

MEMORANDUM – COASTAL ENGINEERING REVIEW

VIRGIN ISLANDS NATIONAL PARK – EROSION STUDY AT CINNAMON BAY

TAR 20205

1 December 2022

INTRODUCTION

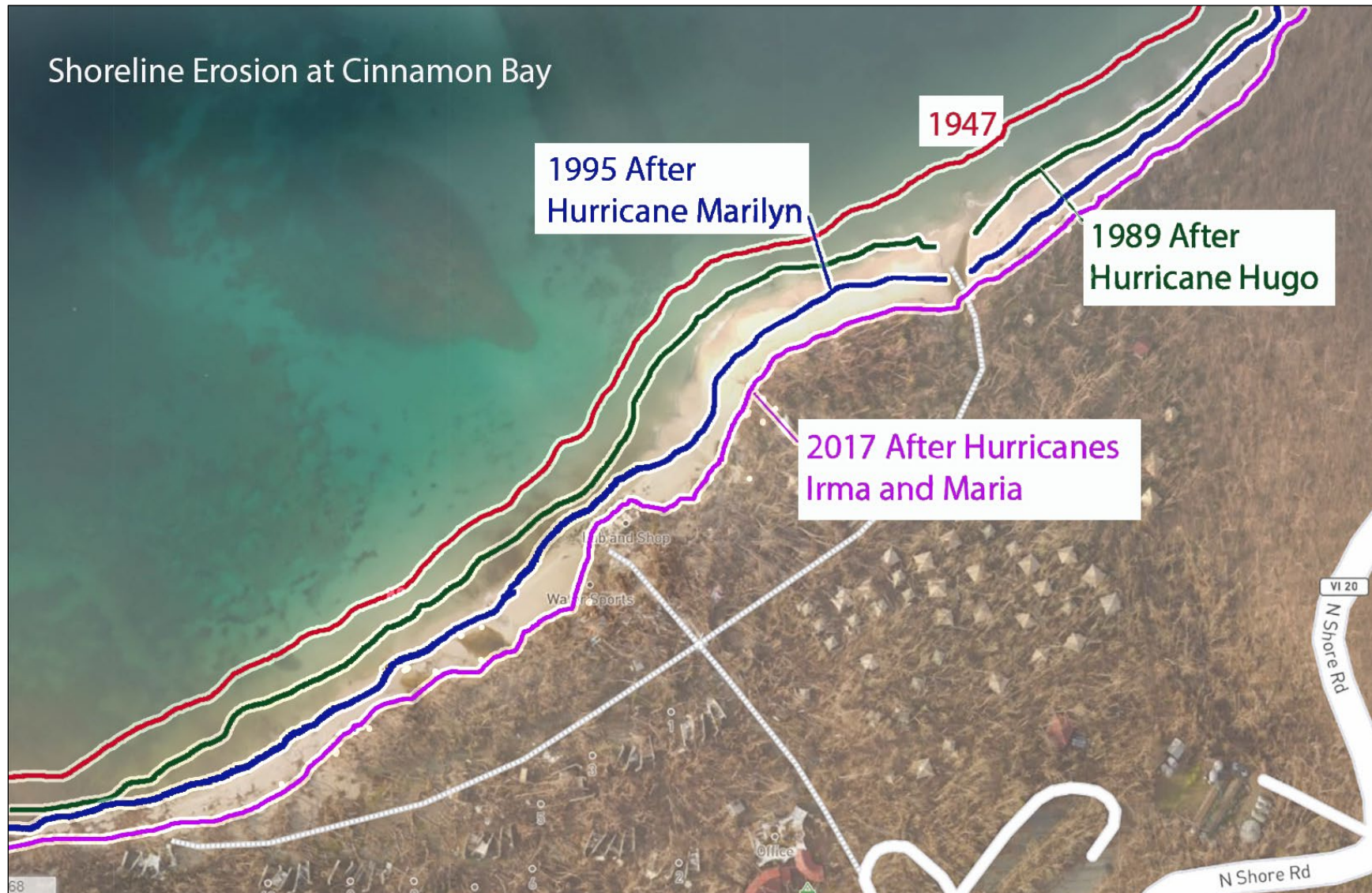
A shoreline erosion mitigation project for Virgin Islands National Park (VIIS) on St John, US Virgin Islands (USVI) is needed to preserve two significant Virgin Islands cultural heritage sites at Cinnamon Bay that are of both national and regional significance. One site consists of the only physical evidence of pre-Danish occupation of the islands by pirates in the 1600s followed by the only evidence of the 1733 slave rebellion. The second site is an important Taino ceremonial site where for 500 years, offerings were made and preserved exactly as they were deposited, making it possible to define the social, political, and religious development of the people that inhabited the area prior to the arrival of Columbus to the western hemisphere.

The hurricanes of 2017 exacerbated ongoing erosion at these sites to where they have limited protection from continuous wave action and storm surge. Large expanses of shoreline have been lost over the past several years (figure 1) and it is anticipated these cultural resources will be lost without some type of shoreline protection.

TECHNICAL ASSISTANCE REQUEST (TAR)

The park has requested a coastal engineer to study the shoreline erosion at Cinnamon Bay along a 100-meter segment where these resources are located. The goal would be to develop recommendations to limit or stop the erosion to preserve these significant heritage sites.

Figure 1. Shoreline erosion at Cinnamon Bay (NPS 2022)



HISTORIC REVIEW

The two cultural heritage sites of interest discussed in the TAR are located along the eastern stretch of Cinnamon Bay Beach, approximately southeast of Cinnamon Cay, the offshore outcrop within Cinnamon Bay. They are depicted in figure 2, a 1780 map (adapted from Wild 2001). Sedimentation patterns along this beach have shown a distinct change between 1972 and 1998, as described in pertinent field visits below.

Historically, the western section of Cinnamon Bay beach was erosive, but the eastern section housing the cultural heritage sites was considered stable, according to a 1972 report prepared by Dr. Dolan, as shown in his field-drawn map in figure 3 (Dolan 1972). This report describes the western section of beach “narrowing rapidly to widths of 25’ and less...with no backshore, so storm waves cut directly into relic dune, beach, and salt pond deposits” (Dolan 1972). Additionally, there was a progressive reduction in grain size noted from east (0.57 millimeter [mm], stable) to west (0.29 mm, erosive). This was attributed to the fact that as the beach receded along the western segment, it cut into relic dune deposits, which are finer in grain size than beach-face material (Dolan 1972). These morphological patterns along the beach can be explained by the offshore hydrology also summarized in the report: (1) water depths offshore from the western section of beach were significantly deeper than the stable section and (2) a live reef was offshore from the eastern section of beach while only dead reef was offshore from the western section. These two conditions allow greater wave energy to propagate further onshore along the western section as compared to the eastern section of beach. The report summarized sediment transport/beach morphology in Cinnamon Bay as a delicate biophysical balance between wave action, the vigor/location of reef growth, sea level changes, and sediment transfer.

A 1998 archeology report from Wild’s site visit to the cultural heritage sites in 1997 describes erosion of 3 to 4 feet in the formerly stable section of beach (Wild 1998). This change is attributed to the loss of a buffer zone that existed at the warehouse prior to this visit (Wild 1998). While not specifically stated, this buffer zone was likely removed during the hurricane activity that occurred between the 1972 and 1998 reports — Hurricane Hugo passed Puerto Rico in 1989 at Category 3 (winds 120 miles per hour) and Hurricane Marilyn passed over St. John in 1995 at Category 2 (with some unconfirmed reports of wind speeds of up to 174 miles per hour) (National Weather Service 2022; NOAA 1996).

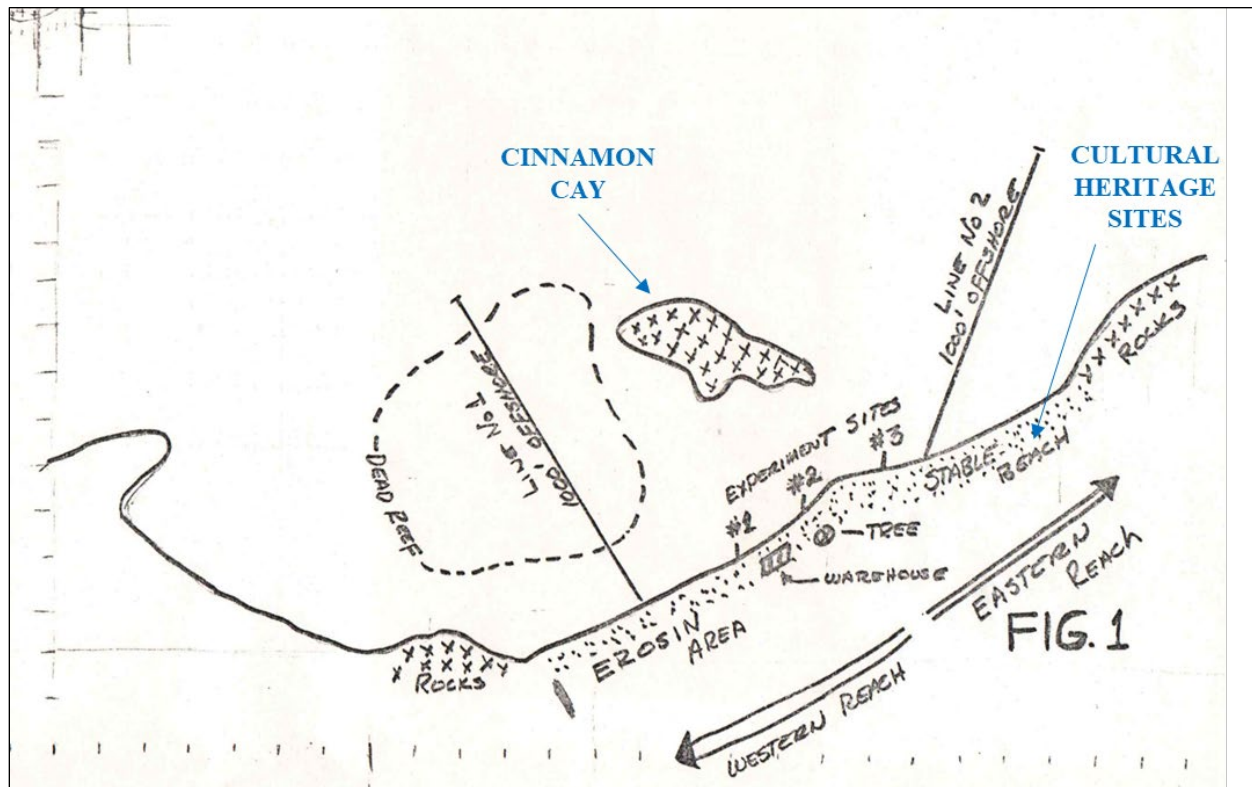
Several studies of landward erosion have been conducted on St. John since the 1980s. Hubbard et al. (1987) found a decline in coral growth rates, which they concluded was due to higher erosion and sediment delivery rates during the plantation era. It was noted that watershed size and bay geometry were primary controls on the impacts of land development. MacDonald et al. (1997) questioned the significance of plantation-era erosion and pointed instead to the unpaved road network as the primary sediment source. A road erosion model (ROADMOD) was developed (based on limited field data), and the application of this model to Cinnamon Bay suggested that sediment yields may be several times higher than during the plantation era (Anderson and MacDonald 1998).

Overall, this historic review indicates that although the area housing the cultural heritage sites was once stable, it is now eroding.

Figure 2. A 1780 rendering of Cinnamon Bay, showing the location of historic cultural resources of interest for this erosion evaluation (Wild 2001)



Figure 3. A rendering of Cinnamon Bay in 1972, showing areas of erosion and stability along the shoreline (Dolan 1972)



EXISTING CONDITIONS

In reviewing more recent aerial imagery through Google Earth (Google Earth Pro 2022) and navigation information through the National Oceanic and Atmospheric Administration (NOAA 2022), there is a significant change in the beach features that occurs in 2017. This change corresponds closely to the dual hurricane strikes of Irma and Maria, both at Category 5 roughly 14 days apart. NOAA has identified Hurricane Irma as the strongest Atlantic-forming hurricane recorded. The damage and adjustment to the local system from these storms would likely have been significant and would necessitate a more recent beach survey than the historic data.

The review of aerial imagery, combined with the sediment grain size distribution recorded in the 1972 study, point to an overall east-to-west sediment transport direction, with currents slowly eroding the sediment and taking away material combined with larger, less frequent, high-energy events.

SEA LEVEL RISE AND FLOODING

To understand the existing coastal flood risk, the corresponding Federal Emergency Management Agency (FEMA) flood insurance study and flood insurance rate map were used to determine the base flood elevation (BFE) for the region (FEMA 2007). The BFE represents the 100-year flood event, including the effects of both storm surge and wave heights.

To understand future coastal flood risk in the study area, relative sea level rise (RSLR) projections for the region were evaluated for the nearest NOAA tidal station, the Charlotte Amalie, USVI station (9751639; NOAA 2022). These NOAA projections are shown in table 1 for five different scenarios, described in Sweet et al. (2022). The estimated RSLR fluctuates significantly depending on the projected impacts of climate change. For a conservative approach, the recently updated 2022 NOAA Intermediate-High scenario was used to assess the future risk to the area of interest. Using this projection scenario, the estimated RSLR is 1.12 feet by 2050 and 5.03 feet by 2100. Note these values are bolded in table 1. The aerial in figure 4 shows that the area of interest for this memo would experience significant flooding during the 100-year event and this flood risk would increase as a result of RSLR.

Table 1. Relative Sea Level Rise Scenarios (Sweet et al. 2022)

Year	Low (feet)	Intermediate-Low (feet)	Intermediate (feet)	Intermediate-High (feet)	High (feet)
2030	0.37	0.42	0.43	0.46	0.49
2040	0.50	0.59	0.64	0.72	0.81
2050	0.65	0.78	0.89	1.12	1.33
2060	0.77	0.98	1.20	1.63	2.06
2070	0.89	1.19	1.57	2.34	3.05
2080	0.99	1.39	2.04	3.11	4.19
2090	1.10	1.61	2.64	4.02	5.48
2100	1.21	1.84	3.38	5.03	6.80
2150	1.71	3.02	6.47	8.51	12.12

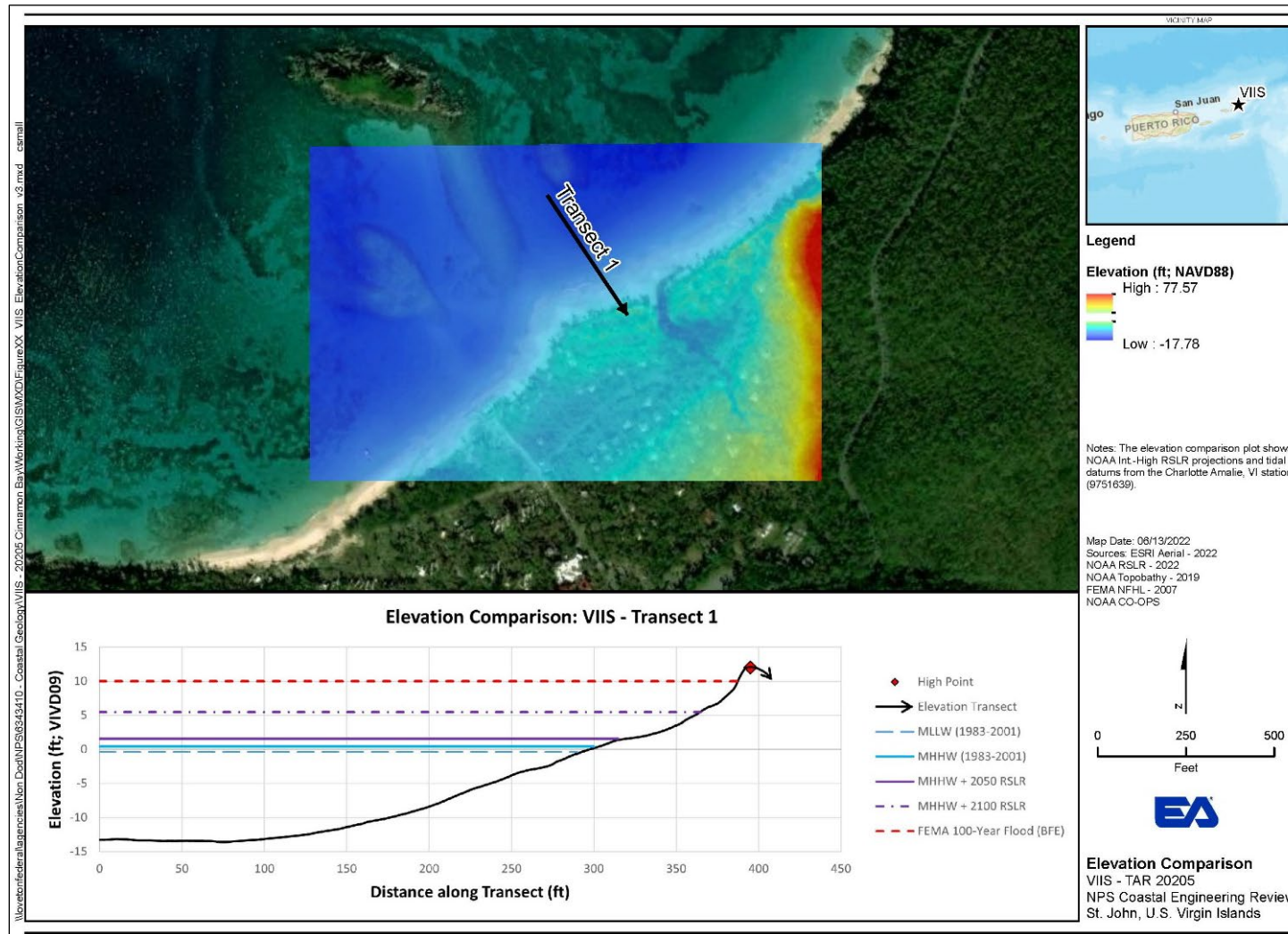
Notes: National Tidal Datum Epoch: 1983-2001

A cross-sectional analysis was performed to visualize existing and future coastal risks along the transect. A shore perpendicular transect was established in the study area, shown in the bottom panel of figure 4, and the elevations along this transect were extracted from the NOAA topobathymetric model (National Geodetic Survey 2022). The following elevations were plotted to compare scenarios, all in VIVD09:

- The FEMA 100-year flood value of 10 feet (FEMA 2007)
- The mean higher high water (MHHW) tidal datum from the NOAA Charlotte Amalie, USVI station's (9751639) of 0.41 feet (NOAA 2022)
- The mean lower low water (MLLW) tidal datum from the NOAA Charlotte Amalie, USVI station's (9751639) of -0.38 feet (NOAA 2022)
- The 2050 projected MHHW value of 1.53 feet for 2050, calculated by adding the NOAA Intermediate-High RSLR projection (Sweet et al. 2022) to the current MHHW datum
- The 2100 projected MHHW value of 5.44 feet, calculated by adding the NOAA Intermediate-High RSLR projection (Sweet et al. 2022) to the current MHHW datum

Figure 4. Existing elevations and water level comparisons at the area of interest

The aerial in this figure shows the elevation at and surrounding the area of interest. On the aerial, transect 1 correlates to the cross-section in the bottom panel approximately where the cultural resources of interest are located. The bottom panel compares elevations for current water levels (MHHW, MLLW, and FEMA 100-year flood) and projected future conditions (MHHW 2050 RSLR and MHHW 2100 RSLR). All elevations are in VIVD09.



POSSIBLE PROTECTION MEASURES

The following represents a cursory review of the possible protection options, as well as a discussion regarding strategic retreat. To evaluate the protection options in further detail and to further determine the efficacy of strategic retreat, updated bathymetric data and coral surveys are suggested.

Natural and Nature Based Features

Because the shoreline of Cinnamon Bay has limited to no backshore area, allowing the shoreline to naturally migrate landward is not an option. Natural and Nature Based Features (NNBF) will be focused on options along the shoreline or offshore.

The historical review suggests that coral degradation has led to reduced wave attenuation, which in turn has caused the entire length of shoreline in Cinnamon Bay to be erosive. Therefore, a potential aid to reducing erosion bay-wide would be coral restoration, which has been recommended in the Caribbean Restoration Sites Supplementary Report (Toline et al. 2020). Within this report, existing conditions show that average coral cover at this site is currently 4%. Restoration goals were developed for this site, including a ten-year goal, which targets a 10% increase in current cover. Restoration at this site will target elkhorn, star, brain, pillar, staghorn, and finger coral (Toline et al. 2020).

A more focused and shorter-term option would be to nourish the beach directly fronting the cultural heritage sites of interest. This option would require cyclical maintenance, as the erosion will not decrease, rather the nourishment would be sacrificed to maintain current beach widths. Any potential sediment source would need to be evaluated for contaminants and compatible sediment size. A potential sediment source could be the dredging planned for the Cruz Bay Visitor Center, located approximately 5 nautical miles southwest of Cinnamon Bay. Approximately 2,000 cubic yards of material are expected to be dredged. Analytical results were included in the *Repair to Cruz Bay Visitor Center, Docks, and Surrounding Grounds Impacted by Hurricanes Irma and Maria Environmental Assessment* (NPS 2021), but grain size data were not included and comparisons of detections to sediment quality criteria were not provided, so additional analyses would need to be completed to determine compatibility for beach nourishment. Based on the environmental assessment (NPS 2021), the material is planned to be placed in a landfill.

Engineered Features

A riprap revetment could be placed along the shoreline proximal to the cultural heritage sites with geotextile fabric and an appropriate layer of gravel underneath. This feature would stabilize the shoreline directly behind it; however, it would also transition the tidal zone from sand into a rocky environment, changing the local ecology significantly. There is the additional complication of sourcing adequate rock without using manufactured elements (i.e., concrete blocks).

Selected, high-priority archeological resources could be protected with a sheet pile or concrete block seawall. This option presents the most feasible, long-term solution that could address the projected sea level rise in the year 2100. It also represents the furthest from a natural condition, both aesthetically and culturally.

It is important to note that hardened engineered features such as this reduce erosion directly behind them, but typically increase erosion down current from them.

Documentation and Strategic Retreat

The solutions discussed above should be viewed in the context of longer-term planning for the park, and it should be noted that they require funding. When reviewing projected RSLR for the longer term to 2100, it provides a scenario that would be very difficult to ultimately protect the cultural resources. Because of this situation, the park may wish to consider relocation of the cultural resources to a more protected location at a higher elevation. The determination of planning for when this will need to occur will be based on review of the projected RSLR.

Prior to relocation, the cultural resources should be extensively documented, including surveying the coordinates of their existing location, photographs, and other means of historic preservation where appropriate.

CONCLUSIONS

Although there are a variety of ways to protect the cultural heritage sites of interest, each provides a different degree and immediacy of protection and environmental impact on Cinnamon Bay and the cultural heritage sites of interest. The concept of strategic retreat also provides an option for consideration. The offshore reef system has declined since the 1972 sediment analysis was performed; therefore, all the options presented could be explored in greater detail once updated bathymetric and hydrodynamic (current direction/speed) data are available.

Natural and Nature Based Features

The immediate protection measure for the site would be nourishment, finding a source of approximately 0.45-mm diameter grain size sand, and placing this material over the existing sand. Additional bathymetric data and a desired nourishment length are needed to determine an appropriate quantity that should be placed. This would significantly slow the erosion rate but would need cyclical maintenance (renourishment on a period basis). It is suggested that coral restoration be explored as soon as possible in conjunction with nourishment. This offshore restoration measure would work towards reducing the energy that reaches the beach and therefore could slow the overall erosion that is occurring. These options would protect current water levels but may not be effective through the 2100 sea level rise projections.

Engineered Features

For a short-term solution, the riprap revetment would provide immediate relief from erosion. This solution would not provide protection from the year 2100 sea level rise projection; therefore, a longer-term solution would be the construction of a seawall feature that ties into a nearby high elevation point. The location of these tie-in features has not been reviewed for the purpose of this sequencing discussion.

NNBF options present the most holistic environmental approaches and should be considered a priority; however, they may need to be employed in combination with the engineered features discussed if immediate relief is needed. It can take time and funding to identify compatible source material for beach nourishment, and coral restoration is a long-term process.

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