Vulnerability of Transportation Assets to Sea Level Rise

Technical Paper 164
January 2015

Rhode Island Statewide Planning Program
Division of Planning
Department of Administration
One Capitol Hill
Providence, RI 02908
www.planning.ri.gov

The Rhode Island Statewide Planning Program in the Division of Planning, Department of Administration, is established by Chapter 42-11 of the General Laws as the central planning agency for state government. The work of the Program is guided by the State Planning Council, comprised of state, local, and public representatives and federal and other advisors. The objectives of the Program are: (1) to prepare strategic and systems plans for the state; (2) to coordinate activities of the public and private sectors within this framework of policies and programs; (3) to assist local governments in management, finance, and planning; and (4) to advise the Governor and others on physical, social, and economic topics.

This Technical Paper is one of a series prepared by the Statewide Planning Program. Technical Papers present information developed through planning activities to state and federal agencies, local governments, and the public. Activities of the Program are supported by state appropriations and federal grants. The contents of this report reflect the views of the Statewide Planning Program which is responsible for the accuracy of the facts and data presented herein. The contents do not necessarily reflect the official views or policies of other sponsoring agencies. This publication is based upon publicly supported research and may not be copyrighted. It may be reprinted, in part or full, with the customary crediting of the source. Copies of this report are available on the web at www.planning.ri.gov. For hard copies, contact the Statewide Planning Program, One Capitol Hill, Providence, RI, (401) 222-7901.

Table of Contents

Executive Summary

Sea level rise and the gradual increase in high tides have been occurring for decades. International, national, and Rhode Island-based experts agree that the rate of rise will increase over coming decades. Sea level rise presents a major challenge to Rhode Island's transportation infrastructure. Sea level rise, as opposed to storm surge or other flooding, is a long-term, permanent trend with implications for our coastal transportation infrastructure as well as coastal residential communities and other infrastructure that serves residents and commerce.

This study analyzes the transportation assets at risk under 1, 3, and 5 feet of sea level rise. Using a GIS-based methodology, the project finds that every coastal Rhode Island community will experience impacts to their transportation infrastructure due to sea level rise. 2.3 miles of roadway are expected to flood at high tide under 1 foot of sea level rise, 28 miles at 3 feet of sea level rise, and up to 85 miles at 5 feet of sea level rise.[1] In addition, numerous coastal bridges, rail segments, bike infrastructure, ports and harbors, and RIPTA routes and stops will flood in these three sea level rise scenarios, along with portions of an airport and several intermodal hubs.

A vulnerability assessment focused on assets under state jurisdiction found that infrastructure at greatest risk is located in Bay communities and on Block Island. In particular, the East Bay communities of Barrington, Bristol, and Warren have very important transportation infrastructure that is vulnerable to sea level rise.

The sea level rise scenarios are based on current conditions and do not include projections of erosion, storm surge, or precipitation. This study aims to provide an overview of key exposures and identify a subset of infrastructure under state jurisdiction that is most vulnerable. The findings should direct readers toward areas and individual assets that require more in-depth research, study of alternatives, and engineering analysis. All maps are available at http://www.planning.ri.gov/geodeminfo/data/slr.php.

---

[1] These figures are based on current conditions and do not account for coastal erosion and other factors that will likely increase the exposure of transportation assets to sea level rise. Please see "Overview of challenge presented by coastal flooding to transportation assets" and "Limitations" sections for a complete accounting of the limitations of this study.

Project Objectives

This project aims to communicate the estimated geographic extent of sea level rise in relation to transportation facilities, and to provide state transportation stakeholders with an overview of assets most vulnerable to sea level rise. The specific objectives of the project include:

- Provide an overview for state, local staff, and the public of the exposure of our transportation assets to coastal inundation
- Provide local DPWs, RIDOT, planners, and other transportation stakeholders our best estimation of the exposure of specific roads under different scenarios
- Develop and pilot a desktop vulnerability and risk method for ranking adaptation priorities
- Identify the state transportation assets considered most vulnerable
- Provide a general overview of adaptation options (including armor, adapt, and retreat) for transportation assets
- Provide an overview of opportunities to integrate adaptation into transportation decision-making

Working Group

- Jane Austin, Save the Bay
- Corey Bobba, Federal Highway Administration
- Jim Boyd, RI Coastal Resources Management Council
- Michelle Burnett, RI Emergency Management Agency
- Scott Buxton, RI Department of Transportation
- Teresa Crean, University of Rhode Island, Coastal Resources Center
- Christopher Damon, University of Rhode Island, Environmental Data Center
- Janet Freedman, RI Coastal Resources Management Council
- Anne LeClerc, RI Public Transit Authority
- Vincent Murray, Town of South Kingstown
- Bill Patenaude, RI Department of Environmental Management
- Dan Porter, RI Airport Corporation
- Jon Reiner, Town of North Kingstown
- Pam Rubinoff, University of Rhode Island, Coastal Resources Center
- Rob Thompson, University of Rhode Island
- Katherine Trapani, Quonset Development Corporation
- Robert Vanderslice, RI Department of Health

Division of Planning Staff

- Christina Delage Baza
- Vincent Flood
- Benjamin Jacobs
- Amanda Martin
- Chris Witt
- Shane White

Overview of challenge presented by coastal flooding to transportation assets

Rhode Island is familiar with minor, and occasionally major, coastal flooding. There are several distinctions between the flooding that the state has experienced and the flooding anticipated with sea level rise. Sea level rise will be a relatively slow, long-term, permanent trend, as opposed to episodic storm flooding. The sea level rise "inundation zones" represent where a twice-daily high tide is projected to occur. While storms are a constant threat, we have more time to adapt to sea level rise – time that will be necessary to undertake research and make investments in our transportation network that address its vulnerabilities. So while the threat will occur over multiple decades, it is important to start making good decisions about transportation investments today.

Although it is possible to project where sea level rise will occur based on current conditions, the natural and built environments will continue to change in ways that make it difficult to predict precisely what the transportation needs of the future will be. Sea level rise, and its impacts on the transportation network, may make some coastal areas uninhabitable or very difficult to access. Coastal neighborhoods and commercial establishments may take new shape or need to relocate altogether, which will change the demand for transportation infrastructure that serves those areas. For this reason, it is critical to plan for the impact of sea level rise on transportation assets in conjunction with planning for other aspects of coastal communities.

With the changing climate, we expect that sea level rise will not be the only hazard to threaten our transportation network: coastal storms with wind and waves, heavier precipitation, and coastal erosion are all likely to contribute to flooding. This study looks at sea level rise based on today's conditions. Erosion, in particular on the south coast, will likely push the areas affected by sea level rise to include streets and neighborhoods farther inland. In the future, more sophisticated statewide modeling may make it possible to look at cumulative impacts like storm surge, riverine precipitation, and erosion, along with sea level rise.

Sea Level Rise Scenarios

The scenarios used in this study were one, three, and five feet of sea level rise. Each of these three scenarios has a timeframe during which the scenario is expected to occur according to recent climate projections for the United States and Rhode Island. Scientists are working to narrow the range of temporal projections for sea level rise, but for now they remain quite wide, leaving open the question about how risk-averse (or conservative) decision-makers wish to be in their approaches to maintaining coastal transportation infrastructure. While considering the probable timeframes for each scenario, it is helpful to compare timeframes to the design life of new transportation infrastructure, routine maintenance and upgrades, and the actual age of existing transportation infrastructure in the state.

Note that in the northeastern United States, sea level rise is occurring more rapidly due to land subsidence and changes in the ocean circulation. Therefore Rhode Island should expect its high tide line to advance faster than the rest of the nation, and in advance of the milestones projected nationally for sea level rise.

Estimates of Sea Level Rise Timelines: State and National Sources			
	1 Foot SLR	**3 Feet SLR**	**5 Feet SLR**
RI CRMC Policy[2]	*Does not specify*	3-5 feet by 2100	3-5 feet by 2100
NOAA "High" Scenario[3]	2029	2061	2083
US ACE "High" Scenario	2035	2070	2095
NOAA "Intermediate High" Scenario	2038	2072	4.25 feet in 2100
US ACE "Intermediate" Scenario	2060	+	+
NOAA "Intermediate Low" Scenario	2060	+	+
National Climate Assessment "low end"[4]	2100	+ (1.95 feet in 2100)	+

[2] *Coastal Resources Management Program*, Section 145

[3] NOAA projections computed using criteria in NOAA SLR Report 06-Dec-2012 using the Newport Tide Gauge

Estimates of Sea Level Rise Timelines: State and National Sources			
National Climate Assessment "high end"	*Does not specify*	4 feet by 2100	+
US ACE "Low" Scenario[5]	0.91 feet in 2100	+	+
NOAA "Low" Scenario	0.91 in 2100	+	+

+ Curve ends at 2100 and does not project this amount of sea level rise at that time

Methodology

Projection of Sea Level Rise Inundation

To determine the geographic areas projected to be underwater with sea level rise, the project used geographic information systems (GIS) analysis in partnership with the URI Environmental Data Center (EDC) and the National Oceanic and Atmospheric Administration (NOAA). The project used a method known as a "modified bathtub" model. The "bathtub" model projects sea level rise by modeling a vertical increase in the current water level over the existing terrain, much like filling a bathtub. It is "modified" because the results were adjusted for major tidal differences in Rhode Island. Using 2011 LiDAR data, URI EDC created a digital elevation model (DEM) of land in Rhode Island. NOAA used this DEM to run VDatum, a program that adjusts the elevation values in the DEM so they are relative to mean higher high water (MHHW), accounting for variability in the tidal activity in Rhode Island's. (VDatum does not account for localized tidal differences in smaller inlets.) Next, NOAA determined the sea level rise inundation zones by capturing all area with elevation less than or equal to the amount of sea level rise under a given scenario.

This coverage included isolated, low-lying inland areas; RI Statewide Planning corrected this problem through individual review of all isolated, low-lying areas against aerial images, streams and rivers data, and Google Maps' Street View to determine whether each area had (or would have) a connection to ocean water. A small number of these areas remain "uncertain" on the final maps for this project because there was not enough evidence to determine if a hydrological connection does or does not exist. Statewide Planning also removed from the flood projections areas inland of dams, using dam height data to determine whether a hydrological connection would exist. Rhode Island Department of Environmental Management provided an update of dam data after the analyses were complete. The new data show that two dams relevant to the sea level rise project were partially removed; areas inland of these two dams and at elevations within five feet of mean higher high water were classified as uncertain.

Transportation Asset Data

The data used to represent transportation assets in the state came from a variety of sources.

Asset	Source
Roads	RIDOT
Rail	RIDOT
RIPTA	RIGIS, RIPTA
Intermodal	Statewide Planning
Bicycle Infrastructure	RIGIS, edited by Statewide Planning
Airports	RIGIS
Ports & Harbors	RIGIS Ports and Commercial Harbors
Bridges	RIDOT Bridge Inspection Data
DOT Maintenance Facilities*	RIDOT
Park and Ride Facilities*	RIDOT

*Not mapped due to minimal impact; results included in findings section

[4] National Climate Assessment Three, May 2014.
[5] USACE projections computed using criteria in USACE EC 1165-2-212 using the Newport Tide Gauge. See http://corpsclimate.us/ccaceslcurves.cfm

There is a need for geographic data on the location of smaller culverts and storm water detention ponds. The latter data are particularly relevant for understanding public health impacts of climate change because of the potential for standing water to generate increased breeding ground for mosquitoes and vector-borne diseases they may carry. The project used available data to identify bridges of concern, but more data inputs are required to understand better the impact of sea level rise on bridges (e.g. scour, materials, bridge structure and design, etc.).

Determining the Exposure of Transportation Assets to Sea Level Rise

The “exposure” phase of the project began with a GIS intersect that projected the exposure to sea level rise of roads, rail, RIPTA routes and stops, bicycle infrastructure, airports, ports and harbors and passenger intermodal hubs. The resulting GIS intersects required additional editing: very narrow strips of some roads, bike paths, and rail that cross bridges were included in the intersect because the inundation zones actually refer to the land or water beneath bridges or elevated infrastructure. Staff used pictometry, aerial photography, and Google Maps Street View to determine where it was likely that the transportation asset was sufficiently elevated that the inundation scenario would not affect the asset.

For bridges, the project took a different approach. The project studies two aspects of bridges’ exposure to sea level rise: (1) exposure of freeboard to sea level rise scenarios and (2) accessibility of the bridge under the sea level rise scenarios. For simplicity’s sake, and to avoid overstating the precision of the methods, all the bridge exposure findings are based on five feet of sea level rise and we use the terminology of “bridges of concern” or “no concern”. Follow-up engineering analysis is necessary to understand the impact of sea level rise on bridges. For freeboard height, staff digitized freeboard height as recorded on RIDOT bridge inspection sheets for all bridges located above any of the sea level rise inundation zones. A standard threshold was used as a barometer of “concern” for freeboard height, based on five feet of sea level rise (60 inches) + average tidal spread at the Newport Tide Gauge (42 inches) = 102 inches. Average tidal spread was incorporated because the bridge inspection sheets do not indicate whether measurements were taken at high tide, low tide, or somewhere in between. Any bridge with freeboard 102 inches or less was determined to be a concern due to freeboard height. For accessibility, staff reviewed the road networks that connect each bridge under the five foot sea level rise scenario. If the facility that the bridge carries would be cut off by inundation on one or both sides, it was considered a concern due to accessibility issues. Some bridges were concerns both due to freeboard height and accessibility.

Vulnerability Assessment

The vulnerability assessment was an exercise in determining the *relative* vulnerability of transportation assets *under state jurisdiction*. Essentially, the vulnerability assessment allows the state to prioritize the assets deemed most vulnerable. The project worked with a concept of vulnerability that included both the characteristics of the physical hazard (e.g. length or area flooded, how soon the asset will flood, the elevation of the infrastructure) and the importance of the asset to society, or in this case, to the transportation network (e.g. use level of the asset, capacity, and existence of alternatives). The concept of vulnerability is summarized by the following equation:

Vulnerability = Likelihood and magnitude of hazard + Social / transportation impact of the hazard occurring

Or, a more visual interpretation:

Social / transportation impact →

Likelihood & magnitude of hazard ↓

	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

To conduct the vulnerability assessment, a basic index of vulnerability was developed for each asset category. The vulnerability assessment creates a composite vulnerability score for each individual affected asset. The vulnerability index was designed specifically for each different asset type, and provides a *relative, not absolute*, ranking of vulnerability. The vulnerability rankings differentiate among assets under state jurisdiction to support prioritization of assets for further study and action. Therefore the index was designed to produce results that would spread across a range of values. Low vulnerability index values should not be interpreted as low vulnerability, but rather, *lower* vulnerability than other assets.

There are limited data that are available for all assets within an individual asset category (e.g. roads, rail), but a vulnerability assessment could incorporate a great deal more additional data. A detailed description of the method used in the composition of the index is available in Appendix 4.

Data Used in Vulnerability Assessment (State Owned or Maintained Assets)		
	Likelihood or Magnitude of Hazard	**Social / Transportation Impact of the Hazard Occurring**
Roads	SLR Scenario when asset first projected to be inundated; linear feet flooded at 1, 3, and 5 feet of sea level rise	Functional classification; whether road is hurricane evacuation route
Rail	Rail assets were not ranked for vulnerability because there is only one affected state-owned rail line. Vulnerability data for all rail lines are summarized in the table on page 13.	
RIPTA	SLR Scenario when asset first projected to be inundated; number of stops flooded at 3 and 5 feet of SLR. No stops were flooded at 1 feet.	Weekly ridership; weekly frequency
Passenger Intermodal Hubs[6]	SLR Scenario when asset first projected to be inundated	Whether ferry is seasonal or year-round; whether a transportation alternative exists for routes served by hub
Bicycle Infrastructure	SLR Scenario when asset first projected to be inundated; linear feet flooded at 1, 3 and 5 feet of SLR	Whether bike infrastructure is on or off road
Bridges	Concern due to freeboard height; Concern due to access issues; height of freeboard (regardless of 102 inch threshold); whether bridge is already over mean higher high water	Average annual daily traffic; whether bridge carries road facility
Airports	Airports were not ranked for vulnerability because there was only one state-owned airport projected to have sea level rise flooding (Quonset).	
Ports and Harbors	Ports and harbors were not ranked for vulnerability due to the complexity of the comparison and the limited amount of available data. Square footage of exposed ports and harbors by city/town and by utilization is on page 18.	

[6] All affected intermodal hubs are ferry terminals.

Limitations

As mentioned previously, the exposure and vulnerability stages of this study did not take into account projections of erosion, storm surge, or precipitation. Areas that appear to lack hydrological connection based on the inundation areas created by NOAA were evaluated on a case-by-case basis; there may be areas affected by sea level rise that are not included in the projections. High tide and subsequent sea level rise scenarios may be higher in inlets. For all assets projected to be inundated, further study is recommended.

Findings: Exposure and Vulnerability

Statewide Exposure Summary Table

	At 1 foot SLR	At 3 feet of SLR	At 5 feet of SLR
Roads (all)	2.3 miles / 12,013 Ft.	28 miles / 147,903 Ft.	84.0 miles / 441,829 Ft.
NHS Roads (linear feet)	93 Ft.	0.5 miles / 2,393 Ft.	6.5 miles / 34,053 Ft.
NHS Roads (% of total)*	0.00%	1.6%	7.7%
Local Roads (linear feet)	2.3 miles / 11,904 Ft.	27.6 miles / 145,488 Ft.	58 miles / 307,585, Ft.
Local Roads (% of total)*	0.04%	0.45%	69.4%
Rail (all)	10 Ft.	145 Ft.	3,685 Ft.
Owned by Amtrak	10 Ft.	120 Ft.	275 Ft.
Owned by State	0 Ft.	25 Ft.	3,278 Ft.
Other ownership	0	0 Ft.	132 Ft.
RIPTA routes	55 Ft.	2.0 miles / 10,694 Ft.	11.0 miles / 58,134 Ft.
Intermodal terminals	2	6	7
Park and Rides	0	0	3
Ports and Harbors	17.4 acres / 759,549 Sq. ft.	56.5acres / 2,463,688, Sq. ft.	220 acres / 9,566,938913 Sq. ft.
Bike Infrastructure (all)	418 Ft.	1.6 miles / 8,671 Ft.	5.6 miles / 29,644 Ft.
Bike Path	364 Ft.	0.8 miles / 4,329 Ft.	2.5 miles / 13,373 Ft.
On-street bike routes	54 Ft.	0.8 miles / 4,342 Ft.	3.1 miles / 16,271 Ft.

* % of total RI roads

Total Bridges of Concern	**77**
Freeboard Height Concern	64
Accessibility Concern	48

City and town summary exposure tables are available as Appendix 2.

ROADS

Key Finding- Exposure

Roads form the largest portion of the transportation network and many Rhode Island roads run very close to the shore, serving businesses and homes and/or providing access to public recreation areas. Miles of road will be affected by sea level rise, and approximately 70% of these roads are local roads, which are ineligible for federal transportation improvement funding.

Key Finding- Vulnerability

The roads vulnerability index finds that, of all the roads that are under state jurisdiction that will be inundated by up to five feet of sea level rise, the ten most vulnerable segments are located in Barrington (three segments), Warren (three segments), Tiverton, Bristol, New Shoreham, and North Kingstown (one segment each). These segments are projected to experience daily high tide flooding at either one or three feet of sea level rise; all but one of the top ten are hurricane evacuation routes. The summary table below highlights these top ten most vulnerable segments and the data on these segments that contributed to their high vulnerability index score. The full vulnerability table for all segments of road owned or maintained by the state is available in Appendix 3.

Top 10 Road Segments Under State Jurisdiction Most Vulnerable to Sea Level Rise

Rank	Road Name	Municipality	Feet of SLR When Road First Floods	Functional Classification	Hurricane Evacuation Route	Linear Feet Flooded at:			Vulnerability Index Score
						1ft SLR	3ft SLR	5ft SLR	
1	County Rd (103)	Barrington	1	Principal Art.	Yes	31	248	2,888	**8.8**
2	Child St	Warren	1	Principal Art.	Yes	32	302	1,198	**8.5**
2	Main St	Warren	1	Principal Art.	Yes	25	318	883	**8.5**
3	Highland Rd	Tiverton	1	Major Collector	Yes	150	834	953	**7.9**
4	Massasoit Ave	Barrington	1	Minor Art.	Yes	15	59	630	**7.5**
5	Wampanoag Trl (114)	Barrington	3	Principal Art., Local	Yes	0	141	6,368	**7.3**
6	Poppasquash Rd	Bristol	1	Minor Collector	No	59	3,156	4,381	**6.9**
6	Hope St	Bristol	3	Principal Art.	Yes	0	583	2,021	**6.9**
7	Phillips St	N. Kingstown	3	Principal Art.	Yes	0	209	583	**6.8**
8	Market St	Warren	3	Principal Art., Minor Art.	Yes	0	1,129	2,164	**6.7**

RAIL

Key Finding- Exposure

While the sea level rise impacts on rail are limited in Rhode Island, rail is an asset to monitor closely due to the permanence of the railbed location, the expense of building and maintaining rail, and its role in commerce in the state. Sea level rise impacts on rail are limited to a small number of locations. At Quonset, 130 feet are projected to flood at five feet of sea level rise. The Newport Secondary Track (the tourist or dinner train) is projected to flood at five feet in Newport, both at the Gateway Center and north of Route 138 (3,228 feet in total, or nearly half a mile). At three and five feet, the Newport Secondary Track is projected to flood near the Sakonnet River Bridge in Portsmouth. In Providence, there is a very short segment in South Harbor near Terminal Road that is projected to be flooded at five feet of SLR. However, much of the rail line in this area runs close to the water, so further study is warranted in this area. Similarly, the Amtrak Northeast Corridor rail line runs underneath Waterplace Park in Providence; this section of rail is located in areas flooded by sea level rise, but because the exact elevation of the rail line is difficult to determine, it is not known whether it will be affected by sea level rise will.

Key Finding- Vulnerability

Because the vulnerability index was intended to rank facilities under state jurisdiction, and the state only owns one track that is projected to experience sea level rise flooding (Newport Secondary), rail segments were not scored with a vulnerability index. However some key information about rail vulnerability is listed in the table below.

Rail Vulnerability Data (alphabetical by name)

Rail segments are not ranked or scored

Name	Town	Rail Use	Owner	Linear Feet Flooded at:		
				1ft SLR	3ft SLR	5ft SLR
Amtrak NEC	Providence	Freight/Passenger	Amtrak	10	110	155
Newport Secondary Track	Newport	Freight/Tourist	State	0	0	3228
Newport Secondary Track	Portsmouth	Freight/Tourist	State	0	24	24
Quonset	North Kingstown	Freight	Seaview	0	0	130
South Harbor	Providence	Freight	Providence	0	0	2

RIPTA

Key Finding- Exposure

RIPTA infrastructure may be affected by sea level rise in a variety of ways. This study looked at RIPTA routes that are located on roads that are projected to flood as well as individual RIPTA stops. Fourteen routes are located in part on roads that are projected to flood, and 52 stops are located in projected sea level rise inundation zones. Only one bus route, the 60, runs on a road segment that is projected to have flooding impacts at 1 foot of SLR (in Barrington). At three and five feet of sea level rise, the number of routes affected grows to 9 and 14, respectively.

Areas of projected sea level rise flooding that affect RIPTA lines include *but are not limited to*: Downtown Providence, including South Water Street and parts of the Jewelry District including Dyer Street and Dorrance Street; Galilee area in Narragansett; Barrington/Warren; Newport Gateway; and Jamestown.

RIPTA Routes Inundated by Sea Level Rise

SLR Scenario	# Routes Affected
1 Foot	1
3 Feet	10
5 Feet	15

RIPTA Stops Inundated by Sea Level Rise

SLR Scenario	# Stops Affected
1 Foot	0
3 Feet	8
5 Feet	44

Key Finding- Vulnerability

The RIPTA route vulnerability index includes data on the exposure of the route to sea level rise, including the route itself and stops, and the social importance of the route, represented by weekly ridership and weekly frequency. By far, the 60 bus is the most vulnerable route, as it has far more stops that would be inundated at three and five feet of sea level rise than other routes. The route is the only one that will be affected even at one foot of sea level rise, and it has high ridership and fairly high frequency.

Top 10 RIPTA Routes Most Vulnerable to Sea Level Rise

Rank	#	Name	Weekly Ridership (people)	Weekly Frequency (trips)	SLR Scenario When Route First Impacted	Stops Flooded at 3 ft SLR	Stops Flooded at 5 ft SLR	Feet Flooded at 5 ft SLR	**Vulnerability Index Score**
1	60	Providence/Newport	332,983	551	1	5	33	15,918	**10.0**
2	66	URI/Galilee	192,375	278	3	1	6	7,561	**5.6**
3	14	West Bay	85,518	190	3	2	9	8,660	**5.2**
4	33	Riverside	158,398	404	3	0	4	1,485	**4.5**
5	64	Newport/URI	41,475	118	3	0	7	6,430	**3.9**
5	65	Wakefield Express	28,935	55	3	1	4	5,605	**3.9**
7	3	Warwick Ave	148,719	399	3	0	0	1,195	**3.8**
8	67	Bellevue Mansion/Salve Regina	54,220	514	5	0	1	2,576	**3.7**
9	1	Eddy St	197,685	516	5	0	0	801	**3.6**
10	32	East Providence/Wampanoag	24,958	189	3	0	4	1485	**3.0**
10	34	East Providence	55,565	209	3	0	4	1,485	**3.0**

Top 10 RIPTA Stops Most Vulnerable to Sea Level Rise						
Rank	Name	Ridership - Weekly	SLR Scenario When Route First Impacted	# Lines Served	Avg # Passengers Getting on On+Off	**Vulnerability Index Score**
1	Gateway Center	Newport	5	5	1,060	**6.8**
2	W Marlborough Ns Thames	Newport	5	3	150	**5.6**
3	S Water At James	Providence	5	4	11	**5.3**
3	S Water Fs Crawford	Providence	5	4	31	**5.3**
5	Hope Fs Washington	Bristol	3	1	15	**5.1**
6	Sand Hill Cove Opp Roger Wheeler Beach	Narragansett	3	2	1	**4.5**
7	Barrington Park N Ride (White Church)	Barrington	5	1	84	**4.4**
7	Barrington Park N Ride (White Church)	Barrington	5	1	77	**4.4**
8	Great Island Rd at Ferry Terminal	Narragansett	5	2	33	**4.1**
8	S Water Opp Power	Providence	5	4	5	**4.1**
8	S Water Between Packet & Planet	Providence	5	4	6	**4.1**

PASSENGER INTERMODAL HUB

Key Finding- Exposure and Vulnerability

The study analyzed passenger intermodal locations in the state: bus, rail, ferry, and air. Seven intermodal hubs in the state are projected to be inundated by sea level rise; all are located at ferry terminals. They are listed in the table below, ranked by vulnerability. Criteria included in the intermodal hub vulnerability index include the sea level rise scenario in which inundation is expected to occur, whether or not the ferry service is seasonal, and whether there is another mode available for the ferry service provided. Note that intermodal hubs are represented as points not polygons in the GIS data and further study should examine whether key aspects of the hub's operation might be inundated before the point location is inundated. The Galilee/Block Island ferry terminal In Narragansett has the highest vulnerability rank both because it serves the year-round population of Block Island, who do not have a road alternative to travel between the mainland and the island, and because the ferry terminal is projected to experience inundation at three feet of sea level rise.

Intermodal Hubs Inundated by Sea Level Rise, Ranked by Vulnerability						
Rank	Intermodal Hub	Town	SLR Scenario when first affected	Seasonal	Road alternative available	Vulnerability Index Score
1	Galilee/BI Ferry	Narragansett	3	No	No	8
2	Block Island Ferry	New Shoreham	5	No	No	6
3	Bristol/Prudence Ferry	Portsmouth	5	No	No	6
4	Newport/Jamestown/BI Ferry (America's Cup near Bowen's Wharf)	Newport	3	Yes	No	5.6
5	Newport/Jamestown Ferry (Fort Adams)	Newport	3	Yes	Yes	4
6	Jamestown/Newport	Jamestown	3	Yes	Yes	4
7	Newport/Jamestown Ferry (Thames St.)	Newport	5	Yes	Yes	2

PORTS AND HARBORS

Key Finding-Exposure

All oceanfront ports and harbors in Rhode Island are exposed to sea level rise. A transportation-related subset of commercial ports and harbors was selected for mapping and analysis, using the following criteria:

- Located on waters zoned Type 5, Commercial and Tourism Oriented, OR Type 6, Ports and Navigation
- Used for marine commercial and industrial purposes OR used for commercial ferry OR commercial rail is active in the parcel

As with roads, the rate of increase in spatial extent of inundation over the assets goes up with additional feet of sea level rise. When considering the figures in the table below, note that the ports and harbors data layer includes structures like piers that may currently exist over ocean water, and will be included as "inundated" under one, three, and five feet of sea level rise. Readers are advised to check maps for individual port and harbor locations.

Exposure of Commercial Ports and Harbors to Sea Level Rise		
SLR Scenario	Square Feet	Acres
1 foot	759,549	17
3 feet	2,463,688	57
5 feet	9,566,938	220

Key Finding- Vulnerability

The impact of rising sea levels will depend, in large part, on the particularities of each port or harbor's infrastructure, needs, and management. This project did not attempt a full comparison of vulnerability among all the ports included in the exposure analysis, in part because available statewide data on ports and harbors do not identify all individual commercial port or harbor names or owners. Two tables are provided to summarize vulnerability of ports and harbors. Facilities at Quonset, in Providence and East Providence, and Point Judith are expected to have significant impacts from sea level rise.

- A summary table by city/town and purpose provides an overview of the magnitude of exposure facing different types of commercial ports and harbors in different parts of the state. Exposure to sea level rise is projected to be particularly significant at the commercial ports and harbors of North Kingstown, Providence, East Providence, and Narragansett.
- A summary table of major port facilities in the state provides an overview of the exposure of major commercial transportation port facilities.

Commercial and Industrial Ports Affected by Sea Level Rise* - by City and Town and Purpose (acres)																
	Feet of SLR	Combo	Comm. Dock Building	Comm. Ferry	Comm. Fishing	Dry Bulk Cargo	Elec. Power Gener.	Fish Process.	General Berthing	Govt./ Inst.	Liquid Cargo	NA**	Roll on/ Roll off	Sewer	Ship Building Repair	**Total**
Bristol	1	0.06		0.15	0.11					0.02						**0.34**
	3	0.12		0.20	0.37					0.06						**0.75**
	5	0.56		0.43	1.09					0.34						**2.42**
E. Greenwich	1				0.09					0.05		0.00				**0.15**
	3				0.50					0.19		0.00				**0.75**
	5				0.91					0.64		0.00				**1.5**
E. Providence	1										1.69					**1.69**
	3										4.43					**4.43**
	5										10.74					**10.74**
Little Compton	1				0.07											**0.07**
	3				0.25											**0.25**
	5				0.57											**0.57**
Narragansett	1	0.00		0.04	0.73										0.23	**1.0**
	3	0.71		0.38	6.73										0.49	**8.31**
	5	6.90		0.38	16.73										1.28	**25.29**
New Shoreham	1			0.01	0.22											**0.23**
	3			0.08	0.29											**0.37**
	5			1.46	0.35											**1.81**
Newport	1			0.08	0.24										0.08	**0.4**
	3			0.26	1.29									0.04	0.21	**1.8**
	5			0.64	4.23									0.12	1.40	**6.39**
N. Kingstown	1	1.00	0.18		0.30					0.11		4.78	0.17		2.21	**8.75**
	3	4.04	0.94		1.3					0.50		13.0	0.7		8.40	**28.88**
	5	11.31	2.68		2.6					1.16		84.0	3.01		36.0	**140.76**
Portsmouth	1	0.04														**0.04**
	3	0.33														**0.33**
	5	1.03														**1.03**
Providence	1					0.00	0.14		0.22		1.94	0.17			1.79	**4.26**
	3					0.05	0.36		1.02		4.31	0.38			2.43	**8.55**
	5					1.12	0.81		4.86		8.16	1.80			7.14	**23.89**
S. Kingstown	1				0.03											**0.10**
	3				0.09											**0.16**
	5				0.46											**0.53**
Tiverton	1										0.04					**0.04**
	3										0.22					**0.22**
	5										0.46					**0.47**
Warren	1				0.14			0.09							0.07	**0.11**
	3				0.25			0.43	0.29						0.73	**1.52**
	5				0.57			1.02	0.74						2.31	**4.46**
Total		**19.79**	**2.68**	**2.91**	**27.58**	**1.12**	**.81**	**1.02**	**5.6**	**2.14**	**19.4**	**85.84**	**3.01**	**0.12**	**64.77**	

* Acreage and square feet are cumulative. In other words, the area that will be flooded by three feet of sea level rise includes the area that will be flooded by one foot of sea level rise.

** Unknown purpose

Major Commercial Port and Harbor Facilities Affected by Sea Level Rise*
Alphabetical by Municipality

Facility	Municipality	Inundated by 1 ft SLR		Inundated by 3 ft SLR		Inundated by 5 ft SLR	
		Acres	Sq. Feet	Acres	Sq. Feet	Acres	Sq. Feet
Prudence Island Ferry Terminal - Bristol	Bristol	0.2	6,729	0.2	8,862	0.4	18,799
USCG Bristol	Bristol	0.0	871	0.1	2,719	0.3	14,974
ExxonMobil	East Providence	0.9	40,405	2.8	120,527	8.7	378,220
Wilkes-Barre	East Providence	0.8	33,238	1.6	72,830	2.0	89,712
Point Judith	Narragansett	0.4	18,866	6.1	265,436	22.1	961,491
Point Judith – Block Is. Ferry Terminal	Narragansett	0.1	3,997	0.7	32,214	0.8	36,222.14
BI Old Harbor Town Dock	New Shoreham	0.2	9,750	0.3	12,469	0.4	15,413
New Shoreham – Block Is. Ferry Terminal	New Shoreham	0.0	574	0.1	3,612	1.5	63,724.32
DEM Newport	Newport	0.0	897	0.2	7,257	2.7	116,525
Newport Ferry - Perrotti Park	Newport	0.1	3,291	0.3	11,324	0.6	27,723
QDC-Davisville	North Kingstown	0.2	8,068	0.8	33,960	3.2	138,889.35
QDC-RIAC	North Kingstown	4.7	182,166	13.0	520,597	84.0	3,573,489
RI Fast Ferry	North Kingstown	0.2	9,134	0.9	29,246	3.0	130,726
Prudence Isl. Ferry Terminal – Prudence Isl.	Portsmouth	0.0	1,640	0.3	14,507	1.0	44,723.29
Abhu Mehri	Providence					0.9	38,879
Glen Falls	Providence	0.0	66	0.0	711	0.1	4,171
Goodison	Providence	0.0	1,040	0.2	8,334	1.6	71,750
Hudson	Providence	0.0	232	0.1	2,258	0.2	8,053
Keyspan LNG	Providence	0.0	1,529	0.1	5,599	0.4	15,896
Motiva	Providence	1.8	79,788	4.0	175,846	7.3	318,382
Simms (formerly Promet)	Providence	1.8	77,108	2.2	97,786	5.5	239,619.44
Providence Steamboat	Providence	0.0	1,956	0.1	4,339	0.3	13,841
ProvPort	Providence	0.0	1,439	0.2	8,615	0.7	28,402.11
Sprague	Providence	0.1	4,419	0.2	9,441	0.7	29,195
St. Lawrence Cement	Providence	0.0	115	0.0	1,373	0.1	5,394
Univar	Providence					0.0	399
Waterson	Providence	0.1	4,542	0.6	25,824	3.5	153,393.12
Inland Fuel - Tiverton	Tiverton	0.0	1,894	0.2	9,782	0.5	20,289

* Acreage and square feet are cumulative. In other words, the area that will be flooded by three feet of sea level rise includes the area that will be flooded by one foot of sea level rise.

BRIDGES

Key Finding- Exposure

Bridges are vulnerable to sea level rise because they may not be designed or engineered to withstand higher sea levels. It is also important to consider where sea level rise may block the accessibility of a bridge, rendering it useless for transportation purposes even if the structure itself may withstand sea level rise. Overall, there are 77 bridges that cause concern because of either freeboard heights or accessibility.[7] Bridges of concern tend to carry smaller facilities in coastal communities. 64 bridges have freeboard concerns only, 48 have accessibility concerns only, and 16 have both. This project was unable to locate the freeboard height for several bridges located over tidal water, most of which are quite high but some of which could pose concerns at their approaches. These include: the Sakonnet River Bridge, the Pawtucket Bridge, the Jamestown-Verrazzano Bridge, the Newport Bridge, the Mount Hope Bridge, and two smaller bridges in East Providence at the Massachusetts border: the Runnins River Slab Bridge and the River Road Bridge.

As of the writing of this technical paper, the White Church Bridge in Barrington is being reconstructed at a higher elevation. The additional feet of under-clearance will provide greater protection for the bridge against sea level rise, among other benefits. Updated data for the bridge under construction was not available at the time of analysis.

Not considered in this report is how sea level rise may diminish freeboard height for bridges that are legally required to maintain a particular freeboard height for navigational purposes.

Key Finding- Vulnerability

Among bridges under state jurisdiction, the Barrington Bridge scored the highest in the vulnerability index score, followed by the Warren Bridge. Both of these bridges carry RI-104/114, which are high volume roadways. Most of the top ten most vulnerable bridges have 72 or fewer inches of freeboard height. [7] The Hussey Bridge in North Kingstown is estimated at only 48 inches of freeboard. All of the facilities carried by these top ten most vulnerable bridges are projected to flood within five feet of sea level rise, which would block access to the bridge. Bridges with unknown freeboard heights were left out of the vulnerability rankings, as were bridges that do not carry road facilities.

[7] The data on freeboard height for bridges over ocean water do not indicate whether the height measurement was taken at high tide, low tide, or somewhere in between. Due to difficulty of working with these data and the complexity of the engineering issues, the analysis was a "first cut" that made a number of assumptions to avoid ruling out impacts that might occur.

Top 10 Bridges Under State Jurisdiction Most Vulnerable to Sea Level Rise									
Bridge Name	Town	Facility	Feature Intersected	Year Built	AADT	Inches of Freeboard[7]	Currently over MHHW?	Access Problem	Vulnerability Index Score
Barrington	Barrington	RI 114/103 CNTY RD	Barrington River	2009	26,000	74	Y	problem	**9.6**
Warren	Barrington	RI 114/103 CNTY RD	Warren River	1914	19,900	98	Y	problem	**9**
C.L. Hussey Memorial	North Kingstown	US 1A BSTN NCK RD	Wickford Cove	1925	9,100	48	Y	problem	**8.85**
Wickford	North Kingstown	US 1A Bstn Nck Rd	Academy Cove	1951	9,100	61	Y	problem	**8.85**
New Harbor Road	New Shoreham	Ocean Av	Trimms Pond	1925	7,000	70	Y	problem	**8.85**
New Shoreham	New Shoreham	Beach Av	Harbor Pond	1997	7,000	73	Y	problem	**8.85**
Barrington Parkway	East Providence	Veterans Mem Pkwy	Watchemoket Cove	1973	12,700	80	Y	problem	**8.25**
Bridgetown	Narragansett	Bridgetown Rd	Pettaquamscutt River	1934	9,800	86	Y	problem	**8.25**
Central	Barrington	Massasoit Av	Barrington River	1940	8,800	99	Y	problem	**8.25**
Silver Creek	Bristol	RI 114 Hope St	Tidal Inlet	1922	18,200	20	N	problem	**8**

BICYCLE INFRASTRUCTURE

Key Finding - Exposure

Bicycle infrastructure assets, including off-road bicycle paths, on-street bicycle lanes, and on-street bicycle routes, are projected to be inundated by sea level rise. RIDOT provided Statewide Planning with a bicycle infrastructure GIS coverage that was last updated around 2008. Statewide Planning staff made minor adjustments to the line work and updated "proposed" projects as complete where the status was known. Statewide Planning staff believes that the off-road bicycle facilities are fairly well represented. The new off-road bicycle path at Rocky Point in Warwick was not included as there is no geographic coverage. Statewide Planning believes that the locally- and state-designated bike routes are fairly up-to-date, but the bike lanes are probably underrepresented in coverage used. Updated bicycle infrastructure coverages for the state would improve the quality of these findings.

Bike Infrastructure Inundated by 1, 3, and 5 Feet of Sea Level Rise			
	1 Foot SLR	**3 Feet SLR**	**5 Feet SLR**
Bike Infrastructure (all)	418 Ft.	1.6 miles / 8,671 Ft.	5.6 miles / 29,644 Ft.
Bike Path	364 Ft.	0.8 miles / 4,329 Ft.	2.5 miles / 13,373 Ft.
On-street bike routes	54 Ft.	0.8 miles / 4,342 Ft.	2.9 miles / 16,271 Ft.

The largest coastal bike infrastructure inundation is to the East Bay Bike Path, which is projected to flood at three feet of sea level rise in several places, particularly in East Providence and Bristol, and may even be affected by one foot of sea level rise which is projected to affect areas quite close to the path. Five feet will bring further flooding. In Warwick, East Greenwich, Narragansett, North Kingstown and South Kingstown, on-street bike routes will flood at three or five feet of SLR.

Key Finding - Vulnerability

The bicycle infrastructure vulnerability index analysis finds that segments that comprise the East Bay Bike Path are the most vulnerable of any bike infrastructure in the state. A small bike path segment built west of the railroad tracks near Crompton Ave in East Greenwich also ranks highly. The vulnerability index for bike infrastructure was a composite score based on the sea level rise scenario under which inundation is expected to begin, the length of inundation in a segment at one, three, and five feet of sea level rise, and whether or not the infrastructure was located on or off road. Off-road infrastructure was weighted more heavily because it is unmovable, unlike on-road bike routes which could be re-routed.

Top 10 Bike Infrastructure Segments Most Vulnerable to Sea Level Rise

Rank	Road Name and/or Bike Network Name	Segment Type	Town	SLR Scenario When First Impacted	Linear Feet Flooded at:			Vulnerability Index Score
					1ft SLR	3ft SLR	5ft SLR	
1	East Bay Bike Path	Path	East Providence	1	222	2,144	5,336	8
2	East Bay Bike Path	Path	Bristol	1	74	1,975	2,916	7.4
3	Crompton Ave Landfill Bikeway Segment	Path	East Greenwich	1	18	376	761	6.2
4	East Bay Bike Path	Path	Warren	1	12	32	2,889	6
5	East Bay Bike Path	Path	Barrington	1	25	69	496	5.4
6	Point Ave - Warwick-East Greenwich Bicycle Network	Local Bike Route	Warwick	3	0	626	3,017	5.2
6	Sand Hill Cove Road	Statewide Route	Narragansett	3	0	1,079	3,936	5.2
6	Shawomet Ave - Warwick-East Greenwich Bicycle Network	Local Bike Route	Warwick	3	0	957	2,350	5.2
6	Calf Pasture Point Bike Path (Old Sanford Rd)	Path	North Kingstown	3	0	72.9	1,638	5.2
9	Eagle St - Northwest Trail-Woonasquatucket River Bikeway	Local Bike Route	Providence	1	3	79	377	4.6
9	Galilee Connector Road	Statewide Route	Narragansett	3	0	738	1,137	4.6
9	Warren Bike Path	Path	Warren	1	12	37	98	4.6
9	Boston Neck Road	Statewide Route	North Kingstown	1	20	35	120	4.6

OTHER ASSETS

Park and Ride Facilities

Park and Ride Facilities Affected by Sea Level Rise			
Municipality	**Type**	**Feet of SLR**	**Location**
Newport	RIPTA Park and Ride	5	Gateway Center At 60 Bus Berth
Barrington	RIPTA Park and Ride	5	Barrington Park N Ride (White Church)

RIDOT Maintenance Facilities

No open RIDOT Maintenance facilities are projected to be affected by sea level rise. A closed RIDOT maintenance facility, located on Block Island, is projected to be exposed to sea level rise at 5 feet. It is currently used by the Town of New Shoreham.

Airports

Quonset State Airport is the only airport projected to experience inundation due to sea level rise of up to five feet. Rhode Island Airport Corporation is aware of the vulnerability of the airport and used the airport master plan process to evaluate the condition and options to address the problem. It conducted an analysis of the airport's existing bulkhead system and potential repair or replacement alternatives. A complete discussion of the topic can be found in Appendix A of the soon to be released Quonset Airport Master Plan.

Adaptation Strategies

By planning ahead, the state and municipalities can make wise and thoughtful investments that align with a particular vision about the best way to manage this hazard. In the best case scenario, decision-makers will select in advance their approach, or approaches, to managing sea level rise risk to transportation assets. Realistically, the state and its cities and towns will like make series of decisions for individual assets and groups of assets over time, learning from their results while taking a longer look at where to spend transportation dollars. There are several options to consider in the context of any individual decision about a facility (e.g. degree of impact if lost, expense associated with different adaptation options). Decisions will need to be timed with other ongoing transportation investments and the common timescales used by transportation decision-makers. For example, major construction projects take years of study before construction, while resurfacing occurs every 10-20 years.

General adaptation options fall into four major categories: protect, accommodate, retreat, and do nothing.

Protect: armor. Often armoring is the initial thought to protect roads and transportation assets from sea level rise. Hard armoring includes protections like sea walls and bulkheads. Hard armor solutions may be necessary to protect critical transportation infrastructure, but they are not a realistic coast-wide solution, given the expense of building and maintenance, the adverse impacts experienced by neighborhoods close to the infrastructure, and the impact to ecological services and systems. Additionally, hard armoring infrastructure located below sea level adds significant stress and cost to a protective structure.

Protect: enhance natural protections. Natural protections include mimicking natural buffers like building dunes and wetlands, re-nourishing beaches, and preserving existing ecosystems that provide protections from ocean waters.

Natural protections will help infrastructure "buy time" as high tides rise and comes closer to infrastructure location, but it is not a long-term solution for in-place maintenance of transportation infrastructure.

Accommodate in place. Many "accommodation" strategies are already in use and could be oriented toward the challenge of accommodating sea level rise. For example, increasing the size of culverts, planning pavement materials to minimize life-cycle costs, and enhancing scour protection on bridges are ongoing activities of transportation planners and engineers that can be adjusted to accommodate higher high tides. However, these strategies are not automatically appropriate for facilities that will regularly be exposed to high tide.

For roads and other facilities that will be exposed to high tide, accommodate in place may mean elevating. The entire roadbed could be elevated, although this is likely to exacerbate wave and storm surge impacts for structures on either side and interrupt ecological processes. Or a causeway-type structure can allow tidal water to flow underneath, but at significant cost and with negative repercussions for transportation connectivity and viewsheds behind the causeway.

Accommodation-in-place strategies also include day-to-day management of sea level rise impacts in place. This category of responses includes putting out cones and deterrents at high tide (or at astronomical high tide), identifying alternative routes to take at high tide, weathering the roadbed to withstand regular saltwater inundation, and managing erosion and debris at the edge of the roadway. These practices can be incorporated into operation and maintenance (O&M) manuals.

Accommodate through realignment. Transportation assets can be realigned out of the path of sea level rise. Realignment is easiest for flexible infrastructure, like RIPTA routes, slightly more challenging for bike infrastructure, more complicated for roads and ports/harbors and probably most challenging for rail. Road realignment may make better use of existing roadways and redundancies that are located further inland. Coastal communities in Rhode Island tend to have dense development and sensitive ecosystems, but there may be a small number of opportunities to reroute transportation facilities by building new infrastructure further inland.

Retreat. Communities may decide that maintaining transportation facilities that are regularly, or constantly, under tidal water is infeasible. Private stakeholders may take on maintenance responsibilities, or the presence of tidal water may indirectly diminish or eliminate the need for a given transportation asset (e.g. if homeowners or commercial property owners leave the area). There are complex legal issues associated with retreat that researchers and policymakers are starting to explore.

Do nothing. Communities may also choose to take no action in response to rising sea levels. In practice this approach may closely resemble retreat. Some transportation facilities may be regularly under tidal water, and resulting impacts on residents and businesses could have significant economic effects on communities

Opportunities to Use Sea Level Rise Information in Decision-Making

There are a variety of ways that the state and its cities and towns can use information about sea level rise, such as this report. There are five general ways that decision-makers and planners can utilize these data:

Spending. Transportation stakeholders are constantly working on decisions about how best to spend a fixed amount of resources on transportation projects. Through asset management programs, planners and decision-makers can determine the wisest use of maintenance dollars, taking into account the expected lifetime viability of different coastal assets. Sea level rise and other climate considerations can be included in transportation planning project selection criteria for the state Transportation Improvement Program and local Capital Improvement Programs. Finally, in generating construction and other kinds of contracts, transportation decision-makers can require that RFP/RFQ respondents or contractors consider sea level rise in their work.

Planning. There are numerous opportunities to address sea level rise through planning. The long range transportation plan (current version: *Transportation 2035*) is a logical place for the state to start exploring options for managing sea level rise while maintaining transportation functions. Local comprehensive plans are required to address natural hazards and the future land use map would be one opportunity to use maps of sea level rise data. State guide plans will also benefit from consideration of sea level rise data and other climate data. Sea level rise should also be considered in both state and local hazard mitigation plans, especially in relation to sudden hazards like coastal storms. And it would make sense to consider both sea level rise and transportation decision-making relation to proposed methods to manage coastal climate hazards, such as overlay zones, transfers of development rights, and rolling easements.

Goal Setting. Transportation and government programs have become more performance-oriented in recent years. The state and its cities and towns might consider goals for the management of sea level rise or incorporation of sea level rise into decision-making, with near-term metrics like referencing sea level rise in official plans and contracts and farther-term goals of minimizing the impact of high tide on transportation function in the state.

Communication and Capacity Building. There is a need in the state for planners, decision-makers, and citizens to build their understanding of sea level rise, the risks it poses to transportation and other aspects of life in Rhode Island, and the options that we have for managing this slow, permanent change to our coastline. Using maps and analysis specific to municipalities or individual assets helps communicate the extent of sea level rise, and other tools such as the NOAA sea level rise visualization tool CanVIS, can help people picture what sea level rise will look like. These “softer” uses of climate information are critical for building support and leadership on climate planning.

Additional Analysis. As this report documents repeatedly, there is a great need for additional analysis on individual assets and on the impact of sea level rise in conjunction with other coastal hazards like erosion and storms. These data, and the associated GIS coverage of sea level rise, are made available to any state agency or other office that wants to build upon them for further study.

Additional resources

Rhode Island is not the only area of the country studying sea level rise and its impact on infrastructure. Below is a list of other reports and publications on sea level rise and vulnerability.

- Caltrans. *Guidance on Incorporating Sea Level Rise: For Use in the Planning and Development of Project Initiation Documents*, 2011.
- Climate's Long-term Impacts on Metro Boston (CLIMB). *Infrastructure Systems, Services and Climate Change: Integrated Impacts and Response Strategies for the Boston Metropolitan Area*, 2004.
- Federal Highway Administration. *Screening Transportation Assets for Vulnerability: Impacts of Climate Change and Variability on Transportation Systems & Infrastructure*, 2012.
- ICLEI-Local Governments for Sustainability USA. *Sea Level Rise Adaptation Strategy for San Diego Bay*, 2012.
- North Jersey Transportation Planning Authority. *Climate Change Vulnerability and Risk Assessment of New Jersey’s Transportation Infrastructure*, 2011.
- Oregon Department of Transportation. *ODOT’s Climate Change Adaptation Strategy Report*, 2012.
- Rhode Island Sea Grant. *Adaption to Natural Hazards & Climate Change in North Kingstown, Rhode Island*, 2014 [DRAFT].

- The San Francisco Bay Conservation and Development Commission. *Adapting to Rising Tides Transportation Vulnerability and Risk Assessment Pilot Project*, November 2011.
- Southeast Florida Regional Climate Change Compact. *Analysis of the Vulnerability of Southeast Florida to Sea Level Rise*, 2012.
- Wilmington Area Planning Council. *Sea-Level Rise: A Transportation Vulnerability Assessment of the Wilmington, Delaware Region*, 2011.

Appendices

Appendix 1. Map Atlas

Maps for the state and municipalities are available as PDF map atlases or as an interactive arcgis.com page at http://www.planning.ri.gov/geodeminfo/data/slr.php.

Appendix 2. Summary Tables of Exposed Assets by City and Town

Barrington

	At 1 foot SLR		At 3 feet SLR		At 5 feet SLR	
Roads	211	Ft.	1.5	miles	5.9	miles
Local Roads	92	Ft.	.81	miles	2.65	miles
NHS Roads	31	Ft.	389	Ft.	1.7	miles
RIPTA Routes	31	Ft.	389	Ft.	1.7	miles
Bike Infrastructure	25	Ft.	69	Ft.	496	Ft.

Total Bridges of Concern	6
Freeboard Height Concern	5
Accessibility Concern	4

Bristol

	At 1 foot SLR		At 3 feet SLR		At 5 feet SLR	
Roads	75	Ft.	1.2	miles	3.6	miles
NHS Roads	0	Ft.	.11	miles	.38	miles
Local Roads	15	Ft.	.43	miles	1.8	miles
RIPTA Routes	0	Ft.	.11	miles	.38	miles
Intermodal Hub	1	Ft.	1	Ft.	1	Ft.
Bike Infrastructure	74	Ft.	.37	miles	.55	miles
Ports & Harbors	.34	acres	0.8	acres	2.4	acres

Total Bridges of Concern	6
Freeboard Height Concern	5
Accessibility Concern	6

Charlestown

	At 1 foot SLR		At 3 feet SLR		At 5 feet SLR	
Roads	.25	miles	3.1	miles	7.1	miles
Local Roads	.21	miles	2.9	miles	6.7	miles

Total Bridges of Concern	1
Freeboard Height Concern	1
Accessibility Concern	1

Cranston

	At 1 foot SLR		At 3 feet SLR		At 5 feet SLR	
Roads	9	Ft.	16	Ft.	.22	miles
NHS Roads	9	Ft.	9	Ft.	9	Ft.
Local Roads	0	Ft.	6	Ft.	.22	miles
Bike Infrastructure	16	Ft.	16	Ft.	16	Ft.

East Greenwich

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	0 Ft.	258 Ft.	.28 miles
Local Roads	0 Ft.	40 Ft.	259 Ft.
Bike Infrastructure	0 Ft.	.11 miles	.37 miles
Ports & Harbors	.15 acres	.75 acres	1.5 acres

East Providence

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	13 Ft.	135 Ft.	.57 miles
NHS Roads	0 Ft.	0 Ft.	.13 miles
Local Roads	0 Ft.	40 Ft.	.13 miles
RIPTA Routes	0	0 Ft.	.13 miles
Bike Infrastructure	231 Ft.	.40 miles	1.0 miles
Ports & Harbors	1.7 acres	4.4 acres	10.7 acres

Total Bridges of Concern	7
Freeboard Height Concern	4
Accessibility Concern	7

Jamestown

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	0 Ft.	.67 miles	1.8 miles
Local Roads	0 Ft.	.38 miles	1.9 miles
RIPTA Routes	0	.58 miles	1.2 miles
Intermodal Hub	0	1	1

Total Bridges of Concern	2
Freeboard Height Concern	2
Accessibility Concern	1

Little Compton

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	.15 miles	.73 miles	1.3 miles
Local Roads	.15 miles	.69 miles	1.0 miles
Ports & Harbors	.05 acres	.25 acres	.57 acres

Middletown

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	49 Ft.	.56 miles	miles 1.9
NHS Roads	0 Ft.	0 Ft.	9 Ft.
Local Roads	49 Ft.	.48 miles	miles 1.4

Total Bridges of Concern	3
Freeboard Height Concern	2
Accessibility Concern	3

Narragansett

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	.31 miles	3.8 miles	9.5 miles
NHS Roads	0 Ft.	.34 miles	1.7 miles
Local Roads	.24 miles	2.3 miles	5.6 miles
RIPTA Routes	0 Ft.	.95 miles	3.3 miles
Intermodal Hub	0	1	1
Bike Infrastructure	12 Ft.	.34 miles	1.4 miles
Ports & Harbors	1.0 acres	8.3 acres	25.3 acres

Total Bridges of Concern	3
Freeboard Height Concern	1
Accessibility Concern	3

New Shoreham

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	57 Ft.	.37 miles	1.8 miles
Local Roads	0 Ft.	.20 miles	.5 miles
Intermodal Hub	0	0	1
Ports & Harbors	.24 acres	.37 acres	1.8 acres

Total Bridges of Concern	2
Freeboard Height Concern	2
Accessibility Concern	2

Newport

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	.34 miles	2.2 miles	9.4 miles
NHS Roads	0 miles	0 miles	1.2 miles
Local Roads	.34 miles	1.8 miles	6.4 miles
Rail	0 miles	0 miles	.61 miles
RIPTA Routes	0 miles	0 miles	1.8 miles
Intermodal Hub	1	3	4
Ports & Harbors	16,901 acres	1.8 acres	6.4 acres

Total Bridges of Concern	3
Freeboard Height Concern	2
Accessibility Concern	3

North Kingstown

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	309 Ft.	0.9 miles	3.8 miles
NHS Roads	0 Ft.	225 Ft.	.18 miles
Local Roads	232 Ft.	0.7 mile	3.2 miles
Rail	0 Ft.	0 Ft.	130 Ft.
RIPTA Routes	0 Ft.	225 Ft.	.14 miles
Bike Infrastructure	20 Ft.	108 Ft.	.33 miles
Ports & Harbors	8.8 acres	28.8 acres	141.0 acres

Total Bridges of Concern	5
Freeboard Height Concern	5
Accessibility Concern	5

Portsmouth

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	10 Ft.	1.8 miles	4.4 miles
Local Roads	10 Ft.	1.4 miles	3.4 miles
Rail	0 Ft.	25 Ft.	50 Ft.
Intermodal Hub	0	0	1
Ports & Harbors	.04 acres	.33 acres	41.03 acres.

Providence

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	151 Ft.	378 Ft.	2.1 miles
NHS Roads	0 Ft.	42 Ft.	.54 miles
Local Roads	56 Ft.	140 Ft.	1.5 miles
Rail	10 Ft.	120 Ft.	277 Ft.
RIPTA Routes	0 Ft.	221 Ft.	1.7 miles
Bike Infrastructure	5 Ft.	101 Ft.	.13 miles
Ports & Harbors	4.3 acres	8.6 acres	24 acres

Total Bridges of Concern	20
Freeboard Height Concern	20
Accessibility Concern	0

South Kingstown

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	.41 miles	2.0 miles	6.0 miles
NHS	0	0	13 Ft.
Local Roads	.40 miles	1.8 miles	4.7 miles
RIPTA Routes	0 Ft.	0 Ft.	13 Ft.
Ports & Harbors	.10 acres	.16 acres	.53 acres

Total Bridges of Concern	4
Freeboard Height Concern	4
Accessibility Concern	3

Tiverton

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	316 Ft.	0.9 miles	2.9 miles
Local Roads	74 Ft.	0.7 miles	2.4 miles
Ports & Harbors	.04 acres	.22 acres	.46 acres

Total Bridges of Concern	6
Freeboard Height Concern	4
Accessibility Concern	5

Warren

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	276 Ft.	1.0 miles	3.4 miles
NHS Roads	57 Ft.	.19 miles	.61 miles
Local Roads	219 Ft.	0.6 miles	2.2 miles
RIPTA Routes	25 Ft.	.23 miles	.56 miles
Bike Infrastructure	25 Ft.	69 Ft.	.56 miles
Ports & Harbors	.30 acres	1.7 acres	4.6 acres

Total Bridges of Concern	2
Freeboard Height Concern	2
Accessibility Concern	2

Warwick

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	.15 acres	2.2 miles	8.1 miles
NHS Roads	15 Ft.	90 Ft.	362 Ft.
Local Roads	.14 miles	2.2 miles	8.0 miles
RIPTA Routes	0 Ft.	112 Ft.	.13 miles
Bike Infrastructure	0 Ft.	.33 miles	1.2 miles

Total Bridges of Concern	5
Freeboard Height Concern	5
Accessibility Concern	1

Westerly

	At 1 foot SLR	At 3 feet SLR	At 5 feet SLR
Roads	.12 miles	4.5 miles	9.8 miles
Local Roads	429 Ft.	2.0 miles	5.9 miles

Total Bridges of Concern	2
Freeboard Height Concern	0
Accessibility Concern	2

Appendix 3. Inventory of Exposed Transportation Assets by City and Town

A complete inventory of all transportation assets projected to be inundated by 1, 3, or 5 feet of sea level rise is available as an Excel spreadsheet at http://www.planning.ri.gov/geodeminfo/data/slr.php.

Appendix 4. Full Vulnerability Methodology

Each asset category has a separate vulnerability methodology. Each vulnerability index sought to balance both the physical impact of sea level rise (e.g. extent of flooding, height of asset) with social impact indicators (e.g. use level, ridership). The indicators used, the scoring rubric, and the relative weightings are included in the table below.

Asset Type	Indicator	Type	Source	Weight	Numeric Assignments (1-10)
RIPTA	Frequency	Social Impact	RIPTA_Routes_2014Jan	0.15	Under 50 = 0, 50-250 = 2, 250-400 = 6, 400+ = 10
RIPTA	Ridership	Social Impact	April14 Ridership Data	0.2	Under 20,000 = 0, 20-100,000 = 2, 100K-200K = 6, 200K+ = 10
RIPTA	SLR Zone	Hazard	SLR Project, RIPTA routes	0.2	1 foot = 10, 3 feet = 6, 5 foot = 2
RIPTA	Stops Flooded 3 feet	Hazard	Jan13BusStopActivity	0.15	0 = 0, 1 stop = 2, 2 stops = 4, 5 stops = 10
RIPTA Routes	Stops Flooded 5 Feet	Hazard	Jan13BusStopActivity	0.15	0 stops = 0, 1 stop = 2, 4-5 stops = 4, 6-7 stops = 6, 8-20 stops = 8, 20+ stops = 10
RIPTA	shapelength 5 feet	Hazard	RIPTA_Routes_2014Jan	0.15	
RIPTA	SLR Zone	Hazard	Jan13BusStopActivity	0.4	1 foot = 10, 3 feet = 6, 5 foot = 2
RIPTA	Avg Weekday	Social Impact	Jan13BusStopActivity	0.3	Less than 10 = 3, 10-50 = 7, 50+ = 10
RIPTA	# of lines served	Social Impact		0.3	1 line = 2, 2 lines = 4, 3 lines = 6, 4 lines = 8, 5 lines = 10
Bike	SLR Zone	Hazard	2013 Bike Path Data (SPP)	0.2	1 foot = 10, 3 feet = 6, 5 foot = 2
Bike	Off-road	Social Impact	2013 Bike Path Data (SPP)	0.2	Path = 10, bike lane = 5, on street = 0
Bike	Shape length 1 foot	Hazard	2013 Bike Path Data (SPP)	0.2	1-10 feet = 3, 10-100 feet = 7, 100+ feet = 10
Bike	Shape length 3 foot	Hazard	2013 Bike Path Data (SPP)	0.2	1-100 feet = 3, 100-500 feet = 7, 500+ feet = 10
Bike	Shape length 5 foot	Hazard	2013 Bike Path Data (SPP)	0.2	1-150 feet = 3, 150-2000 feet = 7, 2000+ feet = 10
Airports	Inundated by SLR	Hazard	ActiveAirports	Qualitative	
Airports	State/private/use	Social Impact		Qualitative	
Intermodal	SLR Zone	Hazard	SLR Scenario	0.5	1 foot = 10, 3 feet = 6, 5 foot = 2
Intermodal	Road Alternative	Social Impact		0.2	Yes or '1' = 0; No or '0' = 10
Intermodal	Seasonal vs year-	Social Impact		0.3	Yes or '1' = 0; No or '0' = 10
Roads	SLR Zone	Hazard	SPP, based on RIDOT Roads	0.3	
Roads	Shape length 1 foot	Hazard	SPP, based on RIDOT Roads	0.1	0-15 feet = 3, 15-100 feet = 7, 100+ feet = 10
Roads	Shape length 3 foot	Hazard	SPP, based on RIDOT Roads	0.1	0-100 feet = 3, 100-800 feet = 7, 800+ feet = 10
Roads	Shape length 5 foot	Hazard	SPP, based on RIDOT Roads	0.1	0-500 feet = 3, 500-1500 feet = 7, 1500+ feet = 10
Roads	Func Class	Social Impact	SPP, based on RIDOT Roads	0.3	See table below

Asset Type	**Indicator**	**Type**	**Source**	**Weight**	**Numeric Assignments (1-10)**
Roads	Evacuation Route	Social Impact	Hevac (RIDOT)	0.1	Yes = 10, No = 0
Bridges	Note: subset is owner or custodial = state				
Bridges	Freeboard	Hazard	RIDOT Bridge Inspection	0.25	Freeboard problem or unknown = 10; No problem = 0
Bridges	Access	Hazard	SPP Analysis of Maps	0.2	Access problem = 10; no problem = 0
Bridges	Very low freeboard	Hazard	RIDOT Bridge Inspection	0.1	<40" = 10; 41-75"=6, more than 75" = 2
Bridges	Over MHHW	Hazard	SLR Scenario	0.2	Yes = 10; No = 0
Bridges	Carries road facility	Social Impact	SPP Analysis	0	Carries road facility = 10; other = 0
Bridges	AADT	Social Impact	RIDOT	0.25	0-1 = 0, 2-5000 = 3, 5000-15000 = 7, 15000+ = 10

Appendix 5. Vulnerability of All State Roads

Full vulnerability listing for roads under state jurisdiction is available as an Excel spreadsheet at http://www.planning.ri.gov/geodeminfo/data/slr.php.