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

[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).

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.

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)

[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.

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 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

[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.

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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 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:

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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

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

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, 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

[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."

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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.

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

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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 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;

[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.

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

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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

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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.

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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.

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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

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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.

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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.

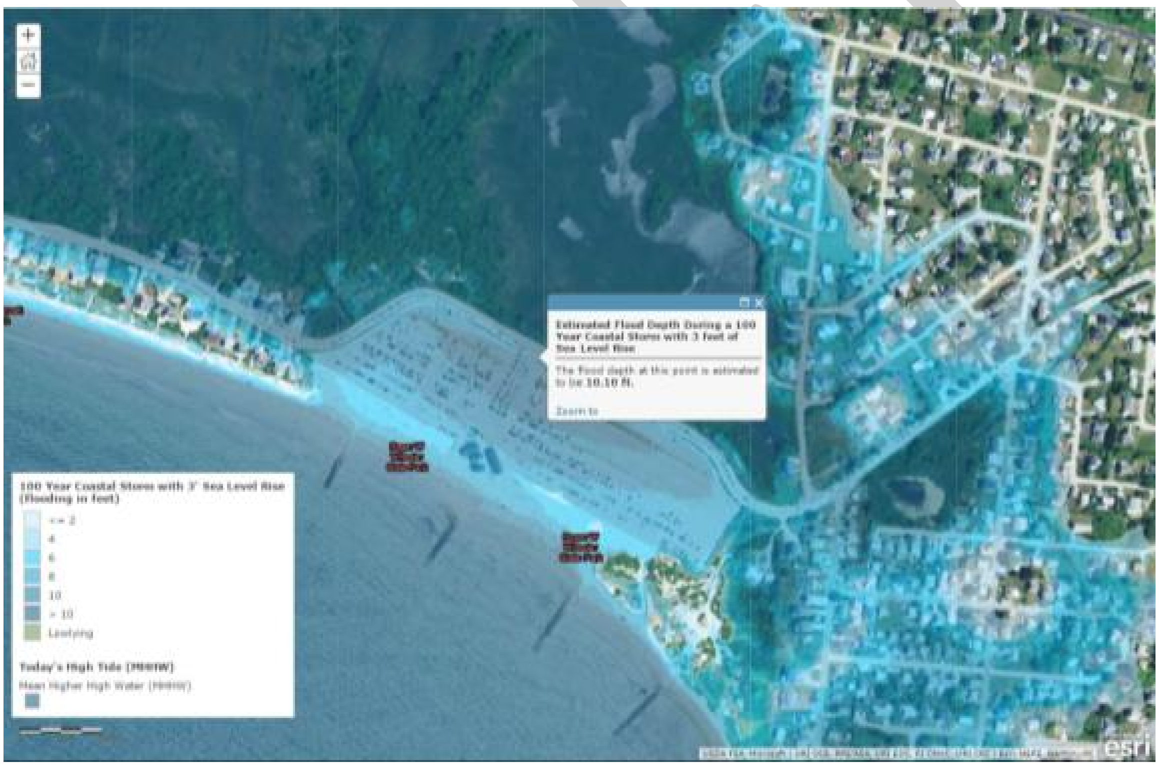

Figure 2. Mid-century Planning Scenario (3-foot sea level rise plus a 100-year return period storm surge) at Roger Wheeler State Park, Narragansett, RI. Colors represent flooding in feet with darker blue representing deeper water. Flooding across the darkest section of the beach parking lot in this picture 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.

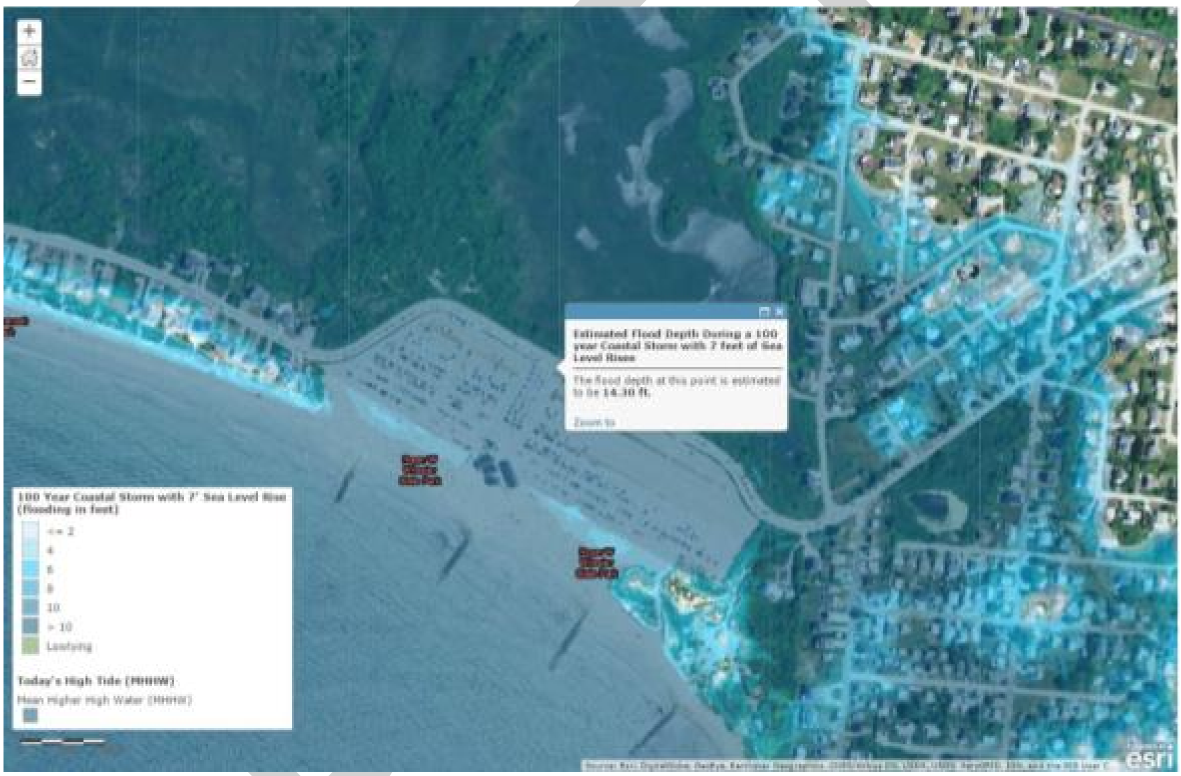

Figure 3. Long-range Planning Scenario (7-foot sea level rise plus a 100-year return period storm surge) at Roger Wheeler State Park, Narragansett, RI. Colors represent flooding in feet with darker blue representing deeper water. Flooding across the dark sections of the beach parking lot in this picture 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

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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.

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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. Table 1 below provides the percent chance of flooding for a range of

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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 Period (yrs)	Percent (%)chance flooding in any given year	Percent(%) chance of flooding occurring in this number of years							
		1	10	25	30	50	100	200	500
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

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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.

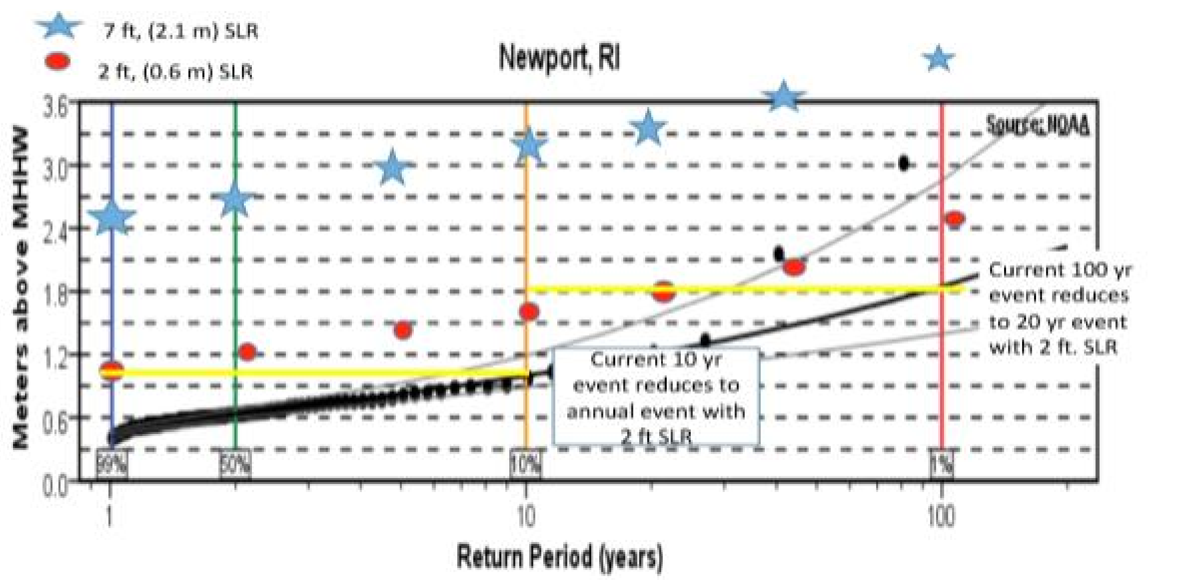

Figure 4. The effect of sea level rise on storm return periods (Spaulding, pers. comm.)

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

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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

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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).

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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

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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.

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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

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3.3 REFERENCES

Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St. Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (eds.)]. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.* Contribution of Working Group II to the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1757-1776.

American Society of Civil Engineers. 2017. *ASCE Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. July 2017. Available online at http://www.asce.org/structural-engineering/asce-7-and-sei-standards/.

Anderson, T.R., C.H. Fletcher, M.M. Barbee, N. Frazer, N., and B.M. Romine. 2015. Doubling of coastal erosion under rising sea level by mid-century in Hawaii. *Natural Hazards* 78, p. 75-103.

California Coastal Commission. 2015. "Sea Level Rise Policy Guidance." Adopted August 12, 2015. Online at https://documents.coastal.ca.gov/assets/slr/guidance/August2015/0_Full_Adopted_Sea_Level_Rise_Policy_Guidance.pdf

Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh. 2012. Determinants of risk: exposure and vulnerability. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

Climate Central. N.d. a. Surging Seas: Risk Zone Map. Online at http://sealevel.climatecentral.org/maps/risk-zone. Last accessed October 10, 2017.

----------. N.d. b. Surging Seas: Risk Finder. Online at https://riskfinder.climatecentral.org/about. Last accessed October 10, 2017.

Cole Ekberg, M.L., K.B. Raposa, W.S. Ferguson, K. Ruddock and E.B. Watson. 2017. Development and application of a method to identify salt marsh vulnerability to sea level rise. *Estuaries and Coasts* 40 (4), 694-710.

Crespin, R. 2013. "Sandy's big price for small businesses." The CSR blog, *Forbes Magazine*, January 23, 2013. Online at https://www.forbes.com/sites/csr/2013/01/23/sandys-big-price-for-small-businesses/#717e1e4c3ae1. Last accessed October 10, 2017.

The Data Center. 2016. "Facts for Features: Katrina Impact." Online at http://www.datacenterresearch.org/data-resources/katrina/facts-for-impact/. Last accessed October 10, 2017.

Federal Emergency Management Agency (FEMA). N.d. a. "Disaster declarations for Rhode Island." Online at https://www.fema.gov/disasters/grid/state-tribal-government/34?field_disaster_type_term_tid_1=All. Last accessed October 10, 2017.

--------. N.d. b. "Freeboard." Online at https://www.fema.gov/freeboard. Last accessed October 10, 2017.

--------. 2017a. "Loss dollars paid by calendar year." Online at https://www.fema.gov/loss-dollars-paid-calendar-year. Last accessed October 10, 2017.

---------. 2017b. "Flood Mapping Products: National Flood Hazard Layer (NFHL)." Online at https://www.fema.gov/national-flood-hazard-layer-nfhl. Last accessed October 10, 2017.

----------. 2017c. FEMA's National Flood Hazard Layer (Official). Online at https://fema.maps.arcgis.com/home/item.html?id=cbe088e7c8704464aa0fc34eb99e7f30. Last accessed October 10, 2017.

---------. 2011. Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas, 4th Edition. FEMA P-55. Online at https://www.fema.gov/media-library/assets/documents/3293.

--------- and National Association of Home Builders (NAHB) Research Center. N.d. "Designing for flood levels above the BFE." Home Builder's Guide to Coastal Construction Technical Fact Sheet No. 1.6. Online at https://www.fema.gov/media-library-data/20130726-1537-20490-8057/fema499_1_6_rev.pdf.

Gall, M., K.A. Borden, C.T. Emrich, and S. Cutter. 2011. The Unsustainable trend of natural hazard losses in the United States. *Sustainability* 3: 2157-2181. doi:10.3390/su3112157

Griggs, G., J. Arvai, D. Cayan, R. DeConto ,J. Fox, H.A. Fricker, R.E. Kopp, C. Tebaldi, E.A. Whitman (California Ocean Protection Council Science Advisory Team Working Group). 2017.

Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust, April 2017. Online at http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf.

Insurance Information Institute. N.d. "Facts about Flood Insurance." Online at http://www.iii.org/article/facts-about-flood-insurance. Last accessed October 10, 2017.

Insurance Institute for Business and Home Safety (IBHS). N.d. "Severe Weather Threatens Small Business Survival." Online at http://disastersafety.org/wp-content/uploads/2017/04/04-EZ-PREP-Infographic_FINAL.pdf. Last accessed October 10, 2017.

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

Lindsay, B. and F. McCarthy. 2015. S*tafford Act Declarations 1953-2014: Trends, Analyses, and Implications for Congress.* Report No. 7-5700, Congressional Research Service, July 14, 2015. Online at https://fas.org/sgp/crs/homesec/R42702.pdf. L

Moore, L.J., J.H. List, S.J. Williams, S.J., and D. Stolper. 2007. Modeling barrier island response to sea-level rise in the outer Banks, North Carolina. *Proceedings of the 6th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes.* Conference Paper, Coastal Sediments '07, New Orleans, LA.

Moser, S. C., M. A. Davidson, P. Kirshen, P. Mulvaney, J. F. Murley, J. E. Neumann, L. Petes, and D. Reed, 2014. Ch. 25: Coastal Zone Development and Ecosystems. In: C*limate Change Impacts in the United States: The Third National Climate Assessment*. J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 579-618. Online at http://nca2014.globalchange.gov/report/regions/coasts.

National Association of Realtors. 2015. "Homeowner Flood Insurance Affordability Act: Frequently Asked Questions." Online at https://www.nar.realtor/topics/national-flood-insurance-program-nfip/homeowner-flood-insurance-affordability-act. Last accessed October 10, 2017.

National Research Council (NRC). 2014. *Reducing Coastal Risk on the East and Gulf Coasts*. Washington, DC: The National Academies Press. doi:https://doi.org/10.17226/18811.

-------. 2012. *Disaster Resilience: A National Imperative*. Washington, DC: The National Academies Press. doi:https://doi.org/10.17226/13457.

NatureServe. 2013. "Tools for Coastal Climate Adaptation Planning: A Guide for Selecting Tools to Assist with Ecosystem-Based Climate Planning." Online at

DRAFT

https://connect.natureserve.org/sites/default/files/documents/EBM-ClimateToolsGuide-FINAL.pdf

NOAA (Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas). 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083, January 2017. Online at https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf.

NOAA. 2012. *Global Sea Level Rise Scenarios for the United States National Climate Assessment*. NOAA Technical Report OAR CPO-1, December 2012. Online at https://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf.

NOAA National Centers for Environmental Information. 2017. "Billion-dollar Weather and Climate Disasters: Summary Stats." Online at https://www.ncdc.noaa.gov/billions/. Last accessed June 22, 2017.

NOAA National Ocean Service. N.d. a. "Sea Level Trends." Online at https://tidesandcurrents.noaa.gov/sltrends/sltrends.html. Last accessed October 10, 2017.

NOAA National Ocean Service. N.d. b. Extreme Water Levels for Stations in Rhode Island. Online https://tidesandcurrents.noaa.gov/est/est_states.shtml?region=ri. Last accessed October 10, 2017.

NOAA National Ocean Service.N.d. c. Inundation Analysis Tool. Online at https://tidesandcurrents.noaa.gov/inundation/. Last accessed October 10, 2017.

NOAA Office for Coastal Management. N.d. a. "Welcome to the Coastal County Snapshots." Online at https://coast.noaa.gov/snapshots/. Last accessed October 10, 2017.

NOAA Office for Coastal Management. N.d. b. Sea Level Rise Viewer. Online at https://coast.noaa.gov/digitalcoast/tools/slr.html. Last accessed October 10, 2017.

----------. 2017a.C-CAP Land Cover Atlas. Online at https://coast.noaa.gov/ccapatlas/. Last accessed October 10, 2017.

----------. 2017b. Coastal Flood Exposure Mapper. Online at https://coast.noaa.gov/snapshots/. Last accessed October 10, 2017.

NOAA Office of Ocean and Coastal Resource Management (currently Office for Coastal Management). 2010. "Adapting to Climate Change: A Planning Guide for State Coastal

Managers." Online at https://coast.noaa.gov/czm/media/adaptationguide.pdf.

Nutter, F. 2013. Presentation from the Reinsurance Association of America at the "Build It Better Leadership Forum," May 17, 2013.

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.* A Technical Report prepared for the Rhode Island Coastal Resources Management Council Shoreline Change Special Area Management Plan.

Rhode Island Building Code Commission. N.d. "Mission Statement." Online at http://www.ribcc.ri.gov/. Last accessed October 10, 2017.

Rhode Island Coastal Resources Management Council (RI CRMC). 2015. RI Sea Level Affecting Marshes Model (SLAMM) Project Summary Report. Online at http://www.crmc.ri.gov/maps/maps_slamm/20150331_RISLAMM_Summary.pdf.

---------- and the University of Rhode Island. N.d. "Stormtools." Online at http://www.beachsamp.org/stormtools/. Last accessed October 10, 2017.

Rhode Island Emergency Management Agency (RIEMA). N.d. a. "Flood Insurance." Online at http://www.riema.ri.gov/resources/citizens/mitigation/insurance.php. Last accessed October 10, 2017.

-----------. N.d. b. "Floodplain Management." Online at http://www.riema.ri.gov//planning/floodplain/index.php. Last accessed October 10, 2017.

Rhode Island Department of Environmental Management (DEM). N.d. a. "Climate Change and Rhode Island." Online at http://www.dem.ri.gov/programs/air/climate-change.php. Last accessed October 10, 2017.

----------. N.d. b. "Wastewater Treatment Facilities." Online at http://www.dem.ri.gov/programs/water/wwtf/. Last accessed October 10, 2017.

Rhode Island Department of Health (DOH). N.d. "Climate Change." Online at http://www.health.state.ri.us/healthrisks/climatechange/. Last accessed October 10, 2017.

----------. 2013. "SafeWater RI: Ensuring Safe Water for Rhode Island's Future." July 2013. Online at http://health.ri.gov/publications/reports/2013EnsuringSafeWaterForRhodeIslandsFuture.pdf

Rhode Island Department of Transportation (DOT). N.d. Homepage. Online at www.dot.ri.gov/. Last accessed October 10, 2017.

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Rhode Island Division of Planning. N.d. "Rhode Island Executive Climate Change Coordinating Council." Online at http://www.planning.ri.gov/planning-areas/climate-change/riec4/. Last accessed October 10, 2017.

Rhode Island Division of Planning Statewide Planning Program. N.d. Homepage. Online at http://www.planning.ri.gov/. Last accessed October 10, 2017.

Rhode Island Infrastructure Bank. N.k. Homepage. Online at https://www.riib.org/. Last accessed October 10, 2017.

Raimondo, Governor Gina M. 2017. E*xecutive Order 17-10: Action Plan to Stand Up to Climate Change*. September 15, 2017. Online at http://www.governor.ri.gov/documents/orders/ExecOrder-17-10-09152017.pdf.

Ruppert, T. 2015. "Questions and Answers about the National Flood Insurance Program." Florida Sea Grant. Online at http://edis.ifas.ufl.edu/sg139. Last accessed October 10, 2017.

Spaulding, M.L., A. Grilli, C. Damon, G. Fugate, B.A. Oakley, T. Isaji and L. Schambach. 2017. 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.

Spaulding, M.L., A. Grilli, C. Damon, G. Fugate, T. Isaji, and L. Schambach. 2017. 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.

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

Spaulding, M. L., T. Isaji, C. Damon, and G. Fugate. 2015. Application of STORMTOOLS's simplified flood inundation model, with and without sea level rise, to RI coastal waters. American Society of Civil Engineers *Solutions to Coastal Disasters* Conference, Boston, MA, September 2015.

U.S. Environmental Protection Agency. N.d. CREAT. Online at https://www.epa.gov/crwu/build-resilience-your-utility. Last accessed October 10,2017.

----------. 2014. "Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans." August 2014. Online at https://www.epa.gov/sites/production/files/2014-09/documents/being_prepared_workbook_508.pdf.

U.S. Geological Survey. n.d. Coastal Hazards Change Portal. Online at

DRAFT

https://www.epa.gov/crwu/build-resilience-your-utility. Last accessed October 10, 2017.

Western Australia Planning Commission. 2014. “Coastal Hazard Risk Management and Adaptation Planning Guidelines.” Online at https://www.planning.wa.gov.au/dop_pub_pdf/CHRMAP_Guidelines.pdf

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3.4 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).

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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).

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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).

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