Regional Climate Resilience for the MBTA Commuter Rail: A Case Study of the Newburyport-Rockport Line

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Abstract

Climate change and sea level rise threaten urban coastal communities and the infrastructure on which they rely. In response, this thesis investigates the projected impacts of coastal flooding on the Massachusetts Bay Transportation Authority commuter rail. Using the MC-FRM statewide dynamic flood model, sensitive components of the commuter rail network are tabulated by location and exposure to a 100-year flood return period. Results reveal that the Commuter Rail Maintenance Facility is the most vulnerable railroad facility location, while the Newburyport-Rockport line is most vulnerable across passenger right-of-way routes. Taking Newburyport-Rockport as a case study of wider adaptation mechanisms, this study undertakes interviews with key informants to consider the potential benefits of transportation network adaptation in collaboration with municipal resilience actions. This work highlights the need for proactive strategies to enhance the resilience of the commuter rail system, taking advantage of ongoing rail network modernization initiatives and state support for regional climate coordination.

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Glossary

Annual Exceedance Probability: The likelihood on any given year of a storm occurring of a certain magnitude. A storm with a 1% Annual Exceedance Probability may also be referred to as a 1-in-100-year storm. Closely linked with *Return Period,* the average time between flood events of a given magnitude.

Capital Investment Plan: The MBTA's rolling 5-year plan detailing its investment strategy for current assets.

Catenary Line: Overhead utility wire that provides electricity to electric powered trains.

Dispatching: Dispatching directs the movement of trains safely and efficiently by monitoring conditions, tracking train locations and communicating with train engineers. MBTA Commuter Rail has two current dispatch offices: Cobble Hill and South Station, with a backup facility preparing to open at Iron Horse Park in Billerica.

Engineer: Railroad engineers drive trains—not to be confused with those who design railroad infrastructure.

Environmental Justice: Environmental justice strives to ensure a clean and healthful environment for everyone regardless of race, color, national origin, income, or English language proficiency. In Massachusetts, 'Environmental Justice populations' experience a disproportionate burden of environmental pollution, or other environmental risks and are defined by income, minority population, or English language proficiency.

Grade Crossing: Locations where railroad pass over roads at the same elevation. Grade crossings require extensive safety precautions to prevent collisions between cars, pedestrians and trains.

Gray Infrastructure: Structures built with traditional "hard" materials and techniques, such as sea walls, roads, and pump stations.

Junction: An intersection containing signal and switch infrastructure where multiple railroad lines cross.

Maintenance of Way Facility: A workshop used to inspect, repair, or store railroad equipment.

Massachusetts Coastal Flood Risk Model: The dynamic probabilistic model used by Massachusetts state agencies to predict coastal flood risk through 2070 according to the International Panel on Climate Change Representative Concentration Pathway 8.5 emissions scenario.

Nature-Based Solutions: Natural features adopted for the purposes of mitigating flooding as well as other benefits, such as recreational space.

Platform: A station designated for train passenger boarding.

Positive Train Control: Computer-based systems of train control that enforce speed restrictions, prevent train collisions, and ensure protections for roadway workers.

Representative Concentration Pathway: A greenhouse gas emissions projection trajectory accepted for use by the IPCC.

Return Period: The average interval between floods of a certain size. Closely linked with *Annual Exceedance Probability*, the likelihood on any given year of a storm occurring of a certain magnitude.

Right of Way: The strip of property owned by the railroad encompassing its tracks and associated assets.

Rolling Stock: Railway vehicles, including powered trains such as locomotives, passenger cars, and non-revenue vehicles such as freight or track repair cars.

Siding: A short, typically low-speed segment of track connected by switches to a main track.

Signal: A display device used to signal instructions to trains, such as to slow or stop. Signals are associated with digital communications equipment to convey information.

Signal Frog: A specialized piece of track that forms part of a railroad switch. Used to help trains roll from one track to another.

Signal Interlocking: An arrangement of signals designed to prevent trains safely through a track intersection, or junction.

Single/Doubled Track: On single-tracked railways, trains traveling in both directions share the same track. Double-tracked railways, each direction of travel has a designated track. Doubled track effectively doubles the length of track contained in the same stretch of right-of-way property.

Switch: Mechanical infrastructure used to transfer trains from one track to another.

Yard: An arrangement of track sidings within which train movements can be made without schedule, train order, or other authority. Used for performing tasks such as assembling, storing, and refueling trains. MOWs and yards are terms that can frequently be treated interchangeably.

Abbreviations

AEP: Annual Exceedance Probability

CIP: Capital Investment Plan

CRMF: Commuter Rail Maintenance Facility

EJ: Environmental Justice

MassCZM: Massachusetts Office of Coastal Zone Management

MassEEA: Massachusetts Office of Energy and Environmental Affairs

MassGIS: Massachusetts Office of Geographic Information Systems

Massport: Massachusetts Port Authority

MC-FRM: Massachusetts Coastal Flood Risk Model

MVP: Municipal Vulnerability Preparedness

PTC: Positive Train Control

ROW: Right-of-Way

SBM: Shore-Based Measures

SHMCAP: State Hazard Mitigation and Climate Adaptation Plan

Chapter One: Introduction

Background

In 2022, the state of Massachusetts issued a Climate Change Assessment reporting that its biggest climate risks include increased heat, precipitation changes, and sea level rise combined with stronger coastal storms. Together, these hazards stress Massachusetts's infrastructure along with its economy, natural environment, and the health of its residents. Within the infrastructure sector, transit systems provide an economic lifeline for essential workers and play a critical function in evacuation and emergency response. Given these issues, the state rates transit damage and service loss among its most urgent climate change adaptation priorities (Massachusetts Office of Energy and Environmental Affairs, 2022).

Transit has deeply shaped urban development in Massachusetts, where Boston's oldest suburbs were built upon railroad and streetcar networks first laid out in the 19th century (Boston Region Metropolitan Planning & Organization, 2019). Long before the Massachusetts Bay Transportation Authority (MBTA) was formally incorporated, cities like Worcester and Providence benefited from greater access to Boston, New England's commercial, cultural, financial, and educational capital (Karr, 1995). Today, the T, as the MBTA is colloquially known, is by far the largest transit provider in the state, offering subway, bus, ferry, paratransit and commuter rail service across eastern Massachusetts and into Rhode Island (Massachusetts Department of Transportation, n.d.) The T also ranks among Massachusetts's largest landowners,

wielding tremendous influence over the nearly 200 cities and towns through which it runs (Massachusetts Bay Transportation Authority, 2023a).

Even as these development patterns have helped support Boston's urban growth, they have also increased the region's current risk of coastal flooding. 19th century industrialists and agriculturalists dammed rivers, drained wetlands, and dumped fill to reclaim land and put water to industrial uses (Seasholes, 2003). These actions have dramatically changed the hydrology of greater Boston, where many railroads were first laid in coastal wetlands nearly 200 years ago (Massachusetts Wildlife Climate Action Team, 2017). While New England is less susceptible to hurricanes than other parts of the Eastern Seaboard, average temperatures and sea level rise are increasing faster than the national average, and well over half of Massachusetts's population lives in coastal communities (Young and Young, 2021; MassCZM, 2021). These factors, along with the increasing frequency and magnitude of coastal storms, mean that coastal flooding is considered the most damaging climate hazard facing transportation infrastructure in the large cities of the urban northeastern United States (Martello et al., 2023). Given its outsize influence and potential risks, the MBTA must work with surrounding landowners and relevant policymakers to address these potential impacts.

Federal transit regulators are primarily oriented towards safety, which means they do not issue climate resilience standards to which state transit authorities must comply. In fact, railroad operations rarely use geospatial data to map elevation or other location-specific railroad information at all, relying instead on decades-old analog track

charts (see Appendix 3). Even so, the MBTA's climate resilience program—established following the disruptions of extreme winter weather in 2015—has to date documented the vulnerability of various elements of the bus and rapid transit (subway and streetcar) system, analyzed adaptation pathways for highly vulnerable locations, and implemented targeted climate resilience projects (Massachusetts Bay Transportation Authority, 2022). The climate vulnerability of the commuter rail differs from that of rapid transit in its infrastructure interdependencies, exposure to flood waters, geographic extent, and operations. For instance, communications with MBTA Railroad Operations staff indicate that the Federal Railroad Administration's stringent maintenance requirements have allowed the commuter railroad to avoid the shutdowns and speed restrictions afflicting the aging subway service, which is regulated separately by the FTA. At the same time, the commuter rail is significantly more vast than the rapid transit network, traveling many dozens of miles through former streambeds and at low elevations in close proximity to the coastline (Martello & Whittle, 2022). With its immense footprint, its tendency to establish low elevation flood paths, and its relative distance from local oversight, the commuter rail is understood to be a potentially ruinous climate hazard by many cities and towns in Eastern Massachusetts (Vicarelli et al., 2021).

Overview of Commuter Rail

The commuter rail serves over 100 towns across 394 route miles and twelve lines (Massachusetts Bay Transportation Authority, 2015). Four of these twelve lines

are split into further branches. Two additional lines include the CapeFLYER, which runs seasonal weekend service, and the South Coast Rail, expected to open in 2024. The railroad is composed of mostly separate North and South sides originating in Boston's North and South Station respectively, with each side overseen by an assigned dispatching office responsible for scheduling the movement of trains. The MBTA does not directly oversee commuter rail operations, which are managed by private French transportation company Keolis under the current contract. The railroad carries 14% of the MBTA's total passengers—roughly 500,000 weekly—making it the fifth-busiest rail transit system in the United States (Keolis Commuter Services, 2021; Massachusetts Bay Transportation Authority, 2024). Figure 1-1 displays an overview of the commuter rail passenger network.



Figure 1-1: Spatial Overview of the MBTA Commuter Rail System.

One way to understand the character of communities served by the commuter rail is using a framework put forth by the Boston Region Metropolitan Planning Organization, which uses transportation patterns to divide greater Boston's constituent municipalities into suburban "radial corridors," plus a "central area" where transit services meet (Boston Region Metropolitan Planning & Organization, 2019). As its name and radial orientation would suggest, the commuter rail has historically been envisioned as a means to connect suburban residents with employment opportunities

in Boston's urban core. More recently, the commuter rail is increasingly being touted as a means to access recreational opportunities like professional sports games or ski hills, or as a way to fill gaps in urban areas underserved by the rapid transit system (Massachusetts Bay Transportation Authority, n.d.; DeCosta-Klipa, 2019).

Among the broader system that is the commuter rail, the Newburyport-Rockport line commands special attention for the purposes of planning for climate change. This route ranks among the highest ridership routes in the network, serving a dense concentration of language-isolated, low-income Environmental Justice communities in Chelsea, Everett, Saugus, Lynn, and Salem (MassGIS, 2020; MBTA, 2024). Climate resilience grant documentation indicates that these municipalities are already dedicating significant municipal resources towards combating coastal flooding, which is encroaching upon their urbanized coastlines (Runsten et al., 2024). Beyond Salem, the commuter rail branches into two sub-lines. One proceeds east through the Cape Ann peninsula, terminating in Rockport, while the other travels north through Massachusetts's largest wetland, terminating on the border of Newbury and Newburyport. As this thesis will explore, this line considered together is considerably more exposed to coastal flooding than the other major lines of the commuter rail, presenting a rich case study to explore possibilities to embed climate resilience measures.

Thesis Outline

In response to the challenges laid out above, this thesis addresses the following research questions:

Primary Research Question: How do adaptation strategies among the municipalities bordering the Newburyport/Rockport line of the MBTA commuter rail affect the railroad's exposure to coastal flooding?

Secondary Research Questions:

- Where is the commuter rail most vulnerable to coastal flooding, according to asset data, usage demographics and climate change models?
- How are coastal flood resilience measures coordinated between municipalities and the MBTA in the service area of the Newburyport-Rockport line?
- What are the range of barriers and opportunities to enhance continuous coastal flood resilience along the MBTA commuter rail system?

This thesis begins by reviewing the literature on climate change vulnerability and resilience while orienting the reader to coastal climate change science and Massachusetts policy. Comparing treatments of resilience in engineered and social systems, a formulation of hazard exposure and sensitivity is presented as a straightforward way of screening vulnerability for further exploration. A Vulnerability Screening then discusses how railroad infrastructural subsystems inform overall system performance and compares their exposure to coastal flooding under present-day and 2070 (+4.3 feet above baseline) sea level rise regimes. These results model the

ways that coastal floods impact the rail network in acting upon various subsystems and affirm the vulnerability of the Newburyport-Rockport line relative to other routes.

Chapter Five combines key informant interviews with a review of state resilience grant documentation and regional planning inventories to assess the cumulative effects of resilience measures being undertaken by municipalities within the Newburyport-Rockport service area. Making special note of how resilience measures are coordinated across political boundaries, I propose recommendations that include steps that the MBTA can take to maintain the integrity of its own transit system, as well as governance changes to better direct climate adaptation efforts on a regional level.

Personal Goals

I have spent the past ten months as a part-time employee within the T's Environmental Department, where I first encountered the gap in research on plans for how best to reconfigure the commuter rail in response to climate change. My position as an employee granted me access to data and personnel, while my role as a graduate student afforded me independence that might not otherwise be offered to full-time MBTA staff. As a participant-observer, I attended meetings where key stakeholders were convened, taking notes for the purposes of this thesis while contributing to the dialogue around commuter rail planning. It is my hope that my master's thesis work will serve as the basis for all forthcoming commuter rail coastal adaptation schemes, including the provisioning of a consultant team to conduct a formal engineering assessment.

Outside the goal of delivering useful insights to the team with which I work, this thesis emerged out of a certain style of understanding environmental change as acting within and across fluid, dynamic social-ecological landscapes. While climate change is a global phenomenon, it is perhaps most immediately graspable in the ways it acts upon the structures with which people routinely interact. Knowing that the effects of climate change do not follow organizational boundaries, I hope to place the changes taking place across the railroad system within its surrounding terrain of different land uses and political priorities. By highlighting the ways in which the commuter rail interfaces with the areas through which it passes, I hope this work can be used to evaluate the effectiveness of existing climate resilience efforts in Massachusetts and to highlight suggestions for potential improvement.

Chapter Two: Literature Review

By virtually any damage or performance-based metric, the worst disaster to afflict transit systems in the history of the United States was 2012's Superstorm Sandy. The storm struck New York City's metropolitan area directly, shutting down service for nearly half the nation's transit riders, inflicting $3.3 billion of direct transit damage, and requiring over 200 days to restore (United States Department of Housing and Urban Development, 2013). Witnessing the results of these and other dramatic events as well as the continuing creep of ongoing extreme weather issues, policymakers in New York City as elsewhere are increasingly recognizing the need to cultivate resilience in transportation systems.

There is a wide-ranging body of scholarship on resilience, drawing from the study of engineered systems, natural hazards, ecology, and urban/community practice to predict complex system performance under changing conditions. This review summarizes existing literature on resilience, tailoring the discussion to coastal flooding, urban transportation infrastructure, and governance.

Resilience Theory

The International Panel on Climate Change (IPCC) describes a resilient system as one that can cope with hazardous disturbance by responding in such a way as to maintain the system's essential purpose, identity, and structure. This formulation positions resilience as the inverse of vulnerability, itself defined as the product of exposure, sensitivity, and adaptive capacity—measures of a system's contents, as well

as their fragility and ability to recover following disruption. At the same time, the IPCC's definition reserves space for the system to learn and grow as it confronts the uncertainties of risk—an important inclusion so as not to equate resilience with stasis (Edenhofer et al., 2014). One foundational challenge in developing resilience in hard engineered systems like transportation infrastructure, then, is how best to provide for existing needs while preparing to rapidly evolve. The IPCC's essential definition of vulnerability, since adapted by the Federal Highway Administration and MBTA, is introduced for reference in Figure 2-1.

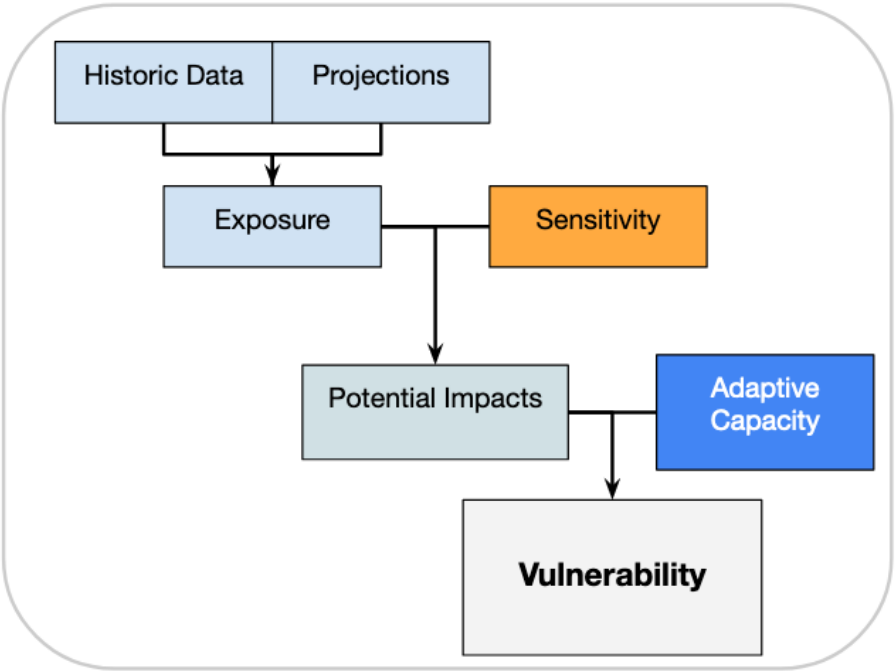


Figure 2-1: Vulnerability Formula adapted from IPCC, MBTA, and FHWA.

Other resilience thinkers add to this basic definition by expanding their inquiry from a system in question—e.g. a city, power plant or electric grid—to also consider trends across the structures surrounding them. Interruptions to transit service due to a flood, for example, will be closely linked to the flood's effects on the wider urban area,

including business closures, highway or airport shutdowns, loss of communications infrastructure, and electrical grid performance (Tyler & Moensch, 2012). Similarly, resilience measures differentially benefit different areas and groups of people depending on their purpose and implementation. Meerow and Newell recognize these complexities in their 5W (Who, What, When, Where and Why?) framework, which questions how resilience is deployed, and for what ends (Meerow & Newell, 2016)

Other collaborations between planners and ecologists reveal the ways that cycles of emergence, stability, collapse and regrowth characterize both social and ecological processes over time (Holling et al., 2003). By prioritizing principles such as flexibility and agility, large organizations like the MBTA can improve their resilience to unexpected shocks even before they undertake more direct risk reduction measures (Markolf et al., 2019). This movement towards dynamism ultimately stands in tension with traditions of engineered resilience that prioritize predictable efficiency by "barricading" existing systems against potential threats.

Bennett et al. take up this question in their 2015 article, "Communities and Change in the Anthropocene," which explores the interplay of sociopolitical and environmental change at multiple scales. While climate change is often described in global terms, Bennett et al. emphasize the ways in which climate change manifests according to the practices and value systems of local communities. By adopting a community-driven approach to building resilience, it becomes possible to identify interventions that do not merely cope with the hazard of climate change but orient towards cohesive reorganization and renewal. Applying these considerations to the

MBTA, the question of climate change adaptation expands beyond simply how to stem the flow of flood waters towards how to meet broader pressures afflicting New England such as loss of public trust in the MBTA, gentrification, urbanization, macroeconomic conditions, and loss of ecosystem services.

Scholars of natural hazards have sought ways to quantify resilience within social and engineered systems. One strategy is Bruneau et al.'s 4R framework, which proposes resilience as consisting of robustness, redundancy, resourcefulness, and rapidity. Robustness refers to a system's ability to withstand stress without losing function, as in the case of waterproofed railroad assets; redundancy, the degree to which system elements are substitutable, as in the case of maintaining backup generators should existing power supplies falter; resourcefulness, the capacity to marshal resources once a problem has been identified, as in the case of effective emergency plans; and rapidity, the ability to respond to hazards in a timely manner. The 4Rs can be further broken down into technical, organizational, social and economic categories in order to elucidate the relationship between exposure, sensitivity, adaptive capacity, vulnerability and resilience within the transit system, even before other dependencies are considered.

Viewing these authors together, it is clear that resilience emerges from the behavior of a system, rather than rooted as a feature of the system *per se*. Against the notion of vulnerability as a problem to be resolved instead of a fluctuating set of circumstances to be managed, resilience scholars insist that even hard infrastructure systems can nurture resilience by welcoming new forms of design thinking in which

creative departure from proven strategies is welcomed (Kim et al., 2013). With this in mind, I employ the 'Exposure-Sensitivity-Adaptive Capacity' vulnerability framework proposed by the IPCC (Figure 2-1) and eventually adopted by the Federal Highway Administration and MBTA throughout the rest of this thesis not to compute final risk scores at different locations, but to elicit further interrogation of how localized failures reverberate occur across the commuter rail network. Knowing that no response will be final, I take up the question of how best to meet these challenges in the recommendations section.

Coastal Flood Processes

Coastal flooding is the byproduct of numerous interacting geophysical processes, each of which are important to account for in preparing plans to foster resilience in infrastructure. When the ocean contacts a land mass, it sends waves inland according to underwater topography, prevailing winds, tides, and currents. On top of this baseline variation in tide level, the ocean propagates water inland in the form of wave runup, where water surges up and breaks along the shore (NOAA 2, n.d.). Storm surges compound these issues, sending huge volumes of water towards the shore via cyclonic winds (NOAA, n.d.-b). Climate change compounds these issues, first, by raising the baseline water levels via sea level rise, and second, by increasing coastal storm intensity. Coupling these processes together in coastal flood models allows communities to recognize which areas of a coastline are prone to more

predictable, ongoing flood events vs. those that only occasionally face catastrophic storm surges.

Coastal processes interact with the built environment in ways that affect communities' adaptive capacity even as their exposure to flooding changes. When storms and extreme high tides repeatedly batter a coastal location, they disturb dune and wetland ecosystems that would otherwise dampen the effects of waves upon the shoreline. Storms also bring intense precipitation to coastal regions, which contributes to erosion and increases riverine outflows. A long history of development in Massachusetts's coastal zone has increased runoff rates, worsening flooding by preventing wetlands from absorbing excess water (MassDEP, 2024). Erosion and groundwater extraction together also cause land subsidence, which lowers the shoreline's position relative to sea levels; Boston is estimated to be subsiding at a rate of approximately 3 centimeters every decade (Kirshen et al., 2008). As rising sea levels send high tides higher, they wear away at infrastructural answers to coastal flooding like sea walls and pump stations, reducing their effectiveness when storms or King Tides send large volumes of ocean water inland (National Oceanic and Atmospheric Administration, 2023).

Given the degree of flooding associated with storms like Hurricanes Irene and Sandy, coastal communities must find ways to preserve access to the waterfront and maintain safety while minimizing exposure to flooding. Some community-wide coastal strategies to reduce the risk of floods include nourishing dunes, establishing living shorelines, and constructing flood gates, berms, or seawalls (NOAA Digital Coast, n.d.).

In addition to or instead of these structural flood barriers, coastal communities may also reduce their vulnerability by elevating, relocating or floodproofing sensitive assets (Aerts et al., 2013). Altogether, one coastal adaptation matrix lists 44 separate strategies to reduce coastal flood exposure, from land use regulation to shoreline restoration and hurricane barriers (McElroy, 2023). With assets arrayed across huge lengths of exposed shoreline, the MBTA relies on surrounding municipal and private landowners to provide layers of flood resilience on top of what the railroad can carry out trackside.

Resilience Governance in Massachusetts

In Massachusetts, climate resilience goals and progress are articulated by the Massachusetts Office of Energy and Environmental Affairs (EEA) and the Massachusetts Emergency Management Agency in the State Hazard Mitigation and Climate Adaptation Plan, known as the SHMCAP (Massachusetts Office of Energy and Environmental Affairs, 2023). The SHMCAP serves as the central document for all climate resilience planning undertaken at a state level in Massachusetts. Since 2017, the EEA distributes resilience grants to via the Municipal Vulnerability Preparedness (MVP) and Coastal Zone Management Resilience grants (Massachusetts Office of Energy and Environmental Affairs, 2024).

With these funds serving as the backbone of Massachusetts resilience planning, comprehensive climate adaptation plans are largely developed on a town-by-town basis. Massachusetts cities and towns do, however, occasionally collaborate on

exercises to establish shared interests and uncover shared vulnerabilities. For example, the Resilient Mystic Collaborative brought together representatives of 21 municipalities along with MassDOT, MassPort and the MBTA to simulate a storm of a magnitude similar to Hurricane Sandy striking the Boston Harbor, finding that power outages would hamper evacuation and emergency service provision in the event of a superstorm (Massachusetts Office of Energy and Environmental Affairs, 2024). Studies of Massachusetts's coastal adaptation strategy have compared the relative benefits of small-scale green infrastructure projects to those of megaprojects like a storm surge harbor barrier, finding that relatively flexible small-scale projects tend to perform best in terms of ecological impacts, cost to benefit ratio and recreational usage (Kirshen et al., 2020). These findings bolster the continued support for locally-driven adaptation governance across the Commonwealth.

Simultaneously, several academic reports have identified shortcomings in this bottom-up approach. A 2018 report published by the University of Massachusetts-Boston noted that resilience regulatory powers in the Commonwealth are split between local zoning ordinances, building codes, and environmental laws, while watershed associations and planning commissions hold knowledge and guide the climate resilience agenda (Kruel et al., 2018). A 2021 survey of Massachusetts municipalities affirmed the downsides of this piecemeal approach to flood resilience planning, with municipalities limited in their staff capacity, political will, and funding to confront transboundary problems such as coastal flooding. As one municipality reported, "We never have time to put heads together and come up with better ways to accomplish

these tasks. Instead, town by town, our small crews go out with insufficient equipment doing it over and over, rather than solve it once for many years" (Vicarelli et al., 2021). In some cases, environmental laws and permitting procedures functionally prevent resilience planning from occurring at all as efforts to establish flood barriers or reclaim coastal land from the ocean would impede waterfront access, harbor navigation, or wetland buffer zones protected by law. Another well-intentioned but poorly targeted law is a recent update to the Lands Subject to Coastal Flowage rule, which aims to raise the cost of rebuilding in FEMA flood plains (Haney, 2023). For owners of large linear properties like the MBTA, these requirements could make it prohibitively expensive to restore service after it was lost due to damage in the coastal zone. Besides these governance issues across different state actors, private landowners control large expanses of coastline, challenging local government's ability to perform comprehensive flood planning (Fitzgerald & Walsh, 2022).

With these issues becoming increasingly urgent, calls for a more centralized regional flood authority have begun to circulate among resilience planners and academics rooted in greater Boston. In a 2022 report for the Boston Foundation, researchers from Northeastern University identified improved governance as one of four "big lifts" needed to respond to barriers to systematic climate action, which include conflicting interests, jurisdictional limits, policy contradictions, and funding gaps (Fitzgerald & Walsh, 2022). The report goes on to review several new governance models. One approach would be for the state legislature to establish a new coastal flood authority similar in scope to the Massachusetts Water Resources Authority

created in the 1980s to clean up Boston Harbor and modernize water provision in the Boston area (Fitzgerald et al., 2023). Another approach would be to construct flexible resilience districts emulating those introduced in Maryland, which hold all powers of municipalities save taxation and eminent domain (Maryland Senate Bill 457: Resilience Authorities, 2020). Here as elsewhere, these proposals for new governance instruments recognize that progress toward coastal climate resilience is also an opportunity to improve quality of life and address inequality across greater Boston.

These calls have not gone ignored. Under Governor Maura Healey and Climate Chief Melissa Hoffer, the Massachusetts Office of Coastal Zone Management announced its rollout of resilience districts, where municipalities that share certain coastal vulnerabilities can collaborate on streamlined funding and permitting opportunities (Hand, 2023). As the MBTA tackles the challenge of how to plan for flooding across its own commuter rail, its own questions of jurisdictional boundaries and flood oversight sit squarely in the middle of these emerging conversations.

Resilience at the MBTA

In 2011, the Federal Transit Administration published a report on the expected impacts of climate change on transit. While noting that intense rainfall events will impact low-lying transit facilities and rights-of-way in the near future, rising sea levels and worsening storm surges along the coast pose the most substantial long-term hazard (Hodges, 2011). Other studies corroborate this finding, predicting exponential increases from coastal flood damages to public transit infrastructure, which tends to

be extremely costly and situated in low-lying historic flood plains (Martello & Whittle, 2023). Sea level rise, combined with increased storm frequency and intensity, can affect other system indicators such as on-time performance by eroding earthen supports, corroding electrical infrastructure, physically inundating tracks, or hampering passenger access (Rosen, 2023).

Much of the current literature on the MBTA's climate vulnerability resilience comes from internal documents. The MBTA has published vulnerability assessments for each line of its rapid transit system along with additional assessments of power and communications systems, pumps, and bus facilities (Massachusetts Bay Transportation Authority, 2022). Martello's thesis (2020) and dissertation (2023) add to this work by simulating water inflows at 'Lowest Critical Locations,' areas where subway tunnels and tracks are expected to fill with water during future storms. This research has limited direct applicability to the commuter rail, whose stations, rolling stock and right-of-way assets differ from those of the rapid transit system. Still, these results set a precedent for assessing and responding to climate vulnerability within the MBTA as an organization.

The first climate resilience report dedicated to the MBTA commuter rail was conducted in 2022, which examines facilities and parking lots connected to the railroad (Martello & Whittle, 2022). Although this document only uses qualitative methods (i.e. assigning 'Minimal' to 'High' vulnerability for all locations examined), itprovides valuable insight into the various support structures that together support the commuter rail. These include many maintenance sites, layovers, offices, trailers, and storage

facilities scattered across Eastern Massachusetts. Complementing this work is a 2024 report compiling interviews from Commuter rail operations and dispatching personnel regarding flooding at well-known locations (Concannon & Lyons-Galante, 2024). Although this report studies observed flood events rather than forecasting future vulnerability, it points to some of the common dynamics historically governing railroads' exposure to water, including land use patterns and localized drainage arrangements.

The MBTA integrates resilience planning across its many departments by way of its five-year rolling Capital Investment Plan (CIP), updated annually. The CIP allocates nearly $10 billion to hundreds of modernization, reliability, repair and transit network expansion projects, each of which are ranked on metrics including cost effectiveness and safety. Recent editions of the CIP have required proposed capital projects to be scored for resilience and sustainability by MBTA employees before being circulated for public comment (Massachusetts Bay Transportation Authority, 2023b). This scoring helps elevate projects with substantive resilience elements, such as the Cabot Bus Yard Modernization Project or Systemwide Tunnel Flood Mitigation Program. The agency has also established a new office of Climate and Resiliency Policy and Planning within the Policy and Strategic Planning Division to supplement resilience work undertaken within the Environmental department (Perdomo-Hernandez, 2023).

As the T looks to protect the commuter rail against the threat of climate change, it must do so within the context of a broader transformation from diesel to electrified "Regional Rail" service. To achieve the decarbonization mandate handed down by the

state legislature, massive investment in new facilities, vehicles, and support infrastructure such as overhead utility lines must also incorporate climate resilience measures in their designs and operations (An Act Relative to Setting Deadlines to Electrify the MBTA Commuter Rail, 2023). In March 2024, the MBTA put forth a Request for Information confirming its interest in amending its contract structure following the expiration of its current contract with Keolis (Dionne, 2024). This RFI signifies a commitment towards decarbonizing and modernizing the Commuter Rail system, shifting from primarily serving daily commuters via diesel locomotives to more frequent, subway-style service delivered by electric vehicles. Modernization represents a pivotal moment where far-reaching commuter rail planning is possible. Still, concerns remain about whether the magnitude of these transformations may eat into money needed for other railroad investment priorities.

Chapter Three: Methods

I employ a mixed methods approach to answer my research questions, integrating literature review, participant-observation, and Geographic Information Systems to evaluate the current and projected vulnerability of the commuter rail system. Then, I conduct a document review and interviews within a case study frame of the commuter rail's most vulnerable line to assess how this vulnerability is expected to change in response to resilience measures coordinated between municipalities and the MBTA. My research questions are as follows:

Primary Research Question: How do adaptation strategies among the municipalities bordering the Newburyport-Rockport line of the MBTA commuter rail affect the railroad's exposure to coastal flooding?

Secondary Research Questions:

- Where is the commuter rail most vulnerable to coastal flooding, according to asset data, usage demographics and climate change models?
- How are coastal flood resilience measures coordinated between municipalities and the MBTA in the service area of the Newburyport-Rockport line?
- Drawing from interviews with key actors/knowledge holders, what are the barriers and opportunities to enhance continuous coastal flood resilience along the MBTA commuter rail system?

Participant Observation

As a part-time employee within the MBTA Environmental department's climate resiliency team, I was responsible for drafting presentations, memos, and reports pertaining to the transit agency's climate risks using geospatial data. By 2023-24, the T had completed several large vulnerability assessments and sponsored academic research projects focusing on coastal flooding, allowing me to gain a sense of resilience decision-making in context. In my role, I performed outreach interviews across departments to learn how ongoing capital projects integrated climate resilience priorities. I also attended site visits and meetings with municipalities and consultant teams to learn where their goals intersected with those of the T.

My role within the MBTA supported the development of this thesis in two major ways. Perhaps most importantly, working for the T provided a basic sense of how resilience planning was conceived and advanced within the agency—from what datasets were most often used, to which theories of resilience were established, as well as some of the common barriers to putting plans into practice. I conducted many early informational interviews in my position as an employee that later found a second life informing the development of this thesis topic (see Table 3-1). Secondly, my role offered me access to key informants acting in various capacities in and around the transit system, as well as to physical spaces where employee safety trainings or escorts were needed.

Position	Organization

Dispatcher	Keolis Commuter Services
Superintendent	Keolis Commuter Services
Director of Transportation	MBTA Railroad Operations
Director of Engineering	MBTA Railroad Operations
Director, Maintenance of Way	MBTA Railroad Operations
Deputy Director	MBTA Regional Transit Planning
Director	Metropolitan Area Planning Council
Program Manager	Boston Metropolitan Planning Organization

Table 3-1: Informational Interviews conducted in role as MBTA Employee.

Literature Review

The literature review serves several purposes. First, it introduces different frameworks of resilience to highlight how best to conceive of interventions intended to strengthen the performance of urban infrastructure. From these frameworks, I identify how related notions of exposure, criticality, vulnerability, and resilience can be used to understand how complex systems respond in general terms to climate change-related hazards. Next, I summarize the science of coastal flooding, an understanding of which guides the response patterns seen among municipalities preparing plans for climate adaptation—including construction of flood barriers, elevation of critical assets, and addition of redundancies. I follow this by reviewing reports on climate resilience governance in Massachusetts, acknowledging the successes of locally-driven

adaptation efforts while pointing to political mechanisms that could overcome the contradictions currently built into the resilience planning process.

Vulnerability Screening

Chapters Four and Five assess the exposure and sensitivity of the Commuter Rail network, using the 'vulnerability screening' method identified in the literature review to follow how railroad infrastructural subsystems inform overall system performance. A vulnerability screening is conceived as a product of both exposure—an indicator of coastal flood timing, likelihood, and severity—and sensitivity, an indicator of railroad system "fragility" as it is impacted by these perturbances. I follow two railroad subsystems: first, facilities, and second, the railroad right-of-way. A formal engineering vulnerability assessment would further decompose these two categories into their contents at specific locations—e.g. each electric box, piece of maintenance equipment, etc.—to prescribe the steps needed to remedy the railroad's most urgent vulnerabilities. Alternatively, this vulnerability screening provides a general sense of how vulnerability is transmitted across the railroad system (i.e. from facilities or segments of right-of-way to railroad operations), and identifies a particularly vulnerable route as a case study for further qualitative analysis (i.e. along the Newburyport-Rockport route).

Chapter Four's discussion of facilities draws heavily from an existing report produced by climate resilience researchers Michael Martello and Andrew Whittle in 2022. This report uses FEMA flood plain maps, the MC-FRM and interviews with MBTA

Railroad Operations staff to produce a qualitative ranking of site sensitivity/criticality and expected flood severity, described on a scale of ‘None’ to ‘Extreme’ across both present day and future conditions with 4.3 feet of modeled sea level rise. These rankings are combined to produce a list of most vulnerable facility locations. I amend these findings to include changes made to facilities since 2022, adding photos and diagrams gathered from site visits to facilities.

The remainder of Chapter Four similarly joins MC-FRM flood modeling with MBTA Railroad operations and Keolis interviews to characterize the sensitivity and exposure of each railroad route making up the commuter rail system. In this chapter, asset-based sensitivity measurements are introduced to suggest how floods interact with physical infrastructure located along the length of the railroad right-of-way. Route sensitivity comparisons are solidified with references to ridership and demographic data. Exposure is evaluated as a simple intersection of railroad right-of-way length with MC-FRM 1-in-100-year storm extents. These intersections are tabulated across separate lines to indicate the extent of flooding expected both presently and with 4.3 feet of sea level rise. This operation is performed across all passenger commuter rail lines, including those that offer seasonal or special-events service such as the CapeFlyer and Foxborough lines, as well as the South Coast Rail, which is preparing to open for passenger service in 2024. Results are further contextualized with elevation data provided by the U.S. Geological Survey and MassGIS.

Vulnerability Screening Data Sources

To model the movement of water along the coast, the Massachusetts Department of Transportation partnered with engineering firm Woods Hole Group to develop the Massachusetts Coast Flood Risk Model (MC-FRM). The MC-FRM incorporates the combined effects of tides, currents, waves, and other factors in simulating thousands of coastal storms at sea levels corresponding to the 2020, 2030, 2050 and 2070 (Woods Hole Group, 2022). Future flood exceedance probabilities are based upon a sea level rise trajectory laid out in a 2012 report by NOAA, which matches the IPCC 8.5 Received Concentration Pathway best understood as a high-emissions scenario with poor global commitment to reduce reliance on fossil fuels (Woods Hole Group, 2023). The MC-FRM's sea level rise inputs tend to exceed the projections of other climate science models and remain subject to uncertainty because of differences in accounting for contributions from different ice sheets; see figure 3-1 for a comparison of sea level rise projections (National Oceanic and Atmospheric Association, 2022). Still, the high inland resolution of the MC-FRM makes it suitable for the MBTA to use for site-specific assessment and design under a full range of possible conditions.

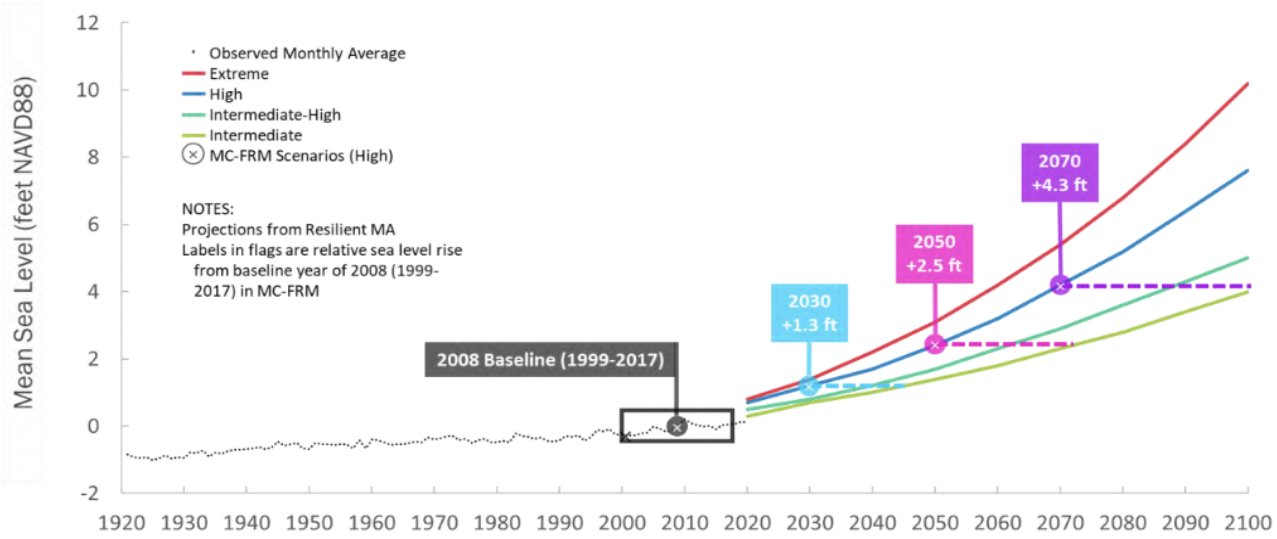


Figure 3-1: Comparison of sea level rise projection scenarios at Mean Sea Level (ft-NAVD88) from Boston Harbor Tide Gauge (Woods Hole Group, 2023); the MC-FRM uses the more conservative dark blue scenario for its sea level rise inputs.

The MC-FRM and other data sources used for visualization and analysis are listed in the table below:

GIS Data Source	Description
US Geological Survey, 2021 USGS LiDAR: Central Eastern Massachusetts	Elevation data with vertical accuracy of 8 centimeters and a horizontal resolution of 1 square meter. Data collected for bare earth, bridge, and water classes. Used to create elevation profiles for railroad routes most exposed to coastal floods.
MassDOT/Woods Hole Group, Massachusetts Coastal Flood Risk Model	Present-day (2020), Level 1 2070 1-in-100-Year flood depth, extent and probability data from coastal storm simulations. Used to generate storm extent layers for vulnerability screening.

MBTA, Positive Train Control LiDAR infrastructure locations	Commuter rail point data for milepost markers, center of track locations, switches, signal infrastructure, and bridges. These data were collected to construct Positive Train Control on MBTA right-of-way in 2019. Used to locate milepost markers to construct elevation profiles.
MBTA, LandTracker Parcels	Polygon feature class of all MBTA properties, including Commuter Rail layover, dispatching and maintenance facilities. Used to overlay facilities with flood boundaries.
MassGIS, Cities and Towns from Survey Points	Labeled polygons with municipality names and borders. Used to identify locations of infrastructure and resilience project locations.
ESRI, Global Terrain	Three-dimensional digital elevation model made publicly available by ESRI. Used to produce flood plain terrain map.
MassGIS, Commuter Rail Lines	Line features used to map railroad right-of-way and elevation profile.

Table 3-2: GIS Data Sources.

Case Study Document Review and Interviews

Robert Yin asserts that case studies are an appropriate tool for answering "how" and "why" questions grounded in their real-world context (Yin, 2003). After screening the commuter rail and surrounding areas for coastal flood vulnerability, I use a case study approach of the Newburyport-Rockport line to understand the process by which municipal coastal flood resilience projects poised to affect the commuter rail's vulnerability interface with the MBTA's own resilience actions. Of these municipal projects, I ask who is responsible for overseeing their implementation, what effects they might exert upon the vulnerability of the commuter rail, and what coordination steps are implied for regional action (i.e. do they support, undermine, or ignore ongoing

MBTA plans?) I note both where projects affect the commuter rail's flood exposure by modifying the hydrology of the study area as well as places where projects induce more indirect changes to the commuter rail's vulnerability. This could include, for example, the preparation of redundant passenger stations or drainage upgrades. I also note areas with few alignment issues between the T and its surroundings to juxtapose against areas where this interplay is better elaborated.

The case study incorporates data from two main sources to better understand the barriers and opportunities for continuous coastal flood resilience across municipal and MBTA efforts. The first source of data consists of MVP grant documentation along with other local and regional plans. The next source of case study data consists of ten thirty to sixty-minute interviews conducted among resilience professionals working at watershed associations, municipalities, and regional planning commissions. Interview questions sought greater detail on the impetus for resilience planning within the communities represented by interviewees, as well as the current status of projects identified in the document review of planning reports. I pair these questions with those asking about commuter rail usage and existing relationships with the MBTA. A table of interview organizations and titles is prepared in Table 3-1, while a set of sample interview questions can be found in Appendix 1.

Department/Title	Municipality Represented
Planning	Lynn
Resilience	Chelsea, Everett, Revere (North Suffolk Office of Resiliency)
Resiliency	Newburyport
Restoration	Newbury, Newburyport, Rowley, Ipswich (Ipswich River Watershed Association)
Conservation	Gloucester
Coastal Resources	Newbury, Newburyport, Rowley, Ipswich (Merrimack Valley Planning Commission)
Sustainability and Resiliency	Salem
Environmental Resiliency	Boston, Cambridge, Somerville, Everett, Chelsea (Mystic River Watershed Association)
Housing and Community Development	Chelsea
Climate Resiliency	Manchester (Fuss & O'Neill)

Table 3-2: Interviews with Municipal Resilience Specialists.

To maintain a manageable interview load, outreach efforts within the Newburyport case study line prioritized municipalities with larger populations and those whose document review displayed evidence of more active resilience projects (see Figure 3-2).

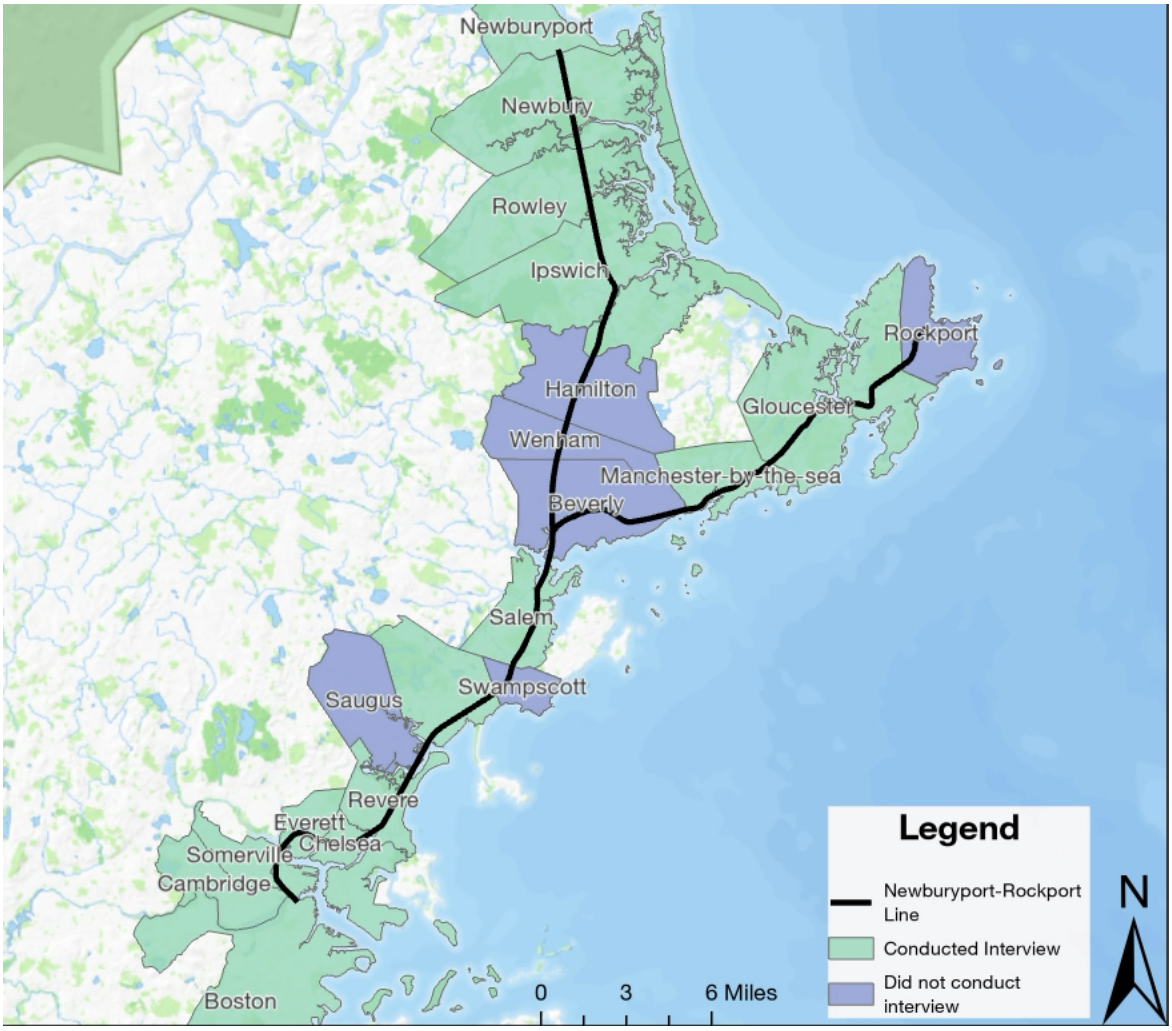


Figure 3-2: Map of Interviewed Municipalities across the Newburyport-Rockport Line.

Chapter Four: Vulnerability Screening

Facilities Sensitivity

As the railroad's "nervous system," facilities include maintenance-of-way (MOW) warehouses, dispatching centers, and layovers. While each of these facility subtypes feed into railroad operations differently, they are all central to the puzzle that makes passenger railroad service possible.

Maintenance-of-Way Facilities (MOWs) are not just used to repair rolling stock (train vehicles) after they malfunction, but also to proactively inspect and maintain them for regular service (Massachusetts Bay Transportation Authority, 2023a). Dispatching offices are responsible for remotely coordinating train movement, similar to the way air traffic controllers govern airspace around an airport. Layover yards are used for overnight storage, fueling and train assembly. With the commuter rail's radial configuration and transfers between North and South sides limited to a single Grand Junction link (see Appendix 3), it is difficult to access backup facilities should the MBTA lose service at one assigned to a certain region of the railroad. For these reasons, the commuter rail is extremely sensitive to facilities damage.

Exposure to flood water can impact maintenance facilities in several ways. Perhaps most dramatically, maintenance yards contain large pits underneath the tracks on which railroad vehicles are moved for inspection. Even moderate flooding can enter these pits, damaging maintenance equipment, spare parts, and any rolling stock

vehicles left in the area. Moreover, interviews with Keolis staff indicate that maintenance facilities contain high quantities of fuel and other point source contaminants, making flood events expensive or even dangerous to deal with. Even if protective measures such as temporary barriers were to be positioned around particularly sensitive areas, these solutions remain temporary and employee access may be obstructed if attached parking lots were to flood to a sufficient depth. Severe flooding at the primary Commuter Rail Maintenance Facility (CRMF) could cripple the entire Commuter Rail for up to two weeks, as some machines required to regularly maintain rolling stock exist nowhere else in the system and are difficult to procure replacements for (Martello & Whittle, 2022). Figures 4-12 and 4-13 illustrate some of the sensitive elements located at the CRMF.

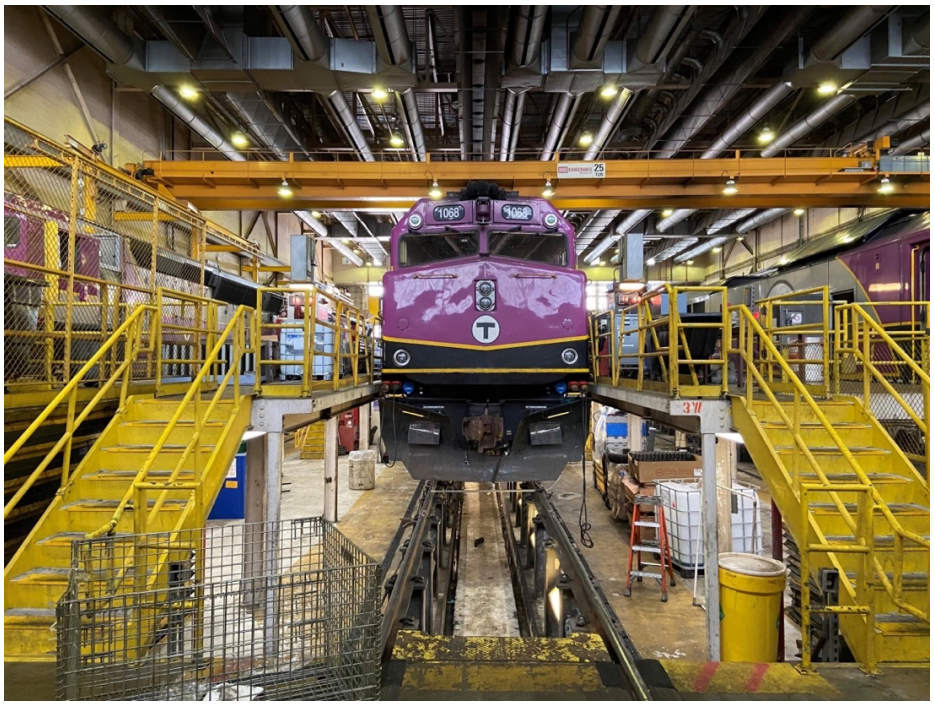


Figure 4-1: Photo of wheel truing pit located in Commuter Rail Maintenance Facility (Massachusetts Bay Transportation Authority, 2023a).

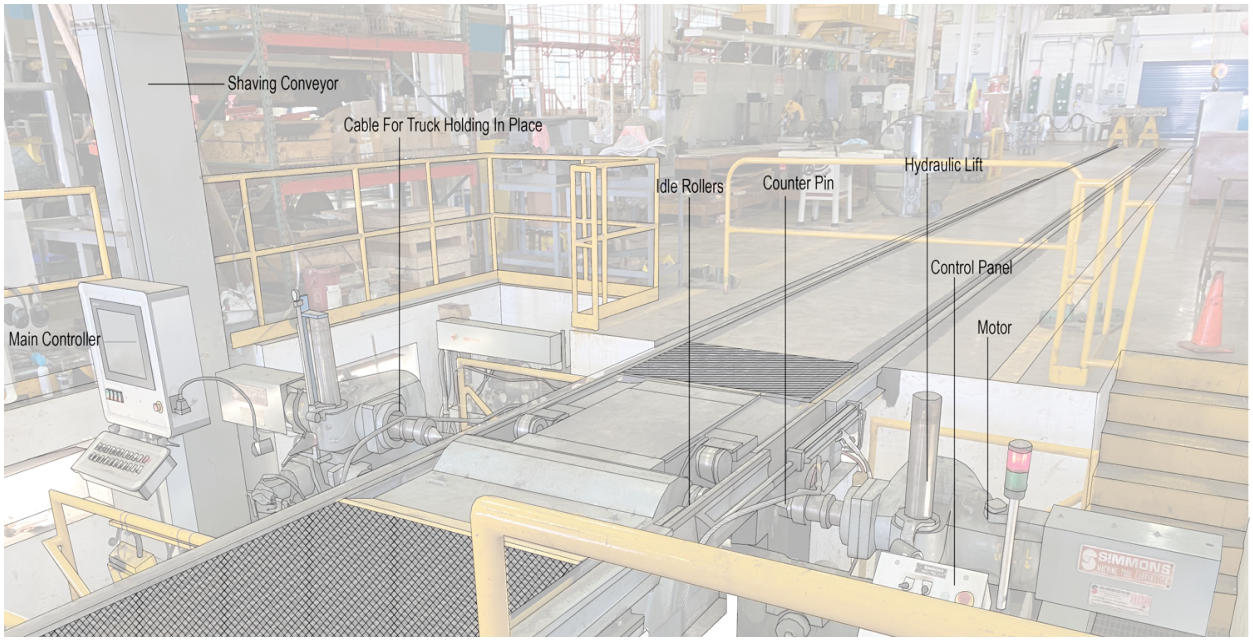


Figure 4-2: Labeled elements of wheel truing pit (Wang, 2022).

Knowing how critical these facilities are, the MBTA is now designing a new maintenance yard to supplement the CRMF at its current Readville MOW in the Hyde Park neighborhood of Boston (Massachusetts Bay Transportation Authority, 2023a). The addition of this yard would not only increase operational efficiency by eliminating the need to bring all southside maintenance needs to the CRMF, but lend redundancy to the commuter rail system, providing a backup location should either facility be rendered unusable.

Somerville's Cobble Hill and Boston's South Station dispatch trains across the north and south sides of the commuter rail, respectively. Each of these locations host trained dispatching personnel as well as the computers and communication systems needed to control the movement of trains across their assigned territories (Armstrong, 2008). As a result, loss of power or access to the dispatching site would hamper the

coordination required for regular passenger service, although a few trains could travel at reduced speeds with greater manual oversight by the train engineer.

To add redundancy to its Cobble Hill dispatching location, the MBTA is in the process of outfitting a new operations control center in the inland city of Billerica. While safe from coastal flood events and equipped with resilient design features such as redundant power supplies and an elevated first floor, the EPA superfund site has been historically prone to precipitation-driven flooding (Taylor & Burns, 2023; Concannon & Lyons-Galante, 2024).

Facilities Vulnerability Discussion

With a relatively small number of discrete locations, it is possible to evaluate all facilities' exposure under various storm return periods and sea level rise scenarios. While future vulnerability assessments will likely be conducted for each of these locations, the table below performs an initial screening of exposure by determining facilities' susceptibility to coastal flooding under present-day and 2070 1-in-100 year storm conditions. 'Minimal', 'moderate', 'severe' and 'extreme' floods are defined as areas projected to receive up to one, three, five, or greater than five feet of flood depth, respectively. This information is combined with a criticality/sensitivity ranking determined by MBTA Railroad Operations staff to produce the qualitative vulnerability ranking found in Table 4-1, adapted from the MBTA's 2022 "Climate Change Coastal Flood Vulnerability Screening of MBTA Commuter Rail Facilities and Parking Lots" (Martello & Whittle, 2022). For brevity, only facilities with a "medium" to "high"

vulnerability ranking are included. A complete list of facilities ranked by sensitivity/criticality is recorded in Appendix 4.

Vulnerability Rating	Category	Name	Municipality	Line	MC-FRM 1-in-100-Year Flood Exposure	
					Present	+4.2 ft SLR (2070 Forecast)
High	Maintenance Facility	Commuter Rail Maintenance Facility	Somerville/ Boston/ Cambridge	All Routes	Minimal	Extreme
High	Maintenance Facility	Widett Service & Maintenance Facility/Amtrak Southampton Street Yard	Boston	All South Side Routes	Minimal	Extreme
High	Maintenance Facility	West Cambridge Maintenance Facility	Cambridge	All Routes	None	Extreme
High	Maintenance Facility	Salem Maintenance Facility, Storage, Offices	Salem	Newburyport-Rockport	None	Extreme
Medium	Dispatch Facility	Cobble Hill	Somerville	All North Side Routes	None	Moderate
Medium	Dispatch Facility	South Station	Boston	All South Side Routes (includes Amtrak Dispatching)	None	Moderate

Table 4-1: Most vulnerable commuter rail facilities.

Right-of-Way Sensitivity

Running alongside the tracks, the Right-of-Way (ROW) includes the tracks themselves as well as other critical support infrastructures such as bridges, signals and communications equipment, switch equipment, passenger platforms, and assorted maintenance supplies. Bridges range from small overhead road crossings to massive moveable drawbridges paired with a control tower. Many MBTA bridges are replaced infrequently due to the costs involved, leaving them fragile and expensive to repair should they be damaged by scour or overtopping from coastal flooding (Massachusetts Bay Transportation Authority, 2023b). Signals act as “stoplights” on the train tracks, indicating when trains can slow, stop or proceed according to the flow of traffic. Switches are mechanical implements connected to electrical circuitry allowing trains to be shunted from one track to another. Platforms hold no mechanical significance but provide passenger parking and boarding locations that comply with American Disability Act requirements. This means that platforms contain specialized equipment, such as elevators, that protract their shutdown times in the event of a flood (City of Boston, 2017). A sampling of how these subsystems are arrayed across greater Boston is shown in Figure 4-3.

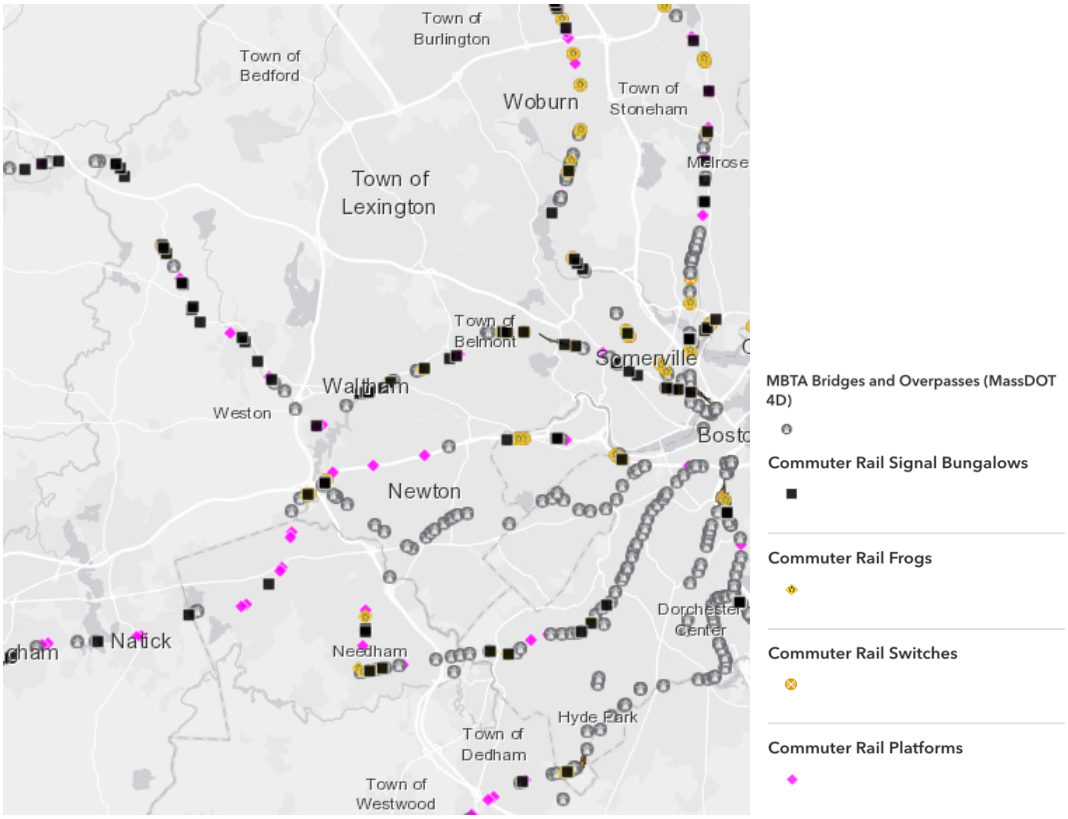


Figure 4-3: A screenshot of commuter rail ROW equipment from the MBTA online GIS viewer.

As figure 4-3 demonstrates, these subsystems are not evenly distributed. Switches and associated machinery (frogs, heaters, electricity supply boxes) are especially concentrated at junctions where multiple tracks meet, while bridges and signals tend to be densest in urban areas where road crossings and other barriers are more common. Interviews with Keolis staff underline the distinction between “direct” and “indirect circuits”—electric machines, like switches, that directly control track infrastructure, as opposed to those that maintain the usability of the track. Direct circuitry tends to be more robust, making it less prone to failure, whereas indirect

circuitry (e.g. signaling) is a common failure point. Keolis dispatchers underscore that in a pinch, train engineers can receive permission from dispatchers to take more manual control, allowing for train service to carry on even as support systems such as signals and switches break down in inclement weather. Tracks themselves also vary, with some areas of the railroad network containing doubled track to let trains run in two directions at once.

For the purposes of a GIS vulnerability screening, it is not necessary to quantitatively model these sensitivity distinctions, or to plot each of their individual locations. Instead, I assume a reasonably even distribution of support infrastructure running alongside tracks, using the exposure of the ROW itself to evaluate the degree of exposure generated by each line with respect to the entire Commuter Rail network.

Railroad standards mandate the material composition and physical clearance distances of the ROW, which affect not only the flow of flood waters but also how railroad assets respond. A standard right-of-way cross section with horizontal and vertical clearances is depicted below along with sample images.

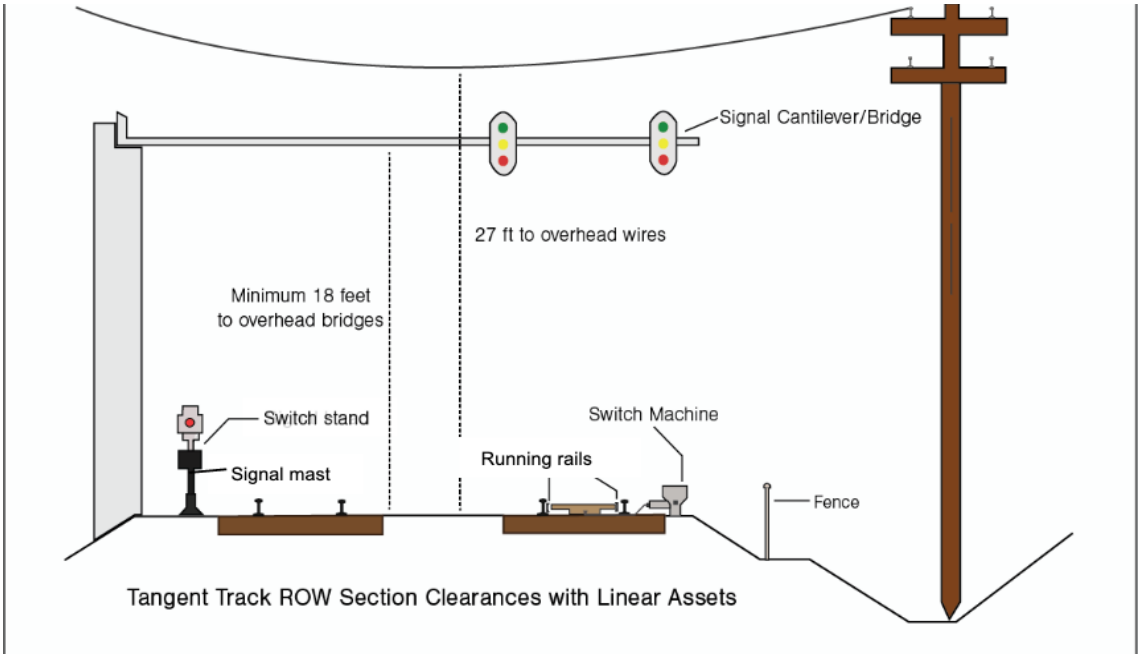


Figure 4-4: A typical cross-section of doubled tangent (straight) Railroad Right-of-Way track, with overhead clearances(Massachusetts Bay Transportation Authority, 1996).

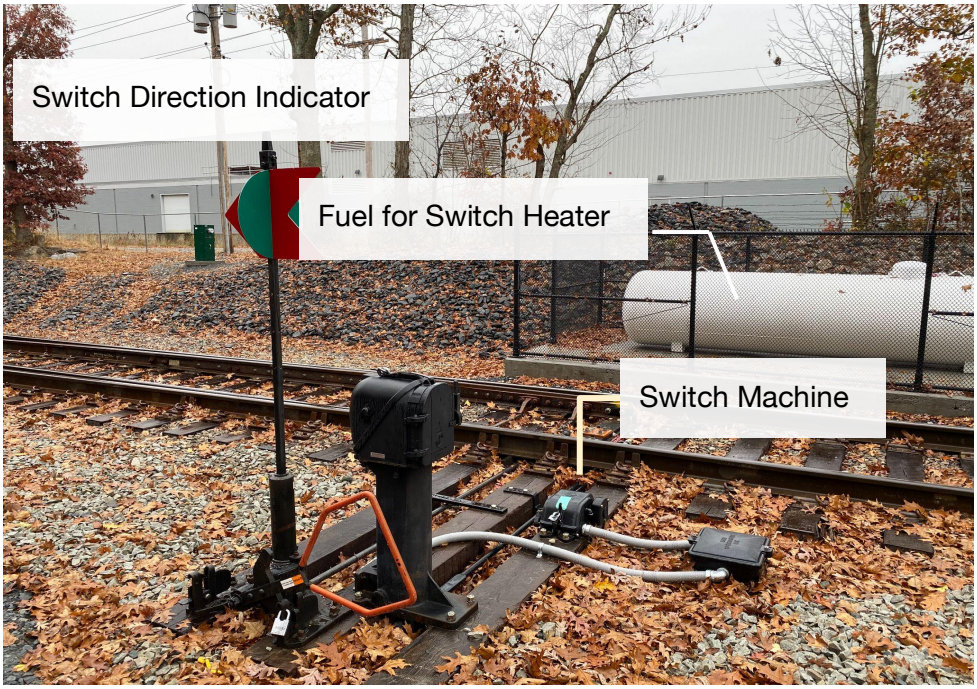


Figure 4-5: Signal and switch on a section of South Coast Rail, November 2023.

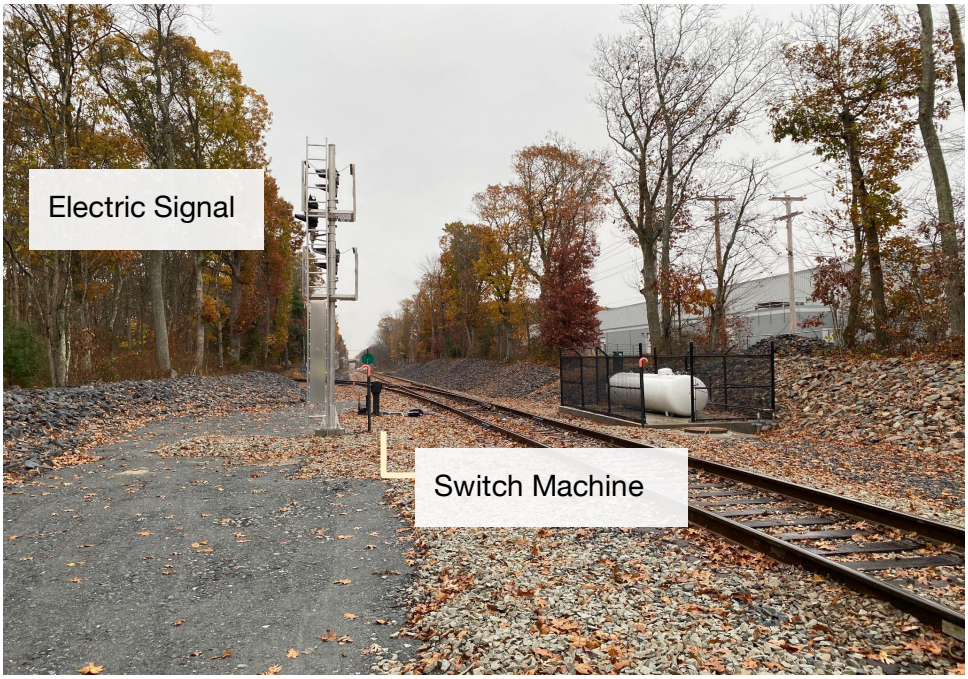


Figure 4-6: Another view showing signal and power equipment with junction in background, November 2023.

While pooling water coupled with poor visibility can slow a train's progress, the primary danger of flooding on the ROW is when water erodes the soil and gravel ballast needed to absorb the weight of trains moving at high speeds. Flooding can also wash debris onto the track, clog drainage culverts, and uproot wooden track ties used to anchor the metal rails (Hodges, 2011). This danger is heightened when large volumes overflow from an existing water body, or when water dumps from impermeable surfaces onto railroad infrastructure (Concannon & Lyons-Galante, 2024).

Another danger of water moving across railroad tracks is when it impacts utility poles, signal boxes, or switch machines. These relatively sophisticated systems sense trains' positions using trackside computers and buried cables. Their associated electronics are especially prone to failure when flooded, impeding railroad service even

when the trains and tracks themselves are dry. Conversations with MBTA Rail Modernization planners suggest that new railroading technologies that monitor train location via satellite rather than trackside signals can overcome some of these sensitivities, but current response protocols require track crew attention to restore performance after signals are lost.

Besides these asset-based markers of sensitivity, another indicator of the degree to which the transportation network would be disrupted by the loss of a line is that of use rate, or ridership. Some commuter rail lines are primarily used for special events or in certain seasons, such as the Foxboro line for New England Patriots games, or the CapeFLYER, which exclusively provides weekend service during the summer. By contrast, the Providence, Worcester and Newburyport-Rockport routes provide year-round service for a commuting population. This comparison is illustrated in Figure 4-7.

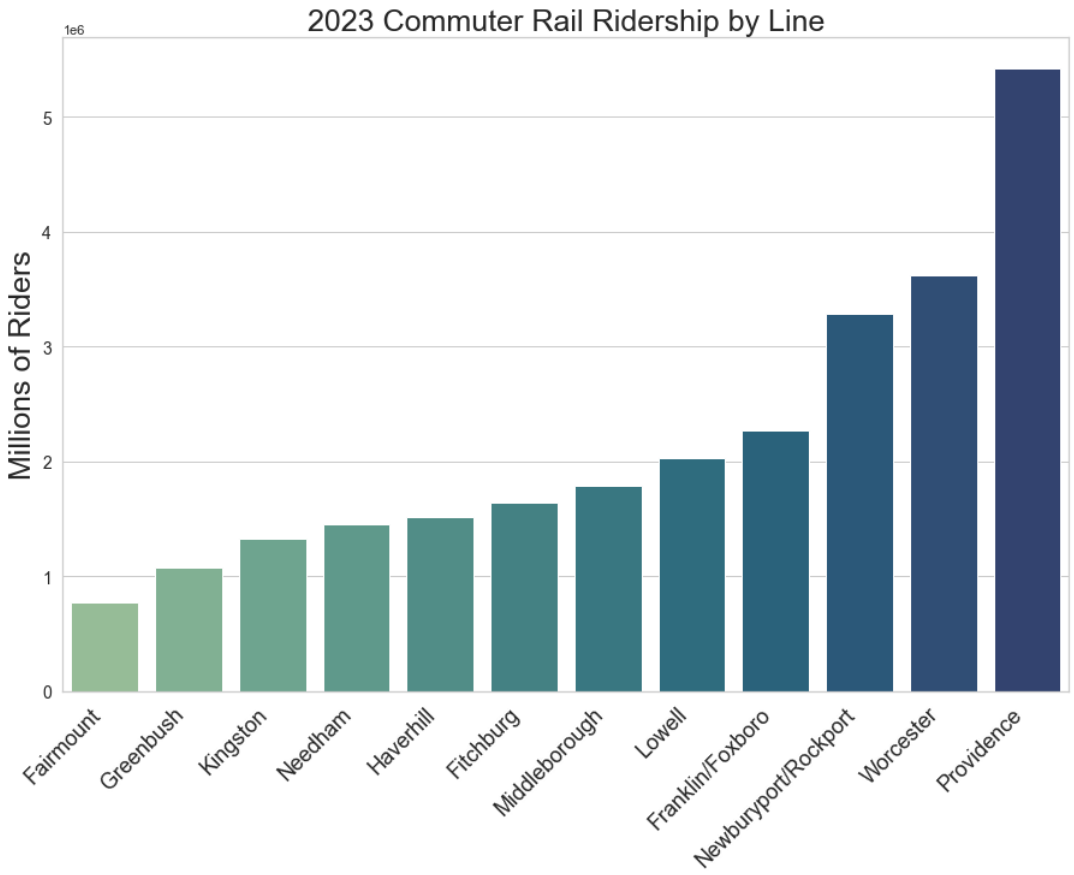


Figure 4-7: Annual Ridership by Commuter Rail Line.

Further supporting the value of this route, the Massachusetts state legislature has identified critical Environmental Justice corridors to prioritize in commuter rail modernization efforts. The Newburyport-Rockport line from North Station to Salem is one such corridor, a designation shared only by the Fairmount and Providence lines (Bill S.9: An Act Creating a next-Generation Roadmap for Massachusetts Climate Policy, 2021). By prioritizing investments in these areas, Massachusetts lawmakers have made it clear to the MBTA that equity concerns must be incorporated into commuter rail sustainability and resilience plans.

Right-of-Way Exposure

The Massachusetts Coastal Flood Risk Model ties wave, wind, tide, and storm surge models to historic water level observations to predict the effects of coastal flooding under a range of sea level rise regimes. This dataset is therefore well positioned to evaluate the exposure of the railroad ROW under both present-day and future conditions.

Exposure is measured by intersecting flood water extents with the Right-of-Way. The GIS exposure comparison as detailed below reveals that the Newburyport-Rockport line is significantly more exposed to coastal flooding than are the next most exposed lines, the Greenbush, Cape Flyer, and South Coast Rail. This exposure is the result of both proximity to the coastline and placement at low elevation in proximity to existing flood paths. This finding can be used to undertake further study of sensitivity to disruption, as well as the complexities of flood adaptation measures along a railroad line.

Figures 4-8 through 4-11 illustrate the results of intersections between a 1-in-100-year storm extent in the present day and with 4.3 feet of sea level rise. Results are also tabulated and compared on a per-line basis. In reality, the severity of flooding will vary considerably within this boundary according to water velocity and depth, but this intersection is sufficient to draw a comparison of exposure across railroad lines at a high level.



Figure 4-8: Map of Right-of-Way exposed to a Present-Day 1-in-100 Year Flood.

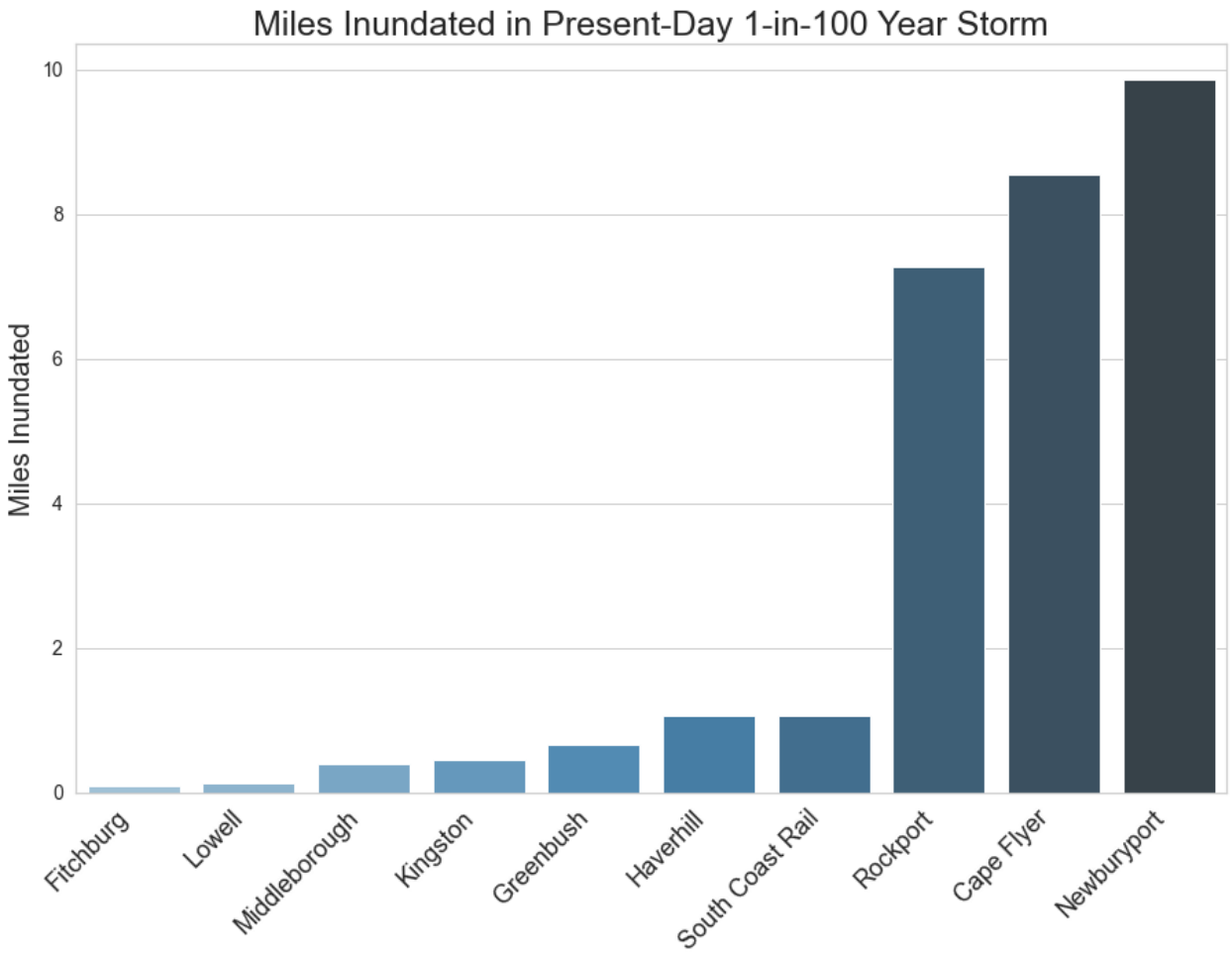


Figure 4-9: Length of ROW Inundated in Present-Day 1-in-100 Year Storm.

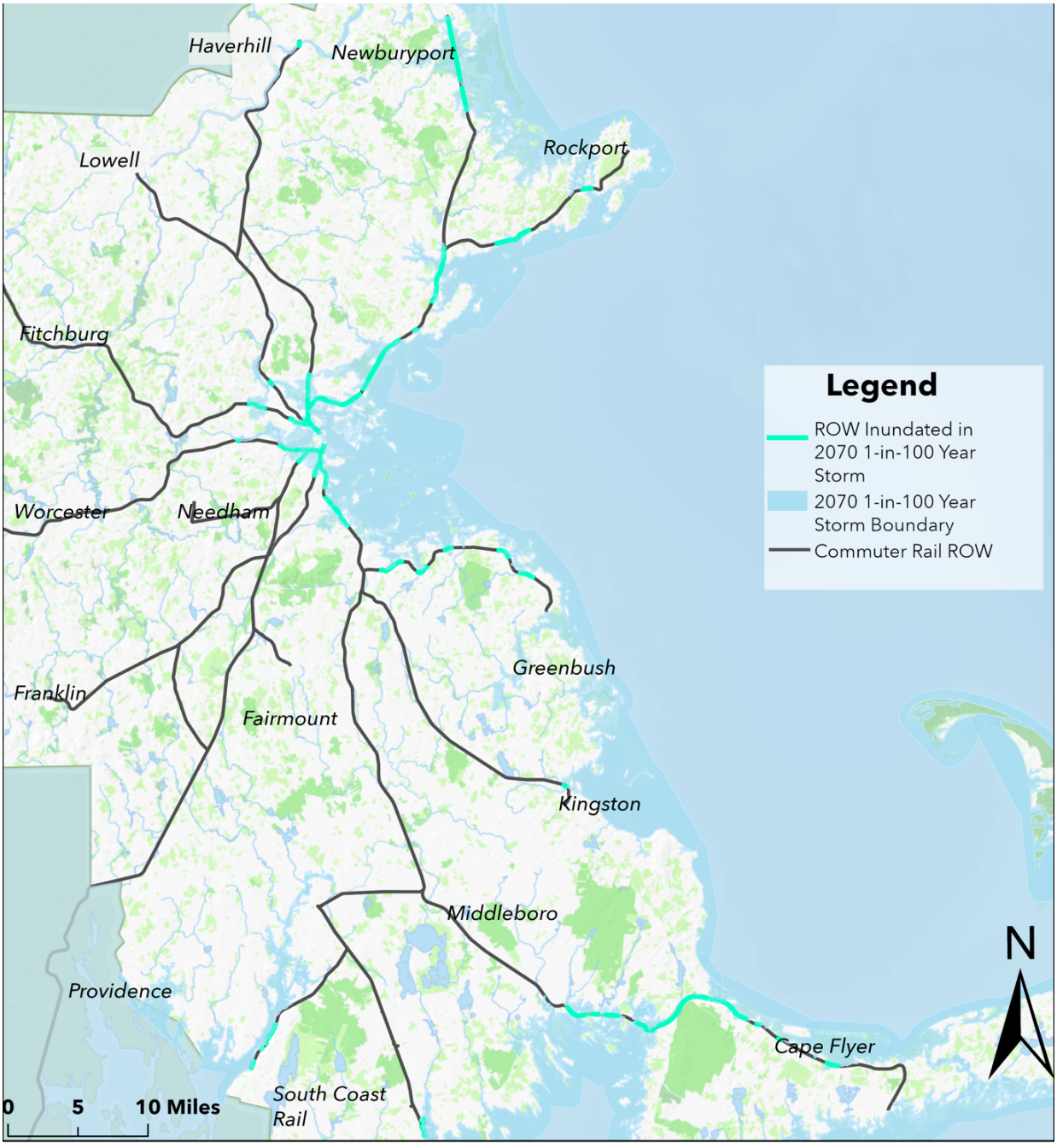


Figure 4-10: Map of Right-of-Way exposed to a 2070 1-in-100 Year Flood.

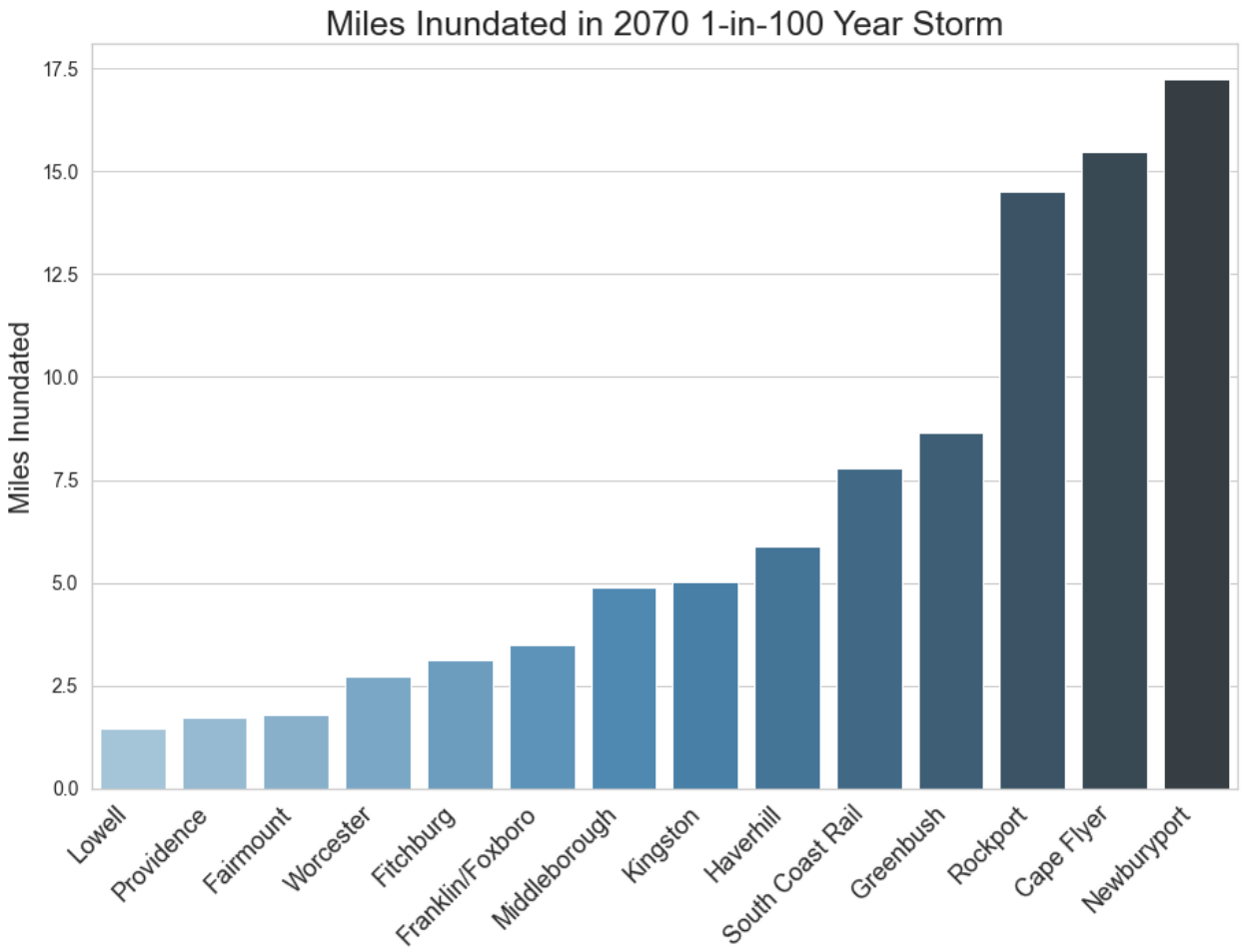


Figure 4-11: Length of ROW Inundated in 2070 1-in-100 Year Storm.

These results match what we might expect given the topographic characteristics of the different lines. Plotting ROW elevation profiles for the most exposed routes reveals that the Newburyport-Rockport line remains between 0 and 20 feet above sea level (NAVD88) for the majority of its first 20 miles after exiting North Station, in addition to other low-lying segments between miles 30 and 35 for the Newburyport line and 23 to 35 for the Rockport line:

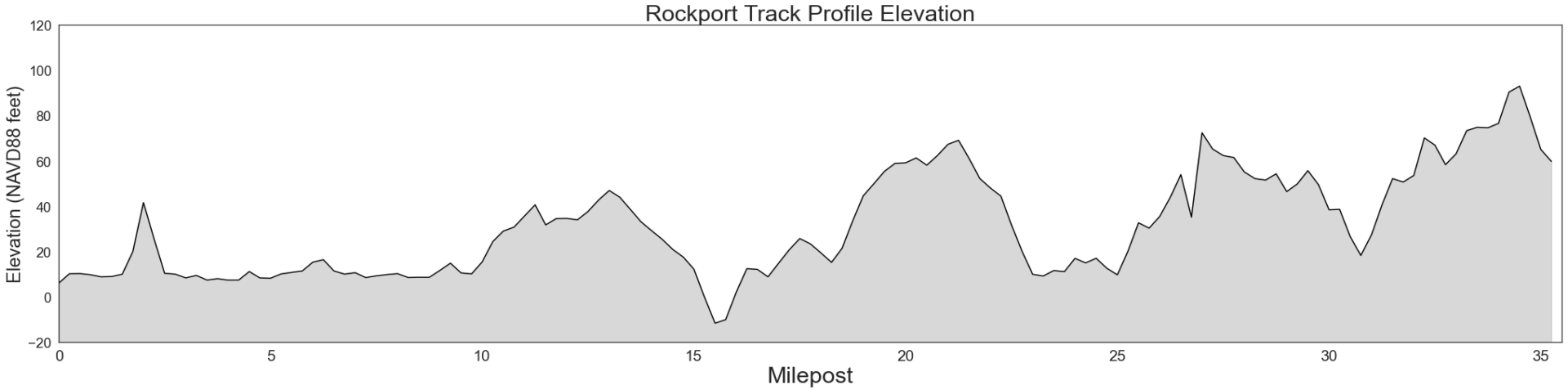


Figure 4-12: Center track elevation profile for Rockport branch.

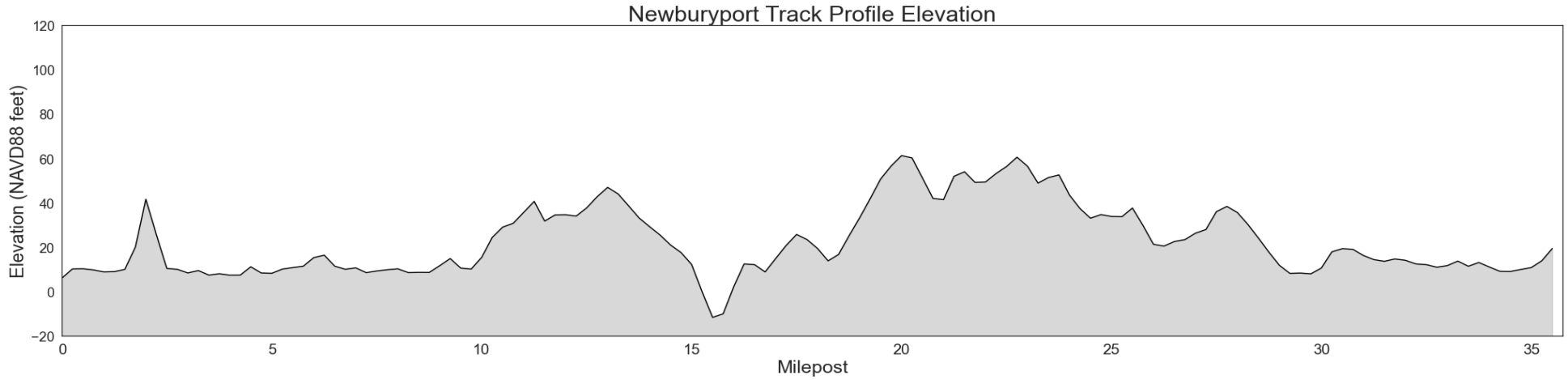
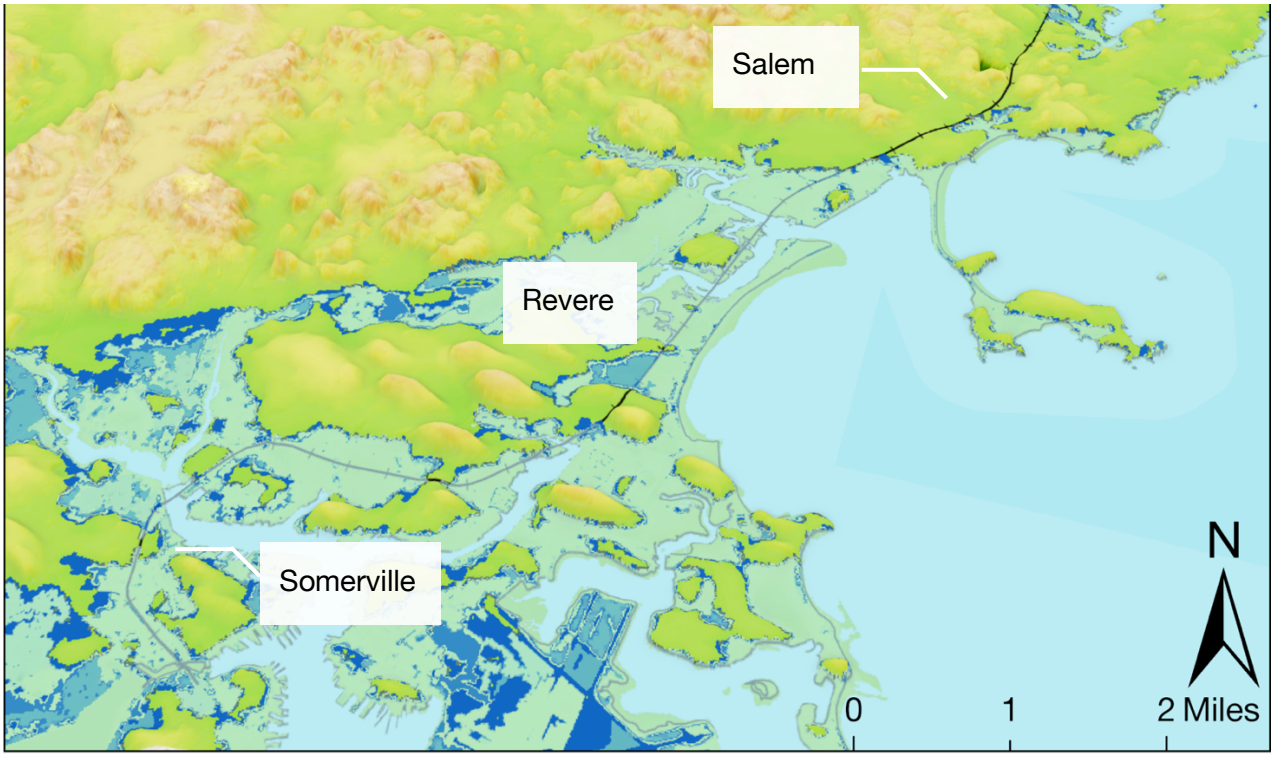


Figure 4-13: Center track elevation profile for Newburyport branch.

Figure 5-14 underscores this finding, revealing how the railroad right-of-way has intensified its flood exposure by virtue of its placement within low-lying, flat terrain in close proximity to the coastline.



Terrain Surrounding Newburyport-Rockport Main Line with 2070 MC-FRM Probabilities: Boston to Salem

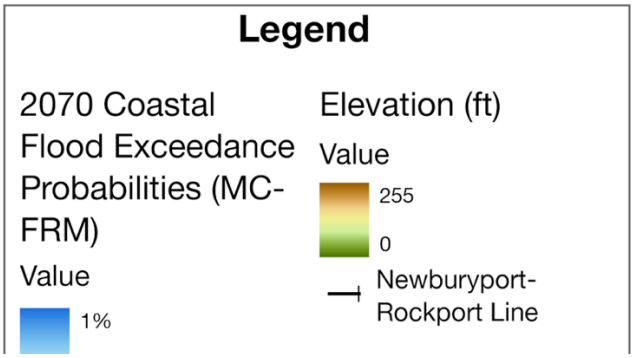


Figure 4-14: Terrain model of the North Shore to Salem illustrating the Newburyport-Rockport line's low position within the surrounding topography.

ROW Vulnerability Discussion

Future vulnerability assessments will likely tackle individual facility site designs and inventory ROW assets across the entire railroad system. Before these steps are taken, this screening helps anticipate where vulnerability is most concentrated on the basis of the railroad's underlying structure and constituent components. When comparing different passenger routes, the combined Newburyport-Rockport line stands out as especially exposed among the commuter rail routes surveyed, coming in 100% higher than the next highest ranked routes. This result is driven by both proximity and elevation with respect to the coast. With the state already giving precedence to projects that improve transportation outcomes in socially marginalized communities, its status as a high-ridership line serving Environmental Justice populations makes analysis of its current vulnerability and emerging resilience needs especially valuable.

Chapter Five: Case Study of Adaptation along the Newburyport-Rockport Line

In Chapter Four, a vulnerability screening unpacked the exposure and sensitivity of the Newburyport-Rockport line relative to other areas of the commuter rail using a model of coastal flooding as water moves across Massachusetts's coastal topography. At the same time, the state has distributed well over $100 million in dedicated resilience funding to municipalities since 2017 (Wormser, 2023a). In line with previous studies suggesting the benefits of an adaptation strategy based on layers of flexible, small to medium-sized coastal flood defenses, these actions frequently take advantage of existing open space and transportation pathways (roads) to erect coastal barriers that reduce flood risks while providing recreational and ecological co-benefits (Kirshen et al., 2008, Kirshen et al., 2020). Accounting for state-administered resilience grants as well as municipal actions undertaken independent of state funding, these shore-based measures form an essential part of an emerging statewide multi-pronged shoreline defense system connecting the sub-tidal zone to inland communities and built infrastructure.

However, since these projects have been largely initiated by municipalities prior to seeking MBTA input, they have yet to be inventoried to understand their cumulative impact upon the commuter rail, nor to track the commitments required by the MBTA to ensure that the railroad does not undermine resilience benefits otherwise sought by cities and towns. Using the Newburyport-Rockport line as a case study, this chapter

follows resilience planning occurring around the commuter rail service area. Each project area is analyzed for impacts to the commuter rail, highlighting junctures where coordination across political boundaries currently takes place. This discussion illustrates the complex considerations required to pursue resilience across large distances of coastline, maintaining its ecological, economic, cultural and infrastructural integrity even as the sea rises and the storms come.

Overview of Resilience Actions

Boston and Somerville

As the Newburyport-Rockport route leaves North Station in Boston, it diverges from other lines at the CRMF in East Somerville. From there, the route proceeds across a large bridge spanning the Mystic River. Along these first five miles of travel, these tracks pass by numerous proposed flood resilience projects introduced by the Resilient Mystic Collaborative, a group of municipalities coordinating at a regional scale to stage resilience measures. Arguably, the two most significant of these sites are proposed elevations of the Charles River and Amelia Earhart dams, which regulate the water levels of the Charles and Mystic Rivers during tidal and/or storm surge-driven flooding events. Raising the crest of these dams by two feet or more would prevent overtopping, cutting off high-consequence flood pathways in the North End and East Somerville/Cambridge under sea level rise conditions through 2070 (Resilient Mystic Collaborative, n.d.) While the dams have yet to be elevated, $13 million has been

secured in state funding to harden the Amelia Earhart Dam, preventing failure were it to be overtopped (Wolberg, 2023).

Plans for dam elevations are complemented by other Resilient Mystic Collaborative projects situated at key flood pathways at the Schrafft Center (425 Medford Street) and Draw 7 Park, both in the Charlestown neighborhood of Boston. These two additional interventions incorporate berms and green infrastructure on the shores of the tidal Mystic River to prevent flanking of the Amelia Earhart Dam and soak up storm surge before it enters the neighborhood. Dams and adjacent flood barriers are illustrated with the Newburyport-Rockport line and 2070 1-in-100-Year flood probabilities in Figure 5-1.

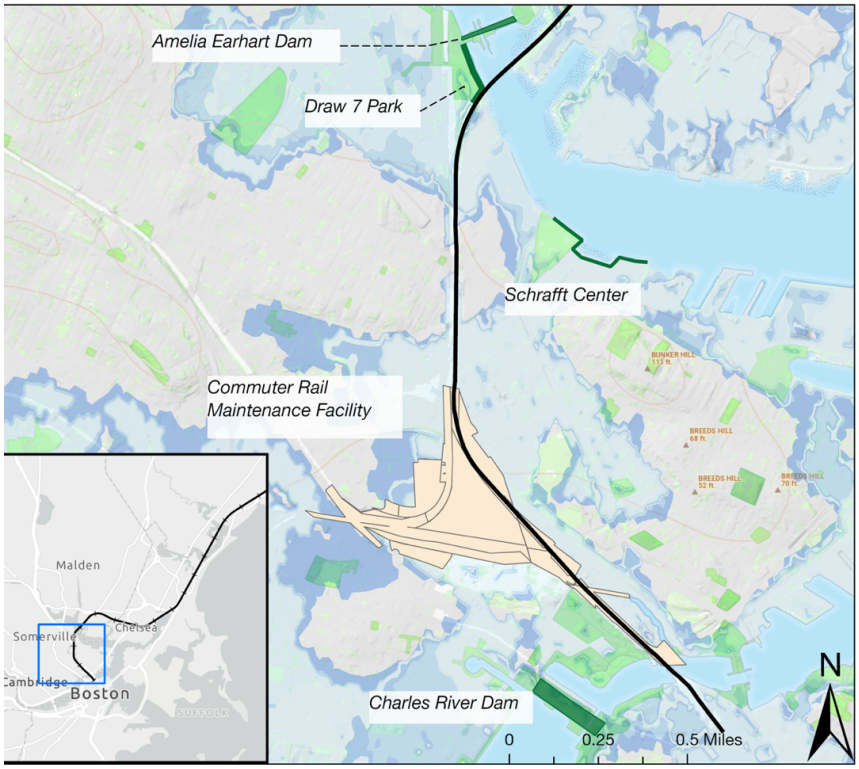


Figure 5-1: Coastal Flood Barriers Proposed by Lower Mystic Collaborative in Boston and Somerville.

Together, these projects represent four of the highest consequence shoreline-based flood barriers underway within the Newburyport-Rockport service area as measured both in terms of investment cost and inland area protected from a 2070 1-in-100 storm. Across all of its initiatives, the Resilient Mystic Collaborative has brought together private developers, numerous municipalities, and the Massachusetts Department of Conservation and Recreation among other stakeholders to secure over $50 million to maintain current levels of flood risk reduction through 2070 (Wormser, 2023b). The Resilient Mystic Collaborative's resilience projects benefit the MBTA by reducing exposure across inland portions of Boston's North End and Charlestown neighborhoods, as well as East Somerville. These areas include critical assets such as North Station, the Commuter Rail Maintenance Facility, and several different commuter rail lines. Moreover, these shore-based measures do not require MBTA investment or operational changes, other than to potentially investigate the potential for increased scour to the MBTA Mystic River bridge due to storm surge rebounding from the Earhart Dam.

Chelsea to Lynn

As the railroad travels through Chelsea, Revere, Saugus, and Lynn, it passes through an area of dense residential, commercial, and industrial land uses. This roughly seven-mile portion of right-of-way contains three passenger platforms and two large bridges. Interviews with North Suffolk Office of Resiliency and Chelsea staff confirm that the cities of Chelsea, Revere, and Lynn have historically been especially vulnerable

to flooding by virtue of being surrounded by tidally influenced water bodies. These cities are nearly entirely composed of Environmental Justice census blocks and are becoming increasingly vulnerable to Nor'easters and hurricanes. Furthermore, interviewees note that coastal flooding is increasingly hampering all forms of transportation in this region—including the regional highway Route 1A and the MBTA Rapid Transit Blue Line—making it especially vital to maintain the viability of the commuter rail.

As measured by project timeline, length of ROW protected and price tag, the two most major flood barriers for consideration in MBTA resilience planning between Chelsea and Lynn are resilient redesigns of the Island End River Park and Eastern Avenue. Now entering its permitting phase, plans to re-envision Island End River Park are shared between the cities of Everett and Chelsea, with input from numerous environmental justice community-based organizations, including the Resilient Mystic Collaborative. The new park will combine a sea wall, storm surge control facility and nature-based flood actions along the Island End River. Interviews with North Suffolk and Chelsea municipal staff emphasize the scope of the Island End project, which received the largest grant award in FEMA region 1 history as well as state MVP dollars over several funding rounds. Altogether, the Resilient Island End project stands to prevent 500 acres of flooding across critical Environmental Justice communities and working waterfront businesses that generate over $4 billion in annual economic output (Wormser, 2023b). Notably, this project also reduces the likelihood of flooding across

approximately one mile of the Newburyport-Rockport Right-of-Way and the Chelsea commuter rail platform, as Figure 5-2 illustrates.

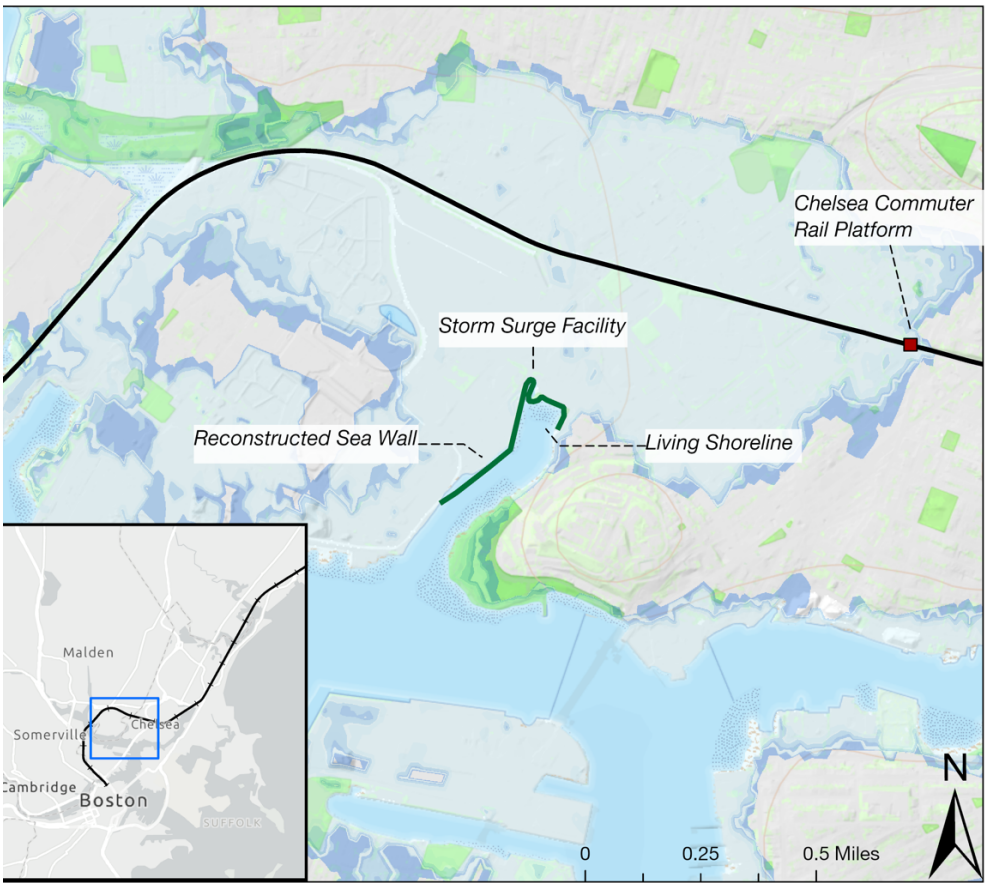


Figure 5-2: Island End River Park.

To prevent stormwater from backing up behind new storm surge barriers, Chelsea, Everett and Resilient Mystic planners have approached the T to request it increase its stormwater flood mitigation capacity in this critical area. 2020 meeting notes indicate that the transit authority has worked over a period of several years with the cities of Chelsea and Everett to come to an agreement regarding culvert and drainage extensions and erosion control. Overall, this project offers benefits to

approximately one mile of the railroad while requiring extensive buy-in and investment from the MBTA.

The city of Chelsea is also pursuing a large project in the name of climate resilience and pedestrian accessibility at Eastern Avenue, which serves as a critical transportation corridor for the North Shore. The city's near-term hope is to place an elevated pedestrian shared path alongside the avenue as a flood barrier, which would protect the surrounding area from 2050 1-in-100-year flood entering from Chelsea Creek. Additional elevations can protect the surrounding neighborhood from more severe flooding, such as that expected from a 2070 1-in-500 year event (City of Chelsea, 2023).

The boundaries of this project site are defined by MBTA commuter rail tracks, which at its current elevation would allow flanking to compromise the flood risk reduction benefits offered by the city's proposed elevation. To seal this flood pathway, the city of Chelsea has requested that the T elevate the commuter rail right-of-way to meet Eastern Avenue at the far northern tip of the study site. If implemented as envisioned, this project site would reduce flood exposure for one-third of a mile of commuter rail ROW. Figure 5-3 illustrates this project site.



Figure 5-3: Eastern Avenue Redesign Project Site.

Meanwhile, this site has long been the focus of MBTA grade separation efforts, which would elevate either Eastern Avenue or the railroad to reduce conflicts between the two for safety reasons. Also, shortly after this intersection, the railroad must pass under several overhead crossings and cross the Mill Creek bridge. Interviewees with MBTA planning staff and March 2024 stakeholder meetings reveal that the railroad grade cannot surpass roughly 2% using diesel locomotives due to weight and related acceleration/deceleration issues. This means that even small elevation changes such as those requested around Eastern Avenue require extensive lead-up distance, accompanied by the removal of overhead crossings to preserve appropriate vertical

clearance. The MBTA has signed a letter of support for this MVP-funded project, signifying their interest in contributing to flood alignment in the Upper Chelsea Creek, yet plans remained challenged by the difficulty of elevating the railroad over short distances without also reimagining several miles of adjacent tracks (Heffernan, 2023). Overall, the Eastern Avenue Resilience Project would offer moderate benefits for commuter rail assets, but safety and vertical alignment issues present challenges to the project for the foreseeable future.

One additional coordination question in Chelsea concerns that of the Forbes Park parcel, pictured in figure 5-4. In an interview, one Chelsea resilience planner points out that this parcel contains undeveloped land that the city and GreenRoots, its Environmental Justice nonprofit partner, have long hoped to repurpose into residential housing coupled with floodable green space to protect the neighborhood around Chelsea Creek from tidal flooding. In a heavily urbanized community like Chelsea, any green space presents an invaluable opportunity for multi-purpose neighborhood improvements. However, the commuter rail separates this parcel from the rest of the city, isolating it from would-be residents or other users. Absent new investments to allow for passage overhead the railroad, municipal and nonprofit organizations interested in establishing shore-based resilience measures at this location in Chelsea are unable to do so. The lot continues to sit unused as of 2024.

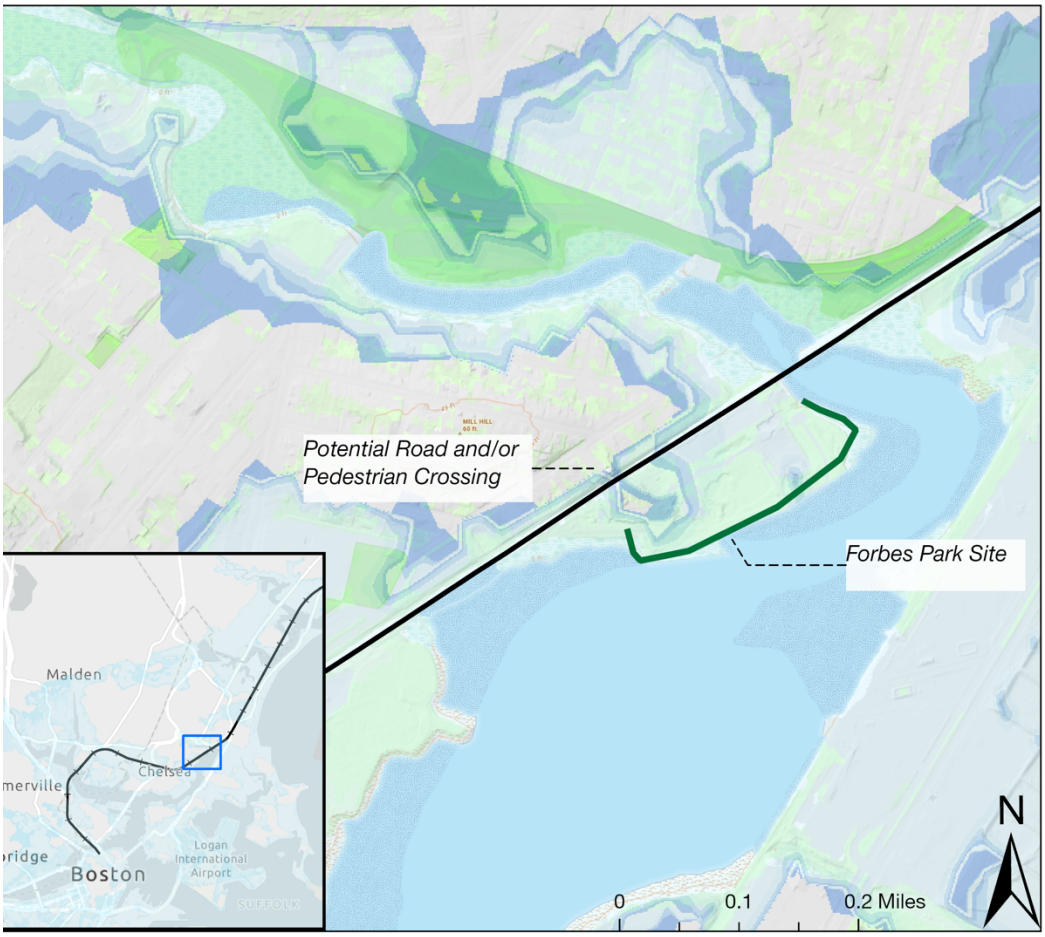


Figure 5-4: Forbes Park in Chelsea.

Looking to emulate the success of the Resilient Mystic Collaborative with which it shares a watershed border, Revere and Lynn have joined a regional planning effort with other cities in the Saugus River watershed known as the Saugus and Pines River Advocacy for Regional Resilience group, abbreviated as SPRARR (City of Lynn, 2024). Evolving out of an abandoned regional planning effort undertaken by the U.S. Army Corps to install flood gates at the mouth of the Saugus River, the consortium is now reviewing proposals to address localized flood pathways using up to ten shoreline-

based protective measures (Hunt, 2020). Little formal planning has yet been devoted to this issue, yet interviews with city of Lynn officials indicate that the group has obtained a 2024 MVP grant to narrow on three to five potential projects with regional benefits. Among this set of actions, the most relevant for the commuter rail is the restoration of Rumney Marsh, whose tidal flushing capacity has been reduced by development-related fill (Woods Hole Group, 2023). This marsh surrounds roughly 1.5 miles of the Newburyport-Rockport ROW, where MBTA Railroad Operations staff complain of routine tidal flooding between Revere's Oak Island neighborhood and the Saugus River. MBTA representatives have been present at some SPRARR working group meetings, but project proposals have not reached a point where specific railroad planning alignments beyond typical drainage upgrades within the marsh have been discussed. Internally, interviews with the former Director of Railroad Operations suggest that one particularly exposed segment through Revere's Rumney Marsh could be raised at a rate of approximately two inches per week, eliminating service issues in the area even before municipal actions are taken.

Although the SPRARR working group has yet to break ground on any new projects, the consortium is notable for its model of regional collaboration that it has used to secure successive rounds of state funding for planning and site selection with early input from the T. Potentially relevant flood barriers using road elevations, as well as marsh restorations, are shown together in figure 5-5.

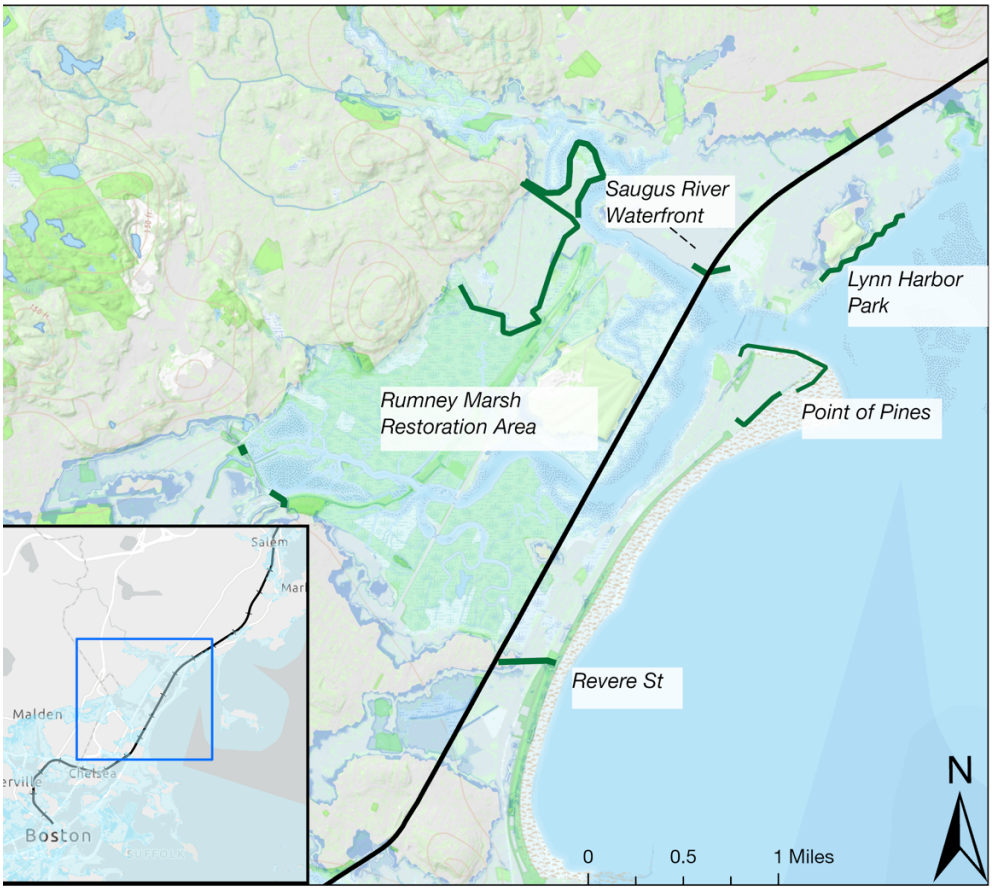


Figure 5-5: Road elevations and marsh restoration area listed in SPRARR regional resilience plan.

Partly in response to the vulnerability of its own waterfront and because of 2022-2023 station closures along its only other publicly accessible platform, municipal officials in Lynn have proposed a closure of the MBTA Riverworks station—currently available only to General Electric plant employees—in favor of opening a new platform along the elevated railroad viaduct that passes through downtown. Moving this station inland to an elevated section of right-of-way would increase passenger accessibility while reducing exposure (Riley, Jr., 2024). As Lynn's municipal resilience officers point out, meanwhile, this change depends upon the MBTA enacting its regional rail electrification plans, which would enable greater deceleration of the train following its

flyover of the Saugus River drawbridge—itself under bid for reconstruction after nearly a century of use. Interviews with MBTA and Lynn staff together point to the challenge of investing in structures like bridges or platform stations that are currently needed, yet may only be compatible with versions of the railroad that do not yet exist. This change in location is shown in Figure 5-6.

Lynn has acquired federal funding for this platform redesign to decrease the burden of planning and designing a new station for the MBTA, yet these plans require installation of the infrastructures necessary to support electrification. Beyond this point, Lynn officials report that establishing shoreline flood barriers within municipal boundaries is otherwise thwarted by a history of environmental contamination and coastal fill as well as waterfront access and environmental permitting laws. These factors collectively make it difficult to find suitable land for green infrastructure or to rebuild gray infrastructure that has fallen into disrepair, reducing the city's adaptive capacity even as flood mitigation becomes an increasingly urgent municipal priority.

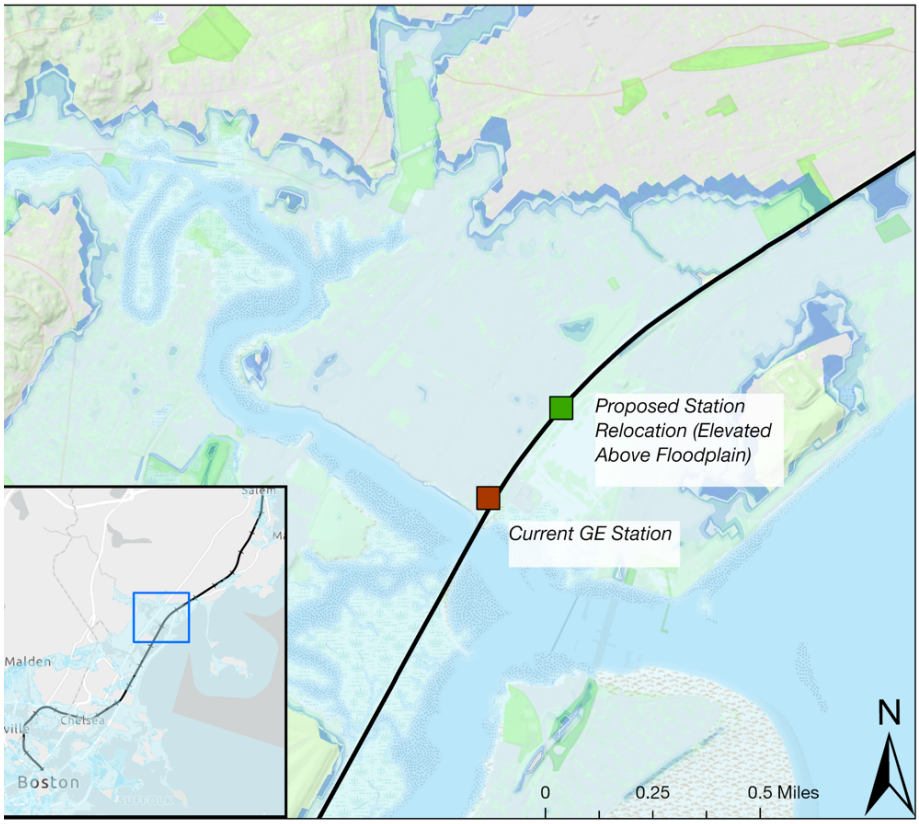


Figure 5-6: Lynn General Electric Station Relocation.

Salem and Beverly

The railroad ROW next approaches the coastline in Salem, where the train stops at its busiest platform on the Newburyport-Rockport line. Salem contains a 0.4-mile long underground tunnel as well as numerous sidings and a layover location, making the area dense with valuable commuter rail assets. Although interviews with Salem municipal officials underscore the value of regional transportation connectivity provided by the railroad to the city, they point out that local resilience planning has so far focused on the development of a climate overlay district to reduce the flood exposure of new development. District-level flood adaptation plans are also being laid

in parts of the city that more directly face the waterfront—specifically, the Point, Collins Cove and Willows neighborhoods (Frye & Warren, 2023). For now, the main project as directly relevant for the MBTA is a suggestion among Salem city staff to open an additional MBTA platform in the Forest River Conservation Area, well before the railroad enters downtown Salem (see Figure 5-7). While this action would not reduce the exposure to railroad assets where they are currently located, it would provide redundancy in the event that the Salem station and associated parking garage were to lose function. Salem municipal interviewees indicate that this project remains only a suggestion at this point, with no immediate intention to approach the T regarding the idea.

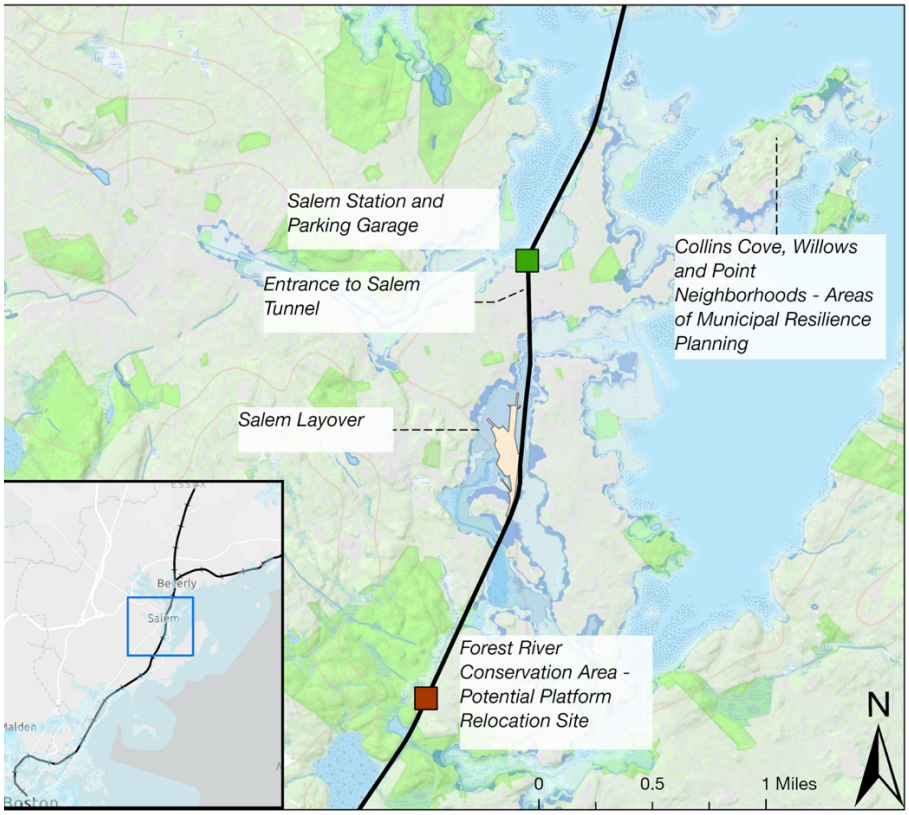


Figure 5-7: Commuter rail infrastructure and resilience measures in Salem.

After crossing the Danvers River, the railroad arrives in Beverly, traveling along the east bank of the Bass River. Another commuter rail station is positioned here amid a waterfront neighborhood containing critical businesses and municipal assets (Woods Hole Group et al., 2023). Here, Beverly and its nonprofit partner, the Salem Sound, are considering a range of district-wide adaptation scenarios within a proposed Bass River Resilience District, including soft and hard shoreline protections and strategic retreat. The Bass River resilience district represents an area of filled urban development extending as far as the commuter rail tracks, where the railroad passes over two sloped streets identified as extremely vulnerable to tidal and stormwater flooding. To make room for the elevation of these two roads, the city of Beverly must work with the MBTA to elevate its own tracks in the area. In return, the MBTA may benefit from other road elevations and/or coastal bank restorations that would reduce flood risk in patches at the nearby platform and Federal Street crossing (Woods Hole Group et al., 2023). So far, correspondence between the MBTA, Beverly, and the Salem Sound has been sporadic, but next steps will likely involve greater collaboration between these parties.

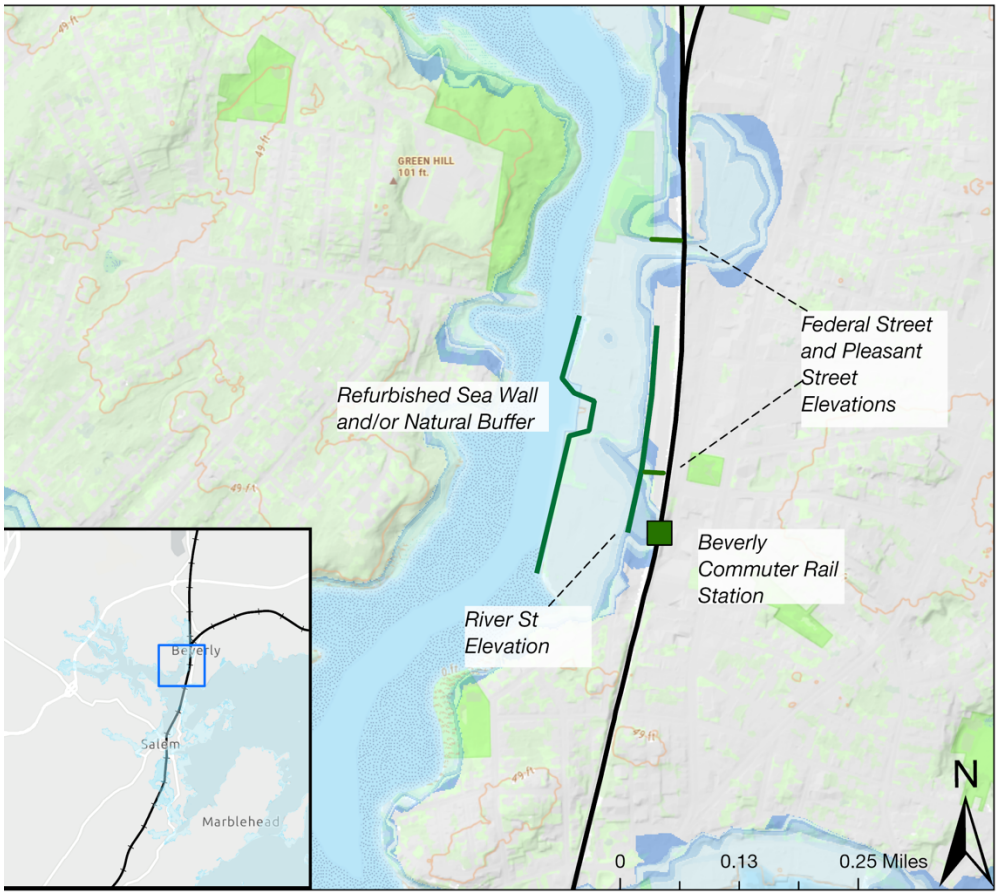


Figure 5-8: Adaptation measures listed in Beverly Bass River Resilience Plan.

Manchester-by-the-Sea

Splitting from the Newburyport branch in Beverly, the Rockport branch of the commuter rail route continues through Manchester-by-the-Sea, which the town most exposed to coastal flooding along the Cape Ann peninsula. Manchester has already undertaken numerous rounds of resilience planning, proposing a range of short- to long-term adaptation scenarios. The commuter rail runs across the opening of Manchester's inner harbor, creating a pinch point for future storm surge to enter. Among other proposals, the Manchester Coastal Resilience plan calls for the MBTA to

elevate its commuter rail tracks to provide vertical space for a tide gate at the mouth of the harbor. Simultaneously, this 2,000-foot elevated berm, constructed at an estimated cost to the MBTA of approximately $20 to $40 million, would provide flood attenuation to nearby homes and businesses when coupled with appropriate residential and municipal actions (Fuss & O'Neill, 2023). While there are few overpasses or other barriers blocking the MBTA from elevating this portion of right-of-way, construction and permitting costs may still make it challenging for the railroad to comply. Furthermore, coordination avenues between the Manchester-by-the-Sea and the T have not yet been established. When these ideas were presented to MBTA representatives from various departments, concerns about becoming the "Bank of the T" were raised, reflecting a suspicion of ballooning construction costs that are not uncommon on large capital investments requiring coordination with municipalities. Figure 5-9 captures this study area.

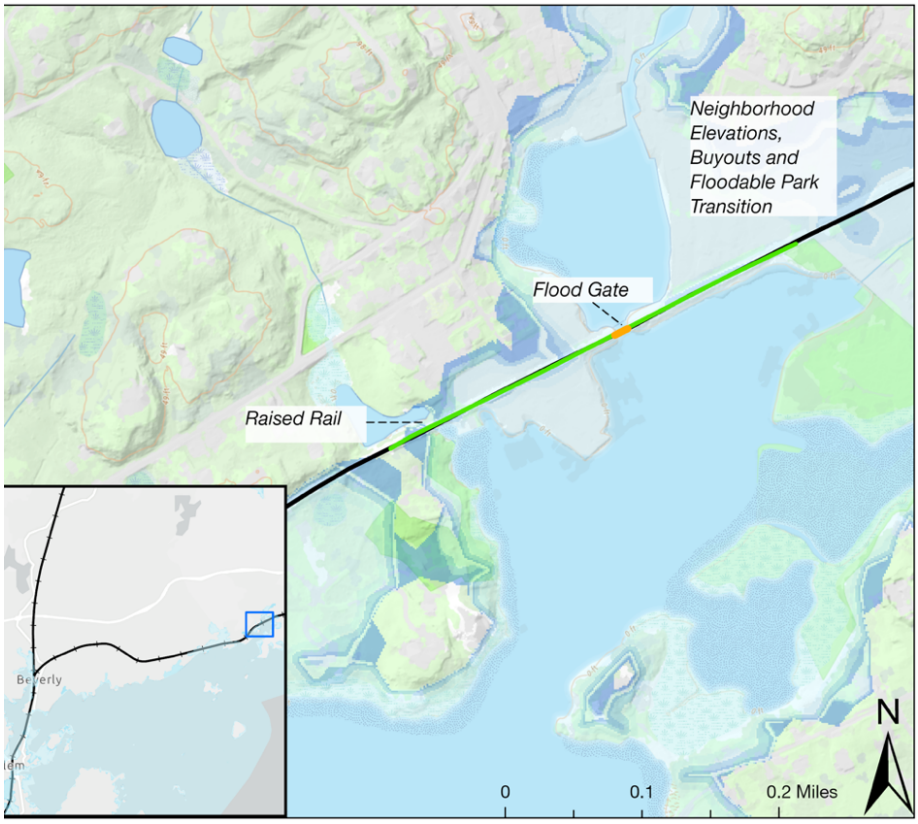


Figure 5-9: Raised Rail and Flood Gates in Manchester-by-the-Sea.

Gloucester and Rockport

The Cape Ann section of the Rockport line finally runs through the town of Gloucester before terminating in Rockport. While the railroad runs directly adjacent to the coast in this area, it remains at a relatively high elevation (see Figure 5-10), reducing its exposure to flood waters in the surrounding area except in isolated locations. Additionally, this area contains an excess of publicly accessible stations (West Gloucester, Gloucester and Rockport), providing redundancy should any one of them be compromised (Woods Hole Group et al., 2023). On top of these advantages, in

2022, the T replaced a drawbridge running over Gloucester Harbor at a cost of $100 million, improving the bridge's resistance within the flood velocity zone where storm surge could potentially wash out fragile structures (Massachusetts Bay Transportation Authority, 2022b). As for other municipal plans in the area, the city of Gloucester proposed a hurricane storm surge barrier flanking the Gloucester Harbor and Annisquam River in its 2015 Coastal Climate Change Vulnerability Assessment and Adaptation Plan, as visualized in Figure 5-10 (City of Gloucester & Kleinfelder, Inc., 2015). While such a project would assuredly affect the MBTA's disposal to flooding as it crosses through Gloucester Harbor, this project remains theoretical due to extreme costs, ecological considerations, and effects on boat access.

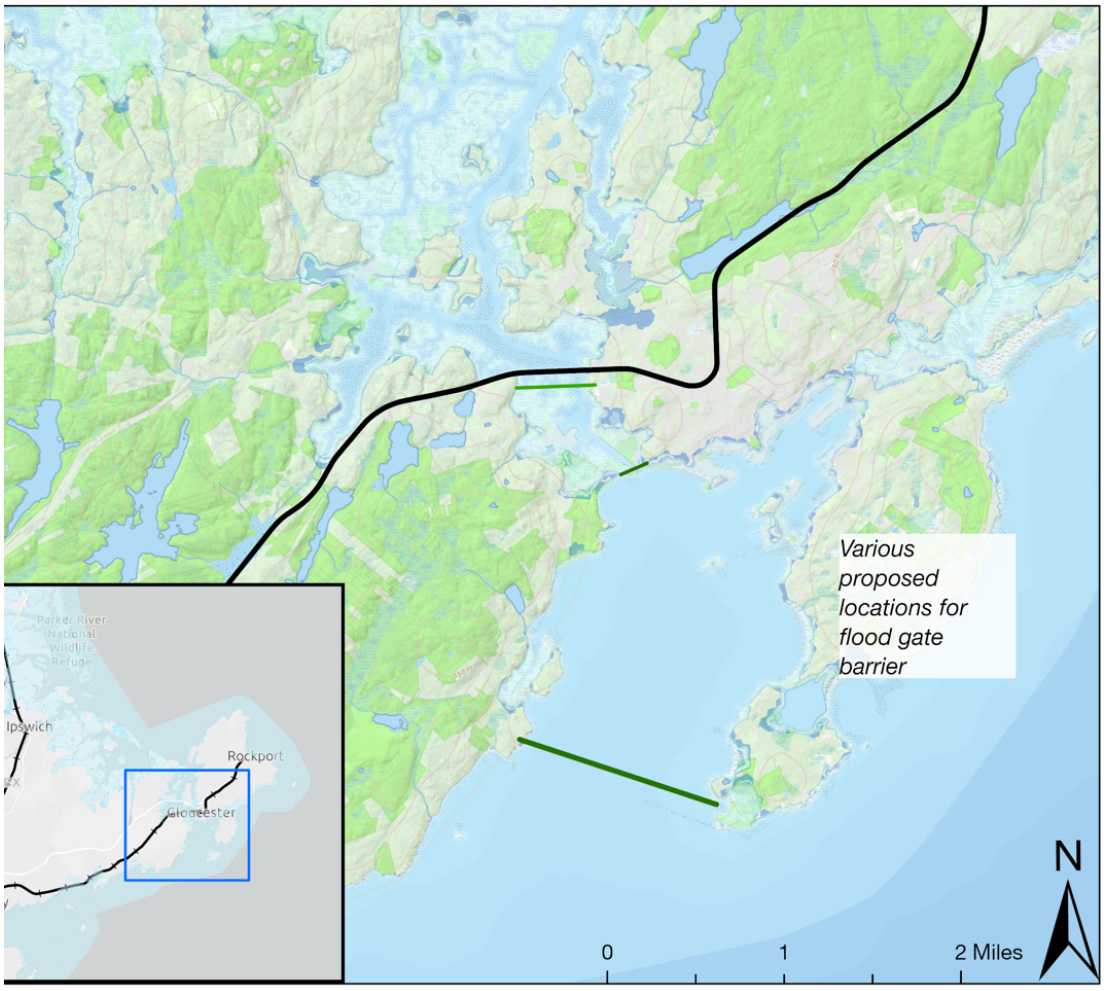


Figure 5-10: Proposed hurricane barrier in Gloucester Harbor.

Overall, municipal plans in Gloucester or Rockport do not pose direct implications for MBTA infrastructure, and the area is less vulnerable than other locations due to its underlying geography, redundant assets and recent investments made by the MBTA.

Wenham to Newburyport

After splitting from the Rockport line, the Newburyport branch travels through the towns of Wenham, Hamilton, Rowley, and Newburyport before terminating at the

border of Newburyport. With none of these towns' populations exceeding 10,000 and little urban development relative to other parts of the state, municipal and regional planning commission staff report that these towns primarily rely upon the commuter rail to bring tourists drawn to the beaches and pristine recreational areas for which this area is known. Notably, the Great Marsh is New England's largest salt marsh, with extensive dunes, barrier beaches, tidal estuaries, and upland islands (Massachusetts DCR, n.d.). Ipswich River Watershed Association staff report that most coastal resilience efforts in the area have relied on dam removals, culvert enhancements, or invasive species removal to restore the marsh's natural ability to dampen storm surge. Municipal capacity in these towns is also limited due to understaffed planning departments. As a result, state resilience funding for structural flood barriers has so far been limited to protecting the most urgent municipal critical infrastructure needs such as drinking water facilities or access roads for areas cut off from the mainland.

The MBTA has occasionally been involved in coordinating resilience actions with other organizations in the area. Ipswich River Watershed representatives have met with MBTA climate resiliency and Railroad Operations staff to open the question of culvert upgrades, as the T's ROW acts as an enormous physical barrier barreling through the middle of the Great Marsh. Unfortunately, efforts to upsize culverts beyond certain thresholds trigger extensive regulatory review, dramatically expanding the time and funding required.

Simultaneously, the MBTA is able to elevate its ROW through these last several miles of ROW with few of the physical impediments that characterize the cities closer

to Boston. However, any construction within a critical salt marsh ecosystem requires special permitting to avoid damage the surrounding ecosystem (see Figure 5-11). In part due to these regulatory restrictions, the MBTA currently has no resilience plans for this area beyond replacing any damaged infrastructure in-kind based upon existing condition and/or age. In interviews and meetings, MBTA Railroad planners indicate that changes to this method of prioritizing maintenance locations would require changes to their contract with private operators, which currently says little about operators' responsibilities to embed long-term resilience in maintenance procedures.



Figure 5-11: The commuter rail passes through a densely vegetated low-lying section of the Great Marsh in 2023 (McCabe, 2019).

A full list of adaptation projects are tabulated from Boston to Newburyport and Rockport in Table 5-1:

Location	Municipal Action	MBTA Action	Coordination Consideration
Boston, Somerville	Dam elevations	None needed	Hardening and eventually elevation of the Amelia Earhart and Charles River dams would prevent dam overtopping to protect large areas of the Lower Mystic and Boston Harbor. The Newburyport-Rockport line would benefit less than other railroad lines on account of its placement directly shoreward of the Earhart dam.
Boston, Somerville	Draw 7 and Schrafft Center waterfront redevelopments	None needed	These two flood barriers would prevent flanking of the Amelia Earhart dam to reduce exposure along approximately one mile of ROW as well as the critical Commuter Rail Maintenance Facility.
Chelsea	Island End Park flood storage and coastal barriers	Additional flood storage	Site redesign with federal funding would create flood storage at the terminus of the Island End River, enhancing the resilience of approximately 1 mile of right-of-way as well as the Chelsea commuter rail station.
Chelsea	Forbes Park Redevelopment	Allow passage over ROW	This longstanding idea seeks to redevelop a parcel of coastal land into residential apartments and a floodable park. If this parcel redevelopment proceeded, it would enhance the resilience of approximately 0.25 miles of railroad right-of-way.
Chelsea	Eastern Avenue Redesign Project	ROW elevation	The MBTA has been asked to elevate a 0.5-mile stretch of commuter rail tracks to meet the vertical position of a new municipal roadway elevation project, which would in turn protect one-third of a mile of right-of-way. The T is limited in its ability to meet this requirement due to nearby bridges and overhead crossings.
Revere, Saugus	Rumney Marsh Restorations, shoreline barriers	Culvert enhancements	The MBTA and surrounding municipalities would benefit from increased tidal storage provided by marsh restoration. Regional efforts to select flood path barriers are

			underway but offer few specifics for MBTA or other agencies to align with yet.
Lynn	Public accessibility and elevation of current GE train station	Regional Rail Electrification	City seeks MBTA buy-in on project using federal funding to relocate and open the GE station for public use. The city has little power to implement shore stabilization measures on its own due to regulatory and funding issues.
Salem	Neighborhood scale resilience plans (Willows to Collins Cove, the Point)	Open new station at Forest River Park	Salem is interested in opening a second commuter rail station in a nearby recreation area to provide redundancy. Other municipal actions focus on oceanfront neighborhoods rather than the Danvers river, where Salem station and tracks are located.
Beverly	Riverfront hardening or elevation	ROW elevation	Bass River Resilience Plan extends up to MBTA commuter rail tracks but does not incorporate them. If the "revitalize district" proposal is selected, low-lying roads would need to be elevated, coming into conflict with overhead railroad.
Manchester	Harborwide elevation	Raised rail as flood control structure	MBTA would be responsible for elevating approximately 2,200 feet of ROW, with raised berm acting as flood control barrier for adjoining neighborhood.
Hamilton, Rowley, Newbury, Newburyport	Great marsh restorations	Culvert enhancements	Wetland migration, elevation and culvert permitting issues are at play in areas regulated as wetlands.

Table 5-1: Summary of major resilience actions alongside Newburyport-Rockport Line.

Collectively, these municipal actions target many of the same problem spots identified as historically commonplace railroad flood locations (Concannon & Lyons-Galante, 2024). For example, drainage systems in Cambridge and Somerville currently backwash from Mystic River tides, bringing flooding to interlockings around the all-important CRMF. Resilient Mystic projects at dams and along the shores of the Mystic River will directly mitigate some of these issues for the T—assuming they are able to maintain the momentum they have gathered in recent funding cycles. As another

example, dispatchers and repair workers report in interviews that another stretch of railroad track from Oak Island to the Saugus River Drawbridge in Revere floods routinely, making it challenging to run service at high tides or during storms. Projects proposed as a result of the SPRARR initiative bring attention to this region, where the commuter rail is seen as a critical connector of the North Shore's working population to downtown Boston's economic opportunities.

At the same time, other municipalities recognize the coastal flood vulnerability they share with the T, yet are unable to directly address the issue due to capacity limitations or regulatory entanglements. Calls for elevation of the Newburyport-Rockport line must reckon with other infrastructures occupying the vertical space surrounding the rail line, as well as operational priorities besides resilience, such as safety, that could change the desirability of external alignments. Railroad arrangements, it turns out, are inflexible in the way they are laid out, occupying much of the same footprint that they did when they were first built. Though there are many promising opportunities to tie transformations in the railroad's location and vertical profile with changes taking place across the municipal landscape, each site must be considered on its own terms to tease apart the potential compromises that can be made across the political borders of the T and surrounding municipalities.

Chapter Six: Discussion

Having reviewed numerous study areas where the commuter rail meets municipal efforts to enhance resilience, it is clear that each site affects the MBTA differently, whether by altering local flood pathways or by imposing changes upon the railroad itself. Within this variety, several consistent themes emerged out of the initial vulnerability screening, the review of local resilience planning reports, and subsequent interviews. This discussion highlights ongoing issues and possibilities for further action.

Coordination Barriers

Even considering the many climate adaptation schemes being considered across Massachusetts' coastal zone, these projects still fail to deliver continuous coastal protection, leaving gaps that will continue to affect regional transportation. When compared to storm barrier mega-projects as discussed by Kirshen et al. (2020), nature-based solutions are found to be more flexible, less costly, and provide greater social and ecological co-benefits. The tradeoff of this approach is that the coastal adaptation process is less synchronized, with results dependent upon local vision and follow-through. MVP projects tend to target sites over which local governments have greater oversight, such as schools, water treatment, emergency provision services, while the T is perceived as existing outside of local jurisdiction. As a result, resilience plans tend to get formulated first, before the T is approached for input—despite the

railroad's ability to make or break certain projects. In some cases, the T is able to make decisions that are mostly compatible with the resilience needs of municipalities, as at the Island End River Park. More common are sites with lopsided benefits—where T compliance would resolve issues faced by municipalities, yet fail to improve railroad resilience, or vice versa. In these scenarios, suspicions about being used as the "Bank of the T" may make it challenging to establish working relationships across political boundaries.

To increase the effectiveness of their coordination, watershed associations have begun adopting a model in which many neighboring municipalities sign onto state resilience grants together, supplementing these funding sources with federal money for higher impact regional projects. This model of regional resilience coordination works especially well where non-municipal players like utilities and state agencies are brought into planning conversations from the start. However, the MBTA's reach exceeds even these regional ventures. Climate adaptation coordination at the scale necessary to cover the entire commuter rail will likely require some form of dedicated flooding department within the MBTA itself, or new governance structures to which all relevant adaptation parties must defer. Some proposals of what this might look like are detailed in the recommendations section below.

Even where municipalities have pursued their own resilience efforts, limitations governing railroad engineering and design can prevent the MBTA from carrying out compatible actions in certain locations. While elevating tracks is an obvious solution to reduce railroad flood exposure, clearance requirements for overhead bridges and utility

lines impede elevations in urban areas like Chelsea. On the ground, at-grade road crossings present safety and service reliability issues that the T would prefer to avoid. This issue can be seen where railroad crossings are generated, which include Lynn's GE Station and Chelsea's Eastern Avenue and Forbes Park. A related issue are railroad investments in components with long service lifespans, particularly bridges. These act as anchors, tying tracks within the surrounding vicinity to set elevations for the foreseeable future. Conversations conducted with the T's policy and planning personnel about the Saugus River Drawbridge point to the challenges of investing in current safety and resilience needs when these projects can potentially hamper future adaptation flexibility.

In comparatively rural portions of the state, there are fewer road or overhead crossings standing in the way of right-of-way elevations. These municipalities north of Salem also have different vulnerability profiles, with larger volumes of green infrastructure, smaller Environmental Justice populations, and less development in highly exposed flood plains. However, these potential advantages are offset by limited municipal staff capacity, with towns relying on volunteers, regional planning commissions or nonprofits to take the lead on resilience efforts. The document review and interviews revealed that shoreline-based stabilization measures with co-benefits for the MBTA were mostly limited to the urban corridor between Boston and Salem.

One challenge facing the development of municipal resilience schemes is that they must address not only the emerging challenges of coastal climate change, but centuries of related environmental problems. Interviewees with expertise in Boston,

Lynn, Chelsea and Beverly repeatedly mentioned how recent coastal storms were recreating the outlines of water bodies that had been filled by urban development over the previous 150 years. To deal with this issue, redeveloping or retreating from especially vulnerable coastal lands may often require additional attention to remediate centuries of contaminated soil and degraded ecosystems.

MBTA Internal Barriers

The current organizational structure surrounding the operation of the commuter rail poses a barrier to its long-term adaptation. Since federal railroad regulations are oriented towards safe service delivery, historic flood events such as those documented in interviews with MBTA and Keolis staff reveal that issues with flooding are usually tackled reactively in order to restore service as quickly as possible. Many current flood solutions are fairly rudimentary—including piling sandbags, deploying temporary jersey barriers, tamping ballast that has been dislodged, or installing drainage pumps (Concannon & Lyons-Galante, 2023). Even when implemented proactively, these measures have historically helped deal with short segments of intermittent flooding and are unsuitable for miles of open coastal water or regular tidal flooding.

Vulnerability screening results suggest that the commuter rail's adaptive capacity is inherently limited by its geometry and placement within the surrounding landscape. The long, narrow properties making up the railroad ROW produce extensive coastal exposure and a limited area on which to implement resilience measures—at least without building maladaptive barriers alongside tracks that would deflect flood

waters onto surrounding landowners' properties. Even compared with other large linear property owners like MassDOT, the railroad is constrained in the possible resilience measures it may carry out due to its inability to exceed certain curve or grade limits on its own tracks. It is harder to redirect a railroad around a curve or over a hill than it is a highway or a park.

The MBTA's Capital Planning Report makes it clear that massive amounts of money are needed simply to bring current infrastructure up to standard operating condition even before transformative visions like rail modernization are contemplated. The current Capital Plan claims that the MBTA requires $25 billion across all travel modes to bring existing equipment up to state of good repair standards (Massachusetts Bay Transportation Authority, 2023b). With such urgent needs across the combined bus, rapid transit, ferry and commuter rail system, the agency must balance its railroad investment priorities against its battered, extremely busy bus and rapid transit systems that are equally vulnerable, albeit in different ways.

Coordination Opportunities

As proposed, multiple municipal projects between Boston and Newburyport/Rockport would protect moderate (0-1 mile) segments of MBTA assets. These ecological restoration and green space redevelopments are intended not only to reduce flood exposure within the surrounding neighborhood but also to provide a basis for improved livability and economic growth, with benefits by extension for transit demand. Considering how much funding and time has gone into planning these

projects, they serve as ideal starting points for further collaboration with the T. The MBTA has already joined several working groups with these municipalities, proving that it is willing to hear what requests are being proposed for the railroad to match.

Knowing that climate change effects are not limited to political boundaries, planning commissions and watershed associations have formed successful regional partnerships that have proven to be highly effective at generating productive collaboration. The Resilient Mystic Collaborative has been a particularly early mover in this regard, gathering dozens of municipalities and state agencies to consider key regional points of coastal flood vulnerability (Resilient Mystic Collaborative Lower Mystic Project Team, 2021). These formal and informal venues for exploratory planning offer an extremely constructive opportunity to identify where to dedicate additional regional attention. It remains to be seen how these collaborations will continue to evolve now that the US Army Corps of Engineers has convened a large-scale project to study coastal flooding in the Greater Boston Harbor with congressional funding available (Massachusetts Office of Energy and Environmental Affairs, 2023b).

MBTA Internal Opportunities

Although it has only begun to study the climate vulnerability of the commuter rail, the MBTA benefits from research and capital improvement projects that it has already completed for its facilities, rapid transit, and bus systems. Existing research has mainly focused on coastal flooding given the agency's extensive infrastructure exposure in coastal zones, but recent work has also begun to explore other climate

hazards, such as extreme heat (Lyons-Galante 2024). This experience in climate planning benefits the T's efforts now focusing on the commuter rail by standardizing its methodology and increasing knowledge-sharing across departments.

The MBTA's intention to pursue Regional Rail Modernization presents a tremendous opportunity to embed climate resilience in any associated rolling stock, ROW, or facilities upgrades. New Electric Multiple Unit vehicles, for example, can accelerate more quickly than diesel trains, allowing them to climb steeper grades. This introduces prospects for new railroad configurations and forms of passenger access, such as the elevation and public opening of a new commuter rail station in Lynn or strategic track elevations in other locations. Simultaneously, concerns exist that sustainability investments will divert resources from necessary resilience-specific changes.

Email correspondence with MBTA Railroad Operations personnel reveals that flood exposure along certain segments can be reduced relatively easily. For instance, one section traveling through Rumney Marsh in Revere can be elevated up to approximately one foot with virtually no service downtime. As the question of right-of-way elevation recurs across resilience study areas, testing elevation in areas where this is relatively straightforward will help inform how the T decides to approach more problematic areas.

Overall, the vulnerability screening performed in this thesis reveals that the most extreme exposure and system sensitivity are concentrated in a few select locations. In terms of assets, these vulnerability hotspots include facilities and junctions, where

signal and switch infrastructure are placed to facilitate the movement of trains across intersecting tracks. These priority locations present obvious starting points for vulnerability assessments, offering an opportunity to make significant resilience headways even before network-wide vulnerability assessments has been conducted.

Policy and Governance

Federal and state governments have extended their support to climate adaptation work, providing an unprecedented opportunity to take advantage of resilience funding. At the same time, regulations passed for the purposes of resilience and sustainability can contradict their stated intentions. For example, MassDEP enforces the Clean Water Act in the state of Massachusetts to discourage development in wetlands. While it is essential to retain wetlands' ecosystem services, these and other regulations can prevent agencies like the T from restoring degraded infrastructure that has fallen into wetlands following extreme weather. This problem is especially noticeable because wetlands such as Rumney Marsh are especially frequent flood locations. Other contradictory regulations include open waterfront requirements where flood barriers are needed, green infrastructure requirements in urban environments with little space for it, and harbor navigation standards that prevent the expansion of green infrastructure.

Broadly speaking, Massachusetts's climate resilience planning currently hinges upon state support being given to projects proposed and implemented by local governments. This leads to variation in in resilience goals and practices both across

different municipalities, and between municipalities and the T. When accounting for private coastline ownership and a division of regulatory, funding and agenda-setting powers across levels and bodies of government, many cities and towns across coastal Massachusetts are limited in their ability to execute meaningful flood resilience projects, even before the question of implications for the railroad are raised.

Implications for Climate Change Adaptation of Transit Systems

This work explores the vulnerability of the MBTA Commuter Rail system based on understandings of system sensitivity and exposure, as well as a multitude of actions being undertaken to alter the effects of flooding across the coastal landscape of Massachusetts. Given its volume of vulnerable assets across all ridership modes, the T is weighing the costs of adapting service as it currently exists against reimagining how service itself will look in the era of climate change. The MBTA is already thinking along these lines under the leadership of General Manager Phil Eng, whose office issued a statement in 2023 of the T's renewed commitment to transparency, modernization, sustainability, dependability and reliability after decades of neglect and public controversy (Massachusetts Bay Transportation Authority, 2023c). By staking its reputation to accountability and addressing its backlog of repair work, the T is honoring the fact that transit service emerges not only out of physical infrastructure, but the way that mobility is perceived amongst the public—as a lifeline, a necessity, or a last resort. Even prior to installing infrastructural answers to flooding, a sustainable, modernized transit network is in many ways a more resilient system than one that

passengers are looking to avoid taking at every opportunity. Although it may currently sound unthinkable to consider proactively replacing commuter rail service with flexible shuttle buses in anticipation of extreme high tides or storms, this sort of creative thinking can help center mobility and dignity as key values even as operating heavy rail becomes increasingly burdensome.

These conversations are embedded within the multi-scale and multi-directional effects of climate change brought to Massachusetts. Climate change increases the volatility of procurement and maintenance costs, exacerbated by turbulent labor bargaining practices and supply chain disruption tied to other macroeconomic and public health conditions. More locally, grid failures during heat waves or other periods of high demand impose direct impacts on the T as Massachusetts's largest consumer of electricity, as do changes to living and working patterns borne out of gentrification, remote work, and suburban development. Within the realm of politics, factors that affect transit resilience include the tax base, funding decisions, regulations, zoning laws, and more informal elements like societal valuation of climate adaptation. Within the realm of natural hazards, responses to coastal flooding must be drawn from an understanding of linked climate hazards like extreme heat, cold, wind, drought, and precipitation—as well as long-term environmental trends such as water, air, and soil degradation, biodiversity loss, and species shifts (Fragapane, 2024). Whether or not Massachusetts eventually experiences its own superstorm rivaling Hurricane Sandy, this accumulation of stressors imposes costs to unwieldy, expensive enterprises like a

transit authority, even as they undercut the agency's ability to proactively address these issues.

In its SHMCAP, the state has called for each agency to submit proposals for how they are intending to reduce the Commonwealth's climate change vulnerabilities (Massachusetts Office of Energy and Environmental Affairs, 2023a). Even with the impressive inter-agency collaboration sparked by such an undertaking, this document still relies on a somewhat formulaic understanding of vulnerability as historically employed by the Federal Highway Administration and the MBTA that decenters social resilience as the guiding object of inquiry. The vulnerability screening formula of exposure, criticality and adaptive capacity is valuable in its simplicity and broad applicability, best used to ignite discussion that can hopefully lead to deeper resilience protocols.

Recommendations

MBTA Recommendations

1. Pursue proactive resilience at critical locations: Based upon the facilities vulnerability screening and any additional assessments conducted next, the MBTA should take immediate steps toward adaptation measures in locations that provide the most significant resilience benefits across the full system. At the Commuter Rail Maintenance Facility, for example, securing backup maintenance equipment and removing fragile fuel lines would lower the chances of the entire transportation network shutting down in the event moderate to severe flooding.

To complement this work, the T should select install resilience measures at commonly flooded lengths of ROW in relatively straightforward locations with fewer political or other complications to work across. This could include, for example, lengths of the Rumney or Great Marshes. Where possible, the T should avoid investments that will anchor the railroad to vulnerable benchmarks in the future.

2. *Align commuter rail operations with long-term resilience goals*: The new commuter rail operations contract and Rail Modernization Program should specify how the system is being equipped to deal with flooding. This could include new forms of technologies that move trackside signal assets into the train cabin, greater integration and publicization of geospatial flood data for other MBTA departments, or new labor arrangements that make it simpler to respond to disruptions caused by severe weather. In elaborating these changes, rail network transformations should not only be oriented towards improving railroad service in the ways that it currently exists, but also incorporate an orientation towards regional mobility as its ultimate goal.

Governance and Coordination Recommendations

1. Coordinate with external stakeholders now: At a minimum, the T should take advantage of existing resilience efforts by learning where they exist and the implications they hold for the railroad in the area. Based on the results of the ROW vulnerability screening, similar resilience inventories could be compiled for the

railroad's south side in Boston, along the Greenbush line, and for the Cape Cod Flyer. Relationships should be established with relevant local governments and community-based organizations.

2. *Consider establishing a regional flood authority*: To overcome jurisdictional discrepancies, funding shortcomings and the contradictory regulatory environment, the state should explore the establishment of new regional flood governance mechanisms. These could grow out of MassCZM resilience districts that have already been proposed or lead to an entirely new regional flood authority to which other governing bodies operating in the coastal zone would defer.

Limitations and Areas for Further Research

Because very few existing studies have been dedicated to the intersection of climate issues and MBTA railroad infrastructure, this work eschewed formal decision matrices or quantified damage costs in favor of a more open, mixed methods approach. This tradeoff means that further research will likely seek to formalize the decisions available to the MBTA, such as payoffs from investments in state of good repair vs. flood barriers shared with municipalities. Likewise, the case study is necessarily limited to one region. It would be worth extending this investigation to other lines of the railroad's north side and the entirety of the south side that received scant mention in this document. Based upon the vulnerability screening conducted in this

study, the logical next routes to review would be the Cape Cod Rail, Greenbush and South Coast Rail lines.

Besides these limitations, I relied exclusively on the MC-FRM to assess flood risk, producing a vulnerability screening that is necessarily limited to the Massachusetts coastline. Further research could expand this inquiry to inland flooding using custom watershed hydrology models or remote sensing analytics that track changes in surface water occurrence over time.

Lastly, interviews were conducted primarily with policy spokespersons both within the T and outside it. Assuming Institutional Review Board approval for Human Subjects Research, conversations with construction workers, emergency response crews, electrical workers, signals and switch repair persons, etc. would help flesh out the day-to-day challenges facing the T's labor force on the ground.

Conclusions

The Massachusetts Bay Transportation Authority's commuter rail is the fifth-busiest rail transit system in the United States, yet its climate vulnerability has received scant research attention. Due to its vast size and low-lying position within the surrounding terrain, the commuter rail is inherently vulnerable to flooding. These issues are aggravated by climate change and competing organizational priorities, which lead to increased damages over time that cripple service. Since 2017, the state of Massachusetts has commenced a locally driven climate resilience campaign in which municipalities respond to coastal flooding with adaptation actions that generate

potentially broad co-benefits. Recognizing that flooding is not constrained by political boundaries, this research situates railroad resilience within the context of its surrounding landscape to address the following question:

- *How do adaptation strategies among the municipalities bordering the Newburyport/Rockport line of the MBTA commuter rail affect the railroad's exposure to coastal flooding?*

The project also incorporates the following sub-questions:

- *Where is the commuter rail most vulnerable to coastal flooding, according to asset data, usage demographics and climate change models?*
- *How are coastal flood resilience measures coordinated between municipalities and the MBTA in the service area of the Newburyport-Rockport line?*
- *What are the range of barriers and opportunities to enhance continuous coastal flood resilience along the MBTA commuter rail system?*

Combining the Massachusetts Coastal Flood Risk Model with site visits and asset data, a vulnerability screening is produced both for facilities and right-of-way track based upon their respective exposure and sensitivity. The screening indicates that the Commuter Rail Maintenance Facility is found to be the most vulnerable among all maintenance and dispatch locations, while the Newburyport-Rockport is the most vulnerable passenger route.

Following this screening, an inventory of coastal resilience actions within the service area of the Newburyport-Rockport line is generated. Using information provided by interviews with municipal climate planners, resilience projects are

assessed for their direct and indirect impacts to the commuter rail, as well as for their approach to political coordination. Findings suggest that municipal coastal resilience actions are most concentrated in the dense urban environment between Boston and Lynn, where their implementation remains challenged by factors such as inadequate funding and contradictory regulations. Even in areas where larger scale municipal shoreline-based flood mitigation is proceeding, the T has a mixed ability to enact complementary actions such as track elevations due to the railroad's inflexible layout (i.e. grade limitations or overpass obstacles) and safety concerns. Acceleration of resilience planning and enhanced collaboration throughout the resilience planning process is needed to ensure that MBTA and municipal resilience visions are transparent and mutually compatible. New governance structures are recommended to better centralize flood mitigation funding, design, and compliance in greater Boston.

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Appendices

Appendix 1: Sample Interview Questions

1) How has your city/town carried out planning to mitigate coastal flooding or associated damages?
2) Please describe the commuter rail infrastructure within the boundaries of your work.
3) What role does the commuter rail (and MBTA) play in your municipal community (e.g. is it used by a specific subset of people, used only during certain times of the year, how long has MBTA infrastructure been in use?)
4) What are the major resilience initiatives in and around the area in which you work? What, in your professional experience, makes these projects especially notable?
5) What are the goals of these resilience initiatives?
6) Are there certain areas in your municipality that are known to be affected by coastal flood events? What factors contribute to this issue (e.g. high tides, floods, drainage issues?)
    a) What are the consequences when these areas are impacted by floods? How have these impacts changed over time, if at all?
7) What sources of support have you and/or your municipality received or expect to receive otherwise to pursue these initiatives?
8) Based on your expertise, what difficulties and opportunities have you witnessed or do you anticipate in partnering with the MBTA to protect your community from coastal flooding?
9) What actions are needed from the MBTA to ensure the greatest possible coordination?

Appendix 2: Historic Flood Locations

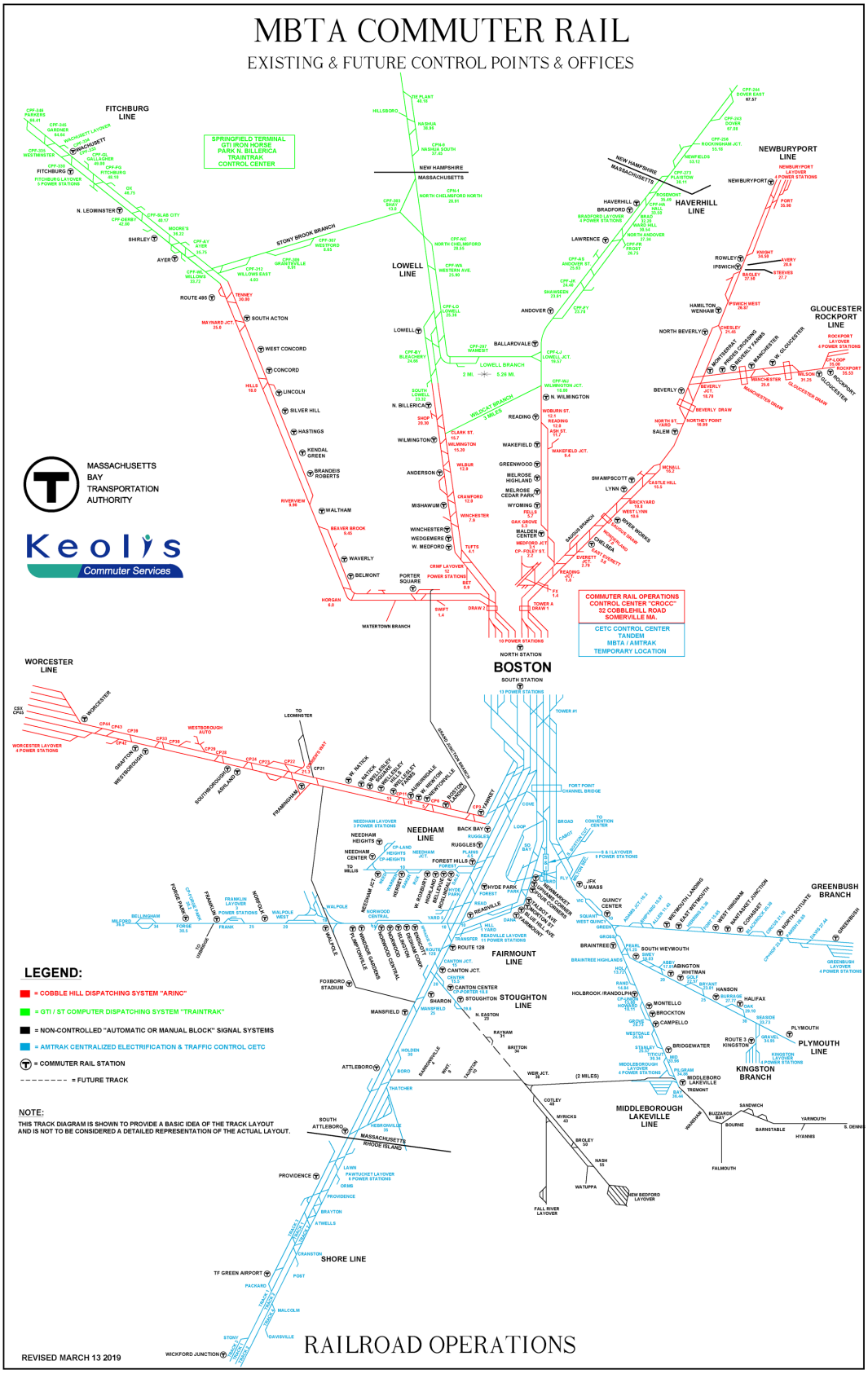
In preparation for the rail modernization project, the T has begun collecting information about common flood locations as recollected by work crews and dispatchers. These segments are by no means comprehensive, but are useful as a first step to addressing problem spots more systematically. Common drivers of flooding at these locations include nearby (historic or current) water bodies, as well as drainage conflicts where other infrastructures (overpasses, culverts, parking lots, residential properties) pool water onto railroad tracks.

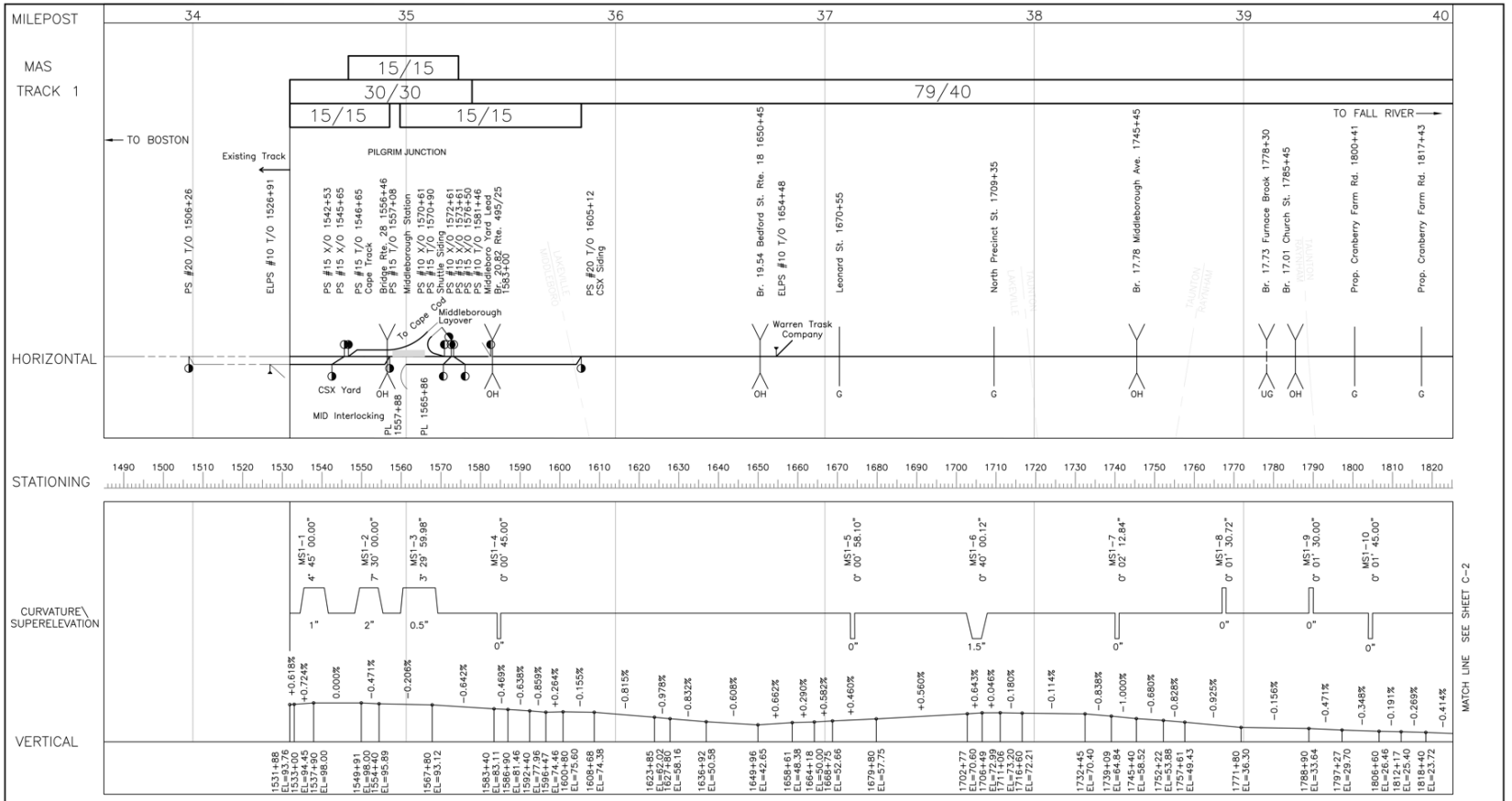
Route	Railroad Location	Municipality
Lowell	Wilmington Station - Middlesex Canal	Wilmington
Newburyport-Rockport	FX Interlocking - Boston Engine Terminal	Boston
Middleborough	Armstrong Crossing to Plain Street	Braintree
Worcester	Natick Station	Natick
Lowell	Medford Hillside	Medford
Fitchburg	Swift Interlocking	Somerville
North Terminal Area	Miller's River outfall adjacent to Tower A	Boston
Danvers (not in active service)	Peabody Square	Peabody/Salem
Rockport	Boardman Avenue - Mill Stream*	Beverly Farms
Fitchburg	Union Square - Webster & Prospect St	Somerville
Newburyport-Rockport	Oak Island to Saugus Drawbridge*	Revere
Newburyport-Rockport	Salem Tunnel*	Salem
Lowell	Butters Row Bridge	Wilmington
Fitchburg	Bridge and Track Washouts	Leominster
Fitchburg	Waltham to Littleton	
Fitchburg	Lincoln Rd	Lincoln
Newburyport-Rockport	Highway Bridge 495	Andover
Newburyport-Rockport	Encore to Oak Island	Saugus, Revere

Haverhill	Wellington Underpass	Medford
Haverhill	Cross St Bridge	Bradford
Newburyport-Rockport	Ipswich River	Ipswich

Appendix 3: Track Chart and Control Points Map

Track charts are used for railroad operations. Reflecting their primary purpose, they focus on key operational features such as track grade, curvature, and landmarks like road crossings. A Control Points map roughly corresponds with railroad track and switch locations in physical space, but the emphasis remains on mechanical structure rather than on spatial accuracy. These documents reflect the current mode of thinking predominant in railroading, in which the transit network is conceived as a self-contained machine dissociated from the surrounding landscape. The work I put forth in this thesis argues that this approach ought to be combined with an appreciation of the broader terrain within which climate hazards occur.


MBTA COMMUTER RAIL
EXISTING & FUTURE CONTROL POINTS & OFFICES
FITCHBURG LINE
SPRINGFIELD TERMINAL
CTI IRON HORSE
PARK N. BILLERICA
TRAINTRAK
CONTROL CENTER
NEW HAMPSHIRE
MASSACHUSETTS
LOWELL LINE
STONY BROOK BRANCH
LOWELL BRANCH
2 MI. 5.26 MI.
WILDCAT BRANCH
3 MILES
NEWBURYPORT LINE
HAVERHILL LINE
GLOUCESTER ROCKPORT LINE
MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
Keolis
Commuter Services
COMMUTER RAIL OPERATIONS CONTROL CENTER "CROCC"
32 COBBLEHILL ROAD
SOMERVILLE MA.
CETC CONTROL CENTER
TANDEM
MBTA / AMTRAK
TEMPORARY LOCATION
WORCESTER LINE
BOSTON
SOUTH STATION
NORTH STATION
NEEDHAM LINE
FAIRMOUNT LINE
STOUGHTON LINE
GREENBUSH BRANCH
PLYMOUTH LINE
KINGSTON BRANCH
MIDDLEBOROUGH LAKEVILLE LINE
SHORE LINE
LEGEND:
= COBBLE HILL DISPATCHING SYSTEM "ARINC"
= GTI / ST COMPUTER DISPATCHING SYSTEM "TRAINTRAK"
= NON-CONTROLLED "AUTOMATIC OR MANUAL BLOCK" SIGNAL SYSTEMS
= AMTRAK CENTRALIZED ELECTRIFICATION & TRAFFIC CONTROL CETC
= COMMUTER RAIL STATION
= FUTURE TRACK
NOTE:
THIS TRACK DIAGRAM IS SHOWN TO PROVIDE A BASIC IDEA OF THE TRACK LAYOUT AND IS NOT TO BE CONSIDERED A DETAILED REPRESENTATION OF THE ACTUAL LAYOUT.
RAILROAD OPERATIONS
REVISED MARCH 13 2019



NOTES:
1. TRACK CHART UPDATED WITH 100% MIDDLEBORO SUBMITTAL.

LEGEND:

- TURNOUT (T/O)/CROSSOVER (X/O)
- ELECTRIC LOCK
- CURVE W/OUT SPIRALS
- CURVE W/ SPIRALS
- 5280 DISTANCES (FT) BETWEEN MP
- PLATFORM CENTER
- PLATFORM ONE SIDED
- MAS MAXIMUM AUTHORIZED TRAIN SPEED (MPH)
- 60/50 MAS PASSENGER/MAS FREIGHT (NF= NO REGULAR FREIGHT, NP= NO REGULAR PASSENGER)
- UG UNDER GRADE BRIDGE ROAD/WATER UNDER RAILROAD
- OH OVERHEAD BRIDGE ROAD/BRIDGE OVER RAILROAD
- G GRADE CROSSING
- GRADE CROSSING TO BE CLOSED
- DEEDED GRADE CROSSING TO BE CLOSED
- G/L GRADE CROSSING TO BE GATED & LOCKED
- TP TRACTION POWER FACILITY
- 0° 00' 0.00" DEGREE OF CURVATURE (CHORD DEFINITION) – SUPERELEVATION

0 1200 2400 3600 4800
SCALE: 1" = 1200'

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
SOUTH COAST RAIL
DESIGN ENGINEERING AND PM/CM SERVICES
CONTRACT NO. K78PS01

MIDDLEBOROUGH SECONDARY
PROPOSED TRACK CHART
SHEET 1 OF 2

vhb HNTB 99 HIGH STREET BOSTON, MA 02110 (617) 728-7777

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
APPROVED BY:

ISSUE | DATE | DESCRIPTION | BY | CHKD. | APP.

PROJECT MANAGER Date
PROJECT MANAGER Date

HORIZ: 1"=1200'
VERT: NTS
DATE: 05/2019
DES. BY | DR. BY | CHK. BY
PLAN NO.
SHEET C-1
ISSUE

FILE NAME: SCR - TRACKCHART - 20190515.DWG
SCR - TRACKCHART - 20190515.DWG Plotted on: May 28, 2019 11:48 AM

Appendix 4: Complete List of Facilities Ranked by System Criticality

Category	Name	Municipality	Line	Vulnerability
Maintenance Facility	Commuter Rail Maintenance Facility	Somerville/ Boston/ Cambridge	All Routes	High
Support Facility	Cobble Hill	Somerville	All North Side Routes	Medium
Support Facility	South Station	Boston	All South Side Routes (includes Amtrak Dispatching)	Medium
Support Facility	Iron Horse Park Complex and Headquarters	Billerica	All Routes	Not
Maintenance Facility	Readville Yard and Maintenance Facility	Boston	All South Side Routes	Not
Maintenance Facility	Widett Service and Inspection Maintenance Facility	Boston	All South Side Routes	High
MOW	West Cambridge Maintenance	Cambridge	All Routes	High
Support Facility	Rochester Heavy Maintenance Shop	Rochester	All Routes	Not
Maintenance Facility	Readville Track and Engineering	Boston	All South Side Routes	Not
Layover	Amtrak Southampton Street Yard	Boston	All South Side Routes	High
Layover	Franklin Layover and Trailers	Franklin	Franklin	Not
Layover	Greenbush Layover and Storage	Scituate	Greenbush	Not
Layover	Kingston Layover	Kingston	Kingston	Not
Layover	Middleborough Layover	Middleborough	Middleborough/Lakeville	Not

Layover	Newburyport Layover	Newburyport	Newburyport	Low
Layover	Rockport Layover	Rockport	Rockport	Not
Layover	Wamsutta Layover	New Bedford	South Coast Rail	Low
Layover	Weaver's Cove Layover	Fall River	South Coast Rail	Low
Layover	Westminster Layover Yard	Westminster	Fitchburg	Not
Layover	Worcester Layover	Worcester	Worcester	Not
Layover	Bradford Layover	Haverhill	Haverhill	Low
Layover	Needham Layover and Storage	Needham	Needham	Not
MOW	Salem Maintenance Facility, Storage, and Offices	Salem	Newburyport	High
MOW	Abington Maintenance Facility and Storage	Abington	Kingston	Not
MOW	Framingham Offices and Trailers	Framingham	Worcester	Not
MOW	Wilmington Storage and Office Complex	Wilmington	Lowell	Low
Layover	East Junction Layover	Attleboro	Providence	Not
MOW	Ayer Staging Area and Maintenance Yard	Ayer	Fitchburg	Low
MOW	Fitchburg Maintenance Facility	Lunenburg	Fitchburg	Not
MOW	Walpole Storage and Access Yard	Walpole	Franklin	Low
MOW	Adams Junction Yard and Storage	Braintree	Middleborough/Lakeville, Kingston/Plymouth, Greenbush	Not
MOW	Meadowcroft Yard and Storage Boxes	Lowell	Lowell	Not

MOW	Rosemount Trailers and Storage	Haverhill	Haverhill	Not
MOW	Worcester Maintenance Facility	Worcester	Worcester	Not
N/A	Salem Tunnel Spur Track	Salem	Newburyport	High
MOW/Storage	Bennett Street Yard	Lynn	Newburyport	Not yet studied