FINAL

GARAPAN AREA SHORELINE ASSESSMENT STUDY

for U.S. Department of the Interior, Office of Insular Affairs

and Commonwealth of the Northern Mariana Islands
Bureau of the Environmental and Coastal Quality

by U.S. Army Corps of Engineers Honolulu District

17 November 2017

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LIST OF ACRONYMS

AMP	American Memorial Park
BECQ	Bureau of Environmental and Coastal Quality
CNMI	Commonwealth of the Northern Mariana Islands’
DCRM	Division of Coastal Resources Management
DSAS	Digital Shoreline Analysis System
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
GASAS	Garapan Area Shoreline Assessment Study
LSL	Living Shore Line
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and Maintenance
OIA	Office of Insular Affairs
SLS	Saipan Lagoon Shoreline
SLUMP	Saipan Lagoon Use Management Plan
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
WIS	Wave Information Study

EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE), Honolulu District has conducted a study for the Saipan Lagoon Shoreline (SLS) due to concerns about erosion and the need to protect coastal ecosystems, upland development, and infrastructure. This report documents the analysis of shoreline change and provides planning and conceptual design guidance for the development of Living Shore Line projects for Saipan Lagoon. A shoreline advance of approximately 20 feet was typical along several portions of the SLS between 2013 and 2017. Three reaches that had the greatest erosion were 1) south of Sugar Dock with 21 feet of recession (wide beach due to Sugar Dock intercepting sediment); 2) north of Saipan World Resort with 15 feet of recession (no development threatened); and 3) the southern shoreline of American Memorial Park receded an averaged 32 feet (resulted in damages to existing infrastructure). By 2070, sea level rise in the study area is predicted to be on the order of 0.7 ft (tide station trend) to 2.9 ft (high rate); and by 2120, it may be 1.1 ft to 7.2 ft higher than the present. Given this amount of uncertainty, it is recommended that LSL projects for the Saipan Lagoon Shoreline be design with adaptive management strategies in mind.

A wide range of planning measures are discussed to provide a basis for selection of appropriate shore protection measures for the SLS. Measures range from green or soft solutions, to gray or hard solutions. Examples of green measures include vegetation, dune enhancement and beach nourishment, while gray measures are structures including breakwaters, revetments, seawalls, and groins. Each measure has different advantages, disadvantages, and environmental impacts that need to be evaluated for each specific location and situation.

Conceptual plans are developed for five reaches of the Saipan Lagoon shoreline as described below. Rough order of magnitude initial construction and 50-year project costs of each conceptual plan are provided in the table below. All conceptual plans are based on a project length of 1,000 feet to facilitate comparison.

1) American Memorial Park (Beach Nourishment with Vegetation): In this conceptual plan, the beach would be advanced seaward on the order of 70 feet along 1,000 feet of shoreline and would require about 28,000 cubic yards of sand. Potential sand sources in the Saipan Lagoon region include sediment that has accreted on the subaerial beach profile south of Sugar Dock and sediment located in an offshore sandbar adjacent to the western shoreline of American Memorial Park. Salt-tolerant species of plants and grasses would provide an effective erosion control for the beach and dune system. Plant species would be selected and incorporated along the beach profile as described in the main text of this report. Walkovers and wind breaks also would be included to help prevent erosion to the beach system and are to be considered in areas where heavy foot traffic and wind could cause erosion.

2) Makaka Beach (Vegetation): As described in the conceptual plan for American Memorial Park, salt-tolerant species of plants and grasses would be planted to stabilize

the beach system. Vegetation that can withstand periodic flooding would be utilized. Blankets and matting material could be used as an aid to control erosion on critical sites during establishment of vegetation. A mangrove's complex root system slows water flow and may be planted to allow sediment to settle and accrete rather than erode. Shrubs can be used that are salt-tolerant, wind-tolerant and thrive in various types of soils, including sand. Intertidal trees that would be planted further landward on the profile include mangrove and *Terminalia catappa*. The wooded area at the landward extent of the profile that would only be inundated during extreme storm surge conditions can be planted with *Pandanus* and *Calophyllum*. The vegetation only measure would stabilize the shoreline by a gradation of locally appropriate, salt-tolerant plant species ranging from grasses, to shrubs, to intertidal trees, and finally to a wooded area at the landward extent of the profile. The vegetation only option may require frequent maintenance due to storm damage, but has the lowest construction and project costs.

3) Fishing Base (Beach Nourishment with Vegetation): The conceptual plan for the Fishing Base shoreline would be comprised of beach nourishment and vegetation (see conceptual plan #1 above for details).

4) Quartermaster Road (Beach nourishment with T-head Groins): Six T-head groins would constructed to retain the sand at the shoreline. Proposed groins are 100 feet-long, the heads would be 60 feet-wide, and they would be spaced approximately 170 feet apart. Similar to the American Memorial Park conceptual plan, the beach would be advanced seaward on the order of 70 feet along 1,000 feet of shoreline and would require about 28,000 cubic yards of sand.

5) Sugar Dock (Beach Nourishment): The updrift (south) shoreline adjacent to Sugar Dock has advanced seaward due to the dock's interception of littoral sediment transport. The downdrift (north) shoreline had receded landward as a result of the dock's interruption of sediment transport. This conceptual plan consists of bypassing sand from the updrift shoreline, around Sugar Dock, and placing it on the downdrift shoreline. The downdrift beach would be advanced seaward on the order of 70 feet along 1,000 feet of shoreline and would require about 28,000 cubic yards of sand. If the accreted sand on the subaerial beach profile south of Sugar Dock is not of sufficient volume, another sand source may need to be identified.

Table ES-1. Cost estimates for various shore protection conceptual plans within the study area.

PLAN	1	2	3	4	5
LOCATIONS	AMP	Makaka Beach	Fishing Base	Quartermaster Road	Sugar Dock
TYPE	BN&V	VO	BN&V	BN&TG	BN
CONSTRUCTION	$5,200,000	$1,000,000	$5,200,000	$7,200,000	$4,200,000
TOTAL [50years]	$23,500,000	$10,000,000	$23,500,000	$21,300,000	$21,000,000

INTRODUCTION

At the request of the U.S. Department of the Interior, Office of Insular Affairs (OIA), the U.S. Army Corps of Engineers, Honolulu District has conducted an analysis of the Saipan Lagoon Shoreline (SLS). The Garapan Area Shoreline Assessment Study (GASAS) was conducted in coordination with the Commonwealth of the Northern Mariana Islands' (CNMI) Bureau of Environmental and Coastal Quality (BECQ). This study was requested due to concerns about erosion and the need to protect coastal ecosystems, upland development, and infrastructure. The study area extended from one quarter mile south of Sugar Dock through American Memorial Park (AMP). Study tasks included conducting local coordination meetings, a site visit, beach profile surveys, shoreline change analysis, conceptual plans, and report preparation. This report documents results from the beach profile surveys, historical shoreline change analysis, presentation of measures, and conceptual plans for erosion control with accompanying order of magnitude cost estimates and discussion of environmental enhancement. It provides fundamental planning and conceptual design guidance for development of Living Shore Line (LSL) projects for Saipan Lagoon.

At the request of the BECQ, conceptual plans for "soft" erosion control measures were developed. Soft erosion control measures include but are not limited to LSL features such as beach nourishment, dune enhancement, and vegetative measures (dune grass, mangrove, etc.). LSL framework consists of various questions to consider when determining approaches for a site that will best stabilize the shoreline and sustain coastal connections between land and water. The following are some of the basic questions that were considered for the GASAS. Other questions will need to be considered during the design and construction phases of the project.

a. What are the physical characteristics of the site?
b. Are ecologically valuable aquatic habitats or animals living along the shoreline?
c. How should effects of sea level rise be considered?
d. What balance between green (soft) and gray (hard) stabilization measures is appropriate?
e. How can functional habitats be incorporated into gray measures?
f. What level of maintenance is associated with each LSL alternative?
g. What state, territory and federal authorities must be considered when developing LSL alternative?
h. How should LSL project planning consider public access and other social contexts (including both green and gray measures)?
i. When do the various environmental resource agencies review, consult on, or permit LSL projects?
j. What types of support are available for planning, design and construction of LSL projects?

BACKGROUND

Project Area Description

The study area (Figure 1) is 6 miles of shoreline located on the west coast of Saipan in the CNMI, extending from approximately one quarter mile south of Sugar Dock to AMP. The shoreline is protected by a fringing reef and Saipan Lagoon, which is the shallow area between the fringing reef and the shoreline. The SLS is comprised of a diverse mixture of aquatic and terrestrial habitats. Sandy and rocky reaches of beach are backed by strands of grass, beach morning glory, various types of bushes, ironwood trees and mangrove trees (at AMP). Anthropogenic and natural impacts have resulted in the loss of backshore vegetation along portions of the shoreline. Coral, seagrass and other types of marine habitat are abundant in the sub-tidal zone. Estuarine systems and drainage outfalls are some of the terrestrial inputs to the lagoon. Typical features along the SLS cross-shore profile, such as the boardwalk, dune vegetation, etc., are shown in

Figure 2.

Current Land Use

The majority of the property adjacent to the SLS consists of private land (e.g. hotels, restaurants, businesses and residences) and public land (e.g. beach parks and shoreline accesses). Various environmental resources are managed by CNMI's Bureau of Environmental and Coastal Quality, Department of Public Lands, and the Department of Lands and Natural Resources. From Monsignor Guerrero Road to Fishing Base (Figure 1), Beach Road runs directly along the coastline (Figure 3).

Current Water Use

Water uses within the lagoon consist of recreational activities such as swimming, boating, sailing, jet skiing and others. Water activities are regulated by a number of commonwealth and federal agencies. Based on the Saipan Lagoon Use Management Plan (SLUMP) User Survey and Mapping Report (APEC 2016), Saipan Lagoon has regular recreational, commercial and extractive users. While not well documented, recreational users are believed to be the most prevalent. Recreational use includes scuba diving, free diving, snorkeling, swimming, paddling, various board sports, recreational motorized boating, sailing, and beach use.

Commercial uses include any activity that is paid for, including scuba diving, snorkeling tours, parasailing, other boating activities, jet skis, dinner cruises, and shipping. Boat traffic is low in most areas and high to moderate in the vicinity of the hotels. The SLUMP User Survey categorized all forms of fishing and harvesting of marine life as extractive uses. Fishing and harvesting in the lagoon are primarily for subsistence, while commercial fishing is conducted in the open ocean. Extractive uses were categorized as hook and line fishing, spearfishing, throw net fishing, gill net fishing, harvesting and gleaning. Figure 4 provides heat maps of the different uses within

Saipan Lagoon. The SLUMP User Survey and Mapping Report can be referenced for additional detailed maps of lagoon use based on the categories described above.

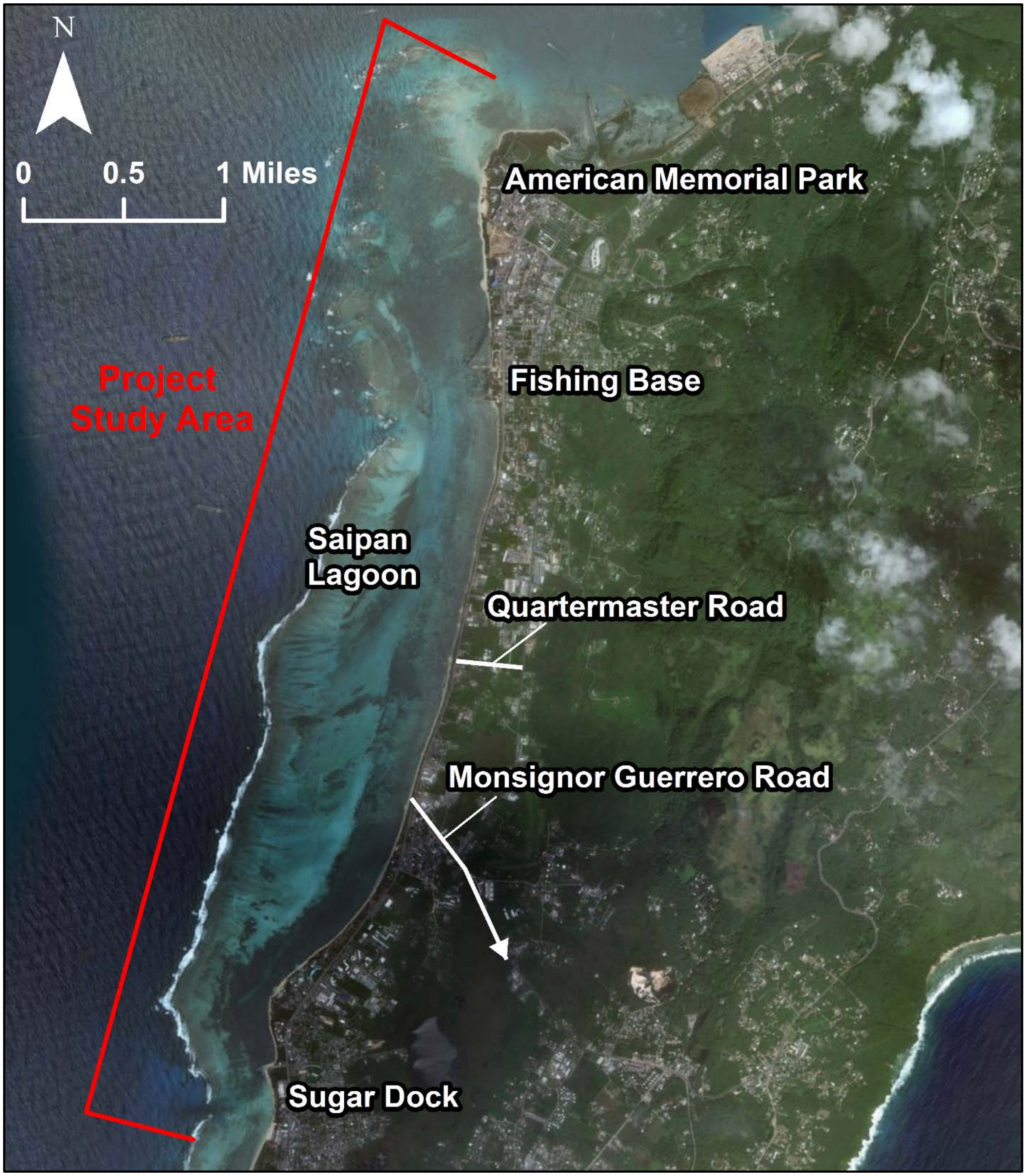

Figure 1. The Garapan Area Shoreline Assessment Study area extends from south of Sugar Dock through the American Memorial Park shoreline.

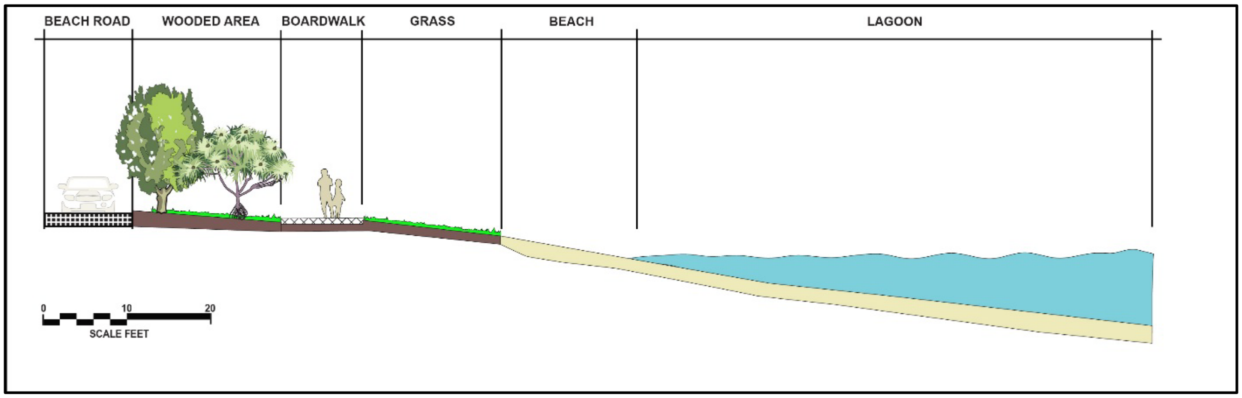

Figure 2. General shoreline features that currently exist along the Saipan Lagoon shoreline.


Figure 3. Typical land uses along Beach Road include transportation, housing, restaurants, commercial businesses and beachside walkway.

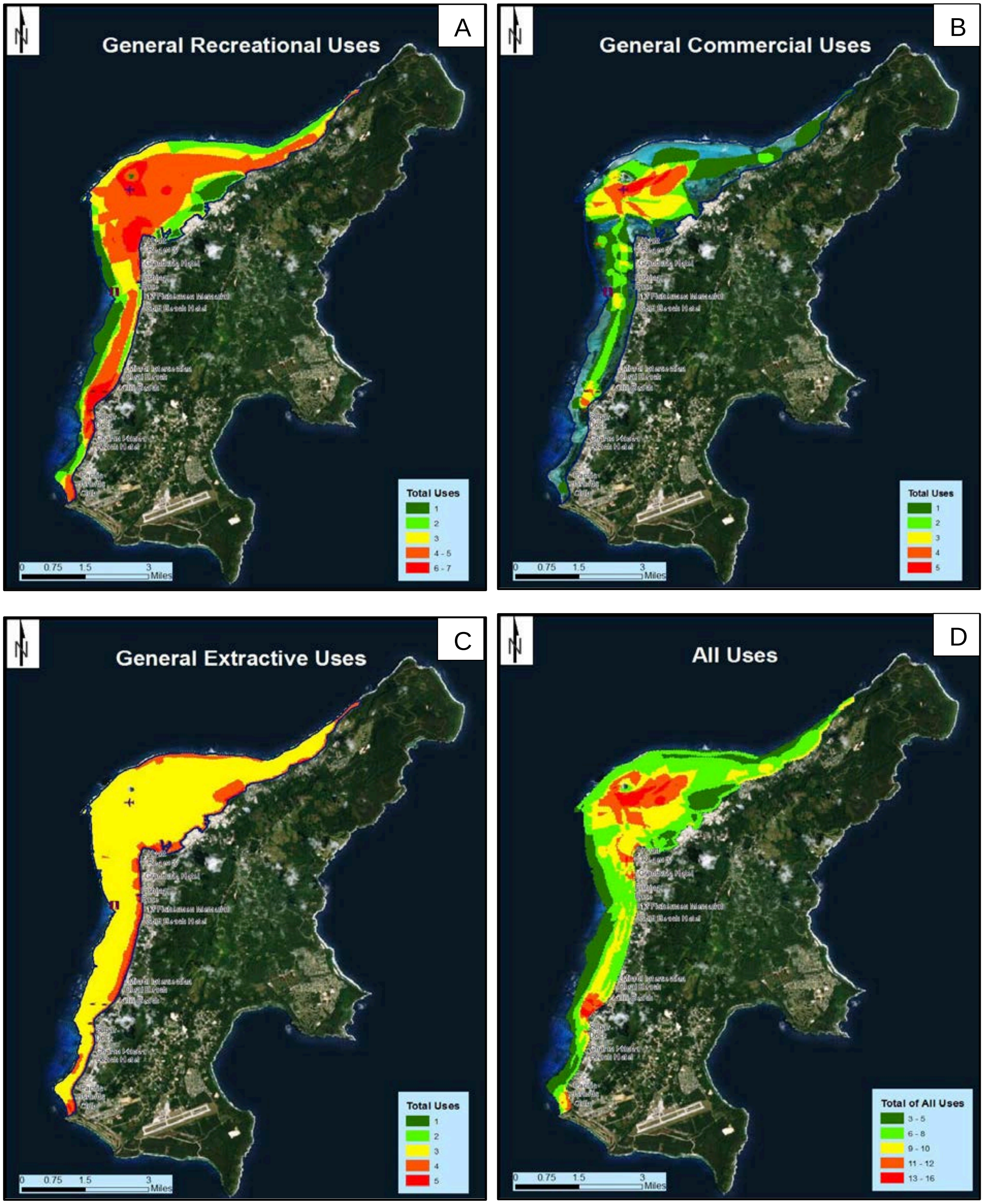

Figure 4. Heat maps of A) Recreational, B) Commercial, C) Extractive, and D) All Uses in the Saipan Lagoon, from the SLUMP User Survey (APEC 2016). The color scale ranges from dark green for low utilization to red for high utilization.

Existing Conditions

Physical Characteristics

The physical characteristics of Saipan Lagoon determine wave transformation dynamics that control storm induced impacts to the shoreline and adjacent infrastructure. The lagoon is oriented north to south and therefore exposed to incident waves originating from the south through north. There are no offshore land bodies in the area sheltering Saipan Lagoon from approaching waves. The reef that defines the lagoon is generally 2,000 to 3,000 feet wide. At typical water levels, the water depth in the lagoon is on the order of 10 to 20 feet. This relatively shallow depth attenuates large, long period, deep water waves as they transform shoreward. Beach slopes are on the order of 1 vertical to 15 horizontal and composed of fine to medium grain carbonate sand.

Land loss is variable along the SLS. The BECQ is conducting shoreline monitoring surveys to quantify the loss of land and other impacts of shoreline change. Land loss occurs mainly during significant storms that result in elevated water levels which enable larger waves to reach the shoreline. As a result of the continued threat to upland development, some portions of the SLS have been hardened with gray shore protection measures (i.e. hard structures instead of soft, natural, or “green” measures). Some buildings close to the shoreline have individual seawalls and drainage outfalls are typically hardened. Sugar Dock and Fishing Base are the most notable hardened areas along the SLS.

Wind and Wave Climate

The U.S. Army Corps of Engineers’ Wave Information Study (WIS) provides 32 years of hindcast wind and wave data at offshore locations around the CNMI. The wind rose in Figure 5 summarizes the 32 years of hindcast wind data from WIS Station 81105. The prevailing winds in this region are tradewinds, which come from the east through northeast. Tradewinds are most consistent between January and June, with wind speeds typically less than 25 mph. However, this area is frequented by tropical storms and typhoons, especially during the wet season from July to December. An average of three tropical storms and one typhoon pass within 180 miles of the CNMI each year (http://weather.unisys.com/hurricane/w_pacific/). Climate patterns in this region are also affected by inter-annual variations driven by the El Niño/Southern Oscillation phenomenon. The threat of storms increase during El Niño years, and Saipan has extra dry conditions in the year following an El Niño event (Lander 2004).

Figure 6 shows the location of Station 81105, to the west of Saipan, and its wave rose for the years 2000 to 2011. Wave occurrences are depicted by 3% frequency bins with percentages indicated by color coded wave height ranges shown in the legend. Waves coming from the eastern half plane (typically tradewind seas) have been excluded from the rose since they do not reach the study area. The majority of waves that are incident to the study area are from southwest through west. Waves from those directions have reached heights of over 5 meters (16.4 feet). Wave heights within the lagoon and at the shoreline are generally depth limited, meaning that their height is controlled by the local water depth by a factor 0.6-1.2 (i.e. wave heights are approximately 0.6-1.2 times the water depth at any location in the lagoon).

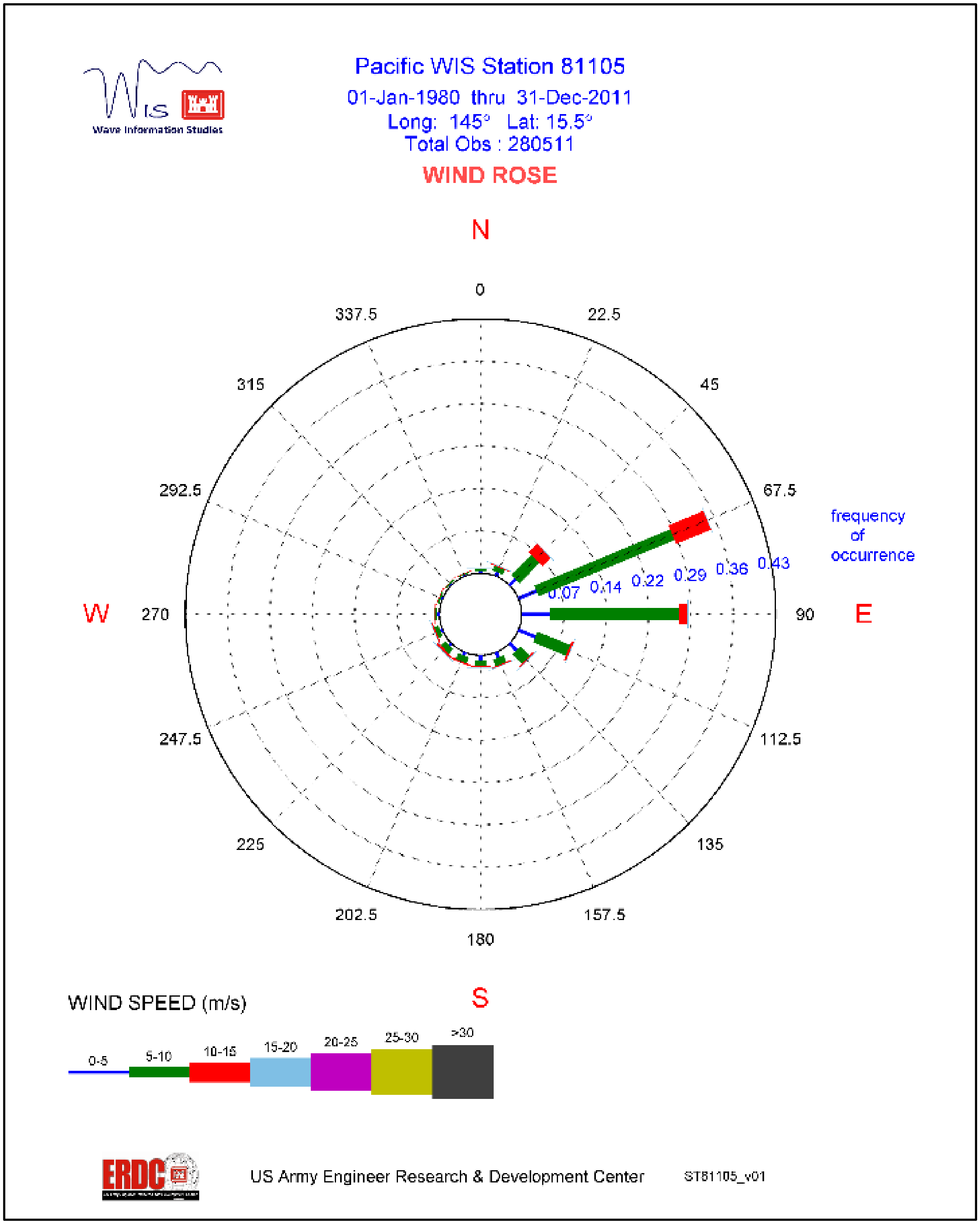

Figure 5. A wind rose from WIS Station 81105, offshore of Saipan, showing 32 years of hindcast data.

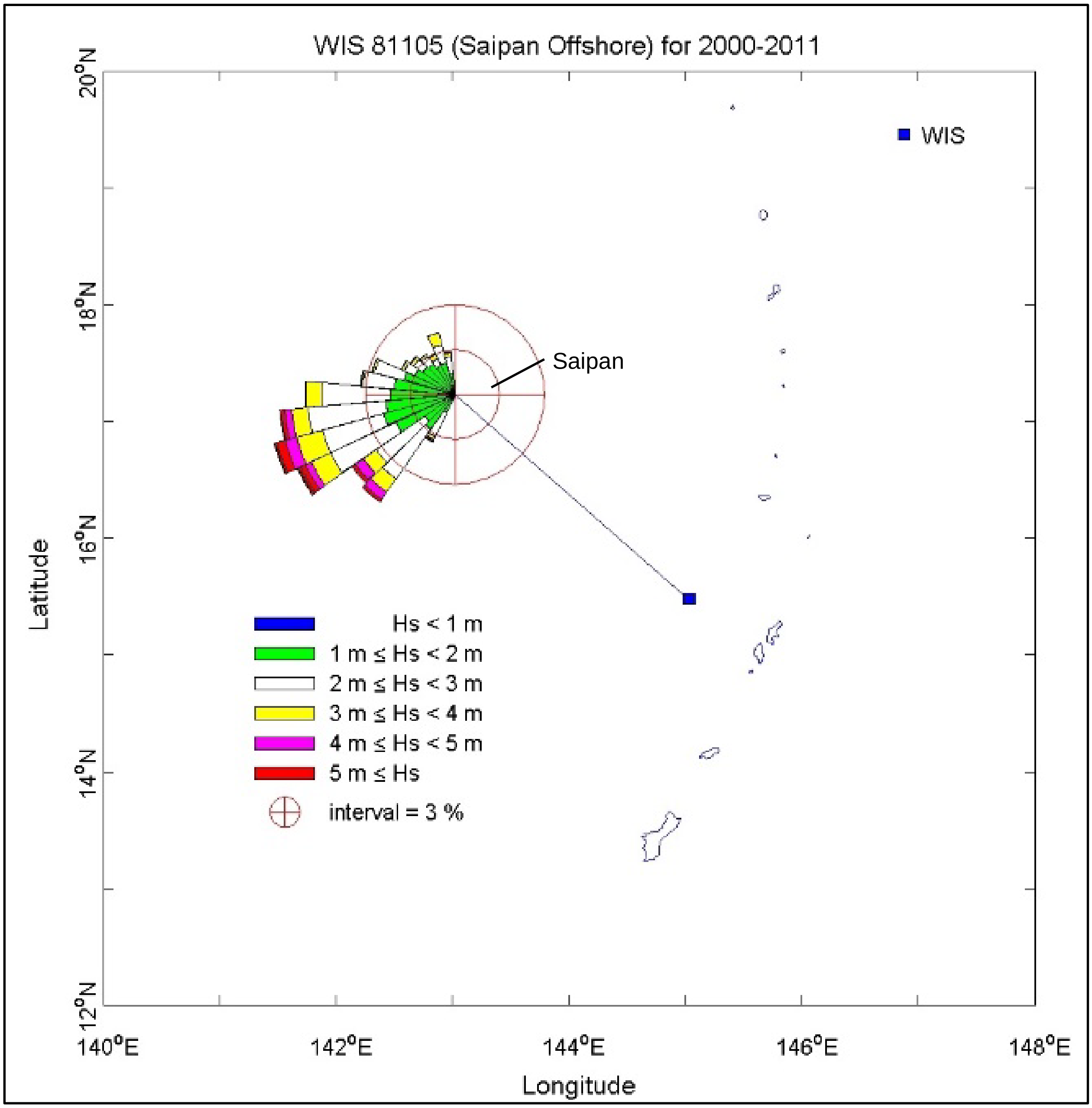

Figure 6. The west half plane wave rose for WIS Station 81105 offshore of Saipan.

SHORELINE CHANGE

Historical shoreline change was evaluated for the study area to provide context for proposed alternatives. This was done by a combination of beach profile surveys and shoreline change analyses. Shoreline change evaluates the erosion or accretion of the shoreline over time. Shorelines are typically classified as being stable (no movement), eroding (receding), or accreting (advancing). Understanding historical shoreline change allows coastal managers to make more informed decisions regarding their shorelines, including whether engineering measures are needed in areas of chronic erosion.

A shoreline change study was conducted for AMP in 2010 by Yuknavage and Palmer using a combination of GIS historical shoreline analysis and beach profile monitoring. By evaluating historical imagery from 1948, 1970, 1999, and 2003, they saw that sand was transported from the western shoreline of the park to the northeastern shoreline by Smiling Cove. The beach profiling monitoring yielded similar results, and it was noted that the public was concerned about the threat of erosion to the park's infrastructure on the western shoreline. It was concluded, however, that more modeling needed to be conducted before an engineering measure could be implemented. Below is an evaluation of beach profiles and historical shorelines for the entire project area, including AMP.

Beach Profile Analysis

Based on analysis of repeated beach profile surveys, portions of the SLS has been relatively stable to mildly erosive over the past 15 years. Figure 7 through Figure 11 display beach profiles for the period 2002 through 2017 at 1,000 ft intervals along the shoreline north of the intersection of Monsignor Guerrero Road and Beach Road. Chronic shoreline recession has occurred over the years generally at rates of less than 1 foot per year. During non-storm conditions, waves transforming across the lagoon are dissipated through mechanisms that include breaking, bottom friction and turbulence as they transform to shore. Episodic shoreline recession is a result of tropical storms and typhoons that regularly impact the Commonwealth of the Northern Mariana Islands and in particular the island of Saipan.

During periods of low water levels, wave heights along the SLS are typically less than 1 foot. Waves at the lagoon shoreline have refracted to the extent that their crests are nearly shore parallel. Under such conditions, longshore sediment transport is minimal. On the other hand, tropical storms increase water levels in the lagoon through storm surge, wave setup, and ponding over the lagoon. Increased water levels allow larger waves to reach the shoreline and increase the longshore transport of sediment. Water circulation within the lagoon is also enhanced during these events which can mobilize sediment, making it more likely to be transported alongshore or cross-shore. Post-storm recovery of the beaches has led to the long-term stability of the lagoon shoreline, except in locations such as AMP. Land cover changes with subsequent shoreline hardening has been the response to storm induced shoreline recession along these erosive portions of the SLS.

Shoreline Change Analysis

As noted above, beach profile surveys indicate relative shoreline stability over recent years within the study area. Shoreline change for the study area was evaluated using the Digital Shoreline Analysis System (DSAS). Satellite imagery dated 11/7/2013, 8/8/2015 (Typhoon Soudelor hit Saipan on 8/2/2015), and 4/16/2017 was downloaded from the DigitalGlobe database and used to estimate and digitize shoreline positions in ArcGIS. The shorelines extend from a quarter mile south of Sugar Dock, north to the sand spit at AMP. However, the 2017 shoreline does not include the reaches from Transect 126 through Transect 138 and Transect 217 through Transect 351 due to obstructions of the shoreline in the satellite image. Using DSAS in ArcGIS, an onshore baseline and 200 meter-long transects were laid out at a 20 meter (65.6 feet) intervals along the entire region (Figure 12). DSAS then calculated the distance between the baseline and each shoreline at each transect.

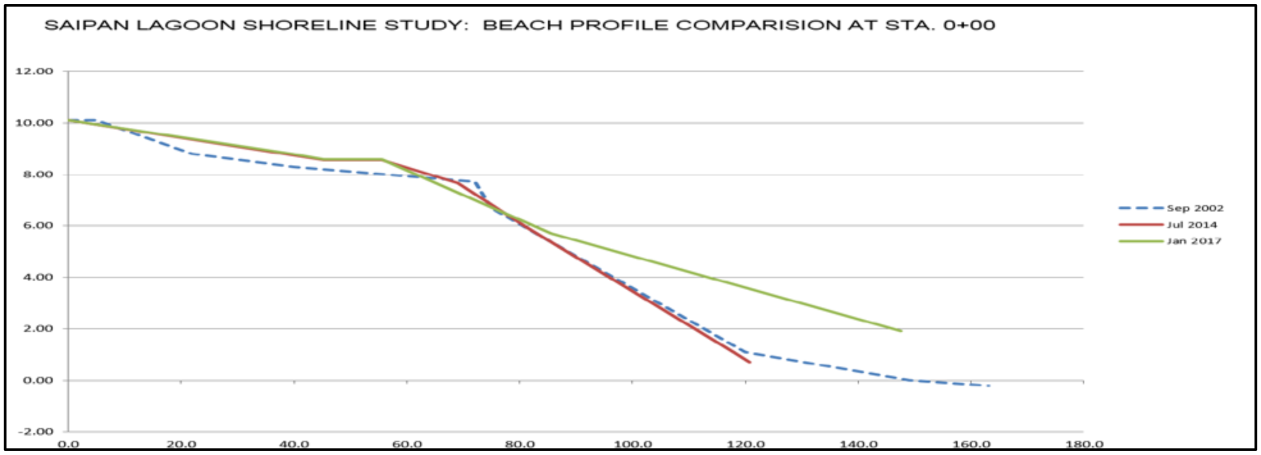

Figure 7. Beach profiles at Station 0+00 from Sept. 2002, Jul. 2014 and Jan. 2017.

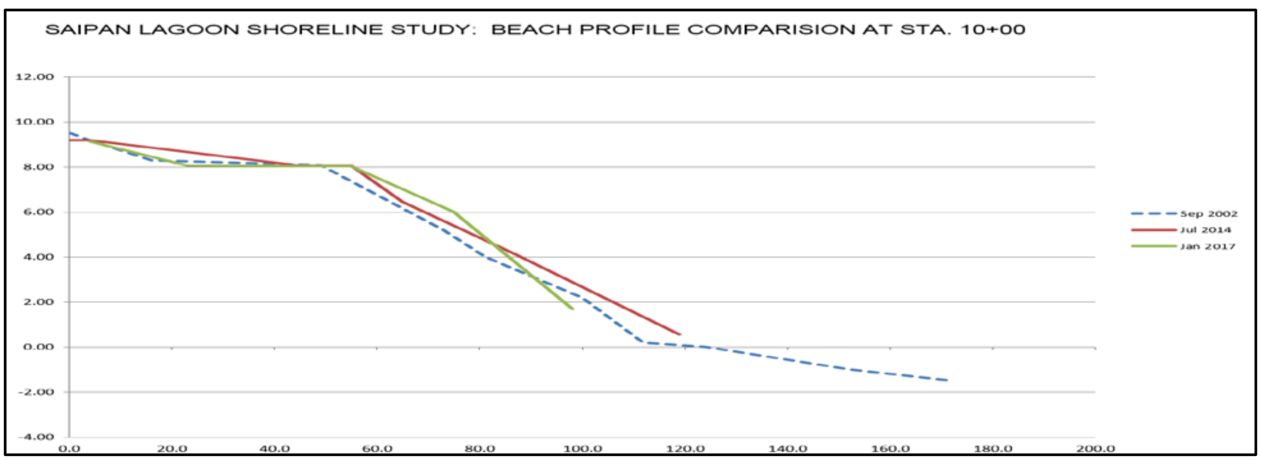

Figure 8. Beach profiles at Station 10+00 from Sept. 2002, Jul. 2014 and Jan. 2017.

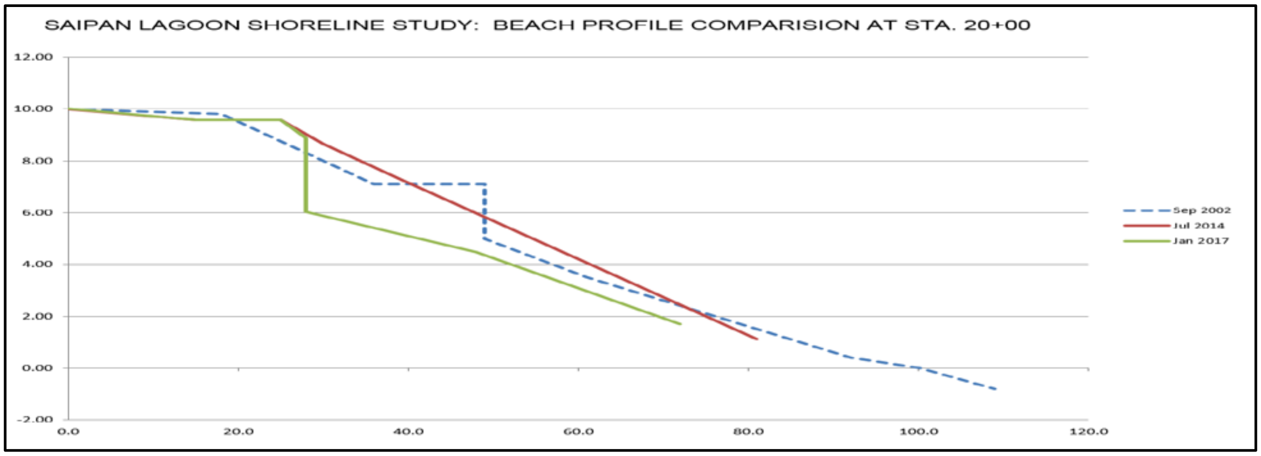

Figure 9. Beach profiles at Station 20+00 from Sept. 2002, Jul. 2014 and Jan. 2017.

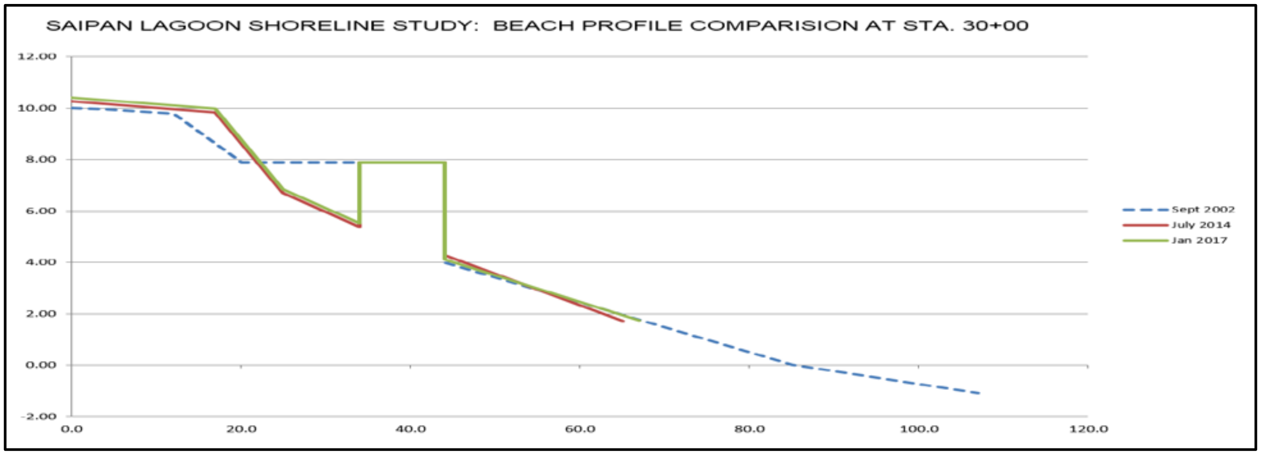

Figure 10. Beach profiles at Station 30+00 from Sept. 2002, Jul. 2014 and Jan. 2017.

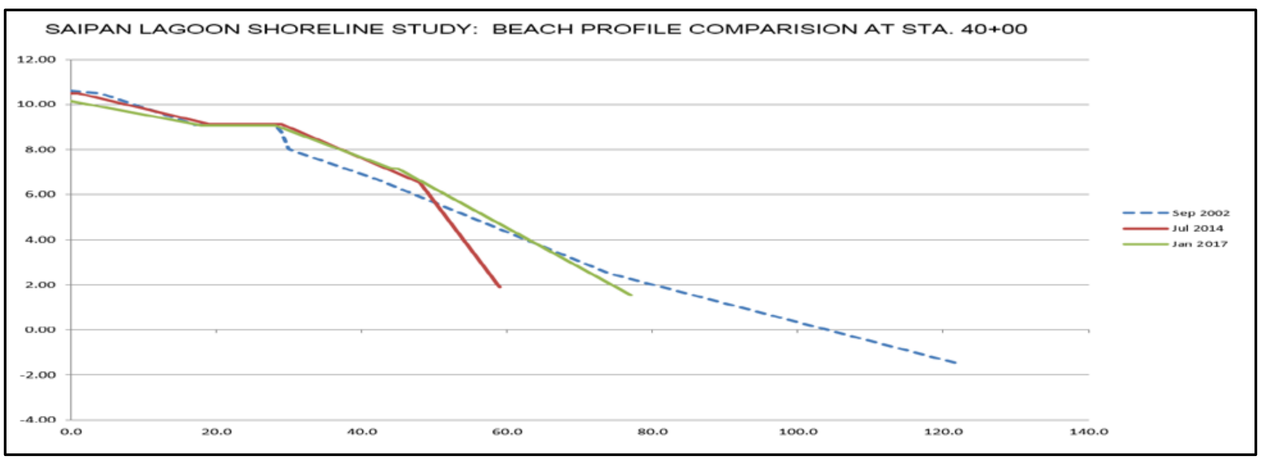

Figure 11. Beach profiles at Station 40+00 from Sept. 2002, Jul. 2014 and Jan. 2017.

Figure 12 shows the results of the shoreline change analysis from 2103 to 2015 (Inset A) along with an image of the region (Inset B) approximately lined up with the transect locations. Comparison of the 2013 and 2015 shorelines indicates that approximately 16 feet of shoreline advance occurred along the study area on average. However, based on DSAS analysis for the time period 2015 to 2017, the average shoreline change was -7.5 feet. It was noted that localized spikes in the shoreline change data are due to abrupt changes in shoreline orientation relative to the DSAS baseline and not due to relative shoreline change (such as adjacent to Sugar Dock from Transect 28 through Transect 33).

Figure 13 is a composite of shoreline locations and shoreline changes at Makaka Beach derived for the years 2013, 2015 and 2017. The bottom portion of the figure is comprised of a 2015 satellite image of Makaka Beach overlaid with the three digitized shorelines. The light purple colored line represents shoreline locations on 11/7/2013, the red line is from 8/8/2015 (Typhoon Soudelor hit Saipan on 8/2/2015) and the dark purple line is from 4/16/2017. It can be seen that the shoreline generally advanced oceanward during the period 2013 to 2015. From 2015 to 2017, the shoreline along this reach of Makaka Beach predominately receded.

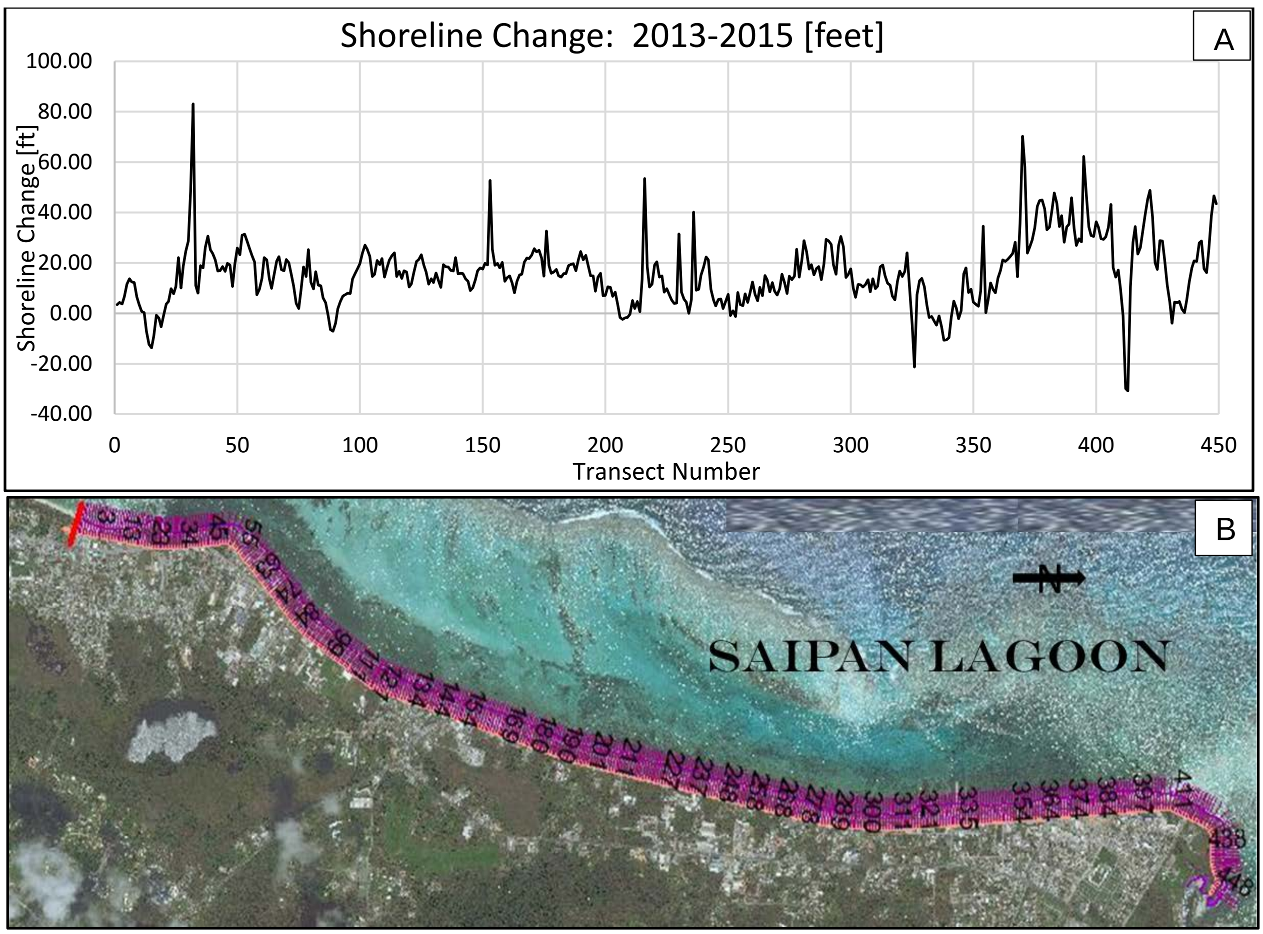

Figure 12. The graph at the top of the figure (Inset A) provides the results of the shoreline change analysis for the SLS from 10/07/2013 to 08/08/2015. The map at the bottom of the figure (Inset B) shows approximate transect locations relative to the SLS and the graph of shoreline change.

The graph of shoreline changes provided at the top of Figure 13 was generated from the DSAS results as previously described. Shoreline changes at Transect 370 through Transect 400 correspond to the reach of shoreline shown in the aerial image below. The maximum shoreline change during the period of analysis (2013 to 2017) occurred at Transect 370. The shoreline advanced on the order of 70 feet from 2013 to 2015 and receded some 60 feet from 2015 to 2017 resulting in a gross shoreline change distance of 130 feet. On the other hand, the net shoreline change at this transect was less than 10 feet. On average, the shoreline between Transect 370 and Transect 400 advanced 38 feet from 2013 to 2015 and receded 18 feet from 2015 to 2017. Overall (2013 to 2017), the shoreline advanced approximately 20 feet along this reach of the SLS. A similar trend in shoreline change was noted along other portions of the SLS for the period of analysis.

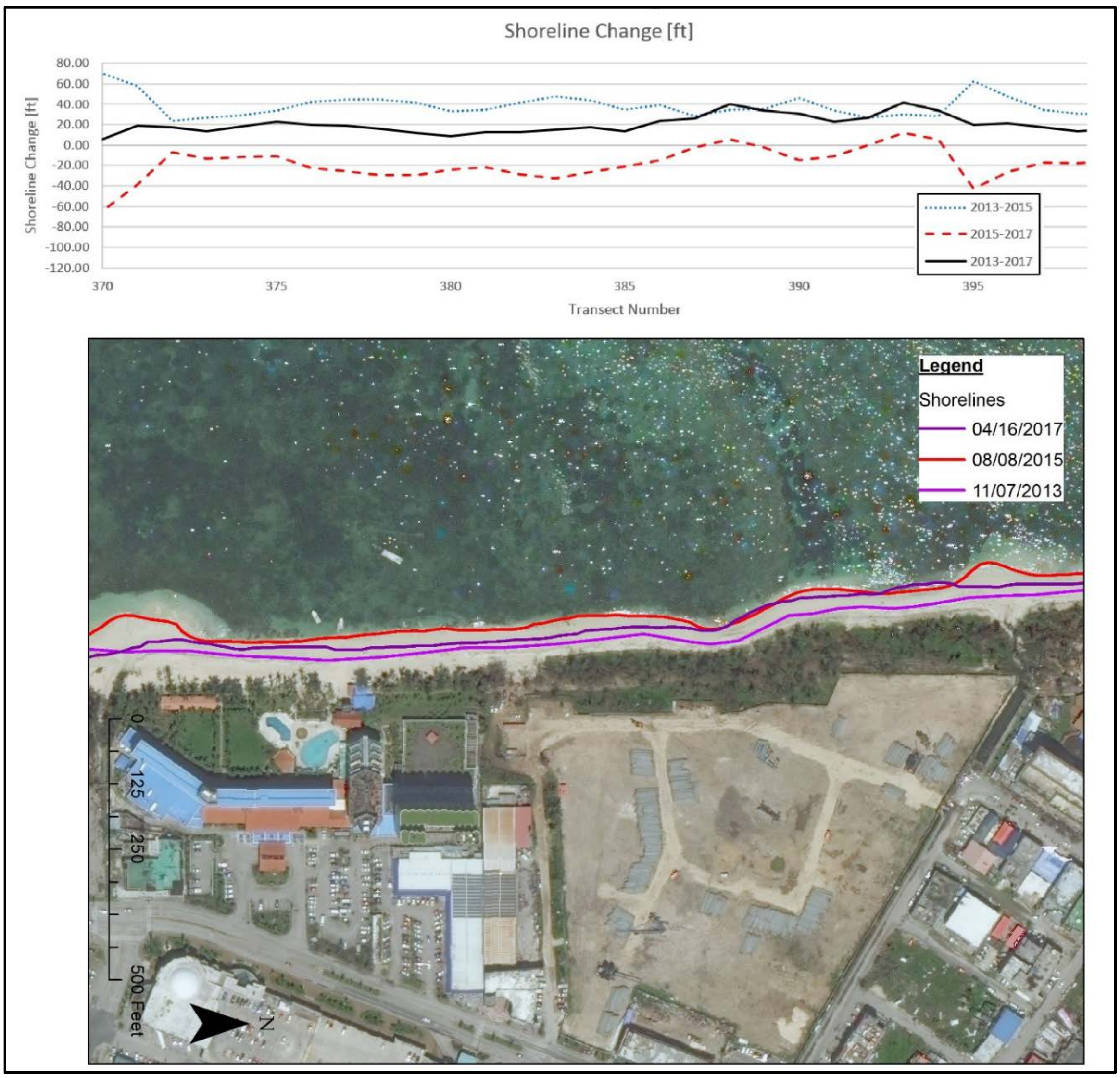

Figure 13. Shoreline locations (bottom) and shoreline changes (top) at Makaka Beach determined utilizing digitized shorelines from 2013, 2015 and 2017.

Reaches of greatest shoreline recession were identified for the period of analysis (2013 to 2017). This excludes the reaches from Transect 126 through Transect 138 and Transect 217 through Transect 351 due to the inability to digitize portions of the 2017 satellite image. Reach 1 (Transect 1 through Transect 25) located south of Sugar Dock experienced an average recession of 21 feet. The beach in this reach is relatively wide due to the accretion caused by Sugar Dock's interception of littoral sediment transport. Reach 2 (Transect 84 through Transect 91) receded 15 feet on average. There is no infrastructure or upland development currently threatened by erosion in this reach located north of Saipan World Resort. In Reach 3 (Transect 411 through Transect 416) shoreline recession averaging 32 feet resulted in damages to existing infrastructure at AMP. Alternating reaches of recession and advance were noted along the AMP shoreline over the period of analysis. The average shoreline change at AMP from 2013 to 2017 was found to be advance of 18 feet.

POTENTIAL IMPACTS OF SEA LEVEL CHANGE

Relative sea level change (SLC) is the local change in sea level relative to the elevation of the land at a specific point on the coast, including the lowering or rising of land through geologic processes such as subsidence and glacial rebound. Relative SLC is a combination of both global and local SLC caused by changes in estuarine and shelf hydrodynamics, regional oceanographic circulation patterns (often caused by changes in regional atmospheric patterns), hydrologic cycles (river flow), and local and/or regional vertical land motion (subsidence or uplift). Thus, relative SLC is variable along the coast.

To incorporate the direct and indirect physical effects of projected future sea level change on design, construction, operation, and maintenance of coastal projects, USACE has provided guidance in the form of Engineering Regulation, ER 1110-2-8162 (USACE 2013). ER 1110-2-8162 provides both a methodology and a procedure for determining a range of sea level change estimates based on global sea level change rates, the local historic sea level change rate, the construction (base) year of the project, and the design life of the project. Three estimates are required by the guidance, a Baseline (or "Low") estimate, which is based on historic sea level change and represents the minimum expected sea level change, an Intermediate estimate (NRC Curve I), and a High estimate (NRC Curve III) representing the maximum expected sea level change. All three scenarios are based on the following eustatic sea level rise (sea level change due to glacial melting and thermal expansion of sea water) equation:

$$\mathrm{E}(t) = 0.0017t + bt^2$$

where E(t) is the eustatic sea level rise (in meters); t represents years, starting in 1992 (the midpoint of the current National Tidal Datum Epoch of 1983-2001); and b is a constant equal to 2.71E-5 (NRC Curve I), 7.00E-5 (NRC Curve II), and 1.13E-4 (NRC Curve III). This equation assumes a global mean sea level change rate of +1.7mm/year.

In order to estimate the eustatic sea level change over the life of the project, the above equation is modified as follows:

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + (t_2^2 - t_1^2)$$

where t_1 is the time between the project's construction date and 1992, and t_2 is the time between the end of the project life and 1992.

In order to estimate the required Baseline, Intermediate, and High Relative Sea Level (RSL) changes over the life of the project, the eustatic sea level rise equation is further modified to include site specific sea level change as follows:

$$RSL(t_2) – RSL(t_1) = (e+M)\ (t_2 – t_1) + b(t_2^2 – t_1^2)$$

where $RSL(t_1)$ and $RSL(t_2)$ are the total RSL at times t_1 and t_2, and the quantity (e + M) is the local sea level rise in mm/year. Local sea level rise accounts for the eustatic change (e) (1.7mm/year or 0.0056 ft/year) as well as uplift, subsidence, and other effects (M) and is generally available from the nearest tide station. That tide station being National Oceanic and Atmospheric Administration (NOAA) Station 1630000 at Apra Harbor, Guam approximately 140 miles from Saipan Lagoon which has a tidal record of approximately 40 years.

Over the past two decades, sea level trends have increased in the western tropical Pacific Ocean with rates that are approximately three times the global average. Several papers including Merrifield and Maltrud (Merrifield 2011) have shown that the high rates of SLC recorded are caused by a gradual intensification of Pacific trade winds since the early 1990s. Multi-decadal tradewind shifts in the Pacific (1950-1990 had weak tradewinds, while 1990-present have shown strong tradewinds) are likely related to the Pacific Decadal Oscillation (Merrifield et al. 2012), a recurring pattern of ocean-atmosphere climate variability centered over the mid-latitude Pacific basin. These low frequency tradewind changes can contribute on the order of 1 cm variations in sea level in western tropical Pacific. Multi-decadal variations such as these can lead to linear trend changes over 20 year time scales that are as large as the global SLC rate, and even higher at individual tide gauges, such as Apra Harbor, Guam (Merrifield 2011, Merrifield et al. 2012).

In addition, higher frequency inter-annual variations in Pacific water levels can be caused by the effect of the El Nino Southern Oscillation; the climate phenomenon in the Pacific evidenced by alternating periods of ocean warming and high air pressure in the western Pacific (El Nino) and cooler sea temperatures accompanied by lower air pressure in the western Pacific (La Nina). In fact, it is known that the largest inter-annual variability of sea level around the globe occurs in the tropical Pacific, due to these climate patterns (Widlansky 2015). During El Nino years, sea level in the western tropical Pacific is known to drop by 20 to 30 cm, while La Nina phases cause an average sea level rise of about 10 cm. Additionally, and throughout the tropical Pacific, prolonged inter-annual sea level inundations are also found to become more likely with greenhouse warming and increased frequency of extreme La Niña events, thus exacerbating the coastal impacts of the projected global mean sea level rise (Widlansky 2015).

Anecdotal reports have suggested a possible recent reversal in the 20+ year trend of dramatically rising sea levels in the western tropical Pacific, possibly due in part to the strong El Nino cycle documented in 2015/2016; however, analysis and published research supporting this change in trend is not yet available. These phenomena are documented here to emphasize the large variability in sea level that is experienced in the western tropical Pacific, and to indicate that sea level trends reported by the nearest NOAA tide gage to Saipan Lagoon (Apra Harbor, Guam) are likely affected by this variability.

The mean sea level trend reported by NOAA at Apra Harbor Station 1630000 is 4.55 mm/year (+/- 4.68 mm/year 95% confidence interval), as shown in Figure 14. The two trend lines in the figure are indicative of rates prior to and following the 1993 earthquake in Guam. The land elevation experienced an approximately 10 cm drop during the earthquake and is now slowly subsiding, which affects the local relative SLC rate. In addition, the division of the MSL trend into pre- and post-earthquake results in a shorter period of record of approximately 24 years (1993 – present), which is less than the suggested 40 year period of record required by ER 1110-2-8162.

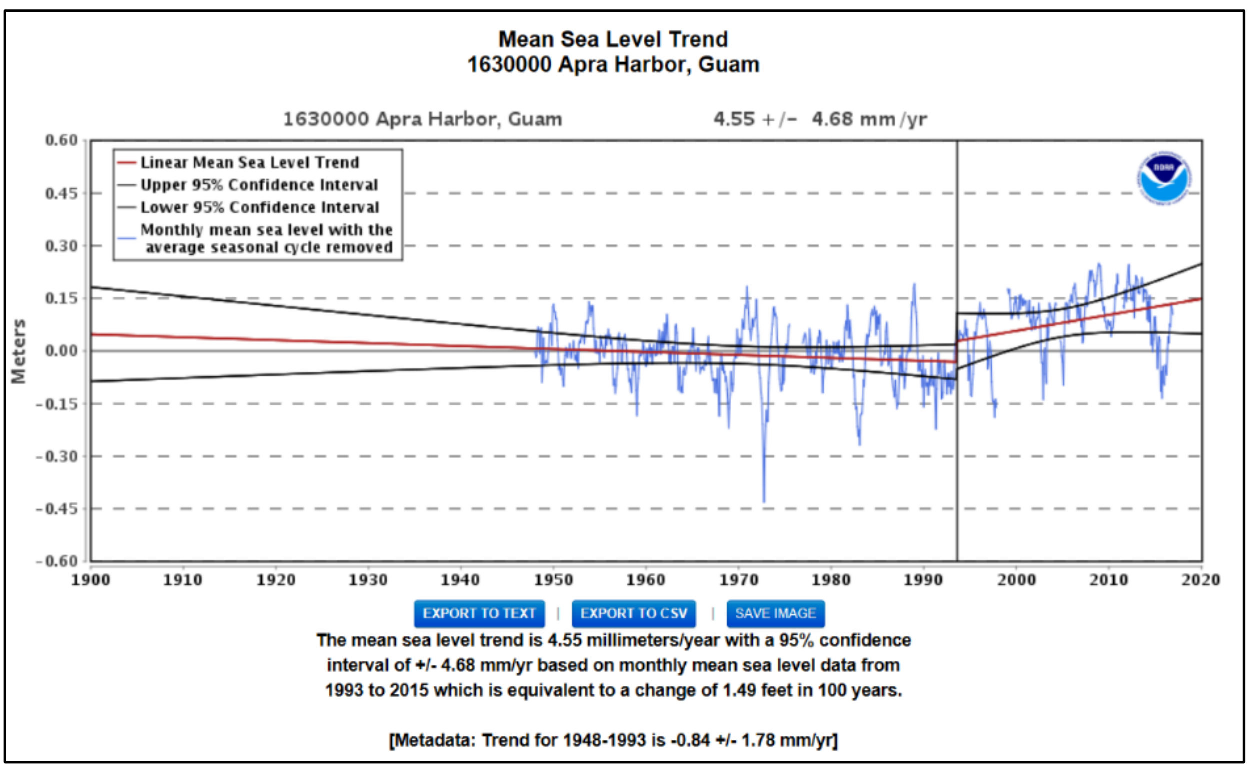

Figure 14. Mean Sea Level Trend from NOAA Tide Gage 1630000 – Apra Harbor, Guam

NOAA also provides information on the historical Mean Sea Level trend, shown in Figure 15. This figure gives additional information on the variability of the average rate of change, as it is basically a look at the historical "trend of the trend". The figure shows that as recently as 2008, the MSL trend was as high as 10.85 mm/year, over 6 mm/year higher than its present rate, a significant difference that would be amplified when calculating the "intermediate" and "high" curves of potential accelerated SLC.

Due to the variability in MSL trends in the western Pacific over recent years outlined above, in addition to the short post-earthquake trend at Apra Harbor, Guam, a different approach was taken for determination of the rate of relative SLC at Saipan Lagoon. The rate for Saipan Lagoon is estimated by using the global eustatic rate of SLC, +1.7 mm/year added to a measured rate of Vertical Land Movement (VLM) rate of -1.0 mm/year (as reported by the NASA Jet Propulsion Laboratory website https://sideshow.jpl.nasa.gov/post/series.html – an average of two monitoring stations on Guam and one on Saipan). Since eustatic sea level is rising, and the land is subsiding, this results in a relative SLC rate of 2.7 mm/year (= +1.7 mm/year – (-1.0 mm/year)) or 0.0089 feet/year for Saipan Lagoon. As an example, the USACE SLC calculator was used to plot the three potential curves based on this rate, shown in Figure 16. The curves show that by 2020 relative SLC in the study area will be between 0.2 ft or 0.06 m (low curve) and 0.5 ft or 0.16 m (high curve). By 2070, sea level will have risen between 0.7 ft and 2.9 ft (0.23 m to 0.9 m); and by 2120, sea level will have risen between 1.1 ft and 7.2 ft (0.33 m and 2.2 m) relative to the existing MSL datum.

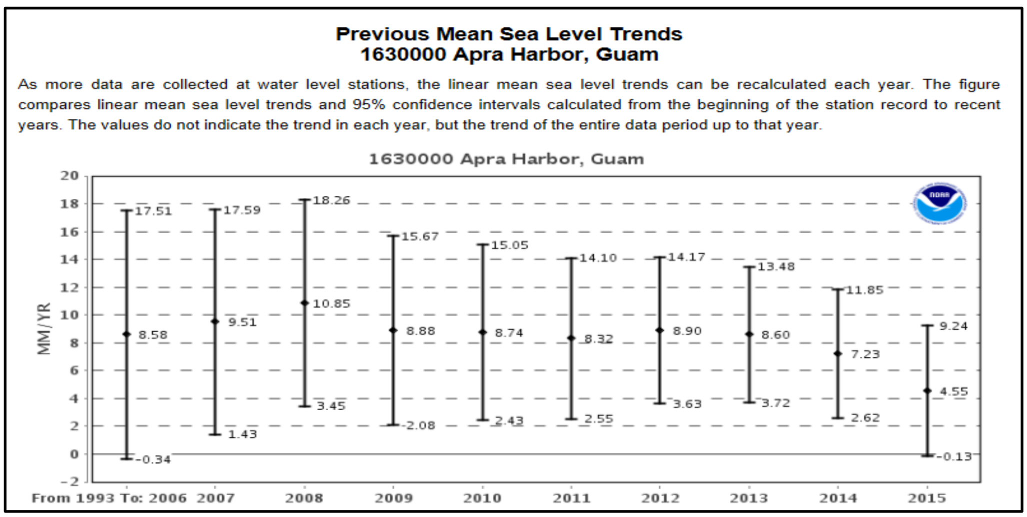

Figure 15. Previous Mean Sea Level Trends from NOAA Tide Gage 1630000 – Apra Harbor, Guam

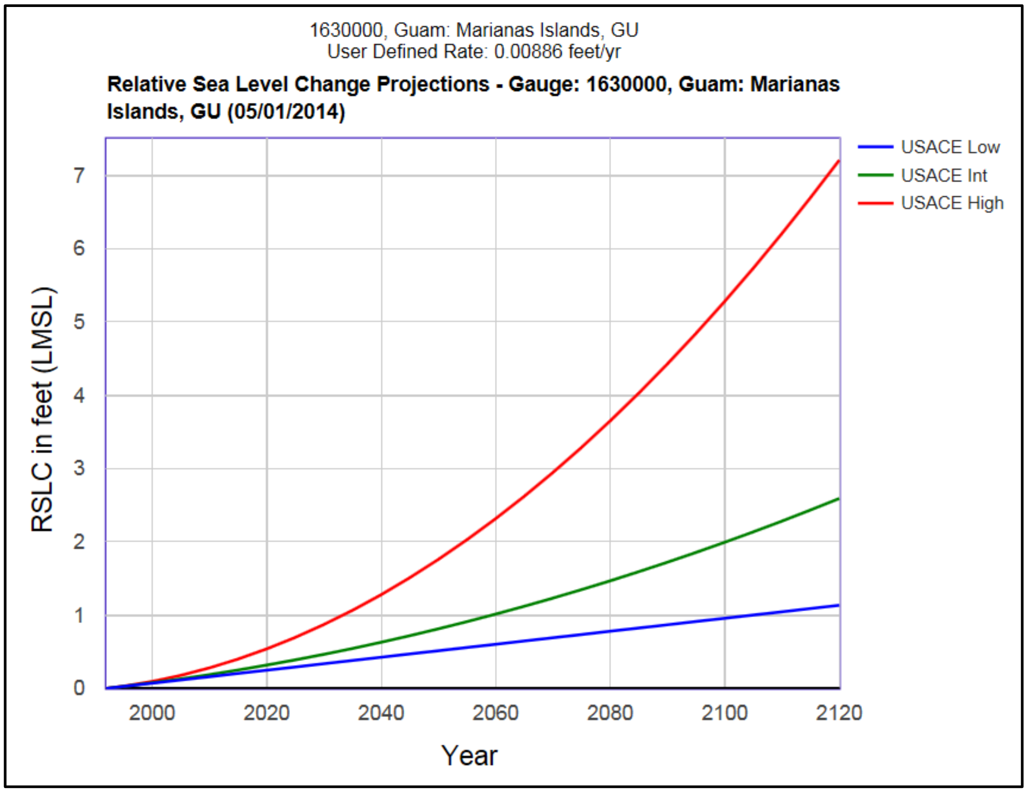

Figure 16. Relative Sea Level Change curves at Saipan Lagoon, based on SLC rate of 2.7 mm/year

PLANNING MEASURES

Living shoreline is a broad term that encompasses a range of shoreline stabilization measures along estuarine coasts, bays, sheltered coastlines, and tributaries. A living shoreline has a footprint that is made up mostly of native material. It incorporates vegetation or other living, natural "soft" elements alone or in combination with some type of harder shoreline structure (e.g. oyster reef or rock sill) for added stability. Living shorelines maintain continuity of the natural land–water interface and reduce erosion while providing habitat value and enhancing coastal resilience.

Living shorelines are sometimes referred to as nature-based, green shorelines, or soft shorelines. A subset of these living shorelines may be hybrid solutions with a mix of natural (e.g. oyster shell) and nature-based (e.g. reef balls or rocks where they do not naturally occur) materials. Vegetative communities are also examples of nature based features including wetlands, sand dunes, and transitional terrestrial ecosystems. In the face of sea level rise, a mechanism by which coastal wetlands maintain their elevation is through accretion of sediments, to mediate vertical accumulation. This can occur via mineral deposition and/or organic matter accumulation (Morris et al. 2002, in Snedden et al). In addition, living shorelines is a form of shoreline erosion control feature that incorporates native vegetation and preserves native habitat (Davis et al. 2015). According to Feagin et al. 2010, coastal wetland plants will move landwards toward higher elevations as sea level rises. Plants are often "keystone" species that hold together entire ecosystems and are important for many ecological processes to occur (Bailey et al. 2017). Plant communities in the environment can provide structure, function, and natural processes to create a sustainable landscape (Bailey 2014).

Wetlands contain hydrophytic plants which are adapted to life in wetlands, can contribute to sediment accumulation, and engineer land elevation through succession (Feagin 2008). In addition, they can contribute to nutrient cycling, and add to biodiversity. Plants are soil binders, hence are able to indirectly limit lateral erosion rate by modifying soil parameters (Feagin 2009). When created along shorelines, they can serve several functions such as flood reduction, water filtration, waste treatment, and wildlife habitat (Biebighauser 2011). Therefore, a wetland is a nature based engineering feature that can be incorporated in coastal areas.

The term living shoreline is aptly applied to a wide variety of stabilization measures. These are effective in minimizing erosion and providing stability along shorelines in inland waters and coastal areas. The concept incorporates the use of plant species along the water's edge. Plants can be used as stand-alone natural features, or in combination with other natural materials such as coir logs, hay bales, rock gabion baskets, geotextile tubes, living reefs (oyster/mussels), stone, sand breakwaters, and erosion control blankets. Living shorelines are suitable in low wave energy environments. Some of these natural materials require periodic maintenance as they degrade over time. For example, coir logs are 100% biodegradable and last up to four years. The mechanism by which natural and nature based features are able to stabilize shore areas include a) Vegetation only - where roots anchor soil in place because they are soil binders, consequently, they help to reduce erosion. In addition, plants serve as upland buffer and wave breaker in low wave energy environments. b) Edging – The structure installed at the toe of the vegetation functions as a shoreline erosion prevention mechanism. This is suitable for most areas except high wave energy systems. c) Sills – The structures such as rock or other materials are placed parallel to vegetated shorelines to reduce wave energy, and prevent erosion (Sage 2015). Figure 17 shows a continuum of project measures along a green (natural materials only) to green/gray (hybrid) to gray (all built materials) scale (NOAA 2015). The projects on the left, green side of this continuum represent possible living shoreline design options. NOAA encourages the use of these softer measures for shoreline stabilization. Details on the purpose, materials, suitability, advantages and disadvantages of each alternative is provided below (USACE & NOAA 2015).

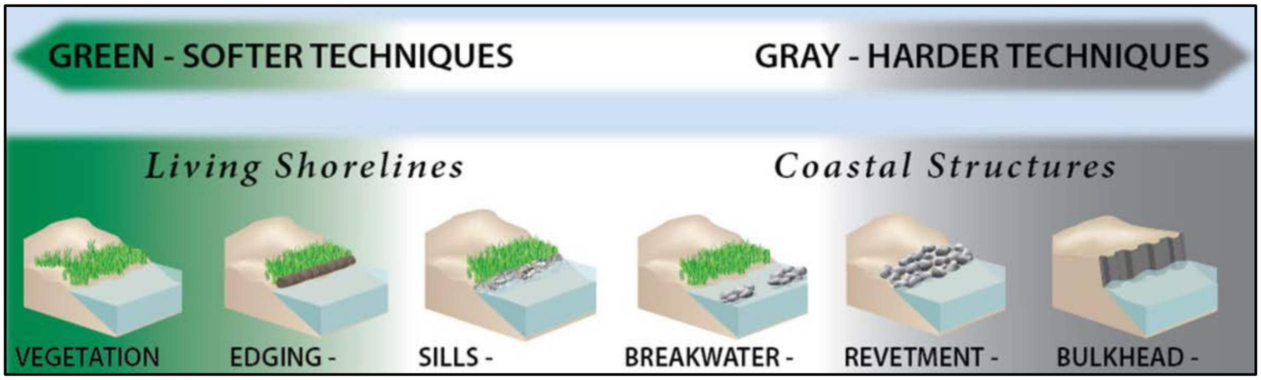

Figure 17. Categories of shore protection ranging from "green" softer to "gray" harder measures.

Vegetation Only

This alternative uses only vegetation (native plants) whose roots hold soil in place to reduce erosion (Figure 18). It provides a buffer to upland areas, breaks small waves and is suitable for low wave energy environments (UH & OCCL 2004). A wave decay study conducted in the laboratory simulating the effect of vegetation density on wave dissipation showed a decrease in wave energy with increasing stem density (Figure 19) (Anderson et al. 2013).

The benefits of vegetation include the fact that it dissipates wave energy, slows inland water transfer, increases natural stormwater infiltration, provides habitat and ecosystem services, exerts minimal impact to natural community and ecosystem processes, maintains aquatic/terrestrial interface and connectivity, and assists in flood water storage. The disadvantages include no storm surge reduction ability, no high water protection, it is appropriate in limited situations (not applicable in high energy environments because it will not be effective), there is uncertainty of successful vegetation growth, and competition with invasive plant species. Environmental considerations include continual maintenance of vegetation, minor environmental impacts, and permits may or may not be required.

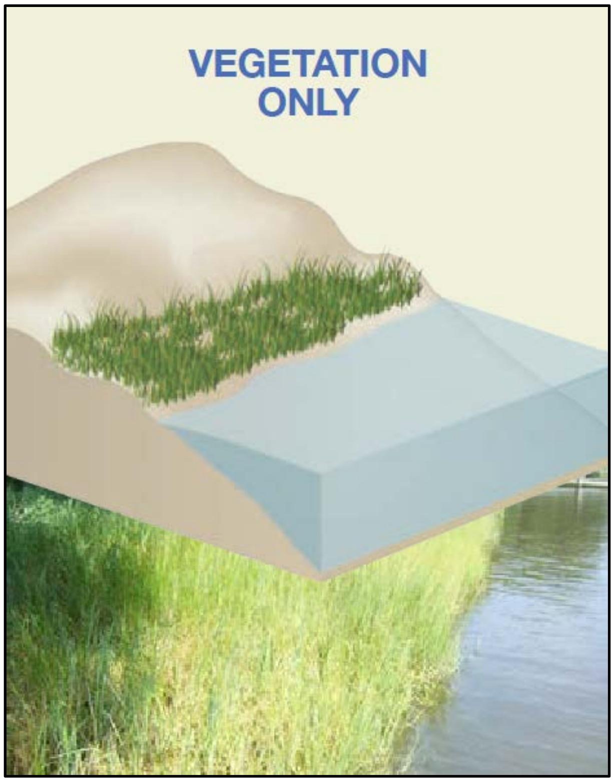

Figure 18. Vegetation only measure.

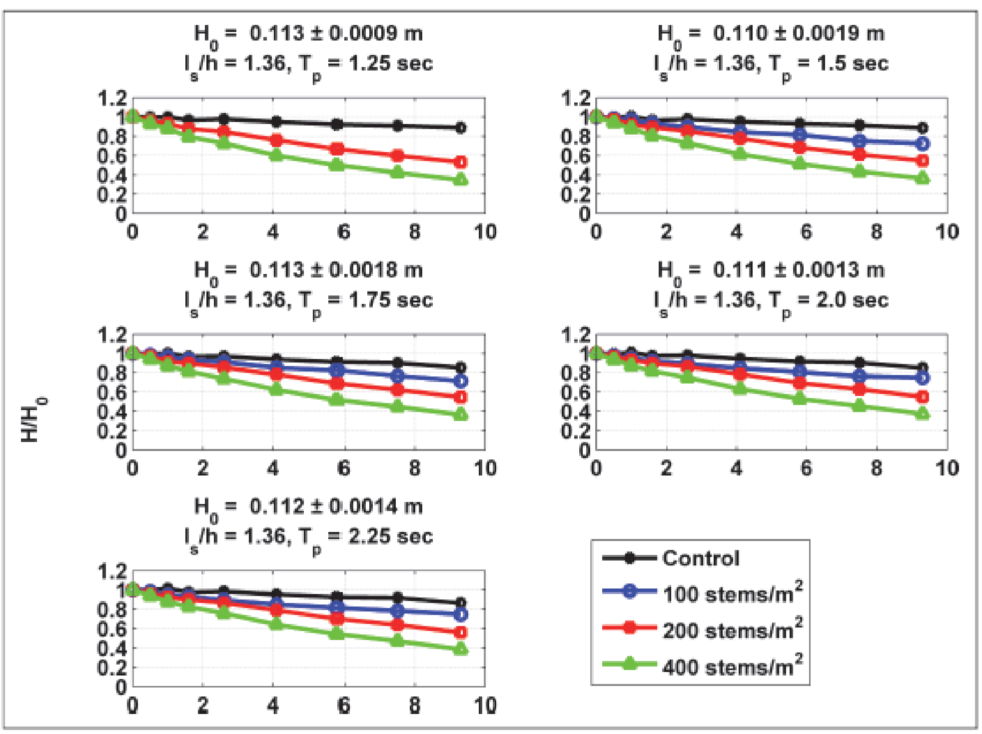

Figure 19. Effect of stem density on wave decay using artificial vegetation where H_o is the initial wave height and H is the wave height at various locations along the wave tank (horizontal axis).

Edging

Same as the vegetation only alternative except a structure is added to hold the toe of existing or vegetated slope in place (Figure 20). It protects against shoreline erosion and is suitable except in high wave energy environments. Edging materials include snow fencing, erosion control blankets, geotextile tubes, living reef (oyster/mussel) and rock gabion baskets. Native plants and materials must be appropriate for salinity levels and site conditions. Similar to vegetation only, the advantages include dissipation of wave energy, slowing down of inland water transfer, provision of habitat and ecosystem services, increase in natural stormwater infiltration, and toe protection helps prevent wetland edge loss. The disadvantages are that there is no high water protection, it is a larger physical footprint, there is uncertainty of successful vegetation growth, and competition with invasive plant species. Environmental considerations include continual maintenance of vegetation, minor environmental impacts, and permits may or may not be required.

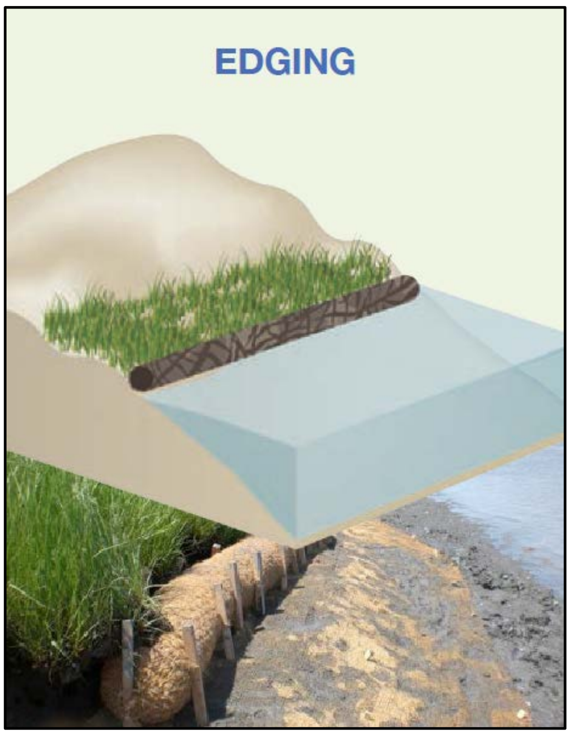

Figure 20. Vegetation with edging measure.

Sill

A sill is constructed parallel to existing or vegetated shoreline, reduces wave energy and prevents erosion (Figure 21). A gapped sill approach allows habitat connectivity, greater tidal exchange, and better waterfront access. It protects against shoreline erosion and is suitable except in high wave energy environments. Sill materials include stone, sand bars, living reef (oyster/mussel) and rock gabion baskets. Advantages of sills include provision of habitat and ecosystem services, dissipation of wave energy, slowing down of inland water transfer, provision of habitat and ecosystem services, increase in natural stormwater infiltration, and toe protection that helps to prevent wetland edge loss. Disadvantages include increased land area requirement, no high water protection, uncertainty of successful vegetation growth, and competition with invasive plant species. Environmental considerations include continual maintenance of vegetation, a larger physical footprint, limited environmental impacts, and permitting is required.

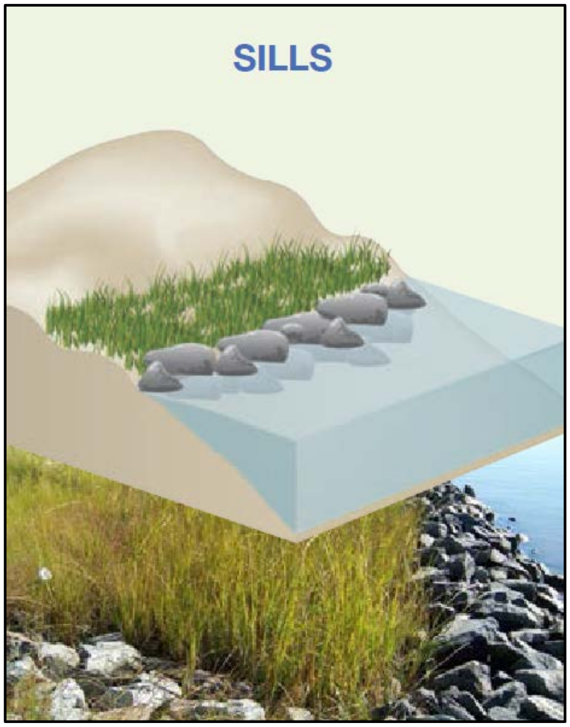

Figure 21. Vegetation with sill measure.

Beach Nourishment with and without Vegetation on Dune

Beach quality sand is added from an adjacent or outside source to nourish an eroding beach (Figure 22). Such nourishment widens the beach and extends the shoreline seaward. Beach nourishment is suitable in low-lying oceanfront areas with available sources of beach quality sand or other native sediments. Vegetated dunes help anchor sand and provide a buffer to protect inland areas from waves, flooding and erosion. Dunes can be strengthened by inclusion of a geotextile tube or rock core. Advantages include the expansion of usable beach area, lower environmental impact than hard structures, flexibility, and ease of redesign along with provision of habitat and ecosystem services. Vegetation can be planted on the dune to increase its resilience to storm events. Disadvantages however include continual sand renourishment required, limited high water protection, application is limited, and there is possible impacts to regional sediment transport. Environmental considerations include large physical footprint requirement, moderate environmental impact, impacts may be reversible, and permitting is required.

Figure 22. Beach nourishment with and without dune vegetation measure.

Breakwater

A breakwater is an offshore structure intended to break waves, reduce the force of wave action and encourage sediment accretion (Figure 23). A breakwater can be floating or placed on the ocean floor, attached to shore or not, and continuous or segmented. A segmented breakwater allows habitat connectivity, greater tidal exchange, and better waterfront access. Breakwaters can be designed for high wave energy environments and are often utilized in conjunction with ports, harbors and marinas. A breakwater can be made of rock, grout-filled bags, wood, concrete armor units and living reef (oyster/mussel) in low wave environments. Artificial reefs can also provide the same types of protection afforded by breakwaters. An example of this is a breakwater constructed with Reef Balls. Reef Balls are made of a special, marine friendly, concrete and are designed to mimic natural reef systems. They are used around the world to create habitat for fish and other marine and freshwater species. Advantages include reduction of wave force and height, stabilization of a wetland, ability to function like reefs, economically feasible in shallow areas, and moderate storm surge flood level reduction ability. Disadvantages include the fact that they are expensive to construct in deep water, can reduce water circulation (minimal for floating breakwater), potential navigational hazards, and require a large footprint. In addition, there is uncertainty of successful vegetation growth and competition with invasive plant species, they provide minimal high water protection, and can reduce water circulation. There is significant environmental impact in and out of water, the impacts are not reversible, there is minimal maintenance, and permits are required.

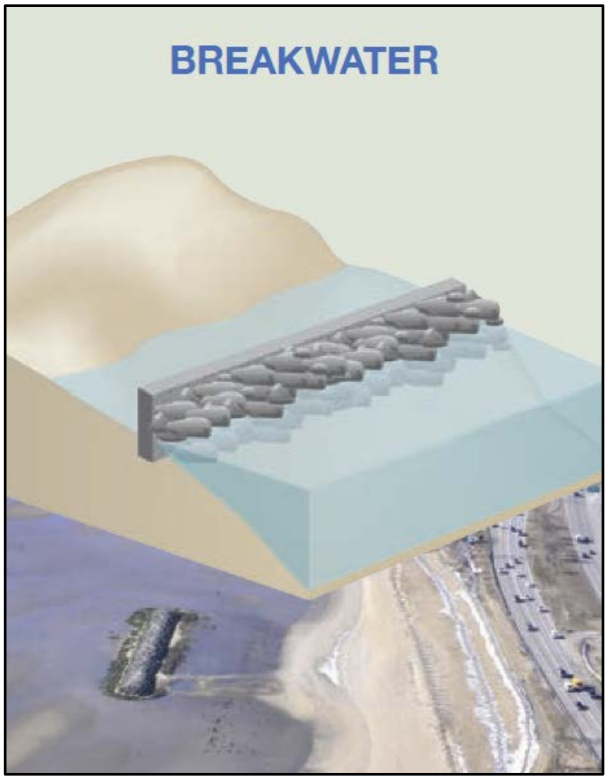

Figure 23. Breakwater measure.

Revetment

A revetment consists of armoring of a shoreline slope designed to hold-the-line (Figure 24) and protect the shoreline slope from wave impacts and erosion. A revetment is suitable in areas of pre-existing hardened shorelines and in some cases along chronically eroding shorelines with limited sediment supply. It may also be appropriate where shoreline recession threatens infrastructure that is not able to be relocated. Materials that are commonly used in revetment construction include stone, concrete armor units, concrete slabs, sand/concrete filled geotextile bags, geo-tubes, and rock-filled gabion baskets. Revetments mitigate wave action, there is limited maintenance, and have an indefinite lifespan. Disadvantages however include significant land area requirement, loss of intertidal habitat, erosion of adjacent unreinforced shoreline, limited high water protection, and prevention of the upland from being a sediment source to the system. Environmental considerations include large impact in and out of water, impacts are not reversible, minimal maintenance required, and permits are required.

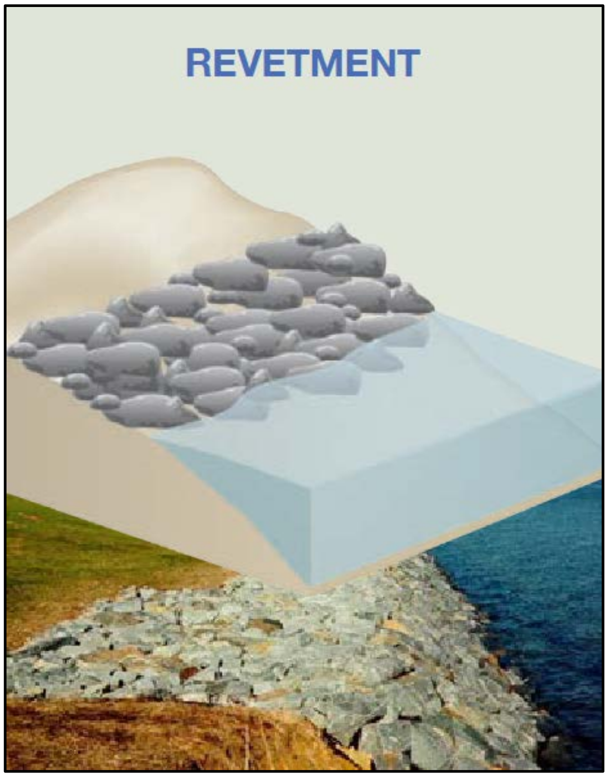

Figure 24. Revetment measure.

Bulkhead

A bulkhead is constructed parallel to the shoreline and is similar to a vertical retaining wall (Figure 25). It is intended to hold soil in place, survive the impacts of waves/currents and provide for a stable shoreline. Suitable applications are in high energy settings and sites with pre-existing hardened shoreline structures. These types of structures are commonly used along working waterfronts in ports, harbors and marinas. Bulkhead material options include various types of sheet pile, timber, reinforced concrete and rock-filled gabions. Bulkheads are suitable in moderate wave action, manage tide level fluctuation, have a long lifespan, simple to repair, and require minimal footprint. Disadvantages of bulkheads are that they don't provide major flood protection, may induce erosion of seabed and adjacent unreinforced shoreline, result in loss of intertidal habitat, may be damaged by overtopping, prevent upland from being a sediment source to the system, and reflect nearly 100% of the incident wave energy. They can cause relatively large environmental impact in and out of water, impacts may not be reversible, there is minimal maintenance, and permits are required.

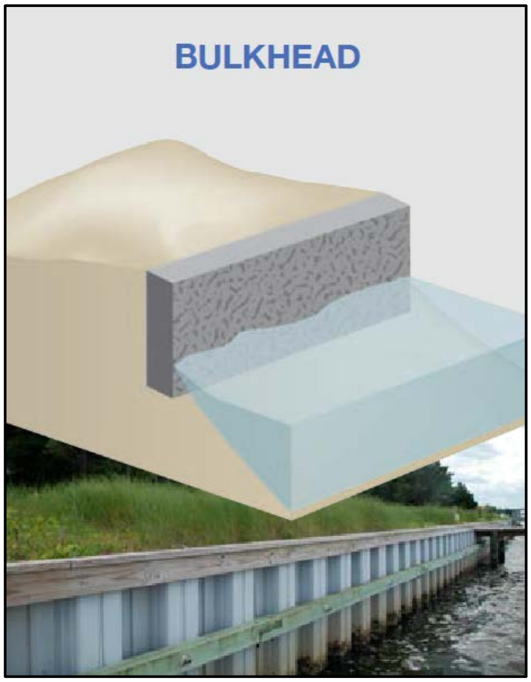

Figure 25. Bulkhead measure.

Seawall

A seawall is similar to a bulkhead in that it is constructed parallel to the shoreline and is basically a vertical retaining wall (Figure 26). It is intended to hold soil in place, survive the impacts of waves/currents and provide for a stable shoreline. Suitable applications are in high energy settings and sites with pre-existing hardened shoreline structures. These types of structures are commonly used along bay and ocean shorelines. Seawall material options include various types of sheet pile and pre-fabricated concrete elements. They are suitable for high wave energy environments which are vulnerable to storm surges. Advantages of seawalls include prevention of storm surge flooding, resistance to strong wave forces, shoreline stabilization behind the structure, low maintenance costs, and a limited footprint. Disadvantages include erosion of seabed, disruption of sediment transport leading to beach erosion, higher up-front costs, visually obstructive, loss of intertidal zone, prevention of upland from being a sediment source to the system, and may be damaged from overtopping. They can cause relatively large environmental impacts in and out of the water, impacts may not be reversible, there is minimal maintenance, and permits are required.

Groin

Groins are built perpendicular to the shoreline and intercept littoral sediment transport on their updrift side (Figure 27). They are designed to reduce currents and hold sand on the adjacent shoreline. A field of properly placed T-groins can result in shoreline planforms that are stable under even severe conditions. They are suitable in combination with a properly sized beach nourishment project. Material options include stone, concrete armor units, timber and sheet pile. Groin design must provide appropriate sized stone for the site specific wave climate. Advantages include protection from wave forces, methods and materials are adaptable, and can be combined with beach nourishment projects to reduce renourishment costs. Disadvantages include erosion of adjacent sites, can be detrimental to shoreline ecosystem, and no high water protection. The environmental considerations are the same as for bulkheads and the seawalls.

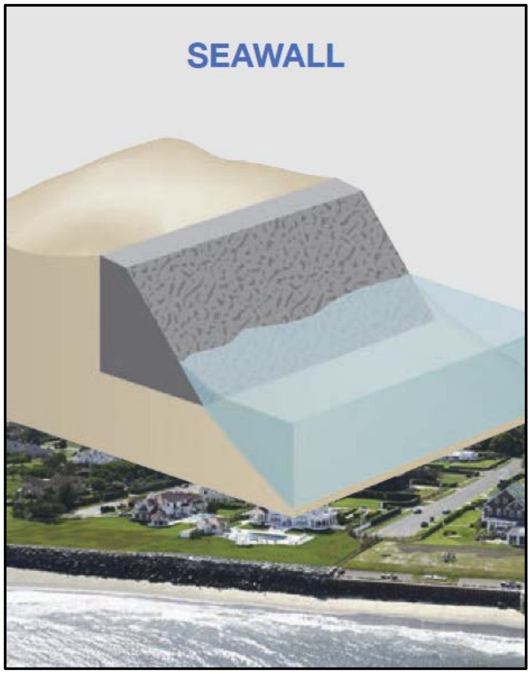

Figure 26. Seawall measure.

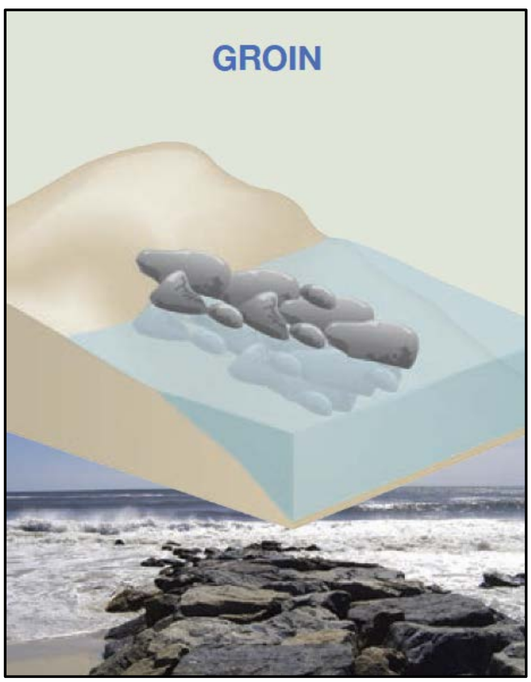

Figure 27. Groin measure.

CONCEPTUAL PLANS

Without implementation of shoreline protection along portions of the study area, the public beach may erode and infrastructure as well as private development may be threatened. If nothing is done to protect the shoreline against storm impacts and sea level change, erosion may claim land between the shoreline and Beach Road.

Living shoreline projects could be implemented within the study area to protect land, infrastructure and coastal habitat. The suitability of living shoreline projects along the SLS is site specific. Generally, non-hardened sites that are not subject to heavy traffic may be suitable for LSL projects. Hardened or high-use sites such as Fishing Base and the TLS building near the McDonald's restaurant have fewer LSL options. There may be restoration opportunities or options for mixed green/gray projects in these areas. Sub-tidal seagrasses could potentially be used at hardened and non-hardened sites (Duarte et al 2013). Although vegetation only projects are not recommended for high wave energy environments, they may be appropriate if the requirement for replanting following major storm events is accounted for in the planning and design phases.

Discussions with the local resource agencies revealed several challenges with building and maintaining gray shore protection structures. One of the main concerns was the high cost of construction and the lack of funding to support building and maintaining a project. Due to Saipan's remote location, the cost of building any structure would be high. Currently there is no source of funding identified to build, operate, or maintain a project. Historically, infrastructure projects are not well maintained after being built due to lack of maintenance funds. Additionally, the resource agencies are concerned that more shoreline hardening will lead to a loss of the natural shoreline or have other unintended impacts to adjacent shorelines. In contrast, softer green measures are more easily built and maintained by the resource agencies themselves. For these reasons, the resource agencies favor greener alternatives for the SLS.

Appropriate Shore Protection Measures

Table 1 presents appropriate LSL shore protection measures for the SLS based on BECQ input

Table 1. Appropriate Shore Protection Measures for SLS

Shore Protection Measure	Is it appropriate for this location?
1. Incorporating oyster or clam shell bags or marine-safe concrete that encourages shellfish to attach or settle	YES & NO - Shellfish anchorage not applicable. Marine-safe concrete for coral establishment or green/gray structures for mangrove re-vegetation may be.
2. Establishing living structure, like corals and oysters, and designing systems to function as closely to natural systems as possible	YES - Coral, seagrass and mangrove re-establishment may be viable at some aquatic sites, and shoreline vegetation re-establishment likely viable at terrestrial sites with lower use pressures.
3. Incorporating native low and high marsh vegetation augmented by regionally specific coastal plants (such as mangrove seedlings)?	YES
4. Incorporating native seagrass	YES
5. Incorporating sandy or cobble beach, mudflats, or other natural shoreline features	YES
6. Maintaining wetlands and/or upland riparian buffers adjacent to a structure	YES & NO - Limited area for expanded buffers in the majority of the Saipan Lagoon area, however, buffer enhancement possible and encouraged in less developed areas (AMP, Tanapag, and San Roque).
7. Adding fish habitat enhancement structures to bulkheads	YES & NO - Possible fish enhancement potential at Garapan Fishing Base.
8. Incorporating breaks or openings in any hard structural elements (excluding bulkheads and seawalls) to facilitate natural water flushing and allow aquatic organisms to access nearshore and shoreline habitat (e.g., fish and turtles for upland nesting)	YES & NO - Not applicable to vegetation only living shoreline projects although this strategy could be incorporated into the design of any proposed hard structural elements.

Conceptual Plan Development

The various living shoreline planning measures that have been introduced and described above were used to develop the following conceptual plans for the SLS. Although gray measures are not preferred by the local resource agencies, they have been included herein for economic comparison with green measures. The conceptual plans are for general application but are recommended for specific sites within the study area.

Vegetation with and without Beach Nourishment

The salt-tolerant species of plants and grasses shown in Figure 28 provide an effective erosion control for beach and dune systems. Natural vegetation is important for stabilizing the dune system. These low-lying plants work well to cover the active dune and protect the backshore against temporary erosion by forming a dense mat that is resistant to wind and wave erosion. *Paspalum distichum* grass is ideally suited in the area behind the frontal dune but still in the erosion zone. This salt tolerant grass can grow directly on the sand with little or no soil needed. It can withstand periodic flooding and can be irrigated with brackish water. As with many of these species, herbicides are not needed because salt water kills most weeds. Dune walkovers and wind breaks also help to prevent erosion to the dune system and should be considered in areas where heavy foot traffic and wind is causing erosion of a dune. Pathways that cross through a dune should be oriented diagonally to the predominant wind direction so that the pathway does not allow windblown sand to be funneled through the depressed pathway (UH & OCCL 2004).

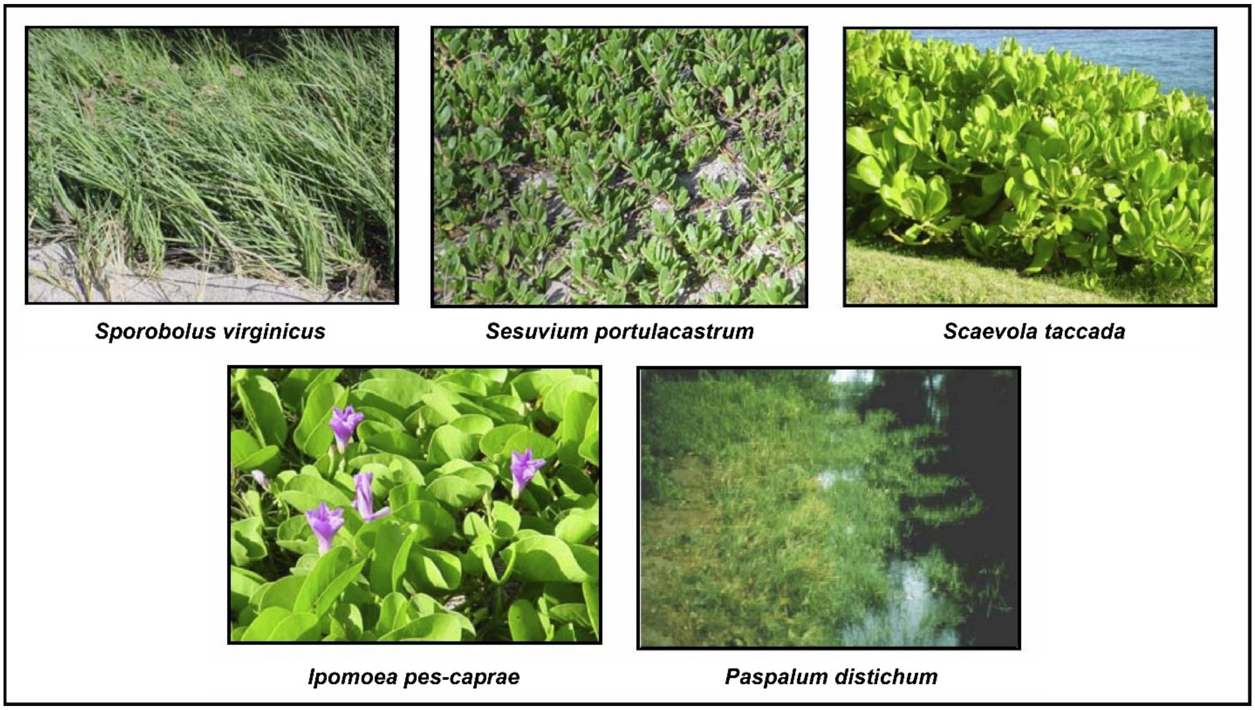

Figure 28. Salt tolerant plant common to tropical beaches and dunes.

Other best management practices include temporary vegetation, which can be used as a temporary or permanent stabilization technique for areas disturbed by construction. Vegetation effectively reduces erosion in swales, stockpiles, berms, mild to medium slopes, and along roadways. Other techniques such as matting, mulches, and grading may be required to assist in the establishment of vegetation. The type of temporary vegetation used on a site is a function of the seasonality and the availability of water for irrigation. Temporary vegetation should be appropriately selected for the area. Agricultural extension agents are a good source for suggestions for temporary vegetation. Grading must be completed prior to seeding. Slopes should be minimized.

Fertilizers should be applied at appropriate rates. Seeding rates should be applied as recommended by the local agricultural extension office. The seed should be applied uniformly. Steep slopes should be covered with appropriate soil stabilization matting.

Blankets and matting material can be used as an aid to control erosion on critical sites during the establishment period of protective vegetation. The most common uses are in channels, interceptor swales, diversion dikes, short, steep slopes, and on tidal or stream banks. New types of blankets and matting materials are continuously being developed. Installation in accordance with the manufacturer's recommendations must be followed, and proper anchoring of the material must be ensured. A uniform trench perpendicular to line of flow may be dug with a spade or a mechanical trencher when applying fertilizer. Erosion stops should be deep enough to penetrate solid material or below level of ruling in sandy soils. Erosion stop mats should be wide enough to allow turnover at bottom of trench for stapling, while maintaining the top edge flush with channel surface.

Mulching is the process of applying a material to the exposed soil surface to protect it from erosion and to conserve soil moisture until plants can become established. When seeding critical sites, sites with adverse soil conditions or seeding on other than optimum seeding dates, mulch material should be applied immediately after seeding. Mulch may be small grain straw, which should be applied uniformly. When mulching on slopes 15 % or greater, a binding chemical must be applied to the surface. Wood-fiber or paper-fiber mulch may be applied by hydro-seeding. Mulch nettings and wood chips may be used where appropriate. Mulch anchoring should be accomplished immediately after mulch placement. This may be done by one of the following methods: peg and twine, mulch netting, mulch anchoring tool, or liquid mulch binders.

Wide mangrove belts are able to maintain sediment flows, reducing sediment losses and erosion (Figure 29). Conversion of even parts of the mangrove belt can lead to reductions in sediment flows, reductions of deposition and increasing erosion. In most places, healthy natural mangroves are likely to be relatively stable habitats with little erosion: complex root systems help slow water flows, allowing sediment to settle and causing sediment to accrete rather than erode. Productive root growth and leaf litter supply are critical to build and bind soils. They also maintain or restore sediment supply and avoid sediment starvation caused by certain coastal and inland engineering works that block the flow of sediments from rivers or along the coast. Processes that lead to subsidence, such as oxidation caused by drainage and deforestation or extraction of deep groundwater and oil should be prevented (Spalding et al. 2014).

With respect to coastal protection, by reducing sediment erodibility, seagrass fields maintain a higher bed elevation that will help to attenuate waves. The sediment anchoring effect by short, grazed seagrass vegetation, which has most of its biomass in roots and rhizomes, increases the critical bed shear stress that is needed for bed erosion. The presence of a dense mat of rhizomes and roots can have similar effects at the sediment-water interface as described for other biota that reduce erosion, such as biofilms of micro-phytobenthos. Seagrass cover causes the sediment level to remain higher compared to eroded unvegetated gaps.

Although the relative value of seagrasses for coastal protection is strongly species dependent, with climax species [e.g. *Enhalus acoroides – known as "ohlot" in Ponape dialect (Stammermann 1981)]* generally having a higher value than more ephemeral species (e.g. *Halodule univervis*) that can be highly variable in biomass and cover, even presence of low-canopy sea grass beds is significant. *Enhalus acoroides* and *Halodule univervis* are seagrass types that are both found to be growing and thriving in the CNMI (Christianen et al. 2013).

		HAZARD				
		Waves	Storm surges	Tsunami	Erosion	Sea level rise
MANGROVE FOREST PROPERTIES	Width	Hundreds of meters needed to significantly reduce waves (wave height is reduced by 13-66% per 100m of mangroves)	Hundreds of meters needed to significantly reduce wind and waves on top of surge Thousands of meters needed to reduce flooding impact (storm surge height is reduced 5 - 50 cm/km)	Hundreds of meters needed to reduce tsunami flood depth by 5 to 30% Mangroves do not provide a secure defence (nor do many engineered defences)	Sufficient mangrove forest width needs to be present to maintain sediment balance. This can help to prevent erosion and may encourage active soil build-up.	
	Structure	The more obstacles the better: dense aerial root systems and branches help attenuate waves	Open channels and lagoons allow free passage, while dense aerial root systems and canopies obstruct flow		Complex aerial root systems help slow water flows, allowing sediment to settle and causing sediment to accrete rather than erode.	
	Tree Size	Young & small mangroves can already be effective	Smaller trees and shrubs may be overtopped by tsunamis and the very largest storm surges		Young trees already enable soils to build up. The more biomass input into the soil the better.	
	Link to other ecosystems	Sand dunes, barrier islands, saltmarshes, seagrasses and coral reefs can all play an additional role in reducing waves				Allow room for landward retreat of the mangrove
	Underpinning factors	Healthy mangroves are a prerequisite for all aspects of coastal protection. Healthy mangroves require: sufficient sediment and fresh water supply and connections with other ecosystems. Conversely, pollution, subsidence (due to deep groundwater/oil extraction or oxidation upon conversion) and unsustainable use jeopardizes mangroves.				

Figure 29. Mangrove forest properties that help mitigate various coastal hazards.

Enhalus acoroides, also known as Tape Seagrass, have thick stems, large root systems, and long leaves that grow up to a length of 5 feet. *Enhalus acoroides* is currently growing in many areas of the CNMI, and therefore an increase in its surface area of growth will allow for protection against erosion. This is because a thick density of thriving *Enhalus acoroides* would have the ability to effectively dissipate wave energy, without the seagrass being damaged simultaneously. Figure 30 shows the placement of the *Enhalus acoroides* in respect to the entire beach profile. Established methods for E. acoroides transplantation have been developed and tested (Thangaradjou and Kannan 2008, Lanuru 2011).

Ipomoea pes-caprae and Scaevola taccada are both shrubs that are salt and wind tolerant, and can thrive in various types of soils, including sand. These beach shrubs are commonly found along shores in the CNMI. Ipomoea and Scaevola should be grown roughly 40 feet into the beach area, as shown in Figure 30. This will allow for the vegetation to grow densely in this area, maximizing erosion control. Intertidal trees that would be planted further landward on the profile include mangrove and Terminalia catappa. These trees would have time to establish themselves firmly into the back beach and would serve as a line of defense if and when the shoreline was to recede landward of its pre-project location. The wooded area at the landward extent of the profile could be planted with *Pandanus* and *Calophyllum* and would only be inundated during extreme storm surge conditions.

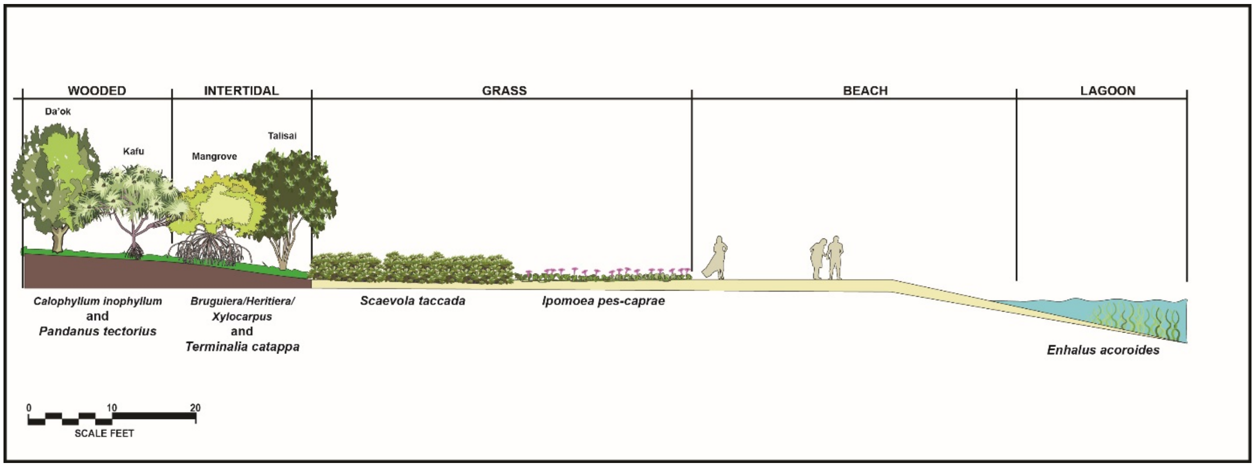

Figure 30. Beach profile with an extended beach area from nourishment showing possible vegetation types to grow in the wooded, inner tidal, grass, beach, and lagoon area.

It is important to note that there are often competing interests for development along shorelines and coastal areas worldwide, more so, in a small island like Saipan in which certain development projects and activities such as hotel construction are considered shoreline dependent activities. It is imperative to maintain and promote the shoreline ecosystem for benefits such as abundance of ecologically and economically important fish and invertebrates, water quality, and erosion control (Bilkovic et al. 2017).

The mangrove or *Calophyllum* are both vegetation types that grow well in coastal areas as they are both salt tolerant, and saline soil tolerant. Additionally, both are already found to be growing and thriving in the CNMI. Mangroves are well known for being highly effective in erosion prevention as mentioned above, and *Calophyllum* have also been proven to help erosion control because of their large root system that has the ability to bind sands and poor soils together. Planting the mangrove in the intertidal area, as shown in Figure 31, will increase erosion protection because the mangrove will collect the incoming sediment. The *Calophyllum* will also retain and compact the sediment. The mangroves and *Calophyllum* can be grown in a similar fashion to the mangroves being grown along the bay shoreline of AMP (Figure 31).

Pandanus and *Calophyllum* are large tree types that are both native to the CNMI. Both tree types are salt and wind tolerant, grow well in the coastal areas, and are known to be planted along shorelines for erosion control. *Pandanus* grows up to 30 feet, while the *Calophyllum* grows up to 82 feet.

Figure 31. Mangrove planting area located along the bay shoreline of American Memorial Park.

Beach Nourishment

Beach nourishment will require identification of a suitable sand source with beach compatible sediment as well as excavation, transport and placement of the sediment. Physical and environmental characteristics of the sand will have to be determined through field and laboratory investigations. Potential sand sources in the Saipan Lagoon region include sediment that has accreted on the subaerial beach profile south of Sugar Dock (Figure 32) and sediment located in an offshore sandbar adjacent to the western shoreline of AMP (Figure 33). From aerial imagery analysis, it is estimated that approximately 13,000 square yards of fast land has accreted down drift of Sugar Dock due to interruption of littoral transport caused by the structure. Assuming a nominal depth of 2 yards, there is an estimated volume of 26,000 cubic yards of sand available in this area. The sandbar offshore of the western shoreline of AMP has an approximate area of 140,000 square yards. Assuming a nominal depth of 1 yard, there is an estimated volume of 140,000 cubic yards of sand available in this area. These are just two examples of sand sources that may be suitable for beach nourishment projects. Other sources may be located offshore, inland or accessible by waterborne transport from other regions outside of the CNMI.

In order to harvest the sand from offshore areas such as the one at AMP, a dredge would need to be mobilized. The material would be dredged either by a clamshell or hydraulic dredge, brought onshore, and dewatered before it could be mechanically placed on the beach. If the depth of the in-situ material is expected to be shallow, dredging to claim the sand could be challenging. Dredging will have an environmental effect on water quality but should be minimal and may not cause any permanent adverse impact on the beach environment. During dredging operations, pelagic aquatic species including fish, crustaceans, mollusks, and other aquatic organisms will be temporarily displaced, but the organisms will reoccupy the area immediately after dredging activity. An inventory of the special aquatic sites such as sanctuaries and refuges, coral reefs, and vegetated shallows must be conducted and documented before the commencement of dredging operations, and must be avoided during dredging activities. Sedimentation from dredging operation may impact seagrass and oysters beds. The dredged material should be suitable for beneficial use such as beach nourishment, and for development of sand dune ecosystems. Bray et al. 1997 documents the potential adverse effects of dredging activities to include turbidity and suspended sediments, coastal erosion, stagnation, biochemical oxygen demand, and noise disturbance to organisms. However, potential beneficial effects of dredging include availability of materials for beach nourishment, coastal protection such as the construction of artificial dunes, increase in water quality due to removal of excessive nutrient input, and removal of aggregates.

Figure 32. Accretionary fillet that has formed to the south of Sugar Dock due to its interception of northerly directed littoral drift.

Figure 33. A sandbar has formed offshore of AMP's western shoreline that could be a potential sand source for beach nourishment.

Figure 34 was developed with a January 2017 beach profile acquired at the intersection of Beach Road and Quartermaster Road. Natural and man-made features that existed along the profile included Beach Road, a tree lined upland wooded area, a 10-foot wide boardwalk, a reach of salt tolerant grass, an intertidal beach face and the nearshore portion of the lagoon. At this location, the shoreline was approximately 60 feet from Beach Road. This is well within the 150-foot jurisdictional purview of the BECQ, yet not wide enough to establish a LSL buffer against impacts of waves and currents. In this location, beach nourishment would provide additional area to establish LSL measures as illustrated in Figure 35. The figure shows the result of beach nourishment extending the shoreline seaward by 70 feet. It would require approximately 0.4 cubic yards of sand to extend 1 foot of shoreline 1 foot seaward. Based on this conversion factor, it would take 28,000 cubic yards of sand to extend the shoreline 70 feet seaward over a distance of 1,000 feet. A plan view of the footprint for such a beach nourishment project is shown in Figure 36.

Others areas that would potentially benefit from beach nourishment include the western shoreline of AMP or the shoreline north of Sugar Dock. A number of AMP facilities have been lost to erosion along this shoreline in recent years. Although there has been an influx of sand into this area since these facilities were damaged, there is no guarantee that the shoreline will be stable in the future. The potential that a suitable sand source is located in the sandbar just offshore of the area makes this alternative promising on an economic basis. At Sugar Dock, the updrift (south) shoreline has advanced seaward due to the dock's interception of littoral sediment transport, but the downdrift (north) shoreline has receded. Beach nourishment in the form of bypassing could offset a portion of the sand that has historically been captured along the shoreline south of Sugar Dock by moving it around the impediment and placing it on the north shoreline.

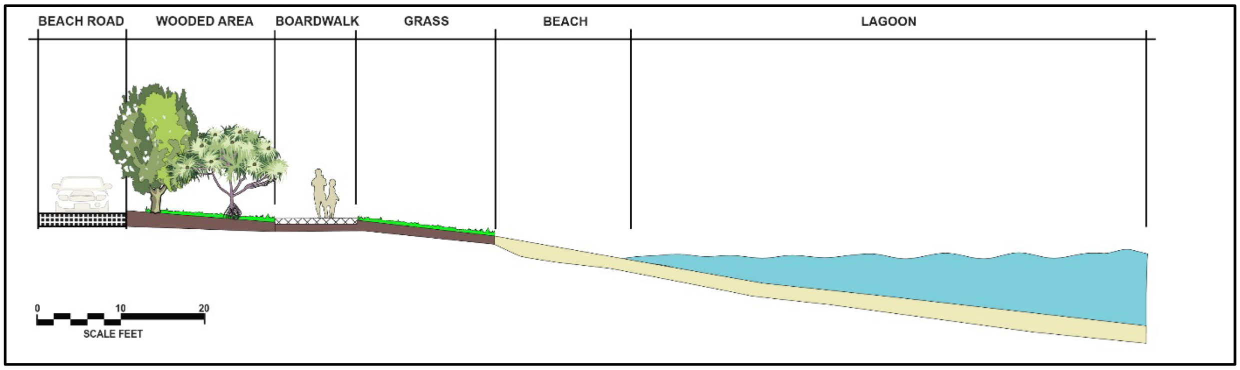

Figure 34. Typical beach profile found along the Saipan Lagoon shoreline. Features identified on the profile include Beach Road, wooded area with various hardwood trees, boardwalk, salt tolerance grasses, narrow beach face and the nearshore lagoon environment.

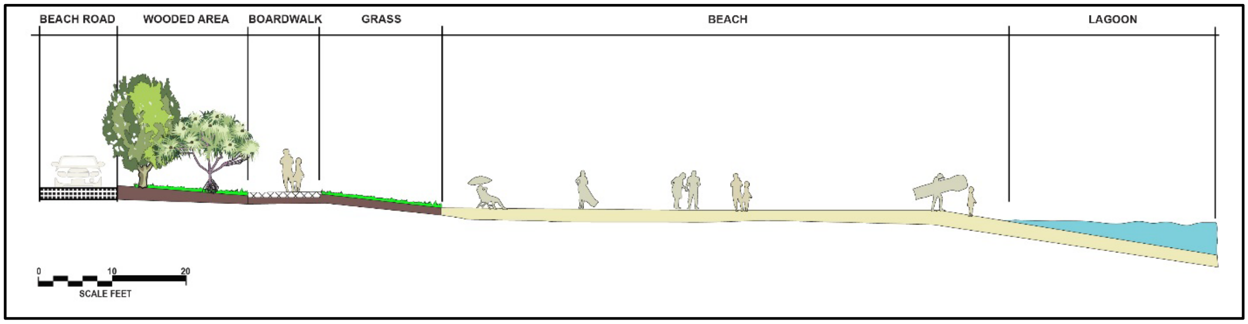

Figure 35. Example of profile adjustment resulting in nourishment of the beach. The beach berm in this case has been widened by approximately 70 feet.

Figure 36. Beach nourishment project footprint with a length of 1,000 feet and a 70-foot seaward extension of the shoreline that could be accomplished with approximately 28,000 cubic yards of beach quality sand.

Beach Nourishment with T-head Groins

Small scale beach renourishment projects such as that presented above are susceptible to longshore and cross shore currents as well as high rates of sand lost at their endpoints. Sand retention structures such as breakwaters and groins are often designed to limit the transport of sand out of beach nourishment project areas. One example of sand retention structures designed in conjunction with beach nourishment is the T-head groin field shown in Figure 37. In this example, six T-head groins are incorporated into a beach nourishment project which established five sheltered embayments that are resistant to sand loss. The spacing between the groins shown is 170 feet, stems are 100-feet long while the heads are 60-feet wide (Figure 38).

The heads of the groins would be tuned to the local wave climate to modify the alignment of wave crests with each embayment shoreline. Properly designed, T-head groins result in waves that break simultaneously along the shoreline which results in minimal longshore sediment transport. Long-term beach nourishment project costs are reduced by inclusion of T-head groins through decreased renourishment requirements. It should be noted that T-head groins and other such shore normal coastal structures would interfere with many of the established recreational uses along the SLS (e.g., surfing, wind surfing, kite surfing, paddle boarding, swimming, fishing, etc.).

Figure 37. Beach fill project stabilized by a T-head groin field.

Figure 38. Approximate dimensions of the T-head groins shown in Figure 37 (spacing 170 feet, stem length 100 feet and head width 60 feet).

Breakwater

Breakwaters dissipate wave energy along their seaward slope and crest while providing calmer water in their lee. They can be designed with various crest elevations based on the desired level of wave and current reduction desired. Figure 39 is an example of a rock sill breakwater with a crest elevation coincident with the mean high water tide level. The rock sill is founded on bedding stone which is wrapped with geotextile fabric to minimize migration of sand through the structure. A rock sill could be constructed to provide protection to existing vegetation along the SLS or in combination with LSL plantings.

Beach nourishment can be augmented by inclusion of a rock sill as displayed in Figure 40. The combination of beach nourishment and a rock sill results in a perched beach which takes less volume of sand to extend the shoreline seaward than if only sand is utilized. This conceptual plan would require about one half the volume of sand needed for beach nourishment only at Beach Road and Quartermaster Road (14,000 cubic yards versus 28,000 cubic yards). Disadvantages of this plan include the fact that if sand is transported seaward over the rock sill it will be lost to deeper areas within the lagoon.

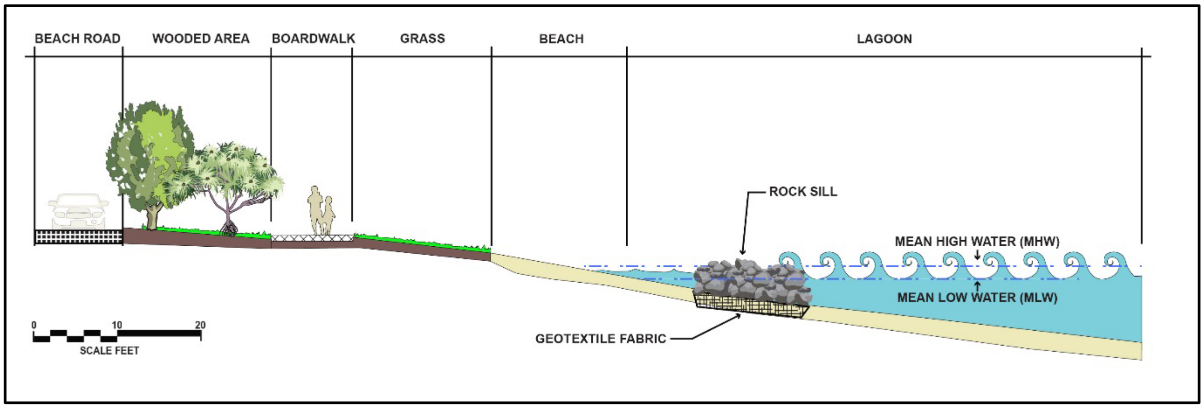

Figure 39. Beach profile showing the addition of a rock sill with a crest elevation at mean high water. Bedding stone and geotextile fabric reduce the potential for the rock still to scour into the existing lagoon bottom.

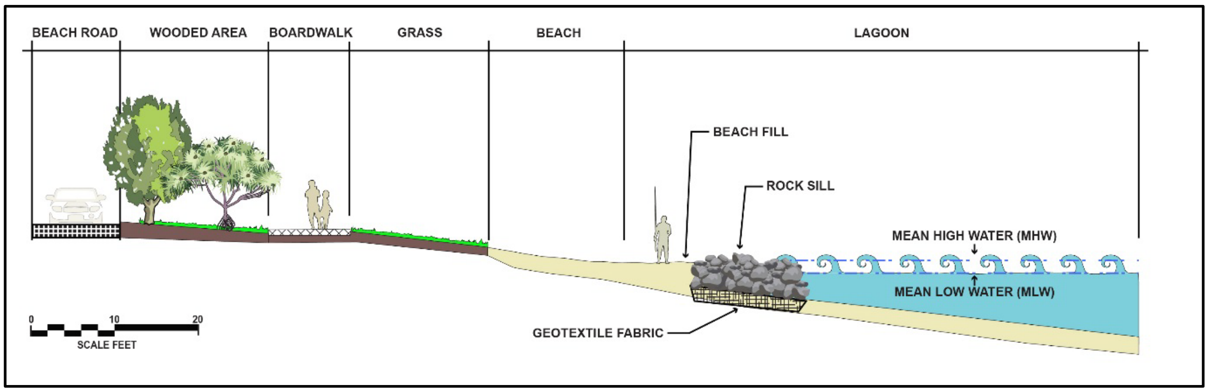

Figure 40. Beach nourishment is shown in conjunction with a rock sill to create a perched beach.

A breakwater can also be constructed with Reef Balls as the main structural unit. Reef Balls are made by pouring concrete into a fiberglass mold containing a central buoy surrounded by various sized inflatable balls to make holes. There are over a dozen different standard mold sizes and custom sizes are possible. Molds obtained from the Reef Ball Foundation are generally supplied with spare parts, tool kits, starting concrete additive supplies, and training. Sometimes, additional items such as coral propagation kits are provided. Additives such as micro-silica and a high range water reducer are needed to give the Reef Balls high strength and to make the concrete conducive to marine life growth.

Reef Balls have been used as submerged breakwaters to protect beaches from erosion or even to build up eroding beaches. They have also been used in a variety of other erosion control applications such as “mangrove pots" for shoreline stabilization. Shorelines have been stabilized using Reef Balls as nearshore breakwaters or to grow oysters to create protective nearshore oyster bars. Figure 41 shows a beach profile with Reef Balls located in the nearshore. One or more rows of these units can be used to build an offshore breakwater. The number of rows or crest width required are similar to traditional breakwaters (usually 3-7 rows of Reef Balls) and is determined by the local wave climate, tide range and desired amount of wave attenuation. The stability of each unit must be ensured since there is no unit-to-unit friction or interlocking forces generated. They can however enhance coral recruitment and be used for coral restoration projects. Specialized methods have been developed for asexually reproducing both hard and soft corals and planting them onto Reef Balls. Rates of coral fragment survival can be as high as 80% but are highly variable, species-specific and dependent on conditions prior to fragmentation (Piyawat et al 2013). Asexual reproduction ensures that coral genetics are preserved on an individual colony basis; to ensure preservation of genetic diversity, a strategic design that incorporates multiple colonies of different representative genotypes is needed. Most hard corals and soft corals with woody stems can be propagated by these methods.

Studies of patch reefs within the project study area indicate low diversity near the northern extent of the project area (Fishing Base Staghorn and Quartermaster Staghorn sites), low recruitment found throughout the project area, as well as low herbivore biomass (Maynard et al 2012). Addition of Reef Balls, or any other reef augmentation should consider these limitations and be strategically placed to optimize potential diversity and recruitment. Augmentation with reef structures should include addition of herbivores to promote grazing and enhance coral success. Addition of reef balls would provide habitat for other invertebrates and fish, adding value to local recreational activities (e.g., snorkeling, and diving).

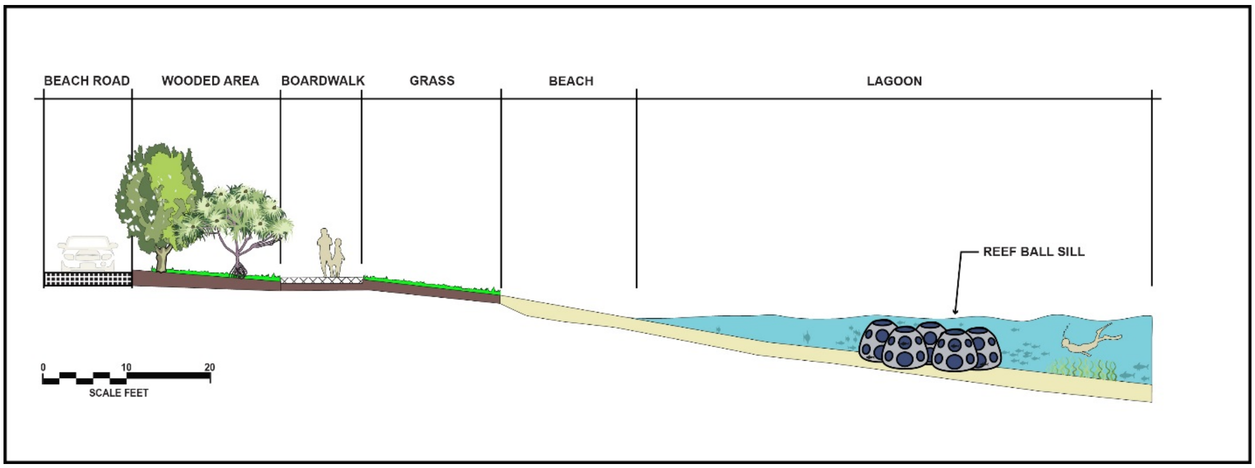

Figure 41. Beach profile showing the addition of a Reef Ball sill with a crest elevation at mean high water. Reef Balls are stable under most conditions because wave energy is dissipated through the holes in their shell and much or their weight is at the base of the unit.

Revetment, Seawall and Bulkhead

If a seawall was to be constructed along the SLS, extensive geotechnical investigations would need to be conducted. In situ soil characteristics would be quantified through core boring analysis and laboratory testing. Geophysical investigations would also provide a continuous approximation of the subsurface soil properties. Rock revetment design would not require the same level of geotechnical study, but construction costs would be reduced if a competent layer of hard substrate were identified for embedment of the revetment toe stone.

The following presents a worst case scenario in which the SLS has eroded to the Beach Road shoulder (Figure 42). In this situation, a seawall may be an acceptable alternative for preventing undermining of the road and traffic disruptions along this high use roadway. Given the use of steel sheet pile in the seawall design, the piles would be sized to account for corrosion in a saline environment with additional protection provided in the structure's intertidal zone. A concrete cap would serve to protect the piles from corrosion in this zone. The top elevation of the piles would likely be coincident with the elevation of the road to accommodate room for a guardrail as required by Federal Highways Administration safety standards. The pile's depth of penetration would be to refusal into hard substrate or to a depth that ensures stability under expected active and passive forces.

Rock or concrete armor units could be utilized in the construction of a revetment along the SLS to protect Beach Road from wave and current attack (Figure 43.). The armor layer of a rock revetment could be of single- or double-layer construction with subsequent layers of smaller rock and geotextile fabric sized to minimize movement of material through the various layers of the structure. Concrete armor units are placed in a single layer but also require appropriate sized underlayer to remain stable over time. If suitable size rock is available, it would be a less expensive alternative than fabricating forms and producing concrete armor units for the revetment.

Toe scour is a common failure mechanism for poorly designed or constructed revetments. To optimize toe stability, placing the toe stone (or first concrete armor unit) in a trench carved into hard substrate is preferred. If hard substrate doesn't exist at the site, a sacrificial toe can be incorporated into the design of a rock revetments. In the same circumstance, the slope of a concrete armor unit revetment must be extended down below the maximum anticipated scour depth.

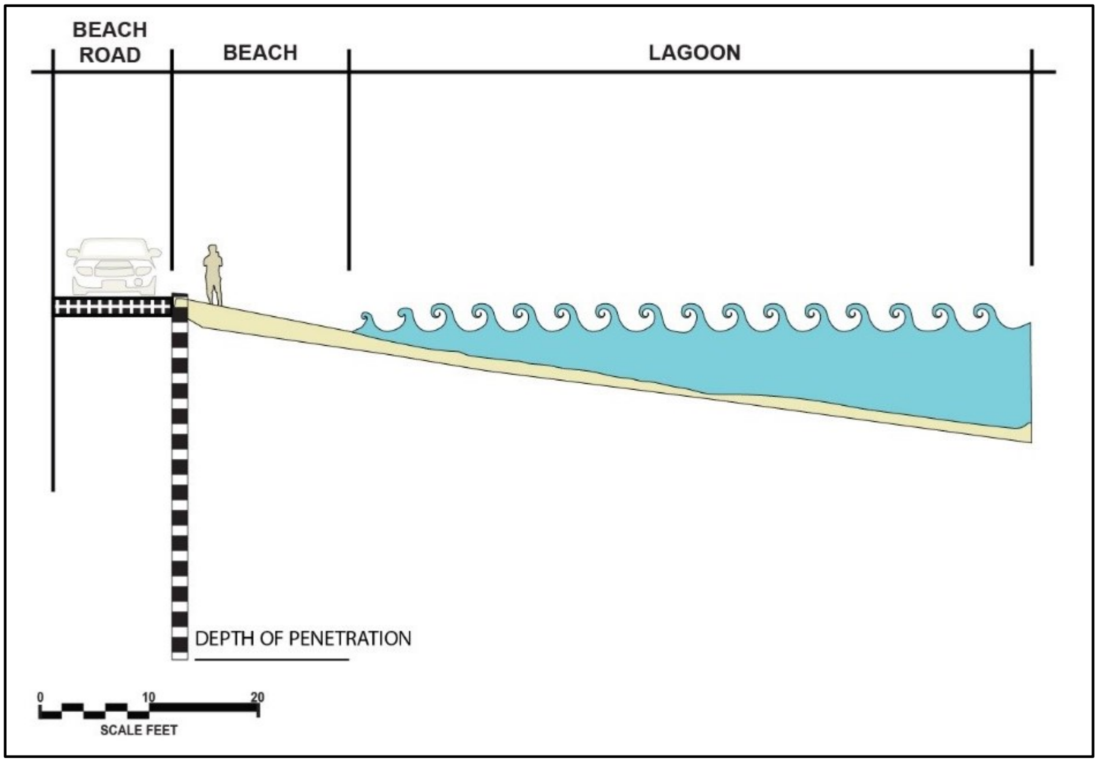

Figure 42. Steel sheet pile seawall designed to prevent undermining of Beach Road.

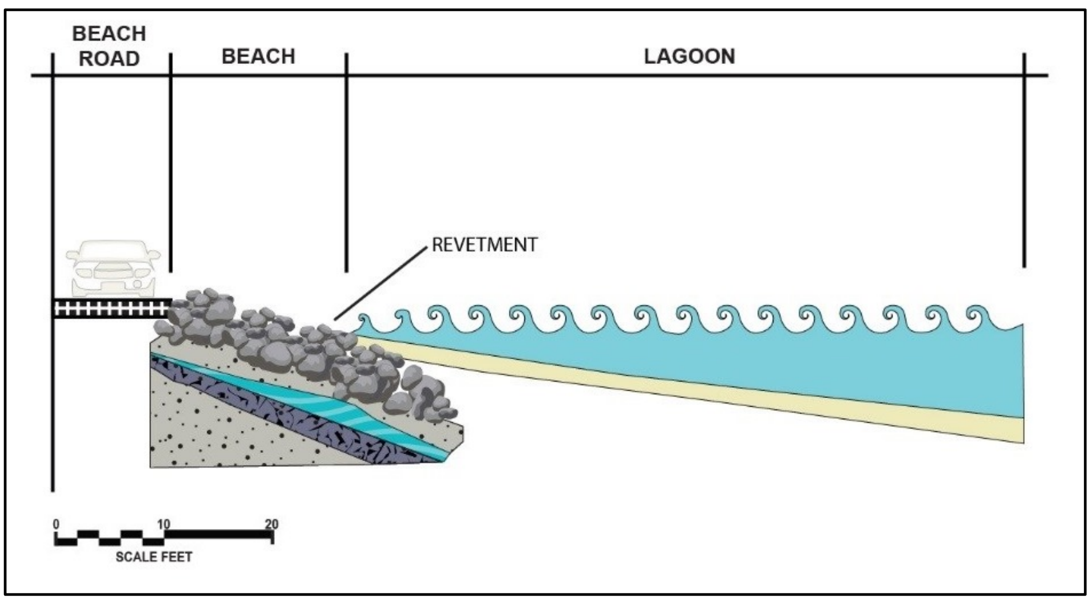

Figure 43. Rock revetment designed to prevent undermining of Beach Road.

COST ESTIMATES AND CONCLUSIONS

Figure 44 displays the locations of proposed shore protection conceptual plans for the Saipan Lagoon Shoreline. From north to south they include beach nourishment with vegetation at American Memorial Park, vegetation only at Makaka Beach, beach nourishment with vegetation at Fishing Base, beach nourishment with T-head groins at Quartermaster Road, and beach nourishment at Sugar Dock. As indicated in Table 2, each of the conceptual plans have a length of 1,000 feet and an assumed project life of 50 years.

The beach nourishment conceptual design is based on a 70-foot extension of the mean high water shoreline, a volume conversion factor requiring 0.4 cubic yards of sand for each foot of shoreline extension along each foot of shoreline. In-place cost per cubic yard of sand is estimated at $150 with operations and maintenance (O&M) costs of 10% of the initial construction each year. O&M would be reduced to 3% per year in combination with T-head Groins.

The T-head Groin conceptual design is based on the need for 6 groins. Each groin element would have the following lengths; root = 40 feet, stem = 100 feet and head = 60 feet, for a total length of 200 feet. In-place cost per foot is estimated at $2,500 with O&M costs of 10% of the initial construction each year.

Vegetation Only conceptual design considers an in-place cost per foot of $1,000 with O&M costs of 20% of the initial construction each year (USACE & NOAA 2015). O&M cost for Vegetation in combination with Beach Nourishment would be reduced to 5% per year (in addition to the 10% O&M costs for the Beach Nourishment).

During the planning and design phases of a shore protection project, is it important to consider both initial construction and life cycle project costs. As shown in Table 2, the Vegetation Only conceptual plan for Makaka Beach has the lowest initial construction cost of $1.0M. Due to the intensity of the wave climate expected at Saipan Lagoon, it is estimated that the vegetation will have to be replaced after major storm events. On average, this is expected to be required every 5 years (resulting in the O&M rate of 20% per year) (USACE & NOAA 2015). This results in a total project cost of $10.0M.

The total project cost of the Beach Nourishment conceptual plan for Sugar Dock is estimated at $21.0M (twice that of the vegetation only plan). The total project cost for Beach Nourishment with T-head Groins conceptual plan at Quartermaster Road is also around $21.0M. The initial construction costs for the Beach Nourishment conceptual plans however is significantly lower than that for Beach Nourishment with T-head Groins at $4.2M and $7.2M, respectively.

The estimated cost for initial construction of the Beach Nourishment with Vegetation conceptual plan at the American Memorial Park and Fishing Base is $5.2M. Total project cost of this conceptual plan is greater than the others at $23.5M. This considers reduction of O&M costs from 20% for Vegetation Only to 5% for Beach Nourishment with Vegetation.

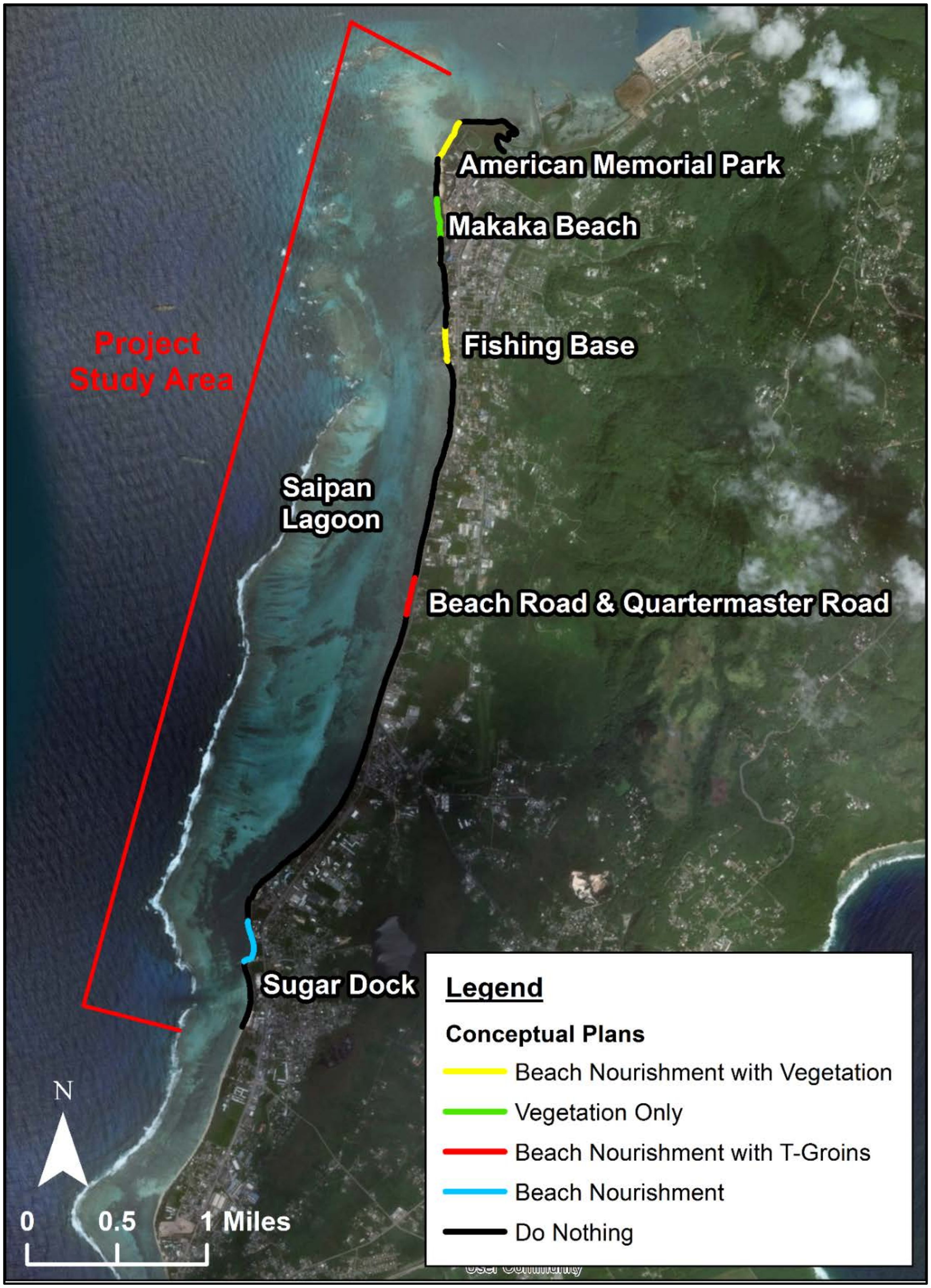

Figure 44. Reaches of shoreline and shore protection conceptual plans recommended for additional study along the Saipan Lagoon Shoreline.

Table 2. Assumptions and cost estimates for various shore protection conceptual plans within the study area.

Project Length		1,000	[feet]		
Project Duration		50	[years]		
BEACH NOURISHMENT (BN)					
Nourishment Width		70	[feet]		
Volume Coefficient		0.4	[cubic yards/square foot]		
Unit Cost		$150	[$/cubic yard]		
Construction Cost		$4,200,000	[$]		
O&M		10%	[%]		
Project Cost		$21,000,000	[$/50years]		
with T-head Groins					
O&M		3%	[%]		
Project Cost		$6,300,000	[$/50years]		
T-HEAD GROINS (TG)		6	[quantity]		
Root		40	[feet]		
Stem		100	[feet]		
Head		60	[feet]		
TOTAL		200	[feet]		
Unit Cost		$2,500	[$/foot]		
Construction Cost		$3,000,000	[$]		
O&M		10%	[%]		
Project Cost		$15,000,000	[$/50years]		
VEGETATION ONLY (VO)					
Unit Cost		$1,000	[$/foot]		
Construction Cost		$1,000,000	[$]		
O&M		20%	[%]		
Project Cost		$10,000,000	[$/50years]		
with Beach Nourishment					
O&M		5%	[%]		
Project Cost		$2,500,000	[$/50years]		
PLAN	1	2	3	4	5
LOCATIONS	AMP	Makaka Beach	Fishing Base	Quartermaster Road	Sugar Dock
TYPE	BN&V	VO	BN&V	BN&TG	BN
DESCRIPTION	Western shoreline of AMP. Offshore sand source.	Enhance the existing naturally vegetated area.	Eroded shoreline not adjacent to Beach Road.	Eroded shoreline adjacent to Beach Road.	Bypass sand from updrift fillet.
CONSTRUCTION	$5,200,000	$1,000,000	$5,200,000	$7,200,000	$4,200,000
TOTAL [50years]	$23,500,000	$10,000,000	$23,500,000	$21,300,000	$21,000,000

Based on input from BECQ and the National Parks Service (NPS), these conceptual plans were further refined to propose realistic projects that may be implemented. The NPS favors the vegetation option, which is similar to projects they have already implemented. Thus, the beach nourishment component has been removed from the

AMP plan. Estimates of realistic project length, construction cost and project cost for the proposed conceptual plans are 1) vegetation only at American Memorial Park (1,000 feet, $1.0M, $10M); 2) vegetation only at Makaka Beach (1,000 feet, $1.0M, $10M); 3) beach nourishment with vegetation at Fishing Base (0.5 mile, $13.7M, $62M); 4) beach nourishment with T-head groins at Quartermaster Road (0.5 mile, $16.5M, $44M); and 5) beach nourishment at Sugar Dock (0.36 mile, $7.9M, $40M).

Utilizing local labor would result in substantial reduction in cost for the vegetation only conceptual plan. An adaptive management plan must be implemented in all living shoreline projects involving vegetation as a component. Vegetation may need to be monitored and replanted following a major storm event or any natural perturbation. Monitoring the change in ecosystems following establishment or restoration over time is a key component in adaptive management (Herman 2017).

To reduce cost, it will be important to collaborate with existing CNMI resource agencies to obtain vegetation from local sources. In addition, mobilizing local volunteers, involving students and paying stipends, seeking out conservation groups to engage in planting activities would be a viable option and would significantly reduce cost. BECQ could facilitate the engagement, involvement, and participation of these entities to conduct successful planting activities. It is possible to encounter challenges with obtaining seed, seedling, sprigs, rhizomes etc. for propagation, however, there are certain options that can be taken to mitigate such challenges. These include:

a. Conducting a vegetative survey to identify subject species and determine the relative abundance of focal species in the vicinity of the proposed planting site.

b. Identifying harvest sites in the vicinity. A look at site aerial imagery and photos show that there are limited sites on the west Saipan side for harvesting, therefore, that may not be a suitable candidate for harvest. East Saipan, however, is dense in vegetation so there be ample opportunities for harvest.

c. Conducting a transplant activity from harvested plants.

d. Developing and implementing an adaptive plan for plant establishment (as applicable).

e. Monitoring for species establishment, plant-mediated accretion of sediments, erosion, etc. This is a critical part of living shoreline project as data need to be obtained and documented.

There are several advantages to harvesting, such as, it is not cost intensive, species are more accessible, local harvesting and transplanting prevents genetic intermix and preserves local genetic diversity. The disadvantages include labor intensiveness, and thriving communities are susceptible to damage if proper harvesting techniques are not implemented, but a proper harvesting plan should be implemented to prevent that issue.

The areas to be planted adjacent to and neighboring the beach front should be zoned into dune, limestone forest, and strand from the beachfront moving inland depending on the soil properties. Further inland a different set of zoning will be applied based on soil-plant properties. For areas using vegetation, there is an array of plant species suggested for propagation based on site specific soil characteristics. Mueller-Dombois and Fosberg (1998) documented the different ecosystems in Saipan based on soil characteristics to include strand vegetation, vegetation on volcanic soils, vegetation on coastal plains, vegetation on limestone forest, mixed species limestone forest, and sand dune vegetation.

Species recommended for strand vegetation include *Tournefortia argenta*, *Pemphis accada*, *Barringtonia asiatica*, *Cordia subcordata*, *Scaevola taccada,* and *Casuarina litora*. Typical vines on the strand include *Ipomea pes-caprae*, *Vigna marina*, and *Cassytha filiformes.* Limestone forest plants include *Pandanus dubious*, *Hernandai sonora*, and *Guettarda speciose*. A conceptual plan indicating the zoning scheme is shown in Figure 45. An additional list of potentially suitable plant species are listed below. The list must be refined based on site specific conditions, local availability of plant materials, and resource criteria to be addressed by the project. Mueller-Dombois and Fosberg (1998) documents an overlap between the sand dune and limestone forest ecosystems in Saipan. Therefore, it is important to engage in strategic species selection when planting at the proposed project site. The proposed plant species list is arranged by genus, species, and Chamorro name, as applicable.

TREES
Casuarina equisetifolia -gagao
Calophyllum inophyllum -da'ok
Thespesia populnea -binaloa
Barringtonia asiatica -putin
Hernandia peltata -nonak
Cocos nucifera -niyok
Pandanus tectorius -kafu
Mammea odorata -chopak
Heriteria littoralis -hufa
Intsia bijuga -ifit
Tournefortia argentea -hunik
Cordia subcordata -niyoron
Premna obtusifolia -aghao
Terminalia catappa -talisai

SMALL TO MEDIUM SIZED TREES
Guamia mariannae - Paipai
Macaranga thompsonii - Pengua
Maytenus thompsonii - Luluhot
Ochrosia mariannensis - Langiti
Melanolepis multiglandulosa – Alom

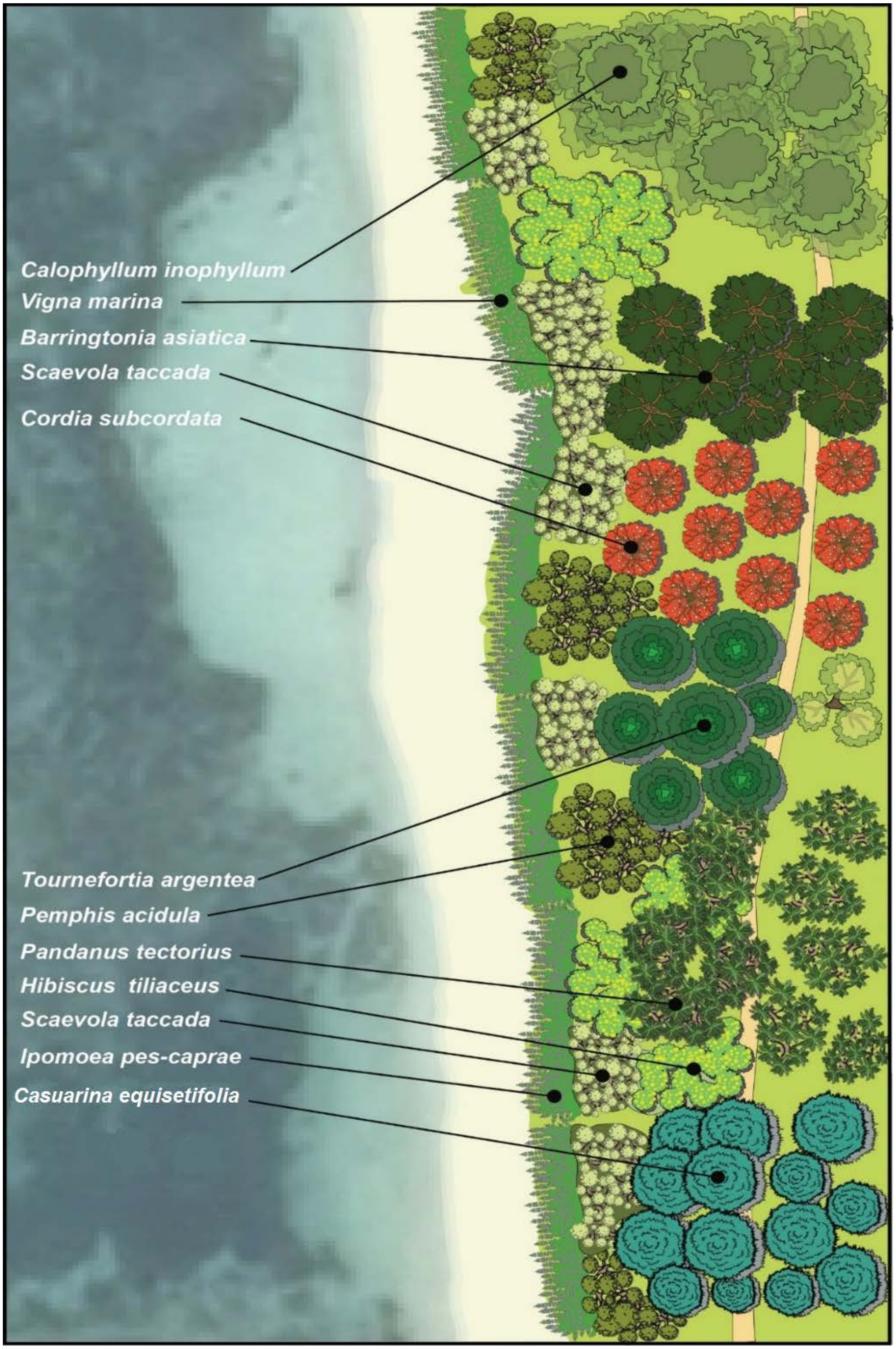

Figure 45. Conceptual plan with vegetation component. This would be applicable in vegetation only and beach nourishment with vegetation scenarios.

SHRUBS
Hibiscus tiliaceus Sophora
Scaevola taccada
Schleinitzia fosbergii
Messerschmidia argentea
Morinda citrifolia
Cerbera dilatata
Pemphis acidula
Callicarpa candicans
Bikkia mariannensis
Tabernaemontana rotensis
Phyllanthus marianus - Gaogao Uchan
Psilotum nudum - Lorem ipsum

HERBS/FORBS/VINES
Ipomoea pes caprae
Lepturus repens
Paspalum distichum
Canavalia maritima
Vigna marina
Hedyotis albido-punctata
Sporobolus virginicus
Paspalum distichum
Mucuna gigantean
Canavalia megalantha
Cyperus sp.

FERNS:
Asplenium nidus - Bird's Nest Fern
Davallia solida - Pugua' Machena

As a regulatory consideration, and to be in compliance with local state and federal laws, any vegetation establishment, ecosystem development, and/or restoration activity must seek approval from regulatory and resource agencies such as, BECQ, United States Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), USACE, and entities such as the NPS to ensure the preservation of the unique ecosystems in the CNMI. The CNMI contains strand forests, which have unique settings and are sensitive in cultural and historical settings. Therefore, any ground disturbance involving investigation or planting, will need to be conducted in collaboration with the local Historic Preservation Office, and in accordance with the National Historic Places Preservation Act. Due to the location of this activity, projects in coastal settings in the CNMI may require concurrence from the local Coastal Zone Management office in accordance with the Coastal Zone Management Act. In addition, the project would require an Environmental Assessment, and/or Environmental Impact Statement to comply with the National Environmental

Policy Act. There are a number of strand habitat nesting species (i.e. shearwater and sea-turtle). Due to the location of the proposed study site, it may be necessary to engage in consultation with the USFWS to ensure that there is no impact on threatened and endangered species. Lastly, coordination with the NMFS may be required to determine that the proposed project will not have an adverse effect on Essential Fish Habitat.

Saipan's fringing and barrier coral reefs are part of a larger living shoreline complex that offer a significant economic importance. Apart from food, shelter, and cultural importance, the reef is a source of income from tourists and recreationists (Van Beukering et al. 2006). The conceptual plans were formulated on the same project length and duration to facilitate comparison of costs. The conceptual plans vary in their ability to withstand sea level rise. Structures are more resilient, while vegetation will be submerged and may have to be replanted frequently. A beach nourishment is dynamic and with continued renourishment will adjust to future sea level changes. Saipan Lagoon Shoreline stakeholders will need to identify the shore protection plans that provide the best balance of green to gray for various locations within the study area.

Answers to the LSL questions introduced at the beginning of this report are provided below.

a. What are the physical characteristics of the site?
    i. Sandy beaches with shoreline vegetation (beach morning glory / upland ironwood trees / some mangroves at American Memorial Park)
    ii. Mixed sandy / rocky beaches with shoreline vegetation
    iii. Sandy beaches with removed / impacted vegetation (natural or unnatural removal)
    iv. Estuarine system / drainage outfall

b. Are ecologically valuable aquatic habitats or animals living along the shoreline?
    i. Sea grass habitat is used by listed sea turtle species.
    ii. Corals present in some areas. There are also threatened corals in Saipan Lagoon.
    iii. Some mangrove estuarine systems exist in AMP/Tanapag area.

c. How should effects of sea level rise be considered?

    By 2070, sea level rise in the study area is predicted to be on the order of 0.7 ft (tide station trend) to 2.9 ft (high rate); and by 2120, it may be 1.1 ft to 7.2 ft higher than the present. In addition, due to the El Nino Southern Oscillation phenomenon, larger water level fluctuations may be observed on shorter timescales when compared to overall sea level rise trends. Given this amount of variability and a high rate of future sea level change scenario, it is recommended that LSL projects for the SLS be design with adaptive management strategies in mind.

d. What balance between green (soft) and gray (hard) stabilization measures is appropriate?

   Similar to the previous question's answer, adaptive management will be the key to the balance between green and gray shoreline stabilization measures. Initial utilization of green only measures will require continual monitoring of project performance. If such measures are found to be unsustainable, introduction of grey measures could be considered to improve project performance.

e. How can functional habitats be incorporated into gray measures?

   Project features such as Reef Balls can be incorporated to provide wave attenuation as well as benthic habitat. Rocks structures contain a large percentage of void space which can serve as habitat for crabs, limpets and other shoreline organisms.

f. What level of maintenance is associated with each LSL alternative?

   Levels Operation and Maintenance (O&M) vary for each conceptual plan developed for the study. Annual O&M costs were based on a percentage of the construction cost as shown below.

   i. Beach Nourishment and Vegetation – 5%
   ii. Vegetation Only – 20%
   iii. Beach Nourishment w/T-Groins – 3%
   iv. Beach Nourishment – 10%

g. What state, territory and federal authorities must be considered when developing LSL alternative?

   As a regulatory consideration, and to be in compliance with local state and federal laws, any vegetation establishment, ecosystem development, and/or restoration activity must seek approval from regulatory and resource agencies such as, USACE, BECQ, USFWS, NMFS, and entities such as the NPS in the case of project proposed for American Memorial Park. This is to ensure the preservation of unique ecosystems in the CNMI.

h. How should LSL project planning consider public access and other social contexts (including both green and gray measures)?

   The public has the right of access to and along the shorelines of the CNMI. LSL projects should accommodate the public's ability of getting to the shoreline in the form of access points, boardwalks and dune walkovers. Properly designed project access will not only provide for the public, but they will ensure that LSL features are not compromised by heavy foot traffic. For greatest public utilization and enjoyment of future LSL projects, sufficient parking should be provided based on existing conditions and future projections of shoreline visitation. Other social effects that need to be accommodated by LSL designs include recreation and anticipated cultural activities in and along Saipan Lagoon.

i. When do the various environmental resource agencies review, consult on, or permit for LSL projects?

Table 3. Permitting timeline for living shoreline projects.

PERMIT	REGULATING AGENCY	REGULATED ACTIVITY	AGENCY REVIEW TIME
Section 401 WQC	BECQ	Discharge into CNMI waters, including any activities located below the high tide line	30 days
Section 402 NPDES	EPA – Region 9	Any land disturbance greater than 1 acre	30 days
CZM Federal Consistency Review	CNMI Division of Coastal Resources Management (DCRM)	Construction activities in and adjacent to the shorelines of the CNMI	60 days
DA Permit	USACE	Cut or fill below the mean high water shoreline in tidal influenced waters	120 days

j. What types of support are available for planning, design and construction of LSL projects?

Existing CNMI government agencies and volunteer groups could provide maintenance for green projects, but would not be able to provide the same for gray projects. OIA as well as other federal and local agencies could potentially support planning, design and construction of LSL projects along the Saipan Lagoon shoreline. Upon request, the Honolulu District would consider conducting an additional site visit along with the team from the Engineer Research and Development Center (ERDC) that assisted in the preparation of this report. This would afford the ERDC team an opportunity to conduct a living shoreline workshop for BECQ and a reconnaissance survey of the study area to gain a better perspective of the ecosystem. The report input provided by the ERDC team is based on literature review, aerial photos, photos, and remote knowledge of the ecosystem and its ecological processes. The ERDC team would be able to provide additional guidance on the planning and creation of living shorelines with enhanced ground knowledge of the study area.

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