

Memorandum – Coastal Engineering Review

George Washington Birthplace National Monument (GEWA) Trail Scour Mitigation

TAR 33213

24 July 2024

REVIEW REQUEST SUMMARY

George Washington Birthplace National Monument (GEWA) is experiencing coastal erosion, resulting in scour along approximately 200 feet of the Natural Trail bordering Popes Creek. This section of the Natural Trail has been closed due to the potential safety hazard caused by the scour. The trail lies behind two sections of wall, constructed of degraded timber posts, and has lost 2 to 3 feet of trail width due to erosion with up to a foot of undercut in some places. The National Park Service is seeking support to identify and evaluate potential solutions for the scoured trail to maintain the trail for public use.

Background

GEWA will engage in a climate change adaptation planning process in the near future. The first phase of this process will categorize facilities investments, but it is not yet known if it will be initiated this year. Long-term solutions will be implemented thereafter. The park needs a strategy to address the current trail erosion that could be effective for 5 to 10 years (or longer) before long-term planning solutions would be fully implemented. The park has completed a climate change vulnerability assessment in which the Nature Trail (including the portion affected by scour) was scored as high vulnerability (Peek et al. 2023; Ricci et al. 2024).

On March 4, 2024, EA Engineering, Science, and Technology, Inc., PBC (EA) staff met with GEWA staff and reviewed the affected area. The group discussed current trail conditions and project goals. GEWA is seeking a wide range of solutions to address the current scour. This memo analyzes the existing conditions and potential solutions with the following considerations:

- Impacts on trail use
- Qualitative cost estimates
- Regulatory considerations
- Longer term sustainability of solution, i.e.—is the solution only short-term or is there potential to support future climate change resilience?

EXISTING CONDITIONS

Trail Conditions

The erosion is affecting approximately 200 feet of trail along Popes Creek, a tidally influenced creek that flows into the Potomac River and the greater Chesapeake Bay. GEWA staff noted the increased frequency of tidal flooding with higher tides flooding the trail around once a month and the water level of Popes Creek sometimes reaching the bottom of the nearby footbridge. The trail connects the picnic area with the

footbridge and the trail along Dancing Marsh (figure 1, NPS 2024). The trail is popular and widely used, hence the park is seeking solutions to keep the trail open to the public.

The erosion is occurring behind and between two existing sections of timber wall, one further east and one west, just south of the park office (figure 1). The walls are constructed of wooden posts lined with geotextile fabric (figures 2 and 3). GEWA staff noted that historical photographs indicate the shoreline was modified in the 1930s, and the shoreline appears to have retreated landward since that time. This is supported by the presence of an older wooden post in the creek, approximately 3 feet waterward of the current walls (figures 4 and 5). The history of these older wooden posts is not known. The current walls were installed in the 1990s. Park staff noted that during the 1990 wall installation, a backhoe was used to push the timber posts in. Gravel, bricks, and other fill material were observed behind the walls (figures 2, 3, and 5), which was likely placed during the 1990 installation although some may have been present prior. The condition of the timber walls varies, with some sections showing no signs of significant degradation (figure 6) and other sections in poor condition (figures 2, 3, 4, and 5). Shoreline erosion has resulted in portions of the trail behind the wall being lost from the formation of scour holes. The erosion varies in magnitude up to approximately 3 feet deep (figure 3) in some locations. Additionally, some areas have undercut up to 1 foot potentially leading to additional instability (figure 7). The section of the trail experiencing undercut lacks timber wall protection and has experienced more shoreline retreat.

Elevations and Projected Sea Level Rise

The most recent elevation data available for the site, downloaded from National Oceanic and Atmospheric Administration (NOAA) Digital Coast, are from the 2018 US Geological Survey (USGS) LiDAR for the Upper Middle Neck, Virginia provided by the NOAA Office for Coastal Management (NOAA OCM 2024). These elevation data indicate the trail has an elevation ranging from 1 to 8 feet, referenced to North American Vertical Datum of 1988 (NAVD88).

The nearest tidal stations to GEWA are Dahlgren, Virginia (Station ID: 8635027), located about 10 miles upstream on the Potomac River, and Lewisetta, Virginia (Station ID: 8635750), located about 30 miles downstream on the Potomac River (figure 8). Tidal datums from these two stations, in feet relative to NAVD88, are shown in figures 9 and 10 (NOAA 2024a, NOAA 2024b). A local datum for GEWA was estimated by interpolating between the Dahlgren and Lewisetta values based on relative distance from the site. These interpolated values are given in table 1.

Figure 1. GEWA Trail Map

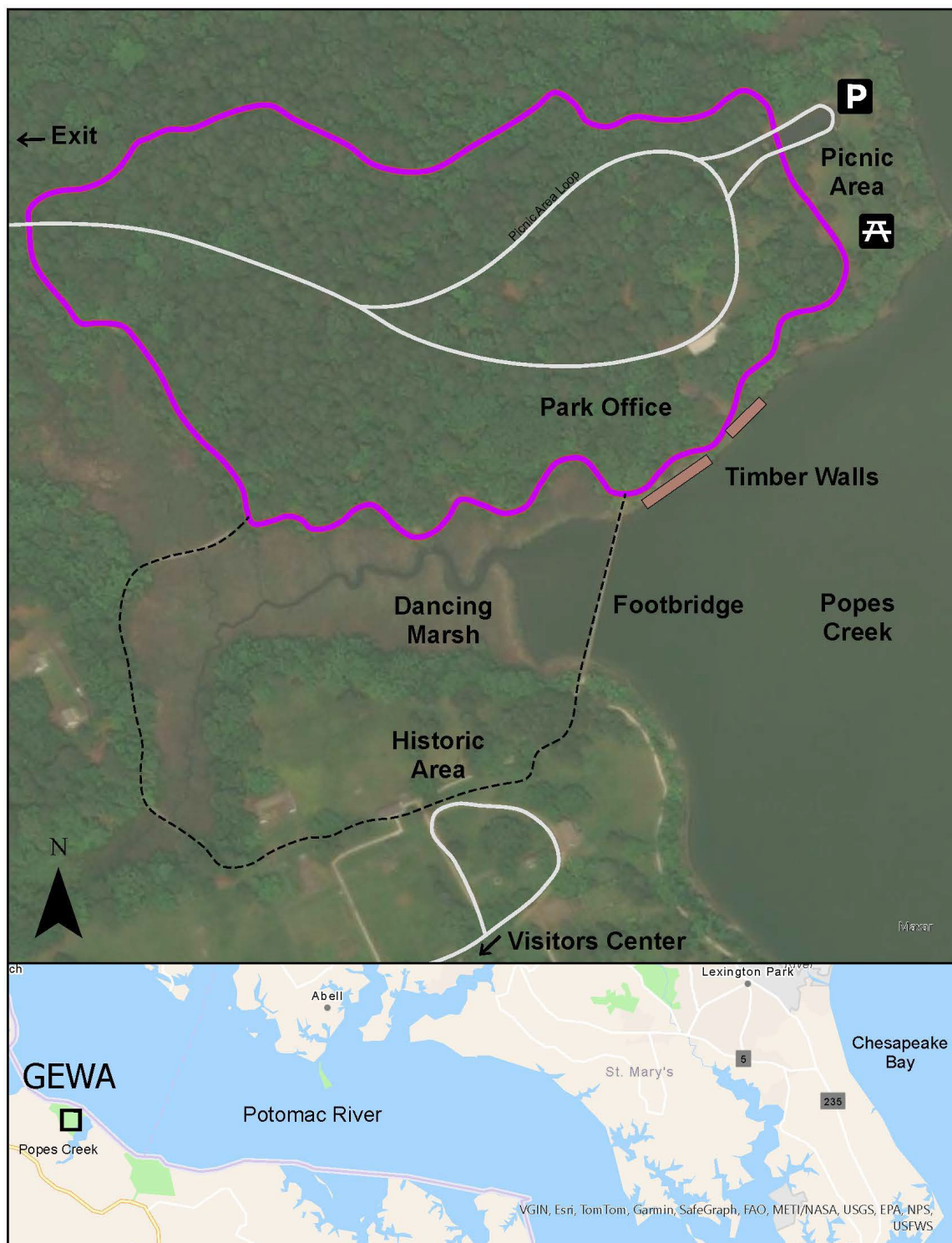


**Figure 2. Timber Wall Scour Revealing
Geotextile Fabric and Fill Material**



**Figure 3. Trail Erosion Behind the Timber Wall
(erosion is up to 3 feet wide)**



**Figure 4. Historic Timber Posts Behind
Western Wall Section**



Figure 6. Western Wall Section



**Figure 5. Historic Timber Posts Behind Edge
of Eastern Wall Section**



Figure 7. Trail Undercut



Figure 8. NOAA Tidal Stations Near GEWA

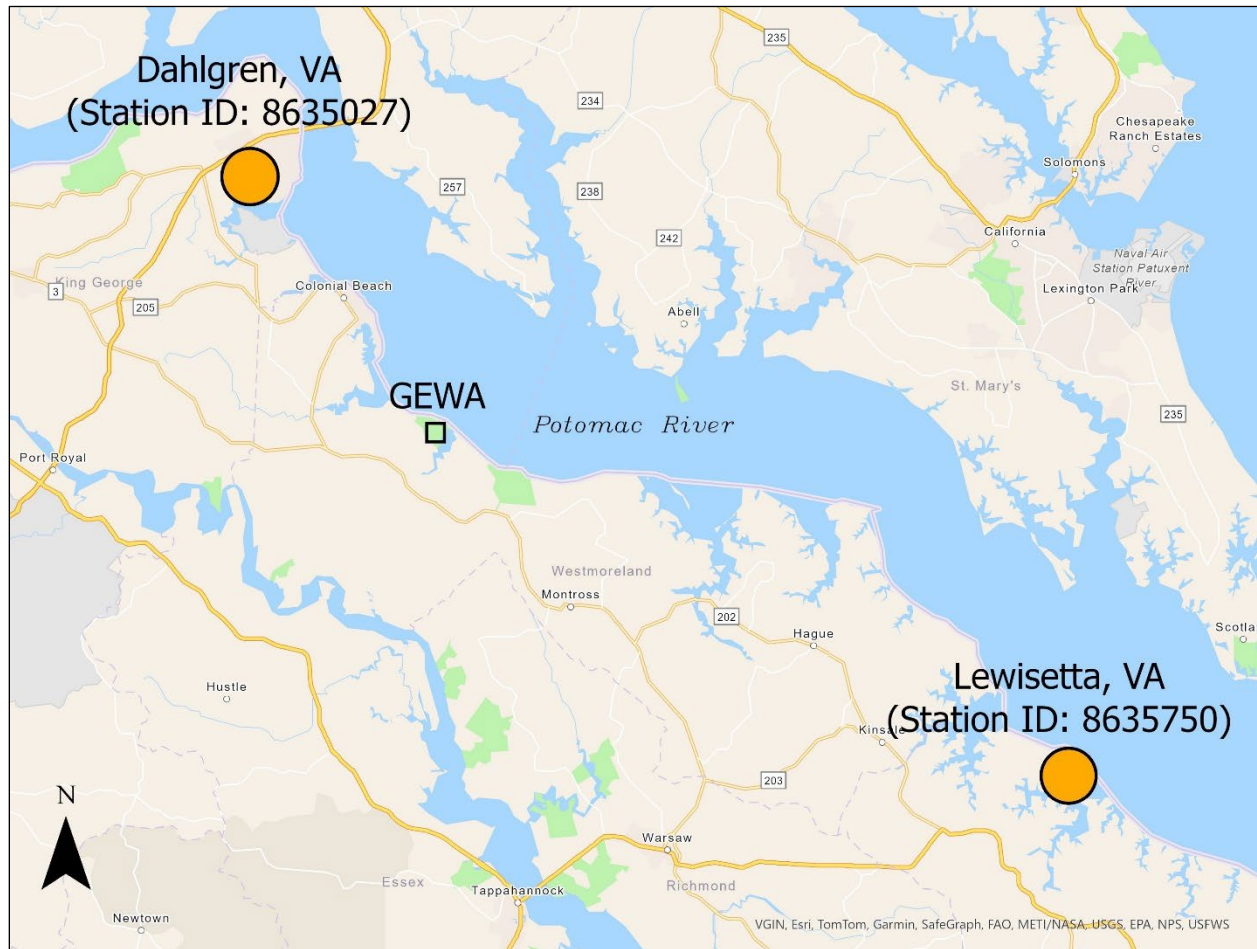
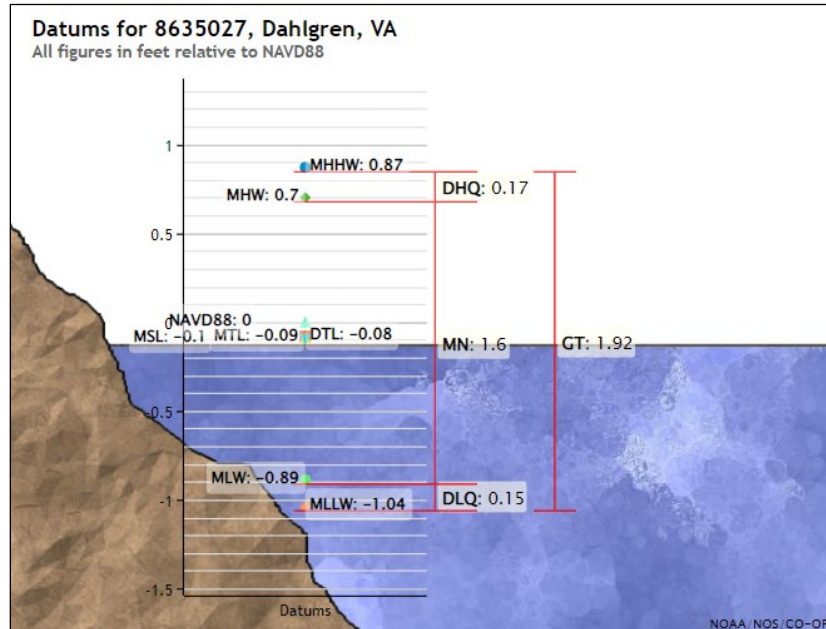


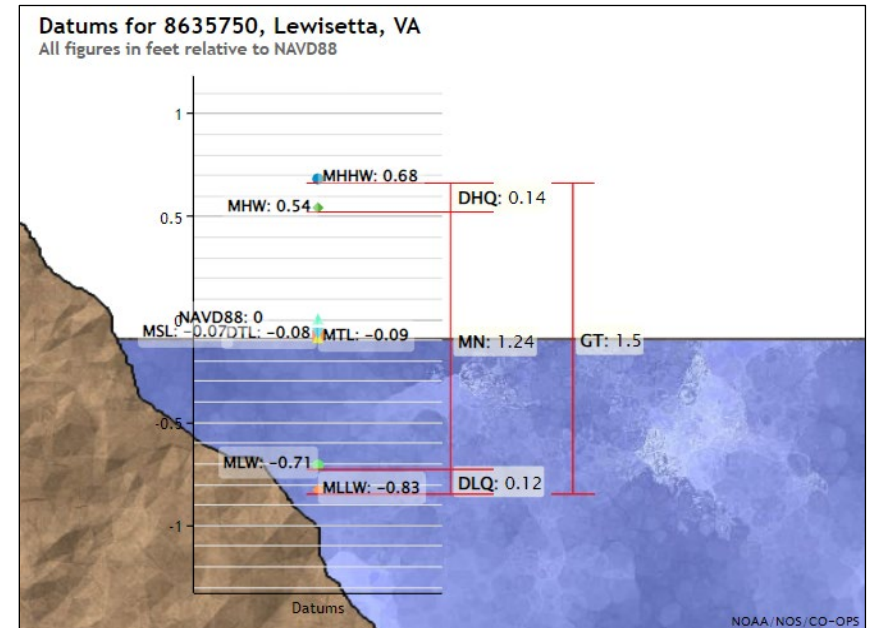
Figure 9. NOAA Tidal Datums for Dahlgren, Virginia



Notes:

Values given in feet NAVD88 (North American Vertical Datum of 1988), rounded to the tenths decimal place
MHHW – mean higher high water
MHW – mean high water
MSL – mean sea level
MLW – mean low water
MLLW – mean lower low water
DHQ – mean diurnal high water inequality
DLQ – mean diurnal low water inequality
DTL – mean diurnal tide level
MTL – mean tide level
GT – great diurnal range

Figure 10. NOAA Tidal Datums for Lewisetta, Virginia



Notes:

Values given in feet NAVD88 (North American Vertical Datum of 1988), rounded to the tenths decimal place
MHHW – mean higher high water
MHW – mean high water
MSL – mean sea level
MLW – mean low water
MLLW – mean lower low water
DHQ – mean diurnal high water inequality
DLQ – mean diurnal low water inequality
DTL – mean diurnal tide level
MTL – mean tide level
GT – great diurnal range

Table 1. Interpolated Tidal Datums, Baseline Year of 1992

Year	MHHW (feet, NAVD88)	MHW (feet, NAVD88)	MSL (feet, NAVD88)	MLW (feet, NAVD88)	MLLW (feet, NAVD88)
1983-2001 Tidal Epoch	0.81	0.65	-0.09	-0.84	-0.98

Notes:

Values given in feet NAVD88 (North American Vertical Datum of 1988), rounded to the tenths decimal place

MHHW – mean higher high water

MHW – mean high water

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MLLW – mean lower low water

DHQ – mean diurnal high water inequality

DLQ – mean diurnal low water inequality

DTL – mean diurnal tide level

MTL – mean tide level

GT – great diurnal range

The tidal datums displayed above are from the last National Tidal Datum Epoch (NTDE) which is calculated from water levels from 1983 to 2001, with a baseline year of 1992. Because this NTDE is over 20 years old, the tidal predictions are generally lower than actual water levels. Currently, NOAA is revising the NTDE to cover the period from 2002 to 2020, and it is anticipated to be released in 2025. For this analysis, current water levels are estimated as the sum of the above-interpolated datums and estimated sea level rise between 1992 and 2020, discussed further below.

The Interagency Task Force 2022 Sea Level Rise Technical Report (Sweet et al. 2022) provides the most recent relative sea level rise (RSLR) projections — the predicted sea level rise based on the conditions of a specific location. Sea level rise data were taken from the Lewisetta station (referenced above), being the closest tidal station to GEWA with RSLR projections. These RSLR projections were adjusted from a baseline year of 2000 to a baseline year of 1992 (matching the NTDE) using the Interagency Task Force’s application guide for the updated projections (Collini et al. 2022), which applies a vertical adjustment factor from the observation extrapolation record of RSLR available at the Lewisetta tidal station. Making this adjustment is necessary to allow for easy addition of the RSLR projections and the site tidal datums.

Table 2 presents the RSLR projections for five different climate change scenarios based on future emissions. The RSLR values are given for the years 2030 and 2040 to show the projected sea level rise in the next decade, the period of interest for current solutions to the trail erosion issue, and for years 2070 and 2150, to show later projections of sea level rise for future planning. The intermediate-high RSLR projections provide a conservative estimate of future conditions. Table 3 shows the projected tidal datums under the intermediate-high RSLR scenario for the same years of interest. Table 3 also gives tidal datum values for 2020, calculated by adding a vertical adjustment factor to account for the estimated sea level rise between 1992 and 2020 (using the same Collini et al. 2022 method as discussed above) to the interpolated tidal datums (table 1).

Table 2. Relative Sea Level Rise Scenarios – Lewisetta, Virginia Station (8635750), Baseline Year of 1992

Year	Low	Intermediate Low	Intermediate	Intermediate High	High
2030	0.92	0.97	0.99	1.02	1.02
2040	1.19	1.27	1.32	1.41	1.47
2070	1.85	2.15	2.52	3.10	3.73
2150	3.26	4.53	7.78	9.28	12.58

Notes:

Values given in feet NAVD88 (North American Vertical Datum of 1988), rounded to the tenths decimal place

Source: Sweet et al. 2022

Table 3. Projected Tidal Datums Under Intermediate-High RSLR Scenario, Baseline Year of 1992

Year	MHHW (feet, NAVD88)	MHW (feet, NAVD88)	MSL (feet, NAVD88)	MLW (feet, NAVD88)	MLLW (feet, NAVD88)
2020	1.51	1.34	0.60	-0.15	-0.29
2030	1.84	1.67	0.93	0.18	0.04
2040	2.23	2.06	1.32	0.57	0.43
2070	3.92	3.75	3.01	2.26	2.12
2150	10.10	9.93	9.19	8.44	8.30

Notes:

Values given in feet NAVD88 (North American Vertical Datum of 1988), rounded to the tenths decimal place

MHHW – mean higher high water

MHW – mean high water

MSL – mean sea level

MLW – mean low water

MLLW – mean lower low water

Future tidal datums were calculated as table 1 datums plus Sweet et al. 2022 intermediate-high RSLR scenario.

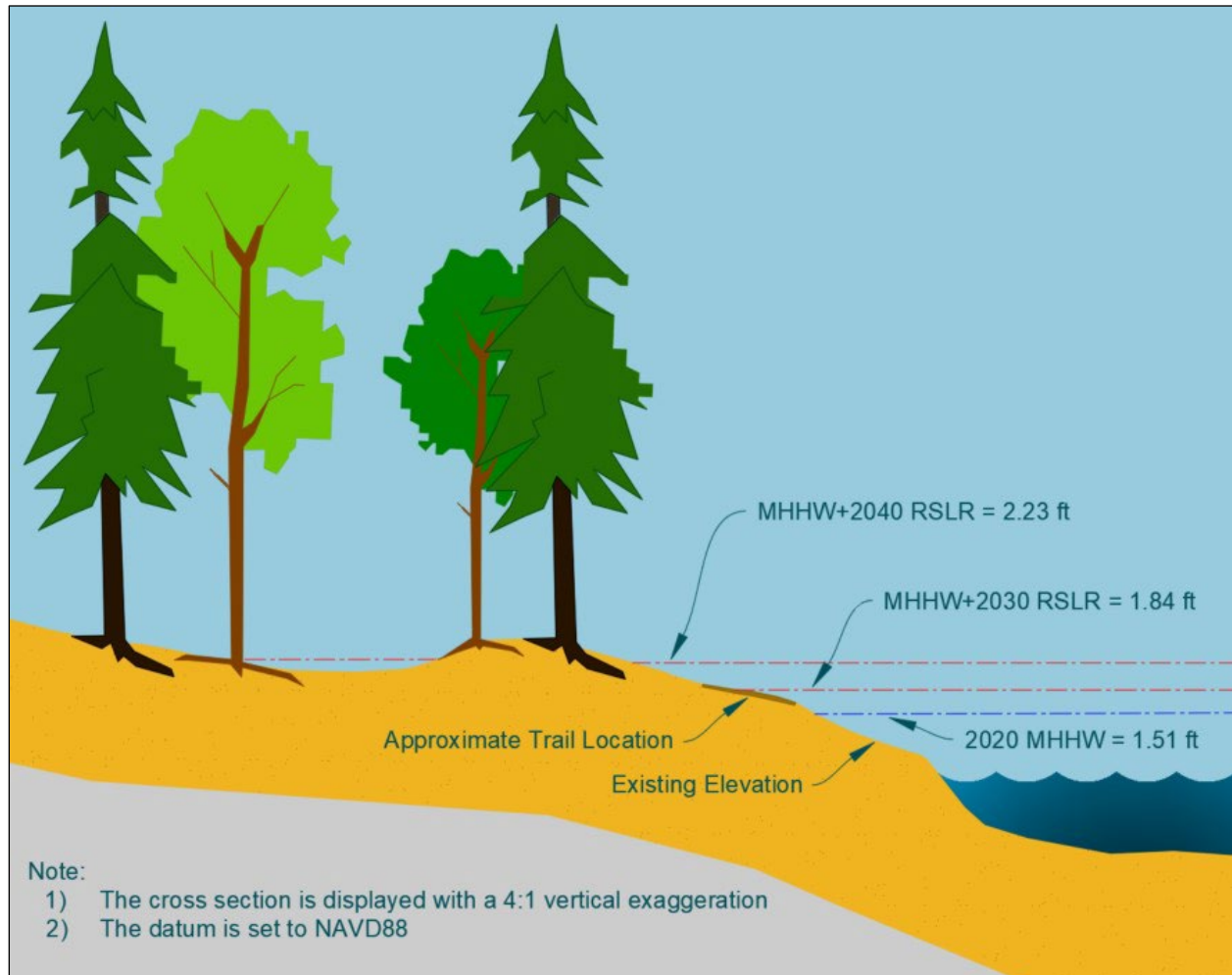
Sources: Dahlgren, Virginia (8635027) and Lewisetta, Virginia. (8635750) stations (NOAA 2023a, NOAA 2023b) and Sweet et al. 2022.

Figure 11 shows the mean higher high water (MHHW), the average of the highest tides within each tidal day, estimated for 2020 and projected for 2030 and 2040 over a cross-section of existing land elevation extracted from the 2018 LiDAR data (NOAA OCM 2024) discussed above.

The cross-section for figure 11 was taken across a section of trail that GEWA staff noted floods almost monthly during especially high tide events. Figure 11 shows the 2020 MHHW of 1.51 feet NAVD88 falls inches below the approximate trail location, supporting the observed flooding conditions. The projected 2030 MHHW reaches the trail elevation, indicating that within the next six years, this section of the trail will be flooded once a day, while the 2040 MHHW indicates the trail section will be almost a half-foot underwater once a day and flooded for a significant portion of the day within just over a decade. The section of trail represented by this cross section is at a relatively lower elevation than other sections of the

trail, therefore this image indicates the most severe flooding case, however other sections of the trail are also expected to experience increased flooding in the coming decade.

Figure 11. Trail Cross Section with Project Sea Level Rise



POTENTIAL SOLUTIONS

The following section outlines potential solutions to trail erosion and discusses the potential impact on trail use, relative cost, and permitting and sustainability considerations for each. An emphasis was put on nature-based solutions (NBS) these types of projects are a priority for the National Park Service and Department of the Interior. These solutions are described in detail below and include the following:

- Shoreline protection and trail elevation including:
 - Replace existing walls in-kind
 - Modified walls
 - Living revetment or gabiond
 - Coir logs

- Boardwalk
 - Free-standing
 - Inground
- Trail relocation
- Partial boardwalk and trail relocation
- Elevation maintenance
- Vegetation and upland runoff management and offshore living structures

Permitting and Regulatory Considerations

Virginia state law defines land below MLW as state land. For a project with impacts on tidal wetlands, which likely include those projects with impacts below MLW, permitting will be required from federal, state, and local agencies. The US Army Corps of Engineers (USACE) issues federal permits, Virginia Water Protection Permits for tidal wetlands are issued by the Virginia Department of Environmental Quality (DEQ), and permits for the intertidal zone are issued locally and overseen by the Virginia Marine Resources Commission (VMRC) (Wetlands Watch 2024). A Joint Permit Application (JPA) can be submitted to the VMRC to be reviewed by all the above-mentioned federal, state, and local (Local Wetland Boards) permitting agencies (Virginia Institute of Marine Science [VIMS] 2024b). The Virginia Tidal Waters regulations § 28.2-104.1. *Living shorelines; development of general permit; guidance* states that living shorelines are the preferred solution for shoreline stabilization, and the VMRC will require living shoreline solutions unless the best available science indicates a living shoreline is unsuitable (Commonwealth of Virginia 2024).

The VMRC collaborates with VIMS to develop technical guidance for tidal shoreline management, which provides a technical basis for permitting (Commonwealth of Virginia 2024). One such guidance tool is the VIMS Virginia Coastal Resources Tool which maps the Preferred Shoreline Best Management Practices (BMP) along the Virginia coast. The BMP identified for most of GEWA's shoreline along Popes Creek, including the stretch along the trail, is a non-structural living shoreline (VIMS 2024a). A non-structural living shoreline is defined as follows by the VIMS tool:

Remove existing shoreline structure if present; grade bank if necessary and install a non-structural living shoreline which may include riparian buffer planting along the bank, and/or marsh plants, coir logs, or oyster reefs along the shoreline. Best choice for low-energy environments.

The living revetment or coir log solutions, discussed below, align with VIMS guidance on the BMP for Popes Creek. Trail relocation, partial relocation, and vegetation management may also be considered as BMPs if they are implemented in conjunction with a living shoreline. The above identified BMP solutions are also NBS, a current priority for the National Park Service.

Shoreline Protection

One solution for the current erosion problem is to enhance shoreline protection and elevate the trail with fill material to a level sufficient to resist nuisance flooding. This solution allows for the continued use of the current trail in the coming decade. Some shoreline protection options include:

- Replacing existing walls in-kind
- Modified walls
- Living revetment or gabions
- Coir logs

Replacing the existing timber walls in kind would require repeating similar maintenance to that which was conducted in the 1990s, replacing the existing wooden posts and refilling the eroded sections between the wall and the trail. While replacing the walls in kind follows the precedence of the existing structure, this solution would likely still require permitting, as discussed at the end of this section.

The existing timber walls could also be modified to provide more robust protection. This could involve connecting the two sections of the wall to fill the gap between the eastern and western sections, building the wall out of stronger material, like rock and concrete, reinforcing the wooden posts with riprap or other material, or a combination of these solutions. These types of modified walls could provide more protection along the trail but pose several challenges. This solution would be more costly than the replace-in-kind solution and does not follow the precedence of the existing structure. Replacement of the existing timber posts with new posts would be expected to have a design life of around 20 years and maintain the current aesthetics. Replacement of the wooden wall with rock or concrete would change the aesthetics of the site and may not be required to prevent further shoreline erosion. However, hardening of the shoreline could also exacerbate erosion at the edges of the walls.

Another shoreline protection option is a living shoreline structure at the toe of the shoreline, which could be a revetment or gabions constructed with materials to target shellfish growth. These structures could provide shoreline stabilization as well as potential habitat for aquatic species. Potential living shoreline revetment materials include stone, oyster bags (figure 12), and oyster castles (figure 13). Gabions are baskets filled with material such as stones or oyster shells (figure 14). Both revetments and gabions would probably be less expensive than a modified wall.

Another shoreline protection option is coir logs, which are biodegradable woven bags filled with biodegradable material (figure 15). This solution is likely the least costly among the shoreline protection options. However, coir logs would be a more temporary solution because they are designed to break down, with an expected life span of 3-5 years, at which point new coir logs would need to be installed or other action taken.

All the above discussed shoreline protection solution may require state and federal permitting, as they would likely include impacts to areas below Mean Low Water (MLW). The permitting preference for a living shoreline and identified VIMS BMP described above indicate a living revetment or coir logs would be the Virginia Marine Resource Commission's preferred solutions from a tidal wetland permitting perspective. Additionally, both a living revetment and coir logs constitute NBSs.

Trail Elevation

Installation of one of the shoreline protection options described above would address shoreline erosion; however, without trail elevation, nuisance flooding would not be resolved. The shoreline protection option could be paired with elevating the trail by the placement of fill material behind the shoreline protection structure. Sections of the trail (figure 11) are already experiencing monthly nuisance flooding and the frequency is likely to increase to daily within the next 5 to 10 years. Therefore, the trail needs to

be elevated to a height of at least 2 feet NAVD88 or greater by 2030 for it to remain operational (refer to table 3). Additional elevation will likely be required in the future to keep addressing sea level rise, and a higher elevation may be required to withstand future impacts of storm surge. Additionally, maintenance of the trail and shoreline protection structure may be needed after significant storm events. Trail elevation using fill material is something that should be discussed with Virginia state regulators early and may pose regulatory challenges due to the location within a tidal area. Fill material selection will require coordination with regulators, but may include gravel, rock, sand, soil, or another native material and should be assessed for appropriateness to the local environment (locally sourced if possible) and the comfort and safety of trail users.

Given the projected sea level rise, the combination of a shore protection method outlined above and elevating the trail will probably not provide long-term protection against the impacts of climate change and would likely only serve as a short-term solution to maintain trail access for the coming 5 to 10 years.

Figure 12. Oyster Bag Revetment



Source: North Carolina Coastal Federation (2016)

Figure 13. Oyster Castle Revetment



Source: US National Science Foundation (2024)

Figure 14. Gabion Baskets



Source: Sri Lanka Coast Conservation & Coastal Resources Management Department (2020)

Figure 15. Coir Logs



Source: Delaware Living Shorelines Committee (2024)

Boardwalk

A boardwalk is another potential solution to the existing trail erosion problem that would allow continued public use of the trail. Two boardwalk types that could be used at GEWA are:

- Free-standing boardwalk
- Inground boardwalk

Free-standing boardwalks sit on the ground without any anchoring into the ground. Inground boardwalks include anchoring with inground piles. A free-standing boardwalk is less expensive and easily reversible compared to an inground boardwalk. However, a free-standing boardwalk may not be appropriate for a shoreline area as storm and flooding events could impact and potentially move the boardwalk. Also, an inground boardwalk could be elevated without using fill material to keep the trail above nuisance flooding. The elevation of a boardwalk should be set to maintain trail access as water levels rise. A boardwalk elevation higher than 2.23 feet NAVD88, the MHHW projection for 2040 given in table 3, is likely to avoid nuisance flooding through 2040; however, a higher elevation may provide greater protection from storm events and future sea level rise projections. An elevation higher than 3.9 feet NAVD88 would likely withstand mean higher high-water levels through 2070 (table 3), but it would still be subject to flooding during storm events. There is a risk that as water levels rise, the land on which the boardwalk sits will be lost, which could require future maintenance or result in the failure of the boardwalk.

GEWA has several boardwalks already, including both free-standing and inground boardwalks, all constructed of wood. Two free-standing boardwalks were permitted and built in 2020 at a cost of around \$8,000 (figure 16). An inground boardwalk was built approximately a decade ago. The cost of a free-standing boardwalk would probably be lower than a modified wall and a revetment or gabions, while a

timber wall replaced-in-kind and coir logs are probably a comparable cost or cheaper than a free-standing boardwalk. An inground boardwalk would provide additional benefits but would be more expensive.

Figure 16. Existing GEWA Free-Standing Boardwalk



Trail Relocation and Partial Trail Relocation with Boardwalk

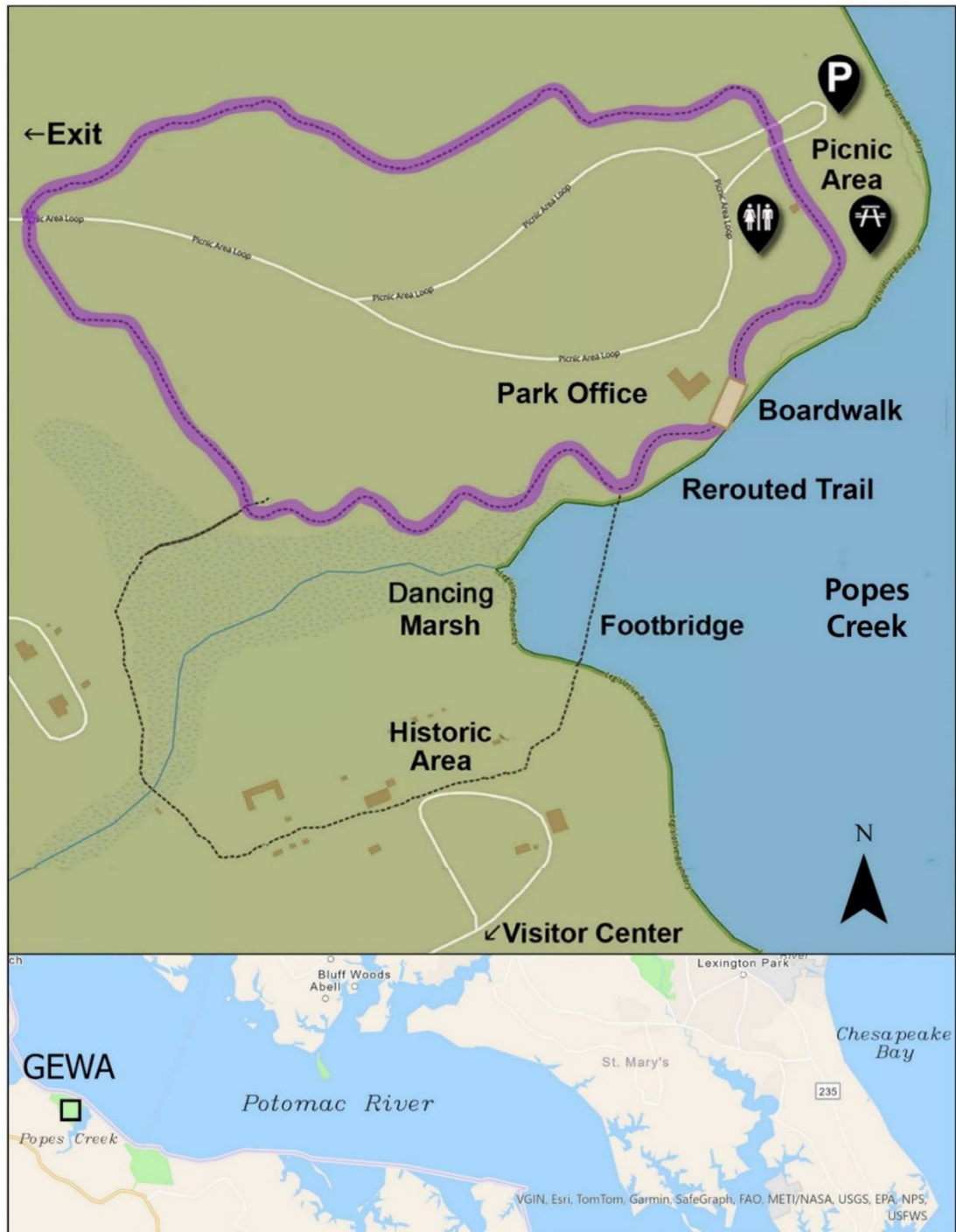
Another solution to the current trail erosion problem is to relocate the section of the trail experiencing erosion, either by closing that section of trail or making a new trail further inland. Relocation is likely cheaper to implement, requiring minimal construction, but may require some earthwork and limited permitting to construct a new trail. GEWA staff noted that if the trail was rerouted around the park office, there are concerns about traffic problems since pedestrians would have to cross the road leading to the picnic site. Also, there is limited space to move the trail further inland because of the proximity to the office building. The office building is also used as staff housing and has been previously used as an event venue, and the park would like to avoid moving the trail closer to the building to maintain privacy and to have the option to use the space for events again in the future.

Another potential solution is to build a boardwalk over the eastern section of erosion, closest to the park office, and reroute the western section of trail back away from the shore (figure 17). This solution would provide the same benefits as the boardwalk solution, by maintaining trail access, while minimizing the cost of boardwalk construction and maintaining some distance between the park office and the trail.

It is noted that both the reroute trail and partial reroute trail solution offer a method to begin strategic retreat of resources from the shoreline. As sea levels continue to rise, managing retreat will be an important step to adapt to the changing conditions. Trail relocation could also be a VIMS BMP and NBS solution if it includes the construction of a living shoreline in this area. Additionally, the retreat of the trail from the coast could allow for the reestablishment of vegetation in its place, supporting future climate

resiliency. There are state and local regulations under the Chesapeake Bay Preservation Act covering a 100-foot-strip shoreline buffer. Significant vegetation alterations within the buffer require an application for a Chesapeake Bay Act exception (Wetlands Watch 2024). Trail relocation might entail significant clearing and in which case would require an exception application.

Figure 17. Map of Boardwalk with Partial Rerouted Trail



Elevation Maintenance

Another solution to address the erosion is to maintain the trail elevation at a level to avoid flooding by continually adding fill material. This solution shares many of the considerations as the shore protection with fill material solutions. Any impacts below MLW would require state and federal permitting. Coordination with state regulators may be required, as discussed in the shoreline protection and trail elevation solution section above. This solution would require continuous maintenance and monitoring, which requires personnel and may impact the overall cost of the solution. Elevation of the trail without improving shoreline protection will result in continued erosion of the trail and will likely require frequent trail closures and maintenance.

Supplemental Measures: Vegetation and Upland Runoff Management and Offshore Living Structures

Vegetation and upland runoff management can serve as additional measures that can help supplement any of the above solutions by reducing erosion. During the site visit, several dying trees near the trail were observed. GEWA staff noted that red oaks suffer from wetter conditions and are not doing well with the changing environment. Vegetation serves as a natural shoreline stabilizing structure. Managing shoreline vegetation, removing dead and dying trees, adding ground cover vegetation, and supporting the growth of species resilient to the predicted impacts of climate change can help provide long-term resistance to erosion.

Meanwhile, runoff management can help reduce the causes of erosion. During the site visit, park staff noted that there is a lot of water that flows to the trail currently facing erosion issues from the nearby upland area around the park office. A gully west of the office was observed that supports this observation. Managing this runoff would aid in reducing erosion along the shore. Options for runoff management include channeling the flow into a stabilized channel with a stabilized outlet, providing flood storage capacity to encourage infiltration and lower peak flow rates, or improving upland conditions to prevent concentration of flow. The park could also consider developing a pond or wetland in a naturally low region behind the trail to help store and slow the flow of upland runoff. Stormwater runoff is not considered the primary driver of shoreline erosion on the trail, but improvement of these conditions will only aid in reducing continued erosion.

An additional supplemental measure that would not address the current erosion issue but could support further coastal resilience is an offshore living structure designed to support shellfish habitat like oyster balls. This NBS could provide habitat for aquatic species and may have the potential to mitigate wakes or storm surge. This solution would likely require state permitting as it would be constructed beyond MLW.

Summary of Potential Solutions

Table 4 summarizes the above-listed alternative solutions to the current trail erosion. Table 5 summarizes a rough order of magnitude cost estimate for the solutions listed.

Table 4. Summary of Alternative Solutions

Solution	Impacts on Trail Use	Cost Estimate	Regulatory Considerations	Sustainability
Replace Timber Walls and Trail Elevation	Continued public trail access	Medium	Likely requires state permitting (JPA - USACE, DEQ, VMRC, and Local Wetland Board); follows structure precedence	Short-term (5 to 10 years), likely unsustainable for 20 to 50 years
Modified Wall and Trail Elevation	Continued public trail access	High	Likely requires state permitting (JPA - USACE, DEQ, VMRC, and Local Wetland Board); does not follow structure precedence	Short-term (5 to 10 years), likely unsustainable for 20 to 50 years
Living Revetment or Gabions and Trail Elevation	Continued public trail access	High	Likely requires state permitting (JPA - USACE, DEQ, VMRC, and Local Wetland Board); does not follow structure precedence; VMRC preferred option	Short-term (5 to 10 years), likely unsustainable for 20 to 50 years; potential habitat for aquatic species
Coir Logs and Trail Elevation	Continued public trail access	Low to Medium	Likely requires state permitting (JPA - USACE, DEQ, VMRC, and Local Wetland Board); VMRC preferred option; NBS	Short-term (3 to 5 years), likely unsustainable for 20 to 50 years
Free-Standing Boardwalk	Continued public trail access	Medium	To be determined based on location	Short-term (5 to 10 years), likely unsustainable for 20 to 50 years
Inground Boardwalk	Continued public trail access	High	To be determined based on location	Potential to design for longer time horizons (up to 20 years)
Trail Relocation	Public access for adjusted trail	Low to Medium	To be determined based on location	Managed retreat; supports future climate change resilience
Partial Boardwalk and Trail Relocation	Public access for adjusted trail	Medium	To be determined based on location	Managed retreat; support future climate change resilience
Elevation Maintenance	Possible temporary trail closures	Low to Medium	Coordination with regulators on fill material – to be determined based on location	Requires continuous maintenance and monitoring and could be washed out
Vegetation & Upland Runoff Management	--	Low	To be determined based on location	Not a stand-alone solution for the erosion problem; Supports future climate change resilience
Offshore Living Structure	--	Medium to High	Likely requires state permitting (JPA - USACE, DEQ, VMRC, and Local Wetland Board); NBS	Not a stand-alone solution for the erosion problem

Table 5 give rough cost estimates for the qualitative cost values summarized in table 4. Costs are approximated in dollars per foot, as the length of the proposed solution may very making it difficult to estimate the total cost. It should be noted that these numbers are rough-order of magnitude estimates and cannot account for the variations in cost or availability of labor, equipment, materials, market conditions, or the Contractors' method of pricing.

Table 5. Rough Cost Estimates

Range	Cost
Low	< \$100 per feet
Medium	\$100 - \$500 per feet
High	> \$500 per feet

CONCLUSIONS

This memo provides options for addressing trail scour conditions at George Washington Birthplace National Monument to sustain trail access for the coming decade. Trail erosion is creating hazardous conditions, resulting in a partial trail closure. Parts of the trail already experience regular flooding, and conservative sea level rise projections indicate the trail will experience daily flooding by 2030.

The following potential solutions are recommended for further consideration and discussion with regulators:

- Replace existing timber walls in-kind
- Living revetment and trail elevation
- Coir logs and trail elevation
- Inground boardwalk
- Partial boardwalk (inground) and trail relocation
- Supplemental measures – vegetation, upland runoff management, and offshore living structures

Replacing the existing timber walls in kind is the only solution that retains the aesthetics of the existing structure. Other solutions would likely require additional study to determine if the existing structure can be modified or removed. Replacing the existing walls is estimated to be a medium cost. A living revetment is estimated to cost more than an existing wall in kind; however, the living revetment is identified by the state as a preferred solution for tidal wetland permitting and, as an NBS, and could provide ecological benefit through potential species habitat. Both of these solutions would be short-term, only likely to maintain trail access for 5 to 10 years; however, the living shoreline could support future shoreline transition from unsubmerged vegetation to wetland vegetation. Coir logs are another alternative. Coir logs also a NBS and BMP, they are likely preferred by the state, cheaper than a living revetment, but have a shorter 3-5 year lifespan. This alternative offers a more flexible, but temporary solution, which may be a low cost way for the trail to remain operational during the development of a long term plan.

An inground boardwalk could be designed for longer-term climate change impacts, set at an elevation to resist flooding for the next 20 years or so, although the boardwalk would likely still require maintenance or modification as water levels rise and landscapes change. A partial inground boardwalk and partial trail retreat could also help with future climate change adaptation—managing the retreat of park resources by

moving part of the trail back away from the shoreline. Vegetation and upland runoff management are two supplemental measures that can reduce the impacts and causes of erosion and provide additional climate change resilience. An offshore living structure could also reduce the impacts of erosion by buffering the shoreline while providing aquatic species habitat. The solutions described in this paragraph could be incorporated into the long-term climate resiliency planning the park noted they are planning to undergo few years during the site visit.

The list of potential solutions identified in this memo is based on currently available data which can only provide a prediction of future conditions. Additional data analysis and study are required for the design advancement of any of the above recommendations.

REFERENCES

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