RHODE ISLAND COSTAL RESOURCES MANAGEMENT COUNCIL
SHORELINE CHANGE SPECIAL AREA MANAGEMENT PLAN (SAMP)

SHORELINE CHANGE SAMP

· VOLUME 1 – JUNE 2018 ·

The Rhode Island Coastal Resources Management Council proudly dedicates this Shoreline Change ("Beach") Special Area Management Plan to

Dr. Jon C. Boothroyd

Jon worked closely with the Coastal Resources Management Council (CRMC) as a mentor to staff scientists, imparting his knowledge and passion for geology, which can be found infused throughout the CRMC's Coastal Program and plans. For this reason alone, Jon has left a large footprint on the Rhode Island coastline. Jon was a measured, consistent, and knowledgeable advocate for Rhode Island's shoreline and he is greatly missed in this role and a friend to the CRMC program.

Jon dedicated himself to his research and equally important passing on his knowledge and love of geological processes through his many students. What set Jon apart from many other scientists was his desire and ability to make himself available to the public to pass that knowledge on to those outside of academia. He was remembered by CRMC Executive Director Grover Fugate who said Jon was, "…constantly imparting his knowledge, and he was always an educator. He was always willing to talk to any audience, and that was a hard skill to replicate."

He left a mark at CRMC, contributing to the Salt Ponds and Narrow River SAMPs, and consistently dedicated many more hours to the Beach SAMP and other CRMC initiatives than grant funding would support.

Jon C. Boothroyd, known to many in the local scientific community simply as 'JCB' passed away at home on the 15th of October, 2015 at the age of 77.

Read more about the life, research, and many contributions of Jon Boothroyd at:
https://web.uri.edu/cels/celebrating-jon/

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Rhode Island Shoreline Change Special Area Management Plan (Beach SAMP) Volume I

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A management program of the Rhode Island Coastal Resources Management Council

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Rhode Island Shoreline Change Special Area Management Plan

VOLUME 1

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3. Assessing Coastal Hazard Risk

4. Rhode Island's Exposure to Coastal Hazards

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CHAPTER 1

Introduction

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1.1 Vision, Purpose, and Context of the Shoreline Change Special Area Management Plan

1. The coastline of Rhode Island is one the state's most iconic and treasured assets. The 420 miles of barrier beaches, historic waterfronts, bluffs, headlands and salt marsh make Rhode Island the 'Ocean State' and give rise to major sectors in the state's economy including tourism and marine trades.

2. It is the Rhode Island Coastal Resources Management Council's responsibility to ensure that decisions made concerning Rhode Island's coastline are well thought out and based on the best available science. **Toward that end, the vision of the Rhode Island Shoreline Change Special Area Management Plan (SAMP) is to provide guidance and tools for state and local decision makers to prepare and plan for, absorb, recover from, and successfully adapt to the impacts of coastal storms, erosion, and sea level rise**.

3. The Shoreline Change SAMP is a collaborative effort between the state's coastal agency, the CRMC, and a University of Rhode Island (URI) team comprised of both researchers from the College of the Environment and Life Sciences [CELS], the Graduate School of Oceanography, the College of Engineering, and outreach experts from the Coastal Resources Center/Rhode Island Sea Grant College Program [CRC/Sea Grant]. Invaluable expertise is also provided by Roger Williams Law School's Marine Affairs Institute, the Rhode Island Sea Grant Legal Program, and Eastern Connecticut State University. Close collaboration with other state agencies and coastal municipalities is also a key component of the Shoreline Change SAMP. This collaboration ensures that cutting-edge science informs an inclusive policy development process focused on practical solutions and outcomes.

4. Because planning for storms, erosion, and sea level rise is so closely tied to land use decision making at the local level, the research, tools and strategies presented in the Shoreline Change SAMP were developed with coastal municipalities and state agencies in mind. The Shoreline Change SAMP has been designed purposefully to be a guidance and planning document rather than a more prescriptive regulatory document with explicit policies, regulations or standards, in order to provide the flexibility to local and state decision makers on the frontline in protecting the health and welfare of their residents, to identify strategies most appropriate for a specific community.

5. The guidance offered by this Shoreline Change SAMP is primarily for applicants seeking coastal permits from CRMC. CRMC is proposing a requirement that coastal permit applicants complete a five-step risk assessment process for proposed developments within CRMC's jurisdiction as part of the permit application.

6. Other audiences for this SAMP, in addition to CRMC members, staff, and coastal permit applicants, are decision makers, planners, boards and commissions in Rhode Island's 21 coastal communities who are principally responsible for coping with the impacts of storms, coastal erosion, and sea level rise outside of CRMC's jurisdiction. The Shoreline Change SAMP is also intended to aid other state and federal agencies responsible for coastal resources, assets and property in Rhode Island in future planning and decision making.

7. Rhode Island's coastline is continuously shaped by storms, erosion, and tidal inundation. As the climate changes, the impacts of these natural coastal processes and hazards are increasingly threatening coastal properties, infrastructure, and social, cultural and environmental assets throughout the state.

8. Rhode Island has long been a leader in innovative thinking and the successful management of its most prized coastal features and resources. While coastal resilience has now become a modern day buzz word following major storm events such as Hurricane Katrina in 2005 and Hurricane ("Superstorm") Sandy in 2012, resilience has long been a part of the fabric and tradition of Rhode Island. One only has to look back to Rhode Island's history in colonial times to see examples of innovation in policy and technology, or to the recovery from the Great Hurricane of 1938 to see the resilience of Rhode Islanders and the coastal communities and ecosystems that make up the state.

9. Dynamic storm events can highlight the damaging impacts of storm surge and flooding on coastal communities, the migratory nature of the coastal barriers along Rhode Island's southern coast, and the importance of preparedness and planning at both the state and local level to expedite recovery. For example, Superstorm Sandy, a hybrid tropical/extratropical storm that made landfall in October 2012, affected the Rhode Island coastline with several days of storm surge and waves but very little rainfall. National Ocean Service tide gauges reported storm surges of 5.3ft and 6.2ft in Newport and Providence respectively, with maximum sustained winds of 64 mph (56kts) and gusts from 81-86mph (70-75kts) (National Hurricane Center, 2013). The damage was felt heavily across the southern coast of the state from Narragansett to Westerly. Ultimately, this storm affected approximately 300,000 Rhode Island residents (28% of the state's population); resulted in over $12.6 million in requested public assistance

from the Federal Emergency Management Agency; and $24 million in claims to the National Flood Insurance Program just for damage in Washington County (RI Office of Housing and Community Development, 2013). However, despite the damage along the south shore, this storm wasn't a hurricane or even a once in 100-year (1% annual chance) storm event when it made landfall in Rhode Island, rather it was a once in 25-year storm (4% annual chance) event for Westerly, and a much less intense storm event for the rest of the state. Had this storm been a hurricane or a 1% annual chance storm event, impacts would have much greater.

10. Tide gauge observations in Newport indicate a rate of 10.8 inches (27.4 cm) of relative sea level rise over the last century or 2.74 mm per year[1]. However, the rate of sea level rise globally and in Rhode Island specifically is accelerating. The CU Sea Level Research Group reports current satellite altimetry measurements of the rate of global sea level rise of 3.3 +/-0.4 mm per year since 1993. Relative sea level rise in Rhode Island measured more than 4 millimeters per year between 1983 and 2009 (Carey et al. 2015). Since the start of this Shoreline Change SAMP effort in 2012, NOAA's sea level rise projections have changed several times. In 2015, NOAA projected the range in sea level rise above 1990 levels to be a maximum of approximately 1 foot by 2035, 2 feet by 2050, and 7 feet by 2100.[2] Currently, NOAA's 2017 "high curve" projections for Newport, Rhode Island suggest that by 2100 sea levels may rise as much as 10 feet above 1990 levels.[3]

11. Looking forward, as sea level rises both hurricanes and "nor'easters" will be more damaging, and the flooding effects will be felt farther inland. Storm surge and wave heights will increase as sea level rises resulting in more properties being damaged or destroyed during a storm, including inland properties that have never before experienced flood damage. Furthermore, not only will the extent of flooding expand and storm surge levels rise during storm events like "Superstorm" Sandy, but more areas will be affected by high tides on a daily basis. Frequent tidal inundation of coastal properties, roadways and parking lots is already an issue in many coastal communities in Rhode Island from Watch Hill, to Wickford, to Warren and Providence.

12. The state's coastal wetlands are highly vulnerable to accelerating sea level rise; essentially they are drowning in place. Permanent flooding of Rhode Island's wetlands is

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[1] NOAA Tide Gauge Data for Newport, RI: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8452660

[2] These planning horizons have been proposed to be included in CRMC's Climate Change and Sea Level Rise Policy (Section 145 of the Coastal Resources Management Program (a.k.a. Red Book).

[3] U.S. Army Corps of Engineers and NOAA Sea Level Rise Curves http://www.corpsclimate.us/ccaceslcurves.cfm

already occurring, as these wetlands cannot gain sufficient elevation to keep up with sea level rise. This trend will continue into the future causing significant loss of habitat for fish, shellfish, birds, and other wildlife, and recreation areas. The loss of coastal wetlands also means a loss of the protection they provide to coastal communities as an important natural barrier to storm surge. In addition, the loss of coastal wetland will reduce the overall carbon storage potential of these ecosystems and result in an increased contribution of CO^2 concentrations to the atmosphere. A recent statewide analysis of sea level rise impacts to salt marshes conducted by CRMC and partners estimates a 52% and 87% loss in existing salt marsh with three and five feet of sea level rise, respectively. Therefore, it is imperative that state and local planning and adaptation efforts start now (see Technical Report #1 in Volume 2 for more information).

13. The Shoreline Change SAMP offers adaptation strategies that coastal permit applicants and the other audiences listed above can consider during the planning and design development phase of their project to protect their assets, accommodate changing coastal conditions, or relocate/retreat from high hazard areas in changing coastal areas.

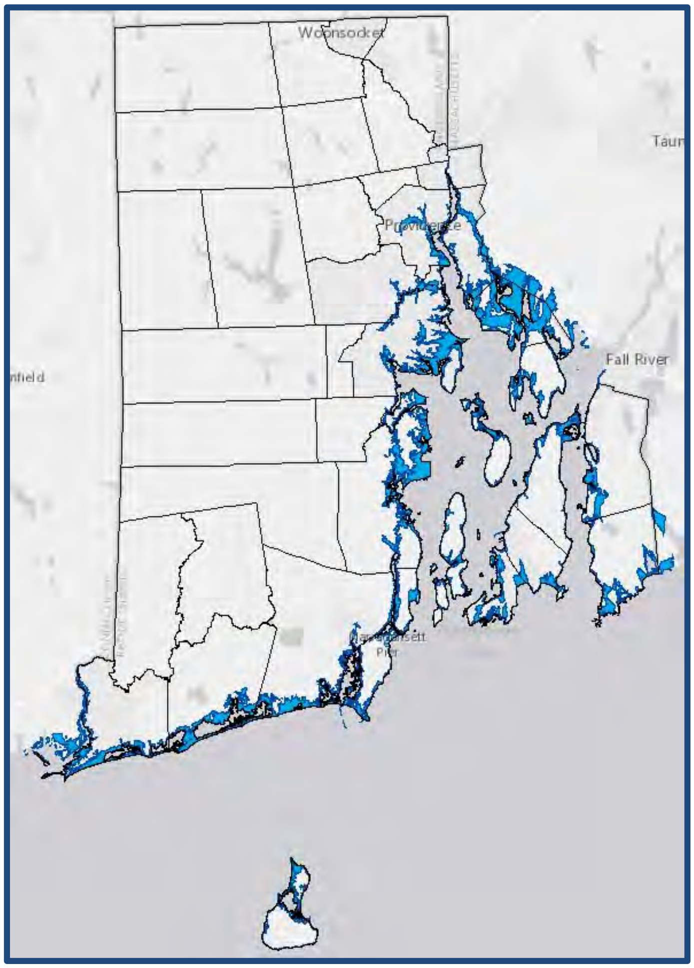

Figure 1. Shoreline Change SAMP Planning Boundary

1.2 The Shoreline Change SAMP Scope and Project Boundary

1. This SAMP is focused on the coastal effects of rising sea levels and the increased frequency and severity of coastal storm events. Other climate change impacts caused by increased precipitation, riverine flooding, heat, etc. are not addressed in

this document.

2. The study area for this SAMP encompasses the entire coastal zone of Rhode Island and all 21 coastal communities impacted by sea level rise, storm surge and tidal flooding, as well as coastal erosion. The planning boundary for the Shoreline Change SAMP was identified through the development and application of STORMTOOLS, a cloud-based online mapping tool that illustrates various storm surge and sea level rise scenarios for all 420-miles of Rhode Island's Coastline. Because CRMC adopted the NOAA High Curve in 2016 as its reference for future sea level rise projections, CRMC has defined the Shoreline Change SAMP Planning Boundary as the 7-feet of sea level rise with a 100-year return period storm event, which can be equated to the water levels documented in Rhode Island during 1954's Hurricane Carol. For more information on sea level rise data, see Section 1.1.5.

3. CRMC's jurisdiction does not cover all the land area within the Shoreline Change SAMP Planning Boundary. For this reason, the Shoreline Change SAMP also includes recommendations and guidance to assist other state agencies and municipal governments with decision making for high hazard coastal areas that are out of CRMC's jurisdiction.

1.3 Goals and Principles of the Shoreline Change SAMP

1. **The Rhode Island Shoreline Change SAMP provides state and local decision makers with information, guidance and a suite of tools to assess, plan for, recover from and adapt to the impacts of coastal storms and sea level rise.** To accomplish this goal, new data and information will be collected and modeled to illustrate areas, resources and infrastructure that may be impacted under different storm and sea level rise scenarios. Planning tools, adaptation strategies and best practices relevant to Rhode Island will be compiled and shared to inform state and local decision making. Tailored technical assistance will be provided to the maximum extent possible to local and state officials to assist in the implementation and use of the information, guidance and tools developed through this SAMP.

2. **Provide a forum for public discourse on current and future impacts and how best to adapt to the short and long-term impacts of coastal storm events and rising tide levels**. The Rhode Island Shoreline Change SAMP stakeholder process will be designed so that information can be shared on how sea level rise, storm events and coastal

erosion will impact the people, places and resources in Rhode Island. In addition, this public forum will provide an avenue for two-way exchange of ideas and concerns regarding adaptation, planning and response to these impacts at both the state and local level.

3. **The Rhode Island Shoreline Change SAMP informs revisions to the policies and standards in the Rhode Island Coastal Resources Management Program and existing CRMC SAMPs to better address the risks posed by erosion, coastal storms and sea level rise.** The Shoreline Change SAMP research, tools and stakeholder process will provide the scientific evidence, background information, and best practices to support updates to Rhode Island's coastal policies aimed at increasing coastal resilience throughout the State.
4. **Minimize the impacts of coastal hazards through proactive planning.** Following the federal mandate set forth in the Coastal Zone Management Act, the development of the Shoreline Change SAMP will aim to provide guidance on how to minimize the impacts and consequences caused by improper development in areas at risk to coastal hazards including erosion, storm surge and sea level rise. Guidance will be focused on reducing damage and supporting wise investments in sustainable coastal development
5. **Maximize the protection of public access, recreation and sensitive coastal resources**. Guidance developed through the Shoreline Change SAMP will consider how public access, recreation and sensitive coastal resources will be impacted by coastal hazards and how planning, development standards, adaptation strategies, or policies can protect or minimize negative impacts.

Guiding Principles of the Shoreline Change SAMP

- Serve as a guidance document to support regulatory changes (CRMC policy and standards), and any regulatory changes will be made to the Red Book and other existing SAMPs;
- Be developed in a transparent manner;
- Use best science available to understand changing conditions of Rhode Island's shoreline and help develop appropriate strategies for response;
- Consider synergistic long-range impacts over time of sea level rise, coastal storms, and erosion;
- Incorporate risk identification and awareness in design and development;
- Identify early actions and recommended strategies to monitor, evaluate, and readjust;
- Encourage incremental phasing of adaptation strategies and actions, and keep flexibility in the system;
- Maximize agency coordination and public participation; and
- Emphasize "No Regrets" decisions.

1.4 Contents of Shoreline Change SAMP Document

1. The Shoreline Change SAMP is comprised of two volumes. Volume 1 provides: a synthesis of the current scientific understanding of sea level rise, storm surge, tidal flooding, and coastal erosion, as well as the impacts these hazards pose to infrastructure, other developed property such as municipal buildings and residential properties, and the social, environmental and cultural assets in Rhode Island; a description of the tools developed to model and map potential future impacts from these coastal hazards; a discussion of risk and risk management within the coastal zone; and recommendations for best management practices and adaptation strategies or techniques to be employed at both the state and local level to minimize future risk. Volume 2 contains all the technical reports that support the new research conducted as part of the SAMP project. These technical reports contain more detailed information on research methodology and findings and ultimately support the synthesis provided in Volume 1.

2. Volume 1 of the Shoreline Change SAMP contains the following chapters:

    - ***Chapter 1- Introduction***: This chapter outlines the purpose and structure of Shoreline Change SAMP.

    - ***Chapter 2- Trends and Status: Current and Future Impacts of Coastal Hazards***: This chapter summarizes the best available science on coastal erosion, storm and sea level rise trends in Rhode Island.

    - ***Chapter 3 Assessing Coastal Hazard Risk***: The purpose of this chapter is to define coastal risk, resilience & related terms, present future planning scenarios that illustrate risk from storm events with projected sea level rise, and present the various mapping and modeling tools developed as part of the Shoreline Change SAMP to aid planning and decision making.

    - ***Chapter 4 Rhode Island's Exposure to Coastal Hazards -*** This chapter summarizes how current and future coastal hazards may impact infrastructure, property, and the social, environmental and cultural assets in Rhode Island.

    - ***Chapter 5- RI CRMC Coastal Hazard Application Guidance.*** This chapter presents a five-step process for how CRMC intends to require coastal development permitting applications to consider the impacts of current and future coastal hazards.

- ***Chapter 6- State and Municipal Considerations:*** The purpose of this chapter is to provide guidance on how to incorporate coastal hazards into state agency and municipal planning and decision making.

- ***Chapter 7- Adaptation Strategies & Techniques:*** The focus of this chapter is on presenting an array of best management practices to improve state and local planning and decision making with respect to shoreline change and coastal hazards. In addition, physical adaptation techniques, retrofits and structural design considerations are also discussed.

- ***Chapter 8- Future Research Needs:*** This final chapter summarizes the data gaps and research needs identified throughout the Shoreline Change SAMP process.

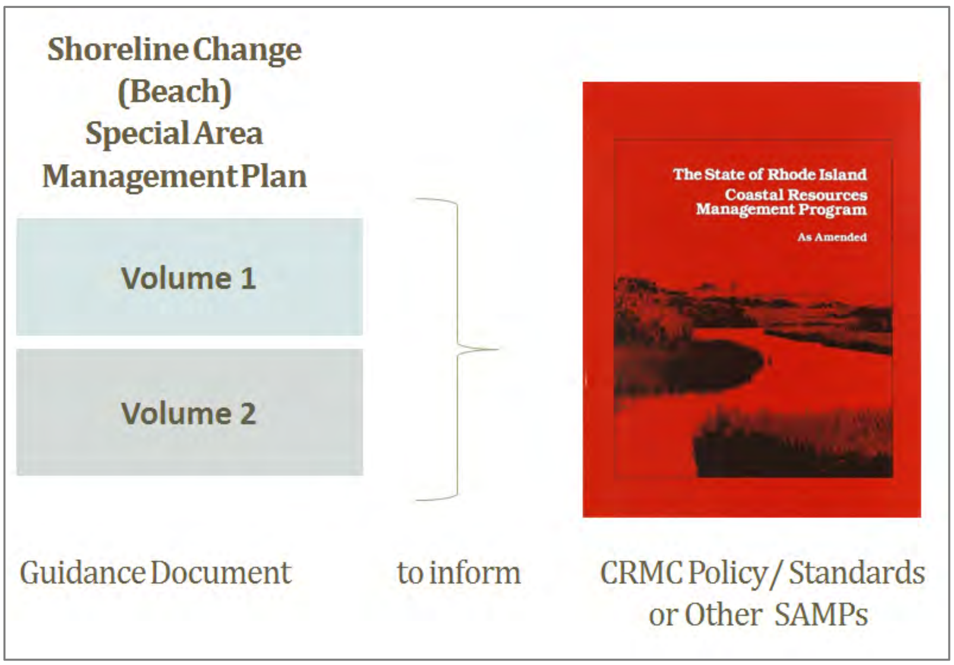

Figure 1. The Shoreline Change SAMP will be a guidance document that is used to inform regulatory changes to the Rhode Island Coastal Resources Management Program.

3. All new or revised CRMC policies and standards concerning sea level rise, storm events and erosion developed through the Shoreline Change SAMP process will be made directly to the RICRMP (also referred to as the Red Book) or existing SAMP policies and standards (see Figure 1). As a result, there will not be a section or chapter within Volume 1 of the Shoreline Change SAMP that lists new policies.

1.5 References

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U.S. Army Corps of Engineers and NOAA Sea Level Rise Curves. Available online at: http://www.corpsclimate.us/ccaceslcurves.cfm

CHAPTER 2

Trends and Status: Current and Future Impacts of Coastal Hazards in Rhode Island

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2.1 Overview

1. The purpose of this chapter is to provide a brief synopsis of the scientific basis underlying the Shoreline Change Special Area Management Plan. The Shoreline Change SAMP is focused on three sources of coastal hazard risk: **storm surge**, **coastal erosion**, and **sea level rise**. Whereas Rhode Island coastal communities have been grappling with these sources of risk for some time, our changing climate is exacerbating these sources of risk. This has driven the CRMC to develop the Shoreline Change SAMP in order to help coastal property owners and state and local decision-makers plan for changing future conditions. The science in this chapter provides a foundation for this document by characterizing trends in our changing climate and describing how those trends are influencing sources of coastal hazard risk.

2. This chapter is not intended to be an exhaustive discussion of the science of climate change, nor of all of the coastal and other hazards which may be influenced by climate change. These areas of science are complex and rapidly changing. Given this dynamism, CRMC chose to develop this chapter as a brief summary that is designed for ease of updating in the future as new data are available.

3. This chapter includes a brief summary of the most updated science available on these topics. It includes a brief, general discussion of the trends associated with climate change that are most relevant to changing conditions on Rhode Island's coast, as well as a summary of the physical effects associated with these trends, both globally and regionally. Discussion is narrowly focused on changing conditions on Rhode Island's coast and in particular on the three sources of coastal hazard risk, in order to retain a focus on the structures within the coastal zone that are under CRMC's jurisdiction and exposed to these sources of coastal hazard risk. The chapter concludes with discussion of future research needs related to these topics.

4. This chapter does not include detailed discussion about the exposure of Rhode Island's coastal communities and coastal resources to storm surge, coastal erosion and sea level rise. Please see Chapter 4 for a detailed discussion of Rhode Island's exposure.

5. CRMC recognizes that its policy and planning horizons will need to be regularly updated into the future as the science changes. CRMC's sea level rise policy is formulated to address the dynamic nature of this science. CRMC policy, as reflected in Section 145 of the RICRMP, relies upon the "high" sea level change curve included in the most recent NOAA sea level rise (SLR) data. The latest "high" curve can be viewed using the U.S. Army Corps of Engineers (USACE) Sea Level Change Curve Calculator at http://www.corpsclimate.us/ccaceslcurves.cfm. This allows CRMC to always base policy

decisions on the most recent SLR projections. CRMC expects to update the Shoreline Change SAMP document, planning tools and analyses on an ongoing basis, using the most recent SLR scenarios, as resources allow.

6. Further, coastal conditions are rapidly changing. In late 2017, three hurricanes – Harvey, Irma, and Maria – hit U.S. coastal communities in rapid succession. These three hurricanes are now among the top five most expensive hurricanes in U.S. history (NOAA National Hurricane Center 2018; NOAA National Centers for Environmental Information 2018). Further, the intensity of these three storms is consistent with scientific predictions that climate change would result in the increasing intensification of storms (see e.g. Sneed 2017).

2.2 Trends

2.2.1 Sea Level Rise

2.2.1.1 Historic Sea Level Rise

1. Sea levels are rising, caused by rising sea temperatures, which causes thermal expansion, and rising air temperatures, which causes melting glaciers and ice sheets.

2. **Sea levels have risen**, both in Rhode Island and around the world. In Rhode Island, sea levels have risen over 10 inches (0.25 meters) since 1930, as measured at the Newport tide gauge. The historic rate of SLR at this gauge, measures from 1930 to 2017, is 0.11 inches (2.75 mm) a year. This is equivalent to a change of 10.8 inches (0.27 meters) in 100 years (NOAA n.d.; see also RI EC4 STAB 2017). Rhode Island's rate of SLR is slightly higher than global SLR statistics. Global mean SLR rose by 7.48 inches (0.19 meters) between 1901 and 2010, at an average rate of 0.07 inches (1.7 mm) a year (Intergovernmental Panel on Climate Change (IPCC) 2014). See Table 1 for a summary of these data.

3. **Sea level rise is accelerating**, both in Rhode Island and globally. In Rhode Island, the mean annual rate of SLR at Newport, is 0.16 inches (3.98 mm) a year over the 30-year period of 1986-2017 (31 years) as measured by the Permanent Service for Mean Sea Level (Permanent Service for Mean Sea Level n.d.) Again, Rhode Island's recent rate of SLR is slightly higher than the global average. The rate of global mean SLR, as measured by satellite altimetry, increased over the period from 1993 to 2017 (24 years) to a rate of 0.12 inches (3.1 mm) a year (University of Colorado CU Sea Level Research Group 2018). However, short-term datasets (less than 30 years) should be used with caution, because of inherently large regression errors and the anomalous sea level increase during 2009-2010 due to a slowdown in the Atlantic Meridonal Overturning Circulation (Goddard et al 2015). See Table 1 for a summary of these data.

Table 1. Historic sea level rise and annual SLR rates, Rhode Island and global average

	Historic sea level rise	**Annual rate of SLR**	**Annual rate – recent acceleration**
Rhode Island	10 in (0.25 m) *(1930 to 2017)*	0.11 in (2.75 mm)/yr *(1930 to 2017)*	0.16 inches (3.98 mm)/yr *(1986-2017)*
Global average	7.48 inches (0.19 m) *(1901 to 2010)*	0.07 inches (1.7 mm)/yr *(1901 to 2010)*	0.12 inches (3.1mm)/yr *(1993-2017)*

4. **Rhode Island is part of an accelerated sea level rise "hotspot."** The above statistics have shown that observed sea level rise in Rhode Island is higher than the global average. This is consistent with a regional trend along the entire North American Atlantic coast between the Canadian Maritimes and North Carolina. Sallenger et al. (2012) found that SLR in this Atlantic coast region was 3-4 times higher than the global average between 1950-1979 and 1980-2009, describing this region as a "hotspot".

2.2.1.2 Projected Sea Level Rise

1. **Further sea level rise is projected for Rhode Island**. At the time of this writing, the National Oceanic and Atmospheric Administration (NOAA) **projects up to 9.6 feet of SLR in Rhode Island by 2100**. This projection is based on NOAA's 2017 analysis of SLR scenarios, and this particular statistic is based on the "high" curve and is estimated at the 83% confidence interval. NOAA's 2017 analysis also included an "extreme" curve which projected up to 11.7 feet of SLR at the 83% confidence interval in Rhode Island by 2100. In the shorter term, the latest NOAA "high" curve

projects 1.67 feet of SLR for 2030, 3.25 feet for 2050, and 6.69 feet for 2080, all at the 83% confidence level (NOAA 2017) (see Table 2 and Figure 1).

Table 2. Sea level rise projections for Rhode Island

	2030	**2050**	**2080**	**2100**
NOAA 2017 projections based on "high curve"	1.67 feet (83% CI)	3.25 feet (83% CI)	6.69 feet (83% CI)	9.6 feet (83% CI)

2. Importantly, NOAA also provides SLR projections at the 17% and 50% confidence intervals, but CRMC has adopted the NOAA high curve at the 83% confidence interval, which represent more extreme SLR scenarios, for two reasons. First, NOAA (2017) has recommended using the "worst-case" or "extreme" scenario to guide overall and long-term risk and adaptation planning. Second, CRMC views use of worse-case scenarios as a way to hedge against the uncertainties inherent in projecting future SLR.

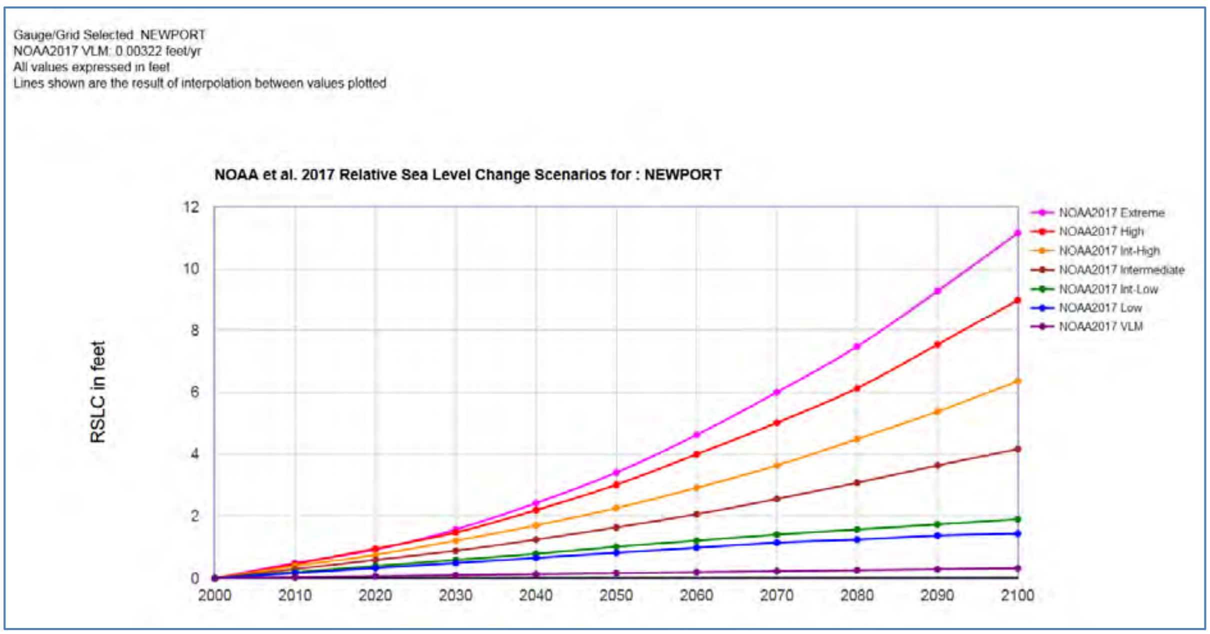

Figure 1. Relative Sea Level Change Scenarios for Newport, RI (NOAA, 2017).

3. **Sea level rise projections have changed**. Importantly, scenarios developed for the Shoreline Change SAMP document, planning tools and analyses are based on 2012 NOAA SLR analyses which projected up to 6.6 feet of SLR in Rhode Island in 2100 under the high curve. In the shorter term, the NOAA 2012 SLR scenarios predicted

0.75 feet of SLR by 2030 0, 1.9 feet by 2050, and 4.39 feet by 2080 (NOAA 2012). **Scenarios in the Shoreline Change SAMP are based on these 2012 projections because these were the best available data at the time when Shoreline Change SAMP analyses and tools were undergoing development**. CRMC plans to update Shoreline Change SAMP tools and analyses with the newest SLR projections as time and resources allow.

4. **Sea level rise projections continue to change.** Just as observed sea level rise has accelerated in recent years (see discussion above), so has the development of new sea level rise projections. Over the course of the Shoreline Change SAMP development process (2011 to 2018), three different sets of sea level rise projections have been in use. Early Shoreline Change SAMP analyses and tools began with consideration of 3- 5 feet of SLR by 2100, which was determined by a team of scientific advisors to the CRMC, based on Rahmstorf 2007 and Rahmstorf et al. 2011, and was incorporated into CRMC policy (see RICRMP section 1.1.10). NOAA's 2012 SLR scenarios offered new projections of up to 6.6 feet of SLR by 2100 under the high curve, and NOAA's most recent 2017 SLR scenarios offered newer projections of up to 9.6 feet of SLR under the high curve and the 83% confidence interval. See Figure 2 for a comparison of 2012 and 2017 SLR projections. This rapid succession of SLR scenarios illustrates the rapidly changing nature of the science and the need for policymakers to be prepared to absorb and incorporate new data and science on these sources of coastal hazard risk.

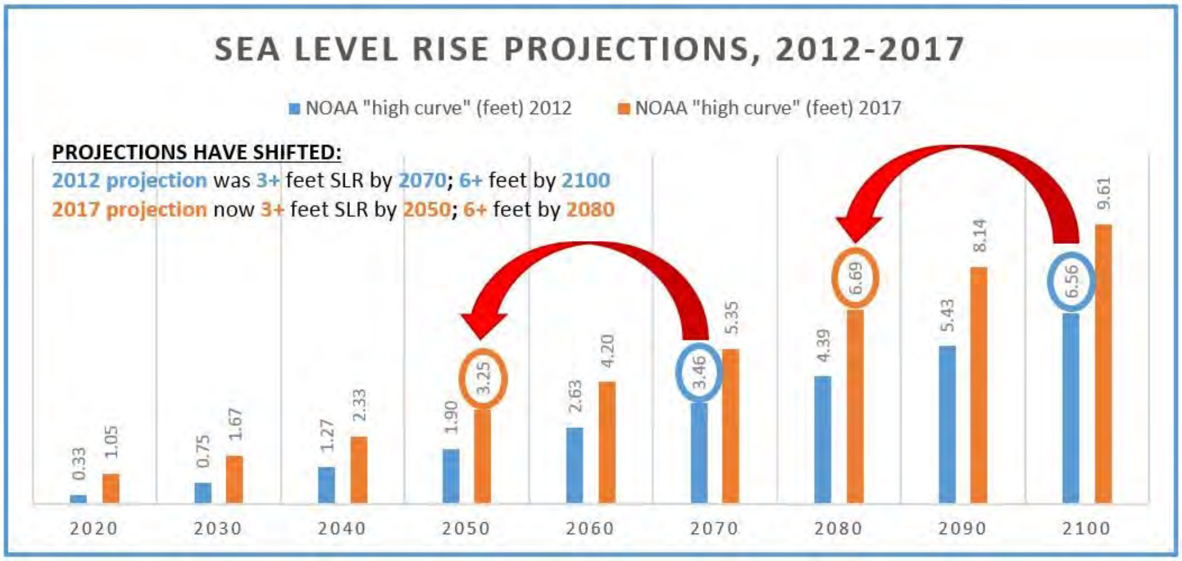

Figure 2. Comparison of NOAA 2012 and NOAA 2017 SLR projections (data sources: NOAA 2012; NOAA 2017)

5. **CRMC has adopted the NOAA high curve**. The CRMC has adopted the NOAA "high curve" at the 83% confidence interval as the foundation of its sea level rise policy as reflected in the Shoreline Change SAMP as well as the RICRMP. CRMC has adopted NOAA's SLR scenarios as foundational to the Shoreline Change SAMP because NOAA, as the nation's leading ocean and atmospheric science agency, has a wealth of experience and longstanding credibility in performing cutting-edge research using high-tech instrumentation to understand and predict changes in climate, weather, oceans, and coasts. CRMC has adopted the high curve and 83% confidence interval, a worse-case scenario, for two reasons. First, NOAA (2017) has recommended using the "worst-case" or "extreme" scenario to guide overall and long-term risk and adaptation planning. Second, CRMC views use of worse-case scenarios as a way to hedge against the uncertainties inherent in projecting future SLR.

6. **CRMC has adopted the U.S. Army Corps of Engineers Sea Level Change Curve Calculator**. The CRMC has also adopted the USACE's sea level change curve calculator for use in identifying and plotting sea level change scenarios. This online calculator offers a simple way for decision-makers to view, for themselves, the latest SLR scenarios and to view short, mid, and long-range SLR projections in both graph and table form. The CRMC has adopted this calculator because of ease of access and use, both for state and local decision-makers and individual coastal property owners. The calculator here: http://www.corpsclimate.us/ccaceslcurves.cfm.

2.2.2 Storm Intensity

1. **Hurricanes and tropical storms *may* be impacted by a changing climate.** The physics driving climate are complex, making it difficult to determine how a changing climate will affect hurricanes and other tropical storms (RI EC4 STAB 2016). Whereas rising sea surface temperatures associated with climate change could influence the frequency and strength of such storms, other effects, such as increasing upper troposphere temperature and vertical wind shear, are detrimental to storm development and intensification (see NOAA GFDL 2018 and the sources cited therein).

2. **The extent to which climate change has affected hurricanes and other tropical storms is unclear**. A recent research review by the NOAA Geophysical Fluid Dynamics Laboratory concluded that it is premature to conclude that climate change has had a detectable impact on Atlantic hurricanes and tropical storms. However, NOAA notes that changes may already be occurring but are undetectable due to observational limitations and other constraints (NOAA GFDL 2018).

3. **Climate change is expected to result in the intensification of hurricanes and tropical storms worldwide**. Research predicts a global increase in the intensity of such storms on average, by to 2 to 11% based on IPCC mid-range emission scenario projections (Knutson et al. 2010), as well as a poleward expansion in the latitude range at which storms reach their highest intensity (Kossin et al. 2014). This increase in intensity also includes higher rainfall rates (discussed below). This increase in very intense storms is expected to take place despite a likely decrease or small change in the number of tropical cyclones worldwide (see NOAA GFDL 2018 and the sources cited therein). Some experts have noted that the three massive storms that characterized the 2017 hurricane season – Harvey, Irma, and Maria – are consistent with this expected intensification (see e.g. Sneed 2017).

4. **Hurricanes and tropical storms are likely to increase in intensity in the Atlantic basin, including the U.S. East Coast**. Overall, based on a synthesis of current science, NOAA GFDL (2018) reported with medium confidence that hurricane and tropical storms will be more intense on average in the coming century (as indicated by higher peak wind speeds and lower central pressures). Bender et al. (2010) projected a significant increase in the frequency of very intense storms (Category 4 and 5), although this increase may not be seen until the latter half of the century. However, based on Knutson et al. (2013) and a review of other studies, NOAA scientists reported *low* confidence that there will be an increase in these very intense Category 4 and 5 hurricanes in the Atlantic basin (NOAA GFDL 2018). Further, a reduction in the number of tropical storms and hurricanes is predicted for the Atlantic basin (Knutson et al. 2008, 2013). This does not, however, change the projection that future storms may be more intense on average (although not reaching the high intensity of a Category 4 or 5 storm).

5. **The frequency and intensity of extra-tropical storms is expected to increase**. The IPCC AR5 (2014) predicts an increase in both the frequency and intensity of extra-tropical storms for the U.S. East Coast. However, less research has been conducted on extra-tropical storms in comparison to hurricanes and tropical storms.

2.2.3 Increasing Precipitation

1. **Hurricanes and tropical storms are expected to result in more rainfall**. This increase has been observed and is expected both globally (IPCC 2014) and for the Atlantic basin, including the U.S. east coast. Based on a synthesis of current science, NOAA GFDL reported with high confidence that Atlantic hurricanes and tropical storms in the coming century will have higher rainfall rates than present storms,

particularly near the storm center (see NOAA GFDL 2018 and the sources cited therein). 2017's Hurricane Harvey, which resulted in a record 51.9" (1318 mm) of rainfall at one station west of Houston, Texas (van Oldenborgh et al. 2017), is one recent example of this trend (see further discussion below).

2. **Heavy precipitation events are becoming more frequent and intense**. Whether a hurricane, tropical storm, or extra-tropical storm (e.g. a nor'easter), there has been a global increase in both the frequency and the intensity of heavy precipitation events (NCA 2017, IPCC 2014). This trend is consistent with physical responses to a warming climate, e.g. an increased amount of moisture in the atmosphere. This trend has both been observed and is expected to continue. An important recent example is 2017's Hurricane Harvey, which resulted in record rainfall in Houston, Texas. Both van Oldenborgh et al. 2017) and Risser and Wehner (2017) found that the extreme precipitation and flooding associated with Harvey was likely enhanced climate change (see also Waldman 2017).

3. Within the United States, this trend is most pronounced in the Northeast. For example, the NCA (2017) reports that between 1958 and 2016, this region has experienced a 55% increase in precipitation events that exceed the 99th percentile, and a 92% in the number of 2-day events exceeding the largest amount that is expected to occur over a 5-year period. Walsh et al. (2014) studied rainfall from 1901 to 2012 in New England and found that the intense rainfall events (heaviest 1% of all daily events) have increased 71% since 1958, although the 1960s were a particularly drought-prone time in the region. For further discussion and more sources please see RI EC4 STAB 2016.

2.3 Coastal Hazards Resulting from These Trends

2.3.1 Flooding

1. **Flooding is expected to increase as a result of sea level rise, increasing intensity of storms, and increased precipitation**. In the coastal environment, this includes both nuisance (tidal) flooding and storm surges, and other coastal flooding events. Inland, this includes riverine flooding. The U.S. Global Change Research Program indicates that both tidal and storm-related flooding are expected to increase in frequency and depth in the U.S. due to these drivers (NCA 2017). The IPCC (2014) found that "coastal systems and low-lying areas will increasingly experience submergence, flooding and erosion throughout the 21st century and beyond, due to sea level rise (*very high confidence*)." Further, the IPCC identified flooding and associated damages as a "key risk" for eastern North America due to its expected large magnitude, high probability or irreversibility of impacts, vulnerability or exposure of the region, and limited potential to reduce risk through adaptation or mitigation. Importantly, increased flooding means both an increase in the *areas* which are flooded as well as the *depth* of floodwaters. This is because sea level rise will expand existing floodplains, causing flooding in places which have not previously experienced flooding, and resulting in deeper floodwaters in previously-flooded areas.

2. **Nuisance flooding** is also sometimes called tidal or high tide flooding, and increasingly occurs in coastal locations both locally and globally as a result of sea level rise, which in turn causes higher than normal high tides. Nuisance flooding may affect individual coastal properties as well as roads, parking lots, and other public or commercial infrastructure in low-lying areas. The U.S. Global Change Research Program (2017) reported that this type of flood event has increased 5 to 10-fold since the 1960s in several U.S. coastal cities, and that rates of increase are accelerating in over 25 cities on the U.S. Atlantic and Gulf coasts. They further reported that this type of flooding will continue increasing in depth, frequency and extent over the 21st century.

3. ***In Rhode Island***, nuisance flooding is already occurring in numerous low-lying locations around the state. STORMTOOLS can be used to view potential inundation in Rhode Island associated with nuisance flood events (1, 3, 5, and 10-year return period storms). Please see www.beachsamp.org.

4. **Storm surge** refers to the rise of water levels caused explicitly by a storm, and is measured as the height above the normal predicted tide. The combination of sea

level rise and increased storm intensity causes storm surges characterized by higher water levels that may extend further inland, causing greater damage. The U.S. Global Change Research Program (2017) reported that this type of extreme flooding is expected to increase due to both sea level rise and increased storm intensity, and associated sea level rise with increased storm surge flooding at a very high confidence level. The IPCC (2014) found that increasing storm surges and other forms of coastal flooding have the potential to disrupt livelihoods and create severe health risks across various sectors.

5. Storm surges are often described with an associated return period, or recurrence interval, which is an estimate of the likelihood that the storm or flooding event will occur (for further discussion see Shoreline Change SAMP Chapter 4). This concept is also useful in illustrating how, over time, rising sea levels result in more damaging storm surges. Over time, as sea levels rise, water levels associated with what is thought of as today's 100-year return period storm will increase, because a higher base sea level will increase the extent and depth of storm-related flooding. As a result, the 100-year return period storm of the future could result in much more flood-related damage than the 100-year return period storm of today. Further, from the perspective of water levels, SLR will cause today's 100-year return period storm to become a more regularly-occurring storm. For example, a future 20-year return period storm on top of a 2-foot SLR will have the same water level and depth as today's 100-year return period storm. For further discussion, please see Shoreline Change SAMP Chapter 4.

6. ***In Rhode Island***, many coastal communities, including individual residential properties as well as commercial and industrial properties, are highly exposed to storm surges. For example, a CRMC-led assessment found that 27,431 (11.5%) of the residential structures in Rhode Island's coastal communities are exposed to the combined effects of sea level rise and storm surge under the Shoreline Change SAMP's Long-range Planning Scenario (a 7-foot SLR + 100-year storm surge, inundating approximately 65 square miles of Rhode Island's existing coastline). STORMTOOLS and the Shoreline Change SAMP provides numerous tools and analyses to help coastal residents and decision-makers understand their exposure under different scenarios representing both storm surge and varying levels of sea level rise. Please see Chapter 3 for discussion of the storm surge scenarios used as planning scenarios in the Shoreline Change SAMP, and please see Chapter 4 for a detailed discussion of the exposure of Rhode Island's coastal communities under a range of storm surge scenarios. Please also see www.beachsamp.org to use STORMTOOLS to view other storm surge scenarios.

7. **Riverine flooding** refers to flooding that takes place throughout the watershed (i.e. inland) along the banks and in the floodplains of rivers and streams. Riverine flooding is expected to be exacerbated by increased storm intensity as well as increased precipitation. The IPCC (2017) identifies inland flooding in some urban regions as a “key risk” in North America which may disrupt livelihood and result in severe health risks. Importantly, riverine flooding and coastal flooding due to sea level rise can have a coupling effect. Rising seas can set a new flood stage in riverine systems, thus increasing flood risk in inland areas adjacent to rivers (Garcia and Loáiciga 2014; Hashemi et al. 2017).

8. ***In Rhode Island***, increased precipitation has been observed and is expected to continue. Increased precipitation, in particular, is expected to increase stream flow in the Northeastern U.S., contributing to increases in flooding risk due to increases in 3-day peak flows (Demara et al. 2015). Vallee and Giuliano (2014) reported a doubling of the frequency of flooding and an increase in the magnitude of flood events, many of which are riverine flooding events, such as in 2010, when the Pawtuxet River crested and caused extensive inland flooding following a series of heavy rain storms that took place over a 5-week period. A great deal of research is needed on projected riverine flooding in Rhode Island, specifically on the coupling effects within Rhode Island watersheds of storm surge and precipitation events, sea level rise and flooding events; please see Chapter 4 for further discussion.

9. Scientists’ understanding of these sources of coastal hazard risk are rapidly evolving, and further research is needed on all of these topics. Please see section 2.4, Future Research Needs, for a discussion of some research needs identified by the Shoreline Change SAMP team.

10. Please see Chapter 4, “Rhode Island’s Exposure to Coastal Hazards,” for a detailed discussion of Rhode Island’s exposure to all of these hazards. This includes a detailed discussion of the exposure of both the built and the natural environment to sea level rise and/or storm surge scenarios, as well as future scientific needs associated with these topics.

2.3.2 Coastal Erosion

1. **Coastal erosion is expected to increase due to the increase in storm intensity and associated flooding**. The IPCC (2017) found that coastal and low-lying areas have been experiencing increased erosion, and will continue to do so, due to sea level rise, in North America and throughout the world. Erosion has been noted to be of particular concern in the northeastern U.S. (Horton et al. 2014). In their study of

climate change impacts in the Northeastern U.S., Horton et al. (2014) noted that increased rates of coastal erosion are likely to compromise aging coastal infrastructure, including transportation, communications, and energy infrastructure.

2. ***In Rhode Island***, coastal erosion is of particular concern because it is characterized by a storm-driven coastline. This is especially the case on Rhode Island's south shore, which has been found to be largely erosional (Boothroyd et al. 2016). Studies of shoreline change in Rhode Island have documented an average annualized rate of shoreline change of 0.57 meters/year (1.9 feet/year), though these annualized rates should be used with caution because coastal erosion is not a gradual process, but rather the result of abrupt changes due to storms. Some of the highest rates of change occur along the Matunuck Headline, where the annualized rate of change exceeds 1.4 meters/year (4.7 feet/year), and total erosion since 1951 has approached 90 meters (300 feet) (Boothroyd et al. 2016). It is difficult to project future rates of shoreline change, but one Shoreline Change SAMP analysis suggested that the RI south shore could experience a total change of 89 meters (292 feet) by 2065 and 216 meters (708 feet) by 2100 (Oakley et al. 2016). These results should be used with caution given the uncertainty associated with projecting future shoreline change.

3. Scientists' understanding of coastal erosion and other coastal processes is rapidly evolving, particularly with regard to how processes are changing due to changing climate trends and what may happen in the future. Please see Chapter 4 for a detailed discussion of what is known about coastal erosion in Rhode Island, and please see section 2.4 Future Research Needs, for a discussion of some research needs identified by the Shoreline Change SAMP team

2.3.3 Groundwater and Saltwater Intrusion

1. **Groundwater levels are expected to increase with rising sea levels, resulting in saltwater intrusion for any structures and systems below grade along the coast.** Research on coastal groundwater systems in Connecticut, New Hampshire, and Massachusetts has suggested that groundwater levels will not only rise with rising sea levels, but are expected to extend farther inland than surface water (Bjerklie et al. 2012, Knott et al. 2017, and Walter et al. 2016). Increases in coastal groundwater levels can: impact the ability of stormwater to infiltrate in coastal areas, increasing the risk of localized flooding and ponding (Bjerklie et al. 2012); pose an increased risk of groundwater seepage into basements of existing buildings

and underground infrastructure (Bjerklie et al. 2012); impact the structural integrity and reduce the lifespan of built infrastructure (Walter et al. 2016, Knott et al. 2017); cause wetlands to expand and possibly form in areas they didn't exist before (Knott et al. 2017); and change the health of natural ecosystems (Knott et al. 2017).

2. ***In Rhode Island,*** many coastal properties rely on onsite wastewater treatment systems (OWTS, a.k.a., septic systems) for wastewater disposal, and private wells for drinking water. Research at the University of Rhode Island suggests that as coastal groundwater is projected to rise, the soil volume that is designed around an OWTS to absorb and treat effluent will decrease, thereby potentially resulting in contaminant transport within the water table, and a threat to aquatic and ecosystem health (Cooper et al. 2016). Additionally, research on sea level rise and salt water intrusion in coastal aquifers and private drinking water well systems along Rhode Island's coast was funded and is underway in 2018. For more information, contact Dr. Soni Pradhanang at the University of Rhode Island's Department of Geosciences.

3. Scientists' understanding of these sources of coastal hazard risk are rapidly evolving, and further research is needed on all of these topics. Please see section 2.4, Future Research Needs, for a discussion of some research needs identified by the Shoreline Change SAMP team.

2.4 Future Research Needs

2.4.1 Flooding

1. Under the STORMTOOLS effort, flooding maps have been generated for once in 25, 50, 100, and 200-year return period storms, with sea level rise (SLR) ranging from 2 to 10-feet. Maps have also been prepared for 2, 3, 5 and 10-year return period nuisance flooding events to assist in emergency response. In addition, maps of inundation from sea level rise from 2- to 10-feet have also been prepared. Through the Coastal Environmental Risk Index (CERI) initiative that set out to assess the risk and damage to structures, STORMTOOLS design elevation maps (SDEs) (including the effects of SLR), which explicitly include surge, coastal erosion, and wave conditions and central to the CRMC permitting process, have been completed for Warwick, Barrington, Bristol, Warren, and Charlestown. Generation of SDE maps for the other coastal communities in the state is currently in progress. The SDE maps are comparable to the FEMA Base Flood Elevation (BFE) maps, with the important exception that they include SLR effects and address a number of technical weaknesses with the FEMA Flood Insurance Rate Maps (FIRMs). Flooding maps for the Pawtuxet River watershed have also been prepared by application of high resolution hydrologic models to the system, with a focus on flood control and management. The riverine flooding maps vs selected return periods are currently available via the STORMTOOLS web site.

2. To continue to bring in new data and modeling that builds on flood risk tools that have been completed or in progress, the following are recommended:

   a) ***Enhancement in wave and associated damage modeling in CERI.*** Theory and field studies show that dynamic wave setup and run-up can extend the inundation zone well beyond that inundated by the storm surge alone. This extended inundation zone is defined as the *swash* zone and is characterized by periodic extreme water elevation (periods on the order of 10 to 100 seconds) with associated high velocities and force. Run-up can significantly increase the coastal hazard and the risk in coastal areas characterized by steep slopes or vertical walls (e.g. Dean and Bender 2005) (selected locations along the southern RI coastline). The method currently employed to model wave dynamics for the SDEs and as input to CERI, uses a phase average model (e.g. STWAVE) that unfortunately does not resolve time dependent processes such as wave diffraction, reflection, and run-up in the swash zone. Phase resolving models (time dependent models of individual wave events) that would address this problem are currently available but the high computational cost has, to date, precluded their routine use in practical applications. Li et al. (2018) have demonstrated the importance of using a phase resolving model to fully represent the damage due to wave run-up and overtopping. URI is part of the team developing a phase-resolving model, FUNWAVE, (Shi et al. 2012) and has developed extensive experience in the use of the model (e.g. Shelby et al. 2016; Grilli et al. 2016). With access to high performance computational systems, this proposed effort would apply phase resolving models to predict wave dynamics in exposed southern RI coastal communities and result in improvements in both SDE maps and CERI damage estimates.

CERI currently uses damage curves for both inundation and waves developed as part of the Army Corp of Engineers North Atlantic Comprehensive Coastal Study (NACCS) based on field surveys performed after hurricane Sandy impacted the NY-NJ area. The uncertainty in the estimates of wave damages, parameterized in terms of upper, mean, and lower values, are quite large. With more detailed modeling of wave dynamics available from FUNWAVE it will be possible to substantially improve damage estimates, including the proximity of other structures, using methodologies based on impulse forces on structures.

b) ***Modeling of riverine flooding in remaining RI watersheds.*** It is proposed to apply the existing hydrologic model suite to the remaining watersheds in the state (Blackstone, Ten Mile/Seekonk, Woonasquatucket, Moshassuck, Warren, Hunt, Taunton, Narrow, and Pawcatuck) to predict flooding in response to changing climate conditions (rainfall rates, sea level rise). This will complete flooding (inland) maps for all riverine systems in the state. It will also allow improvement in flooding estimates where riverine and coastal systems meet. All mapping products will be available via the STORMTOOLS web site.

2.4.2 Coastal Erosion

1. There is a significant need to fund the ongoing and expanded study of shoreline change in Rhode Island. Shoreline change monitoring has been a longstanding practice in Rhode Island but is currently running on diminishing funds and/or volunteer efforts which are insufficient given the importance of this issue. Efforts beyond 2018 to expand these efforts and to continue measuring conditions within Block Island Sound remain unfunded. These previous and ongoing efforts, and the funding status of each, are detailed below.

2. Rhode Island has had long-term monitoring of the shoreline using beach profiles/transects for >50 years. This represents a wealth of data at the short-term (event scale (storms + recovery)) and long-term (annual – decadal) scale along the Rhode Island south shore (RISS). The Graduate School of Oceanography has maintained seven profiles along the RISS for several decades. The GSO beach survey was established in the early 1960s and expanded to the current scope by the late 1970s. Currently, these profiles are run by the King Lab at URI-GSO, funded by a graduate assistantship and the King Lab.

3. Jon Boothroyd (now deceased), URI Geosciences Professor and RI State Geologist, measured various profiles along the RISS, with the primary profile located on the Charlestown Barrier (CHA-EZ) measured near weekly since 1977. Two of Boothroyd's profiles (CHA-EZ and SK-TB (South Kingstown Town Beach) continue to be measured by Scott Rasmussen, URI-EDC, funded by RICRMC. Additional profiles are measured by Bryan Oakley (Eastern Connecticut State University (ECSU)): Napatree Point (5 profiles) (2013-present) measured quarterly and post-storm; and Misquamicut State Beach (five profiles) also measured quarterly and post-storm. These profiles began in 2014 in response to beach replenishment. An additional eight profiles initiated by Oakley are measured on Block Island (monthly 2013-2017; quarterly 2018-present) by citizen scientists who send the data to ECSU for interpretation and archiving. These profiles have contributed greatly to the understanding of the RISS, published in numerous theses, papers, and conference presentations, and have helped to inform RICRMC policy greatly over the last 30 years.

4. Recent acquisition and a successful proof of concept for terrestrial laser scanning (TLS), a method of measuring elevations from a mobile platform (boat), coupled with swath bathymetric mapping shows that this technology could become a significant component of a robust coastal monitoring program. Boat-based TLS coupled with swath bathymetric mapping can be rapidly mobilized, providing a

coast-wide assessment of the shoreline shortly after a storm event, in addition to periodic seasonal monitoring surveys.

5. Significant challenges remain for keeping these efforts funded in the long-term. Profiles measured by the URI-EDC remain funded by the RICRMC but are not a permanent line item in their budget. URI-GSO profiles depend on a research assistantship for a graduate student from the university, as well as in-kind support (equipment, vehicles, personnel) from the King Lab. ECSU profiles on Block Island and Misquamicut had some initial funding from the RIBRWCT, however these remain volunteer efforts by Oakley, citizen scientists and ECSU students. Napatree profiles are supported by the Watch Hill Conservancy. No current funding has been identified to incorporate TLS into the current coastal monitoring efforts.

6. While the current and historic coastal monitoring provides insight along the beaches of the RISS, significant data gaps exist in the offshore environment. Understanding the response of the shoreface (area from the beach extending offshore) at similar time scales as the beach profiles (event to decadal scale) remains a significant data gap along the RISS. The shoreface represents potentially a significant source and sink of sediment for the shoreline, and a lack of observations limits understanding of the complex relationships between the shoreface characteristics (sediment type, morphology) and coastal processes.

7. There is a DOI-NFWF funded project underway to deploy four ADCP wave/tide sensors along the RISS and four water level monitoring stations within the coastal ponds, and will be maintained through 2018. This will provide similar data products to Woods Hole Group (2012). This represents important information on the real conditions during a storm. Coupled with coastal monitoring, the resulting parameterization of environmental data offers opportunities to use detailed observations to calibrate and expand the recent modeling efforts along the RISS

8. Geologic habitats mapped on the shoreface numerous times in part over the last 3 decades (Morang, JCB, Oakley, King) including recent mapping in 2015/2016 (DOI-NFWF funded). This provides baseline information on the extent and distribution of geologic habitats on the upper shoreface, as well as thickness and volume of sand on the uppermost shoreface.

2.4.3 Groundwater and Saltwater Intrusion

1. Future research is needed on the effects that sea level rise will have on groundwater dynamics and saltwater intrusion impacts within coastal areas. Research specific to the Rhode Island coastline that is modeled after current research on coastal groundwater systems in Connecticut, New Hampshire, and Massachusetts (as discussed in Section 2.3.3), is needed to determine:

    a. the inland extent of impacts from groundwater levels increasing with rising sea levels;

    b. the ability of stormwater to infiltrate in coastal areas, and impacts caused by related flooding and ponding;

    c. impacts of groundwater seepage into basements of existing buildings and underground infrastructure;

    d. impacts to the structural integrity and lifespan of built infrastructure;

    e. expansion of wetland areas in the coastal zone;

    f. changes to the overall health of coastal and inland freshwater ecosystems; and

    g. contaminant transport within coastal groundwater systems.

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CHAPTER 3

Assessing Coastal Hazard Risk

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3.1 Assessing Coastal Risk and Resilience

3.1.1 Overview

1. This chapter provides a discussion of coastal risk. It explains CRMC's approach to coastal risk, and how and why CRMC is providing decision-makers and property owners with information and tools to assess their coastal risk. The general information included in this chapter provides a foundation for Chapter 4, which summarizes what is known to date about Rhode Island's exposure to sources of coastal risk. This information is provided to help CRMC achieve the Shoreline Change SAMP's vision of providing guidance and tools for property owners and state and local decision-makers to prepare and plan for, absorb, recover from, and successfully adapt to changing conditions associated with storm surge, coastal erosion, and sea level rise.

2. The Shoreline Change SAMP addresses the risks associated with three coastal hazards, storm surge, coastal erosion and sea level rise, in order to provide guidance for property owners and state and local decision-makers so that they can plan for and manage their risk. However, there are numerous other coastal hazards that are sources of risk in coastal Rhode Island. Other sources of risk include but are not limited to wind, waves and precipitation that may also be associated with coastal storms, as well as the coupling effects of sea level rise, storm surge, and precipitation with riverine systems. For a scientific discussion of these coastal hazards as well as broader projected changes associated with climate change, see Chapter 2. For a discussion of Rhode Island's exposure to these sources of risk, see Chapter 4. Chapter 4 also discusses areas of ongoing and future research, including but not limited to topics such as new sea level rise scenarios and riverine systems.

3. The Shoreline Change SAMP is an initiative of the RI Coastal Resources Management Council. As described in Chapter 1 and detailed in Chapter 5, the CRMC is mandated by federal law to provide for "the management of coastal development to minimize the loss of life and property caused by improper development in flood-prone, storm surge, geological hazard, and erosion-prone areas and in areas likely to be affected by or vulnerable to sea level rise, land subsidence, and saltwater intrusion, and by the destruction of natural protective features such as beaches, dunes, wetlands, and barrier islands" in Rhode Island. It is also mandated to undertake "the study and development….of plans for addressing the adverse effects upon the coastal zone of land subsidence and of sea level rise." Further, the Act declares that it is national policy "to encourage the preparation of special area management plans" to provide for several goals, including "improved protection of life and property in hazardous areas, including

those areas likely to be affected by land subsidence, [and] sea level rise" (16 USC 1452 *et. seq.*).These requirements are incorporated into the CRMC's powers and duties, as established in the RI General Laws (RIGL 46-23). See Chapter 5 for a detailed discussion of CRMC's role and authority regarding the management of coastal risk.

4. The CRMC has addressed coastal hazards through the RI Coastal Resources Management Program, as amended (RICRMP), for over 30 years.[1] In 2008 the RICRMP was amended to add Section 145, "Sea Level Rise," which included a policy calling for the Council to "review its policies, plans and regulations to proactively plan for and adapt to climate change and sea level rise." Through the Shoreline Change SAMP, the CRMC is responding directly to this policy by developing guidance and tools that will help property owners and municipal and state decision-makers plan for these changing *future* conditions. This forward-looking planning approach complements that of existing coastal hazards programs, such as the FEMA National Flood Insurance Program (NFIP), whose mapping products and regulations are based on historic data and are designed to help property owners and municipalities deal with *present* conditions.

5. CRMC policy, as reflected in Section 145 of the RICRMP, relies upon the "high" sea level change curve included in the most recent NOAA sea level rise (SLR) data. As of the time of this writing, the high curve included in the most recent NOAA analysis projects a maximum of 9.6 feet of SLR at the 83% confidence interval in Rhode Island by 2100 (NOAA 2017). However, scenarios developed for the Shoreline Change SAMP document, planning tools and analyses are based on earlier NOAA SLR analyses which projected up to 6.6 feet of SLR in Rhode Island in 2100 under the high curve (see NOAA 2012). NOAA's 2017 analysis also included an "extreme" curve which projected up to 11.7 feet of SLR at the 83% confidence interval in Rhode Island by 2100 (NOAA 2017). CRMC expects to update the Shoreline Change SAMP document, planning tools and analyses on an ongoing basis, using the most recent SLR scenarios, as resources allow. See the USACE sea level change curve calculator at http://www.corpsclimate.us/ccaceslcurves.cfm to view SLR projections for Newport under the full range of scenarios for both the 2012 and the 2017 NOAA analyses.

[1] Specifically, CRMC has had the following provisions in place since the 1980s: required coastal erosion setbacks (RICRMP § 140); prohibited new development on undeveloped and moderately-developed barriers (RICRMP § 210.2.D.4 and 210.2.D.6, respectively); prohibited new infrastructure on all barriers (RICRMP § 210.2.D.5); requirement to prevent, minimize or mitigate risk of coastal hazards for construction of new residential, commercial and industrial structures (RICRMP 300.3.B.1); requirement for flood zone construction standards (RICRMP § 300.3.F).

6. In providing this guidance, the Shoreline Change SAMP represents what CRMC envisions as the first step toward addressing the risks that climate change and sea level rise present for Rhode Island's coastal communities. A key objective of the Shoreline Change SAMP is to help property owners and state and local decision-makers understand these sources of risk and understand what these mean for their own property or jurisdiction.

3.1.2 Why Assess and Plan for Coastal Risk?

3.1.2.1 Coastal Risk by the Numbers

1. Why has the CRMC undertaken the RI Shoreline Change SAMP to plan for the impacts of storm surge, coastal erosion and sea level rise on Rhode Island's coastal communities? The following statistics provide some insight:

    a. Nationwide, the number of annual federal disaster declarations has increased since 1953. For example, the number of "major disaster" declarations began to increase notably in the 1990s: from 1990 to 1999 there was an average of 46 major disasters declared each year, and from 2000 to 2009, there was an average of 56 per year. Over 70% of major disaster declarations have been issued for severe storms and floods. This rise in disaster declarations could be attributed in part to an increase in severe weather events and to increased population and development, especially in coastal areas (Lindsay and McCarthy 2015).

    b. In Rhode Island, there have been 22 "major disaster" or "emergency" declarations since 1953. Eight (36%) of the 22 have taken place since 2010, and 12 of the 22 have been issued in response to hurricanes (including tropical storms) or floods (FEMA n.d. a).[2]

    c. Costly damage due to storms and flooding events is increasing. Economic losses due to tropical storms and floods have tripled over the past 50 years (Gall et al. 2011) and account for approximately half of all natural disaster losses (NOAA National Center for Environmental Information 2017).

    d. Flooding is the costliest natural disaster facing the United States. 90% of all natural disasters in the U.S. involve flooding, yet standard homeowners insurance does not cover flooding (Insurance Information Institute n.d.). FEMA's National Flood Insurance Program paid out nearly $792 million in losses in 2015, but losses have

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[2] Terms such as "hurricanes" and "floods" are reported as they are used by the data source, FEMA; please see www.fema.gov/disasters for information on how these terms are defined. For further information on these and other disaster declarations please see this same website.

been much higher in others years (e.g. over $9 billion in 2012 in connection with Hurricane Sandy) (FEMA 2017a).

e. From 1980 to 2016 there were 203 weather- or climate-related "billion-dollar events" in the U.S – i.e. natural disasters resulting in more than $1 billion in costs. 83 of these events were caused by severe storms, 35 by tropical cyclones and 26 by floods. 74 (36%) of these events have taken place since 2010 (NOAA National Center for Environmental Information 2017).

f. The insurance industry reports that in 2012, there were $101.1 billion in losses due to natural catastrophes in the United States. Only $57.9 billion (57%) of these losses were insured. This was the second highest year on record for insured losses (Munich Re cited in Nutter 2013).

g. In the U.S., insured catastrophic losses from 1992 to 2011 cost $384.3 billion, and 42% of these losses ($161.3 billion) were due to hurricanes and tropical storms (ISO Property Claims Service cited in Nutter 2013).[3]

h. Small businesses are particularly vulnerable to severe weather, with an estimated 40% closing and never re-opening following a storm (IBHS n.d.). FEMA has reported that 80% of businesses failed after Hurricane Katrina in 2005 (Fugate pers. comm. 2017). One estimate indicated that 60,000 to 100,000 small businesses were negatively affected by Superstorm Sandy in 2012 and that 30% failed as a direct result of the storm (Crespin 2013).

i. Vulnerability to flooding affects property values. For example, the National Association of Realtors reports that every $500 increase in flood insurance premiums causes a $10,000 decrease in property value (National Association of Realtors 2015).

j. Studies of coastal vulnerability and climate change have shown that the cost of inaction is 4 to 10 times greater than the cost associated with preventive hazard mitigation (Moser et al. 2014 and the sources cited therein).

2. These statistics illustrate that coastal storms are increasingly costly and damaging. Moreover, this problem is expected to increase due to the effects of climate change. Storm surge, coastal erosion and sea level rise are expected to exacerbate the impacts and costs of coastal storms and flood-related events. As discussed above, the most

[3] Terms such as "hurricanes and tropical storms" are reported as they are used by the data source, the ISO Property Claim Services unit; please see ISO for details on how these terms are defined.

recent NOAA projections indicate that sea levels in Rhode Island are expected to rise 9.6 feet by 2100 under the most recent "high" SLR curve (NOAA 2017). Analyses of Rhode Island's exposure conducted for the Shoreline Change SAMP indicate that Rhode Island's coastal residences, businesses, and infrastructure are highly exposed to these sources of risk under a range of scenarios (see Chapter 4).

3. CRMC's goal is to help property owners, municipalities and decision-makers assess their coastal risk so that they can prepare accordingly. *Risk* generally refers the potential for a hazard to occur and to cause adverse effects (see more detailed discussion in Section 3.2 below). Risk can be characterized along a continuum ranging from extreme high risk to extreme low risk. Importantly, coastal risk cannot be fully eliminated due in part to the uncertainties associated with coastal storms and processes (see Chapter 2). However, it can be reduced and managed through risk assessment and adaptation (see Chapter 7).

3.1.2.2 Coastal Risk: Lessons Learned and Case Examples

1. Some property owners and state and local decision-makers may wonder why they should take the time to assess coastal risk and plan for conditions that are uncertain or that may not take place for decades. Here, CRMC shares five lessons that have been learned through the Shoreline Change SAMP development process, accompanied by illustrative examples, which explain why assessing coastal risk is important:

   A. Short-term coastal development decisions can lead to long-term management problems and investment commitments.

   Development decisions made to address immediate community needs can result in long-term problems and financial commitments, especially within the context of rapidly changing coastal conditions. Consider, for example, a road running parallel to the shore, which experiences periodic flooding and erosion during storm events.

   A community may choose to repair such a road in place, and perhaps add flood protection for that road, in order to restore transportation access to nearby homes. However, flood protection for the road may not protect homes and other infrastructure adjacent to the road. Further, over time this will likely result in the need for more frequent repairs or larger maintenance projects, which will become costly and burdensome – or a potential cause of litigation - for the community. Such a road was the centerpiece of a 2011 Florida case. *Jordan et al. v. St. Johns County* addressed the maintenance of a county-owned road, exposed to flooding and erosion, which was the sole means of vehicular access for several homes on a barrier island. Homeowners sued the county for failure to adequately maintain the road, and the Florida 5th District Court of Appeals found in favor of the homeowners, finding that the county must provide a "reasonable level of maintenance that affords meaningful access" to homes, unless the county abandons the road.[4]

In another example, a decision may be made to repair or replace a bridge at its existing elevation above sea level. This bridge could begin experiencing regular flooding during nuisance storms and high tides just ten or twenty years into its life, creating unsafe conditions and costly management problems. Rising seas could also reduce air draft for vessels traveling under the bridge. Additionally, the bridge could be rendered inaccessible by flooding of on and off-ramps or the network of roads leading to or from the bridge. In both cases, long-term solutions such as road relocation, bridge elevation, or reconfiguring the transportation network, which acknowledge and respond to changing future conditions, are likely to be more cost-effective and efficient, yet may not be chosen because of the lack of political support or funds.

B. Coastal development decisions can result in the unintended consequence of increased community exposure.

Development decisions that are intended to facilitate community growth, economic opportunity, improved storm protection or other objectives can have the unintended consequence of increasing a community's exposure to storm and flooding-related impacts. Consider, for example, municipal or state sewer or transportation infrastructure projects intended to facilitate year-round residential development in coastal areas. The influx of residential development that likely follows this infrastructure investment will inadvertently increase the number of people and residential units exposed to the impacts of storm surge, coastal erosion and sea level rise. In such a scenario, this same infrastructure is also exposed to these sources of risk, compounding the problem (NRC 2014).

New Orleans, Louisiana provides well-known examples of this type of problem. The development of a large-scale hurricane protection levee project along Lake Pontchartrain in the 1960s led to significant residential and commercial development in low-lying eastern New Orleans, including 47,000 housing units in Jefferson Parish and 29,000 in Orleans Parish. During Hurricane Katrina in 2005,

[4] *Jordan et al. v. St. Johns County*, 63 So. 3d 835- Fla: Dist. Court of Appeals, 5th Dist. 2011.

this urban growth area was completely flooded because the levees failed, resulting in extensive property damage and numerous deaths (NRC 2014).

C. Property owners and decision-makers may not be aware of the residual risk[5] that remains in the coastal zone despite existing programs and management measures.

Existing regulations, insurance programs and management measures may create a false sense of security for property owners and decision-makers. No risk protection measure provides absolute protection, resulting in "residual risk," or the risk that remains despite such measures (NRC 2014). Moreover, some existing risk protection measures provide less protection than some might think. One example of this is the FEMA requirement that properties within mapped "Special Flood Hazard Areas" (SFHA's), or the mapped areas FEMA deems at risk of a 100-year flood event, obtain flood insurance through the National Flood Insurance Program (NFIP).[6] Importantly, SFHA's and associated FEMA regulations are static, based on past conditions and do not address sea level rise and other changing conditions. FEMA's requirement that SFHA properties obtain flood insurance may lead property owners to believe that flood risk is limited to those structures located within the SFHA, or mapped floodplain. FEMA acknowledges that buildings outside the floodplain are also at risk, reporting that over 20% of NFIP claims came from locations outside of mapped high-risk areas (FEMA 2011), and that between 66 and 80% of flood losses occur outside of the floodplain (Ruppert 2015). FEMA also acknowledges that constructing buildings *inside* the mapped floodplain according to minimum NFIP requirements does not guarantee that a building will not be damaged by flooding, and encourages those building in the floodplain to elevate homes beyond the minimum height required according to the "base flood elevation" (BFE) on their floodplain map, also called a flood insurance rate map or FIRM (FEMA and NAHB Research Center 2010). While FEMA makes these limitations clear, their regulations nonetheless do not account for changing conditions and future risk. It is likely that some property owners and decision-makers do not fully understand these limitations and therefore underestimate their risk. These limitations point to the need for new, proactive management approaches like the Shoreline Change SAMP.

[5] Please see Chapter Appendix for definitions of "residual risk" and other terms.

[6] FEMA also maps areas estimated to be impacted by 500-year return period events. For further information visit www.fema.gov and search "Flood Zones."

D. **Existing regulations assume a static environment based on past or current conditions, but the environment is dynamic and conditions are changing.**
Existing regulations and programs designed to protect communities from storm and flooding impacts are largely static and based on past conditions. However, coastal conditions are rapidly changing, as is scientific understanding of changing future conditions. This is illustrated by past and projected future rates of sea level change. Sea level in Newport rose 0.9 feet (10.8 inches) from 1930 to 2016 (NOAA NOS n.d.) but is projected to rise 9.6 feet by 2100 under NOAA's most recent "high" SLR curve (NOAA 2017). For example, FEMA's flood insurance rate maps (FIRMs), which determine whether homeowners must purchase flood insurance and meet other building and site requirements, are based on historic conditions and do not account for projected sea level rise and its effects on coastal erosion. These changing future conditions may require new, adaptive building and site considerations. For example, the NFIP currently encourages communities to adopt a one-foot freeboard (height above base flood elevation) in home construction to provide additional flood protection (FEMA n.d. b), but NOAA's 2012 "high" SLR curve, utilized as the basis of Shoreline Change SAMP analyses (see Chapter 2), projects a 1-foot SLR by roughly 2035, well within the life of a new 30-year mortgage. A homeowner who adopted the one-foot freeboard would thus be unprepared for these conditions and could experience increased flood risk, a substantial increase in flood insurance premiums, and even a decrease in property value or home marketability during the life of their current mortgage.

E. **A community's ability to weather just one storm can shape its future for years to come.**
A community's resilience through just one storm event can have major implications for its future. Major storm events can result in the loss of residences and businesses that can have long-term economic and social impacts on that community or an entire state. For example, Hurricane Katrina (2005) resulted in both short-term population dislocations and long-term population loss in the Gulf Coast region and the city of New Orleans in particular. Katrina initially displaced more than 1 million people – approximately the size of Rhode Island's population. 600,000 households were still displaced one month after the storm. New Orleans' population fell from over 484,000 before the storm to an estimated 230,000 in 2006 (a loss of more than 50%); a decade later, in 2015, the city's population had bounced back up to over 386,000, still only 80% of what it was in 2000 (The Data Center 2016). For Rhode Island, with a statewide population just over 1 million, such a population loss would mean a reduction of Rhode Island's labor pool, a

reduced tax base, and a diminished economy due to the loss of residents' in-state spending – not to mention the social and cultural impacts of such a loss.

2. These lessons learned and examples demonstrate how changing conditions require new ways of thinking and responding moving forward. Property owners and decision-makers may be required to make difficult decisions and short-term sacrifices in order to prepare for these long-term changes. CRMC's Shoreline Change SAMP provides property owners and decision-makers with information and tools to help them make these decisions.

3.1.3 Institutional Context of Managing Coastal Risk in Rhode Island

3.1.3.1 Overview

1. The purpose of this section is to identify and briefly describe the main responsibilities of many of the federal, state, and local government authorities who play key roles in assessing, planning for and managing coastal risk in Rhode Island. This information is provided because understanding and managing coastal risk in Rhode Island requires a basic understanding of the institutional landscape of the agencies and authorities who play a role in coastal risk management. This section is not exhaustive in listing all such authorities, nor does it offer detailed description of each authority's roles and responsibilities. In each section readers are referred to individual agency or authority websites for further information.

2. As stated in Section 3.1.1, the Shoreline Change SAMP is an initiative of the RI Coastal Resources Management Council, which is mandated by federal and state law[7] to manage coastal development to minimize the loss of life and property due to coastal hazards, and to address the adverse effects of sea level rise. Further, CRMC's own sea level rise policy requires that the Council proactively plan for and adapt to climate change and sea level rise. See Chapter 5 for a detailed discussion of CRMC's role and authority regarding the management of coastal risk.

3.1.3.2 Federal Agencies

1. **Federal Emergency Management Agency (FEMA)**: FEMA plays several roles regarding coastal hazard risks, ranging from disaster response to mitigation and insurance (see NRC 2014 for a full discussion). These include managing the National Flood Insurance Program (NFIP), which provides property owners the opportunity to purchase flood insurance in cases where municipalities meet or exceed FEMA floodplain management requirements. FEMA flood insurance rate maps, or FIRMs, include delineations of Special Flood Hazard Areas (SFHA) and other hazard areas as well as Base Flood Elevations (BFE), which are the elevations to which waters are expected to rise during a flood. SFHAs are the areas that FEMA has determined are at risk of a base flood, or a flood that has a 1% chance of being equaled or exceeded in a given year (in other words, a 100-year storm).[8] Property owners in the SFHA and other high-risk areas and who have a federally-backed mortgage or similar banking product are required to

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[7] Please see the federal Coastal Zone Management Act, 16 U.S.C. § 1452 *et. seq.*, and RI General Laws Chapter 46-23.

[8] SFHA's do not include consideration of sea level rise. See section 3.2.3 for discussion of STORMTOOLS and CERI mapping applications and how they differ from FEMA map products.

purchase flood insurance. The federal government backs flood insurance in communities which enact and enforce minimum floodplain regulations. Communities participating in the Community Rating System (CRS), through which a municipality exceeds minimum floodplain management requirements, receive discounted flood insurance premiums (RIEMA n.d. a). Other FEMA programs include hazard mitigation grant programs as well as disaster response assistance. For discussion of FEMA program implementation in Rhode Island, see below for a section on the RI Emergency Management Agency. For further information please see www.fema.gov or www.riema.ri.gov.

3.1.3.3 Other State Agencies

1. **Rhode Island Executive Climate Change Coordinating Council (EC4):** The EC4 was established in 2014 by the Resilient Rhode Island Act of 2014. The EC4's duties include assessing, integrating, and coordinating climate change efforts throughout the state; advancing the state's understanding of climate change effects and identifying strategies to prepare for and communicate these effects; identifying strategies to reduce greenhouse gas emissions; working to support the development of sustainable and resilient communities; and identifying and leveraging funding opportunities for mitigation, preparedness and adaptation work. The CRMC is one of nine state agencies with membership on the EC4. Governor Raimondo's Executive Order 17-10, "Action Plan to Stand up to Climate Change," (September 15, 2017) reinforced the importance of the EC4 by establishing a state Chief Resiliency Officer who will work with the EC4 and other partners to develop a statewide "Action Plan to Stand Up to Climate Change." For further information on the EC4 please see http://www.planning.ri.gov/planning-areas/climate-change/riec4/. For further information on the Executive Order please see http://www.governor.ri.gov/documents/orders/ExecOrder-17-10-09152017.pdf.

2. **Rhode Island Building Code Commission**: The Building Code Commission's purpose is to establish minimum building code requirements for the protection of public health, safety, and welfare in the built environment. Building code requirements address coastal hazards in numerous ways; for example the RI State Building Code incorporates the vast majority of the NFIP floodplain management requirements. Towns in turn use the design standards set by the state building code. For further information please see http://www.ribcc.ri.gov/.

3. **Rhode Island Department of Environmental Management (DEM):** DEM manages Rhode Island's natural resources and state-owned public lands, focusing in particular

on air and water resources, agriculture, fish and wildlife, parks and recreation, and waste management. DEM manages state parks and beaches, wastewater treatment infrastructure, and other facilities which may be vulnerable to the impacts of storm surge, coastal erosion and sea level rise. DEM administers a series of climate change-related initiatives, many of which are targeted at greenhouse gas emissions; most relevant to the Shoreline Change SAMP include a 2017 analysis of the effects of climate change on Rhode Island's wastewater treatment plants (see Chapter 4 for further discussion). For further information please see http://www.dem.ri.gov/programs/air/climate-change.php and http://www.dem.ri.gov/programs/water/wwtf/.

4. **Rhode Island Department of Health (DOH)**: DOH works to prevent disease and protect and promote the health and safety of the people of Rhode Island. DOH also manages Rhode Island's drinking water system. DOH administers several climate change-related health programs, but most relevant to the Shoreline Change SAMP is the 2013 SafeWater RI initiative, which examined the impacts of climate change on Rhode Island's drinking water utilities. For further information please see http://www.health.state.ri.us/healthrisks/climatechange/ and http://health.ri.gov/publications/reports/2013EnsuringSafeWaterForRhodeIslandsFuture.pdf.

5. **Rhode Island Department of Transportation (RIDOT)**: RIDOT is responsible for the design, construction, and maintenance of the state's surface transportation system, including state roadways, bridges, rail stations, and bike and pedestrian paths. RIDOT manages many of the transportation assets that are or may become vulnerable to the impacts of storm surge, coastal erosion, and sea level rise; see results of the SPP transportation analysis in Chapter 4. For further information on RIDOT please see http://www.dot.ri.gov/.

6. **Rhode Island Emergency Management Agency (RIEMA):** RIEMA's mission is to coordinate statewide efforts to prepare for, protect against, respond to, recover from, and mitigate all hazards, including storms, floods and other natural hazards. RIEMA's Planning and Mitigation Section administers the NFIP in Rhode Island (see discussion above under Federal Emergency Management Agency) as well as various FEMA hazard mitigation grant programs. RIEMA administers the state's hazard mitigation plan, last updated in 2014, which includes consideration of storms, flooding and sea level rise. RIEMA also provides local hazard mitigation planning guidance for municipalities. For further information please see http://www.riema.ri.gov//planning/floodplain/index.php.

7. **Rhode Island Statewide Planning Program (SPP):** SPP, housed within the Department of Administration's Division of Planning, develops and implements plans for the physical, economic and social development of the state and coordinates among federal, state, and local agencies and other actors with regard to the state's development goals and policies. SPP is overseen by the State Planning Council, which also functions as RI's metropolitan planning organization (MPO), a federally mandated and funded transportation policy-making organization. Recent SPP initiatives related to the Shoreline Change SAMP include analyses and maps illustrating the impacts of storm surge and sea level rise on transportation assets and statewide demographics. Results of SPP's most recent analyses are included in Chapter 4. For further information please see http://www.planning.ri.gov/.

8. **Rhode Island Infrastructure Bank (RIIB):** RIIB is a state financing agency whose purpose is to finance infrastructure improvements for municipalities, businesses, and homeowners. Infrastructure projects which may be supported by the RIIB include those addressing flooding, water quality, energy efficiency, renewable energy, and others. Rhode Island's first Chief Resiliency Officer was appointed in 2017 and works at the RIIB. The Chief Resiliency Officer is charged with producing the first statewide resiliency strategy for Rhode Island. For further information please see https://www.riib.org/.

3.1.3.4 Rhode Island Municipalities

1. Rhode Island's cities and towns administer a broad range of programs related to the coastal hazards addressed in the Shoreline Change SAMP. Additionally, cities and towns have jurisdiction beyond that of FEMA's NFIP (generally limited to that of the mapped floodplain) or that of CRMC (generally extending to 200 feet inland from a coastal feature). The roles Rhode Island's cities and towns play with regard to managing coastal risk are further discussed in Chapter 6.

3.1.4 The Components of Coastal Risk: Terms and Concepts

1. This section provides a brief discussion of the concept of coastal risk and its components. This information is provided because a basic understanding of these concepts will help Rhode Island property owners and decision-makers assess and respond to coastal risk. There are numerous publications and resources that provide detailed information on coastal risk; several are cited herein, and readers are referred to these sources for in-depth discussion of these issues. This section includes definitions and discussion of some key risk-related terms. For an alphabetized glossary of these and other terms used in this chapter, please see the Appendix.

2. ***Coastal risk:*** Risk generally refers to the potential for a hazard to occur and to cause or result in consequences for people and property. The National Research Council defines coastal risk as “the potential for coastal storm hazards, such as storm surge–induced flooding and wave attack, to cause adverse effects on human health and wellbeing; economic conditions; social, environmental, and cultural resources; infrastructure; and the services provided within a community” (NRC 2014). Risk can be understood as a continuum ranging from extreme low to extreme high risk (Cardona et al. 2012). Importantly, risk cannot be completely eliminated from the coastal zone or any other system, due in part to scientific uncertainty and the chance that risk protection measures won’t work as expected (NRC 2014). There are both short-term term or immediate sources of risk (e.g. coastal storms) and long –term sources of risk (e.g. sea level rise), with long-term sources of risk having an additive effect on short-term sources of risk.

3. Within the context of coastal and other natural hazards, risk is often presented as a statement of the likelihood that a particular hazard will occur at a particular time and place, coupled with the potential impacts of that hazard at that time and place (NRC 2014). In other words, risk can be expressed as the probability of a *hazard* multiplied by the *consequences* that may derive from a hazard, or:

   RISK = HAZARD x CONSEQUENCE (NRC 2014)

4. ***Hazard***: A Hazard is “the physical event with the potential to result in harm” (NRC 2014). For example, one coastal hazard in Rhode Island is sea level rise, which can cause flooding and other harmful effects.

5. ***Consequence***: Consequence refers to the impact or damage caused by a hazard (NRC 2014). Consequences can be short or long-term and can include economic impacts, people or properties affected, harm to individuals, and environmental impacts (NRC

2014). For example, the consequences associated with sea level rise could include flooding damage to homes and businesses, environmental impacts to beaches and natural habitats, and disruption of coastal recreation opportunities having important economic and social value. While sea levels rise slowly over a long period of time, sea level rise could result in consequences which are as great as, if not greater than, the consequences of storms and other hazards.

6. Consequence is often expressed as a function of two other components of risk, vulnerability and exposure:

   CONSEQUENCE = *function* (VULNERABILITY and EXPOSURE) (NRC 2014)

7. ***Exposure***: Exposure refers to the density of people, property, systems or other elements in an area potentially affected by a hazard (NRC 2014). For example, a coastal community with a great deal of high-value residential or commercial development in areas that are expected to be inundated by sea level rise is more exposed than one with less development.

8. ***Vulnerability***: Vulnerability refers to the potential for a community to be harmed, or the level of sensitivity of a community to a hazard (NRC 2014). Vulnerability is determined by physical assets as well as social and political factors (NRC 2012). For example, a coastal community including hospitals or nursing homes with many sick or elderly people requiring special assistance may be more susceptible, or vulnerable, to harm than others.

   These concepts and equations are often combined into one equation:

   RISK = HAZARD x CONSEQUENCE (*function* (EXPOSURE, VULNERABILITY))
   (NRC 2014)

9. ***Design life***: Design life refers to the projected lifespan of a structure or object. Design life can be approached from an engineering perspective, in which design standards are used to design structures or objects to last a given length of time (see e.g. American Society of Civil Engineers 2017), or from a planning perspective, which considers how conditions may change at the site over the course of a project life cycle. When used within the context of coastal risk, design life refers to how long a structure or project – such as a residential building, road, or shoreline protection structure – is expected to last at a given coastal site. Design life is a critical consideration within the context of coastal risk because the risks associated with hazards like sea level rise are expected to change over time. For example, an individual constructing a home with a 30-year design life should consider mid-century sea level rise projections, whereas a

municipality or state agency building a road or bridge with an 80- or 100-year design life should consider end-of-century sea level rise projections. Structures not planned with consideration of projected future conditions within their design life will be more vulnerable than others and experience greater consequences in the event of a coastal hazard. See Chapter 5 for discussion of applying this concept within CRMC's coastal hazard permitting process.

10. These concepts illustrate the complexity of coastal risk. Importantly, coastal risk is not merely a function of a storm or natural hazard but is strongly influenced by social and economic factors including who lives and works in coastal communities, where and how they live, the economic and social value of their homes and businesses, and their ability to adapt in the event of a hazard. For this reason, CRMC has created tools and guidance to help property owners and decision-makers assess their own coastal risk and to plan accordingly.

11. For a table summarizing these and related terms and concepts, please see the chapter Appendix. For in-depth discussion of these topics, see the National Research Council's two recent reports, *Reducing Coastal Risk on the East and Gulf Coasts* (https://www.nap.edu/catalog/18811/reducing-coastal-risk-on-the-east-and-gulf-coasts) and *Disaster Resilience: A National Imperative* (https://www.nap.edu/catalog/13457/disaster-resilience-a-national-imperative). Please also refer to the Shoreline Change SAMP Glossary which contains definitions of terms used throughout the entire Shoreline Change SAMP document.

3.1.5 An Overview of the Coastal Risk Assessment and Management Process

3.1.5.1 Overview

1. The process of assessing coastal risk is one of many aspects of planning for and managing coastal risk, whether on the scale of an individual property or an entire community. This section provides a generalized overview of the coastal risk assessment and management process. This general information is provided to illustrate and provide context for CRMC's approach to coastal risk and the ways in which the Shoreline Change SAMP helps property owners and decision-makers perform this assessment. It also illustrates how the Shoreline Change SAMP is just the first step toward addressing the risks that climate change and sea level rise present for Rhode Island's coastal communities.

2. The coastal risk assessment and management process described here is a generalized process that echoes elements of many similar such processes developed by other

jurisdictions or interests (e.g. U.S. EPA 2014; NOAA OCM 2010; NatureServe 2013; Western Australia Planning Commission 2013). This is a scalable process that can be undertaken by individual property owners, municipalities, or state agencies. Importantly, it is also an iterative, adaptive process that may involve replicating one or more stages of the process multiple times. In many cases, risk assessment and management does not involve going through all of these stages in the exact order laid out here. Further, because risk can never be entirely eliminated from the coastal zone, coastal risk management is an iterative process - property owners and decision-makers may need to periodically repeat parts of the process in order to continually manage their risk within the context of changing conditions.

3. The stages of the generalized process described here correlate roughly to different elements of the Shoreline Change SAMP, including but not limited to the guidance for property owners included in Chapter 5. Where appropriate, the connection between these generalized stages and specific elements of the Shoreline Change SAMP are highlighted.

3.1.5.2 Stage 1: Identify sources of risk and scenarios for planning purposes

1. A first step in the coastal risk assessment and management process is to identify the coastal hazards that are sources of risk, as well as scenarios illustrating when and how these hazards might affect coastal areas. Chapter 2 discusses the Shoreline Change SAMP's focus on three coastal hazards which are sources of risk: storm surge, coastal erosion, and sea level rise.

2. The Shoreline Change SAMP team identified a series of scenarios, related to these sources of risk, for the purposes of coastal risk assessment and planning here in Rhode Island. As discussed in Chapter 2, there are uncertainties about the precise trajectory of future climate change and its associated impacts. Given this, scenarios based on different scientific models and assumptions are frequently used to project potential future trends associated with climate change and help decision-makers plan accordingly. This is particularly useful with regard to sea level rise, where the difference in scenarios can mean significant inundation differences between individual coastal communities considering site-specific residential, commercial, and industrial infrastructure and development decisions.

3. In their 2017 technical report issuing new sea level rise scenarios for the United States, NOAA provided guidelines for selecting and using scenarios within the context of risk assessment and management. This report notes that the most useful scenarios will create clear distinctions between risk-related policies or plans that will succeed or fail,

and that scenarios should be selected to address both short-term and long-term planning. For long planning horizons that look toward the latter part of the twenty-first century, this report emphasizes the importance of accounting for low-probability, high-consequence outcomes, noting that "for many decisions, it is essential to assess worst-case scenarios, not only those assessed as the scientifically 'likely' to happen" and that "the growing evidence of accelerated ice loss from Antarctica and Greenland only strengthens an argument for considering worst-case scenarios in coastal risk management " (NOAA 2017 p. 14 and p. 34). This approach has been adapted by other agencies, including the California Coastal Commission, whose 2015 sea level rise policy recommends that communities "analyze the highest projections of sea level rise in order to understand the implications of a worst case scenario" (California Coastal Commission 2015 p. 38). A 2017 report by the California Ocean Science Trust reinforced this, stating that "consideration of high and even extreme sea levels in decisions with implications past 2050 is needed to safeguard the people and resources of coastal California" (Griggs et al. 2017 p. 4).

4. Based on a literature review, NOAA (2017) outlined a scenario selection strategy for long-term planning and risk management. The report first recommends defining a "scientifically plausible upper-bound" scenario which is the amount of sea level rise that cannot be ruled out, even if it is low probability. They recommend using this "worst-case" or "extreme" scenario to guide overall risk and adaptation planning. Second, the report recommends defining a second central, or "mid-range," scenario that can be used as a baseline for short to mid-term planning over the next two decades. The report describes the two scenarios as together providing a "general planning envelope."

5. This approach has been incorporated into the Shoreline Change SAMP process and document. As discussed below in section 3.2, STORMTOOLS was designed around a series of storm and sea level rise scenarios.

6. Of these, CRMC has identified three primary scenarios as foci for present day and mid- and long-range coastal risk planning and management. Each scenario is described below and accompanied by a map of Roger Wheeler State Park in Narragansett to illustrate what this scenario looks like for one place in Rhode Island. As stated above, scenarios developed for the Shoreline Change SAMP are based on NOAA's 2012 sea level change analysis (NOAA 2012) as these data were the most recent available as of December 2016. CRMC expects to update these and other Shoreline Change SAMP planning tools and analyses on an ongoing basis, using the most recent SLR scenarios, as resources allow.

a. **The Present Day** scenario is characterized by a 100-year return period storm surge (see Figure 1).

Figure 1. Present-Day Scenario (100-year return period storm surge, no sea level rise) at Roger Wheeler State Park, Narragansett, RI. Colors represent flooding in feet with darker orange representing deeper water. Flooding across the dark section of the beach parking lot in this picture is approximately 7 feet deep. Shades of orange and yellow are used in this figure to represent risk under present day conditions. Map created using STORMTOOLS.

b. The **Mid-century Planning Scenario** is characterized by a 3-foot sea level rise plus a 100-year return period storm surge (see Figure 2). This scenario represents projected conditions in 2065 based on the NOAA high curve as of 2012 (NOAA 2012), upon which Shoreline Change SAMP analyses are based. Alternatively, this scenario can be thought of as a short to mid-term scenario insofar as it could also represent a 1-foot sea level rise (projected for 2035) plus an additional 2 feet of water that could be caused by an extreme high tide or wind-driven tide event. When thought of this way, this scenario addresses changing environmental conditions within the timeframe of many current 30-year residential mortgages, and is most appropriate for use by individual property owners planning structures with a shorter (e.g. 30-year) design life.

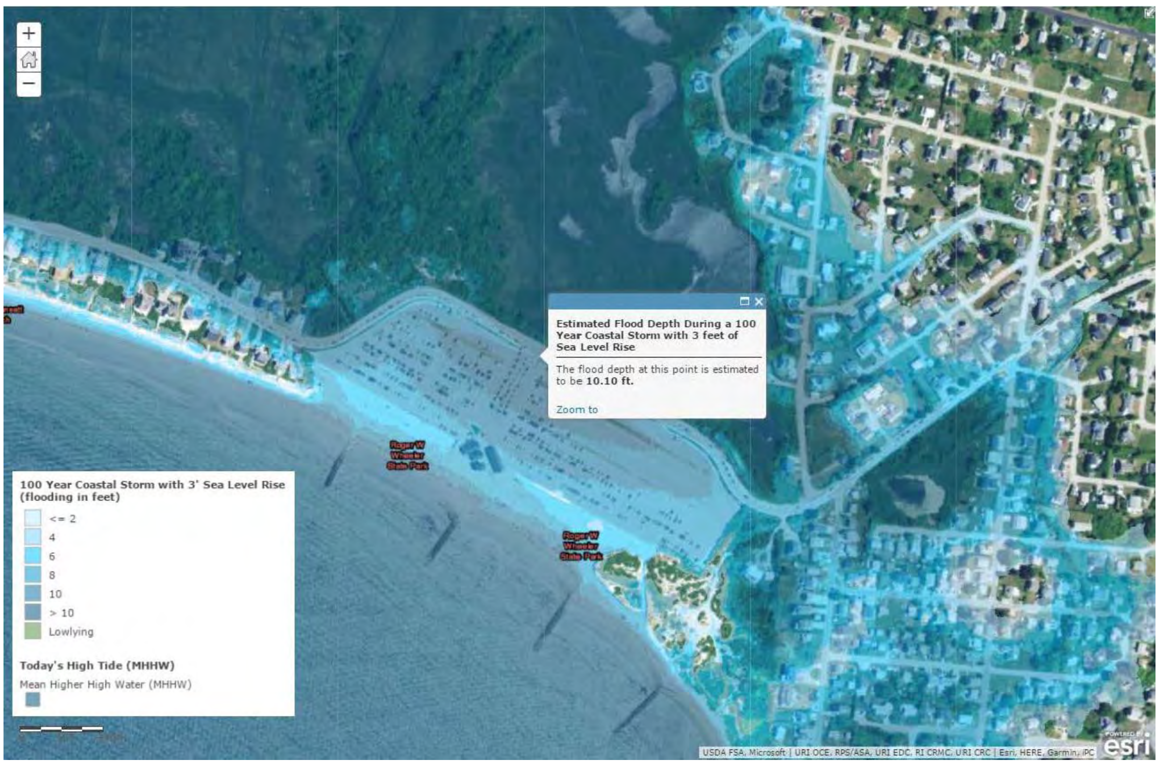

Figure 2. Mid-century Planning Scenario (3-foot sea level rise plus a 100-year return period storm surge) at Roger Wheeler State Park, Narragansett, RI. Colors represent flooding in feet with darker blue representing deeper water. Flooding across the darkest section of the beach parking lot in this picture is greater than 10 feet deep. Shades of blue are used in this map to represent risk under future conditions, as opposed to shades of orange which are used in other figures to represent present day conditions. Map created using STORMTOOLS.

c. The **Long-range Planning Scenario**, characterized by a 7-foot sea level rise plus a 100-year return period storm surge (see Figure 3). This scenario represents projected conditions in 2100 based on the NOAA high curve (NOAA 2012). It is the Shoreline Change SAMP's plausible "upper-bound" or "extreme" scenario as recommended in the NOAA National Ocean Service's guidance, addressing conditions that are currently considered low probability but high consequence. This scenario addresses long-term condition changes and is most appropriate for use by planners considering longer design life projects (e.g. bridges and sewage treatment plants) requiring significant capital investment.

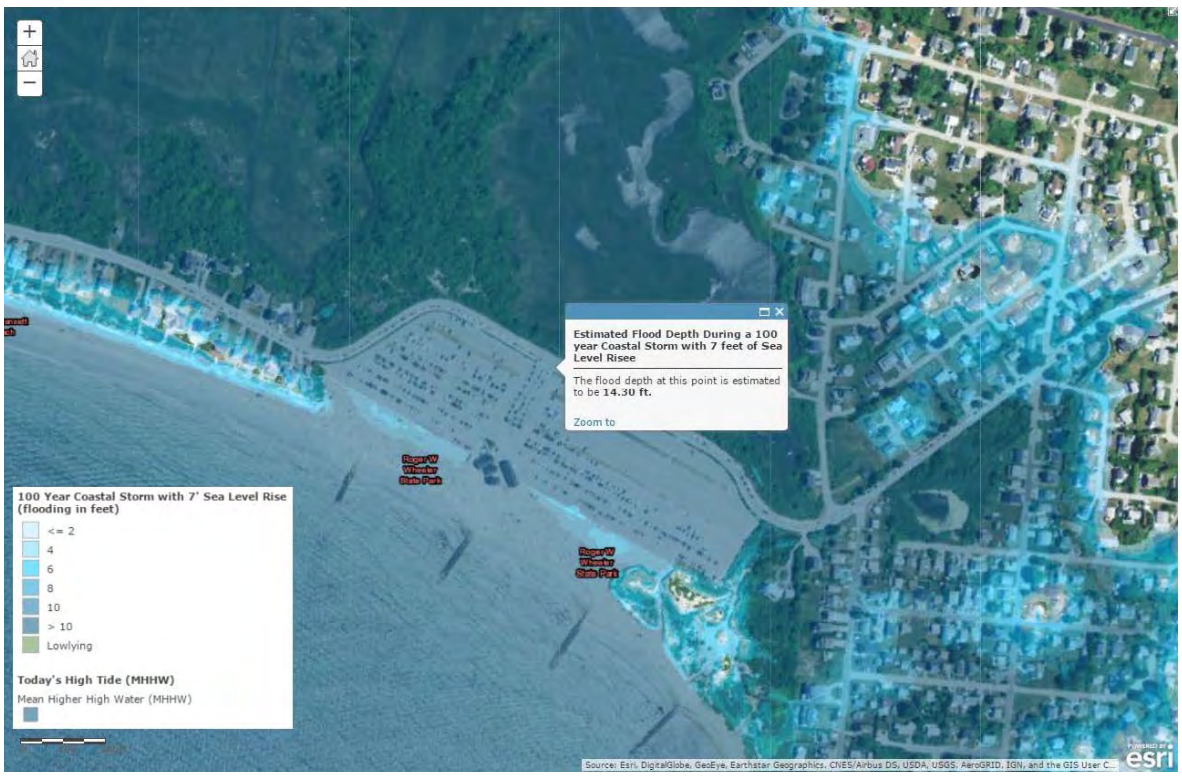

Figure 3. Long-range Planning Scenario (7-foot sea level rise plus a 100-year return period storm surge) at Roger Wheeler State Park, Narragansett, RI. Colors represent flooding in feet with darker blue representing deeper water. Flooding across the dark sections of the beach parking lot in this picture is over 14 feet deep in some places. Shades of blue are used in this map to represent risk under future conditions, as opposed to shades of orange which are used in other figures to represent present day conditions. Map created using STORMTOOLS.

7. CRMC selected the Mid-century and Long-range scenarios to clearly distinguish between mid- and long-range planning. CRMC also selected the Mid-century scenario because at mid-century the differences between the 2012 NOAA "high" curve, adopted for the Shoreline Change SAMP, and other projected sea level rise curves is relatively small, whereas by the end of the 21st century, the differences between these curves are much greater (see Chapter 2 for further discussion and figures).

8. CRMC recommends that individual property owners use the Mid-century Planning Scenario *at a minimum* in order to assess their risk between now and mid-century. This shorter timeframe may be more accessible for property owners, especially given that it conceivably includes conditions that could take place during the timeframe of a 30-year mortgage. CRMC recommends that decision-makers use the Long-range Planning Scenario for infrastructure planning, capital investment decisions, and other long-term planning. Adaptation measures that can be used to plan for these scenarios are discussed in Chapter 7.

3.1.5.3 Stage 2: Assess risk

1. The second stage of the coastal risk assessment and management process is to assess risk for a particular location, utilizing information about the sources of risk and the planning scenarios described above. This process can help property owners or decision-makers better understand the coastal hazards of concern as well as the consequences of that hazard affecting their property or jurisdiction. CRMC has developed tools and guidance and has assembled a suite of data and information to help decision-makers and property owners assess their risk.

2. Section 3.2 of this chapter describes tools that can be used to assess coastal risk in Rhode Island. Shoreline Change SAMP Chapter 4 includes a suite of data and information about the state's exposure to sources of risk that provides context for more focused or site-specific risk assessment. Chapter 5 includes guidance for individual property owner applicants to help them assess and minimize risk to their properties. Chapter 6 includes guidance for municipalities and other state agencies. These tools, guidance, and chapters are all based upon the sources of risk and planning scenarios discussed in this chapter.

3.1.5.4 Stage 3: Choose measures of adaptation

1. The third stage of the coastal risk assessment and management process involves choosing measures of adaptation in order to manage risk. Importantly, this stage also involves employing adaptive management: adaptation measures may need to be modified over time to respond to changing conditions. This may also require reassessing risk (Stage 2), revisiting other stages of this process, or considering alternative sites. Shoreline Change SAMP Chapter 7 outlines a suite of adaptation measures from which property owners and decision-makers can choose. The guidance for applicants provided in Chapter 5 includes steps that encourage property owners and decision-makers to identify, document, and assess the feasibility of design techniques that could help avoid or minimize risk.

3.1.5.5 Stage 4: Implementation

1. The fourth stage of this process is to implement adaptation measures, i.e. those intended to avoid or minimize risk. Implementation occurs after the steps outlined in Chapter 5 have been completed and a property owner has received a coastal permit.

3.1.5.6 Stage 5: Monitoring and evaluation

1. The final stage of this process involves monitoring and evaluating adaptation measures to determine whether and how they are helping the property owner or decision-maker to manage coastal risk. Monitoring and evaluation may be conducted by the individual property owner or contractor and also by a permitting agency like CRMC. Monitoring and evaluation involves adaptive management. If monitoring and evaluation reveal that adaptation measures are not sufficient to manage coastal risk, a property owner or decision-maker may choose to modify the adaptation measure, or may revisit earlier stages of the coastal risk management and assessment process.

3.2 Tools to Assess Coastal Risk in Rhode Island

3.2.1 Overview

1. In order to understand risks, plan wisely, and prepare for the future, the RI Shoreline Change SAMP placed emphasis on developing mapping tools specific to Rhode Island's coastline that offer an accurate depiction of exposure to coastal hazards. Using the best available science and data from both federal agencies and the researchers at the University of Rhode Island, modeling techniques can illustrate flooding levels from a historic hurricane, such as Hurricane Carol (1954), and simulate the exposure to Rhode Island's coastline if it occurred today. Through application of sea level rise projections from NOAA, Rhode Island can also estimate future risk with these same tools to show how our shoreline might change in the future, and what areas are most at risk from future storm events.

2. To illustrate exposure from storm surge and projected sea level rise, the RI Shoreline Change SAMP developed STORMTOOLS. The vision for STORMTOOLS is to provide access a suite of coastal planning tools (numerical models, etc.), available as a web service, that allows widespread accessibly and applicability at high resolution for user selected coastal areas of interest (Spaulding et al., 2015).

3. Developing decision support tools in the form of maps and online analyses of the maps positions Rhode Island to be more accurate in providing information to coastal property owners in the state's 21 coastal municipalities. The Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps (FIRMs) have historically been used by state and local land managers to understand flood risk across Rhode Island, and by property owners to understand how their flood insurance premiums are calculated (see https://www.fema.gov/flood-mapping-products). The STORMTOOLS suite of online maps will provide the foundation for CRMC's decision making for coastal permit applications, while addressing concerns over the accuracy of the FEMA FIRMs, and the fact that FEMA does not map or model future risk from sea level rise.

3.2.2 Pre-Existing Regulatory Tools to Assess Coastal Risk

3.2.2.1 FEMA Flood Insurance Rate Maps (FIRMs)

1. The FEMA Flood Map Service Center (MSC) is the official public source for flood hazard information produced in support of the National Flood Insurance Program (NFIP). The National Flood Hazard Layer (NFHL) is a digital database that contains flood hazard mapping data from FEMA's NFIP. This map data is derived from FIRM databases and Letters of Map Revision (LOMRs).The NFHL is for community officials and members looking to view effective regulatory flood hazard information in a Geographic Information Systems (GIS) application.

2. The RI Floodplain Mapping Tool (https://www.arcgis.com/home/item.html?id=4d2f5d2c277e45e2b771b04c76c02f0e) helps visualize regulatory FEMA flood insurance rate maps or FIRMs. The tool allows you to zoom into any Rhode Island location to determine the designated FEMA floodplain. These maps illustrate today's flood zones calculated using past storm events, but do not project future conditions. These maps inform property owners about the level of flood risk which determines the flood insurance rate for a given property. The floodplain designation also carries with it development requirements outlined in the Rhode Island Building Code.

3.2.2.2 CRMC Historic Shoreline Change maps

1. The purpose of these maps is to show shoreline rates of change that will be applied to pertinent sections of CRMC's regulatory programs to address issues including setbacks of activities from coastal features.

2. The Shoreline Change maps illustrate shoreline rates of change over time and how erosion is affecting coastal properties. Shorelines may be viewed as stable but the rate of erosion can change dramatically with every storm event that hits Rhode Island. The erosion rates are used by CRMC to determine setbacks for coastal developments: residential structures are evaluated with a 30-year annualized erosion rate, and commercial structures require a 60-year annualized erosion rate. These maps are all in a downloadable PDF format for an area of interest. Transects have been drawn across all of RI's coastline. Maps show the actual shoreline change distance and the long term rate of change between 1939 and 2003/2004 for Narragansett Bay and between 1939 and 2014 for Washington County. The colored lines on the map correspond with the year that the shoreline as mapped. To access the CRMC Historic Shoreline Change Maps, see http://www.crmc.ri.gov/maps/maps_shorechange.html.

3.2.3 RI Shoreline Change SAMP Planning Tools to Assess Coastal Risk in Rhode Island

What is a return period?

A return period (***recurrence interval***) is a statistical estimate of the likelihood that an event (such as flooding, normally expressed in terms of the water level for a given return period) is exceeded in any one year. As an example, a 100 yr flood event has a 1/100= 0.01 or 1% chance of being exceeded in any one year, while a 500 yr flood event has a 1/500 =0.002 or 0.2% chance of being exceeded in any one year. The 100 and 500 yr return period water levels are most commonly used to assess flooding risk, establish flood insurance rates, and the design of structures and infrastructure. Nuisance flooding is typically described as events that have shorter return periods (1 to 10 yr). For storm surge, the analyses are typically based on historical observations at selected locations or predictions made by numerical hydrodynamic models. Statistical methods are required to perform the analyses for risk assessment since the record lengths of observations are typically less than 100 yrs and hence the number of observations at the longer return periods are very limited. The analysis assumes that the probability of the event occurring does not vary over time and is independent of past events.

1. To illustrate the threat of sea level rise and coastal storms, including nor'easters, tropical storms, and hurricanes over the 400+ miles of Rhode Island's coastline, the CRMC and University of Rhode Island partners created STORMTOOLS. STORMTOOLS is intended for use by coastal cities and towns in Rhode Island to better understand the inland reach of floodwaters from high tides and storm events, and estimate the possible depth of water during flooding. STORMTOOLS offers a risk profile for coastal inundation only. It does not include wind speeds nor storm-generated waves, nor other storm parameters that might be used to estimate storm strength or estimate the damage from hurricanes. STORMTOOLS can be accessed at http://www.beachsamp.org/stormtools/.

2. The user interface for STORMTOOLS has been designed to operate on ESRI's ArcGIS Online platform, and includes two types of mapping tools: (1) interactive maps, where users can control which layers are viewable on a given map, and (2) ArcGIS online story maps or map journals that serve to walk a user through a narrative with corresponding maps tailored to the specific scenario or issue. Both tools allow users to enter any address in Rhode Island to zoom into an area of interest and view different storm and sea level scenarios. The user can click on map itself to see pop-up boxes with data specific to the location of interest, such as the water depth at a desired location. STORMTOOLS was designed to be accessed online through

ArcGIS.com and be publicly available without requiring software downloads or extensive training.

3. Spaulding, Isaji, Damon, and Fugate (2015) summarized the science behind STORMTOOLS in the paper "Application of STORMTOOLS's simplified flood inundation model, with and without sea level rise, to RI coastal waters." STORMTOOLS maps use statewide LiDAR digital elevation model data, provided in 2011 by the Army Corps of Engineers, and inundation layers generated based on state of the art model wind, surge, and wave predictions for tropical and extratropical storms that were completed in 2015 during the U.S. Army Corps of Engineers' North Atlantic Coast Comprehensive Study (NACCS) initiative. The major steps included the following:

   a. Determine the spatial structure of the surge response in RI, relative to water level data at Newport, RI, a primary NOAA gauging station.

   b. Use water levels vs. return period data at Newport at the upper 95% confidence level and then estimate the water levels at all other locations using the scaling laws developed in Step 1 for the selected recurrence interval.

   c. Water levels are referenced to NAVD88 but can easily be changed to a Mean Higher High Water (MHHW) reference. Maps are available that give water levels relative to both NAVD88 and MHHW.

   d. Flood depths (inundation depths) are determined by subtracting the local land elevation (topography) from the water height.

4. A return period, also known as a recurrence interval, is an estimate of the likelihood of an event, such as a flood or storm, to occur. It is a statistical measurement typically based on historical storms. For example, a "100-year return period storm" refers to the statistical probability that there will be one storm of that magnitude within a given 100-year period. Another way to understand this is as annual chance: a 100-year return period storm means there is a 1 in 100, or 1%, chance that a storm of that magnitude will take place in any given year. Return periods are commonly used to describe storms that have a low annual probability of taking place, such as a 100- or a 500-year return period storm. However this same concept applies to storms that may occur more frequently, such as a 10-year so-called "nuisance" storm, which has a 10% chance of taking place in any given year.

5. Return periods are especially useful when used to determine the likelihood of a property being flooded over shorter timeframes, such as the course of a 30-year mortgage. below provides the percent chance of flooding for a range of different

return periods and years. For example, over the course of a 30-year mortgage, a 100-year return period storm has a 26% chance of occurring in any one of those 30 years while a 10-year return period storm has a 95.8% chance of occurring in one of those 30 years.

Table 1. Percent chance of flooding for a given return period and a given number of years (Spaulding, pers. comm.)

Percent chance of flooding for a given return period and a given number of years									
Flood Return	Percent (%)chance	Percent(%) chance of flooding occurring in this number of years							
Period (yrs)	flooding in any	1	10	25	30	50	100	200	500
	given year								
10	10.0%	10.0%	65.1%	92.8%	95.8%	99.5%	100.0%	100.0%	100.0%
25	4.0%	4.0%	33.5%	64.0%	70.6%	87.0%	98.3%	100.0%	100.0%
30	3.3%	3.3%	28.8%	57.2%	63.8%	81.6%	96.6%	99.9%	100.0%
50	2.0%	2.0%	18.3%	39.7%	45.5%	63.6%	86.7%	98.2%	100.0%
100	1.0%	1.0%	9.6%	22.2%	26.0%	39.5%	63.4%	86.6%	99.3%
200	0.5%	0.5%	4.9%	11.8%	14.0%	22.2%	39.4%	63.3%	91.8%
500	0.2%	0.2%	2.0%	4.9%	5.8%	9.5%	18.1%	33.0%	63.2%

6. The CRMC utilizes return period terminology throughout this Shoreline Change SAMP document and in STORMTOOLS for future planning purposes. For example, STORMTOOLS enables users to examine the water extent and depth associated with 25, 50, 100 and 500-year return period storm events now and in the future, and several scenarios used in Chapter 4 to characterize Rhode Island's exposure are premised upon the 100-year return period storm scenario. In another example of the use of this concept in planning, the CRMC used a 1,000-year return period storm to evaluate the engineering specs of the Block Island Wind Farm.

7. The terms "100-year return period storm" and "500-year return period storm" as utilized in STORMTOOLS are similar to terms used to characterize the 100-year and 500-year floodplains as used by the Federal Emergency Management Agency (FEMA), but the water levels may be different due to the use of different confidence intervals. Storm return periods included in the RI Shoreline Change SAMP and STORMTOOLS characterize future conditions for planning purposes, whereas floodplains defined by FEMA are mapped based on past conditions and are used for regulatory purposes.

8. The concept of a water level return period assumes that the probability of a water level associated with a storm's occurrence will not change over time. However this does not account for sea level rise and other effects of climate change, such as changing storm intensity. Over time, as sea levels rise, water levels associated with

what is thought of as today's 100-year return period storm will increase, because a higher base sea level will increase the extent and depth of storm-related flooding. As a result, the 100-year return period storm of the future could result in much more flood-related damage than the 100-year return period storm of today. Further, from the perspective of water levels, SLR will cause today's 100-year return period storm to become a more regularly-occurring storm. For example, Figure 4 illustrates how a 2-foot SLR changes the 100-year return period storm event of today to a 20-year return period storm (Spaulding, pers. comm.). In other words, a future 20-year return period storm on top of a 2-foot SLR will have the same water level and depth as today's 100-year return period storm.

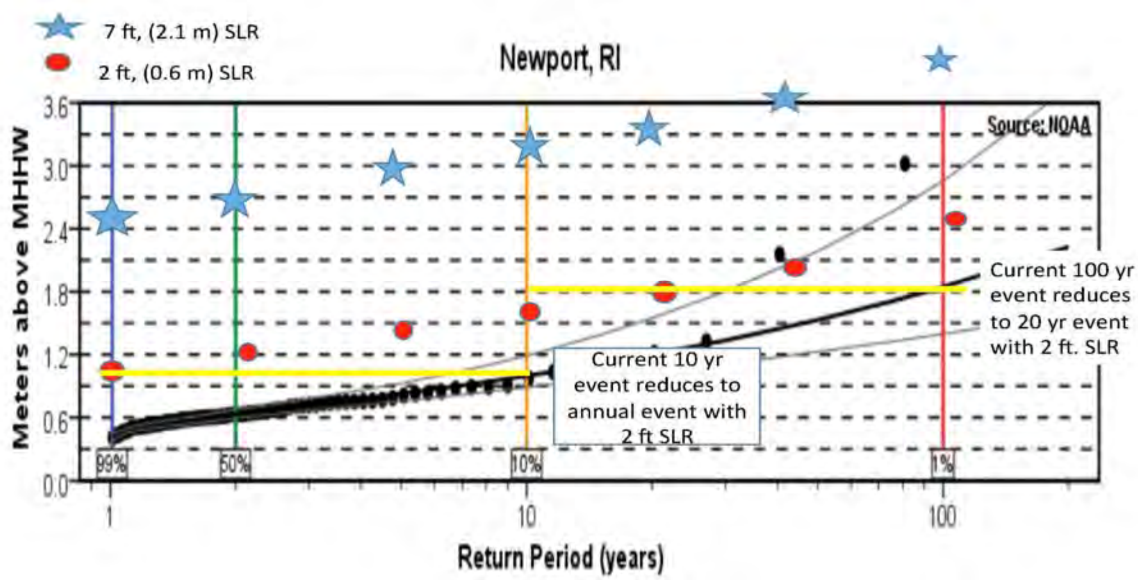

Figure 4. The effect of sea level rise on storm return periods (Spaulding, pers. comm.)

9. STORMTOOLS illustrates water extent and depth at any given point for nuisance floods (1, 3, 5, and 10-year return periods) and the 25, 50, 100, and 500 year return period storm scenarios at the 95% confidence interval. The 95% confidence interval incorporates some of the uncertainty associated with higher intensity storms. Sea level rise scenarios of 1, 2, 3, 5, and 7 feet on their own, and combined with each storm surge scenario, are also modeled. Flooding maps are also provided for historical hurricanes to include 1938, 1954 (Carol), 1991 (Bob), and 2012 (Sandy). See Table 2 for a summary of the storm and sea level scenarios mapped as part of STORMTOOLS.

Table 2. STORMTOOLS mapped sea level and storm scenarios

	NUISANCE STORMS return period (% annual chance)				EXTRA-TROPICAL/HURRICANES return period (% annual chance)			
Sea Level Rise Scenario	**1-yr (100%)**	**3-yr (33%)**	**5-yr (20%)**	**10-yr (10%)**	**25-yr (4%)**	**50-yr (2%)**	**100-yr (1%)**	**500-yr (0.2%)**
Today (MHHW)	✓	✓	✓	✓	✓	✓	✓	✓
1-foot	✓	✓	✓	✓	✓	✓	✓	
2-feet	✓	✓	✓	✓	✓	✓	✓	
3-feet	✓	✓	✓	✓	✓	✓	✓	
5-feet	✓	✓	✓	✓	✓	✓	✓	
7-feet	✓	✓	✓	✓	✓	✓	✓	
10-feet							✓	
12-feet							✓	

10. As stated above, in STORMTOOLS, SLR scenarios are derived from the NOAA "high" SLR curve based on a 2012 analysis (NOAA 2012). These were the most current available data as of December 2016. CRMC expects to update STORMTOOLS scenarios and other Shoreline Change SAMP tools and analyses in the future as resources allow.

11. In STORMTOOLS, flood levels are typically referenced to NAVD 88 (but can be depicted relative to MHHW) in order to show the maximum extent and depth the flooding would reach. The sea level scenarios illustrated in STORMTOOLS can also be used to show impacts of astronomical high tides (Perigean Spring Tides), which are especially large tidal ranges (difference between High and Low Water) that happen on a predictable basis throughout the year. Spring Tides occur roughly every 14 days, when the sun and the moon are lined up and the combined pull of their gravitational force makes the tides more extreme. These occur at the full and new moons and usually last for three to four days. "King Tides" is a non-scientific term that is given to especially large spring tides, at least 1 foot higher than MHHW. During King Tides in Rhode Island, high tide can be over 1.5 feet higher than MHHW and can cause coastal flooding without any help from a storm.

12. Currently, STORMTOOLS shows coastal flooding but *does not* show freshwater flooding from rainfall or rivers and *does not* show flooding entering streets through stormwater drains, nor does it evaluate rising groundwater tables. The inundation levels do not reflect wave height but the still water level. For information on modeled local wave height during an event, use our NACCS wave point layer.

13. For STORMTOOLS, the 95% confidence interval is the widely accepted confidence level required to make scientific and statistically reliable assumptions. Some flood mappers use the 50% confidence interval, or the average. This would mean that there is a 50% chance that the flood will be as high as the estimated water level, and a 50% chance it could be worse. STORMTOOLS uses the 95% confidence interval, meaning there is a 95% chance the flood level and associated inundation depth will not reach higher than that level, and a 5% chance it will be worse.

14. At the simplest level, STORMTOOLS can be used to access flooding estimates for the study area and problem of interest for coastal planners and current and potential homeowners. At a more sophisticated level, the system can be used by professionals to perform studies in support of coastal planning and engineering design. The impact of variations in coastal topography and implementation of potential shoreline protection studies can be evaluated for varying return period events, with or without sea level rise. STORMTOOLS dramatically enhances the ability to use state-of-the-art tools in support of coastal resilience planning and management.

3.2.3.2 Projected Shoreline Change Maps

1. Oakley, Hollis, Patrolia, Rinaldi and Boothroyd (2016) conducted an analysis of projected shoreline change, out to 2100, for the Rhode Island south shore. The projection of future shoreline change is a complex and sometimes controversial practice and findings should be interpreted with caution. The authors built upon previous studies of projected shoreline change including Anderson et al. (2015) and Moore (2007). For a complete discussion of methods, see the study technical report at www.beachsamp.org. Importantly, this study should not be confused with CRMC's historic shoreline change maps discussed above in section 3.2.2.

2. Oakley et al.'s analysis employed a qualitative modeling approach and examined shoreline change projections for an "exponential high scenario" for 2100 based on a shoreline change rate that increases at an exponential rate of 2.5 times the historical trend by 2065. This rate was further extrapolated to increase exponentially to 2100.

3. Oakley et al. produced 90 large-format maps depicting projected shoreline change for all of Rhode Island's south shore communities. Sample results are highlighted in section 4.6.2; see www.beachsamp.org to view projected shoreline change maps for all communities. CRMC's historic shoreline change maps are an entirely separate product which can be viewed at www.crmc.ri.gov/maps/maps_shorechange.html.

4. Oakley et al.'s analysis also considered the policy implications of these projections by projecting future setbacks for coastal development based on CRMC's existing coastal policy. The projected shoreline change analysis assumed that the coastal feature (e.g. dune or bluff), as defined in the RICRMP, would migrate as well, maintaining a constant distance from the location of the shoreline. The projected future location of coastal features was used with some of CRMC's existing coastal construction setback requirements (30x the annual erosion rate for residential structures and 60x for commercial) to project future setback requirements, thus illustrating the potential effect of projected shoreline change on coastal development. Sample results are highlighted in section 4.3.3; see www.beachsamp.org to view maps for all communities.

3.2.3.3 STORMTOOLS: Coastal Environmental Risk Index (CERI)

1. To address challenges facing coastal zone managers and municipal planners, the RI Shoreline Change SAMP identified the need to development an objective, quantitative assessment of the risk to structures, infrastructure, and public safety that coastal communities face from storm surge in the presence of changing climatic conditions, particularly sea level rise and coastal erosion.

2. CERI was developed as a proof-of-concept within the context of the on-going STORMTOOLS mapping effort for two pilot coastal communities, one located in Washington County (subject to a more severe wave environment) and the other in upper Narragansett Bay. The project team selected the Town of Charlestown and the City of Warwick as the representative project pilot communities. The next phase of the project, which is ongoing as of the time of this writing, will focus on the municipalities of Barrington, Bristol and Warren.

3. The CERI project set out to holistically examine the impacts of coastal erosion, storm surge and waves associated with different storm intensities, and the increased tidal inundation due to sea level rise across all coastal communities in Rhode Island; and to develop a single exposure index to help municipalities and the state better plan for future environmental conditions. CERI will be shared through the CRMC, in partnership with the University of Rhode Island (URI), with state and local decision makers to better inform land use decisions and adaptation strategies aimed at increasing community coastal resiliency.

4. The CERI project goal is to develop an index and mapping tool that provides a summary of the risk coastal areas face from storm-induced flooding and the associated wave environment, sea level rise, and shoreline erosion/accretion, and apply it to RI coastal communities. These parameters represent the principal environmental variables that dominate the physical aspects of coastal vulnerability. The spatial scale of the index will be consistent with the best available digital elevation model along the coastline, with a user selected temporal scale, using the standard return period analysis based approach (e.g., 100-year return period storm, with and without sea level rise scenarios).

5. The CERI pilot project set out to test the application of CERI in an area with more erosion and wave action (Charlestown), and a second Bay community (Warwick) that is more influenced by inundation due to sea level rise or storm surge. These two pilot sites allow the CERI framework to be developed and tested under different environmental conditions and will allow for future application across the entire Rhode Island coastline. Eventually, the plan is to generate maps for all flood inundated coastal waters of the state of RI for the 100-year return period storm with 2 and 7 feet of sea level rise.

6. To create CERI, state of the art modeling tools (ADCIRC and STWAVE) were applied to predict storm surge and wave, combined with shoreline change maps (erosion), and damage functions. Access to the state E911 emergency database of structures provides information on structure characteristics and the ability to perform analyses for individual structures.

7. CERI is being designed as an online Geographic Information System (GIS) based tool, and hence is fully compatible with current flooding maps, including those from FEMA. The basic framework and associated GIS methods can be readily applied to any coastal area. The approach can be used by local and state planners to objectively evaluate different policy options for effectiveness and cost/benefit.

8. Three peer-reviewed technical papers have been developed (listed below), as well as two online mapping tools: the generic base maps and the more detailed maps by structure/infrastructure. The maps are available via the STORMTOOLS web-based map viewer. The maps can then be viewed on the website or downloaded and used to support state and local planning efforts.

    a. Spaulding, M.L.; Grilli, A.; Damon, C.; Crean, T.; Fugate, G.; Oakley, B.A.; Stempel, P. STORMTOOLS: Coastal Environmental Risk Index (CERI). *Journal of Marine Science and Engineering* 2016, *4*, 54.

    b. Spaulding, M.L.; Grilli, A.; Damon, C.; Fugate, G.; Oakley, B.A.; Isaji, T.; Schambach, L. Application of State of Art Modeling Techniques to Predict Flooding and Waves for an Exposed Coastal Area. *Journal of Marine Science and Engineering* 2017, *5*, 10.

    c. Spaulding, M.L.; Grilli, A.; Damon, C.; Fugate, G.; Isaji, T.; Schambach, L. Application of State of the Art Modeling Techniques to Predict Flooding and Waves for a Coastal Area within a Protected Bay. *Journal of Marine Science and Engineering* 2017, *5*, 14.

3.2.3.4 STORMTOOLS: CERI-STORMTOOLS Design Elevations (CERI-SDE)

1. This section describes the development of STORMTOOLS: CERI-STORMTOOLS Design Elevations (CERI-SDE). As described earlier in this Chapter, FEMA's mapping products and regulations are based on historical data and are designed to help property owners prepare for and address possible current conditions. FEMA FIRMs are embedded in the state building code and have regulatory status. Consideration is also given to freeboard requirements that have been continually adjusted by state law. The FIRMs do not, however, include sea level rise. An in depth review of the FEMA FIRMs and comparison to similar maps generated as part of the CERI initiative for Warwick and Charlestown, RI (Spaulding et al., 2016, 2017) show some very serious concerns with the FEMA maps, in particular related to wave forcing and dune erosion dominating those communities along the southern RI coast and setting the inundation levels inside Narragansett Bay.

2. Considering that STORMTOOLS offers property owners a glimpse into future conditions, the RI Shoreline Change SAMP set out to provide a new set of elevation numbers that property owners could consider when proposing new development or improvements as part of a CRMC coastal development permit application. The STORMTOOLS: CERI - STORMTOOLS Design Elevation (CERI-SDE) seeks to develop a recommended base flood elevation to account for sea level rise when comparing with the base flood elevation represented in the FEMA FIRMs. The CERI-SDE name has been selected to distinguish the proposed maps, which are intended to be used as guidelines for coastal planning, from FEMA FIRMS which are regulatory.

3. Under the STORMTOOLS initiative, a series of maps for the 100-year return period flood, with varying values of sea level rise (1 to 12 feet), have been developed and made accessible in an online map viewer. These maps are useful in providing insight into areas that will potentially be inundated in the future from sea level rise. The maps, however, do not provide the corresponding estimate of waves in these flood inundated areas. Thus, it is impossible to develop estimates of the Base Flood Elevation (BFE) (inundation plus wave heights) that are used in the design of structures and infrastructure based on the STORMTOOLS flooding maps. The FEMA FIRMs, while providing estimates of the BFEs for the 100-year event, do not provide maps that address the effects of sea level rise.

4. Under the STORMTOOLS: CERI initiative (Spaulding et al., 2016) maps are being developed as part of the effort to assess damage to structures. To date, these CERI-SDE maps have been developed for Charlestown and Warwick, RI (Spaulding et al.,

2016, 2017). Maps have been generated for the 100-year return period storm, with 0, 2, and 7 feet of sea level rise. Application of CERI, including the generation of the CERI-SDE maps, for Warren, Barrington, and Bristol, and the south coast communities of Narragansett, South Kingstown and Westerly are under development.

5. CRMC adopted STORMTOOLS as part of their Sea Level Rise policy and planning activities in 2016 and, at the time of this writing, is working to generate these CERI-SDE maps for all 21 coastal communities.

3.2.3.5 Sea Level Affecting Marshes Model (SLAMM)

1. In 2015, the CRMC completed an analysis of the potential impacts of sea level rise on coastal wetlands. The analysis included modeling of potential coastal wetland loss as well as the landward migration potential of coastal wetlands located within Rhode Island’s 21 coastal communities (RI CRMC 2015; hereafter “SLAMM study”). This analysis applied the Sea Level Affecting Marshes Model (SLAMM) and used 2011 state LiDAR elevation data and the 2010 National Wetland Inventory dataset to model SLR projections of 1, 3, and 5 feet (above 1990 levels).

2. The SLAMM maps illustrate sea level rise and how future wetland migration is projected to transform the landscape. These models were used to both simulate short- and long-term impacts on coastal wetlands and to assess potential upland wetland migration pathways. The maps illustrate where new marshes are likely to appear from daily tides at the higher sea level, as well as potential marsh loss, or where the marshes will be permanently covered by sea water.

3. Importantly the SLAMM study acknowledges several limitations of the SLAMM model and findings. Data used in the study to characterize wetland baseline conditions did not include information on some key indicators of wetland condition that reflect stress and degradation due to SLR. Additionally, the authors point out model limitations that may indicate that future new marsh development is overestimated, rate and extent of wetland loss are underestimated, and results regarding barrier systems contain a higher degree of uncertainty (RICRMC 2015). Specifically, limitations associated with model inputs such as existing wetlands data, LiDAR elevation data, accretion rates, barrier system dynamics and recently updated sea level rise rates may mean that model results may overestimate future new marsh migration and underestimate the rate and extent of future wetland loss. This assumption is supported by recent observational data. Cole Ekberg et al. (2017) also point out that LiDAR elevations (which were used in the SLAMM) consistently overestimate marsh elevation. For these

reasons, SLAMM study results should be used with caution and as a general planning tool only, especially when considering potential marsh migration.

4. SLAMM maps are intended to support state and local community planning efforts and to help decision makers prepare for and adapt to future coastal wetland conditions despite the inherent uncertainties associated with future rates of sea level rise. For further information see RI CRMC (2015). Specific community results are included in sections 4.3.2.3 and 4.3.2.4.

3.2.4 Regional Coastal Mapping Services

1. While the tools above have been developed to illustrate coastal hazard exposure for Rhode Island's 400 miles of coastline, the RI Shoreline Change SAMP project team also relies upon the following tools to investigate regional trends of coastal hazards, and supplement data and information not currently offered by the STORMTOOLS suite of maps.
2. **"Coastal Flood Exposure Mapper"** (created by the NOAA Office for Coastal Management as part of NOAA Digital Coast): This online visualization tool supports communities that are assessing their coastal hazard risks and vulnerabilities. The tool creates a collection of user-defined maps that show the people, places, and natural resources exposed to coastal flooding. The maps can be saved, downloaded, or shared to communicate flood exposure and potential impacts. In addition, the tool provides guidance for using these maps to engage community members and stakeholders. The current geography includes the East Coast and Gulf of Mexico. For further information see https://coast.noaa.gov/digitalcoast/tools/flood-exposure.html.
3. **"Surging Seas Risk Finder"** (created by Climate Central) - Climate Central's Surging Seas Risk Finder aims to provide citizens, communities and policymakers with easily accessible, science-based, local information to help you understand and respond to the risks of sea level rise and coastal flooding. Risk Finder also provides customized downloadable tables and figures to make it easier for you to spread the word. The interactive toolkit includes maps, local sea level and flood risk projections, and potential impacts for population, land, and, depending upon location, other variables. It analyzes and compares risks among different administrative units as a way to identify hot spots of concern. For further information see https://riskfinder.climatecentral.org/about/.
4. See Table 3 below for a comparison of STORMTOOLS with these and other mapping tools.

Table 3. Comparison of STORMTOOLS with other mapping tools

NAME OF TOOL OR ONLINE MAPPER	Property Level Resolution	Storm Inundation Extent	Surge Levels/ Height	SLR Inundation Extent	Pixel-Level Inundation Depth	Wave Height	Erosion: Current Rates & Projected Change	Socio-economic data	Emergency Services Locations	Synergistic Interactions among Forces
STORMTOOLS (1m resolution)[a]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C-CAP[b]	✓	✓	✓	✓						
CREAT[c]										
Coastal Change Hazards Portal[d]										
Coastal County Snapshot[e]		✓						✓	✓	
Coastal Flood Exposure Mapper[f]		✓	✓	✓				✓	✓	
Extreme Water Levels[g]			✓							
FEMA GeoPlatform[h]		✓	✓						✓	
Inundation Analysis Tool[i]			✓							

Sea Level Rise Viewer[j]	✓		✓	✓				✓		
Sea Level Trends[k]			✓							
Surging Seas: Risk Zone Map[l]		✓	✓	✓				✓		
Surging Seas: Risk Finder[m]		✓	✓	✓				✓		

a. STORMTOOLS: http://www.beachsamp.org/stormtools/
b. C-CAP: https://coast.noaa.gov/ccapatlas/
c. CREAT: https://www.epa.gov/crwu/build-climate-resilience-your-utility
d. Coastal Change Hazards Portal: http://marine.usgs.gov/coastalchangehazardsportal/
e. Coastal County Snapshot: https://coast.noaa.gov/snapshots/
f. Coastal Flood Exposure Mapper: https://coast.noaa.gov/digitalcoast/tools/flood-exposure
g. Extreme Water Levels: http://tidesandcurrents.noaa.gov/est/est_states.shtml?region=ri
h. FEMA GeoPlatform: https://fema.maps.arcgis.com/home/item.html?id=cbe088e7c8704464aa0fc34eb99e7f30
i. Inundation Analysis Tool: https://tidesandcurrents.noaa.gov/inundation/
j. Sea Level Rise Viewer: https://coast.noaa.gov/digitalcoast/tools/slr.html
k. Sea Level Trends: http://tidesandcurrents.noaa.gov/sltrends/sltrends.html
l. Surging Seas: Risk Zone Map: http://sealevel.climatecentral.org/maps/risk-zone
m. Surging Seas: Risk Finder: http://riskfinder.climatecentral.org/about

3.3 Future Research Needs

1. The STORMTOOLS Coastal Environmental Risk Index (CERI) was developed as part of this Shoreline Change SAMP to assess the risk and damage to structures, has been applied to Warwick and Charlestown, with application to Barrington, Bristol, and Warren currently in progress. Seniors in the University of Rhode Island Ocean Engineering program have applied the method to Matunuck and Misquamicut and to downtown Providence and the area protected by the Fox Point hurricane barrier. To continue to build on work that has been completed or in progress the following are recommended.

    a) ***CERI Mobile Risk and Damage APP.*** In presenting results of STORMTOOLS flooding maps and CERI to regulators, permit applicants, state and town planners, builders, insurance and real estate agents, bankers, and the public, the issue of how best to provide access to the information was a repeated theme. While web access was found to be very useful, the overwhelming response was to take the next step and develop a mobile telephone app to meet this need. The goal of this effort is therefore to develop an app that will provide access to flood and wind risk and associated damages for a user selected structure. The app would provide an overview of key attributes of the site (e.g. grade elevation, inundation depth for selected SLR, location relative to erosion setback, freeboard allowance, building height restrictions, etc.), the ASCE 7-16 hazard assessment for the site (American Society of Civil Engineers 2017), and the results of CERI for the structure selected for both flooding and wind damage, as well as, the risk levels (low to extremely high) in the immediate vicinity of the site. This app would be fully integrated into CRMC’s newly developed risk based, permitting process. As of early 2018, a proposal for development of this app has been submitted to the NOAA Office of Coastal Management (OCM), Projects of Special Merit (PSM), and received partial funding. Extension of the app to include an economic component that will allow the cost of damages to be estimated and as well the implication of alternative structure design (e.g. elevating the structure) on present and future flood insurance costs would be included.

b) ***Extension of CERI to remaining coastal communities.*** CERI should be extended to the remaining coastal communities in RI. This will allow statewide assessment of the risk and damage for all structures located in the state. A procedure needs to be developed to automate the process of assigning structure types that is consistent with CERI and the current methods for collecting and updating appraisal/parcel data for the individual towns.

c) ***Estimating wind damages.*** CERI currently estimates flooding damages including the impact of SLR. A protocol has been developed to assess wind damages from storm events by structure class (Spaulding 2016) and applied to the Misquamicut area. The protocol requires more detailed information on the structure classification and wind speed contour maps for extreme winds by structure risk level. The former is available from the parcel/appraisal data for the towns and the later from the American Society of Civil Engineers (ASCE) Minimum Design Standards on line hazard tool (American Society of Civil Engineers 2017). The goal is to extend the wind damage protocol for all coastal communities in the state.

d) ***Extension of CERI to infrastructure damages and mitigation measures.*** CERI has been applied to date to assess risk and damages to structures, with a primary focus on residential structures in coastal communities and commercial buildings in major cities. To enhance CERI's utility it is proposed to extend the approach to include infrastructure as well. This would include bridges, roads, emergency access roads, waste water treatment facilities, petroleum/chemical storage tanks, and electrical infrastructure (transformers, major distribution lines). The electrical infrastructure application would also include estimates of wind damage as well since these have been responsible for the large scale loss of electrical power during recent (March 2018) extratropical storm events. In addition, CERI could be extend to explore the potential of mitigation methods, such as beach nourishment (e.g., Gonzalez et al. 2010), perched beach (e.g., Gonzalez et al. 1999), and synthetic bags (e.g., Wishaw et al. 2011) on shoreline protection.

e) ***Real time application of CERI***. To date CERI has been applied to assess the risk and damage to structures from various return period storm events, including the effects of SLR. To enhance its use in emergence response, it is proposed to extend CERI into a real time system for forecasting damage for selected tropical and extratropical storm events. To that end a very high resolution hydrodynamic model has been established for RI coastal waters, nested inside the Northeast Coastal Ocean Forecasting System (NECOFS) (Northeast Regional Coastal Ocean Observation System n.d.) under a project funded by the NOAA OCM Coastal Resilience program.

The model is forced by regional wind fields available from either the NECOFS mesoscale wind forecast model (WRF) or other international wind modeling products. The model has been validated for selected storm events (Torres et al. 2018) and linking to CERI is currently in progress. The focus of a future effort will be to bring the system to operational status, which will allow high resolution wind, wave, and surge predictions and associated damage estimates to be forecast for selected storm events that are expected to have substantial local impacts.

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3.5 Appendix

Adaptation	The IPCC defines the term adaptation to mean "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (Agard et al. 2014).
Adaptive capacity	The Intergovernmental Panel on Climate Change (IPCC) defines adaptive capacity as "The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (Agard et al. 2014).
Consequence	The National Research Council defines consequence as the impact or damage caused by a hazard. Consequences can be short or long-term and can include economic impacts, people or properties affected, harm to individuals, and environmental impacts (NRC 2014).
Exposure	According to the National Research Council, exposure refers the density of people, property, systems or other elements in an area potentially affected by a hazard (NRC 2014).
Hazard	The National Research Council defines a hazard as "the physical event with the potential to result in harm" (NRC 2014).
Impacts	The IPCC considers "impacts" as synonymous with "consequences and outcomes" and defines them as "Effects on natural and human systems.." They further explain the IPCC's use of "impacts" to refer to "the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts" (Agard et al. 2014).

Residual Risk	The National Research Council defines residual risk as the risk that remains even after risk reduction measures are taken, because "no risk reduction measure ever provides absolute protection." The NRC points out that residual risk in the coastal zone exists because storms larger than those anticipated may occur, or risk reduction measures put in place may not perform as expected (NRC 2014).
Resilience	The National Research Council defines resilience as "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events" (NRC 2012). According to the NRC, resilient communities are informed about threats, have the tools and capacity to assess and manage risks, and have a clear understanding of agencies' and organizations' roles and responsibilities with regard to managing risk (NRC 2012). It is the vision of the RI Shoreline Change SAMP to build Rhode Island coastal communities' capacity in these three areas so that they become more resilient.
Risk	The National Research Council defines coastal risk as "the potential for coastal storm hazards, such as storm surge–induced flooding and wave attack, to cause adverse effects on human health and wellbeing; economic conditions; social, environmental, and cultural resources; infrastructure; and the services provided within a community" (NRC 2014).
Sensitivity:	The IPCC defines sensitivity as "the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)" (Agard et al. 2014).
Uncertainty	The Intergovernmental Panel on Climate Change (IPCC) defines uncertainty as "a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts)" (Agard et al. 2014).
Vulnerability	According to the National Research Council, vulnerability refers to the potential for a community to be harmed, or the level of sensitivity of a community to a hazard (NRC 2014). Vulnerability is determined by physical assets as well as social and political factors (NRC 2012).

CHAPTER 4

Rhode Island's Exposure to Coastal Hazards

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4.1 Chapter Highlights

1. This chapter provides an overview of what is known to date about Rhode Island's exposure to coastal hazards associated with climate change. Exposure refers to a community's assets, including people, property, infrastructure, and the natural environment, subject to a hazard's damaging impacts. Coastal hazards considered here include storm surge, coastal erosion and sea level rise; other hazards including waves, storm frequency and intensity, debris damage, and wind are not included in this analysis. This chapter examines the exposure of the natural and built environment, focusing in particular on the coastal structures, features, and natural resources that are within coastal communities within CRMC's jurisdiction.

2. Salt marshes in RI and throughout southern New England are considered among the most vulnerable to SLR in the entire U.S. Accelerating SLR is outpacing accretion in RI, and as a result, salt marshes are showing signs of erosion, ponding, drowning, and vegetation shifts. These SLR impacts may work in synergistic ways with other human-induced and natural stressors to further degrade marsh condition.

3. A CRMC analysis of SLR and marsh migration suggested that RI is likely to face a substantial loss of coastal wetlands due to SLR, with south shore communities disproportionately impacted, under 1, 3, and 5-foot SLR scenarios. This analysis suggested that communities within Narragansett Bay may experience a net gain of new coastal wetlands through the process of marsh migration, although the authors caution that these results are likely overestimates of wetland gain.

4. A scientific study of the vulnerability of RI salt marshes to SLR revealed that south coast marshes are generally much more vulnerable to SLR. Marshes up Narragansett Bay are relatively less vulnerable although there are contrasting patterns of vulnerability among bay locations. This study found that low marsh elevation above mean high water and presence of tall *Spartina alterniflora* are indications of high vulnerability to SLR.

5. The Rhode Island south shore consists of a series of barrier spits alternating with headland bluffs which are largely erosional. By contrast the Narragansett Bay shoreline includes many hardened shorelines; it is estimated that 30% of the Narragansett Bay shoreline is hardened through shoreline protection structures, although a comprehensive inventory of the type and condition of shoreline protection structures has not been undertaken statewide.

6. Rhode Island has not experienced a significant shoreline change event with widespread overwash over the entire south shore since Hurricane Carol in 1954. More recent storms

(e.g. Hurricane Bob in 1991 and Superstorm Sandy in 2012) were smaller events and are not an indication of how future storms could change the Rhode Island shoreline.

7. The construction of new structural shoreline protection facilities on all barriers classified as undeveloped, moderately developed and developed and along all Type I waters is prohibited pursuant to Section 300.7 of the RICRMP. Shore parallel shoreline protection structures along eroding bluffs and dunes have numerous negative physical impacts to beaches directly in front of the structure as well as adjacent shorelines. They also have deleterious ecological impacts on adjacent structures, impact the loss of lateral shoreline access in front of these structures.

8. A Shoreline Change SAMP analysis revealed that the entire Rhode Island south shore is largely erosional, characterized by systematic retreat driven by storms and SLR. The south shore barriers in this region have an average annualized rate of shoreline change of 0.57 meters/year (1.9 ft/year). The stratified headlands in this region have an average annualized rate of shoreline change of 0.75 meters/year (2.46 feet/year). Some of the highest rates of change occur along the Matunuck Headlands, where the annualized rate of change exceeds 1.4 meters/year (4.7 feet/year) and total erosion since 1951 approaches 90 meters (300 feet).

9. A Shoreline Change SAMP analysis of projected future shoreline change suggested that the RI south shore could experience a total change of 89 meters (292 feet) by 2065 and 216 meters (708 feet) by 2100.

10. A CRMC-led assessment found that 27,431 (11.5%) of the residential structures in Rhode Island's coastal communities are exposed to the combined effects of sea level rise and storm surge under the Shoreline Change SAMP's Long-range Planning Scenario (a 7-foot SLR + a 100-year storm surge). Residential structures included in this assessment were single and multi-family homes, seasonal homes, mobile homes, camps, and other residential structures listed in the state's E-911 database. By percentage, the most exposed community is Barrington, with 64.4% (6,100) of its residential structures exposed.

11. With regard to residential structures, South Kingstown and Westerly are the state's top two most exposed communities under projected 3, 5, and 7-foot SLR scenarios. Warwick and Barrington are the top two most exposed communities to a present-day 100-year storm surge as well as 100-year storm surges when combined with the 3, 5, and 7-foot SLR scenarios. Evaluated together, by number of structures exposed, South Kingstown is among the state's top five most exposed communities under all of these scenarios.

12. 3,082 (18.9%) of the commercial structures in Rhode Island's coastal communities are exposed to the combined effects of sea level rise and storm surge under the Long-range Planning Scenario. Commercial structures in this assessment included all lodging, farm, and other commercial structures listed in the state's E-911 database. Providence has the highest number of exposed structures (993, or 23.2%) whereas Barrington has the highest percentage of its commercial structures exposed (70.8%, or 154 structures). Importantly, findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge. This is because this assessment assumed that the Fox Point Hurricane Barrier is not present. The barrier was originally designed to address storm surge, based on conditions at the time, but not sea level rise.

13. With regard to commercial structures, Newport, North Kingstown, Providence, and Westerly are among the top five most exposed municipalities under projected, 3, 5, and 7-foot SLR scenarios. Newport, Providence, Warren, Warwick and Westerly are the top five most exposed communities to a present-day 100-year storm surge as well as 100-year storm surges combined with projected 3, 5, and 7-foot SLR scenarios. Under all three combined SLR and storm surge scenarios, over 50% of the exposed commercial structures in the state's coastal communities are concentrated in just five municipalities: Newport, Providence, Warren, Warwick and Westerly.

14. 566, or 13.8%, of the public service structures in Rhode Island's coastal communities are exposed under the Long-range Planning Scenario. Newport has the greatest number of such structures exposed (110 structures, or 31.8%) whereas some communities have a greater percentage of their public service structures exposed (e.g. Warren at 55%, or 38 structures).

15. With regard to public service structures, Narragansett is among the top three most exposed communities under projected 3, 5, and 7-foot SLR scenarios. Providence, Newport, and North Kingstown are the top three most exposed communities to a present-day 100-year storm surge as well as 100-year storm surges combined with projected 3, 5, and 7-foot SLR scenarios. Under the Long-range Planning Scenario, the five municipalities of Newport, Providence, North Kingstown, Warwick and Narragansett together contain 65% of the coastal municipalities' exposed public service structures.

16. A RI Statewide Planning Program demographic study estimated that 6,945 individuals live in an estimated 3,321 occupied housing units that are exposed to a projected 7-foot SLR.

17. A RI Department of Environmental Management study found that 10 coastal wastewater treatment facilities are at risk of inundation under projected 1, 2, 3, and 5-foot SLR scenarios.

18. A RI Department of Health study which utilized conservative sea level rise projections found that by 2084, 20 drinking water utilities in the state may be impacted by sea level rise and 11 by coastal flooding.

19. A RI Statewide Planning Program transportation study found that up to 85 miles of road are expected to flood under a 5-foot SLR scenario, 70% of which are local roads which do not qualify for federal transportation funding.

20. A study commissioned by the RI Historic Preservation and Heritage Commission found that there are 1,971 National Register-listed or eligible assets located in FEMA-mapped flood zones, with 72.9% located in just the five municipalities of Newport, North Kingstown, Warren, Bristol, and Westerly. These results are conservative because this study did not consider SLR or changing future conditions.

21. Another Shoreline Change SAMP analysis examined areas of the RI coast which are particularly at-risk for the combined effects of storm surge, coastal erosion, and sea level rise. On the south shore, at-risk areas include the Matunuck Headland, where shoreline change exceeded 90 meters (295 feet) between 1951 and 2014. Areas of particular concern included Roy Carpenter's Beach and South Kingstown Town Beach, as well as the commercial and residential neighborhood east of the beach. Misquamicut was also identified as an at-risk area, including both the Misquamicut Headland and the Misquamicut Barrier. In Misquamicut, most of the revetments were damaged and many of the dikes failed during Superstorm Sandy in 2012; projected shoreline change for this area indicates that, over time, all but the largest such structures will likely fail. Shoreline change projections for both of these areas are extensive.

22. The Shoreline Change SAMP at-risk area analysis revealed that in Narragansett Bay, Barrington, Warren and Bristol are particularly exposed to the combined effects of storm surge, coastal erosion, and sea level rise. In this area, SLR and storm surge are the primary threats due to the low-lying nature of these communities. Low-lying residential and commercial districts, especially waterfront commercial areas, are projected to experience dramatic changes over time. Areas of Warwick were also identified as highly exposed to these hazards; for example, inundation associated with 5 feet of sea level rise and a 100-year storm surge could extend as far inland as the southern end of T.F. Green airport.

23. Storm surge, coastal erosion and sea level rise interact with each other, resulting in synergistic effects. For example, the combination of sea level rise and storm surge can accelerate the process of coastal erosion. Another such example is the way in which sea level rise increases the return period of storms, i.e. increasing water levels such that

today's 100-year storm will eventually become a 20-year ("nuisance") storm. These synergistic effects have not been fully examined by all of the tools and analyses incorporated into the Shoreline Change SAMP nor those developed by other agencies and organizations. Importantly this indicates that exposure assessments discussed in this chapter may underestimate the potential impacts to Rhode Island discussed herein, and points to the importance of long-term planning and adaptation.

24. The data and information included in this chapter are the best available to date, but scientific understanding of these issues is rapidly changing and additional research is needed on a wide range of topics. Some of these needs are being addressed by ongoing studies whereas others require future research.

4.2 Introduction

1. This chapter provides an overview of what is known to date about the exposure of Rhode Island's coast to coastal hazards associated with climate change. Exposure refers to a community's assets, including people, property, infrastructure, and the natural environment, subject to a hazard's damaging impacts. Hazards considered here include storm surge, coastal erosion and sea level rise.

2. CRMC policy, as reflected in Section 145 of the RICRMP, relies upon the "high" sea level change curve included in the most recent NOAA sea level rise (SLR) data. As of the time of this writing, the high curve included in the most recent NOAA analysis projects a maximum of 9.6 feet of SLR at the 83% confidence interval in Rhode Island by 2100 (NOAA 2017). However, scenarios developed for the Shoreline Change SAMP document, planning tools and analyses are based on earlier NOAA SLR analyses which projected up to 6.6 feet of SLR in Rhode Island in 2100 under the high curve (see NOAA 2012). NOAA's 2017 analysis also included an "extreme" curve which projected up to 11.7 feet of SLR at the 83% confidence interval in Rhode Island by 2100 (NOAA 2017). CRMC expects to update the Shoreline Change SAMP document, planning tools and analyses on an ongoing basis, using the most recent SLR scenarios, as resources allow. See the USACE sea level change curve calculator at http://www.corpsclimate.us/ccaceslcurves.cfm to view SLR projections for Newport under the full range of scenarios for both the 2012 and the 2017 NOAA analyses.

3. As is noted throughout this chapter, some studies summarized herein were conducted at CRMC's direction in support of the Rhode Island Shoreline Change SAMP, and therefore use the SLR data described above, while others were conducted by other agencies, organizations and experts for other purposes. Readers are advised to use caution in interpreting study results reported herein or in trying to integrate, compare, or apply

results. Studies included here utilized a variety of different data sources, methods, and assumptions. Many different SLR and storm surge inundation scenarios were used, and in some cases either SLR or storm surge was not considered. Because of this inconsistency in data sources, methods, and scenarios, these studies cannot be directly compared. Additionally, scenarios projecting SLR or storm surges for specific locations should all be interpreted as underestimates in that they do not account for the approximately 1 to 2 feet of additional water depth above and beyond these projections that can be caused by an astronomical high tide plus the effects of storm-driven wind, which is above and beyond those projections.[1] Nor do they account for the effects of waves, storm frequency and intensity, debris damage, and wind. The effects of wind are not limited to the coastal environments but are relevant statewide; for further information please see the 2014 Rhode Island Hazard Mitigation Plan update at www.riema.ri.gov. Finally, studies summarized herein are, for the most part, statewide analyses that did not involve in-depth analysis of individual municipalities. CRMC encourages municipalities to conduct their own high-resolution site-specific analyses using available risk assessment tools (see Chapter 3) as well as the most up-to-date data.

4. This chapter examines the exposure of both the built and the natural environment, but is explicitly focused on the coastal structures, features, and natural resources that are within coastal communities within CRMC's jurisdiction. This information is designed to complement CRMC's existing regulatory program, particularly the RICRMP and the Salt Ponds Special Area Management Plan, which can be found at www.crmc.ri.gov. Where appropriate, this chapter directs readers to other federal, state and local agencies and programs charged with managing coastal structures, features and resources outside of CRMC's jurisdiction.

5. Importantly, this chapter is not exhaustive in characterizing the structures, features and resources of Rhode Island's coast which may be affected by coastal hazards and climate change, nor of the ways in which those structures, features and resources may be impacted. Additionally, scientific understanding of climate change, associated hazards, and their effects on coastal structures, features and resources in Rhode Island and elsewhere is rapidly changing. While the information included herein represents the best available data to date on Rhode Island's exposure to these hazards, there are multiple

[1] According to data available through the NOAA National Ocean Service, predicted water levels at Newport, Conomicut and Providence can be up to 1.6 feet higher than mean higher high water (MHHW) during an astronomic high tide; see https://tidesandcurrents.noaa.gov/tide_predictions.html. Wind setup can raise this number to 2 feet or more.

other such studies and assessments in progress. For further information on ongoing projects, please see Section 4.8.

4.3 Natural Environment

1. Rhode Island's natural environment is exposed in multiple ways to coastal hazards associated with climate change. This section summarizes what is known to date about the exposure of Rhode Island's coastal beaches, barriers, and headlands; coastal wetlands; and other coastal habitats. This section also highlights recent or ongoing restoration efforts targeted at these resources.

2. The Shoreline Change SAMP Planning Boundary encompasses a diverse range of natural resources and habitats and intersects multiple different ecosystems connecting inland areas with the waters of Narragansett Bay and Block Island and Rhode Island Sounds. While resources and habitats within the planning area and the surrounding ecosystems may be exposed to the impacts of climate change, the Shoreline Change SAMP focuses specifically on the natural environment located within the Shoreline SAMP Planning Boundary and in particular those shoreline features which are under CRMC's jurisdiction. Further, the Shoreline Change SAMP focuses specifically on the impacts of coastal hazards to these shoreline features. This information is designed to complement CRMC's existing regulatory program, particularly the RICRMP and the Salt Ponds Special Area Management Plan, which can be found at www.crmc.ri.gov.

3. This section refers to some studies that were not conducted by CRMC or as part of the RI Shoreline Change SAMP. Readers are advised to use caution in interpreting these study results or in trying to integrate, compare, or apply results. Studies included here utilized a variety of different data sources, methods, and assumptions, including different SLR and/or storm surge inundation scenarios. In some cases either SLR or storm surge was not considered.

4.3.1 Beaches, Barriers and Headlands

4.3.1.1 Overview

1. This section summarizes some of what is known to date about the exposure of Rhode Island's shoreline (beaches, barriers and headlands) to storm surge, coastal erosion and sea level rise. For CRMC's policies regarding these coastal features, see the RICRMP. The RI Shoreline Change SAMP process included multiple studies and mapping initiatives on these topics. In each case these studies and initiatives are either summarized or example findings are included in this chapter, and the reader is referred to the original source(s) of information for further information. Findings included here are the best available information at the time of this writing; however it is important to note that scientific understanding of these processes and their potential impacts on Rhode Island is rapidly changing.

2. It is important to note that Rhode Island has not experienced a significant shoreline change event with widespread overwash over the entire Rhode Island south shore since Hurricane Carol in 1954. While there have been smaller storms more recently (e.g. Hurricane Bob in 1991 and Superstorm Sandy in 2012), stakeholders and decision-makers should not rely on these recent storms as an indication of how future storms could impact and alter Rhode Island's coastal region.

4.3.1.2 Geologic Setting of the Rhode Island South Shore

1. The >30 km (18.6 mile) long Rhode Island south shore (RISS), bounded by the Napatree Point headland on the west and by the Point Judith headland on the east (see Figure 1), is a microtidal, wave dominated coastline in the classification of Hayes (1979) and Nummedal and Fischer (1978). Mean tidal range in the open ocean ranges from 0.8-1.2 m (2.62-3.9 ft). The shoreline is oriented generally east to west (70°) and consists of low, narrow barrier spits alternating with headland bluffs. The barriers are 1-8 km (0.6-5 mi) long, 200-300 meters (656-984 feet) wide, have foredune zones commonly 1-4 meters (3.3- 13.1 feet) in relief, and backbarrier flats dominated by overwash processes during major storms (Boothroyd et al., 1985). The headland bluffs range in relief from 1-25 meters (3.3-82 feet) and are fronted by sand or gravel beaches, but lack an aquatic habitat landward of the beach. The bluffs here are composed largely of Pleistocene-age glacial deposits (Boothroyd and McCandless, 2001; Boothroyd et al., 2003; Schafer, 1961, 1965; Smith, 2010). Napatree Point, Watch Hill, Weekapaug, Green Hill and Point Judith headlands are composed of glacial till, a poorly sorted mixture of gravel (including boulders), sand, silt and clay. The Misquamicut, Quonochontaug and Matunuck

headlands are composed of stratified deposits, comprising sand and gravel deposited by meltwater emanating from retreating Laurentide Ice Sheet during deglaciation.

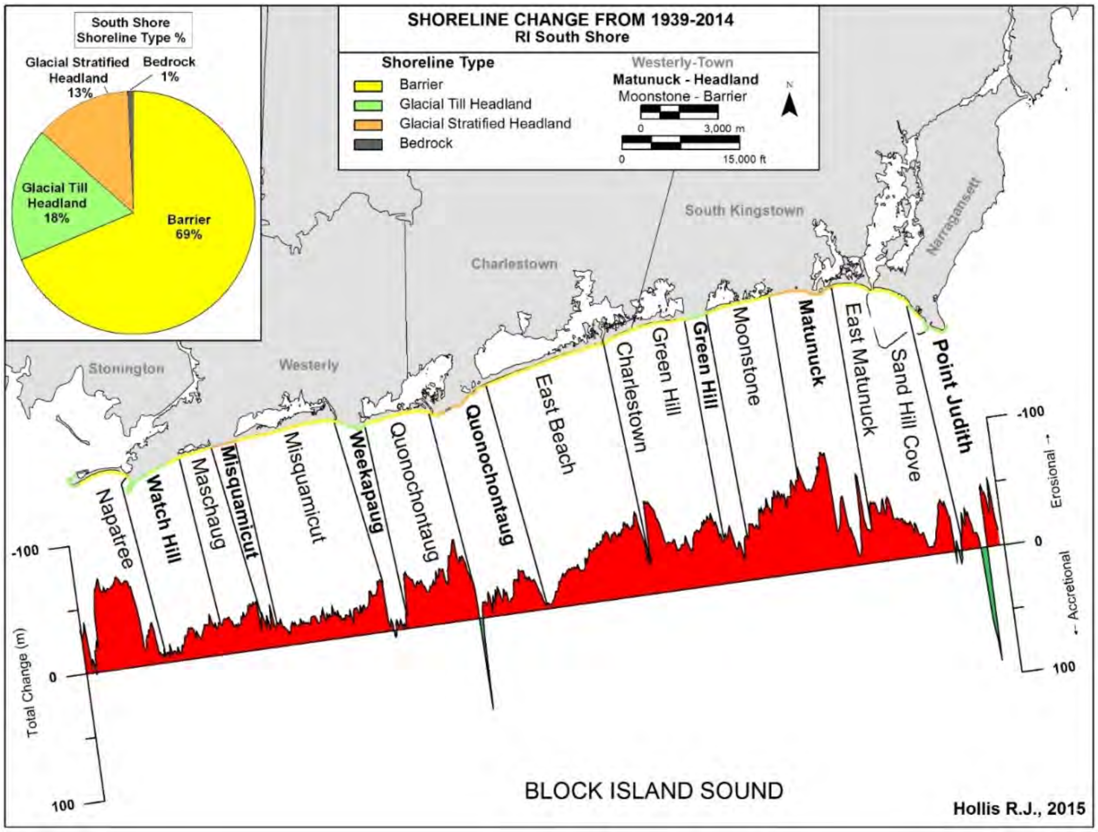

Figure 1. Shoreline type indicated as shoreline segments on the map as percentage (inset). Total shoreline change from 1939-2014 (m) along the Rhode Island south shore on the graph plotted parallel to shore. In this figure and subsequent figures, red indicates erosion and green deposition (Hollis et al. in preparation; Oakley, Hollis and Boothroyd 2016).

2. Over the long-term (decadal scale) the entire south shore is largely erosional (see Figure 1), with erosion rates ranging from near 0 to >1.5 meters/year (0 - 4.9 ft/year) (Boothroyd et al. 2016). Along the RISS, the barriers have an average annualized rate of shoreline change of 0.57 meters/year (1.9 ft/year). Coastal erosion does not occur slowly over time, rather it is the result of abrupt changes due to storms. For that reason, these annualized rates should be used with caution, and rates vary along the shoreline considerably in both space and time. The till headlands, often fronted by accumulations of boulders (i.e. Weekapaug and Green Hill), have generally lower erosion rates. The stratified headlands (Misquamicut and Matunuck), composed mostly of sand and pebble to cobble-sized gravel, have an average erosion rate of 0.75 meters/year (2.46 ft/year) comparable to (and even higher than) the barriers in some places. Some of the highest

rates of change along the RISS occur along the Matunuck Headland where the annualized rate of change exceeds 1.4 meters/year (4.7 ft/year), with total erosion approaching 90 m (300 ft) since 1951 (Boothroyd et al. 2016). See Figure 1 above.

3. Lagoons, called salt ponds in local terminology, are situated landward of the barriers. Small tidal inlets, both natural and maintained (locally called breachways) separate the spits. Natural inlets are shallow, less than 1 meter (3.3 feet) deep, and close intermittently as the longshore transport of sand tends to seal the inlet throat. Tidal range in all the lagoons is 7 to 10 centimeters (0.2 to 0.3 ft) (mean) and 16 centimeters (0.5 ft) (spring) due to the constriction of tidal-current flow through the inlets (breachways) (Boothroyd et al., 1985). The exception to this is Point Judith Pond which is connected to Block Island Sound through a relatively wider and deeper inlet and has a similar tidal range to that of the open ocean (Boothroyd et al., 1985). The maintained inlets have rubble-mound jetties and remain permanently open. The Pt. Judith Harbor of Refuge, at the east end of the RISS, is enclosed by a complex of breakwaters and functions as a large sediment sink (see Figure 1). Lastly, although the alongshore circulation picture is complex, potentially with several cells, data collected thus far suggest a net transport to the east from Watch Hill.

4.3.1.3 Geologic Setting of Narragansett Bay

1. The present geologic framework of Narragansett Bay (see Figure 2) is heavily dependent on the bedrock geology and the configuration of glacial processes, landforms and sediment type. Glacial deposits from the Late Wisconsinan deglaciation range from till to stratified deposits (gravel, sand and mud). The most prominent glacial features of western Narragansett Bay and adjacent watersheds are the large alluvial fans and deltas that drained into Glacial Lake Narragansett between 20,000 and 18,900 years before present (Oakley and Boothroyd 2013) These deltas are located primarily along the western shoreline of Narragansett Bay (i.e. the Warwick Plains delta north of Greenwich Bay) (see Figure 2) (Boothroyd and McCandless, 2003). Postglacial (Late Pleistocene to Holocene) sediment began accumulating as soon as Glacial Lake Narragansett, which occupied much of the bay and adjacent watershed during deglaciation (Oakley, 2012), drained and a rudimentary fresh-water drainage system became established on the newly emergent floor of the Bay. Holocene sediment accumulation accelerated as marine water entered the Bay and submerged the former glacial lacustrine environments (McMaster, 1984).

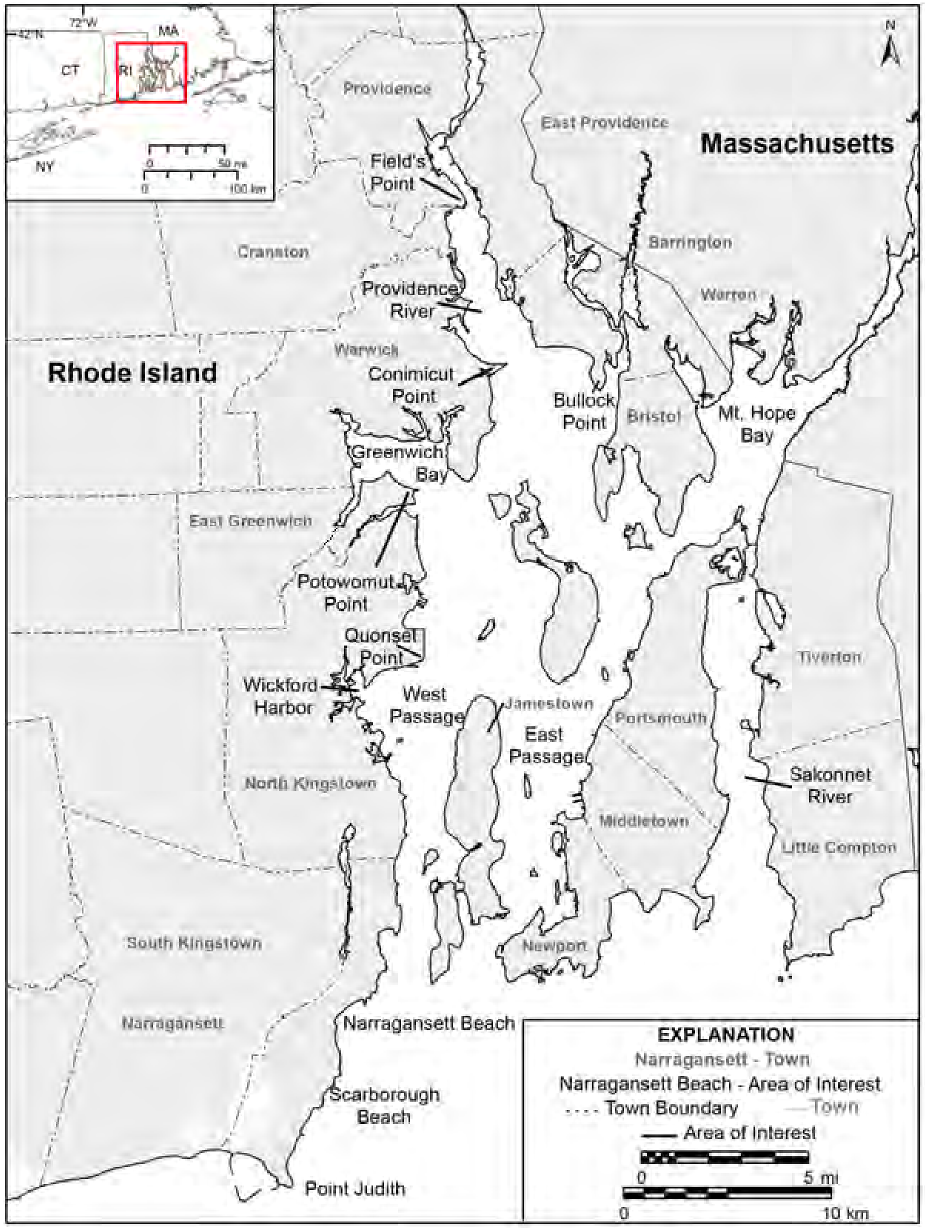

Figure 2. Location map of Narragansett Bay

2. Erosion of the Narragansett Bay shoreline contributed all sediment sizes to subtidal environments as the high-energy areas of the shoreline receded under the impact of storm events. The eroded silt and minor clay is deposited in the deeper, low-energy channels and basins along with organic silt-sized sediment formed from decaying plant material. The sand and gravel-sized sediment is deposited adjacent to the shoreline as depositional platforms and erosional terraces, and in coves as barrier spits and flood-tidal deltas. Shoreline types mapped by Boothroyd and Al-Saud, (1978) and summarized by Hehre (2007), comprise six main types (see Table 1).

Table 1. Geologic shoreline types in Narragansett Bay (modified from Boothroyd and Al-Saud, (1978) and Hehre (2007))

Shoreline Type	Percent-age of shoreline	Description	Example
Beach plain and barrier spit	25%	Barriers are islands or spits comprised of sand and/or gravel, formed and maintained by wave or wind energy, extending parallel to the coast and separated from the mainland by a coastal pond, tidal water body, or coastal wetland. Beach plains have a wide berm backed by a coastal feature (e.g. bluff, foredune zone).	Rhode Island School of Design beach adjacent to the RI Country Club in Barrington
Stratified glacial deposits bluff	8%	Bluff composed of unconsolidated glacial stratified material that is subject to erosion during moderate storm events. Bluff is fronted by a narrow beach composed of sand and/or gravel.	Nayatt Point
Till bluff	23%	Bluff composed of till that is subject to erosion during moderate storm events. Bluff is fronted by a beach composed of sand, gravel, and boulders.	Warwick Point
Bedrock	13%	Outcrops of metamorphosed sedimentary, igneous and metamorphosed igneous bedrock. Often overlain by till deposits or backed by a by bluffs of either glacial stratified material or till that are protected from wave erosion by all but the largest storms Small, gravelly, pocket beaches are sometimes present.	Beavertail, Cormorant Point (Narragansett)
Discontinuous bedrock	1%	Discontinuous bedrock outcrops shelter areas of unconsolidated material between outcrops including, beach plains and barrier spits, glacial stratified material, and till.	Common Fence Point (Portsmouth)
Shoreline protection structures	30%	Characterized by physical alterations to shoreline including groins, jetties, revetments, bulkheads, and seawalls. If the structure is effective, the natural shoreline features are no longer dominant.	Various throughout Narragansett Bay

4.3.1.4 Physical Processes

Wind Speed and Direction

1. A comprehensive review of wind conditions for inland areas and coastal waters of the state can be found in work performed as part of the RI Renewable Energy Siting Partnership and the RI Ocean Special Area Management Plan. See Grilli et al. (2012) and Merrill et al. (2012) for the inland areas, and see Grilli et al. (2010) and Spaulding et al. (2010a and 2010b) for coastal waters. Only a high level summary is presented here.

2. Winds in the area are predominantly from the west, with winds from the northwest in the winter, the southwest in the summer, and the west in the transition seasons. Wind speeds are typically stronger in the winter from the northwest. Wind speed increases with distance offshore from the coast and decreases landward due to enhanced friction caused by the roughness of the land cover. Mean annual wind speeds increase from approximately 7 m/sec (16 mi/hr) for coastal stations to 8 m/sec (18 mi/hr) for offshore locations. Extreme wind speeds also typically increase with distance offshore increasing from 35 m/sec (78 mi/hr) nearshore to 39 m/sec (87mi/hr) offshore for the 100 year return period winds. Winds used for design of coastal structures are included in the state building code. The 100-year, 3-sec peak gust design wind speeds immediately adjacent to the Rhode Island coast are 49 m/sec (160.8 ft/sec) and decrease with distance inland.

3. The strongest winds observed in the area are the result of extratropical storms (nor'easters) generally occurring in late fall, winter, and early spring and tropical storms (hurricanes) in the summer and early fall. Of the two, hurricanes typically result in the strongest winds and the speeds are dependent on the storm strength; the higher the strength the stronger the winds. NOAA categories storms from Category 1 to 5, with increasing strength as the category number increases. Hurricanes with tracks to the west of the state result in the highest storm damage in Rhode Island given the superposition of the cyclonic storm winds being reinforced by the forward motion of the storm (Hashemi et al. 2016, 2015). The strongest storm Rhode Island has experienced in recent history is the 1938 Hurricane which was downgraded from a Category 4 to a Category 3 storm as it made landfall at the western end of Long Island Sound. The most recent storm to impact Rhode Island was Superstorm Sandy (2012), which reached the coast as a tropical storm and merged with an extratropical storm to generate a hybrid storm. The path of Sandy was quite unusual with a sharp turn to the northwest from its earlier shore parallel path.

4. Figure 3 illustrates how the most destructive area of a storm in the Northern Hemisphere is the right front quadrant. Applying this concept to Rhode Island, Figure 4 illustrates how

the most dangerous storms track to the west. Such storms have winds from the south or southeast in excess of 40 m/second (131 ft/second) (Wright and Sullivan, 1982). Figure 5 and Figure 6 show the tracks of historic hurricanes which have impacted Rhode Island (the hurricane of 1938, Hurricane Carol (1954), Hurricane Bob (1991) and superstorm Sandy (2012)) and illustrate how most of these storms tracked to the west of the state. The impact of a tropical storm depends on its path as well as the storm's strength, forward speed, and radius to maximum winds. The forward speed of a storm adds to the rotation speed of the storm, which is dependent on the storm's strength. With regard to Rhode Island, this leads to the right front quadrant being the location where the winds are strongest in the up-Bay direction. The strongest storm surges are also dependent on the radius to maximum winds and how far the center of the storm is from the area of interest. While the historic storms shown in Figure 5 and Figure 6 illustrate the right front quadrant issue, these storms differed with regard to other parameters. For example, the 1938 hurricane's strength was high (Category 3), forward speed was extremely high (60 mph), and the path and radius of maximum winds put RI in its bullseye. For Sandy, the storm was very weak (Tropical Storm) and forward speed was not very high, but the storm had a very large radius to maximum winds, thus its impact to RI.

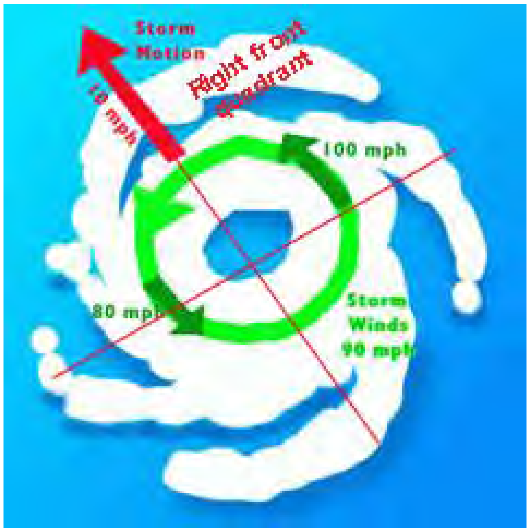

Figure 3. In the Northern Hemisphere, the right front quadrant of a storm is the most destructive area of the storm, with the strongest winds, seas, and resultant storm surge. (Source: University of Rhode Island, "Hurricanes: Science and Society," 2015; image adapted from the NOAA Atlantic Oceanographic & Meteorological Laboratory Hurricane Research Division.)

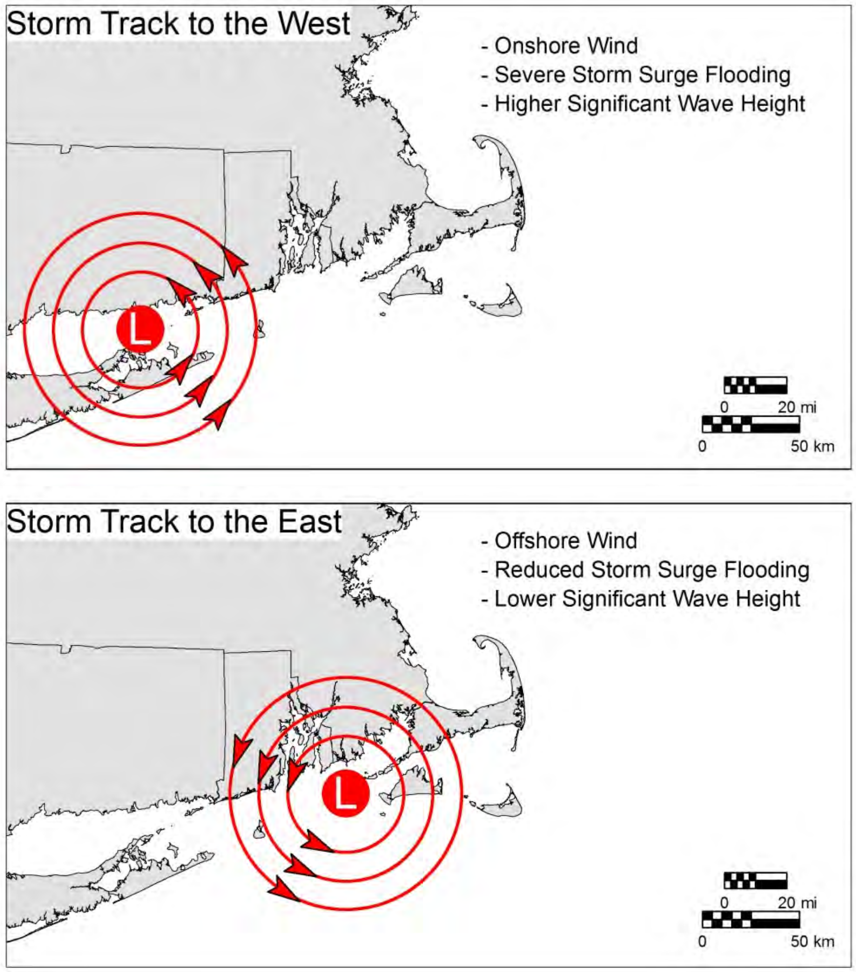

Figure 4. Wind, storm surge and wave height effects of westerly and easterly storm tracks (modified from Wright and Sullivan 1982)

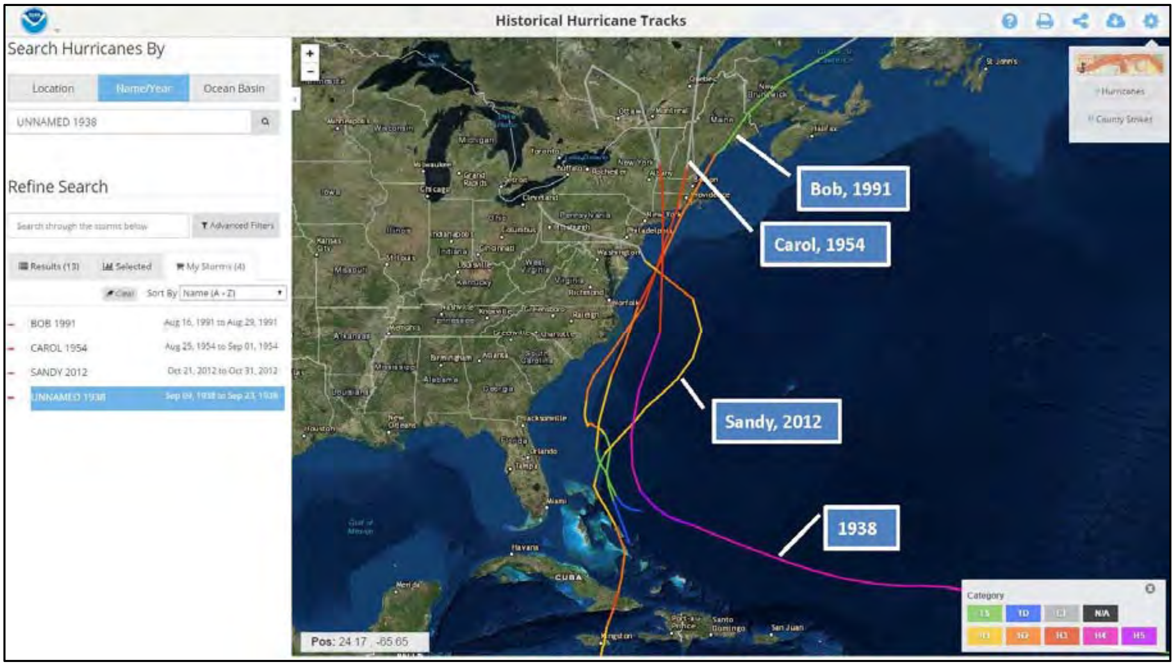

Figure 5. Map of historic hurricane tracks, Atlantic coast (Source: NOAA Digital Coast 2017, "Historical Hurricane Tracks," https://coast.noaa.gov/digitalcoast/tools/hurricanes.html)

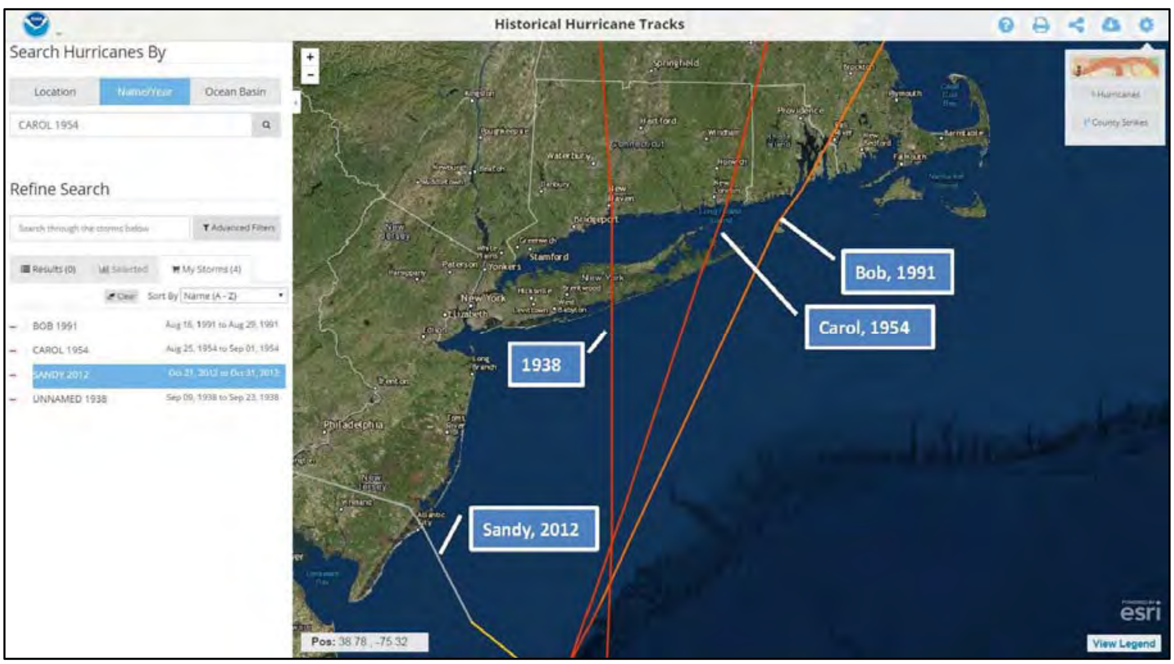

Figure 6. Map of historic hurricane tracks, northeastern U.S. (Source: NOAA Digital Coast 2017, "Historical Hurricane Tracks," https://coast.noaa.gov/digitalcoast/tools/hurricanes.html)

Circulation in Narragansett Bay and RI Coastal Waters.

1. A recent comprehensive review of the circulation in Narragansett Bay is presented in Spaulding and Swanson (2008), and in Codiga and Ullman (2010) and Ullman and Codiga (2010) for RI coastal waters (RI and Block Island Sound). Grilli et al (2010) have also performed detailed, high resolution hydrodynamic modeling of the Block Island and RI Sounds, Buzzards Bay, and adjacent coastal waters. Only a high level summary is presented here.
2. The circulation in RI waters is dominated by semi-diurnal tides, with a periodicity of 12.42 hrs. On flood/ebb, the tide propagates from offshore toward coast/from the coast toward offshore and bifurcates in RI Sound, with flooding/ebbing to the west/east into Block Island (and eventually Long Island Sound), to the north/south into Narragansett Bay, and to the east/west into Buzzards Bay. The mean tidal range along the southern RI coastline is approximately 1 m (3.3 ft), comparable to the value at the NOAA NOS Newport gauging station of 1.06 m (3.08 ft). The greater tidal range at Newport is 1.17 m (3.84 ft); greater tidal range is defined as the difference between Mean Higher High Water(MHHW) and Mean Lower Low Water(MLLW). The mean tidal range increases approximately linearly with distance up Narragansett Bay and reaches a value of 1.35 m (4.43 ft) at Providence. The greater tidal range at Providence is 1.48 m (4.86 ft). The tides hence are amplified by approximately 28% with distance up Narragansett Bay as a result of the standing wave nature of the system.
3. Tidal currents in RI waters are typically quite modest (below 50 cm/sec at peak values) given the relatively low tidal range and lack of strong geographic constraints, with the exception of currents at tidal inlets where higher velocities have been observed. Tidal currents (typically two dimensional) in the bay display an unusual double peak flood, single peak ebb behavior due to the resonance of harmonics (over-tides) of the principal semi-diurnal. This behavior is absent in offshore waters. Stratification of the water column is typically quite limited. Density-induced (fresh water) currents are typically observed in areas close to river discharges, such as where the Seekonk/Blackstone River discharge into the Providence River and the Taunton River discharges into Mt Hope Bay. Wind driven flows are strongly dependent on the wind forcing events, both in terms of dynamics of the event and its passage relative to the tides.

Storm Surge

1. The strongest variations in water level and currents are caused by storm winds from either extratropical (nor'easter) or tropical (hurricanes) storms. The surge resulting from these events is superimposed on the existing tides and hence the tidal stage can make a

significant difference in the surge heights. As an example, if the peak surge of 1 m (3.3 ft) arrives at low tide, the peak water level at Newport is no higher than the water level at high tide. If it occurs at high tide, the water level effectively doubles to 2 m (6.6 ft). To further complicate the situation, the time scale for passage of storms is several days for an extratropical storm, but only 6 to 10 hrs for a tropical storm, the latter being consistent with the semi-diurnal time scale. Alignment of peak storm surge with spring high tide results in the highest surge levels.

2. Elevation of storm surge can be measured using water level gauge records (i.e. the Newport gauge) and estimated from observations and photographs taken during and after storm events. The NACCS reported surge elevations during a 100-year storm event exceeding 3.6 m (12 feet) throughout the bay, and reaching 5.3 meters (17.5 feet) in the Providence River. A review of the extreme water elevations recorded by NOAA NOS at Newport and Providence show that the highest levels are attributed to tropical storms with 1938, 1944, Carol (1954) and Bob (1991) dominating. The 1938 Hurricane surge in Newport peaked at 2.9 m (9.5 ft) above MHHW (3.5 m (11.3 ft) relative to NAVD88)); and in Providence, 1938 Hurricane surges peaked at 3.9 m (12.8 ft) above MHHW (4.6 m (15.1 ft) relative to NAVD88)) (NOS, 2017b). During Hurricane Carol in 1954, storm surges in Newport peaked at 2.1 m (6.9 ft) above MHHW (2.62 m (8.6 ft) above NAVD88) (1954 data are not for Providence) (NOS 2017c). The largest extratropical storm of January and February 1978 ranks 4th in Providence and 6th in Newport out of the top ten events. Spaulding et al. (2015a, 2015b) have performed an analysis of the top ranked events, when data are available at both Newport and Providence, and show the surge levels scale with distance up the bay. Scaling values vary from a low of 1.1 to a high of 1.4, with an average of 1.3. The latter is comparable to the tidal amplification in the bay noted above. The scaling is strongly correlated to the strength, forward speed, radius of maximum winds, and track of the storm (Hashemi et al, 2016).

3. Spaulding et al. (2015a) have performed a detailed analysis of simulations performed by NOAA using their Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model for tropical storm events by strength (Category 1 to 4).[2] Category 5 is excluded since no storm of that strength has reached Rhode Island waters. The analysis shows that surge levels are approximately constant along the southern RI coastline and comparable to the level at Newport. Surge levels then increase linearly with distance up Narragansett Bay, with a scale factor of 1.4 when referenced to Newport. Spaulding et al. (2015b) also performed a detailed analysis of the predicted surge levels performed as part of the

[2] For further information see www.nhc.noaa.gov/surge/slosh.php.

Army Corp of Engineers, North Atlantic Coast Comprehensive Study (NACCS) for 1,050 synthetic tropical storms (Cialone et al, 2015). Simulations were performed for surge only and surge plus tide cases. The analysis once again shows that the surge levels are approximately constant along the southern RI coastline and increase linearly with distance from the mouth to the head of the bay. The surge levels for the 100-year return period surge scale linearly with distance up the bay, with the scale factor dependent on inclusion of the tides and whether the mean or upper 95% confidence value return value is used. STORMTOOLS flooding maps are based on the scaling factors from this analysis for the selected return periods of interest (e.g. 25, 50, and 100 yrs) using the Newport levels as the base. The scaling is based on the upper 95% confidence interval value, surge plus tide case to address uncertainty in the modeling and data analysis methods and to ensure the effects of tides are considered. The 100 yr water level at Providence for this case is 5.49 m (18.0 ft), compared to a value of 3.93 m (12.9 ft) at Newport (both NAVD88 referenced), giving a scale factor of 1.4 relative to Newport. As an alternative, the NACCS study provided return period analysis for water levels at selected save points (approximately 1,000) covering the RI area. Most of the save points are located immediately along the shoreline. These data are also available via STORMTOOLS and can be used to give very high resolution estimates of surge heights (with and without tide) over the entire range of return periods, including mean and upper and lower 95% confidence interval values.

4. When the elevation of the storm surge and wave runup exceeds the elevation of the coastal feature, water moves rapidly over low barrier spits and headlands in a process called overwash. Driven by the wind, waves and swash of the storm, overwash delivers sediment eroded from the beach, dunes, and front of the barrier onto the backbarrier flat and into the lagoon, or onto the low surfaces of headlands. The overwash process results in deposition of washover fans on the back of the barrier or top of the headland and the formation of storm-surge platforms in the lagoons. During overwash, temporary storm-surge channels are eroded through the barriers, providing a conduit for sediment and water into the lagoon. Shallow, temporary inlets, or surge channels formed along the Misquamicut Barrier during the 1938 Hurricane and Hurricane Carol (1954); deeper inlets also formed along Napatree, Quonchontaug and Winnapaug Barriers in the 1938 hurricane (Nichols and Martson, 1939) . These areas will likely be subject to similar breaches during future significant storm events.

5. The resulting storm-surge deposits form extensive storm-surge platforms within the coastal lagoons and raise the elevation of the back barrier flat, making the barriers more resilient to sea level rise and storm impacts. It has been known for some time (Godfrey and Godfrey, 1976; Leatherman, 1979), and more recently reinforced (Houser and

Hamilton, 2009; Timmons et al., 2010), that overwash and subsequent deposition of washover fans onto the backbarrier is critical for barriers to continue to migrate in response to storms and sea level rise. This geologic process, which can look catastrophic in the immediate aftermath of a storm, is vital to the evolution of the shoreline in response to future storms and sea level rise. While the response and fate of barriers to sea level rise is complicated and ultimately dependent on a number of factors (Moore et al., 2010), leaving these deposits in place following a storm allows for a better chance of the barriers to migrate in response to sea level rise and future storms (FitzGerald et al., 2008).

6. Coastal processes during storms remain difficult to quantify, however surge velocity can be estimated from photographs taken after the 1938 and 1954 hurricanes. Bedforms (small dunes), created by the flow of surge across the spit, and visible in post-storm photographs of Conimicut Point, have a crest-to-crest spacing of > 2 meters (6.6 feet) (Ashley, 1990). These bedforms require a flow velocity of close to 1 meter/second (3.3 feet/second), and represent a *minimum* velocity of storm surge. Calculated design flood velocities (velocities associated with base flooding) during 100-year events increase with increasing surge depth, and the upper limit of the design flood velocity for a water depth of 3.3 meters (10 feet) approaches 5 meters/second (17 feet/second) (FEMA, 2011).

Wave

1. Observations of waves in Rhode Island Sound and Block Island Sound have been very limited with no long term observation stations in the area. Wave observations were collected at three stations located along the immediately offshore of the southern RI coastal line (Misquamicut, Charlestown and Matunuck) from a recent study performed on behalf of the US Army Corps of Engineers (WHG, 2012). Measurements were made from approximately July 2010 to September 2011 and show significant wave heights were typically 1 m (3.3 ft) or less, with periods typically ranging from 5 to 11 sec, and directions generally from the southwest to southeast. The observations captured wave heights during the passage of Tropical Storm Irene, which made landfall 200 km (125 mi) west of Charlestown on August 28, 2011), which included a maximum significant wave height of 4.1 m (13.5 ft), with a peak period of 10 sec, at the Charlestown station. A maximum wave height exceeding 6 meters (19.7 feet) (WHG, 2012) was observed during that same storm at Acoustic Doppler Current Profiler sites in 9 meters (29.5 feet) of water in Block Island Sound.

2. The U.S. Army Corps of Engineers performed wind and wave hindcast in the Wave Information Study (WIS)[3] for selected locations off the coast from 1980 to 2014 . WIS provides time series of wave spectral parameters as well as some general statistical analysis. As an example, for the site closest to the coast and directly east of Block Island in a water depth of 33 m (108.3 ft) (# 63079), the annual mean significant wave heights is in average of the order of 1.0 m (3.3 ft), varying between 0.5 to 1.6 m and the annual mean peak period is 8 seconds,in average varying between 5 and 11 seconds. Waves are predominately from the south and south-southeast sectors. The 100-yr significant wave height at this station is estimated to be 9.7 m (30.8 ft) with a peak period of the order of 17 sec. During superstorm Sandy significant wave height at this location was hindcast to be 8.6 m (28.3 ft), with a peak period of 15 sec, from the southeast.

[3] For further information see http://wis.usace.army.mil/.

3. The U.S. Army Corps of Engineers, in the context of the North Atlantic Coast Comprensive Study (NACCS),[4] has performed simulations of synthetic tropical storms (1,050) and historical extratropical storms using state of art, coupled surge and wave models providing estimations of the wave characteristics at thousands of virtual stations or "save points" (Cialone et al 2015; Jensen et al. 2016). In addition the NACCS provided an extreme value statistical analysis of the simulated data at the save points. The data have been provided in the form of peak values for each event and in the terms of wave heights vs return periods. The data is provided at the same save points as the surge level data describe above. This data has been analyzed in depth and compared WIS data at selected locations by Spaulding et al. (2015b, 2017a, 2017b). The NACCS data generally show slightly higher wave heights and longer periods for the 100 yr return period than the WIS hindcast, consistent with the limited length of the WIS hindcast period. Access to the NACCS wave data is available via STORMTOOLS, providing contour maps of the 100-yr surge as well as wave heights vs return period curves for the save points The focus of the NACCS analysis is on wave heights associated with tropical storm events and not locally generated waves(Spaulding et al. 2015b, 2017a, 2017b). The wave pattern in RI coastal waters is quite complicated as a result of the complex bathymetry and associated refraction and diffraction in the vicinity of Block Island Sound. In particular, the shielding from the eastern end of Long Island Sound ,the shoal from Montauk to Block Island fronting the deeper Block Island Sound and the presence of Block Island strongly affect the tropical storms'wave pattern generally propagating from the South (Spaulding et al, 2017a). Additional information on these effects can be found in recent work performed as part of the Ocean SAMP (Asher et al, 2010; Grilli et al, 2010) with a particular focus on the area in the vicinity of the Block Island wind farm.

4. A review of the NACCS 100-yr return period significant wave height immediately offshore shows values of approximately 9 m (29.5 ft) at the entrance to Narragansett Bay decreasing to 7 m (23.0 ft) at Charlestown and finally to 6 m (19.7 ft) at Misquamicut. The wave period is about 20 sec and the direction typically from South to South East. 100-y significant wave height south of Block Island is typically 9 m (29.5 ft) or greater. The pattern of decreasing wave height with distance westward along the RI shoreline from the bay entrance is a result of the complex interaction of the wave field with the coastal topography and bathymetry. The interaction of these large waves as they break with shallowing water depths results in wave induced set up typically on the order of 0.5 to 1 m and a substantial reduction in wave heights (Spaulding et al, 2017a).

[4] For further information see http://www.nad.usace.army.mil/CompStudy/

5. Historically there have been no observations of the waves in Narragansett Bay. The bay is thought to have a relatively low wave energy environment given the shallow water. Wave modeling predict (Spaulding et al. 2017b) significant wave heights for the 100 yr event of the order of 9 m (29.5 ft) and 20 sec of peak- period at the bay mouth. These large waves decrease dramatically once entering the bay. Indeed the shallow water in the bay induces dissipation by friction for the longer waves as well as wave breaking limiting the wave energy propagating in bay. However, southerly wind conditions provide enough fetch to create local short-waves which can grow significantly in the upper part of the bay reaching up to 2 m (6.6 ft), although limited by whitecapping (breaking due to high curvature of short waves). A good example of significant wave action in the upper section of the bay is shown by the significant erosion observed at Oakland Beach on the northern shore of Greenwich Bay. The pattern in the bay is hence quite complex, with southern facing coastlines showing the largest wave heights. The model predicts waves that are consistent with observations of erosion on Oakland Beach and other exposed shorelines.

4.3.1.5 Shoreline Protection Structures

1. Where a shoreline type (see Table 1) has been modified by the construction of a shoreline protection structure that is viable and functional (that is, the structure either traps sediment or offers protection from direct wave action on a bluff or foredune), the shoreline is reclassified to reflect the shoreline protection structure ("hardened shorelines"). Great care was taken in Boothroyd and Al-Saud's original study of shoreline protection structures in 1978 to ensure that the structure actually was viable. If not, the shoreline was classified based on the geologic habitat even though a structure may have been present. Shoreline protection structures (working) comprised 24.5 percent of the Bay shoreline in 1978 (Boothroyd and Al-Saud, 1978). A complete inventory of the type and condition of shoreline protection structures has not been undertaken statewide. However, shoreline change mapping in the Bay using 2003 orthophotography suggest that 30 percent may more closely represent actual length of these structures, as additional structures were likely constructed in areas where they are not prohibited (Boothroyd and Hehre, 2007). This points to the need for a new, systematic review of the state's shoreline protection structures; see Section 4.8, Future Research Needs, for further discussion.

2. Shoreline protection structures may be revetments, bulkheads, seawalls, groins, breakwaters or jetties. See Section 300.7 of the RI Coastal Resources Management Plan (Redbook) (RI CRMC 1996, as amended) for a fuller discussion of structures. Other structures, such as piers, are not strictly protection structures but often have a

protection element such as a seawall incorporated in the facility. Structural installation ideas have evolved through time. Pre-1954 seawalls were often concrete, and newer walls constructed of wood, sheet pile or rip-rap have replaced or in some areas, have been placed in front of, the pre-1954 concrete walls. Based on CRMC's permitting history and experience, the design of most such structures (i.e. wall height, stone size, return period event for which wall is designed, and other construction features) is insufficient to protect against the intensifying storm conditions discussed in this document (see Chapter 2 for detailed discussion and references). Further,such structures are typically designed to protect adjacent land, not necessarily the residential and other structures constructed on that land.

Impact of shoreline protection structures

1. The construction of new structural shoreline protection facilities on all barriers classified as undeveloped, moderately developed and developed and along all Type 1 waters has been prohibited in Rhode Island for more than 30 years pursuant to Section 300.7 of the RI Coastal Resources Management Program. Only maintenance of existing structural shoreline protection facilities is permissible in these cases, and these facilities cannot be expanded beyond preexisting conditions. If a shoreline protection structure has been physically destroyed 50% or more by wind, storm surge, waves or other coastal processes, or must be demolished to be maintained or repaired, such an application is subject to current CRMC prohibitions and regulations. Construction of shore parallel shoreline protection structures (seawalls, revetments, bulkheads etc.) along eroding bluffs and dunes have negative impacts to beaches directly in front of the structure, as well as adjacent shorelines. There can be an immediate response (placement loss), or loss can occur over time (loss of fronting beach and impacts to adjacent shorelines due to sediment impoundment. Impoundment refers to the retention of sediment behind structures which otherwise would be available to replenish beaches when eroded from the bluff/dune). Placement loss represents a direct and instant loss of the beach when the construction of structures (i.e. revetments) extend onto the adjacent beach (Griggs, 2005; Pilkey and Wright, 1988). While vertical structures can impact some portions of the beach, sloping structures typically have a greater impact. Revetments are typically constructed at slopes of 1.5 or 2 to 1, so a revetment built on a 15-foot bluff face has a footprint of at least 30 feet at the base. This encroachment onto the adjacent beach may have minimal impact on wide beaches, however this impact can be significant on narrower, steeper (frequently gravelly) beaches (Griggs, 2005). Additional impacts occur in cases where one protected structure extends further seaward than adjacent structures. This disrupts longshore sediment transport, causing sediment accretion on the updrift side of the structure but erosion to the downdrift shoreline(USACE 2002).

2. Significant controversy remains regarding the acceleration of erosion (i.e. "active erosion" in the parlance of Pilkey and Wright, (1988)) in front of the shoreline protection structures (Dean, 1987; Griggs, 2005; Kraus, 1988; Kraus and McDougal, 1996; USACE, 2002). Less controversial is additional erosion immediately adjacent to the shoreline protection structures (known as edge effects or flanking) as well as the potential for additional impacts for structures down the sediment transport direction (USACE, 2002). The Coastal Engineering Manual (USACE 2002) provides a review of the potential impacts of shoreline protection structures (accelerated erosion, hindering post-storm recovery etc.). Largely based on Dean (1987), the manual concludes that many of the notions regarding the impact of structures on the frontal beach are not definitive and may require further research. This represents a change from the earlier USACE Shore Protection Manual (USACE, 1984), which noted that when constructed on eroding shorelines, erosional processes may be intensified.

3. Regardless of whether shoreline protection structures accelerate shoreline change in front OR simply makes the continuation of shoreline migration more noticeable, the fact remains that along an eroding coast, the position of the shoreline will continue to migrate. This results in a narrowing beach in front of the structure (Pilkey and Wright, 1988; USACE 2002). Once the shoreline reaches the structure, the beach in front will be lost. While this is sometimes referred to as "passive erosion" (Pilkey and Wright, 1988), it can simply be thought of as the continuation of the coastal processes on a migrating shoreline. Once the adjacent shorelines migrate landward of the shoreline protection structure, the protruding structure can change the local wave refraction patterns and interrupt longshore sediment transport along the coast, affecting downdrift shorelines (USACE, 2002).

4. Sediment impoundment behind armored bluffs (and dunes) is another impact of shoreline protection structures (Griggs, 2005; O'Connell, 2010). Armoring the coastal bluffs impounds sediment behind the structure that would otherwise have been eroded from the bluff, contributing sediment to the coastal system. The coastal bluffs (headlands) in Rhode Island are composed of a glacially deposited sediment ranging from sand and gravel along the stratified headlands to glacial till (a diamict composed of gravel, sand silt and clay) (Boothroyd et al., 2001; Kaye, 1960, Schafer, 1961, 1965). With an instantaneous berm volume of approximately 1,000,000 m^3 (approximately 1,100,000 yd^3) along the 30 km (18.6 mile) south shore, this represents a relatively sediment starved system (Boothroyd, 2002). Most of the sediment within the coastal system is derived from the erosion of the glacial bluffs, and transported by longshore currents to adjacent shorelines. Longshore transport of sediment eroded from the bluffs is the primary mechanism responsible for the formation of the barrier spits along the shoreline.

Some sediment may be brought onshore in a manner as observed along Fire Island, NY (Schwab et al., 2013), however the lack of an offshore bar system in Rhode Island suggests this is likely not a significant source of sediment. Little to no sediment is transported down the rivers to the coastal system in Rhode Island (Ji et al., 2002).

5. The amount of sediment impounded behind shoreline protection structures that is lost to the coastal system varies depending the height of bluff/dune being armored, alongshore extent of the structure and estimated shoreline change (erosion) rate of the bluff, combined with the proportion of sediment within the bluff that is compatible with the beach, (generally any sediment sand-sized and larger). As an example, a 30 meter (100 ft) wide structure installed on a sandy bluff that is 3 meters (10 feet) tall, with a historic shoreline change rate of 1.1 m/year (3.3 ft/year), represents a loss of 90m^3/yr (120 yd^3/yr) to the coastal system. Without on-going (and permanent) beach replenishment, this loss of sediment will impact the beach in front of the structure as well as adjacent shorelines (Griggs, 2005).

6. Shoreline protection structures result in negative impacts including loss of lateral access; ecological impacts; and cumulative impacts. A significant negative outcome of these structures and the processes described above is the loss of lateral access along the shoreline in front of these structures. Beyond the physical alteration of the structure and loss of access, construction of hardened structures has deleterious ecological impacts on adjacent structures (Cooper et al., 2017; Dugan et al., 2008). The construction of these structures can have a significant cumulative impact, and it has been estimated that on Cape Cod, complete armoring of the bluffs would lead to a loss of fronting beaches within a century (Giese et al., 2015). Similar values have been reported from California, where modelling suggests 31-67% of southern California beaches could erode completely by 2100 with >2 m (6.6 ft) of sea level rise (Vitousek et al., 2017).

4.3.2 Coastal Wetlands

4.3.2.1 Overview

1. This section summarizes what is known to date about the exposure of Rhode Island's coastal wetlands to storm surge, coastal erosion and sea level rise. For CRMC's policies regarding coastal wetlands, see the RICRMP. For information on adaptation strategies regarding coastal wetlands, see Chapter 7 of the RI Shoreline Change SAMP.

2. Coastal wetlands include salt marshes as well as brackish or freshwater wetlands. This section focuses on salt and brackish marshes, i.e. those that are mostly vegetated, tidal, and saline. Coastal wetlands include areas of open waters within coastal wetlands,

wetlands directly associated with non-tidal coastal ponds, or wetlands located on a barrier beach or separated from tidal waters by a barrier beach. As of 2010, according to the National Wetlands Inventory there were 3,742 acres of coastal wetlands within the state of Rhode Island and 4,172 acres when including Connecticut and Massachusetts contiguous areas that are part of RI's coastal wetlands complex (see RI CRMC 2015).

3. Salt marshes are typically characterized by distinct high and low salt marsh zones. High salt marsh is the marsh area typically flooded by spring, moon or storm tides but not on a daily basis. Low salt marsh is the portion of a marsh that is flooded daily. Each zone is dominated by distinct types of vegetation with varying tolerances to salt water, which makes these areas particularly dependent on and sensitive to changes in frequency and duration of flooding.

4. Coastal wetlands are critically important because of the functions and values they provide to humans and the environment. These ecosystem services include providing habitat for finfish, shellfish, birds, mammals, and invertebrates, including species important to commercial and recreational fishermen, hunters, birders, and other outdoor enthusiasts (Kutcher 2017). Examples of species of commercial interest in Rhode Island include summer and winter flounder and blue crabs (Raposa and Roman 2001, Raposa 2003). Ecosystem services also include influencing water quality through the filtering, uptake and storage of sediment, nutrients and pollutants (Kutcher 2017). Additionally, coastal wetlands serve as important and effective long-term carbon sinks. Coastal wetlands are known to sequester substantial amounts of carbon, primarily in the organic underlying soils, aiding in climate change mitigation (Howard et al. 2017). Drake et al. (2015) estimate that the annual carbon sequestration rate for northeast tidal marshes is 74 – 127 grams of carbon per square meter per year.

5. Coastal wetlands provide habitat for finfish and shellfish species that are important to Rhode Island's commercial and recreational fishing industries. These industries are of great economic, social and cultural value to the state and the region. In 2015, NOAA reported that RI recreational fishing generated $332 million in sales, $141 million in income, $217 million in value added to the economy, and supported 3,554 jobs. In that same year RI commercial fishing – excluding imports - generated $100 million in sales, $44 million in income, $57 million in value added to the economy, and supported 2,107 jobs (NOAA 2015). The loss of nursery habitat for finfish and shellfish species important to commercial and recreational fisheries could result in impacts to these valuable industries and in particular to the fishing community of Point Judith, which supports these industries. For more detailed information on Rhode Island's recreational and

commercial fisheries please see CRMC's Rhode Island Ocean Special Area Management Plan (2010) at http://www.crmc.ri.gov/samp_ocean.html.

6. Ecosystem services provided by coastal wetlands also include flood protection for residential and commercial properties as well as erosion control for the natural and built environments. Coastal wetlands can enhance coastal resilience through wave attenuation and shoreline stabilization, protecting adjacent structures from these impacts (Shepard et al. 2011; Kutcher 2017). A 2008 study estimated that salt marshes provide $8,240 worth of protection, per hectare, from coastal storms each year, totaling $23.4 billion in coastal storm protection throughout the United States (Costanza et al. 2008).

7. Coastal wetlands in Rhode Island and elsewhere have suffered widespread degradation over time due to past and ongoing human-induced stressors. Human activities impacting coastal wetlands have included filling, mosquito ditching, impoundment, nutrient loading, and the influx of invasive plant and animal species as well as alterations to tidal hydrology (e.g. infrastructure that impedes tidal exchange) (see Kutcher 2017 and the sources cited therein). A 2005 study that analyzed historical maps estimated that Rhode Island lost approximately 1,831 hectares (4,524 acres), or 53%, of salt marshes over the previous 200 years (Bromberg and Bertness 2005).

4.3.2.2 The Effects of Sea Level Rise and Other Coastal Hazards on Coastal Wetlands

1. Salt marshes are unique in that the frequency and duration of tidal flooding play a significant role in controlling physical and biological processes, making marshes especially sensitive to changes in flooding (Roman et al. 1997, Mitsch and Gosselink 2000). Additionally, salt marshes are sustained through the accretion of sediment and the settling of organic matter, but in Rhode Island accelerating sea level rise is outpacing accretion (Raposa et al. 2015). As a result, salt marshes in Rhode Island and elsewhere are showing signs of erosion, ponding, drowning, and shifts in vegetation (Warren and Niering 1993, Donnelly and Bertness 2001, Raposa et al. 2016a, Watson et al. 2016).

2. Recently, evidence is mounting that accelerating sea level rise is having demonstrable impacts on coastal wetlands in Rhode Island and elsewhere, exacerbating the trend of marsh degradation and loss (Kutcher 2017). A nationwide study found that southern New England salt marshes are among the most vulnerable to sea level rise in the entire U.S. (Raposa et al. 2016b).

3. Coastal wetlands face many human-induced stressors, and sea level rise may work in a synergistic way with some of these stressors (and other natural factors such as herbivory) to further degrade marsh condition. For example, high nutrient inputs may decrease

below-ground marsh biomass, making marshes more susceptible to erosion and subsidence with increased flooding from sea level rise (Watson et al. 2014). Increased inundation periods may be related to increases in crab populations that graze on marsh plants and exacerbate erosion (Bertness et al. 2014).

4. In 2012 and 2013, a research team led by Save the Bay and the Narragansett Bay National Estuarine Research Reserve (Cole Ekberg et al. 2014) evaluated the potential impacts of sea level rise on Rhode Island salt marshes. The team chose 39 marsh units from 31 marshes throughout Rhode Island and the Massachusetts section of the Bay as study sites in order to capture the geographic range of marshes from north to south, east to west, and along the coastal ponds. The team used a three-tiered assessment comprising a GIS analysis of land use; a rapid field assessment; and in-depth biological, biogeochemical and physical studies at select sites. The assessment protocol and results from this first round of the Rhode Island Salt Marsh Assessment (RISMA) are presented in Cole Ekberg et al. 2014.

5. Subsequently, Cole Ekberg and other researchers (Cole Ekberg et al. 2017) built upon elements of the RISMA to assess the vulnerability of Rhode Island's coastal wetlands to sea level rise. Focusing on the same 31 marshes (see Figure 7), Cole Ekberg et al. used a variety of methods and tools to assess coastal wetland vulnerability to SLR: field measurements made as part of rapid condition assessments; field and remote sensing measurements of elevation; outputs of a VDatum model which estimated marsh platform height relative to mean high water (MHW); and outputs of a Sea Level Affecting Marshes Model (SLAMM; discussed below). The authors examined these metrics together with the goal of developing and testing an integrated vulnerability assessment tool that considered elevation capital, marsh vegetation, and sea level rise projections.

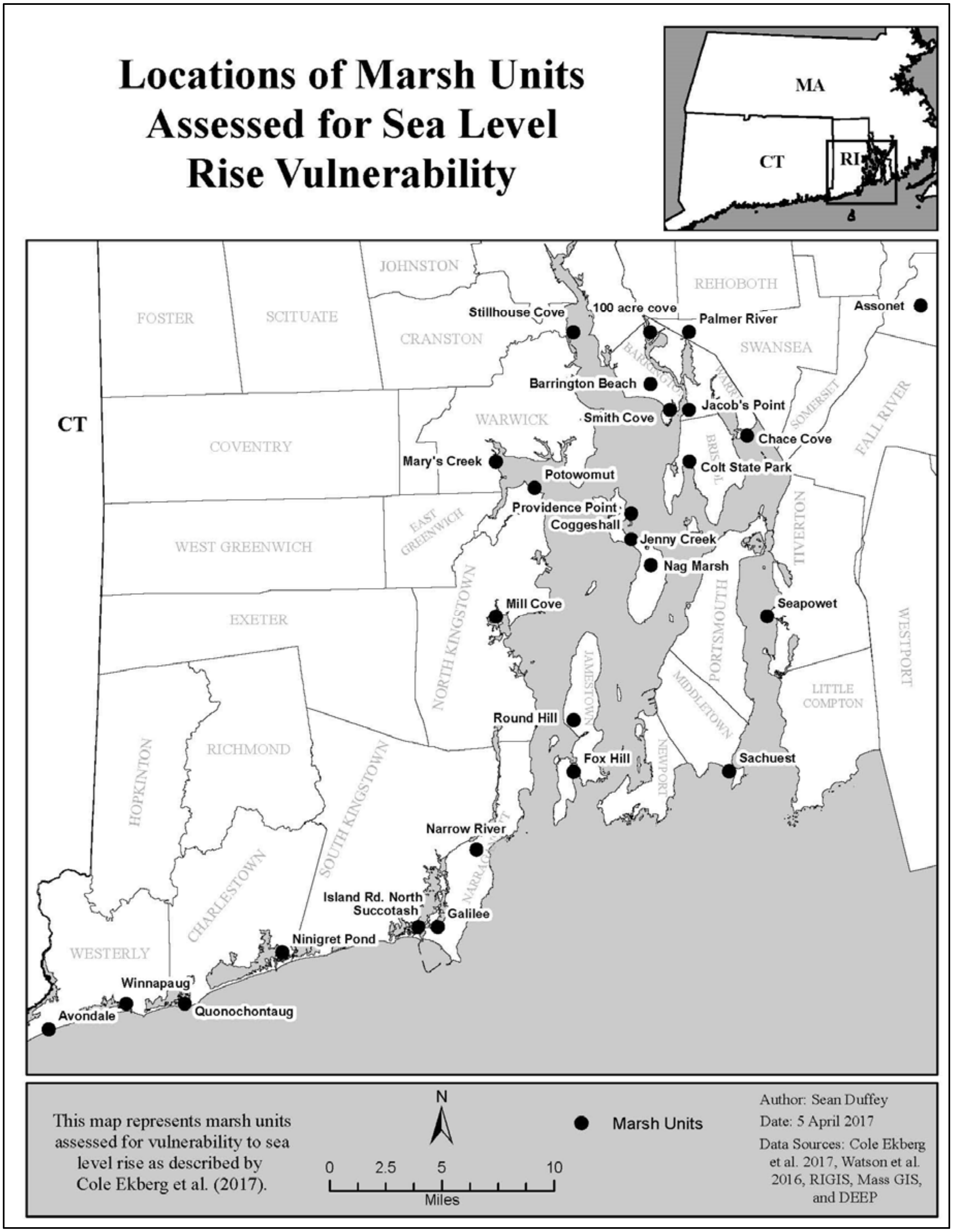

Figure 7. Location of marsh units assessed for sea level rise vulnerability (based on data used by Cole Ekberg et al. 2017).

6. Cole Ekberg et al. (2017) report vulnerability rankings for a subset of these marshes; these results are discussed below in sections 4.3.2.3 and 4.3.2.4. The authors also report findings on the best indicators to use to measure coastal wetland vulnerability to SLR. The authors found that elevation of the marsh above MHW was the single factor with the greatest impact on vulnerability, identifying it as a crucial component of measuring vulnerability to SLR moving forward. They also note that vegetation metrics explained the largest variability in marsh loss data, with high percentages of tall *Spartina alterniflora* and low marsh vegetation as indicators of high vulnerability (see Table 3 and Table 5 below). The authors further note a correlation between tidal range and marsh loss and SLR vulnerability, finding that marshes with a tidal range below 0.4 meters (1.3 feet) were particularly vulnerable.

7. Cole Ekberg et al.'s analysis revealed contrasting patterns of vulnerability between Rhode Island regions, with south coast marshes generally much more vulnerable to SLR, and marshes up Narragansett Bay much less vulnerable. For a summary of some site-specific results see discussion below in sections 4.3.2.3 and 4.3.2.4. For complete study methods and results see Cole Ekberg et al. (2017).

8. In 2015, the CRMC completed an analysis of the potential impacts of sea level rise on coastal wetlands. The analysis included modeling of potential coastal wetland loss as well as the landward migration potential of coastal wetlands located within Rhode Island's 21 coastal communities (RI CRMC 2015; hereafter "SLAMM study"). This analysis applied the Sea Level Affecting Marshes Model (SLAMM) and used 2011 state LiDAR elevation data and the 2010 National Wetland Inventory dataset to model SLR projections of 1, 3, and 5 feet (above 1990 levels). These models were used to both simulate short- and long-term impacts on coastal wetlands and to assess potential upland wetland migration pathways.

9. The SLAMM study revealed that Rhode Island is likely to face a substantial loss of coastal wetlands. Total statewide losses are expected to be 13% under the 1-foot SLR scenario, 52% under the 3-foot SLR scenario, and 87% under the 5-foot SLR scenario. Under the assumption that marshes would be able to migrate onto adjacent developed upland areas, the SLAMM study projects that there would be a net gain of new coastal wetlands statewide under all three of the SLR scenarios, although individual communities may experience an overall net loss of coastal wetlands under some scenarios. Importantly, much is not known about marsh migration processes and how substrate types and upland vegetation will affect migration extent and rates; this is currently an area of CRMC-funded research in Rhode Island and is an area recommended for future research (see Section 4.6). Under the assumption that marshes would be unable to migrate onto adjacent developed areas, lower net wetland acreage is projected, which illustrates how

upland development decisions will have great influence on the ability of coastal wetlands to migrate. For further information see RI CRMC (2015). Specific community results are included in sections 4.3.2.3 and 4.3.2.4 below.

10. Importantly the SLAMM study acknowledges several limitations of the SLAMM model and findings. Data used in the study to characterize wetland baseline conditions did not include information on some key indicators of wetland condition that reflect stress and degradation due to SLR. Additionally, the authors point out model limitations that may indicate that future new marsh development is overestimated, rate and extent of wetland loss are underestimated, and results regarding barrier systems contain a higher degree of uncertainty (RI CRMC 2015). Specifically, limitations associated with model inputs such as existing wetlands data, LiDAR elevation data, accretion rates, barrier system dynamics and recently updated sea level rise rates may mean that model results may overestimate future new marsh migration and underestimate the rate and extent of future wetland loss. This assumption is supported by recent observational data. Cole Ekberg et al. (2017) also point out that LiDAR elevations (which were used in the SLAMM) consistently overestimate marsh elevation. For these reasons, SLAMM study results should be used with caution and as a general planning tool only, especially when considering potential marsh migration.

4.3.2.3 South County and Block Island

1. Coastal wetlands found along Rhode Island's south shore include marshes located along the back-barriers and in small embayments that are less exposed to wave energy. The south coast back-barrier marshes have a restricted tidal range (Boothroyd et al. 1985; Lee and Olsen 1985) in comparison to the full tidal exposure of tidal riverine and fringing marshes. Many of these wetlands have been identified as highly exposed to the effects of sea level rise (although marshes are by definition located in lower-energy shoreline areas and are thus relatively less exposed compared to other shoreline types), and are vulnerable to being buried by sand from overwash events during coastal storms. Block Island salt marshes are relatively small in area, limited to mainly fringing marshes bordering the tidally connected ponds.

2. CRMC's 2015 SLAMM study projected the net change of coastal wetlands for each municipality under 1, 3 and 5-foot SLR scenarios. Separate projections were made under the assumption that wetlands could migrate upland where there is currently existing development such as impervious surfaces or structures ("unprotected development") and could *not* migrate upland where there is currently existing development ("protected development"). In undeveloped areas, the model assumed that marsh migration would occur if the appropriate elevation and flooding conditions were present. It did not take

into account current upland vegetation types, soil substrate types, variations in accretion rates or other factors that may impact marsh migration processes. See Table 2 for summary results. The entire town of Narragansett is included among south coast communities although much of its shoreline faces east toward Narragansett Bay or Rhode Island Sound. Importantly, although summary statewide data (discussed above) projected the state overall seeing net gains of coastal wetlands under all SLR scenarios, the south coast communities would be disproportionately negatively impacted, with Charlestown, Narragansett, South Kingstown and Westerly projected to see net coastal wetland losses under the 3- and 5-foot SLR scenarios, mainly due to losses of large back-barrier marsh complexes.

Table 2. Net change of coastal wetlands in acres by south coast municipality (adapted from RI CRMC 2015). The unprotected development scenario assumes that wetlands can migrate onto developed upland areas whereas the protected development scenario assumes that wetlands cannot migrate onto developed upland areas.*

		Net change (acres) of coastal wetlands: Unprotected development scenario			Net change (acres) of coastal wetlands: Protected development scenario		
Municipality	**Coastal wetlands (acres) in 2010**	**1 ft. SLR**	**3 ft. SLR**	**5 ft. SLR**	**1 ft. SLR**	**3 ft. SLR**	**5 ft. SLR**
Charlestown	340.1	7.0	-97.0	-41.7	12.0	-114.4	-113.8
Little Compton	159.9	34.2	20.2	67.0	30.7	9.7	46.8
Narragansett	396.6	82.3	-104.7	-92.5	67.2	-166.9	-212.0
New Shoreham	71.6	144.7	106.1	100.2	117.1	60.0	36.0
South Kingstown	311.1	43.1	-85.8	-40.8	43.8	-108.4	-86.9
Westerly	269.6	67.6	21.4	-1.1	60.3	-71.4	-139.6
Total	**1548.9**	**378.9**	**-139.8**	**-8.9**	**331.1**	**-391.4**	**-469.5**

** SLAMM results should be used with caution and as a general planning tool only. Limitations associated with model inputs such as existing wetlands data, LiDAR elevation data, accretion rates, barrier system dynamics and recently updated sea level rise rates may mean that model results may overestimate future new marsh migration and underestimate the rate and extent of future wetland loss.*

3. Cole Ekberg et al. (2017)'s analysis of the vulnerability of Rhode Island marshes to sea level rise resulted in a series of marsh assessment values for each site, rated according to relative vulnerability from red (most vulnerable to SLR) to green (least vulnerable to SLR). Table 3 includes values for elevation above MHW, mean *Spartina alterniflora* height, and percentage of low marsh vegetation; for complete marsh assessment values see Cole Ekberg et al. (2017). As discussed above, the authors found that elevation above MHW is the single factor with the greatest impact on vulnerability to SLR. Additionally, the authors found that the presence of tall *S. alterniflora* and high percentages of low marsh vegetation were indicative of high vulnerability to SLR.

Table 3. South coast marsh assessment values rated according to relative vulnerability. Values are outputs of marsh vulnerability assessment and are rated from red (most vulnerable to SLR) to green (least vulnerable to SLR). Adapted from Cole Ekberg et al. 2017

Marsh	Municipality	Elevation MHW	Mean S. alterniflora height	% low marsh veg.
Avondale	Westerly	-0.06	67	1.3
Galilee	Narragansett	0.23	51	0.5
Island Rd. North	South Kingstown	0.12	55	4.9
Ninigret Pond	Charlestown	-0.26	50	0.6
Quonochotaug	Charlestown	-0.09	58	2.5
Succotash	South Kingstown	-0.07	54	10.6
Winnapaug	Westerly	-0.16	42	4.1

4. Cole Ekberg et al. (2017) found that marsh attributes that are associated with vulnerability are common in the marshes along Rhode Island's southern coast. Marshes with these characteristics were identified at marsh units in Winnapaug pond (Westerly), Quonochontaug and Ninigret ponds (Charlestown), and Pt. Judith pond (South Kingstown/Narragansett) (see Table 3). Most prominently, these attributes included lower relative marsh elevations above MHW.

5. Together, study results indicate that salt marshes in Rhode Island's south shore region are expected to be disproportionately negatively affected by SLR when compared to other marshes in the state. Study results further indicate that elevation above MHW is a key indicator of marsh vulnerability to SLR, and that numerous south shore marshes have relatively low elevations.

4.3.2.4 Narragansett Bay

1. Coastal wetlands within Narragansett Bay are located throughout the estuary in small embayments off the bay, and in tidal rivers—areas that are less exposed to wave energy. Many coastal communities within the bay, particularly in urban areas like Providence and Quonset, have suffered significant wetland loss over time due in part to the historic practice of filling wetland areas. Many of the remaining coastal wetlands are narrow fringing marshes. These remaining wetlands provide important ecosystem services such as nutrient uptake and shoreline protection.

2. As discussed above, CRMC's 2015 SLAMM study projected the net change of coastal wetlands for each municipality under 1, 3 and 5-foot SLR scenarios. Projections were made under the assumption that wetlands could migrate upland where there is currently existing development such as impervious surfaces or structures ("unprotected development") and could *not* migrate upland where there is currently existing development ("protected development"). In undeveloped areas, the model assumed that marsh migration would occur if the appropriate elevation and flooding conditions were present. It did not take into account current upland vegetation types, soil substrate types, variations in accretion rates or other factors that may impact marsh migration processes. See Table 4 for summary results for Narragansett Bay, which project a net gain for coastal wetlands for every municipality under all scenarios through the process of marsh migration. However, as noted above, these results should be interpreted with caution as the SLAMM study reports that these results likely overestimate wetland gain.

Table 4. Net change of coastal wetlands in acres of Narragansett Bay municipalities (adapted from RI CRMC 2015). The unprotected development scenario assumes that wetlands can migrate onto developed upland areas whereas the protected development scenario assumes that wetlands cannot migrate onto developed upland areas.*

		Net change (acres) of coastal wetlands: Unprotected development scenario			Net change (acres) of coastal wetlands: Protected development scenario		
Municipality	**Coastal wetlands (acres) in 2010**	**1 ft. SLR**	**3 ft. SLR**	**5 ft. SLR**	**1 ft. SLR**	**3 ft. SLR**	**5 ft. SLR**
Barrington	365.1	206.9	418.7	395.6	130.8	253.4	80.4
Bristol	121.3	58.1	109.8	137.5	38.8	52.4	28.9
Cranston	2.9	5.9	20.3	76.7	0.2	11.9	43.0
East Greenwich	0.5	6.5	5.0	10.4	4.3	1.4	1.5
East Providence	80.3	84.6	130.7	174.1	51.1	74.9	62.6
Jamestown	121.7	77.0	17.8	21.7	66.8	2.1	-17.6
Middletown	49.4	48.0	18.7	3.5	32.6	12.2	-7.1
Newport	20.7	100.0	202.1	396.7	68.5	62.1	105.0
North Kingstown	180.3	223.0	336.2	719.9	176.0	174.9	214.8
Pawtucket	0	9.1	7.8	14.3	7.9	6.6	9.6
Portsmouth	434.9	220.9	156.5	145.0	182.4	75.7	-25.1
Providence	4.2	35.5	63.6	190.1	8.1	7.5	10.2
Tiverton	291.0	116.1	55.8	14.5	99.2	24.3	-40.0
Warren	280.4	120.8	299.1	268.6	80.1	186.3	84.7
Warwick	240.5	228.1	302.8	436.9	159.9	140.9	119.6
Total	**2193.2**	**1540.5**	**2144.9**	**3005.5**	**1106.7**	**1086.6**	**670.5**

** SLAMM results should be used with caution and as a general planning tool only. Limitations associated with model inputs such as existing wetlands data, LiDAR elevation data, accretion rates, barrier system dynamics and recently updated sea level rise rates may mean that model results may overestimate future new marsh migration and underestimate the rate and extent of future wetland loss.*

3. Cole Ekberg et al. (2017)'s analysis of the vulnerability of Rhode Island marshes to sea level rise resulted in a series of marsh assessment values for each site, rated according to relative vulnerability from red (most vulnerable to SLR) to green (least vulnerable to SLR). Assessment values for marsh sites in Narragansett Bay and its tributaries are included in Table 5 below. As with Table 3 above, values for elevation above MHW, mean *Spartina alterniflora* height, and percentage of low marsh vegetation are included here because of their importance in indicating vulnerability to SLR; for complete marsh assessment values see Cole Ekberg et al. (2017).

Table 5. Narragansett Bay and tributaries marsh assessment values rated according to relative vulnerability. Values outputs of marsh vulnerability assessment and are are rated from red (most vulnerable to SLR) to green (least vulnerable to SLR). Adapted from Cole Ekberg et al. 2017.

Marsh	Municipality	Elevation MHW	Mean S. alterniflora height	% low marsh veg.
100 acre cove	Barrington	0.02	61	3.8
Assonet	Assonet, MA	0.18	84	7.7
Barrington Beach	Barrington	0.16	38	0.5
Chace Cove	Warren	0.07	68	12.7
Coggeshall	Portsmouth	0.08	49	11.8
Colt State Park	Bristol	0.14	51	2.2
Fox Hill	Jamestown	-0.02	37	1.9
Jacob's Point	Warren	0.13	54	0.6
Jenny Creek	Portsmouth	0	43	2.2
Mary's Creek	Warwick	-0.01	71	21
Mill Cove	North Kingstown	0.07	78	8
Nag Marsh	Portsmouth	0.13	63	7.9
Narrow River	Narragansett	-0.06	30	0.4
Palmer River	Swansea MA	-0.01	47	0.7
Potowomut	East Greenwich	0.02	68	29.1
Providence Point	Portsmouth	0.09	60	4.4
Round Hill	Jamestown	0.07	35	4.2
Sachuest	Middletown	0.11	75	1.8
Seapowet	Tiverton	0.16	45	1.5
Smith Cove	Barrington	0.14	102	5.7
Stillhouse Cove	Cranston	-0.03	96	30.4

4. Cole Ekberg et al. (2017) found contrasting patterns of vulnerability between regions. While the most notable differences are between Narragansett Bay and the Rhode Island south coast (discussed above; see also Table 3), contrasting patterns of vulnerability were also evident within Narragansett Bay and its tributaries. For example, some sites closer to the mouth of the Bay (e.g. Fox Hill in Jamestown and the Narrow River in Narragansett) may be more vulnerable to SLR than those up the Bay, while in other cases marshes up the Bay and its tributaries (e.g. Stillhouse Cove in Providence and Mary's Creek in Warwick) exhibit relatively high vulnerability. See also Figure 8.

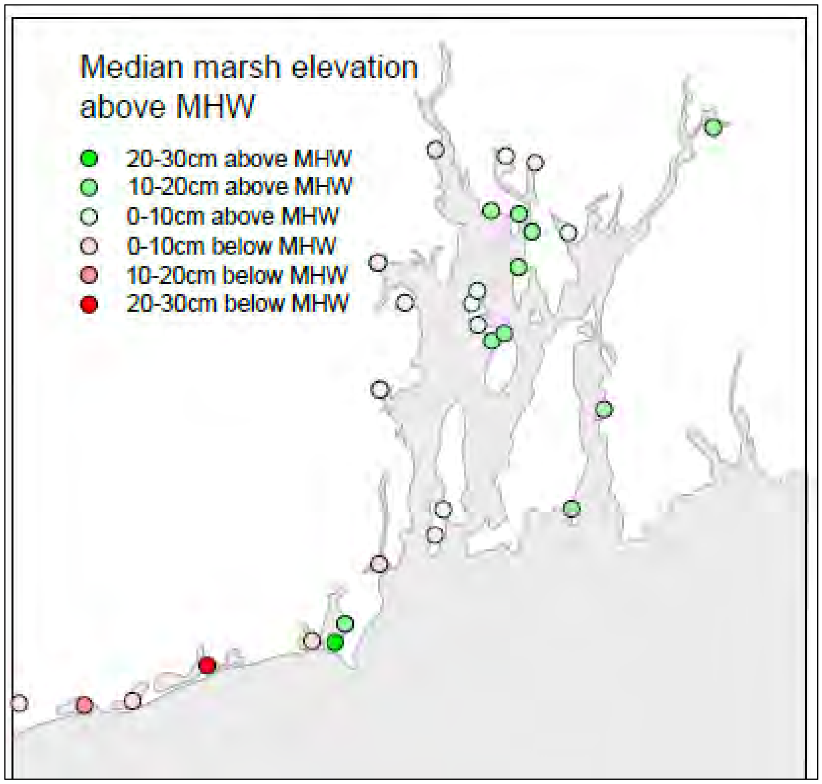

Figure 8. Median marsh elevation above MHW as an indication of marsh vulnerability to SLR (Source: Cole Ekberg et al. 2017)

5. In sum, study results indicate that Narragansett Bay marshes may be generally less vulnerable to the effects of SLR than south shore marshes, though there is considerable variability between bay locations.

4.3.3 Other Coastal Habitats

1. Other habitats of particular concern include low-lying coastal uplands and freshwater wetlands adjacent to coastal wetlands. Many of these freshwater wetland areas have been identified through modeling to be areas of future potential marsh migration. For example, the SLAMM study projected freshwater wetland losses of 204 acres with a 1-foot SLR, 635 acres with a 3-foot SLR, and 1060 acres with a 5-foot SLR statewide. Almost one half of the total freshwater wetland loss statewide is projected in just five towns: Barrington, Charlestown, South Kingstown, Warren and Westerly (RI CRMC 2015).

2. These areas may also include rare or threatened species, such as those found in sea level fens, that are at risk of being lost with future increases in sea level. Sea level fens are an emergent wetland community found at the interface at the upper end of tidal marshes where there is an upland freshwater source such as groundwater seepage. Sea level fens have a distinct species assemblage; in Rhode Island they are often dominated by the

grasses twig-rush (*Cladium*), bulrush (*Scirpus*) and spike-rush (*Elocharis*). There are only two sea level fens in Rhode Island, making them unique and rare in the state (RI CRMC 2015).

4.4 Effects of Erosion on Rhode Island's Coast

4.4.1 Historic Shoreline Change

1. Rhode Island's shoreline has experienced erosion over time, resulting in patterns of shoreline change that can be observed over the decadal time scale. These patterns vary by location depending on physical characteristics of the shoreline itself and the physical processes (e.g. wind, waves) to which the shoreline is exposed. Studies of shoreline change in Rhode Island and elsewhere indicate that shoreline change is not a consistently incremental process but rather is driven by storm events such as hurricanes or nor'easters which can cause significant shoreline change within short periods of time.

2. An assessment of historic shoreline change for portions of the Rhode Island coast was performed in support of the Shoreline Change SAMP. This section includes a brief summary of this analysis. For a complete set of shoreline change maps see Boothroyd et al. (2016) or http://www.crmc.ri.gov/maps/maps_shorechange.html. For a technical report summarizing methods and results see Oakley, Hollis and Boothroyd (2016).

3. Boothroyd et al. (2016) updated existing shoreline change maps for portions of the Rhode Island coast. Their mapping focused on the southern shoreline of Washington County, from Napatree Point to Point Judith (excluding Block Island), as well as the east facing shoreline of Narragansett and North Kingstown, from Point Judith to the Potowomut River, facing Rhode Island Sound and Narragansett Bay (see Figure 9). Shoreline change maps show the position of the shoreline at a given time based on measurements from georeferenced aerial and digital orthophotographs.

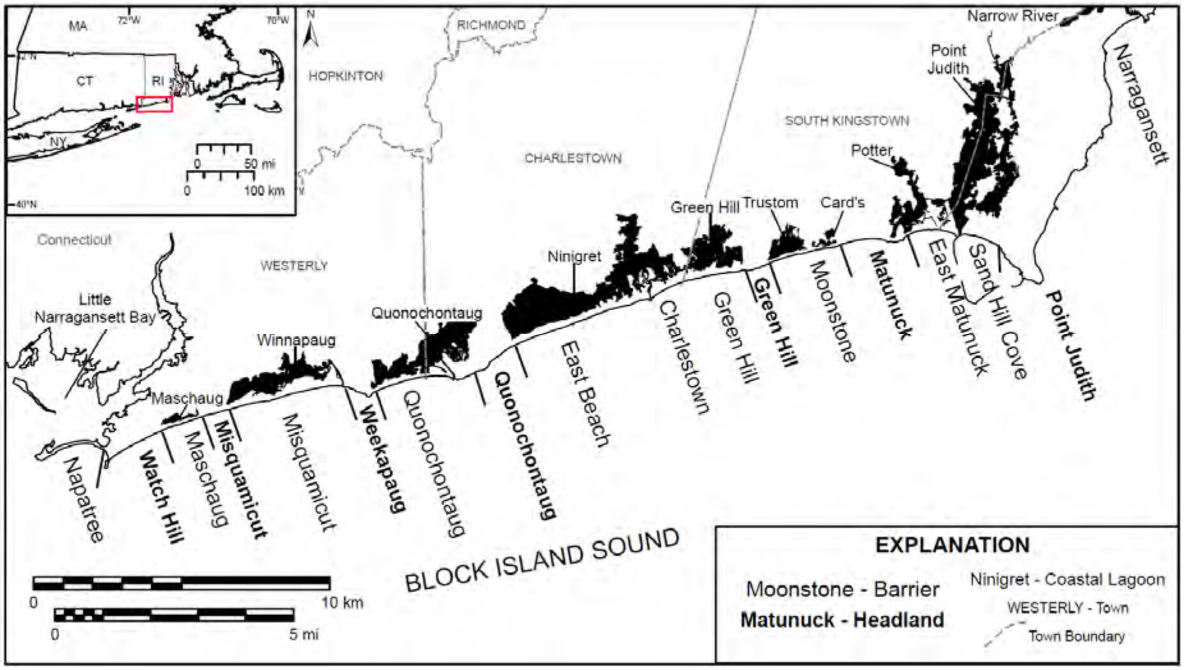

Figure 9. Barriers and headlands of the Rhode Island South Shore with headlands labeled in bold font. Modified from Boothroyd et al. 1998.

4. Shoreline change between 1939 and 2014 was mapped using the position of the last high tide swash, which is the limit of wave run-up on the beach and is used as a proxy for the position of mean high water (MHW). Transects were run at 50 meter intervals along the shoreline using the Digital Shoreline Analysis System 4.0 (DSAS) to measure these positions. Shoreline change rates and statistics for each transect were calculated using the shoreline change envelope (SCE) method which takes the absolute value of the total distance between the most landward and seaward shoreline positions. The annualized rate of change was calculated using this information in addition to the years of the most landward and seaward shoreline positions and the difference in time (years) between these two shoreline positions. An alternative measure, end-point rate (EPR), was used to calculate the annualized rate of change along marsh shorelines and in developed areas where fill and shoreline protection structures create complications for interpreting shoreline change. For further information on data sources, measurements and methods see Oakley, Hollis and Boothroyd (2016).

5. Oakley, Hollis and Boothroyd (2016) report that the Rhode Island coast is largely erosional: 95% of transects measured in the study area showed varying rates of shoreline retreat. The authors attributed this “systematic retreat” to storms and, to a lesser degree, sea level rise. While this study identified some areas of net accretion, or accumulation of sediment (e.g. at the north end of Scarborough Beach), the authors note

that most such areas are the result of interventions such as filling or the construction of shoreline protection structures (e.g. Quonochontaug Headland and Quonset Point).

6. Maps produced by Boothroyd et al. (2016) illustrate that the Rhode Island south shore (from Napatree Point to Point Judith) experienced higher amounts of erosion than the east-facing shoreline from Point Judith to the Potowomut River. Shoreline change ranged over the south shore from near zero to a total retreat of 90 meters (295 feet) along areas of the Matunuck Headland between 1951 and 2014.

7. Oakley, Hollis and Boothroyd (2016) calculated average annualized rates of shoreline change by shoreline type (e.g. glacial stratified, barrier/beach). The authors report that shoreline areas with the highest (most negative) shoreline change were those backed by glacial stratified bluffs with an average annualized loss of 0.75 meters (2.46 feet) per year. This statistic was influenced by the particularly high rate of erosion in an area of Matunuck from Cards Point to the east end of the South Kingstown Town Beach, where total shoreline change exceeded 90 meters (295 feet) between 1951 and 2014. Barriers averaged an annualized rate of loss of 0.57 meters (1.87 feet) per year, with rates of retreat greater than 1 meter (3.28 feet) per year found in portions of the Quonochontaug and Moonstone barriers. These statistics illustrate the finding that the Rhode Island south shore has experienced higher amounts of erosion than other parts of the state. Additionally, this area in particular experienced a great deal of overwash and migrated via washover fan deposition.

8. Oakley, Hollis and Boothroyd (2016) found that erosion rates were generally lower along the coast from Point Judith to the Potowomut River, and attribute this difference in part to the prevalence of bedrock and lower number of barriers in comparison to the south shore. They also found that the mixed energy environment inside Narragansett Bay (in comparison to the wave-dominate south shore environment), plus the larger number of shoreline protection structures inside the Bay, influence these lower erosion rates as they limit natural shoreline migration.

4.4.2 Projected Shoreline Change

1. Oakley, Hollis, Patrolia, Rinaldi and Boothroyd (2016) conducted an analysis of projected shoreline change, out to 2100, for the Rhode Island south shore. The projection of future shoreline change is a complex and sometimes controversial practice and findings should be interpreted with caution. The authors built upon previous studies of projected shoreline change including Anderson et al. (2015) and Moore et al. (2007). For a complete discussion of methods, see the study technical report at www.beachsamp.org. For maps depicting results, see the Hollis at-risk report discussed below.

2. Oakley et al.'s analysis employed a qualitative modeling approach and examined shoreline change projections for an "exponential high scenario" for 2100 based on a shoreline change rate that increases at an exponential rate of 2.5 times the historical trend by 2065. This rate was further extrapolated to increase exponentially to 2100.[5] Assuming an initial rate of 1 meter (3.28 feet) of shoreline change per year, this would produce a total change of 89 meters (292 feet) by 2065 and 216 meters (708 feet) by 2100. Oakley et al. produced 90 large-format maps depicting shoreline change for all of Rhode Island's south shore communities. Sample results are highlighted in section 4.6.2 below; see www.beachsamp.org to view maps for all communities.

3. Oakley et al.'s analysis also considered the policy implications of these projections by projecting future setbacks for coastal development based on CRMC's existing coastal policy. The projected shoreline change analysis assumed that the coastal feature (e.g. dune or bluff), as defined in the RICRMP, would migrate as well, maintaining a constant distance from the location of the shoreline. The projected future location of coastal features was used with some of CRMC's existing coastal construction setback requirements (30x the annual erosion rate for residential structures and 60x for commercial) to project future setback requirements, thus illustrating the potential effect of projected shoreline change on coastal development. Sample results are highlighted in section 4.3.3 below; see www.beachsamp.org to view maps for all communities.

4.5 Built Environment

1. Rhode Island's built environment is exposed in multiple ways to coastal hazards associated with climate change. Exposure refers to a community's assets, including people, property, infrastructure, and the natural environment, subject to a hazard's damaging impacts. The coastal hazards considered in this document include storm surge, coastal erosion and sea level rise. This section summarizes what is known to date about the exposure of Rhode Island's coastal residential, commercial, and industrial structures; public infrastructure; transportation infrastructure; ports and maritime infrastructure; public access and recreation facilities; and historic and archaeological assets.

[5] This results in a shoreline change rate 4.8 times the current rate by 2100.

4.5.1 CRMC Exposure Assessment

1. The exposure assessment presented below is a summary of a CRMC-led analysis of the impacts of sea level rise and storm surge on structures in all 21 Rhode Island coastal municipalities (Leporacci et al. 2016). CRMC's analysis used STORMTOOLS flood inundation data layers and Rhode Island's E-911 site database, which includes every known building or structure in the state, and analyzed future flooding risk to these structures through several sea level rise and storm surge scenarios. [6] Throughout this assessment, Prudence Island is listed separately, because this is how it is treated in the E-911 database, although it is part of the town of Portsmouth. The results illustrate future flood risk under SLR scenarios up to and including 7 feet, which are based upon the "high" sea level change curve included in NOAA's 2012 SLR analysis (NOAA 2012). These were the most up-to-date SLR data as of 2016 when this study was performed. Assessment findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge. This is because this assessment assumed that the Fox Point Hurricane Barrier is not present. The barrier was originally designed to address storm surge, based on conditions at the time, but not sea level rise. For further information on study methods and results see Leporacci et al. 2016 or www.beachsamp.org/STORMTOOLS/e911/. In 2017, NOAA issued an updated SLR analysis which projected up to 9.6 feet of SLR under the high curve and up to 11.7 feet of SLR under the "extreme" curve, at the 83% confidence interval, for Rhode Island (NOAA 2017a).

2. Seven sea level rise (SLR) and storm surge scenarios were selected from the range of scenarios analyzed by Leporacci et al. (2016) for inclusion in this chapter. These scenarios are all based on the NOAA high SLR curve included in NOAA's 2012 analysis (NOAA 2012), which was the most current analysis as of December 2016. The first three scenarios address SLR, considering 3, 5, and 7-foot projections. The last four scenarios address storm surges. One addresses a 100-foot storm surge with no projected SLR scenario, which is the current standard in floodplain mapping. This can be considered a present day scenario. The last three scenarios consider a 100-foot storm surge combined with the 3, 5, and 7-foot SLR scenarios, which represent different points in the future (see Table 6).

[6] This geospatial data analysis was conducted using STORMTOOLS and used 2015 inundation surfaces based on LiDar/Digital Elevation Models as well as the state of Rhode Island's 2011 E911 database for categories of structures (i.e., commercial, residential, industrial, public service, utility).

3. The SLR scenarios considered here represent different points in the future, with the higher SLR projections representing projected conditions in the latter part of the 21st-century. The Shoreline Change SAMP identifies the 3-foot SLR + 100-year storm surge scenario as the "**Mid-century Planning Scenario**" because it represents projected conditions in 2065. CRMC recommends that property owners use this scenario to assess their risk between now and mid-century. The Shoreline Change SAMP identifies the 7-foot SLR + 100-year storm surge scenario as the "**Long-range Planning Scenario**" because it represents projected conditions in 2100. CRMC recommends that decision-makers use this scenario to inform long-term infrastructure planning and capital investment decisions (see Table 6).

Table 6. SLR and storm surge scenarios addressed in CRMC Statewide Assessment

Scenario	Explanation
Sea Level Rise (SLR) *based on the NOAA high SLR curve as of December 2016 (see NOAA 2012)*	
3-foot SLR	Equivalent of projected SLR in 2065.
5-foot SLR	Equivalent of projected SLR in 2085.
7-foot SLR	Equivalent of projected SLR in 2100.
Storm Surge + SLR *based on STORMTOOLS inundation mapping and the NOAA high SLR curve as of December 2016 (see NOAA 2012)*	
100-year storm surge	Current standard for floodplain mapping; excludes any SLR.
3-foot SLR + 100-year storm surge **("Mid-century Planning Scenario")**	Equivalent of projected SLR in 2065 combined with a 100-year storm surge. ***Recommended for use by property owners to assess their risk between now and mid-century.***
5-foot SLR + 100-year storm surge	Equivalent of projected SLR in 2085 combined with a 100-year storm surge.
7-foot SLR + 100-year storm surge **("Long-range Planning Scenario")**	Equivalent of projected SLR in 2100 combined with a 100-year storm surge. ***Recommended for use by state and municipal decision makers to inform long-term infrastructure planning and capital investment decisions.***

4. When considering these scenarios, it is important to note that STORMTOOLS surge elevations are based on a modeled 100-year storm surge event that occurs at every point along the shoreline, due to the point that there is no one event that produces 100-year storm surge water levels at all points of interest. Depending on a storm's track, not every storm will have this kind of impact on Rhode Island. For example, Superstorm Sandy in 2012 was a 25-year event in Westerly and an even smaller storm event in Newport. For further information on STORMTOOLS see Chapter 3.

5. The Long-range Planning Scenario, based on a 7-foot SLR + 100-year storm surge and representing projected conditions in 2100, is used as a reference point for much of the discussion in this section (see Figure 10 for a map depicting conditions during this scenario).

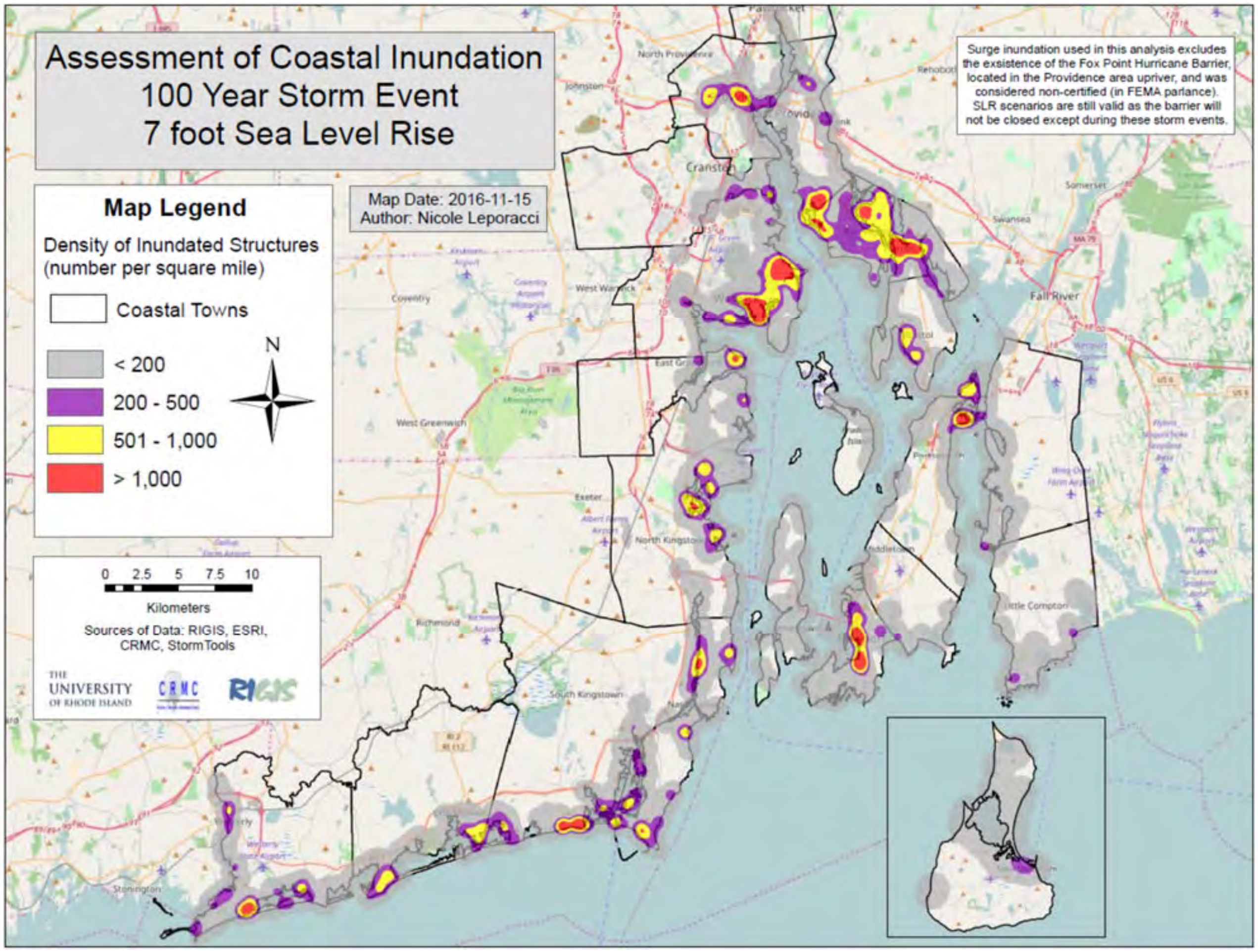

Figure 10. Long-range Planning Scenario (7-foot SLR + 100-year storm surge, representing projected conditions in 2100). This figure shows the density of inundated structures based on the number of structures by square mile, with red indicating the highest density of inundated structures and grey indicating the lowest. For example, red areas contain a density of greater than 1,000 inundated structures per square mile, and are the most exposed areas under this scenario.

4.5.1.1 Exposed Residential Structures

1. Leporacci et al. (2016) assessed residential structures in Rhode Island's 21 coastal communities. Residential structures evaluated in this assessment include single and multi-family homes, seasonal homes, mobile homes, camps, and other residential structures. This section presents some summary data from this assessment. See www.beachsamp.org/STORMTOOLS/e911/ for complete lists of exposed structures in all 21 coastal communities and by municipality under all planning scenarios considered in this assessment.

2. Leporacci et al. (2016) found that there is a total of 27,431 residential structures in the 21 coastal communities that are exposed to the combined effects of SLR and storm surge under the Long-range Planning Scenario. This represents 11.5% of the total such structures in these communities. See Table 7. This table illustrates that the exposure of individual municipalities varies widely under this scenario, ranging from Barrington, where 64% (3,930) residential structures are exposed, to Pawtucket, where only 1 residential structure (less than 1% of those in the town) is exposed. Importantly, findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge. This is because this assessment assumed that the Fox Point Hurricane Barrier is not present. The barrier was originally designed to address storm surge, based on conditions at the time, but not sea level rise.

Table 7. Exposed residential structures by municipality under Long-range Planning Scenario (7-foot SLR + 100-year storm surge; projected conditions in 2100)

Community	No. structures exposed	No. total structures in municipality	% of total structures in municipality	% of exposed structures in 21 coastal communities
Barrington	3930	6100	64.43%	14.33%
Block Island	101	1451	6.96%	0.37%
Bristol	922	7171	12.86%	3.36%
Charlestown	1384	5121	27.03%	5.05%
Cranston	302	26477	1.14%	1.10%
East Greenwich	68	4574	1.49%	0.25%
East Providence	1596	15712	10.16%	5.82%
Jamestown	210	2794	7.52%	0.77%
Little Compton	282	2389	11.80%	1.03%
Middletown	57	6353	0.90%	0.21%
Narragansett	2343	8794	26.64%	8.54%
Newport	1406	8313	16.91%	5.13%
North Kingstown	1869	10233	18.26%	6.81%
Pawtucket	1	20695	0.00%	0.00%
Portsmouth	1294	7284	17.76%	4.72%
Providence*	311	40841	0.76%	1.13%
Prudence Island (Portsmouth)	97	441	22.0%	3.54%
South Kingstown	2046	11857	17.26%	7.46%
Tiverton	349	6596	5.29%	1.27%
Warren	1703	3808	44.72%	6.21%
Warwick	5422	30498	17.78%	19.77%
Westerly	1738	10747	16.17%	6.34%
Sum	**27431**	**238249**	**11.51%**	**100.00%**

**Findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge. This is because this assessment assumed that the Fox Point Hurricane Barrier is not present. The barrier was originally designed to address storm surge, based on conditions at the time, but not sea level rise.*

3. The exposure of residential structures in individual municipalities varies by scenario. Table 8 and Table 9 list the top five most vulnerable communities based on the number of exposed residential structures under each of the seven scenarios considered here. These tables also present the sum of total exposed structures in those municipalities, and the percentage this sum represents of the total exposed residential structures within RI’s 21 coastal communities based on the Long-range Planning Scenario (27,431 structures).

Table 8. Top five municipalities with exposed residential structures under sea level rise scenarios

	3-foot SLR			**5-foot SLR**			**7-foot SLR**		
	Muni.	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*
1	South Kingstown	130	1.1%	Westerly	360	3.3%	Westerly	600	5.6%
2	Westerly	98	0.9%	South Kingstown	320	2.7%	South Kingstown	546	4.6%
3	Narragansett	91	1.0%	Newport	225	2.7%	Warwick	499	1.6%
4	Charlestown	38	0.7%	Narragansett	203	2.3%	Narragansett	477	5.4%
5	Tiverton	25	0.4%	Warren	180	4.7%	Newport	438	5.3%
Sum		**382**			**1288**			**2560**	
% of exposed structures*		**1.4%**			**4.7%**			**9.3%**	

**in 21 coastal communities based on long-term planning scenario*

Table 9. Top five municipalities with exposed residential structures under storm surge and sea level rise scenarios

	100-year surge			**3-foot SLR + 100-year surge**			**5-foot SLR + 100-year surge**			**7-foot SLR + 100-year surge**		
	Muni.	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*
1	Warwick	2636	8.6%	Warwick	3895	12.8%	Warwick	4624	15.2%	Warwick	5422	17.8%
2	Barrington	2619	42.9%	Barrington	3413	56.0%	Barringto n	3686	60.4%	Barrington	3930	64.4%
3	South Kingstown	1139	9.6%	South Kingstown	1636	13.8%	Narra-gansett	1997	22.7%	Narra-gansett	2343	26.6%
4	Warren	1090	28.6%	Narra-gansett	1576	17.9%	South Kingstown	1851	15.6%	South Kingstown	2046	17.3%
5	Westerly	1043	9.7%	Warren	1404	36.9%	North Kingstown	1578	15.4%	North Kingstown	1869	18.3%
Sum		**8527**			**11924**			**13736**			**15610**	
% of exposed structures*		**31.1%**			**43.5%**			**50.1%**			**56.9%**	

****total structures in 21 coastal communities based on long-term planning scenario***

4. Table 8 reveals that Narragansett, South Kingstown and Westerly are among the most exposed municipalities in the 21 coastal communities, with regard to exposure of residential structures, based on all three SLR scenarios. South Kingstown and Westerly are the top two most exposed municipalities under all three SLR scenarios.

5. Table 9 reveals that Barrington, South Kingstown, and Warwick are among the most exposed municipalities in the 21 coastal communities, with regard to exposure of residential structures, based on all four storm surge scenarios. Warwick is ranked first, and Barrington second, as the most exposed municipalities under all scenarios. This table also indicates that under the 5-foot and 7-foot SLR + 100-year storm surge scenarios, over 50% of the state's most exposed residential structures are located in just five communities: Barrington, Narragansett, North Kingstown, South Kingstown, and Warwick.

6. Evaluated together, these tables revealed that South Kingstown is among the most exposed municipalities in the 21 coastal communities, with regard to exposed residential structures, under all seven scenarios.

7. While this discussion only emphasizes a subset of Rhode Island coastal municipalities, it is important to note that there are exposed residential structures in all of Rhode Island's coastal communities. For further information see Leporacci et al. (2016) or www.beachsamp.org/STORMTOOLS/e911/.

4.5.1.2 Exposed Commercial Structures

1. Leporacci et al. (2016) also evaluated the exposure of commercial structures in all 21 coastal municipalities. Commercial structures in this assessment include all lodging, farm, and other commercial structures as described in the E911 database. This section presents some summary data from this assessment. See www.beachsamp.org/STORMTOOLS/e911/ for complete lists of exposed structures in all of the coastal communities and by municipality under all planning scenarios considered in this assessment.

2. Table 10 reveals that there is a total of 3,082 commercial structures in the 21 coastal communities that are exposed under the Long-range Planning Scenario (7-foot SLR + 100-year storm surge). This represents 18.9% of all such structures in the 21 coastal communities. This analysis also reveals that exposed commercial structures vary considerably by municipality, from 993 in Providence (23.2% of all such structures in the city) to just 5 in Pawtucket (less than 1% of all such structures in the city). As stated above, findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge. This is because this assessment

assumed that the Fox Point Hurricane Barrier is not present. The barrier was originally designed to address storm surge, based on conditions at the time, but not sea level rise.

3. While Providence has the greatest number of exposed commercial structures included in this analysis, Barrington has the greatest percentage of its commercial structures exposed under this scenario with 70.8% (109 exposed structures). As stated above, findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge.

Table 10. Exposed commercial structures by municipality under Long-range Planning Scenario (7-foot SLR + 100-year storm surge; projected conditions in 2100)

Municipality	No. structures exposed	Total no. structures in municipality	% of total municipality structures	% of structures exposed in 21 coastal communities
Barrington	109	154	70.78%	3.54%
Block Island	84	155	54.19%	2.73%
Bristol	78	438	17.81%	2.53%
Charlestown	17	156	10.90%	0.55%
Cranston	57	1761	3.24%	1.85%
East Greenwich	8	306	2.61%	0.26%
East Providence	167	1246	13.40%	5.42%
Jamestown	20	91	21.98%	0.65%
Little Compton	11	64	17.19%	0.36%
Middletown	31	435	7.13%	1.01%
Narragansett	93	239	38.91%	3.02%
Newport	471	915	51.48%	15.28%
North Kingstown	138	603	22.89%	4.48%
Pawtucket	5	1318	0.38%	0.16%
Portsmouth	56	281	19.93%	1.82%
Providence*	993	4282	23.19%	32.22%
Prudence Island (Portsmouth)	1	2	50.0%	0.03%
South Kingstown	69	511	13.50%	2.24%
Tiverton	51	334	15.27%	1.65%
Warren	184	328	56.10%	5.97%
Warwick	200	1987	10.07%	6.49%
Westerly	239	678	35.25%	7.75%
Sum	**3082**	**16284**	**18.92%**	**100.00%**

**Findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge. This is because this assessment assumed that the Fox Point Hurricane Barrier is not present. The barrier was originally designed to address storm surge, based on conditions at the time, but not sea level rise.*

4. The exposure of commercial structures in individual municipalities varies by scenario, although there is somewhat less variation with regard to affected municipalities when compared to residential exposure. Table 11 and Table 12 list the top five most vulnerable communities based on the number of exposed commercial structures under each of the seven scenarios considered here. These tables also present the sum of total exposed structures in those municipalities, and the percentage this sum represents of the total exposed commercial structures in the 21 coastal communities (3,082) based on the Long-range Planning Scenario.

Table 11. Top five municipalities with exposed commercial structures under sea level rise scenarios

	3-foot SLR			5-foot SLR			7-foot SLR		
	Muni.	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*
1	Newport	23	2.5%	Newport	102	11.1%	Providence	196	4.6%
2	Westerly	23	3.4%	Westerly	62	9.1%	Newport	195	21.3%
3	Providence	19	0.4%	Providence	48	1.1%	Westerly	121	17.8%
4	Narragansett	13	5.4%	North Kingstown	42	7.0%	North Kingstown	65	10.8%
5	North Kingstown	9	1.5%	Narragansett	28	11.7%	Warren	48	14.6%
Sum		**87**			**282**			**625**	
% of exposed structures*		**2.82%**			**9.15%**			**20.28%**	

**total structures in 21 coastal communities based on long-term planning scenario*

Table 12. Top five municipalities with exposed commercial structures under both storm surge and sea level rise scenarios

	100-year surge			3-foot SLR + 100-year surge			5-foot SLR + 100-year surge			7-foot SLR + 100-year surge		
	Muni.	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*
1	Providence	767	17.9%	Providence	878	20.5%	Providence	919	21.5%	Providence	993	23.2%
2	Newport	346	37.8%	Newport	439	48.0%	Newport	460	50.3%	Newport	471	51.5%
3	Westerly	194	28.6%	Westerly	216	31.9%	Westerly	229	33.8%	Westerly	239	35.3%
4	Warren	123	37.5%	Warren	155	47.3%	Warren	174	53.0%	Warwick	200	10.1%
5	Warwick	109	5.5%	Warwick	143	7.2%	Warwick	170	8.6%	Warren	184	56.1%
Sum		**1539**			**1831**			**1952**			**2087**	
% of exposed structures *		**49.9%**			**59.4%**			**63.3%**			**67.7%**	

**total structures in 21 coastal communities based on long-term planning scenario*

5. Table 11 reveals that Newport, North Kingstown, Providence, and Westerly are among the top five most exposed municipalities, with regard to commercial structures, under all three SLR scenarios. Narragansett is included in this number under the 3- and 5-foot SLR scenarios, but is surpassed by Warren under the 7-foot SLR scenario.

6. Table 12 reveals that Newport, Providence, Warren, Warwick and Westerly are the top five most exposed municipalities with regard to commercial structures under all four storm surge scenarios. A comparison of these four scenarios reveals that while the number of commercial structures increases as SLR increases, the ranking of these five municipalities changes very little. Providence, Newport, and Westerly remain the first, second, and third most exposed municipalities, respectively, under all four scenarios. Warren remains the fourth most exposed municipality with regard to commercial structures in all but the final Long-range Planning Scenario.

7. Table 12 also reveals that, under all three of the combined SLR and storm surge scenarios, over 50% of the exposed commercial structures in the 21 coastal communities are concentrated in just these top five municipalities: Newport, Providence, Warren, Warwick and Westerly. Under the Long-range Planning Scenario, over two-thirds (67.72%) of the state's exposed commercial structures are located in these five municipalities.

8. Examined together, these two tables reveal that Newport, Providence and Westerly are the top three most exposed municipalities in the 21 coastal communities, with regard to commercial structures, under all four SLR and storm surge scenarios.

4.5.1.3 Exposed Public Service Structures

1. Leporacci et al. (2016) also evaluated the exposure of public service structures in the 21 coastal municipalities. Public service structures, as defined and included in the E-911 database, include emergency service facilities such as police and fire department structures and ambulance houses; healthcare facilities; and government, educational and public gathering structures. This section presents some summary data from this assessment. See www.beachsamp.org/STORMTOOLS/e911/ for complete lists of exposed structures in the 21 coastal communities and by municipality under all planning scenarios considered in this assessment. Importantly, this analysis did not address the relative importance of each individual public service structure to its coastal community, and therefore may underrepresent the community's exposure. For example, the exposure of just one public service structure could mean that a community is very highly exposed if that one structure is its only police or fire station.

2. Table 13 lists exposed public service structures by municipality under the Long-range Planning Scenario of 7-foot SLR + a 100-year storm surge. Leporacci et al. (2016) found that there are 566 public service structures that are exposed under this scenario. This represents 13.8% of all such structures in the 21 coastal communities. There is a wide range of exposed structures between municipalities, from Newport at 110 public service structures (representing 32% of such structures in Newport) to Little Compton at 1 public service structure (4% of such structures in the town). Although some municipalities have small numbers of exposed public service structures, those may represent a high percentage of such structures in that municipality. For example, Tiverton has 2 exposed structures which represent 55% of all public service structures in the municipality.

Table 13. Exposed public service structures by municipality under the Long-range Planning Scenario (7-foot SLR + 100-year storm surge; projected conditions in 2100)

Municipality	No. structures Exposed	No. total structures in municipality	% of total municipality structures	% of structures exposed in 21 coastal communities
Barrington	33	74	44.59%	5.83%
Block Island	12	28	42.86%	2.12%
Bristol	14	110	12.73%	2.47%
Charlestown	7	68	10.29%	1.24%
Cranston	11	310	3.55%	1.94%
East Greenwich	4	116	3.45%	0.71%
East Providence	14	145	9.66%	2.47%
Jamestown	8	43	18.60%	1.41%
Little Compton	1	24	4.17%	0.18%
Middletown	15	258	5.81%	2.65%
Narragansett	44	148	29.73%	7.77%
Newport	110	346	31.79%	19.43%
North Kingstown	60	165	36.36%	10.60%
Pawtucket	3	241	1.24%	0.53%
Portsmouth	7	87	8.05%	1.24%
Providence*	108	1104	9.78%	19.08%
Prudence Island (Portsmouth)	1	9	11.11%	0.18%
South Kingstown	9	256	3.52%	1.59%
Tiverton	2	44	4.55%	0.35%
Warren	38	69	55.07%	6.71%
Warwick	46	326	14.11%	8.13%
Westerly	19	139	13.67%	3.36%
Sum	**566**	**4110**	**13.77%**	**100.00%**

**Findings about Providence are valid with regard to the impacts of sea level rise but may overestimate damage due to storm surge. This is because this assessment assumed that the Fox Point Hurricane Barrier is not present. The barrier was originally designed to address storm surge, based on conditions at the time, but not sea level rise.*

3. As with residential and commercial structures, the exposure of each municipality's public service structures varies by scenario. Table 14 and Table 15 show the top five municipalities with the largest number of exposed public service structures under each of the seven scenarios.

Table 14. Top five municipalities with exposed public service structures under SLR scenarios

	3-foot SLR			**5-foot SLR**			**7-foot SLR**		
	Muni.	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*
1	Narragansett	2	1.4%	Newport	14	4.0%	Newport	22	6.4%
2	Block Island	1**	3.6%	Narragansett	6	4.1%	North Kingstown	12	7.3%
3	Bristol	1**	0.9%	Warren	6	8.7%	Narragansett	11	7.4%
4	East Providence	1**	0.7%	Westerly	4	2.9%	Providence	7**	0.6%
5	North Kingstown	1**	0.6%	Bristol	4	3.6%	Warren	7**	10.1%
	Prudence Is. (Portsmouth)	*1***	*11.1%*				*Westerly*	*7***	*5.0%*
	Warwick	*1***	*0.3%*						
Sum		**6**			**34**			**59**	
% of exposed structures*		**1.1%**			**6.0%**			**10.4%**	

**Total structures in the 21 coastal communities based on long-term planning scenario. **Six municipalities have one exposed public service structure under the 3-foot scenario, and three have seven exposed structures under the 7-foot scenario. All are listed here although in each case only the top five are included in the 'top five' sum and percentage.*

Table 15. Top five municipalities with exposed public service structures under storm surge and SLR scenarios

	100-year surge			**3-foot SLR + 100-year surge**			**5-foot SLR + 100-year surge**			**7-foot SLR + 100-year surge**		
	Muni.	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*	*Muni.*	*No. structures*	*% structures in muni.*
1	Providence	69	6.3%	Providence	93	8.4%	Newport	103	29.8%	Newport	110	31.8%
2	Newport	60	17.3%	Newport	87	25.1%	Providence	96	8.7%	Providence	108	9.8%
3	North Kingstown	43	26.1%	North Kingstown	46	27.9%	North Kingstown	52	31.5%	North Kingstown	60	36.4%
4	Narra-gansett	37	25.0%	Narra-gansett	40	27.0%	Narra-gansett	44	29.7%	Warwick	46	14.1%
5	Barrington	20	27.0%	Warwick	30	9.2%	Warwick	39	12.0%	Narra-gansett	44	29.7%
Sum		**229**			**296**			**334**			**368**	
% of exposed structures*		**40.5%**			**52.3%**			**59.0%**			**65.0%**	

**total structures in 21 coastal communities based on long-term planning scenario*

4. Table 14 reveals that Narragansett is among the top three municipalities with the most exposed public service structures under all three SLR scenarios. Other than Narragansett, there is a fair amount of vulnerability in the municipalities listed among the top five most exposed with regard to public service structures. In several cases there are ties for inclusion among the top five (e.g. Providence, Warren and Westerly all have seven public service structures exposed under the 7-foot SLR scenario).

5. There is some consistency among the storm surge scenarios. Table 15 reveals that Providence, Newport and North Kingstown are the top three most exposed communities with regard to public service structures across all four storm surge scenarios. Narragansett is also included among the top five most exposed communities in all four of these scenarios, and Warwick is included in three of the four scenarios.

6. Importantly, with only a 100-year storm surge and no sea level rise (i.e. current conditions), the top five municipalities of Providence, Newport, North Kingstown, Narragansett and Barrington included 40% of all exposed public service structures in the 21 coastal communities. Additionally, for all three of the scenarios combining SLR and storm surge, over 50% of the exposed public service structures in the 21 coastal communities are concentrated in just five municipalities. Under the Long-range Planning Scenario, the top five municipalities of Newport, Providence, North Kingstown, Warwick and Narragansett included 65% of the all exposed public service structures in the 21 coastal communities.

4.5.2 Other State Assessments

1. This section provides insight into what is known to date about the exposure of other aspects of Rhode Island's built environment. This includes the demographics of potentially exposed populations; critical infrastructure; wastewater treatment facilities; drinking water utilities; transportation; ports and maritime infrastructure; public access and recreation assets; and historic and archaeological assets. In many cases the information included here summarizes studies completed by other state agencies or organizations, and/or addresses infrastructure, facilities or assets that are not managed by the CRMC. In all cases the reader is referred to the relevant agency or organization for further information.

2. Because the following state assessments each considered different sea level rise and/or storm surge scenarios, each study is preceded with a statement in bold highlighting the relevant scenarios.

4.5.2.1 Demographics

1. ***The following study considered SEA LEVEL RISE (1, 3, 5, and 7-foot scenarios).***

2. The Rhode Island Statewide Planning Program (RI SPP) conducted a "Socioeconomics of Sea Level Rise Project" which assessed population and characteristics of people living within the 1, 3, 5, and 7-foot STORMTOOLS sea level rise inundation zones in Rhode Island's coastal communities (RI SPP 2016a). Although this study used STORMTOOLS, it only considered sea level rise scenarios, not the additional inundation that would be caused by storm surges. This study utilized the statewide E911 dataset in addition to the 2010 U.S. census. For the complete study see http://www.planning.ri.gov/geodeminfo/data/socio-slr.php.

3. This study found that all but one of Rhode Island's 21 coastal communities – Pawtucket - have residential units in at least one of the SLR inundation zones. The average household size in the coastal communities ranges from 1.96-2.5. Residential units included in inundation zones include single- and multi-family homes as well as mobile home residential units. Not all of these housing units are occupied year round; this study found that approximately 70-73% of the units located within these four SLR inundation zones are occupied on a full-time basis (as a primary residence).

4. Analysis of residential units and occupation estimates within the 21 coastal communities revealed that an estimated 6,945 individuals live in an estimated 3,321 occupied housing units within the 7-foot SLR scenario. See Table 16 below.

Table 16. Occupied residential units and population estimates, 21 RI coastal communities (adapted from RI SPP 2016a)

SLR Inundation Zone	**Residential Units**	**Occupied Unit Calculation** (total units x occupied housing unit rate)	**Population Calculation** *(occupied units x 21 coastal community average household size)*
1-foot SLR	9 single-family, 1 multi-family, 1 mobile	8 *(70% occupancy rate per housing unit)*	20
3-foot SLR	300 single-family, 18 multi-family, 15 mobile	246 *(70% occupancy rate per housing unit)*	481
5-foot SLR	1646 single-family, 203 multi-family, 42 mobile	1487 *(71% occupancy rate per housing unit)*	2975
7-foot SLR	3642 single-family, 430 multi-family, 47 mobile	3321 *(73% occupancy rate per housing unit)*	6945

4.5.2.2 Critical Infrastructure

1. ***The following analysis considered STORM SURGE.***

2. Rhode Island's coastal communities include critical infrastructure of importance to the safety, security and economy of both Rhode Island and the nation. "Critical infrastructure" is a term used by the U.S. Department of Homeland Security (DHS) to describe sectors whose physical or virtual assets, systems, and networks are so vital to the United States that their damage or destruction would have a major impact on public safety, security, and the economy (DHS 2017). DHS defines 16 critical infrastructure sectors: chemical, commercial facilities, communications, critical manufacturing, dams, defense industrial base, emergency services, energy, financial services, food and agriculture, government facilities, healthcare and public health, information technology, nuclear, transportation systems, and waste. The "public service structures" described above as part of CRMC's exposure assessment includes many of these same sectors. The Rhode Island Emergency Management Agency (RIEMA) oversees an Infrastructure Protection Program whose purpose is to enhance critical infrastructure protection statewide as part of its hazard mitigation program. For further information see www.riema.ri.gov.

3. RIEMA's 2014 Hazard Mitigation Plan Update (RIEMA 2014) included a vulnerability assessment of Rhode Island's critical infrastructure to hurricanes and tropical storms, using DHS critical infrastructure data as well as Rhode Island "critical facilities" and "state-owned facilities" data. To conduct this assessment, RIEMA used inundation data provided by the U.S. Army Corps of Engineers (USACE) which were derived by overlaying storm surge water elevations from the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model results on ground elevations from FEMA LiDAR data. This analysis did not include sea level rise and other changing future conditions. RIEMA's assessment also identified the number of critical infrastructure facilities located within FEMA Special Flood Hazard Areas. For further information see the 2014 Hazard Mitigation Plan Update at www.riema.ri.gov.

4.5.2.3 Wastewater Treatment Facilities

1. ***The following study considered STORM SURGE and SEA LEVEL RISE (1, 2, 3, and 5-foot scenarios).***

2. The state of Rhode Island has 19 wastewater treatment facilities (WWTF). 15 of these facilities are located in coastal municipalities and therefore potentially exposed to coastal storms, sea level rise and coastal erosion. These facilities are regulated by the RI Department of Environmental Management (DEM) Office of Water Resources.

3. In March 2017 the RI DEM Office of Water Resources released the results of a RI DEM *Wastewater Infrastructure Vulnerability Study* (RI DEM 2017). This study evaluated both historic and projected impacts from coastal storms and other natural hazards and recommended adaptation strategies for potentially impacted facilities. This included use of STORMTOOLS inundation models that projected 1, 2, 3, and 5-foot SLR scenarios plus a 100-year storm surge. For further information on this study or the findings discussed below please contact the DEM Office of Water Resources.

4. This study found that six coastal WWTFs are at risk of being "predominantly inundated" through coastal flooding and four coastal WWTFs are at risk of being "partially inundated." Those facilities at risk of being predominantly inundated are: Bucklin Point (East Providence), East Greenwich, East Providence, Fields Point, Quonset Point, and Warren. Facilities at risk of being partially inundated are: Bristol, Cranston, Newport, and Westerly.

5. This study also found that while five coastal WWTFs are not at risk of being inundated, coastal hazards could still create other problems at those facilities, such as facility access or within facility collection systems. Those facilities are: Jamestown, Narragansett, New Shoreham, South Kingstown, and Warwick.

4.5.2.4 Drinking Water Utilities

1. ***The following study considered SEA LEVEL RISE (2.8, 2.92 and 5 ft. scenarios) and FLOODING.***

2. The state of Rhode Island's drinking water utilities include freshwater wells and reservoirs as well as pretreatment and treatment facilities, interconnections, pump stations, and pipelines which are owned and/or managed by a mix of municipal, regional and other public utilities. Many of these utilities are located in or serve Rhode Island's coastal municipalities and are thus potentially vulnerable to the impacts of coastal storms, sea level rise and coastal erosion. The RI Department of Health (DOH) is charged with ensuring the safety of Rhode Island's public water supplies. This includes planning for and implementing measures to ensure water security.

3. In 2013 the RI DOH Office of Drinking Water Quality released the results of the SafeWater RI initiative (RI DOH 2013) which sought to plan for the future of Rhode Island's drinking water supply in the face of threats associated with climate change. This assessment involved surveys and interviews with drinking water utilities; an assessment of the impacts of changing environmental conditions on these facilities; and the identification of management strategies and site-specific recommendations to address these impacts. Climate change indicators considered in this analysis included air temperature, precipitation, watershed hydrology, and sea level rise.

4. The SafeWater RI initiative considered conservative sea level rise scenarios as well as a hurricane storm surge model which considered coastal erosion and tidal movements. This assessment was based on a projected 2.8-foot sea level rise in Providence and a 2.92-foot sea level rise in Newport, but also considered a 5-foot "worst-case scenario," by 2084. Findings based on these scenarios were released in the 2013 final report *SafeWater RI: Ensuring Safe Water for Rhode Island's Future*. For further information see http://www.health.ri.gov/publications/reports/2013EnsuringSafeWaterForRhodeIslandsFuture.pdf.

5. It is notable that even with these conservative sea level rise projections, the SafeWater RI analysis considered the risk of hurricanes to the state's drinking water utilities and found that by 2084, 20 utilities may be impacted by sea level rise and 11 by coastal flooding.

4.5.2.5 Transportation Infrastructure

1. ***The following study considered SEA LEVEL RISE (1, 3, and 5-foot scenarios).***

2. The state of Rhode Island relies on a network of surface, marine, and air transportation assets throughout the state which include roads, rail, bike paths, ports and harbors, airports, bus routes, intermodal hubs, and bridges. Much of this infrastructure is located in coastal areas and is thus potentially vulnerable to the effects of coastal storms, sea level rise and coastal erosion. Much of this infrastructure is owned and/or managed by the RI Department of Transportation (RI DOT), which designs, maintains and constructs the state's surface transportation system.

3. In 2015 the Rhode Island Statewide Planning Program (RI SPP) completed a "Vulnerability of Transportation Assets to Sea Level Rise" study (RI SPP 2015) which assessed the vulnerability of state-owned or managed transportation assets to sea level rise, considering 1-foot, 3-foot and 5-foot sea level rise scenarios. This analysis did not include storm surge scenarios. This analysis involved conducting an exposure assessment and developing a simple vulnerability index to provide insight into the relative vulnerability of transportation assets. It was followed in late 2016 with a second study which focused on municipal transportation assets (see RI SPP 2016b). Some study results of the 2015 state analysis are highlighted below. For further details on this study including methods and full results please see http://www.planning.ri.gov/geodeminfo/data/slr.php.

4. **Roads**: SPP's analysis examined the exposure of roads throughout the state, and found that 2.3 miles of roadway are expected to flood at high tide under a 1-foot SLR; 28 miles under a 3-foot SLR; and up to 85 miles under a 5-foot SLR. SPP further determined that while miles of road will be affected by SLR, roughly 70% of these are local roads which do not qualify for federal transportation funding. SPP's vulnerability assessment found that, of all roads under state jurisdiction which will be impacted by a 5-foot SLR, the most vulnerable road segments are located in Barrington, Warren, Tiverton, Bristol, New Shoreham, and North Kingstown. For Barrington and Warren, this includes three road segments each. Importantly, all ten of these road segments are expected to experience daily high tide flooding even under the lower SLR scenarios. Additionally, nine out of these ten segments are currently designated as hurricane evacuation routes.[7]

5. **Railways**: SPP's analysis addressed the impacts of SLR on railways in Rhode Island and found that an area of railway at Quonset, and two areas of the Newport Secondary Track (the dinner train), are projected to flood under a 5-foot SLR, while additional areas of the Newport Secondary Track are projected to flood under both 3- and 5-foot SLR scenarios. Importantly, as this assessment was focused on state facilities, this did not fully consider Amtrak railways which are expected to experience SLR impacts.

6. **Rhode Island Public Transit Authority (RIPTA):** SPP's analysis also addressed RIPTA infrastructure, including bus stops and roadways, and found that in total (under all SLR scenarios), 16 routes are expected to experience flooding, and 52 bus stops are located within projected inundation zones. SPP's vulnerability index identified Bus 60 (the Providence/Newport route) as the single most vulnerable route statewide given flooding risk when combined with ridership and trip frequency.

7. **Bridges**: SPP examined the exposure and vulnerability of Rhode Island's bridges, which are of concern regarding SLR both because of bridge height itself (measured by freeboard) and bridge accessibility from the roadway. SPP identified 77 bridges of concern because of either freeboard heights or accessibility. Their vulnerability index identified the Barrington Bridge and the Warren Bridge, both of which carry RI-103/114 over the Barrington River in Barrington, as the top two most vulnerable bridges in the state under the 5-foot SLR scenario. The Barrington Bridge was built in 2009.

[7] Although SPP's analysis focused on which roads may be inundated through surface water flooding, it is important to note that changes in groundwater levels associated with sea level rise could also intersect with road infrastructure, reducing their service life (see Knott et al. 2017).

8. **Bicycle infrastructure**: SPP's analysis also included off-road paths and on-street lanes and routes. SPP identified the East Bay Bike Path as the most exposed bicycle infrastructure, projecting inundation at several places along this path under both the 3- and 5-foot SLR scenarios. They also identified several on-street bike routes as vulnerable to SLR. SPP's vulnerability index identified East Providence and Bristol segments of the East Bay Bike Path as the top two most vulnerable places in the state.

9. **Passenger intermodal hubs**: SPP's analysis also assessed the exposure and vulnerability of bus, rail, air, and ferry transportation facilities. This analysis indicated that seven intermodal hubs – all of which are ferry terminals – are expected to be inundated by SLR. The Galilee Block Island Ferry terminal was listed as the most vulnerable such hub statewide, followed by the Block Island Ferry terminal located in New Shoreham. The Galilee facility will be inundated under the 3-foot SLR scenario, while the New Shoreham facility will be inundated under the 5-foot SLR scenario. Both facilities provide critical lifeline ferry service for New Shoreham's year-round residents, who do not have a surface transportation alternative to reach the mainland.

10. **Maritime infrastructure**: SPP's analysis also addressed the exposure and vulnerability of "oceanfront ports and harbors." SPP did not conduct a full vulnerability assessment of these facilities. Instead, this study provided general insight into the impacts of SLR on such facilities by calculating the acreage of individual commercial/industrial port facilities and of commercial/industrial port areas within each municipality that is expected to be inundated through the different SLR scenarios. Based on this, SPP found that commercial/industrial port areas' exposure to SLR will be particularly significant in North Kingstown, Providence, East Providence, and Narragansett. They also found that individual facilities at Quonset, in Providence and East Providence, and Point Judith are expected to experience significant SLR impacts. As discussed above, Point Judith supports much of Rhode Island's commercial and recreational fisheries; see section 4.3.2.1 for further discussion.

4.5.2.6 Public Access and Recreation Assets

1. Rhode Island's 21 coastal communities include numerous shoreline public access points and recreational assets that together provide Rhode Island residents and visitors with opportunities to participate in a wide range of active and passive recreational activities. These activities may include swimming, fishing, boating, surfing, hiking, viewing of wildlife, historic sites, or scenic areas, and others. Sites and assets that provide these opportunities may include publicly-owned and managed beaches, parks, boat ramps, fishing piers and campgrounds. State-owned and managed facilities are overseen by the Rhode Island Department of Environmental Management (DEM) Office of Parks and

Recreation; for further information see http://www.riparks.com/. Public access sites and assets may also include designated public rights-of-way (ROW), established in some cases over private land, which provide access to coastal waters. The CRMC oversees the designation of public rights-of-way; for further information see http://www.crmc.ri.gov/publicaccess.html.

2. Many coastal recreation and public access sites and facilities are by definition exposed to the impacts of storm surge, coastal erosion and sea level rise due to their location in low-lying waterfront areas. To date, no systematic study has been conducted of the exposure of recreational assets to storm surge, coastal erosion and sea level rise (see Section 4.8). Generally, sites and facilities located in at-risk areas are of particular concern; see Section 4.6.1 below.

3. According to the RI CRMC, a public ROW to the shore is a piece of land over which the public has right to pass in order to access Rhode Island's tidal waters. CRMC reports in its 2016 ROW progress report (RI CRMC 2016) that there are currently 222 rights of way designations in the state. Table 17 lists the number of ROWs in each municipality. The top three municipalities with the most ROWs are Warwick, Bristol and Newport, which together have 40% of the entire state's ROWs; it is important to note that the Shoreline Change SAMP's at-risk area analysis (see Section 4.6.1) identified Bristol as one of the most at-risk areas for sea level rise and storm surge.

Table 17. Public shoreline rights-of-way listed by municipality (RI CRMC 2016)

Municipality	**Number of shoreline public ROWs**
Barrington	2
Bristol	30
Charlestown	2
Cranston	3
East Greenwich	6
East Providence	13
Jamestown	14
Little Compton	3
Middletown	10
Narragansett	13
New Shoreham	7
Newport	23
North Kingstown	3
Pawtucket	1
Portsmouth	17
Providence	3
South Kingstown	4
Tiverton	7

Warren	9
Warwick	41
Westerly	11

4.5.2.7 Historic and Archaeological Assets

1. Rhode Island's coastal communities contain numerous historic and archaeological assets which are of cultural, historic, social and economic importance to these communities as well as to other Rhode Island residents and visitors. The Rhode Island Historic Preservation and Heritage Commission (RI HPHC) is the state agency which oversees historic preservation and heritage throughout the state. RI HPHC maintains a State Register of Historic Places and facilitates the National Register for Historic Places, a federal program, throughout the state; see http://www.preservation.ri.gov/ for further information.

2. In 2015 the RI HPHC commissioned a study (Youngken Associates 2015) that evaluated the potential impacts of flood-related regulations to historic properties in Rhode Island's 21 coastal communities. This study did not evaluate the potential effects of sea level rise or other changing future conditions, and emphasized FEMA's National Flood Insurance Program, flood resiliency programs targeted at historic structures, and other topics only marginally related to the Shoreline Change SAMP.

3. This study found that there are 1,971 National Register-listed or eligible assets located in FEMA mapped "coastal and estuarine flood zones" in these 21 coastal communities. Numbers of assets per community range from 548 in Newport to just 4 in Middletown. The top five communities, by number of assets in flood zones, are Newport (548), North Kingstown (294), Warren (223), Bristol (194), and Westerly (178). In other words, 72.9% of the state's historic assets located in current flood zones are located in just these five municipalities. This study also found that the assessed value of Newport's exposed historical assets alone was over $432 million (Youngken Associates 2015).

4. Youngken Associates (2015) acknowledge that their study is a conservative estimate of flood-related impacts because it does not consider sea level rise or other changing future conditions. The authors provide a series of detailed recommendations for historic property owners and community officials; see summary report for further information.

4.6 Synthesis: Exposure of Rhode Island's Coastal Region to Storm Surge, Coastal Erosion and Sea Level Rise

4.6.1 At-Risk Areas

1. Areas of the Rhode Island coast that are at risk of the impacts of storm surge, coastal erosion and sea level rise were analyzed by Oakley, Hollis, and colleagues (Oakley, Hollis, Boothroyd, Freedman, Boyd and Fugate 2016; Hollis, Oakley, Rasmussen, Boothroyd, Freedman and Fugate 2016; hereafter "Oakley and Hollis at-risk area studies"). "At-risk areas" were defined as those where "existing state, municipal or private infrastructure and/or public access are susceptible to erosion, shoreline migration, and/or inundation from sea level rise or storm surge." These studies were intended as initial, broad-brush analyses of the exposure of coastal areas and as coarse initial risk identification tools to be followed up with more detailed analyses at the municipal or individual site scale. The research reflected in these reports was developed prior to the development of STORMTOOLS, the development of the 7-foot SLR scenario, and other tools that are central to the Shoreline Change SAMP. As such, these study results are best used in conjunction with other more recent data and tools referenced in this document. Select results are presented below. Oakley and Hollis's reports include methods as well as detailed findings for each individual municipality; please see the full reports at www.beachsamp.org.

4.6.2 Storm surge, coastal erosion and sea level rise in RI

1. The analyses of historic shoreline change, at-risk areas, and projected shoreline change discussed in this chapter together provide insight into how areas of Rhode Island's coast may be impacted by the combined effects of storm surge, coastal erosion and sea level rise. This section provides examples of some of the ways in which a subset of communities on the south shore and in Narragansett Bay may be impacted based on the above-mentioned studies. Importantly, communities discussed in this section were also identified as highly exposed in Leporacci et al. (2016), discussed earlier in this chapter. This section is not exhaustive and the inclusion of only these communities does not mean that only these communities are at risk, nor that other communities are free from risk. Decision-makers and property owners are strongly encouraged to review findings related to their individual municipality in the reports and collections of online maps described above.

4.6.2.1 Matunuck Headland

1. The combined results of these studies indicates that the Matunuck Headland area is one of the most at risk in the state to the combined effects of storm surge, sea level rise and coastal erosion. Evaluation of historic shoreline change revealed a very high rate of erosion along a stretch of Matunuck from Cards Pond to the east end of South Kingstown Town Beach. Individual transects in this area exceed a loss of 1.4 meters/year (1.6 feet/yr), and total shoreline change in this area exceeded 90 meters (295.2 ft) between 1951 and 2014 (see Figure 11) (Boothroyd et al. 2016). Oakley et al. (2016) reported that high erosion rates in this area are most likely due to a combination of bluff composition (easily erodible glacial stratified deposits) and bluff elevation (impacted by many storms), as well as wave refraction and focusing around the adjacent gravel terraces.

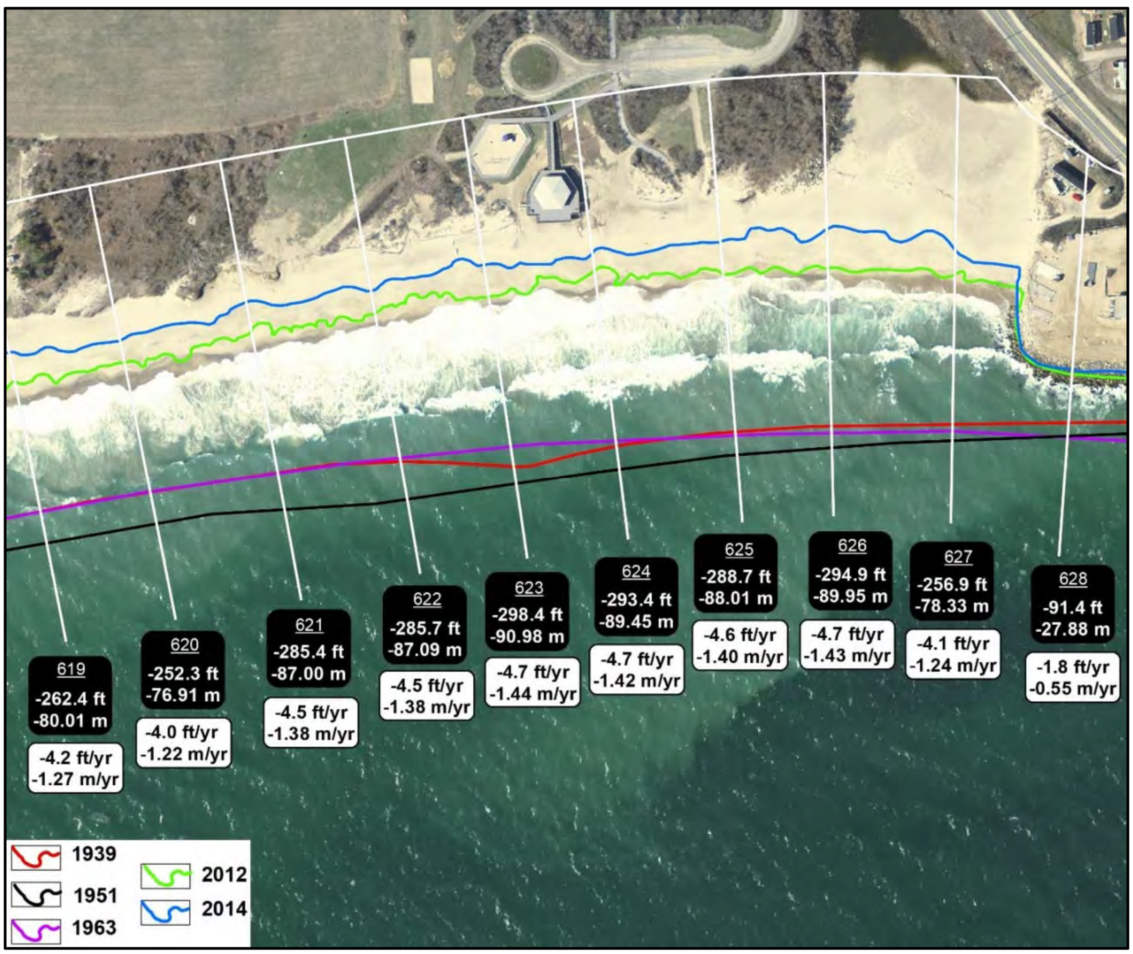

Figure 11. Portion of the Matunuck Headland Shoreline Change Map (Boothroyd et al. 2016).

2. The Hollis at-risk study, which considered these historic rates of shoreline change in addition to storm surge, SLR, and projected shoreline change, identified two areas of the Matunuck headland area at risk: the segment containing Roy Carpenter's Beach and South Kingstown Town Beach, and the commercial/residential neighborhood east of South Kingstown Town Beach. The following information is derived from this study; for further information please see Hollis, Oakley, Rasmussen, Boothroyd, Freedman and Fugate 2016.

3. Roy Carpenter's Beach includes a high-density area of small cottages which were damaged in 2012 during Superstorm Sandy. This area exhibited a very high rate of erosion between 1939 and 2014 of 62 to 73 meters (206 to 240 feet). This area, particularly the seaward rows of cottage, will continue to be impacted by erosion and storm surge. As discussed above, the South Kingstown Town Beach area has exhibited very high erosion rates, exceeding 90 meters (295.2 ft). Beach profiling conducted by the Rhode Island Geological Survey found 29 meters (96 feet) of bluff migration since 1996, indicating that this area has been extremely erosional over the last 20 years. Infrastructure at risk includes the town beach pavilion, which was relocated landward after Sandy, and a revetment at the east end of the beach which encompasses a trailer park and Matunuck Beach Road. The commercial/residential area east of South Kingstown Town Beach is also at risk from continued erosion. Matunuck Beach Road, which runs parallel to the shoreline, provides the only road access to and evacuation route for over 200 homes and businesses east of South Kingstown Town Beach. Historic shoreline change in this area has been higher in the western section than the eastern.

4. Projected shoreline change reveals what the authors call "an incredible extent of land at risk to erosion in both sections of the headland" for these areas – the low-lying cottages on Roy Carpenter's beach; South Kingstown Town Beach; the mobile home park east of the beach; and Matunuck Beach Road. Homes to the east of these areas will be either directly impacted through erosion or indirectly impacted through lack of road access. See Figure 12 which also shows projected future CRMC setback requirements based on the projected future location of the coastal feature (see Section 4.4.2 above for further discussion).

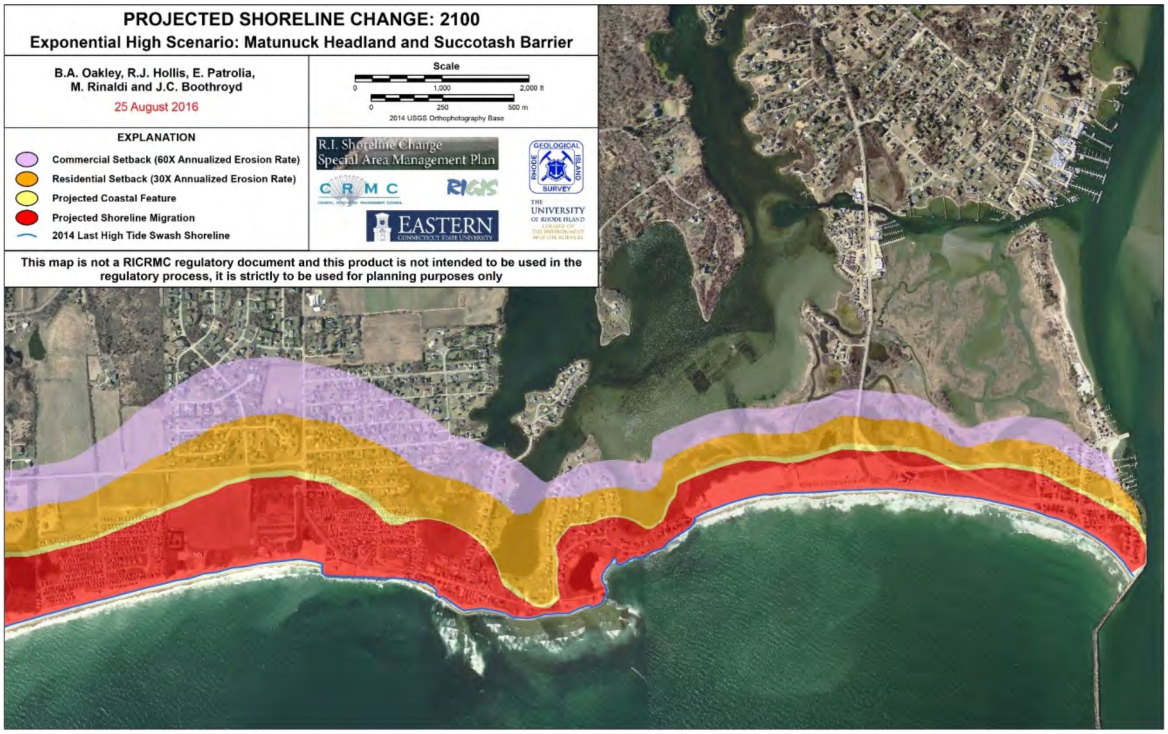

Figure 12. Projected shoreline position, controlling coastal feature, residential and commercial setbacks of Matunuck headland for the year 2100, where historical shoreline change between 1939 and 2014 was exponentially accelerated to the year 2100 (Source: Hollis, Oakley, Rasmussen, Boothroyd, Freedman and Fugate 2016).

5. Sea level rise and storm surges will affect these as well as other areas. A five-foot SLR will inundate areas seaward of Theater by the Sea including the Browning Cottages, Roy Carpenters beach cottages, and Cards Pond Road. Importantly, flooding will also affect non-oceanfront areas such as Potter's Pond, raising water levels within the pond that will in turn affect adjacent homes and roads. See Figure 13. For further information see Hollis, Oakley, Rasmussen, Boothroyd, Freedman and Fugate 2016.

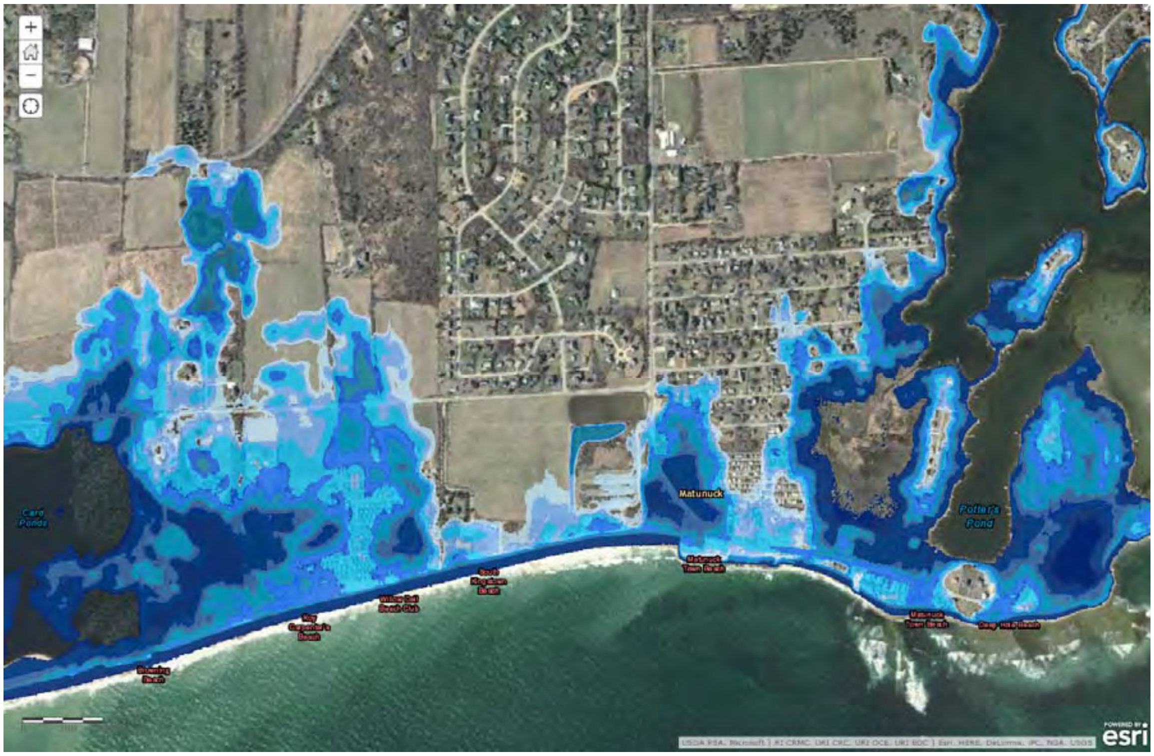

Figure 13. Five-foot SLR plus a 100-year storm surge affecting Matunuck Headland and adjacent areas. The blue-shaded areas indicate the extent of inundation; darker shades of blue indicate deeper waters. (Source: Hollis, Oakley, Rasmussen, Boothroyd, Freedman and Fugate 2016).

4.6.2.2 Misquamicut

1. The combined results of these studies indicate that Misquamicut is another notable area at risk of the combined effects of storm surge, coastal erosion and SLR. Additionally, Misquamicut has greater exposure because of the higher density of development in this area compared to Matunuck. For analytical purposes, Misquamicut is treated as two separate areas: the Misquamicut Headland (west of Misquamicut State Beach) and the Misquamicut Barrier (including the beach and areas east). The barrier comprises three areas: the Misquamicut State Beach; the commercial area along Atlantic Avenue to the east; and the residential area along Atlantic Avenue to the east of the commercial area. For figures illustrating Misquamicut's at-risk areas, see the Hollis at-risk area report at www.beachsamp.org.

2. Historic shoreline change analysis revealed that the Misquamicut Headland area's shoreline change rate from 1939 to 2014 ranged from 12 to 28 meters (40 to 93 feet) of retreat (Boothroyd et al. 2016). Historic shoreline changes along the barrier are seemingly low with 16 meters (56 feet) at Misquamicut State Beach, between 13 and 25 meters (45 and 83 feet) along the Atlantic Avenue commercial district, and between 10 and 39 meters (33 and 130 feet) along the Atlantic Avenue residential district

(Boothroyd et al. 2016). It is important to note that semi-permanent inlets formed along the barrier during both the 1938 Hurricane and Hurricane Carol in 1954. Based on this history and the low elevation of this area, it is expected that the barrier will breach again during future storms. This is consistent with other studies which have shown that inlet formation is likely at the lowest and narrowest portions of barriers, which may coincide with the location of former inlets (Sallenger 2000; Stockdon et al. 2007; Stockdon et al. 2009).

3. Based on these data, it would seem that the Misquamicut Barrier is not subject to significant erosion risk compared to other areas along the south shore, but this is not the case. The Oakley et al. at-risk area reports notes that there have been multiple federal and private local investments in beach replenishment projects and other interventions designed to maintain the barrier for tourism and other purposes.

4. The Hollis et al. at-risk area report reported projected shoreline change analysis for Misquamicut, which reveals significant at-risk areas. By 2100, it is expected that all structures seaward of Atlantic Avenue in the Headland area will be at risk of erosion. Similarly, along the barrier, all structures seaward of Atlantic Avenue will be at risk of erosion, as will be portions of Atlantic Avenue itself, the shore parallel road. Additionally, some of the properties north of Atlantic Avenue would protrude out onto the beach; such structures can cause shore parallel access issues or be at extreme risk of storm damages.

5. The Hollis et al. at-risk area study reported that inundation due to a 5-foot SLR in addition to a 100-year storm surge will have extensive impacts on Misquamicut. Residential areas on the low-lying southern part of the Headland will be impacted by SLR. Storm surge penetrated more than 300 meters (984.2 feet) inland during Superstorm Sandy, and even further inland during the 1938 Hurricane and Hurricane Carol in 1954; this is considered a useful approximation for inundation associated with a 5-foot SLR. A 5-foot SLR coupled with a 100-year storm surge is expected to result in inundation extending 500 meters – 1 km (0.3 – 0.62 miles) inland. On the barrier, a 5-foot SLR coupled with a 100-year storm surge is projected to inundate the entire barrier, including the beach and all commercial and residential properties. Access roads off the barrier would be completely flooded, and historic storms in the area suggest the possibility that the barrier could breach, effectively cutting it in half. During storms with sufficient surge, the barrier migrates as sediment is transported landward via overwash and deposited as washover fans. However, it is important to note that during smaller storms the barrier may not be inundated nor migrate through the process of overwash, but rather could be narrowed via frontal erosion.

6. Hollis et al.'s report points out the presence of numerous discontinuous revetments along both the Misquamicut headland and barrier. Additionally, anthropogenic dikes are located in several places including seaward of the Misquamicut Beach pavilion and parking lot. Most of the revetments were damaged, and many of the dikes failed, during Superstorm Sandy in 2012. Projected shoreline change for this area indicates that, over time, all but the largest such structures in this area will likely fail. For further information see Hollis, Oakley, Rasmussen, Boothroyd, Freedman and Fugate 2016.

4.6.2.3 Barrington, Warren and Bristol

1. Inside Narragansett Bay, the municipalities of Barrington, Warren and Bristol together represent an area that is expected to be highly impacted by storm surge, coastal erosion and SLR. These three municipalities are grouped together as one region for this summary discussion. Unlike the south shore, Oakley et al.'s at-risk study for Narragansett Bay focused on historic shoreline change, not projected shoreline change, and identified areas where 50 feet or more of shoreline change had been observed; see below for results for each municipality. The following information is summarized from Oakley et al.'s at-risk study; please see Oakley, Hollis, Boothroyd, Freedman, Boyd and Fugate 2016 for more information.

2. Historic shoreline change analysis for the Barrington, Warren and Bristol region revealed some at-risk areas. Some portions of Barrington Beach experienced up to 60 meters (197 feet) of landward shoreline migration between 1939 and 2003, and structures at the eastern end of Barrington Beach will be at risk from future shoreline migration. In Warren, small sections of the marsh shoreline along the Palmer River and Belcher Cove, as well as the head of the Kickemuit River and a small barrier spit at the mouth of the river, exceeded 50 feet of shoreline change from 1939 to 2003, thus meeting the study's 'at risk' threshold.

3. SLR and storm surge are the primary threats to Barrington due to its low-lying nature. In Barrington, many low-lying areas are already inundated during spring tides. SLR will cause more extensive flooding, even at less than the 5-foot SLR scenario. For example, along the Warren River, even a 1-foot SLR impacts access roads, and a 3-foot SLR isolates properties along these roads. A 2-foot SLR will partially inundate the Barrington Yacht Club on Tyler Point, and at a 5-foot SLR, Tyler Point will be largely flooded. SLR alone will inundate some properties and isolate others by flooding access roads such as County Road (Rte. 103), one of the main access roads for the town. A 100-year storm surge on top of a 5-foot SLR will inundate significant portions of Barrington. This will result in isolation of large portions of the town due to the Providence River merging with the Barrington River via Massachuck Creek and another small creek. Many of these

same areas are expected to flood even during a 25-year "nuisance" storm event. Properties in multiple neighborhoods will be inundated, and others will be isolated due to flooding of access and evacuation routes. Major roads including Rt. 114/103 (Wampanoag Trail and County Road) will be flooded at multiple points. Almost all of New Meadow Neck, which has dense residential development, is projected to be inundated by surge.

4. SLR and storm surge represent significant threats to Warren. The Oakley et al. at-risk study reports that a 1-foot SLR will "begin to alter the configuration of the commercial district" along the Warren waterfront, whereas a 3-foot SLR will bring about "dramatic changes to the waterfront." A 5-foot SLR will further inundate these same areas. The Warren Reservoir, which is part of the Bristol County Water Supply, may be inundated by as little as a 2-foot SLR. A 100-year storm surge on top of a 5-foot SLR will inundate significant portions of downtown Warren, and inundation across Main Street will isolate portions of downtown, affecting access and evacuation routes. The Kickemuit River and Belcher Cove will become connected under this flood inundation scenario, limiting access between downtown and east Warren, and the bridge to Warren from Barrington (Rte 103/114) will be inundated, further limiting access and evacuation.

5. Bristol is also at risk from the threats of sea level rise and storm surge, especially the waterfront commercial district and low-lying areas adjacent to several creeks and ponds. Oakley et al. report that a 1-foot SLR will begin to "alter the configuration of the commercial district along the waterfront" and that a 5-foot SLR will cause "dramatic changes to the waterfront." A 5-foot SLR will also limit access to portions of the town and inundate several properties. A 100-year storm surge on top of a 5-foot SLR will have significant impacts on downtown Bristol, particularly the commercial district along Thames Street and residential areas along Hope Street. Projected inundations will limit access and evacuation from Poppasquash Point because Bristol Harbor will become connected to the Providence River via Mill Gut. Projected inundations will also affect Roger Williams University facilities including its southernmost dorm.

4.7 Synergistic Effects of Storm Surge, Coastal Erosion and Sea Level Rise

1. Storm surge, coastal erosion and sea level rise are coastal hazards that interact with each other and with other hazards (e.g. wind), resulting in synergistic effects. A synergistic effect is caused when the interaction between two or more structures or

processes results in effects that are greater than the sum of each individual effect. Whereas many tools and studies have been developed to date to examine these coastal hazards, both by the CRMC and other agencies and organizations, many such tools only consider one coastal hazard at a time, not addressing the interactions between hazards. This means that many tools and analyses may underestimate the collective impacts of these hazards. Synergistic effects may result in greater exposure of Rhode Island's built and natural environment than any one of these processes and are thus critical considerations for long-term planning.

2. Some of these synergistic effects have been considered by Rhode Island studies and tools referenced in this chapter, whereas others require further research and analysis to understand how they affect the exposure of the Rhode Island coast. Importantly, this means that in many cases exposure assessments discussed in this chapter may underestimate the potential impact of a specific hazard to Rhode Island.

3. One example of a synergistic effect that may mean increased exposure along the Rhode Island coast is the way in which sea level rise will increase the return period of stormsJ (Lin et al. 2012). The concept of a storm return period assumes that the probability of a storm's occurrence will not change over time, but this does not account for sea level rise and other effects of climate change. Over time, as sea levels rise, a relatively low-probability storm event such as the 100-year storm will increase in probability because higher base water levels will increase the extent and depth of storm-related flooding. For example, Figure 14 illustrates how a 2-foot SLR reduces a 100-year storm event to a 20-year storm event (Spaulding, pers. comm.).

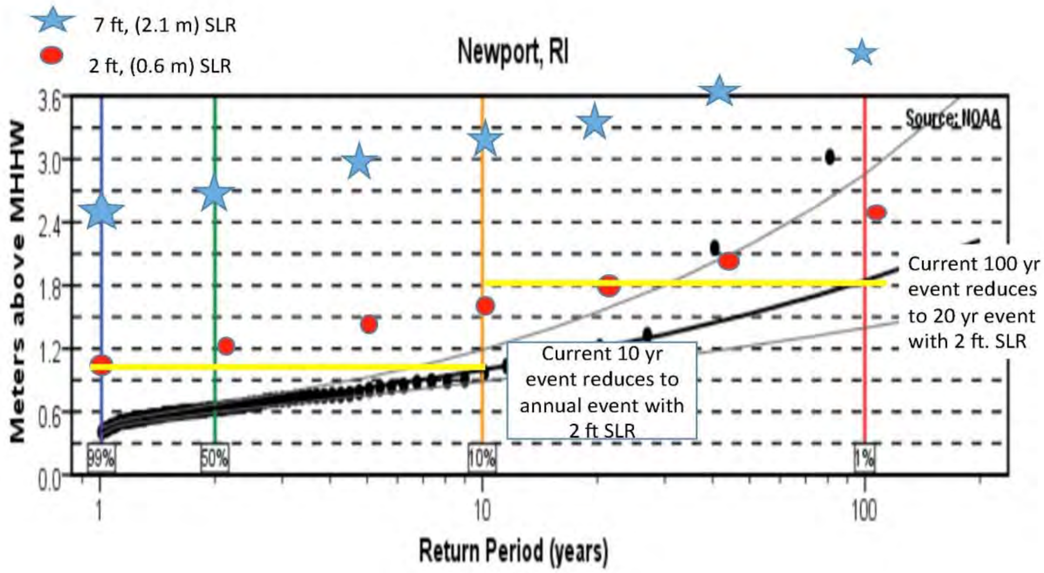

Figure 14. The effect of sea level rise on storm return periods (Spaulding, pers. comm.).

4. There are numerous other synergistic effects which may lead to increased exposure the Rhode Island coast. For example, storm surges on top of projected sea level rise will exacerbate existing storm-driven coastal erosion processes, accelerating future erosion. This is illustrated by the projected shoreline change maps included in Oakley, Hollis, Patrolia, Rinaldi and Boothroyd (2016). Storm surges on top of projected sea level rise will also increase the frequency of a given surge elevation occurring (i.e. a 100 year storm becomes a once in a decade storm) (Tebaldi et al., 2012; Grilli et al. 2017). Because rising seas raise the base water level, this could result in greater damage to coastal structures due to elevated storm surges and wave action. Additionally, synergistic effects will result from the interaction between rising seas and freshwater systems. These include setting a new flood stage in riverine systems, thus increasing flood risk in inland areas adjacent to rivers (Garcia and Loáiciga 2014; Hashemi et al. 2017), and causing a rise in the groundwater table, reducing groundwater separation distance to on-site wastewater treatment systems (Cooper et al. 2016). These are just a few of many synergistic effects which may increase the exposure of coastal Rhode Island's built and natural environment.

5. The synergistic effects of coastal hazards underscore the importance of long-term planning and adaptation. See Chapter 7 for adaptation strategies which can be used to reduce Rhode Islanders' exposure to these effects.

4.8 Ongoing and Future Research and Analysis

4.8.1 Overview

1. This chapter summarized much of the best available data and information on the exposure of Rhode Island's coast to the impacts of storm surge, sea level rise and coastal erosion. However, understanding of Rhode Island's exposure is rapidly changing, and research is under way in Rhode Island and elsewhere that may improve our understanding of Rhode Island's exposure. Additionally, other research questions and needs have arisen through the Shoreline Change SAMP development process that merit investigation. This section summarizes ongoing research projects with which CRMC is familiar, and describes future research needs which CRMC identifies as high priorities.

4.8.2 Ongoing Research

1. A team led by University of Rhode Island emeritus professor Dr. Malcolm Spaulding and other URI and CRMC colleagues is developing STORMTOOLS: Coastal Environmental Risk Index (CERI), a web-based GIS mapping tool. CERI uses state of the art modeling tools to predict storm surge and wave, combined with shoreline change maps (erosion), and damage functions, and applies these to Rhode Island's E-911 database of structures to perform exposure analyses for individual structures. CERI has been applied to two Rhode Island communities, Charlestown (representing a typical coastal barrier system directly exposed to ocean waves andhigh erosion rates), and Warwick (located within Narragansett Bay, with more limited wave exposure, lower erosion rates, and higher residential housing density. The CERI team is currently investigating the expansion of CERI to other communities and how best to help state and local decision-makers apply CERI to inform planning and policy decisions. For further information please see http://www.beachsamp.org/STORMTOOLS/STORMTOOLS-coastal-environmental-risk-index-ceri/.

2. University of Rhode Island professor Austin Becker is leading a U.S. Army Corps of Engineers (USACE)-funded study comparing the vulnerability of medium and high-use seaports in the North Atlantic. This study is piloting a climate vulnerability indexing method and will contribute to better understanding of climate vulnerability across North Atlantic ports. This vulnerability index includes SLR and storm surge. This study includes the port of Providence, and is expected to be completed by July 2019. For more information please see http://web.uri.edu/abecker/risk-indices/.

3. A team at the University of Rhode Island has partnered with the Coastal Resilience Center of Excellence at the University of North Carolina at Chapel Hill on a coastal resilience project funded by the U.S. Department of Homeland Security. URI's part of this project comprises three studies. The first, led by Dr. Chris Kincaid and Dr. Isaac Ginis, uses coastal prediction models to develop and apply the hypothetical scenario of Rhode Island's worst-case scenario storm, "Hurricane Rhody," in order to better understand the local effects of such a storm. The second, led by Dr. James Opaluch, tests the effectiveness of various incentives and policies with the goal of overcoming barriers to community actions that can reduce storm vulnerability. The third, led by Dr. James Prochaska, involves applying an established model of behavior change to coastal residents and tailoring interventions to encourage residents to choose mitigation options. For more information on this project please contact Pam Rubinoff at the URI Coastal Resources Center (rubi@crc.uri.edu).

4. A multi-agency assessment team led by the Narragansett Bay National Estuarine Research Reserve (NERR) has applied the Climate Change Vulnerability Assessment Tool for Coastal Habitats (CCVATCH) to fourteen different marshes within Rhode Island. A final report is forthcoming highlighting key findings including specific climate and climate/non-climate stressor interactions that were identified as primary drivers of potential future habitat condition change. For further information please visit www.ccvatch.com or contact Robin Weber at the Narragansett Bay NERR (robin@nbnerr.org).

4.8.3 Future Research Needs

4.8.3.1 The Built Environment

1. **New sea level rise projections**: Future research is needed to address new sea level rise data released by NOAA in early 2017, which project up to 9.6 feet of SLR under the "high" curve and up to 11.7 feet under the "extreme" curve, at the 83% confidence interval, for Rhode Island (see NOAA 2017a). Research should build new STORMTOOLS inundation layers that consider these new data and should examine the extent to which these new inundation layers change Rhode Island's exposure to storm surge and sea level rise. Additionally, all Shoreline Change SAMP and other studies included in this document should be updated to include these new SLR projections.

2. **Hurricane barrier**: Future research is needed on the Fox Point Hurricane Protection Barrier within the context of the broader Narragansett Bay system. This research should apply new knowledge of sea level rise and storm surge projections for Narragansett Bay to the hurricane barrier and examine the extent to which this structure will need to be

modified or any other changes should be made to accommodate these projected changes within the system. Any such analysis should be coordinated with others who are working on this or related issues, including but not limited to the Providence Office of Sustainability and the URI team working on the hypothetical "Hurricane Rhody" scenario (see section 4.8.2 above). If significant modifications are found to be necessary, then examining how best to deal with both storm surge and sea level rise at the facility might be warranted.

3. **Property values**: Future research is needed to determine the assessed value of properties that might be impacted by storm surge, coastal erosion and sea level rise. This research should also consider the property taxes associated with these properties and the potential impact of losses to municipal budgets. Last, research should address the broader economic impacts of damage to these properties.

4. **Recreational sites and infrastructure**: Future research is needed on the exposure of recreational sites and infrastructure to storm surge, coastal erosion and sea level rise. Recreational sites and infrastructure to be researched should include designated public rights of way (ROWs) which may be impacted by these hazards. This research could build upon existing Shoreline Change SAMP tools, such as STORMTOOLS, but should also consider the social, economic and cultural attributes of Rhode Island's shoreline recreational assets.

5. **Ports and working waterfronts**: Future research is needed on the exposure of Rhode Island's ports and working waterfronts to storm surge, coastal erosion and sea level rise. Ports and working waterfront facilities have unique vulnerabilities insofar as they must be located on the waterfront and allow access to waters of sufficient depth for commercial vessels. Analysis of these facilities could build upon existing Shoreline Change SAMP tools, such as STORMTOOLS, but should also consider the unique siting needs of these facilities as well as their economic importance to Rhode Island and to the nation.

6. **Existing shoreline protection structures**: Future research is needed to inventory and assess existing shoreline protection structures. Such an inventory has not been conducted, and the latest review of such structures took place in 2007 and only involved estimating structure length based on 2003 orthophotography. Current estimates of the length of the Rhode Island coast that is protected through such structures are only approximations. Such an assessment should examine the elevation and present condition of the structures.

7. **Railways**: Further research is needed on the exposure and vulnerability of Amtrak railways and infrastructure in Rhode Island to sea level rise. The RI Statewide Planning Program's 2015 state transportation infrastructure assessment referenced above focused on state infrastructure and did not fully assess Amtrak railways, which provides important services to Rhode Island and the region and which is expected to be vulnerable to SLR.

4.8.3.2 The Natural Environment

1. **Riverine systems**: Future research is needed on the effects that sea level rise and storm surge may have on Rhode Island's riverine systems, including but not limited to the Pawtuxet River, which has been modeled by the URI Department of Ocean Engineering (Hashemi et al. 2017).[8] There are multiple areas of research need regarding the Pawtuxet and other RI watersheds, which could inform the development of an operational flood forecasting system for these systems. First, research is needed on the coupling effect of storm surge and a precipitation event in the watershed. Second, research is needed on the coupling effect of new sea level rise scenarios with a flooding event in the watershed, considering both coastal and freshwater precipitation events. Third, research should consider scenarios in which a storm results in both storm surges and significant precipitation, potentially causing storm surge and inland flooding at the same time. Finally, research is needed on the problem of storm debris creating choke points on rivers, affecting river drainage and flooding.

2. **Groundwater**: Future research is needed on the effects that sea level rise will have on groundwater. Research should address two problems. The first is the problem of saltwater intrusion into drinking water supplies, which could have cascading effects through the state's water supply system. The second is the problem of sea level rise decreasing the separation distance between septic fields and groundwater, thus decreasing the effectiveness of the field in eliminating pathogens. Recent research examining how soil-based onsite wastewater treatment systems are affected by climate change in coastal regions can be found in Cooper et al. (2016).

[8] A team led by Dr. Reza Hashemi with the URI Department of Ocean Engineering has developed a spatially distributed hydrological/hydraulic modeling system for the Pawxuet watershed and river. The team simulated the March 2010 flood and developed a series of other scenarios, including multiple flood scenarios (see http://edc.maps.arcgis.com/home/webmap/viewer.html?webmap=d025e9fc58ae440a88b5ce590ddfa4cd). For further information please see Hashemi et al. 2017.

3. **Salt marshes**: Future research is needed on salt marsh migration, including how landward migration reacts to natural migration impediments, such as common coastal vegetation communities. Such research will be important for determining the marsh migration potential of adjacent lands and to help prioritize conservation of appropriate parcels as well as the effectiveness and cost of migration management practices. For further information on this and other salt marsh research needs, please see the Rhode Island Coastal Wetland Restoration Strategy (Kutcher 2017).

4. **SLAMM**: A Sea Level Affecting Marshes Model (SLAMM) analysis should be performed again, incorporating new assumptions including new sea level rise scenarios. The SLAMM analysis discussed in this chapter included only 1, 3 and 5-foot scenarios. Future analyses should include the 7-foot scenario used in this document as well as the new 9.6-11.7-foot scenarios introduced in early 2017 by NOAA (NOAA 2017a).

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CHAPTER 5

RI CRMC Coastal Hazard Application Guidance

5.1 Overview of Process

The steps presented below provide guidance for applicants to address Coastal Hazards for selected projects in the design and permitting process for the Rhode Island Coastal Resources Management Council (CRMC).

STEP 1: PROJECT DESIGN LIFE	**In this step, the applicant will choose an appropriate design life, or lifespan, for the project, and identify a projected sea level for the project site based on the selected design life.**
STEP 2: SITE ASSESSMENT & BASE FLOOD ELEVATION	**In this step the applicant will review specified maps and tools to assess the exposure and potential risk from coastal hazards at the project site.**
STEP 3: LARGE PROJECTS	**This step is for Large Projects and Subdivisions only. If not such a project, this step may be skipped.**
STEP 4: DESIGN EVALUATION	**The applicant will identify, document, and assess the feasibility of design techniques that could serve to avoid or minimize risk of losses.**
STEP 5: SUBMIT AN APPLICATION	**The applicant will submit the permit application and include the assessment from the previous steps in the application package to the CRMC.**

5.2 Using this Document

This chapter of the Shoreline Change SAMP outlines a process through which applicants will address the coastal hazards associated with climate change as part of coastal applications for new and substantially improved projects, as specified in Section 110 of the Rhode Island Coastal Resources Management Program (RICRMP, also known as the "Red Book"). The goal of this process is to ensure that CRMC approved projects are designed and built with the applicant's acknowledgement of the risks of building in coastal hazard areas exposed to storm surge, erosion and future sea level rise conditions. Additionally, this process will help to: protect public health, safety, and welfare; minimize damage and losses to nearby infrastructure and properties; and, reduce overall impacts to coastal resources. Adapting to these ongoing and future conditions will ensure Rhode Island is building resilient communities, as well as a strong coastal economy and environment.

The guidance outlined here is intended to help CRMC applicants recognize and minimize risks to protect their investments for the design life of their project. The information contained in this chapter will assist the applicant in evaluating potential impacts from storm surge, erosion and projected future sea level rise, as well as the cumulative impacts of these risks over time (hereafter "Coastal Hazards") based on the best available science.

This process applies to applications for new and substantial improvements to properties within the planning boundary for the Shoreline Change Special Area Management Plan (Shoreline Change SAMP). The Shoreline Change SAMP Planning Boundary is defined as the land area along the Rhode Island coastline (all 21 coastal communities) projected to be inundated by a 100-year return period storm event (1% annual chance) plus seven feet of sea level rise as illustrated in STORMTOOLS (www.beachsamp.org/stormtools). See Figure 1.

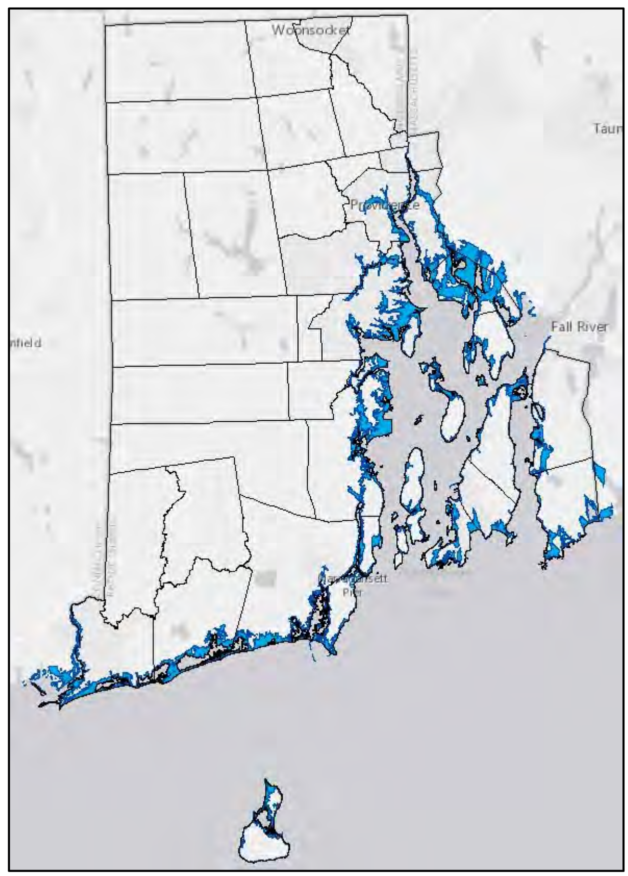

Figure 1. Shoreline Change SAMP Planning

Additional background information for each step of the process outlined in the following pages can be found following Page 10. For background information on CRMC's enabling legislation, Shoreline Change SAMP guiding principles, and overall context for the process outlined in this chapter, please refer to Page 16 of this chapter, or review Chapter 1: Introduction.

Chapter 1, Introduction, of this Shoreline Change SAMP (Section 1.1.4), lays out CRMC's responsibility to ensure that decisions made concerning Rhode Island's coastline are well thought out and based on the best available science. **Toward that end, the vision of the Shoreline Change SAMP is to provide guidance and tools for state and local decision makers to prepare and plan for, absorb, recover from, and successfully adapt to the impacts of coastal storms, erosion, and sea level rise**.

Guiding Principles of the Shoreline Change SAMP

- Serve as a guidance document to support regulatory changes (CRMC policy and standards), and any regulatory changes will be made to the Red Book and other existing SAMPs;
- Be developed in a transparent manner;
- Use best science available to understand changing conditions of Rhode Island's shoreline and help develop appropriate strategies for response;
- Consider synergistic long-range impacts over time of sea level rise, coastal storms, and erosion;
- Incorporate risk identification and awareness in design and development;
- Identify early actions and recommended strategies to monitor, evaluate, and readjust;
- Encourage incremental phasing of adaptation strategies and actions, and keep flexibility in the system;
- Maximize agency coordination and public participation; and
- Emphasize "No Regrets" decisions.

STEP 1: PROJECT DESIGN LIFE

In this step, the applicant will choose a projected design life, or lifespan, for the project, and identify a projected Sea Level Rise (SLR) for the project site for exposure to coastal flooding.

STEP 1 *(Please see Page 11 for background information.)*

1. The applicant or their chosen design professional will contact the municipal building official to document their FEMA Flood Insurance Rate Map (FIRM) Base Flood Elevation (BFE) for the project site.
2. Using the CRMC Shoreline Erosion Maps available on the CRMC's website, identify the historic erosion rate for the project site.
3. Choose an expected design life of your proposed project by considering how long the development is expected to last on the project site. ***NOTE: CRMC recommends a minimum 30-year design life to correspond to the length of a typical mortgage.***
4. Using *Table 1 – Sea Level Rise (SLR) Projections (Feb. 2017)* below, identify the sea level projections that match the expected design life of your proposed project.
5. *Expected outcome from STEP 1:* ***Take the SLR value from Table 1 and carry it forward to STEP 2 to define the risk profile for the project site.***

Year	2020	2030	2040	2050	2060	2070	2080	2090	2100
SLR	1.05	1.67	2.33	3.25	4.20	5.35	6.69	8.14	9.61

Table 1 – Sea Level Rise (SLR) Projections (Feb. 2017). NOAA High Curve, 83% Confidence Interval. Newport, RI Tide Gauge. All values are expressed in feet relative to NAVD88. http://www.corpsclimate.us/ccaceslcurves.cfm

STEP 2: SITE ASSESSMENT AND BASE FLOOD ELEVATION

The applicant will review available maps and tools to assess the exposure and potential risk from coastal hazards at the project site.

STEP 2 *(Please see Page 12 for background information.)*

Step 2A: What does SLR do to my site (plus access roads)?

- Go to STORMTOOLS for CRMC Permit Applicants. This online Map Journal will provide interactive maps that assist applicants in addressing the requirements of this Step.
- Select the SLR Map Layer that comes closest to the SLR value you derived from STEP 1 to see how SLR impacts your project site and access roads. If your SLR value is between two values, round up to the higher SLR Map Layer.
- Type in or Zoom to your project site address in the address field.
- Identify the roads that connect to your project site and if they show exposure to SLR.

Step 2B: STORMTOOLS Design Elevation (SDE)

- Determine your recommended STORMTOOLS Design Elevation (SDE) using (xxx.xxxx.xxx) ***NOTE: SDE maps are currently under development and are expected to be online and available for the entire Rhode Island coastline by mid-2018.***
- Reference State Law Elevation Allowances. ***NOTE: 1-foot of freeboard (elevation) is required, above BFE is required but up to 5-feet of additional freeboard may be provided voluntarily.***
- Applicant should coordinate with the design engineer on this issue.

Step 2C: Erosion

- See Erosion Maps in RICRMP and meet the Regulatory setbacks (Section 140).
- To calculate projected erosion at the project site, select the multiplier in the Table 2 below that corresponds to the design life year you selected in STEP 1. Multiply the historic erosion rate you identified in STEP 1.2 by the multiplier in the Table 2 to determine projected future erosion for the project site.

Year	2020	2030	2040	2050	2060	2070	2080	2090	2100
Projected Future Erosion Multiplier	1.05	1.14	1.23	1.34	1.45	1.57	1.70	1.84	2.00

Table 2 – Projected Erosion Rate multipliers. (Oakley et al., 2016[1])

Step 2D: Other Site Considerations

- Consider other risk factors that might impact the development, such as coastal habitats, shoreline features, public access, wastewater, stormwater, depth to water table/groundwater dynamics, saltwater intrusion, or other issues not listed above.

Step 2E: STORMTOOLS/Coastal Environmental Risk Index (CERI) - ***UNDER DEVELOPMENT***

[1] Oakley, B.A., R.J. Hollis, E. Patrolia, M. Rinaldi, and J.C. Boothroyd. 2016. Projected Shorelines and Coastal Setbacks: A Planning Tool for the Rhode Island South Shore: Technical report prepared for the RICRMC Shoreline Change Special Area Management Plan.

STEP 3: LARGE PROJECTS AND SUBDIVISIONS (6 OR MORE UNITS)

This step is for Large Projects and Subdivisions only.
This step may be skipped for other projects.

STEP 3 *(Please see Page 13 for background information.)*

The CRMC recommends consulting its Sea Level Affecting Marshes Model (SLAMM) Maps to assess potential impacts to large projects and subdivisions from salt marsh migration resulting from projected sea level rise.[2] CRMC SLAMM maps can be accessed here: http://www.crmc.ri.gov/maps/maps_slamm.html.

The CRMC recommends using the 5-foot SLR projection within SLAMM to assess future potential project impacts on migrating marshes.

[2] The final report on sea level and marshes can be viewed here: http://www.beachsamp.org/wp-content/uploads/2015/06/Rhode-Island-Sea-Level-Affecting-Marshes-Model-Technical-Report-11.pdf

STEP 4: DESIGN EVALUATION

The applicant will identify, document, and assess the feasibility of design techniques that could serve to avoid or minimize risk of losses.

STEP 4 *(Please see Page 14 for background information.)*

1. *Expected outcomes from Step 4:* ***This step may involve an iterative process of project modifications and reexamination of impacts, leading to one or more alternatives for the project site. Designs may include relocation, fortification, and/or employ other alternatives to accommodate Coastal Hazards impacts. The alternative that will minimize risks from coastal hazards and avoid or minimize impacts to coastal resources should be identified. The applicant is encouraged to select the alternative that will avoid and/or minimize the risks to the project, abutting structures, infrastructure, and coastal resources.***

2. The design decisions and creativity to meet this challenge is up to the applicant. On hazard-constrained sites with a high level of exposure from Coastal Hazards, minimizing risk may be the only option for the proposed project and, in some cases, relocation of the project may be the best option. In all cases, projects must be sited and designed to address all applicable regulatory standards. Considerations involved in choosing and designing an appropriate adaptation strategy are further described below:

    a. **Assess Design Constraints and Validate Project Design Life:** Determine whether there are any significant site or design constraints that might prevent future implementation of possible adaptation measures. Based on the analysis, some project locations may be constrained due to lot size, elevation, preserve of protected resource (i.e., wetland), steep slopes, and/or limited access, such that no viable development area can be identified on the parcel for the design life chosen. In some cases applications may proceed in the face of these risks but, care should be taken to avoid resource impacts and minimize risks as much as possible, including identifying alternative routes or access to and from the project site.

    b. **Identify and Document Adaptation Options:** Identify possible adaptation strategies for the proposed project, and evaluate each adaptation option for the ability to minimize risk for the PROPOSED DEVELOPMENT and potential adverse impacts on coastal resources. Options for adaptation should be considered for the chosen design life of the proposed project to ensure that CURRENT development does not negatively impact coastal resources in the future. Applicants are expected to describe and evaluate the viability of the strategies considered, and provide an example or reference that can be reviewed by CRMC in its review.

For example, an option that is often considered for sea level rise is to elevate structures to provide flood protection. However, while elevating the structure may decrease the risk of flood damage, the additional elevation of the building may subject it to greater from wind exposure. *Therefore, construction methods and materials must meet applicable building code requirements for the expected wind loads. It should be considered that although elevation of buildings may be of little long-term utility if the supporting infrastructure, such as the driveways, roads, utilities, wells, or on-site wastewater treatment systems, is subject to flooding, erosion, or storm damage.*

c. **Ensure Design Flexibility:** If the likelihood of exposure and damage is expected to increase over time, it may be appropriate to design the project with some exposure to risk, but with design flexibility that will allow future project modifications and improvements to further minimize risks or losses in the future.

For example, modifications and improvements could include the use of fortification and foundation elements that will allow for building relocations or removal of portions of a building as it is threatened by Coastal Hazards over time. For related on-site waste treatment systems, planning for relocation of these systems away from areas susceptible to tidal inundation, storm surge, erosion or rising water tables may be necessary to ensure long-term use of the site.

d. **Develop Project Modifications:** If the project site is highly constrained from exposure to Coastal Hazards, the applicant may benefit from plans to incrementally relocate the project as site conditions change to a point where the site is unable to support continued use. For example, identifying triggers through monitoring sea level rise and tidal inundation levels, or erosion rates may result in a change to the design of the project and need to implement improvements. Applicants are encouraged to prepare an implementation plan that outlines how and when adaptation measures will be incorporated into the project over the design life.

e. **Plan for Monitoring:** Where impacts are realized, the applicant is expected to implement adaptation measures in a timely manner. Potential Coastal Hazard impacts over time should be considered to ensure project modifications, or additional adaptation efforts can be implemented in the future.

STEP 5: SUBMIT AN APPLICATION

The applicant will submit the permit application and include the assessment from the previous steps in the application package to the CRMC.

CRMC expects that this process will result in a more resilient shoreline across the state of Rhode Island. The intent of this process is to reduce risk, ensure longevity of developments, and increase awareness of coastal hazards among coastal property owners and business sectors.

STEP 5

1. **Complete the permit application.** Prepare the analysis as described above. The Application Checklist for permit applications, provided at the end of this document, covers the typical information that might be included in a permit application necessary for CRMC review. Applicants who are unfamiliar with the permit process should consult CRMC or its website for instructions on how to complete a permit application, or consider hiring the appropriate environmental and/or design consultants.[3]

2. **Submit a complete permit application.** CRMC Staff will review the application for completeness to ensure that there is sufficient information to analyze the project for all appropriate CRMC policies and regulatory standards, as applicable.

3. **Once a complete application has been accepted**, CRMC Staff will review the analysis of the potential hazards and resource impacts associated with the proposed project and site access. Ideally, the application will provide all necessary project information at the filing stage. In some instances, additional information may be needed after the application has been accepted. This is normally limited to clarifications or further details regarding the submittal. During this stage in the permit application process, the permit staff may suggest appropriate project modifications that were not part of the initial application, or place conditions on the project permit if it is to be approved. Completion of these steps does not guarantee an approval of the application or an agreement that the design life will be met if approved.

4. *Expected outcomes from STEP 5:* ***This step, combined with supporting documentation from the previous steps, should provide a basis for evaluating impacts from Coastal Hazards and on coastal resources, and provide the basis for a complete application.***

[3] http://www.crmc.ri.gov/applicationforms.html

5.3 Background Information for the 5-Step Application Process

STEP 1 - BACKGROUND:

1. In this step, the applicant will consider the viability of their project site, and the expected life span for their project, referred to in this process as "design life," and determine if projected future sea level scenarios and related tidal cycles are expected to expose their project to tidal waters.

2. Given the current uncertainty about the magnitude and timing of future sea level rise, an analysis based on the applicant's chosen design life will examine the consequences associated with specific planning horizons using the most recent NOAA seal level rise data curve with the expectation that water levels are not likely to exceed the indicated height within the chosen planning horizon.

3. Section 145 of the RI CRMP provides timelines for short-, mid-, and long-term planning for 2035, 2050, and 2100, respectively (see Table 2), based on the Newport, RI NOAA tide gauge.

Table 2. Design planning horizons recommended by CRMC4 (Feb. 2017)

Time Horizon	Projected Sea Level Rise: NOAA Sea Level Rise High Curve in Rhode Island	Projected Sea Level Rise with Annual Extreme High Tides
2035	1 foot	2-3 feet
2050	2 feet	3-4 feet
2100	7 feet	8-9 feet

[4] The projections for these planning horizons reflect NOAA's high curve on the USACE Sea Level Change Curve Calculator as of February 2017, and are based on sea level in 1990 from the Newport Tide Gauge.

4. The design life for the project will help determine the appropriate projections of Coastal Hazards to which the project site could be exposed while the development is in place. Importantly, the point of this step is to consider the level of risk from Coastal Hazards a property owner is willing to assume.

5. The projections for the impacts of Coastal Hazards associated with this design life are expected to be used throughout this analysis and evaluation. If constraints are identified with this analysis, defining adaptation measures will be expected as outlined in Step 4 of this process. If a developable area on the site is identified with no long-term resource impacts from Coastal Hazards, the applicant will be expected to document this in their permit application package.

STEP 2 - BACKGROUND:

1. Online mapping tools have been developed by the CRMC and the University of Rhode Island to assess spatial relationships of project sites and the related ingress/egress areas within the Shoreline Change SAMP Planning Boundary to Coastal Hazards.[5] STORMTOOLS is an online mapping tool intended for use by coastal dwellers, property owners, and government decision makers to understand risk from changing coastal conditions, including storm surge, coastal erosion, and projected sea level rise. STORMTOOLS is hosted online using ESRI software, ArcGIS.com, and individual data layers are downloadable for use in desktop GIS software through Rhode Island Geographic Information Systems (RIGIS.org). The following pages illustrate the tools and provide applicants with instructions on how to use the information and data provided within each tool for use in evaluating the Coastal Hazards that may interact with the project site or ingress/egress areas.

2. **STORMTOOLS for Coastal Permit Applicants** has been designed for permit applicants to assess the exposure and risk from coastal processes, and for RI CRMC permit review staff to evaluate permit applications. The applicant is expected to review and document the following six Coastal Hazards using the tools indicated below.

    2A. **Sea Level Rise** – illustrate inundation using STORMTOOLS

    2B. **STORMTOOLS Design Elevation (SDE)** – identify the SDE and compare that to the FEMA Flood Insurance Rate Map (FIRM) BFE assigned to the project site

[5] These tools are identified in Section 145 (STORMTOOLS for sea level rise and storm surge), Section 140 (shoreline change maps) and Section 210.3 (SLAMM for marsh migration), respectively.

2C. **Coastal Erosion** – determine historical and projected exponential rate and amount of change using SHORELINE CHANGE MAPS with the multipliers provided to determine future conditions

2D. **Other Site Considerations** – document other forces or factors that might impact the development, such as depth to water table/groundwater dynamics, or assessment of coastal resources which may include consideration of coastal habitats, shoreline features, public access, wastewater and stormwater, and how the proposed development may impact these over your chosen design life with the potential effects of Coastal Hazards as identified in Step 2.

Coastal permit applications are expected to identify: 1) the presence of any of the following types of coastal resources in the area of the proposed project; 2) if exposure to Coastal Hazards might result in impacts to the coastal resource or the proposed development; and 3) how these may change over time.

i. **Coastal Habitats:** Coastal habitats, especially those that have a connection to water, such as beaches, dunes and coastal wetlands, are likely to be impacted by Coastal Hazards.

ii. **Shoreline Features:** Shoreline features include coastal beaches, barrier islands and spits, coastal wetlands, coastal headlands, bluffs and cliffs, rocky shores, manmade shorelines, and dunes. CRMC jurisdiction and regulations for setbacks and buffer zones surrounding onshore development includes land area within a 200 foot distance from the inland edge of the coastal feature. [6]

iii. **Public Access:** In the RI CRMP, the term public access is "a general term used to describe the ways and means by which the public may legally reach and enjoy the coastal areas and resources of the State" (RI CRMP § 335(A)(1)). New and substantially improved development must protect existing public access ensure access along the coastline.[7] Public access resources include both lateral and perpendicular public access ways, public access easements, beaches, public trust areas and lands, and trails. These areas may become hazardous or unusable during the project life as a result of impacts from Coastal Hazards. Coastal erosion and sea level rise may present barriers to or eliminate public access over time because adjacent

[6] See Section 210 of the CRMP for more information about Shoreline Features http://www.crmc.ri.gov/regulations/RICRMP.pdf

[7] See Section 335 of the CRMP for more information on Public Access http://www.crmc.ri.gov/regulations/RICRMP.pdf

land uses may not allow that access to migrate with the shoreline. Additionally, hardening of the shoreline can create barriers to public access along lateral access ways as erosion takes place.[8]

iv. **Wastewater and Stormwater:** Coastal Hazards may cause stormwater drainage outfalls with low elevations to back up during rainfall events, or push seawater inland through stormwater infrastructure, causing flooding in areas that are not in direct contact with the sea. Coastal Hazards, sea level rise in particular, may also cause a rise in the groundwater table, reducing the groundwater separation distance to on-site wastewater treatment systems (OWTS) and shortening the life of the system. Both of these changes could alter on-site drainage and limit future drainage options. These changes can also affect regimes of freshwater wetlands near saltwater wetlands.[9] Recent research covering the ability of soil-based OWTS to treat wastewater in coastal regions of the Northeastern United States can be found in Cooper et al., 2016. [10]

v. **Groundwater and Salt Water Intrusion:** Consider how salt water intrusion or rising groundwater tables associated with sea level rise may impact private drinking water wells and septic systems.

2E. **STORMTOOLS/Coastal Environmental Risk Index** ***– UNDER DEVELOPMENT***

STEP 3 - BACKGROUND:

1. In addition to the other Steps above, large projects and subdivisions of 6 or more units located in the vicinity of coastal wetlands should evaluate the project for potential impacts to coastal wetlands under future conditions. For example, will a proposed project accommodate or impede coastal wetland migration into upland areas? Coastal salt marshes are projected to either migrate or drown in place as a result of rising sea levels. This step offers an opportunity for the applicant to provide for migration of wetlands and increase the resilience of the project site.

[8] See Section 300.7 of the CRMP for more information about Shoreline Protection Facilities http://www.crmc.ri.gov/regulations/RICRMP.pdf

[9] The final report on sea level and marshes can be viewed here: http://www.beachsamp.org/wp-content/uploads/2015/06/Rhode-Island-Sea-Level-Affecting-Marshes-Model-Technical-Report-11.pdf

[10] http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0162104 - "Hell and High Water: Diminished Septic System Performance in Coastal Regions Due to Climate Change"

STEP 4 - BACKGROUND:

1. Given the results of the analysis conducted in Steps 1 - 3 above, the applicant is expected to consider project changes, types of adaptation strategies, and design alternatives that would be most appropriate given the degree of risk posed by Coastal Hazards, and how long the development might be free from risk. The permit application might identify triggers within the chosen design life (e.g., a certain amount of sea level rise) when certain adaptation measures should be implemented to reduce risk and/or impacts to coastal resources.

2. Protective devices including seawalls, revetments, and groins substantially alter natural landforms along the shoreline. **Shoreline protection structures are prohibited along shorelines classified as Type 1 Conservation Areas** in the CRMP. Type 1 waters make up 50% of Rhode Island's coastline, and thus these protective devices would not be considered appropriate mitigation measures in many cases.

3. When structural shoreline protection is proposed, the Council shall require that the owner **exhaust all reasonable and practical alternatives** including, but not limited to, the relocation of the structure and nonstructural shoreline protection methods[11], including use of natural/nature based infrastructure designed to adapt to changing conditions over time.

4. Land divisions and lot line adjustments in high hazard areas can change hazard exposure and should therefore be undertaken only when they can be shown to **not degrade or create new vulnerability**. In particular, new lots or reconfigured lots with new development potential should be created to minimize shoreline hazard risks.

5. It is important, in identifying adaptation measures to prevent hazards impacts to the development, that **these measures should not exacerbate other risks**[12]. For example, placing fill into an area that is predicted to be affected by Coastal Hazards could negatively impact adjacent resources, such as wetlands, if the fill is displaced during a storm event or increases stormwater flooding. Additionally, permit reviews will assess if proposed developments will rob sediment supply to beaches. The RI CRMP may limit certain adaptation measures in these cases.

6. The best way to minimize risks to both development and coastal resources is to **avoid areas or portions of the site that are or will become hazardous** as identified by the analysis in the previous steps. Such avoidance often includes changes to the proposed project to bring the size and scale of the proposed development in line with the capacity of the project site.

[11] RI CRMP Section 300.7.
[12] See Chapter 7 for more information on specific adaptation measures.

7. If it is not feasible to site or design a structure to completely avoid impacts from Coastal Hazards, the application may need to include **measures that fortify or otherwise modify the development** to prevent risks to the development or to coastal resources. Some changes, such as the use of additional setbacks, may be necessary at the outset of the project. Other changes, such as elevation, added floodproofing, or relocation of the project to another site during the design life may be viable adaptive strategies that can be applied in the future after the initial project completion. The CRMC currently offers applicants in its regulations, RI Code of Regulations (RICR) 650-RICR-10-00-01.4.3, an incentive for expedited review of projects seeking Insurance Institute for Business & Home Safety (IBHS) Fortified Home™ program designation.

8. The applicant may consider **designing the project to be moved or relocated** in the future when conditions warrant. This is especially important for severely constrained lots, or lots that are expected to experience significant change when threatened by coastal hazards.

5.4 Why has CRMC developed this process?

The CRMC is mandated to uphold all applicable sections of the federal **Coastal Zone Management Act of 1972 (CZMA).** The CZMA requires that the CRMC provide for the protection of natural resources within the coastal zone, including wetlands, floodplains, estuaries, beaches, dunes, barrier islands, and fish and wildlife and their habitat, and must manage coastal development to improve, safeguard, and restore the quality of coastal waters, and protect existing uses of those waters. The CRMC must develop management plans that give full consideration to ecological, cultural, historic, and aesthetic values, as well as needs for compatible economic development. SAMPs are identified in the CZMA as effective tools to meet this mandate (16 U.S.C. §1456b).

In 16 U.S.C. § 1451 Congressional findings (Section 302), the Congress finds that:

> *(l) Because global warming may result in a substantial sea level rise with serious adverse effects in the coastal zone, coastal states must anticipate and plan for such an occurrence.*

In 16 U.S.C. § 1452 Congressional declaration of policy (Section 303), the Congress finds and declares that it is the national policy—

> *2) to encourage and assist the states to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone, giving full consideration to ecological, cultural, historic, and esthetic values as well as the needs for compatible economic development, which programs should at least provide for—*
>
> > *(B) the management of coastal development to minimize the loss of life and property caused by improper development in flood-prone, storm surge, geological hazard, and erosion-prone areas and in areas likely to be affected by or vulnerable to sea level rise, land subsidence, and saltwater intrusion, and by the destruction of natural protective features such as beaches, dunes, wetlands, and barrier islands; and*
> >
> > *(K) the study and development, in any case in which the Secretary considers it to be appropriate, of plans for addressing the adverse effects upon the coastal zone of land subsidence and of sea level rise.*
>
> *(3) to encourage the preparation of special area management plans which provide for increased specificity in protecting significant natural resources, reasonable coastal-dependent economic growth, improved protection of life and property in hazardous areas, including those areas likely to be affected by land subsidence, sea level rise, or fluctuating water levels of the Great Lakes, and improved predictability in governmental decision making*

CRMC is Rhode Island's responsible agency for carrying out the Shoreline Change SAMP effort and abiding by the guiding principles outlined above. The enabling legislation is documented in **Title 46, Chapter 23 of the Rhode Island General Laws**. Section 46-23-1, Legislative Findings, states:

> *46-23-1 (a)(1) Under article 1, § 17 of the Rhode Island Constitution, the people shall continue to enjoy and freely exercise all the rights of fishery, and the privileges of the shore, to which they have been heretofore entitled under the charter and usages of this state, including but not limited to fishing from the shore, the gathering of seaweed, leaving the shore to swim in the sea and passage along the shore; and they shall be secure in their rights to use and enjoyment of the natural resources of the state with due regard for the preservation of their values; and it is the duty of the general assembly to provide for the conservation of the air, land, water, plant, animal, mineral and other natural resources of the state, and to adopt all means necessary and proper by law to protect the natural environment of the people of the state by providing adequate resource planning for the control and regulation of the use of the natural resources of the state and for the preservation, regeneration, and restoration of the natural environment of the state.*
>
> *46-23-1(a)(2) The general assembly recognizes and declares that the coastal resources of Rhode Island, a rich variety of natural, commercial, industrial, recreational, and aesthetic assets, are of*

> *immediate and potential value to the present and future development of this state; that unplanned or poorly planned development of this basic natural environment has already damaged or destroyed, or has the potential of damaging or destroying, the state's coastal resources, and has restricted the most efficient and beneficial utilization of these resources; that it shall be the policy of this state to preserve, protect, develop, and, where possible, restore the coastal resources of the state for this and succeeding generations through comprehensive and coordinated long range planning and management designed to produce the maximum benefit for society from these coastal resources; and that preservation and restoration of ecological systems shall be the primary guiding principle upon which environmental alteration of coastal resources will be measured, judged, and regulated.*
>
> *46-23-1 (b)(1) That effective implementation of these policies is essential to the social and economic well-being of the people of Rhode Island because the sea and its adjacent lands are major sources of food and public recreation, because these resources are used by and for industry, transportation, waste disposal, and other purposes, and because the demands made on these resources are increasing in number, magnitude, and complexity; and that these policies are necessary to protect the public health, safety, and general welfare. Pursuant to 16 U.S.C. § 1452 ("The Coastal Zone Management Act"), the General Assembly hereby directs the council (referred to as "CRMC") to exercise effectively its responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone.*
>
> *46-23-1 (b)(2) Furthermore, that implementation of these policies is necessary in order to secure the rights of the people of Rhode Island to the use and enjoyment of the natural resources of the state with due regard for the preservation of their values, and in order to allow the general assembly to fulfill its duty to provide for the conservation of the air, land, water, plant, animal, mineral, and other natural resources of the state, and to adopt all means necessary and proper by law to protect the natural environment of the people of the state by providing adequate resource planning for the control and regulation of the use of the natural resources of the state and for the preservation, regeneration, and restoration of the natural environment of the state.*

Section 46-23-6 states the **RI CRMC Powers and Duties** as:

> *The primary responsibility of the council shall be the continuing planning for and management of the resources of the state's coastal region. The council shall be able to make any studies of conditions, activities, or problems of the state's coastal region needed to carry out its responsibilities*

In the Rhode Island State Building Code (2012 Rhode Island General Laws, Title 23 - Health and Safety; Chapter 23-27.3 - State Building Code), Chapter 23-27.3-100.1.5.5 states **CRMC's role in hurricane, storm, and flood standards:**

> *23-27.3-100.1.5.5 Hurricane, storm, and flood standards. – The state building code standards committee has the authority in consultation with the building code commissioner, to adopt, maintain, amend, and repeal code provisions, which shall be reasonably consistent with recognized and accepted standards and codes, including for existing buildings, for storm and flood resistance. Such code provisions shall, to the extent reasonable and feasible, take into account climatic changes and potential climatic changes and sea level rise. Flood velocity zones may incorporate freeboard calculations adopted by the Coastal Resources Management Council pursuant to its power to formulate standards under the provisions of § 46-23-6.*

In addition to services provided to the state of Rhode Island by its CRMC, the **Resilient Rhode Island Act of 2014 established** the Rhode Island Climate Change Coordinating Council (EC4), and states in Section 42-6.2-2 (3), Purpose of the Council, duties shall include:

> *Advance the state's understanding of the effects of climate change including, but not limited to, sea level rise, coastal and shoreline changes, severe weather events, critical infrastructure vulnerability, and ecosystem, economic, and health impacts;*

And in the same Act, Section 42-6.2-8 states the powers and duties of state agencies, exercise of existing authority:

> *Consideration of the impacts of climate change shall be deemed to be within the powers and duties of all state departments. agencies, commissions, councils, and instrumentalities, including quasi-public agencies, and each shall be deemed to have and to exercise among its purposes in the exercise of its existing authority, the purposes set forth in this chapter pertaining to climate change mitigation, adaption, and resilience in so far as climate change affects the mission, duties, responsibilities, projects, or programs of the entity.*

To meet the challenges presented by sea level rise and coastal shoreline change, CRMC has been working to gather and monitor the best available science and data for use in effective decision making. Data provided by the U.S. National Oceanic and Atmospheric Administration (NOAA), points to accelerating sea levels globally and in the northeastern U.S. As sea levels rise, storm surge and the effects of coastal flooding and erosion are projected to impact areas farther inland. These processes will result in damage to more properties and infrastructure in Rhode Island coastal cities and towns, including those that have never before experienced flood damage.

The following sources have been consulted to ensure CRMC is using the best available data on sea level change, as well as a multitude of other studies and data:

- U.S. Army Corps of Engineers (USACE), Sea Level Change Curve Calculator (http://www.corpsclimate.us/ccaceslcurves.cfm). This web-based tool allows users to select a tide gauge of interest and view both USACE and NOAA historic rates of sea level change, and projections of sea level change by year in a table and graphically as a curve.

- University of Colorado (UC) Sea Level Research Group - (http://sealevel.colorado.edu/) The Group reports current satellite altimetry measurements of the rate of global sea level rise of 3.4 +/-0.4mm per year since 1993.
- Relative sea level rise in Rhode Island measured more than 4 millimeters per year between 1983 and 2009 (Carey et al. 2015).

In 2016, CRMC adopted an update to the **RI Coastal Resources Management Plan (RICRMP), Section 145, Policies, of the "Red Book"** that addresses these changes:

> *1. The Council will review its policies, plans and regulations to proactively plan for and adapt to climate change and sea level rise. The Council will integrate climate change and sea level rise scenarios into its programs to prepare Rhode Island for these new, evolving conditions and make our coastal areas more resilient.*
>
> *2. The Council's sea level rise policies are based upon the CRMC's legislative mandate to preserve, protect, and where possible, restore the coastal resources of the state through comprehensive and coordinated long-range planning.*
>
> *3. The Council recognizes that sea level rise is ongoing and its foremost concern is the accelerated rate of rise and the associated risks to Rhode Island coastal areas today and in the future. The Council recognizes that the lower the sea level rise estimate used, the greater the risk that policies and efforts to adapt sea level rise and climate change will prove to be inadequate. Therefore, the policies of the Council may take into account different risk tolerances for differing types of public and private coastal activities. In addition, the Council will regularly review new scientific evidence regarding sea level change.*
>
> *4. The Council relies upon the most recent NOAA sea level rise data to address both short- and long term planning horizons and the design life considerations for public and private infrastructure. The Council's policy is to adopt and use the sea level change scenarios published by NOAA in Technical Report OAR CPO-1 (Parris et al., 2012), and the sea level rise change curves for Newport and Providence as provided in the USACE sea level rise calculator. As of 2015 the range in sea level rise change is projected by NOAA to be a maximum of approximately 1.0 foot in 2035, 2.0 feet in 2050 and 7.0 feet in 2100. In addition, the Council adopts and recommends the use of the StormTools online mapping tool developed on behalf of the CRMC by the University of Rhode Island Ocean Engineering program to evaluate the flood extent and inundation from sea level rise and storm surge.*

The process described in this document is intended to provide applicants the information to assess the changing future conditions and allow applicants seeking coastal permits to plan for adaptation to those conditions. Throughout the permit application process, applicants are expected to consult specific requirements for various project types, which are detailed within the RI CRMP.[13]

Coastal Hazards described in this process will also trigger applicants seeking coastal permits to consider the following for their project site:

- Identify the level of exposure of proposed project site to Coastal Hazards including projected sea level rise scenarios, storm surge inundation, wave impacts, and erosion. Depending on the site boundaries, applicants will be expected to examine the potential for expansion of the floodplain within the Shoreline Change SAMP Planning Boundary.
- Applicants will be asked to consider site exposure to Coastal Hazards as well as exposure/impacts to the transportation system offering ingress and egress. For example, the project site may not be inundated by projected Coastal Hazards, but roads may be unpassable or access to infrastructure could be suspended.
- In cases of projects subject to review in RI CRMP Section 320, such as subdivisions, major commercial developments, and public infrastructure which are expected to have a long design life, applicants may want to conduct a pre-application meeting with CRMC to clarify which analyses are recommended for the proposed project.

As mentioned at the start of this Chapter, this document is intended to provide guidance and tools for state and local decision makers to prepare and plan for, absorb, recover from, and successfully adapt to the impacts of coastal storms, erosion, and sea level rise. Any regulatory changes resulting from this guidance document will be subject to the CRMC review and adoption process, and documented in Section 110 of the RI CRMP.

5.5 How does this process relate to other local, state and federal programs?

Currently, projects reviewed through the CRMC application process are examined for sea level rise as part of the hazards analysis, but to date projects have not been mandated to meet specific requirements to adapt to future conditions. The guidelines in this document offer direction and support for a thorough examination of Coastal Hazards and their associated impacts based on current climate science and coastal responses to changing sea levels over time. This information is

[13] The RI CRMP (Red Book) can be accessed online here: http://www.crmc.ri.gov/regulations/RICRMP.pdf

expected to assist in evaluating consequences of future change, thereby empowering the applicant to make an informed decision on the long term use and viability of their project.

While CRMC is offering this guidance, the Rhode Island State Building Code regulates construction in the state of Rhode Island. The mission and purpose of the State Building Commission is to, "…safeguard and establish minimum requirements necessary to protect public health, safety and welfare in the built environment. Model building codes provide for protection from fire, structure collapse and general deterioration."[14] While the Rhode Island State Building Code is the required source for regulations on any proposed construction project, the guidelines offered in this document for coastal permit applications are intended to assist applicants in making informed decisions based on future coastal conditions.

At the municipal level, state law mandates that local comprehensive plans consider the effects of sea level rise along with other natural hazards.[15] Such coordination between local comprehensive plans and CRMC adaptation policies, standards, and the coastal permit process will help ensure that coastal development and resources are resilient over time.

The National Flood Insurance Program (NFIP), managed by the U.S. Federal Emergency Management Agency (FEMA), and locally by the Rhode Island Emergency Management Agency (RIEMA), identifies properties at risk from coastal and riverine flooding based on past storm events. In addition, structures that are built within FEMA designated floodplains are regulated by the Rhode Island State Building Code.

The process described in this document differs from the FEMA floodplain analysis in that it requires the applicant to consider future risk from coastal hazards. From this assessment, the applicant will have an opportunity to address future conditions that might include setbacks, elevation, or fortification to reduce the exposure of the development to coastal hazards, possibly resulting in reduced flood insurance premiums for some developments. In addition, this process offers applicants an opportunity to consider "code-plus" techniques, such as the Insurance Institute for Business and Home Safety's (IBHS) FORTIFIED™ program[16], which can serve to increase the ability of the development to withstand storm impacts beyond minimum requirements outlined in the Rhode Island State Building Code.

[14] State of Rhode Island, Building Code Commission, http://www.ribcc.ri.gov/
[15] RIGL 45-22.2-2 (a) and RIGL 45-22.2-6 (b) (10)
[16] Insurance Institute for Business and Home Safety, FORTIFIED program, https://disastersafety.org/fortified/

While the result of the analysis outlined in this document may encourage an applicant to elevate or otherwise floodproof/stormproof their proposed project, thereby resulting in a positive change in homeowners or flood insurance premiums, the process outlined in this document is independent from the National Flood Insurance Program.

5.6 Which projects are expected to follow this process?

The process described below will be used for: new development projects, substantially improved development projects; and all projects which:

- Require Council Assent based on the Guidelines for Applicants in the introduction of the RI CRMP; and
- Are defined in Section 110 of the RI CRMP.

5.7 What are the roles of the Applicant and CRMC?

This document and the process described herein are intended to ensure the applicant and CRMC are using the same information and data sources to:

- Evaluate the current site conditions for a project and assist in evaluating the possible future conditions; and
- Clearly articulate the level of coastal risk the applicant is willing to accept during and after construction of their project.

The applicant is expected to follow the 5-step process outlined earlier in this Chapter. The applicant will pay particular attention to the "Projected Outcomes" identified within each Step, and document the outcomes in their application to CRMC.

CRMC will use the process outlined in this document to assess exposure and potential impacts to coastal developments based on identified Coastal Hazards. It is expected that the resulting application and Council Assent will acknowledge the results of this assessment and include this information in the formal documentation issued with the permit, regardless if the applicant has chosen to use the outcomes identified from the process in the design of the project.

Definitions used in this document:

Shoreline Change SAMP Planning Boundary	Includes the land area within each of the 21 Rhode Island coastal communities projected to be inundated by a 100-year return period (1% annual chance) storm event plus seven feet of sea level rise as illustrated in STORMTOOLS (www.beachsamp.org/stormtools).
Coastal Resilience	*Coastal resilience means building the ability of a community to "bounce back" after hazardous events such as hurricanes, coastal storms, and flooding – rather than simply reacting to impacts.* Source: NOAA, National Ocean Service, Office for Coastal Management
Coastal Hazards	Projections for sea level rise, storm surge, wave action, coastal erosion, and their cumulative impacts (e.g. storm surge with sea level rise).
Critical Infrastructure	*There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof. Those sectors include: chemical; commercial facilities; communications; critical manufacturing; dams; defense industrial base; emergency services; energy; financial services; food and agriculture; government facilities; healthcare and public health; information technology; nuclear reactors, materials and waste; transportation systems; and, water and wastewater systems.* Source: U.S. Department of Homeland Security, Critical Infrastructure Sectors
Ingress/Egress	The area around the proposed development where state and local roadways provide vehicular and other access to a property.
Return Period	Also referred to as "Recurrence Interval," this term indicates the probability of water levels resulting from storm events of different intensities.
RI Coastal Resources Management Program (RI CRMP, a.k.a. "Red Book")	The RI CRMP is the regulatory document that guides coastal decision making and permitting in Rhode Island: *Pursuant to 16 U.S.C. § 1452 ("The Coastal Zone Management Act"), the General Assembly hereby directs the council (referred to as "CRMC") to exercise effectively its responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the*

	land and water resources of the coastal zone.
STORMTOOLS	STORMTOOLS is a web-based map viewer that allows the Rhode Island user to access high resolution maps that illustrates coastal risk at a parcel level.

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CHAPTER 6

State and Municipal Considerations

Table of Contents

6.1 Overview

6.1.1 Chapter Objectives

1. This chapter outlines how CRMC's Coastal Hazard Application Guidance might be applied to other Rhode Island state agencies or to municipal governments. With the development of the CRMC Coastal Hazard Application Guidance, CRMC is actively amending its program to be forward-thinking about coastal resilience and adaptation to coastal risk, and is one of the first coastal regulatory programs in the U.S. to put forward permit requirements that address future risk from storm surge, coastal erosion, and projected sea level rise. CRMC hopes this process will be a model to other state agencies and municipal governments, and programs can be adapted and evolve accordingly.

2. The Shoreline Change SAMP Planning Boundary includes land area exposed to water levels from a modeled 100-year return period storm, similar to 1954's Hurricane Carol, plus seven-feet of sea level rise. Accordingly, the Shoreline Change SAMP Boundary extends inland beyond CRMC's jurisdiction, demonstrating that there is a substantial amount of land area at risk from coastal hazards but outside of CRMCs jurisdiction, and likely outside of currently-mapped FEMA Special Flood Hazard Areas.

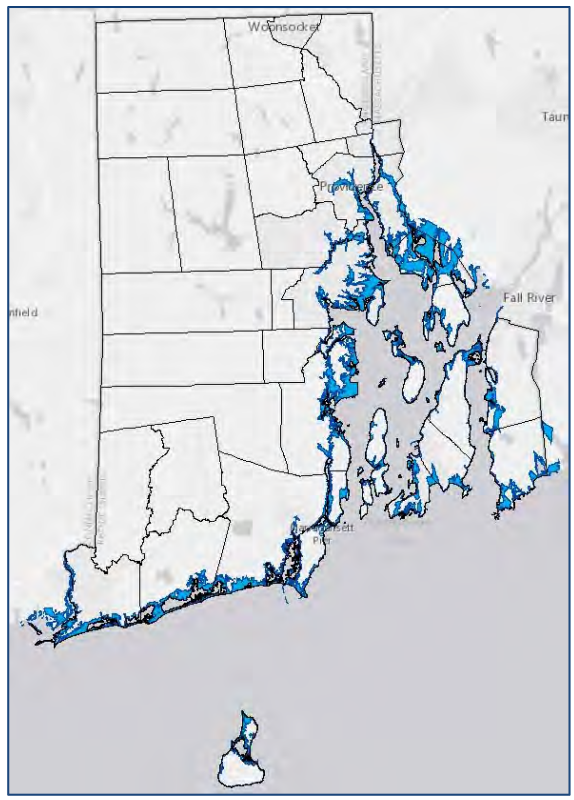

Figure 1. Shoreline Change SAMP Planning Boundary

3. CRMC has set the stage for risk assessment process in providing STORMTOOLS to each of the 21 municipalities along Rhode Island's coastline. Through development of STORMTOOLS, offering high resolution scenario-based coastal inundation mapping, Rhode Island has provided the ability to assess risk at the individual structure and parcel level for all properties along the coast and within the Shoreline Change SAMP Project Boundary.

4. State agencies embarking on state or regionally significant projects will benefit from a process by which they evaluate future conditions to ensure public dollars are spent wisely. Municipal decision makers, including elected officials, staff, and board/commission members, will be making decisions on future use of land within the Shoreline Change SAMP Planning Boundary, and must be aware of current and future risks of flooding across properties along the coast that may not be adequately represented in current flood risk maps.

5. Enacting CRMC's Coastal Hazard Application Guidance serves to educate municipal staff and decision makers, and especially coastal property owners who are considering the long-term viability of their coastal dwelling or development. CRMC's adoption of the five-step application process outlined in Chapter 5 serves as a model for municipalities and could offer the cities and towns protection from development challenges if they choose to follow the state's lead in communicating and assessing coastal risks in their community.

6. As of 2017, municipal board and commission members are required to receive two-hours of training every two years on, "…the effects of development in a flood plain and the effects of sea-level rise…" per RI General Laws 45-22-7. There are several sources of trainings available, but in 2017 Rhode Island launched a series of video training modules called PREP-RI, Providing Resilience Education for Planning in Rhode Island (http://prep-ri.seagrant.gso.uri.edu/), that are targeted to municipal volunteer board and commission members. These video modules cover the following topics: Climate Change in Rhode Island, Infrastructure, Stormwater, Flooding, Mapping Tools, and Adaptation.

6.2 Projects of State or Regional Significance

1. CRMC is providing forward-thinking guidance and related regulations, as well as decision support tools to guide responsible development in the coastal zone that addresses current risk from hazards, and anticipates future risk from storms, coastal erosion, and sea level rise. CRMC's Coastal Hazard Application Guidance outlined in Chapter 5 is well-suited for evaluating the risk profile of state-sponsored projects in coastal high risk areas. To ensure that federal, state, and other public funds are applied to projects in a manner that minimizes long-term losses and reflects the intended design life of the project, project coordination among federal and state agencies is strongly encouraged. Coordination and review of site risk from coastal hazards early in the project planning process has shown to be an effective strategy to ensure all relevant considerations are discussed up front, thus preventing delays due to redesign of projects in later stages of a project's schedule.

2. Throughout the Shoreline Change SAMP effort, CRMC staff consulted on large-infrastructure projects, including transportation and wastewater management, and used STORMTOOLS to illustrate and inform project planning and engineering teams on the coastal forces that are projected to impact the project today and in the future. Because FEMA maps do not adequately illustrate risk from current and future conditions, specifically pertaining to sea level rise, CRMC encourages other state agencies to use STORMTOOLS and the SDE maps for planning and design purposes.

3. CRMC expects to continue the service of bringing the best available coastal risk and hazard information to other state agencies to consult on infrastructure projects in both the current CRMC jurisdiction, and also in the Shoreline Change SAMP planning boundary representing a 100-year return period storm plus 7-feet of sea level rise. Long-term funds for maintenance and management of STORMTOOLS are being sought to ensure this invaluable mapping tool, specific to the state of Rhode Island's 420-miles of coastline, will be available for state agencies and municipalities in the future for project planning and evaluation.

4. For state agencies considering projects in the coastal zone, both currently within CRMC's jurisdiction from the inland edge of the coastal feature, and for projects that lie within the Shoreline Change SAMP boundary (as illustrated in STORMTOOLS' 100-year return period storm plus 7-feet of sea level rise layer), a Pre-Application coordination meeting early in the project planning process with CRMC is required within its jurisdiction. For projects outside of CRMC's jurisdiction, but within the Shoreline Change SAMP project boundary, the state agency leading the project is encouraged to

include both the municipality and CRMC staff in early stages of project planning. As an example, considering that resiliency to the impacts of climate change is stated as a "Cost Effectiveness" principle driving the State Transportation Improvement Program[1], and this program is likely to include projects within CRMC's jurisdiction, a coordination meeting with CRMC could help RI Statewide Planning Program staff with site evaluation and selection for projects proposed within the Shoreline Change SAMP Planning Boundary. In addition, the RI Department of Transportation (RIDOT) is encouraged to address shoreline risk in the assessment of projects considered for inclusion in the State Transportation Improvement Program. They could assign specific point criteria for projects that remove risk from direct impact of sea level rise and associated storm surges. In the alternative, the RIDOT could establish a new category of projects entitled: "Coastal Resiliency Projects". This category would separate out those projects in need of action in the 10 year STIP timeframe to eliminate risk of impact from sea-level rise and storm-surge damage. It would target projects for funding based on the immediacy of the need.

5. In the case of post-storm response and recovery, Section 1.1.14 (Formerly Section 180) of the RICRMP details the procedures for securing Emergency Assents and post-storm permits from CRMC. This section emphasizes the importance of state agencies and municipalities having emergency permitting procedures in place to, "speed appropriate reconstruction and minimize adverse economic and environmental impacts." (RICRMP 1.1.14.C.2). Procedures for enacting a post-storm moratorium to allow for adequate assessment of damage and potential for rebuilding are outlined, as are a strategy for prioritizing, "…emergency alterations, reconstruction, or replacement of essential public facilities, such as roads, bridges, and public utilities." (RICRMP 1.1.14.C.4).
6. Communities have expressed concern over the long-term resilience of state and local roads shown to be at risk from coastal hazards, and the ability to fund implementation actions and construction projects.

6.3 Municipal Application of RI CRMC Coastal Hazard Application Guidance

1. RI CRMC's Coastal Hazard Application Guidance outlined in Chapter 5 of this Shoreline Change SAMP provides a model process that municipalities can voluntarily apply to

[1] RI Statewide Planning Program. 2015. "An Overview of TIP Guiding Principles: Federal Fiscal Years 2017-2025." http://www.planning.ri.gov/planning-areas/transportation/tip.php

projects within the flood envelope of the Shoreline Change SAMP Project Boundary, but outside of CRMC's current jurisdiction.

2. Currently at the municipal level, for land outside of the FEMA-defined Special Flood Hazard Area (SFHA), there are no flood-related regulations that exist to guide development for land projected to be inundated as a result of future sea level rise. Outside of CRMC's jurisdiction, the municipality has jurisdiction for land development within the Shoreline Change SAMP Boundary. By using STORMTOOLS, municipalities can apply the best available mapping tools provided by the state of Rhode Island, and apply these tools to advise applicants as to whether proposed developments are designed to adequately address future risk, thus overcoming the identified limitations of the existing FEMA Flood Insurance Rate Maps (FIRMS).

3. In order for municipalities to implement the five-step CRMC Coastal Hazard Application Guidance, and follow the state's lead in evaluating coastal development projects for their exposure to coastal risks, adequate staffing and changes to local site plan application procedures will be needed. Considering that CRMC's five-step Coastal Hazard Application Guidance process for development proposals may not be immediately adopted by municipalities, municipalities have suggested expanding CRMC's jurisdiction within the full expanse of the Shoreline Change SAMP Boundary. At this time, however, CRMC does not have the statutory authority, nor additional resources to address all future development applications that may be put forward in the Shoreline Change SAMP Project Boundary.

4. Depending on municipal staff availability and support from local elected officials and boards/commissions, municipalities could refer applicants to the mapping tools offered by CRMC, and encourage voluntary use of the 5-step process outlined in Chapter 5 of this document. As an example, municipalities could require submittal or reference to this material as part of the application process. CRMC's 5-step Coastal Hazard Application Guidance process, and related mapping tools, are designed to be user-friendly to multiple audiences and are intended to educate applicants on the risk profile for the development, potentially reducing risk from coastal hazards and in turn, flood insurance premiums, over the near and long term.

5. Strategies that municipalities may consider as short-term demonstration or pilot projects to replicate CRMC's 5-step Coastal Hazard Application Guidance process at the local level might include:

    a. Establish thresholds for types of development that are subject to this process, and apply the CRMC risk assessment process only to projects that meet specific criteria. For example, municipalities could test this process on projects that are triggered by existing stormwater management regulations, or on larger-scale projects with a specified minimum building footprint or that propose to add fill or materials in excess of a defined area or volume.

b. Hold advisory pre-application site plan meetings with property owners and developers to share CRMC's risk assessment tools. Advise applicants during this meeting to identify design life of their proposed development, identify a date that relates to future conditions, and consider the relationship of their proposed development with future flood and erosion scenarios. Discuss with applicants the uncertainty of future conditions, including flood insurance premiums, in order to relay that a decrease in the risk profile for a property will likely result in a decrease in long-term flood insurance premiums. Municipal staffers can make CRMC's risk assessment tools and resources available to applicants, without requiring they be used.

c. Consider incentives for applicants who voluntarily follow the CRMC Coastal Hazard Application Guidance process and submit those findings to the town for building permits outside of CRMC's jurisdiction. Examples of incentives could include decreased application fees or expedited review or permitting for projects that apply CRMC's five-step Coastal Hazard Application Guidance.

6. For significant infrastructure or transportation projects that fall within the Shoreline Change SAMP Boundary but lie outside of CRMC's jurisdiction, municipalities are encouraged to use the risk assessment tools (STORMTOOLS or CERI, as available), to evaluate future conditions for these projects and coordinate with CRMC and other relevant agencies to enact a procedure to review project alternatives. For example, if a road project submitted for funding under the State Transportation Improvement Program (STIP) identifies a road for resurfacing, but the area is showing exposure or long-term impact from current or future coastal hazards, planners from the municipality and the Statewide Planning Program are encouraged to reconsider investment in that project until a more thorough analysis is completed to consider the long-term cost/benefits of improving or enhancing that roadway.

7. Municipalities must decide how they want to offer CRMC's voluntary design elevation levels to educate and inform permit seekers of future coastal hazard risk. Considering the inaccuracy of existing FEMA maps for Rhode Island, and the uncertainty of how FEMA will handle these changes in the future, the STORMTOOLS Design Elevation (SDE) maps described in Chapters 3 and 5 will assist municipalities in evaluating the future risk

profile in coastal areas under varying sea level and storm scenarios with a 95% confidence level that the flood water will not exceed that depth during defined storm scenarios. Because the FEMA-defined “special flood hazard area” and related V and A zones are expected to shift inland as conditions change into the future, CRMC is also mapping where potential V and A zones could be as a result of changing coastal conditions and related hazards. Surge and wave will be higher in these zones. These forces act higher on the structure, increasing damage potential.

8. Additionally, municipalities are encouraged to use CRMC’s maps and data to evaluate the assessed value of coastal structures at risk and the potential threat to tax base and municipal finance. For future municipal financial stability, it is important to consider and develop decision support strategies related to uncertainty with the long-term market value of homes in high hazard areas, and resulting implications on municipal tax base. Moody’s Investors Service is currently considering future risk conditions attributed to climate change when determining municipal bond ratings.[2]

6.4 Addressing Coastal Risk in Municipal Planning Initiatives

1. Municipal governments are responsible for defining a future vision for the growth and management of land uses, and for documenting strategies for addressing local hazards to protect public health, safety and welfare. Two municipal tools that guide local planning and emergency management are the Comprehensive Plan and the Hazard Mitigation Plan.

2. A local Comprehensive Plan is 20-year “blueprint” for a municipality that defines aspirations for growth and strategies for implementing projects that support the vision outlined in the plan.[3] In the 2012 update to Rhode Island’s Comprehensive Planning and Land Use Act, section § 45-22.2-6(10) added a requirement for Comprehensive Plans to address natural hazards, including, “…the effects of sea-level rise, flooding, storm damage, drought, or other natural hazards.” Local Comprehensive Plans are prepared by each municipality in coordination with the state’s Division of Planning/Statewide Planning Program.

[2] Moody’s Investors Service. 2017. "*Environmental Risks -- Evaluating the impact of climate change on US state and local issuers*." https://www.moodys.com/research/Moodys-Climate-change-is-forecast-to-heighten-US-exposure-to--PR_376056
[3] RI Statewide Planning Program. 2015. *Comprehensive Planning Guidance Handbook #1: The Comprehensive Plan 101*. http://www.planning.ri.gov/documents/comp_handbook/1_CompPlan101.pdf

3. The 2014 Rhode Island State Hazard Mitigation Plan states its vision as, "Rhode Island is resilient to natural hazards and climate change.",[4] and states as one of its goals, "Local communities address natural hazards and long-term risk reduction in local decision making and planning." Local hazard mitigation plans are prepared by each municipality in coordination with the Rhode Island Emergency Management Agency.

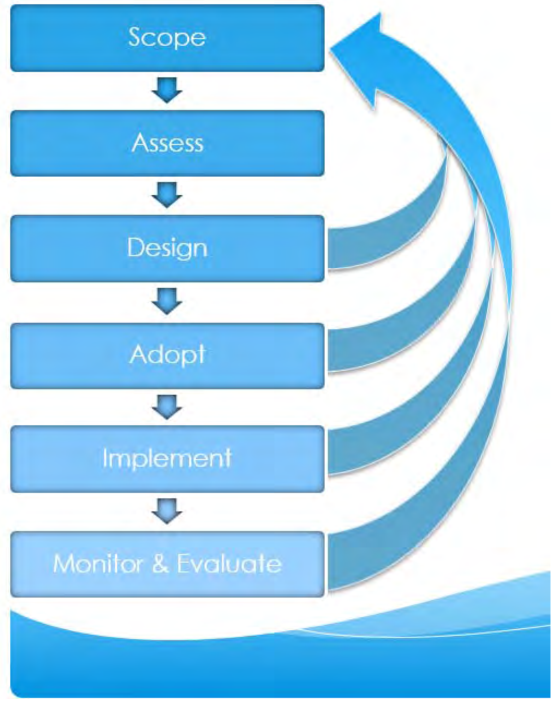

Figure 2. Model process for Community Resilience.

6.4.1 Model Process for Coastal Risk Assessment and Local Comprehensive Plans

1. In 2014, the RI Statewide Planning Program worked with the University of Rhode Island's Coastal Resources Center to develop a pilot project for the town of North Kingstown focused on adaptation to future sea level rise conditions.[5] This document analyzed parcels within 12 sub-areas of the town within a one, three, and five-foot sea level rise scenario, and went on to identify adaptation strategies for 18 different sectors of the town that corresponded to different sections of the Comprehensive Plan. This pilot project formed the basis of a statewide "model process" for coastal risk assessment that other coastal communities in Rhode Island could follow to address the "Natural Hazards" requirement in their Comprehensive Plan.

2. In 2015, RI Statewide Planning and the URI Coastal Resources Center produced, "*Resilient Communities: Natural Hazards & Climate Change Adaptation, a how-to guide on incorporating natural hazards planning and climate change adaptation into local comprehensive plans*." [6] This "model process" document outlined the base information

[4] RI Emergency Management Agency. 2014. *Rhode Island Hazard Mitigation Plan Update.* http://www.riema.ri.gov/resources/emergencymanager/mitigation/documents/RI%20HMP_2014_FINAL.pdf
5 Crean, T., M. Carnevale, P. Rubinoff. 2014. Adaptation to Natural Hazards and Climate Change in North Kingstown, RI. Narragansett, RI. http://rhody.crc.uri.edu/accnk/sample-page/

[6] Crean, T., Carnevale, M. and Rubinoff, P. 2015. Resilient Communities: Natural Hazards & Climate Change Adaptation, a how-to guide on incorporating natural hazards planning and climate change adaptation into local

that communities could use to meet the requirement of the 2012 Comprehensive Plan Act update requiring Rhode Island municipalities to include natural hazards and climate change into municipal comprehensive plans.

3. Upon completion of the North Kingstown pilot project and the release of the "model process" document described above, RI Statewide Planning then compiled this information with other data and process offered by the RI Emergency Management Agency to produce, "The Rhode Island Comprehensive Planning Standards, Guidance Handbook #12, Planning for Natural Hazards and Climate Change." This guidance document has been in place since 2016 and is an invaluable resource being used by Rhode Island cities and towns to meet the Natural Hazards requirement of the 2012 Comprehensive Plan Act update. The handbook offers all 39 Rhode Island cities and towns a step-by-step process to consider relevant hazards, exposed and vulnerable resources, assets, populations, a one-stop menu of adaptation strategies that can be applied to their municipality, a strategy to develop priorities for implementation.

4. Since a local Comprehensive Community Plan serves as a 20-year blueprint for a municipality, it is important to consider that, as mentioned throughout this Shoreline Change SAMP document, the science is rapidly changing and the conditions along Rhode Island coast are also rapidly changing. As discussed in Section 6.3 of this chapter, municipalities are encouraged to coordinate closely with CRMC to ensure the best available science and updated tools are being applied to evaluate existing and future risk from coastal hazards. Municipalities also have an opportunity to apply a natural hazards and climate change "lens" to all the elements of a Comprehensive Plan, and consider where the exposed and vulnerable assets valued by the municipality can be protected in the face of future coastal flood risk.

5. Considering that the RI Statewide Planning Comprehensive Plan Guidebook is not being continually updated, municipalities are encouraged to refer to CRMC for the most current data and trends related to shoreline change and coastal hazards in Rhode Island. See Chapter 2 of this Shoreline Change SAMP for more information.

6. Local Comprehensive Community Plans are encouraged to reference the Shoreline Change SAMP process and tools, include a map of the SAMP planning boundary, and recommend that development plans are reviewed based on the CRMC Coastal Hazard Application Guidance.

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comprehensive plans. University of Rhode Island Coastal Resources Center and Rhode Island Sea Grant College Program, Narragansett, RI. http://www.beachsamp.org/relatedprojects/

6.4.2 Local Hazard Mitigation Plans & Community Rating System

1. In order to receive FEMA grant funds per the Disaster Mitigation Act of 2000, municipalities must have an approved local Hazard Mitigation Plan (HMP). HMP's are written as a 5-year plan that set out policies and actions to prepare for and reduce risk and losses from natural hazards. The HMPs are guided, in part, by a Statewide Hazard Mitigation Plan that is managed and administered by the Rhode Island Emergency Management Agency (RIEMA). RIEMA assists Rhode Island municipalities with development of the local HMPs by offering report templates, funds, and technical assistance to municipalities by the State Hazard Mitigation Officer (SHMO).

2. The Community Rating System (CRS) program is a voluntary effort administered by FEMA/RIEMA that allows municipalities to offer flood insurance premium reductions across their city or town upon documentation of the municipality meeting or exceeding targets for floodplain management and risk reduction. CRS ratings range from a score of "1" to "9," and correspond to savings on flood insurance premiums in increments of five percent. For example, a community with a CRS rating of "9" is the first level in the CRS and allows a 5% reduction in flood insurance premiums for all flood insurance policy holders in that municipality, while a CRS rating of "7" means a community has met even more targets to reduce risk and manage floodplains across the municipality, resulting in a 15% reduction in flood insurance premiums for all policy holders.

3. STORMTOOLS, the Coastal Environmental Risk Index (CERI), and the STORMTOOLS Design Elevation (SDE) maps offer methods to document both current and future risk from coastal hazards in the LHMP and CRS programs. Integrating the Shoreline Change SAMP tools into these RIEMA–managed programs can ultimately offer financial benefits that are passed on to taxpayers through grant programs and savings on flood insurance premiums, and tangible implementation actions across the community that protects public health, safety, and welfare by reducing the overall risk profile and threat of losses from coastal hazards.

6.5 Relationship of State Law to CRMC's Coastal Hazard Application Process and Municipal Implementation

1. Rhode Island's cities and towns have authority over several aspects of building and land development in the coastal area that are granted to them by the RI Legislature through enabling legislation. Because of the statewide application of this enabling legislation, the authority to regulate development extends beyond CRMC's jurisdiction but within the Shoreline Change SAMP Boundary (land area inland of CRMC's legal jurisdiction). This presents an opportunity for coastal communities to implement the CRMC's five step Coastal Hazard Application Guidance as a means to educate property owners.

2. Because the enabling legislation described below does apply on a statewide basis, many of the recommendations that are intended to address resiliency and climate change preparedness can be applied outside of the SAMP Boundary and to inland areas of Rhode Island as well, which have their own unique challenges related to changing weather patterns.

3. Considering the CRMC five-step Coastal Hazard Application Guidance, as outlined in Chapter 5, may not be immediately adopted by the municipalities, suggestions of expanding CRMC's jurisdiction to educate property owners within the full expanse of the Shoreline Change SAMP Boundary may be considered desirable by local officials. As mentioned in Section 6.3.4, CRMC does not currently have the statutory authority, nor additional resources to address all future development applications that may be put forward within the Shoreline Change SAMP Project Boundary.

6.5.1 State Building Code, Rhode Island General Laws 23-27.3

1. Municipalities cannot require applicants to build to standards that exceed the State Building Code, but can recommend or suggest voluntary strategies that are allowable but not mandated by the State Building Code. As described in Chapter 3, the Building Code Commission's purpose is to establish minimum building code requirements for the protection of public health, safety, and welfare in the built environment. Building code requirements address coastal hazards in numerous ways; for example, the RI State Building Code incorporates the vast majority of the NFIP floodplain management requirements. Towns in turn use the design standards set by the state building code. For further information please see http://www.ribcc.ri.gov/.

2. As mentioned in Chapter 5, Section 23-27.3-100.1.5.5 of the RI State Building Code defines hurricane, storm, and flood standards:

   The state building code standards committee has the authority in consultation with the building code commissioner, to adopt, maintain, amend, and repeal code provisions, which shall be reasonably consistent with recognized and accepted standards and codes, including for existing buildings, for storm and flood resistance. Such code provisions shall, to the extent reasonable and feasible, take into account climatic changes and potential climatic changes and sea level rise. Flood velocity zones may incorporate freeboard calculations adopted by the Coastal Resources Management Council pursuant to its power to formulate standards under the provisions of § 46-23-6.

3. The RI State Building Code lays out requirements for construction of different categories of structures, and outlines details of load requirements to withstand high winds and flooding; lowest floor elevation requirements, including basements; and design parameters to address hydrostatic flood forces in accordance with standards defined by the American Society of Civil Engineers (ASCE). For example, for One and Two Family Dwellings, the RI State Building Code section R322.3.6.1 addresses Flood Hazard Certificates. Certifications for construction in flood hazard areas both with and without high-velocity wave action are defined in the code, and are required to be submitted to municipal building officials.

4. The RI Building Code Commission is the only authority who can change or increase the resiliency requirements of the State Building Code. Municipalities can only encourage or incentivize voluntary actions that surpass the requirements of the building code. Examples could include increased freeboard or application of the FORTIFIED standard, both of which are discussed in more detail in Chapter 7.

6.5.2 Rhode Island Comprehensive Planning and Land Use Act 45-22.2

1. Section § 45-22.2-3 of the Rhode Island General Laws outlines the Comprehensive Planning and Land Use Act that guides municipalities in developing a Comprehensive Community Plan to serve as the 20-year "blueprint" for the municipality as a whole, and serves as the guiding document to which all zoning changes must be consistent.

2. Section 45-22.2-6 outlines the required content of a comprehensive plan, which includes maps illustrating existing conditions, land use, housing density, zoning, roads, water and sewer service areas, cultural resources, open space, and natural resources, including floodplains. The Comprehensive Plan's featured map illustrates "future land use" and indicates where the municipality envisions its growth and change over the course of the 20-year planning horizon of the plan.

3. In 2012, the Comprehensive Planning and Land Use Act was updated to require that Rhode Island cities and towns address "Natural Hazards" in their municipal Comprehensive Plans. Section 45-22.2-6(b)(10) lists this requirement as:

   Natural hazards. The plan must include an identification of areas that could be vulnerable to the effects of sea-level rise, flooding, storm damage, drought, or other natural hazards. Goals, policies, and implementation techniques must be identified that would help to avoid or minimize the effects that natural hazards pose to lives, infrastructure, and property.

4. Section 45-22.2-4. defines "Floodplains" or "flood hazard area" as:

   …an area that is subject to a flood from a storm having a one percent (1%) chance of being equaled or exceeded in any given year, as delineated on a community's flood hazard map as approved by the federal emergency management agency pursuant to the National Flood Insurance Act of 1968, as amended (P.L. 90-448), 42 U.S.C. § 4011 et seq.

5. As outlined in this Shoreline Change SAMP, the FEMA floodplain maps for Rhode Island, while still regulatory for purposes of determining flood insurance premiums for policy holders, have been determined to be inaccurate and not appropriate for projecting

future risk along the Rhode Island coast. For this reason, as mentioned in Chapter 5, CRMC has developed STORMTOOLS Design Elevation (SDE) maps to illustrate future risk to coastal developments and offer a recommended design elevation for use in design and construction.

6. Considering that stated goals of comprehensive plans in Section 45-22.2 include promotion of suitability of land for use that protects public health 45-22.2-6(c)(1), and encourages use of innovative development regulations that promote suitable land development while protecting valued resources, 45-22.2-6(c)(6), evaluating long-term coastal risk and the exposure of valued resources in the coastal zone is necessary to meet these goals. Through this Shoreline Change SAMP, and the associated mapping tools offered through STORMTOOLS, the Coastal Environmental Risk Index (CERI) (where available), and the SDE maps, local comprehensive plans are now able to appropriately document this risk and indicate through the Future Land Use Map how the municipality might adjust land use patterns within the Shoreline Change SAMP Planning Boundary.

6.5.3 Zoning Ordinances, Rhode Island General Laws 45-24

1. The Rhode Island Zoning Enabling Act of 1991 requires that zoning ordinances for each municipality be consistent with the adopted Comprehensive Community Plan (see 6.2.2). Zoning ordinances are regulatory and define current and future community needs, enforce standards and procedures for management and protection of natural resources, emphasize current concepts that address emerging demand for land use, and consider economic impacts of proposed changes. (RIGL §45-24-29)

2. The general purposes of zoning ordinances stated § 45-24-30(a) that are relevant to the Shoreline Change SAMP and present opportunities for municipalities to expand CRMC's Coastal Hazard Application Guidance to municipal jurisdiction beyond CRMC's jurisdiction include:

   *(1) Promoting the **public health, safety, and general welfare**.*

   *(2) Providing for a range of uses and intensities of use appropriate to the character of the city or town and reflecting current and **expected future needs**.*

   (3) Providing for orderly growth and development that recognizes:

   *(i) The goals and patterns of land use contained in the **comprehensive plan** of the city or town adopted pursuant to chapter 22.2 of this title;*

   *(ii) The **natural characteristics of the land**, including its suitability for use based on soil characteristics, topography, and susceptibility to surface or groundwater pollution;*

*(iii) The **values and dynamic nature of coastal and freshwater ponds, the shoreline, and freshwater and coastal wetlands;***

*(iv) The **values of unique or valuable natural resources and features**;*

*(v) The availability and capacity of **existing and planned public and/or private services and facilities;***

*(vi) The need to **shape and balance urban and rural development**; and*

*(vii) The use of **innovative development regulations and techniques**.*

*(4) Providing for the **control, protection, and/or abatement of air, water, groundwater, and noise pollution, and soil erosion and sedimentation.***

*(5) Providing for the **protection of the natural, historic, cultural, and scenic character** of the city or town or areas in the municipality.*

*(6) Providing for the **protection of public investment** in transportation, water, stormwater management systems, sewage treatment and disposal, solid waste treatment and disposal, schools, recreation, public facilities, open space, and other public requirements.*

*(7) Promoting **safety from fire, flood, and other natural or unnatural disasters**.*

*(8) Providing for **procedures for the administration of the zoning ordinance**, including, but not limited to, variances, special-use permits, and, where adopted, procedures for modifications.*

3. Considering the purposes listed above, coupled with direct input from municipal planning officials throughout the Shoreline Change SAMP process, amending the purposes of zoning to include resiliency provisions that reflect the best available science related to climate change, storm surge, coastal erosion, sea level rise is encouraged to increase overall resiliency of Rhode Island's coastal communities.

4. As an example, in 2017, Section 45-24-31 of the Zoning Enabling Act was amended to allow for additional freeboard and height allowances for properties elevating to reduce their flood risk in coastal high hazard areas.

   For a vacant parcel of land, building height shall be measured from the average existing grade elevation where the foundation of the structure is proposed. For an existing structure, building height shall be measured from average grade taken from the outermost four (4) corners of the existing foundation. In all cases, building height shall be measured to the top of the highest point of the existing or proposed roof or structure. This distance shall exclude spires, chimneys, flag poles, and the like. For any property or structure located in a Special flood hazard area, as shown on the official FEMA Flood

Insurance Rate LC004786/SUB A/2 - Page 3 of 10 1 Maps (FIRMs), where freeboard as defined in this section, is being utilized or proposed, such 2 freeboard area, not to exceed five feet (5'), shall be excluded from the building height calculation.

5. As mentioned in 6.2.3.4 above, CRMC is currently developing STORMTOOOLS Design Elevations (SDEs) that will offer a recommended base flood elevation to account for sea level rise when comparing with the base flood elevation in the FEMA FIRMs. Municipalities have the option of sharing the SDEs with property owners as developers submit plans to the cities and towns for review outside of CRMC's jurisdiction. Section § 45-24-47(c) of the Zoning Enabling Act outlines special provisions for land development projects that may be amended to reflect: (1) "future conditions" as a special provision for land development projects, thus reflecting new data and information available to increase coastal resilience, (2) the guiding principles of the Shoreline Change SAMP, including a requirement to document the SDE in development applications, and (3) relevant resiliency measures to be consistent with the adopted local Comprehensive Plan.

6.5.4 Subdivision of Land, Rhode Island General Laws 45-23

1. The Rhode Island Land Development and Subdivision Review Enabling Act of 1992 requires that all municipalities: (a) adopt land development and subdivision review regulations; and (b) establish the standard review procedures for local land development and subdivision review and approval that are thorough, orderly, and lead to expeditious processing of development project applications. (§ 45-23-26.)

2. The following five bullets in Section 45-23-29, "Legislative findings and intent", illustrate potential to implement the Shoreline Change SAMP by requiring documentation of future risk consistently among several municipal planning tools to assist municipalities in addressing future risk from coastal hazards:

   (1) That the land development and subdivision enabling authority contained in this chapter provide all cities and towns with the ability to adequately address the ***present and future needs*** *of the communities;*

   (2) That the land development and subdivision enabling authority contained in this chapter require each city and town to develop land development and subdivision regulations ***in accordance with the community comprehensive plan, capital improvement plan, and zoning ordinance*** *and to ensure the consistency of all local development regulations;*

*(3) That **certain local procedures** for review and approval of land development and subdivision **are the same** in every city and town;*

*(4) That the local procedure for **integrating the approvals of state regulatory agencies** into the local review and approval process for land development and subdivision is the same in every city and town; and*

*(5) That all proposed land developments and subdivisions are **reviewed by local officials**, following a standard process, prior to recording in local land evidence records.*

3. For properties that sit outside of CRMC's jurisdiction, municipalities can utilize STORMTOOLS to educate property owners on flood risk for proposed developments on one parcel, or for proposals that recommend subdivision of land into two or more lots. Chapter 3, Section 3.2.3.4 also explains that CRMC has developed STORMTOOOLS Design Elevations (SDEs) that will offer a recommended base flood elevation to account for sea level rise when comparing with the base flood elevation in the FEMA FIRMs. Municipalities have the option of sharing the SDEs with property owners as developers submit plans to the cities and towns for review. The municipalities can consider several approaches to share the coastal risk profile of a particular development with applicants proposing development outside of CRMC's jurisdiction:

    a. Replicate CRMC's proposed five-step process as outlined in Chapter 5 of this Shoreline Change SAMP document, and consider requirements for (1) type of development; (2) procedures for evaluating risk assessment; and (3) design standards; or

    b. Require the developer complete an online assessment developed by the University of Rhode Island, known as a Rapid Property Assessment for Coastal Exposure (Rapid PACE). This tool can be used to compile all state data illustrating coastal risk for individual properties across all 420 miles of Rhode Island's coastline.

4. Considering that documentation of current and future risks, as stated in Section 45-23-29 (see 6.5.3.2 above), is an intent of the legislation, the data and tools presented in this Shoreline Change SAMP can be used to revise the "required findings" outlined in Section 45-23-60 of the Rhode Island Land Development and Subdivision Review Enabling Act of 1992 and offer municipalities clear strategies for requiring applicants to document future risk. The "required findings" for location regulations regarding land development and subdivision review currently include:

   (a) All local regulations shall require that for all administrative, minor, and major development applications the approving authorities responsible for land development and subdivision review and approval shall address each of the general purposes stated in § 45-23-30 and make positive findings on the following standard provisions, as part of the proposed project's record prior to approval:

      (1) The proposed development ***is consistent with the comprehensive community plan*** *and/or has satisfactorily addressed the issues where there may be inconsistencies;*

      (2) The proposed development is ***in compliance*** *with the standards and provisions of the municipality's* ***zoning ordinance****;*

      (3) There will be ***no significant negative environmental impacts*** *from the proposed development as shown on the final plan, with all required conditions for approval;*

      (4) The subdivision, as proposed, will ***not result in the creation of individual lots with any physical constraints to development*** *that building on those lots according to pertinent regulations and building standards would be impracticable. (See definition of Buildable lot). Lots with physical constraints to development may be created only if identified as permanent open space or permanently reserved for a public purpose on the approved, recorded plans; and*

      (5) All proposed land developments and all subdivision lots have ***adequate and permanent physical access to a public street****. Lot frontage on a public street without physical access shall not be considered in compliance with this requirement.*

      (b) Except for administrative subdivisions, findings of fact must be supported by ***legally competent evidence on the record which discloses the nature and character of the observations*** *upon which the fact finders acted.*

5. To adequately address coastal change as documented throughout this Shoreline Change SAMP, a future amendment to Section 45-23-60, specifically to sections (a)(4) and (a)(5) stated above, could include documentation of "future conditions" as a required finding. For example, municipalities could consider future conditions that they can enact without changes to current state zoning law when determining considering permanent access to lots, developments, structures, such as prohibiting new public or private streets within defined coastal and riverine Special Flood Hazard Areas (SFHAs).

6. Considering that CRMC's STORMTOOLS, CERI (where available), and the SDE maps provide more accurate and reliable mapping of the Rhode Island landscape and coastal flooding scenarios – both from twice daily tides from projected sea level rise, and from episodic coastal storm events – documentation of the risk profile of any development within the Beach SAMP Project Boundary would illustrate the risk of various properties within the high-hazard coastal areas, and alert the municipality and any prospective buyers of that property of the risk they are buying into.

7. Strengthening the language regarding the documentation of future risk in the Subdivision Review Act, especially related to preventing or mitigating negative environmental impacts, avoiding areas with physical constraints to development and ensuring permanent physical access, can be applied to all land developments and subdivisions not just those potentially impacted by coastal hazards. These include areas subjected to inland flooding, high winds and severe erosion.

6.5.5 Highways and Mapped Streets

1. An additional consideration for long-term resilience at the municipal level is the location, management, and long-term maintenance of highways and mapped streets, and their exposure and vulnerability to recurring damage from storms, coastal erosion and sea level rise. The "Highways" and "Mapped Streets" sections of Rhode Island General Laws included below will be important to consider as future risks and associated costs/benefits of capital improvement investments are evaluated.

2. Title 24 of the Rhode Island General Laws, "Highways," Section 24-8-1.2. defines the establishment of the Rhode Island highway system:

   There is hereby established a Rhode Island highway system which shall include state roads and municipal roads. The determination of those roads designated as state roads and those designated as municipal roads shall be based upon a functional classification system, as established by the state planning council.

3. Title 45 of the Rhode Island General Laws, "Towns and cities," Section 45-23.1 addresses mapped streets and the establishment of official maps.

   Section 45-23.1-2 *(e) The locating, widening, or closing, or the approval of the locating, widening, or closing of streets by the city or town, under provisions of law other than those contained in this chapter, are deemed* ***to be changes or additions to the official map,*** *and are subject to all the provisions of this chapter except provisions relating to public hearing and referral to the plan commission.*

4. Title 24 of the Rhode Island General Laws, "Highways," Section 24-6 addresses Abandonment By Towns:

   § 24-6-3 Damages payable to abutting landowners. – The owners of land abutting upon a highway or driftway in any town shall be entitled, upon the abandonment of the highway or driftway, either wholly or in part, to receive compensation from the town for the damages, if any, sustained by them by reason of the abandonment; and the town council, whenever it abandons the whole or any part of a public highway or driftway, shall at the same time appraise and award the damages.

5. The concern with long term resilience of coastal roads is if a shore-parallel roadway, as seen in many coastal communities throughout Rhode Island (Atlantic Avenue in Westerly, Matunuck Beach Road in South Kingstown, etc.), becomes damaged abruptly from a coastal storm, or over time by sea level rise and gradual erosion, the state and town are responsible for providing access from that roadway to the properties it was designed to serve. Abandoning these roadways could result in a financial burden to the municipality if they are required to compensate landowners, which could lead to decisions to continue investing funds into roadways in high risk coastal hazard zones that will eventually be inundated on a regular basis from future sea level conditions, or undermined by future coastal erosion. As the expense of the maintenance cost for these roads or the cost to reimburse property owners is expected to place an extra financial burden on communities in the future, a statutory revision that defines and limits community financial exposure related to coastal and other natural hazards will be needed. Additionally, establishing special assessment or tax districts could be evaluated to determine if improvements in high risk or hazard areas can be supported by the property owners in that specific area.

6.5.6 Other Land Use Considerations

1. In addition to suggestions outlined above to strengthen state regulations in support of coastal resilience measures, several other issues and concerns have been raised during the Shoreline Change SAMP process that are worthy of future policy review and consideration:

    a. **Debris management for properties in coastal high hazard areas with first floor enclosures below the FEMA-designated Base Flood Elevation (BFE).** First floor enclosures that are subject to flooding have the potential to create debris if the first floor enclosure is damaged or flooded during a storm event. Drafting regulations that regulate construction and contents of first floor enclosures below BFE would help minimize damage created by storm-related debris and reduce public expenditures for cleanup and disaster relief.

    b. **Long-term impacts of structures that are designed to weather future storm events, but are in active erosion areas with shorelines that are projected to migrate inland.** Consideration of future coastal conditions will serve to address land use policy conflicts that may arise when structures along the coast are designed to be more resilient to extreme storm events, but the land around those structures is projected to erode. Stipulations in CRMC assents for future structure removal or relocation in “active erosion” areas, including barriers and beaches on headlands, could be considered for future permit requirements.

6.6 Future Research Needs

6.6.1 Financial Impacts, Incentives, and Cost/Benefit Analyses

1. The Shoreline Change SAMP has created tools for assessing risk across all 420 miles of Rhode Island's coastline. This baseline information of risk exposure can serve as the foundation for municipal cost/benefit analysis to begin assessing feasibility of implementing adaptation measures, some of which are described in Chapter 7 of this document. For example, assessed property values for each municipality have been compiled for all 21 coastal towns during the course of the Shoreline Change SAMP effort. From the assessed value data, a similar exposure assessment can be completed as was done for the e-911 data presented in the CRMC Exposure Assessment described in Section 4.5.1. Analyzing the assessed value of structures in each coastal flooding scenario can illustrate potential implications to a town's tax base and overall municipal finance strategy, and broader economic impacts of coastal hazards at a municipal scale. Defining different scenarios, financial implications, adaptation measures and potential return on investment of implementation strategies can assist cities and towns in sound decision making and wise investment of capital improvement funds.

2. For both regulators and individual property owners, information and decision support tools related to market forces and the potential for enacting financial and other incentives that encourage implementation of resiliency measures are needed. For example, defining tax incentives for property owners who voluntarily implement and document accepted measures to address resiliency, and ensuring those property owners are not penalized with higher property tax after their property is improved and valued at a higher assessment. Additionally, identification of financing strategies for making improvements that can be amortized over a defined period of time could assist property owners in making improvements in the near term to reduce their risk from projected future conditions outlined in this Shoreline Change SAMP.

3. Following resilience initiatives in other flood-prone states and in communities with a high coastal risk profile such as Norfolk, Virginia, will allow decision makers in Rhode Island to evaluate "lessons learned" in other communities and techniques that might be feasible in Rhode Island coastal cities and towns. As mentioned in Section 6.3.8, Moody's Investors Service is considering future risk conditions attributed to climate change when determining municipal bond ratings. A case study like Norfolk, VA where the city's involvement in the "100 Resilient Cities" initiative is helping to assess strategies that could protect the city's bond rating over the long term, could offer strategies to protect and sustain long term financial stability in Rhode Island's high-risk coastal municipalities.

6.6.2 Municipal Liability

1. The process of adopting the CRMC's Coastal Hazard Application Guidance into the RI Coastal Resources Management Program will require coastal permit applicants to complete and submit a risk assessment for their proposed development that will then be attached to the Council Assent. This initiative will allow CRMC to disclose risk from coastal hazards to those who wish to own and occupy property in high hazard coastal areas, and ensure that the best available science is made available to those property owners.

2. Roger Williams University School of Law produced a technical memorandum[7] titled "RI CRMC Liability Exposure for Permit Granting in Flood-Risk Areas," summarizing potential for state liability, public duty defense, special duty, and egregious conduct, and presenting examples of case law as "cautionary tales" for wrongful permitting. This type of effort would also assist municipalities in considering their liability for issuing building permits in areas of high coastal risk recently identified by CRMC in their decision support mapping tools, but outside of CRMC's jurisdiction.

3. In December of 2015, a conversation with municipal solicitors was initiated through a one-day event at Roger Williams University that addressed emerging legal issues related to coastal hazards and land use, including municipal liability and takings law, among other topics. Video and presentations from that event can be found on line https://law.rwu.edu/academics/marine-affairs-institute/research-and-outreach/symposiaconferences/legal-aspects-coastal-adaptation-resilience-ri-dec-2015

[7] Ryan-Henry, J. and D. Esposito. 2014. Technical Memorandum, *"RI CRMC Liability Exposure for Permit Granting in Flood-Risk Areas."* Roger Williams University. Bristol, RI.

4. Future contributions to Rhode Island's body of knowledge could include national case law monitoring by the Roger Williams School of Law, Marine Affairs Institute and the RI Sea Grant Legal Program.

5. The Conservation Law Foundation's (CLF) 2018 document, "Climate Adaptation and Liability: A Legal Primer and Workshop Summary Report,"[8] addresses not only government sector liability, but also liability for design and environmental professionals. The workshops held by CLF resulted in recommendations summarized in this document that include continuing dialogue and education among the private-sector design community and regulators at different levels of government, as well as exploration of standards and codes that consider disclosures, incentives, and financing for long-term climate adaptation.

6.6.3 Site Systems and Groundwater Dynamics

1. As outlined at the end of Chapter 4 of this Shoreline Change SAMP document, future research is needed on the effects that sea level rise will have on groundwater. For state permitting and municipal decision making on land development projects, the considerations include saltwater intrusion into drinking water supplies, contaminant mobilization throughout groundwater systems, and reduction of efficiency of on-site wastewater treatment and stormwater management systems.

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CHAPTER 7

Adaptation Strategies and Techniques for Coastal Properties

Table of Contents

7.1 Overview

1. Chapter 7, "*Adaptation Strategies and Techniques for Coastal Properties*," is intended to support CRMC's vision of providing guidance and tools for property owners and state and local decision-makers to proactively prepare and plan for, absorb, recover from, and successfully adapt to changing conditions associated with storm surge, coastal erosion and sea level rise. Information and tools contained in this chapter are designed to encourage "no regrets" decision-making within the Rhode Island Shoreline Change SAMP area.

2. This chapter is the culminating chapter of the Shoreline Change SAMP. It provides adaptation strategies and techniques that support Stage 3, "Choose measures of adaptation," of the overarching coastal risk assessment and management process discussed in Chapter 3. These adaptation strategies and techniques also provide specific options supporting Step 4, "Design Evaluation," of CRMC's Coastal Hazard Application Guidance for property owners, detailed in Chapter 5.

7.1.1 Chapter Objectives

1. This chapter provides an overview of adaptation strategies and tools that Rhode Island coastal property owners may be able to use in order to prepare their properties for the effects of climate change. Specifically, this chapter focuses on adaptation measures which can help property owners prepare for the risk associated with storm surge, coastal erosion and sea level rise. This chapter includes a definition of adaptation, discussion of associated concepts, and an explanation of how this relates to CRMC's regulatory authority and the goals, objectives and components of the Shoreline Change SAMP. Additionally, it includes short descriptions of a number of coastal adaptation strategies and techniques coupled with suggestions of sources of more information about these and other adaptation strategies.

2. Adaptation strategies and tools discussed in this chapter are suggested for possible use within the entire Shoreline Change SAMP area, including areas outside of CRMC jurisdiction. ***It is important to note that adaptation strategies and tools included in this chapter are not necessarily limited to those that are currently eligible for permitting by all relevant regulatory agencies, including CRMC, and some adaptation measures may require permitting by other agencies and/or may be prohibited by those agencies***. Rather, CRMC has included a broad suite of strategies and tools here in order to encourage consideration of the full range of options that may need to be considered in order to adapt Rhode Island's coastal communities to the full range of possible impacts

associated with storm surge, coastal erosion and sea level rise. Please refer to the RICRMP for current CRMC regulations.

3. CRMC recommends that coastal property owners adapt to the coastal hazards associated with climate change. This is recommended because of the risk associated with storm surge, coastal erosion, and sea level rise, coupled with the exposure and vulnerability of Rhode Island's coastal communities. Coastal communities will experience increasing damage to coastal properties, which may impact coastal communities and economies in a number of ways. Rhode Islanders' best protection against these damages is to begin implementing adaptation measures today.

4. This chapter focuses specifically on technical adaptation measures which can be implemented at the individual site or structural level by individual coastal property owners. This distinguishes this chapter from other adaptation guidance available from other state and federal agencies and non-governmental organizations, which often focus on planning, policy and legal solutions to be implemented at larger scales. Sources referenced in this chapter include some of the best available information on individual site or structural adaptation measures, and include publications from government entities, non-governmental organizations, scientists, and private companies known for their research on adaptation techniques.

7.1.2 Defining Adaptation and Associated Concepts

1. According to the Intergovernmental Panel on Climate Change (IPCC), adaptation refers to "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (Agard et al. 2014). Within the context of the Shoreline Change SAMP, adaptation refers to moderating or avoiding harm in Rhode Island's coastal communities by making adjustments to existing and future coastal development, whether on the structural, site-specific, or community-wide scales.

2. Proactive adaptation tools and strategies are typically framed within three main categories: protection, accommodation, and retreat. **Protection** strategies typically include use of either engineered or natural structures or measures to shield adjacent development or infrastructure from coastal hazards, without modifying the development or infrastructure itself. Coastal protection strategies are typically divided into so-called "**hard**" measures (e.g. seawalls or bulkheads) and "**soft**" measures (e.g. dunes or wetlands). **Accommodation** strategies typically include those involving the modification of the development or infrastructure (e.g. through elevation or

retrofitting). **Retreat** strategies include those involving moving or removing development or infrastructure (e.g. moving a structure further inland on a waterfront parcel) (California Coastal Commission 2015). This chapter includes discussion of adaptation strategies fitting into all three categories. Each adaptation strategy discussed herein is framed within the context of these categories.

3. Adaptation measures can include both **technical** approaches (e.g. elevating a home) and **policy or planning** approaches (e.g. developing an overlay zone). Additionally, adaptation measures can be applied to a range of scales, from the **individual structure** (e.g. a home), to a **site** (e.g. the parcel on which the home is based), to a **community or entire municipality**. Some adaptation measures are appropriate for retrofitting existing sites or structures, while others are intended only for new sites or structures. Last, different types of adaptation measures can be used independently or in combination (sometimes called “hybrid” approaches), depending on the unique needs of the site(s) and/or structure(s) in question. This chapter focuses primarily on technical adaptation measures appropriate for individual structures or sites on coastal properties, but illustrates those which can be applied across this full range of scales and for both existing and new sites or structures. This chapter includes explanation of the appropriate scale(s) of each adaptation strategy discussed herein.

4. Importantly, adaptation should not be confused with other approaches to emergency management. Emergency management, with regard to coastal hazards and other sources of risk, is typically framed as four phases: **mitigation**, **preparedness**, **response**, and **recovery**.

5. **Preparedness** typically refers to preparing for a coastal hazard immediately before a storm event (e.g. placing sandbags in front of your home). **Response** typically refers to actions taken during or immediately after a storm event to protect people and property (e.g. removing storm debris to gain access to your damaged home). **Recovery** typically refers to actions taken in the weeks or months following a storm event (e.g. rebuilding your home). By contrast, **mitigation** refers to changes to the building or site that are designed long before a storm that will reduce exposure. These changes can be solutions that do not require pre-storm preparedness actions, e.g. elevating your home, or solutions that require pre-planned preparedness actions using designed devices.

6. This document, and this chapter in particular, focuses primarily on adaptation as a type of **mitigation**. It does not address short-term preparedness actions. However, employing adaptation techniques may help coastal property owners reduce their overall risk by mitigating potential storm impacts, reducing the need for some types of preparedness actions, and reduce their post-storm recovery time.

7.1.3 Choosing to Adapt: Choices and Challenges

1. While this chapter lays out a broad range of adaptation choices, it is important to emphasize that Rhode Island's coastal property owners *must* adapt – because the coastal hazards that are the focus of the Shoreline Change SAMP will require proactive planning in order to avoid future economic, environmental, and personal harm. Coastal property owners and decision-makers will need to choose *which* adaptation measures are most appropriate for use at the structure, site or area under consideration.

2. While adaptation may seem costly and inconvenient to some, it can actually be a significant cost savings in the long run. A 2017 study by the National Institute of Building Sciences found that investments in mitigation measures in new construction that exceeded provisions of 2015 model building codes resulted in a benefit-cost ratio of 5 to 1 for riverine flood hazards and 7 to 1 for hurricane surge hazards. In other words, for every $1 spent on adaptation, $5 is saved with regard to riverine flood risk and $7 is saved with regard to hurricane surge risk. Further, this study found that in Rhode Island, choice of first floor building height above BFE (2 to 6 feet) resulted in a benefit-cost ratio of 6.7 to 3.8. For further information, please see National Institute of Building Sciences 2017.

3. In all cases, choice of adaptation measure(s) is context-specific. Individual coastal property owners and decision-makers must evaluate the specific structure, site, or area in question, and what is known about the exposure of that structure or site to sources of coastal hazard risk. The property owner and decision-maker can then use this contextual information to select adaptation measures that best suit the structure or site as well as the sources of risk.

4. Coastal property owners attempting to proactively choose adaptation measures will be challenged to look to the future, beyond existing regulatory requirements. For example, over time, rising sea levels may cause an area in a mapped FEMA A Zone, subject to at least a 1% annual chance flood event, to be remapped in the future as a V Zone, with the same annual flood chance but now subject to severe wave action. In another example, an area that is *outside* of the current mapped FEMA floodplain may be remapped in the future as *inside* the floodplain.[1] (For information on how property owners can use CERI STORMTOOLS Design Elevations to address this problem, see Shoreline Change SAMP Chapter 3.) This future scenario would require different

[1] The A and V flood zones were designed for insurance rate pricing for the National Flood Insurance Program (NFIP) and for regulatory enforcement rather than an acceptable risk for the building owner. History has shown nature does not care about regulations; Hurricanes Katrina, Sandy, and Harvey are examples where the flooding exceeded the mapped regulatory boundaries/flood elevations and thus had severe impact on the flooded properties.

adaptation measures. While uncertainty about this and other aspects of the changing coast creates challenges for choosing adaptation measures, it also underscores the importance of proactive planning for the future.

5. Choice of adaptation measure(s) to apply to a specific structure, site or region must take into account all coastal hazard risk factors. The Shoreline Change SAMP is focused on three sources of coastal hazard risk: storm surge, coastal erosion, and sea level rise. Choice of adaptation measure must consider all three of these risk factors as well as the synergistic effects of these sources of risk. Further, adaptation measures must be evaluated for potential inclusion in the design phase of a new construction project, or for the feasibility of using in the modification or retrofit of an existing structure. Additionally, adaptation choice must consider tradeoffs between different adaptation measures that address different sources of risk. For example, a property owner concerned about flooding associated with storm surge and sea level rise may choose elevation as an appropriate adaptation measure. However, while elevation might *reduce* a structure's exposure to flooding, it may *increase* that structure's exposure to high winds. Further, elevation may increase the likelihood of damage to infrastructure which cannot be elevated, such as onsite wastewater treatment systems, utility connections, decks, and stairways.

6. Choice of adaptation measure must also include consideration of its effect on shoreline public access. CRMC requires that any adaptation measures implemented avoid loss of shoreline public access.

7. Choice of adaptation measure(s) to apply, and how best to apply them, must be informed by context, i.e. the specific attributes of the structure, site, or region as well as what is known to date about the exposure of that place to storm surge, coastal erosion, and sea level rise. This must include consideration of the **design life** of the structure (s) in question.

8. Choice of adaptation measure must also include consideration of the **best available projections of flood risk** at that site. As discussed in Chapter 3, STORMTOOLS Design Elevations, under development for all Rhode Island coastal communities, will provide alternative base flood elevation (BFE) estimates for 100-year storms that can be used to guide site-specific adaptation decisions.

7.1.4 Adaptation: A Rapidly Developing Field

1. The field of adaptation is rapidly evolving, along with scientists' and managers' understanding of climate change and the associated sources of coastal hazard risk. New

adaptation strategies, tools and technologies are being developed and existing adaptation measures improved at a rapid pace. As such, it is not possible to include an exhaustive list of all potential adaptation strategies and tools here, nor to include all of the most current development in the field. This chapter is thus intended to introduce coastal property owners and decision-makers to the concept of adaptation; provide examples of the range of adaptation options which may be available; and direct readers to sources of more detailed or up-to-date information.

2. Given the rapidly-evolving nature of the adaptation field, many adaptation techniques are not yet allowable under existing state and municipal permitting programs or in all potentially vulnerable areas. Individual coastal property owners should check with their regulatory agencies regarding the potential use of specific adaptation techniques in specific sites.

7.2 Adaptation Tools and Strategies for Coastal Properties

7.2.1 CRMC Guidance on Coastal Property Adaptation Tools and Strategies

1. This section includes brief descriptions of a range of adaptation tools and strategies which property owners and decision-makers may choose to consider for use at individual coastal properties. **It is important to note that adaptation strategies and tools included here are not necessarily limited to those that are currently eligible for permitting by all relevant regulatory agencies, including CRMC, and some adaptation measures may require permitting by other agencies and/or may be prohibited by those agencies. Please refer to the RICRMP for current CRMC regulations**.

2. In general, the CRMC prefers “natural” or “nature-based infrastructure” solutions for adaptation; many such solutions are described below in section 7.2.6. Such solutions are often particularly appropriate at the site level. However, the CRMC recognizes that so-called “grey infrastructure” solutions, such as those described below in section 7.2.7 and section 7.2.8, are appropriate in certain cases, particularly for public infrastructure.

3. Table 1 includes a summary of the coastal property adaptation tools and strategies discussed in this chapter. Each tool and strategy is detailed in the chapter text. Additionally, references are included throughout the chapter and at the end for more information on each adaptation measure.

Table 1. Summary table of coastal property adaptation tools and techniques

Strategy	Existing or New Construction	Protection, Accommodation or Retreat	Site or Structure
Site selection	New	Accommodation or Retreat	Site or structure
Distance inland	Existing or new	Retreat	Site or structure
Elevation	Existing or new	Accommodation	Site or structure
Terrain management			
Site grading	New	Accommodation	Site
Site layout	New	Accommodation	Site
Drainage	Existing or new	Accommodation	Site or structure
Natural or nature-based measures			
Coastal bank protection	Existing or new	Protection	Site
Living breakwaters	Existing or new	Protection	Site
Dune restoration	Existing or new	Protection	Site
Beach replenishment	Existing or new	Protection	Site
Coastal wetland or enhancement	Existing or new	Protection	Site
Flood barriers			
Floodwalls	Existing or new	Protection	Site
Temporary flood barriers	Existing or new	Protection	Site
Floodgates and tide gates	Existing or new	Protection	Site
Berms	Existing or new	Protection	Site
Structural shoreline protection measures			
Seawalls	Existing or new	Protection	Site
Revetments	Existing or new	Protection	Site
Bulkheads	Existing or new	Protection	Site
Wet Floodproofing			
Choice of building materials	Existing or new	Accommodation	Structure
Wall openings and vents	Existing or new	Accommodation	Structure
Protect underside of elevated buildings	Existing or new	Accommodation	Structure
Elevation of utilities and living quarters	Existing or new	Accommodation	Structure
Breakaway walls	Existing or new	Accommodation	Structure
Dry Floodproofing			
Impermeable building materials or sealants	Existing or new	Protection	Structure
Watertight doors or windows	Existing or new	Protection	Structure
Pumps and drains	Existing or new	Protection	Structure
Backflow valves	Existing or new	Protection	Structure
Other Retrofitting Techniques			
Fortified™	Existing or new	Protection	Structure
Relocation or Managed Retreat			

Site selection	Existing or new	Retreat	Site or structure
Construct moveable structure	New	Retreat	Structure
Relocate	Existing	Retreat	Site or structure

7.2.2 Site Selection

Box 1. FM GLOBAL: A RHODE ISLAND-BASED SOURCE OF INFORMATION ON ADAPTATION STRATEGIES

FM Global is a property insurance company with corporate headquarters in Johnston, RI dedicated to helping businesses manage risk, prevent losses and build resilience to a broad range of natural and human-made hazards. CRMC has drawn upon FM Global's expertise in developing the Shoreline Change SAMP because the Rhode Island-based company is widely recognized as a leader in conducting adaptation research and certifying new adaptation products, and has developed an approach to the adaptation process that CRMC considers useful for individual coastal property owners. FM Global is known for its work developing adaptation solutions to facilitate property and business continuity; their business model is based on working with the corporate clients they insure to help them design resilient infrastructure and systems. They conduct engineering research on adaptation for use with their own clients and to enhance external standards and codes. A wealth of this information is available in the form of FM Global data sheets. Detailed data sheets are available on general topics such as floods, green roof systems, and wind design, as well as specific strategies for types of infrastructure including electrical systems and fire suppression. While this information is primarily assembled for business clients, many of these adaptation strategies are appropriate for residential coastal property owners. Data sheets can be accessed at www.fmglobaldatasheets.com.

1. Site selection is one of the most important adaptation strategies, and is recommended as the place to start, when considering **new construction**. New construction can include either partial construction (e.g. an addition or modification of an existing structure) or full construction, and can include either development of a previously undeveloped site, or demolition and reconstruction of a developed site. This adaptation measure, a form of **accommodation**, can apply to either **the entire site** (in other words, the parcel of land being purchased and developed) or to the specific building site on the parcel where **structures** or infrastructure will be developed.

2. In some cases, a prospective property owner may be choosing among possible coastal parcels for purchase and development. When choosing among parcels, site selection should be informed by the best available science showing the exposure of that parcel to

storm surge, coastal erosion and sea level rise. Additionally it should consider other potential risks, including but not limited to riverine flooding or ponding from insufficient stormwater drainage. Further, it should consider both horizontal and vertical dimensions – in other words, ***elevation*** above projected flood areas as well as ***distance*** inland (see below for further discussion). Choice of a parcel that is minimally exposed to sources of coastal hazard risk is one of the most effective adaptation strategies and can be much easier and less expensive than implementing adaptation at a highly-exposed site.

3. In other cases, a property owner may already own a parcel, but may be able to choose among possible sites on that parcel for building a home or other structure. When choosing a building site on a given parcel, site selection should similarly consider both horizontal and vertical dimensions – ***elevation*** above projected flood areas as well as ***distance*** inland (see below for further discussion). Building site selection at this scale could make a significant difference in reducing a property's exposure to sources of coastal hazard risk.

4. Whether at the scale of an entire parcel or a specific structure, site selection must also include ***site access.*** Site access includes transportation routes facilitating access to/from the parcel (e.g. public or private roads), as well as driveways, parking areas, paths, and other means of access on the parcel to/from the buildings themselves. It also includes access for other infrastructure, including power, water, and sewer. Again, property owners should consider both ***elevation*** above projected flood areas as well as ***distance*** inland. Choice of low-exposure access areas is critical for enabling safe access to/from the site in the event of a storm.

5. For example, FM Global recommends that sites be chosen where the entire site and all access routes are outside of 500-year return period flood areas, by both elevation and footprint. They further recommend that sites where structures will be placed be above the 500-year return period flood area as well as an additional 1 to 2 feet of freeboard. Last, they suggest that the building site be at least 500 feet away from areas of direct wave impacts and/or high flood velocities (FM Global 2016). Importantly, these recommendations do not consider projected sea level rise. CRMC recommends that coastal property owners consider all three coastal hazards addressed in the Shoreline Change SAMP – storm surge, coastal erosion, and projected sea level rise – when selecting a site.

7.2.3 Distance Inland

1. Distance inland is another important and effective adaptation strategy that allows for **accommodation** of changing coastal conditions. This strategy was discussed above within the context of site selection, but is further detailed here because of its fundamental importance as an adaptation measure. This strategy can be applied to both **new construction** and **existing construction**, and to both the **entire site** or to individual **structures**. Selection of an appropriate distance inland enables property owners to avoid direct wave impacts or high flood velocities (FM Global 2016). When considering distance inland, property owners should consider the best available site-specific information about potential exposure to storm surge, coastal erosion, and sea level rise.

2. In cases of **new construction**, choice of distance inland can inform both selection of the overall site as well as where on the site buildings and infrastructure are constructed (e.g. a home could be constructed on a waterfront parcel, but as far inland as possible). In cases of **existing construction**, there may be opportunities to modify existing structures with consideration of distance inland. For example, an addition onto an existing building could be designed and constructed on the upland side of the building, or an entire building could be relocated toward the upland side of an existing parcel. The latter can be considered a form of **managed retreat**, which is further discussed below in section 7.2.11.

7.2.4 Elevation

1. A widely-used adaptation technique is **elevation** of either an entire site or of individual buildings and/or key equipment on that site. This strategy was discussed above within the context of site selection, but is further detailed here because of its fundamental importance as an adaptation measure. Elevation is a form of **accommodation**. While it may mitigate exposure to flooding, it does not reduce exposure to erosion. When applied at a **site** scale, elevation involves filling or regrading a site to a height above a given predicted flood elevation, and is more commonly applied in cases of new construction. At the **structural** scale, elevation involves designing a new building or retrofitting an existing building to raise it above flood elevation through the use of raised foundations or elevated structures. In some cases, buildings may be elevated on piles; in other cases, primary living quarters and utilities may be elevated to the second floor, minimizing the exposure of first-floor infrastructure to flooding (Snow and Presad 2011). FM Global (2016) recommends additional considerations, including not building foundations in areas subject to high or moderate velocity flows; building structures to resist all flood-related loads and conditions; ensuring consideration of other applicable

loads, such as gravity and wind; considering all appropriate load combinations; and using load combinations, load factors, and resistance factors as specified in governing model codes and standards (FM Global 2016).

2. One challenge with the use of elevation as an adaptation measure is elevating on **fill**. Elevation is required in certain FEMA mapped flood zones to meet minimum heights in accordance with mapped FEMA base flood elevations (BFEs). Some forms of elevation may involve fill. However, fill is prohibited as a means of structural support in FEMA mapped V-zones (44 CFR 60.3(e)(6); see generally the FEMA National Flood Insurance Program's floodplain management regulations for more information). Further, using fill to elevate homes may not always be an appropriate solution. Use of fill in coastal areas can be very costly. Fill can also have downstream impacts because it is susceptible to erosion (e.g. FEMA 2009) - for example, a flood event could wash fill material into adjacent coastal wetlands or other sensitive habitat types. Further, fill can increase flooding and/or erosion on the site and/or on adjacent properties.

3. A critical consideration for elevation, whether at the site or structural scale, is what height to which the site or structure should be raised. The FEMA National Flood Insurance Program requires the lowest floor of structures built in Special Flood Hazard Areas, areas FEMA deems to be exposed to the 100-year return period flood event, to be at or above the base flood elevation shown on Flood Insurance Rate Maps (FIRMs). These maps are based on past conditions and do not account for projected sea level rise. FM Global recommends additional precautions, elevating buildings above the predicted 500-year flood elevation and including 1 to 2 feet of freeboard (FM Global 2016). The STORMTOOLS Design Elevation (SDE) maps produced through the Shoreline Change SAMP provide information that will enable homeowners to take further precautions by elevating to a height that considers projected sea level rise. For more information, please see Chapter 3 as well as www.beachsamp.org.

7.2.5 Terrain Management

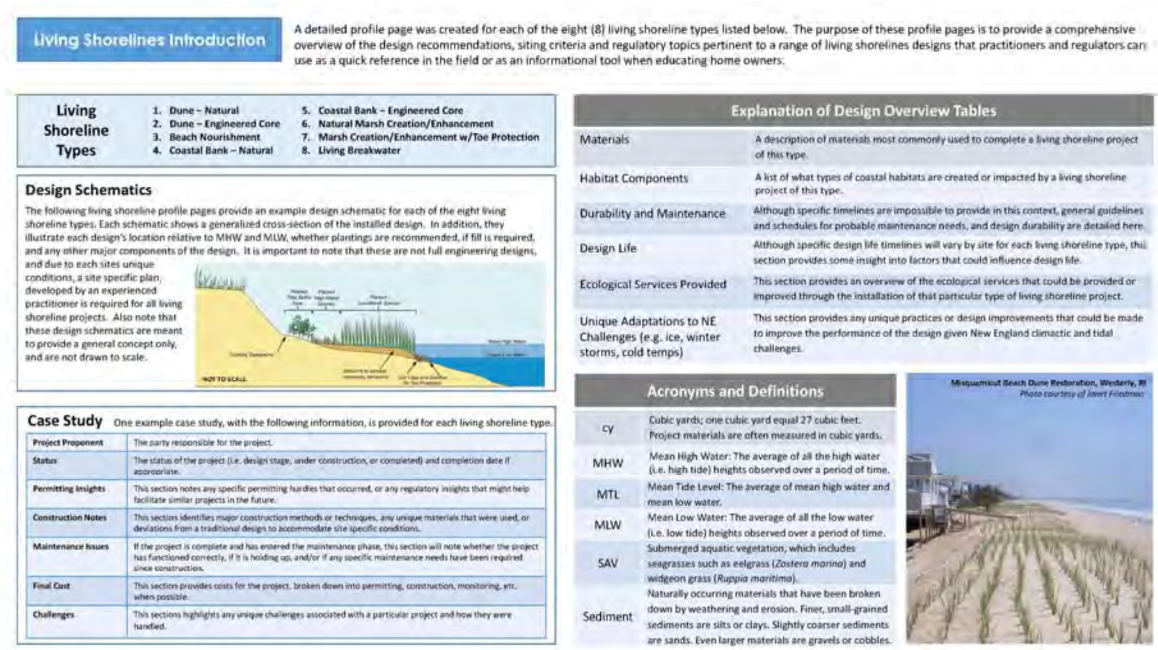
1. This section describes some commonly-used terrain management adaptation strategies. Terrain management strategies are generally reserved for FEMA mapped A Zones, because V Zones are subject to wave attack. Some terrain management strategies may also be considered standard construction practices, while others may also be considered forms of natural or nature-based adaptation. Other adaptation strategies described below in Section 7.2.6, Natural and Nature-Based Adaptation Strategies, and Section 7.2.7, Site Protection Through Flood Barriers, may also be considered forms of terrain management; please refer to those sections accordingly.

2. Terrain management strategies to address flooding include a range of related adaptation strategies that can be applied at the **site** scale as means of **accommodation**. In some cases, adaptation strategies described in this section may also be built into a **structure**. These strategies help manage flood waters by ensuring that flood exposure is neither created nor exacerbated by site layout, grading, and flood and stormwater (e.g. rain and melting snow) management.

3. Specific means of managing terrain to manage floodwaters include: **grading** a site such that flood and stormwater flows away from buildings and infrastructure; designing **site layout** such that runoff from off-site areas is considered and that water routing is planned to avoid contact with buildings and infrastructure; and designing site-wide **drainage systems** to accommodate flood and stormwater volumes and velocities associated with future storm events and to avoid potential clogging due to storm debris or landscaping materials (FM Global 2016). There are many natural or nature-based techniques that can be incorporated into terrain management strategies to further manage flooding; please see section 7.2.6 below.

Box 2. THE STATE OF THE PRACTICE OF LIVING SHORELINES IN NEW ENGLAND

In 2017, the Northeast Regional Ocean Council (NROC) partnered with The Nature Conservancy (TNC) under a grant from NOAA to assess the state of practice of living shorelines in New England. NROC and TNC hired Woods Hole Group, which completed a comprehensive review of the state of the practice of coastal natural and nature-based adaptation approaches in New England. This project, "Living Shorelines in New England: State of the Practice," culminated in a comprehensive report, a series of profiles of living shoreline techniques, and a living shorelines applicability index. These resources provide Rhode Island coastal property owners and decision-makers with an up-to-date and accessible review of natural and nature-based adaptation techniques that can work in New England, despite limitations such as colder waters and a shorter growing season. Of particular use are the profile pages, which provide a comprehensive overview of design recommendations, siting criteria, and regulatory information for eight different living shoreline types (natural or engineered dunes; beach replenishment; natural or engineered coastal banks; marsh creation/enhancement, either natural or with toe protection; and living breakwaters). These profile pages contain design schematics, illustrative case studies, and a key explaining selection characteristics (e.g. "tidal range" and "nearby sensitive resources").



Living Shorelines Introduction

A detailed profile page was created for each of the eight (8) living shoreline types listed below. The purpose of these profile pages is to provide a comprehensive overview of the design recommendations, siting criteria and regulatory topics pertinent to a range of living shorelines designs that practitioners and regulators can use as a quick reference in the field or as an informational tool when educating home owners.

Living Shoreline Types

1. Dune – Natural
2. Dune – Engineered Core
3. Beach Nourishment
4. Coastal Bank – Natural
5. Coastal Bank – Engineered Core
6. Natural Marsh Creation/Enhancement
7. Marsh Creation/Enhancement w/Toe Protection
8. Living Breakwater

Design Schematics

The following living shoreline profile pages provide an example design schematic for each of the eight living shoreline types. Each schematic shows a generalized cross-section of the installed design. In addition, they illustrate each design's location relative to MHW and MLW, whether plantings are recommended, if fill is required, and any other major components of the design. It is important to note that these are not full engineering designs, and due to each sites unique conditions, a site specific plan, developed by an experienced practitioner is required for all living shoreline projects. Also note that these design schematics are meant to provide a general concept only, and are not drawn to scale.

NOT TO SCALE

Case Study One example case study, with the following information, is provided for each living shoreline type.

Project Proponent	The party responsible for the project.
Status	The status of the project (i.e. design stage, under construction, or completed) and completion date if appropriate.
Permitting Insights	This section notes any specific permitting hurdles that occurred, or any regulatory insights that might help facilitate similar projects in the future.
Construction Notes	This section identifies major construction methods or techniques, any unique materials that were used, or deviations from a traditional design to accommodate site specific conditions.
Maintenance Issues	If the project is complete and has entered the maintenance phase, this section will note whether the project has functioned correctly, if it is holding up, and/or if any specific maintenance needs have been required since construction.
Final Cost	This section provides costs for the project, broken down into permitting, construction, monitoring, etc. when possible.
Challenges	This sections highlights any unique challenges associated with a particular project and how they were handled.

Explanation of Design Overview Tables	
Materials	A description of materials most commonly used to complete a living shoreline project of this type.
Habitat Components	A list of what types of coastal habitats are created or impacted by a living shoreline project of this type.
Durability and Maintenance	Although specific timelines are impossible to provide in this context, general guidelines and schedules for probable maintenance needs, and design durability are detailed here.
Design Life	Although specific design life timelines will vary by site for each living shoreline type, this section provides some insight into factors that could influence design life.
Ecological Services Provided	This section provides an overview of the ecological services that could be provided or improved through the installation of that particular type of living shoreline project.
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	This section provides any unique practices or design improvements that could be made to improve the performance of the design given New England climactic and tidal challenges.

Acronyms and Definitions	
CY	Cubic yards; one cubic yard equal 27 cubic feet. Project materials are often measured in cubic yards.
MHW	Mean High Water: The average of all the high water (i.e. high tide) heights observed over a period of time.
MTL	Mean Tide Level: The average of mean high water and mean low water.
MLW	Mean Low Water: The average of all the low water (i.e. low tide) heights observed over a period of time.
SAV	Submerged aquatic vegetation, which includes seagrasses such as eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*).
Sediment	Naturally occurring materials that have been broken down by weathering and erosion. Finer, small-grained sediments are silts or clays. Slightly coarser sediments are sands. Even larger materials are gravels or cobbles.

Misquamicut Beach Dune Restoration, Westerly, RI
Photo courtesy of Janet Freedman

The state of practice of natural and nature-based adaptation measures is rapidly changing, and so property owners using this 2017 guide are advised to seek out the most up-to-date information on the technique of interest to them. For further information please see https://www.conservationgateway.org/ConservationPractices/Marine/Pages/new-england-living-shorelines.aspx.

7.2.6 Natural and Nature-Based Adaptation Measures

1. Natural or nature-based adaptation measures, sometimes described as “non-structural,” “living shorelines,” “natural” or “green infrastructure,” “soft armoring,” or similar terms, refers to the use of natural features and systems to reduce the exposure of residential and other coastal properties and infrastructure while enhancing habitat and ecosystem services. Common examples include protection or restoration of beaches sand dunes; vegetated buffers; and protection or restoration of coastal wetland systems (California Coastal Commission 2015). Natural and nature-based adaptation measures include a broad suite of strategies that can be implemented at either the **site** or the **structural** scale, and for either **existing** or **new construction**, as a means of either **protection** or **accommodation**. Natural or nature-based strategies can be used by themselves or in combination with traditional (“hard” or “grey infrastructure” strategies) to create hybrid adaptation approaches. Such hybrid approaches are under consideration by CRMC, but some may not be permitted under the current regulations. Please refer to the RICRMP for the most current CRMC regulations.

2. The CRMC prohibits new structural shoreline protection measures on barriers classified as undeveloped, moderately developed, and developed, and on all shorelines adjacent to Type I waters (see the RICRMP §1.3.1(G)(3)). Additionally, the CRMC favors non-structural methods of shoreline protection (see the RICRMP §1.3.1(G)(1)).

3. Natural or nature-based adaptation strategies are frequently advocated over “hard” adaptation strategies because they can provide other ecological, economic, social and cultural benefits. These can include recreational areas, positive visual impacts, water quality improvements, and habitat for a broad range of species (California Coastal Commission 2015; NRC 2014).

4. When considering natural or nature-based adaptation strategies, property owners and decision-makers should consider a few important caveats. First, the use of natural or nature-based approaches in coastal adaptation is relatively new, many such approaches are still being tested and refined, and more research is needed on these topics; the property owner should evaluate what is known about the effectiveness of a given approach when considering its use on her or his property. Additionally, natural or nature-based approaches can be costly and can require large amounts of space, though are potentially less costly than structural shoreline protection measures. Finally, not all such approaches may be ecologically beneficial in all such places. Property owners should consider natural or nature-based approaches that are appropriate to the amount

of space available and the ecological characteristics of their site and the surrounding area (California Coastal Commission 2015; NRC 2014).

5. **Coastal bank protection** encompasses a suite of methods used to stabilize the sediment in coastal banks. These methods can involve a variety of "hard" and "soft" materials and differing degrees of engineering in their design. Coastal bank protection strategies are designed to absorb storm surge, reduce wave energy and protect against coastal erosion, and are implemented as a natural alternative to bulkheads and revetments. Coastal bank **protection** projects can be applied at the **site** scale adjacent to **existing** or **new construction** (Woods Hole Group 2017).

6. **Natural** coastal bank protection projects include use of coir (natural fiber) rolls or logs, root wads, natural fiber blankets, and planted native vegetation such as marine grasses. Combining these materials with re-grading of the bank to reduce steepness and create a more dissipative slope can help to minimize erosion. **Engineered** coastal bank protection projects involve similar techniques such as regrading or terracing banks and planting native vegetation, but also incorporate the use of engineered cores, such as coir envelopes or sand-filled tubes (Woods Hole Group 2017). Engineered coastal bank designs might also incorporate the limited use of hard materials such as stone to stabilize the toe of the slope. For detailed guidance on these techniques, including local examples and siting criteria, please see Woods Hole Group 2017, particularly profile pages 4 and 5 ("Coastal Bank – Natural" and "Coastal Bank – Engineered Core").

7. **Living breakwaters** are structures constructed in the nearshore environment as a means of breaking waves before they reach the shoreline. They are designed as a means of wave attenuation and coastal erosion control and a means of promoting sediment retention. Living breakwaters are typically oyster or mussel reefs. Their structure is often constructed out of shell bags, stone, or cast concrete structures such as reef balls (Woods Hole Group 2017). For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile page 8 ("Living Breakwater").

8. **Dune restoration** is the practice of constructing new or restoring existing dunes as a means of dissipating wave energy and addressing storm surge and coastal erosion. Dune restoration can involve both natural and engineered techniques. For natural projects, sediments are either placed on an existing dune, or a mound of sediments are built up in an appropriate site in order to create an artificial dune. Engineered projects involve use of an engineered core, constructed using coir envelopes or similar structures, in order to stabilize the dune (Woods Hole Group 2017). For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile pages 1 and 2 ("Dune – Natural" and "Dune – Engineered Core").

9. **Beach replenishment** (also sometimes called "beach fill" or "beach nourishment") is the practice of replacing sediment along eroding beaches, often elevating or widening a beach. This activity is often thought of as a means of managing a recreational resource, but beach replenishment increases beaches' ability to protect upland structures against wave energy and storm surge. This activity is often paired with dune restoration (above) (Woods Hole Group 2017). For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile page 3 ("Beach Nourishment").

10. **Coastal wetland creation or enhancement** involves a range of methods to stabilize or enhance coastal wetlands, which can help stabilize shorelines and dissipate wave energy. Natural coastal wetland creation or enhancement involves planting marsh vegetation such as cordgrass, which provides a minimally intrusive means of enhancing marsh. Coastal wetland enhancement may also include installing toe protection materials in order to assist with coastal wetland stabilization. These techniques may include natural fiber rolls, shell bags, or stone (Woods Hole Group 2017). In some cases, fill material can be used to create elevations suitable for marsh vegetation, though it should be noted that additional state and regulatory restrictions apply to projects that involve placement of material below Mean High Water. For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile pages 6 and 7 ("Natural Marsh Creation/Enhancement" and "Marsh Creation/Enhancement w/ Toe Protection."). See Shoreline Change SAMP Chapter 4 for further discussion of Rhode Island's coastal wetlands' exposure to sources of coastal hazard risk and of ongoing marsh restoration efforts.

7.2.7 Flood Barriers

1. Flood barriers provide one means of **protection** from exposure to flooding. Although commonly used, flood barriers must be considered with extreme caution. CRMC staff have found that flood barriers are often either undersized or under-designed for the sources of coastal hazard risk they are intended to address. Further, flood barriers may simply not be feasible means of protecting a site from storm surge and sea level rise given the latest sea level rise estimates (discussed in Chapters 2 and 3 of the Shoreline Change SAMP). CRMC staff have also found that flood barriers may be particularly ineffective in a FEMA mapped V-Zone or Coastal A-Zone as they do not effectively protect against wave energy, and may simply contribute to the amount of debris generated during a storm event. Designing flood barriers to address these sources of risk can therefore be very costly and may also lead to legal issues given the permitting and construction of such large structures.

2. Flood barriers can be applied to **existing** or **new construction**, and can protect a **site** or in some cases be built into a **structure**. Flood barriers are typically constructed along the perimeter of a site and may include a mix of different types of flood barriers. Choice of flood barrier adaptation measure(s) must be guided by the best available information on the exposure of the site to flooding associated with storm surge and sea level rise. Flood barriers should be specifically engineered and designed for their purpose; this includes certification to a national standard. FM Global (2016) advises that flood barrier design must address site-specific characteristics including the adjacent structures, site hydrology, hydraulics, drainage, and soils. Further, FM Global advises consideration of the property owner's ability to operate and maintain the system. Any flood barrier must be designed by an engineering professional who will evaluate all of these considerations and design a barrier appropriate for the site. Again, CRMC staff have found that flood barriers may be particularly ineffective in a FEMA mapped V-Zone or Coastal A-Zone as they do not adequately protect against wave energy.

3. Flood barriers include **permanent** and semi-permanent barriers as well as **temporary** structures. Permanent barriers are those which are permanently installed, even though they may not always be in use, and include but are not limited to **floodwalls, flood gates, berms,** and **tide gates**. Semi-permanent flood barriers have permanent foundations with removable columns and barrier panels that can be installed in advance of flood conditions, and taken down after flood waters recede (see e.g. EKO Flood USA n.d. or Flood Control America 2016). Temporary flood barriers include those which are not permanently installed but can be deployed in anticipation of a flood, and include inflatable plastic barriers (see e.g. A Better City n.d.).

4. **Floodwalls** are vertical engineered structures, typically built out of concrete or similar materials, that can be scaled as a means of **protection** for one or multiple structures on a small **site** scale (FEMA 2007). Floodwalls are generally not designed to resist high-energy waves, unlike seawalls and other similar shoreline protections structures (see section 7.2.8 below). As such they are often located in areas inland of coastal wetlands or other features that reduce wave energy (NRC 2014). Floodwalls are often used in areas where there is insufficient space for levees, which have a larger footprint (FEMA 2007).

5. Floodwalls sometimes incorporate **flood gates**, which provide a means of controlling water flow in such systems. Flood gates are typically designed as passive devices, automatically opening and closing in response to the hydrostatic pressure of floodwaters (FEMA 2015). Flood gates are not limited to installation in flood walls, but

can be installed as stand-alone devices protecting **sites** or individual **structures**. They can also be installed on roadways or walkways (A Better City 2015).

6. While floodwalls can protect adjacent structures on a site from inundation, they have many limitations as a coastal adaptation measure, including cost and effort of construction and maintenance (FEMA 2007). Further, floodwalls are not immune from failure, as demonstrated in some cases in New Orleans during Hurricane Katrina (NRC 2014). Floodwalls may also have impacts including exacerbated flooding of adjacent areas and environmental impacts such as construction in or adjacent to coastal wetlands and changes to flood conditions (NRC 2014). For detailed guidance on constructing floodwalls, see FEMA 2007.

7. **Berms**, sometimes also described as embankments, raised ground, or dikes, are structures typically constructed of soil, clay or other earthen materials and used as means of flood **protection** on a small **site** scale (e.g. one residential structure). Berms differ from levees in scale (FEMA 2007). Levees may be constructed of similar materials but may protect an entire neighborhood or part of a city, such as New Orleans (NRC 2014). A berm can be constructed along one side of a building or can completely encircle a building (FEMA 2007). Even a small berm can require a large amount of space and a lot of earthen material; as such, berms are often incorporated into site terrain management (section 7.2.5 above) through site layout and grading.

8. **Tide gates** are another form of flood barrier used in low-lying areas. They are a means of flood **protection** typically applied on a **site** scale, and are designed specifically to close during incoming tides, preventing downstream waters from coming further inland, and open during outgoing tides, allowing upstream waters to drain. It is important to note that tide gates are of limited effectiveness given rising sea levels. A study by Walsh and Miskewitz (2012) found that sea level rise limits the effectiveness of tide gates because it impacts the hydraulic systems used to control tide gates, resulting in longer and deeper flooding events.

7.2.8 Structural Shoreline Protection Measures

1. The CRMC prohibits new structural shoreline protection measures on barriers classified as undeveloped, moderately developed, and developed, as well as on all shorelines adjacent to Type I waters (see the RICRMP §1.3.1(G)(3)). Additionally, the CRMC favors non-structural methods of shoreline protection (see the RICRMP §1.3.1(G)(1)); the reasons for this are enumerated in Chapter 4, Section 4.3.1.5, “Shoreline Protection Structures.”.

2. Structural shoreline protection measures designed to protect adjacent structures are among the most well-known adaptation measures. Although commonly used, structural shoreline protection measures must be considered with extreme caution. Like flood barriers, CRMC staff have found that structural shoreline protection measures are often either undersized or under-designed for the sources of coastal hazard risk they are intended to address. Further, they may not be feasible means of protecting a site from storm surge and sea level rise given the latest sea level rise estimates (discussed in Chapters 2 and 3 of the Shoreline Change SAMP). Structural shoreline protection measures can thus be a very costly adaptation measure with little return on investment.

3. Such structures are designed as **protection** strategies for adjacent structures and are typically constructed at the **site** scale, parallel to the shore. In some cases, structural shoreline protection measures are built in to individual **structures**. Conceptually, such structures can be applied to **existing or new construction**. Examples of such "hard" shore-parallel shoreline protection structures include **seawalls, revetments, and bulkheads**. Such structures are designed to address flooding and coastal erosion as well as to reduce wave attack (NRC 2014).

4. The terms seawall, revetment, and bulkhead are frequently used interchangeably. A **seawall** is a hard, static, shore-parallel structure typically built out of concrete or stone. Seawalls vary widely in length; some protect one residential parcel while others may run the length of a beach or road. Seawalls are typically vertical structures. A **revetment** is also a hard shore-parallel structure, but is typically sloped rather than vertical, and is typically composed of materials like rock or rip rap. A **bulkhead** is a vertical structure, like a seawall, but in general is applied in commercial or industrial settings (e.g. a marina) solely to retain upland soils from sliding into the water.

5. Structural shoreline protection measures can have a broad range of negative impacts on adjacent beaches and properties, on the natural environment, and on shoreline public access. Further, they are insufficient adaptation measures to respond to the latest sea level rise projections. For an in-depth discussion of these issues please see Chapter 4, Section 4.3.1.5, "Shoreline Protection Structures."

7.2.9 Modifying or Retrofitting Structures: Wet and Dry Floodproofing

1. In cases where flooding is anticipated under present or future conditions, property owners may choose to modify or retrofit residential, commercial, or industrial **structures** as a means of either **accommodation** or **protection**. This form of adaptation includes a series of floodproofing techniques which can be applied to **new construction** as well as to **existing construction** through a retrofit process. As with all adaptation

measures discussed in this chapter, options discussed here are not necessarily limited to those that would be permissible by all relevant regulatory agencies, including but not limited to the Rhode Island Building Code.

2. Some floodproofing techniques are designed to **accommodate** floodwaters in portions of a building that are most likely to flood (sometimes called “wet floodproofing”). The modifications are not designed to keep water out, but to minimize damage and facilitate easy cleanup. Techniques may include using **building materials** on lower, uninhabited building levels to ensure that walls and floors can be easily cleaned and dried (e.g. tile floors over wood floors; concrete walls rather than drywall) (FM Global 2016). They also include installing **wall openings, vents, and other mechanisms** to allow water to flow in and out, minimizing the potentially damaging effects of hydrostatic pressure on the building (NRC 2013; FEMA 2014), protecting the **underside of elevated buildings** (FEMA 2014), or the installation of **breakaway walls** that can be carried away during a storm without compromising the structural integrity of a building (NRC 2013). Last, techniques include **elevating primary living quarters and utilities** to the second floor, minimizing the exposure of first-floor infrastructure to flooding (Snow and Presad 2011).

3. Other floodproofing techniques are designed to **protect** structures and infrastructure from flooding by keeping the water out (“dry floodproofing”). These modifications are designed to seal the exterior of a building by using **impermeable building material or sealants** on lower-level infrastructure and installing **water-tight doors and windows** or enclosures over such openings (FM Global 2016; FEMA 2014). Use of flood barrier products certified to meet ANSI/FM 2510 standards is recommended, and a listing of certified products can be found in the National Flood Barrier Testing and Certification Program (Association of State Floodplain Managers 2018).

4. Other techniques may include installing **pumps** on all dry floodproofing to remove any water that does seep in (FEMA 2014). Pumps should be designed and installed with backup power in the event of a power outage (FM Global 2016). Another technique includes installing **backflow valves** to prevent potential backflow from sewer systems (FM Global 2016).

Box 3. FORTIFIED™:
The Insurance Institute for Business and Home Safety's Program for Resilient Home Construction

The Insurance Institute for Business and Home Safety (IBHS) offers the FORTIFIED™ program as a possible "code plus" adaptation measure for coastal property owners seeking to make their homes resilient to hazards. IBHS offers FORTIFIED™ programs for both homeowners and businesses. The FORTIFIED™ Home program encompasses a suite of engineering and building standards that can be applied to individual **structures** as either **existing** or **new construction**. Participating homeowners work with certified FORTIFIED™ evaluators and professionals (e.g. contractors or engineers). FORTIFIED™ addresses the hazards of hail, high winds, and hurricanes, and utilizes an incremental approach, outlining three levels of **protection** (Bronze, Silver, and Gold) that homeowners can choose in order to reduce their exposure to these hazards. Through the FORTIFIED™ program, coastal property owners can begin by redesigning their roof system (Bronze), but can improve their resilience by addressing windows, doors, and attached structures (Silver), and, further, by connecting their roof to their walls and their floors to their foundation (Gold).

Importantly, the FORTIFIED™ program does NOT address the primary sources of coastal hazard risk addressed in the Shoreline Change SAMP (storm surge, coastal erosion and sea level rise). Nonetheless, it represents the types of adaptation measures available to Rhode Island coastal property owners and decision-makers. It is important to note that CRMC offers an incentive for expedited permit review for applicants seeking FORTIFIED™ program designation. For further information, please see https://disastersafety.org/fortified/.

7.2.10 Relocation or Managed Retreat

1. **Relocation or managed retreat** refers to a suite of adaptation measures designed to remove people and property from potential exposure to sources of coastal hazard risk. This suite of adaptation measures can be applied to both **existing** or **new construction** and at the **site** or **structural scale**. While relocation or managed retreat can sound to some like a dramatic or daunting adaptation measure, there are a number of practical ways that coastal property owners and decision-makers can apply this approach incrementally in order to reduce their exposure to sources of coastal hazard risk.

2. Some of these practical methods of managed retreat were discussed earlier in this chapter within the context of **site selection**. Coastal property owners can select sites that are located sufficiently inland, away from sources of current and potential future

coastal hazard risk. This form of managed retreat can take place at the site or parcel level: a new potential coastal property owner can choose a parcel that is sufficiently inland. This can also take place at the structural level: a coastal property owner who already has a coastal parcel can choose to build – or rebuild – a structure at a site on that parcel that is furthest away from sources of coastal hazard risk.

3. When building on a site that is exposed to sources of coastal hazard risk, a coastal property owner can choose to build a structure that would be easy to **relocate** inland at some point in the near future. For example, the California Coastal Commission's Sea Level Rise Policy Guidance indicated that foundation designs and other aspects of new development should be designed to "not preclude future incremental relocation or managed retreat," further noting that deepened perimeter foundations, caissons, and basements may be difficult to remove in the future (California Coastal Commission 2015, p. 131).

4. In cases of existing construction, if possible, a property owner may choose to relocate that structure inland to another location on the same parcel, or to a new parcel entirely. For example, one of Matunuck's historic Browning Cottages was relocated after Superstorm Sandy in 2012. This cottage was the last of three iconic coastal cottages dating back to 1900. In 2013 the owner of the surviving cottage relocated it 35 feet inland on the same lot, and elevated it onto concrete pilings, following a CRMC permitting process (see e.g. Wilson 2013).

5. Last, at its most extreme, relocation or managed retreat may involve abandoning coastal properties or structures completely. A severe storm may even leave a property owner with insufficient land left on which to rebuild. For example, in the case of severe property damage due to a coastal storm, a property owner may choose to abandon the coastal property rather than rebuild on the same parcel.

7.3 Future Research Needs

1. This chapter has focused on technical adaptation techniques that can be applied at the individual site or structural level by individual coastal property owners. As has been stated throughout this chapter, the field of adaptation is rapidly changing. Further research is needed on the subject of adaptation in general and on the adaptation tools and techniques described in this chapter in order to refine and improve adaptation practices in the face of changing future conditions.

2. This chapter has not considered planning, policy and legal solutions to adaptation, nor the legal implications of the adaptation measures discussed herein. Topics not discussed herein, but which may be considered in this regard, include buy-out programs and legal options such as rolling easements. Further research is needed on all of these topics, particularly within the context of Rhode Island.

Box 4. ADAPTATION RESOURCES PROVIDED BY THE UNIVERSITY OF RHODE ISLAND COASTAL RESOURCES CENTER AND RHODE ISLAND SEA GRANT COLLEGE PROGRAM

Catalog of Adaptation Techniques for Coastal and Waterfront Businesses: Options to Help Deal with the Impacts of Storms and Sea Level Rise
http://www.beachsamp.org/wp-content/uploads/2015/05/adaptation_catalogue.pdf

Newport Resilience Assessment Tour: Newport Waterfront Overview Summary
http://www.beachsamp.org/wp-content/uploads/2015/06/NRAT.pdf.

Rhode Island Coastal Property Guide
http://www.beachsamp.org/relatedprojects/coastalpropertyguide/

Staying Afloat: Adapting Waterfront Businesses to Rising Seas and Extreme Storms (Proceedings of the 2014 Ronald C. Baird Rhode Island Sea Grant Science Symposium)
http://www.beachsamp.org/wp-content/uploads/2015/07/2014_baird_proceedings.pdf

7.4 References

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