PUERTO RICO COASTAL

DRAFT INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL ASSESSMENT

APPENDIX F
Plan Formulation




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US Army Corps of Engineers ®
Jacksonville District

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1 INTRODUCTION

This appendix gives a full account of the plan formulation analysis. **Chapter 3** of the main report can be referenced for a briefer summary.

Plan formulation is the process of developing alternative plans to address a given problem. The Corps uses a 6 step planning process: 1) Plan identification, 2) Inventory existing conditions and forecast future conditions, 3) Formulate alternatives, 4) Evaluate alternatives, 5) Compare alternatives, and 6) Choose an alternative.

This appendix describes the process in steps 3-6. Step 3 begins with the identification of management measures. A management measure is an action that can be implemented at a specific geographic site to address one or more planning objectives. Measures are then screened against planning criteria, including objectives and constraints, and remaining measures are combined into alternative plans. An alternative plan can then include one or more management measures to address the problem. Alternative plans can differ by types of measures, or how measures are combined or defined, including dimensions, quantities, materials, locations or implementation time frames. Alternative plans are then screened and then modeled to determine benefits of each plan.

The immediate section below gives a full account of the scoping of the study since its initiation in 2018. The following sections detail the plan formulation conducted with an integrated team, data, modeling and analysis, to arrive at the tentatively selected plans presented in the main report.

2 SCOPING OF STUDY

The Puerto Rico Coastal feasibility study initially did a preliminary assessment of the shoreline problems along approximately 30 miles of coastline island-wide, which encompassed 13 vulnerable locations identified by the Department of Natural and Environmental Resources (DNER). These areas were located in San Juan, Carolina, Vega Baja, Arecibo, Aguadilla, Aguada, Rincón, Añasco, Mayaguez, Cabo Rojo, Loiza, Luquillo, and Humacao Municipalities[1].

The study area was further refined to focus specifically on areas with the highest potential to support a Federal project. Potential Federal interest was based on apparent vulnerability of structures and critical infrastructure and evidence of damages from past storms. Several important factors were considered in the criteria selected for this initial scoping:

- Four Planning and Guidance (P&G) accounts: The four accounts were used to track benefit categories. In this case, they were used to see which reaches had the most potential for Federal Interest. These accounts are: National Economic Development (NED), Environmental Quality (EQ), Other Social Effects (OSE), and Regional Economic Development (RED).
- Presence of critical Infrastructure like hospitals, fire stations, shelters, schools, utilities, and major evacuation routes: The “coastal zone” is being defined by the DNER as “all land within 1 kilometer of the shoreline”. The main island of Puerto Rico has about 580 kilometers of coastline. Along this coastline there are several different types of structures that are vulnerable to storm damages and climate change. The critical infrastructure around the island includes power plants, hospitals,

[1] The municipality of San Juan includes Old San Juan, Condado, and Ocean Park. The municipality of Carolina includes Isla Verde and Carolina shoreline.

airports, seaports, schools, bridges, roads, shelters and government buildings. Information used for this criteria includes the 2018 Vulnerability Analysis Report, which is part of the Puerto Rico Hurricane Evacuation Study prepared by the USACE, FEMA and the National Hurricane Center. The Puerto Rico HES Vulnerability Report identifies and map the people and infrastructure exposed to hurricane-induced storm surge.

- Sea Level Change Consideration: Identifying areas at lower elevations which may have increased vulnerability to sea level rise. The future sea level change exposure envelope represented by the three SLC curves over 50-year period of analysis and the 100-year adaptation horizon provided the basis for the initial scoping.
- High Background Erosion Rates of Hot Spots: Identifying areas known to suffer high erosion during storms or due to natural processes occurring in the area.
- High Risk of Flooding: Identifying areas known to experience flooding along the ocean shoreline as a result of coastal storms. 500-year flood zone maps and coordination with communities that experience past flooding events.

While all of the above criteria were considered during the initial scoping, the criteria indicating potential for economic justification under the NED account was the main factor in deciding which reaches were carried forward.

Figure 1-2 shows the map with the location of the preliminary study areas, and **Figure 1-3** summarizes the initial scoping considerations for each location, and the reaches initially carried forward for further analysis, highlighted in blue. As a result of the initial scoping using the criteria previously described, the following areas showed the greatest potential for economic justification under the NED account: the San Juan (Condado, Ocean Park, Isla Verde, and Carolina) and Rincon coastlines; and a segment of the hurricane/tsunami evacuation routes in Mayaguez (PR-102) and Humacao (PR-3). Those areas are highlighted in green on **Figure 1-2**. The areas in Catano and Condado backbay areas became part of the San Juan Metropolitan CSRM study, to allow that study for focus on backbay problems, and this study to focus on shoreline problems. During further investigation, evacuation routes in Mayaguez (PR-102) and Humacao (PR-3) were screened out from further analysis in this study. The rational for this determination is described in the following discussions.

Figure 2-1 Location of the Preliminary Study Areas

Figure 2-2 Initial Scoping for the Puerto Rico Coastal Study

PUERTO RICO COASTAL STORM RISK MANAGEMENT (CSRM) PROJECTS - Study Scoping to Determine Areas of Focus

CRITERIA FOR SCOPING

Criteria which Indicate Federal Interest

USACE uses four accounts (Principles, 1983), which are used to track benefit categories. In this case, they were used to see which reaches had the most potential to support Federal projects, known as Federal Interest.

- National Economic Development (NED)
  - ✓ This account displays changes in the economic value of goods and services. This category is the most important of the four accounts as it is used for economic justification of Federal interest. Benefits of damage reduction must be greater than the cost to implement the project; the benefit to cost ratio (BCR) must be greater than 1. Dense infrastructure or critical infrastructure over a large area is a primary indicator of strong economic justification.
- Environmental Quality (EQ)
  - ✓ This account displays nonmonetary effects on significant natural and cultural resources. This screening considered areas that show potential for to maintain or increase environmental benefits (sea turtles, improve reef or increase reefs, mangroves, etc) are given high marks.
- Other Social Effects (OSE)
  - ✓ This account registers plan effects from perspectives that are relevant to the planning process, but are not relevant in the other three accounts. This screening included consideration of areas that cold require public safety, maintain recreation, or other community effects.
- Regional Economic Development (RED)
  - ✓ This account registers changes in the distribution of regional economic activity. This screening considered reaches that had potential for temporary or permanent growth in local economy.

Factors Which Indicate Increased Risk

These categories were used to determine important features of each reach, to understand areas of increased risk which would take priority over other reaches, I conjunction with potential for Federal Interest.

- Critical Infrastructure
  - ✓ Hospitals, Fire Stations, Utilities, Major Evacuation Routes
- Sea Level Rise Consideration
  - ✓ Per SKA assessment tools, these areas are lower elevations and may have increased vulnerability to sea level rise.
- Erosion from storms, High Background Erosion Rates of Hot Spots
  - ✓ Per SKA assessment tools or evidence, these areas are known to suffer high erosion during storms or due to natural processes.
- High Risk of Flooding
  - ✓ Per SKA assessment tools or evidence, these areas are known to be in the 500 year floodplain or suffer flooding during storms.

	Would Provide Significant Benefits from a Federal Project				Prioritized Need for a Federal Project			
Planning Study Reaches	National Economic Development (NED)	Environmental Quality (EQ)	Other Social Effects (OSE)	Regional Economic Development (RED)	Critical Infrastructure	Sea Level rise Consideration	High background Erosion Rates, Hot spots, or erosion from storms	High risk of Flooding (in 500 year flood zone or flooding evidence)
								
Aguadilla	✓	✓	✓	✓	✓	✓	X	✓
Aquada	✓	✓	✓	X	✓	✓	✓	X
Rincon	✓	✓	✓	✓	✓	✓	✓	✓
Bay of Anasco	X	X	X	X	X	✓	X	✓
Mayaguez	✓	✓	✓	✓	✓	✓	X	✓
Cabo Rojo	✓	✓	✓	✓	✓	✓	X	✓
Arecibo	✓	✓	✓	✓	✓	✓	X	✓
Vega Baja	✓	X	✓	✓	X	✓	✓	✓
Loiza	X	X	✓	✓	X	✓	✓	X
Luquillo	X	X	X	X	X	✓	✓	X
Humacao	✓	X	✓	✓	✓	✓	✓	✓
Old San Juan	✓	✓	✓	✓	X	✓	✓	X
Condado Shoreline	✓	✓	✓	✓	✓	✓	✓	✓
Condado Back Bay	✓	✓	✓	✓	✓	✓	✓	✓
Ocean Park	✓	✓	✓	✓	✓	✓	✓	✓
Isla Verde	✓	✓	✓	✓	✓	✓	✓	✓
Carolina	✓	✓	✓	✓	✓	✓	✓	✓
Catano	✓	✓	✓	✓	✓	✓	✓	✓

✓ Most fully Meets ✓ Partially Meets X Does not meet

U.S. ARMY CORPS OF ENGINEERS

Screening out of Evacuation route in Mayaguez (PR-102):

To identify the potential for the economic justification of protecting evacuation routes in Mayaguez (PR-102) and Humacao (PR-3), the NOAA Coastal Flood Exposure Mapper (Storm Surge – Category 1 to 5 Hurricane) shows that part of this area can expect flooding up to 6 feet above ground. In addition, aerial imagery from NOAA's Hurricane Maria imagery site and cost estimates for post-Maria road repairs in Mayaguez and Humacao areas were obtained from the Puerto Rico Department of Transportation to inform this decision.

The Mayaguez reach focuses on highway PR-102, approximately from Km 4.4 through 7.3, where the road is closer to the coastline. There are approximately eight structures that lie between the ocean and the highway and there are two small neighborhoods in this reach, Brisas De Mal and Guanajiro Homes, that are separated from the coastline by PR-102. Consultations with the Puerto Rico Highway and Transportation Authority reported no damage or reconstruction efforts to highway PR-102 in Mayaguez after Hurricane Maria. The **Figure 1-4** below shows the reference area (north and south) immediately following Hurricane Maria, and shows no physical damage to the road. All of the previously described reasons supported the decision to not carry forward the Mayaguez study area.

While this study focusses in the damages coming from coastal flooding, there is residual risk in this area associated with inland flooding. The Brisas De Mal and Guanajiro Homes neighborhoods are highly vulnerable due to inland flooding coming from the Rio Guanajibo. However, a riverine flood risk management project along Rio Guanajibo will lower flood risk to these neighborhoods once it is in place. The Rio Guanajibo Project was authorized in 1996, but never constructed. The accelerated scope verification report has been approved (2020) and the team is undergoing concurrent efforts for PED and a validation report to verify the project is economically justified, environmentally acceptable and feasible from an engineering perspective. The recommended flood control project includes a channel plan with a 10-year level of protection at San German in the upper basin and a system of levees that will provide 100-year protection for the urban areas at Hormigueros and Mayaguez in the lower basin. **Figure 1-5** presents the authorized features of the Rio Guanajibo Project in the vicinity of Mayaguez.

Figure 2-3. Mayaguez (PR-102) Post Hurricane Maria

Source: https://storms.ngs.noaa.gov/storms/maria/index.html#20/18.18727/-67.16171

Source: https://storms.ngs.noaa.gov/storms/maria/index.html#20/18.18727/-67.16171

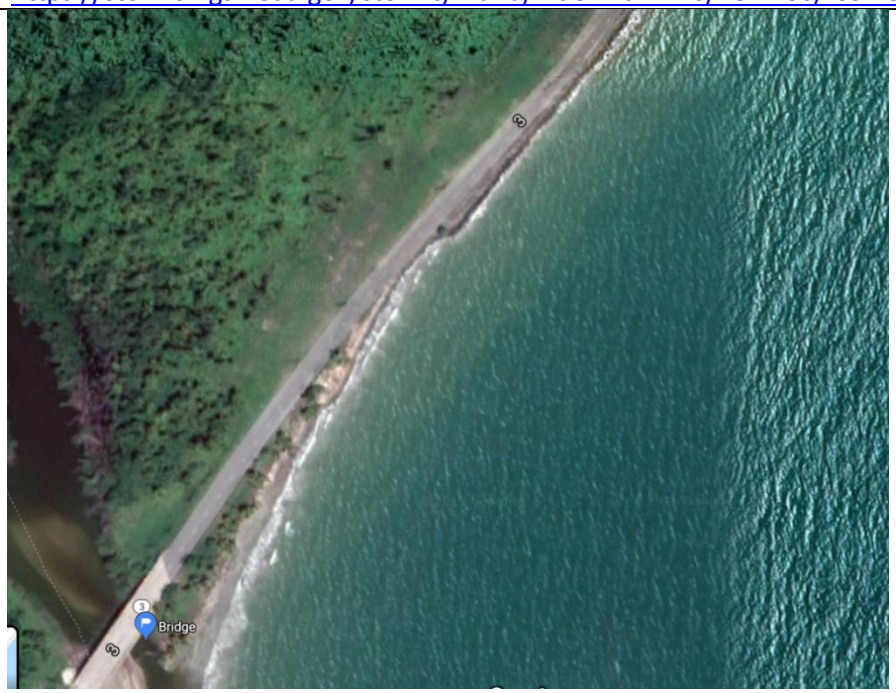
Figure 2-4 Rio Guanajibo Flood Control Project in the Mayaguez area

<u>Screening out of Evacuation route in Humacao (PR-3):</u>

The Humacao reach includes highway PR-3, from Km 69.3 through 71.8, just northeast of the confluence of Rio Antonio Ruiz with the ocean. PR-3 connects the community of Punta Santiago, located south of the river mouth, with the community of Naguabo, located about 2 miles in the northeast direction. A portion of this stretch of highway is less than 10 feet from the coastline and is protected from ocean scour by stone revetment. Based on the NOAA Coastal Flood Exposure Mapper (Storm Surge – Category 5 Hurricane), this area is highly vulnerable, and can expect flooding of up to 6 feet above ground. However, the highway lies between the coast and a nature reserve part of the Rio Antonio Ruiz floodplain and there are no structures in this reach, which indicates a lack of potential for economic justification. Consultations with the Puerto Rico Department of Transportation confirmed that the road suffered considerable damage from Hurricane Maria, but it was reconstructed by that agency in 2018. The project included repairing the pavement and portions of the stone revetment at a cost of $289,311 (See **Figure 1-6**).
These considerations led to the decision for the Humacao study area not being carried forward.

Figure 2-5. Humacao (PR-3) Post Hurricane Maria

Source: https://storms.ngs.noaa.gov/storms/maria/index.html#16/18.1766/-65.7383



Source: Google Maps

Refined study area and determination of focus areas

As a result of the initial scoping, the refined study area encompassed approximately 7 miles of coastline in the San Juan and Carolina municipalities, and approximately 2.4 miles of coastline in Rincon municipality. The San Juan area fronts the Atlantic Ocean on the north coast of Puerto Rico, from el Boqueron to Boca de Cangrejos and it is located in the municipalities of San Juan and Carolina, which are part of Metropolitan San Juan. This stretch of ocean coastline was referred to as the "San Juan Study Area" in the draft report which was released in November 2020 and it was divided into four focus areas. The focus areas included Condado Beach, Ocean Park Beach, Isla Verde Beach and Carolina Beach. The Rincon study area fronts the Atlantic Ocean on the west coast of Puerto Rico from Punta Ensenada to Corcega Beach and is considered to be one single focus area. **Figure 1-7** and **Figure 1-8** present the focus areas in San Juan and Rincon respectively. The Rincón focus area was originally comprised of two planning reaches geographically separated by a stream, Rincón A lies north of Quebrada Los Ramos and Rincón B lies south. Rincón A was not carried forward due to very low erosion, as well as lack of structures and critical infrastructure to be protected in the area.

Further investigations during the forecasting of existing and future without project conditions led to the screening out of the Carolina focus area due to the lack of potential for economic justification; therefore, modeling was performed only on the remaining focus areas of Condado, Ocean Park, Isla Verde and Rincón B, called Rincón for simplicity in this report, shown in **Figure 2-6** and **Figure 2-7**.

CONSIDERATIONS RELATIVE TO CRITICAL INFRASTRUCTURE IN THE BACKBAY AREAS

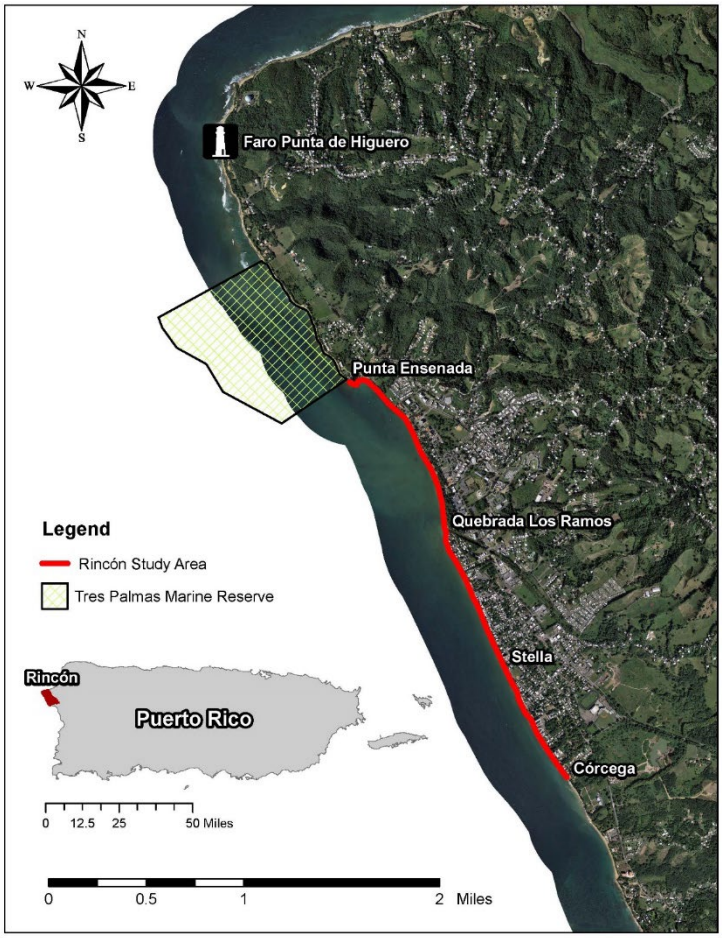
Because Puerto Rico is an island, its airports and seaports are extremely important. Without these ports, there would be a major problem with receiving supplies and transporting people from the mainland U.S. to the island, and vice versa. The San Juan Airport and Port of San Juan facilities were evaluated under a separate study, called the San Juan Metro Area CSRM study. The reach which includes the Port, called Reach 2, was screened from further analysis, with support from the sponsor. The majority of the area is owned, operated and maintained by the Port of San Juan, with some residential areas around the perimeter area on higher ground. Modeling of future without-project conditions showed that damages were very low. After further analysis, it was determined that the cost of the most likely alternatives to reduce damages in the area would be higher than the benefits, creating negative net benefits and a benefit to cost ratio less than 1.0. There would appear to be minimal risk of coastal flooding damages in this area in the future without-project condition due to structures and infrastructure existing on high ground that is set back from coast. The Luis Munoz Marin International airport in Carolina municipality, San Juan Metro Area is located about 100 ft from the coast at an approximate 10 ft elevation. There are not historical records of damages to the airport due to flooding. The San Juan Metro Area CSRM study concluded that the Luis Munoz Marin International airport area has multiple sources of potential coastal flooding influences and is within a hydrologically complex system identified as Reaches 4-6; therefore, the study recommended that those reaches should be evaluated under a separate study in order to adequately address both storm surge and precipitation.

Figure 2-6. San Juan Focus Areas Location – November 2020

Following the public release of the November 2020 Draft Integrated Feasibility Report and Environmental Assessment, after consideration of public and agency comments, as well as the need for updated environmental surveys, the Jacksonville District, with the support of the vertical team, made the decision to request more time and funding to allow the team to reassess technical and environmental aspects of the study area. The study team requested an additional 31 months and $3.3M, and this additional time and funding was approved in October 2021 which effectively restarted the study.

At the re-initiation of the study effort in October 2022, the focus areas of Condado, Ocean Park, Isla Verde and Rincón B (called Rincón for simplicity in this report) were then delineated into planning reaches. The they were delineated based on shoreline dynamics and coastal flooding properties. Each planning reach is separable, or self-contained, meaning any proposed alternatives within those planning reaches would not have effects (positive or negative) to the other planning reaches.

Figure 2-7. Rincon Focus Area Location – November 2020



Each planning reach was modeled in Beach-fx and Generation II Coastal Storm Risk Model (G2CRM) to better understand the damage drivers in the future without project-condition (FWOP). Chapter 2 of the main report gives a brief account of the results of the modeling, as does the **Appendix D, Economics.** The conclusions based on the modeling results is presented below:

Ocean Park FWOP Conclusion (R1 to R15 to R11): Total FWOP damages including emergency clean-up and evacuation cost **(**ERC&E) costs are estimated at $7,078,000. Ocean Park is relatively more vulnerable due to the many structures with low first floor elevations (FFE's) and a lower ground-surface elevation across the entire planning reach. Damages in the FWOP increase dramatically in the high SLR scenario but are also very high in the baseline condition indicating a high level of vulnerability for Ocean Park planning reach. Based on the FWOP results, the Ocean Park planning reach will move forward for formulation and evaluation of alternatives.

Rincón FWOP Conclusion (R11 to R22): FWOP damages are largely driven by erosion damage and are estimated to be $1,010,900 (AAEQ). The majority of the damage is structural in nature. Residential structures account for 64% of all damages with additional repair costs associated with residential armor. Damages in the FWOP increase significantly in the high sea level rise scenario. Although the damages are lower relative to the Ocean Park planning reach, this reach is being carried forward for further analysis to better understand if there are potential alternatives whose benefits would outweigh the costs.

Condado FWOP Conclusion (R1 to R10): Total damages in the intermediate SLR FWOP condition are $89,000 AAEQ, representing a very low level of estimated risk to infrastructure. Most of the structure and content damages are attributed to a single private structure and the majority of overall damages come from coastal armor construction or repair to a limited spatial extent. Storm risks increase dramatically in the high sea level rise scenario as the impacts from erosion increase greatly. Over 90% of all damages in the high scenario accrue to a single private structure. After careful consideration and support by the non-federal sponsor, due to this low risk, this planning reach was not carried forward for further analysis. As a note, coastal flooding in the backbay areas in the Condado community was addressed in the San Juan Metro Area Coastal Storm Risk Management Study (CSRM). The study recommended an elevated living shoreline to reduce risk of coastal flooding in the Condado area. The project was authorized in September 2021 and is expected to be constructed by 2029. Both the San Juan Metro Area CSRM and Puerto Rico Coastal Study work in concert to improve coastal resilience in Puerto Rico.

Isla Verde FWOP Conclusion (R10 to R1): Early modeling of Isla Verde planning reach indicated very low FWOP damages, estimated at $318,000 AAEQ. After careful consideration and support by the non-federal sponsor, due to this low risk, this planning reach was not carried forward for further analysis. Moreover, some portion of the actual Isla Verde community was included in the Ocean Park planning reach (R15 to R11) and those flooding problems will be addressed in the study in that reach.

3 PROBLEMS, OPPORTUNITIES, OBJECTIVES AND CONSTRAINTS

3.1 OCEAN PARK PLANNING REACH

The key problems within the Ocean Park planning reach are coastal storms causing damage to structures, property and critical infrastructure due to coastal flooding, erosion and wave attack, which will be exacerbated in the future with sea level rise.

There are other opportunities that may result from implementation of a Federal project, including:

- Maintain existing coastal (beach) related recreation and tourism: this area depends heavily on tourism, as well as aesthetic quality and cultural identity of community.
- Maintain existing non-coastal recreation in Barbosa Park: this area becomes flooded routinely due to coastal storms, bringing sand and debris which impacts local recreation.
- Maintain or restore beach habitat and environmental resources: reefs and turtle and shore bird nesting areas.

- Improve access to roads after coastal flooding events: Roads are frequently flooded after storm events, preventing access into and out of communities for critical economic functions such as jobs, school, etc.
- Improve overall community resilience within the San Juan Metropolitan Area.
- Improve overall resilience over the island of Puerto Rico.

This study developed the following objectives to address each of the identified problems and opportunities, and ultimately improve the overall community resilience within the entire San Juan Metropolitan Area.

It should be noted that the strategy for Ocean Park planning reach was to reduce coastal flooding first and foremost, since that is the hazard which is causing the vast majority of the immediate vulnerability and damages for the community. Erosion and wave attack reduction are also considered as the primary objective, but were considered after coastal flooding in terms of prioritizing formulation strategies.

- **Primary Objective:** Manage the risk of damages to structures, property and critical infrastructure as a result of coastal flooding, erosion, and wave attack caused by coastal storms, with an emphasis on maintaining life safety, within the study area over a 50-year period of analysis (2029 – 2078).(NED)

- **Secondary Objectives:**
  - Maintain recreational use of coastal and non-coastal areas. (NED)
  - Maintain environmental quality. (EQ)
  - Reduce disruptions to the economy after coastal storms . (RED)
  - Improve life safety during and after coastal flooding events. (OSE)

This study will work to avoid undesirable changes between the future without project and future with-project conditions. In addition to avoiding conflict with Federal regulations, as stated in Federal law, USACE regulations, and executive orders, the study will also work to avoid or minimize negative effects to every extent possible to listed species, cultural resources, reef resources, and submerged aquatic vegetation.

3.2 RINCÓN PLANNING REACH

The key problems within the Rincón planning reach are coastal storms causing damage to structures, property and critical infrastructure due to erosion and wave attack, which will be exacerbated in the future with sea level rise.

There are other opportunities that may result from implementation of a Federal project, including:

- Maintain existing coastal (beach) related recreation and tourism: this area depends heavily on tourism, as well as aesthetic quality and cultural identity of the community.
- Maintain or restore beach habitat and environmental resources: reefs and turtle and shore bird nesting areas.

- Improve overall community resilience within the entire Rincón area.
- Improve overall resilience over the island of Puerto Rico.

This study developed the following objectives to address each of the identified problems and opportunities, and ultimately improve the overall community resilience within the entire Rincón area:

- **Primary Objective:** Manage the risk of damages to structures, property and critical infrastructure as a result of erosion and wave attack caused by coastal storms, with an emphasis on maintaining life safety, within the study area over a 50-year period of analysis (2029 – 2078). (NED)

- **Secondary Objectives:**
  - Maintain recreational use of coastal areas. (NED)
  - Maintain environmental quality. (EQ)
  - Maintain or increase tourism, local property tax revenue and number of jobs. (RED)
  - Reduce risk of local communities abandoning the area. (OSE)

This study will work to avoid undesirable changes between the future without project and future with-project conditions. In addition to avoiding conflict with Federal regulations, as stated in Federal law, USACE regulations, and executive orders, the study will also work to avoid or minimize negative effects to every extent possible to listed species, cultural resources, reef resources, and submerged aquatic vegetation.

4 MANAGEMENT MEASURES

4.1 IDENTIFICATION OF MANAGEMENT MEASURES

Management measures were selected to accomplish at least one of the planning objectives for this study, which were formulated based on the problems. All possible measures were considered, including those beyond the authority of USACE to implement. Coastal storm risk management measures consist of three basic types: structural, nonstructural, and natural or nature-based features. The following is a summary of the types of management measures considered.

Structural coastal storm risk management measures are man-made, constructed measures that counteract a flood event in order to reduce the hazard or to influence the course or probability of occurrence of the event. This includes gates, levees, and seawalls that are implemented to reduce risk of damage to assets, while maintaining public safety.

Nonstructural coastal storm risk management measures are permanent measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding. Nonstructural measures differ from structural measures in that they focus on reducing the consequences of flooding instead of focusing on reducing the probability of flooding. Relocation, floodproofing (wet and dry), home elevation, and flood warning systems are examples of nonstructural measures.

Natural and nature-based coastal storm risk management measures work with or restore natural

processes with the aim of wave attenuation and storm surge reduction. Examples are submerged breakwaters that can also act as an artificial reef, elevated living shorelines and addition of vegetation for redundancy of coastal risk reduction functions.

Some measures serve the purpose of raising up the existing low elevations, to reduce the risk of coastal flooding from a respective water elevation as a result of flooding from waves, tides combined with sea level rise. These measures are identified are noted as "CF" for coastal flooding. Some measures serve the purpose to reduce wave energy, as they are noted as "WE". Some measures serve the function of reducing or slowing erosion, and they are noted as "E". Some measures serve multiple purposes, which can be favorable from a cost and benefit standpoint, and are noted as such.

The following measures were identified and considered for the Ocean Park and Rincón planning reaches. Measures appropriate to address these objectives are outlined in the discussions below.

It should be noted that the strategy for Ocean Park planning reach was to reduce coastal flooding first and foremost, since that is the hazard which is causing the vast majority of the immediate vulnerability and damages for the community. Erosion and wave attack are also considered as the primary objective, but were considered after coastal flooding in terms of prioritizing measures to reduce to hazards.

STRUCTURAL

S-1: Seawall/Floodwall with toe protection (CF, WA, E)): Seawalls and floodwalls are interchangeable at this phase of the study in terms of the function they provide. Seawalls and floodwalls are delineated further in this report in terms of design footprint (i.e.: Seawalls use a slightly wider footprint than floodwalls when backfill and/or toe protection is included). Seawall/floodwalls structures in the study area could be constructed either seaward of existing seawalls, to protect historic value as well as to avoid disruption of engineering structural integrity of the existing seawall function, or landward, to provide access to existing waterfront features. COMBINABILITY: This measure would need to allow outflow of water from behind the landward side of the structure to carry the water to seaward sides, ensuring that functions to meet appropriate rainfall runoff needs are met. This measure is mutually exclusive of S-2, but could be adjacent to S-2.

S-2: Revetment (E/WA): This measure would involve placement of large rock, designed to withstand the wave environment, seaward of structures which are most vulnerable to storm damages. The engineered structure would have a sloped profile designed to dissipate wave energy before it reaches the protected structures. The revetment could be covered by a dune or some degree of beach fill for additional protection and for aesthetic reasons. Construction would be from the beach, with intermittent access from roads. Impacts to the nearshore resources during construction would be avoided. COMBINABILITY: This could be a stand-alone alternative, or combined with S-1 but it is mutually exclusive of NNBF-1 (WA) and NNBF-2 (WA).

S-3: Groins/T-Head Groins (E/WA). A series of groins in the problem area would help hold a beach in front of existing development and prevent further losses of land. The construction of groins would have to be supplemented with nourishment so that adjacent beaches would not be starved of sand. For this reason, groins are considered a method to help hold the fill in place and to reduce periodic nourishment

requirements. The groins would be constructed of large size rock, designed to interlock together and with a foundation such to avoid subsidence. The groins would be placed perpendicular to the shoreline and would extend from above the mean high-water line out into shallow water. The length, orientation, and head of the structure (T-head or not) would be designed based on wave conditions, storms and sediment transport. The beach fill material would come from offshore and/or upland borrow areas. Combinability: This measure would need to be combined with beach nourishment or dunes only.

S-4: Breakwaters (E/WA). The construction of breakwaters offshore along the study focus areas is considered as a management measure to stabilize the existing beach and reduce damages to shorefront properties. Such structures reduce the amount of wave energy reaching the shoreline behind them. As a result, the rate of annual erosion could decrease. The breakwaters would be constructed of large size rock with foundation materials to prevent subsidence. The breakwaters would be trapezoidal in profile and would be placed parallel to the shoreline in shallow water. The breakwaters would be constructed in segments separated from each other to prevent infilling between the existing beach and the breakwaters. The elevation and length of each breakwater segment and the distance between segments would be designed using the wave and sediment transport characteristics of the reach. This measure could benefit the environmental resources in the area, with the rock mimicking natural reefs adjacent to the study area, and potentially creating foraging habitat for benthic species. Combinability: This could be a stand- alone alternative, but better storm damage reduction is achieved when combined with beach nourishment or dunes only.

NATURAL AND NATURE-BASED FEATURES

NNBF-1: Beach nourishment with vegetated dune (E/WA). This management measure includes initial construction of a beach fill, as well as a smaller vegetated dune, and future renourishments at regular intervals. Dunes interactions are widely known to be essential to beach functions in terms of adding valuable storm damage reduction protection during and after storm events, and therefore they are proposed together for this feature. Renourishment of the beach would be undertaken periodically to maintain the erosion control features within design dimensions. Dimensions of the beach fill would be based on economic optimization of benefits provided with consideration to cost, as well as the potential environmental impacts. Beach nourishment material is anticipated to be available in adequate quantities from offshore and/or upland borrow areas. Combinability: This could be a stand- alone alternative or combined with seawalls, revetments, breakwaters and groins.

NNBF-2: Vegetated Dune (E/WA). The presence of dunes is essential if a beach is to remain stable and able to accommodate the stress from unpredictable storms and extreme conditions of wind, wave, and elevated sea surfaces. Dunes maintain a sand repository that, during storms, provides sacrificial sand before structures would be damaged. The dune system provides a measure of public safety and property protection. Proper vegetation on dunes increases sand erosion resistance by binding the sand together via extensive root masses penetrating deep into the sand. Further, such vegetation promotes dune growth through its sand trapping action when significant wind action transports substantial quantities of sand. This measure would include placement of beach compatible material, from either upland or offshore sources, in a dune feature where a berm is not feasible. If in the existing conditions there is a dune, the top elevation of the constructed dune would tie into the existing dune. The front slope of the dune would be a function of the material grain size and construction equipment. Vegetation would be planted after placement of the dune material. Combinability: This could be a stand- alone alternative, but

better storm damage reduction is achieved when combined with groins and breakwaters.

NNBF-3 (WA): Artificial Reef: Offshore breakwaters reduce the amount of wave energy reaching the shoreline, and in this case, would reduce risk of damage to the storm surge measure. The breakwaters would be constructed of large rock with foundation materials to prevent subsidence. The breakwaters would be trapezoidal in profile and would be placed parallel to the shoreline in shallow water. The breakwater would be constructed in segments, separated from each other, to prevent infilling between the beach and the breakwater. The elevation and length of each breakwater segment and the distance between segments would be designed considering the local wave and sediment transport characteristics. This measure could benefit the environmental resources in the area, with the rock mimicking natural reefs adjacent to the study area, and potentially creating foraging habitat for benthic species. Mangroves could grow on top of the breakwaters as well for additional habitat and foraging opportunities for birds. COMBINABILITY: This measure would need to be combined with other coastal flooding reduction measures to fulfill both the coastal flooding, erosion, and wave attack reduction objectives.

NON-STRUCTURAL

NS-1: Relocation of Critical Infrastructure (CF/E/WA): This measure would allow the area experience wave attack while relocating infrastructure to a higher elevation to reduce risk of critical damage. Structures vulnerable to storm damage in the study area would be identified, and where feasible, such structures would be moved further landward on their parcels to escape the vulnerable area. COMBINABILITY: This measure would need to be combined with other structural or NNBF measures that would reduce coastal flooding.

NS-2: Floodproofing (Wet) (CF): Wet floodproofing involves making a series of modifications to a structure to allow an enclosed area below the base flood elevation to flood. The method of floodproofing reduces risk to the building but not to the contents of the building. COMBINABILITY: This measure could be a stand-alone alternative or could be combined with other measures.

NS-3: Elevate structures (CF): This measure, in combination with other measures, could reduce damages to structures by re-building them to higher elevations. COMBINABILITY: This measure could be a stand-alone alternative or could be combined with other measures.

NS-4: Acquisition of structures and property (CF/E/WA): Structures within the area vulnerable to damage would be identified for acquisition. Structures on the acquired parcels would be demolished and natural areas restored. Such parcels would become public property and would reduce the number of structures vulnerable to storm damages. COMBINABILITY: This measure alone would not meet the objective to reduce risk since coastal flooding would still occur and many communities would still be affected; it would need to be combined with other structural or NNBF measures that would reduce coastal flooding.

NS-5: Coastal Regulatory Program: A coastal regulatory program could be established, similar to the state of Florida's Coastal Construction Control Line (CCCL). It does not prohibit construction, but does provide stringent structural restrictions and provides for improving building regulations that could be implemented by the Commonwealth of Puerto Rico. The island-wide implementation of this measure would allow increasing the setback for future construction or increasing the standards for future

construction to reduce the risk of storm damages. The erosion of the shoreline would continue at the present rate, unabated by this measure. Although, this kind of regulation could not be implemented by the USACE, this measure could be enforced by the Commonwealth or local governments. Combinability: This measure would need to be combined with other measures to achieve project purposes.

NS-6: Re-Zoning: Re-zoning could apply to phasing out development in low lying areas over time. This would be a measure implemented by the non-federal sponsor. COMBINABILITY: This measure would need to be combined with other structural or NNBF measures that would reduce coastal flooding.

NS-7 (SS): Improved public outreach: Measures to convey wave action risk to communities could help community better understand how it could affect them during a storm. An example used in other areas is storm surge posts, which visually show the storm surge stages which could be expected in various areas associated with category 1-5 storms. This would be a measure implemented by the non-federal sponsor. COMBINABILITY: This measure would need to be combined with other structural or NNBF measures that would reduce coastal flooding.

NS-8 (SS): Improved evacuation plan and notification systems: The Puerto Rico Hurricane Evacuation Study was released in October 2018, and references evacuation zones. Conclusions from surveys conducted in the Puerto Rico Hurricane Evacuation Study, Behavioral Study, Final Report March 2014 generally indicated that residents would be more likely to evacuate out of the evacuation zone to higher ground if directed to do so. This would be a measure implemented by the non-federal sponsor. COMBINABILITY: This measure alone would not meet the objective to reduce risk since coastal flooding would still occur and many communities would still be affected whether they evacuate or not; it would need to be combined with other structural or NNBF measures that would reduce coastal flooding.

As a note, dry floodproofing involves making building and site modifications to prevent water from entering during a flooding event. Dry floodproofing methods would be to seal flood prone structures from water with door and window barriers, small scale rapid deployable floodwalls, or sealants. Dry floodproofing is generally feasible up to 3 feet and is prohibited in FEMA VE zones which is designated for both planning reaches, and therefore was not eligible for the initial measures list.

4.2 EVALUATION AND COMPARISON OF MEASURES

During this stage, measures were evaluated and compared. The following text describes this process in more detail.

4.2.1 PLANNING CRITERIA

Criteria to evaluate study measures was derived first from the ability of the measures to meet the primary project objectives in each planning reach. The figure below shows the hazard in each reach and the if the measures could sufficiently reduce the hazard. A green check mark is noted where that measure would be expected to reduce risk and was carried forward, a grayed out “x” denotes where a measure could potentially reduce risk but would not be as effective as other measures and therefore was screened from further analysis, and a N/A shows where measures would not be applicable. The text below this figure describes why certain measures were screened out during this first analysis.

Figure 4-1. Initial Measures Screening

	Hazard			Structural				Natural and Nature-Based Features			Non-Structural							
Ocean Park Planning Reach	**Coastal Flooding**	**Erosion**	**Wave Attack**	**S-1 Seawalls with toe protection**	**S-2 Revetments (Rock)**	**S-3 Groins (Rock)**	**S-4 Break water**	**NNBF-1 Beach and Dune/ Veg**	**NNBF-2 Dune/ Veg**	**NNBF-3 Artificial reef**	**NS-1 Relocate Critical Infrastructure**	**NS-2 Flood Proofing Wet**	**NS-3 Elevate Structures**	**NS-4 Acquisition**	**NS-5 CCCL**	**NS-6 - Re-zoning**	**NS-7 - Improve public outreach**	**NS-8 - Improved evac plan and notification**
Pocket Beach	N/A	✓	✓	✓	x	x	x	✓	x	x	x	N/A	N/A	x	✓	✓	✓	✓
Punta Las Marias	N/A	N/A	✓	x	x	N/A	x	N/A	N/A	x	x	N/A	N/A	x	✓	✓	✓	✓
Barbosa	✓	N/A	N/A	✓	N/A	N/A	N/A	N/A	x	N/A	x	x	x	x	✓	✓	✓	✓
Skate Park	✓	N/A	N/A	✓	x	N/A	N/A	N/A	x	N/A	x	x	x	x	✓	✓	✓	✓
Rincon Planning Reach	N/A	✓	✓	x	✓	✓	x	✓	x	x	N/A	N/A	N/A	✓	✓	✓	✓	✓

OCEAN PARK PLANNING REACH

The following measures for potential Federal action were carried forward:

- For erosion and wave attack along E10 to E19:
  - S-1 Seawall/Floodwall with toe protection
  - NNBF-1 Beach and dune/vegetation
- For Coastal flooding from Barbosa Park and Skate Park:
  - S-1 Seawall/Floodwall with toe protection
  - NS-4 Acquisition of structures and property - Similar to NS-2 and NS-3, there are hundreds of structures at potential risk for coastal flooding. This would be a very high cost. However, it could be used for limited areas.

The following measures for potential Federal action were screened out, or removed, from further analysis:

- For erosion and wave attack along E10 to E19:
  - S-2 Revetments (rock)– The surrounding area has sandy beaches, and rock revetment would negatively impact the existing protective beaches in the area, likely increasing erosive and wave attack forces. Other measures carried forward more effectively reduce erosion and wave attack.
  - S-3 Groins (rock) – Groins would be paired with NNBF-1 Beach and dune/vegetation, but it is anticipated that NNBF-1 would be stable without this additional measure.
  - S-4 Breakwaters (rock) – Breakwaters are effective at reducing wave energy and erosion, but would need to be paired with NNBF-1 Beach and dune/vegetation to fully ensure effectiveness. NNBF-1 without a breakwater is anticipated to be as effective, without the additional cost of adding a breakwater.
  - NNBF-2 Dunes/vegetation – Vegetated dunes are effective on areas with available land, but in this area, there is very limited available real estate. Additionally, it is estimated that dunes would be less effective than a beach with small dune in this wave climate.
  - NNBF-3 Artificial reef – Similar to S-4 breakwaters, this measure would need to be paired with NNBF-1 Beach and dune/vegetation to fully ensure effectiveness. NNBF-1 without an artificial reef is anticipated to be as effective, without the additional cost of adding an artificial reef.
  - NS-1 Relocation of critical infrastructure – There is little to no critical infrastructure in the vicinity of high erosional areas. This could be done in areas where there is little to no coastal flooding. However, when considering this planning reach as a system, coastal flooding does not make this option viable.
- For wave attack at Punta Las Marias: This area is already protected by natural hardbottom, and additionally has minimal structures and minimal erosion. The natural hardbottom is expected to continue protecting the area from wave attack. Therefore, no measures are carried forward for this area.
- For Coastal flooding from Barbosa Park and Skate Park:
  - NNBF-2 Dunes/vegetation – Vegetated dunes could be somewhat effective for coastal flooding, but have a risk of failure, which could impose life safety risk. This measure is not as robust as a seawall/floodwall would be to reduce coastal flooding in this area.
  - NS-1 Relocation of critical infrastructure – There is little to no critical infrastructure in the vicinity of high erosional areas. This could be done in areas where there is little to no coastal flooding. However, when considering this planning reach as a system, coastal

flooding does not make this option viable.

- NS-2 Wet Flood Proofing – There are hundreds of structures at potential risk for coastal flooding. All of these structures would need to be elevated or if they were already elevated, allow first floor to become a floodable space, in order to benefit from this measure. Most of the structures in this area are slab on concrete, and would need to be elevated -this would be a very high cost, and would not include elevating local roadways for access. Other measures that were carried forward are more effective and with less cost.
- NS-3 Elevating Structures – Similar to NS-2, there are hundreds of structures at potential risk for coastal flooding. All of these structures would need to be elevated in order to benefit from this measure. Most of the structures in this area are slab on concrete, and would need to be elevated -this would be a very high cost, and would not include elevating local roadways for access. Other measures that were carried forward are more effective and with less cost.

RINCÓN PLANNING REACH

The following measures for potential Federal action were carried forward:

- S-2 Revetments (rock)
- S-3 Groins (rock)
- NNBF-1 Beach and vegetated dune
- NS-4 Acquisition of structures and property

The following measures for potential Federal action were screened out, or removed, from further analysis:

- S-1 Seawall/Floodwall with toe protection – A large extent of this area is already highly eroded. Constructing a seawall with toe protection would be extremely difficult to build in this area due to very limited space in a water environment. Other measures that were carried forward are more effective and with less cost.
- S-4 Breakwaters (rock) – Breakwaters are effective at reducing wave energy and erosion, but would need to be paired with NNBF-1 Beach and dune/vegetation to fully ensure effectiveness. NNBF-1 without a breakwater is anticipated to be as effective if paired with a groin, without the additional cost of adding a breakwater.
- NNBF-2 Dunes/vegetation – Vegetated dunes are effective on areas with available land, but in this area, there is very limited available real estate. Additionally, it is estimated that dunes would be less effective than a beach with small dune in this wave climate.
- NNBF-3 Artificial reef – Similar to S-4 breakwaters, this measure would need to be paired with NNBF-1 Beach and dune/vegetation to fully ensure effectiveness. NNBF-1 without an artificial reef is anticipated to be more effective with groins.
- NS-1 Relocation of critical infrastructure – There is little to no critical infrastructure in the vicinity of high erosional areas.

In all both Ocean Park and Rincón Planning Reaches, the following measures for potential non-federal action were carried forward:

- NS-5 Coastal Regulatory Program (shown as CCCL)
- NS-6 Rezoning

- NS-7 Improved public outreach
- NS-8 Improved evacuation plan and notification

4.2.2 PLANNING CRITERIA SCORING

Criteria to evaluate the study measures, to inform plan formulation of alternatives, consisted of meeting specific project objectives, evaluations under the four P&G accounts, long term consideration, as well as avoiding constraints. The following information summarizes key considerations. It should be noted that at this point in the study, planning objectives were still in development. These early versions, along with more information that became apparent during study investigations, then informed the more refined planning objectives that were used to evaluate the alternatives.

Figure 4-2. Planning Criteria for Evaluation and Comparison of Measures

Contribution to Planning objectives

- **Ocean Park Planning Reach–**
    - Primary - Manage the risk of damages to structures, property and critical infrastructure as a result of coastal flooding, erosion, and wave attack caused by coastal storms, with an emphasis on life safety, within the study area over a 50-year period of analysis (2029 – 2078).

    - Secondary
        - Maintain Existing Recreation
        - Maintain Environmental Quality
- Rincon Planning Reach –
    - Primary - Manage the risk of damages to structures, property and critical infrastructure as a result of erosion and wave attack caused by coastal storms, with an emphasis on life safety, within the study area over a 50-year period of analysis (2029 – 2078).

    - Secondary
        - Maintain Existing Recreation
        - Maintain Environmental Quality

The four P&G Accounts

- National Economic Development (NED): For each measure, the quantitative assessment of NED was documented, relative to the other measures.
- Other Social Effects (OSE): For each measure, OSE was considered in terms of life safety as the most paramount criteria in areas where life safety was assessed to be high risk, as described earlier. This is described further in **Section 3.8.2** below. Other considerations as described earlier were design height, public acceptability, and impact to existing urban development (ie: footprint of the feature).
- Environmental Quality (EQ): For each measures, EQ was considered, including tradeoffs of avoidance of resources, estimated acreages of impacts, and creation of additional habitat.
- Regional Economic Development (RED): For each measures, RED was considered in terms of economic infusion during construction and in terms of resilience.

Long-term Considerations

- Long-term ease of use/adaptability to sea level rise: For each measure, the adaptability of features, including risk of sea level rise, was considered.

Avoid Constraints

- Avoid conflict with state and Federal regulations: For each measure, ability to avoid conflicts with state and Federal regulations was considered.
- Cannot increase life loss compared to the FWOP conditions: Each measure was assessed to ensure life safety and to ensure life loss would not be made worse.

Table 4-1. Measures evaluation and comparison – Ocean Park Planning Reach.

MEASURES	PRIMARY PLANNING OBJECTIVE	SECONDARY PLANNING OBJECTIVES			FOUR PRINCIPLES & GUIDELINES ACCOUNTS					TOTAL	Avoids all Fed/State laws	Maintains life safety
	Meets Primary Objectives (Coastal Flooding, Erosion, Wave Attack)	Maintain Existing Recreation (Beach and Nearshore) (Max 2 point)	Maintain Environmental Quality/Maintain Beach/Dune Interaction (Max 2 point)	SLC Considerations - adaptability and effectiveness (max 2 points)	National Economic Development (NED) (Max 2 points)	Environmental Quality (Max 2 point)	Other Social Effects (Max 2 point)	Regional Economic Development (RED) (Max 2 point)	Four Accounts Sub score			
STRUCTURAL (S)												
S-1 Seawalls/Floodwalls	Yes (coastal flooding, erosion and wave attack)	seawall set back from shoreline along existing wall would preserve beach area at Barbosa Park for continued recreation	seawall set back from shoreline along existing wall would preserve beach area at Barbosa Park for habitat	seawalls are somewhat adaptable in height up to certain elevations, but would then need to be rebuilt	Likely that benefits will exceed cost	seawall set back from shoreline along existing wall would preserve beach area at Barbosa Park for habitat	seawall is not inherently aesthetic but could be build to integrate into the community as well reduce threat to life safety from coastal flooding	seawall would reduce risk of coastal flooding and help economy rebound after a storm event			Y	Y
	3	1	0	0.5	1.5	0.5	0.5	1	3.5	8		
NATURAL AND NATURE-BASED FEATURES (NNBF)												
NNBF-1 Beach with small vegetated dune	Yes (erosion and wave attack)	allows for continued recreation	allows for restored beach habitat; may cover currently exposed hardbottom	highly adaptable by adding more sand	Less likely that benefits will exceed cost due to high cost of sand in this area	allows for restored beach habitat; may cover currently exposed hardbottom	will integrate into natural environment in the community	will allow economy to rebound after a storm event				
	3	2	1	2	0.5	1	2	1.5	5	13	Y	Y

Table 4-2. Measures evaluation and comparison – Rincon Planning Reach.

MEASURES		PRIMARY PLANNING OBJECTIVES	SECONDARY PLANNING OBJECTIVES			FOUR PRINCIPLES & GUIDELINES ACCOUNTS					TOTAL	Avoids all Fed/State laws	Maintains life safety
		Erosion & Wave Attack (Max 3 points)	Maintain Existing Recreation (Beach and Nearshore) (Max 2 point)	Maintain Environmental Quality/Maintain Beach/Dune Interaction (Max 2 point)	SLC Considerations - adaptability and effectiveness (max 2 points)	National Economic Development (NED) (Max 2 points)	Environmental Quality (Max 2 point)	Other Social Effects (Max 2 point)	Regional Economic Development (RED) (Max 2 point)	Four Accounts Sub score		Y/N	Y/N
STRUCTURAL (S)													
S-2	Revetments (Rock)	3	-1	-1	1.5	0.5	0	0.5	1	2	4.5	Y	Y
S-3	Groins (Rock)	3	1	1	1	0.5	1	1	1	3.5	9.5	Y	Y
NATURAL AND NATURE-BASED FEATURES (NNBF)													
NNBF-1	Beach Nourishment w/dune	3	2	1	2	0.5	1	1.5	1.5	4.5	12.5	Y	Y
NON-STRUCTURAL MEASURES (NS)													
NS-4	Acquistion	3	2	0	2	0.5	1	1	1	3.5	10.5	Y	Y

5 ALTERNATIVE FORMULATION CONSIDERATIONS

5.1 FORMULATION STRATEGY

The overarching objective was to formulate plans to contribute to coastal resiliency in Puerto Rico. The overall planning strategy was to formulate comprehensives plans for each planning reach to focus on the key measures to reduce coastal storm risk first, and then focus on configuring and refining those measures into alternatives to gain comprehensive benefits towards community resiliency. Following the Assistant Secretary of the Army (ASA(CW) directive from 5 January 2021, the team then identified an NED plan, comprehensive benefits plan, and/or Locally Preferred Plan (LPP). Due to the nature of these very different study areas, in terms of geographical distances, different problems, and different coastal dynamics, a tentatively selected plan was recommended for each planning reach, as a stand-alone project.

Measures that met criteria to be carried forward were combined using the combinability thought process as described earlier, as well as refined geographical elevation information, existing site conditions, and professional engineering judgment as to the most feasible combinations per reach. The P&G four accounts (OSE, EQ, NED, RED) were integrated into the secondary planning objectives during plan formulation of the alternatives, and are discussed below.

5.2 OTHER SOCIAL EFFECTS

Key areas of focus were considered in the Other Social Effects (OSE) account. In this account, life safety considerations were paramount, and the robustness of measures in terms of life safety considerations were most fully considered. Life safety was considered as the most paramount criteria in areas where life safety was assessed to be high risk. Other focus areas of consideration included design heights, which looked at the most realistic scenarios in terms of water level under annual exceedance probabilities and public acceptability of height of structures. Available land was another key focus area. In an urban setting, available land is important and as such, the footprints of various measures would need were considered.

LIFE SAFETY CONSIDERATIONS

There is an existing Puerto Rico Evacuation Plan and in the future in absence of a Federal project, it is assumed that the Evacuation Plan will be carried out by government officials. It is also assumed that evacuation orders would be in place as required, and followed by communities prior to hurricanes and storm events to increase life safety and reduce the risk of life loss.

When considering potential alternatives and the effects they may have after construction, however, the assumptions when comparing the future without-project condition to the future with-project condition may change. Building new features to reduce damages to structures will reduce the risk of damage to structures and should also increase life safety as well; however, evacuation plans and evacuation orders should still be followed. However, if evacuation plans are not followed, in the case of failure of a structure, water piled behind the structure would have the potential to put life safety at risk. This risk was carefully considered during the plan formulation process. In areas where life safety may be at a higher risk due to factors such as low lying elevations, structures on grade (rather than raised), and existing waterways in the area, certain measures are lower risk than others. For any floodwalls/seawalls, inland hydrology features would have to be implemented as associated features to ensure that rainfall runoff would continue to drain properly through the new feature to ensure continued life safety.

DESIGN HEIGHT CONSIDERATIONS

The team performed due diligence to ensure that likely scenarios were forecast during preliminary design, to provide reasonable assurance that the top of the feature would not be overtopped. To produce risk-based design elevations for the desired measures the study team followed ECB 2019-15 and ER 1105-2-101. ER 1105-2-101 states the assurance, also known as conditional non-exceedance probability, is based on the uncertainty in the flow and stages associated with a given exceedance probability event. This study utilized the 90% Confidence Intervals (CI) from Federal Emergency Management Administration (FEMA) to incorporate the total water level uncertainty. To represent the design elevation, the study used the 90% CI of the 1% AEP event with mean higher high water (MHHW) and the intermediate sea level Change (SLC) out to the end of the assumed period of analysis (2079). The team analyzed the stage-damage output from the future without-project (FWOP) G2CRM model runs to confirm that the design elevations would provide sufficient damage reduction to each planning reach. The team assumed the average design elevation to be between 6.5 to 8.5 feet PRVD02 during this stage of the planning process. To incorporate sea level change, the intermediate curve was chosen for plan formulation, based on trends for 5-year and 19-year MSL moving average. Sensitivities for the high SLC curve were conducted and are discussed in the risk and uncertainty section of the main report.

PUBLIC ACCEPTABILITY

Public acceptability was an important consideration within the communities in the study area. One aspect of this is the height of the feature. The team performed due diligence, as discussed earlier to provide reasonable assurance that the top of the feature would not be overtopped. However, the team also took into account existing community features as much as possible and kept public acceptability and aesthetics of the viewshed in mind. Another key aspect of public acceptability, as discussed in Chapter 2, is that many of the reaches in the study area offer important opportunities for community gathering and recreation. Maintaining access to those opportunities were also kept in mind during formulation.

URBAN SETTING AND LAND CONSIDERATIONS

Several alternatives have wide variations in terms of the bottom width, or footprint they would require, translating to needed land in a higher urban setting. Available land and avoidance of excessive land acquisition was considered with along with several other factors as mentioned during plan formulation.

5.3 ENVIRONMENTAL QUALITY CONSIDERATIONS

The environmental quality account considers non-monetary effects on ecological, cultural, and aesthetic resources. Under this account, the preferred plan should avoid or minimize environmental impacts and maximize environmental quality in the project area to the extent practicable considering other criteria and planning objectives. For the purposes of alternatives analysis, all action plans were compared to the future without-project condition (i.e., NEPA No Action), which factors in 50 years of sea level change (to 2079). Effects for each alternative were evaluated and were carefully considered during plan formulation and for selection of the tentatively selected plan.

Similar to the land considerations discussed above, effects to environmental resources in the area were also dependent in some cases on the footprint of the various alternatives, with tradeoffs as well in some cases. During plan formulation throughout the alternatives analysis, creation of habitat, avoidance of impacts to habitat, as well as loss of habitat (resulting in mitigation) were accounted for, factored into

plan selection, and are documented in this report.

5.4 ECONOMIC CONSIDERATIONS

The national economic development (NED) is considered in terms of the function of the feature and how well it will reduce the risk of damages to structures, thus providing monetary savings or benefits to the nation when compared to the costs of constructing and maintaining the feature. Recreation is important within each planning each, and both maintaining and improving recreation while reducing damages from coastal storms was a very important consideration during plan formulation. Similarly, regional economic development (RED) is considered in terms of how the feature may contribute to the local economy.

6 ALTERNATIVE FORMULATION

6.1 THE FOCUSED ARRAY OF ALTERNATIVES

Using the key information as described above in concert with ground elevations and key hazards leading to the highest risk of damages, the focused array of alternatives was formulated and is provided below.

Additionally, all alternatives sufficiently met the completeness, effectiveness, efficiency and acceptability criteria below, as required by USAE policy in ER 1105-2-100.

- Completeness: Completeness is the extent to which the alternative plans provide and account for all necessary investments or other actions to ensure the realization of the planning objectives, including actions by other Federal and non-Federal entities. For each alternative, ability of the alternative to provide a complete response to the problem was considered.
- Effectiveness: Effectiveness is the extent to which the alternative plans contribute to achieve the planning objectives. For each alternative, ability of the alternative to a be an efficient solution to meet project objectives was considered.
- Efficiency: Efficiency is the extent to which an alternative plan is the most cost effective means of achieving the objectives. For each alternative, ability of the alternative to a be cost effective solution was considered.
- Acceptability: Acceptability is the extent to which the alternative plans are acceptable in terms of applicable laws, regulations and public policies. For each alternative, ability of the alternative be acceptable was considered.

All floodwall/seawall alternatives in the focused array include inland hydrology measures, to allow to outflow of rainfall runoff. The no-action alternative is also carried forward into the final array. Although this alternative does not include any Federal action or risk reduction from hazards as outlined within this study, it provides a comparison for all other alternatives.

Although the key objectives are generally the same in each planning reach, it is important to note that the planning reaches represent very different and unique communities in Puerto Rico. While each planning reach has been defined as a separate unit, the goal is to provide a cohesive storm risk reduction plan for the communities at risk in Puerto Rico, focusing on Ocean Park Planning Reach to improve resilience in the San Juan Metro Area and improving resilience within the entirety of Stella and in the municipality of Rincon.

Each of the alternatives listed below is described further in the subsequent text. Rationale for how each alternative is conceptually considered and how is was further refined for the final array is presented.

Table 6-1. Focused Array of Alternatives.

Alternative	Description
Ocean Park Planning Reach	
Alternative 1	**No Action**
Alternative 2	**Floodwall with toe protection (E13 to E15, R14)**
Alternative 3	**Floodwall with toe protection (E13 to E15, R14) + beach nourishment with vegetated dunes (E10-E19)**
Alternative 4	**Floodwall (up to E10-E19) + R14**
Alternative 5	**Floodwall with toe protection (E13 to E15, R14) + Acquisition of structures and property**
Rincón Planning Reach	
Alternative 1	**No Action**
Alternative 2	**Revetment (Rock) R11 to R22**
Alternative 3	**Beach Nourishment with vegetated dunes (R11 to R22) plus groins**
Alternative 4	**Acquisition (R11 to R22)**

OCEAN PARK PLANNING REACH

Alternative 1 – No Action: In absence of an actionable plan, coastal flooding will continue to occur routinely during minor and major storm events. Life safety from coastal flooding will continue to be at risk, road access to critical infrastructure will be limited or non-accessible, and homes, business buildings and other structures and property will be damaged.

Alternative 2 –Seawall with toe protection* (E13 to E15, R14): This alternative would reduce the risk of coastal flooding at the most critical areas, Barbosa Park and the skate park. The seawall would be set back from the shoreline along the existing small seawall/bench or could be placed further inland in place of the existing road. It would have small backfill behind it. This option would preserve the beach in front of the seawall, and also allow public access over it to maintain existing accessibility to the beach park. It would also be set back from the shoreline in the skate park area to allow for ease of construction (R14 into smaller portion of R15 and R13). Portions of the seawall which are not set back on dry land would require some small sand fill to be feasible for construction due to limited existing land in those areas, and would include toe protection which would likely be rock armoring.

Alternative 3 - Seawall with toe protection* (E13 to E15, R14) + beach nourishment with vegetated dunes (E10-E19): See the seawall description from Alt 2. In addition to reducing the risk of coastal flooding, this alternative also would include a berm and vegetated dune with a periodic nourishment over a 50-year period of analysis to reduce the risk of erosion and wave attack for the adjacent coastal

fronting structures along the areas which were shown in modeling results to receive the most erosion related damages, along E10 to E19. The width and height of the dune would be refined prior to the final array of alternatives and is discussed further prior to the final array of alternatives.

Alternative 4 – Seawall* (up to E10-E19) + R14: See the seawall description from Alt 2. In additional to reduction in the risk of coastal flooding, this alternative would extend the seawall west and east to reduce the risk of not only coastal flooding but also erosion in the adjacent coastal fronting structures along E10 to E19. The extended seawalls would require some small sand fill to be feasible for construction due to limited existing land in those areas, and would include toe protection which would likely be rock revetment.

Alternative 5 – Seawall* (up to E10-E19) + R14 + Acquisition: Alternative 5 is the same as Alternative 2, but also introduces a non-structural measure and nature-based feature which is acquisition of structures to the west of Barbosa park and restoration of those parcels to a natural beach.

RINCÓN PLANNING REACH

Alternative 1 – No Action: The In absence of an actionable plan, individual property owners along the shoreline will attempt to reduce risk locally with low-cost, ad hoc solutions such as rock, gabions (metal meshes containing rocks), or seawalls, incurring repeated expense and probable failure and condemnation by local government due to safety reasons. Approximately 60 structures are projected to structurally fail, and become condemned. Condemned structures would likely become derelict and are unlikely to be removed which would further exacerbate erosion on surrounding shorelines. Residents will be forced to move, likely out of the area and potentially out of Puerto Rico, reducing not only the strength of the cultural identity of the community but also reducing the tax base and impairing the economy. Structures would become derelict and are unlikely to be removed which would further exacerbate erosion on surrounding shorelines. This is identified as the NED plan by default.

Alternative 2 - Revetment (Rock) R11 to R22: This alternative would propose rock revetment, along the coastal fronting areas from R11 to R22 to reduce the risk of erosion and wave attack and protect structures and property from existing damages or damages in the future. In areas already set back from the ocean with existing sandy beach, the revetment would be seaward of the rock revetment, thus holding the existing sand in place. In areas already critically eroded, the rock revetment would be close to the shoreline and could be directly in front of existing structures.

Alternative 3: Beach nourishment with vegetated dunes (R11 to R22) plus groins: This alternative would include a beach and vegetated dune to reduce the risk of erosion and wave attack. It would require rock groins perpendicular to the shoreline to effectively hold the sand until the next renourishment. The width and height of the beach and dune, as well as the number of groins estimated to be most effective, would be refined prior to the final array of alternatives and is discussed further in Section 5.2.

Alternative 4: Acquisition (R11 to R22): With this plan, high-risk structures along approximately 1.1 miles of shoreline would be included for acquisition and residents would be relocated. The structures would be demolished, and the land would be returned to its natural sandy state which would include revegetation with native species. This alternative would reset the shoreline and an appropriate distance behind it to natural beach to reduce the risk of erosion and wave attack to structures behind the established line.

6.2 DEVELOPMENT OF THE FOCUSED ARRAY TOWARDS THE FINAL ARRAY OF ALTERNATIVES

OCEAN PARK PLANNING REACH

Refinement of Planning Objectives

It should be noted that at this stage, planning objectives for this reach were refined with additional information during the investigations, which then were used to refine alternatives, as well as evaluate and compare each of the alternatives later in the process. These objectives are stated in Section 3.1 of this appendix.

Floodwall Alternatives

The floodwall elevations were optimized in the focused array of alternatives to become the final array of alternatives. For the floodwall elevations, the team considered elevations ranging from 6 – 8.5 ft relative to the PRVD02 datum. The linear extent of the floodwall (shown in the image with a white line) changes for each floodwall elevation, due to the new water flood paths that are introduced at increased water elevations, as shown in **Figure 6-1**. The costs and benefits were considered, as well as the social effects and environmental effects of greater extent of seawall. The floodwall elevation at 7 ft PRVD02 is most effective from an economic standpoint, showing the highest net benefits, shown in **Figure 6-2**. Additionally, a smaller floodwall footprint would be better received by the community and would have much less environmental impacts.

Figure 6-1. Extent of floodwall with various elevations considered.

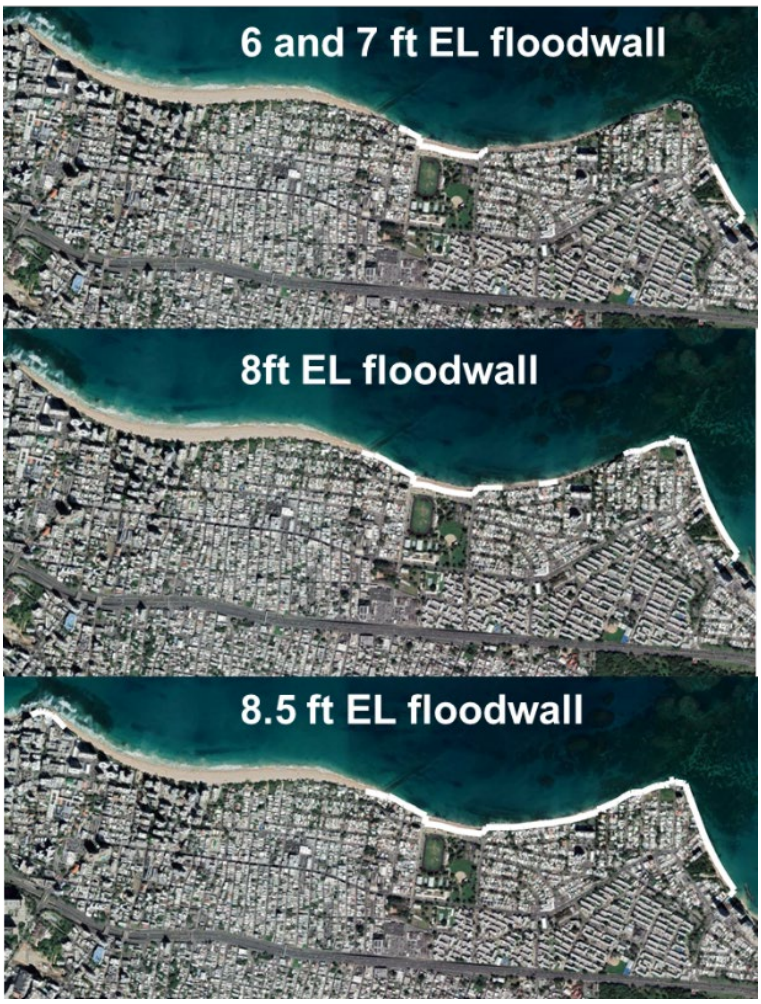


Figure 6-2. Floodwall Elevations – Costa and Benefits Analysis.

FLOODWALL ALTERNATIVES

Floodwall Elevation Assessment				
Alt	Elevation (PRVD02)	Benefits (PV)	Total Cost (PV)	Net-Benefits (PV)
Floodwall	6	$78,493,000	$ 31,267,000	$47,226,000
Floodwall	7	$85,632,000	$ 31,267,000	$54,365,000
Floodwall	8	$101,367,000	$ 66,921,000	$34,446,000

Elevation optimized at 7 foot (highest net benefits)& carried forward for all alternatives

With all of these considerations, the 7 ft EL PRVD02 floodwall was carried forward for all alternatives.

Beach and Vegetated Dune Alternatives

For Alternative 3 (beach nourishment with vegetated dune), various berm widths and dune heights were considered along with periodic nourishment intervals. High costs of sand in this area (assuming an upland source) combined with erosion rates, physical forces, environmental conditions, and effectiveness in damage reduction were a key factor in determining optimum parameters to carry forward. Beach berm widths ranging from 10 feet wide to 20 feet wide were evaluated. Associated dune heights and widths, ranging from 10 to 20 feet high ((PRVD02) and 8 to 12 feet wide were considered. Period nourishments from 5 to 10 years were evaluated as well.

First, the study team established that any combination had to be at least 75% effective at reducing storm damages. Second, the combination needed to be cost effective. Additional benefits from recreation as a result of beach berm widths was not considered during this time, but was considered later in the final array. Only three combinations were found to meet the above criteria, which were as follows:

- 3a - B10_H12W20_10 (10' Berm with Dune 12' High and 20' Wide, nourished every 10 years,
- 3b - B10_H12W20_5 (10' Berm with Dune 12' High and 20' Wide, nourished every 5 years), and
- 3c - B20_H12W20_5 (10' Berm with Dune 12' High and 20' Wide, nourished every 5 years)

Figure 6-3. Ocean Park Refinement of Beach and Vegetated Dune with Periodic Nourishment

Alt	FWOP R10-R19	Total FWOP	R10-19 FWP Armor	R10-19 FWP S&C	R10-R19 FWP	Total FWP	R10-R19 Damage Reduction	Total Damage Reduction	Benefits	Total Cost	Net-Benefits	Cost Effective	BCR
B10_H8W10_10YR	$ 41,538	$ 55,997	$ 2,105	$ 21,549	$ 23,654	$ 38,113	43%	8%	$ 3,425	$ 83,958	$ (80,533)	Yes	0.04
B10_H10W10_10YR	$ 41,538	$ 55,997	$ 1,569	$ 17,334	$ 18,902	$ 33,361	54%	20%	$ 8,177	$ 101,206	$ (93,029)	Yes	0.08
B10_H8W10_5YR	$ 41,538	$ 55,997	$ 1,710	$ 19,723	$ 21,433	$ 35,892	48%	14%	$ 5,646	$ 105,546	$ (99,900)	No	0.05
B10_H10W20_10YR	$ 41,538	$ 55,997	$ 1,272	$ 15,105	$ 16,378	$ 30,837	61%	26%	$ 10,701	$ 110,539	$ (99,838)	Yes	0.10
B20_H10W10_10YR	$ 41,538	$ 55,997	$ 1,816	$ 16,212	$ 18,027	$ 32,486	57%	22%	$ 9,052	$ 116,286	$ (107,234)	No	0.08
B10_H8W20_5YR	$ 41,538	$ 55,997	$ 1,297	$ 18,569	$ 19,867	$ 34,326	52%	17%	$ 7,212	$ 117,156	$ (109,944)	No	0.06
B10_H8W20_5YR	$ 41,538	$ 55,997	$ 1,297	$ 18,569	$ 19,867	$ 34,326	52%	17%	$ 7,212	$ 117,156	$ (109,944)	No	0.06
B10_H12W10_10YR	$ 41,538	$ 55,997	$ 849	$ 11,188	$ 12,037	$ 26,496	71%	36%	$ 15,042	$ 118,827	$ (103,784)	Yes	0.13
B20_H10W20_10YR	$ 41,538	$ 55,997	$ 1,392	$ 14,295	$ 15,687	$ 30,146	62%	27%	$ 11,392	$ 124,972	$ (113,579)	No	0.09
B10_H12W20_10YR	$ 41,538	$ 55,997	$ 747	$ 8,501	$ 9,248	$ 23,707	78%	43%	$ 17,831	$ 126,270	$ (108,438)	Yes	0.14
B10_H10W10_5YR	$ 41,538	$ 55,997	$ 957	$ 12,381	$ 13,338	$ 27,797	68%	33%	$ 13,741	$ 130,423	$ (116,682)	No	0.11
B10_H10W20_5YR	$ 41,538	$ 55,997	$ 706	$ 9,105	$ 9,810	$ 24,269	76%	42%	$ 17,269	$ 130,676	$ (113,407)	No	0.13
B20_H12W10_10YR	$ 41,538	$ 55,997	$ 883	$ 10,672	$ 11,555	$ 26,014	72%	37%	$ 15,524	$ 132,480	$ (116,957)	No	0.12
B20_H10W10_5YR	$ 41,538	$ 55,997	$ 959	$ 10,323	$ 11,282	$ 25,741	73%	38%	$ 15,797	$ 138,106	$ (122,309)	No	0.11
B10_H12W20_5YR	$ 41,538	$ 55,997	$ 403	$ 891	$ 1,294	$ 15,753	97%	62%	$ 25,785	$ 140,317	$ (114,531)	Yes	0.18
B20_H12W20_10YR	$ 41,538	$ 55,997	$ 793	$ 8,226	$ 9,019	$ 23,478	78%	43%	$ 18,060	$ 140,680	$ (122,619)	No	0.13
B10_H12W10_5YR	$ 41,538	$ 55,997	$ 185	$ 3,432	$ 3,618	$ 18,077	91%	56%	$ 23,461	$ 142,031	$ (118,569)	No	0.17
B20_H10W20_5YR	$ 41,538	$ 55,997	$ 524	$ 7,110	$ 7,634	$ 22,093	82%	47%	$ 19,445	$ 144,426	$ (124,980)	No	0.13
B20_H12W10_5YR	$ 41,538	$ 55,997	$ 416	$ 2,458	$ 2,874	$ 17,333	93%	58%	$ 24,205	$ 147,066	$ (122,861)	No	0.16
B20_H12W20_5YR	$ 41,538	$ 55,997	$ 409	$ 1,370	$ 1,779	$ 16,238	96%	61%	$ 25,300	$ 154,175	$ (128,875)	No	0.16

Further analysis with refined information showed that 3a, although still significantly low incremental net benefits (when looking at how many more benefits would be obtained after coastal flooding benefits from the first increment of seawall are received in Alternative 2, is still shown to have the highest net benefits relative to the 3b and 3c. Therefore, this dimension of beach and dune, with periodic nourishment of 5 year intervals, was found to be the most effective and cost effective, out of all combinations and was carried forward to the final array for Alternative 3 for further analysis.

Table 6-2. Refinement of Beach Nourishment Alternatives.

Increment 2 - Nourishment without Sewall Extensions					
Alt	Nourished Reaches	Incremental Benefits	Incremental Cost	Incremental BCR	Incremental Net-Benefits
B10H12W20_5	R10-R19	$ 27,152,000	$ 136,401,000	0.20	$ (109,249,000)
B10H12W20_10	R10-R19	$ 20,551,000	$ 121,592,000	0.17	$ (101,041,000)
B20H12W20_5	R10-R19	$ 27,276,000	$ 150,617,000	0.18	$ (123,341,000)

Highest net benefits of the three, carried forward

RINCÓN PLANNING REACH

Refinement of Planning Objectives

It should be noted that at this stage, planning objectives for this reach were refined with additional information during the investigations, which then were used to refine alternatives, as well as evaluate and compare each of the alternatives later in the process. These objectives are stated in Section 3.2 of this appendix.

Beach and Vegetated Dune Alternatives

For Alternative 3 (beach nourishment with vegetated dune), various berm widths and dune heights were considered along with periodic nourishment intervals and number of groins needed. High costs of sand in this area (assuming an offshore source) combined with erosion rates, physical forces, environmental conditions, and effectiveness in damage reduction were a key factor in determining optimum parameters to carry forward. Beach berm widths ranging from 10 feet wide to 30 feet wide were evaluated. Associated dune heights and widths, ranging from 10 to 20 feet high ((PRVD02) and 8 to 12 feet wide were considered. Period nourishments from 5 to 10 years were evaluated as well.

First, the study team established that approximately 12 groins would be required to effectively hold the sand in place between nourishment intervals. Second, the combination needed to be effective at reducing damages and cost effective. Additional benefits from recreation as a result of beach berm widths was not considered during this time, but was considered later in the final array. Only two combinations were found to meet the above criteria, which were as follows:

- 4a - G50_B10_5 (Field of 12 groin structures, 10’ Berm, Existing Dune, Nourished every 5 Years)
- 4b - G50_B20_5 (Field of 12 groin structures, 20’ Berm, Existing Dune, Nourished every 5 Years)

For Alternative 4, the back extent of the first row of structures were considered to be a proxy for a reasonable setback line for this level of analysis. Structures seaward would be included for acquisition. Structures set back beyond that would not be included and would be considered to already be at a

reasonable distance to maintain low risk of damages. In general, hotels and large condominiums would not be included in the acquisition.

6.3 FINAL ARRAY OF ALTERNATIVES

The discussions provided above lead to the development of the final array of alternatives presented in this section and found in the table below. Details on the engineering modeling and preliminary design assumptions for all alternatives at this stage of the final array can be found in **Appendix A, Engineering**.

Figure 6-4. Final Array of Alternatives.

Alternative	Description
Ocean Park Planning Reach	
Alternative 1	**No Action**
Alternative 2	**Floodwall with toe protection* (E13 to E15, R14)**
Alternative 3	**Floodwall with toe protection* (E13 to E15, R14) + beach nourishment with vegetated dune (E10-E19) (***10' Berm with Dune 12' and 20' Wide, nourished every 5 years*)
Alternative 4	**Floodwall with toe protection* (up to E10-E19) + R14**
Alternative 5	**Floodwall with toe protection* (E13 to E15, R14) + Acquisition of structures and property**
Rincón Planning Reach	
Alternative 1	**No Action**
Alternative 2	**Revetment (Rock) R11 to R22**
Alternative 3	**Beach Nourishment with vegetated dunes (R11 to R22) plus groins (***Field of 12 groin structures, 10' Berm, Existing Dune, Nourished every 5 Years)*
Alternative 4	**Acquisition (R11 to R20)**

*Floodwall would be at an elevation of 7-foot (PRVD02) for all seawall alternatives shown above. Seawall construction for Ocean Park Alts 2,3,4 and 5 would also require toe protection which is assumed to be rock armoring.
**Elevations of dunes are referenced at PRDV02
***Floodwall construction for alternatives west of E13 would require small initial sand fill for construction feasibility in those areas.
****The floodwall would tie into high ground for all ocean park alternatives, causing them to be constructed slightly beyond the reference points.

6.4 EVALUATION AND COMPARISON OF THE FINAL ARRAY OF ALTERNATIVES

In this stage of the planning process (steps 4 and 5), the focused array of alternatives were qualitatively and quantitatively compared and evaluated against criteria under integrated secondary planning objectives which represented the 4 P&G accounts (NED, EQ, OSE, RED). Then, the team identified the

NED Plan, comprehensive benefits plan and ultimately selection of the Tentatively Selected Plan (TSP). Discussion of those evaluations are found in text below. The results are visually summarized in provided as a graphic reference while reading the following discussions.

OCEAN PARK PLANNNG REACH

An extensive analysis of all effects, both positive and negative, under NED, EQ, RED and OSE was conducted during the study. The discussions below capture both the qualitative and quantitative results of the analysis. **Figure 6-5** can be referenced for a brief overview of the analysis in quantitative terms. Chapter 4 of this report assesses environmental quality effects for each of the alternatives in detail, as required under NEPA. The sections that follow here include the results of that analysis.

Alternative 1 is the no action plan. In absence of an actionable plan, coastal flooding will continue to occur routinely during minor and major storm events. Life safety from coastal flooding will continue to be at risk, road access to critical infrastructure will be limited or non-accessible, and homes, business buildings and other structures and property will be damaged.

Alternative 2 is a floodwall rock armor for toe protection. This alternative would reduce the risk of coastal flooding entry at the most critical areas, Barbosa Park and the "skate park" (Figure 3). This alternative is preferred by the non-federal sponsor. At Barbosa Park, the floodwall would be set back from the shoreline in place of the existing park access road. The floodwall would be aligned between the beach and the park in Barbosa Park, and would align landward of a block of existing structures, to tie into high ground. Those structures currently have a seawall at a higher elevation than what is proposed and already have reduced risk from coastal flooding. In short, this plan would not induce additional flooding for those properties. The floodwall at Barbosa Park would have buried rock armoring and would have a small initial sand backfill seaward of it, in the form of a small vegetated dune. This option would preserve the beach in front of the floodwall (approximately 2 foot high ground elevation on average), and also allow public access over it to maintain existing accessibility to the beach park. This option would preserve the beach in front of the floodwall (approximately 2 foot high ground elevation on average in Barbosa Park), and also allow public access over it to maintain existing accessibility to the beach park. In this area, it would be aligned along the shoreline and would have rock armoring for toe protection seaward of it. Access to Barbosa Park would be maintained along the side access roads. The existing sidewalk in the area would need to be removed during construction but would be re-constructed landward of the new floodwall. In the Barbosa Park location, some temporary easements would be required during construction and a permanent acquisition on one property would be required to provide necessary land to construct and maintain the floodwall. Approximately 6 removable floodgates are proposed to allow property access to current residents during non-flooding events, and would be placed prior to flooding events. In the skate park location, some temporary easements would be required during construction and a permanent acquisition on three properties would be required to provide necessary land to construct and maintain the floodwall. Approximately 1 removable floodgate is proposed to allow property access to current residents during non-flooding events, and would be placed prior to flooding events. Based on this alternative's work limits, there would be no significant overlap with existing natural habitats. Avoidance planning was conducted to eliminate or minimize direct effects to aquatic habitats, and to maintain existing beach habitat conditions post construction. Prescribed conservation measures and monitoring would be implemented and environmental mitigation would not be required. Ongoing coordination of study alternatives with the NMFS and USFWS indicate concurrence. This alternative has an estimated cost of $65,000,000 and delivers $2,869,000 in average annual NED benefits, $700,000 in average annual net benefits over a 50 year period of analysis with a benefit to cost ratio (BCR) of 1.3. Approximately 6,878 days of business

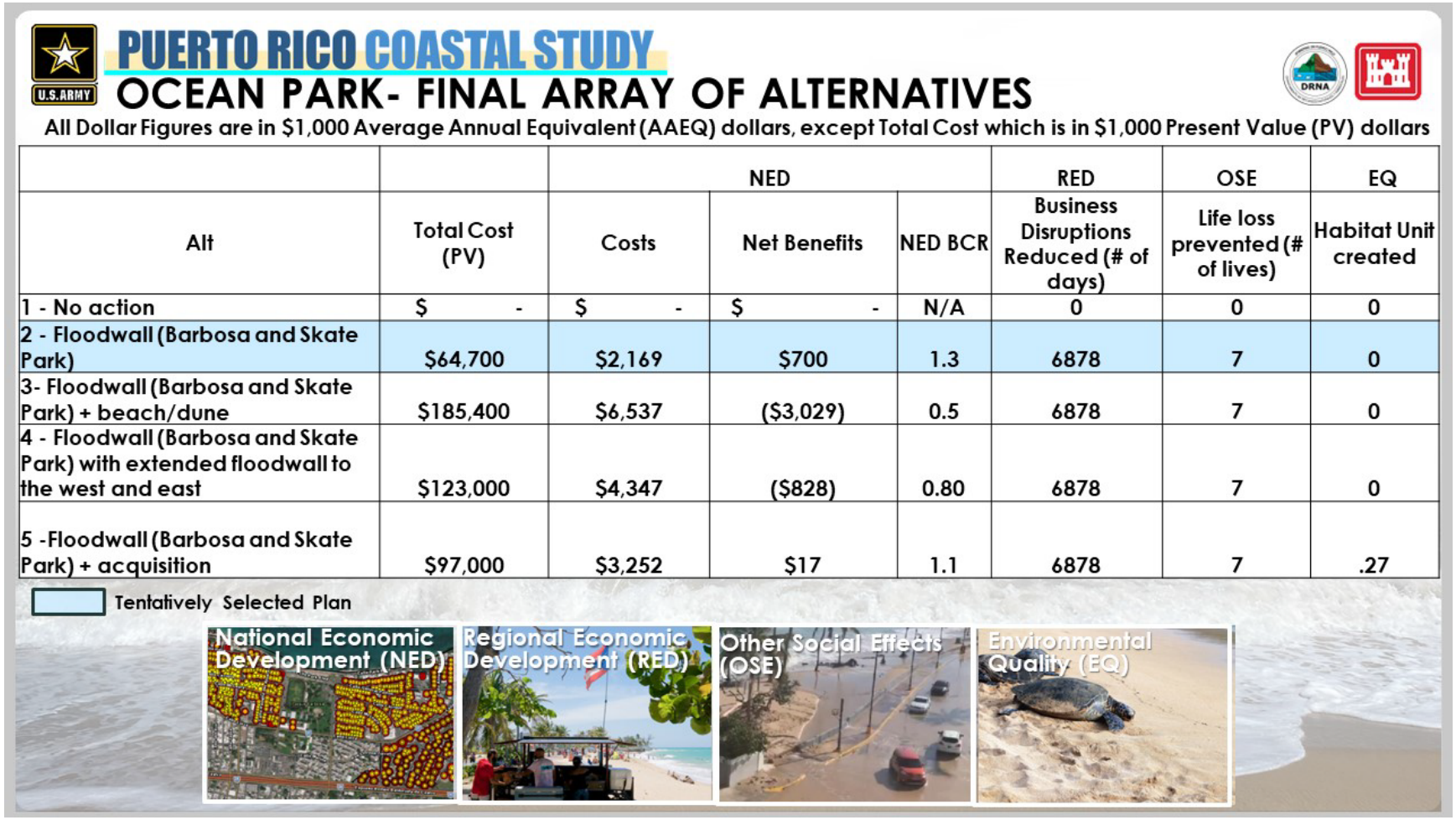
disruption due to coastal flooding are reduced and life safety risk is reduced. Nearly 40% of the benefits would be gained by the most socially vulnerable populations by reducing coastal flooding damages due to the Residencial Luis Llorens Torres (public housing) community, which is historically an economically disadvantaged community. This benefit applies to the subsequent alternatives as well.

Alternative 3 proposes the same floodwalls as in Alternative 2. This alternative would reduce the risk of coastal flooding entry at the most critical areas, Barbosa Park and the skate park. A natural and nature based feature of beach nourishment (10-ft berm) with vegetated dunes and would add sand back to this location and to the system to address erosion. The area would be expected to retain sand for roughly 5 years before requiring periodic nourishment and would continue on that average cycle for a 50-year period. This alternative is similar to what many other projects ultimately decide on as the least cost and full comprehensive benefits plan. However, in this case, sand is extremely scarce, and the closest feasible option is still approximately 10 miles away at an upland mine. Further, due to the significant benthic resources in the area, placement of sand would incur direct impacts to nearshore corals ,sponges, and SAV, resulting in mitigation between 17 and 50 acres of mixed hardbottom and SAV habitats. This alternative has an estimated cost of $185,400,000, $3,328,000 in average annual NED benefits and has negative average annual net benefits of -$3,029,000 over a 50 year period of analysis with a BCR of 0.5. Approximately 6,878 days of business disruption due to coastal flooding are reduced and life safety risk is reduced.

Alternative 4 proposes the same floodwalls as in Alternative 2. This alternative would reduce the risk of coastal flooding entry at the most critical areas, Barbosa Park and the skate park. This alternative would extend the floodwall west and east to reduce the risk of not only coastal flooding but also erosion in the surrounding areas. The extended floodwalls would require some small sand fill to be feasible for construction due to limited existing land in those areas, and would include toe protection in the form of rock armoring seaward of the floodwall. This plan would require environmental mitigation for a low acreage of lost beach and nearshore coral reef habitat. This alternative has an estimated cost of $123,000,000, $3,519,000 in average annual NED benefits and has negative net benefits of -$828,000 over a 50 year period of analysis with a BCR of 0.8. Approximately 6,878 days of business disruption due to coastal flooding are reduced and life safety risk is reduced.

Alternative 5 proposes the same floodwalls as in Alternative 2. This alternative would reduce the risk of coastal flooding entry at the most critical areas, Barbosa Park and the skate park. The floodwall would be aligned between the beach and the park in Barbosa Park and would align landward of a block of existing structures. This alternative varies from Alternative 2 in that the block of structures and property would be acquired and relocated, with subsequent demolition and grading of the land to its natural beach state. This alternative has an estimated cost of $97,000,000 and delivers $3,269,000 in average annual NED benefits, $17,000 in net average annual benefits, including recreation benefits of $360,000, over a 50 year period of analysis with a BCR of 1.1. Approximately 6,878 days of business disruption due to coastal flooding are reduced and life safety risk is reduced. This plan would not require environmental mitigation and is also the only plan to create habitat units (0.27 Average Annual Habitat Units, or AAHU) by increasing about 1.1-acre of beach habitat for nesting Sea Turtles and shoreline birds

Figure 6-5. Average Annual Costs and Comprehensive Benefits for the Final Array of Alternatives.



		NED			RED	OSE	EQ
Alt	Total Cost (PV)	Costs	Net Benefits	NED BCR	Business Disruptions Reduced (# of days)	Life loss prevented (# of lives)	Habitat Unit created
1 - No action	$ -	$ -	$ -	N/A	0	0	0
2 - Floodwall (Barbosa and Skate Park)	$64,700	$2,169	$700	1.3	6878	7	0
3- Floodwall (Barbosa and Skate Park) + beach/dune	$185,400	$6,537	($3,029)	0.5	6878	7	0
4 - Floodwall (Barbosa and Skate Park) with extended floodwall to the west and east	$123,000	$4,347	($828)	0.80	6878	7	0
5 -Floodwall (Barbosa and Skate Park) + acquisition	$97,000	$3,252	$17	1.1	6878	7	.27

RINCÓN PLANNING REACH

An extensive analysis of all effects, both positive and negative, under NED, EQ, RED and OSE was conducted during the study. The discussions below capture both the qualitative and quantitative results of the analysis. **Figure 6-6** can be referenced for a brief overview of the analysis in quantitative terms. Chapter 4 of this report assesses environmental quality effects for each of the four accounts in detail, as required under NEPA. The sections that follow here include the results of that analysis.

Alternative 1 is the no action plan. In absence of an actionable plan, individual property owners along the shoreline will attempt to reduce risk locally with low-cost, ad hoc solutions such as rock, gabions (metal meshes containing rocks), or seawalls, incurring repeated expense and probable failure of structures with likely condemnation by local government due to safety reasons. Approximately 60 structures are projected to structurally fail, and become condemned. Condemned structures would likely become derelict and are unlikely to be removed which would further exacerbate erosion on surrounding shorelines. Residents will be forced to move, likely out of the area and potentially out of Puerto Rico, reducing not only the strength of the cultural identity of the community but also reducing the tax base and impairing the economy. Structures would become derelict and are unlikely to be removed which would further exacerbate erosion on surrounding shorelines. This is identified as the NED plan by default.

Alternative 2 is rock revetment along approximately 1.3 miles of shoreline would stop the line of erosion Alternative 2 proposes a substantial rock revetment along approximately 1.3 miles of shoreline to stop the line of erosion and greatly reduce risk to the structure inventory. However, this alternative with a large rock footprint spanning the entire shoreline incurs great losses for the community as it ensures permanent loss of any remaining existing sandy beach, which are described further below. While this plan would incur permanent loss of sandy beaches, as well as species that require them, it would also displace and have direct impacts to hardbottom habitats, thus requiring extensive compensatory mitigation. All of these losses would negatively affect the community in terms of aesthetics of the beach and access to the beach in a community where the sandy shores have been part of the cultural identity. It would also pose a systemic risk to the tourism industry with adverse impacts to adjacent beaches up and down the coast, which, if lost, would permanently impair the local economy. It is strongly opposed by the non-federal sponsor and the community and did not receive coastal zone management consistency determination from the Puerto Rico Planning Board when proposed as the Tentatively Selected Plan in the November 2020 Draft Report Release. This plan currently has an estimated cost of $110,000,000 (FY23). It has an NED cost of $3,910,000 (AAEQ), NED benefits of $1,055,000, with negative net national economic development (NED) benefits of -$2,855,000, and a benefit-to-cost ratio (BCR) of 0.27.

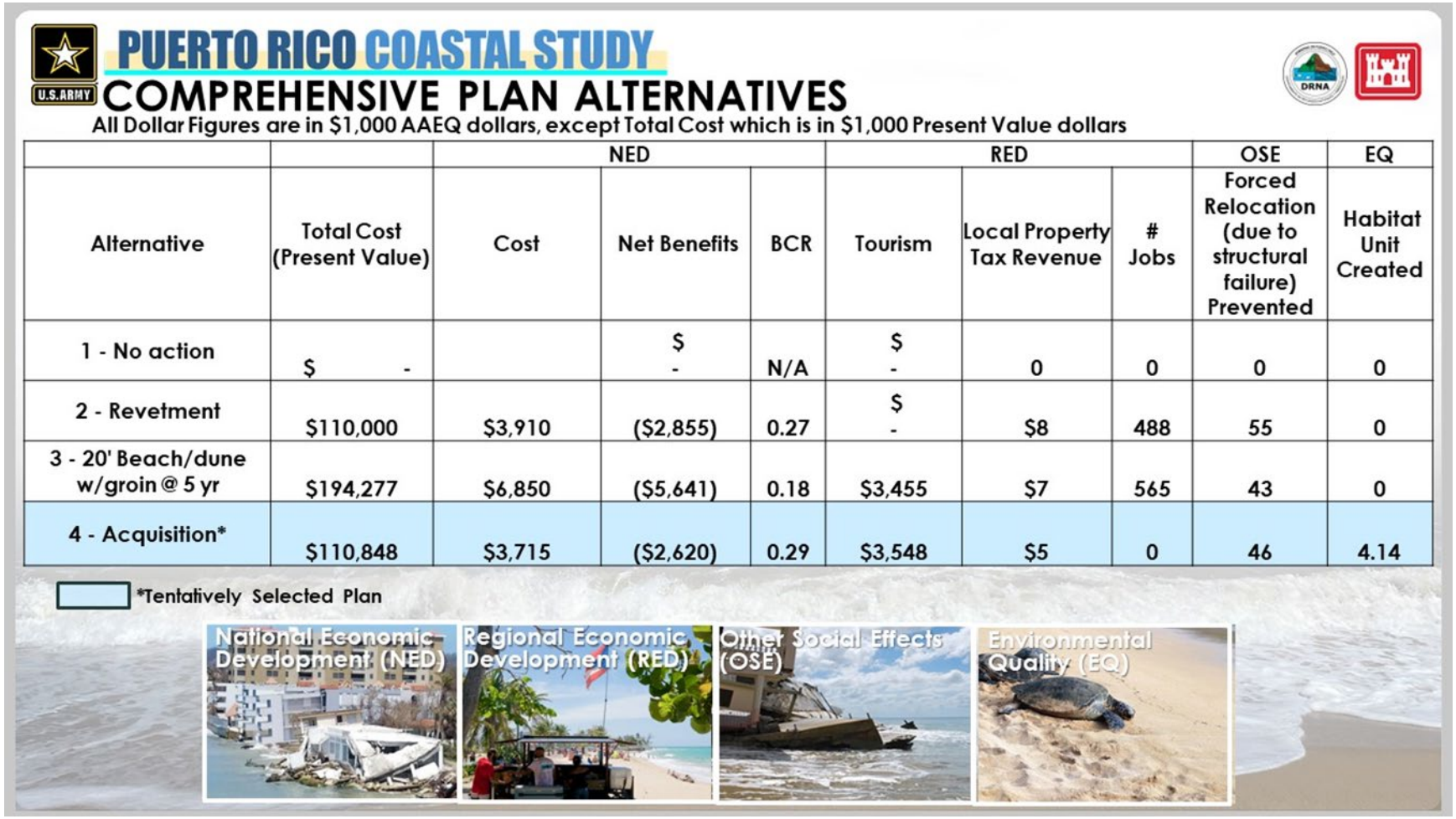
Alternative 3 proposes beach nourishment (10-ft wide berm) with small, vegetated dunes and approximately 12 stone groins along approximately 1.3 miles of shoreline which would add sand back to this location and to the system. The area would be expected to retain sand for roughly 5 years before requiring periodic nourishment and would continue on that average cycle over the 50-year period of analysis. This alternative is similar to what many other projects ultimately decide on as the least cost and full comprehensive benefits plan. However, in this case, sand is extremely scarce, and the closest feasible borrow option is approximately 25 to 30 miles offshore. This results in a cost higher than any of the other alternatives. Due to the significant benthic resources in the area, placement of sand and the pipeline corridors would likely adversely affect nearby corals and sponges identified in the recent environmental surveys, resulting in the need for extensive compensatory mitigation. This plan currently has an estimated cost of $194,000,000. It has an NED cost of $6,850,000 (AAEQ), NED benefits of $919,000 (AAEQ) with

negative net NED benefits of -$5,641,000 (AAEQ), and a BCR of 0.18.

Alternative 4 is acquisition. With this plan, high-risk structures along approximately 1.1 miles of shoreline would be included for acquisition, and residents would be relocated following guidelines under the Uniform Relocation Assistance and Real Property Acquisition Act (URA). There would be approximately 115 property acquisitions[2], which were identified based on their vulnerability to erosion and impact to the shoreline. After relocations and acquisitions are complete, the structures would be demolished, the land would be graded and returned to its natural sandy state which would involve some revegetation with native species. It would not require compensatory mitigation and would instead re-establish 4.14 AAHU within the acquisition footprint (eventually creating 17 acres of beach habitat for nesting federally-listed sea turtles and shore birds). The sandy shoreline would be allowed to naturally recover and would support the tourism-based regional economy into the future by maintaining $3,548,000 (AAEQ) worth of local tourism spending. It has an NED cost of $3,715,000 (AAEQ) with NED benefits of $1,095,000, including $496,000 AAEQ in increased recreation, negative net benefits of -$2,620,000 and a BCR of 0.29. This is the most effective plan of all the comprehensive plans considered and it is supported by the Governor of Puerto Rico, DNER and the Mayor of Rincón.

[2] As mentioned above, the approximate 115 properties are units within the individual structures subject to damage/condemnation. A single structure can contain multiple units of property.

Figure 6-6. Average Annual Costs and Comprehensive Benefits for the Final Array of Alternatives.



		NED			RED			OSE	EQ
Alternative	Total Cost (Present Value)	Cost	Net Benefits	BCR	Tourism	Local Property Tax Revenue	# Jobs	Forced Relocation (due to structural failure) Prevented	Habitat Unit Created
1 - No action	$ -		$ -	N/A	$ -	0	0	0	0
2 - Revetment	$110,000	$3,910	($2,855)	0.27	$ -	$8	488	55	0
3 - 20' Beach/dune w/groin @ 5 yr	$194,277	$6,850	($5,641)	0.18	$3,455	$7	565	43	0
4 - Acquisition*	$110,848	$3,715	($2,620)	0.29	$3,548	$5	0	46	4.14

6.4.1 PLAN SELECTION DISCUSSION

As discussed in the previous sections, the alternatives were evaluated and compared using planning criteria, environmental minimization and avoidance factors, and the USACE economic analysis.

Consideration and care has been taken by the team in the recommending the tentatively selected plans. The team held open house meetings in both Rincon and Ocean Park in September 2022, where the team presented the focused array of alternatives and obtained feedback from members of the community and other agencies. During this time, the team also met with the Secretary of DNER, and her staff, as well as the Mayor of Rincon. The team continued to work on the study with those valuable insights, which lead to the final array of alternatives.

The team then met with the Governor of Puerto Rico and the Secretary of DNER of 29 NOV 2022. At that meeting, the team recommended the following potential TSPs for consideration of support by DNER, the non-federal sponsor:

- Ocean Park Alternative 2 – For reasons explained earlier, this is a very streamlined engineering solution to reduce coastal flooding risk in the Ocean Park Planning Reach, which included the Ocean Park and Isla Verde communities. This would add overall resilience to the entire San Juan Metropolitan Area and Puerto Rico. This plan is the NED plan.
- Ocean Park Alternative 5 – This alternative is the same as alternative 2, but it would include acquisition of the entire block of properties west of Barbosa Park. This would be combined with nature-based features, to add additional recreation, environmental habitat, and resilience to the San Juan Metropolitan Area and Puerto Rico. This would involve significant acquisitions of homes and property within that block, and is understood to be a large loss to the homeowners in this area. This plan could be a locally preferred plan.
- Rincón Alternative 4 – This alternative proposes acquisition along 1.1 miles of shoreline in the Stella community within the Rincon municipality. This is an extreme and bold plan, to address the devasting and very immediate effects erosion is having on the community. This plan would involve extremely significant acquisitions of homes and property within that block, and is understood to be a large immediate loss to the homeowners along the ocean-fronting shoreline. However, this would give those homeowners options and incentives to proactively relocate to new safe homes before structures fail completely. It would also revive the rest of the community and allow a long term management of the shoreline for resilience of the coastline and community into the long-term future. This plan is the most effective plan but it has a benefit to cost ratio less than 1.0 and requires a policy exception, which has been approved by the Assistant Secretary of the Army, Civil Works, ASA,CW.
- Rincón Alternative 1 –This alternative is the no action plan. Although this is not recommended by the team, it is the most likely option since none of the other alternatives are policy compliant with a benefit to cost ratio at or above 1.0. Any alternative other than this one in Rincón would need to have a policy exception approved by the ASA(CW) to move forward.

At that meeting, the Governor requested that his staff hold several meetings with landowners, with USACE

staff to present key technical information, in order to gage feedback on the most likely set of alternatives to recommend as the TSPs for each planning reach.

A series of meetings were held by the Governor's staff on 12 December 2022 and 14 December 2022. A letter was sent on 27 December 2022 by the Secretary of DNER on behalf of the Governor of Puerto Rico, expressing his support of Ocean Park Alternative 2 and Rincon Alternative 4.

With consideration of the technical analysis and feedback as described above, Ocean Park Alternative 2 (Floodwall) and Rincón Alternative 4 (Acquisition), were selected as the TSPs. These plans were then further developed by the team and more detailed information can be found in **Appendix A, Engineering and Chapter 6 of the Main Report.**

Since Rincón Alternative 4 (Acquisition) deviates from the National Economic Development (NED) plan, a policy exception for this plan was requested, and approved by the Assistant Secretary of the Army, Civil Works (ASA, CW) on 8 May 2023.