

Memorandum – Coastal Engineering Review George Washington Birthplace National Monument (GEWA) – Shoreline Erosion Strategy TAR 21316

9 March 2023

INTRODUCTION AND TAR REQUEST

Shoreline erosion has become an increasing concern at the George Washington Birthplace National Monument (GEWA or park) over the past several years and is causing the park's beach to rapidly disappear according to NPS staff. At the beach, damage from recent storms (on 29 October 2021 and 3 January 2022, as reported by NPS staff) is more extreme than in the past and lends increased importance to the need to develop a strategy. The park anticipates the need to develop a shoreline management strategy that includes immediate and long-term recommendations and actions. The park is in need of expertise to determine what actions should be taken to address erosion at the beach, as well as longer-term recommendations for the park's larger shoreline and assistance with a path toward developing a formal shoreline management strategy. The park is currently working with Interior Region 1 Cultural Resources and the Virginia State Historic Preservation Office (VA SHPO) on a plan to remove the remains of an old pier recently exposed by coastal erosion.

BACKGROUND

Encompassing 550 acres in Westmoreland County, Virginia, GEWA is bordered by the tidal Potomac River to the north, and by tidal tributaries Popes Creek and Bridges Creek to the east and west, respectively. The park preserves lands occupied by generations of the Washington family, as well as commemorative structures and landscapes from the 1930s. Additionally, the park contains paleontological sites, Native American sites, early European settlement sites, and late Mission 66 resources. Natural resources include a variety of animals and plants, including two globally rare plant communities. The GEWA coast contains diverse topographies, namely high vertical bluffs, lower banks, and low swamp drainage areas with fronting beaches (see figure 1). The wave climate in the Chesapeake Bay estuarine system is limited by water depth and fetch (Hardaway et al. 2009). Erosion at the park has already resulted in the loss of archeological and paleontological resources (Hardaway et al. 2009).

Fetch – The effective distance that waves travel in open water from their point of origin to the point where they break.

Existing coastal protection structures in the vicinity of GEWA include a wooden bulkhead downriver of the forested embayment (just west of Longwood Swamp) and groins on the east shoreline outlet of Popes Creek (figure 1) (CCRM 2019), likely installed in the 1960s, which provided some erosion protection before deteriorating significantly (Hardaway et al. 2009). Within Popes Creek, a wooden bulkhead is located near the Log House to help stabilize the adjacent trail. In 2017, a 262.5-foot-long riprap wall revetment was constructed on private property near Digwood Swamp with a large amount of fill placed behind it (Psuty et al. 2019). Roughly a third of the shoreline upriver of GEWA is armored with

revetments, which remove sediment from longshore transport (Hardaway et al. 2009). These revetments include riprap, groinfields, and bulkheads, often with groinfields fronting bulkheads (CCRM 2019).

Figure 1. Location and extent of shoreline position collection at GEWA.

The inset map in this figure shows the location of GEWA, the Colonial Beach tide gauge, and the Lewisetta tide gauge in the Potomac River estuary (adapted from Psuty et al. 2019).



The erosion caused by two storms in late 2021 and early 2022 prompted this TAR. The 29 October 2021 storm was slow-moving, driving water into the Chesapeake Bay and the Potomac River and causing a seiche effect, resulting in major tidal flooding (NWS 2021). The 3 January 2022 storm occurred when there were higher than normal tides due to a new moon the prior day, which coupled with onshore flow from storm surge, caused flooding (NWS 2022). Observed water levels at the Lewisetta, VA NOAA tidal station (8635750) peaked at 3.91 feet NAVD 88 (where predicted elevation was 0.50 feet) during the October 29, 2021 storm event (NOAA 2022a) and 2.05 feet NAVD 88 (where predicted elevation was 0.25 feet) during the January 3, 2022 storm (NOAA 2022b). The erosion caused by these storms created an escarpment along almost the entire length of the beach. The first storm also revealed the remains of a 19th century pier, which was further uncovered by the second storm. This has left large bolts and wide flanges exposed, creating a safety hazard.

Shoreline Assessments

Two assessments of shoreline change at GEWA have been conducted to date: *Shore Status, Evolution, and Storm Vulnerability Assessments for George Washington Birthplace National Monument: Technical Report* (Hardaway et al. 2009) and *Shoreline Position (1D) Monitoring at George Washington Birthplace National Monument: 2010–2017 Trend Report* (Psuty et al. 2019). Together, these assessments cover an 80-year period of shoreline change at GEWA; Hardaway et al. (2009) by studying records of the Potomac River and Popes Creek shorelines from 1937 to 2007, and Psuty et al. (2019) by describing Potomac River shoreline monitoring results from 2010 to 2017. Hardaway et al. (2009) found that the GEWA Potomac River shoreline eroded at an average rate of 1 foot/year between 1937 and 2007, while Psuty et al. (2019) found 1.90 feet/year of erosion along the GEWA Potomac River shoreline between 2010 and 2017.

GEWA is one of eight national park units within the Northeast Coastal and Barrier Network (NCBN), which defines monitoring protocols for geomorphological and other studies. The NCBN program monitors the health of coastal shores, salt marshes, estuaries, upland forests, and weather and climate. Additionally, the NCBN program inventories rare and endangered species, migratory wildlife, and local plant communities. There are three NCBN geomorphological monitoring protocols:

- **Part I – Ocean Shoreline Position** (Psuty et al. 2010), for gathering shoreline position via Global Positioning Systems (GPS) surveys and using United States Geological Survey (USGS) Digital Shoreline Analysis System (DSAS) for statistical geographic information system (GIS) post-processing of shoreline position and erosion/accretion rates.
- **Part II – Coastal Topography** (Psuty et al. 2012), for gathering and synthesizing two-dimensional coastal topography for delineating beach, dune, and bluff systems.
- **Part III – Coastal Landform Elevation Models** (Psuty et al. 2018), for gathering and synthesizing three-dimensional coastal features in local areas of interest and creating digital elevation models for calculating sediment volume changes for features over time.

The shoreline monitoring documented in Psuty et al. (2019) followed the ocean shoreline position (Part I) protocols. Monitoring of the GEWA Potomac River shoreline with Part I protocols has been continuous since 2010, except for a gap in 2020–2021 due to COVID-19 restrictions. Projects following coastal topography (Part II) and coastal landform elevation models (Part III) protocols have yet to be

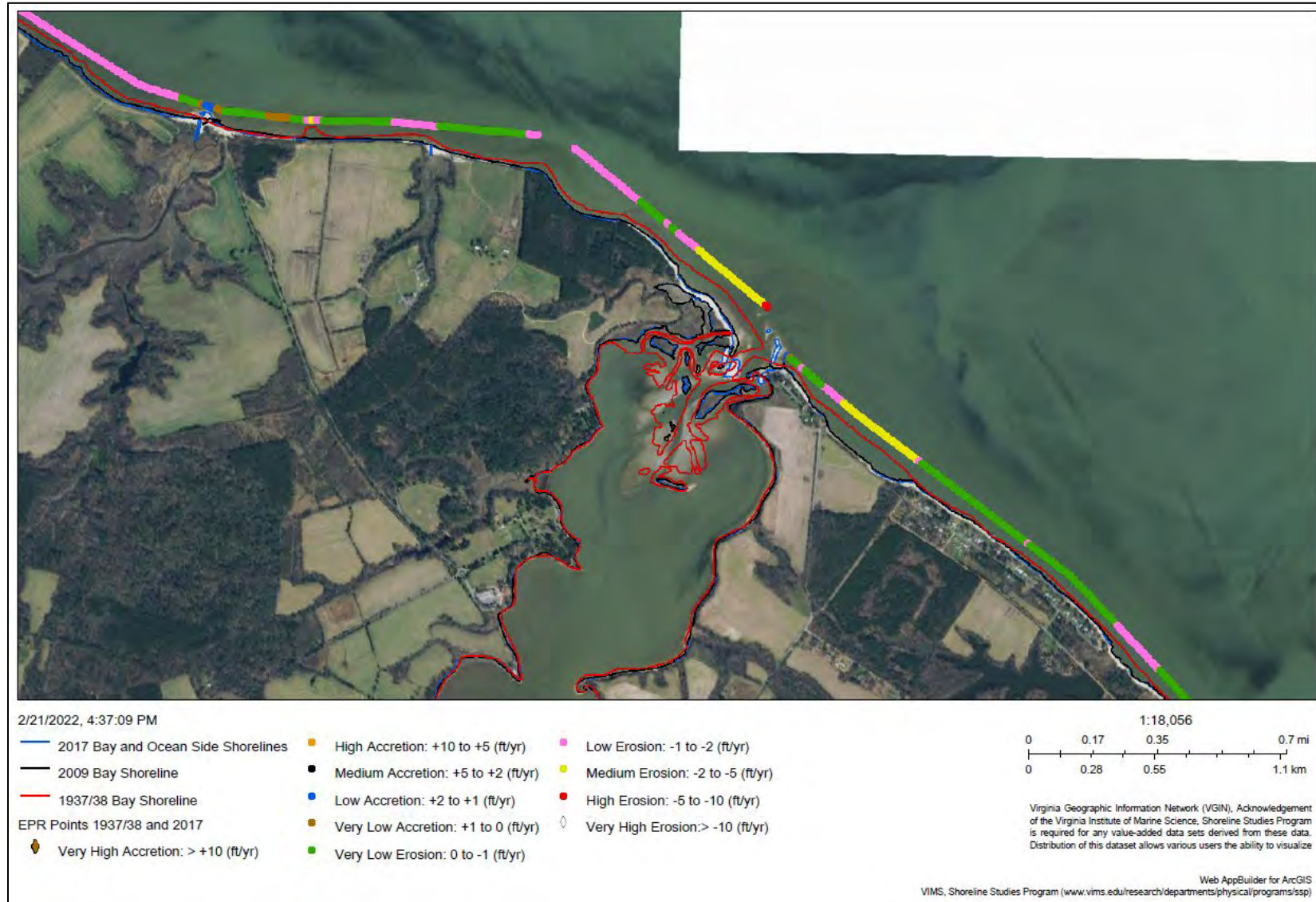
implemented at GEWA. Other NCBN monitoring at GEWA besides coastal shoreline position includes estuarine water quality in Popes Creek and forest health in various locations in the park.

GEWA shoreline position data from 1937/38 to 2017, spanning both Hardaway et al. (2009) and Psuty et al. (2019) timeframes, is visualized in the Shoreline Evolution GIS Map by the Virginia Institute of Marine Science (VIMS) (figure 2, Hardaway et al. 2020). Figure 2 shows a hot spot of high erosion (-5 to -10 feet/year) at the outlet of Popes Creek, medium erosion (-2 to -5 feet/year) in front of Longwood Swamp, low erosion (-1 to -2 feet/year) and very low erosion (0 to -1 feet/year) interspersed moving westward, very low accretion (+1 to 0 feet/year) in front of the pond, and low accretion (+2 to +1 feet/year) by Bridges Creek. While the area in front of the pond shows accretion over time, it has experienced major erosion at the top of the bank and is identified as vulnerable in both Hardaway et al. (2009) and Psuty et al. (2019). The other area most vulnerable to erosion and breaches along the GEWA Potomac shoreline was found to be the easternmost portion (i.e., Longwood Swamp and Popes Creek Spit) (Hardaway et al. 2009; Psuty et al. 2019). Additional information from the two shoreline assessment reports is provided in the sections below.

Psuty et al. (2019) Summary. Shoreline position surveys conducted semi-annually (spring and fall) from Spring 2010 through Spring 2017 at GEWA are summarized by Psuty et al. (2019). GPS surveys were conducted with a hand-held GPS unit capable of collecting positions with < 1-meter precision, a hand-held unit was needed due to the extensive bluffs within the survey region. USGS DSAS was used for statistical GIS post-processing of shoreline position and erosion/accretion rates. The shoreline position surveys were collected along the GEWA Potomac River-facing coast from Bridges Creek to Popes Creek, extending about 1.8 miles alongshore, including collection of the data for the spit near Popes Creek, when present. The trend report includes statistical data and spatial representation of annual changes and 7-year net changes in the shoreline position.

The trend report found that low and high bluff areas with no beach incurred slight landward displacement. Net landward displacement increased to the west and east of the forested embayment. Areas that contained sandy beach or an accumulation of sand, such as the base of the eastern low bluff and the easternmost and westernmost edges of the site, showed increased erosion because the loose sediment was more easily mobilized than the more hardened bluff material. There was a linear trend of 1.90 feet/year of shoreline landward displacement with an average 13.32 feet of landward loss over the 7-year period. Sediment availability, exposure, and natural events (storms) were the main factors influencing the shoreline change at GEWA over the 7-year survey period. Since GEWA is located on a tributary of the Chesapeake Bay, it is not directly exposed to ocean surges from long fetch; however, the GEWA coastline did suffer breaches and erosion from Hurricane Irene in 2011. Relative sea level rise (RSLR) combined with a lack of sediment entering the system will continue to displace the GEWA shoreline landward.

Figure 2. GEWA Shoreline Evolution (Hardaway et al. 2020)



Hardaway et al. (2009) Summary. This report documents shore and bank dynamics at GEWA by digitizing shoreline extents from orthorectified images from 1937, 1953, 1969, 1987, 1994, 2002, and 2007 and a physical topographic survey (via a real-time kinematic [RTK] GPS and a total station) in 2008. Lidar data collected in 2008 were compared to the results of the RTK GPS survey. The net rate of change of the GEWA Potomac River shoreline between 1937 and 2007 was found to be -1 foot/year, which is slightly less than the finding by Psuty et al. (2019) of 1.90 feet/year of erosion. Up to 30 feet of bank width was lost due to storms between 2002 and 2007, including Hurricane Isabel in 2003 and Tropical Storm Ernesto in 2006. The Popes Creek shoreline is eroding at a lower rate of 0.3 to 0.7 foot/year. Some takeaways for the GEWA Potomac River shoreline and the Popes Creek shoreline are below, followed by identification of “vulnerable areas,” apparently where relatively high erosion was found to coincide with park assets such as cultural resources, important habitats, or built infrastructure.

The GEWA Potomac River shoreline is exposed to storms, wave energy, and RSLR and is experiencing shore change and bank erosion. Most of the shoreline is eroding, but there is slight net accretion by the outlet of Bridges Creek. Moving east along the Potomac River shoreline, long-term erosion rates increase, particularly when the orientation of the shoreline changes from north-facing to northeast-facing. These findings were confirmed by Psuty et al. (2019), who identified increased erosion east of the forested embayment. The easternmost section (i.e., Longwood Swamp) experienced the shoreline’s maximum erosion rate of 4 feet/year, apparently due to hydrodynamic processes on the northeast face. The northeast-facing shoreline is exposed to longer fetch than the north-facing shoreline and therefore experiences more intense wind-waves and storm surge. The tops of the lower banks experienced the most erosion from the storm impacts of Hurricane Isabel (2003), Tropical Storm Ernesto (2006), and the northeast storms of 6 October and 22 November 2006, not from overtopping of surge but from waves breaking onto the banks. Per the changing formation of the spit fronting Popes Creek, there is presumably a net movement of sand down the Potomac River.

The Popes Creek shoreline is less vulnerable to storms and erosion than the Potomac River shoreline, but it is also facing changes. For instance, washovers into Longwood Swamp may eventually alter the number and location of tidal inlets. Additionally, tidal marsh islands have declined by over 75% from 1953 to 2007 due to a combination of limited sediment supply, tidal and wave effects, and sea level rise (SLR).

Hardaway et al. (2009) attempts to identify the areas of the shoreline that are “vulnerable” and “most vulnerable” to erosion; however, the methodology for this analysis is inadequately documented, and appears to involve a qualitative accounting of whether an area contains or is nearby archeological resources, built infrastructure, or particular habitats:

“Vulnerability from a management perspective took into account bank height, shore type, erosion rates, proximity to infrastructure, and potential loss of archaeological resources.” – p. x

“In order to determine the areas of the shore that are most vulnerable to erosion, bank height, shore type, erosion rates, proximity to infrastructure, and potential loss of archaeological resources were taken into consideration when sections of shore were determined to be vulnerable or highly vulnerable. Generally archaeological resources were given the highest priority since their loss is irrevocable. Conversion or loss of significant habitats also was a high priority.” – p. 15

“While not directly part of this study, shore erosion is occurring at the Visitor Center which is placed close to the shore. In addition, the height of the bank is lower in this region. For these reasons, it was considered vulnerable.” – p. 57

The assignment of the labels “vulnerable” and “most vulnerable” apparently conveys the coincidence of high erosion rates with the presence of park assets or resources. This approach can be interpreted as an assessment of “priority” and “higher priority” sites for the management of erosion risk and is therefore not an assessment of geomorphological vulnerability alone. Along the GEWA Potomac River and Popes Creek shorelines, Hardaway et al. (2009) identify 3,800 feet of shoreline as “most vulnerable”, and an additional 1,000 feet as “vulnerable”. For archeological resources to be preserved, Hardaway et al. (2009) recommended swift action for the “most vulnerable” shores.

Figure 3 shows the areas identified as “vulnerable” on the GEWA Potomac River shoreline with local erosion trends and mapped archeological areas. Vulnerability of the park’s resources in Hardaway et al. (2009) was determined by the position of archeological sites relative to the proximity of local erosion trends. There is a “most vulnerable” area in front of Bridges Creek and the Pond (a variable beach/eroding low bank area), and another longer stretch in front of Longwood Swamp (the eastern end of the small subaerial beach/eroding low bank, the eroding low, sandy marsh barrier in the middle, and the eroding low, sandy spit on the eastern end). The area in front of Bridges Creek and the Pond are directly adjacent to archeological resources. Longwood Swamp is marked as “most vulnerable” due to the erosion and overwash occurring at the mouth of the inlet, threatening natural resources. As these processes continue, Popes Creek will likely become fully open to the river, which will change habitat and cause marsh loss. The frequency of future storms will play an important role as well. While Longwood Swamp is not directly adjacent to archeological resources like the Bridges Creek Area, it provides protection to an island on its interior side that does have archeological resources, shown in figure 4 and discussed below.

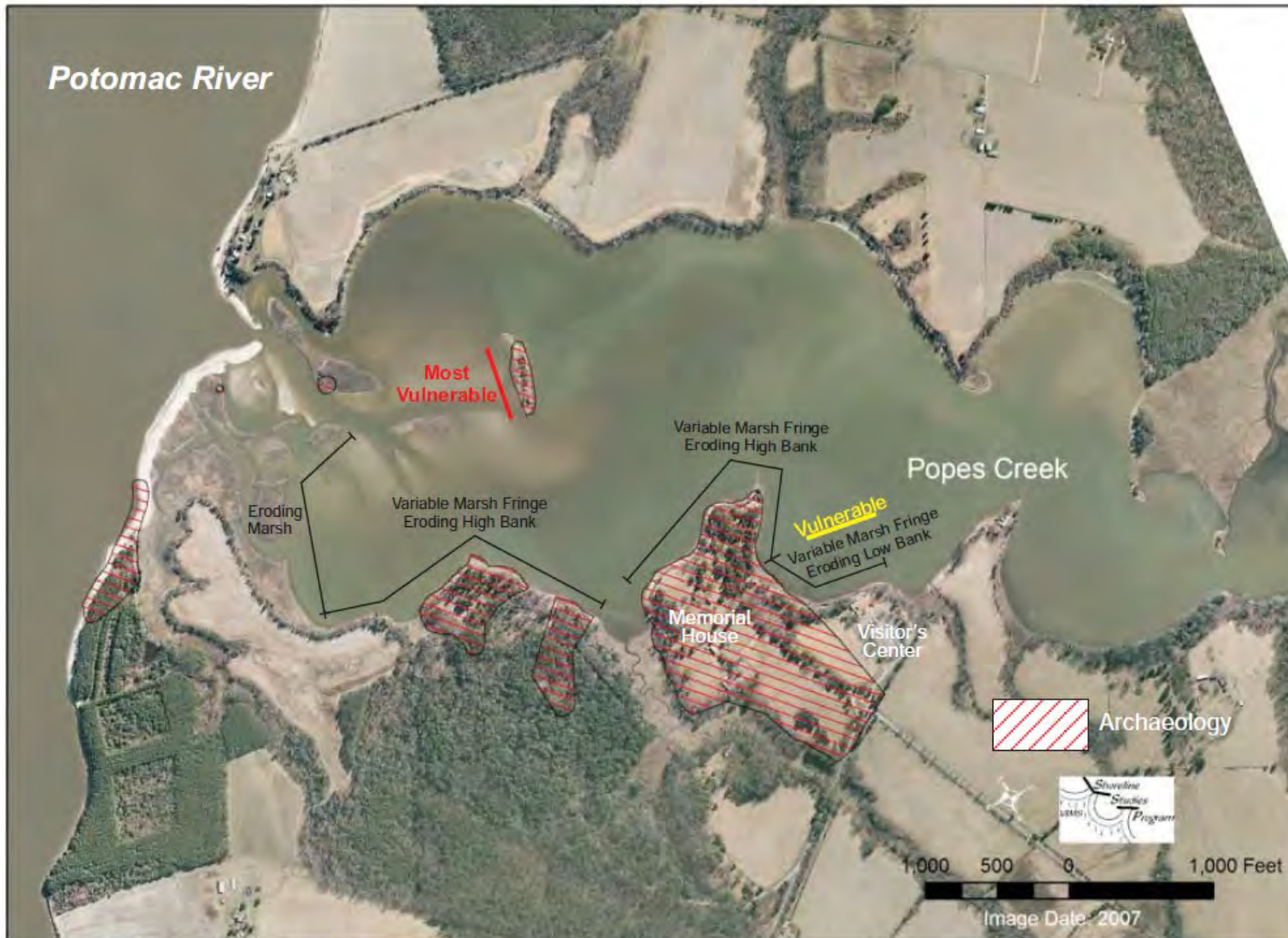
A “vulnerable” area is identified at Digwood Swamp (eroding low beach), which is located between the two “most vulnerable” areas discussed previously. Digwood Swamp is subject to washover and breach-widening stressors, but no archeological resources are known to exist there. In this area, three flowing inlets were observed in April 2022. This has resulted in an improvement in the health of the salt marsh vegetation in the brackish marsh directly behind the beach. In addition, *Phragmites australis* has been significantly reduced in this area, presumably due to increased salinity from overwashes and breaches. Overall, low marsh areas will be impacted by SLR and will become increasingly susceptible to flooding.

Figure 4 shows vulnerable areas for the Popes Creek shoreline. A “most vulnerable” area identified for Popes Creek is a small island with archeological resources, which is likely to disappear due to sea level rise. A “vulnerable” area is in front of the Visitor Center since the bank is low. While there is a wave-cut scarp at the shoreline fronting the Memorial House, this area was not deemed vulnerable because the shore is high with a vegetative edge, and infrastructure is 150 feet or more away from the shoreline.

Figure 3. Summary of major findings and vulnerability map for GEWA's Potomac River shoreline (Hardaway et al. 2009)



Figure 4. Summary of major findings and vulnerability map for GEWA's Popes Creek shoreline (Hardaway et al. 2009)



Sea Level Rise and Flooding

Climate science is constantly advancing, resulting in periodic updates to SLR projections, using new data and methods. This section presents a review of the SLR projections and flooding for the project site, using the recently published updated SLR projections from the US Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force (Interagency Task Force). This Interagency Task Force is led by the National Oceanic and Atmospheric Administration (NOAA) and comprises scientists from several federal agencies and academic institutions (Sweet et al. 2022). Additional background on these global and regional scenarios is provided in appendix A. Caffrey et al. (2018) was considered as a source since it provides SLR and storm surge projections for national park units (including for GEWA); however, Sweet et al. (2022) provides more accurate projections for GEWA as it uses up to date greenhouse gas emissions and vertical land movement (land subsidence and uplift) to better assess future risk.

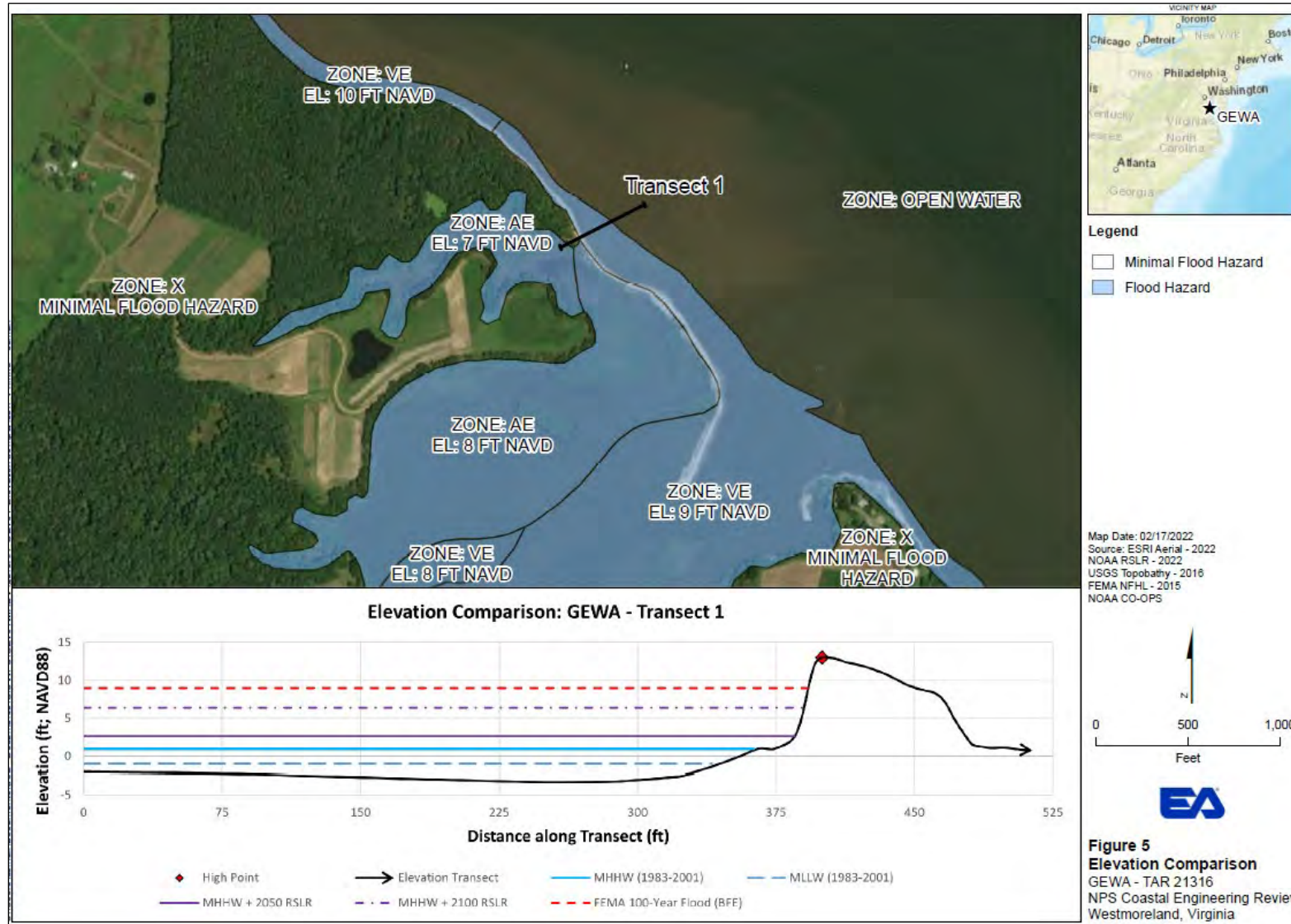
To aid in understanding the coastal risk in the study area, the Federal Emergency Management Agency (FEMA) flood insurance study and flood insurance rate map were used to identify the base flood elevation (BFE) for the region. The BFE refers to the elevation at which there is a 1% chance that a flood would exceed this elevation in any given year. This is commonly referred to as the 100-year flood elevation and includes effects of both storm surge and wave heights. Elevations in the following discussion are referenced to North American Vertical Datum of 1988 (NAVD 88) unless otherwise stated. For the study area, the estimated BFE varied between 7 and 10 feet. The spatial distribution of the different BFEs and the corresponding flood zone designations are depicted in the top half of figure 5. As seen in figure 5, there are Zones AE¹ and VE² for different BFEs, Zone X for minimal flood hazard, and open water zone.

Additionally, RSLR projections for the region were identified from the nearest NOAA tidal station, the Lewisetta, VA station (8635750). These local interagency report projections (Sweet et al. 2022) are shown in table A.1 in appendix A for five different scenarios based on projected greenhouse gas emission scenarios. The estimated RSLR changes significantly depending on the projected greenhouse gas (GHG) emission scenario. For a conservative approach, the Intermediate-High scenario was considered to assess the potential future risk to the study area. Using this projection scenario, the estimated RSLR is 1.66 feet by 2050 and 5.44 feet by 2100; these values are bolded in table A-1.

¹ Zone AE = Areas subject to inundation by 1% annual chance flood. Mandatory floodplain management standards and flood insurance purchase requirements apply.

² Zone VE = Areas subject to inundation by 1% annual chance flood with additional hazards from velocity wave action caused by storms. Mandatory floodplain management standards and flood insurance purchase requirements apply.

Figure 5. Elevation comparison



To provide a general understanding of the expected impacts of RSLR and storm impacts at the site, a cross-sectional analysis was performed (see figure 5) using a 100-year flood value of 9 feet NAVD 88, the 2022 interagency report Intermediate-High RSLR projections for the years 2050 and 2100, the NOAA Colonial Beach station's (8635150) tidal datums, and a 2016 USGS topobathymetric model. From the Colonial Beach station, the mean higher high water (MHHW) and mean lower low water (MLLW) tidal datums were used, with values of 0.95 foot and -0.99 foot referenced to NAVD 88, respectively. To further convey the future risk associated with rising sea levels, the RSLR values for 2050 and 2100 were added on top of the MHHW tidal datum. Next, a shore perpendicular transect (transect 1) was established in the study area, shown in figure 5, and the elevations along this transect were extracted from the USGS topobathymetric model. The previously discussed tidal datums and risk factors were then superimposed onto this elevation transect to visualize the coastal risk along the transect. As depicted in the bottom portion of figure 5, with 2100 RSLR at an elevation higher than present day MHHW, half of the bank face will become inundated and subject to regular wave erosion, compared to the bank exposed at current MHHW per the National Tidal Datum Epoch (NTDE).

RECOMMENDATIONS

The following recommendations for shoreline stabilization are based on a cursory review of existing information and, as such, should be considered as initial concepts that may be applicable at GEWA for implementation within a formal shoreline management strategy. There are a variety of techniques available that could enhance shoreline resilience at GEWA. The options focus on natural infrastructure, also known as natural and nature-based features, either as stand-alone solutions or in combination with hard structural measures (i.e., a hybrid approach), when feasible. These recommendations are also based on the identified conditions at the site reviewed within the previous summary sections of this memo, and they include key items, such as reduction of available sediment (Psuty et al. 2019) and erosion from northeast hydrodynamic forcing (Hardaway et al. 2009), among others. It should also be noted that for each of these coastal resilience options, an adaptive approach, which takes into account sea level rise and other climate change-related impacts over time, will be critical to implementation success.

As noted above, this review is cursory, so before beginning design of the identified options as a first step in developing a shoreline management strategy, it is recommended to complete a more thorough analysis of existing information, as briefed within this memo, to identify data gaps. This review of existing information may include, but is not limited to, the following items:

- SLR, land subsidence, and storm surge
- Topography/bathymetry
- Hydrodynamic and hydrological
- Geotechnical
- Sediment budget analysis
- Ecological assessment (e.g., intertidal and subtidal vegetation) and water quality
- Cultural, archeological, and paleontology resources
- Park use considerations (e.g., infrastructure, land use, and park visitors)

With this analysis complete, further data-gathering needs can be implemented. This information can then be used to inform hydrodynamic model development which will be critical in identifying specific coastal resilience needs both immediate and over time as SLR and climate change impacts continue to impact the site. The initial step of evaluation of existing data will also allow for identification of shoreline monitoring needs, which will be another key component of a shoreline management strategy. This information will also be able to draw on the NCBN protocols as well.

Based on the cursory review several possible shoreline stabilization strategies are likely to yield benefits at the site as identified below based on location. Additionally, further information on these concepts and a rough order of magnitude cost review are provided in Appendix B.

Shoreline Stabilization Options

Beach Areas along GEWA Potomac River

For the sandy beach areas of the Potomac River shoreline, in particular, the “most vulnerable” areas (in front of the pond, in front of Longwood Swamp, and the sandy spit at Popes Creek) and the “vulnerable” area (in front of Digwood Swamp), beach nourishment with living breakwater elements could be used to stabilize the shoreline. As a possible adaptive measure, the beaches could be nourished to a historical position further offshore as well. Restoring the shoreline to historical positions could possibly encounter resistance from the regulatory community; however, the increasing impacts of SLR and climate change are causing agencies to reconsider these as viable alternatives.

It is also recommended that as an initial, immediate action, nourishment of the existing identified “most vulnerable” and “vulnerable” beach areas could be undertaken as soon as possible at GEWA to prevent shoreline erosion and impacts to the bluff areas while other ideas are further developed and designed. These would include the living breakwater element and the other shoreline stabilization elements presented within this section of the memo.

Beach Nourishment. Beaches are valuable for shoreline stabilization as they can dissipate wave energy, trap sediments, and have adaptive capacity to be expanded with SLR through nourishment. To combat beach erosion, beach levels and width can be increased with the desired volume and geometry of sand nourishment to best enhance the existing beach against inundation and erosion (Bridges et al. 2021). Factors to consider are matching the sediment types/grain size and supply, beach slope, active profile height, *in situ* beach volume, width, and orientation (Bridges et al. 2021). As SLR increases, beach nourishment activities will have to be repeated over time. The addition of vegetative plantings to the renourished beach area can also be included to aid in stabilization (CCRM 2019).

Living Breakwater. If a living breakwater is included this could provide further shoreline resilience. Breakwaters are typically made of rocks, placed in series offshore parallel to the shore. They reduce wave height and thereby reduce erosion from longshore and cross-shore sediment transport (EA 2019). The size of a breakwater depends on the wave climate and length of shoreline. Deployed breakwaters at GEWA will need to be oriented appropriately to reduce erosion from northeast hydrodynamic factors (Hardaway et al. 2009). Living breakwaters are a hybrid between a traditional hard structure breakwater and a more natural barrier island (EA 2019). A living breakwater may have the same concrete or riprap core as a traditional breakwater or could be made of a natural material, such as repurposed oyster shells or oyster

castles (concrete structures designed for colonization by oysters). A functional living breakwater will increase the natural habitat available for aquatic species providing a myriad of ecosystem benefits.

Bluffs Areas along GEWA Potomac River

For the identified vulnerable bluff areas (eroding low bank area in front of the pond and eroding low bank to the east of the forested embayment), high sills could be a solution for the nearshore/intertidal area, and upland drainage control may be a solution for the tops of the bluffs.

High Sills. The design of coastal resiliency measures for bluffs can be completed so that sediments from the eroding banks may fill in between the bluff face and the protection measure (Hardaway et al. 2013). Except for low drainage areas, most sediment is transported alongshore or offshore at GEWA (Hardaway et al. 2009). High sills composed of rock or other materials placed at vulnerable bluff locations could capture material that slumps off the bank, putting the material into the littoral system, leading to accretion along the shoreline. The captured material then is available to protect against wave energy, which will enhance bluff stabilization (Hardaway et al. 2013). As with other shoreline stabilization designs, bluff stabilization will need to take into account such items as wave exposure, prevailing wind direction, and nearshore bathymetry. Additional considerations required for design of bluffs include bank height, bank geology, bank toe factors (height and width of beach in front of bluff), and bank face factors (sloughing, freeze-thaw, runoff, and groundwater). An example exists at nearby Westmoreland State Park along the Potomac River east of GEWA where high sills are used for stabilizing 150-foot-high bluffs. Further analysis of this existing design may provide further insight into bluff solutions at GEWA.

Upland Drainage Control. When the toe of a bluff is protected, the top of the bluff may still be impacted by erosive forces leading to retreat. Although this was not specifically identified within the reviewed documentation it is recommended that it be considered within further site evaluations. The mechanism in such erosion is upland drainage at or near the top of the bluffs, particularly over-bluff stormwater runoff. Additionally, if there is subsurface groundwater flow near the bluff due to infiltration, it could be exiting through the face of the bluff leading to erosion. If identified as an issue at the site, management techniques could reduce the impact, such as preserving upland vegetation, minimizing ponding areas (if there are any), planting trees to provide phytopumping (removal of excess water through evapotranspiration), or installing engineered drain systems (e.g., French drains or subsurface tile drains). If there is visitor access near the bluff crests, this traffic could be diverted further inland by a fence or other methods to minimize the potential for erosion impacts as well.

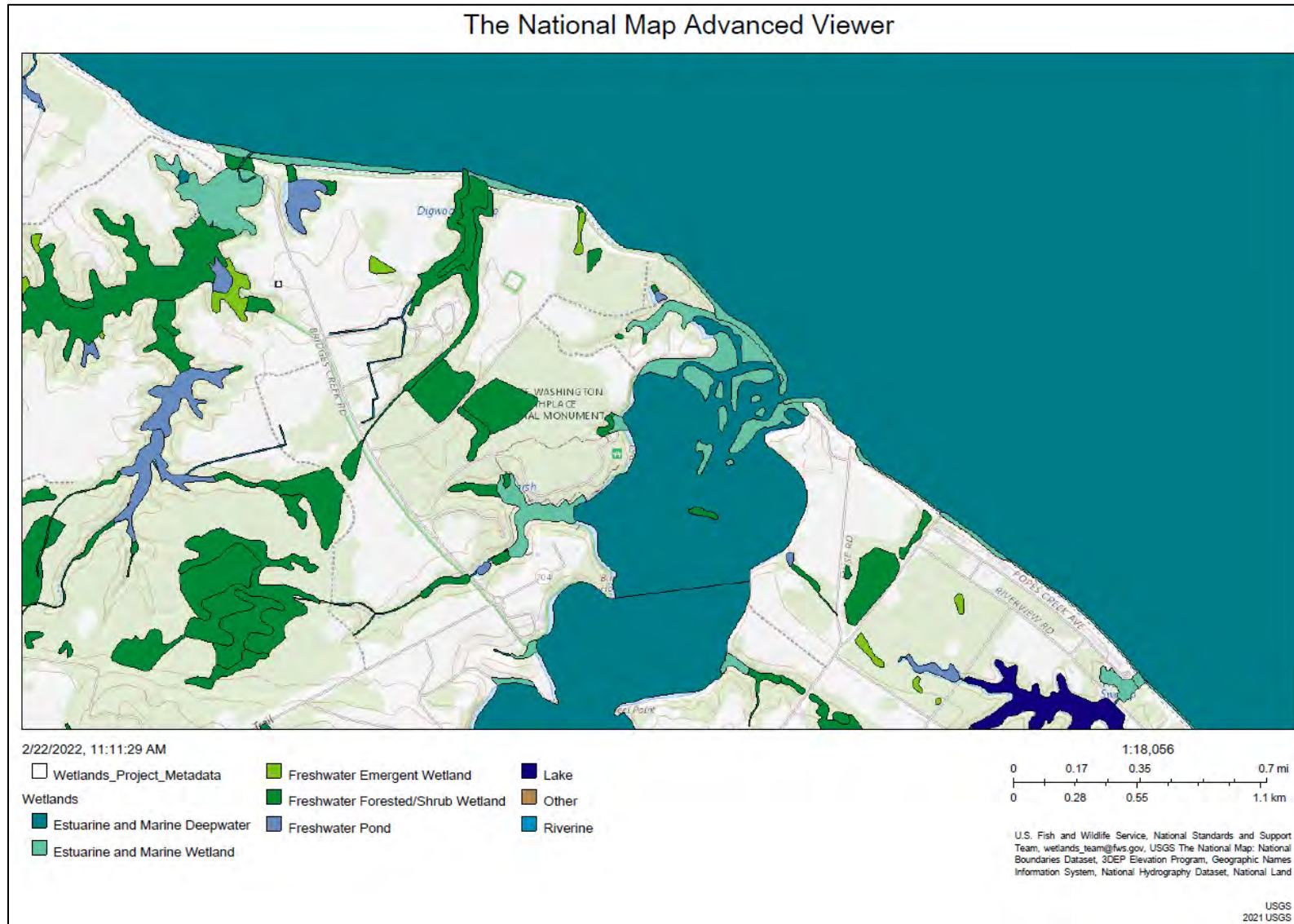
Popes Creek

Living Shoreline. For the shoreline of Popes Creek, a living shoreline is a possible option for providing shoreline stabilization in front of the Visitor's Center. An effectively designed living shoreline can protect against erosion from wave energy by using native vegetation and sediment and is a commonly deployed strategy in the Chesapeake Bay region (Hardaway et al. 2013). Living shorelines also provide ecosystem services, such as habitat, water quality improvement, and food production. A living shoreline design may or may not include, depending on wave energy, an integrated structure parallel to the shore which could be comprised of natural elements (Bridges et al. 2021), such as oyster castles or other shellfish-based structures. If using natural elements for the structure is deemed infeasible due to wave force, then a stone sill could also be used. Additional sediment may be added behind the parallel structure on which wetland and transitional upland vegetation would be planted. (CCRM 2019).

Wetland and Submerged Aquatic Vegetation Restoration. Popes Creek shoreline stabilization could also possibly be enhanced by wetland and submerged aquatic vegetation (SAV) restoration. As noted previously, Longwood Swamp, which includes an island identified as most vulnerable in Popes Creek, is eroding (Hardaway et al. 2009) and is at risk of disappearing. Historically, there was SAV in Popes Creek and Longwood Swamp (VIMS 2022), and the mouth of Popes Creek used to be a contiguous flood delta marsh, but it has disbanded into marsh islands (Hardaway et al. 2009). This is a condition that tracks with regional trends. Historically and up to the year 2001, SAV beds were prolific in the Lower Potomac River (Chesapeake Bay Program 2019). As seen in figure 6, GEWA includes estuarine and marine wetlands in Longwood Swamp, around Popes Creek mouth, to the north of the Memorial House, and a few other patches along the Potomac River; freshwater emergent wetlands to the west of the forested embayment; and freshwater forested/shrub wetlands in Digwood Swamp, on the “most vulnerable” island in Popes Creek and connected to Popes Creek in a few other locations (USGS 2021). Shoreline wetlands and SAV (e.g., seagrass beds) provide sediment stabilization, wave attenuation, and valuable ecological benefits. As an initial step, a focus on restoration efforts at Longwood Swamp and at the “most vulnerable” island would possibly provide the most benefit.

Factors to be considered for implementing SAV and tidal wetland restoration include turbidity/water clarity, salinity, and water temperature, which will also dictate possible species to include (Chesapeake Bay Program 2019). As sea level increases, an adaptive management strategy using the technique of thin layer placement of a few inches of placed sediment onto the wetland and/or SAV beds can increase elevation of the beds, allowing the vegetation to persist as the water rises (EA 2019).

Figure 6. USGS National Map Viewer, GEWA Wetlands (USGS 2021)



Future Conditions without Stabilization Efforts

This information is provided for perspective if no efforts to stabilize the shoreline are implemented. Without efforts to stabilize the shoreline, the shoreline will continue to erode, and the low drainage areas will continue to be impacted, due to the effects of climate change including advancing SLR and storm impacts. In such a situation, a strategy of managed retreat would need to be established, which would allow for the movement of archeological and cultural elements to areas outside of flood impact zones over time. Conditions of natural resources would be left to conform to the ongoing changes in the environment.

When considering managed retreat as an option alone or in combination with other techniques described within the document, it is also important to consider that it may be the most viable and desirable choice when certain factors are taken into consideration, such as:

1. Would the negative ecological impacts of an engineering solution outweigh the benefits (e.g., exacerbating along-shore sediment deprivation)?
2. Would the cost of construction and maintenance be prohibitive over time? What would be the design life of a given project?
3. Would planned structures possibly be detrimental to the historic uses, character, viewshed, etc., of the park?

To meet management objectives for the future, the park will need to identify the resources that are at risk (infrastructure such as the beach parking lot; known and unknown cultural, archeological, or paleontological resources; natural systems such as the Potomac shoreline and tidal wetlands) and then make difficult but informed decisions about how much it is willing and able to invest in maintaining those resources in their current state.

Adaptive Management Considerations

For all the shoreline stabilization measures identified, it is important to implementation success that projected climate change impacts including SLR, increased precipitation, and storm surge be considered throughout the design life of the measure. Adaptive management strategies to accommodate these changes include site monitoring and setting of threshold points which may trigger a follow-on design and implementation actions such as additional beach nourishment to protect against further erosion or thin layer placement to elevate tidal wetlands.

Timing of Implementation

The timing of implementation of shoreline stabilization solutions is going to be driven by consideration of design elements based on existing data, data to be collected, and robust modeling. Each option presented will take considerable design and permitting time to fully implement. However, as noted previously, as an immediate first step, a beach nourishment project for the vulnerable areas along the Potomac shoreline, could be initiated. Beach nourishment would involve preliminary design and permitting but could be implemented much more quickly than the other recommendations.

Shoreline Management Strategy Considerations

When developing the full shoreline management strategy, in addition to the information provided, it is recommended that the listed shoreline resiliency measures be evaluated further in an alternatives report which will allow prioritization of alternatives. This could include a ranking scheme with items such as permitting/regulatory considerations, site use, impacted cultural and/or archeological resources, cost, construction constraints, and maintenance obligations factored.

CONCLUSIONS

Through the cursory review of existing information as part of this TAR, the team has gained an understanding of some of the key coastal erosion dynamics at work at the GEWA shoreline associated with climate change, storm intensity, hydrodynamics, and associated site vulnerabilities. The two noted storms of October 2021 and January 2022, although less than the record water level experienced during Hurricane Isabel in 2003, are examples of storm impacts that could be expected to occur more regularly in the future as the impacts of climate change increase in intensity. Based on these current and projected impacts, we have presented a review of possible solutions which can address erosion in the beach area as well as the park's larger shoreline areas. These solutions include both immediate and longer-term options which can be included as a basis for a shoreline management strategy. The proposed shoreline management strategy will be key to defining the future steps for GEWA of not just the shoreline elements but of park use in general and should be crafted to provide a robust review of adaptation options.

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**APPENDIX A – THE US SEA LEVEL RISE AND COASTAL FLOOD HAZARDS SCENARIOS
AND TOOLS INTERAGENCY TASK FORCE (2022) SEA LEVEL RISE PROJECTIONS**

Future water levels resulting from sea level rise (SLR) are important factors in determining the long-term resiliency of coastal regions. Global SLR (GSLR) is driven by climate change, causing the sea level to increase because of thermal expansion as oceans warm and from melting ice sheets and glaciers. Global mean sea level has increased by approximately 6.7 inches (17.0 centimeters) over the last 100 years with noted acceleration since about 1970 (Sweet et al. 2022). However, sea level does not increase uniformly around the globe, it is spatially variable and can change significantly by region. This more locally focused increase is referred to as relative SLR (RSLR), which can be more or less than the global average (Sweet et al. 2022). For example, the RSLR averaged along the contiguous United States has risen about 11.0 inches (27.9 centimeters), which is 4.3 inches (10.9 centimeters) higher than the global mean sea level over the same period. RSLR is a function of vertical land movement (land subsidence/uplift) and changes in regional ocean currents.

The US Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force (Interagency Task Force), which is led by the National Oceanic and Atmospheric Administration (NOAA) and comprised of scientists from several federal agencies and academic institutions, recently published an updated SLR technical report (Sweet et al. 2022). This technical report provides five SLR scenarios projected to 2150 at global, regional, and local scales for all US states and territories. Numerous previous studies based on prior data from the Intergovernmental Panel on Climate Change (IPCC) also characterized SLR around the United States and its territories. These reports, such as Caffrey et al. 2018, provided the foundation for the updated models and observations of Sweet et al. 2022.

The GSLR scenarios, which can be obtained from the Interagency Sea Level Rise Scenario Tool (NASA 2022), are used in conjunction with site-specific data to produce the RSLR projections. These five scenarios cover low, intermediate-low, intermediate, intermediate-high, and high projections of RSLR for the study area, and are shown in table A-1. The projections for GEWA were extracted from the NOAA Lewisetta, VA tidal station (863570) due to the close proximity. The scenario ranges vary as a function of the Shared Socioeconomic Pathways (SSPs) that the climate could be subjected to in the future. SSPs are replacing the terminology of representative concentration pathways and refer to the greenhouse gas (GHG) emission levels that may occur based on societal decisions. Five SSPs were used in the Interagency Task Force study that were integrated from the IPCC's Sixth Assessment Report (IPCC 2021) and each represents possible socioeconomic conditions and technological considerations. These included low-emissions (SSP1-1.9 or SSP1-2.6), intermediate-emissions (SSP2-4.5), and high-emissions (SSP3-7.0 or SSP5-8.5) (Sweet et al. 2022). The low-emission pathways would require strong mitigation of GHG and net negative emissions in the last decades of the 21st century. The intermediate-emission pathways involve stabilizing GHG emissions through 2050 and then decreasing emissions thereafter. The high-emission pathways are considered more "business-as-usual" GHG emission scenarios and involve roughly doubling the current GHG emissions by 2100 and 2050, respectively (Fox-Kemper et al. 2021).

The potential RSLR forecasts cover a broad range depending on which SSP the global climate follows. For example, the low scenario projects 2.12 feet of increase by 2100, while the high scenario projects 7.03 feet of increase by 2100. This is a difference of 4.91 feet, which would have significant implications on the expected risk for the study area. Each scenario has an expected probability of exceedance for the varying SSPs, shown in table A-2, that is useful in determining the acceptable level of risk tolerance when

planning for future water levels. The probabilities shown are specific to the global SLR estimates; however, they still provide useful insight into the exceedance potential of the RSLR estimates. Typically, a conservative approach is recommended due to the amount of uncertainty associated with the projections after the year 2050. This conservative approach is most applicable to projects that are not easily altered to increase resilience, such as fixed structures and infrastructure. Using a conservative approach for projects of this type (i.e., seawalls) can prevent future costs associated with adapting/retrofitting a project that underestimated RSLR over the design life. Comparatively, adaptable projects, such as most nature-based solutions and easily moved/retrofitted structures and infrastructure, could be designed with a less conservative approach. Using a less conservative approach increases the risk that the estimated sea level increase may be exceeded during the project design life, but the upfront cost savings may be a worthwhile exchange when compared to potential future adaptation/retrofitting costs.

The conservative approach is accomplished by using the intermediate-high RSLR projection scenario. As table A-2 depicts, the intermediate-high RSLR scenario has an approximate probability of exceedance that ranges from <1% up to 2%, depending on the severity of future climate change. This means that by 2100, there is only a 2% chance that the estimated sea level increase would be exceeded. Designing and implementing projects with this conservative RSLR approach would help ensure resiliency in the face of ongoing climate change. Additionally, it should be noted that each potential coastal project should go through a cost-benefit analysis to determine the acceptable level of risk and identify the design RSLR scenario and planning timeframe.

Table A-1 Relative Sea Level Rise Scenarios and Projections

Year	Low (feet)	Intermediate-Low (feet)	Intermediate (feet)	Intermediate-High (feet)	High (feet)
2030	0.75	0.80	0.82	0.85	0.86
2040	1.00	1.09	1.14	1.23	1.29
2050	1.25	1.37	1.48	1.66	1.83
2060	1.46	1.66	1.87	2.23	2.57
2070	1.64	1.94	2.32	2.89	3.54
2080	1.79	2.21	2.81	3.63	4.61
2090	1.94	2.47	3.45	4.54	5.74
2100	2.12	2.72	4.16	5.44	7.03
2150	2.97	4.24	7.50	9.05	12.35

Notes:

NOAA Station: Lewisetta, VA station (863570)

National Tidal Datum Epoch: 1983 to 2002

Baseline Year: 2000

Source: Sweet et al. 2022

Table A-2 Probability of Exceeding Global Sea Level Rise Scenarios by 2100

Global SLR Scenario	Low (SSP1-2.6)	Low (SSP1-2.6) to Intermediate (SSP2-4.5)	Intermediate (SSP2-4.5) to High (SSP3-7.0)	High (SSP3-7.0)	Very High (SSP5-8.5)
Low (0.98 feet)	92%	98%	>99%	>99%	>99%
Intermediate-Low (1.64 feet)	37%	50%	82%	97%	>99%
Intermediate (3.28 feet)	<1%	2%	5%	10%	23%
Intermediate-High (4.92 feet)	<1%	<1%	<1%	1%	2%
High (6.56 feet)	<1%	<1%	<1%	<1%	<1%

Notes:

SSP = Shared Socioeconomic Pathway

National Tidal Datum Epoch: 1983-2002

Probabilities are imprecise probabilities, representing a consensus among all projection methods applied. For imprecise probabilities >50%, all methods agree that the probability of the outcome stated is at least that value; for imprecise probabilities <50%, all methods are the probability of the outcome stated is less than or equal to the value stated.

Source: Sweet et al. 2022

Additionally, it should be noted that all these scenarios are initially tied into a baseline year of 2000 while the National Tidal Datum Epoch (NTDE), which covers the period of 1983 to 2001, is tied to a baseline year (mid-point) of 1992. The NTDE covers a 19-year period to ensure that an 18.6-year astronomical cycle that includes all significant variations in the distances to the moon and sun, which produce slowly varying changes in the tidal range, is accounted for in the epoch (Sweet et al. 2017). The current NTDE is more than 20 years old, and it is NOAA's policy to consider revising the NTDE every 20 to 25 years. The NTDE needs to be regularly revised to account for changes in tidal constituents, SLR, and vertical land movement. Tidal constituents describe the effects that the cyclical motion of the earth, sun, and moon have on the tides by breaking these motions down into mathematical constants that essentially form the "building blocks" of the tides, allowing for the prediction of future tides. Currently, NOAA is working on revising the NTDE to cover the period from 2002 to 2020, and it is anticipated to be released in 2025.

As an example of the importance of revising the current NTDE, the NOAA Lewisetta, Virginia tidal station (8635750) near GEWA has an observation-based, historical RSLR trend of 0.22 inches per year. Averaging this RSLR trend over the revised NTDE period of 2002 to 2020 (19 years) results in an expected minimum increase of 4.18 inches (0.35 feet) above the current NTDE tidal datums. This difference conveys that since the establishment of the current NTDE sea levels have increased at this station and this increase is not accounted for in NOAA's currently published tidal datums. It should be noted this is a simplified and static view of the possible increase due to RSLR but highlights that tidal datums referenced to the current NTDE are underestimated in areas experiencing RSLR. The significance of this underestimation varies from location to location and is most pronounced in regions experiencing the highest rates of RSLR. Additional methods exist to account for the increase in sea level since the

NTDE was established. These can involve recalculating tidal datums when adequate data is available or using RSLR projections to adjust the current tidal datums, which is discussed more below.

In many cases, it is of interest to analyze how current tidal datums for a location will change in the future under various RSLR time horizons. Due to the difference in reference baseline years (1992 vs 2000), it is not sufficient to simply add the projected RSLR to the current tidal datums. The baseline year of the RSLR projections (2000) should be shifted backward in time to match the baseline year of the tidal projections (1992). This can be accomplished using one of the three different methods outlined by the Interagency Task Force in their application guide for the updated projections (Collini et al. 2022, Appendix A). These methods involve local observation-based extrapolation, regional observation-based extrapolation, and local linear trend extrapolation. Essentially, when using one of these methods, the goal is to account for the RSLR that occurred between 1992 and 2000 to more accurately estimate the future water levels above the current tidal datums. The most applicable method will vary by location and should be determined on an individual project basis. An example of the results of these three methods is provided in table A-3, which shows the variability that can exist within the different approaches at a given location.

Table A-3. Comparison of three methods results to adjust RSLR for Lewisetta, Virginia

Sea level rise in inches in Lewisetta, Virginia from 1992 to 2020 was determined using local and regional tide-gauge observations. Values are provided relative to the baseline year associated with the data source. The data are presented based on linear and non-linear models of sea level change.

SLR Source	Trend Type	Period	1992	2000	2005	2020	Change
Local Observation-Based Extrapolation ¹	Non-linear	1970 to 2019	-1.8	0.0	1.4	6.5	8.3
Regional Observation-Based Extrapolation ²	Non-linear	1970 to 2019	-2.0	-0.8	0.0	3.5	5.5

1 – Extrapolated observation for tide-gauge PSMSL ID #2324 from NASA Interagency SLR Scenario Tool

2 – Offset values for the Northeast region from Table A1.2 in the 2022 SLR Technical Report

3 – Relative sea level trend data for Station ID #8635750 from NOAA CO-OPS sea level trend database

In summary, understanding the difference between GSLR and RSLR is important for properly characterizing the risk coastal regions face from climate change. Site-specific localized factors can lead to a region experiencing RSLR at a rate above or below the GSLR rate for a given projection scenario. The projections for GSLR and RSLR are easily accessible through the online Interagency Sea Level Rise Scenario Tool and should be reviewed for all coastal projects. Once reviewed, an analysis should be performed to determine the appropriate RSLR scenario and time horizon for incorporation into coastal project planning and design. Lastly, special care needs to be taken to account for the difference in baseline years between NOAA's published tidal datums and the Interagency Task Force's RSLR projections. When properly adjusted, the RSLR projections can be added to the tidal datums to estimate how the datums will change over time.

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APPENDIX B – CONCEPTUAL PROJECTS AND ROUGH ORDER OF MAGNITUDE COSTS

As noted in the Recommendations section of this memo, several possible projects could be executed to provide resilience at GEWA. This appendix provides more details about these possible projects and their rough order of magnitude costs. Additional information was gathered for the analysis within this appendix during a site visit by EA on July 11, 2022. Similar to the recommendations section, the analysis presented in the following text remains cursory. In developing a shoreline management strategy, it is recommended to complete a more thorough analysis of existing information, as briefed within this memo, to identify data gaps, before beginning design of the identified projects.

This appendix does not intend to provide guidance on the specific management decisions for GEWA regarding ongoing coastal erosion but is meant to provide additional description. This information, then, is provided for discussion purposes so that informed decisions can be made by NPS regarding future steps. Additionally, sequencing of implementation of these project scenarios is dependent on management objectives and beyond the scope of the current discussion to elaborate on.

Rough Order of Magnitude Cost Estimates

The rough order of magnitude (ROM) project cost estimates presented in this appendix are based on the National Park Service 2016 Coastal Adaptation Strategies Handbook and the 2013 VIMS Westmoreland County Shoreline Management Plan as well as other project cost information sources. These costs were updated to present-day values using the USACE EM 1110-2-1304 Civil Works Construction Cost Index System, which provides the federal government with a standard procedure for updating construction costs. Design and permitting is included in the overall project costs and estimated at 15 percent of construction cost, which is an industry rule of thumb. Due to the cursory level of the design review and the current uncertainty in material and labor costs due to inflation, a contingency of 30 percent of the construction cost estimate has also been added to the total project cost.

Shoreline Stabilization Options***Beach Areas along GEWA Potomac River******Project Scenario 1 – Living Breakwater and Sediment Nourishment Bridges Creek to Digwood Swamp***

This project proposes shoreline stabilization using living breakwater structures and providing shoreline nourishment to an elevation at the projected 2050 RSLR levels for the area (figure B-1). Figure B-2 shows a schematic of the cross-section of this full project concept. The living breakwaters could range from rip rap structures with integrated vegetation to oyster castles structures. The project is proposed to connect Bridges Creek and Digwood Swamp which are indicated as most vulnerable and vulnerable (respectively) in Hardaway et al. 2009 and would provide an opportunity to provide protection to the eroding high vertical bank in this area of shoreline.

The project proposes to establish the living breakwater at the limit of the 1937 shoreline. This will facilitate easier permitting than if the breakwater location was placed beyond the 1937 shoreline. Considerations such as analysis of hydrodynamic impacts on adjacent shorelines would need to be analyzed through data collection and modeling before proceeding with such a design.

The portion of the design that is situated in front of the high vertical bank would also act to provide stabilization for the base of the bank and provide an area of deposition for eroding material within the nourished area. Subsequently, the material from the bank erosion would add to the stabilizing benefit of the nourished area. Although not presented as a project scenario, this same treatment could be used in front of other high and low bluff locations at GEWA to help provide resilience to these formations.

Other options which can be considered to help stabilize the top of the bluff areas and reduce the impacts of erosion over time include:

- Maintain fencing to keep pedestrian traffic away from the erodible bluff crest. Fencing should be a minimum of 10 to 15 feet back from the bluff edge and tall enough to prevent visitors from crossing it.
- Establish further vegetation on the bluff up to the crest as much as feasible. This would include species of local flora which can be determined through careful planning to maximize protective benefits. This vegetation would generally provide greater stability to the bluff through root action. With the pedestrian fence in place, this would provide further protection for the vegetative growth that in turn will help stabilize the bluff surface.
- If there are areas where ponding or higher infiltration of stormwater is occurring, alternatives for reducing infiltration in these flow-concentrating areas could be developed. One approach could be to fill and regrade ponding areas that currently hold water to shed water away from the bluff. In addition, selective planting of trees in the ponding areas could allow for phytopumping (removal of excess water through evapotranspiration) of water from the bluff. Another approach could be to install an engineered system such as French drains or subsurface tile drains which can spread the infiltration area. This would aid in subsurface flow distribution and reduce flow along the face of the bluff slope. This type of focal point exfiltration is a condition that can lead to increased erosion on the slope.

The overall cost of Project Scenario 1 is approximately \$2,100,000, and the project element costs are presented in Table B-1. This cost does not include specific upland treatments for bluff erosion.

Table B-1 Project Scenario 1 – Living Breakwater and Sediment Nourishment Bridges Creek to Digwood Swamp – Rough Order of Magnitude Cost Estimate

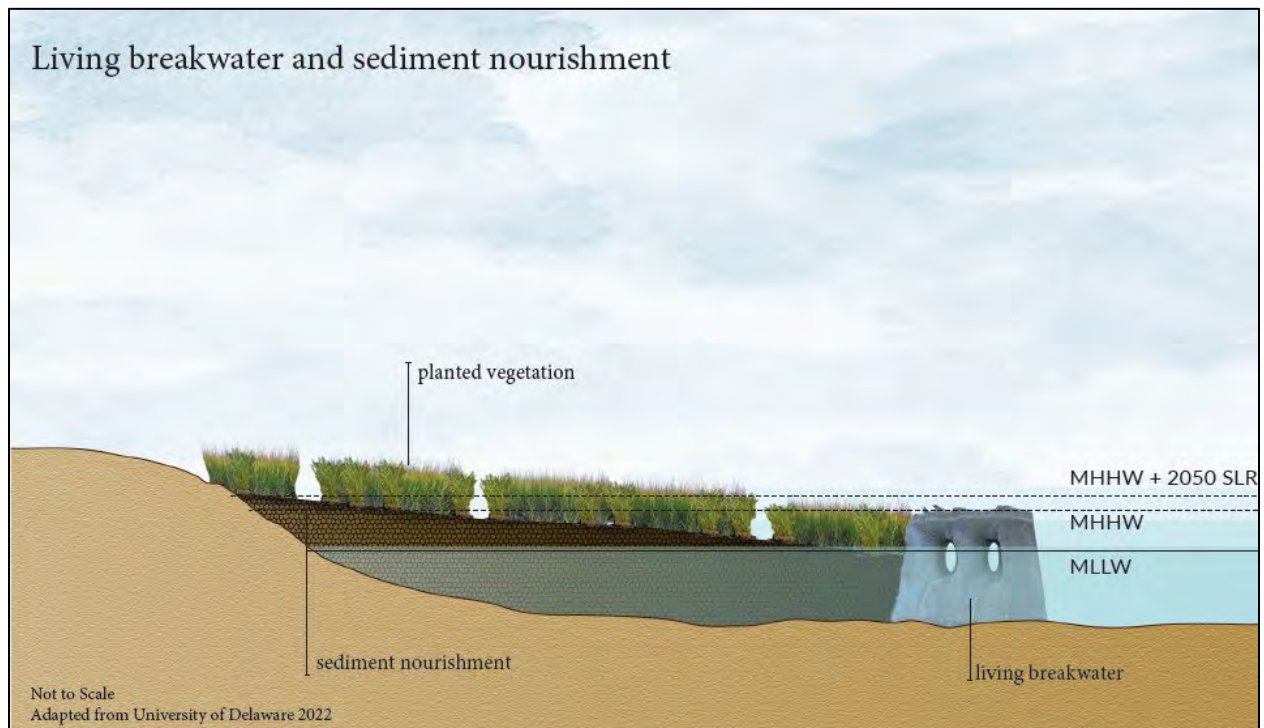
Project Element	Quantity	Units	Construction Cost	Cost
Living Breakwater	3,790	feet	\$150	\$568,500
Sediment Placement	9,700	cubic yards	\$40	\$388,000
Vegetation	241,400	plugs	\$2	\$482,800
Construction Cost	1	—	—	\$1,439,300
Design and Permitting	1	—	—	\$215,895
Contingency	1	—	—	\$431,790
Total Project Cost	1	—	—	\$2,086,985

Notes: 1) All values shown are in Fiscal Year 2023 (October 2022) costs
 2) Vegetation assumes a 1-foot-on-center planting scheme
 3) The Design and Permitting is based on 15% of the Construction Costs
 4) The Contingency is based on 30% of the Construction Costs

Figure B-1. Shoreline stabilization conceptual projects



Figure B-2. Living breakwater and sediment nourishment



Project Scenario 2 – Living Breakwater and Sediment Nourishment Popes Creek Bar

This project would be similar in configuration elements to Project Scenario 1 and proposes stabilizing the Potomac River shoreline using living breakwater structures (oyster castles) and providing nourishment of the shoreline to an elevation at projected 2050 RSLR levels for the area (figure B-1). This area has been highly eroded over time and the proposed project would aim to establish the footprint of the land to the 1937 configuration. The establishment of the breakwater is depicted as being functionally deployed around the nourished area, however, as with Project Scenario 1, this project configuration will need to be modeled to determine impacts to adjacent shorelines.

The overall cost of Project Scenario 2 is approximately \$3,500,000, and the project element costs are presented in table B-2.

Table B-2. Project Scenario 2 – Living Breakwater and Sediment Nourishment Popes Creek Bar – Rough Order of Magnitude Cost Estimate

Project Element	Quantity	Units	Construction Cost	Cost
Living Breakwater	2,770	feet	\$2,500	\$415,500
Sediment Placement	22,500	cubic yards	\$40	\$900,000
Vegetation	544,400	plugs	\$2	\$1,088,800
Construction Cost	1	—	—	\$2,404,300
Design and Permitting	1	—	—	\$360,645
Contingency	1	—	—	\$721,290
Total Project Cost	1	—	—	\$3,486,235

Notes: 1) All values shown are in Fiscal Year 2023 (October 2022) costs

2) Vegetation assumes a 1-foot-on-center planting scheme

3) The Design and Permitting is based on 15% of the Construction Costs

4) The Contingency is based on 30% of the Construction Costs

Popes Creek

Project Scenario 3 –Popes Creek Wetland Restoration

The significant reduction in tidal wetlands over time within Popes Creek along with the reduction in size of the Popes Creek Bar, allows more wave energy to enter this area. This Project Scenario would look to restore the wetland configuration that existed in 1937. As seen from figure B-1, this would include placement of sediment in these areas to a depth that would allow for most efficient plant establishment. The elevation would also be set so that the plantings would be as resilient as possible to 2050 RSLR in areas where islands and marsh no longer exist. On the areas which include existing marsh islands, the option of using thin layer placement of sediment will be evaluated and it is assumed that these existing areas will have sediment placed to a depth to provide resilience to 2050 RSLR while also increasing the depth not more than existing vegetation could be expected to continue to grow. In addition to these treatments, one area of living breakwater (oyster castles) would be placed in front of the central island within this area to provide additional resilience at this location.

The overall cost of Project Scenario 3 is approximately \$7,600,000, and the project element costs are presented in table B-3.

Table B-3. Project Scenario 3 –Popes Creek Wetland Restoration – Rough Order of Magnitude Cost Estimate

Project Element	Quantity	Units	Construction Cost	Cost
Living Breakwater	720	feet	\$2,500	\$108,000
Sediment Placement	62,000	cubic yards	\$40	\$2,480,000
Vegetation	1,328,900	plugs	\$2	\$2,657,800
Construction Cost	1	—	—	\$5,245,800
Design and Permitting	1	—	—	\$786,870
Contingency	1	—	—	\$1,573,740
Total Project Cost	1	—	—	\$7,606,410

Notes: 1) All values shown are in Fiscal Year 2023 (October 2022) costs

2) Vegetation assumes a 1-foot-on-center planting scheme

3) The Design and Permitting is based on 15% of the Construction Costs

4) The Contingency is based on 30% of the Construction Costs

Project Scenario 4 –Popes Creek Visitor’s Center Shoreline Stabilization

One area of concern along the Popes Creek shoreline of GEWA is the Visitor’s Center. For this project scenario, an oyster castle configured to provide resilience to 2050 RSLR would be situated on the shoreline adjacent to the Visitor’s Center placed to the 1937 shoreline. For this project scenario, no sediment placement is proposed as the oyster castles will function to reduce wave impacts to the shoreline, and also act to retain sediment from erosion of this area of the shoreline.

The overall cost of Project Scenario 4 is approximately \$126,100, and the project element costs are presented in table B-4.

Table B-4. Project Scenario 4 – Popes Creek Visitor's Center Shoreline Stabilization – Rough Order of Magnitude Cost Estimate

Project Element	Quantity	Units	Construction Cost	Cost
Living Breakwater	580	feet	\$2,500	\$87,000
Construction Cost	1	—	—	\$87,000
Design and Permitting	1	—	—	\$13,050
Contingency	1	—	—	\$26,100
Total Project Cost	1	—	—	\$126,150

Notes: 1) All values shown are in Fiscal Year 2023 (October 2022) costs

2) The Design and Permitting is based on 15% of the Construction Costs

3) The Contingency is based on 30% of the Construction Costs

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