented in Table 15. The BCR is calculated by dividing the present value benefits by the present value costs.

Table 15: WWTP Resilience Project BCA Results (discounted)

Input	Value
Capital costs	$4,850,000
Operating cost	$4,065,000
Upfront capital and project lifetime maintenance costs	**$8,915,000**
Avoided physical damages	$6,149,000
Avoided resident impact	$12,459,000
Avoided economic disruption	$3,391,000
Avoided environmental damages	$298,000
Benefits over project lifetime	**$22,298,000**
BCR	**2.5**

Notes: Analysis applies a 3.1% discount rate over 50-year project useful life. Benefits and costs are highly variable and unique to each project. BCRs shown here do not represent all projects of this type.

2.7 Heat Preparedness and Relief

Description: *Invest in heat preparedness and relief including:*

- *Increase in access to cooling for residents, unhoused people, and outdoor workers such as through expanded cooling in buildings and cooling centers*
- *Increase in shade structures, splash pads, parks, swimming areas, and waterfront access*

2.7.1 Background

By 2050, it is projected that Massachusetts will experience between 19 and 25 more days per year above 90°F compared to historical averages (currently, ~5 days per year). Wamer air can hold more moisture; by 2050, the impacts of higher temperatures and greater humidity will make hot summer days feel like 94°F compared to this historic average of 81°F. By 2050, New England summers will feel more like summers in the Southeastern US.[319] By 2030, the average summertime temperature will feel like summers in New York; by 2050, like Maryland; by 2070, like North Carolina; and by 2090, summer in Massachusetts could feel like summer in Georgia today (2022).[320] Extreme heat has many adverse effects, including increased mortality and morbidity rates, higher energy costs, and strain on existing infrastructure. Higher temperatures also lead to decreased labor productivity and contribute to poor air quality, including increases in aeroallergens and the number of days with air quality alerts.[321] These changes could have significant consequences, as human populations and ecosystems in Massachusetts are not adapted or accustomed to these temperatures.[322] Resilience measures can be implemented to mitigate these adverse effects.

The 2023 ResilientMass Plan describes three priority actions to address health and cognitive effects from extreme heat:

- Conduct workforce heat exposure outreach
- Address risk of extreme heat to building occupants
- Inventory and categorize shade shelters on DCR sites and strategically improve shading and cooling structures in parks, prioritizing those parks located in environmental justice communities.[323]

Local heat plans, such as Heat Resilience Solutions for Boston, identify strategies to prepare for extreme heat categorized into two main buckets: relief during heat waves (e.g., education and outreach, enhanced and expanded city-run cooling centers) and cooler communities (e.g., home energy retrofits and increased shade on municipal sites).[324]

DCR is responsible for the protection and enhancement of Massachusetts' natural, cultural, and recreational resources and improvement of the connection between people and the environment. DCR is taking action to address climate impacts from extreme heat by installing additional shade structures and expanding native tree canopy, through Project Shade. This will protect the health and well-being of park visitors and staff, particularly vulnerable populations, through sustainable solutions that mitigate the impacts of extreme heat.[325] DCR also manages aquatic venues, which include public pools, spray decks, and beaches and will extend opening hours during periods of high heat. EEA's Parkland Acquisitions and Renovations for Communities (PARC) Grant Program assists cities and towns in developing land for park and outdoor recreation purposes. Many of the funding awards are used to provide shade structures in new and existing parks.

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[319] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022), 18–20.
[320] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022), 18–20.
[321] Massachusetts Department of Public Health, "Extreme Heat and Poor Air Quality," https://www.mass.gov/info-details/extreme-heat-and-poor-air-quality.
[322] Massachusetts, *ResilientMass Plan: 2023 Massachusetts State Hazard Mitigation and Climate Adaptation Plan*.
[323] Massachusetts, *ResilientMass Plan: 2023 Massachusetts State Hazard Mitigation and Climate Adaptation Plan*.
[324] *Heat Resilience Solutions for Boston* (City of Boston, 2022), https://www.boston.gov/sites/default/files/file/2022/04/04212022_Boston%20Heat%20Resilience%20Plan_highres-with%20Appendix%20%281%29.pdf.
[325] "DCR Project Shade | Mass.Gov," accessed June 16, 2025, https://www.mass.gov/info-details/dcr-project-shade.

MassSave is a collaborative effort of Massachusetts' electric and natural gas utilities and energy efficiency service providers to support residents, businesses, and communities to make energy efficient upgrades by offering rebates, incentives, training, and information. MassSave aims to increase access to more efficient cooling systems while lowering carbon emissions.[326]

2.7.2 Investment Need

2.7.2.1 Cost Data and Considerations

2.7.2.1.1 Cooling in Buildings

Schools: The Center for Climate Integrity Resilient Analytics analyzed localized heat trends during the school year from 1970 to 2025.[327] The analysis identified a threshold of 32 days above 80°F during the school year as the point at which air conditioning is needed, based on engineering protocols, peer-reviewed studies examining the relationship between heat and learning, and actual practice in school systems across the country. For every school district, climate model outputs were used to tally the number of days above the 80°F threshold during the school year in 1970 and 2025. Under 2025 conditions, the study estimates climate-driven warming in Massachusetts will require nearly 900 schools to install air conditioning at a cost of ~$2.6B, across 137 school districts (a cost of ~$2.9M per school). Under 2055 conditions, the cost will be ~$4.6B for 1,500 schools (~$3M per school). This cost is for upgrades and/or installation only and does not include additional O&M costs. The Heat Resilience Solutions for Boston also included estimated costs for school cooling; the study estimates $4.7M per school for preliminary design, engineering, and construction.[328]

Government buildings: Many government buildings do not have cooling or require upgrades to their existing cooling systems. DCR noted that for their buildings, this may cost ~$50,000 to $100,000 per building.[329] However, DCR also noted that the majority of their buildings are less than 5,000 square feet (ft²) and include repurposed historic barns, estates, cabins, and bathrooms, and that their cost estimates would not necessarily be typical government building costs.

US Energy Information Administration (EIA) estimates the gross area of an average commercial building in Massachusetts is ~42,000 ft², with a cost to install air conditioning (heat pumps) of ~$260,000 per building.[330] This estimate considers a broad range of commercial property types, such as restaurants, hospitals, hotels, offices, and warehouses. Division of Capital Asset Management and Maintenance (DCAMM) estimates that the average state-owned building is ~16,000 ft² to 17,000 ft² (gross).[331,332] This portfolio consists primarily of small- to medium-sized office buildings. Scaling the EIA commercial building cost proportionally to reflect the smaller building size of the DCAMM government building portfolio, the estimated cost of a heat pump for a government building is ~$100,000 to $110,000.

The investment need analysis estimated how many government buildings do not have cooling or require upgrades to cooling using data from the Commercial Buildings Energy Consumption Survey (CBECS).[333] The analysis indicates that there may be nearly 3,000 government buildings in Massachusetts with no cooling, with a total area of 7.6M ft².[334]

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326 "Mass Save | About Us," Mass Save, accessed July 1, 2025, https://www.masssave.com/en/about-us.
327 *Hotter Days, Higher Costs: The Cooling Crisis in America's Classrooms*, n.d.
328 *Heat Resilience Solutions for Boston*.
329 It is noted that the costs provided by DCR do not represent the cooling costs for all government buildings, and variations in building use, location, size etc. may significantly alter cost estimates.
330 "Energy Information Administration (EIA)- Commercial Buildings Energy Consumption Survey (CBECS)," accessed May 22, 2025, https://www.eia.gov/consumption/commercial/.
331 "SD2497_DCAMM Real Property Report 2021," n.d.
332 Includes state and higher education authority-owned land and buildings.
333 "Energy Information Administration (EIA)- Commercial Buildings Energy Consumption Survey (CBECS)."
334 CBECS data relies on survey methods of data collection, where a small sample has been extrapolated to a statewide figure. Additionally, filters on the national data attempt to segment data for Massachusetts by selecting the census divisions (New England) and climate zone ('cool'). However, this approach includes Connecticut and there is no method to filter exclusively by state. It is assumed the proportion of government buildings in Connecticut is similar to that of Massachusetts.

Homes: Currently,13% of households (an estimated 400,000 households) across Massachusetts do not have air conditioning.[335,336] US Census Bureau data for Massachusetts indicates 5,700 Department of Housing and Urban Development (HUD)-assisted public housing units do not have air conditioning, ~20% of the total public housing units in the state.[337] It is currently not required for public housing landlords to provide air conditioning in units. While providing air conditioning in public housing units may improve cooling for vulnerable populations, even if air conditioning is present, households may not use it due to affordability concerns. Programs that can reduce energy bills are critical for realizing the benefits of expanding cooling.

Heat Resilience Solutions for Boston includes cost estimates for home energy retrofits for Boston's affordable housing stock (triple-decker and multi-family residential buildings).[338] The report estimates upfront capital and design costs to be $115,000 for a triple-decker building and nearly $12M for multi-family residential (adjusted to 2024 $). Costs for both structure types include both cost-effective and marginal measures, such as trees, cool roofs, air conditioning, fabric awnings, window replacement, and blinds. Multi-family residential building costs additionally include cool pavements and parking canopy.

Heat pumps can more efficiently cool during summer and heat in the winter while also transitioning buildings away from fossil fuel equipment. The CECP estimates heat pumps will be installed in at least 100,000 households by 2025 and 500,000 by 2030.[339] As of May 2025, there are federal tax credits to lower the price of purchasing and installing air-source heat pumps, as well as greater discounts and no-cost options for income-qualifying residents. MassSave also offers rebates and incentives that support energy efficiency solutions.[340] Programs that can reduce energy bills are critical for realizing the benefits of expanding cooling. Costs for residential heat pump installation reviewed range from $8,000 to $22,000. A cost of just under $20,000 was applied based on a 3-ton unit from the Residential Heat Pump Invoice Cost Analysis submitted to the Massachusetts Program Administrators and Energy Efficiency Advisory Council.[341,342,343,344,345,346]

Shade structures, pools and splash pads costs for shade structures ranged between $15,000 and $125,000 per shade structure based on PARC Grant Program application budgets (2023 to 2025). These were for smaller shade sails/structures. DCR provided a range of $300,000 to $1M for shade structures (not including survey and permitting costs). AECOM cost estimators estimated $5,000 to $50,000 per shade structure with a coverage of 400 ft^2.

AECOM estimated a splash pad could cost $200,000 to $1.2M for a splashpad between 2,000 to 4,000 ft^2. Cost drivers include features and number of spray outlets. DCR advised that splash pads can cost $500,000 to $800,000, depending on the distance of existing utilities at the project site. DCR capital estimates for a new pool were around $8M and for pool rehabilitation or upgrades between $5M and

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335 Census Bureau, "Selected Housing Characteristics," n.d., https://data.census.gov/table?q=DP04&g=040XX00US25.

336 U.S. Energy Information Administration, *Highlights for Air Conditioning in U.S. Homes by State, 2020*. (2023), https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Air%20Conditioning.pdf.

337 "American Housing Survey (AHS)," accessed June 16, 2025, https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00025&s_year=2023&s_tablename=TABLE3&s_bygroup1=28&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1.

338 *Heat Resilience Solutions for Boston*.

339 *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*.

340 Mass Save, "Mass Save | About Us."

341 NMR Group, Inc., *Residential Heat Pump Invoice Cost Analysis (MA23X14-B-RHPINV)* (2024), https://ma-eeac.org/wp-content/uploads/MA23X14-B-RHPINV-Residential-Heat-Pump-Invoice-Cost-Study-Web.pdf.

342 Liam McCabe, *How Much Does a Heat Pump Cost in 2024?*, February 1, 2024, https://www.energysage.com/heat-pumps/costs-and-benefits-air-source-heat-pumps/.

343 Kearney HVAC Inc, "How Much Does a Heat Pump Cost?," September 4, 2024, https://www.kearneyhvac.com/blog/how-much-heat-pump/.

344 Green Energy Consumers Alliance, "FAQ," https://www.greenenergyconsumers.org/heatpumps/faqs.

345 Rewiring , *Report: Upfront Cost of Home Electrification*, March 1, 2024, https://www.rewiringamerica.org/research/home-electrification-cost-estimates.

346 There may be cost variation due to pre-weatherization barriers. To insulate, which should be done with heat pump installation, existing wiring and mold issues may arise. This has not been costed as part of this study but can drive the costs up closer to six figures in some cases, according to EEA.

$7M. AECOM cost estimators estimated $15 to $22M for a new pool including site improvements. DCR may consider locating these new assets in counties with high proportions of impervious surface, such as Suffolk (56%), Norfolk (17%), and Middlesex (17%).[347]

2.7.2.1.2 Other Considerations

Community cooling centers are in air-conditioned buildings that are open to the public and provide temporary relief from extreme heat. They can include public libraries, town halls, and senior centers, as well as shopping malls, places of worship, or other areas with sufficient capacity.[348] Cooling centers can be helpful for people without air conditioning even in times without power disruption. Presence of back-up power is a helpful attribute, but typically not a requirement. US Centers for Disease Control and Prevention provides recommendations for implementation of cooling centers, including considerations for scoping, landscape assessment and partner identification, vulnerability assessment, planning, implementation, and evaluation.[349] Designating existing service locations as cooling centers requires minimal capital costs, though additional costs may be incurred related to staffing, energy, provision of additional services (e.g., water distribution), and extending operational hours (particularly over weekends). Additional costs may include advertising and planning and delivering communications and providing transportation services (e.g., shuttles).[350] Because the focus of this assessment is on capital costs, costs for cooling centers have not been included.

Cool roofs are designed to reflect more sunlight than a conventional roof, absorbing less solar energy and reducing indoor temperatures and localized extreme temperatures.[351] Green roofs, where vegetation is planted on the roof surface, also provide similar cooling benefits as well as stormwater management benefits. Determining the type of roof depends on several factors such as a building's climate and surroundings, existing insulation, capacity and budget to undertake maintenance (i.e. for green roofs) and the efficiency of a building's heating/cooling system.[352] For Boston's heat plan, the study noted that green roofs provide a significant decrease for surface temperatures, but less so for perceived temperatures (what the surrounding temperature feels like to people), and recommended installing shade canopies to enhance perceived thermal comfort. [353] Statewide costs for installing cool and green roofs were not included. In addition, cool roofs can also incur a winter heating penalty where they absorb less sunlight through the roof, reducing heat conduction into the building and increasing the need for mechanical heating in winter.[354,355]

Cool pavements can increase solar radiance reflectance and reduce the surface temperature of the paved area. There is mixed evidence, however, on the effectiveness of cool pavements on providing human-related ambient cooling benefits, with some studies finding that the radiant heat reflected can increase temperatures at the aboveground level.[356] Cool pavements were not costed for this analysis but should be considered with additional localized research.

Urban greening is the network of planned and unplanned green spaces within an urban area spanning both the public and private places and includes urban forestry, vegetated parks and open space, GSI, and

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[347] MassGIS Data: 2016 Land Cover/Land Use (2019).

[348] Department of Public Health, "Cooling Centers Guidance," https://www.mass.gov/info-details/cooling-centers-guidance.

[349] Stasia Widerynski et al., *Use of Cooling Centers to Prevent Heat-Related Illness: Summary of Evidence and Strategies for Implementation*, Climate and Health Technical Report Series (National Center for Environmental Health. Division of Environmental Hazards and Health Effects., 2017).

[350] Jeremy J. Hess, "Risk Reduction Guidance. Cooling Centers.," University of Washington Center for Health and the Global Environment, June 10, 2023, https://climatesmarthealth.org/articles/cooling-centers.pdf.

[351] US Department of Energy, "Cool Roofs," https://www.energy.gov/energysaver/cool-roofs.

[352] US Department of Energy, "Cool Roofs."

[353] *Heat Resilience Solutions for Boston*.

[354] US Department of Energy, "Cool Roofs."
It is noted that some heat experts believe the winter heating penalty is overstated because of the shorter daylight hours in the winter and often cloudier days, which means buildings are not absorbing as much solar radiation as they are in the summer regardless of their roofing situation. Then, as winters get warmer from climate change, heating needs will also decrease over time, while cooling needs will increase. This would require a separate study to identify whether the winter heating penalty exceeds the energy savings from reduced cooling demand in the summer in Massachusetts. Cool roofs would be a clear benefit for homes without air conditioning or only window units, as cold is relatively less deadly, and all homes have heating.

[355] US Department of Energy, "Cool Roofs."

[356] deBoer et al., *Economic Assessment of Heat in the Phoenix Metro Area*.

water features. Urban greening provides heat mitigation benefits as well as multiple benefits to the community and local ecosystems. Vegetation cools surrounding areas through evapotranspiration and trees provide shade, as well as reducing urban flood risk.[357] Urban greening has not been included here as it is the focus of the Forest Conservation and Tree Planting key resilience measure.

Some communities and areas in Massachusetts experience greater risk to the impacts of extreme heat due to environmental factors, the legacy of past investment decisions, health factors, and age. Improving urban heat resilience requires holistic strategies that consider the connections between different urban systems across scales and ensuring that heat risks and mitigation strategies are fairly distributed.[358]

2.7.2.2 Investment Need Analysis

Cooling in buildings (homes, schools, and government buildings): For cooling in buildings, the Center for Climate Integrity cost of ~$4.6B was applied to estimate school cooling costs. It was assumed half of the estimated 3,000 government buildings would install air conditioning at a cost of $100,000 per building for the low-end estimate and a cost of $200,000 for the high-end estimate (a combination of DCR and EIA/DCAMM cost estimates). For homes, it was assumed that half of the 400,000 households would install heat pumps for the high-end estimate, and a quarter would install heat pumps for the low-end estimate at a cost of just under $20,000 for both.[359] These numbers fall within the range of households without air conditioning as well as the CECP estimates for transitioning away from fossil-fuel equipment for home heating and cooling.

Shade structures, pools, and splash pads (DCR properties): For shade structures, pools, and splash pads, the investment need analysis focused on DCR-managed properties/facilities given data limitations regarding properties/facilities owned by other agencies and/or municipalities.

DCR manages 75 playgrounds across Massachusetts, 57 of which do not have built shade structures.[360] For the 57 playgrounds without built shade structures, the low-end cost is based on the median of DCR and AECOM cost estimator cost estimates ($175,000); the high-end cost assumes half are costed at this median, and the other half are estimated at $650,000 (the middle of the range provided by DCR).

DCR operates aquatic venues across Massachusetts, including 34 pools/wading pools and 18 splash pads (or a combination of these assets).[361] DCR noted that it has not investigated the needs for adding splash pads or swimming pools (where and how many). To estimate the cost of new pools and splash pads for heat preparedness, the investment need analysis utilized the $8M from DCR for each new pool and a range of $500,000 (low end) to $800,000 (high end) for splash pads. A 20% increase in aquatic venues (i.e., seven new pools and four new splash pads) was assumed. The rough order of magnitude estimated investment need for this key resilience measure is displayed in Table 16.

Table 16: Rough Order of Magnitude Investment Need Estimates for Heat Preparedness and Relief

Investment Need	Low Estimate	High Estimate
Implement cooling measures in buildings		
Homes	$2B	$4B
Schools	$5B	$5B

[357] Ladd Keith and Sara Meerow, *Planning for Urban Heat Resilience* (American Planning Association, 2022).
[358] Keith and Meerow, *Planning for Urban Heat Resilience*.
[359] In absence of a specific target, the analysis assumes that half of the 3,000 government buildings and 400,000 households without air conditioning install cooling. The analysis does not assume 100% of buildings have cooling installed due to structural limitations, cost, or occupant preference. Estimate is focused on cost of installing cooling, which may vary depending on presence of existing systems.
[360] "DCR Playgrounds | ResilientMass Maps and Data Center," accessed June 16, 2025, https://resilientma-mapcenter-mass-eoeea.hub.arcgis.com/maps/00bda7dd8d014879a1e14965cd2ef90b/about. *Data A Playgrounds*
[361] "DCR Aquatic Venues (2023)," accessed June 16, 2025, https://mass-eoeea.maps.arcgis.com/apps/dashboards/c7a7a70210a341ffbee1e7b81753e929.

Investment Need	Low Estimate	High Estimate
Government buildings	$150M	$300M
Install shade structures, pools, and splash pads at DCR properties	$100M	$100M
Total (Rounded)	**$7B**	**$9B**

Note: Results are rounded.

2.7.2.3 Investment Need Analysis Limitations and Other Considerations

- The type and extent of adaptation strategy to address heat is highly variable with limited information. Furthermore, some strategies, such as increasing presence of air conditioning, will require additional investment in decarbonization efforts. Effort was made to incorporate strategies that align with other statewide efforts, including those related to decarbonization.
- Estimates for installing heat pumps in buildings can vary widely and can be impacted by pre-weatherization barriers in buildings.
- Affordability of air conditioning can be a barrier to uptake and programs that can reduce energy bills are critical for realizing the benefits of expanding cooling.
- Estimates for shade structures, pools, and splash pad installation are limited to DCR-managed parks. It is noted that there are many other parks and playgrounds across Massachusetts that are owned/managed by cities; however, an inventory of city parks without shade structures could not be sourced.
- Urban tree planting as a cooling mechanism has not been costed as part of this key resilience measure, as they are costed in Forest Conservation and Tree Planting.

2.7.3 Resilience Value

Vulnerable populations and public health outcomes: Certain communities across the Commonwealth are particularly at risk for extreme heat impacts due to their exposure, vulnerability, and adaptive capacity. For example, historically redlined areas of Boston experience 7.5°F hotter days than the rest of the city and have 20% less parklands and 40% less tree canopies than other areas of the city. [362] People experiencing homelessness, people with chronic health conditions, pregnant people, outdoor workers, low-income people, children and youth, older adults, and homebound individuals are all at an increased risk for health and mortality impacts from extreme heat events. If no adaptation action is taken by 2090, Massachusetts will experience an estimated 400 additional premature deaths attributable to extreme temperature annually with an economic impact totaling over $6B by the end of this century.[363] These impacts are exacerbated for minority and language-isolated populations, which have a 22% and 28%, respectively, higher rate of premature death due to extreme heat.[364]

Resilience measures such as access to air conditioning can significantly improve health outcomes for vulnerable residents. Access to an air-conditioned space or cooling center during a heat event can lower the risk of mortality by 66%, while access to home air conditioning can reduce the risk of mortality by 77%.[365]

Productivity and wages: A statewide analysis of lost wages and hours due to heat impacts for Massachusetts found that, by 2090, high-heat impacts could result in lost work hours equal to over 10,000 full-time equivalent workers and lost wages of over $775M annually.[366] In 2024, ~580,000

[362] *Boston Heat Resilience Plan*.
[363] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022).
[364] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022).
[365] Abderrezak Bouchama et al., "Prognostic Factors in Heat Wave Related Deaths: A Meta-Analysis," *Archives of Internal Medicine* 167, no. 20 (2007): 2170–76, https://doi.org/10.1001/archinte.167.20.ira70009.
[366] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022), 131–37, https://www.mass.gov/doc/2022-massachusetts-climate-change-assessment-december-2022-volume-ii-statewide-report/download.

workers, or 15% of the state's workforce, were employed in high-risk industries for exposure to extreme heat, such as construction, manufacturing, transportation and warehousing, agriculture, utilities, and mining.[367] The negative wage impacts of high-heat exposure have a disproportionate impact on minority workers, as the share of non-Asian minority workers in laborer occupations is 160% of the same group's representation in the Massachusetts workforce.[368]

Heat exposure also reduces mental productivity. An analysis of over 10M Preliminary Scholastic Aptitude Test (PSAT) scores in the US finds that, in schools without air conditioning, a 1°F hotter school year reduces that year's learning by 1%. Each additional school day with temperatures in the 90s (°F) relative to the 60s (°F) reduces student achievement by 1/6% of a year's worth of learning.[369] The effects of heat on human capital accumulation are cumulative and disproportionately impact minority students, accounting for roughly 5% of the racial achievement gap.[370] However, these impacts are mitigated through heat-relief measures such as installing air conditioning in schools or planning for shade at worksites.[371,372]

Government services and infrastructure: Hotter temperatures place additional burdens on local government services. In Massachusetts, emergency department visits are 17% above baseline for days at or above the current 95th-percentile maximum temperature.[373] A 2022 study conducted by the New England Public Policy Center (NEPPC) in the Federal Reserve Bank of Boston Research Department estimated the impact of temperature on municipal expenditures, finding average annual per capita expenditures could be $924 higher by the end of the century compared to the period of 1990 to 2019.[374] Heat degrades capital infrastructure such as buildings and transportation assets and places additional strain on heating, ventilation and air-conditioning (HVAC) systems. In public and commercial buildings, extreme heat shortens the lifecycle of roofs and reduces cooling system efficiency.[375] An analysis of heat resilience measures in select cities finds that installing cool roofs yields between $4 and $8 of quantifiable benefits including energy savings, stormwater, health, climate change, and employment impacts for every $1 in costs.[376]

Quality of life and air quality: Heat resilience measures such as splash pads, urban tree canopies, and shade structures can provide relief from heat, while offering co-benefits such as recreation and improved outdoor air quality. Recreational cooling features like community splash pads enhance community assets while providing an opportunity for children to continue to play outside on high-temperature days.

3 Overall Analysis Key Limitations

A summary of overarching limitations of the Investment Assessment follows. The limitations specific to each key resilience measure are discussed separately in the Investment Need and Resilience Value of Key Resilience Measures section above.

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[367] Lightcast, "Massachusetts Employment by Industry 2024," version Datarun 2025.2, May 2025, https://lightcast.io/.
[368] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022).
[369] R. Jisung Park et al., "Heat and Learning," *American Economic Journal: Economic Policy* 12, no. 2 (2020): 306–39, https://doi.org/10.1257/pol.20180612.
[370] Park et al., "Heat and Learning."
[371] Park et al., "Heat and Learning."
[372] Wangyang Lai et al., "The Effects of Temperature on Labor Productivity," *Annual Review of Resource Economics* 15, no. Volume 15, 2023 (2023): 213–32, https://doi.org/10.1146/annurev-resource-101222-125630.
[373] *2022 Massachusetts Climate Change Assessment* (Commonwealth of Massachusetts, 2022).
[374] Bo Zhao, *The Effects of Weather on Massachusetts Municipal Expenditures: Implications of Climate Change for Local Governments in New England*, 22–2 (New England Public Policy Center, 2022), https://www.bostonfed.org/publications/new-england-public-policy-center-research-report/2022/effects-of-weather-on-massachusetts-expenditures-implications-of-climate-change-in-new-england.aspx.
[375] "Climate Change Is Killing Buildings in Slow Motion," *Bloomberg.Com*, October 21, 2024, https://www.bloomberg.com/news/features/2024-10-21/how-climate-change-exacts-a-hidden-toll-on-buildings.
[376] Greg Kats and Keith Glassbrook, *Delivering Urban Resilience* (2018), https://static1.squarespace.com/static/5b104d0b365f02ddb7b29576/t/5b4e3d7988251b2bcae24210/1531854209103/delivering-urban-resilience-2018.pdf.

- The key resilience measures represent a subset of resilience measures and do not encompass all resilience investments. In each key resilience measure, the values presented also typically encompass only a subset of strategies based on available data. The investment need and resilience value do not represent all resilience investment needs or all resilience value for Massachusetts.
- While effort was made to distinguish between key resilience measures, there is inherent overlap between key resilience measures with the potential for double counting.
- Resilience to which end goal relates, in part, to existing goals and regulations, and to how much risk the Commonwealth is comfortable with accepting. There is a different cost (and benefit) associated with investing to protect assets against a 100-year storm event today (2025) versus a 100-year storm event in 2050. The Investment Assessment focuses primarily on resilience investments through 2050 for publicly owned assets, though the methodology varies by key resilience measure.
- The analysis focuses on infrastructure that exists as is represented in data at this time. There is no effort to predict the resilience costs associated with infrastructure yet unbuilt.
- In some cases, the investment need estimate may include costs not directly addressing or solely focused on resilience. There are significant costs associated with investing in infrastructure to meet a state of good repair regardless of climate resilience needs. It can be challenging to separate the costs of resilience from the costs of deferred maintenance. The investment need estimates may also exclude other costs or expenses unknown at this time.
- The investment need and resilience value analysis was a desktop exercise, with engagement, input, and feedback from the ResilientMass Finance Advisory Committee and state agencies throughout. No design, project-level cost estimating, or engineering analysis was undertaken.
- Asset-specific interventions and project-level design/prioritization are not included in this analysis. Site-specific and asset-level analysis is required to identify specific measures, their costs, and their benefits. This study is not an assessment of whether specific projects are justified based on expected benefits. Projects/assets can be prioritized and/or designed with specific outcomes that can help support broader social, economic, and environmental goals. Projects can be located in areas to provide benefits for vulnerable populations or designed to offer co-benefits such as habitat creation. Concurrent projects, strategic priorities, and practical feasibility constraints will all impact implementation considerations.
- Extensive review of relevant projects and cost data was undertaken to inform inputs for the investment analysis; however, the costs and projects cited represent only a sample of projects in each key resilience measure. Some analysis relies on studies completed nationally with a regional focus and downscaling assumptions were required. Statewide extrapolation and downscaling calculations rely on underlying assumptions, all of which introduce additional uncertainty.
- The timing of implementation will impact the investment need, which is not accounted for in this analysis. No costs for financing are included; escalation is not included. Additional costs related to O&M and renewal are not captured. Changes in policy (including discount rate changes) and economic conditions will affect cost and resilience value assessments. Policy recommendations, or the impact of policy on costs, such as streamlining permitting, are not included.
- Flooding, and particularly coastal flooding, has more information than other hazards. Other hazards, such as extreme heat and wildfire, have less information available regarding assets vulnerable to the hazard and project information.
- Prototype projects are intended to be representative of a typical project, but every project is unique and context-dependent. In the prototypical BCAs presented, not all benefits are readily monetizable and as such benefits are likely understated in the quantitative analyses. Not all projects that further resilience realize the resilience value discussed in the Investment Assessment. Some projects may have negative impacts. Increasing the size of a culvert in one

location, for example, may increase flooding downstream which can cause damage or decrease property values. Individual projects must be independently evaluated for their benefits and costs.

With these overarching considerations in mind, this technical appendix has attempted to clearly and transparently present the methods used to estimate the statewide cost of resilience for the selected key resilience measures and discuss the key limitations and resilience value of each.

4 General Limiting Conditions

AECOM devoted effort consistent with: (i) the level of diligence ordinarily exercised by competent professionals practicing in the area under the same or similar circumstances and (ii) the time and budget available for its work, to ensure that the data contained in this report is accurate as of the date of its preparation. This study is based on estimates, assumptions and other information developed by AECOM from its independent research effort, general knowledge of the industry, and information provided by and consultations with the client and the client's representatives. No responsibility is assumed for inaccuracies in reporting by the Client, the Client's agents and representatives, or any third-party data source used in preparing or presenting this study. AECOM assumes no duty to update the information contained herein unless it is separately retained to do so pursuant to a written agreement signed by AECOM and the Client.

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This document may include "forward-looking statements". These statements relate to AECOM's expectations, beliefs, intentions or strategies regarding the future. These statements may be identified by the use of words like "anticipate," "believe," "estimate," "expect," "intend," "may," "plan," "project," "will," "should," "seek," and similar expressions. The forward-looking statements reflect AECOM's views and assumptions with respect to future events as of the date of this study and are subject to future economic conditions, and other risks and uncertainties. Actual and future results and trends could differ materially from those set forth in such statements due to various factors, including, without limitation, those discussed in this study. These factors are beyond AECOM's ability to control or predict. Accordingly, AECOM makes no warranty or representation that any of the projected values or results contained in this study will actually be achieved.

This study is qualified in its entirety by, and should be considered in light of, these limitations, conditions and considerations.

Attachment 1: Sources Provided

Table A1.1 Sources of Information Provided by Project Management Team, State Agencies, and Partners

Key Resilience Measure (Shorthand)	Sources Provided
Dam Removal/Repair	• DER inventory of agency projects and existing project costs • ODS Report 25-04-03 (jurisdictional and non-jurisdictional dam count) • DFG existing dam project costs • Permit Streamlining Form – Project Feedback – Becker Pond Dam – TNC (002) (Mass Audubon)
Undersized Bridges and Culverts	• DER cost estimates • DER inventory estimates • MassDOT culvert inventory and replacement cost estimates • Massachusetts Culverts and Small Bridges Working Group, *Recommendations for Improving the Efficiency of Culvert and Small Bridge Replacement Projects* • MassGIS Bridges inventory (MassDOT) • MassGIS Culvert inventory (MassDOT) • Culvert Cost Estimates REV 1 (MassDEP) • Culvert Cost Estimates developed by TNC
Coastal and Riverine Floodplains	• DER inventory of agency projects and existing project costs • Massachusetts Department of Environmental Protection (MassDEP) RFI response • CZM project costing • EEA, Climate Grant Viewer – MVP Grant Programs • Pending and Planned Salt Marsh Restoration Projects 2024 (MassAudubon) • Case Study: Great Marsh ACEC (MassAudubon)
Forest Conservation and Tree Planting	• EEA Urban Forestry (and Reforestation) Strategic Plan Study
Strategic Transportation Infrastructure	• MassDOT Domain A analysis for OCIR • MBTA information on existing programs • Blue Line track elevation options (MBTA) • 2025 Power Master Plan 02022025 (MBTA) • Climate Change Adaptation Planning and Decision Making for Transit Infrastructure (MBTA) • MBTA GIS for bridges and critical infrastructure
Drinking Water and Wastewater Infrastructure	• EEA MWIP project information • Massachusetts Water Infrastructure Finance Commission’s water infrastructure report • MassDEP RFI response • Water Infrastructure Advisory Committee request for recommendations
Heat Preparedness & Relief	• PARC Grant Program, various project budgets • DCR cost estimates for shade structures • DCR cost estimates for cooling in government buildings • MAPC project costing

Attachment 2: Collected Project Information

It is important to note that the information provided below was collected through the various data collection efforts completed to date. **Information is presented as it was provided at time of delivery, with limited or no additional post-processing.**

Dam Projects

Table A2.1: Dam Removal Project Costs

Dam Name	Agency	Cost
High Street Dam	DER	$9,356,500
Burnshirt River Dam	DFG	$3,687,000
Quinapoxet Dam	DER	$3,235,445
Cusky Pond Dam*	DFG	$1,800,000
Lyman Pond Dam	DER	$940,000
Schoolhouse Pond Dam*	DFG	$648,100

**ARPA-funded removal underway*

Table A2.2: Dam Repair Project Costs

Dam Name	Agency	Cost
White Island Pond Dam	DFG	$4,420,000
Nye Pond Dam	DFG	$1,650,000
Threemile Pond Dam	DFG	$907,300
Town Farm Pond Dam	DFG	$90,000

Table A2.3: Additional Dam Removal Projects

Dam Name	Owner	Town	Grant Funding	Match	Total Known Cost	Source
Mill Street Dam[377]	The Nash Realty Trust	Pittsfield	$99,000 (MVP FY 2020)	$33,368	About $3.8M from 2008-2020	MVP Case Study
Armstrong Dam	F.X. Messina Enterprises	Braintree	$2,000,000 (NOAA FY23)	Unknown	Unknown	NOAA
Mill Pond Dam	Private	Norwood	$991,967 (MVP FY22/FY23)	$335,781	Unknown	MVP Case Study

[377] Also known as Tel-Electric Dam

Dam Name	Owner	Town	Grant Funding	Match	Total Known Cost	Source
Mill Pond Dam	Private	Norwood	$991,967 (MVP FY22/FY23)	$335,781	Unknown	MVP Case Study
Powdermill Dam	City of Westfield and Hampden Hampshire Conservation District	Westfield	$5,599,800	$2,135,000	$7,734,800	USDA NRCS

Small Bridges and Culvert Projects

Table A2.4: Culvert and Small Bridge Replacement Project Costs

Project Name	Source	Cost	Project Description
Central Street Bridge Improvements and Sawmill Brook Restoration, Culvert Retrofit and Restoration Project	FEMA[378]	$4,480,000	This project will utilize projected future discharge conditions and rebuilds the culvert system to protect up to the 100-year storm event for the year 2100.
Farm Pond Culvert and Tide Gate, Oak Bluffs	NOAA CZM ResilientCoasts CRRC Project Narrative	Funding Request: $4,000,000	Project replaces undersized Farm Pond culvert and replace or upgrade existing tide gate to allow water to drain from Farm Pond quicker.
Weir Creek Flood Remediation and Tidal Restoration Project, Dennis	NOAA CZM ResilientCoasts CRRC Project Narrative	Funding Request: $4,000,001	Project replaces two collapsing culverts that are jeopardizing other infrastructure and increasing flood risk.
Municipal Small Bridge Program	MassDOT MBTA Transportation Climate Cost Tracker	$369,000,000	Between 2025 and 2029, program capped at $15M annually. In latest grant round (awarded in November 2023), 37 awards were made totaling $11.1M.
MassDOT Culvert Enlargement on roads across the Commonwealth	MassDOT MBTA Transportation Climate Cost Tracker	$2B	MassDOT owns nearly 6,000 culverts, with ~1,200 identified as hydraulically vulnerable.
Various MEMA projects	MEMA	$24,100,000	MEMA has eight ongoing culvert resilience construction projects with a total combined cost of $24.1M.
Old State Road Culvert Replacement Project	MassWorks	$580,000	Culvert is proposed to be replaced with a larger culvert section, a corrugated aluminum structure with headwalls
Culvert Replacement at Elm Street & Pine Street	MassWorks	$1,087,000	Project to design and replace three existing culverts

[378] FEMA 2023

Project Name	Source	Cost	Project Description
Number Nine Rd Overhaul	MassWorks	$950,804	Project to replace 20 outdated and deteriorating culverts over a 3.6-mile length of Number Nine Road, followed by a leveling course and overlay pavement on 1.9 miles of the same road and FDR and winter binder on 1.7 miles of the same road and dress-up shoulders on entire 3.6-mile length of road.
King Corner Culvert Replacement	MassWorks	$2,131,751	Project to replace failing 90-inch culvert on Route 8A with 25-foot pre-cast concrete.
Whitman Road Culvert	MassWorks	$751,500	Project to replace a failing undersized existing culvert.
New Templeton Rd Reconstruction	MassWorks	$2,100,000	Project to reconstruct the deteriorated New Templeton Road and upgrade failing, flood-prone culverts and drainage.

Coastal and Riverine Wetlands and Floodplain Projects

Table A2.5: Coastal Wetland Projects

<table>
<tr><th>Project Name</th><th>Source</th><th>Planning Cost</th><th>Construction Cost</th><th>Project Details</th><th>Notes</th></tr>
<tr><td>Marsh Island Restoration Project</td><td>DER</td><td>$300,000</td><td>$3,100,000</td><td>Restore 6 acres of salt marsh.</td><td>This is Phase I</td></tr>
<tr><td>Eagle Neck Creek Restoration Project</td><td>DER</td><td>$600,000</td><td>$3,000,000</td><td>Recover/expand salt marsh vegetation.</td><td></td></tr>
<tr><td>Sawmill Brook Restoration Project</td><td>CZM</td><td></td><td>$1,561,511</td><td>Implement shoreline stabilization and restore salt marsh (1 acre).</td><td></td></tr>
<tr><td>The Pamet River Restoration Project</td><td>CZM</td><td>$2,183,779</td><td></td><td>Model, design, and permit to restore 120 acres at four locations.</td><td></td></tr>
<tr><td>Restoration of Ram Island Wildlife Sanctuary</td><td>USFWS</td><td colspan="2">$5,534,000</td><td>Enhance habitat by restoring and expanding salt marsh, shoreline protection measures.</td><td></td></tr>
</table>

Table A2.6: Habitat Restoration Projects, CZM Coastal Habitat, and Water Quality Grants

Project Name	Funds Awarded	Year	Project Details
Building Coastal Resilience within the Plymouth, Duxbury, Kingston (PDK) Bay Area	$48,685	2025	Develop a comprehensive habitat restoration plan for the PDK Bay area.
South Shore Salt Marsh Restoration Prioritization	$88,129	2024	Complete a comprehensive habitat restoration plan for the tidal marshes across the South Shore of Massachusetts.
Assisting Salt Marsh Migration in the Jones River Estuary, Kingston, MA	$18,000	2024	Conduct an analysis of land parcels for acquisition or CR establishment to facilitate marsh migration, or the landward movement of marshes into suitable adjacent lands with sea level rise.

Project Name	Funds Awarded	Year	Project Details
Habitat Restoration Plan for the Mattapoisett Neck Salt Marshes	$82,856	2024	Complete a comprehensive habitat restoration plan for the tidal marshes through the collection of aerial imagery, natural resource delineation, and modeling to project impacts of climate change.
Assessment of Coastal Habitat and Water Quality in the Fresh River System, Falmouth, MA with Evaluation of Conceptual Alternatives for Tidal Restoration	$90,237	2024	Develop a comprehensive habitat restoration plan to identify and prioritize restoration opportunities in the Fresh River system.
Cheesecake Brook Subwatershed Planning and Best Management Practice (BMP) Design	$99,992	2024	Develop GSI designs to treat stormwater runoff into Cheesecake Brook, for nutrients and bacteria.
Rock Island Cove Marsh Conservation Planning	$44,662	2023	Identify stressors and threats to the resilience and health of salt marsh habitat.
Comprehensive Habitat Restoration Plan, Jones River, Kingston, MA	$72,000	2023	Develop habitat restoration plan.

Table A2.7: Shoreline Projects

Project Type	2006 Cost	2024 Cost[379]	Project Description	Note
Beach/Dune Nourishment	$21,714,418	$39,849,700	Beach or dune nourishment for 21 Massachusetts beaches along 10.3 miles of shoreline	2006 cost
Beach/Dune Nourishment	$13,060,799	$23,968,800	Beach or dune nourishment for 42 municipal beaches along 10.4 miles of shoreline	2006 cost
Seawall and Revetment Repair/Reconstruction	$106,369,574	$195,206,500	Seawall and revetment repair or reconstruction for 198 state structures along 28.1 miles of shoreline	2006 cost including construction plus a 10% estimate for design and permitting; cost does not include 2013 rating, design improvements for higher water levels or needed beach nourishment
Seawall and Revetment Repair/Reconstruction	$4,847,541,894	$8,896,074,400	Seawall and revetment repair or reconstruction for 1,086 municipal structures along 88.9 miles of shoreline	2006 cost including construction plus a 10% estimate for design and permitting; cost does not include 2013 rating, design improvements for higher water levels or needed beach nourishment

[379] Figures inflated from 2006 source data using NAVFAC Building Cost Index. This doesn't account for changes in the system since 2006 (e.g., erosion/accretion and higher water levels).

Project Type	2006 Cost	2024 Cost[379]	Project Description	Note
Town of Dennis, Dennis North Road		$3,500,000	Bridge replacement and road elevation for crossing downstream of the Upper Bass River headwaters that needs	

Table A2.8: Land Acquisition Projects

Project Name	Source	Cost	Project Details
EEA Resilient Lands Initiative	CZM (CRRC proposal)	$5.1M	Acquisition of ~300 acres
BBC Acquisition of Coastal Lands Buzzards Bay	CZM (CRRC proposal)	$8.2M	Acquisition of ~500 acres
Salt Marsh Acquisition and Framework for Blue Carbon Incentives Program	NOAA CZM ResilientCoasts CRRC Project Narrative	Funding Request: $3,284,770	Protect salt marshes with Fee Simple acquisitions and CRs through the existing MassWildlife Land Protection Program

Table A2.9: Massachusetts Bog Restoration Projects

Project Name	Source	Cost	Project Details
Barnstable Clean Water Action Marstons Mills Cranberry Bog Restoration	CZM (CRRC proposal)	$3,187,206	60 acres of retired cranberry bogs
Nantucket Conservation Foundation Windswept Cranberry Bog Restoration	CZM (CRRC proposal)	$1,500,00	This cost is just for Phase II; goal to restore 40 acres, remove 2,500 ft of berms, and remove 28 water control structures
Cape Cod Conservation District Bayview Bogs Restoration Project	CZM (CRRC proposal)	$3,660,000	
Cold Brook	DER	$3,985,000	46 acres of wetlands restored, marsh migration corridor
Windswept Bog	DER	$4,070,000	40 acres of wetlands restored, rare species habitat
Bayview Bogs Restoration	NOAA CZM ResilientCoasts CRRC Project Narrative	$3,660,000	89 acres if retired cranberry bogs; remove culverts, ditches, and dikes to restore natural water flow
Correira Bogs	NOAA CZM ResilientCoasts CRRC Project Narrative	$2,000,000	Parcel purchase to protect 47 acres with 28 acres of retired bog included
Upper Bass River Coastal Habitat Restoration Project	CZM Habitat Restoration	$4,666,515	Restore 57 acres of coastal wetland at retired cranberry bogs

Project Name	Source	Cost	Project Details
Puritan Bog Coastal Wetland Restoration Project	CZM Habitat Restoration	$338,035	Complete modeling, design, and permitting to restore 15 acres of coastal wetland at retired cranberry bog
Red Brook Dam and Retired Cranberry Bog Restoration	NOAA CZM ResilientCoasts CRRC Project Narrative	Funding Request: $1,638,980	Replace hazardous dam structure with new culvert. Purchase land parcels adjacent to the dam to prepare for future restoration.
Retired Cranberry Bog Periodization	NOAA CZM ResilientCoasts CRRC Project Narrative	Funding Request: $930,000	Assess and prioritize old bog sites to restore and then design implementation plans.

Table A2.10: Other Relevant Local, District-Scale Projects

Project Name	Project Details	Related Grant Program	Cost	Source
Plymouth: Nourishment of Eroded Overwash Areas at Long Beach	Town wanted to elevate severely eroded wash over areas to the same height as surrounding dune spreads. The Town used rounded cobbles, gravel, and sand to fill the wash over areas to protect against storm damage and flood.	Costal Resilience Grant Program (CRGP)	FY15 Grant Award: $279,080 Match: $162,675 (37% of total project cost)	https://www.mass.gov/info-details/plymouth-nourishment-of-eroded-overwash-areas-at-long-beach
Island End River Flood Resilience Project	This project included the permitting and design work for flood planning. The project included climate modeling, community engagement, strategy and timeline preparation, BCA, and plan development. Project implementation combined vegetated berms, floodwalls, flood gates, and living shoreline.	MVP	Funding for permitting and design work- Grant: $716,500 Match: $241,388 (Local Cash/In-Kind) Implementation: $50M	https://www.mass.gov/doc/everett-island-end-river-flood-resilience/download

Project Name	Project Details	Related Grant Program	Cost	Source
Brewster: Relocation of Vulnerable Infrastructure	This project included the planning and construction of relocating a vulnerable parking structure due to erosion and sea level rise. The Town constructed vegetated dunes in place of the original parking lot to provide damage protection.	CRGP	Planning, Design, Permitting: $200,000 Construction: $500,000 Total Match: $167,750	Brewster: Relocation of Vulnerable Infrastructure | Mass.gov
Hull: Atlantic Avenue Storm-Damage Adaptation	The Town redesigned and retrofit a revetment and seawall to combat sea level rise. The project included modeling 7 design options and selecting an option to raise the seawall by 2 feet.	CRGP	CRGP FY14 Grant Award: $41,250 Total Match for CRPG: $13,750 (25% of total project cost) Massachusetts Dam & Seawall Repair or Removal Program final design/permitting/construction grant: $3M	https://www.mass.gov/info-details/hull-atlantic-avenue-storm-damage-adaptation
Massachusetts: Equitable Climate Resilience at Boston's Moakley Park	The project aims to protect an environmental justice neighborhood from an anticipated 51.5 inches of sea level rise by 2070. The project includes an earthen berm with a core wall, stormwater management, and other coastal protection.	FEMA Pre-Disaster Mitigation Grant Program	$24.06M	https://www.fema.gov/case-study/boston-massachusetts
Resilient Border Street Waterfront Project, Boston	This project includes the design and implementation of a green/gray coastal resilience solution to protect East Boston from current and future flood damage.	NOAA CZM	Funding Request: $10,000,000, Total Project Cost: $30,000,000	NOAA CZM ResilientCoasts CRRC Project Narrative
Riverside Park, New Bedford	This project supports the restoration of shoreline including salt marsh restoration.	NOAA CZM	Funding Request: $1,075,830	NOAA CZM ResilientCoasts CRRC Project Narrative

Project Name	Project Details	Related Grant Program	Cost	Source
Forest River Conservation Area Accessible and Equitable Greenspace, Salem	Repair bridge to support resilience of the area, assess current salt marsh condition, and evaluate future mitigation opportunities.	NOAA CZM	Funding Request: $300,000	NOAA CZM ResilientCoasts CRRC Project Narrative
Chelsea Street Bridge Overlook, Chelsea	The City will reduce flood risks through different green and gray infrastructure upgrades including permeable pavers, bioretention, salt marsh meadow, and native plantings as well as retaining walls.	NOAA CZM	Funding Request: $1,887,782	NOAA CZM ResilientCoasts CRRC Project Narrative
Sandy Neck Beach Facility Coastal Resilience Project, Barnstable	The Town already completed an alternatives analysis, public participation, and design development that led to the conclusion that the primary dune system that protects the beach facility from flooding and storm damage must be restored.	NOAA CZM	Funding Request: $1,300,000	NOAA CZM ResilientCoasts CRRC Project Narrative
Risk Assessment for State-Owned Lands	Project includes assessing, identifying, prioritizing, and advancing opportunities for solutions to reduce risks on properties. The assessment includes looking at relocating infrastructure.	NOAA CZM	Funding Request: $918,000	NOAA CZM ResilientCoasts CRRC Project Narrative
South Cape Beach State Park, Mashpee	The project intends to replace undersized culverts that threaten washouts. The project team will conduct assessments to design and implement a solution.	NOAA CZM	Funding Request: $1,466,216	NOAA CZM ResilientCoasts CRRC Project Narrative

Project Name	Project Details	Related Grant Program	Cost	Source
Great Marsh Barriers Project, Newbury and Ipswich	Project will implement Great Marsh Barriers to decrease risk of coastal and inland flooding. This project includes fixing undersized and at-risk infrastructure.	NOAA CZM	Funding Request: $1,999,215	NOAA CZM ResilientCoasts CRRC Project Narrative
Parker River National Wildlife Refuge Stage Island Impoundment, Ipswich	This project will restore salt marsh from the removal of a water control structure and a berm.	NOAA CZM	Funding Request: $2,935,613	NOAA CZM ResilientCoasts CRRC Project Narrative
Tidal Crossings Assessment	Identify projects that will help infrastructure resilience, restore wetlands, and promote marsh migration.	NOAA CZM	Funding Request: $930,000	NOAA CZM ResilientCoasts CRRC Project Narrative
Greening Lord Pond Plaza Feasibility Analysis	The goal of this project was to redevelop the plaza to reduce the issues of urban heat island effect and inland floodings.	MVP	Grant award: $189,030 (2020) Match: $6,408 in-kind hours and $72,450 cash match	https://www.mass.gov/doc/athol-greening-lord-pond-plaza/download
Ipswich River Sewer Interceptor Bank Biostabilization Project	Construction and on-the-ground implementation services. Replace existing sewer siphon, rehabilitate and physically protect sewer interceptor, stabilize shoreline, remove invasive species, stabilize bank from erosion	MVP	Grant: $117,802.50 (FY22) match amount: $46,710 Town cash match; $8,000 Town in-kind services match	https://www.mass.gov/doc/ipswich-ipswich-river-sewer-interceptor-bank-biostabilization-project/download
Monoosnoc Brook Resilient Redesign & Retrofit Project.	The project will redesign Monoosnoc Brook and surrounding infrastructure. Includes: culvert, reshape stream bank, widen open channel, upgrade sewer main.	MVP, FEMA HMGP	$6M	https://eeaonline.eea.state.ma.us/EEA/emepa/mepadocs/2021/070921em/sc/enf/16376%20ENF%20Monoosnoc%20Brook%20Resilient%20Redesign%20and%20Retrofit%20Project%20Leominster.pdf

Project Name	Project Details	Related Grant Program	Cost	Source
Mid-term district-level adaptation measures in Boston	Reducing physical risk, reducing social vulnerability, increasing capacity for emergency response and disaster recovery		Total cost of near to mid-term district-level adaptation measures in Boston could be between $1–$2.4B	Financing Climate Resilience Report - Boston Green Ribbon Commission
Coastal Resilience Solutions for Downtown Boston and North End	Create a coastal resilience plan for Boston. Proposed strategies for integrating flood protection: - spines: linear elements in the landscape should be elevated (bike paths, roadways) - open spaces: elevate existing and new public areas - harbor walk enhancements: raised and integrated along current bulkhead lines - offshore elements: filled land allowing for space to raise elevations or breakwaters		Estimated capital costs (Including planning and construction): $189 to $315M Estimated maintenance costs: $2.8 to $4.7M	https://www.boston.gov/departments/climate-resilience/coastal-resilience-planning

Forest Conservation and Tree Planting Projects

Table A2.11: Massachusetts Forest Conservation, Tree Planting, and Care Projects

Project Title	Project Description	Cost	Source
Greening the Gateway City Tree Planting Program	The Greening the Gateway Cities Tree Planting Program is designed to bring the energy efficiency and environmental benefits of a healthy tree canopy to Gateway Cities, former industrial cities identified by the administration for targeted redevelopment efforts. So far, over 8,000 trees have been planted throughout 13 Gateway Cities.	Partnerships	https://www.mass.gov/doc/greening-the-gateway-cities-program-fact-sheet/download

Project Title	Project Description	Cost	Source
Boston Tree Alliance	This program provides grants and technical support to community-based organizations. Its goal is to create grants and build capacity to plant and care for trees on privately-owned land, with a focus on increasing canopy in environmental justice neighborhoods and specifically areas that are documented heat islands.	The City will use $1M of ARPA funding for the first three years of the program.	https://www.boston.gov/departments/climate-resilience/boston-tree-alliance-program#:~:text=The%20Boston%20Tree%20Alliance%20is%20a%20long%2Dterm%20tree%20planting,long%2Dterm%20public%20health%20outcomes
Cooling Corridors	EEA's new Cooling Corridors program will support municipalities, non-profits, and other organizations in their tree-planting initiatives. The program will specifically target walking routes in areas that suffer from extreme heat, such as urban heat islands and hotspots, within environmental justice neighborhoods. The program will prioritize projects that help reduce local heat sinks, facilitate urban heat mitigation, and increase the regional tree canopy.	Unknown	https://www.mass.gov/news/in-celebration-of-arbor-day-healey-driscoll-administration-announces-new-program-to-expand-tree-plantings-in-environmental-justice-communities
Working Forests Initiative	The Working Forest Initiative streamlines programs and services offered to woodland owners who want to experience the full benefits of their private forests. Includes Forest Stewardship Program, Estate Planning, and Foresters for the Birds.	Unknown	https://www.mass.gov/guides/working-forest-initiative
Cambridge Grant	Ashburnham, Massachusetts The Cambridge Grant Project will conserve 49 acres of forestland and State-designated priority habitat through a conservation easement. It provides connectivity for the movement of species, buffers priority core habitat on Fitchburg Reservoir and provides public access to open space. Seventy percent of the tract is in the City of Fitchburg's public water supply watershed, which serves 41,500 residents.	$225,000 in Forest Legacy (Inflation Reduction Act)	https://www.fs.usda.gov/managing-land/private-land/forest-legacy/program/funded-projects

Project Title	Project Description	Cost	Source
Jones Hill Connection	Ashby, Massachusetts The Jones Hill Connection project will permanently conserve 105 forested acres in Ashby, MA by municipal fee acquisition. The property has high strategic value and would become a part of a large network of other conservation land, including other Forest Legacy Program tracts in the area. The property is an upper headwaters area for cold-water fishery tributaries to the federally designated Wild and Scenic Squannacook River.	$445,000 in Forest Legacy (IRA)	https://www.fs.usda.gov/managing-land/private-land/forest-legacy/program/funded-projects

Strategic Transportation Infrastructure Projects

Table A2.12: Sample Cape Cod Low-Lying Roads Cost

Town	Street	Solution	Road Length (linear feet)	Height/Elevation Increase (feet)	Cost	Source
Barnstable	Bridge Street	Road elevation	1711	8.2	$1,360,000	Link
Barnstable	Bridge Street	Hybrid: Road Elevation and Side Slope	611	4.2	$585,000	Link
Barnstable	Bridge Street	Berm construction	N/A	2.9	$28,000	Link
Barnstable	Ocean Street	Road elevation	944	3.3	$626,000	Link
Barnstable	Ocean Street	Hybrid: Walls, Berms, and Gates	N/A	4.1	$1,870,000	Link
Harwich	Bay Road	Road elevation	577	2.9	$1,140,000	Link
Harwich	Bay Road	Deployable barriers	600	4	$320,000	Link
Harwich	Bay Road	Dune restoration	N/A	9.5	$378,000	Link
Provincetown	Point Street	Road elevation	373	2.3	$273,000	Link
Provincetown	Point Street	Deployable barriers	380	4	$155,000	Link
Provincetown	Point Street	Dune restoration	N/A	N/A	$187,000	Link

Notes: All those on the same street are alternatives to each other; as such, costs should not be added together.

Table A2. 13: Additional Transportation Infrastructure Projects

Project	Project Description	Agency	Cost
Bus Shelters	Out of 8,500 bus stops, less than 700 have shelters and a majority not owned by MBTA. Shelter owners may need to implement resilience projects.	MBTA	~$150,000 per shelter to build and $6,000 per year for maintenance
Pump Room Upgrades	Costs do not necessarily cover all soft costs (e.g., Under Harbor East and West pump room implementation cost initially provided at $16M for both due to diversion soft costs, anticipating new cost estimate in September 2024).	MBTA	$134M total for all projects not including soft costs; soft costs can run as high as $16M due to diversion costs
Fenway Portal	Installation of floodgates and large steel doors to close off the Fenway tunnel portal to prevent flooding from the Muddy River, including third rail extension and upgrades to one pump room	MBTA	$22M (2020 $)
Blue Line Airport Portal	Installation of 13-foot-wide-by-17-foot-tall, hinged flood doors that close off the two tunnel portal openings during a flood event, including third rail extension and upgrades to two pump rooms (currently in design, final cost to be determined)	MBTA	$25-40M (2025 $)
Charlestown Seawall	Reconstruction, including elevation and of seawall near the Charlestown Garage to protect the facility from waterfront erosion and future sea level rise	MBTA	$32M
Headhouses	Near-term resilience solution is deployables similar to Aquarium station headhouses. Long-term may include station/headhouse redesign or other measures to dry or wet floodproof.	MBTA	$2M for Aquarium (2021 $)
Other MBTA Assets	~170 assets identified in Mike Martello, PhD research as "Lowest Critical Locations" - additional analysis required to categorize, map against initial identified option in vulnerability assessments, and assign high-level costs	MBTA	Unknown
Catch basin cleaning and maintenance	To maintain 125,000 catch basins in good working order	MassDOT	$20M per year
CNAI – Power SGR Investment	MBTA has a total $24.5B SGR backlog – this is for power fixes	MBTA	$9,615,163,115
Domain A Summary for OCIR	Summary results for Domain A only vulnerable transportation infrastructure to flooding	MassDOT	N/A

Table A2.14: MassWorks Transportation Projects

Project	Project Description	Total Project Cost
North Pleasant Street Multi-Use Path	new pedestrian and bicycle infrastructure	$1,923,000

Project	Project Description	Total Project Cost
Leonhardt Road repair	Construction of a full-depth roadway pavement structure, permanent erosion control measures, and stormwater management measures	$1,700,000
County Rd/ Yokum Pond Rd Phase I	Improve the road condition and safety	$1,380,686
Beech Hill Road Full Depth/Overlay	Enhance transportation safety of 3.5 miles of road	$1,582,447
Gore Road Reconstruction	Depth reclamation, redefined paved swales, and minor ditch work	$682,742
Zoar Road Bridge Rehabilitation	Cleaning and Painting of Structural Steel and repair of deteriorated substructure concrete.	$750,000
Fred Mason/West Road/Friend Street Resurfacing	Full Depth Reclamation including all structure work, curbing and driveway aprons	$2,041,965
Blandford Rd repaving	Rehabilitate the pavement, improve drainage features to reduce storm damage, and add roadside safety features	$1,000,000
Cross Road Retaining Wall	Remove the existing wall, replace it with a pre-cast block retaining wall, riprap slopes adjacent thereto, install drainage	$471,981
South Middle Road Artery Project	Paving project with culvert replacement	$1,131,000
Bridge Street Multimodal Improvement Project	New pedestrian and bicycle infrastructure	$2,512,574
Washington Street Dam & Culvert Reconstruction	Replace a culvert, headwall, and guard rail	$1,000,000
Stow Road Safety Improvements	Safety improvements: milling of the entire road, adjustment to the drainage structures, paving with hot mix asphalt and line striping	$1,100,000
Downtown TDI Gateway ADA Access- Merrimack Street	Project creates an Americans with Disabilities Act accessible ramp system, stair and public seating to connect the proposed public plaza to the northern portion of downtown	$3,000,000
Downtown Parking Improvements	Comprehensive repairs, upgrades, and enhancements to downtown municipal parking infrastructure	$6,500,000
Suffolk Place Infrastructure Improvements	Various infrastructure and streetscape improvements such as sidewalk reconstruction, re-curbing, and striping	$1,363,968
Overlook Ridge Development	Advance a regional transportation improvement project	$8,250,000
Norfolk Road in the village of Southfield	Full-depth reclamation and rebuilding of ~1.33 miles	$1,000,000
North Brookfield STRAP Road Renovation	Mill and rehabilitate roads as well as repave the sidewalks	$999,941

Project	Project Description	Total Project Cost
Dodd Road	Establish Dodd Road as a safe and accessible road	$1,107,600
Lime Kiln Road Bridge Replacement	Construction of a 24' long concrete bridge, roadway improvements to prevent flooding, and wetland mitigation efforts	$2,525,000
Powder Mill Road Reconstruction Project	Reconstruction of a roadway	$5,400,000
Bridge 183	Upgrade a bridge	$1,500,000
Modernization of Schoolhouse Road Phase Two	Full depth reclamation	$1,096,600
128 NB OnRamp @ 1265 Main	Constructing a northbound on-ramp, minor traffic signal adjustments, sidewalk work along Main Street, and the closure and relocation of a driveway	$3,490,000
Columbian-Forest Streets Streetscape and Traffic	Install a traffic signal and expand walking/biking access	$2,347,232
Main Dalton Road FDR Project	Project will include replacing ~800 feet of guardrails, replacing one drain culvert, and cleaning and repairing ~12 other drain culverts	$1,136,187
Quincy Center Public Parking Garage	Site preparation, earthwork, utility installation, and substructure construction, ensuring a solid foundation for vertical development	$70,000,000

Drinking Water and Wastewater Infrastructure Projects

Table A2.15: Water/Sewer EEA MWIP Applicant Project Costs

Project Name	Infrastructure Type	Project Description	Cost
Acton Sewer Pump Station Rehabilitation	Municipal Sewer System	Rehabilitate pump stations with safety and efficiency upgrades, replace old pump impellers, and install Variable Frequency Drives	$4,550,000
State Road Corridor Water Infrastructure Project	Watermain	Replace the existing 10-inch, cast-iron water main installed in 1958 on State Road with 2,300 linear feet of 12-inch, cement-lined ductile iron.	$1,440,000
North St Utility Infrastructure and Roadway Upgrades	Water/Sewer/Stormwater Infrastructure	Substantial water/sewer/stormwater infrastructure upgrades and road widening/realignment improvements	$13,294,200
Northampton Street Water and Sewer Infrastructure	Domestic Water Supply	Upgrade existing waterline and sanitary sewer infrastructure	$3,444,995

Project Name	Infrastructure Type	Project Description	Cost
Five Corners Secondary Pump Station Construction	Sewer Pump Station	Construction of an additional pump station	$5,026,000
Second Street Resiliency Upgrades	Watermain	Upgrade the water main	$2,650,000
Pleasant Street Infrastructure	Sewer and Water Lines	Extend sewer, water and sidewalks	$6,279,241
Infrastructure Improvements to Mitigate Flooding	Drainage Infrastructure	Install larger connections between drains and increase size of pipe diameter	$2,314,137
Preliminary Engineering Wastewater Collection System	Sewer Structures	Perform conditions assessment	$36,000
Acquire and Replace Wastewater Pump	Pumping Station	Acquire and replace pump	$2,682,670
Wastewater Treatment Plant Upgrades	WWTP	Upgrade aging equipment	$4,285,000
Town of Pelham and Amherst Water and Sewer upgrade	Sewer Line	Extend the existing sewer line	$2,715,000
Town Center Infrastructure Improvements	Distribution and Stormwater Infrastructure	Improve water distribution and bury utilities	$4,033,000
Egypt Road - Water Main Loop Connection	Watermain	Construct 900 linear feet of water main	$361,499
Various	Various	MEMA staff noted that MEMA has 15 ongoing generator and microgrid projects totaling $6.4M for Critical Facilities. These facility types range from hospitals, fire stations, DPWs, EOC, police stations, pump stations, and shelters. No other project information was provided.	$6,400,000

Table A2.16: Sample of MVP FY25 Critical Infrastructure Projects

Project Name	Grantee	Project Description	Cost
Stormwater Retrofit Program at the Dudley Municipal Complex	Dudley	Reduce the quantity and improve the quality of stormwater runoff	$281,000
Nature-based Solutions for a Resilient Coolidge Park	Fitchburg	Design project to increase stormwater storage	$323,160

Project Name	Grantee	Project Description	Cost
Increasing Resilience to Harmful Algal Blooms in Santuit Pond: Construction of Town Landing Resilience Improvements	Mashpee	This project received funding for various phases in FY22, FY23, and FY24 to reduce stormwater sediment in a pond	$1,669,956
School Street Parking Lot Project	Middleborough	Reduce stormwater runoff via drainage upgrades	$171,230
Resilient Central Vacuum Station	Provincetown	Construct resilient upgrades at critical sewer service stations	$1,000,000
Fall River CSO Treatment Study	Fall River	Study to address impacts of CSO on community and determine a path forward to address issues	$1,163,000
Generating Resiliency in Downtown Fitchburg with Nature-Based Solutions	Fitchburg	Look into nature-based solutions for stormwater and urban heat incorporation into streetscape during CSO construction	$109,000
Ipswich River Sewer Interceptor Bank Bio-stabilization Project	Ipswich	Conduct bio-stabilization to implement nature-based solution to protect sewer infrastructure	$117,803

Table A2.17: Additional Critical Infrastructure Projects

Project Name	Project Description	Cost	Source
Separate Combined Sewer System	Boston is separating sewer pipes from stormwater pipes to be able to handle the large increase in stormwater	~$340,000 per acre	https://grist.org/cities/climate-change-is-messing-with-city-sewers-and-the-solutions-are-even-messier/
Detached Rain Management Infrastructure	New York City is using green infrastructure for temporary stormwater storage	$84M	https://grist.org/cities/climate-change-is-messing-with-city-sewers-and-the-solutions-are-even-messier/
Massachusetts: Emergency Interconnection Pump Station Project	This project will replace and install a new emergency drinking water connection between Brockton and Stoughton. The project will also remove the underground South Street Pump Station and install a fully equipped above-ground pump station that will allow for flows among all three water systems. The interconnection will address emergency supply deficiencies as well as make drinking water more reliable.	$745,500	https://www.fema.gov/case-study/massachusetts-emergency-interconnection-pump-station-project
Greenfield dewatering project	Add sludge dewatering equipment to the Greenfield Wastewater Treatment Plant. Project will also include demolition of old equipment, upgrading electrical equipment, and constructing new steel building	$3.6 M	https://www.wwlp.com/news/local-news/franklin-county/3-6m-to-go-towards-greenfield-dewatering-project/

Heat Preparedness and Relief Projects

Table A2.18: Metropolitan Area Planning Council (MAPC) Projects

Project Name	Planning Cost	Construction Cost
Chelsea's Green Roof	Assess: $12,000 Design: $20,000	Unknown
Everett's Main Street Meadow	$30,000	$290k
Cambridge's Shade Structures	$60,000	$100k

Table A2.19: PARC Project Costs

Asset	Cost	Source
Shade sail (including installation)	$97,000	Riverside Shade Design and Cost Estimate
Shade pavilion	$58,000	Whitney Park Master Plan
Shade structures	$125,000	Walsh Playground Concept Estimate
Shade sail	$27,000	Chelsea 212 Congress Estimate
Shade sail	$15,000	Yarmouth Riverwalk Park Cost Estimate
Shade sail	$100,000	Lowell South Common Phase III Budget Details
Shade trellis	$22,000	Bosson Park Cost Estimate Site Development Plans
Shade structures	$60,000	O Day Site Development Plan Cost Estimate

Table A2.20: Cooling in Buildings

Source	Cost	Link
Mass Save – Heat Pump costs	$22,000 each	https://www.masssave.com/residential/rebates-and-incentives/heating-and-cooling/heat-pumps/air-source-heat-pumps
The Centre for Climate Integrity Resilient Analytics	$2B	Hotter Days, Higher Costs: the Cooling Crisis in America's Classrooms. Accessed at https://coolingcrisis.org/uploads/media/HotterDaysHigherCosts-CCI-September2021.pdf
Cooling per government building	$50,000 to $100,000 per building	DCR provided

Table A2.21: Other Projects/Costs

Project	Asset(s)	Cost	Source
N/A	Pool	Capital investment for a new pool is estimated around $8M. Rehabilitation or upgrades could be between $5 and $7M.	DCR RFI response
N/A	Splashpad	Splashpad costs between $500,000 with no water/sewer utilities and $800,000 if utilities are present.	DCR RFI response
DCR Project Shade	Many types (e.g., tree canopy, pavilion, and umbrellas)	Different costs depending on asset (e.g., umbrella is $452 plus tax/shipping with a base of $423 plus tax/shipping)	DCR Project Shade | Mass.gov

Attachment 3: Resilience Value Methodology for Project Prototype Benefit-Cost Analysis

A quantitative analysis was conducted to demonstrate resilience value for a subset of project types in several resilience measures. For each, a prototype project (or two) were developed to model based on a set of assumptions which are described herein. Universal assumptions for the resilience value quantitative analysis include:

- **Static built environment:** This analysis superimposes potential future physical conditions on the existing built environment. It is likely that the built environment in Massachusetts will undergo changes between the present year and the end of the project's useful project life. To accurately capture these dynamics, detailed information on future development plans at the building level scale are needed. This information was not available or appropriate for this level of analysis.
- **Discounting:** Discount rates are applied in a benefit-cost analysis (BCA) to account for the social "opportunity cost" or the time value of money, allowing for a comparison of future costs and benefits in present dollars (2024). Per economic theory, the value of future benefits is assumed to be lower than the value of present benefits. A 3.1% discount rate was used in this analysis, consistent with FEMA guidance as of early 2025.

Culvert Prototype Project Resilience Value Benefit-Cost Analysis

A prototype culvert project in Massachusetts was developed to demonstrate the resilience value of upgrading undersized culverts. For replacement of a pipe culvert in a suburban area of Massachusetts, the analysis estimated avoided costs from reduced flooding (including avoided costs from physical damages (culvert/road and nearby property), traffic delays, and emergency services impacts) and co-benefits from restoration/enhancement of ecosystem services. Table A3.1 displays the assumptions for the prototype.

Table A3.1: Culvert Prototype Specifications

Variable	Assumptions
Location	Suburban area in Massachusetts, population of town less than 100,000
Culvert type	Pipe culvert: • Elliptical reinforced concrete pipe with 32-inch rise and 50-inch span with concrete headwalls • 80-inch length
Design	Designed to meet Massachusetts Stream Crossing Standards of: • Hydraulic Design Flood: 50-year • Scour Design Flood: 100-year • Scour Check Flood: 200-year
Modeled climate conditions	2025 (current) 2050 (RCP 4.5)
Modeled benefits	• Avoided physical damage to road/culvert structure and nearby property (residential and commercial) • Avoided routine maintenance costs • Avoided traffic delays • Avoided business interruption • Avoided critical services delays • Ecosystem services (wetlands)

Variable	Assumptions
Estimated engineering, permitting, design, capital costs (2024 $)	$800,000 to $1.2M
Estimated annual O&M (2024 $)	$8,000 to $12,000
Assumed project useful life	50 years[380]

Avoided Physical Damages

To determine direct physical damage costs for the culvert, the project team used rainfall condition modeling from the FEMA Flood Insurance Study (FIS) Profiles. It was assumed that the current condition of the prototype culvert, similar to many throughout Massachusetts, is undersized and deteriorated. It was assumed that, under current conditions (2025), the culvert would be approaching capacity at the 10-year storm pre-mitigation, with more intense damages for this storm under 2050 pre-mitigation conditions. Damages steadily increase for larger return periods. With the project (i.e., post-mitigation), it was assumed that the prototype culvert project would provide protection against the 100-year storm under existing conditions, but not under 2050 conditions.

It was assumed that a nearby single-family, two-story structure (no basement, measuring ~1,800 ft²) and a small commercial structure (small retail store, measuring ~2,650 ft²) would be damaged for higher return periods. The project team estimated structure and content damages assuming a building replacement value of $142.43 per ft² for the single-family structure and $143.21 per ft² for the commercial structure[381] and FEMA generic depth damage functions.[382]

Assumed pre- and post-mitigation asset performance, culvert damages, road closures, and property flood depths at the building level are outlined in Table A3.2 and Table A3.3.

Table A3.2: Culvert Prototype Damage Assumptions by Return Period, Current (2025) Conditions

Return Period (year)	Status	Asset/Adjacent Asset Performance	Culvert Damage	Road Closure	Property Flooding
10	Pre-Mitigation	Approaching capacity Minor erosion and moderate debris cleanup	10%	1	None
	Post-Mitigation	Under capacity No damage or erosion and minor debris cleanup	0%	0	None
25	Pre-Mitigation	At capacity Moderate erosion and major debris cleanup	20%	3	None
	Post-Mitigation	Under capacity Minor erosion and minor debris cleanup	5%	0	None
50	Pre-Mitigation	Over capacity, likely road overtopping Major erosion, major debris cleanup, and major road repairs	50%	14	None
	Post-Mitigation	Approaching capacity Minor erosion and moderate debris cleanup	10%	1	None
100	Pre-Mitigation	Complete failure Complete erosion of roadway	100%	30	2ft
	Post-Mitigation	At capacity Moderate erosion and major debris cleanup	20%	3	None

380 FEMA, *BCA Reference Guide*, 2009.
381 *Hazus 6.0 Inventory Technical Manual*, n.d.
382 FEMA

Return Period (year)	Status	Asset/Adjacent Asset Performance	Culvert Damage	Road Closure	Property Flooding
200	Pre-Mitigation	Complete failure Complete erosion of roadway	100%	30	3ft
	Post-Mitigation	Over capacity Road overtopping, substantial erosion, major debris cleanup, and road repairs	30%	7	3ft
500	Pre-Mitigation	Complete failure Complete erosion of roadway	100%	30	3ft
	Post-Mitigation	Over capacity High-velocity road overtopping, major erosion, major debris cleanup, and major road repairs	50%	14	3ft

Notes: Road closure shown in days, culvert damage shown as percentage of damage of culvert replacement value.

Table A3.3: Culvert Prototype Damage Assumptions by Return Period, Future (2050, RCP 4.5) Conditions

Return Period (-year)	Status	Asset/Adjacent Asset Performance	Culvert Damage	Road Closure	Property Flooding
10	Pre-Mitigation	At capacity Moderate erosion and major debris cleanup	20%	3	None
	Post-Mitigation	Under capacity No damage or erosion and minor debris cleanup	5%	0	None
25	Pre-Mitigation	Over capacity, likely road overtopping Major erosion, major debris cleanup, and road repair	50%	14	None
	Post-Mitigation	Approaching capacity Minor erosion and moderate debris cleanup	10%	1	None
50	Pre-Mitigation	Complete failure Complete erosion of roadway	100%	30	None
	Post-Mitigation	At capacity Moderate erosion and major debris cleanup	20%	3	None
100	Pre-Mitigation	Complete failure Complete erosion of roadway	100%	30	2ft
	Post-Mitigation	Over capacity, like road overtopping Substantial erosion, major debris cleanup, and minor road repair	30%	7	None
200	Pre-Mitigation	Complete failure Complete erosion of roadway	100%	30	3ft
	Post-Mitigation	Over capacity, high velocity road overtopping Major erosion, major debris cleanup, and major road repairs	50%	14	3ft
500	Pre-Mitigation	Complete failure Complete erosion of roadway	100%	30	3ft
	Post-Mitigation	Complete failure Complete erosion of roadway	100%	30	3ft

Notes: Road closure is shown in days; culvert damage is shown as percentage of damage of culvert replacement value.

Avoided Routine Maintenance Costs

Storm-induced flooding at undersized culverts may result in frequent physical damage and debris buildup at the site of the culvert and road, as well as downstream. There are significant costs for ongoing maintenance of undersized culverts, such as frequently removing debris and blockages, and costly recurring road and culvert repairs. A study in Maine estimated that the benefits of reduced repair and replacement costs of improved culverts would exceed lifetime project costs over a 50-year timeframe.[383] Upgrading undersized culverts that allow stream flow and debris to pass through can relieve the need for frequent maintenance.

It was assumed that the avoided routine maintenance costs are primarily due to the avoided debris and damage that builds up from the 2- and 5-year storm. This is likely to be made up of woody debris, sediment, and small rocks from upstream that cannot pass through the undersized culvert and require frequent physical removal.

Assumed pre- and post-mitigation asset performance and avoided routine maintenance costs (shown as a percentage of culvert replacement value) are outlined in Table A3.4.

Table A3.4: Avoided Maintenance Assumptions by Return Period

Return Period (year)	Status	Current (2025) Conditions		Future (2050, RCP 4.5) Conditions	
		Asset/Adjacent Asset Performance	Avoided Maintenance	Asset/Adjacent Asset Performance	Avoided Maintenance
2	Pre-Mitigation	Under capacity No damage or erosion	0%	Under capacity Minor erosion and minor debris cleanup	1%
	Post-Mitigation	Under capacity No damage or erosion	0%	Under capacity No damage or erosion	0%
5	Pre-Mitigation	Under capacity No damage or erosion and minor debris cleanup	1%	Approaching capacity Minor erosion and moderate debris cleanup	10%
	Post-Mitigation	Under capacity No damage or erosion	0%	Under capacity No damage or erosion	0%

Notes: Avoided maintenance is shown as a percentage of culvert replacement value and is representative of debris cleanup costs.

Avoided Traffic Delays

Failed culverts can result in flooding and damage to roadways, leading to road closures. Individuals who use roads impacted by culvert failure may experience travel delays and need to travel longer distances. This results in added time and vehicle operating costs. Road closures can also lead to lost income for businesses located on the road or workers that reside in properties along closed roads, delayed school buses and mass transit, though these have not been quantified here.

To estimate costs of traffic delays, standard FEMA methodology was used and annual average daily traffic data. Detour time and distance is the one-way travel time/distance required for detour around the project area, while traffic count is the estimated number of vehicles impacted that must detour around the project area. Table A3.5 presents the inputs used to calculate losses. The delays are assumed for each day of the road closures (summarized for pre- and post-mitigation in Table A3.4 and Table A3.5).

[383] Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.

Table A3.5: Avoided Traffic Delay Modeling Assumptions

Item	Metric	Source
Detour (time and length)	Detour time: 9 minutes Detour length: 4 miles	Project team detour mapping
Traffic count	13,965 vehicles per day	MassDOT Traffic Count Database System (TCDS),[384] average traffic count for suburban location
Vehicle operating cost per mile	Mileage rate: 70 cents per mile	FEMA BCA Toolkit[385]
Traffic delays for roads and bridges	$36.63 per hour	FEMA BCA Toolkit[386]

Avoided Business Interruption

Flooding directly impacts businesses through the destruction of their property and assets as well as interruption of business processes due to road closures caused by a flooded or damaged culvert.[387] A business may incur disruption costs, such as the cost to shift or transfer goods, as well as lost output due to physical damages in the building or road closures due to flooding. Business-related losses from disaster events can be recouped, to some extent, by working overtime after the event (accounted for through a recapture factor). Table A3.6 presents the inputs for business interruption costs.

Table A3.6: Inputs for avoided business interruption modeling assumptions

Item	Metric	Source
Building area	2,646 ft²	Project team assumption for small retail shop in suburban town
Disruption cost	$1.69 / ft²	FEMA Hazus Inventory Technical Manual 6.0, 2022[388]
Vacancy rate	2.1%	CoStar Analytics, Retail Vacancy Rate for suburban location in Massachusetts
Output (sales) per ft² per day	$2.32	FEMA Hazus Inventory Technical Manual 6.0, 2022[389]
Recapture factor	0.87	FEMA Hazus Inventory Technical Manual 6.0, 2022[390]
Loss of function days	2-foot flood depth: 90 days 3-foot flood depth: 135 days	FEMA Hazus Earthquake Model Technical Manual 6.1[391]

[384] "Transportation Data Management System," accessed June 16, 2025, https://mhd.public.ms2soft.com/tcds/tsearch.asp?loc=Mhd&mod=.
[385] Standard mileage rates used to calculate the costs of operating an automobile are issued by the Internal Revenue Service (IRS). The current default mileage rate is 70 cents per mile. This value is updated annually based on IRS determinations.
[386] Standard mileage rates used to calculate the costs of operating an automobile are issued by the Internal Revenue Service (IRS). The current default mileage rate is 70 cents per mile. This value is updated annually based on IRS determinations.
[387] Thijs Endendijk et al., "Enhancing Resilience: Understanding the Impact of Flood Hazard and Vulnerability on Business Interruption and Losses," *Water Resources and Economics* 46 (April 2024): 100244, https://doi.org/10.1016/j.wre.2024.100244.
[388] *Hazus 6.0 Inventory Technical Manual*.
[389] *Hazus 6.0 Inventory Technical Manual*.
[390] *Hazus 6.0 Inventory Technical Manual*.
[391] *Hazus 6.1 Flood Model Technical Manual*, n.d.

Avoided Critical Services Delays

In life-threatening situations, timely emergency care is a key factor that affects chances of survival. If the route of a critical service provider is impacted by a road closure due to a failed culvert, there may be an increase in the response time, which may be a result in a cost in lives.

The analysis estimates the potential cost resulting from the increased response time of an EMS provider and a fire response provider. FEMA methodology was utilized:[392]

- EMS: Uses a survival function based on cardiac arrests. A survival function measures the probability of survival for a patient as a function of the response time of an EMS vehicle to the patient.[393] Table A3.7 presents the inputs used to calculate the loss of lives from increased EMS response time. The EMS delays are assumed for each day of the road closures (summarized for pre- and post-mitigation in Table A3.4 and Table A3.5).
- Fire: Estimates the social cost for a loss of a fire station's services, also referred to as a "loss of function". Specifically, the methodology estimates how the increased response time from a fire station will affect fire losses (human injuries and mortality, direct financial loss to property, and indirect losses). A universal measure used across public safety functions is response time.

Table A3.7: Inputs for Avoided EMS Delay Modeling Assumptions

Item	Input	Source
Service population impacted	~2,900 people	Reviewed US Census data[394]
Response time delay	6 minutes	Project team detour mapping in suburban location
Detour distance	4.8 miles	Project team detour mapping in suburban location

Ecosystem Services

Adequately sized culverts and small bridges provide a range of important environmental benefits. Well-designed and sized culverts that allow wildlife, sediment and debris to pass naturally through a stream provide water quality improvements, improved habitat and biodiversity benefits. Replacing undersized and poorly designed culverts with larger and more ecologically friendly structures can restore natural stream flow patterns and improve resilience to the impacts of climate change on the stream, such as increased precipitation and flooding. Resilient stream crossings are also less likely to fail during storm events which can lead to adverse environmental impacts at the project site and downstream. An acreage of wetlands was assumed to be restored/enhanced for the prototype project (0.3 acres) and standard FEMA methodology was used to estimate ecosystem service benefits.

Other Non-Monetized Benefits

Property value benefits

Upgraded culverts and small bridges that can successfully move stormwater can reduce the risk of flooding to surrounding properties. While the increase in property value specifically attributable to upgrading culverts is difficult to quantify, people are more likely to pay more for homes that are not exposed to flooding. The reduced potential for flooding of roads used to access homes may also make these properties more attractive to buyers.[395] Upgrading culverts can also increase the value of developable residential and industrial properties due to the reduction in flood risk.[396] It is important to note

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[392] It is important to note that AECOM altered the FEMA methodology to reflect an increase in response time due to a road closure, not an increase in response time due to an EMS/fire station not operating.
[393] "Fema-Standard-Economic-Values-Methodology-Report-V13-2024.Pd," n.d.
[394] US Census (2025). Block Group data – population.
[395] Massachusetts Clean Water Trust and MA Department of Fish and Game Division of Ecological Restoration, *Economic and Community Benefits from Stream Barrier Removal Projects in Massachusetts*.
[396] *Hill Street Culvert Reconstruction, Raynham*.

that upgrading culverts can potentially increase the risk of flooding to nearby properties and that the geographic context should be considered prior to any upsizing initiative.

Community safety and social impacts

Culverts and small bridges can mitigate flood impacts and keep communities safe. Poorly maintained and undersized culverts can erode stream banks and roads and become obstructed with debris, exacerbating flooding upstream. The storm flow from a culvert can also erode the sides of a paved channel or the bottom of a graded channel. When these water channels erode, they can create gullies on the side slopes that can trip the wheels of an errant vehicle or bicycle causing instability, loss of control or initiating a vehicle rollover.[397]

Storm-induced flooding can cause several forms of human impact, including mental stress and anxiety, as well as lost worker productivity, both during and in the aftermath of a natural disaster. Storm-induced flooding at residential structures can result in injury and loss of life during a disaster and in the following days and weeks. Longer-term expected effects include medical and psychological treatment and lower worker productivity. These types of human impacts have not been estimated for this prototype.[398]

Benefit-Cost Analysis

To calculate benefits over the project lifetime, the analysis estimated an expected annual damage pre- and post-mitigation accounting for the storm recurrence intervals (i.e., return periods). The most benefits represent the avoided losses, or the difference between the pre- and post-mitigation damages over the project lifetime. Ecosystem service benefits are estimated to be an annual additive co-benefit of the mitigation, where presence of these project elements enhances mitigation projects. Capital costs are estimated as a one-time upfront cost in year one, with O&M costs recurring over the project lifetime. All benefits and costs are discounted to present value (2024 $). A summary of the BCA results, accounting for the total estimated present value of project costs and project benefits, as well as the resulting BCRs, is presented in Table A3.8. The BCR is calculated by dividing the present value benefits by the present value costs.

Table A3.8: BCA Results for Culvert Prototype Project (Discounted at 3.1%)

Input	Low	High
Capital cost	$1.2M	$776,000
Maintenance cost	$294,000	$196,000
Upfront capital and project lifetime maintenance costs (discounted)	**$1.5M**	**$972,000**
Avoided physical damages	$1M	$714,000
Avoided routine maintenance costs	$206,000	$138,000
Avoided traffic delays	$2M	$2M
Avoided critical services delays	$300,000	$300,000
Avoided business disruption	$40,000	$40,000
Ecosystem service benefits	$60,000	$60,000
Benefits over project lifetime (discounted)	**$3.8M**	**$3.3M**
BCR	**2.6**	**3.5**

[397] FHWA, "Correcting Unsafe Drainage Features."
[398] *Unit 3 - The Benefit Cost Model* (FEMA, n.d.), https://www.fema.gov/sites/default/files/2020-04/fema_bca_instructor-guide_unit-3.pdf.

Note benefits and costs are highly variable and unique to each project. BCRs shown here do not represent all projects of this type.

Green Stormwater Infrastructure Prototype Project Resilience Value Benefit-Cost Analysis

Stormwater management is critical to community resilience needs as communities face the impacts of a changing climate, including more frequent and stronger storms. As cities and towns continue to grow, the amount of impervious surfaces increases, leading to urban flooding. GSI, such as rain gardens, infiltration basins and trenches, swales, green roofs, and pervious pavement use natural systems to control stormwater and urban flooding.[399] It is based on the principle of source reduction, where GSI decreases the volume of water that enters waterways as direct runoff through a combination of planning practices, natural elements, and engineered devices that infiltrate, evapotranspire, or store runoff for beneficial use.[400]

GSI is effective at reducing flooding at a variety of scales and can lead to significant reductions in flood loss damages on an average annual basis.[401] In areas impacted by localized flooding, GSI can be used to absorb stormwater and reduce surface flow, pooling, and seepage, all of which can cause property damage. In areas impacted by riverine flooding, green infrastructure, open space preservation, and floodplain management can complement gray infrastructure approaches and reduce the extent of flood damage from channel overflows.[402] In addition to avoided damages, GSI provides several economic benefits to neighborhoods, including species habitat, improvements in water quality, recreation places, improved aesthetic of an area, increased property values, and cooling on hot days.[403] GSI can also significantly reduce negative downstream impacts such as increased discharges after storms, stream scour, and channel/bank erosion.

GSI complements gray infrastructure such as catch basins and drainage pipes, and lengthens the lifespan of traditional gray stormwater infrastructure.[404] Green and gray stormwater infrastructure are often used in tandem, as GSI helps to address stormwater issues at the source, while drainage improvements can manage the excess water that GSI does not capture. This combined approach offers a more sustainable and effective way to manage stormwater in urban environments.

To understand the resilience benefits of improved stormwater infrastructure, a prototype hybrid green/gray stormwater project was developed for a suburban area of Massachusetts. The project involves upgrading a drainage pipe to increase capacity, removing an area of impervious surface (such as a parking lot or vacant lot in a residential area) and replacing this area with GSI and nature-based solutions to reduce stormwater runoff.

Typical project costs were estimated and co-benefits quantified primarily using FEMA methodology for the different components of the hybrid GSI project. Table A3.9 displays the assumptions for the prototype.

Table A3.9: GSI Prototype Specifications

Variable	Assumptions
Location	Suburban

[399] *Green Stormwater Infrastructure: Impact on Property Values* (Center for Neighborhood Technology, n.d.).
[400] *Flood Loss Avoidance Benefits of Green Infrastructure for Stormwater Management*, n.d.
[401] Roxanne Blackwell et al., *Jeffrey Odefey Stacey Detwiler Katie Rousseau Amy Trice*, n.d. Blackwell et al., *Jeffrey Odefey Stacey Detwiler Katie Rousseau Amy Trice*.
[402] US Environmental Protection Agency, “Economic Benefits of Green Infrastructure,” Overviews and Factsheets, July 17, 2024, https://www.epa.gov/green-infrastructure/economic-benefits-green-infrastructure.
[403] *Green Stormwater Infrastructure: Impact on Property Values*.
[404] “Benefits of Green Infrastructure,” *Global Designing Cities Initiative*, n.d., accessed June 16, 2025, https://globaldesigningcities.org/publication/global-street-design-guide/utilities-and-infrastructure/green-infrastructure-stormwater-management/benefits-green-infrastructure/.

Variable	Assumptions
Project components	• Urban trees: 17 • Rain garden: 1,428 ft² • Urban open space: 8,215 ft² • Upgrade of drainage pipeline from 15-inch to 36-inch reinforced concrete pipe, 112 linear feet
Modeled benefits	Ecosystem service value enhancements Avoided property damage
Estimated engineering, permitting, design, capital costs (2024 $)	$741,000
Estimated annual O&M costs	$4,000
Assumed project useful life	30 years[405]

Benefits of different types of GSI components have been quantified by FEMA and include several other economic benefits in addition to stormwater management.

GSI components

Urban trees

Trees provide significant stormwater volume control through rainfall interception and intensity reduction, stormwater infiltration and uptake, and nutrient load reduction.[406] Rain stored in tree canopy reduces the intensity of rainfall below the canopy and delays peak stormwater runoff rates, increasing the time it takes runoff to concentrate at the outlet of a catchment or drainage area (e.g., a storm drain or bioretention practice). Depending on rainfall volume and intensity as well as tree species, this delay can be from 10 minutes to over 3 hours.[407] Trees also help increase infiltration of water into the soil. Tree roots can condition disturbed soils and loosen compacted soil, increasing infiltration and percolation of stormwater runoff. Studies have shown that significantly greater volumes of water infiltrated into soil under tree canopy compared to soils not under tree canopy cover.[408]

In addition to stormwater management and water quality, urban trees provide several other economic benefits such as raising property value, recreation opportunities, heat risk reduction, building energy cost savings, habitat enhancements, air quality improvements, and carbon sequestration.[409]

Rain garden

A rain garden, a type of bioretention practice, is a strategically located low area planted with native vegetation that intercepts stormwater runoff.[410] They are used to collect stormwater and filter it through a mixture of soil, sand and/or gravel. The designs of bioretention practices mimic volume reduction and pollutant removal mechanisms that work in natural systems where the filtered stormwater soaks into the ground, provides water to plants and can help recharge the local groundwater supply. Through these processes, bioretention practices reduce peak flows within downstream sewer systems and allow pollutant removal through filtration and plant uptake.[411]

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[405] FEMA, *BCA Reference Guide*.
[406] *Urban Forest Systems and Green Stormwater Infrastructure*, n.d.
[407] *Urban Forest Systems and Green Stormwater Infrastructure*.
[408] *Urban Forest Systems and Green Stormwater Infrastructure*.
[409] FEMA, *FEMA Economic Benefit Values for Green Infrastructure*, July 2022, https://www.fema.gov/sites/default/files/documents/fema_economic-benefit-values-green-infrastructure.pdf. FEMA, *FEMA Economic Benefit Values for Green Infrastructure*.
[410] Blackwell et al., *Jeffrey Odefey Stacey Detwiler Katie Rousseau Amy Trice*. Blackwell et al., *Jeffrey Odefey Stacey Detwiler Katie Rousseau Amy Trice*.
[411] *NPDES: Stormwater Best Management Practice, Bioretention (Rain Gardens)*, n.d.

Rain gardens also provide other economic benefits, including raising property value, recreation opportunities, heat risk reduction, habitat enhancements, drought risk reduction, air quality improvements, and carbon sequestration.[412]

Urban green space

Green urban open space areas are those in which vegetated pervious surfaces account for at least 80% of total cover (impervious surfaces account for less than 20% of total cover), and may include urban parks and recreational sites, neighborhood green spaces, pocket parks, green corridors, and lawns. Green spaces reduce stormwater by capturing precipitation, slowing its runoff, and reducing the volume of water that enters the stormwater system.[413]

Increasing urban green open space also delivers a range of ecosystem service benefits, such as increasing aesthetic value of neighborhoods, improving air quality, climate regulation, erosion control, habitat enhancements, pollination, and recreational opportunities.

Avoided property damage

It was assumed that four nearby single-family, two-story structures (no basement, measuring ~1,800 ft²) and a small commercial structure (small retail store, measuring ~2,650 ft²) would be damaged for higher return periods. Structure and content damages were estimated assuming a building replacement value of $142.43 per ft² for the single-family structure and $143.21 per ft² for the commercial structure[414] and FEMA generic depth damage functions.[415] Assumed pre- and post-mitigation property flood depths at the building level are outlined in Table A3.10.

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[412] FEMA, *FEMA Economic Benefit Values for Green Infrastructure*. FEMA, *FEMA Economic Benefit Values for Green Infrastructure*.

[413] The Trust for Public Land, *The Economic Benefits of the Public Park and Recreation System in the City of Los Angeles, California* (2017), https://www.tpl.org/wp-content/uploads/2017/05/Los-Angeles_fact-sheet_final_lowres.pdf.

[414] *Hazus 6.0 Inventory Technical Manual*.

[415] FEMA

Table A3.10: GSI Prototype - Property Flood Depth Assumptions

Return Period	Status	Flood depth (feet, 2025 conditions)	Flood depth (feet, 2050 conditions)
2-year	Pre-mitigation	0	0
	Post-mitigation	0	0
5-year	Pre-mitigation	0	1
	Post-mitigation	0	0
10-year	Pre-mitigation	1	1
	Post-mitigation	0	0
25-year	Pre-mitigation	1	2
	Post-mitigation	0	0
50-year	Pre-mitigation	2	2
	Post-mitigation	0	1
100-year	Pre-mitigation	2	2
	Post-mitigation	1	1
200-year	Pre-mitigation	2	3
	Post-mitigation	2	1
500-year	Pre-mitigation	3	3
	Post-mitigation	3	2

Benefit-Cost Analysis

Resilience benefits from the prototype hybrid GSI project are captured using FEMA methodology for each GSI component and property damage. Capital costs are estimated as a one-time upfront cost in year one, with O&M costs recurring over the project lifetime. All benefits and costs are discounted to present value (2024 $). A summary of the BCA results, accounting for the total estimated present value of project costs and project benefits, as well as the resulting BCRs, is presented in Table A3.11. The BCR is calculated by dividing the present value benefits by the present value costs.

Table A3.11: BCA Results for GSI Prototype Project (Discounted at 3.1%)

Input	Value
Capital costs	$719,000
Operating cost	$76,000
Upfront capital and project lifetime maintenance costs (discounted)	**$795,000**
Urban tree benefits	$390,000
Rain garden benefits	$89,000
Open space benefits	$89,000
Avoided property damage	$1,000,000
Benefits over project lifetime (discounted)	**$1,600,000**
BCR	**2.0**

Note benefits and costs are highly variable and unique to each project. BCRs shown here do not represent all projects of this type.

Wastewater Treatment Plant Prototype Project Resilience Value Benefit-Cost Analysis

As sea level rise progresses, disruptive flooding will impact many critical buildings and facilities situated along coastlines.[416] Resilience against rising sea levels, extreme storms, and ocean tide events are a key concern for the WWTP due to their proximity to the ocean.[417] Many WWTPs are built by design to be gravity-fed so are located at the lowest point next to a body of water.[418]

Facilities are prone to failure from structural, electrical, and process disruptions from high water level events, impacting residents and businesses served by the WWTP. Flooding and resulting facility failure can result in water and environmental contamination if solids escape containment, and can expose communities to harmful pollutants.[419] As storms become more frequent and intense and as sea levels rise, flooding will be an ongoing challenge for wastewater utilities.[420]

A prototype WWTP resilience project in Massachusetts was developed to demonstrate the resilience value of protecting critical infrastructure, a vegetated earthen berm built around the perimeter of a small coastal WWTP. A berm can provide protection from ocean flood events and wave action and can provide protection to the biological treatment processes at a WWTP.

Avoided costs from reduced flooding (including avoided costs from physical damages to the plant, costs to residents and businesses) and co-benefits from avoided environmental damages were estimated. Table A3.12 displays the assumptions for each prototype.

Table A3.12: WWTP Prototype Specifications

Variable	Assumptions
Location	Suburban area in Massachusetts
Service population	~16,500 people
WTTP size	Current average flow: 1.5 million gallons per day (MGD) Expected future average flow: 2.5 MGD
Mitigation action	Vegetated earthen berm around perimeter of WTTP, ~0.3 miles
Modeled climate conditions	2025 (current) 2050 (RCP 4.5)
Modeled benefits	Avoided physical damages to WWTP Avoided impacts to residents Avoided business/economic impact Avoided environmental damages
Estimated engineering, permitting, design, and capital costs (2024 $)	$5,000,000
Estimated annual O&M (2024 $)	$166,000
Assumed project useful life	50 years

Notes: The service population represents the total number of individuals whose wastewater is collected and treated by a particular WWTP. The average service population of a WWTP varies significantly, as individual plants can serve anywhere from a few hundred to millions of people. A rough estimate can be derived from data on the national number of plants (~16,000) and the population served (249M people) by centralized plants,

416 Union of Concerned Scientists et al., *Looming Deadlines for Coastal Resilience: Rising Seas, Disruptive Tides, and Risks to Coastal Infrastructure* (Union of Concerned Scientists, 2024), https://doi.org/10.47923/2024.15502.

417 *Facility and Resilience Plan Update* (Hull, Massachusetts Sewer Department, n.d.).

418 Julia Nielsen, "Tips for Flood-Proofing Wastewater Treatment Plants - ATS Innova Water," *ATS Innova: Water Treatment | Wastewater Treatment | Clean Water Chemistry*, October 17, 2018, https://atsinnovawatertreatment.com/blog/flood-proof-wastewater-treatment-plant/.

419 Union of Concerned Scientists et al., *Looming Deadlines for Coastal Resilience*.

420 David Goldbloom-Helzner et al., "Flood Resilience: A Basic Guide for Water and Wastewater Utilities," *Proceedings of the Water Environment Federation* 2015, no. 8 (2015): 2029–32, https://doi.org/10.2175/193864715819555715.

equaling 15,500 people per plant. A slightly higher number was used for this prototype, based on review of service populations in Massachusetts.

Avoided Physical Damages

To determine direct physical damage costs for the WWTP, rainfall condition modeling from the FEMA FIS Profiles was used alongside reference data from plants in Massachusetts. FEMA's Hazus Flood Model Technical Manual was used to estimate direct physical damages. The Hazus Flood Model provides a depth damage function for a typical WWTP and assumes a maximum level of damage is reached at 10 feet of flooding.[421] The methodology provides distinction between WWTPs of different sizes (i.e., small, medium, and large) and an associated repair and replacement cost for each size of WWTP.[422] The prototype project size is assumed to be small (capacity less than 50 MGD).

It was assumed that, under current conditions (2025), flooding would occur starting with the 100-year storm pre-mitigation, and under 2050 conditions, would occur earlier at the 50-year storm, with damages steadily increasing for larger return periods. With the project (i.e., post-mitigation), it was assumed that the berm would provide significant protection against the 200-year storm under existing conditions but not under 2050 conditions. Physical damages modelling assumptions and flood depths are outlined in Table A3.13 and Table A3.14.

Table A3.13: Avoided Physical Damages Modelling Assumptions

Item	Metric	Source
Depth damage function	% damage equals depth of water at facility minus equipment height (height = 0ft)	FEMA[423]
Replacement value	$174,921,238	FEMA,[424] replacement value of small WWTP, inflated to 2024 $.

Table A3.14: WWTP Prototype Flood Depth Assumptions

Return Period	Status	Flood Depth (feet, 2025 Conditions)	Flood Depth (feet, 2050 Conditions)
2-year	Pre-mitigation	0	0
	Post-mitigation	0	0
5-year	Pre-mitigation	0	0
	Post-mitigation	0	0
10-year	Pre-mitigation	0	0
	Post-mitigation	0	0
25-year	Pre-mitigation	0	0
	Post-mitigation	0	0
50-year	Pre-mitigation	0	1
	Post-mitigation	0	0

[421] *Hazus 6.1 Flood Model Technical Manual*.
[422] *Hazus 6.0 Inventory Technical Manual*.
[423] *Hazus 6.1 Flood Model Technical Manual*.
[424] *Hazus 6.0 Inventory Technical Manual*.

Return Period	Status	Flood Depth (feet, 2025 Conditions)	Flood Depth (feet, 2050 Conditions)
100-year	Pre-mitigation	1	2
	Post-mitigation	0	0
200-year	Pre-mitigation	2	4
	Post-mitigation	0	0
500-year	Pre-mitigation	3	5
	Post-mitigation	1	1

Avoided Impacts to Residents from Lost Service

Methodology in Natural Hazard Mitigation Saves 2019 Report was utilized to estimate impacts to residents when the prototype WWTP fails due to flooding.[425] When the WWTP is not functioning, it is assumed that residents cannot use toilets and showers in their homes and must relocate temporarily. They may stay in hotels, at a cost assumed to be the US General Services Administration (GSA) per diem for lodging plus the per-diem rate for meals and incidental expenses per person.[426] Natural Hazard Mitigation Saves 2019 Report notes that residents may stay with friends or family or in a shelter at little or no cost; however, the lost value is quantifiable as residents would rather be at home, and the measure of that preference is taken as the GSA per-diem rates.[427]

Natural Hazard Mitigation Saves 2019 Report assumes that restoring the function of a WWTP requires one day per foot of flooding for floodwater to recede plus one week to disassemble, clean, and dry motors, pumps, and other rotating equipment, and time to clean and dry electrical equipment. Impacts to residents modelling assumptions are presented in Table A3.15.

Table A3.15: Avoided Impacts to Residents Model Assumptions

Item	Metric	Source
GSA per-diem rates	Accommodation: $126 per person per day Meals and incidentals: $80 per person per day	US General Services Administration[428]
Service population	16,500 people	Project team assumption for prototype project

Avoided Impacts to Economic Activity

Similar to households, businesses cannot operate without functioning bathrooms. If a WWTP is inoperative, all businesses are similarly affected. The analysis assumes that without water, impacts to businesses can be measured by the per-capita daily gross domestic product (GDP). FEMA provides methodology for estimating the value of the loss of wastewater service resulting from the closure of, or damage to, a WWTP. The value of the loss of wastewater service is measured by the impact to the economic activity of the county and utilizes GDP and population statistics alongside FEMA's "wastewater

[425] *Natural Hazard Mitigation Saves 2019 Report*, 2019.
[426] "FY 2024 per Diem Rates for Hull, Massachusetts," accessed June 16, 2025, https://www.gsa.gov/travel/plan-book/per-diem-rates/per-diem-rates-results?action=perdiems_report&city=Hull&fiscal_year=2024&state=MA&zip=.
[427] *Natural Hazard Mitigation Saves 2019 Report*.
[428] "FY 2024 per Diem Rates for Hull, Massachusetts."

treatment importance factors", which are applied to the output of each industry.[429] Impacts to the economy model assumptions are outlined in Table A3.16.

Table A3.16: Avoided Impacts to Economy Model Assumptions

Item	Metric	Source
Annual GDP of prototype county	$36M	Bureau of Economic Analysis, GDP by county and metropolitan area (thousands of current 2024 $)[430]
Population of prototype county	530,000 people	Project team assumption for prototype project
Service population	16,500 people	Project team assumption for prototype project
Economic impact per capita per day of lost service (2024)	$56.07	Calculation

Avoided Environmental Damages

Flooding of WWTPs can result in significant environmental damage. While many WWTPs have dry floodproofing systems, these are not designed to prevent flooding above a certain point after which the building structure could fail due to overwhelming hydrostatic forces. When water exceeds a certain depth against the WWTP building, it can flow over or breach protective barriers and flood the building, equalizing the pressure inside and out. This can interfere with discharges and untreated effluent, causing damages to the surrounding environment and contamination of nearby waterbodies. Barrier protection, such as a berm, can prevent flooding at the WWTP and avoid environmental damages.

Environmental damages from a WWTP spill are difficult to quantify, as they are highly specific to the volume of effluent released, surrounding ecosystems, impacted population, and effectiveness of remediation efforts, amongst other things. To quantify the avoided environmental damages, the value of a penalty paid by a similar sized (2.5 MGD) WWTP in Massachusetts for a 10M-gallon spill in 2018 was applied. The penalty for this spill was $2.2M (in 2024 $).[431] It is assumed that a spill occurs at flood depths greater than 3 feet, and the berm project would protect the WWTP from spills up to and including the 200-year flood. This is a conservative approach, and it is likely that environmental damages are much higher.

Benefit-Cost Analysis

To calculate benefits over the project lifetime, expected annual damage pre- and post-mitigation accounting for the storm recurrence intervals (i.e., return periods) was estimated. The most benefits represent the impacts to residents, or the difference between the pre- and post-mitigation impacts over the project lifetime.

Capital costs are estimated as a one-time upfront cost in the first year, with O&M costs recurring over the project lifetime. All benefits and costs are discounted to present value (2024 $). A summary of the BCA results, accounting for the total estimated present value of project costs and project benefits, as well as the resulting BCRs, is presented in Table A3.17. The BCR is calculated by dividing the present value benefits by the present value costs.

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[429] *Benefit-Cost Analysis Sustainment and Enhancements Standard Economic Value Methodology Report V.13* (FEMA, 2024), https://www.fema.gov/sites/default/files/documents/fema-standard-economic-values-methodology-report-v13-2024.pdf.pdf.

[430] "Gross Domestic Product | U.S. Bureau of Economic Analysis (BEA)," accessed June 16, 2025, https://www.bea.gov/data/gdp/gross-domestic-product.

[431] "Veolia to Pay $1.6 Million for Massive Sewage Spills, Discharges Causing Shellfish Bed Closures in Plymouth Harbor | Mass.Gov," accessed June 16, 2025, https://www.mass.gov/news/veolia-to-pay-16-million-for-massive-sewage-spills-discharges-causing-shellfish-bed-closures-in-plymouth-harbor.

Table A3.17: BCA Results for WWTP Project (Discounted at 3.1%)

Input	Value
Capital costs	$4,850,000
Operating cost	$4,065,000
Upfront capital and project lifetime maintenance costs (discounted)	**$8,915,000**
Avoided physical damages	$6,149,000
Avoided impacts to residents	$12,459,000
Avoided Impacts to economy	$3,391,000
Avoided environmental damages	$298,000
Benefits over project lifetime (discounted)	**$22,298,000**
BCR	**2.5**

Note benefits and costs are highly variable and unique to each project. BCRs shown here do not represent all projects of this type.