4. COASTAL RESILIENCE STRATEGIES

When developing the Adaptation Plan for a particular area, as defined within Chapter 3, there are three principal coastal resilience strategies that can be considered (Dronkers et al. 1990):

- Managed Retreat
- Accommodate
- Protect.

Once a principal strategy is identified then one or a variety of resiliency measures can be deployed to accomplish the overall management strategy. As climatic conditions change and sea levels rise over time, the Adaptation Plan may be accomplished using different coastal resilience measures. Resilience strategies and measures should be implemented based on the known and projected impacts from flooding as well as the goals and objectives for each managed area. Additionally, the measures chosen may need to change over time as conditions change and as previous areas of uncertainty and unknown variables become more certain (ESA 2018).

4.1 MANAGED RETREAT

Managed retreat is a resilience strategy that focuses on the relocation of existing structures, infrastructure, or natural features and limits the construction of new infrastructure within a specific area anticipated to be impacted by SLR or storm surge in the future (ESA 2018). As a result of managed retreat, fewer people and structures would be located in areas that are anticipated to be impacted by rising sea levels, thus reducing the risk of impact due to SLR in the area over time.

In many areas, relocation will be most feasible where property is owned or controlled by the government. Examples where this strategy would be used in the near term could be relocation of public facilities, road and utility infrastructure. Managed retreat is appropriate as a relatively long-term strategy. Even if policies are altered to promote managed retreat due to the design life of many structures and infrastructure, it may take some time to see the implementation action in terms of the location of infrastructure. When structures or infrastructure reach the end of their service life, it provides a prime opportunity for relocation if it is possible to wait until that time. In certain situations, managed retreat could be applied to a relatively large area (e.g., city or county wide), although managed retreat may be unfavorable in areas where waterfront property is desirable and valuable (ESA 2018).

Resilience measures, which are the techniques used to execute the overall strategy for an area, are described in the following sections. These measures could be used to help facilitate a managed retreat strategy for an area. For instance, a breakwater system could be constructed to provide wave attenuation to gain additional time, in years, until a full managed retreat strategy could be accomplished for an area.

4.2 ACCOMMODATE

Accommodate is a resilience strategy that focuses on the alteration or adaptation of existing structures, infrastructure, or natural areas and the development of new infrastructure that decreases the hazard risks and increases the resiliency of developed areas to sea level alterations and storm surge (ESA 2018). This strategy resolves to accomplish these items in the same location as existing development. Accommodation measures can include altering buildings to make them more resistant, such as elevating on pilings or retrofitting with materials that increase the strength of the structure. In some cases, buildings or infrastructure could be designed to be submersible, such as providing sealed manholes for sanitary sewer systems within flood zones. Other examples of the accommodation strategy include raising existing seawall height or raising bridges to accommodate the increased frequency and magnitude of storm events (Wong et al. 2014).

In the case of implementing accommodation as an overall strategy for an area, resilience measures that could be integral to the strategy may include, for instance, restoration of coastal marshes in conjunction with thin layer placement to reduce the impacts of waves to a developed area.

4.3 PROTECT

The goal of protection as a resilience strategy is to defend an area against rising seas and storm impacts. This overall strategy uses engineered solutions to decrease risks for existing natural areas, structures, and infrastructure without changing these existing items or features. The engineered solutions or resilience measures can be either structural or nature-based or both (U.S. Army Corps of Engineers [USACE] 2013). Protection of an area may be accomplished by a combination of many resilience measures that collectively comprise or contribute to the full protection strategy for an area (ESA 2018).

Protection as a strategy may require extensive capital investment, but in cases of critical infrastructure, such as wastewater treatment facilities, the protection costs may be negligible compared to relocation of the treatment facility complex. In the same example, the planned strategy may be to 'protect' the wastewater treatment plant up to the end of the service life of the plant, at which time, managed retreat through relocation may be implemented.

4.4 RESILENCE MEASURES

As discussed within the introduction to this section, the function of the coastal resilience measure or measures selected will need to be matched with the specific conditions of an area and the overall resilience strategy proposed for that area. For example, if erosion is a primary issue, a resilience measure that prevents or reduces erosive impacts is needed. It is important to note that there may be a variety of alternative resilience measures that could be applicable for an area. Implementing a combination of resilience measures may be necessary to meet the resiliency goals and objectives of an area. The resiliency measures or combination of measures applicable for an area are also likely to change over time as impacts from sea level rise increase (USACE 2013).

This section presents an overview of coastal resilience measures and provides a listing of the applicability under certain situations. The section also provides discussion of some locations within the Project Area where the measures could be implemented. The overview also includes the functions of each resilience measure (e.g., breaking of waves, erosion control) and associated performance factors. The performance factors are the design criteria and characteristics for each resilience measure. Performance factors are site-specific and need to be considered and incorporated into the design for successful application (USACE 2013).

4.4.1 Nature-Based Resilience Measures

Natural features occur and evolve over time through the actions of physical, biological, geological, and chemical processes operating in nature. Nature-based resilience measures are influenced by the same processes as natural features, but are created by design, engineering, and construction to provide specific services (USACE 2013). Natural and nature-based features can also enhance the resilience of coastal areas being impacted by sea level rise (USACE 2015a).

The following is a discussion of nature-based resilience measures that could be designed and deployed within the Project Area. The list of natural and nature-based features including the benefits and performance factors are provided in **Table 4-1**. An important factor involved in most of the nature-based resilience measures is sediment availability. This topic is discussed in detail in the next section in the context of dredging and regional sediment management.

Beaches and Dunes—Beaches are natural features that can provide coastal storm risk reduction and resilience. The sloping nearshore bottom causes waves to break, dissipating wave energy in the surf zone. Breaking waves on beaches typically form an offshore bar in front of the beach that then helps to dissipate higher energy waves as well. Dunes constructed behind a beach can act as a physical barrier that reduces inundation and further wave attack on the coast on the landward side of the dune. Beach levels can also be raised through sand nourishment with rising sea level depending on dynamics such as existing landward elevation (USACE 2013). The effectiveness in the long term as sea level rise progresses would be determined by the topography of the site (ESA 2018). Beach and dunes can be stabilized through the use vegetation and/or geotechnical mesh as part of the design. Stabilized beaches can also be paired with structures such as disconnected breakwaters to provide more capacity to absorb storm-induced wave energy.

There are a variety of performance factors to consider when designing for beach nourishment and dune construction. These include berm height and width of the dunes, slope of the beach, sediment grain size and supply, and the presence of vegetation. Beach nourishment is used extensively in coastal areas to provide resiliency against storms. Because storms frequently remove beach material, nourishment actions to resupply material are required to reoccur periodically in many areas (USACE 2013). This method could also be used to stabilize areas that have undergone significant coastal erosion historically, such as some of the coastal areas within APG. Sediment management will be a critical factor in deployment of beach and dune projects, the specifics within the Project Area regarding dredging and placement of material is discussed in the next section.

Photo 1 Beach Stabilization and Detached Breakwaters (Chesapeake Bay Program 2019)

Salt Marshes—Coastal wetland and salt marshes can contribute to coastal storm protection through wave attenuation and sediment stabilization. The vegetation is available to slow the advance of storm surge to a degree as well as reduce the landward movement of the surge. Wetlands can also dissipate wave energy and reduce the wave forces propagating on top of a surge flow. The ability of the wetland to perform these services depends on the specific characteristics of the wetland including the type of vegetation, rigidity, structure, and extent (such as depth relative to the shoreline). Engineered and constructed wetlands act in the same manner as natural wetlands; however, design features such as selection of plants, and the wetland footprint can be designed to enhance risk reduction (USACE 2013).

One of the options for salt marsh resiliency is known as thin layer placement (TLP). TLP, which is a relatively new technique, allows for the raising of a wetland through placement of additional sediment, usually dredged sediment, directly onto existing tidal marshland. The thickness is determined so that existing plants will be able to penetrate the new sediment layer, which is usually several inches in thickness. This technique, if repeated over time, will allow a tidal marsh to continue to exist as sea levels rise as long as the rate of sediment placement meets or exceeds SLR. In many cases the dredging for TLP is associated with areas directly adjacent to the placement site. Therefore, dredged material associated with opening-up of flow channels for more effective drainage of an area could be placed onto adjacent wetlands to raise the elevation. The overall effectiveness and applicability of TLP is based upon the characteristics of the material used, the placement technique, as well as the types of vegetation within the marsh. The TLP procedure was used recently at Prime Hook National Wildlife Refuge, an estuary of Delaware Bay, to provide elevation of existing salt marsh wetlands and was paired with channel dredging to create resiliency after the Wildlife Refuge sustained damage from Superstorm Sandy in 2012 (Georgetown Climate Center 2016).

The TLP technique, depending on the source of the dredged sediment and the material needs, may play a factor in the sediment management strategies for the region. In the Project Area, TLP could potentially be used in a variety of existing salt marsh areas that are expected to be impacted by SLR. These areas include the low-lying and tidal wetlands within APG as well as in each of the Project Area counties.

Photo 2 Thin Layer Placement Construction Underway at Prime Hook National Wildlife (USFWS Website 2019)

Seagrass Beds—Seagrass beds also known as submerged aquatic vegetation (SAV) provide functions similar to coastal salt marshes. These functions include providing breaking of offshore waves, attenuation of wave energy, and the slowing of inland transfer of water. SAV can also provide for increased infiltration of stormwater flow in an area that will decrease the volume of runoff. In addition, SAV beds provide important ecological benefits by filtering runoff, providing food for waterfowl, and providing habitat for aquatic species. SAV beds also help to filter the water and improve overall water quality. Design considerations include elevation of the bed layers, vegetation type and density (USACE 2013). SAV bed elevations can also be adjusted by TLP to provide resiliency of beds to sea level rise in the future.

As is discussed within the following section, the Susquehanna Flats include a large area of SAV beds encompassing approximately 20 square miles. This SAV bed formation provides for wave attenuation to adjacent lands in the Northern Chesapeake Bay depending on storm intensity, track, and speed. Interestingly, the SAV beds within the Susquehanna Flats are expected to experience a natural form of TLP as sea levels rise. This will be based on two factors, sediment deposition from the Susquehanna River and rate of sea level rise (USACE 2015).

Photo 3 Submerged Aquatic Vegetation – Susquehanna Flats (U.S. Environmental Protection Agency [EPA] Website 2019)

Oyster Reefs—The low salinity in the upper portion of the Chesapeake Bay, including the Project Area, has historically limited the ability of oyster populations to exist in large number in the Northern Chesapeake Bay. Oyster reefs, or bars, of sufficient size can provide breaking of waves offshore, attenuation of wave energy, and the slowing of the inland transfer of water. The performance factors that determine the effectiveness of an oyster reef include width, elevation, and roughness (USACE 2013).

Oyster reefs played a major role as natural shoreline erosion control structures in the mid and southern portions of Chesapeake Bay prior to being almost entirely removed by overfishing and disease impacts within the last two centuries. Based on the salinity requirements, the use of oyster reefs in the Project Area as a resiliency measure could possibly be a significant factor in the future depending on the specific changes to sea level and climatic conditions. However, for planning, such oyster bars are not applicable as a near-term resiliency measure.

Barrier Islands—Barrier islands can be of varying shapes and sizes based upon the specific objectives of the design. As discussed in the section below regarding land restoration or creation, these structures can be designed to mimic historical footprints of barrier islands that once existed or have significantly eroded. The Whiskey Island barrier island in Terrebonne Bay, Louisiana, provides one such example of a large-scale project as depicted below. This restoration, which included 13.4 million cubic yards of dredged material, is meant to provide resiliency to coastal Louisiana through attenuation of storm surge and was completed in 2017.

Photo 4 Whiskey Island, Louisiana – Restoration Barrier Island (www.nola.com 2019)

A more common smaller scale version of a barrier island resiliency measure is to establish an in-water berm just off an existing shoreline. These structures can provide wave attenuation and dissipation and sediment stabilization. The factors effecting performance include island elevation, length, and width. Land cover, breach susceptibility, and proximity to the mainland shore are also important design parameters. In-water berms provide a similar function to the structural measures of detached breakwater (USACE 2013).

Barrier islands can also be part of a long-term sea level rise resiliency plan. The islands could be configured as a first step to reduce shoreline erosion in an area and provide for the utilization of dredged sediment. In the case of shorelines in the Project Area that have been eroded over time, the barrier islands could be situated at the location of the historical shoreline. As sea levels continue to rise, the gaps in the island could be closed with connective sections. At the same time the elevation of the barrier islands could be raised to a level to sufficiently protect against a projected water level with associated storm surge. The final phase in this scenario would be to provide for design to fill in the area between the barrier island and the mainland with dredged or other material to establish made-land of high enough elevation to protect adjacent land from sea level rise. For this scenario to be successful, the performance factors must also take into account the adjacent upland land elevations as well as the use objectives for that land. This scenario could possibly be deployed along certain sections of the shoreline within the Project Area, including portions of APG.

Land Restoration or Creation—Restoration of land involves constructing made-land in the footprint of historical coastal or island areas lost to erosion over time. This approach was used to recreate Popular Island in mid-Chesapeake Bay in the 2000s and more recently on a smaller scale at Fishing Battery Island, within the Susquehanna Flats portion of the Project Area (see Photo 5, which portrays the island before and after the land restoration). In the case of Fishing Battery Island, dredged material from the Susquehanna Flats Navigation Channel was used to recreate the footprint of this island to prevent further erosion.

Photo 5 Fishing Battery Island, Susquehanna Flats—Restored with the use of Dredged Material—Pre- and Post-Restoration, 2017 (USFWS Website 2019)

This procedure could also be used to create new land to protect areas against sea level rise. Construction of new land or islands in the Chesapeake Bay is unlikely to be approved by regulators at present. However, SLR, depending on the planned objectives of the project compared to overall sea level rise projections, will create the need for changes to regulatory approaches over time. As described above, if lands were restored in an area that has endured coastal erosion over time, planning for this project would have to consider the upland elevation and the objectives and uses for this land in the future.

Table 4-1 Summary Table of Benefits (Functions) and Performance Factors for Natural and Nature-Based Features

Natural and Nature-Based Features	Benefits/Processes	Performance Factors
Beaches and Dunes	• Breaking of offshore waves • Attenuation of wave energy • Slow inland water transfer	• Berm height and width • Beach slope • Sediment grain size and supply • Dune height, crest, and width • Presence of vegetation
Salt Marshes and Seagrass Beds	• Breaking of offshore waves • Attenuation of wave energy • Slow inland water transfer • Increased infiltration	• Marsh, wetland, or SAV elevation and continuity • Vegetation type and density
Oyster Reefs	• Breaking of offshore waves • Attenuation of wave energy • Slow inland water transfer	• Reef width, elevation, and roughness
Barrier Islands	• Wave attenuation and/or dissipation • Sediment stabilization	• Island elevation, length, and width • Land cover • Breach susceptibility • Proximity to mainland shoreline
Land Restoration or Creation	• Wave attenuation and/or dissipation • Shoreline erosion stabilization • Soil retention	• Land elevation, length, and width • Land cover • Breach susceptibility • Proximity to mainland shoreline
General coastal risk reduction performance factors: Storm intensity, track, and forward speed; surrounding local bathymetry and topography (USACE 2013).		

4.4.2 Structural Resilience Measures

Structural measures can be designed to decrease shoreline erosion or reduce coastal risks associated with wave damage and flooding. Common, or traditional structures used for such applications include levees, storm surge barrier gates, seawalls, revetments, groins, and breakwaters. The purpose of levees, seawalls, and storm surge barrier gates is to reduce coastal flooding, while revetments, groins, and breakwaters are intended to reduce coastal erosion. All structural measures are designed to reduce storm wave impacts to some extent (USACE 2013).

In reviewing the applicability of structural measures for sea level rise, erosion control, or storm damage reduction, it is important to consider the effects of placement on the surrounding areas. This is the case because such structures in most cases modify sediment transport and wave energy at the construction site and in surrounding natural and built environments. This may have effects on the shoreline in both current and future sea level and storm conditions. Common structural resilience measures that are implementable in the Project Area are discussed in the following sections. The list of common structural resilience features including the benefits and performance factors are provided in **Table 4-2**.

Levees—Levees are usually onshore structures with the principal function of protecting lower elevation areas against flooding. These structures provide surge and wave attenuation, reduce flooding, and reduce risk to vulnerable areas. Performance factors in levee design include the height, crest width, water level, and slope of the levee as well as wave height and period. Levees can also be used in conjunction with storm surge barriers in larger system (as described in the storm surge barrier section). Levees can be constructed with dredged sediment depending on the physical characteristics of the material (USACE 2013). Amendments to the sediment could be utilized to improve the structural characteristics of this material for use in levee construction. Levees could be constructed within the Project Area on lands to protect critical infrastructure such as ranges within APG or water or wastewater treatment facilities.

Storm Surge Barriers—Storm surge barriers are often required within a levee system to prevent surge from propagating up waterways. It is common for the barrier to consist of a series of movable gates that normally stay open to let flow pass in normal conditions. During a storm surge situation or extreme tide event the gates can be closed to prevent landward flooding. Storm surge barriers provide the benefits of surge and wave attenuation as well as reduced salinity intrusion. Performance factors for storm surge barriers include height, design wave height, period, and water level. Storm surge barriers can be designed with the option of being elevated should the need arise with future sea level rise. Such designs should focus the base of the wall system to create a base that would be able to support elevation.

The largest storm surge barrier system in the United States was constructed post-Hurricane Katrina (2006) to protect New Orleans from coastal flooding. This system is extensive, providing 133 miles of continuous levee and storm surge barrier protection against a 100-year storm event of 12 ft. The overall cost of the system was $14.5 billion. The cost included new sections such as the storm surge barrier pictured below and also the retrofitting of existing levees surrounding the city.

Photo 6 Storm Surge Barrier – Louisiana
(https://www.nbcnews.com/storyline/hurricane-katrina-anniversary/new-orleans-14-5-billion-walls-n415816 2015)

Seawalls—Seawalls are structures built onshore parallel to the shoreline with the objective of reducing overtopping and flooding of land and infrastructure behind due to storm surge and waves. Seawalls limit erosion of the area landward; however, if the seawall is exposed to waves during tidal cycles, erosion of the seabed immediately in front of the wall will increase. This effect is due to the increased wave reflection force as well as the isolation of the area from inland sediment sources. Over time, this will result in deeper water seaward, which will allow larger wave forces to reach the structure. In these situations, sediment transport pathways can be significantly altered resulting in enhanced erosion of adjacent shorelines (USACE 2013). Seawalls reduce flooding and prevent waves from reaching areas behind the structure. These structures also provide shoreline stabilization behind the wall. Performance factors include wave height, period, and water level. Scour protection at the base of the wall is also important to the performance.

Seawalls could be deployed in certain situations within the Project Area to protect critical infrastructure such as sewage pumping stations or historical structures. Seawall design should consider resiliency to allow for providing a base design and height that could be augmented with higher sections in the future should the need arise. In the context of future planning, the seawall could also act as a Phase 1 configuration, which could later be filled behind on the landward side as protected infrastructure is reconstructed and raised by increasing the land side elevation. A seawall surrounds the U.S. Naval Academy, which exists on made-land. In response to sea level rise, this structure is anticipated to be raised by 3 ft in the coming decades (www.military.com 2019).

**Photo 7 U.S. Naval Academy Sewall –
Annapolis, Maryland (www.military.com 2019)**

Revetments—Revetments are common onshore structures that function to protect shorelines from erosion. These are commonly armor-rock placements along an otherwise soft-scape area. Like seawalls, revetments reduce flooding and prevent waves from reaching areas behind the structure. These structures also provide shoreline stabilization behind the revetment. Performance factors include wave height, period, and water level. Scour protection is also important to the performance. The applicability of revetments for long-term sea level rise planning needs to be based on a systematic approach at any given location. Revetment structures have an effect on sediment transport where constructed, and adjacent shorelines can expect see a variation in the amount of sedimentation due to wave force changes (USACE 2013). Revetments could be constructed within the Project Area to stabilize shorelines experiencing erosion. They could also be constructed to protect against erosion expected with future SLR. In the resiliency planning stages, design for future revetments based on SLR could also be completed in advance of a streamlining permitting process for structures. A similar advanced design strategy could be employed for other resiliency measures.

Photo 8 Typical Riprap Rock Revetment – Chesapeake Bay (https://www.researchgate.net/publication/235211387)

Groins—Groins are narrow structures, usually positioned perpendicular to the shoreline, that function to stabilize an area against erosion due to a net longshore loss of material. The effect of a groin is accretion of material on the updrift side and erosion on the downdrift side. Factors in performance of groins include length, height and orientation, permeability, and spacing. Also of importance are depth at the seaward end of the groin, design wave height, and water level. Longshore sediment transportation rates and distribution are also performance factors (USACE 2013).

Photo 9 Stone Groin System under Construction (http://www.dorsetlife.co.uk 2019)

Breakwaters—Breakwaters can be constructed as detached or as nearshore structures built parallel to the shore just seaward of the shoreline in shallow water depths. These are generally low-crested structures, whose main function is to reduce erosion by reducing wave height and, therefore, longshore and cross-shore sediment transport. Submerged detached breakwaters can also be used but present a safety issue to boats and swimmers. Performance factors and design criteria for breakwaters include height and width, permeability, proximity to shoreline, orientation, and spacing (USACE 2013).

A recent use of breakwaters for coastal resiliency is being planned to protect Staten Island in New York as a result of the damage sustained by Superstorm Sandy (Georgetown Climate Center 2016). This breakwater design is a cross between a traditional detached breakwater system and a more natural barrier island. The system of breakwaters is being configured to provide living breakwaters, which provide habitat for marine creatures. These structures will have a core similar to a traditional concrete or riprap design. However, the outer portion is constructed to allow for use and colonization by marine growth, oysters, and other aquatic creatures (Georgetown Climate Center 2016). In addition, the newly protected shoreline will also be restored as a living shoreline with natural beach grass and other vegetative planting to create further resiliency within the coastal system. The extent of the breakwater is such that it will protect the southern tip of Staten Island from the most damaging wave forces to be expected from significant offshore storm systems. Similar systems could be deployed in vulnerable or degraded shoreline within the Project Area such as areas of APG shoreline. As noted in the previous discussion regarding barrier islands, these structures could also be considered as the first step in a phased approach as sea level rise progresses.

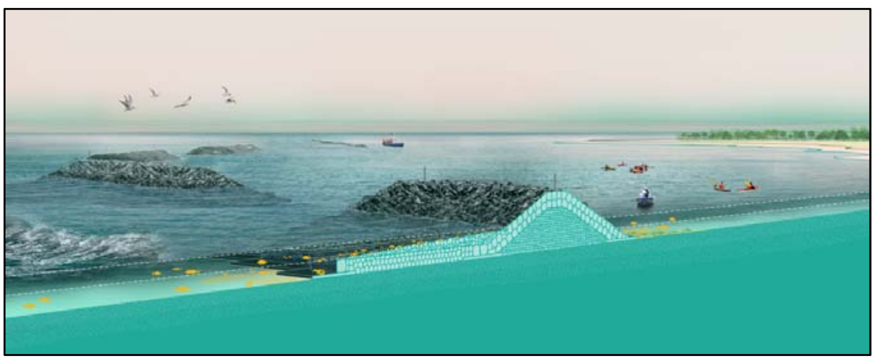

Photo 10 Living Breakwater Configuration Plan – Staten Island (https://stormrecovery.ny.gov/learn-more-about-living-breakwaters-project 2019)

Table 4-2 Summary Table of Benefits (Functions) and Performance Factors for Structural Features

Structural Features	Benefits/Processes	Performance Factors
Levees	• Surge and wave attenuation and/or dissipation • Reduced flooding • Reduced risk for vulnerable areas	• Levee height, crest width, and slope • Wave height and period • Water level
Storm Surge Barriers	• Surge and wave attenuation • Reduced salinity intrusion	• Barrier height • Wave height • Wave period • Water level
Seawalls and Revetments	• Reduced flooding • Reduced wave overtopping • Shoreline stabilization behind structure	• Wave height • Wave period • Water level • Scour protection
Groins	• Shoreline stabilization	• Groin length, height, orientation, permeability, and spacing • Depth at seaward end • Wave height • Water level • Longshore transportation rates and distribution
Breakwaters	• Shoreline stabilization behind structure • Wave attenuation	• Breakwater height and width • Breakwater permeability, proximity to shoreline, orientation, and spacing
General coastal risk reduction performance factors: Storm surge and wave height/period, water level (USACE 2013).		

4.4.3 Non-Structural Resilience Measures

Non-structural resilience measures provide a selection of alternatives that can reduce exposure to coastal flood risks. Non-structural measures essentially reduce the consequences of flooding, as compared to structural and nature-based measures which may also reduce the probability of flooding. These measures, as defined by USACE, include structural acquisitions, relocations, flood-proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, development of restrictions within the greatest flood hazard area, and elevated development. These measures can be integrated effectively with nature-based and structural resilience measures (USACE 2013).

Non-structural resilience measures are most often developed, implemented, and regulated under the jurisdiction of state and local governments. These measures can be encouraged or incentivized but not imposed by the federal government. As a result, the effective full range of flood and coastal resiliency measures rely on a collaborative, shared responsibility between federal, state, local agencies and the public (USACE 2013). Non-structural opportunities for areas faced with coastal flood threats from sea level rise in many cases focus on changes to policy and land use regulations. In areas of aging coastal infrastructure, the potential threats from sea level rise also create an opportunity to reconsider infrastructure investment measures and the possibility of applying a broad array of resiliency measures to achieve long-term community goals. The following is a discussion of common non-structural resilience measures which are available and are likely to be deployed in the Project Area. The list of non-structural resilience features including the benefits and performance factors are provided in **Table 4-3**.

Floodplain Policy and Management—This method, if executed effectively over time, can provide the framework for managed retreat of infrastructure and dwellings outside of flood risk areas. The immediate impact is improved and controlled development within floodplains. It will also reduce, over time, the opportunity for damage resulting from flooding.

Floodplain management should also be considered a major item for providing resiliency in an area as it can provide for effective planning on how to mitigate stormwater impacts. Floodplain management in this context will take into account stormwater flow conditions and draining efficiencies. Stormwater issues can be alleviated in some cases by providing for more effective infiltration of stormwater through redesigned or new Best Management Practices (BMPs), thereby reducing the water available for flooding during storm events. These types of stormwater systems are sometimes known as green infrastructure. In the same manner, dredging of flow channels can be planned and executed in areas where flow restrictions may exist. This dredging will also allow easier flow pathways to open water during storm events, reducing landward flooding. In this context, as noted in the next section, dredging can be considered a resiliency measure as well.

Floodproofing and Impact Reduction—This measure includes a wide array of items such as raising of structures to elevate them above expected flood levels (such as placing existing structures on pilings) or re-fitting structures to make them flood proof or even submersible. These actions reduce the opportunity for damage and increase resilience (USACE 2013). These measures also, generally, do not cause an increase in flood potential in adjacent areas. This can sometimes be the case with other measures, such as sea wall or revetment construction, in which wave energy and flow patterns can be modified to create negative effects to adjacent lands. The effectiveness of floodproofing and impact reduction is based upon expected wave heights and water levels as well as storm duration.

Also included within the measure of impact reduction, elevating or raising of structures and infrastructure is a common resiliency practice. The ground floor elevation of homes and buildings or infrastructure such as roads can be raised to above the desired flood level at a certain point in the future. Raising of structures is many times accomplished by retrofitting buildings with pilings. Raising of roads, railroads, and vulnerable utilities can be accomplished by placing fill to rebuild roads and replacing utilities at higher elevations. Other options for raising roads and utilities may include replacing at-grade roads with pile-supported causeways (ESA 2018). As noted in the next section, dredged sediment could potentially be a source of material for elevating roads and other infrastructure.

Flood Warning and Preparedness—An increase in flood warning and community preparedness will reduce the opportunity for damages from a flooding event and increase community resiliency. In addition, it will generally provide more community involvement leading to high levels of shared responsibility and improved public awareness (USACE 2013).

Relocation—Relocation of population or infrastructure from areas under threat of flooding through managed retreat will obviously have profound effects on flood damage risks. There is reduced opportunity for flooding, no transfer of flood potential elsewhere, and the opportunity for an improved natural coast environment. Performance factors for relocation include expected water level and wave heights, as well as storm duration. These factors will be important to setting the plan for relocation far enough inland to obtain the desired protection from SLR (USACE 2013).

Table 4-3 Summary Table of Benefits (Functions) and Performance Factors for Non-Structural Features

Non-Structural Features	Benefits/Processes	Performance Factors
Floodplain Policy and Management	• Improved and controlled floodplain development • Reduced opportunity for damages • Improved natural coast environment	• Wave height • Water level • Storm duration • Agency collaboration
Floodproofing and Impact Reduction	• Reduced opportunity for damages • Increased community resiliency • No increase in flood potential elsewhere	• Wave height • Water level • Storm duration
Flood Warning and Preparedness	• Reduced opportunity for damages • Increased community resiliency • Improved public awareness and responsibility	• Wave height • Water level • Storm duration
Relocation	• Reduced opportunity for damages • No increase in flood potential elsewhere • Improved natural coast environment	• Wave height • Water level • Storm duration
General coastal risk reduction performance factors: Collaboration and shared responsibility framework, wave height, water level, and storm duration (USACE 2013).		