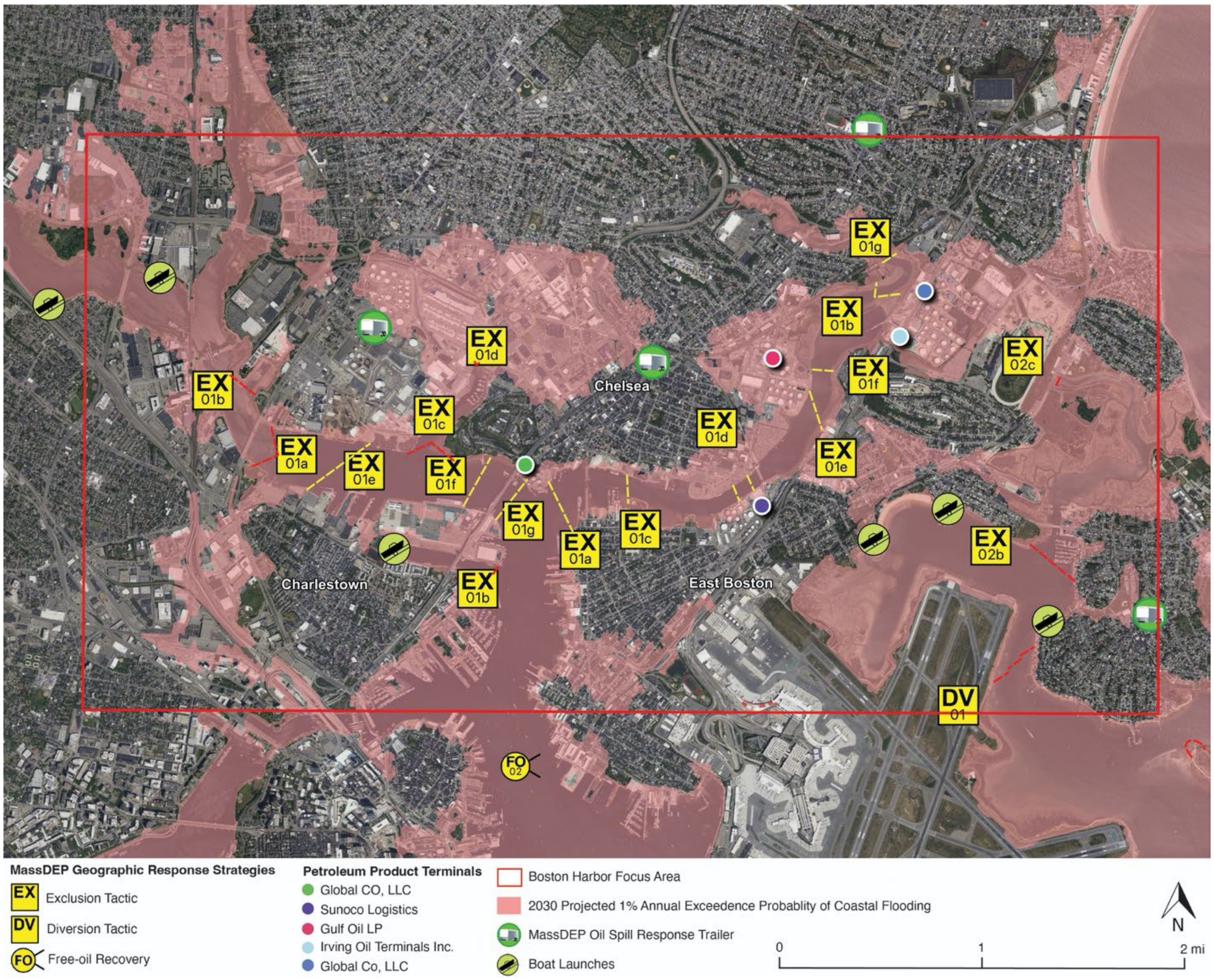
Evaluating and Adapting Oil Spill Preparedness and Response Capabilities for a Changing Climate



Final Report to
Massachusetts Department of Environmental Protection
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EXECUTIVE SUMMARY

The Massachusetts Department of Environmental Protection (MassDEP) commissioned this project in 2021 to consider the changing landscape of risks and hazards associated with climate change. This report culminates a multi-faceted study designed to address the requirement for State agencies to integrate climate considerations into planning and operations (Massachusetts Exec. Order No. 569, 2016). This study was co-led by Nuka Research and Resilience and Foresight Services (MAROIL #102039).

This study examines how climate hazards, adaptation, and resilience efforts, and decarbonization relate to the Massachusetts Oil Spill Prevention and Response Act (MOSPRA) program activities led by MassDEP. The linkages between climate change and oil spills are complex and evolving. This study began with a 2021 literature review that established the baseline (at that time) for climate hazards, adaptation, and resilience measures, and decarbonization policy in Massachusetts (Nuka Research, 2021). The literature review was distributed to expert stakeholders, including MOSPRA program managers, oil spill response experts, and climate experts both within Massachusetts and at the national and international level.

To inform current threat levels from oil storage and transportation, an update to the 2009 Marine Oil Spill Threat Assessment, also commissioned by MassDEP, was developed. The updated threat assessment compiled data on oil imports through marine terminals and examined vessel traffic movements over a five-year period (2017-2020) to estimate and compare threats to Massachusetts harbors and waterways (Nuka Research, 2024). The outputs from that analysis helped to focus this study on three case study areas for deeper analysis: Boston Harbor, New Bedford/Fairhaven, and Vineyard Haven.

Over the course of this three-year study, expert interviews informed reporting and analysis, culminating in a Climate Ready workshop held in May 2023 (Nuka Research, 2023). At this workshop, participants engaged in a series of exercises and discussions to flesh out plausible future scenarios illustrating the interactions between climate change, decarbonization, and oil spill risks and response.

This report synthesizes key concepts and findings from the literature review, threat assessment, and expert workshop study to examine how climate change, resilience, and decarbonization could influence marine oil spill risk, prevention, and response in Massachusetts and beyond.

In the context of both climate change and decarbonization, the next decade will see significant transition and change. Climate hazards will continue to become more extreme, sea level will rise, and adaptation efforts will be implemented. The use and transportation of fossil fuels will decline significantly, though fossil fuels will still be imported, and risk will remain throughout the two-decade transitions towards 2050 decarbonization targets.

This study concludes with a series of recommendations for adapting MOSPRA programs and activities to a changing climate. These include:

- Preparing for complex incidents where oil spills may be one component to a larger climate disaster;
- Preparing for and reducing the risk of marine oil spills during decarbonization transitions;

- Incorporating climate hazards and resilience initiatives into Geographic Response Strategies (GRS) planning;
- Creating opportunities to enhance GRS training and exercise program in consideration of climate hazards, adaptations, and decarbonization; and
- Ensuring that MassDEP spill response trailers are climate-ready.

Many of the risks, opportunities and risk factors identified in this study are outside the scope of any single agency, and many will be influenced by political, economic, and environmental factors that are well beyond the control of the MOSPRA Program. This report recommends that the MOSPRA Program pursue opportunities to create connections and foster collaboration to ensure that the MOSPRA program is climate-ready and to identify opportunities to use MOSPRA activities and funding to reduce oil spill risks via innovative approaches; possibly including decarbonization activities.

CONTENTS

ACRONYM LIST

Table 1: Acronyms

AIS	Automated Information System
AGCS	Allianz Global Corporate & Specialties
ACM	Area Committee Meeting
CBA	Community Benefit Agreement
ASCE	American Society of Civil Engineers
DPA	Designated Port Area
DOE	Department of Energy (U.S.)
DOJ	Department of Justice (U.S.)
EMA	Emergency Management Agency
EOEEA	Executive Office of Energy and Environmental Affairs (Massachusetts)
EPA	Environmental Protection Agency (U.S.)
EV	Electric Vehicle
FEMA	Federal Emergency Management Agency
GHG	Greenhouse Gas
GIS	Geographic Information System
GRS	Geographic Response Strategy
GW	Gigiwatts
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LEPC	Local Emergency Planning Committee
MBTA	Massachusetts Bay Transportation Agency
MassDEP	Massachusetts Department of Environmental Protection
M-CFRM	Massachusetts Coastal Flood Risk Model

MEMA	Massachusetts Emergency Management Agency
M.G.L.	Massachusetts General Laws
MOSPRA	Massachusetts Oil Spill Prevention and Response Act
MRC	Mystic River Collaborative
MVP	Municipal Vulnerability Preparedness
MW	Megawatts
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NOAA	National Oceanic and Atmospheric Administration
NRC	National Response Center
OSRO	Oil Spill Response Organization
OSW	Offshore Wind
PBC	Polychlorinated Biphenyls
PORTS	Physical Oceanographic Real Time System
RRT	Regional Response Team
RMAT	Resilient MA Action Team
RMC	Resilient Mystic Collaborative
SHMCAP	State Hazard Mitigation and Climate Adaptation Plan (Massachusetts)
SLR	Sea Level Rise
SOP	Standard Operating Procedure
T/V	Tank Vessel
VOC	Volatile Organic Compounds

1. INTRODUCTION

The Commonwealth of Massachusetts is home to a thriving marine-based economy that includes, but is not limited to fisheries, tourism, transportation, marine shipping, and a growing offshore wind energy industry. Marine transport of petroleum represents a critical element of the Commonwealth's supply chain. In addition to the petroleum required to fuel commercial and recreational vessels, a significant volume of petroleum products consumed in the Commonwealth is imported in bulk via tankers, transported to coastal communities by barge and ferry, and stored in bulk facilities on or near the shoreline. While major accidents are rare, vessel traffic and the bulk transport of petroleum expose communities and coastlines to the risk of petroleum spills that must be mitigated.

Healthy oceans and shorelines are vital to the economy and culture of coastal communities and the Commonwealth, and protecting these areas is a growing concern. Beyond the threat of oil spills, climate change threatens critical ecological functions of shorelines, and the livelihoods of those that live, work, and play in coastal Massachusetts. Government, citizens, and private and non-profit sector agencies across the Commonwealth are investing heavily in climate resilience and have undertaken significant research to anticipate and understand the complex and cascading impacts of climate hazards, such as extreme weather and sea level rise, for communities, the environment and critical infrastructure.

Commissioned by the Massachusetts Department of Environmental Protection (MassDEP) Marine Oil Spill Prevention and Response Act (MOSPRA) Program, this first-of-its-kind study explores the interaction between oil spill risk, state climate change hazards, and state and global climate-related policy, targets and technologies, and makes recommendations to support MassDEP in achieving climate-ready oil spill prevention and response.

1.1. Background

1.1.1. Massachusetts Oil Spill Prevention and Response Act & Program

The Massachusetts Oil Spill Prevention and Response Act (MOSPRA) was passed in 2004 in response to the grounding and subsequent oil spill from the B-120 barge in Buzzards Bay. MOSPRA strengthened several statutes that govern Massachusetts' ability to prevent and respond to oil spills in the coastal waters of the Commonwealth. It created M.G.L. Chapter 21M, which contains most of the provisions related to the implementation of MOSPRA, including provisions for establishing a Trust Fund financed by a 5-cent per-barrel fee on petroleum products delivered to marine terminals in the state.

As directed by MOSPRA, the Massachusetts Department of Environmental Protection (MassDEP) MOSPRA Program utilizes funds from the Trust Fund to ensure that the Massachusetts coastline is protected from oil spills through spill prevention and response efforts and programs. These include the development of Geographic Response Strategies (GRS) for sensitive areas throughout Massachusetts; procurement and maintenance of spill response equipment; development and implementation of spill response drills and exercises; development of spill prevention/response studies and risk analysis efforts; and a grant program to promote oil spill prevention and response activities.

In 2021, in recognition of the changing landscape of risks and hazards associated with climate change, and the requirement for State agencies to integrate climate considerations into planning and operations (Massachusetts Exec. Order No. 569, 2016), MassDEP commissioned this project (MAROIL #102039).

1.1.2. Massachusetts Climate Policy

The Commonwealth of Massachusetts has long been recognized as a leader in climate adaptation and mitigation. In 2008, the Global Warming Solutions Act was signed into law, committing to an 80% reduction from 1990 Greenhouse Gas (GHG) levels by 2050 (Massachusetts EOEEA, 2022b). In 2016, former Governor Baker issued *Executive Order 569: Establishing an Integrated Climate Change Strategy for the Commonwealth*. This comprehensive order set out broad requirements for the State and state agencies to: develop and implement Climate Adaptation and Mitigation Plans; support local governments to enhance climate resilience and mitigate disaster risk; and create climate change coordinator positions to advance related efforts state-wide (Massachusetts Exec. Order No. 569, 2016). Underpinned by investments in scientifically sound data, and supported by consistent guidance documents and tools, Order 569 resulted in the first integrated *State Hazard Mitigation and Climate Adaptation Plan*, and accelerated climate resilience efforts across state agencies. In March 2021, Senate Bill-9 was passed, codifying commitments to reduce overall carbon emissions by 80% and reach net-zero emissions by 2050, while concurrently supporting economic opportunities and reducing stresses for equity-seeking groups (Massachusetts Legislature, 2021). Released in June 2022, the Clean Energy and Climate Plan for 2025 and 2030 supports the Commonwealth in achieving legislated emissions reductions targets and net-zero by 2050 (Massachusetts EOEEA, 2022b).

Collectively, actions stemming from legislation and plans will impact the threat and risk landscape for oil spills, while also providing sound data and state agency precedence for integrating climate hazards and adaptation into MOSPRA programming.

1.2. Purpose

This report summarizes the MOSPRA project *Evaluating and Adapting Oil Spill Preparedness and Response Capabilities for a Changing Climate* in its entirety. It is supported by three interim studies that apply quantitative and qualitative methods to: (1) summarize the literature on climate change and oil spills (Nuka Research, 2021); (2) update a 2009 Oil Spill Threat Assessment (Nuka Research, 2024); and (3) report on the process and outcomes of a Climate-Ready Oil Spill future scenarios workshop held in May 2023 (Nuka Research, 2023). This report synthesizes the key findings from these three interim studies and makes recommendations to enable the adaptation and continued success of MOSPRA activities considering new and changing hazards, policies, and climate mitigation efforts.

1.3. Scope

This study began with the following high level research questions:

- How might climate change and related hazards affect future marine oil spill risk, prevention, and response in Massachusetts?

- How might coastal climate adaptation efforts affect future marine oil spill risk, prevention, and response in Massachusetts?
- How might decarbonization policy and targets influence marine oil spill risk?
- What actions or initiatives could be considered to adapt marine oil spill prevention and response for the future?

In scope for this project was the examination of state, regional and local climate projections, hazards, and adaptation and decarbonization policy, as well as relevant national and global projections and policy.

Out of scope for this study was specific analysis of storage at non-federally regulated facilities, technical analysis of hazard and pollution prevention plans or emergency plans, and the analysis and update of specific GR oil spill response plans or regulations.

1.4. Organization of this Report

This report begins (Section 2) by describing the project methodology to develop this report and the three companion reports listed in Section 1.2. Section 3 provides context on the MOSPRA oil spill prevention and response program activities that may be impacted by climate hazards, adaptations, or decarbonization policies. Section 4 provides context to global, national, state, and local climate hazards and resilience efforts that may intersect with MOSPRA program activities. Section 5 provides three case studies to illustrate specific scenarios across three focus areas experience rapid changes due to climate hazards and resilience efforts: Boston Harbor; New Bedford/Fairhaven; and Vineyard Haven. The scenarios were developed using Foresight Theory and building from findings in companion reports, culminating in a May 2023 expert workshop (Nuka Research, 2023). While locally specific, the scenario analyses highlight risks and opportunities to adapt MOSPRA program activities for a changing climate.

Section 6 focuses on decarbonization trends and policies, the most uncertain area of future change. This section discusses decarbonization trends and technologies and considers potential interactions with oil spill risk, preparedness, and response. The report concludes with Section 7, which presents a series of recommendations for integrating climate hazards, adaptations, and decarbonization policies into future MOSPRA program planning.

2. METHODS

This report integrates findings from multiple inputs developed in service of the research questions described above. Specific methodologies for each supporting study are discussed within cited technical reports. This section provides an overview of inputs and a high-level illustration of their interaction.

2.1. Literature Review

The starting point for this study was a desktop literature review and series of interviews with local experts to identify current trends, policies and targets related to climate change and decarbonization. The 2021 literature review, *Evaluating and Adapting Oil Spill Preparedness and Response Capabilities for a Changing Climate,* provides a high-level evaluation of research and emerging issues related to climate change, adaptation, hazards and decarbonization in relation to oil spill risk (Nuka Research, 2021).

Since this literature review was completed in 2021, major updates have been made to global climate projections and policy, and significant work has been undertaken towards decarbonization in Massachusetts and around the world. While not reflected in the 2021 report, updated research is referenced in this report.

2.2. Oil Spill Threat Evaluation

In 2008-2009, MassDEP funded a study to inform MOSPRA program activities by evaluating marine oil spill threats and response capabilities in Massachusetts. The threat assessment was developed with consideration of future updates to evaluate and compare changing threats and to inform long-term strategies for MOSPRA. In the years since that study, the MOSPRA program has grown and expanded, while there have been changes to the factors impacting oil spill risk and response. In 2022, an updated *Oil Spill Threat Assessment* was conducted to establish a baseline understanding of historical and current vessel traffic and petroleum transportation and storage patterns (Nuka Research, 2024).

The updated threat assessment re-evaluated the threat of oil spills by fuel type, source, and location across Massachusetts. The updated assessment focused on two primary data sources: OR-1 reports and AIS data. OR-1 reports are generated by marine terminal operators for the Department of Revenue, which applies a per-barrel tax on all bulk oil imported through marine terminals. Automated Information System (AIS) data tracks vessel movement and characterizes the types of vessels transiting through Massachusetts ports, harbors, and waterways. A third data source – *Notice of Intent to Transit* reports documenting tug and oil barge movements through Buzzards Bay and Cape Cod Canal – also provided important information to evaluate the overall risk picture. The combined analysis of bulk oil storage and marine transportation data spanning 2015-2020 provides an updated estimate of marine oil spill threats in the Commonwealth.

The resulting analysis showed a relatively stable threat level when compared to the 2009 study. Apart from 2020, when the global pandemic limited travel and reduced gasoline and aviation fuel consumption, the general trend has been a slight increase in petroleum imports into Massachusetts harbors. When comparing geographic areas of the state, Boston Harbor had the highest threat level, based on both oil storage and vessel traffic. At the harbor level, three additional harbors were identified as having high threats of oil spills: New Bedford, Vineyard Haven, and Nantucket.

2.3. Expert Interviews

Two rounds of interviews were conducted for this study. The first round of interviews was conducted upon completion of the Literature Review and included Commonwealth of Massachusetts staff with expert knowledge and responsibility for climate-related policy, as well as external experts in marine decarbonization and climate change. These interviews validated findings and clarified key questions arising out of the literature review. Participants were also invited to share their expert perspectives on the future of climate policy and ideas on the intersection of climate change and oil spill risk reduction.

A second round of interviews focused on local municipal and port staff with expertise in climate change, climate policy and oil spill risk. These two rounds of interviews, along with the outputs from the updated threat evaluation, helped to identify trends and focus planning for the Climate Ready Workshop discussed in Section 2.4.

2.4. Climate-Ready Oil Spill Preparedness and Response Workshop

Strategic foresight is “a discipline that allows us to create functional views of alternative futures and possibilities. Through this process, organizations and people are better prepared for potential threats and capitalize on hidden opportunities.” (Kedge, 2019). Strategic foresight is particularly well suited to areas that are characterized by future uncertainty and complexity and is increasingly used in the contexts of climate change, energy and policy making (Monteiro & Borgo, 2023; Bengston, 2015).

A Climate Ready Oil Spill Workshop was conducted utilizing strategic foresight to bring together all components of this study and challenge participants to consider how different trends related to climate change, decarbonization and oil spills could intersect and evolve over the next several decades. Tools utilized during this workshop included plausible future climate scenarios, impact and certainty matrices and futures wheels.

2.4.1. Focus Areas for Scenario Discussions

Two lines of evidence were considered when identifying areas for workshop scenario discussions. A vulnerability analysis was conducted to identify harbor areas with a high vulnerability to climate hazards. Outputs from the updated threat assessment were used to identify areas with high levels of shipping and bulk oil storage, which may increase the potential for an oil spill to occur.

To assess vulnerability, sea level rise and high tide inundation potential were evaluated based on NOAA’s record of historical data (NOAA, 2023a) and projected occurrences based on the ResilientMass Action Team (RMAT) recommended RCP 8.5 (high emissions) climate scenario, along with local flood and high tide maps (RMAT, 2022). The combined impacts of SLR and storm surge for oil spill risk and response were evaluated using the M-CFRM 1 % exceedance probability (100-year flood) projections for 2030 and 2050 (Woods Hole Group, 2022). The study utilized environmental justice maps and data (Massachusetts EOEEA, 2022c) from Resilient MA to inform demographic and socio-economic conditions and related social exposure and vulnerability to oil spills.

This modelling, considered in conjunction with the location of critical infrastructure and coastal assets, environmental sensitivity indices, and GRSs, helps to establish likely and plausible future oil spill risks, and identify opportunities to adapt prevention and response systems to future climate conditions.

Final selection of the three focus areas was determined based on the following key differentiators:

- Surrounding landscape (urban, industrial, rural, residential, natural)
- Seasonal marine and petroleum transportation patterns
- Potential sources and exposure to spills
- Future development plans
- Climate resilience plans
- Historical spill occurrences
- Regional response capabilities

New Bedford/Fairhaven, East Boston Harbor and Vineyard Haven Harbor were selected, as they represent 3 regions facing significant risk due to climate change, and relatively high but different threat profiles in terms of the exposure, vulnerability, and potential consequences of oil spills. Each area, shown in Figure 2-1, has invested in climate adaptation and resilience planning, and these plans are in various phases of development and implementation.

2.4.2. Workshop Design and Conduct

In May 2023, a full day Climate Ready Oil Spill workshop was held in Plymouth, MA. The workshop brought together information and data gathered during the Literature Review, Threat Assessment Update, and Expert Interviews to support a highly interactive discussion on the intersection of climate change – inclusive of hazards, adaptations, and decarbonization strategies - and marine oil spill risk and response. The workshop report documents the workshop approach and outcomes (Nuka Research, 2023).

The outcomes of this workshop included identification of emerging risks, opportunities and stakeholders related to a changing landscape of oil spill risk, prevention, and response across three different harbors.

Figure 2-1: Study Focus Areas – East Boston Harbor, New Bedford Harbor and Vineyard Haven Harbor were selected as focus areas for regional analysis

3. MASSACHUSETTS COASTAL SPILL RESPONSE SYSTEMS AND MOSPRA PROGRAM ACTIVITIES

Since its inception, the MOSPRA program has engaged in a range of efforts, both past and ongoing, to reduce oil spill risks, enhance preparedness, and ensure an effective response. This section provides context on MOSPRA program activities, to support subsequent discussions about how these activities may be impacted by climate hazards, adaptation measures, and decarbonization strategies.

3.1. SPILL PREVENTION AND RISK REDUCTION

MOSPRA spill prevention efforts include several measures specific to Buzzards Bay and the Cape Cod Canal, including the tug escort program, Notice of Intent to Transit Reporting, and placement of wave sensor buoys. These measures aim to improve vessel navigational safety in these designated areas of special interest. Spill prevention efforts have also included localized projects like the New Bedford Harbor Clean Bilge Program, which aims to limit the frequency and occurrence of smaller, mystery oil spills in New Bedford Harbor.

3.1.1. Tug Escorts

MOSPRA tug escort program regulations require that tank barges carrying more than 6,000 barrels of oil as cargo hire a tug escort while operating in Buzzards Bay and the Cape Cod Canal. The program also defines the instances where tugs need to either escort (accompany) or assist (provide powered assistance to) a transiting tug and barge. Tug escorts ensure there is a tug on standby in case an assist is needed to help the vessel safely navigate through issues such as low visibility, extreme weather, mechanical problems, and marine traffic.

Since the program's inception in 2011, MassDEP has been tracking compliance with tug escort requirements and monitoring areas of special interest for navigational safety incidents. In the initial ten-year span, a total of 5,827 escorts and 298 tug assists were completed, with the most activity in 2013, 2014, and 2018 and the least in 2020 and 2021. On average, less than 5% of tug escorts turned into assists. Of those incidents where tug assists have been needed, over half were considered "general" assists for additional safety when operating conditions were challenging (e.g., strong currents). About one-fourth of all assists have been due to extreme weather incidents such as ice, high winds, or low visibility.

Moving forward, climate hazards such as changes in precipitation, sea level rise, rising temperatures, and extreme weather, may impact the ability of vessels to safely navigate through Buzzards Bay and the Cape Cod Canal. This could change the frequency of tug escorts needed. Reduced demand for petroleum products could also change the pattern of tug escorts.

3.1.2. Notice of Intent to Transit Reporting

Notice of Intent to Transit Reports require that owners/operators of tank barges carrying more than 6,000 barrels of oil as cargo provide a Notice of Intent to Transit through Buzzards Bay and the Cape Cod Canal at least twenty-four hours prior to transit, or as soon as operationally feasible. These reports include information such as the name of the vessel owner/operator, name and type of the vessel, the type and quantity of oil on board, and the vessel's destination.

Notice of Intent to Transit Reporting enhances vessel traffic monitoring and provides the opportunity for officials to alert other mariners of potential navigation hazards. This system enables MassDEP to plan for and anticipate potential hazards and resource needs, which is especially beneficial in extreme weather events and other occasions where resource availability may be limited.

Moving forward, as the impacts of climate change affect weather patterns, optimizing the ability to anticipate hazards and resource needs becomes even more important.

3.1.3. New Bedford Clean Bilge Program

The New Bedford Harbor Clean Bilge Program began in 2015 to address the problem of chronic, small oil spills. Many of these spills have been attributed to poor waste oil management, excessive oil in vessel bilges, improper bilge water handling, and negligent disposal practices.

The Clean Bilge Program consisted of a three-pronged approach, which included a complimentary vessel bilge pump-out program to assist in the prevention of discharged oil into the harbor, development of outreach and education materials to increase overall public awareness of the program's benefits, and courtesy bilge and oil-handling system inspections to identify recommendations for reducing the potential for oil leaks and spills.

The program ran from 2015 through 2020, recovering approximately 150,651 gallons of oil and bilge water (478 vessel pump outs from 243 vessels). In 2023, MassDEP resumed the program through December 2023, focusing on working commercial fishing vessels (one pump out per vessel), and recovered approximately 20,379 gallons of oil and bilge water (from 48 vessels). Pollution from chronic oil spills will continue to be a threat until fishing and recreational vessels transition away from petroleum fuels. Targeted prevention measures like the Clean Bilge Pilot may be tailored to existing or future chronic spill sources in local ports and harbors.

3.1.4. Wave Buoys and Other Real Time Data Instrumentation

MassDEP partnered with the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) and the National Oceanic and Atmospheric Administration (NOAA) to support the long-term operation of two high-tech wave-monitoring buoys in Buzzards Bay and Cape Cod Bay and a current meter located at the west end of the Cape Cod Canal. The wave buoys and current meter comprise the Cape Cod/Buzzards Bay Physical Oceanographic Real Time System (PORTS). The first buoy (Cape Cod Bay) was deployed in 2016 with the current meter and Buzzards Bay wave buoy added in subsequent years. The buoys and current meter improve marine forecasts and provide real-time information about sea conditions (i.e., wave height and direction, wave period, and surface water temperature) to transiting vessels. The PORTS data helps improve vessel operators' abilities to make timely, accurate, and informed navigational decisions to ensure safe passage through Buzzards Bay and Cape Cod Bay, while also creating a historic data set of sea condition observations to monitor changes to sea conditions and water temperatures to assess and adapt to a changing climate.

Starting in 2022, MassDEP has partnered with NOAA to support a water level sensor, meteorological station and a visibility station that are part of the extensive Narragansett Bay PORTS. These instruments are all located in Fall River and provide valuable information for vessels transiting Mount Hope Bay- an Area of Special Interest defined under M.G.L. c. 21M.

3.2. OIL SPILL PREPAREDNESS AND PLANNING

3.2.1. Geographic Response Strategies (GRS)

Geographic Response Strategies (GRS) are spill response plans tailored to protect a specific sensitive area from the impacts following a spill. These map-based strategies can save time during the critical first few hours of an oil spill response by showing responders where sensitive areas are located and where to place oil spill protection resources.

GRS are widely used across the U.S. as an oil spill planning and response tool. The GRS development process brings together diverse groups, such as local conservation officers, state and federal spill response agencies, and vessel and facility operators. GRS development fosters local buy-in and creates realistic community expectations for protecting sensitive areas from oil spill impacts. Massachusetts began developing GRS in 2007 using a regional work-group approach. From 2007 to 2012, MassDEP led the development of 160 sites in the six coastal GRS sub-regions (Figure 3-1).

Since GRS are site-specific strategies and tie to ecological sensitivities, they may be impacted by climate hazards and adaptations that result in changes to shoreline geomorphology or to the ecological resources present at a site. The tactics and strategies that are typically applied in GRS reflect the type of petroleum products currently used to fuel vehicles and vessels and to generate heat and power. Changes to the types of energy and fuel sources could necessitate a re-evaluation of GRS tactics and strategies.

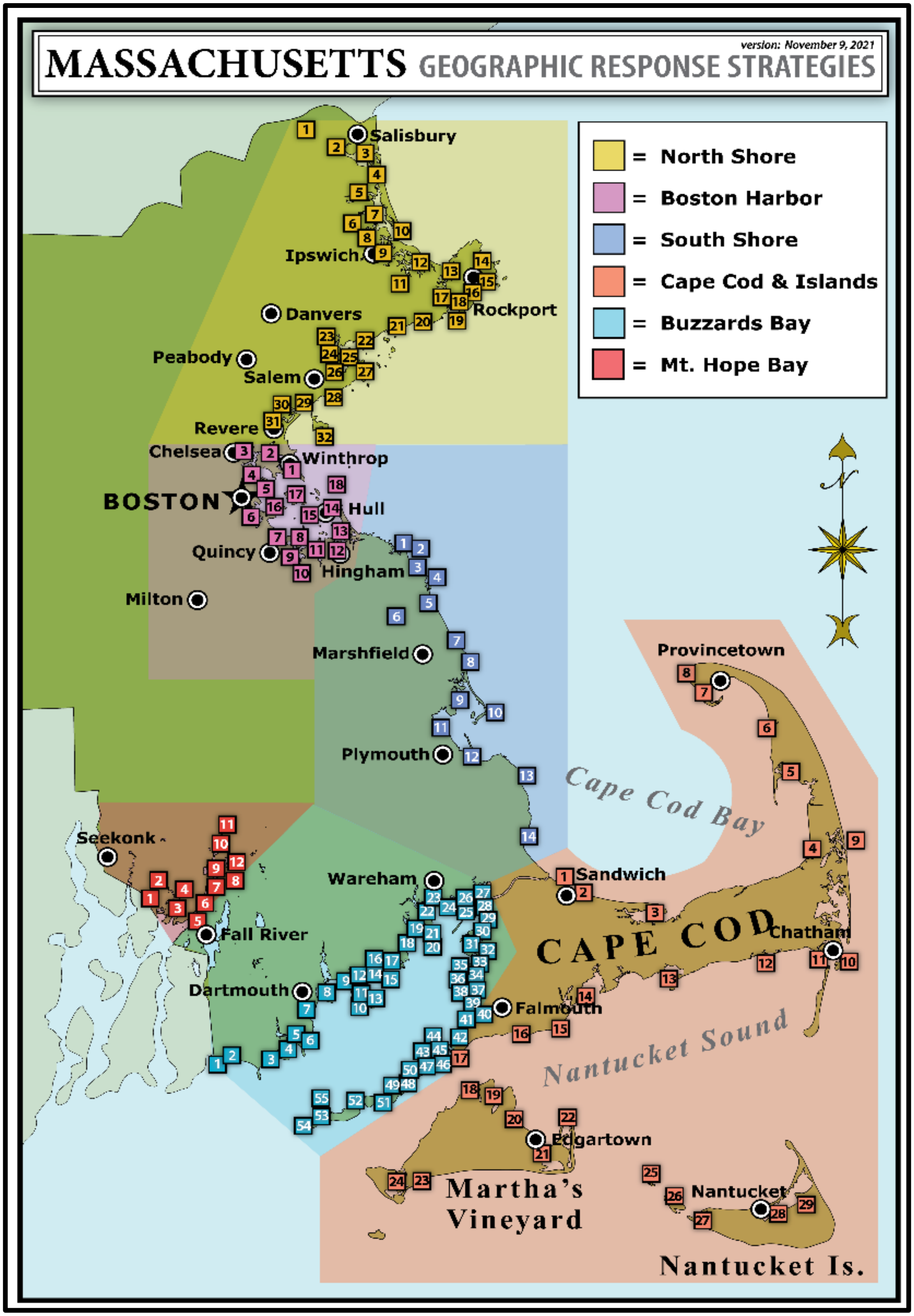

Figure 3-1: Coastal GRS sites in Massachusetts by region

3.3. COASTAL GRS EXERCISE PROGRAM

The Coastal GRS Exercise Program provides local and state first responders with hands on experience deploying state-provided oil spill equipment, to build and refresh local capabilities to deploy GRS. The Exercise Program began with a GRS field deployment in 2009 and has evolved to include classroom training and equipment familiarization, instruction to support towing and deploying boom, testing inter-town communications, interoperability, and procedures for oil spill equipment allocation, and a field-test of protection strategies found in the GRS.

The GRS Exercise Program rotates among communities and provides an opportunity to maintain awareness of the MOSPRA program and GRS response plans. As coastal communities face climate-related hazards and implement adaptation measures, there is an opportunity for the GRS Exercise Program to connect oil spill preparedness and response to climate change. For example, future trainings or field deployments could also build awareness of how changing coastal features may necessitate GRS changes. Planning for GRS exercises could also incorporate awareness of oil spill prevention and decarbonization strategies to reduce local spill risks.

3.4. COASTAL SPILL RESPONSE TRAILERS

3.4.1. Massachusetts Oil Spill Response Equipment

MassDEP has provided oil spill response trailers to 71 coastal communities, containing boom of various sizes with the ancillary equipment (anchors, lines, floats, etc.) required to deploy it. In total, the state owns and maintains 101,000 feet of boom to support oil spill response by local first responders.

The equipment that Massachusetts stockpiles ties primarily to protective actions that would prevent oil from reaching vulnerable coastal areas. The type and location of boom reflects the priority for a distributed, community-based capacity to respond to spills from ships and coastal facilities. The type of boom stockpiled in Massachusetts is appropriate for a range of floating oils, from diesel to heavy fuel oils. Changes to the types of oils that are used for vessel fuel or stored and transported in the Commonwealth may warrant a re-evaluation of the type and quantity of equipment in state-owned response trailers.

Figure 3-1 shows the location of response trailers throughout coastal Massachusetts. Communities with spill response trailers have an agreement with the state that enables them to deploy equipment from the trailers as needed. In the event of a major oil spill incident, there are mutual aid procedures in place to promote a coordinated regional response if multiple trailers are needed. To ensure that all equipment remains intact and response ready, MassDEP funds the ongoing maintenance and inspection of each trailer and its contents. This information is kept in a trailer tracking database and accessible to MassDEP to allow for the timely coordination of resource repair, replacement, and replenishment.

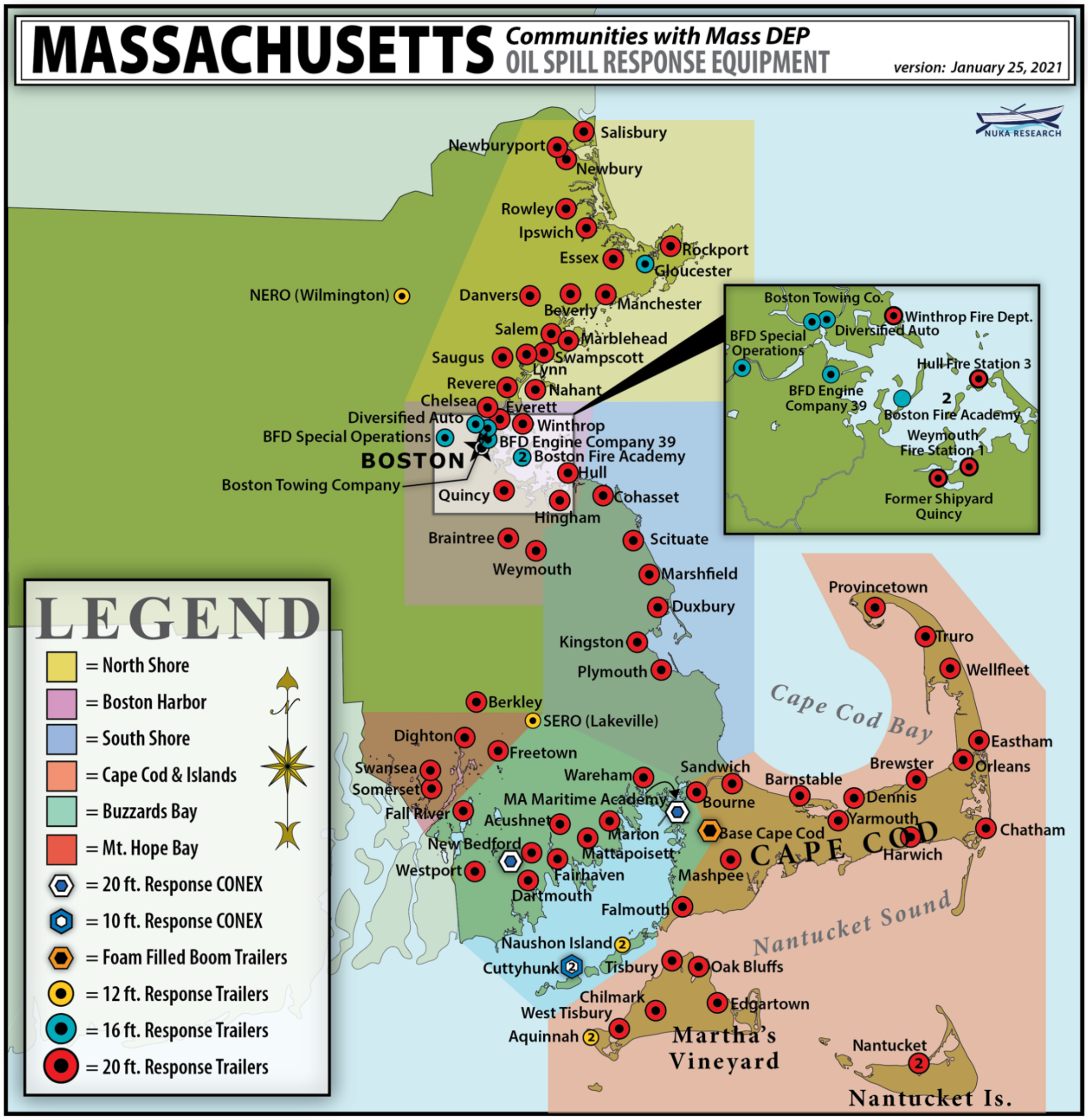

Figure 3-1: Massachusetts coastal oil spill response equipment trailer locations

4. CLIMATE HAZARDS AND CLIMATE RESILIENCE EFFORTS

4.1. Commonwealth of Massachusetts Climate Resilience Policy & Resources

The Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA) has established the ResilientMA portal as a "climate change clearinghouse" that provides open access to up-to-date and vetted climate resources, including data, research, maps, assessment and planning tools, as well as state and local plans and policies. The primary sources used in this study for state and local climate projections, and adaptation and hazard mitigation information are the ResilientMA portal, including the map viewer and climate projection dashboard, the Massachusetts Coastal Flood Risk Model (MC-FRM) and the Massachusetts State Hazard Mitigation and Climate Adaptation Plan (SHMCAP). Local plans and policies were also evaluated, including Municipal Vulnerability Preparedness (MVP) program documentation, as well as, local hazard mitigation plans, climate adaptation and resilience plans, and research publications.

4.1.1. Climate Change & Hazards

Understanding climate change hazards and adaptation efforts are important for identifying changes to the environment that may impact oil spill risk, prevention, response, and recovery.

The SHMCAP identifies four climate change factors of concern to the Commonwealth (Massachusetts EMA & EOEEA, 2018, p. 4-74):

- Changes in Precipitation - precipitation is projected to become more intense when it falls, and to fall in different forms as temperatures increase. Drought is also expected to be more prevalent.
- Sea Level Rise - across the Massachusetts coastline, sea levels are projected to rise as arctic and Antarctic ice caps melt and global temperatures warm.
- Rising Temperatures - average temperatures are expected to rise in all seasons, extreme temperature events will become more common.
- Extreme Weather - the above climate impacts will contribute to more frequent and more severe extreme weather events, such as hurricanes and Nor'easters.

For coastal Massachusetts, sea level rise, high tide flooding, and storm surge from extreme weather present the greatest threats to potential marine oil spill sources and response capabilities over the coming decade and are the focus of this study moving forward.

4.1.2. Climate Adaptation

In Massachusetts, coastal climate adaptation measures and policies prioritize nature-based solutions, such as revitalizing salt marshes to buffer against storms and sea level rise and replacing hard infrastructure with natural shorelines. Nature-based solutions are defined in the SHMCAP as:

> *The conservation, enhancement, and restoration of nature to reduce emissions, adaptation, and enhance resiliency. These types of solutions use natural systems, mimic natural processes, or work in tandem with traditional engineering approaches to address*

> *natural hazards like flooding, erosion, drought, and heat islands*. (Massachusetts EMA & EOEEA, 2018, p. 7-3)

While nature-based solutions are preferred, grey infrastructure still has an important role to play in adaptation and may be recommended in some cases. Examples of grey infrastructure adaptation include elevating piers, railways, and roadways (Carr, 2023). Perhaps the best-known grey infrastructure solution is the New Bedford Hurricane Barrier, constructed in the 1960s to protect the harbor from hurricanes and nor'easters.

Massachusetts' state-level initiatives are complemented by adaptation policies and initiatives at the port and local level. The State-funded Municipal Vulnerability Preparedness (MVP) Program funds local risk assessments and planning and adaptation actions (Runsten, 2021).

4.2. Climate Change, Hazards & Adaptation: General Implications for Oil Spill risk & response

As articulated by Katopodis and Sfetsos, "Extreme temperatures, sea level rise, hurricanes, droughts, flash flooding, storm surges, and forest fires are expected to increase globally, with potentially severe off-site consequences through toxic release, oil spillages, fire, or explosion scenarios." (Katopodis and Sfetsos, 2019).

While limited work has been done to explore the specific interactions of climate hazards and oil spill risk and response in the marine context (Nuka Research, 2021), the evaluation of impacts of previous spills linked to storms and flooding, along with input on risk from experts in the field of marine oil spills, indicates that climate change, hazards and adaptation efforts could interact to influence marine oil spill risk in Massachusetts via three main pathways:

- Through threats and adaptation efforts related to potential sources of spills, for example to storage facilities, vessels and pipelines;
- Through direct impacts to critical elements of oil spill response plans and systems, for example by impacting access and transportation to oil spill response trailers, and;
- Through changes to the receiving environment and shoreline that affect oil spill fate and effect, and the consequences of oiling, for example the natural restoration of industrialized shorelines.

These pathways are not mutually exclusive.

The following section explores how sea level rise, high tide flooding, extreme weather and storm surge could interact with oil spill risk. It presents general findings from the literature review and stakeholder interviews, followed by three local case studies that explore future climate projections and evolving spill risk in Massachusetts harbors to 2030.

4.2.1. Sea Level Rise & Coastal Flooding

According to the 2018 SHMCAP "mean sea level rise across the Commonwealth's coastline could reach 1.3-3.1 feet by 2050" (Massachusetts EOEEA, 2018, p. 4-80) and 4.0 to 10.5 feet by 2100 (Massachusetts EOEEA, 2018, Executive Summary). High-tide flooding, also referred to as sunny-day or nuisance flooding, occurs more frequently as a result of sea level rise, even in the absence of extreme weather (NOAA, 2018). According to NOAA, "high tide flooding occurs when water levels reach from 1-2 feet above the daily average high tide, depending on location." (NOAA, 2023b). To understand this risk, it is useful to consider that "today's flood will become tomorrow's high tide." (NOAA, 2018). In other words, in the absence of adaptation, areas that are inundated today only during flood events (e.g., King Tide and storm surge) will in future be consistently inundated at high tide.

Consequences of SLR include but are not limited to: shoreline erosion; loss of land mass to subsidence; saltwater intrusion; more frequent coastal flooding; and impacts to ecosystems, critical infrastructure, and assets (Commonwealth of Massachusetts, n.d., p. 207-208; Massachusetts EOEEA, 2018). In 2021, the American Society of Civil Engineers (ASCE) Report Card for America's Infrastructure identified a $12 billion funding gap in waterside infrastructure across America's ports, and highlighted the poor condition of 'intermodal connector pavement' – the roads and railways that connect marine operations to landside operations and the national highway system – as a threat to Port activities. The report noted that SLR will exacerbate these challenges, requiring investment to systematically raise and increase the resilience of roads, piers, and coastal assets (ASCE, 2021).

Beyond day-to-day operations, sea level rise interacts with extreme weather to increase the extent of flooding and storm surge, threaten critical infrastructure, and impede the safety and capabilities of first responders attempting to access impacted communities and infrastructure (Kirshen et al. 2020). As will be discussed further on, government and non-governmental organizations, regional ports, and commercial enterprises in Massachusetts are investing heavily in climate resilience; however, many of the impacts of sea level rise and high tide flooding are already being experienced, and planned structural and nature-based adaptation efforts remain unfunded and are likely to be implemented on a time line that leaves many communities, ecosystems and assets exposed over the coming years.

With respect to oil spills, sea level rise and more frequent high tide inundation threatens the structural integrity of coastal infrastructure and has the potential to influence the trajectory of oil that is spilled from vessels and coastal facilities (Lavine et al. 2020). Day-to-day deterioration of intermodal connector routes may directly or indirectly affect both risk and response. More frequent high tide flooding affecting roads and rail lines that connect to petroleum terminals, may pose a risk to land-based bulk transport, as well as access for emergency responders and equipment during high tide. In addition, sea level rise also results in changes to coastal ecosystems that impact environmental sensitivity indices (Petersen et al. 2019), and the strategies and prioritization of response and recovery efforts.

4.2.2. Extreme Weather

Extreme weather, including heavy precipitation and high wind events, hurricanes and nor'easters already contribute to flooding, storm surge, and wind damage in Massachusetts. Driven by climate change, these events are projected to increase in frequency and severity over the coming decades (Massachusetts EOEEA, 2018; IPCC, 2022).

The 2022 Allianz Global Corporate & Specialties (AGCS) Safety and Shipping Review reported that "extreme weather was a factor in at least 13 [of 54] vessel losses during 2021." (AGCS, 2022, p.

4). In the U.S. and around the world, extreme weather events have triggered large volume oil spills. For example, the Murphy Oil Spill in New Orleans, LA occurred when storm surge from Hurricane Katrina dislodged a storage tank, releasing more than 25,000 barrels or petroleum into a residential neighborhood and impacting 1,800 homes (Ade, n.d.; U.S. EPA, 2006). During Superstorm Sandy, the Motiva Refinery spill in Sewaren, New Jersey released more than 330,000 gallons of diesel into the Arthur Kill River (NOAA, 2014).

While land-based bulk storage tanks present a clear threat, extreme weather also has the potential to trigger concurrent small and medium volume spills. Although no major spills were reported during Hurricane Maria in 2017, responders still recovered nearly 30,000 gallons of oil and fuel from waters in Puerto Rico and the U.S. Virgin Islands, assumed to have leaked from sunken vessels and land-based storage containers and tanks (Wilson et al. 2018). Pine (2006) identified more than 50 spills triggered by hazards associated with Hurricane Katrina, from sources located along the Lower Mississippi corridor in Louisiana, including pipelines, off-shore platforms, and near-shore storage (Pine, 2006). Following Superstorm Sandy in 2012, the Coast Guard responded to reports of "petroleum products, biodiesel, and other chemicals...leaking into the waters from pollution sources such as damaged coastal industries, ruptured petroleum storage tanks, and sunken and stranded vessels" in New Jersey and adjacent areas (NOAA, 2013a). Where smaller sources of petroleum may not have been considered a threat based on the relatively low consequence of isolated spills, the cumulative effect of multiple simultaneous releases during storms may change the threat landscape.

Storm surge may impact access to response trailers. An overlay of the current location of MOSPRA response trailers with the 2030 coastal flood map identifies 15 trailers directly within the future 100-year flood zone, and the submergence of every identified GRS access point and boat launch. Many other trailers would effectively be islands, inaccessible due to flooding of nearby roads.

Extreme weather can also lead to "severe marine debris events." NOAA's impact assessment of Superstorm Sandy found that marine debris was widespread along the mid-Atlantic coast, with significant impacts for commerce and the transit of vessels (Figure 4-1). According to the Impact Assessment:

> *"Not only does this marine debris pose potential hazards to navigation safety, commercial fishing grounds, and sensitive ecosystems, but a storm of such a magnitude as Sandy stirred up hazardous substances including paints, fuel, cleaners, and solvents from homes and sunken vessels."* (NOAA, 2013b)

Marine debris events have led directly to new oil spills. For example, in the aftermath of Hurricane Rita a barge struck a sunken oil platform near Port Arthur, Texas, spilling 2 million gallons of oil (Wilson et al. 2018).

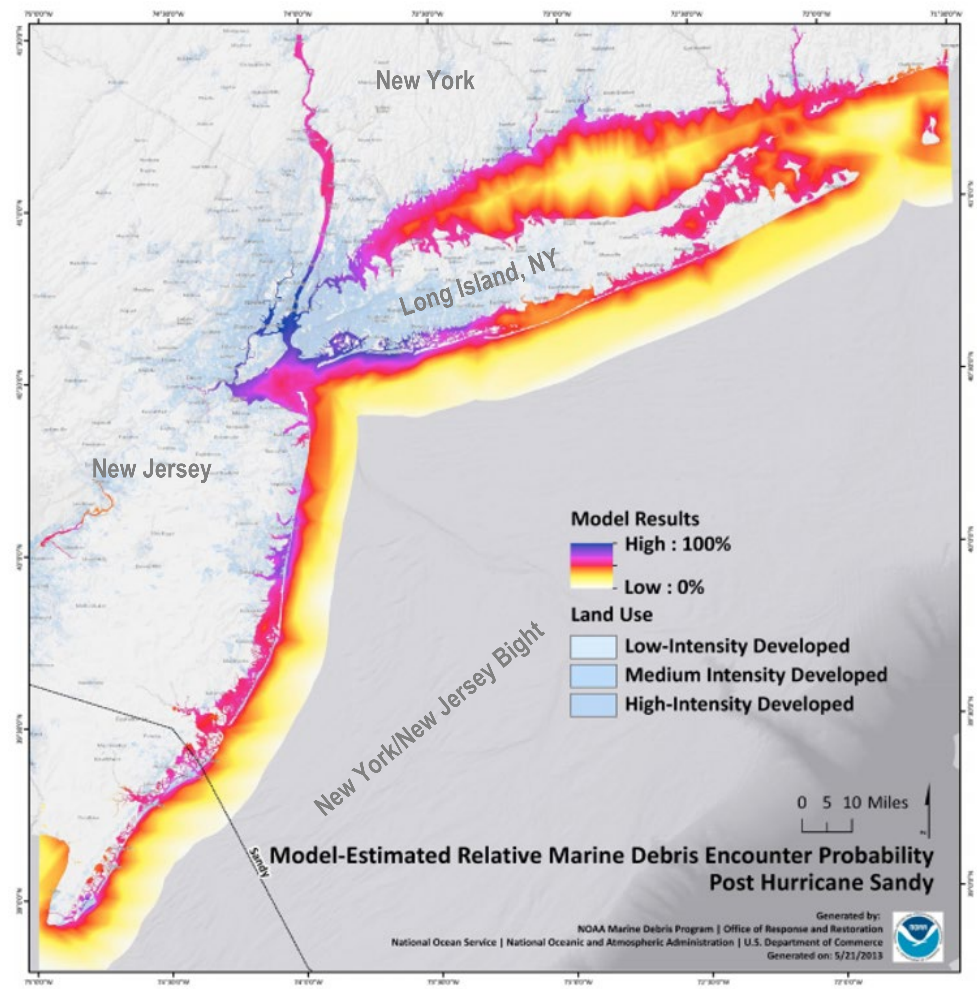

Figure 4-1: NOAA model-estimated map of marine debris post Hurricane Sandy along the coast of New York and New Jersey (NOAA, 2013)

4.2.3. Adaptation

Climate adaptation and hazard mitigation efforts influence land-use planning, infrastructure design, and service planning and delivery. Many planned adaptation measures are co-located with areas where oil spill GRS have been completed, or where critical oil storage and transportation infrastructure exist. Investment in adaptation measures, by governments and industry, may result in changes to the risk profile of spills and present opportunities for oil spill risk reduction by reducing vulnerability to climate-caused oil spills or improving site access in areas prone to flooding.

5. CASE STUDIES

5.1. Focus Areas for Future Scenario Analysis

Section 4 describes potential implications of climate change and related hazards for oil spill risk and response based on available literature and expert analysis. To understand how these issues could manifest locally, primary research was conducted through interviews and workshops with local climate experts and experts in marine oil spill prevention and response. Nuka Research and Resilience and Foresight Services designed a scenario-based, strategic foresight workshop to identify a range of plausible and possible impacts of climate change for oil spills across the three geographic focus areas: East Boston Harbor, New Bedford/Fairhaven, and Vineyard Haven (Figure 5-1). Future scenarios were developed based on existing climate adaptation and resilience plans, climate projections, input from local stakeholders, and analysis of the potential evolution of policy, infrastructure, and technology.

Table 5-1 provides an overview of the future scenario conditions used in the three case studies to identify potential implications of the interaction of climate hazards, adaptation, and oil spills. Case studies bring together findings from the workshop process (Nuka Research, 2023), literature review (Nuka Research, 2021), expert interviews, and desktop research and analysis. The future scenarios are the basis for examining how the landscape for oil spill risk and response may change over the next decade and identifying opportunities for proactive prevention and preparedness.

Figure 5-1: Case study focus areas

Table 5-1: Summary of 2033 future scenarios utilized to explore implications of climate change for oil spill risk, prevention, and response

	East Boston Harbor	New Bedford Harbor	Vineyard Haven Harbor
Sea Level Rise & High Tide Flooding	• Sunny Day flooding reached 35 days in 2030, projects to 100 days by 2050 • More frequent flooding and disruption of Massachusetts Bay Transportation Agency (MBTA) stations, rail lines, and major transportation routes, including those routes used for tanker trucks leaving marine terminals	• Increased closure of the hurricane barrier for non-storm/high tide flood events • Evaluation of options to reduce closures of hurricane barrier and allowing flooding to occur with greater frequency • New construction at Port in line with resilient design guidelines; historical piers remain at risk	• Sunny Day flooding reached 14 days in 2030, projects to 135 days by 2050 • Critical infrastructure in high-risk areas have limited options for retreat • Growing concern about the health and function of salt marshes and wetlands in flood-prone areas
Extreme Weather & Storm Surge	• Extreme weather leads to increased calls to the National Response Center (NRC) about spills • Evacuation of residents living in high-risk areas around the Designated Port Area. • Shoreline infrastructure and roads are more frequently damaged	• Increased intensity of storms has caused infrastructure damage inside the hurricane barrier • Recreational and fishing vessels encounter navigational issues due to extreme weather events	• More frequent Nor'easters • Oak Bluffs Harbor is at risk, with its future viability unclear • Increase in ferry cancellations • Supply chain delays and increased cost of goods
Climate Adaptation & Local Resilience	• Restoration underway for Belle Isle Marsh. • 30,000 new residents in the area rely on marsh access for recreation/nature • Route 1A corridor adaptations underway • 40% of current industrial shoreline slated to be 'greened' using nature-based solutions	• Significant investment in nature-based solutions for SLR/Flooding, including the New Bedford Riverwalk • Port Resilient Design Guidelines applied to new construction • Infrastructure funding gap remains for some • Massive investment in wind energy	• Bylaws preventing new development in floodplain • Vineyard Wind Community Benefit Agreement (CBA) investment in resilient port • Raise the Lagoon Pond causeway. • 30% growth in aquaculture

5.2. Case Study 1: East Boston Harbor

5.2.1. Local Context and Vulnerabilities

The East Boston Harbor focus area includes Chelsea Creek, Mystic River, and Belle Isle Marsh. Adjacent cities include Boston, Revere, Chelsea, and Everett. This area is home to a mix of residential neighborhoods, some Environmental Justice neighborhoods, highly industrialized shorelines, and ecologically sensitive areas – including the last remaining salt marsh in Boston Harbor. Currently, there are 5 federally regulated petroleum terminals located on the shores of Chelsea Creek and the Mystic River. Petroleum is transported to these terminals via tanker and barge, and inland from the terminals via truck and rail. Based on tax reporting data from 2017-2019, the volume of petroleum deliveries to all Boston Harbor terminals (not limited to East Boston) averaged about 68 million barrels per year.

Spills in Boston Harbor have historically come from a range of different sources. Notable historical spills include a 15,000-gallon diesel spill from an Everett terminal into the Mystic River in 2006 (U.S. DOJ, 2008) and the 2000 *T/V Posavina* incident where a tanker departing its berth in Chelsea Creek collided with a tugboat, puncturing the hull and releasing approximately 59,600 gallons of intermediate fuel oil (UPI, 2000). MassDEP has also been activated to respond to many smaller marine spills over the years originating from truck roll overs, drainage pipes, and unknown sources. There are three MassDEP oil spill response trailers located in the study area, as well as privately maintained spill and pollution response equipment located at bulk storage facilities, fuel docks and other commercial sites.

Marine oil spills in East Boston Harbor have the potential to cause a range of adverse consequences. Factors that may influence the vulnerability of this area to marine oil spills include:

- A high density of environmental justice communities, who are more likely to experience harm as a result of climate change, pollution, and environmental crises.
- Belle Isle Marsh is an important and fragile salt marsh ecosystem that supports access to nature, biological diversity, and flood protection, and it has been the focus of significant restoration efforts.
- A high density of critical infrastructure, including MassPort, Logan Airport and marine transportation routes could be disrupted due to spills and clean-up operations.
- Dense marine traffic, including ferries, recreational vessels, government vessels, and large commercial vessels.

5.2.2. Sea Level Rise, High Tide Flooding and Extreme Weather

The number of high tide flood days has trended upwards in Boston Harbor, from 4 in 2000, to 13 in 2020, with an outlook of 11-18 projected for 2023-24 (NOAA, n.d.). In many locations, high tide flooding already impacts homes, businesses, and infrastructure, as shown in the image from a high tide flood in Revere in 2021 (Figure 5-2) (Wasser, 2021).

Figure 5-2: High tide waters inundate properties in Revere near Belle Isle March (source: Robin Lubbock/WBUR)

Figure 5-3 shows NOAA's high tide flood outlook for the northeastern U.S. predicts that mean sea level will be higher in the early spring and early fall months, due to warmer waters and changes in weather patterns (NOAA, 2023c). Boston Harbor can anticipate increased high tide flooding days each decade to 2050, with 24-27 high tide flooding events projected for 2030, and 50-87 for 2050 depending upon emissions scenario (NOAA, 2023a). At current sea levels, sunny-day flooding is not likely to cause significant damage in the absence of extreme weather or storm surge; however, as sea levels rise, the impact of more frequent and persistent inundation will have increasingly damaging effects to ecosystems and infrastructure (NOAA, 2023c).

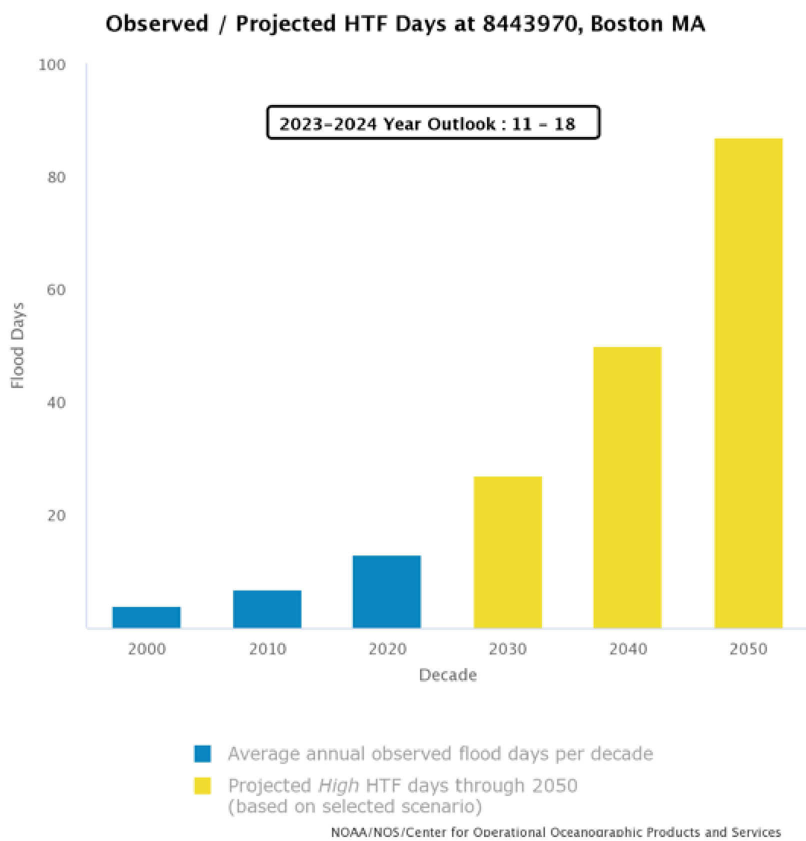

Figure 5-3: Observed and Projected High Tide Flooding (HTF) days in Boston, based on high emissions scenarios

Figure 5-4 shows how Boston Harbor, which is already vulnerable to flooding and storm surge, may become increasingly vulnerable over time. The 2030 annual coastal flood exceedance probability for the study area shows different probabilities, ranging from the daily high tide (100% exceedance) to the 100-year (1% exceedance) and 1,000-year (0.1% exceedance) flood events.

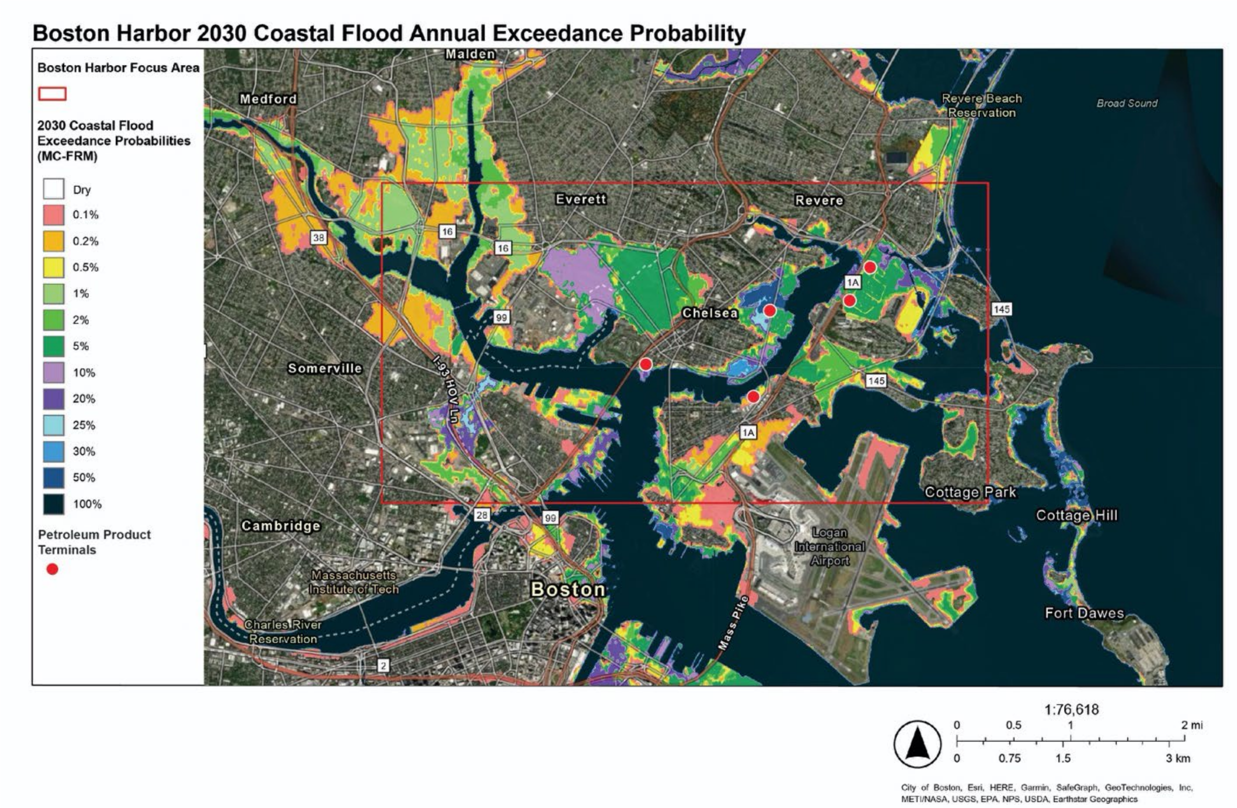

Figure 5-4: 2030 annual coastal flood exceedance probability for East Boston

Figure 5-5 illustrates inundation from a modelled 100-year flood event overlayed with the location of response trailers and geographic response strategies. Under a high emissions scenario, a 100-year event in 2030 is anticipated to be a 20-year event by 2070, demonstrating the urgency of infrastructure adaptation and the need to consider long-term projections in infrastructure life-cycle analysis.

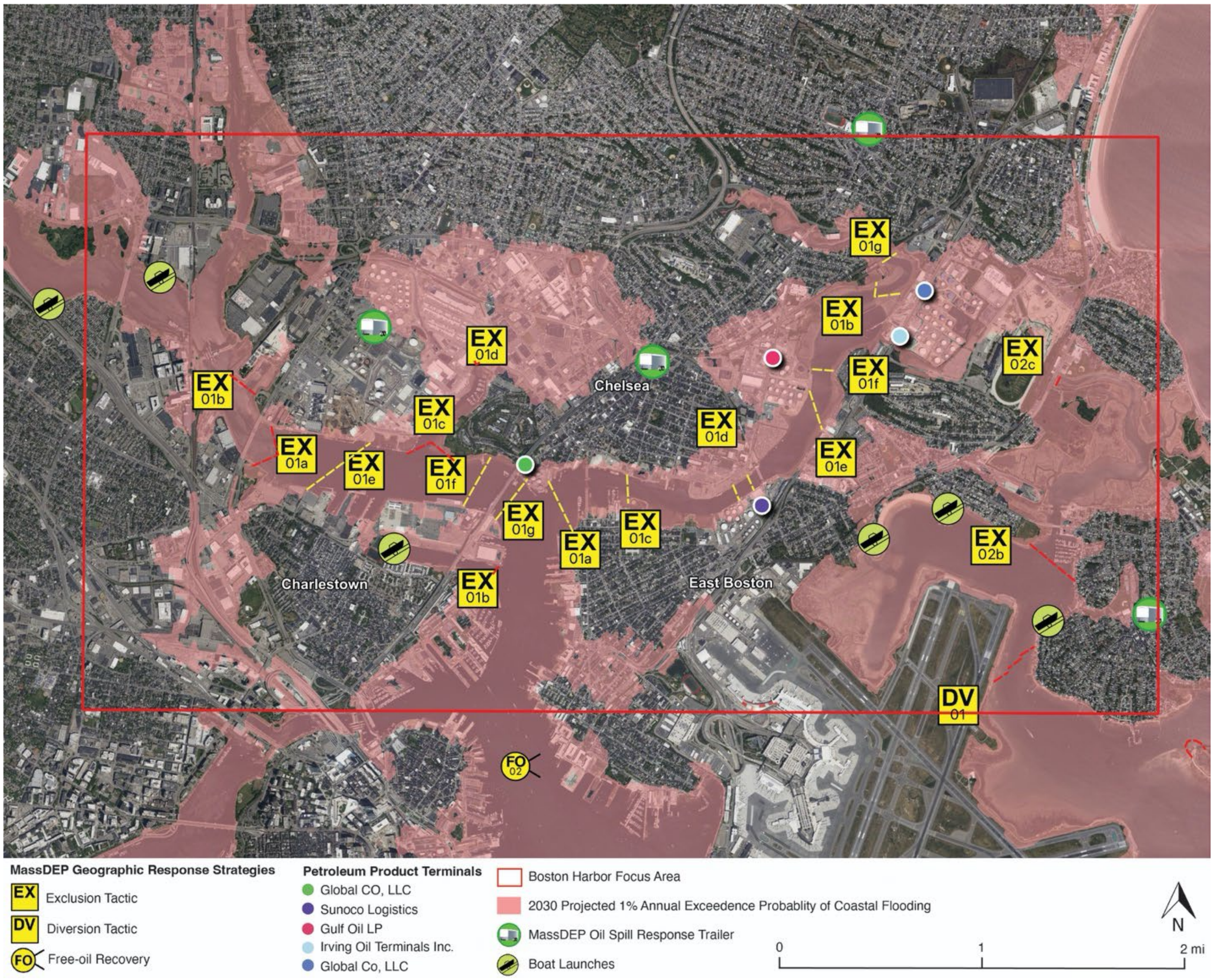

Figure 5-5: Modeled inundation from 100-year flood event in Boston Harbor overlaid with geographic response strategies (GRS)

5.2.3. Climate Resilience Efforts

Municipal governments, MassPort, and various non-governmental organizations have completed significant analysis of the impacts of climate change within the East Boston Harbor focus area and are collectively designing and implementing a wide range of adaptation and resilience measures. All of the surrounding communities are part of the Commonwealth's Municipal Vulnerability Program (MVP). The City of Boston is considered a global leader in flood adaptation, and the recently released Massachusetts-Coastal Flood Risk Model builds upon modelling work done for Boston Harbor (City of Boston, 2023).

The Resilient Boston Harbor Plan, which includes a specific Climate Ready East Boston Resilience Plan, proposes significant greening of the shoreline in areas that are currently grey, (City of Boston, 2021, 2022) while MassPort has released a Floodproofing Design Guide (MassPort & Kleinfelder, 2018) and Sustainability and Resilience Design Guidelines (MassPort, 2018) to enhance resilience of Port-managed infrastructure. These plans are reviewed in more detail in the literature review (Nuka Research, 2021).

If implemented, adaptation recommendations and plans have the potential to transform the shoreline and waterfront of East Boston Harbor, from a highly industrialized area exposed to serious flood risk, to a resilient shoreline, inclusive of both grey and nature-based solutions intended to protect communities, provide space for recreational activities, and minimize risk to critical infrastructure. Figure 5-6 maps the location of the City of Boston's proposed adaptation efforts, as well as areas under the authority of MassPort.

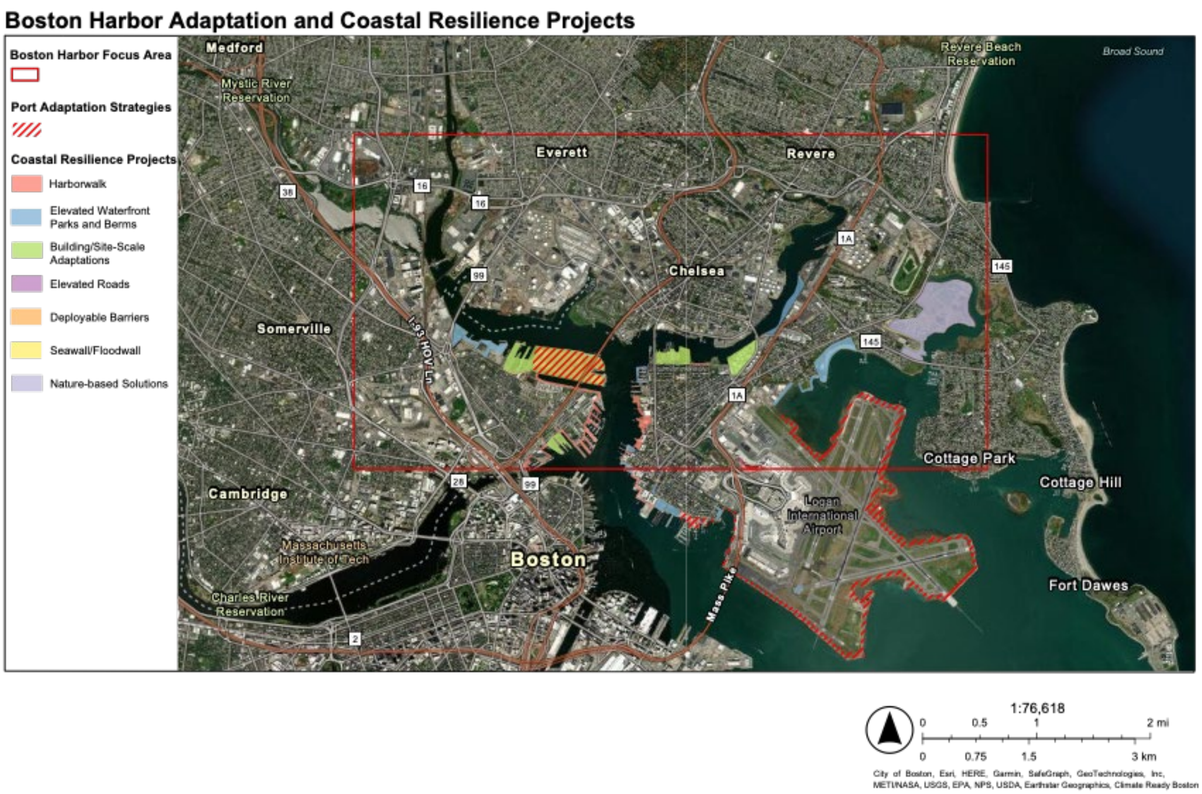

Figure 5-6: Boston Harbor Adaptation and Resilience initiatives, note this map does not illustrate planned adaptation efforts outside of the City of Boston. (Credit: City of Boston, 2023)

In 2021, the Resilient Mystic Collaborative (RMC) released a report and series of recommendations to center social equity in the context of critical infrastructure failure (including bulk fuel storage) associated with extreme weather. In addition, RMC is actively involved in planning and protection around Belle Isle Marsh, completing a Climate Vulnerability Assessment for the marsh in June 2023 (Woods Hole Group, 2023).

To date, these activities have not been integrated into MOSPRA program activities, though an opportunity for collaboration has been identified as discussed in the following section.

5.2.4. Evolving Oil Spill Risk & Opportunities

An analysis of oil spill prevention and risk factors combined with future climate hazards and adaptation efforts revealed potential implications and opportunities for East Boston Harbor.

Seasonal Risk Patterns

The updated Marine Oil Spill Threat Assessment (Nuka Research, 2024) identified historical monthly petroleum product deliveries to bulk terminals in Massachusetts. Between 2017 – 2020, gasoline and aviation fuels remained relatively stable throughout the year, with minor increases during the summer months, while diesel and heating oil deliveries peaked significantly during the winter months. Meanwhile, the combination of high tide flooding and extreme weather is more likely to have damaging and disruptive impacts in the fall and spring (though not exclusively). These patterns would indicate that in the future, there may be an elevated threat of hazard-triggered oil spills and barriers for response during the spring and fall months as compared to previous decades. Seasonal exercises for these conditions could help prepare responders and mitigate impacts.

Access

More frequent high tide flooding and storm surge events are likely to impact access for responders to MassDEP response trailers, fuel, boat launches, and spill response staging areas. In the context of high tide flooding, these impacts may be temporary in nature, while in the case of storm surge, serious damage to roads may isolate equipment and responders for longer periods of time. In Boston, responders may experience the most significant access disruption during the fall, winter, and spring, due to a combination of high tide flooding days and extreme weather. Although the three MassDEP response trailers are currently located outside the 100-year flood zone, they are all located in areas that may be completely surrounded by flood waters. Accessing and transporting response trailers to coastal areas for response may not be feasible given projected impacts to identified boat launches and roadways, including to major routes, such as Route 1A (See Figure 5-4).

Flooding and storm surge may also disrupt access to and from large petroleum facilities, impeding proactive site assessment. In the event of storm surge, marine debris may pose access challenges, and additional risk of incidents related to vessel traffic and navigation. Exercising these logistics and response functions under simulated storm conditions could help identify new strategies to ensure rapid deployment of resources. This may include alternative siting of spill response equipment, and the use of alternative technologies (drones, etc.).

In the case of major storms events, restricted access and operations at Logan Airport may affect the capacity to engage and bring in out-of-state response organizations and equipment.

Response Coordination & Measures

The potential intersection of climate hazards, such as damaging hurricanes and storm surge, with oil spills and other cascading impacts, presents complex coordination requirements across multiple agencies. Flooding and storm surge that leads to widespread marine debris also has the potential to carry oil inland to residential neighborhoods. This dynamic presents potential coordination challenges with respect to establishing authority and responsibility for clean-up on land and on water, and for recovery in the greater context of humanitarian crises. This could become more urgent as neighborhoods densify.

Study contributors with experience in events such as Hurricane Katrina and Superstorm Sandy noted that these events demonstrated the challenges in coordinating critical supplies for responders and victims alike. One contributor noted that during a major storm event, it was unlikely that oil spill response would be a top priority, and that recovery efforts would be less effective as a result. As extreme events become more prevalent, exercising response plans in these scenarios with partner agencies presents an opportunity to explore dependencies and limitations, mitigate potential long-term impacts, and enhance response and recovery capabilities.

Sea level rise and high tide flooding may also trigger more land-based and mystery spills and sheens in Boston Harbor, leading to an increase in spill reports and subsequent activation of MassDEP responders and contractors. For example, one contributor noted that severe flooding of auto mechanics and parking lots in the industrial area could represent a new source of oil into the marine environment that could be difficult to track or mitigate (Carr, 2023). Given that high tide flooding is predictable, it would be possible to collect data and track to determine if there is a correlation between flood events and mystery spills or sheens.

Adaptive and Natural Infrastructure Protection

The planned implementation of nature-based solutions and the potential greening of shorelines around East Boston Harbor will protect communities and infrastructure from coastal flooding and sea level rise. Restored shorelines may also require changes to current oil spill response plans and preferred recovery methods. For example, restored shorelines may mean the relocation of boat launches and access points. In some cases, plans call for the replacement of rip rap and other grey infrastructure with higher value natural ecosystems that also serve as critical flood protection infrastructure. These changes should be monitored and GRSs updated accordingly to capture the added value of restored shorelines. As coastal adaptation measures are implemented in East Boston Harbor, there may be an opportunity for MOSPRA to work proactively with climate planners to promote shoreline design that would be more resilient to oil spills.

Spill response experts noted that in past spills, shorelines are sometimes left to recover naturally from oil spills, when this approach has been assessed as less damaging than alternative options. Given the planned investment in nature-based solutions, the social and ecological value of Belle Isle Marsh, and the need to protect the biological integrity of these sites to provide critical flood protection services, responders may experience intense public pressure to engage in active and visible recovery operations along restored natural shorelines and marsh areas.

5.2.5 Oil Spill Risk Reduction and Preparedness Opportunities

The changes to the oil spill risk landscape summarized above allow for consideration of risk reduction opportunities. Table 5-2 summarizes the ideas expressed by participants during the Climate Ready Workshop, as opportunities to reduce exposure and vulnerability of East Boston Harbor to oil spill risks as a result of climate change. These ideas help to inform the final recommendations of this report.

Table 5-2: Oil spill risk reduction and opportunities for East Boston Harbor

What is already happening today that should continue or grow to reduce risk and ensure preparedness?	• Local, state, & federal coordination of activities • Continuous evaluation of existing strategies • Tracking of spills and spill types • Continuous improvements to training offerings to adhere to evolving needs of communities
What are the indicators of future risk (R) or opportunity (O) that we should monitor?	• At-risk existing infrastructure (R) • Tracking/monitoring of petroleum throughput at bulk facilities (O) • Changes in carbon use • Increase in alternative energy; emergence of new hazards • Changes in population and exposed communities
What could we be doing today to be prepared for the future?	• Review & update GRS to align with adaptation efforts and changing climate impacts • Increase public outreach and education around spill risk and risk reduction • Incorporate spill protection & treatment procedures into design of (adaptive) infrastructure (green or grey) • Increase outreach to communities & stakeholders working in the climate space
What does climate-ready oil spill response look like in 2030 and beyond?	• Better technology for spill identification and response • Less autonomy for responders – more eyes on response, higher public interest in ecological protection • Greater public sensitivity • Faster, broader assessments

5.3. Case Study 2: Vineyard Haven Harbor

5.3.1. Local Context and Vulnerabilities

Vineyard Haven Harbor is considered the gateway to the Vineyard, with the island's only year-round ferry service and many other essential services located on or near the water. Vineyard Haven (Tisbury) is home to about 5,000 residents. It is the most densely trafficked harbor on Martha's Vineyard, with a combination of ferries, tug/barges, pleasure crafts, government vessels, and fishing vessels frequently traversing the area. Bulk oil is transported by tug and barge to Martha's Vineyard through a fuel facility on the Vineyard Haven shoreline. Fuel and oil for vehicles, airplanes, homes, and businesses is transported to the island by tanker trucks loaded onto vehicle ferries.

Vineyard Haven's oil spill risks are highly seasonal. Summer (high season) sees increased ferry traffic, more recreational boating activity, more cars on the roads (tourists and seasonal residents), and increased flights to and from the island. Gas and diesel deliveries (for transportation) peak during this time, as does aviation fuel. Conversely, winter is much quieter in terms of overall activity. During these winter months, Martha's Vineyard sees a decline in gasoline deliveries and an increase in home heating oil deliveries.

In the past, the majority of oil spills in Vineyard Haven Harbor have been related to recreational boating incidents, or parked vehicles leaking fuel into the waterways. There is a single GRS for Vineyard Haven Harbor, with the primary objective to boom off the area under the Lagoon Pond bridge to keep oil out of Lagoon Pond. There is one MassDEP response trailer located in the study area.

Marine oil spills in Vineyard Haven Harbor have the potential to cause a range of adverse consequences. Factors that may influence the vulnerability of this area to marine oil spills include:

- Lagoon Pond is an ecologically fragile and important area within Vineyard Haven Harbor.
- Local beaches and shorelines are important to the tourism economy and also have ecological value.
- Historical waterfront buildings and businesses also have high value to the tourism economy.
- A growing aquaculture industry is important to food security, tourism, and local economic development.
- There are many low-lying homes, businesses, and infrastructure, including those supporting local residents and the tourism industry.
- The harbor provides access for essential supply chains, including food and fuel delivery, ferry traffic, and emergency services; in the future, this may also include maintenance and service operations for the Vineyard Wind electric utility.

5.3.2. Sea Level Rise, Coastal Flooding, and Extreme Weather

Martha's Vineyard, like all coastal islands, is highly vulnerable to climate change. Sea level is rising faster here than the global average, in part due to the subsidence of the land itself (Martha's Vineyard Commission, 2022c, p. 39). Average sea level on the island has risen 6 inches since 1970 and is expected to increase by another 0.6 – 1.8 feet by 2050 (Martha's Vineyard Commission, 2022a).

Low-lying coastal roads and buildings in Tisbury are already subject to regular flooding, including the 5-Corners intersection, which is a through-point to the island's hospital and ferry terminal. NOAA does not provide high tide flooding data or projections for Vineyard Haven; however, data for Nantucket and Woods Hole are utilized by the Dukes Hazard Mitigation Plan as proxies for Martha's Vineyard. As shown in Figure 5-7 and Figure 5-8, the number of annual flood inundation days on Nantucket Island has been trending upwards since 1980, with a majority of high tide flood days concentrated during the winter months from 2010-2023 (NOAA, 2023a). Under the high emissions climate change scenario, both Woods Hole and Nantucket are projected to experience an exponential increase in high-tide flooding by 2050. (Figure 5-9).

According to the Vineyard Way Climate Action Plan, by 2050, communities of Martha's Vineyard could experience 35 – 135 sunny-day flood days per year (Martha's Vineyard Commission, 2022a, p. 12).

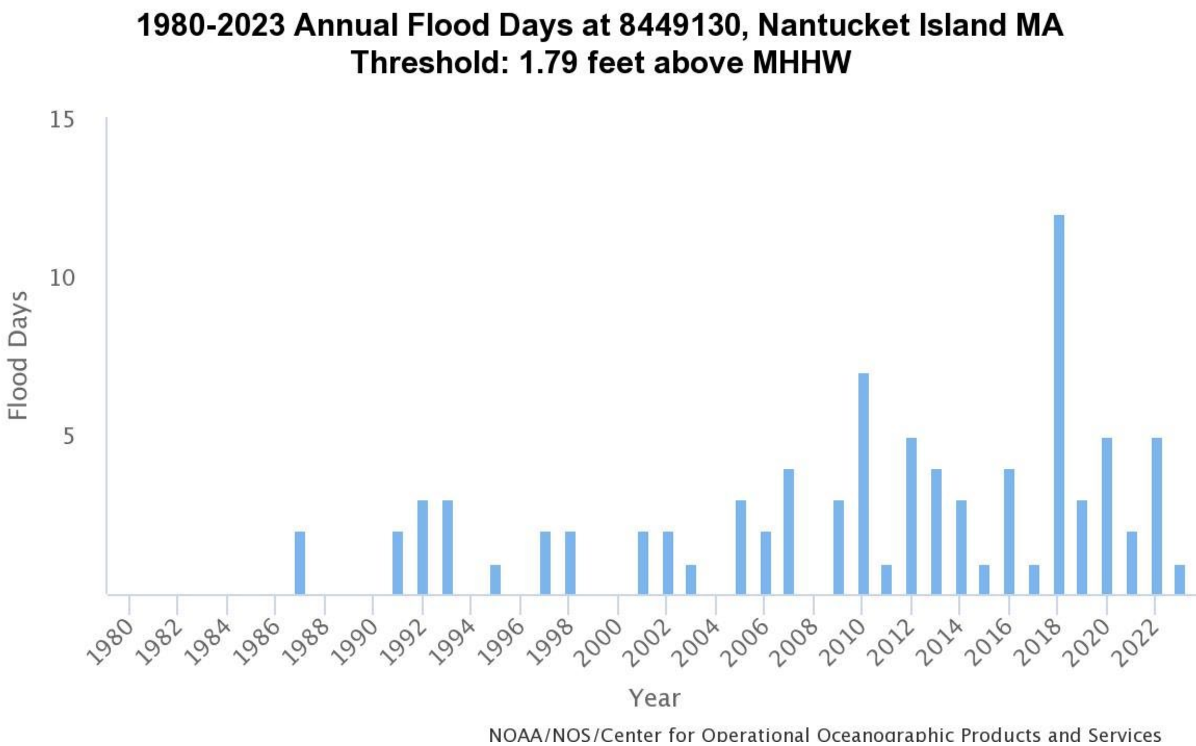

Figure 5-7: Annual flood days for Nantucket (proxy for Martha's Vineyard)

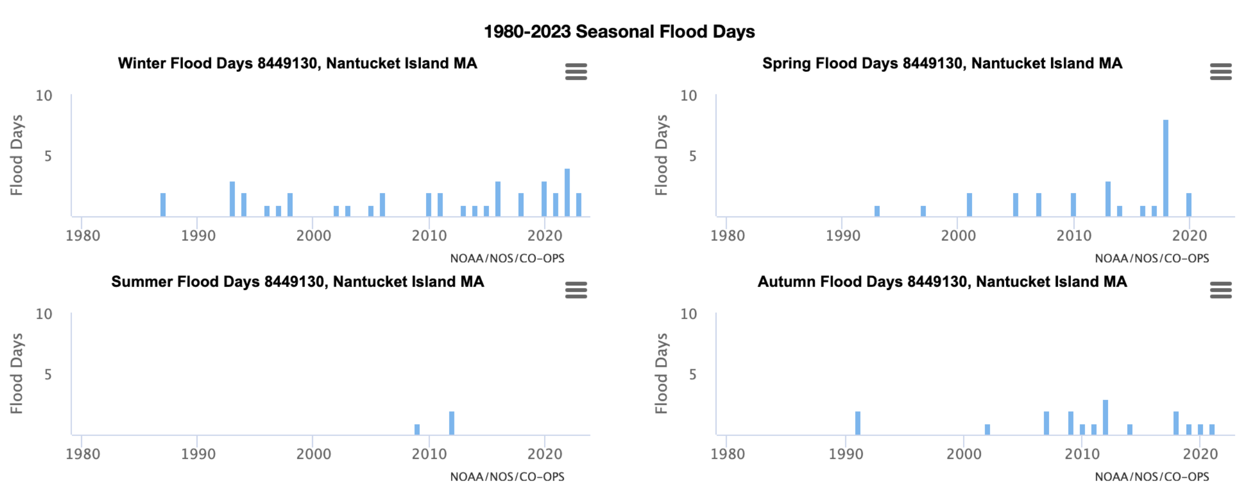

Figure 5-8: Seasonal flood information for Nantucket (proxy for Martha's Vineyard)

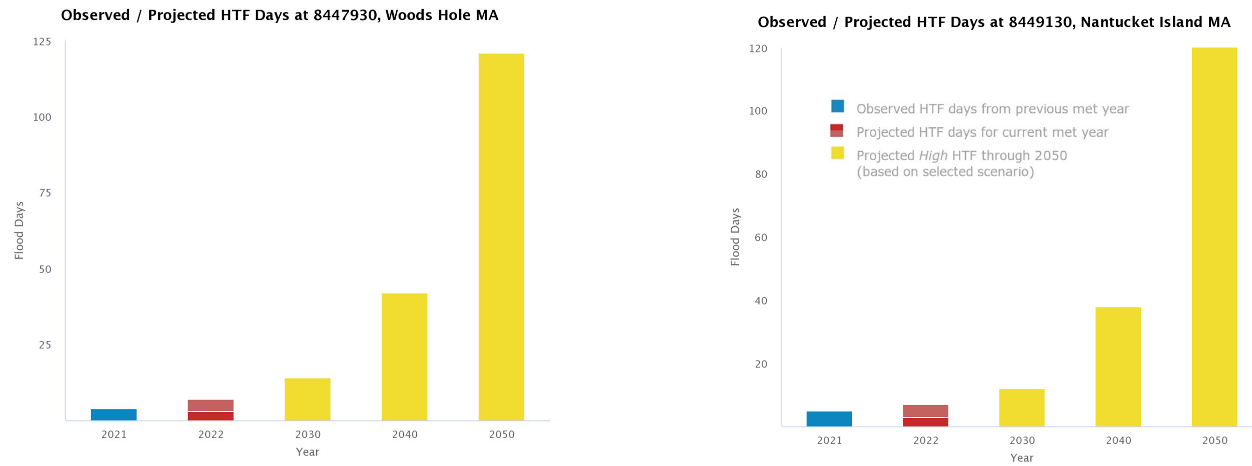

Figure 5-9: Projected high tide flooding for Woods Hold and Nantucket (proxies for Martha's Vineyard)

The 2021 Duke County Hazard Mitigation Plan identifies nor'easters, hurricanes, winter storms and storm surge as among the highest risk hazards for the island. These events can cause damage from wind and flooding and can lead to an acceleration of erosion processes that threaten coastal ecosystems, infrastructure, and nearby homes. Several homes have already been relocated or abandoned given their proximity to these eroding cliffs and shorelines (Durkee, 2023). Extreme weather also threatens critical supply chains and access to and from the Islands – between 2018-2021, there were more than 1,700 weather-related ferry cancellations to and from the Islands (The Trustees of Reservations, 2021).

Figure 5-10 and Figure 5-11 identify critical facilities and transportation routes in Vineyard Haven that are currently vulnerable and within the inundation zones of category 1-4 hurricanes. This includes the local facility and dock, Steamship Authority Ferry Terminal, Beach and Lagoon Pond Road (including the bridge and culvert). Figure 5-10 shows the projected Annual Exceedance Probability for coastal flooding in 2030.

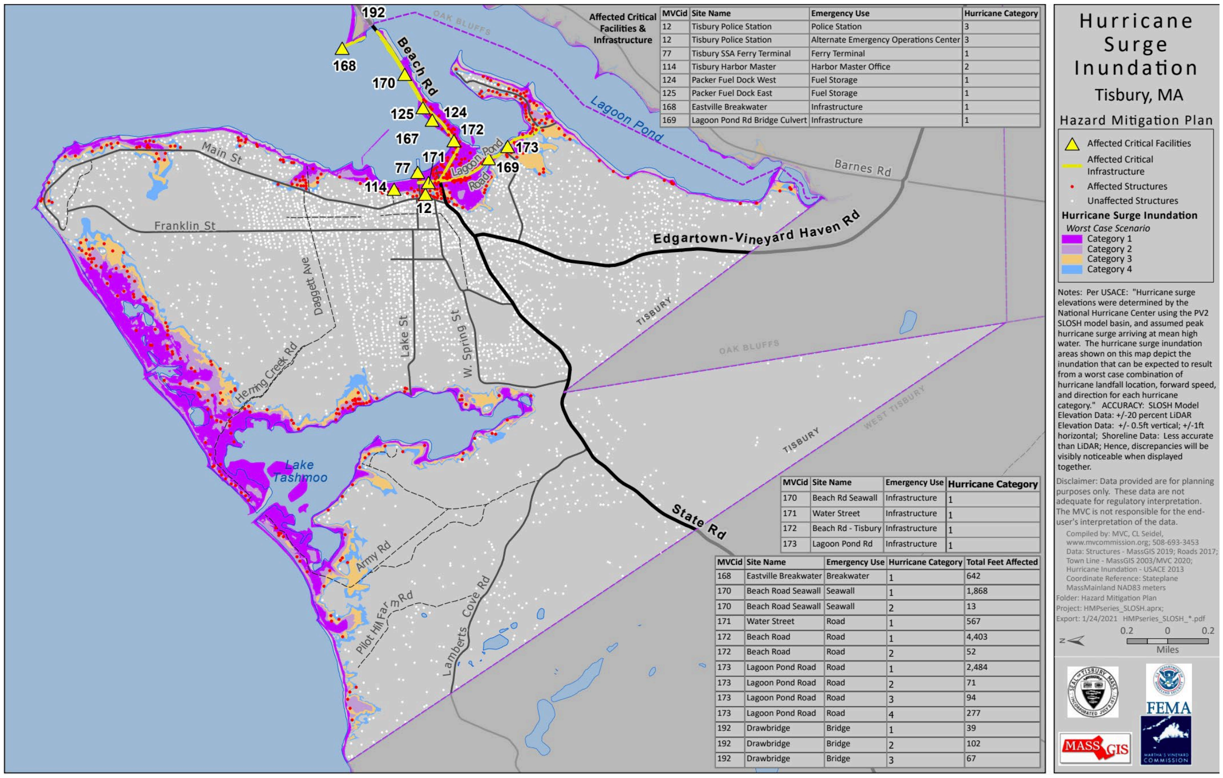

Figure 5-10: Town of Tisbury Hurricane Inundation Map (Dukes County Hazard Mitigation Plan, 2022)

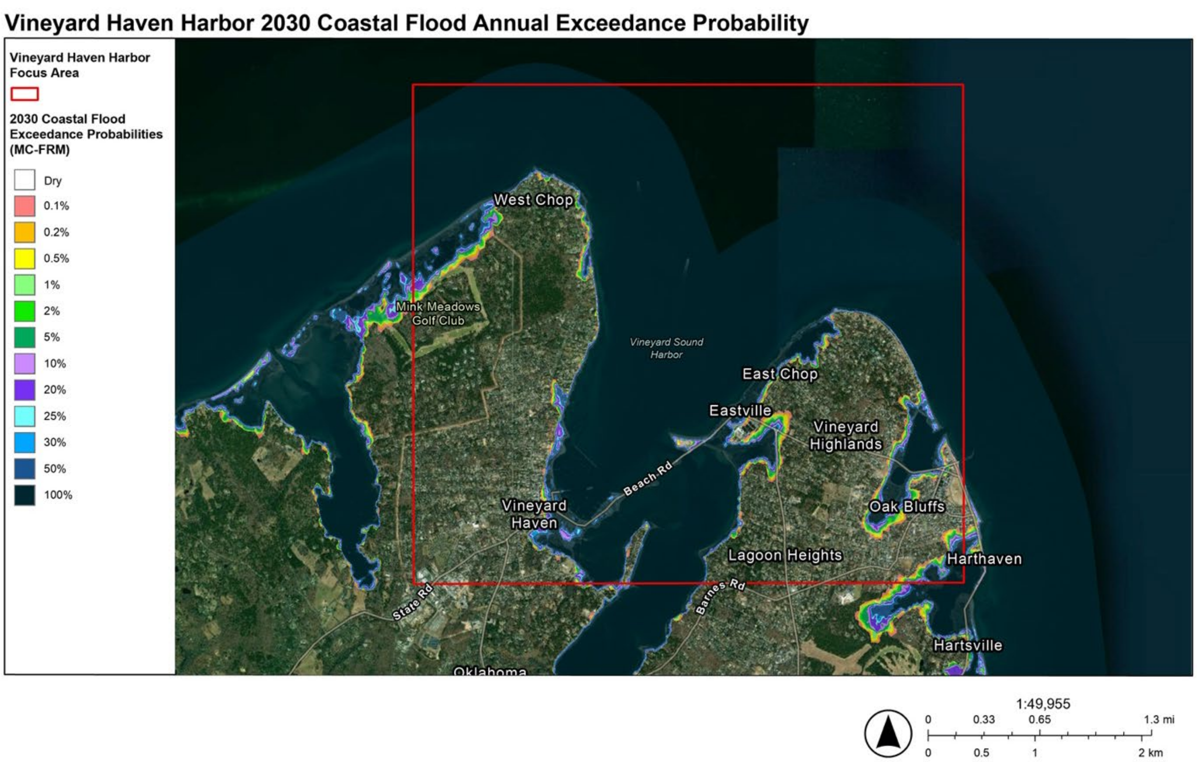

Figure 5-11: Projected annual exceedance probability for coastal flooding in Vineyard Haven Harbor in 2030

5.3.3. Climate Resilience Efforts

Tisbury and Oak Bluffs are both part of the MVP Program and are actively working to implement climate plans that protect and reduce risk to residents, businesses, infrastructure, and ecosystems. MVP community assessments have informed the 2021 Duke's County Hazard Mitigation Plan and were integral to the development of "The Vineyard Way," a highly participatory and ambitious plan led by the Martha's Vineyard Commission, and aimed at "… reducing greenhouse gas emissions, managing the impacts of climate change, and creating a healthier and more resilient community for everyone." (Martha's Vineyard Commission, n.d.) The Vineyard Way establishes targets to decarbonize transportation and buildings earlier than the statewide target of 2050 and sets out goals and actions to protect communities and the environment from the impacts of climate change and related hazards.

The Town of Tisbury faces particular challenges in planning for coastal hazards, coordinating planning efforts, and securing funding to raise roads and infrastructure and retreat at-risk structures (Robinson, 2023). Bylaws that would limit development within flood plains have been adopted by some Martha's Vineyard communities. Beyond structural hazard mitigation, plans and proposals related to climate resilience include decreasing reliance on vulnerable marine supply chains by increasing local food production, decreasing waste (that must be transported off island), investing in renewable energy (to decrease fuel delivery), and increasing local economic opportunities (Martha's Vineyard Commission, 2022a; Robinson, 2023; Durkee, 2023).

Operations and maintenance for Vineyard Wind, the first major offshore wind project to be developed, will be centered at Vineyard Haven Harbor. The project is intended to support accelerated decarbonization of Martha's Vineyard and employ a significant number of residents. New port infrastructure is planned at Vineyard Haven Harbor to support these operations and the maintenance for this project (Vineyard Wind, LLC, n.d.).

5.3.4. Evolving Oil Spill Risk

An analysis of oil spill prevention and risk factors combined with future climate hazards and adaptation efforts revealed potential implications and opportunities for Vineyard Haven.

Seasonal Risks

Projected increases in winter flooding and storms coincides with higher volume and frequency of heating oil deliveries to Vineyard Haven, indicating that there may be greater potential of weather-related incidents involving heating oil during winter months (until decarbonization targets are achieved). This may include changes in the composition of heating fuel, as biofuel blends are introduced. Conversely, increased tourism during the summer months correlates with increased vessel traffic associated with tourism and freight to support higher populations of tourists on the Island. This indicates there may be a higher potential for spills from recreational vessels during summer months. This seasonal differentiation offers the chance for training and drills to be developed that account for seasonal risk patterns, and the seasonal staging of equipment based on risk levels.

Access and Responder Safety

Given projected and current coastal flooding patterns, access routes for emergency services and to the hospital and ferry terminal are likely to be ongoing and growing issues. Situations in which the Martha's Vineyard hospital is cut off pose a risk for spill response personnel in the event of a health and safety issue. Planning for emergency medical support will be increasingly important here and could be integrated into emergency oil spill response exercises.

In the case of extreme weather and storm surge, damage to piers and roadways may prevent responders from accessing and transporting the local MassDEP response trailer. In addition, reliance on local fire and harbor personnel to deploy equipment may be compromised during extreme events if responders are also personally impacted or they are tasked with other emergency response functions such as evacuations or emergency medical response. Given access challenges for oil spill responders, it may be worthwhile to add emergency response trailers, store response equipment on the water, or expand boom deployment training to other residents so that spill impacts can be mitigated if professional responders are delayed or unavailable.

Vessel Traffic and Navigation

In the future, the significant exposure of Oak Bluffs to storm surge and sea level rise may result in temporary or permanent closures of the Oak Bluffs marina and Steamship Authority terminal – this would bring even more traffic to Vineyard Haven Harbor, increasing the potential for incidents in the harbor. Ensuring that spill response equipment is sufficient for increased or changing vessel traffic will be important.

Many vessels already seek shelter in Vineyard Haven Harbor during high wind events. If this pattern continues, there may be an increase in the incidence of vessels sunk and/or abandoned in the harbor, leading to greater potential for leaking oil. Efforts to educate and promote awareness of reporting for mystery spills and best practices for removing fuel and other oils from abandoned vessels will be important.

In the case of a 100-year storm by 2030, there is significant potential for marine debris throughout the harbor that may impede and complicate oil spill response. Exercising oil spill response plans in the context of large storms could inform improvements. In addition, there may be a need for new technologies that could be useful for spill response in high-risk situations.

Infrastructure Integrity

Many critical facilities are located within flood zones. The R.M. Packer fuel docks and storage facilities in Vineyard Haven present the risk of large bulk oil spills. Understanding infrastructure vulnerability and condition, and testing response plans in the context of bulk oil spills would enhance spill readiness in this region.

GRS and Ecological Impacts

Flooding of the Lagoon Road bridge would prevent effective booming of Lagoon Pond – requiring alternative response and protection measures. Lagoon Pond is also a high value area for aquaculture and increasing aquaculture is a priority in the Vineyard Way Plan, so an oil spill here would have negative impacts for commercial operators, the local economy, and food security.

As shoreline changes take place – either due to climate hazards or structural adaptation – there is an opportunity to revisit the Vineyard Haven GRS to identify potential updates and additional protection strategies. It may also be helpful to test the GRS during a particularly high tide, to envision how high tide flooding might impact the tactics.

5.3.5. Oil Spill Risk Reduction and Preparedness Opportunities

The changes to the oil spill risk landscape allow for consideration of risk reduction opportunities. Table 5-3 sets out ideas expressed by participants during the May 2023 workshop, as opportunities to reduce exposure and vulnerability of Vineyard Haven Harbor to oil spill risks as a result of climate change. Many of the ideas and opportunities do not fall under the mandate of the MOSPRA program, however they point to an opportunity for a realignment of stakeholders and closer coordination with climate planners to support identified opportunities for monitoring and risk reduction.

Table 5-3: Oil spill risk reduction opportunities for Vineyard Haven Harbor

What is already happening today that should continue or grow to reduce risk and ensure preparedness?	• Remove & secure spill sources in and near flood zones • Drills & training • Projections of impacts & monitoring trends • Residential participation in spill prevention (education and training) • Decreasing oil dependency & increasing environmentally friendly solutions.
What are the indicators of future risk (R) or opportunity (O) that we should monitor?	• Shoreline erosion (R) • Vessel traffic (R/O) • Uptake of alternative fuels and biofuel blends (R/O) • Migration routes of animals/evolving habitats (R/O) • Water temperatures rising • Navigational hazards with SLR & marine debris (R) • Weather patterns & storm frequency (R)
What could we be doing today to be prepared for the future?	• Modify tabletop exercises to incorporate climate change • Beach & coastline restoration • Explore new technologies for oil spill response in complex situations • Increase regulation and oversight of new builds to decrease threat of mystery spills and protect critical response infrastructure • Improve existing shoreline infrastructure • Invest in alternative fuels & electric infrastructure • Man-made reefs for protection

What does climate-ready oil spill response look like in 2030 and beyond?	• Identified safe staging locations outside of flood zones and accessible during hazard events • Revised GRS's that account for changing shorelines and sea level rise • An island-wide response plan that can respond to multiple concurrent spills during complex events • Mainland mutual aid • Improved communications • Less oil dependency (and lower risk) • More flexibility & robust contingency plans • New tech/response equipment to allow for response during 'new normal' marine and flood conditions.

5.4. Case Study 3: New Bedford Harbor

5.4.1. Local Context and Vulnerabilities

Bordered by the City of New Bedford (population 95,315) and the Town of Fairhaven (population 16,072), historical New Bedford Harbor is home to the largest fishing fleet in Massachusetts, and the top fishing port in the nation based on dollar value (NOAA Fisheries, 2022), generating over $11 billion in economic value annually. In addition to the resident fishing fleet, vessels based out of regional harbors rely on the facilities at New Bedford Harbor to offload and process their catch.

Today, with the growth of the offshore wind industry, the Port of New Bedford and surrounding communities are on the verge of significant transformation. Recently, the New Bedford Marine Commerce Terminal (a multi-purpose facility designed to support the construction, assembly, and deployment of offshore wind projects and the handling of bulk, break-bulk, container shipping, and large specialty marine cargo) has been developed at the site of the former Sprague Oil Facility. Initiatives like the New Bedford Ocean Cluster aim to guide future development initiatives and increase commercial cooperation to balance the needs of local fishing fleets, with new and growing opportunities in the offshore wind and aquaculture industries (Port of New Bedford, n.d.).

With its large fishing fleet, growing offshore wind industry, and fuel transportation to and from Nantucket and Martha's Vineyard, there are a multitude of spill risks in New Bedford Harbor. Over the past several years, New Bedford Harbor has experienced a disproportionately high incidence of harbor spills – many from "mystery" sources. Because of this, New Bedford's MassDEP oil spill response trailer has been deployed more frequently than any other trailers in coastal communities.

In recent years, MOSPRA has funded an outreach campaign to reduce oily bilge releases and the pump out of bilge water to remove fishing vessel pollution risks. Long-term options are also being considered, and include a range of more permanent solutions, such as mobile or stationary waste oil storage and treatment.

Marine oil spills in New Bedford Harbor have the potential to cause a range of adverse consequences. Factors that may influence the vulnerability of this area to marine oil spills include:

- Oil spills would have adverse environmental impacts and economic consequences to commercial fishing and all the marine industries it supports.
- Oiling of local beaches and recreational sites would have social, environmental, and economic impacts.
- Local sites that have undergone restorative treatments (such as marsh replanting) or remediation for legacy pollution through state and federal programs could be damaged.
- A major spill response could disrupt vessel traffic and transportation networks in the event of a large spills, including for ferries, fisheries, fuel transportation, offshore wind construction, operation and maintenance, and emergency services.

5.4.2. Sea Level Rise, Coastal Flooding, and Extreme Weather

NOAA historical sea level and coastal flood data is not available for New Bedford Harbor; however, the New Bedford/Fairhaven Coastal Viewer illustrates the projected 2030 Mean High High Water (MHHW) mark (Figure 5-12) (Woods Hole Group, n.d.). Highly vulnerable areas include salt marshes and shorelines outside the hurricane barrier, low-lying areas on the Fairhaven side of the harbor and several industrial and commercial properties within the Port of New Bedford. Even without climate impacts, historical piers are under pressure from natural deterioration, and will require upgrades to ensure there are sufficient docking locations for vessels, and to address safety concerns (Port of New Bedford, 2022, p. 1).

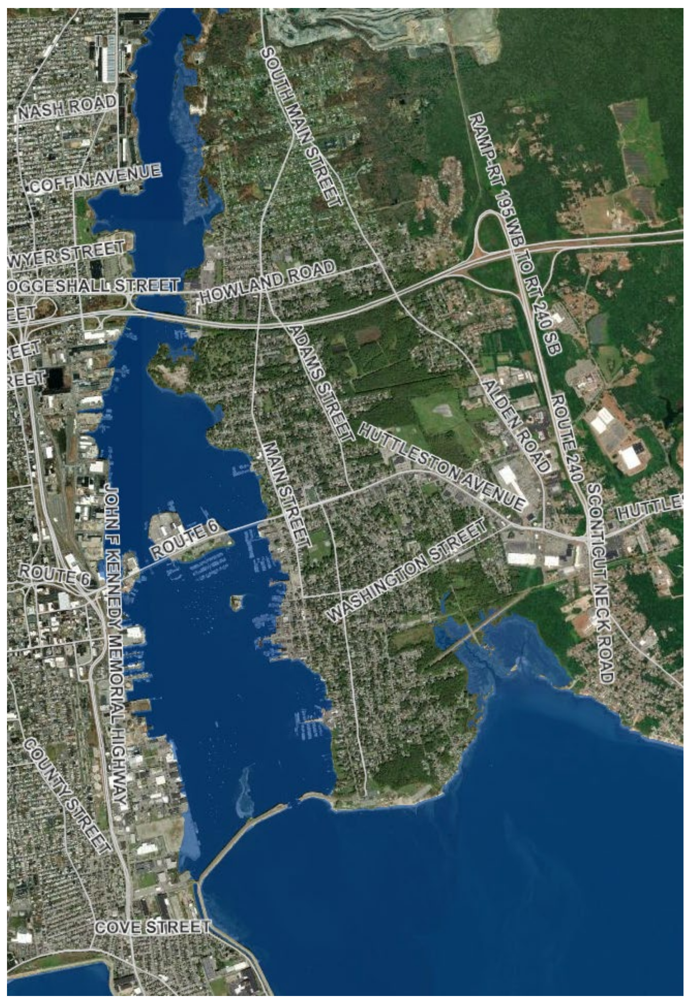

Figure 5-12: Screenshot of Mean High High Water Mark projected in 2030 as mapped and modelled by the Woods Hole Group (NBResilient.com, 2022).

Figure 5-13: New Bedford Hurricane Barrier was designed for the storm of the time in the 1960s and may not stand up to future severe events

Since its completion in 1966, a hurricane barrier has protected the harbor from serious storm surge and flooding (Figure 5-13). In 2011, FEMA deemed the barrier sufficient to withstand a 100-year flood event (Town of Fairhaven, 2020, p. 12); however, projections show that the severity of a 100-year event is worsening. Port and city officials have warned that the hurricane barrier alone is not enough to protect the harbor from future storms.

Climate Risk Assessments completed by the Port and City of New Bedford and the Town of Fairhaven have identified the need for additional storm mitigation measures inside the barrier given the trajectory of sea level rise, coastal flooding, and extreme weather hazards. Figure 5-14 illustrates the projected impact of a 1% (100-year) flood event in 2030, overlayed with current GRS and MassDEP trailer locations. There are currently no GRSs within the hurricane barrier.

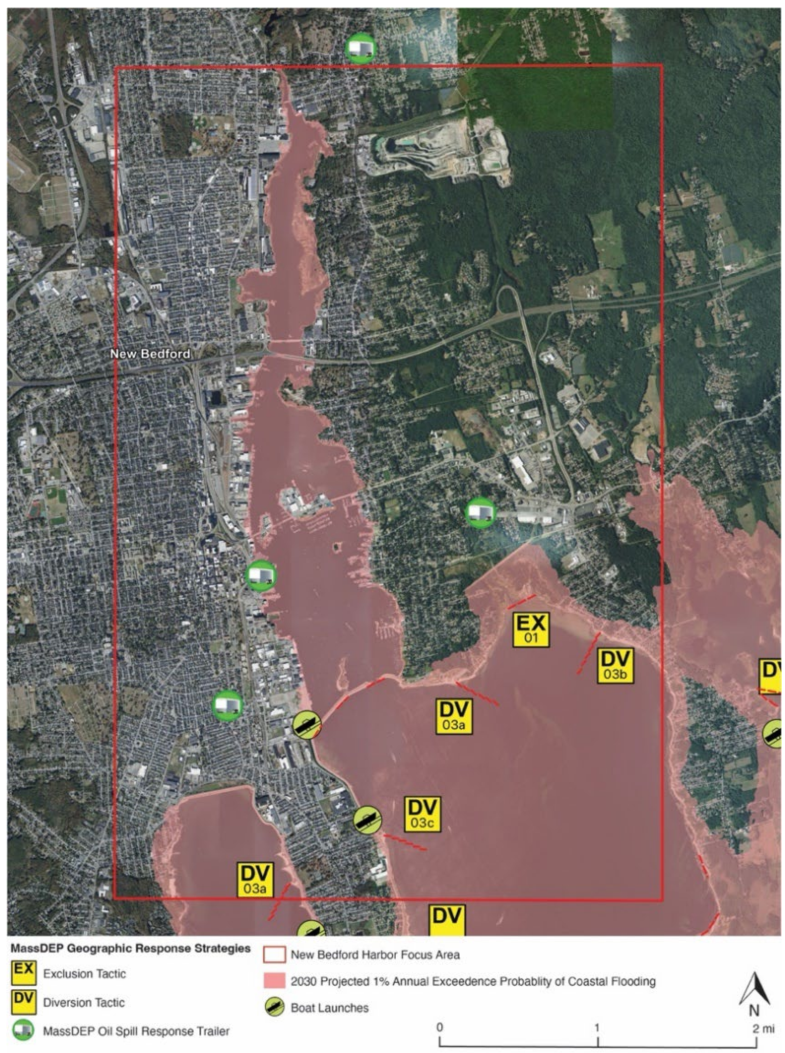

Figure 5-14: 100-year flood event in 2030, overlaid with GRS for New Bedford harbor

Until recently, high tides have not been a major concern for most people living and working here, given the protection provided by the hurricane barrier. However, the barrier has been closed more frequently in recent years due to non-storm related high tides, a practice that disrupts Port users and vessel traffic (Town of Fairhaven, 2020, p. 12).

Future projections indicate that, under current closure criteria, by 2050 the barrier would need to be closed as much as 1-2 times per day due to high tide events alone, compared to a total of 26 times in 2019 due to primarily weather-related events.

5.4.3. Climate Resilience Efforts

New Bedford Harbor encompasses an EPA Superfund site. The work and investment required to restore this Site has set a strong foundation for tackling complex climate challenges (Paul, 2023). In 2021, The City of New Bedford released NB Resilient - a holistic climate action plan that encompasses climate adaptation, mitigation, and resilience through the lens of social equity (City of New Bedford, 2021). This work includes the identification of a range of nature-based and grey infrastructure solutions. A strong example of nature-based adaptation is the New Bedford Riverwalk – a $20 million plan to revitalize natural shorelines, protect biodiversity, improve access to nature, and protect against climate change (Paul, 2023). Beyond the hurricane barrier, the replacement of parking areas at Clarks Point with impervious pavement and other green infrastructure options is another example of adaptation for sea level rise and storms.

The working waterfront is a more challenging space for adaptation. An assessment of municipal piers has identified required upgrades, costs and timelines based on projected sea level rise (Port of New Bedford, 2022). In addition, the New Bedford Harbor Resilience Design Guidelines serve as a resource for shoreline infrastructure upgrades and development (Port of New Bedford, 2020). With significant new development planned to support the offshore wind energy industry, the Port of New Bedford has an opportunity to develop new infrastructure that will be fit for the future. Historical piers, existing private facilities and roadways pose a greater challenge for adaptation, and the expectation is that government and port owned properties will be the first to invest in adaptive measures. Future work is needed to address the longevity of the hurricane barrier and its capacity to mitigate future extreme weather events.

5.4.4. Evolving Oil Spill Risk and Opportunities

Seasonal Risks

The hurricane barrier is a major asset in terms of moderating the impacts of high tide flood events in the near term, particularly in the winter months. However, the regular closure of the hurricane barrier during high tide events may be untenable in the future due to the economic impacts for fisheries and the offshore wind industry when the barrier is closed. This is one driver of Port and municipal adaptation efforts, and, over the long term, New Bedford Harbor may expect the hurricane barrier to remain open during high tide events, with a greater likelihood of coastal inundation during the winter months. Extreme weather events in the fall, winter and spring are increasingly likely to exceed the capacity of the hurricane barrier to fully protect the harbor. Oil spill risks may change seasonally based on increased barge traffic delivering home heating oil to the islands during winter months. Fall and winter storm seasons may also disrupt ferry service more frequently than spring and summer.

Access

Investment in the Riverwalk and other planned shoreline adaptations may have a positive effect in opening up access routes for responders to deploy boom and protect sensitive shorelines in the event of a spill. On the other hand, more frequent closure of the hurricane barrier may impact access to and from the harbor for responders and response organizations, whether they are responding to spills locally or providing aid to other regions.

Response Measures and Coordination

With massive investment having already gone into the EPA Superfund site, and millions more planned to restore shorelines and enhance waterfront access, the value of shorelines in New Bedford is growing. Ensuring that GRS account for changes to shorelines will be important. As flooding becomes more common in New Bedford, there may be a need for sandbags and flood protection equipment to be co-located and stocked with oil spill response equipment – this would serve to protected potential spill sources from flooding and prevent contaminated flood waters from reaching sensitive sites.

There is also an opportunity to include new partners in oil spill prevention and response activities. This includes the urban planners and engineers designing flood prevention measures, local emergency managers, and local volunteers and the public who have a strong interest in the protection and recovery of shorelines.

Infrastructure Integrity and Resilience

Construction in the harbor and the growth of aquaculture and offshore wind may increase vessel traffic and the risk of spills in the harbor. The service platforms connecting Massachusetts offshore wind turbines may store 40,000 gallons of dielectric oil and another 2,000 of other oil-based fluids (diesel fuel, lubricating oils). Each turbine also stores approximately 190 gallons of dielectric oil, supplied by vessels. This creates the potential for small, operational spills from the turbines as well as larger volume spills from the service platforms. These spill scenarios may require new plans or equipment to ensure adequate preparedness (LSU and MAR, 2011).

The size of vessels for the offshore wind industry, particularly during construction phases, poses a risk to the hurricane barrier itself because of very limited clearance when transporting larger components of windmills. Damage to the barrier could prevent it from functioning to protect the harbor from storms. Damage to the hurricane barrier is a top factor in the potential exposure of the harbor to extreme weather and could increase the potential for oil spills and marine debris as a result of hurricanes and storms. As in Boston Harbor, the integrity of shoreline roads and infrastructure may be affected by sea level rise and storm surge. Damage to these areas could also affect the safety and operation of industrial and commercial activities. Finally, as noted in the Port Climate Assessment, the integrity of piers is essential to safety for fishing and other vessels docked locally. Overcrowding creates risk in terms of storms and sea level rise, increasing the potential for damage to vessels which may lead to spills.

Beyond major storms, the siting of new fuel facilities to service the offshore wind industry may introduce new risks related to bulk fuel spills. At the same time, these new facilities, if developed in line with resilient design guidelines, could provide safer options for fuel storage.

5.4.5. Oil Spill Risk Reduction and Prevention Opportunities

The identification of emerging risks in New Bedford allowed for the identification of opportunities and actions to reduce future risk of oil spills associated with climate change and adaptation. These are captured in Table 5-4.

Table 5-4: Oil spill risk reduction opportunities for New Bedford Harbor

What is already happening today that should continue or grow to reduce risk and ensure preparedness?	• Modeling & mapping of climate impacts • Development of climate-resilient infrastructure (i.e., new docks, Riverwalk) • More training for the right audience (i.e. workers & management related to climate change & oil spills) • Conversion to clean energy (including for vessels) • Building resilience of current electric grid
What are the indicators of future risk (R) or opportunity (O) that we should monitor?	• Development of offshore wind products to support electrification (O) • Diversification of fishing fleets (O) • Tourism & implications for a changing waterfront (O) • Forecasting to improve spill preparedness (O) • Is spill policy proactive (opportunity based) or reactive (risk based) ?
What could we be doing today to be prepared for the future?	• Invest funding in resilient infrastructure, increasing incentives for infrastructure owners to upgrade piers and protect vessels • Education, awareness, & training for workers, permitting of projects, government, local volunteers • Improve data collection on weather & tides to track potential association between spill reports and extreme weather & tide events • Introduce new prevention & response technologies (for new hazard conditions)
What does climate-ready oil spill response look like in 2030 and beyond?	• Different players in the response industry • Increased multidisciplinary coordination of activities • More proactive planning and preparations • Impacts from the continued erosion of coastline • Potential for increased navigational hazards (i.e., marine debris)

5.5. Summary of Key Themes

While there were unique impacts identified across the three case studies, five common themes emerged that could be considered in planning for the influence of climate hazards and adaptation on oil spill risk and response. These are summarized in Table 5-5.

Table 5-5: Impacts and influences of climate hazards and adaptations for oil spill risk reduction, preparedness, and response

Access	• To responders for equipment, fuel, and vessel staging areas • To assess and respond to spills when roads, boat launches, and infrastructure are flooded/damaged • To petroleum storage facilities • To out-of-state responders due to potential closures of Logan Airport during a major storm • To/from New Bedford Harbor with more frequent closures of the hurricane barrier, impacting spill response speed and capacity • Opportunity for improved access to Acushnet River shoreline due to new riverwalk in New Bedford • Responder access to Vineyard Haven hospitals in an emergency
Response Measures and Coordination	• Clean-up of natural/restored shorelines and marshes is more complex than for rip rap/seawalls • Clean-up does not always happen in marshes – it can be more damaging than the spill • Complications from flooding and storm surge carrying oil inland; authority for clean-up of debris, standards for safe return home • Need to stock and stage flood protection equipment and sandbags as a spill prevention measure • Shoreline changes may negate the ability to implement GRSs • Environmental Sensitivity Index (ESI) data may not be up-to-date/aligned with new/restored shorelines
Vessel Traffic and Navigation	• In most cases increasing, leading to fewer dock /anchorage locations, and overcrowding of marinas and ports • Navigational challenges for responders related to increased debris from storm surge/extreme weather events • Construction-related traffic issues in/around new port facilities, Offshore Wind (OSW) • Risk of allisions with New Bedford's hurricane barrier as vessels grow in size.
Socio-Economic Factors	• Greater focus and concern for health and protection of restored shorelines and marshes, meaning increased public and political interest in spill impacts, response, and recover • Population growth leads to increased focus on risk as more people are at risk of large spills (in urban areas)

	• Food, fuel, responders, and spill response equipment are all reliant on supply chains that may be damaged post-flooding/storm • Risks to aquaculture, fishing, and OSW economies from large spills
Infrastructure Integrity and Resilience	• Potential for increased risk of spills from fuel storage facilities located in flood zones • Siting of new fuel facilities is limited/more challenging as shorelines transform from grey to green • Old /abandoned infrastructure poses navigational challenges • Flooding of businesses and residences that utilize different oils leads to more mystery/land-based spills entering marine environment • Resilient and green infrastructure implementation may be an opportunity to integrate resilience to oil spills • Impact of risk to marine and land infrastructure if New Bedford's hurricane barrier is damaged (i.e., allision) or breached during storm surge

6. DECARBONIZATION AND OIL SPILL RISK

The third component of this study relates to decarbonization policy, targets, and technologies and their influence on oil spill risk and response. Climate change mitigation refers to actions taken to limit the extent of greenhouse gasses (GHG) released into the atmosphere, and therefore the rate and extent of climate change impacts and hazards. Decarbonization is an essential element of climate change mitigation and refers to the reduction of various sources of carbon emissions. The burning of fossil fuels is the primary source of carbon emissions globally.

Many federal and state climate mitigation and decarbonization targets are linked to the 2015 Paris Agreement, a legally binding international agreement that aims to limit global warming to below 2 degrees Celsius (United Nations Climate Change, n.d.). Since then, myriad policies have been established by governments and financial regulators globally to achieve rapid reduction of carbon emissions, with most centering around a goal of net-zero carbon emissions by 2050, with various interim targets. This has been accompanied by research, investment, and innovation across sectors, including marine shipping. Collectively, these efforts indicate high potential for significant shifts in the transportation, storage and consumption of petroleum products, and the introduction of new risks and opportunities with respect to the transportation of alternative fuels and adoption of new energy technologies.

Decarbonization is a dynamic area of high uncertainty that presents a range of potential impacts for oil spill risk as well as other types of marine emergencies. For the purposes of this study, analysis of the interaction of decarbonization and oil spill risk consists of the following:

- Study of Massachusetts' decarbonization policy and targets
- Study of global marine industry decarbonization trends, targets & technologies
- Identification of potential medium to long term implications for oil spill and marine emergency risk and response through participatory strategic foresight methods involving local and industry experts (May 2023 workshop)

As decarbonization targets, technologies and policy continue to evolve, there is still significant uncertainty about local and regional impacts.

6.1. Commonwealth of Massachusetts Decarbonization policy

In 2020, Massachusetts released the *Massachusetts 2050 Decarbonization Roadmap* (Ismay et al. 2020) including a comprehensive analysis of the mechanisms, implications, costs, and benefits to achieve net-zero emissions via eight different scenarios. In 2021, *The Act Creating A Next Generation Roadmap for Massachusetts Climate Policy* was signed into law, setting emissions reduction targets for 2030 (50%), 2040 (70 %) and 2050 (net-zero) (Massachusetts EOEEA, 2023). In 2022, the Commonwealth finalized the *Clean Energy and Climate Plan for 2025 & 2030* (CECP 2025/30) which sets specific sector emissions targets, and established actions, incentives, and policy to meet these targets (Massachusetts EOEEA, 2020b). Figure 6-1 below is taken from the CECP 2025/30 and illustrates historical sector emissions and modelled statutory emissions reductions to 2030 (Massachusetts EOEEA, 2022a, p. 13).

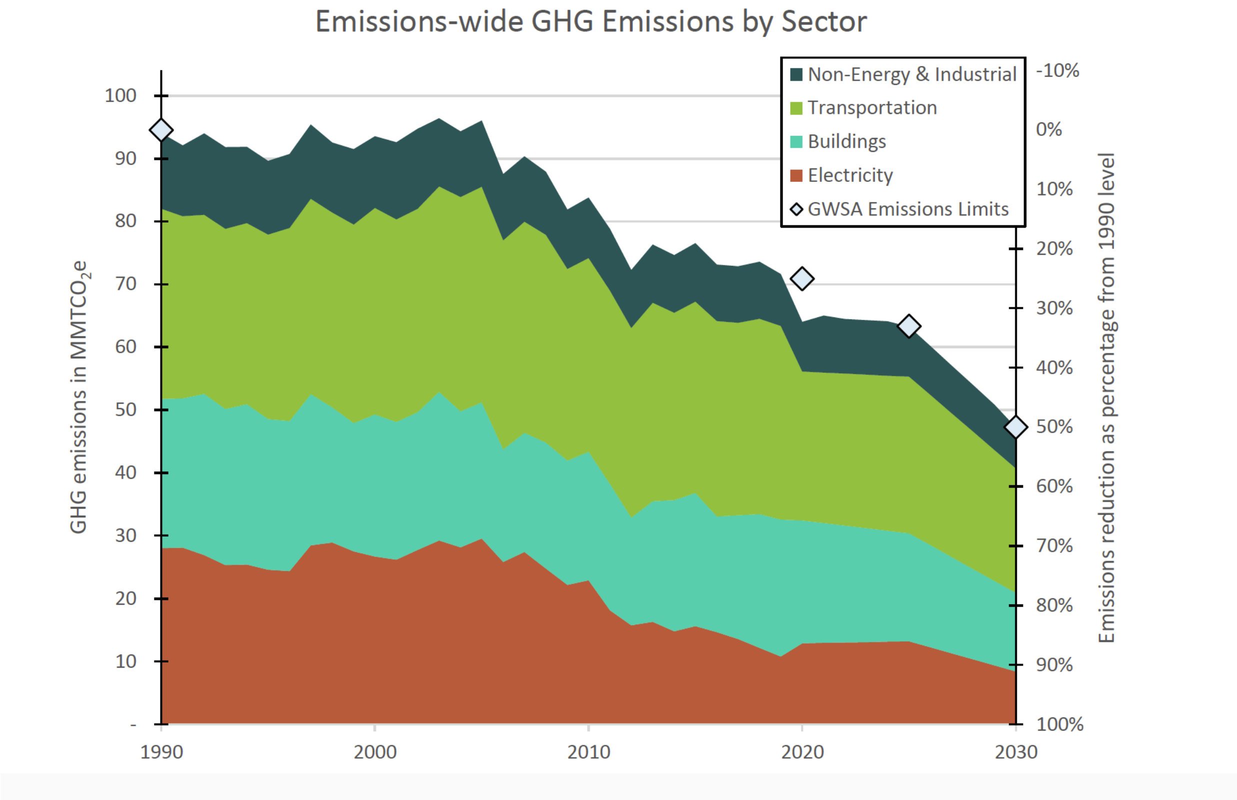

Figure 6-1: Massachusetts emissions reduction targets for 2030

Both the Decarbonization Roadmap and the 2025 and 2030 CECP identify common elements that are essential to act on during the next decade to achieve a 2050 net-zero goal. This includes:

> *"[A] balanced clean energy portfolio, anchored by significant offshore wind resources, more interstate transmission, widespread electrification of transportation and building heat, and reducing costs by taking action at the point of replacement for equipment."*

The targets anticipated to have the most substantive impact on oil spill risk factors are those related to the transportation and buildings sectors and investment in offshore wind.

6.1.1. Comparing Historical Movement of Oil with Buildings Sector and Transportation Sector Emissions Sub-limits

According to the Executive Office of Energy and Environmental Affairs (EOEEA), gross emissions within Massachusetts have declined by 31% from 1990 to 2021. This has occurred concurrent to a net gain in both population and GDP, indicating that policies to date have been relatively effective. However, as demonstrated by the OR-1 data analyzed in the updated Oil Spill Threat Assessment (Nuka Research, 2024), this has not translated to significant reductions in the gross volume of petroleum products imported via marine terminals. In the future, given ambitious targets set out in more recent legislation, petroleum import and transportation patterns will likely change. Collectively the buildings sector (Massachusetts EOEEA, 2020a) and the transportation sector (Massachusetts EOEEA, 2020c) are the leading contributors to GHG emissions in the Commonwealth, and the target of significant near- and long-term emissions reductions policy.

To begin to understand the potential implication of newly adopted decarbonization policy on oil import and transportation patterns, it is useful to consider how current and targeted consumption patterns compare to existing marine transportation patterns. In comparing historical state consumption data from the U.S. Energy Information Administration (EIA) with OR-1 data on historical petroleum deliveries to marine terminals, it is difficult to align the two. Table 6-1 compares Massachusetts consumption reduction targets and enabling policy from the CECP 2025/2030 with information from the Threat Assessment on oil imports from 2015-2020.

Generally, these policies and targets are likely to influence oil spill risk primarily through a net reduction in the volume of gasoline, diesel and heating oil imported and transported through coastal waters, as well as the potential for closure of petroleum storage facilities.

Table 6-1: Comparing transportation and building sector energy consumption targets with historical oil imports from 2015-2020

Sector	Current Consumption (data from 2015-2020)	Future Target Consumption (2030)
Massachusetts Transportation Sector Emissions Targets and Enabling Policy to 2030	• Average of 62,426,750-barrels of motor gasoline was consumed annually, and an average of 61.3% of this was imported via marine terminals in Boston Harbor. • It is not possible to break out the sector-use of diesel and distillate fuel oils (DFO) imported via marine terminals, however, approximately 50% of combine diesel and DFO consumed in Massachusetts annually was delivered to marine terminals. • On average, 10,390,000 barrels of jet and aviation fuels were consumed annually between 2015-2020. Nearly 100% of these fuels were delivered to Massachusetts via marine terminals. • Gasoline, diesel, jet and aviation fuel is transported to the Islands via tug and barge, and via trucks on ferries.	• 45% reduction in motor gasoline consumption for transportation from 2015 levels • 17% reduction in diesel consumption for transportation from 2025 levels • 18% increase in volume of jet fuel consumed • 75,000 new electric vehicle chargers installed and over 1 million electric vehicles on the road • Widespread electrification of public transit • Support for the electrification of short-haul aviation, including for regional airports • No specific marine-related targets identified
Massachusetts Building Sector Emissions Targets and	• Approximately 50% of home heating oil consumed in Massachusetts is imported via terminals in Boston Harbor.	• 45% reduction in home heating oil consumption from 2015 • 20% reduction of carbon intensity of heating fuel, through biofuel blends. • Electrification of 38% of all homes (compared to 14% in 2015)

Sector	Current Consumption (data from 2015-2020)	Future Target Consumption (2030)
Enabling Policy to 2030	• Historically biofuel blends have not been utilized for heating oils in the Commonwealth • Home heating oil is transported via tug and barge and tanker to terminals in Boston Harbor and New Bedford • Home heating oil is transported via tug and barge and tanker truck from Massachusetts terminals to Martha's Vineyard and Nantucket	• Incentives for installation of heat pumps and solar energy to replace oil and gas heat

6.1.2. Investment in Offshore Wind

The acceleration of the offshore wind industry is central to both federal and state decarbonization goals and is one aspect of policy likely to impact marine oil spill risk. The federal government has set the first standard of 30 gigawatts (GW) offshore wind capacity by 2050 and committed funding to port infrastructure development and jobs training to service the industry. Massachusetts intends to solicit proposals to contract for 5,600 megawatts (MW) of offshore wind power by 2027, with major projects already underway (Massachusetts EOEEA, 2022a, p. 64). Figure 6-2 identifies nine offshore wind lease areas, many of which will be serviced by offshore wind terminals located in Massachusetts waters. New Bedford, Vineyard Haven, and Salem Harbor are among those locations identified for onshore development to service these projects.

The major impact of offshore wind investment for oil spill risk relates to increased vessel traffic, and changes in vessel traffic patterns to service wind farms. Figure 6-3 shows statewide vessel traffic density based on an analysis of ship movements from 2017-2020. Because the data used to develop these maps came from shoreside Automatic Information Systems (AIS) data, it does not capture offshore vessel traffic patterns or density. The data does allow for a comparison of traffic at various ports, and of the three areas identified as potentially supporting offshore wind, two of them (New Bedford and Vineyard Haven Harbor) already have high vessel traffic activities. Salem Harbor has much lower vessel traffic density and may face a more significant increase in vessel traffic relative to current levels. Additional analysis of offshore vessel movements, derived from satellite AIS, would provide a baseline for assessing future changes to vessel movements associated with offshore wind development.

A secondary impact to ports supporting offshore wind may relate to the innovation opportunities for the electrification of vessel fleets and port operations as the industry matures.

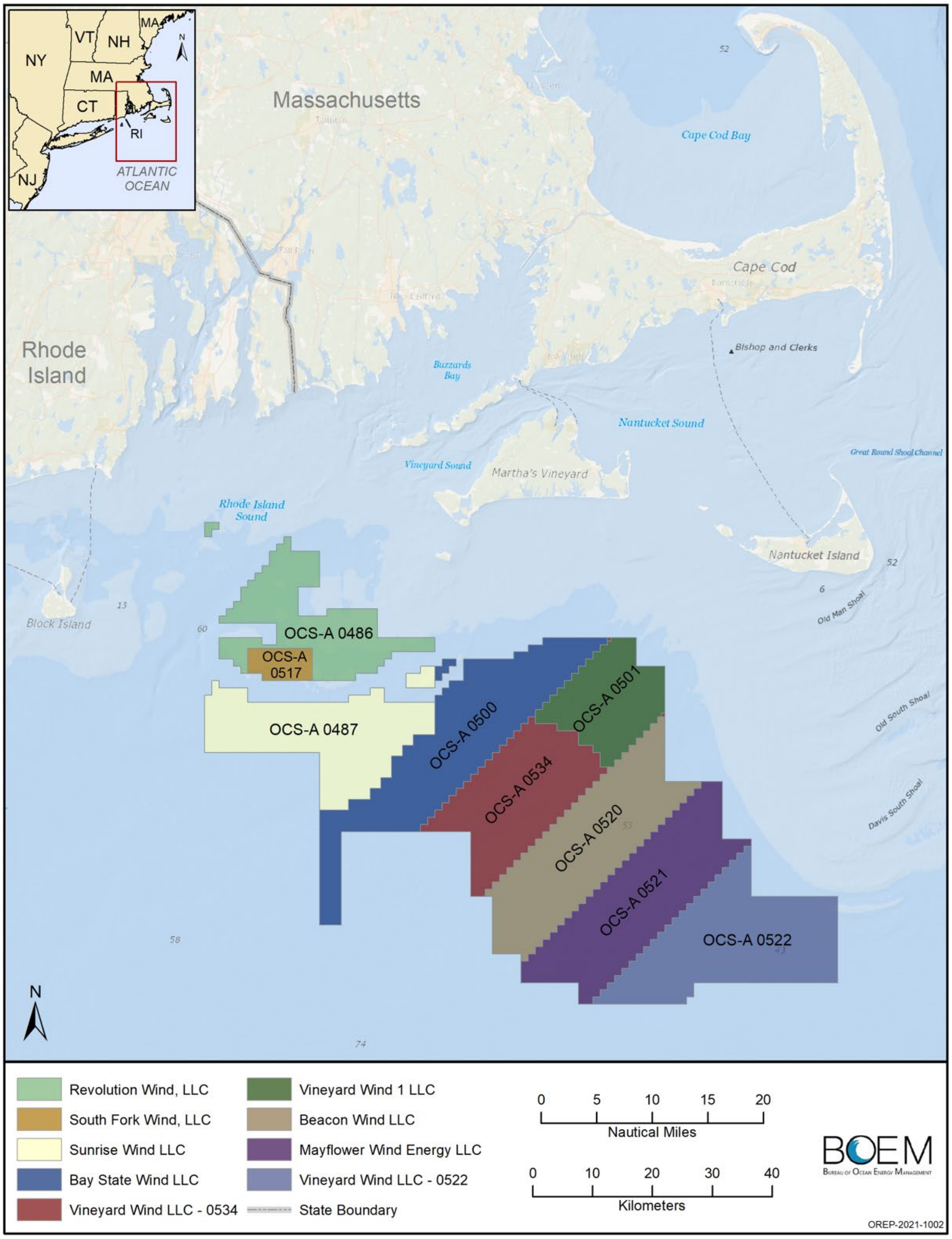

Figure 6-2: Bureau of Ocean Energy Management (BOEM) offshore wind lease areas

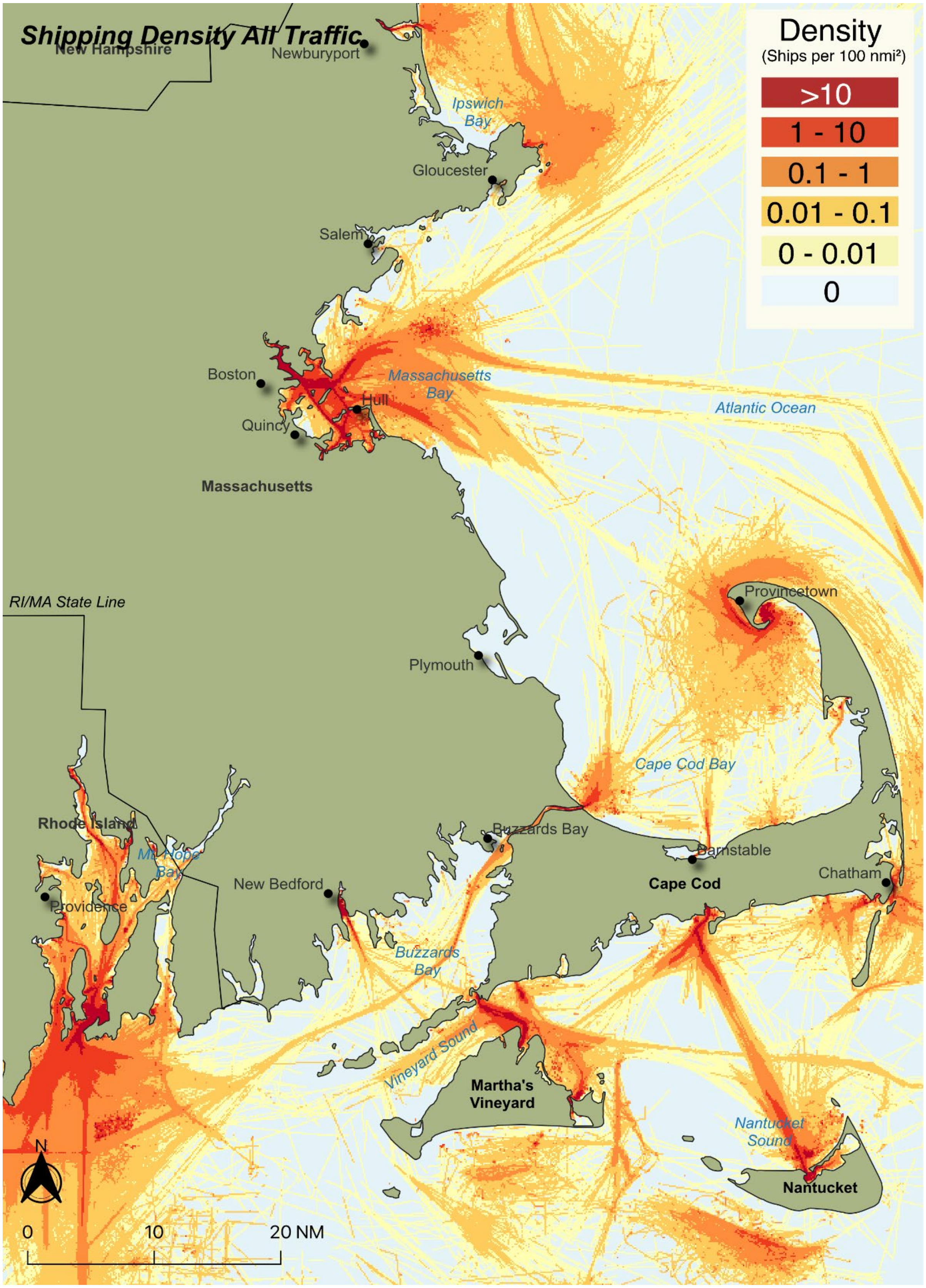

Figure 6-3: Statewide vessel traffic density (2017-2020) for all vessels, based on shoreside AIS receivers

6.2. Decarbonization of Marine Vessels and Ports: Trends, Targets, and Technologies

6.2.1. International and Industry Commitments and Consortiums

In 2018, maritime shipping accounted for approximately 3% of global emissions. Projections show that, in the absence of major technological shifts, this emission contribution will grow substantially and undermine international efforts towards the Paris Agreement (European Commission, 2023).

The landscape of research, policy, and technologies in support of the decarbonization of marine shipping has changed drastically over the past several years driven, in part, by the targets set by the Paris Agreement, and by various national legislations. At the time of publication, the literature review for this project identified only a handful of high-level commitments and announcements pertaining to industry-wide decarbonization, and limited sources examining the implications of emerging technologies and alternative fuels for marine safety and oil spills (Nuka Research, 2021). Since then, new commitments and consortiums have been established to progress towards these goals, and research and technology in the area has grown substantially. Four major initiatives are summarized in Table 6-2. Table 6-2: Summary of major decarbonization policies and targets established after 2021

Table 6-2: Summary of major decarbonization policies and targets established after 2021

Organization	Initiative	Description	Timeframe
International Maritime Organization (IMO)	2023 IMO Strategy on Reduction of GHG Emissions from Ships (IMO, 2023)	Establishes targets and actions to reduce GHG emissions from international shipping by at least 20% by 2030, and at least 70% by 2040 to achieve net-zero near 2050.	Comes into force 2023 with targets in 2030, 2040 and 2050
IMO	Green Voyage 2050 (IMO, n.d.-c)	An initiative to support maritime GHG reduction with the involvement of less developed countries, UN agencies and industry partners, including activities such as training in decarbonization, alternative marine fuels mapping, and the Low Carbon Shipping Global Industry Alliance.	In line with 2023 IMO GHG Reduction Strategy
C40 Cities	Green Ports Forum (C40 Cities, 2023a)	A consortium of ports and cities from around the world committed to finding solutions to finance, coordinate and deliver decarbonized shipping corridors and ports.	Ongoing
European Union	FuelEU Maritime (IMO, n.d.-a)	Regulation setting GHG intensity requirements on 100% of energy used on voyages within the	Comes into force January, 2025

Organization	Initiative	Description	Timeframe
		EU, and 50% of energy used on voyages into or out of the EU (DNV, 2023).	

Neither the Commonwealth of Massachusetts nor the federal government have established specific targets with respect to decarbonization of the marine shipping industry or for smaller commercial fleets and recreational vessels. Both have pointed to reliance on the IMO (Massachusetts EOEEA, 2022a) and the need for international collaboration towards the regulations, infrastructure, and investment required to launch alternative fuels and reduce emissions (U.S. DOE et al. 2023, p. 69).

6.2.2. Trends and Technologies: Vessels, Shipping Industry, and Ports

Collaboration, Research, and Investment

As a result of IMO commitments and government targets, stakeholder groups have been established to explore technological options and regulatory requirements to comply. In 2020, Maersk announced an industry initiative "to develop new fuel types and technologies by launching the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping." (Maersk, 2020). In 2021, the Vancouver Maritime Centre for Climate (Vancouver Maritime Centre for Climate, n.d.) was launched to mobilize funding, research and innovation required to achieve zero-emissions shipping in British Columbia, Canada.

According to an industry perspectives report, this decarbonization effort requires mass investment and adoption of new technologies and supporting government policy at an estimated cost of $1.65 trillion by 2050 (Shell & Deloitte, 2020). Assuming that industry collaboration, financial investment, and government policy will continue to drive decarbonization efforts, experts estimate that the first "net-zero vessels" could enter the commercial fleet by the year 2030 (Shell & Deloitte, 2020).

Alternative Fuels: LNG, Hydrogen, Ammonia, Biofuels, and Renewables

While only a few years ago many industry leaders viewed alternative fuels, such as hydrogen, as a very far off possibility, today efforts are underway to invest in new shipping technologies and research to incorporate climate mitigation. Research and pilot initiatives are currently underway to determine the viability of a range of fuels for commercial shipping, including but not limited to wind energy, hydrogen, ammonia, natural gas, and biofuels (Nyhus, 2021). In 2023, the Global Industry Alliance to Support Low Carbon Shipping published the results of a regulatory readiness exercise, which mapped the regulatory status of 10 different types of fuels and alternative energy sources. This effort highlights gaps and opportunities to ensure that global regulation supports a transition low carbon fuels (IMO, n.d.-b).

Liquified Natural Gas (LNG), hydrogen, ammonia, and biofuels are the most commonly referenced alternatives to petroleum fuel oil in the literature. LNG use in ships is currently increasing, in part because burning LNG results in relatively low emissions, (Shell & Deloitte, 2020) and there are a record number of LNG-powered vessels on order as of 2023 (DNV, 2023). As Pavlenko et al. (2020) point out, the viability of LNG as a long-term solution is problematic, given the high upstream GHG emissions associated with production (Pavlenko et al. 2020). Hydrogen and ammonia are perceived to be the most "promising alternatives" to oil; however, technology and infrastructure are not yet in place globally to support their widespread use (Shell & Deloitte, 2020; McKinlay et al. 2020; DNV, 2019).

Ammonia is perceived by some industry experts to be a viable alternative fuel in part because the shipping industry has experience handling ammonia over the last several decades (Shell & Deloitte, 2020). Hydrogen technology is also being developed both to enable vessels to transport and meet global demand for hydrogen (Aarnes et al. 2018), and as a fuel for commercial vessels. Following a successful pilot project in 2019, Kawasaki Heavy Industries announced approval to develop a hydrogen carrier with capacity "on par with LNG carriers." (Kawasaki Heavy Industries, 2021). Starting in 2021, hydrogen is being used to power ferries and cruise ships including in Norway (Radowitz, 2021) and the U.S. (Sampson, 2021). In 2022, Yara Clean Ammonia and Azane Fuels established a partnership to develop an ammonia bunkering network across 15 Scandinavian ports, including land-based and offshore bunkering operations (Yara International, 2022). This network is set to be operational in 2024 (NorSea Group, 2023).

Hseih and Felby (2017) conducted an analysis funded by the International Energy Agency (IEA) on the feasibility of biofuels for the marine sector and identified both challenges and opportunities for the adoption of biofuels (Carmen Hseih & Felby, 2017). Similar to hydrogen and ammonia, the widespread adoption of biofuels in the shipping sector is dependent on production capacity and infrastructure. Several sources note that reliability of supply and competition for biofuels from other sectors may be an impediment to their adoption in the shipping sector (Ismay et al. 2020; Shell & Deloitte, 2020). While biofuel blends may play a role as an in interim low-carbon fuel, in the near term they are more likely to be adopted by smaller commercial and recreational vessels than by the commercial shipping sector (Carmen Hseih & Felby, 2017).

Green Shipping Corridors

With a broad range of low-carbon shipping fuels and technologies under development, Shell and Deloitte (Shell & Deloitte, 2020) highlighted in 2020 the need for global coordination to align efforts and recommend the establishment of Port Coalitions to enable infrastructure investment required to achieve IMO and government low-carbon shipping targets. Since then, several global coalitions have come together to invest in infrastructure networks and green shipping corridors and maritime hubs. Examples include a green and digital shipping corridor between Southern California ports and Shanghai (C40 Cities, 2023b), and a green shipping corridor between Singapore and Rotterdam (The Maritime Executive, 2023). These initiatives aim to reduce GHGs and introduce new technologies to increase efficiency across some of the world's busiest cargo shipping routes.

In Massachusetts, MassPort has committed to a net-zero target by 2031. According to MassPort, "The Roadmap to Net Zero focuses on 100% of the greenhouse gas (GHG) emissions directly controlled by MassPort-owned facilities, equipment, and purchased electricity, with continued influence in areas the Authority does not control."

At present (November 2023), there are no international green shipping corridors associated with Massachusetts, and no government or port commitments in Massachusetts to invest in alternative fuels infrastructure. Uncertainty around future fuels, lack of regulation, and limited physical space to site new storage and bunkering infrastructure were all identified as significant barriers to the adoption of alternative marine fuels in Massachusetts. This puts Massachusetts behind some West Coast, Asian and European ports with respect to investment to support low-carbon marine shipping.

Vessel Electrification & Automation

As with land-based transport, electrification and automation are growing components of decarbonization strategies and technologies, in particular for ferries, smaller vessels and regional routes. In the spring of 2023, the Martha's Vineyard Commission hosted "Ferries Now," a forum on the electrification of ferries, highlighting agencies that had successfully adopted hybrid and fully electric vessels (Hufstader, 2023). Electric tugboats are currently operational in a number of ports including: Vancouver and Prince Rupert, Canada; Auckland, New Zealand, and San Diego. Currently there are not electric ferries or tugs operating in Massachusetts. Some barriers to electrification of fleets in Massachusetts were identified as access to chargers for vessels, concerns about grid stability, and a lack of trained personnel to operate and maintain new technologies. As more electric vessels come online globally, solutions to these issues are likely to emerge.

Autonomous vessels (AV) are also on the rise. Globally, AVs have been deployed for spill response, research, tourism, and cargo. In 2020 the Mayflower Autonomous Ship (MAS) sailed from Plymouth, UK to Plymouth, Massachusetts, and today continues to sail autonomously, powered by solar, collecting data about the world's oceans (Mayflower Autonomous Ship, 2023). In 2022, the US Coast Guard issued guidelines for the testing of autonomous or remote controlled vessels (Edwards, 2022). The *Maju 510* tug, based on the Port of Singapore, was the first "vessel in the world to receive the Autonomous Notation from ABS classification society." (The Maritime Executive, 2022). Companies are turning to electric and autonomous vessels as an alternative to high-emission trucking on a regional scale. For example, the *Yara Birkeland,* an electric-autonomous cargo vessel operating in Norway, aims to remove "40,000 diesel-powered truck journeys every year" by transporting mineral fertilizer that would otherwise move by truck (Yara, 2022). Proponents of electric and autonomous vessels promote benefits including energy efficiency, safety, and crew and public health through noise reduction and air quality improvements.

6.3. Case Study: Mapping Decarbonization Trends and Future Impacts in Three Massachusetts Harbors

The pathways to achieving decarbonization across sectors range from high to low certainty, as does the identification of potential future implications of decarbonization for marine oil spill risk and response. While the decline in the consumption of oil is ultimately positive for direct oil spill risk reduction, the uncertainty inherent in this transition presents a number of potential risks and opportunities.

To explore this transition in the context of Massachusetts ports and harbors, this study applied strategic foresight tools, including the use of Futures Wheels (a tool designed to help explore direct and indirect consequences of a specific change or trend) during the May 2023 workshop to consider different ways in which decarbonization trends, policies, technologies, and targets may play out and influence marine oil spill risk and response. Given the pace of transition, and the net-zero targets, analysis was loosely confined within the 2030-2050 time frame. This began with the identification of first tier implications of the policies, trends and targets discussed above, based on Massachusetts energy transition plans and decarbonization targets and the introduction of alternative fuels and electric and autonomous vessel technologies.

Elements of these themes were then evaluated in the context of each of the three focus area harbors and used as the foundation for a Futures Wheel exercise during the workshop. The outcome is a broad picture of potential risks and emerging opportunities related to the future of marine oil spill prevention and response, along with the identification of new issues linked to marine safety and emergency response more generally. Table 6-3 summarizes the trends discussed in relation to each harbor.

Table 6-3: Trends and guiding questions related to shipping decarbonization in the context of three Massachusetts port (Boston, New Bedford, and Vineyard Haven)

Category	Harbor	Current Trend	Guiding Questions…"Given what you know about this harbor…
Massachusetts decarbonization policy & targets	Boston Harbor	Closure of large fuel terminals	• How might a decrease in imports & a net-zero future impact petroleum terminal operations & safety?
	Vineyard Haven Harbor	Energy transition through local resilience, freight reduction and EV adoption. Expansion of offshore wind operations	• How might this transition affect oil spill risk and marine safety? • What might be done to facilitate a safe transition?
	New Bedford Harbor	Offshore Wind Expansion and Innovation	• How could the OSW industry catalyze decarbonization efforts for the Port and on water? • How could OSW growth change spill risk & response?
Alternative fuels & technologies for marine industry	Boston Harbor	Global transition to low carbon marine fuels Electrification and automation of cargo vessels	• Is there a future where growth in marine transport contributes to state decarbonization goals? • What could the adoption of new fuels mean for shipping? • What happens if Boston Harbor lags behind?

Category	Harbor	Current Trend	Guiding Questions…"Given what you know about this harbor…
			• What risks and opportunities exist if Boston accelerates investment?
	Vineyard Haven Harbor	Electrification of recreational and commercial vessels	• How might electrification move forward? • What might this mean for existing operations and infrastructure?
	New Bedford Harbor	Electrification and automation of tugs and ferries	• What opportunities are there for new technology in New Bedford? • What impacts, risks and opportunities could emerge?

6.3.1. Mapping Potential Impacts, Risks and Opportunities in a Decarbonized Marine Economy

For the purpose of this report, the Futures Wheel exercise utilized during the May 2023 workshop was expanded upon based on information gathered through interviews and research. The consolidated futures wheels for each focus area are shown in Figures 6-4 through 6-6. The first, second, and third tier implications help to envision a new future landscape within which oil spill prevention and response activities will take place. With this picture, it is then possible to identify actions to adapt oil spill prevention and response to ensure continued effectiveness with respect to marine safety and the protection of coastal communities and ecosystems.

These implications are not predictions; they represent a range of plausible features of different future pathways and offer a starting point to investigate and prioritize potential risks and opportunities that could emerge. From here, strategies can be developed that may include near and long-term action, investment, monitoring, or additional research.

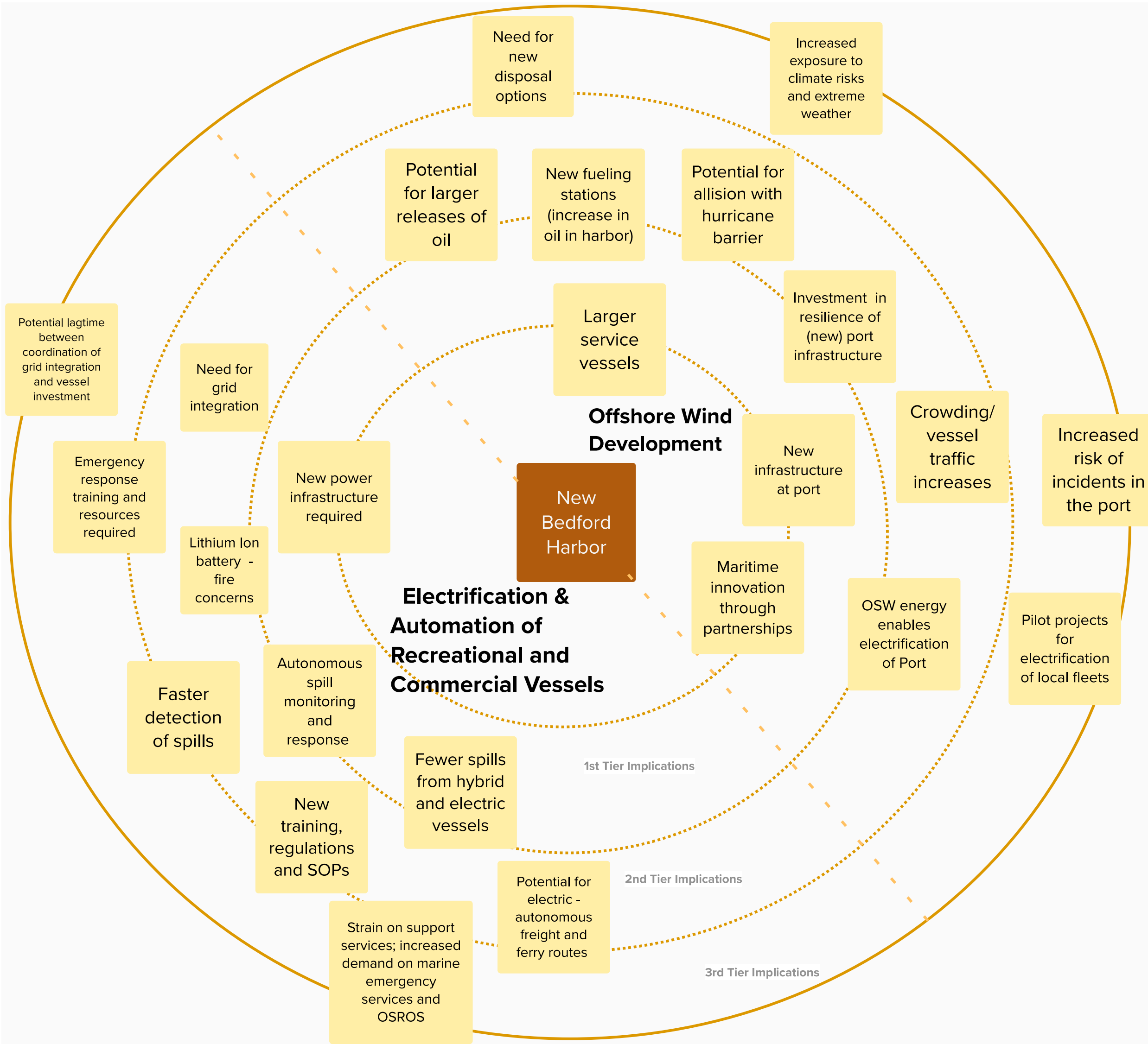

Figure 6-4: New Bedford Harbor futures wheel explores the plausible implications of the growth of offshore wind energy and the introduction of electric and autonomous vessels

Figure 6-5: Vineyard Haven Harbor futures wheel explores the plausible implications related to decarbonization through energy transition targets, offshore wind, and the electrification of vessels

Figure 6-6: Boston Harbor futures wheel explores the plausible implications of decarbonization trends, including the potential closure of fuel terminals, the uptake of low-carbon marine fuels, and the introduction of electric and autonomous vessel

6.3.2. Potential Marine Oil Spill Risks & Risk Reduction Opportunities

Across all three focus areas, the Futures Wheels exercise identified a long-term opportunity to decrease the threat of marine oil spills through the adoption of electric and autonomous vessels. However, during this transition, rising fuel costs and economic pressures may lead to an increase in the abandonment of gas- and diesel-powered vessels, and the incidence of spills associated with abandoned or derelict vessels. Alternatively, new incentives similar to those offered for electric vehicles could become available to support marine operators to adopt new technologies and safely retire gas-powered engines. This pathway would require a complementary investment in electric vessel charging infrastructure.

In the long term, the introduction of alternative marine fuels should lead to a decreased risk of oil spills from cargo and passenger vessels. In the mid-term, however, the current lack of investment and policy direction related to infrastructure for alternative marine fuels on the US East coast compared to the West coast and the European Union, may result in the concentration of aging diesel-powered vessels in Boston Harbor, and vessel age is a contributor to oil spill risk.

As Massachusetts implements its decarbonization strategy, the annual volume of petroleum imported and stored at bulk facilities will decline, with the potential for closure and decommissioning of these sites. This would mean a decline in the risk associated with the transport and storage of petroleum products in the three focus areas and statewide. Decommissioning oil storage infrastructure may create interim, near-term risks but will ultimately reduce the potential for oil spills.

The growth of offshore wind is also associated with new risks in the near and long term. Within harbors this includes risks inherent in the construction of new port facilities and an increase in vessel traffic and congestion associated with windfarm operations and maintenance. Unique to New Bedford Harbor is concern related to size of offshore wind service vessels and the potential for allision with the hurricane barrier. This latter issue was of concern in part because an allision would expose the harbor to greater climate threats. The potential for dielectric insulating oil spills from wind turbines, service platforms, and resupply activities may require new response techniques, plans, or equipment.

Offshore wind investment also brings the potential for innovation and investment in decarbonized marine operations and the electrification of port operations. Over the long-term, it is possible that offshore wind investment could lead to faster uptake and piloting of electric commercial and recreational vessels across Massachusetts. The Port of New Bedford is already home to partnerships, such as the New Bedford Ocean Cluster (New Bedford Ocean Cluster, n.d.), that could plausibly support such efforts in the future, while Vineyard Haven Harbor is home to a local wooden boat builder that has already developed an electric-engine powered vessel (Vineyard Haven Staff, 2023).

6.3.3. Potential Impacts to Marine Oil Spill Preparedness and Response

The Future Wheels exercises identified potential challenges with respect to ongoing preparedness for oil spills. The rapid decline of the import of gasoline and diesel to Massachusetts will directly impact MOSPRA funding through the decline in the per-barrel fee. In addition, the perceived decline in risk associated with the decrease in oil consumption may result in declining levels of preparedness, even as the oil spill risk landscape becomes more complex.

As technology evolves, there are challenges and opportunities for oil spill responders. As the cost of petroleum increases and the volume of fuel available decreases, the cost of oil spill response training and operations may also increase. One way to offset this could be the adoption of electric vessels for oil spill response organizations and other stakeholder groups. The utilization of autonomous vessels for spill monitoring and response could also improve oil spill recovery and safety for first responders. Incentivizing such innovation could accelerate decarbonization and improve spill response outcomes.

The potential for increased vessel traffic and larger vessels associated with offshore wind development creates the potential for larger releases from larger vessels. This may require a reconsideration of worst-case discharge scenarios for ports like New Bedford or Salem.

6.3.4. Emerging Marine Risks and Opportunities

The Futures Wheels identified that new technologies and fuels may bring with them safety concerns and new types of risks. With the uptake of alternative marine fuels, there are concerns about where these fuels would be stored and how bunkering could take place. As bulk petroleum storage facilities close or transition to other uses, there may be a demand for offshore bunkering, or bunkering in different port areas.

As electric vehicles and electric vessels (EV) come online, the risk of fires associated with lithium-ion batteries is a growing concern for marine emergency responders and ferry operators. More training and regulation for EV fires on vessels (including ferries), will be required. The number of catastrophic losses of cargo vessels has increased internationally, in part due to the incidence of fires on board these vessels caused by EV technologies. OSROs will need to be aware of risks associated with EV and hybrid engines, and battery cargo when responding to incidents.

In the context of autonomous vessels, cyber risks, as well as the prevalence of unmanned recreational drones and vessels could impact vessel traffic and lead to accidents.

As new fuels are adopted, accident prevention and emergency response plans and procedures must be established, and responders trained. As these fuels come on board in the next decades, there may be a shift from a focus on oil spills to a focus on accidents associated with new fuel types. In the future, there may be a need for emergency response regimes that address multiple alternative fuels and technologies.

6.3.5. Potential Public Safety Risks and Concerns

New fuels and technologies come with concerns for the public and public safety. Many alternative marine fuels have a low flashpoint. The siting of alternative fuels will need to consider and mitigate impacts to environmental justice communities and ecosystems. New regulations will be required for the safe handling of these fuels. First responders will also have safety concerns associated with marine decarbonization and the introduction of new fuels and technologies. Training and Standard Operating Procedures (SOPs) for responders will be necessary.

As the availability of conventional fuel declines, there may be concerns about fuel shortages, especially during complex emergencies, and the capacity of gas and diesel-powered oil spill response operations to advance given competition for fuel for other types of emergency response also reliant on petroleum (i.e., firefighting, evacuations, emergency power supply). Planning may evolve to account for shifts in petroleum availability.

7. DISCUSSION & RECOMMENDATIONS

7.1. Anticipating Changes to Risk and Response

This study identified several ways that a changing climate and adaptation and decarbonization efforts could influence marine oil spill risk, prevention, and response in Massachusetts and beyond. While there are high levels of uncertainty around what the future will hold, there remains an opportunity to be prepared and flexible to adapt, and to take no-regret actions that can help to ensure the continued safety of coastal communities and ecosystems from evolving oil spill risk.

In the context of both climate change and decarbonization, the next decade will see significant transition and change. Climate hazards will continue to become more extreme, sea level will rise, and adaptation efforts will be implemented. During this time the use and transportation of fossil fuels will decline significantly, though fossil fuels will still be imported, and risk will remain. It seems unlikely that there will be consensus and infrastructure development for alternative marine fuels in Massachusetts prior to 2030, meaning that large vessels are likely to continue to be powered by petroleum; however, the pace of change globally may motivate faster uptake in the market and drive infrastructure development.

The risk of very large storm events brings with it greater potential for multiple spills embedded within complex humanitarian emergencies. During events like this it is unlikely that local first responders will prioritize oil spill response and recovery. Planning for these events now may assist in mitigating widespread environmental impacts. After 2030, while hazards will continue to evolve, there should be more certainty as to what types of fuel will be used in a low-carbon shipping industry, and to the evolution of petroleum storage and transportation patterns in Massachusetts overall. The electrification and automation of vessels may happen more quickly, especially as offshore wind energy projects come online. Many of the risks, opportunities and risk factors identified in this study are outside the scope of any single agency, and many will be influenced by political, economic, and environmental factors that are well beyond the control of MOSPRA.

Recommendations for risk reduction focus primarily on options within the scope and mandate of MOSPRA. They also identify areas where MOSPRA could adapt to emerging risks, align programming to support state decarbonization targets, monitor for indicators of change, or where multi-stakeholder collaboration may be required to address emerging issues.

7.2. Adapting MOSPRA Programs and Activities to a Changing Climate

Table 7-1 summarizes recommendations for MOSPRA program activities that have been identified through this study. It also identifies other stakeholders whose participation or collaboration may benefit MOSPRA. These recommendations could be incorporated into broader strategic plans for MOSPRA over the next five to ten years.

Table 7-1: Recommendations for adapting MOSPRA program activities for climate hazards, adaptations, and decarbonization

<table>
<tr><th>MOSPRA Program or Activity</th><th>Recommendation</th><th>Stakeholders and Potential Collaborators</th></tr>
<tr><td rowspan="2">Oil Spill Prevention, Preparedness, and Risk Analysis</td><td>Prepare for complex incidents where oil spills may be one component to a larger climate disaster by:
Integrating oil spill response during large scale/multi-hazard disaster planning and exercise efforts, particularly for those events with significant coastal impacts
Exploring ways to support responder safety and rapid response during marine debris and flood events
Exploring the potential use of autonomous technologies (vessels & drones) for oil spill monitoring, assessment and response to reduce burden on first responders
Monitoring the consequences of extreme weather events in other locations in the country, and integrate learnings about marine oil spill risk and response during extreme events</td><td rowspan="2">MEMA, FEMA, and local emergency management agencies

SERC and LEPCs

Area Committees/ RRTs

OSROs

Local first responders

Port managers

Bunkering facilities

Other granting entities or programs (e.g., MVP)

NOAA</td></tr>
<tr><td>Prepare for and reduce the risk of marine oil spills during decarbonization transitions by:
Collaborating with broader oil spill response community to ensure preparedness and response training and resources for alternative marine fuels
Exercising and evaluating GRS deployment in the context of complex scenarios involving alternative fuels, EV cargo, etc.
Tracking the state of emerging marine fuels, fuel storage, and fueling locations, their associated risks, and the impacts of those risks for marine oil spill and emergency preparedness, response, and mitigation options.
Tracking and projecting the impact of declining petroleum imports on the MOSPRA program fund and ensure sufficient funding for continued response and recovery.
Consider MOSPRA Grant Program to allow eligible activities to reduce spill risk through electrification initiatives targeting local marinas and vessels
Exploring opportunities to promote the safe and effective decommissioning of existing oil infrastructure and prevent abandonment of petroleum-powered vessels.</td></tr>
</table>

MOSPRA Program or Activity	Recommendation	Stakeholders and Potential Collaborators
Geographic Response Strategies (GRS)	Incorporate climate hazards and resilience initiatives into GRS planning by: • Including flood maps and data with existing GRS packages so responders can anticipate potential impacts during high tide and extreme events • Adapting existing GRS based on coastal flood projections and hazard impacts • Identifying forthcoming coastal resilience and green infrastructure projects and creating new GRS that reflect a changing coastline • Identifying planned shoreline adaptation efforts and ensuring that GRS are updated or revised in consideration of shoreline changes resulting from adaptation initiatives • Consider changing protection priorities for GRS development or enhancement to protect critical habitat that is experiencing changes to stressors or threats from climate hazards or adaptations • Consider the need for new/changed GRS for potential spills from dielectric oil associated with offshore wind	State & federal flood modelers and planners Port managers Local climate resilience planners RMAT to build awareness of GRS among state & local climate experts
First Responder Training/GRS Exercises	Create opportunities to enhance GRS training and exercise program in consideration of climate hazards, adaptations, and decarbonization by: • Utilizing first responder training/GRS exercise program as an opportunity to coordinate with local climate resilience experts, emergency managers and activities • Exercise and validate responder capacity to deploy multiple GRS at once during a complex incident, and identify opportunities to address limitations, including through training of local volunteers or staff • Evaluating GRS tactics and equipment in the context of alternative fuels	Local climate resilience experts Local first responders Local emergency managers OSROs and spill response experts
Spill Response Trailers	Ensure that MassDEP spill response trailers are climate-ready by: • Considering the need to relocate and/or stage additional resources to increase response capabilities in areas of evolving risk, for example where response access challenges are acute and where vessel traffic is on the rise.	Local climate resilience planners Port managers

MOSPRA Program or Activity	Recommendation	Stakeholders and Potential Collaborators
	• Ensuring spill response equipment staged is appropriate for biofuel blends and other alternative marine fuels as they come online • Include equipment specific for response to dielectric oil used in windfarms	

Table 7-1 identifies key collaborators and stakeholders to support MOSPRA program activities. This reflects a common theme throughout this study: the interdisciplinary nature of climate change and the importance of connecting MOSPRA program activities to broader statewide climate resilience and decarbonization efforts. By building connections and leveraging partnerships, MOSPRA will be better poised to address the emerging risks and challenges to maintaining the current state of oil spill preparedness in the face of a changing climate. Opportunities to create connections may include:

- Continuing to facilitate ongoing discussions related to climate initiatives at Area Committee and RRT meetings, and at other local and regional oil spill planning forums.
- Connecting MOSPRA programs to state and local climate adaptation and decarbonization efforts to look for potential synergies.
- Sharing the outcomes of this work with partners to identify future collaboration and mutual aid opportunities, especially in areas of high complexity and uncertainty, and for those initiatives with unclear responsibility.
- Building on the momentum and energy of the study workshops, by facilitating additional multi-stakeholder workshops, potentially at the regional or local level and with enhanced community involvement (including a focus on Environmental Justice communities).
- Expanding the training and preparedness for meaningful community stakeholder engagement during oil spill response.
- Exploring options for public oil spill prevention education campaigns, including with respect to reducing oil spill risk during storms and flooding.

8. REFERENCES

Aarnes, J., Ejgelaar, M., & Hektor, E. A. (2018). Hydrogen as an Energy Carrier. Det Norske Veritas.

Ade, N. (n.d.). Murphy Oil USA Refinery Spill–An Insight into Natech Disasters. Texas A&M University, 26AD. http://psctac.tamu.edu/wp-content/uploads/Nilesh_TAC_Case_Study-JJT-comments.pdf

AGCS. (2022). Safety and Shipping Review 2022; An annual review of trends and developments in shipping losses and safety. Allianz Global Corporate & Specialty. https://commercial.allianz.com/content/dam/onemarketing/commercial/commercial/reports/AGCS-Safety-Shipping-Review-2022.pdf

ASCE. (2021). 2021 Infrastructure Report Card: Ports. American Society of Civil Engineers. https://infrastructurereportcard.org/cat-item/ports-infrastructure/#:~:text=However%2C%20there%20is%20a%20funding,difficulty%20competing%20for%20federal%20grants

Bengston, D. N. (2015). “The futures wheel: a method for exploring the implications of social-ecological change.” Society & Natural Resources. 29(3): 374-379. https://doi.org/10.1080/08941920.2015.1054980

Carmen Hseih, C. & Felby, C. (2017). Biofuels for the marine shipping sector: An overview and analysis of sector infrastructure, fuel technologies and regulations. IEA Bioenergy. https://www.ieabioenergy.com/wp-content/uploads/2018/02/Marine-biofuel-report-final-Oct-2017.pdf

Carr, Gordon. (2023). Personal Interview with Executive Director Port of New Bedford by Katie McPherson, via virtual teleconference (April 2023).

City of Boston. (2021, 2022). Coastal Resilience Solutions for East Boston and Charlestown (Phase I & II). Boston.gov https://www.boston.gov/departments/environment/climate-ready-boston/coastal-resilience-east-boston (Accessed Sept 2022)

City of Boston (2023, September). City of Boston Awarded Grant to Advance Coastal Resilience and Prepare for the Impacts of Climate Change. Boston.gov https://www.boston.gov/news/city-boston-awarded-grant-advance-coastal-resilience-and-prepare-impacts-climate-change

City of New Bedford. (2021). NB Resilient. City of New Bedford Office of Environmental Stewardship. https://nbresilient.com/home

Commonwealth of Massachusetts. (n.d.). Massachusetts Climate Change Projections. Mass.gov. https://www.mass.gov/files/ma-statewide-and-majorbasins-climate-projections-final.pdf?_ga=2.134461041.1617887890.1701110673-1956866838.1700159763&_gl=1*11aulla*_ga*MTk1Njg2NjgzOC4xNzAwMTU5NzYz*_ga_MCLPEGW7WM*MTcwMTEyODQwMi4xLjEuMTcwMTEyODQxMC4wLjAuMA

C40 Cities. (2023a). Green Ports Forum. C40 Cities Climate Leadership Group, Inc. https://www.c40.org (Accessed: March 2023)

C40 Cities. (2023b, September). Ports of Los Angeles, Long Beach, and Shanghai unveil Implementation Plan Outline for first trans-Pacific green shipping corridor. C40 Cities Climate Leadership Group, Inc. https://www.c40.org/news/la-shanghai-implementation-plan-outline-green-shipping-corridor/ (Accessed: September 2023)

DNV. (2019, June). Assessment of selected alternative fuels and technologies in shipping. Det Norske Veritas. https://www.dnv.com/maritime/publications/alternative-fuel-assessment-download.html

DNV (2023). FuelEU Maritime. Det Norske Veritas. https://www.dnv.com/maritime/insights/topics/fuel-eu-maritime/index.html (Accessed: September 2023)

Durkee, Elizabeth. (2023). Personal Interview with Martha's Vineyard Commission Climate Planner by Katie McPherson, via virtual teleconference (March 2023).

Edwards, M., Capt. Comdt. US Coast Guard. (2022, February). Guidelines for Human-Supervised Testing of Remote Controlled and Autonomous Systems on Vessels. CG-CVC Policy Letter 22-01. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/CG-CVC/Policy%20Letters/2022/CVC%20PL%2022-01%20Testing%20of%20remote%20and%20autonomous%20systems.pdf

European Commission. (2023). Reducing emissions from the shipping sector. EU Energy, Climate Change, Environment. https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-shipping-sector_en (Accessed: September 2023)

IMO. (2023, July). Resolution MEPC.377(80): 2023 IMO Strategy on Reduction of GHG Emissions from Ships. International Maritime Organization. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf

IMO. (n.d.-a). 2023 IMO Strategy on Reduction of GHG Emissions from Ships. International Maritime Organization. https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

IMO. (n.d.-b). Alternative marine fuels: Regulatory mapping. GreenVoyage2050. International Maritime Organization. https://greenvoyage2050.imo.org/alternative-marine-fuels-regulatory-mapping/ (Accessed: September 2023)

IMO. (n.d.-c). GeenVoyage2050. International Maritime Organization. https://greenvoyage2050.imo.org/ (Accessed: October 2023)

IPCC. (2022). Climate Change 2022; Mitigation of Climate Change. Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

Ismay, D., Miller, B., Chu, H., Mizeolek, C., Walsh, M., Edington, A., Hanson, L., Perry, D., & Laurent, C. (2020, December). Massachusetts 2050 Decarbonization Roadmap.

Massachusetts Executive Office of Energy and Environmental Affairs. https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download

Hufstader, L. (2023, April). Ferries Now Event Makes Case for Move to Electric Ferry Boats. The Vineyard Gazette. https://vineyardgazette.com/news/2023/04/03/ferries-now-makes-case-move-electric-ferry-boats (Accessed: April 2023)

Kedge. (2019, November). Introduction to Natural Foresight: Chapter 1: What is Strategic Foresight? The Futures School. https://tfsx.com/2019/11/defining-strategic-foresight/#:~:text=Strategic%20Foresight%20is%20a%20decades,to%20capitalize%20on%20hidden%20opportunities

Katopodis, T. & Sfetsos, A. (2019) "A Review of Climate Change Impacts to Oil Sector Critical Services and Suggested Recommendations for Industry Uptake." Infrastructures 4, no. 4, https://doi.org/10.3390/infrastructures4040074

Kawasaki Heavy Industries. (2021, May). Kawasaki Develops Cargo Containment System for Large Liquified Hydrogen Carrier with World's Highest Carrying Capacity – AiP Obtained from Class NK. https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20210506_9983#:~:text=Tokyo%2C%20May%206%2C%202021%20—,a%20large%20liquefied%20hydrogen%20carrier

Kirshen, P., Borrelli, M., Byrnes, J., Chen, R., Lockwood, L., Watson, C., Starbuck, K., Wiggin, J., Novelly, A., Uiterwyk, K., Thurson, K., McMann, B., Foster, C., Sprague, H., Roberts, H. J., Bosma, K., Jin, D., & Herst, R. (2020). "Integrated assessment of storm surge barrier systems under present and future climates and comparison to alternatives: A case study of Boston, USA." Climatic Change, 162(2), 445–464. https://doi.org/10.1007/s10584-020-02781-8

Lavine, W., Jamal, M. H., Abd Wahab, A. K., & Kasiman, E. H. (2020). "Effect of sea level rise on oil spill model drift using TELEMAC-2d." Journal of Water and Climate Change, 11(4), 1021–1031. https://doi.org/10.2166/wcc.2019.057

Louisiana State University (LSU) and MAR, Incorporated (2011, June). "Characteristics, Behavior, and Response Effectiveness of Spilled Dielectric Insulating oil in the Marine Environment." Report to Bureau of Ocean Energy Management, Regulation, and Enforcement. https://www.bsee.gov/sites/bsee.gov/files/osrr-oil-spill-response-research/636aa.pdf

Maersk. (2020, June). New Research Center Will Lead the Way for Decarbonizing Shipping. A.P. Møller – Mærsk. https://www.maersk.com/news/articles/2020/06/25/new-research-center-will-lead-the-way-for-decarbonizing-shipping

Martha's Vineyard Commission. (2022a, June). Climate Action Plan – The Vineyard Way. https://kladashboard-clientsourcefiles.s3.amazonaws.com/Marthas+Vineyard/KLA_Martha_Vineyard_CAP_Design_FINAL.pdf

Martha's Vineyard Commission. (2022b). Dukes County Hazard Mitigation Plan Tisbury Maps Series. Developed with data from MassGIS and FEMA. https://www.mvcommission.org/sites/default/files/docs/HMP_2020_TS_mapseries_website.pdf

Martha's Vineyard Commission. (2022c, May). Dukes County Multi-Jurisdiction Hazard Mitigation Plan Update 2021. Prepared by The Martha's Vineyard Commission in conjunction with the emergency managers and planning teams of the seven Dukes County towns. https://www.mvcommission.org/sites/default/files/docs/Dukes%20County%20Multi-Jurisdictional%20Hazard%20Mitigation%20Plan%20Update%20Oct%202021_CWPPamend.pdf

Martha's Vineyard Commission. (n.d.). Plan development. Martha's Vineyard Climate Action Plan. https://www.thevineyardway.org/plan-development

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). (2020a, December). Buildings Sector Report. A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. Mass.gov https://www.mass.gov/doc/building-sector-technical-report/download.

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). (2020b, December). Draft Interim Massachusetts Clean Energy and Climate Plan for 2030. Mass.gov https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2025-and-2030#interim-clean-energy-and-climate-report-for-2030- (Accessed: 2021)

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). (2020c, December). Transportation Sector Report. A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. https://www.mass.gov/doc/building-sector-technical-report/download.

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). (2022a, June). Clean Energy and Climate Plan for 2025 and 2030. Mass.gov https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2025-and-2030

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). (2022b). Clean Energy and Climate Plan for 2050. Mass.gov https://www.mass.gov/doc/2050-clean-energy-and-climate-plan/download

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). (2022c). MassGIS Data: 2020 Environmental Justice Populations. Commonwealth of Massachusetts. https://www.mass.gov/info-details/massgis-data-2020-environmental-justice-populations (Accessed: January 2023)

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). (2023). Mitigating Greenhouse Gas Emissions. Commonwealth of Massachusetts. https://www.mass.gov/mitigating-greenhouse-gas-emissions

Massachusetts Exec. Order No. 569. (2016, September). Executive Order No. 569: Establishing an Integrated Climate Change Strategy for the Commonwealth. Mass.gov. Office of Governor Charlie Baker and Lt. Governor Karyn Polito, September 16, 2016. https://www.mass.gov/executive-orders/no-569-establishing-an-integrated-climate-change-strategy-for-the-commonwealth

Massachusetts Emergency Management Agency (EMA) & Executive Office of Energy and Environmental Affairs (EOEEA). (2018). Massachusetts State Hazard Mitigation and Climate Adaptation Plan. Commonwealth of Massachusetts. https://www.mass.gov/files/documents/2018/10/26/SHMCAP-September2018-Full-Plan-web.pdf

Massachusetts Legislature. (2021). Massachusetts Legislature Bill – S.9. Senate Docket No. 169. https://malegislature.gov/Bills/192/S9.Html

MassPort & Kleinfelder (2018, November). Massachusetts Port Authority Floodproofing Design Guide. https://www.massport.com/media/2xacmacm/massport-floodproofing-design-guide-revised-november-2018.pdf

MassPort. (2018, December). Sustainability and Resiliency Design Standards and Guidelines (SRDSGs). Massachusetts Port Authority Capital Programs and Environmental Affairs Department. https://www.massport.com/media/3111/massport-sustainability-and-resiliency-design-standards-and-guidelines-dec2018.pdf

Mayflower Autonomous Ship (2023). https://mas400.com (Accessed: September 2023)

McKinlay, C., Turnock, S. R., & Hudson, D. A. (2020, January). "A comparison of hydrogen and ammonia for future long distance shipping fuels." Conference: LNG/LPG and Alternative Fuel Ships (29/01/20 – 30/01/20). The Royal Institute of Naval Architects. https://www.researchgate.net/publication/339106527_A_Comparison_of_hydrogen_and_ammonia_for_future_long_distance_shipping_fuels

Monteiro, B. & Dal Borgo, R. (2023). "Supporting decision making with strategic foresight: An emerging framework for proactive and prospective governments." OECD Working Papers on Public Governance, No. 63, OECD Publishing, Paris, https://doi.org/10.1787/1d78c791-en.

NE Climate Change Science Center at UMASS Amherst, "MA Climate Projections Guidebook Supplement," p 13.

New Bedford Ocean Cluster. (n.d.). Technology & Innovation. https://nboc.org/technology-and-innovation/ (Accessed: March 2023).

NOAA. (n.d.) Projected Inundation Events & Sea Level Rise Scenarios at 8443970, Boston MA. National Oceanic and Atmospheric Administration. https://tidesandcurrents.noaa.gov/inundationdb/outlook.html?id=8443970 - htfannualoutlook (Accessed: September 2023)

NOAA. (2013a). Sandy, One Year Later: Where Are We Now? Office of Response and Restoration (National Oceanic and Atmospheric Administration, October 29, 2013), https://response.restoration.noaa.gov/about/media/sandy-one-year-later-where-are-we-now.html.

NOAA. (2013b). Severe Marine Debris Event Report: Superstorm Sandy. Overview and Update to Congress. National Oceanic and Atmospheric Administration. https://marinedebris.noaa.gov/sites/default/files/publications-files/Electronic_2013SuperstormSandy_SMDE_report_to_Congress.pdf

NOAA. (2014). Out of Sandy, Lessons in Helping Coastal Marshes Recover from Storms. National Oceanic and Atmospheric Administration. https://response.restoration.noaa.gov/about/media/out-sandy-lessons-helping-coastal-marshes-recover-storms.html.

NOAA. (2018). Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold. National Oceanic and Atmospheric Administration, National Ocean Service. Technical Report NOS CO-OPS 086, Silver Springs, MD. https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.pdf

NOAA. (2023a). Coastal inundation dashboard. NOAA Tides & Currents. National Oceanic and Atmospheric Administration. https://tidesandcurrents.noaa.gov/inundationdb_info.html#:~:text=Inundation%20is%20most%20commonly%20referenced,datums%20and%20the%20land%20elevation (Accessed: November 2023)

NOAA. (2023b). High Tide Flooding: Northeast Region Fact Sheet. National Oceanic and Atmospheric Administration. https://tidesandcurrents.noaa.gov/publications/2023_Northeast_High_Tide_Flooding_Fact_Sheet.pdf (Accessed: Sept 2023)

NOAA. (2023c). Monthly High Tide Flooding Outlook: Northeast. National Oceanic and Atmospheric Administration. https://tidesandcurrents.noaa.gov/high-tide-flooding/monthly-outlook.html (accessed June 2023)

NOAA Fisheries. (2022, October). The numbers are in! Commercial Landings and Value See Increase in 2021. National Oceanic and Atmospheric Administration, Office of Science and Technology. https://www.fisheries.noaa.gov/content/numbers-are-commercial-landings-and-value-see-increase-2021#:~:text=Dutch%20Harbor%2C%20AK%20took%20the,a%20robust%20sea%20scallop%20harvest

NorSea Group. (2023). NorSea takes part in world's first network of filling stations for green ammonia. https://norseagroup.com/en/news/norsea-takes-part-in-worlds-first-network-of-filling-stations-for-green-ammonia

Nuka Research and Planning Group, LLC. (2009). Evaluation of Marine Oil Spill Threat to Massachusetts Coastal Communities. Prepared for Massachusetts Department of Environmental Protection. https://www.mass.gov/doc/evaluation-of-marine-oil-spill-threat-to-massachusetts-coastal-communities/download

Nuka Research and Planning Group, LLC. (2021). Evaluating and Adapting Oil Spill Preparedness and Response Capabilities for a Changing Climate: Literature Review and Synthesis. Report to Massachusetts Department of Environmental Protection.

Nuka Research and Planning Group, LLC. (2023, August). Climate Ready Oil Spill Preparedness and Response Workshop: Summary Report. Prepared for Massachusetts Department of Environmental Protection.

Nuka Research and Planning Group, LLC. (2024, January). Marine Oil Spill Threats to Massachusetts Coastal Communities: Updated Assessment. Report to Massachusetts Department of Environmental Protection.

Nyhus, E. (2021, July). What did we learn about CII and SEEMP at MEPC 76? Impact: A DNV Podcast, Podcast audio. https://www.dnv.com/expert-story/maritime-impact/What-did-we-learn-about-CII-and-SEEMP-at-MEPC-76.html

Paul, Michele. (2023) Personal Interview with the Director of Resilience and Environmental Stewardship by Katie McPherson, via virtual teleconference (March 2023).

Pavlenko, N., Comer, B., Zhou, Y., Clark, N., & Rutherford. (2020, January). The climate implications of using LNG as a marine fuel. The International Council on Clean Transportation, 2020. Working Paper 2020-02. https://theicct.org/sites/default/files/publications/LNG%20as%20marine%20fuel%2C%20working%20paper-02_FINAL_20200416.pdf

Pine, J. C. (2006). Hurricane Katrina and Oil Spills: Impact on Coastal and Ocean Environments," Oceanography, Vol 19, No. 2, https://tos.org/oceanography/assets/docs/19-2_pine.pdf.

Petersen, J., Neslon, D., Marcella, T., Michel, J., Atkinson, M., White, M., Boring, C., Szathmary, L., Horsman, J., & Weaver, J. (2019). Environmental Sensitivity Index Guidelines, Version 4.0. National Oceanic and Atmospheric Administration. https://response.restoration.noaa.gov/sites/default/files/ESI_Guidelines.pdf

Port of New Bedford. (2020, June). Resilient Design Guidelines: New Bedford Harbor. https://kladashboard-clientsourcefiles.s3.amazonaws.com/New+Bedford/NB-FHV+Resilient+Design+Guidlines.pdf

Port of New Bedford. (2022). New Bedford Harbor Port Assessment Summary. https://kladashboard-clientsourcefiles.s3.amazonaws.com/New+Bedford/NB+Resilient+Port+Assessment+Design_Final.pdf

Port of New Bedford. (n.d.) New Bedford Ocean Cluster. https://portofnewbedford.org/new-bedford-ocean-cluster/

Radowitz, B. (2021, March). World's first hydrogen-powered ferry in Norway to run on green gas from Germany. Recharge, Global news and intelligence for the Energy Transition. https://www.rechargenews.com/technology/worlds-first-hydrogen-powered-ferry-in-norway-to-run-on-green-gas-from-germany/2-1-976939 (Accessed: April 2021)

ResilientMass Action Team. (2022). Climate Resilience Design Standards & Guidance. https://resilient.mass.gov/rmat_home/designstandards/

Robinson, Ben. (2023, March). Personal interview with the Chair of the Tisbury Planning Board by Katie McPherson, via virtual teleconference (March 2023)

Runsten, Kara. (2021). Personal Interview with the Municipal Vulnerability Preparedness (MVP) Program Manager by Katie McPherson, via virtual teleconference.

Sampson, J. (2021, February). Cummins fuel cells to power North America's first commercial hydrogen-powered ferry. H2View. https://www.h2-view.com/story/cummins-fuel-cells-to-power-north-americas-first-commercial-hydrogen-powered-ferry/ (Accessed: April 2021)

Shell & Deloitte. (2020). Decarbonising Shipping: All Hands on Deck. https://www.deloitte.com/global/en/Industries/energy/perspectives/decarbonising-shipping.html (Accessed: July 2021)

The Maritime Executive. (2022, April). Keppel O&M Demonstrates Singapore's First Autonomous Tug. https://maritime-executive.com/article/keppel-o-m-demonstrates-singapore-s-first-autonomous-tug (Accessed: March 2023)

The Maritime Executive. (2023, September). Singapore-Rotterdam Green Corridor Targets up to 30% GHG Reductions. https://maritime-executive.com/article/singapore-rotterdam-green-corridor-targets-up-to-30-ghg-reductions (Accessed: September 2023)

The Trustees of Reservations. (2021). State of the Coast Report: The Islands. https://static1.squarespace.com/static/5ce308a7514487000112e19b/t/610729cb96cbc243b9e38fdb/1627859414380/SOC_2021_IslandsReport_Web.pdf#page=38

Town of Fairhaven. (2020, April). Community Resilience Building Workshop Summary of Findings Report. Prepared by Punchard Consulting. Town of Fairhaven Municipal Vulnerability Preparedness Planning. https://www.fairhaven-ma.gov/sites/g/files/vyhlif7541/f/pages/fairhaven_mvp_summary_of_findings_apr2020.pdf

United Nations Climate Change (n.d.). What Is the Paris Agreement?, The Paris Agreement https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (Accessed: May 2021)

UPI. (2000). Oil spill said to be largest ever in Boston Harbor. United Press International, Inc. https://www.upi.com/Archives/2000/06/10/Oil-spill-said-to-be-largest-ever-in-Boston-Harbor/1225960609600/

U.S. DOE, U.S. DOT, U.S. EPA, & U.S. HUD. (2023). The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation. United States Department of Energy, Department of Transportation, Environmental Protection Agency, and Department of Housing and Urban Development. https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf

U.S. DOJ. (2008). ExxonMobil Charged in Boston Harbor Oil Spill: Corporation to Pay $6 Million for Criminal Violation of the Clean Water Act. United States Department of Justice. https://www.justice.gov/archive/opa/pr/2008/December/08-enrd-1147.html

U.S. EPA. (2006, May). Murphy Oil Refinery Spill Chalmette & Meraux, LA. U.S. EPA Region 6 Response and Prevention Branch Oil Team https://archive.epa.gov/emergencies/content/fss/web/pdf/franklin_2.pdf

Vancouver Maritime Centre for Climate. (n.d.) About us. Vancouver, BC, Canada. https://vmcclimate.ca/about-us (Accessed: 2021)

Vineyard Haven Staff. (2023, March). Interview by K. McPherson [via web conference].

Vineyard Wind, LLC. (n.d.) Nation's first commercial-scale offshore wind project. New Bedford, MA. https://www.vineyardwind.com/partners

Wasser, M. (2021). On Revere's Pearl Avenue, Residents Grapple with the Rising Tide of Climate Change. WBUR, Boston's National Public Radio News Station. https://www.wbur.org/news/2021/04/23/beachmont-pearl-avenue-flooding-climate-change

Wilson, M., Graham, L., Hale, C., Maung-Douglass, E., Sempier, S., Skelton, T., & Swann, L. (2018). Storms and spills. GOMSG-G-18-006. https://masgc.org/oilscience/storms-and-spills.pdf

Woods Hole Group. (n.d.). Massachusetts Coast Flood Risk Model: New Bedford/Fairhaven Coastal Viewer. Developed for the Massachusetts Department of Transportation (MassDOT). https://www.arcgis.com/apps/View/index.html?appid=a850f0c6a2fa4bb591aea7da293fa2a4 (Accessed: November 2023)

Woods Hole Group. (2022). Massachusetts Coast Flood Risk Model (MC-FRM) 1% Annual Exceedance Probability: 2030. Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA). https://resilientma-mapcenter-mass-eoeea.hub.arcgis.com/maps/618b3924d62241109d44fc60eb6a6d8f/about (Accessed: January 2023)

Woods Hole Group. (2023, June). Belle Isle Marsh Climate Vulnerability Assessment. Prepared for Town of Winthrop, Winthrop, MA and Mystic River Watershed Association, Arlington, MA. https://static1.squarespace.com/static/563d6078e4b0396c216603c8/t/64c184ca84316d44a8d5f988/1690404047425/_FINAL+REPORT+2023.06.29_BIM_ClimateVulnerabilityAssessment_ExecutiveSummary_final_wAppendix+-+rev-compressed.pdf

Yara. (2022). MV Yara Birkland. Oslo, Norway. https://yara.com/news-and-media/media-library/press-kits/yara-birkeland-press-kit/ (Accessed: March 2023)

Yara International. (2022, April). Yara International and Azane Fuel Solutions to launch world's first carbon-free bunkering network; delivering green ammonia fuel to the shipping industry. https://www.yara.com/news-and-media/news/archive/news-2022/yara-international-and-azane-fuel-solutions-to-launch-worlds-first-carbon-free-bunkering-network-delivering-green-ammonia-fuel-to-the-shipping-industry/ (Accessed: September 2022.)