CHAPTER 7

Adaptation Strategies and Techniques for Coastal Properties

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7.1 Overview

1. Chapter 7, "*Adaptation Strategies and Techniques for Coastal Properties*," is intended to support CRMC's vision of providing guidance and tools for property owners and state and local decision-makers to proactively prepare and plan for, absorb, recover from, and successfully adapt to changing conditions associated with storm surge, coastal erosion and sea level rise. Information and tools contained in this chapter are designed to encourage "no regrets" decision-making within the Rhode Island Shoreline Change SAMP area.

2. This chapter is the culminating chapter of the Shoreline Change SAMP. It provides adaptation strategies and techniques that support Stage 3, "Choose measures of adaptation," of the overarching coastal risk assessment and management process discussed in Chapter 3. These adaptation strategies and techniques also provide specific options supporting Step 4, "Design Evaluation," of CRMC's Coastal Hazard Application Guidance for property owners, detailed in Chapter 5.

7.1.1 Chapter Objectives

1. This chapter provides an overview of adaptation strategies and tools that Rhode Island coastal property owners may be able to use in order to prepare their properties for the effects of climate change. Specifically, this chapter focuses on adaptation measures which can help property owners prepare for the risk associated with storm surge, coastal erosion and sea level rise. This chapter includes a definition of adaptation, discussion of associated concepts, and an explanation of how this relates to CRMC's regulatory authority and the goals, objectives and components of the Shoreline Change SAMP. Additionally, it includes short descriptions of a number of coastal adaptation strategies and techniques coupled with suggestions of sources of more information about these and other adaptation strategies.

2. Adaptation strategies and tools discussed in this chapter are suggested for possible use within the entire Shoreline Change SAMP area, including areas outside of CRMC jurisdiction. ***It is important to note that adaptation strategies and tools included in this chapter are not necessarily limited to those that are currently eligible for permitting by all relevant regulatory agencies, including CRMC, and some adaptation measures may require permitting by other agencies and/or may be prohibited by those agencies***. Rather, CRMC has included a broad suite of strategies and tools here in order to encourage consideration of the full range of options that may need to be considered in order to adapt Rhode Island's coastal communities to the full range of possible impacts

associated with storm surge, coastal erosion and sea level rise. Please refer to the RICRMP for current CRMC regulations.

3. CRMC recommends that coastal property owners adapt to the coastal hazards associated with climate change. This is recommended because of the risk associated with storm surge, coastal erosion, and sea level rise, coupled with the exposure and vulnerability of Rhode Island's coastal communities. Coastal communities will experience increasing damage to coastal properties, which may impact coastal communities and economies in a number of ways. Rhode Islanders' best protection against these damages is to begin implementing adaptation measures today.

4. This chapter focuses specifically on technical adaptation measures which can be implemented at the individual site or structural level by individual coastal property owners. This distinguishes this chapter from other adaptation guidance available from other state and federal agencies and non-governmental organizations, which often focus on planning, policy and legal solutions to be implemented at larger scales. Sources referenced in this chapter include some of the best available information on individual site or structural adaptation measures, and include publications from government entities, non-governmental organizations, scientists, and private companies known for their research on adaptation techniques.

7.1.2 Defining Adaptation and Associated Concepts

1. According to the Intergovernmental Panel on Climate Change (IPCC), adaptation refers to "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (Agard et al. 2014). Within the context of the Shoreline Change SAMP, adaptation refers to moderating or avoiding harm in Rhode Island's coastal communities by making adjustments to existing and future coastal development, whether on the structural, site-specific, or community-wide scales.

2. Proactive adaptation tools and strategies are typically framed within three main categories: protection, accommodation, and retreat. **Protection** strategies typically include use of either engineered or natural structures or measures to shield adjacent development or infrastructure from coastal hazards, without modifying the development or infrastructure itself. Coastal protection strategies are typically divided into so-called "**hard**" measures (e.g. seawalls or bulkheads) and "**soft**" measures (e.g. dunes or wetlands). **Accommodation** strategies typically include those involving the modification of the development or infrastructure (e.g. through elevation or

retrofitting). **Retreat** strategies include those involving moving or removing development or infrastructure (e.g. moving a structure further inland on a waterfront parcel) (California Coastal Commission 2015). This chapter includes discussion of adaptation strategies fitting into all three categories. Each adaptation strategy discussed herein is framed within the context of these categories.

3. Adaptation measures can include both **technical** approaches (e.g. elevating a home) and **policy or planning** approaches (e.g. developing an overlay zone). Additionally, adaptation measures can be applied to a range of scales, from the **individual structure** (e.g. a home), to a **site** (e.g. the parcel on which the home is based), to a **community or entire municipality**. Some adaptation measures are appropriate for retrofitting existing sites or structures, while others are intended only for new sites or structures. Last, different types of adaptation measures can be used independently or in combination (sometimes called "hybrid" approaches), depending on the unique needs of the site(s) and/or structure(s) in question. This chapter focuses primarily on technical adaptation measures appropriate for individual structures or sites on coastal properties, but illustrates those which can be applied across this full range of scales and for both existing and new sites or structures. This chapter includes explanation of the appropriate scale(s) of each adaptation strategy discussed herein.

4. Importantly, adaptation should not be confused with other approaches to emergency management. Emergency management, with regard to coastal hazards and other sources of risk, is typically framed as four phases: **mitigation**, **preparedness**, **response**, and **recovery**.

5. **Preparedness** typically refers to preparing for a coastal hazard immediately before a storm event (e.g. placing sandbags in front of your home). **Response** typically refers to actions taken during or immediately after a storm event to protect people and property (e.g. removing storm debris to gain access to your damaged home). **Recovery** typically refers to actions taken in the weeks or months following a storm event (e.g. rebuilding your home). By contrast, **mitigation** refers to changes to the building or site that are designed long before a storm that will reduce exposure. These changes can be solutions that do not require pre-storm preparedness actions, e.g. elevating your home, or solutions that require pre-planned preparedness actions using designed devices.

6. This document, and this chapter in particular, focuses primarily on adaptation as a type of **mitigation**. It does not address short-term preparedness actions. However, employing adaptation techniques may help coastal property owners reduce their overall risk by mitigating potential storm impacts, reducing the need for some types of preparedness actions, and reduce their post-storm recovery time.

7.1.3 Choosing to Adapt: Choices and Challenges

1. While this chapter lays out a broad range of adaptation choices, it is important to emphasize that Rhode Island's coastal property owners *must* adapt – because the coastal hazards that are the focus of the Shoreline Change SAMP will require proactive planning in order to avoid future economic, environmental, and personal harm. Coastal property owners and decision-makers will need to choose *which* adaptation measures are most appropriate for use at the structure, site or area under consideration.

2. While adaptation may seem costly and inconvenient to some, it can actually be a significant cost savings in the long run. A 2017 study by the National Institute of Building Sciences found that investments in mitigation measures in new construction that exceeded provisions of 2015 model building codes resulted in a benefit-cost ratio of 5 to 1 for riverine flood hazards and 7 to 1 for hurricane surge hazards. In other words, for every $1 spent on adaptation, $5 is saved with regard to riverine flood risk and $7 is saved with regard to hurricane surge risk. Further, this study found that in Rhode Island, choice of first floor building height above BFE (2 to 6 feet) resulted in a benefit-cost ratio of 6.7 to 3.8. For further information, please see National Institute of Building Sciences 2017.

3. In all cases, choice of adaptation measure(s) is context-specific. Individual coastal property owners and decision-makers must evaluate the specific structure, site, or area in question, and what is known about the exposure of that structure or site to sources of coastal hazard risk. The property owner and decision-maker can then use this contextual information to select adaptation measures that best suit the structure or site as well as the sources of risk.

4. Coastal property owners attempting to proactively choose adaptation measures will be challenged to look to the future, beyond existing regulatory requirements. For example, over time, rising sea levels may cause an area in a mapped FEMA A Zone, subject to at least a 1% annual chance flood event, to be remapped in the future as a V Zone, with the same annual flood chance but now subject to severe wave action. In another example, an area that is *outside* of the current mapped FEMA floodplain may be remapped in the future as *inside* the floodplain.[1] (For information on how property owners can use CERI STORMTOOLS Design Elevations to address this problem, see Shoreline Change SAMP Chapter 3.) This future scenario would require different

[1] The A and V flood zones were designed for insurance rate pricing for the National Flood Insurance Program (NFIP) and for regulatory enforcement rather than an acceptable risk for the building owner. History has shown nature does not care about regulations; Hurricanes Katrina, Sandy, and Harvey are examples where the flooding exceeded the mapped regulatory boundaries/flood elevations and thus had severe impact on the flooded properties.

adaptation measures. While uncertainty about this and other aspects of the changing coast creates challenges for choosing adaptation measures, it also underscores the importance of proactive planning for the future.

5. Choice of adaptation measure(s) to apply to a specific structure, site or region must take into account all coastal hazard risk factors. The Shoreline Change SAMP is focused on three sources of coastal hazard risk: storm surge, coastal erosion, and sea level rise. Choice of adaptation measure must consider all three of these risk factors as well as the synergistic effects of these sources of risk. Further, adaptation measures must be evaluated for potential inclusion in the design phase of a new construction project, or for the feasibility of using in the modification or retrofit of an existing structure. Additionally, adaptation choice must consider tradeoffs between different adaptation measures that address different sources of risk. For example, a property owner concerned about flooding associated with storm surge and sea level rise may choose elevation as an appropriate adaptation measure. However, while elevation might *reduce* a structure's exposure to flooding, it may *increase* that structure's exposure to high winds. Further, elevation may increase the likelihood of damage to infrastructure which cannot be elevated, such as onsite wastewater treatment systems, utility connections, decks, and stairways.

6. Choice of adaptation measure must also include consideration of its effect on shoreline public access. CRMC requires that any adaptation measures implemented avoid loss of shoreline public access.

7. Choice of adaptation measure(s) to apply, and how best to apply them, must be informed by context, i.e. the specific attributes of the structure, site, or region as well as what is known to date about the exposure of that place to storm surge, coastal erosion, and sea level rise. This must include consideration of the **design life** of the structure (s) in question.

8. Choice of adaptation measure must also include consideration of the **best available projections of flood risk** at that site. As discussed in Chapter 3, STORMTOOLS Design Elevations, under development for all Rhode Island coastal communities, will provide alternative base flood elevation (BFE) estimates for 100-year storms that can be used to guide site-specific adaptation decisions.

7.1.4 Adaptation: A Rapidly Developing Field

1. The field of adaptation is rapidly evolving, along with scientists' and managers' understanding of climate change and the associated sources of coastal hazard risk. New

adaptation strategies, tools and technologies are being developed and existing adaptation measures improved at a rapid pace. As such, it is not possible to include an exhaustive list of all potential adaptation strategies and tools here, nor to include all of the most current development in the field. This chapter is thus intended to introduce coastal property owners and decision-makers to the concept of adaptation; provide examples of the range of adaptation options which may be available; and direct readers to sources of more detailed or up-to-date information.

2. Given the rapidly-evolving nature of the adaptation field, many adaptation techniques are not yet allowable under existing state and municipal permitting programs or in all potentially vulnerable areas. Individual coastal property owners should check with their regulatory agencies regarding the potential use of specific adaptation techniques in specific sites.

7.2 Adaptation Tools and Strategies for Coastal Properties

7.2.1 CRMC Guidance on Coastal Property Adaptation Tools and Strategies

1. This section includes brief descriptions of a range of adaptation tools and strategies which property owners and decision-makers may choose to consider for use at individual coastal properties. **It is important to note that adaptation strategies and tools included here are not necessarily limited to those that are currently eligible for permitting by all relevant regulatory agencies, including CRMC, and some adaptation measures may require permitting by other agencies and/or may be prohibited by those agencies. Please refer to the RICRMP for current CRMC regulations**.

2. In general, the CRMC prefers “natural” or “nature-based infrastructure” solutions for adaptation; many such solutions are described below in section 7.2.6. Such solutions are often particularly appropriate at the site level. However, the CRMC recognizes that so-called “grey infrastructure” solutions, such as those described below in section 7.2.7 and section 7.2.8, are appropriate in certain cases, particularly for public infrastructure.

3. Table 1 includes a summary of the coastal property adaptation tools and strategies discussed in this chapter. Each tool and strategy is detailed in the chapter text. Additionally, references are included throughout the chapter and at the end for more information on each adaptation measure.

Table 1. Summary table of coastal property adaptation tools and techniques

Strategy	Existing or New Construction	Protection, Accommodation or Retreat	Site or Structure
Site selection	New	Accommodation or Retreat	Site or structure
Distance inland	Existing or new	Retreat	Site or structure
Elevation	Existing or new	Accommodation	Site or structure
Terrain management			
Site grading	New	Accommodation	Site
Site layout	New	Accommodation	Site
Drainage	Existing or new	Accommodation	Site or structure
Natural or nature-based measures			
Coastal bank protection	Existing or new	Protection	Site
Living breakwaters	Existing or new	Protection	Site
Dune restoration	Existing or new	Protection	Site
Beach replenishment	Existing or new	Protection	Site
Coastal wetland or enhancement	Existing or new	Protection	Site
Flood barriers			
Floodwalls	Existing or new	Protection	Site
Temporary flood barriers	Existing or new	Protection	Site
Floodgates and tide gates	Existing or new	Protection	Site
Berms	Existing or new	Protection	Site
Structural shoreline protection measures			
Seawalls	Existing or new	Protection	Site
Revetments	Existing or new	Protection	Site
Bulkheads	Existing or new	Protection	Site
Wet Floodproofing			
Choice of building materials	Existing or new	Accommodation	Structure
Wall openings and vents	Existing or new	Accommodation	Structure
Protect underside of elevated buildings	Existing or new	Accommodation	Structure
Elevation of utilities and living quarters	Existing or new	Accommodation	Structure
Breakaway walls	Existing or new	Accommodation	Structure
Dry Floodproofing			
Impermeable building materials or sealants	Existing or new	Protection	Structure
Watertight doors or windows	Existing or new	Protection	Structure
Pumps and drains	Existing or new	Protection	Structure
Backflow valves	Existing or new	Protection	Structure
Other Retrofitting Techniques			
Fortified™	Existing or new	Protection	Structure
Relocation or Managed Retreat			

Site selection	Existing or new	Retreat	Site or structure
Construct moveable structure	New	Retreat	Structure
Relocate	Existing	Retreat	Site or structure

7.2.2 Site Selection

Box 1. FM GLOBAL: A RHODE ISLAND-BASED SOURCE OF INFORMATION ON ADAPTATION STRATEGIES

FM Global is a property insurance company with corporate headquarters in Johnston, RI dedicated to helping businesses manage risk, prevent losses and build resilience to a broad range of natural and human-made hazards. CRMC has drawn upon FM Global's expertise in developing the Shoreline Change SAMP because the Rhode Island-based company is widely recognized as a leader in conducting adaptation research and certifying new adaptation products, and has developed an approach to the adaptation process that CRMC considers useful for individual coastal property owners. FM Global is known for its work developing adaptation solutions to facilitate property and business continuity; their business model is based on working with the corporate clients they insure to help them design resilient infrastructure and systems. They conduct engineering research on adaptation for use with their own clients and to enhance external standards and codes. A wealth of this information is available in the form of FM Global data sheets. Detailed data sheets are available on general topics such as floods, green roof systems, and wind design, as well as specific strategies for types of infrastructure including electrical systems and fire suppression. While this information is primarily assembled for business clients, many of these adaptation strategies are appropriate for residential coastal property owners. Data sheets can be accessed at www.fmglobaldatasheets.com.

1. Site selection is one of the most important adaptation strategies, and is recommended as the place to start, when considering **new construction**. New construction can include either partial construction (e.g. an addition or modification of an existing structure) or full construction, and can include either development of a previously undeveloped site, or demolition and reconstruction of a developed site. This adaptation measure, a form of **accommodation**, can apply to either **the entire site** (in other words, the parcel of land being purchased and developed) or to the specific building site on the parcel where **structures** or infrastructure will be developed.

2. In some cases, a prospective property owner may be choosing among possible coastal parcels for purchase and development. When choosing among parcels, site selection should be informed by the best available science showing the exposure of that parcel to

storm surge, coastal erosion and sea level rise. Additionally it should consider other potential risks, including but not limited to riverine flooding or ponding from insufficient stormwater drainage. Further, it should consider both horizontal and vertical dimensions – in other words, ***elevation*** above projected flood areas as well as ***distance*** inland (see below for further discussion). Choice of a parcel that is minimally exposed to sources of coastal hazard risk is one of the most effective adaptation strategies and can be much easier and less expensive than implementing adaptation at a highly-exposed site.

3. In other cases, a property owner may already own a parcel, but may be able to choose among possible sites on that parcel for building a home or other structure. When choosing a building site on a given parcel, site selection should similarly consider both horizontal and vertical dimensions – ***elevation*** above projected flood areas as well as ***distance*** inland (see below for further discussion). Building site selection at this scale could make a significant difference in reducing a property's exposure to sources of coastal hazard risk.

4. Whether at the scale of an entire parcel or a specific structure, site selection must also include ***site access.*** Site access includes transportation routes facilitating access to/from the parcel (e.g. public or private roads), as well as driveways, parking areas, paths, and other means of access on the parcel to/from the buildings themselves. It also includes access for other infrastructure, including power, water, and sewer. Again, property owners should consider both ***elevation*** above projected flood areas as well as ***distance*** inland. Choice of low-exposure access areas is critical for enabling safe access to/from the site in the event of a storm.

5. For example, FM Global recommends that sites be chosen where the entire site and all access routes are outside of 500-year return period flood areas, by both elevation and footprint. They further recommend that sites where structures will be placed be above the 500-year return period flood area as well as an additional 1 to 2 feet of freeboard. Last, they suggest that the building site be at least 500 feet away from areas of direct wave impacts and/or high flood velocities (FM Global 2016). Importantly, these recommendations do not consider projected sea level rise. CRMC recommends that coastal property owners consider all three coastal hazards addressed in the Shoreline Change SAMP – storm surge, coastal erosion, and projected sea level rise – when selecting a site.

7.2.3 Distance Inland

1. Distance inland is another important and effective adaptation strategy that allows for **accommodation** of changing coastal conditions. This strategy was discussed above within the context of site selection, but is further detailed here because of its fundamental importance as an adaptation measure. This strategy can be applied to both **new construction** and **existing construction**, and to both the **entire site** or to individual **structures**. Selection of an appropriate distance inland enables property owners to avoid direct wave impacts or high flood velocities (FM Global 2016). When considering distance inland, property owners should consider the best available site-specific information about potential exposure to storm surge, coastal erosion, and sea level rise.

2. In cases of **new construction**, choice of distance inland can inform both selection of the overall site as well as where on the site buildings and infrastructure are constructed (e.g. a home could be constructed on a waterfront parcel, but as far inland as possible). In cases of **existing construction**, there may be opportunities to modify existing structures with consideration of distance inland. For example, an addition onto an existing building could be designed and constructed on the upland side of the building, or an entire building could be relocated toward the upland side of an existing parcel. The latter can be considered a form of **managed retreat**, which is further discussed below in section 7.2.11.

7.2.4 Elevation

1. A widely-used adaptation technique is **elevation** of either an entire site or of individual buildings and/or key equipment on that site. This strategy was discussed above within the context of site selection, but is further detailed here because of its fundamental importance as an adaptation measure. Elevation is a form of **accommodation**. While it may mitigate exposure to flooding, it does not reduce exposure to erosion. When applied at a **site** scale, elevation involves filling or regrading a site to a height above a given predicted flood elevation, and is more commonly applied in cases of new construction. At the **structural** scale, elevation involves designing a new building or retrofitting an existing building to raise it above flood elevation through the use of raised foundations or elevated structures. In some cases, buildings may be elevated on piles; in other cases, primary living quarters and utilities may be elevated to the second floor, minimizing the exposure of first-floor infrastructure to flooding (Snow and Presad 2011). FM Global (2016) recommends additional considerations, including not building foundations in areas subject to high or moderate velocity flows; building structures to resist all flood-related loads and conditions; ensuring consideration of other applicable

loads, such as gravity and wind; considering all appropriate load combinations; and using load combinations, load factors, and resistance factors as specified in governing model codes and standards (FM Global 2016).

2. One challenge with the use of elevation as an adaptation measure is elevating on **fill**. Elevation is required in certain FEMA mapped flood zones to meet minimum heights in accordance with mapped FEMA base flood elevations (BFEs). Some forms of elevation may involve fill. However, fill is prohibited as a means of structural support in FEMA mapped V-zones (44 CFR 60.3(e)(6); see generally the FEMA National Flood Insurance Program's floodplain management regulations for more information). Further, using fill to elevate homes may not always be an appropriate solution. Use of fill in coastal areas can be very costly. Fill can also have downstream impacts because it is susceptible to erosion (e.g. FEMA 2009) - for example, a flood event could wash fill material into adjacent coastal wetlands or other sensitive habitat types. Further, fill can increase flooding and/or erosion on the site and/or on adjacent properties.

3. A critical consideration for elevation, whether at the site or structural scale, is what height to which the site or structure should be raised. The FEMA National Flood Insurance Program requires the lowest floor of structures built in Special Flood Hazard Areas, areas FEMA deems to be exposed to the 100-year return period flood event, to be at or above the base flood elevation shown on Flood Insurance Rate Maps (FIRMs). These maps are based on past conditions and do not account for projected sea level rise. FM Global recommends additional precautions, elevating buildings above the predicted 500-year flood elevation and including 1 to 2 feet of freeboard (FM Global 2016). The STORMTOOLS Design Elevation (SDE) maps produced through the Shoreline Change SAMP provide information that will enable homeowners to take further precautions by elevating to a height that considers projected sea level rise. For more information, please see Chapter 3 as well as www.beachsamp.org.

7.2.5 Terrain Management

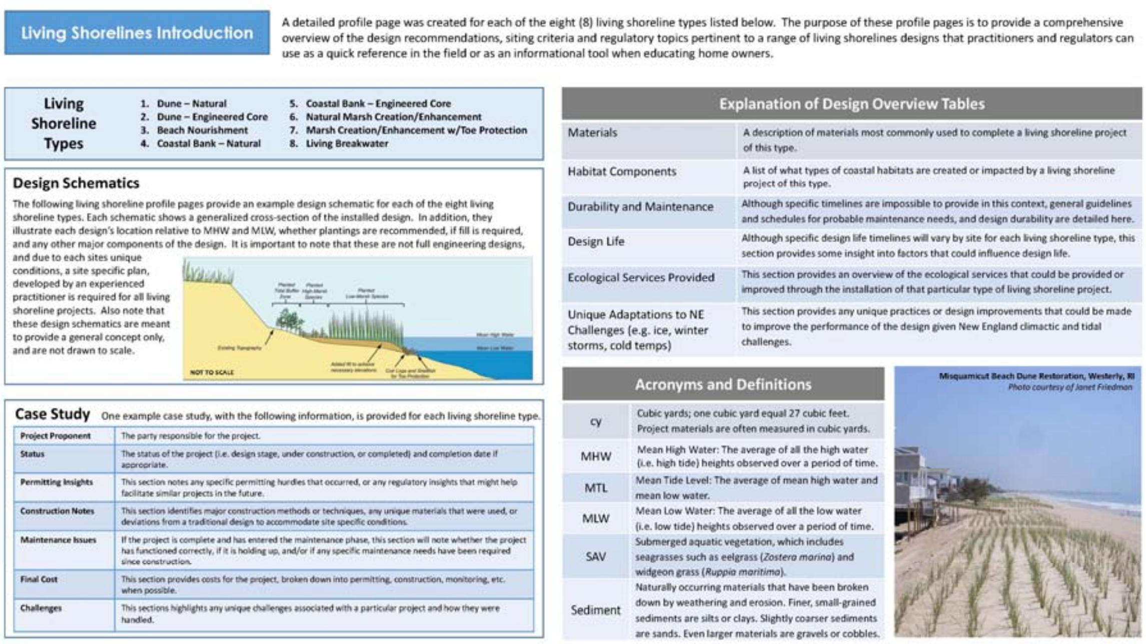
1. This section describes some commonly-used terrain management adaptation strategies. Terrain management strategies are generally reserved for FEMA mapped A Zones, because V Zones are subject to wave attack. Some terrain management strategies may also be considered standard construction practices, while others may also be considered forms of natural or nature-based adaptation. Other adaptation strategies described below in Section 7.2.6, Natural and Nature-Based Adaptation Strategies, and Section 7.2.7, Site Protection Through Flood Barriers, may also be considered forms of terrain management; please refer to those sections accordingly.

2. Terrain management strategies to address flooding include a range of related adaptation strategies that can be applied at the **site** scale as means of **accommodation**. In some cases, adaptation strategies described in this section may also be built into a **structure**. These strategies help manage flood waters by ensuring that flood exposure is neither created nor exacerbated by site layout, grading, and flood and stormwater (e.g. rain and melting snow) management.

3. Specific means of managing terrain to manage floodwaters include: **grading** a site such that flood and stormwater flows away from buildings and infrastructure; designing **site layout** such that runoff from off-site areas is considered and that water routing is planned to avoid contact with buildings and infrastructure; and designing site-wide **drainage systems** to accommodate flood and stormwater volumes and velocities associated with future storm events and to avoid potential clogging due to storm debris or landscaping materials (FM Global 2016). There are many natural or nature-based techniques that can be incorporated into terrain management strategies to further manage flooding; please see section 7.2.6 below.

Box 2. THE STATE OF THE PRACTICE OF LIVING SHORELINES IN NEW ENGLAND

In 2017, the Northeast Regional Ocean Council (NROC) partnered with The Nature Conservancy (TNC) under a grant from NOAA to assess the state of practice of living shorelines in New England. NROC and TNC hired Woods Hole Group, which completed a comprehensive review of the state of the practice of coastal natural and nature-based adaptation approaches in New England. This project, "Living Shorelines in New England: State of the Practice," culminated in a comprehensive report, a series of profiles of living shoreline techniques, and a living shorelines applicability index. These resources provide Rhode Island coastal property owners and decision-makers with an up-to-date and accessible review of natural and nature-based adaptation techniques that can work in New England, despite limitations such as colder waters and a shorter growing season. Of particular use are the profile pages, which provide a comprehensive overview of design recommendations, siting criteria, and regulatory information for eight different living shoreline types (natural or engineered dunes; beach replenishment; natural or engineered coastal banks; marsh creation/enhancement, either natural or with toe protection; and living breakwaters). These profile pages contain design schematics, illustrative case studies, and a key explaining selection characteristics (e.g. "tidal range" and "nearby sensitive resources").



Living Shorelines Introduction

A detailed profile page was created for each of the eight (8) living shoreline types listed below. The purpose of these profile pages is to provide a comprehensive overview of the design recommendations, siting criteria and regulatory topics pertinent to a range of living shorelines designs that practitioners and regulators can use as a quick reference in the field or as an informational tool when educating home owners.

Living Shoreline Types

1. Dune – Natural
2. Dune – Engineered Core
3. Beach Nourishment
4. Coastal Bank – Natural
5. Coastal Bank – Engineered Core
6. Natural Marsh Creation/Enhancement
7. Marsh Creation/Enhancement w/Toe Protection
8. Living Breakwater

Design Schematics

The following living shoreline profile pages provide an example design schematic for each of the eight living shoreline types. Each schematic shows a generalized cross-section of the installed design. In addition, they illustrate each design's location relative to MHW and MLW, whether plantings are recommended, if fill is required, and any other major components of the design. It is important to note that these are not full engineering designs, and due to each sites unique conditions, a site specific plan, developed by an experienced practitioner is required for all living shoreline projects. Also note that these design schematics are meant to provide a general concept only, and are not drawn to scale.

NOT TO SCALE

Case Study One example case study, with the following information, is provided for each living shoreline type.

Project Proponent	The party responsible for the project.
Status	The status of the project (i.e. design stage, under construction, or completed) and completion date if appropriate.
Permitting Insights	This section notes any specific permitting hurdles that occurred, or any regulatory insights that might help facilitate similar projects in the future.
Construction Notes	This section identifies major construction methods or techniques, any unique materials that were used, or deviations from a traditional design to accommodate site specific conditions.
Maintenance Issues	If the project is complete and has entered the maintenance phase, this section will note whether the project has functioned correctly, if it is holding up, and/or if any specific maintenance needs have been required since construction.
Final Cost	This section provides costs for the project, broken down into permitting, construction, monitoring, etc. when possible.
Challenges	This sections highlights any unique challenges associated with a particular project and how they were handled.

Explanation of Design Overview Tables	
Materials	A description of materials most commonly used to complete a living shoreline project of this type.
Habitat Components	A list of what types of coastal habitats are created or impacted by a living shoreline project of this type.
Durability and Maintenance	Although specific timelines are impossible to provide in this context, general guidelines and schedules for probable maintenance needs, and design durability are detailed here.
Design Life	Although specific design life timelines will vary by site for each living shoreline type, this section provides some insight into factors that could influence design life.
Ecological Services Provided	This section provides an overview of the ecological services that could be provided or improved through the installation of that particular type of living shoreline project.
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	This section provides any unique practices or design improvements that could be made to improve the performance of the design given New England climactic and tidal challenges.

Acronyms and Definitions	
cy	Cubic yards; one cubic yard equal 27 cubic feet. Project materials are often measured in cubic yards.
MHW	Mean High Water: The average of all the high water (i.e. high tide) heights observed over a period of time.
MTL	Mean Tide Level: The average of mean high water and mean low water.
MLW	Mean Low Water: The average of all the low water (i.e. low tide) heights observed over a period of time.
SAV	Submerged aquatic vegetation, which includes seagrasses such as eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*).
Sediment	Naturally occurring materials that have been broken down by weathering and erosion. Finer, small-grained sediments are silts or clays. Slightly coarser sediments are sands. Even larger materials are gravels or cobbles.

Misquamicut Beach Dune Restoration, Westerly, RI
Photo courtesy of Janet Friedman

The state of practice of natural and nature-based adaptation measures is rapidly changing, and so property owners using this 2017 guide are advised to seek out the most up-to-date information on the technique of interest to them. For further information please see https://www.conservationgateway.org/ConservationPractices/Marine/Pages/new-england-living-shorelines.aspx.

7.2.6 Natural and Nature-Based Adaptation Measures

1. Natural or nature-based adaptation measures, sometimes described as "non-structural," "living shorelines," "natural" or "green infrastructure," "soft armoring," or similar terms, refers to the use of natural features and systems to reduce the exposure of residential and other coastal properties and infrastructure while enhancing habitat and ecosystem services. Common examples include protection or restoration of beaches sand dunes; vegetated buffers; and protection or restoration of coastal wetland systems (California Coastal Commission 2015). Natural and nature-based adaptation measures include a broad suite of strategies that can be implemented at either the **site** or the **structural** scale, and for either **existing** or **new construction**, as a means of either **protection** or **accommodation**. Natural or nature-based strategies can be used by themselves or in combination with traditional ("hard" or "grey infrastructure" strategies) to create hybrid adaptation approaches. Such hybrid approaches are under consideration by CRMC, but some may not be permitted under the current regulations. Please refer to the RICRMP for the most current CRMC regulations.

2. The CRMC prohibits new structural shoreline protection measures on barriers classified as undeveloped, moderately developed, and developed, and on all shorelines adjacent to Type I waters (see the RICRMP §1.3.1(G)(3)). Additionally, the CRMC favors non-structural methods of shoreline protection (see the RICRMP §1.3.1(G)(1)).

3. Natural or nature-based adaptation strategies are frequently advocated over "hard" adaptation strategies because they can provide other ecological, economic, social and cultural benefits. These can include recreational areas, positive visual impacts, water quality improvements, and habitat for a broad range of species (California Coastal Commission 2015; NRC 2014).

4. When considering natural or nature-based adaptation strategies, property owners and decision-makers should consider a few important caveats. First, the use of natural or nature-based approaches in coastal adaptation is relatively new, many such approaches are still being tested and refined, and more research is needed on these topics; the property owner should evaluate what is known about the effectiveness of a given approach when considering its use on her or his property. Additionally, natural or nature-based approaches can be costly and can require large amounts of space, though are potentially less costly than structural shoreline protection measures. Finally, not all such approaches may be ecologically beneficial in all such places. Property owners should consider natural or nature-based approaches that are appropriate to the amount

of space available and the ecological characteristics of their site and the surrounding area (California Coastal Commission 2015; NRC 2014).

5. **Coastal bank protection** encompasses a suite of methods used to stabilize the sediment in coastal banks. These methods can involve a variety of “hard” and “soft” materials and differing degrees of engineering in their design. Coastal bank protection strategies are designed to absorb storm surge, reduce wave energy and protect against coastal erosion, and are implemented as a natural alternative to bulkheads and revetments. Coastal bank **protection** projects can be applied at the **site** scale adjacent to **existing** or **new construction** (Woods Hole Group 2017).

6. **Natural** coastal bank protection projects include use of coir (natural fiber) rolls or logs, root wads, natural fiber blankets, and planted native vegetation such as marine grasses. Combining these materials with re-grading of the bank to reduce steepness and create a more dissipative slope can help to minimize erosion. **Engineered** coastal bank protection projects involve similar techniques such as regrading or terracing banks and planting native vegetation, but also incorporate the use of engineered cores, such as coir envelopes or sand-filled tubes (Woods Hole Group 2017). Engineered coastal bank designs might also incorporate the limited use of hard materials such as stone to stabilize the toe of the slope. For detailed guidance on these techniques, including local examples and siting criteria, please see Woods Hole Group 2017, particularly profile pages 4 and 5 (“Coastal Bank – Natural” and “Coastal Bank – Engineered Core”).

7. **Living breakwaters** are structures constructed in the nearshore environment as a means of breaking waves before they reach the shoreline. They are designed as a means of wave attenuation and coastal erosion control and a means of promoting sediment retention. Living breakwaters are typically oyster or mussel reefs. Their structure is often constructed out of shell bags, stone, or cast concrete structures such as reef balls (Woods Hole Group 2017). For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile page 8 (“Living Breakwater”).

8. **Dune restoration** is the practice of constructing new or restoring existing dunes as a means of dissipating wave energy and addressing storm surge and coastal erosion. Dune restoration can involve both natural and engineered techniques. For natural projects, sediments are either placed on an existing dune, or a mound of sediments are built up in an appropriate site in order to create an artificial dune. Engineered projects involve use of an engineered core, constructed using coir envelopes or similar structures, in order to stabilize the dune (Woods Hole Group 2017). For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile pages 1 and 2 (“Dune – Natural” and “Dune – Engineered Core”).

9. **Beach replenishment** (also sometimes called "beach fill" or "beach nourishment") is the practice of replacing sediment along eroding beaches, often elevating or widening a beach. This activity is often thought of as a means of managing a recreational resource, but beach replenishment increases beaches' ability to protect upland structures against wave energy and storm surge. This activity is often paired with dune restoration (above) (Woods Hole Group 2017). For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile page 3 ("Beach Nourishment").

10. **Coastal wetland creation or enhancement** involves a range of methods to stabilize or enhance coastal wetlands, which can help stabilize shorelines and dissipate wave energy. Natural coastal wetland creation or enhancement involves planting marsh vegetation such as cordgrass, which provides a minimally intrusive means of enhancing marsh. Coastal wetland enhancement may also include installing toe protection materials in order to assist with coastal wetland stabilization. These techniques may include natural fiber rolls, shell bags, or stone (Woods Hole Group 2017). In some cases, fill material can be used to create elevations suitable for marsh vegetation, though it should be noted that additional state and regulatory restrictions apply to projects that involve placement of material below Mean High Water. For detailed guidance on these techniques please see Woods Hole Group 2017, particularly profile pages 6 and 7 ("Natural Marsh Creation/Enhancement" and "Marsh Creation/Enhancement w/ Toe Protection."). See Shoreline Change SAMP Chapter 4 for further discussion of Rhode Island's coastal wetlands' exposure to sources of coastal hazard risk and of ongoing marsh restoration efforts.

7.2.7 Flood Barriers

1. Flood barriers provide one means of **protection** from exposure to flooding. Although commonly used, flood barriers must be considered with extreme caution. CRMC staff have found that flood barriers are often either undersized or under-designed for the sources of coastal hazard risk they are intended to address. Further, flood barriers may simply not be feasible means of protecting a site from storm surge and sea level rise given the latest sea level rise estimates (discussed in Chapters 2 and 3 of the Shoreline Change SAMP). CRMC staff have also found that flood barriers may be particularly ineffective in a FEMA mapped V-Zone or Coastal A-Zone as they do not effectively protect against wave energy, and may simply contribute to the amount of debris generated during a storm event. Designing flood barriers to address these sources of risk can therefore be very costly and may also lead to legal issues given the permitting and construction of such large structures.

2. Flood barriers can be applied to **existing** or **new construction**, and can protect a **site** or in some cases be built into a **structure**. Flood barriers are typically constructed along the perimeter of a site and may include a mix of different types of flood barriers. Choice of flood barrier adaptation measure(s) must be guided by the best available information on the exposure of the site to flooding associated with storm surge and sea level rise. Flood barriers should be specifically engineered and designed for their purpose; this includes certification to a national standard. FM Global (2016) advises that flood barrier design must address site-specific characteristics including the adjacent structures, site hydrology, hydraulics, drainage, and soils. Further, FM Global advises consideration of the property owner's ability to operate and maintain the system. Any flood barrier must be designed by an engineering professional who will evaluate all of these considerations and design a barrier appropriate for the site. Again, CRMC staff have found that flood barriers may be particularly ineffective in a FEMA mapped V-Zone or Coastal A-Zone as they do not adequately protect against wave energy.

3. Flood barriers include **permanent** and semi-permanent barriers as well as **temporary** structures. Permanent barriers are those which are permanently installed, even though they may not always be in use, and include but are not limited to **floodwalls, flood gates, berms,** and **tide gates**. Semi-permanent flood barriers have permanent foundations with removable columns and barrier panels that can be installed in advance of flood conditions, and taken down after flood waters recede (see e.g. EKO Flood USA n.d. or Flood Control America 2016). Temporary flood barriers include those which are not permanently installed but can be deployed in anticipation of a flood, and include inflatable plastic barriers (see e.g. A Better City n.d.).

4. **Floodwalls** are vertical engineered structures, typically built out of concrete or similar materials, that can be scaled as a means of **protection** for one or multiple structures on a small **site** scale (FEMA 2007). Floodwalls are generally not designed to resist high-energy waves, unlike seawalls and other similar shoreline protections structures (see section 7.2.8 below). As such they are often located in areas inland of coastal wetlands or other features that reduce wave energy (NRC 2014). Floodwalls are often used in areas where there is insufficient space for levees, which have a larger footprint (FEMA 2007).

5. Floodwalls sometimes incorporate **flood gates**, which provide a means of controlling water flow in such systems. Flood gates are typically designed as passive devices, automatically opening and closing in response to the hydrostatic pressure of floodwaters (FEMA 2015). Flood gates are not limited to installation in flood walls, but

can be installed as stand-alone devices protecting **sites** or individual **structures**. They can also be installed on roadways or walkways (A Better City 2015).

6. While floodwalls can protect adjacent structures on a site from inundation, they have many limitations as a coastal adaptation measure, including cost and effort of construction and maintenance (FEMA 2007). Further, floodwalls are not immune from failure, as demonstrated in some cases in New Orleans during Hurricane Katrina (NRC 2014). Floodwalls may also have impacts including exacerbated flooding of adjacent areas and environmental impacts such as construction in or adjacent to coastal wetlands and changes to flood conditions (NRC 2014). For detailed guidance on constructing floodwalls, see FEMA 2007.

7. **Berms**, sometimes also described as embankments, raised ground, or dikes, are structures typically constructed of soil, clay or other earthen materials and used as means of flood **protection** on a small **site** scale (e.g. one residential structure). Berms differ from levees in scale (FEMA 2007). Levees may be constructed of similar materials but may protect an entire neighborhood or part of a city, such as New Orleans (NRC 2014). A berm can be constructed along one side of a building or can completely encircle a building (FEMA 2007). Even a small berm can require a large amount of space and a lot of earthen material; as such, berms are often incorporated into site terrain management (section 7.2.5 above) through site layout and grading.

8. **Tide gates** are another form of flood barrier used in low-lying areas. They are a means of flood **protection** typically applied on a **site** scale, and are designed specifically to close during incoming tides, preventing downstream waters from coming further inland, and open during outgoing tides, allowing upstream waters to drain. It is important to note that tide gates are of limited effectiveness given rising sea levels. A study by Walsh and Miskewitz (2012) found that sea level rise limits the effectiveness of tide gates because it impacts the hydraulic systems used to control tide gates, resulting in longer and deeper flooding events.

7.2.8 Structural Shoreline Protection Measures

1. The CRMC prohibits new structural shoreline protection measures on barriers classified as undeveloped, moderately developed, and developed, as well as on all shorelines adjacent to Type I waters (see the RICRMP §1.3.1(G)(3)). Additionally, the CRMC favors non-structural methods of shoreline protection (see the RICRMP §1.3.1(G)(1)); the reasons for this are enumerated in Chapter 4, Section 4.3.1.5, "Shoreline Protection Structures.".

2. Structural shoreline protection measures designed to protect adjacent structures are among the most well-known adaptation measures. Although commonly used, structural shoreline protection measures must be considered with extreme caution. Like flood barriers, CRMC staff have found that structural shoreline protection measures are often either undersized or under-designed for the sources of coastal hazard risk they are intended to address. Further, they may not be feasible means of protecting a site from storm surge and sea level rise given the latest sea level rise estimates (discussed in Chapters 2 and 3 of the Shoreline Change SAMP). Structural shoreline protection measures can thus be a very costly adaptation measure with little return on investment.

3. Such structures are designed as **protection** strategies for adjacent structures and are typically constructed at the **site** scale, parallel to the shore. In some cases, structural shoreline protection measures are built in to individual **structures**. Conceptually, such structures can be applied to **existing or new construction**. Examples of such "hard" shore-parallel shoreline protection structures include **seawalls, revetments, and bulkheads**. Such structures are designed to address flooding and coastal erosion as well as to reduce wave attack (NRC 2014).

4. The terms seawall, revetment, and bulkhead are frequently used interchangeably. A **seawall** is a hard, static, shore-parallel structure typically built out of concrete or stone. Seawalls vary widely in length; some protect one residential parcel while others may run the length of a beach or road. Seawalls are typically vertical structures. A **revetment** is also a hard shore-parallel structure, but is typically sloped rather than vertical, and is typically composed of materials like rock or rip rap. A **bulkhead** is a vertical structure, like a seawall, but in general is applied in commercial or industrial settings (e.g. a marina) solely to retain upland soils from sliding into the water.

5. Structural shoreline protection measures can have a broad range of negative impacts on adjacent beaches and properties, on the natural environment, and on shoreline public access. Further, they are insufficient adaptation measures to respond to the latest sea level rise projections. For an in-depth discussion of these issues please see Chapter 4, Section 4.3.1.5, "Shoreline Protection Structures."

7.2.9 Modifying or Retrofitting Structures: Wet and Dry Floodproofing

1. In cases where flooding is anticipated under present or future conditions, property owners may choose to modify or retrofit residential, commercial, or industrial **structures** as a means of either **accommodation** or **protection**. This form of adaptation includes a series of floodproofing techniques which can be applied to **new construction** as well as to **existing construction** through a retrofit process. As with all adaptation

measures discussed in this chapter, options discussed here are not necessarily limited to those that would be permissible by all relevant regulatory agencies, including but not limited to the Rhode Island Building Code.

2. Some floodproofing techniques are designed to **accommodate** floodwaters in portions of a building that are most likely to flood (sometimes called "wet floodproofing"). The modifications are not designed to keep water out, but to minimize damage and facilitate easy cleanup. Techniques may include using **building materials** on lower, uninhabited building levels to ensure that walls and floors can be easily cleaned and dried (e.g. tile floors over wood floors; concrete walls rather than drywall) (FM Global 2016). They also include installing **wall openings, vents, and other mechanisms** to allow water to flow in and out, minimizing the potentially damaging effects of hydrostatic pressure on the building (NRC 2013; FEMA 2014), protecting the **underside of elevated buildings** (FEMA 2014), or the installation of **breakaway walls** that can be carried away during a storm without compromising the structural integrity of a building (NRC 2013). Last, techniques include **elevating primary living quarters and utilities** to the second floor, minimizing the exposure of first-floor infrastructure to flooding (Snow and Presad 2011).

3. Other floodproofing techniques are designed to **protect** structures and infrastructure from flooding by keeping the water out ("dry floodproofing"). These modifications are designed to seal the exterior of a building by using **impermeable building material or sealants** on lower-level infrastructure and installing **water-tight doors and windows** or enclosures over such openings (FM Global 2016; FEMA 2014). Use of flood barrier products certified to meet ANSI/FM 2510 standards is recommended, and a listing of certified products can be found in the National Flood Barrier Testing and Certification Program (Association of State Floodplain Managers 2018).

4. Other techniques may include installing **pumps** on all dry floodproofing to remove any water that does seep in (FEMA 2014). Pumps should be designed and installed with backup power in the event of a power outage (FM Global 2016). Another technique includes installing **backflow valves** to prevent potential backflow from sewer systems (FM Global 2016).

Box 3. FORTIFIED™:
The Insurance Institute for Business and Home Safety's Program for Resilient Home Construction

The Insurance Institute for Business and Home Safety (IBHS) offers the FORTIFIED™ program as a possible "code plus" adaptation measure for coastal property owners seeking to make their homes resilient to hazards. IBHS offers FORTIFIED™ programs for both homeowners and businesses. The FORTIFIED™ Home program encompasses a suite of engineering and building standards that can be applied to individual **structures** as either **existing** or **new construction**. Participating homeowners work with certified FORTIFIED™ evaluators and professionals (e.g. contractors or engineers). FORTIFIED™ addresses the hazards of hail, high winds, and hurricanes, and utilizes an incremental approach, outlining three levels of **protection** (Bronze, Silver, and Gold) that homeowners can choose in order to reduce their exposure to these hazards. Through the FORTIFIED™ program, coastal property owners can begin by redesigning their roof system (Bronze), but can improve their resilience by addressing windows, doors, and attached structures (Silver), and, further, by connecting their roof to their walls and their floors to their foundation (Gold).

Importantly, the FORTIFIED™ program does NOT address the primary sources of coastal hazard risk addressed in the Shoreline Change SAMP (storm surge, coastal erosion and sea level rise). Nonetheless, it represents the types of adaptation measures available to Rhode Island coastal property owners and decision-makers. It is important to note that CRMC offers an incentive for expedited permit review for applicants seeking FORTIFIED™ program designation. For further information, please see https://disastersafety.org/fortified/.

7.2.10 Relocation or Managed Retreat

1. **Relocation or managed retreat** refers to a suite of adaptation measures designed to remove people and property from potential exposure to sources of coastal hazard risk. This suite of adaptation measures can be applied to both **existing** or **new construction** and at the **site** or **structural scale**. While relocation or managed retreat can sound to some like a dramatic or daunting adaptation measure, there are a number of practical ways that coastal property owners and decision-makers can apply this approach incrementally in order to reduce their exposure to sources of coastal hazard risk.

2. Some of these practical methods of managed retreat were discussed earlier in this chapter within the context of **site selection**. Coastal property owners can select sites that are located sufficiently inland, away from sources of current and potential future

coastal hazard risk. This form of managed retreat can take place at the site or parcel level: a new potential coastal property owner can choose a parcel that is sufficiently inland. This can also take place at the structural level: a coastal property owner who already has a coastal parcel can choose to build – or rebuild – a structure at a site on that parcel that is furthest away from sources of coastal hazard risk.

3. When building on a site that is exposed to sources of coastal hazard risk, a coastal property owner can choose to build a structure that would be easy to **relocate** inland at some point in the near future. For example, the California Coastal Commission's Sea Level Rise Policy Guidance indicated that foundation designs and other aspects of new development should be designed to "not preclude future incremental relocation or managed retreat," further noting that deepened perimeter foundations, caissons, and basements may be difficult to remove in the future (California Coastal Commission 2015, p. 131).

4. In cases of existing construction, if possible, a property owner may choose to relocate that structure inland to another location on the same parcel, or to a new parcel entirely. For example, one of Matunuck's historic Browning Cottages was relocated after Superstorm Sandy in 2012. This cottage was the last of three iconic coastal cottages dating back to 1900. In 2013 the owner of the surviving cottage relocated it 35 feet inland on the same lot, and elevated it onto concrete pilings, following a CRMC permitting process (see e.g. Wilson 2013).

5. Last, at its most extreme, relocation or managed retreat may involve abandoning coastal properties or structures completely. A severe storm may even leave a property owner with insufficient land left on which to rebuild. For example, in the case of severe property damage due to a coastal storm, a property owner may choose to abandon the coastal property rather than rebuild on the same parcel.

7.3 Future Research Needs

1. This chapter has focused on technical adaptation techniques that can be applied at the individual site or structural level by individual coastal property owners. As has been stated throughout this chapter, the field of adaptation is rapidly changing. Further research is needed on the subject of adaptation in general and on the adaptation tools and techniques described in this chapter in order to refine and improve adaptation practices in the face of changing future conditions.

2. This chapter has not considered planning, policy and legal solutions to adaptation, nor the legal implications of the adaptation measures discussed herein. Topics not discussed herein, but which may be considered in this regard, include buy-out programs and legal options such as rolling easements. Further research is needed on all of these topics, particularly within the context of Rhode Island.

Box 4. ADAPTATION RESOURCES PROVIDED BY THE UNIVERSITY OF RHODE ISLAND COASTAL RESOURCES CENTER AND RHODE ISLAND SEA GRANT COLLEGE PROGRAM

Catalog of Adaptation Techniques for Coastal and Waterfront Businesses: Options to Help Deal with the Impacts of Storms and Sea Level Rise
http://www.beachsamp.org/wp-content/uploads/2015/05/adaptation_catalogue.pdf

Newport Resilience Assessment Tour: Newport Waterfront Overview Summary
http://www.beachsamp.org/wp-content/uploads/2015/06/NRAT.pdf.

Rhode Island Coastal Property Guide
http://www.beachsamp.org/relatedprojects/coastalpropertyguide/

Staying Afloat: Adapting Waterfront Businesses to Rising Seas and Extreme Storms (Proceedings of the 2014 Ronald C. Baird Rhode Island Sea Grant Science Symposium)
http://www.beachsamp.org/wp-content/uploads/2015/07/2014_baird_proceedings.pdf

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