CAPE COD COMMISSION

**2024 REGIONAL TRANSPORTATION PLAN**

# Technical Appendix H: Climate Change Adaptation and Mitigation

**jULY 2023**

**2023**

COUNTY OF BARNSTABLE MASSACHUSETTS

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# Technical Appendix H: Climate Change Adaptation and Mitigation

To supplement the discussion provided in Chapter 4, this appendix provides additional information on the following:

- Low Lying Roads
- Transportation electrification elements of the Cape Cod Climate Action Plan

## LOW LYING ROADS

Low lying roads are prone to flooding from the combined effects of hazards such as sea level rise, storm surge, and erosion. Cape Cod is especially vulnerable to coastal storms because of its unique geography and flooding is currently a regular event on several road segments during extreme high tides and storm events. As seas rise and storms intensify the impact to our coastlines and flooding occurrences will increase in frequency and depth.

Cape Cod Commission (Commission) staff are working with the towns of Barnstable, Bourne, Brewster, Dennis, Eastham, Orleans, Sandwich, Wellfleet, Truro, and Yarmouth to examine vulnerabilities in the roadway network and identify adaptation alternatives. With funding support from the U.S. Economic Development Administration and the Massachusetts Municipal Vulnerability Preparedness (MVP) program, the Commission has contracted with the Woods Hole Group to conduct a vulnerability assessment of roadway segments, bridges, and culverts due to flooding from the combined effects of sea level rise and storm surge. The project employs state of the art modeling and community engagement to identify and prioritize low lying roads to target for coastal resiliency action.

The project[1] began in September 2021 and will conclude in June 2023. Project elements for each town include:

- Vulnerability and Criticality Assessments: Coastal inundation projections and roadway vulnerability will be modeled for road segments in 2030, 2050, and 2070 planning horizons and a roadway criticality analysis will be applied to each road segment.

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[1] https://capecodcommission.org/our-work/low-lying-roads-project/

- Roadway and Bridge Risk Assessment: Road segments and bridges that may be impacted during the three planning time horizons will be identified and prioritized for analysis by calculating risk scores.
- Map Viewer: Each town will have a GIS-based map viewer developed to present data and map layers for review. The map viewer will include a tool to capture public comment on vulnerable road segments identified, or other locations the town may want to consider for developing adaptation solutions.
- Public Workshop: A public workshop will be held for each town to review the outcomes of the vulnerability and risk assessments, and to present the criticality framework and top road segments projected to be vulnerable during the three planning time horizons.
- Road Segment Selection: Using the information gathered in the analyses and public comment, town staff will choose two road segments to further for conceptual adaptation design solutions.
- Roadway Design Solutions: Up to three conceptual road adaptation design solutions and estimated costs will be prepared for the prioritized road segments. These solutions, where applicable, will include a nature-based solution ("green"), a traditional engineering solution ("gray"), and a hybrid (nature-based with traditional engineering elements) solution.

Final conceptual designs will then be presented to town staff, who may use these deliverables to further project development. A second public workshop will be held to present the conceptual design solutions to those towns receiving MVP funding.

## Process for Identifying Low Lying Roads

### VULNERABILITY

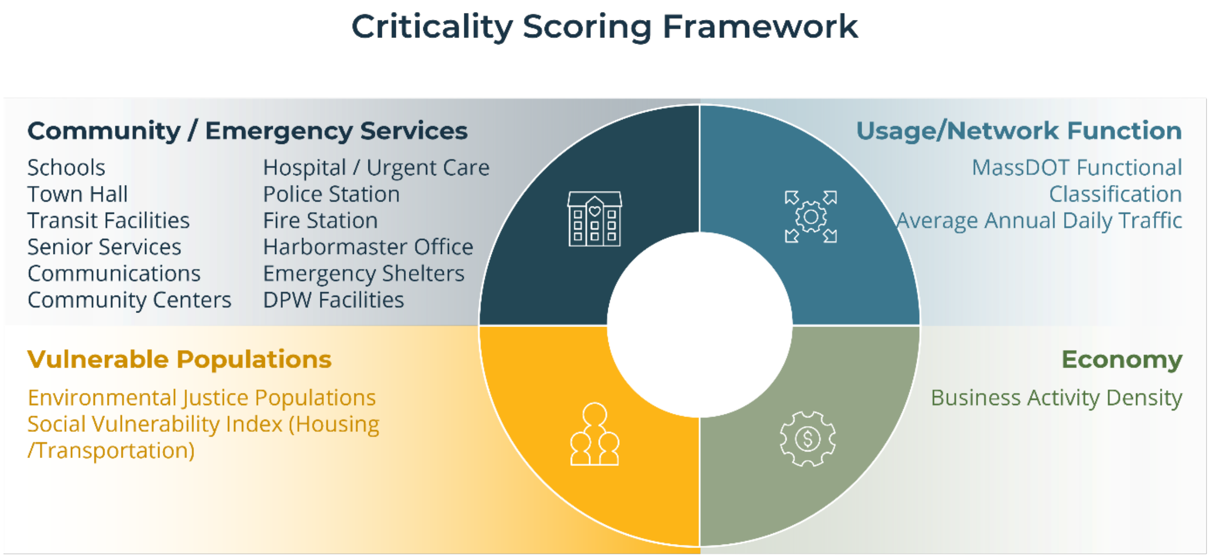
Roads are more or less likely to flood depending on a number of factors such as proximity to the coast and road elevation. Significant rain events may also result in inland road flooding but are not a focus of this project. The vulnerability of a road is determined by the probability or likelihood that it will flood on an annual basis. The terms vulnerability and probability are used interchangeably in this project. The probability of a road flooding annually is determined by the elevation of the road surface as compared to the elevation of the anticipated water surface during a storm event, under future time horizons.

### CRITICALITY

Criticality is how important a road is to the community's transportation needs. The project team used regionally available data to score roads and road segments according to their criticality within a community. The scoring framework used to determine road criticality includes variables such as:

- Usage/Network Function - the type of road and average daily traffic
- Vulnerable Populations - environmental justice or social vulnerability communities
- Emergency/Community Services - access to critical, emergency, or community facilities

- Economy - business activity density




Adapted from Woods Hole Group

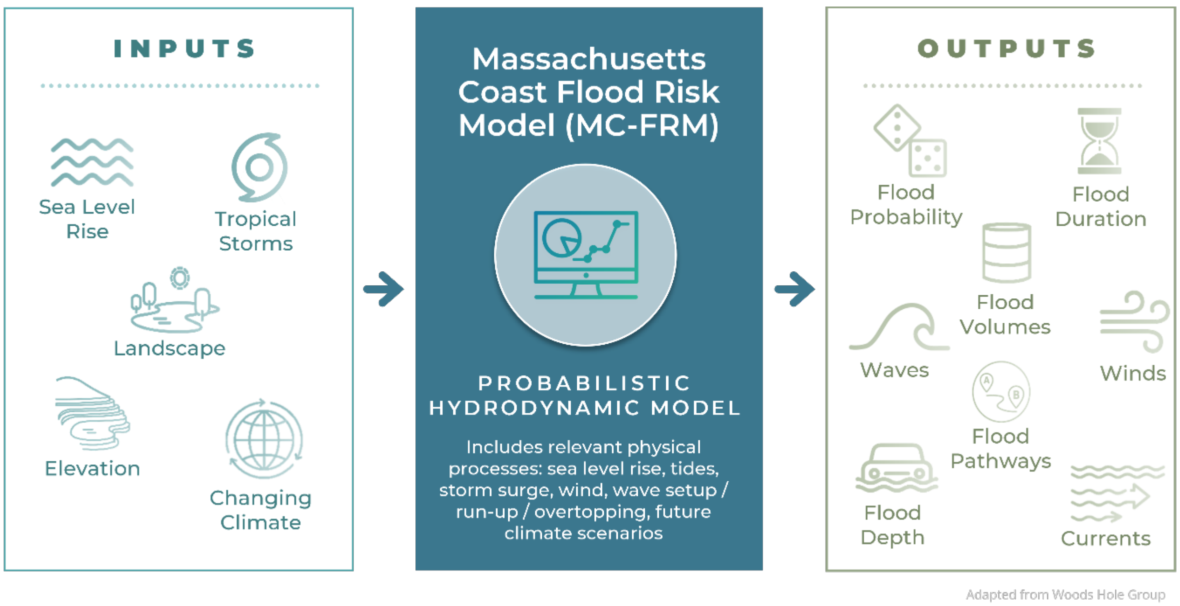
## RISK

For this project risk is more than the probability of flooding. It is defined as criticality times vulnerability. The roads in a community that are both highly critical and have a high probability of flooding are ranked as high-risk roads or road segments that may require adaptation alternatives, as depicted in this visual.


Adapted from Woods Hole Group

## Model Introduction

The low lying roads project utilizes the Massachusetts Coast Flood Risk Model (MC-FRM), a state-of-the-art model that projects flooding under future time horizons. The model includes the dynamic impacts of tides, waves, wave run-up and overtopping, storm surge, winds, and currents over a range of storm conditions to generate the probability of inundation. The MC-FRM generates hydrodynamically modeled projections for sea level rise and storm surge to determine projected changes in the likelihood of flooding under climate conditions for 2030, 2050, and 2070. The model uses inputs displayed below to create multiple outputs. Flood probability and flood depth are the primary outputs used in this assessment to evaluate roadways.




## Results

The following section highlights model outputs, presenting examples for the town of Bourne.

The results of the model include assessments of high tide flooding, inundation probability, criticality, and risk for the entire town.

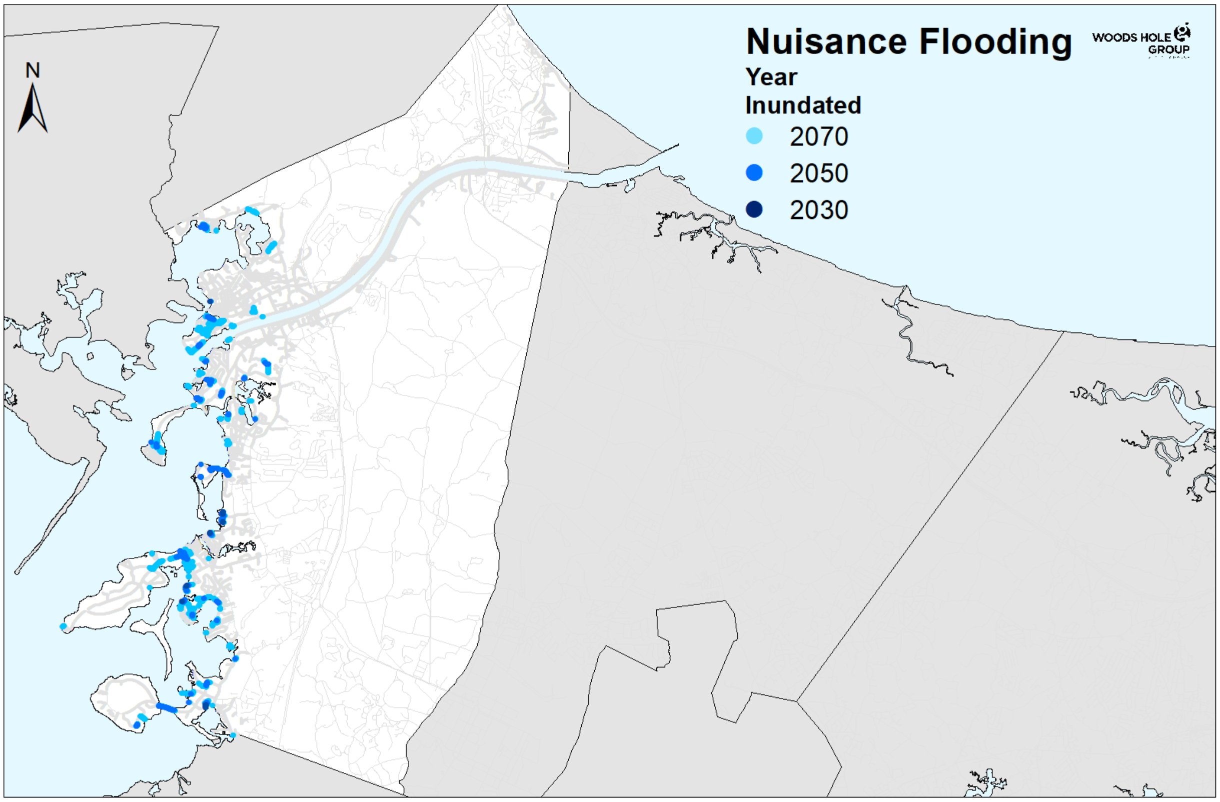



FIGURE A-1. Projected Low Lying Roads Nuisance (MHW) Flooding

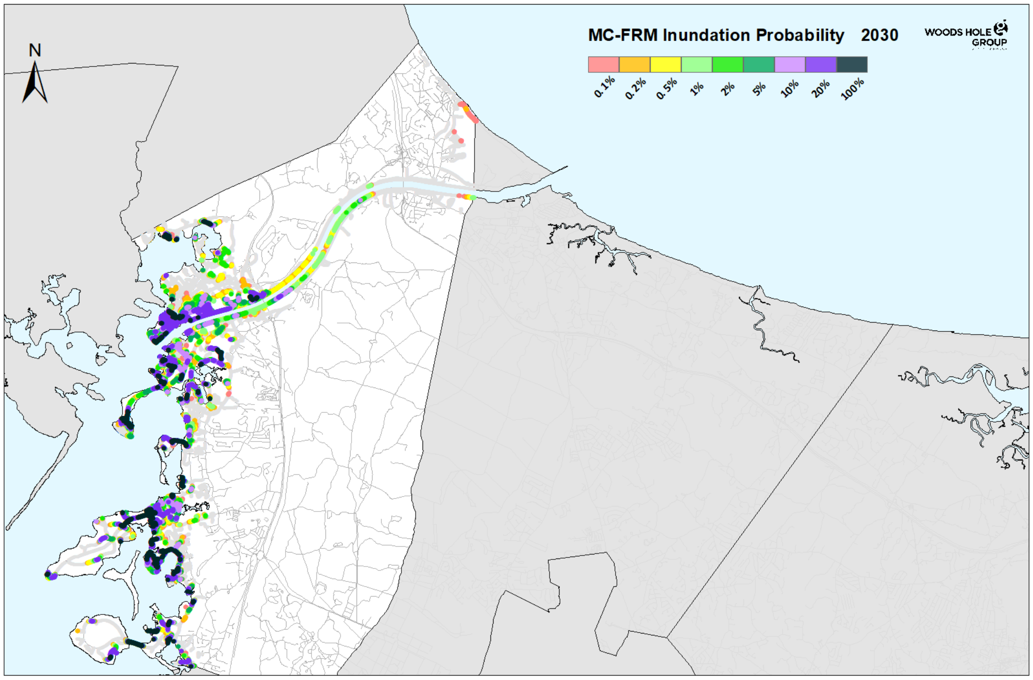



FIGURE A-2. Low Lying Roads Inundation Probability - 2030

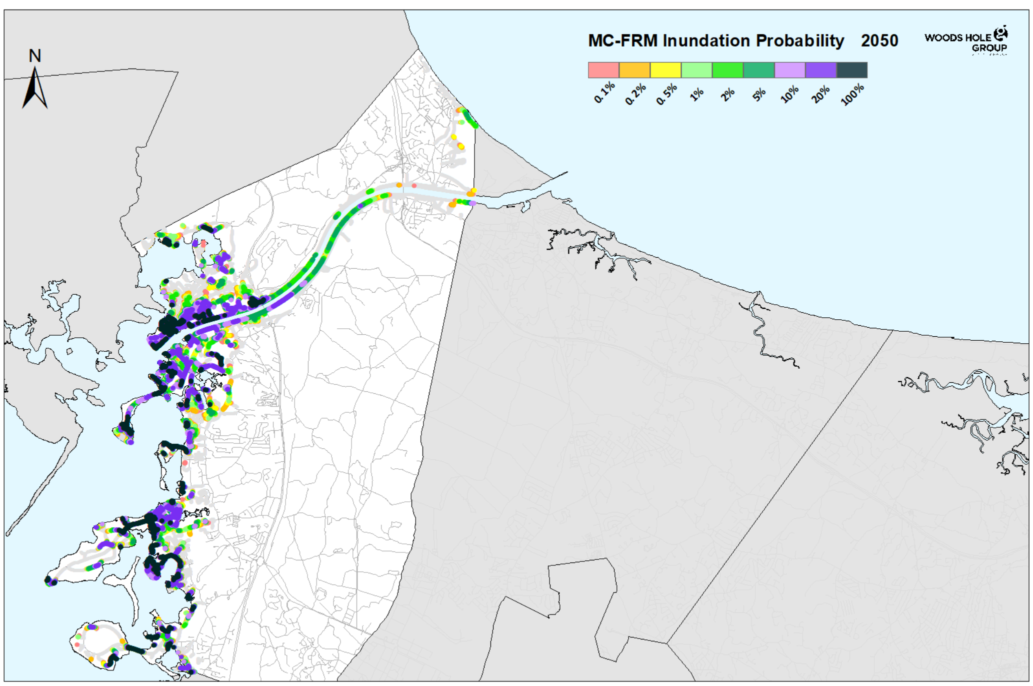



FIGURE A-3. Low Lying Roads Inundation Probability - 2050

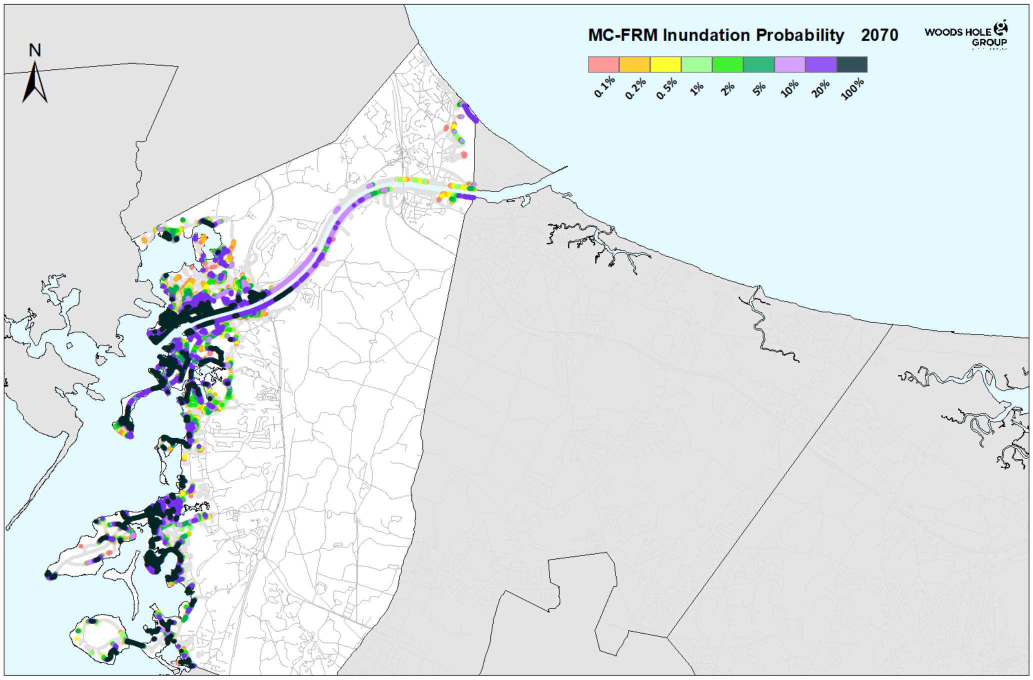



FIGURE A-4. Low Lying Roads Inundation Probability - 2070

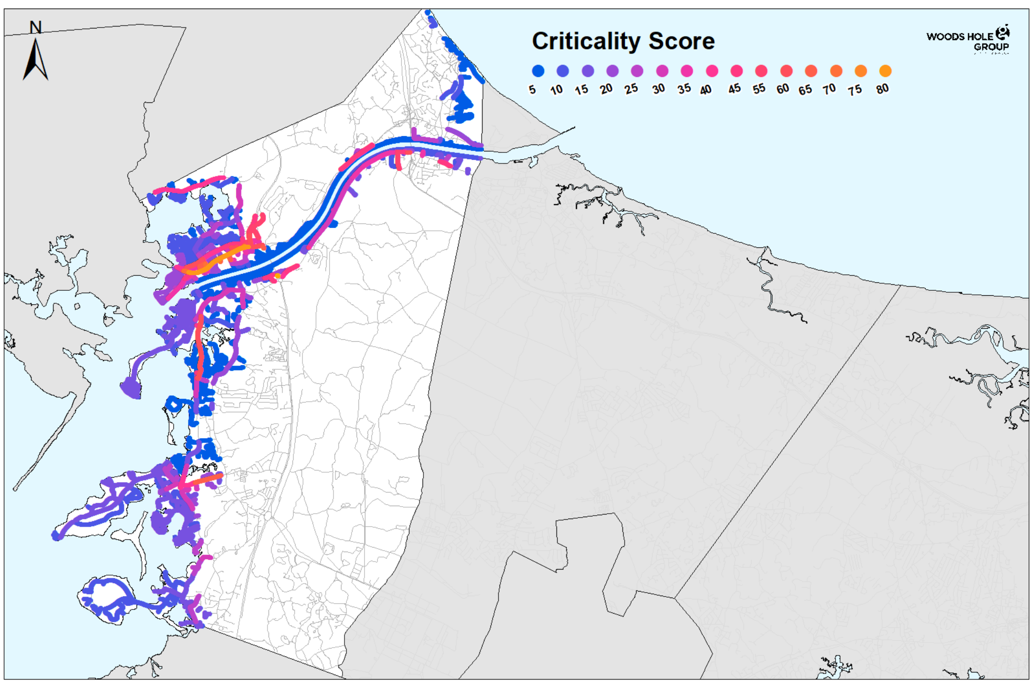



FIGURE A-5. Road Network Criticality Scoring

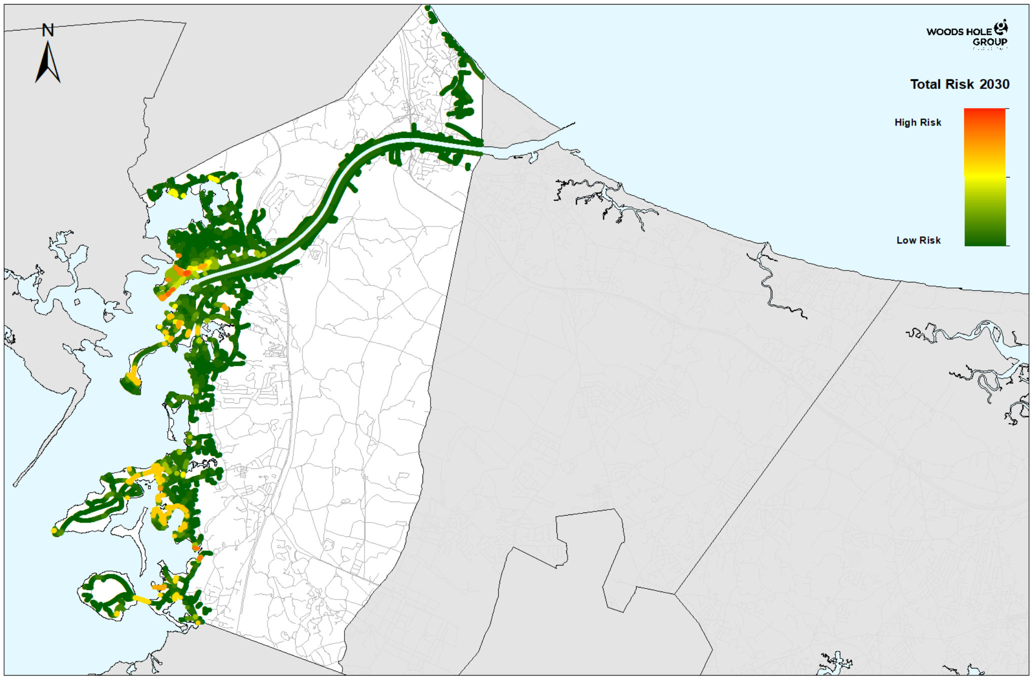



FIGURE A-6. Risk Results - 2030

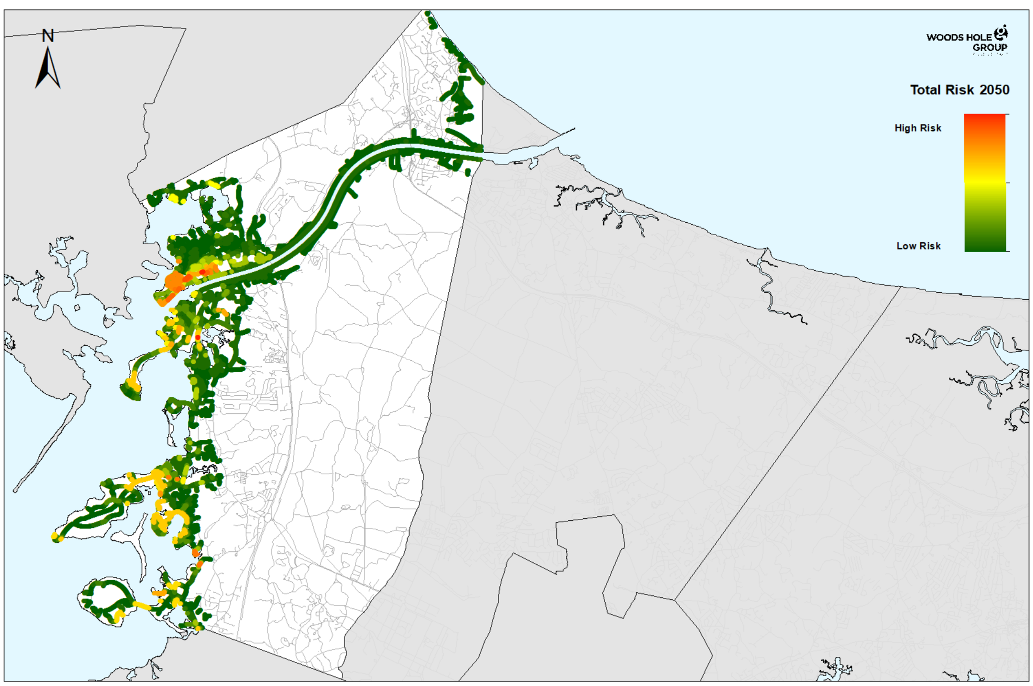



FIGURE A-7. Risk Results - 2050

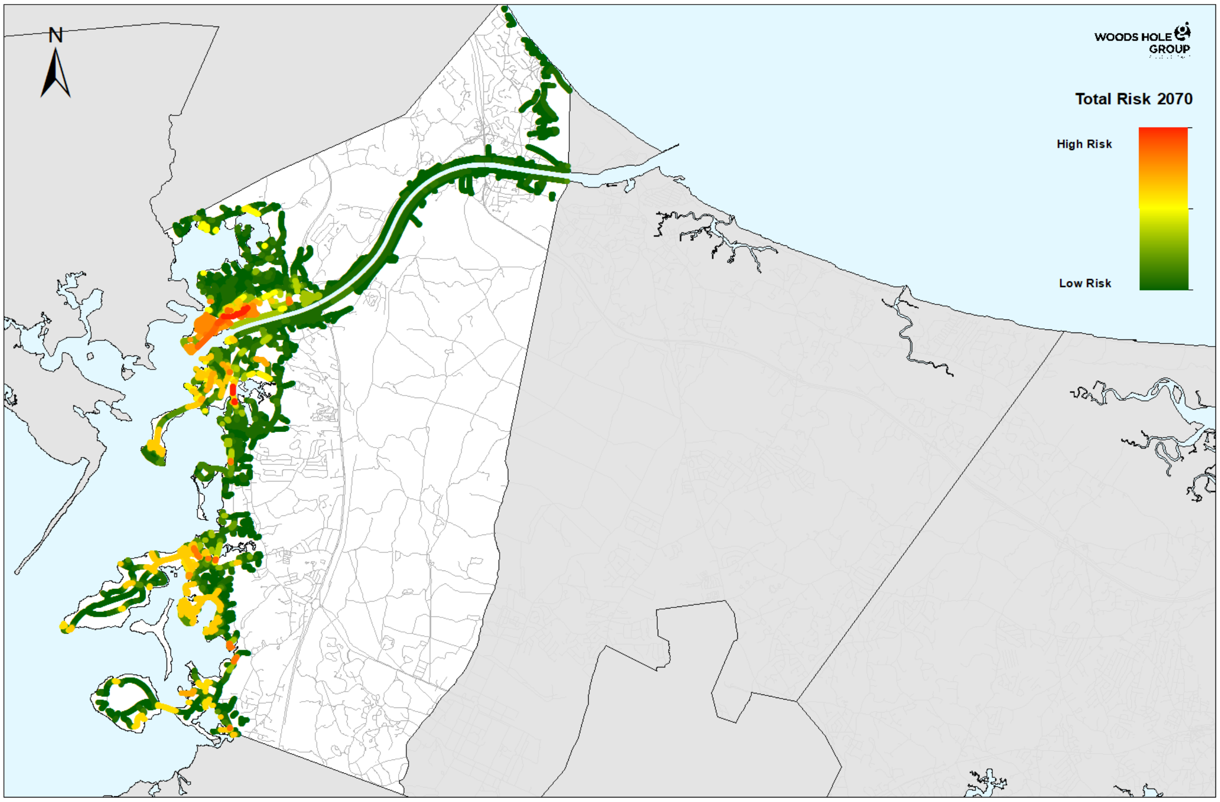



FIGURE A-8. Risk Results - 2070

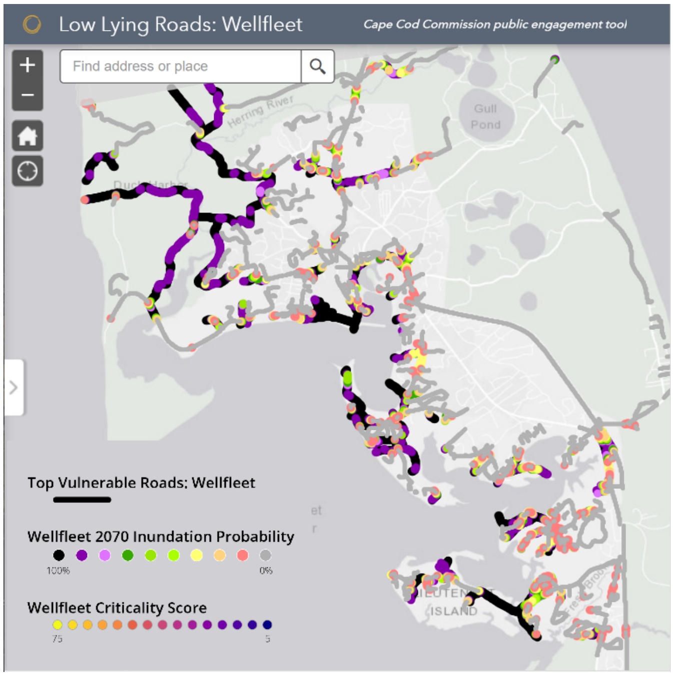
A list of top priority roads that have a high flood-risk is developed from these town-wide results. The list provides the road name, the length of road segment that will flood, and the probability of flooding under each time scenario: 2030, 2050, and 2070.

| | Name | Length (ft) | Description | Segment Storm Probability (%) | | | Nuisance Length (ft) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2030 | 2050 | 2070 | 2030 | 2050 | 2070 |
| A | Academy Dr, Taylor Rd and Wright Ln | 4020 | Main road leading Mass Maritime | 10-100 | 20-100 | 100 | | 260 | 2100 |
| B | Red Brook Harbor Rd | 440 | Road backing Parkers Boat Yard | 10-100 | 20-100 | 100 | | 20 | 180 |
| C | Harbor Pl | 320 | Road segment along Taylor Point Marina | 100 | 100 | 100 | | 220 | 320 |
| D | Main St, Holt Rd and Canal St | 3700 | Long segment between Academy Dr and Smalley Rd | 5-20 | 20-100 | 100 | | | |
| E | Shore Rd (Back River) | 720 | Road and bridge crossing Back River | 10-20 | 20-100 | 100 | | | |
| F | Wings Neck Rd and North Shore Rd | 4180 | Leads to Wings Neck Island, isolated neighborhood | 10-100 | 20-100 | 100 | | 720 | 2720 |
| G | Shore Rd (Pocasset River) | 180 | South of Pocasset River Bridge | 10-20 | 20 | 100 | | | |
| H | Cohasset Ave and Buzzards Bay Ave | 400 | E to W road between Buzzars Bay Bypass and Main St | 5-10 | 20 | 100 | | | |
| I | Shore Rd (Monument Beach) | 180 | Backing Monument Beach | 10-20 | 20 | 100 | | | |
| J | Megansett Rd | 320 | Road intersection leading to Amrita Island | 2-20 | 10-100 | 100 | | | |
| K | Circuit Ave and Bell Buoy Rd | 3260 | Backing Hen's Cove Beach, isolated neighborhood | 0.2-100 | 2-100 | 5-100 | | 200 | 1660 |
| L | Mashnee Rd* | 580 (5240) | Access to Mashnee Island, isolated neighborhood | 0.5-100 | 2-100 | 10-100 | | | 1120 |
| M | Monument Neck Rd and Presidents Rd | 1120 | Main access point to large neighborhoods | 1-20 | 5-20 | 20-100 | | | |
| N | Emmons Rd | 1580 | Road / bridge at Monument Beach, isolated neighborhood | 5-100 | 20-100 | 20-100 | | 1080 | 1280 |
| O | Scraggy Neck Rd* | (1300) | Isolated neighborhood | 5-100 | 10-100 | 20-100 | | | 1220 |

* = Private or partially private

FIGURE A-9. Summary of High Priority Road Segments

The model results have been compiled into an interactive map viewer displaying data used in the analysis and a public comment feature tool for stakeholders to provide feedback on areas of interest.




**Map Viewer**

**LOW LYING ROADS**

**Customized by Town**
Individual applications available for each of the 10 participating towns

**Interactive Data Visuals**
Explore the Criticality Score, along with Inundation Probability and Risk for 2030, 2050, and 2070

**Public Comment Feature**
Allows for public feedback within the map interface

## Solutions

Conceptual adaptation design solutions will be developed for chosen high priority road segments. The project looks to identify nature -based solutions for each priority segment; however existing site conditions may constrain possible alternatives.

Green infrastructure, also known as nature-based solutions, are engineered designs that mimic or enhance natural processes. Green infrastructure has the potential to provide co-benefits, such as creating habitat or improving water quality. Examples include dune nourishment and enhanced marsh habitat.

Gray Infrastructure are also known as traditional engineering structures. Examples include bridges, seawalls, and roadway elevation.

Other approaches include realignment of roadways or managed retreat, which is the purposeful and coordinated movement of infrastructure (e.g., roads) away from the risk (e.g., flooding).

## Adaptation Strategies


The spectrum of possible strategies ranges from “do nothing” to “coastal armoring.” The most feasible solutions will consider site conditions and likely combine green and gray options.

Vulnerable road segments in Bourne selected to move forward with adaptation solutions were Circuit Avenue and Wings Neck Road. The following presents existing conditions and possible road adaptation design solutions for Circuit Avenue, highlighting a road cross-section (B) adjacent to the public beach at Hen Cove.

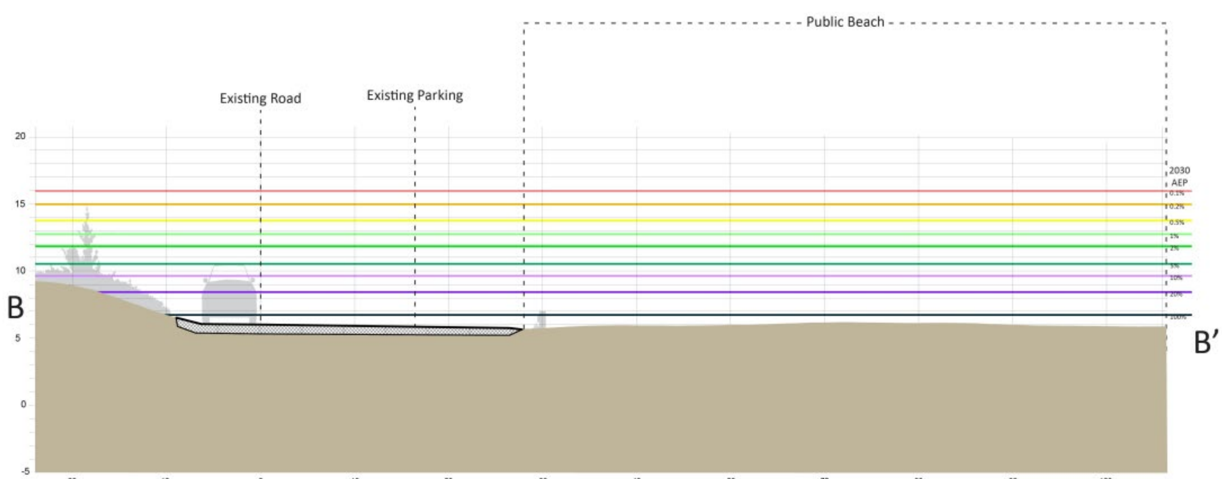



FIGURE A-10. Existing Conditions – Cross-Section

The colored, horizontal lines represent different flood probabilities for 2030 using the MC-FRM.

The gray alternative presents a conceptual design that would raise 2,452 linear feet of the road from a lowest elevation point of 3.8 feet NAVD88 to a lowest point of 9.5 feet NAVD88, and would include sheet piling to elevate portions of the road with traditional vegetated side slopes in other locations.


FIGURE A-11. Circuit Avenue Alternative 1 - Gray

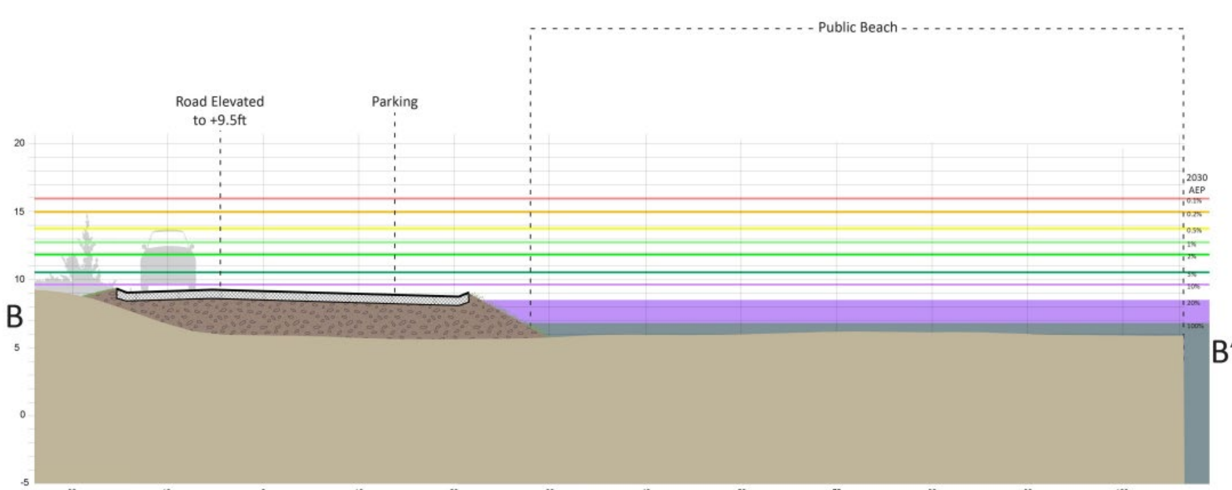



FIGURE A-12. Circuit Avenue Alternative 1 – Gray, Cross-Section

The hybrid alternative presents a conceptual design that would incorporate parapet walls to 8.6 feet NAVD88 to tie together high points along Circuit Avenue. A tide gate would be added to an existing culvert and raised sections of pavement would be added to side streets to prevent flanking. A dune would be constructed at the public beach with access provided by a wooden walkover structure.


FIGURE A-13. Circuit Avenue Alternative 2 - Hybrid

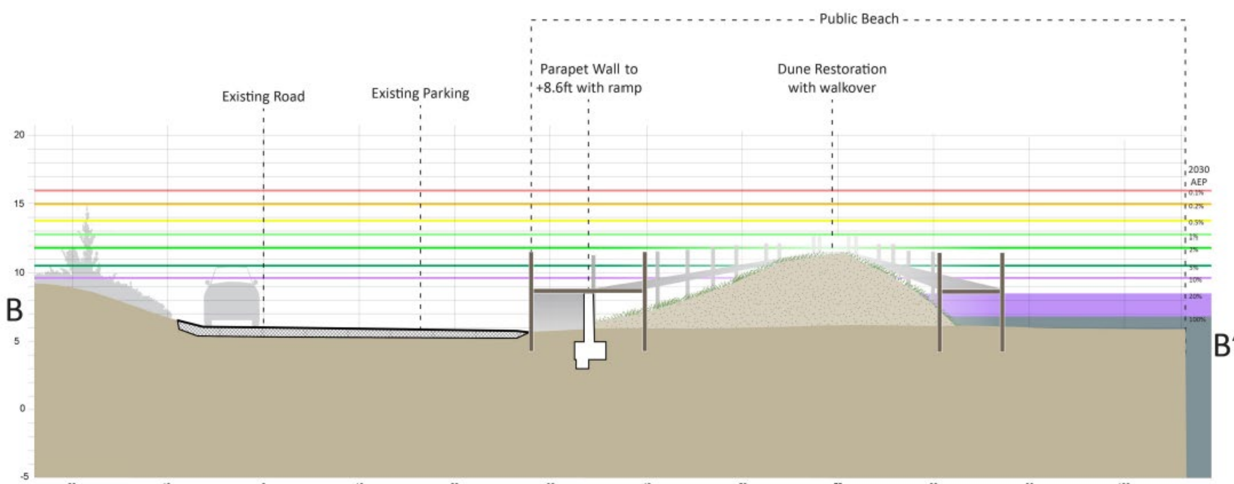



FIGURE A-14. Circuit Avenue Alternative 2 – Hybrid, Cross-Section

The green alternative presents a conceptual design that would include a combination of coastal bank and dune enhancements to protect the road to 6.9 feet NAVD88. A dune enhancement to 10 feet NAVD88 would protect the beach and parking lot from erosion. The existing culvert would be replaced and an operable tide gate would be installed.


FIGURE A-15. Circuit Avenue Alternative 3 - Green

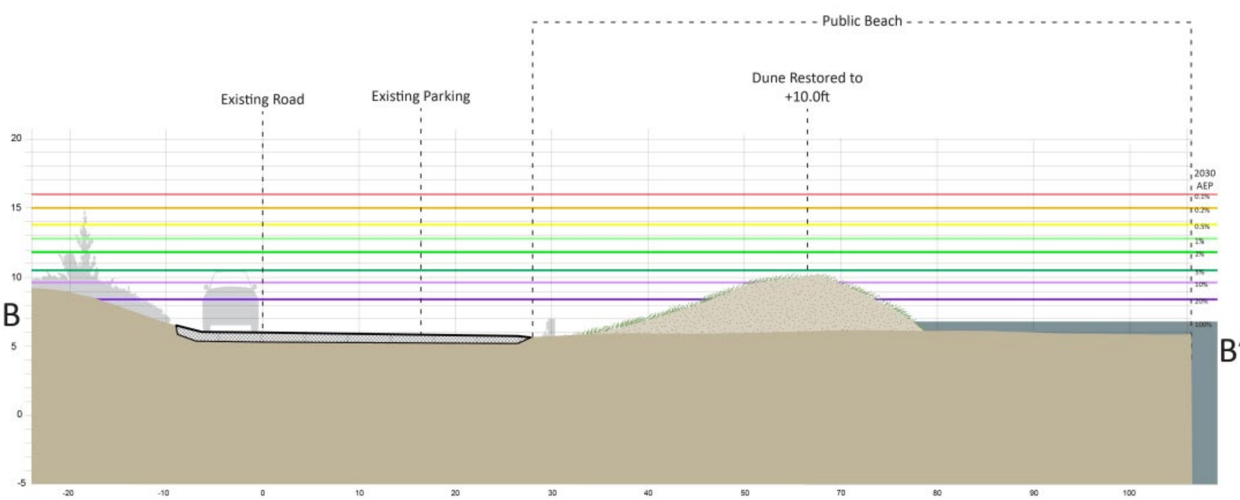



FIGURE A-16. Circuit Avenue Alternative 3 – Green, Cross-Section

A summary of alternatives can be used to compare considerations and tradeoffs of employing a particular solution.

CIRCUIT AVENUE, BOURNE

Summary of alternatives

| | Description | Critical Elevation | Annual Exceedance Probability 2030 | 2050 | 2070 | Vulnerable to Tidal Flooding | Impacts to Wetlands | Impacts to Private Property | Estimated Cost* |
|---|---|---|---|---|---|---|---|---|---|
| EXISTING | A segment of 20 foot wide road with a public beach and a culvert. | 3.8 feet | 100% | 100% | 100% | 2050 | N/A | N/A | N/A |
| ALTERNATIVE 1: GRAY | 2452 linear feet of Town-owned road are elevated from a lowest point of 3.8 feet to a lowest point of 9.5 feet. Sheet pile is used to elevate the road at the cranberry bog and culvert crossing, and traditional vegetated side slopes are used at other locations. | 9.5 feet | 10% | 20% | 100% | N/A | N/A | Yes | $1,133,000 |
| ALTERNATIVE 2: HYBRID | A parapet wall to 8.6 feet is installed to tie together high points along Circuit Ave. A tide flap is added to the culvert to prevent flanking. A dune is constructed at the public beach, and access is preserved with a wooden walkover. | 8.6 feet | 10% | 20% | 100% | N/A | Possible Positive | No | $1,386,000 |
| ALTERNATIVE 3: GREEN | A combination of coastal bank and dune enhancements protect the road to 6.9 feet. Additional dune enhancements at the beach protect the parking lot and beach from erosion. The culvert is replaced and an operable tide gate is installed. | 6.9 feet | 20% | 100% | 100% | N/A | Positive | Yes | $1,108,000 |

*Installed material cost +20% contingency. Excludes design, permitting, mobilization, stormwater and wastewater infrastructure, and site controls. Costs based on RSMeans 2021 cost book and adjusted for inflation and region.

FIGURE A-17. Comparison of Alternatives

Each town can use these conceptual design solutions and comparison of alternatives to further a preferred option to additional design and permitting for roadway adaptation. The probability and risk analyses can be used to plan for and prioritize future road work over the projected planning horizons.

Additional funding through the MVP program was secured last fall to continue this work with the remaining Cape Cod communities: Chatham, Falmouth, Harwich, Mashpee, and Provincetown. Modeling and analysis are underway for these towns, and workshops will be scheduled in the spring of 2023. Work under this second MVP Action grant will conclude in June 2024.

## CAPE COD CLIMATE ACTION PLAN

Climate change is transforming Cape Cod. Though rising seas and changes to the coastline may be the most dramatic evidence of climate change, it is impacting every facet of Cape Cod's natural, built, and community systems. Climate action is necessary to slow the effects of climate change and improve the region's resilience to its impacts.

In 2021, the Cape Cod Commission developed the Cape Cod Climate Action Plan[2] (CAP), which provides a way forward for the region to mitigate and adapt to our changing climate and aligns with the Commonwealth's goal of reaching net-zero emissions by 2050. The CAP is the result of an intensive effort, coordinated by the Cape Cod Commission, to engage the Cape Cod community, identify paths toward climate resiliency, and further develop partnerships necessary to implement climate actions.

The Climate Action Plan identifies strategies and actions that can aid in reducing greenhouse gas emissions (GHG) and enhance local resiliency to climate threats. The identified strategies and actions will require significant changes in how we build, rebuild, work, travel, plan for and implement our infrastructural investments.

The Cape's transportation hub for intra- and inter-regional transportation, as well as the region's main hospital and supporting infrastructure, along with regional businesses, road infrastructure, and hundreds of local critical facilities are located within areas vulnerable to flooding, sea level rise and extreme weather events.

## Regional GHG Emissions

Cape Cod's 2017 GHG emissions were estimated to equal 3,564,875 $MTCO_2e$, approximately 4-5% of Massachusetts state emissions. Transportation is the highest local contributing sector of emissions, accounting for 55.5% of total Cape Cod emissions. The second highest contributing sector locally is stationary energy use, which is responsible for 39% of total inventory emissions. The remaining 5% of emissions come from the waste (3%), industrial processes (1.9%), and agriculture (0.4%) sectors.

[2] More information is available at www.capecodcommission.org/climate

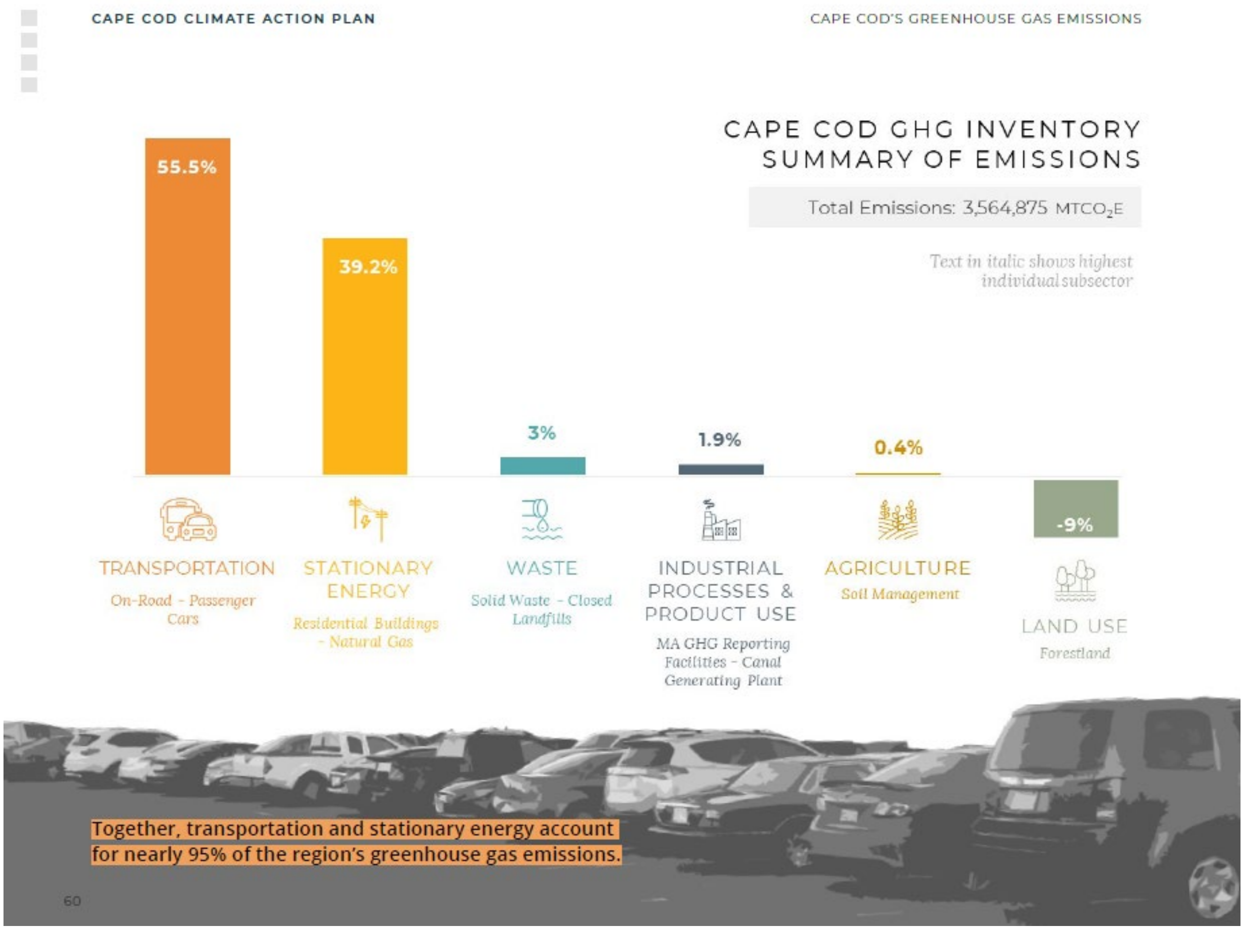



FIGURE A-18. Summary of Cape Cod Greenhouse Gas Emissions

Transportation accounts for 55.5% of GHG emissions for the region, compared with 45.7% of state emissions. On-road vehicles account for 43% of the region's emissions and nearly 80% of transportation emissions.

## Future GHG Emissions Scenarios

Future GHG emissions scenarios were developed by Eastern Research Group and Synapse Energy Economics as part of the CAP to help better understand how the region could contribute to GHG emissions reductions in support of the Commonwealth's GHG emissions reductions goals to reduce GHG emissions to 50% below 1990 levels by 2030 and to 85% below 1990 levels by 2050.

The future emissions scenarios provide context for the extent of actions necessary within each modeled sector to contribute to achievement of the Commonwealth's goals. For each of the scenarios, Synapse modeled several key metrics, which will help the region understand the necessary magnitude of change—and progress toward it—to play its part in achieving the Commonwealth's GHG emissions reduction targets.

All decarbonization scenarios require significant growth in the share of new, light-duty electric vehicle (EV) sales. Even an aggressive energy efficiency scenario (SER2), with reduced vehicle miles traveled (VMT) relative to the other decarbonization cases, requires 63% of new vehicle sales to be EVs by 2030. An increased year-round population scenario (SER3) requires 85% by 2030. The aggressive electrification scenario (SER1) and the carbon neutral scenario (CEN) each require 93% of new sales to be EVs by 2030. By 2050, all decarbonization scenarios require 100% of new vehicle sales to be EVs.

To accommodate about 214,000 light-duty EVs on the road by 2050 (as required to reach 2050 emissions goals in the SER1 scenario), 8,800 public charging stations will need to be installed, which is nearly 4,000 more (at an additional cost of around $10 million) than would be needed in a sustained policy case.

## Strategies for Climate Action

With input from stakeholders during the CAP development process, the Commission created a Climate Actions Database, which presents strategies, actions, and steps to achieve the goals of the CAP. One priority strategy identified is to accelerate the electrification of the transportation system.

Actions within this strategy include:

- **Encourage investments in EV charging infrastructure –** To accelerate the adoption of EVs, additional investment in charging infrastructure is required. Residential and commercial developments and redevelopments should be designed and built with EVs in mind. While the majority of EV charging may take place at home there is a clear need for public charging stations, particularly for a region where a significant proportion of motorists on the roadway are visitors. This will require action from both the public and private sectors.
- **Support programs that incentivize EV adoption –** With lower operating and maintenance costs, the lifetime cost of owning an EV could be less than a gas-powered vehicle. Unfortunately, the higher upfront cost of EVs still presents a barrier to ownership for many. While advances in technology are expected to ultimately make the EV the most economical choice, in the near- and medium-term, rebates and other incentives can help to promote EV adoption. These incentives are particularly important to ensure equitable access to EVs. Additionally, the local availability of dealers and repair facilities for EVs will be important for large-scale adoption.
- **Explore opportunities for electrification of public transit and fleet vehicles and vessels –** As technology advances, EV options will become more feasible for public transit vehicles, municipal vehicles, school buses, police vehicles, delivery vehicles, and various marine vessels. Feasibility

studies could help inform decision-makers of the current opportunities, barriers, costs, and grant options for electrification.

## Implementation and Measuring Performance

The strategies and actions identified through the Climate Action Plan process require implementation by the region as a whole. Partnerships within government, and with and between nongovernmental organizations, researchers, and the business community, will be critical for success. Partnerships must be forged and strengthened to advance the implementation of many actions. Implementation will require all those who live, work, and visit Cape Cod to advance climate action.

In addition to partnerships, the region must focus on those actions which will begin to have significant impacts on reducing GHG emissions from the sectors with the biggest contributions, such as transportation, and those which will help improve the resilience of the region's natural and built systems.

Measuring progress towards meeting the goals of the Climate Action Plan will require both long-term tracking of regional performance measures and shorter-term tracking of the implementation of specific strategies and actions. One measure within the CAP of reduced emissions from the transportation sector is the percent of vehicles powered by electricity, including:

- Percent of new vehicle purchases that are EVs
- Number of EVs
- Number of EVs in municipal fleets
- Number of EV charging stations

Measuring performance of transportation electrification over time is needed to show progress towards electrification goals.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