APPENDIX P- AVOIDANCE, MINIMIZATION, AND MITIGATION PLAN, REV 1

I-64 Hampton Roads Bridge-Tunnel Expansion Project

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Hampton-Norfolk, Virginia
September 18, 2019

DOCUMENT HISTORY

Issue Date	Description	By	Revision
September 18, 2019	Revised for consistency with Revision 1 of the Appendix G – Impact Tables	R. Wilk	1

TABLE OF CONTENTS

FIGURES

ATTACHMENTS

P.1 INTRODUCTION

Wetlands are regulated under section 404 of the Clean Water Act (CWA) which is administered by the U.S. Army Corps of Engineers (USACE) with oversight by the U.S. Environmental Protection Agency (EPA). The 404 permitting program indicates that no discharge into Waters of the US (WOUS) shall be permitted if first, a practicable alternative exists that is less damaging to the aquatic environment, or if the discharge would cause the nation's waters to be significantly degraded. For a project to be permitted, it must be demonstrated that, to the extent practicable, steps have been taken to avoid impacts to wetlands and other aquatic resources, potential impacts have been minimized, and compensation will be provided for any remaining unavoidable impacts. Additional regulations are provided by the Commonwealth of Virginia through the state's certification under Section 401, Virginia Water Protection Permit Program Regulation (9 VAC 25 - 210) and Virginia Marine Resources Commission's (VMRC's) wetlands mitigation guidelines (4 VAC 20 - 390). The Hampton Road Connector partners (HRCP) identifies the avoidance, minimization, and mitigation steps (see attached) the Hampton Roads Bridge Tunnel Expansion project has taken to meet 404 requirements and Virginia regulations.

P.2 AVOIDANCE AND MINIMIZATION OVERVIEW

P.2.1 IMMERSED TUBE TUNNEL VS BORED TUNNEL

Two methods of tunnel construction were considered for the Hampton Roads Bridge-Tunnel (HRBT) Project design. An immersed tube tunnel (ITT) is currently in place today and was proposed as an option during the planning and procurement stage for this Project. The Hampton Roads Connector Partners (HRCP) incorporated a bored tunnel construction method during the initial stages of design. A tunnel bored underneath the sediment-water interface will avoid substantial in-water impacts related to dredging and avoid direct navigation impacts to the federally- maintained channel. Less disturbance to the channel and open water reduces concerns to commercial ships and military vessels, which will minimize the impact on the economy, tourism, and national security as the tunnel is being constructed.

The bored tunnel construction also reduces overall costs, shortens schedule, and improves worker safety. The use of a bored tunnel approach would substantially reduce the volume of dredging when compared to the ITT approach minimizing the need for ocean disposal. For example, 1,200,000 cubic yards of dredging are required just for the Immersed Tunnel Tube (ITT). Construction of the bored tunnel will have less impacts to marine wildlife than the ITT approach This method would lessen the disturbance to the main channel that marine life use as a travel corridor. An ITT approach would require building tunnel sections on land and sinking them in place in a dredged trench, then backfilling the trench and covering with stones to protect it from impacts once the sections are connected. This method is more likely to disturb wildlife due to the increased dredging and back-filling as compared to the bored tunnel construction. Construction of the bored tunnel underground results in a reduction of noise, dust, and visual impacts. Additionally, the bored tunnel construction would minimize impacts to marine life by boring under the James River and avoiding the need for extensive dredging required for ITT. Finally, the bored tunnel creates substantially less exposure to weather risks such as wind and wave action during construction as the deeper elevations of the tunnel are constructed under the surface of the James River.

During the initial planning stage following NEPA guidelines, it was determined that an ITT tunnel will require mechanized or hydraulic dredging of approximately 60 acres for a trench the length of the tunnel, which is approximately 6,300 feet. The 1,200,000 cubic yards of dredged material would be removed via barge or truck and disposed of at an offsite location. Island expansion as a result of the ITT will be similar to TBM, if not worse. With the bored tunnel approach, the impacts to aquatic resources will only be temporary for the jet grout trestles (in place for greater than 6 months), a tunnel boring machine platform, and conveyor belt. The jet grout trestles, tunnel boring machine platform and conveyor structures will be removed after construction. No dredging will be required for the tunnel itself.

The tunnel grades, and both vertical and horizontal alignments, were selected to minimize and mitigate construction impacts and schedule risks. The alignments were found to reduce impacts to the existing HRBT infrastructure. The final tunnel grades were selected because they allow:

- A reduced island expansion footprint as compared with a berm solution, with less environmental impact. The slope of the island was increased to 5% to avoid berms which would be required if the island slope was 4%.
- Eliminated marine works in the channel, facilitating Section 408 coordination and minimizing impacts to the Navy and other marine stakeholders.
- Reduced depth and extent of the tunnel approach structures (TAS), minimizing potential for settlement impacts to adjacent existing island infrastructure, and Virginia Department of Transportation (VDOT) operations.
- Minimized tunnel construction risks by maintaining sufficient tunnel cover, controlling tunnel buoyancy, scour protection, and avoiding areas of poor ground conditions. This benefits the overall durability of the tunnel during its service life.

This tunnel alignment also reduces the amount of marine work required, minimizing impacts to marine resources and stakeholders. Specifically, the alignments were selected because they allow for:

- Locating the tunnels and TAS (TBM launch and reception shafts) away from the existing infrastructure, including the existing trestles and ITT, to minimize impacts to VDOT infrastructure and day-to-day VDOT operations.
- Avoiding direct impacts to the rock protection above the ITT; this allows HRCP to perform ground improvement without needing to remove the rock protection and expose the existing ITTs.
- Providing adequate separation between the new bored tunnels, allowing HRCP to quickly separate the tunnels and therefore avoid unnecessary risks associated with the proximity of the two tunnels.
- Minimizing extent of the island modification work. Alternative alignments from the SEIS could have required greater island expansion.
- Optimizing the roadway alignment and improving overall traffic flow on and off the islands.
- Considering local ground conditions and efficiently determine the extent of the ground improvement work.

After construction, the bored tunnel will reduce environmental impacts, operational costs, future maintenance, community impacts, and increase safety compared to ITT's. The use of pipe piles would reduce surface water impacts because fewer pipe piles would be required than h-piles, for example.

P.2.2 CONSTRUCTION

P.2.2.1 TEMPORARY CONSTRUCTION TRESTLES

Temporary construction trestles will be used to facilitate work over the water and over some wetland locations. The use of temporary construction trestles was chosen over traditional stone or earthen causeways. These temporary trestles are designed to occupy less ground space by using a bridge-like support system, unlike stone or earthen causeways, which are typically built entirely on the ground or seafloor. Trestles ultimately minimize impacts to waterways and wetlands by decreasing impacts to marine habitat and corridors, even though the cost of construction for trestles is typically higher than stone causeways.

The placement of stone or earthen causeways in wetlands, even temporarily, has greater potential for adverse environmental impact than temporary work trestles. Causeways are unlike bridges in that there is no available space underneath them, as they are built entirely on substrate or existing habitat. Causeways temporarily eliminate the habitat provided by the vegetation and substrate and crush or smother animals such as mollusks within and upon the surface of the substrate covered by the construction materials. Causeways temporarily eliminate water quality enhancement functions provided by vegetation that is displaced. Long-term impacts may remain once causeways are removed. Compaction of the substrate by the causeway can alter the variety and density of fauna living within it as well as change the community structure of the plants living upon it. Upon removal of the causeway, vegetation will have to be re-established. Depending upon the degree of subsidence due to the weight of the causeway materials, re-grading of the substrate may also be required to obtain elevations that restore previous hydrologic conditions.

Temporary work trestles, as utilized by this project, minimize impacts by avoiding direct fill that causeway construction would otherwise require into WOUS. Within the site, temporary trestles eliminate the dredging requirement in shallow areas. For example the temporary North Shore work trestle will support construction of the permanent eastbound North Trestle in the shallow water (< 4-6 feet Mean Low Water) closer to the North Shore. The temporary trestle will avoid the placement of a stone causeway which requires fill and armor stone, thus creating substantially greater impacts to subaqueous bottom. If construction in these areas were to occur without a trestle, the area would need to be dredged or deepened to provide barge access. This would cause additional impacts to the adjacent submerged aquatic vegetation (SAV). The temporary work trestle provides less impacts as compared to a stone causeway or access via a barge.

Primary impacts will result from shading; however, shading impacts from trestles in place greater than six months are less detrimental to sub-aqueous bottom than direct placement of a stone causeway. There will be limited disturbance to surface water due to pile placement however all temporary trestle piles will be removed upon completion of construction. Pipe-piles will be used in place of H-piles or solid piles, which reduces surface water impacts since fewer need to be used to accomplish the same job.

P.2.2.2 GENERAL CONSTRUCTION

HRCP's construction methods are environmentally friendly and minimize risk and need for tracking leakage into the Chesapeake Bay. Additives are required for TBM operation for ground stabilization when the substrate is soft.

All tunneling activities requiring the use of additives, conditioners, slurry, or grout will be designed and planned to prevent leakage into the ground. During construction, operation parameters will be maintained within the calculated ranges with special care taken for the maximum pressures applied to avoid generating ground cracking. These operations will be continuously monitored and compared to the anticipated baseline. In the extreme case of sudden variations in the main parameters, monitoring will trigger different alerts so leakages may be detected. The depth of the TBM below the river bottom also reduces the risk of fluid migrating through the substrate into the James River. The TBM process is a closed system, with its treatment system designed specifically to remove additives from process water, securing a Virginia Pollution Discharge Elimination System point discharge permit.

Preliminary calculations have assessed maximum TBM operation pressures, preventing blow out and additive leakage into the waterways. These calculations are being refined and the TBM operator will be provided with a clear TBM operation pressure range, station by station, so maximum and minimum pressures are not exceeded to minimize this risk.

HRCP's approach will consist of using environmentally-friendly additives to not adversely impact the environment. In order to validate this approach, extensive testing will be required prior to TBM excavation to confirm that the selected additives do not damage the environment according to existing regulations. A similar approach is currently being used on the Parallel Thimble Shoal Tunnel (PTST) project, and as a result HRCP has gained valuable information regarding the testing and approval process, as well as specific products that could be used. The selected TBM type will not use foaming agents for ground conditioning and will use bentonite and the natural fines existing in the excavated material as ground conditioning. From an environmental perspective choosing this TBM type is a risk mitigation.

P.2.2.3 EROSION AND SEDIMENT CONTROL

Erosion and sedimentation Best Management Practices (BMPs) will be installed under the guidance of an approved construction general permit (CGP) prior to construction in compliance with the Virginia Erosion and Sediment Control Handbook (VESCH) and according to the Projects approved Erosion and Sediment Control Plan. BMP's implement the best possible strategy to mitigate, minimize, or prevent as much erosion as possible. The goal of this project is to avoid and minimize environmental degradation to the utmost extent in the Project site. BMP's provide a guideline of suggested methods to pursue to reach that goal. Water will be diverted around individual work areas (i.e. culvert work) to prevent sedimentation of downstream aquatic resources. Impacts will be minimized by strict enforcement of the requirements of the approved Erosion and Sediment Control Plan for the protection of surface waters, restrictions against the staging of equipment in or adjacent to waters of the U.S., and coordination with the permitting agencies.

BMPs allow for construction operations while minimizing impacts. This will be accomplished by avoiding the removal of existing vegetation to the maximum extent practicable and including the implementation and maintenance of strict erosion and sediment control measures and storm water management BMPs following the direction of VESCH. Construction BMPs must meet VESCH guidelines to ensure the reduction of turbidity and sediment disturbance. Examples of BMPs include: silt fence installation, culvert outlet protection, storm water conveyance channels, soil stabilization blankets and matting, dust control, and temporary and permanent seeding. When seeding, the use of plants with high feed value that may attract wildlife will be avoided in order to reduce wildlife encounters within the travel lanes. Seeding will follow VDOT guidelines.

P.2.2.4 TEMPORARY CONSTRUCTION ACCESS IN WETLANDS

In areas where heavy equipment will temporarily enter wetlands, all equipment will be placed on mats, or other measures of avoidance entirely will be taken to minimize soil disturbance and compaction, such as the use of low ground pressure equipment. Matting will follow the guidelines outlined in the USACE Construction Mat Best Management Practices. Mats will be monitored to assure that they are functioning correctly and will be inspected after usage. For site restoration, all matted areas within wetland will be restored to their original condition and elevation (e.g. re-seeding of native species, wee-free mulch, etc.) (USACE 2016). During the permitting process, HRCP will coordinate with regulatory agencies to develop practices acceptable for restoration of temporarily impacted vegetated wetlands. Matting will be conducted as follows:

Installation:

- Mats will be in good condition to ensure proper installation, use and removal.
- Mats will not be dragged into position in waters of the U.S.
- Woody vegetation (trees, shrubs, etc.) shall be cut at or above ground level with no grubbing.
- Install adequate erosion and sediment controls at approaches to mats to promote a smooth transition to, and minimize sediment tracking onto mats.
- Where possible individual boards are placed perpendicular to the direction of traffic. No gaps should exist between mats.

Maintenance:

- Matted wetland crossings will be monitored to assure correct functioning of the mats. Mats will be inspected after use. Mats which become covered with soils or construction debris will be cleaned and the materials removed and disposed of in an upland location.

Removal:

- Matting will be removed by “backing” out of the site, removing mats one at a time. Any rutting or significant indentations identified during mat removal will be re-graded immediately.
- Mats will be cleaned before transport or installed at another wetland location to remove soil and any invasive plant species seed stock or plant material.

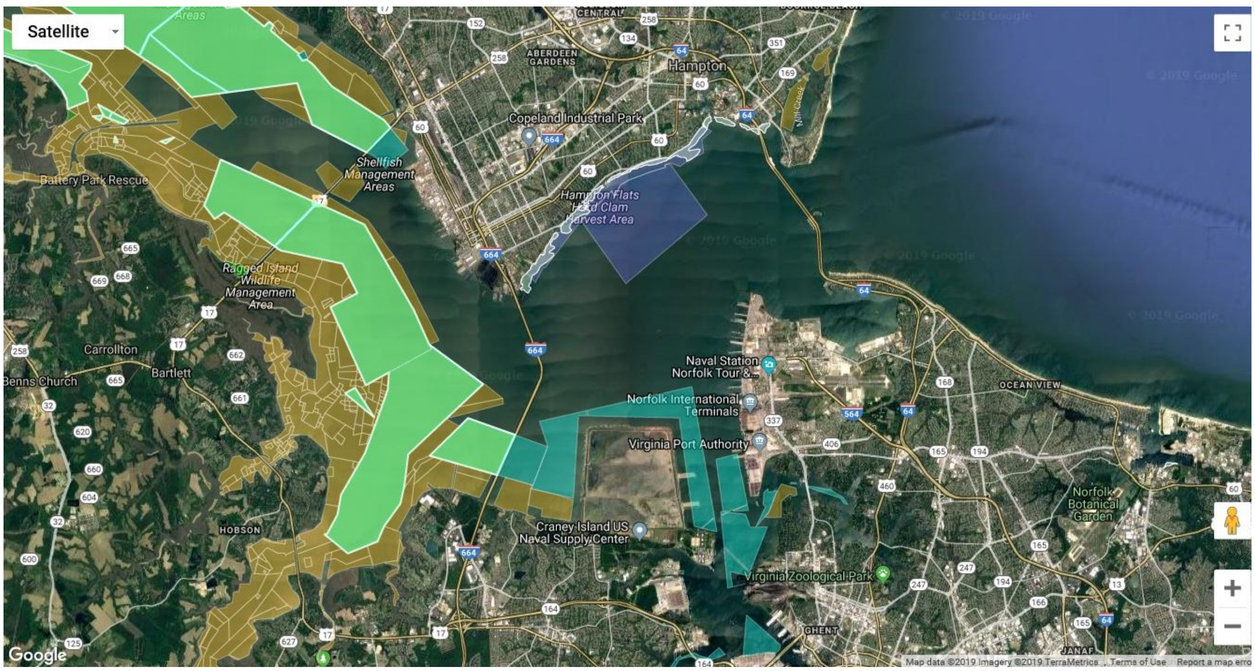
Restoration:

- Matted areas within wetlands will be restored to their original contours and elevation. Planting and the broadcast of an appropriate wetland seed mix over the matted area will be completed upon removal and restoration of the wetland area.

P.2.2.5 MOORINGS

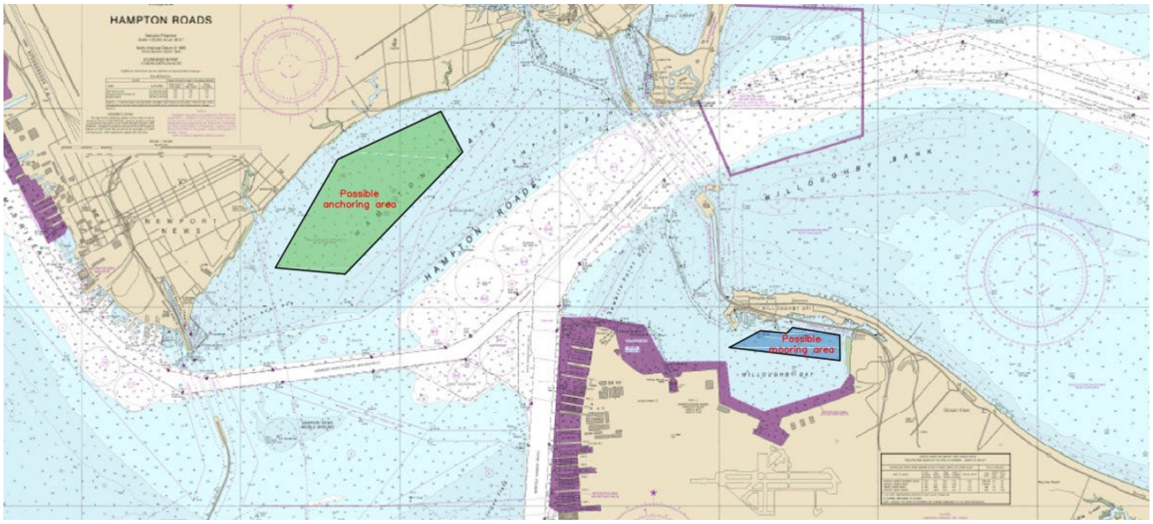
VDOT acquired Willoughby Spit to accommodate docking and stationing necessary for increased vessel traffic. There are no suitable mooring locations east of the HRBT as the mouth of the river opens to the Chesapeake Bay and offers little protection for vessels. The choppy conditions in the bay and heavily trafficked James River do not allow for many adequate mooring locations near the project area. Figure P-1 depicts private shellfish leases, Baylor Grounds and public clam grounds which would further constrain mooring locations as these areas may not allow mooring. The only suitable mooring location that does not impact the Norfolk Naval Station, Newport News Marine Terminal, Navigation Channels, Port Hampton Flats Clamming Ground, Baylor Grounds, or known shipwrecks, is within Willoughby Bay (Figure P-1). The dark blue represents public clamming grounds, teal represents Baylor Grounds, and green depicts Baylor Grounds with open harvest areas 4 VAC 20-720

Figure P-1: Chesapeake Bay Shellfish Grounds



Possible mooring and anchoring locations have been depicted in Figure P-2. Efforts will be made to avoid and minimize impacts to shellfish grounds and submerged aquatic vegetation through strategic adjacent construction and placement of mooring locations. Locations around Craney Island have been avoided so there will be no impact to Baylor Grounds.

Figure P-2: Potential Mooring and Anchoring Areas



P.3 AVOIDANCE AND MINIMIZATION BY IMPACT AREA

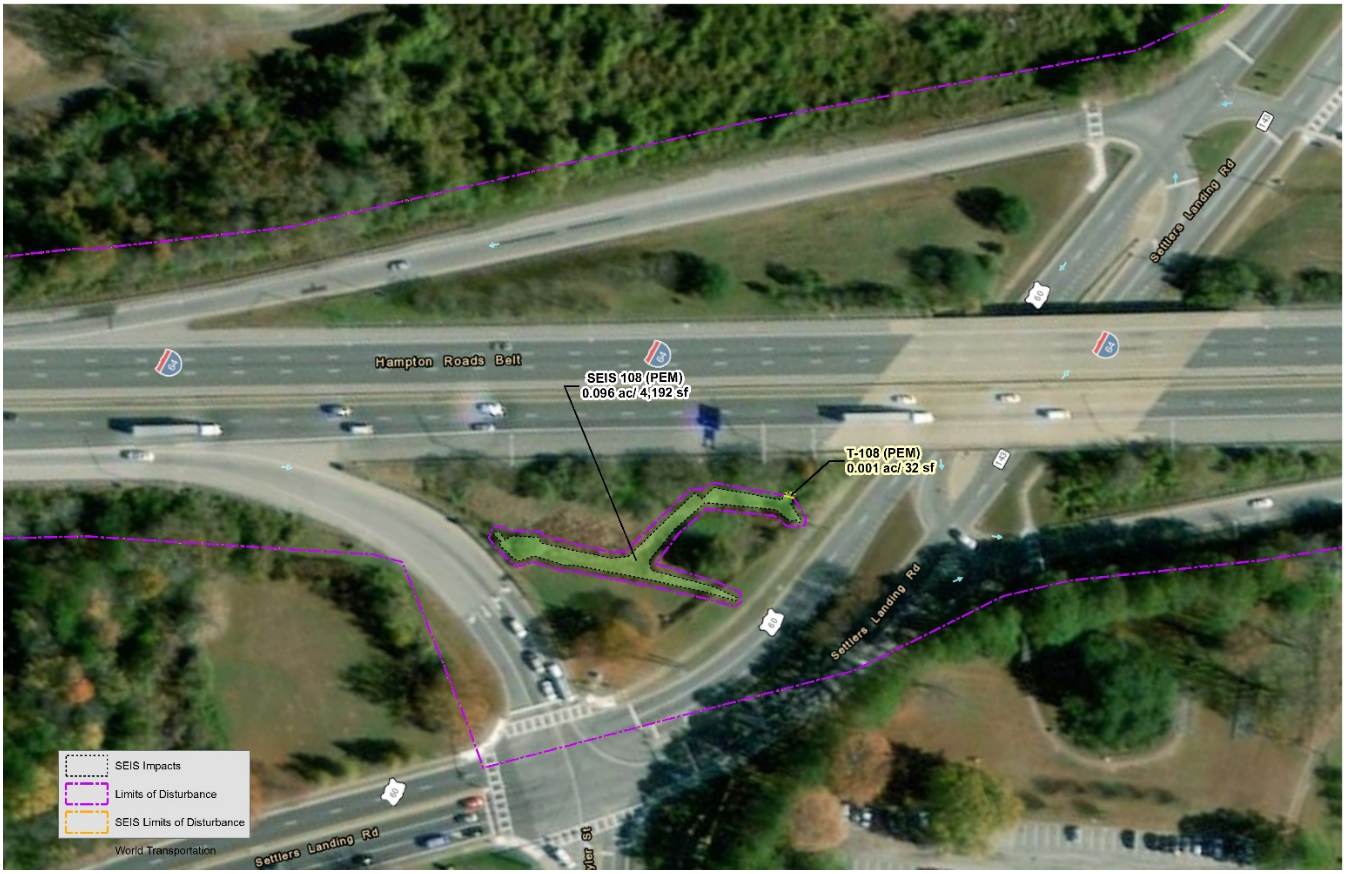
The following describes the avoidance and minimization efforts at impact areas.

P.3.1 HAMPTON

P.3.1.1 SETTLER'S LANDING ROAD INTERCHANGE

Potential noise barrier walls have been placed closer to the interstate to avoid impacts to wetlands in both the east and west bound directions. In the 2017 SEIS, 0.098 acres of palustrine emergent (PEM) wetland impacts (Wetland SEIS-108) were included in the Limits of Disturbance (LOD). Through design, the cut/fill line was moved closer to the interstate, thus eliminating all permanent impacts to the site, and only requiring 32 square feet of temporary impacts for culvert repair (Figure P-3, Sheet 1 of Attachment G-1).

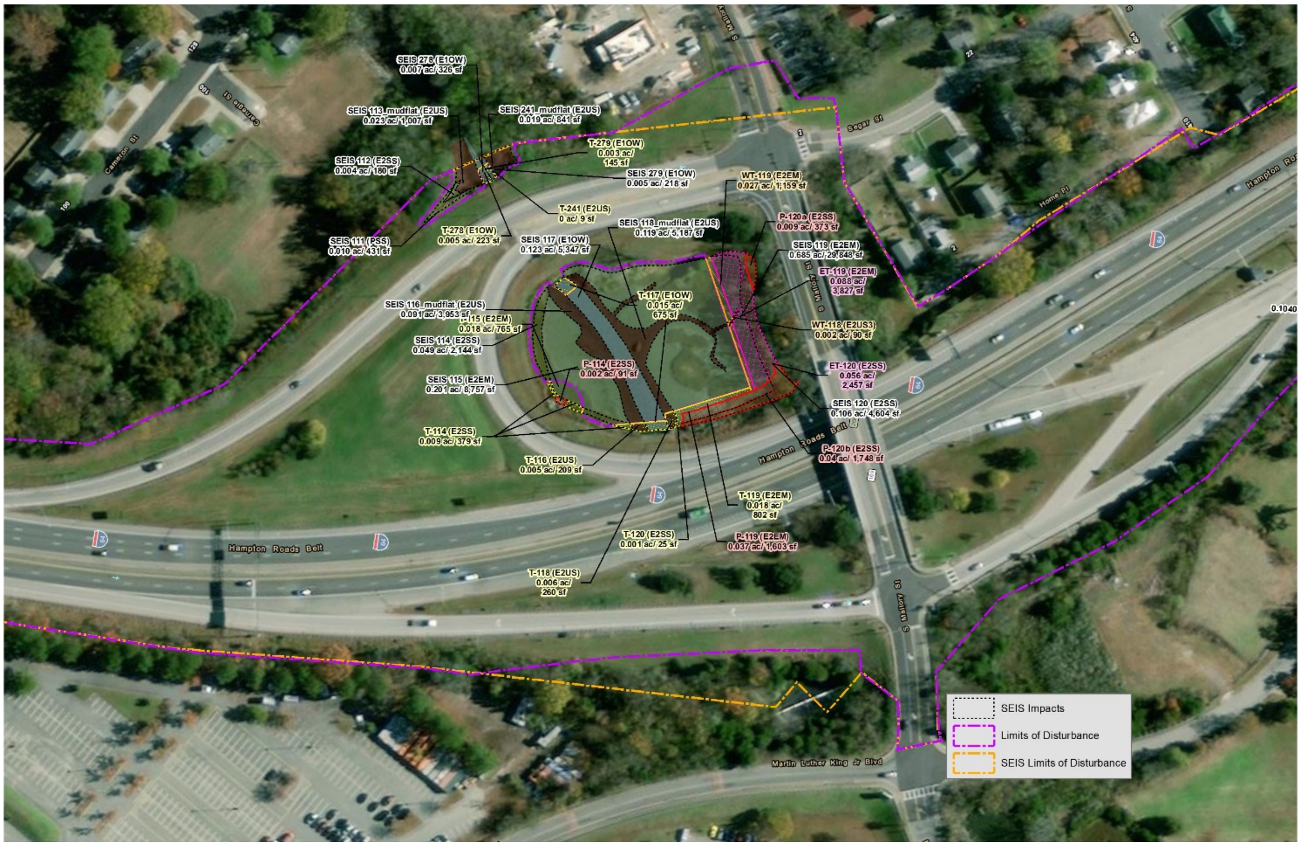
Figure P-3: Settler's Landing Road



P.3.1.2 MALLORY STREET INTERCHANGE / JOHNS CREEK

Impacts to estuarine intertidal emergent (E2EM) for BMP-1 outfall and E2EM and estuarine intertidal scrub-shrub (E2SS) for grading are associated with road widening and paved shoulder. The SEIS included impacts to 1.442 acres of wetlands at the Mallory Street clover leaf, which is a VDOT mitigation site. Permanent impacts have been reduced to 0.088 acres (0.037 to P-119 [E2EM], 0.049 to P-120 [E2SS], and 0.002 acre to P-114 [E2SS]) for grading associated with road widening and culvert repair, and 0.14 acre of shading (0.088 acre to ET-119 [E2EM] and 0.056 acre of ET-120 [E2SS]) for a temporary trestle that will be in place for longer than six months (Figure P-4, Sheet 3 of Attachment G-1). The temporary trestle will be pile supported, which will cause shading impacts, however there will be minimal ground disturbance as opposed to the alternative, which would consist of placing fill material to reach the existing bridge height. Impacts within the Mallory Street cloverleaf mitigation site will be compensated at higher ratios, 3:1 for fill and 2:1 for shading.

Figure P-4: Mallory Street



P.3.2 BRIDGE/TUNNEL

P.3.2.1 NORTH TRESTLE

The north trestles were designed to reduce the amount of temporary work, minimize overwater crossovers and traffic shifts, shrink the trestle footprint to fit within the existing LOD, limit island expansion, and use the existing eastbound trestle as a main delivery work area once the traffic has been shifted to the new trestle. As discussed previously, the trestles are pile-supported which substantially reduced impacts to subaqueous bottom when compared to a causeway or barge traffic.

The LOD was pulled back from the eastern side of the north shore to avoid impacts to approximately 0.2 acre of SAV and 0.2 acre of intertidal reef habitat. Fewer piles are being used for the new trestles than the old trestles, which helps reduce impacts. A detailed description of construction methods for demolition is provided in Appendix E. Further avoidance and minimization resulted from the agreement to stay off the property owned by Hampton University.

There is no dredging required for the North Trestle.

P.3.2.2 NORTH ISLAND

The North Island will need to be expanded to accommodate the additional travel lanes. The island will be expanded westward which avoids impacts to approximately 1.6 acres of SAV on the east side of the island. Design includes rocky intertidal shelf for habitat enhancement. The exterior engineered bund will prevent fill material from entering the water column outside of the island expansion footprint.

Subaqueous bottom will be removed with a mechanical style bucket which will help reduce suspended materials during dredging. Dredging will only occur within the tunnel island footprint. A mechanical style grapple bucket will be used to remove any armor stones and obstructions. Dredging BMPs will be performed for site mitigation. Materials will be disposed in at an approved and appropriately permitted facility.

P.3.2.3 SOUTH ISLAND

Island expansion will be confined to the south western portion of the existing island. Expanding the land on the south avoids the need to construct a berm on the channel side on the north side of the island.

Like the north island, subaqueous bottom will be removed with a mechanical style bucket which will help reduce suspended materials during dredging. Dredging will only occur within the tunnel island footprint. A mechanical style grapple bucket will be used to remove any armor stones and obstructions. Dredging BMPs will be performed for site mitigation. Materials will be disposed in at an approved and appropriately permitted facility.

P.3.2.4 SOUTH TRESTLE

One trestle instead of two separate eastbound and westbound trestles will reduce impacts as it requires fewer piles. Reduction to impacts from demolition can be attributed to BMPs such as fencing around the demolished site to capture debris, and solid waste removal. Pile removal will be achieved through direct pull, vibratory extraction, clamshell removal, or cutting. Vibratory is the preferred, which in the literal sense means vibrating the pile out of the ground. Clam shell removal involves dealing with broken and damaged pilings that cannot be vibrated out and must be gripped by a steel apparatus similar to a set of jaws. Cutting is the least extractive and is done when the piling breaks off at a point to where it is unable for full removal.

During the design phase, a Bayville exit alternative was considered and has since been removed from the design, eliminating 0.174 acre of impacts to estuarine subtidal open water (E1OW) and estuarine intertidal unconsolidated shore-sand (E2US2).

P.3.3 NORFOLK

P.3.3.1 WILLOUGHBY SPIT

LOD has been shifted landward from the north shore and south shore of the spit resulting in a reduction of approximately 0.50 acre of impacts to E2US2 (T-127 and T-247). Willoughby Spit is a previously disturbed area that will be used for staging of construction activities and materials, particularly for small vessel loading and unloading. The existing bulkhead on the south side will be repaired or replaced, thus no additional impacts in open water will occur. There will be impacts to 0.061 acre E2SS, 0.114 acre E2EM, and 0.176 acre E2US2 wetlands around the bulkhead to ensure protection and safety during construction. The temporary structures for the piers will be removed at the completion of the project, including removal or platforms and associated piles.

P.3.3.2 WILLOUGHBY BAY

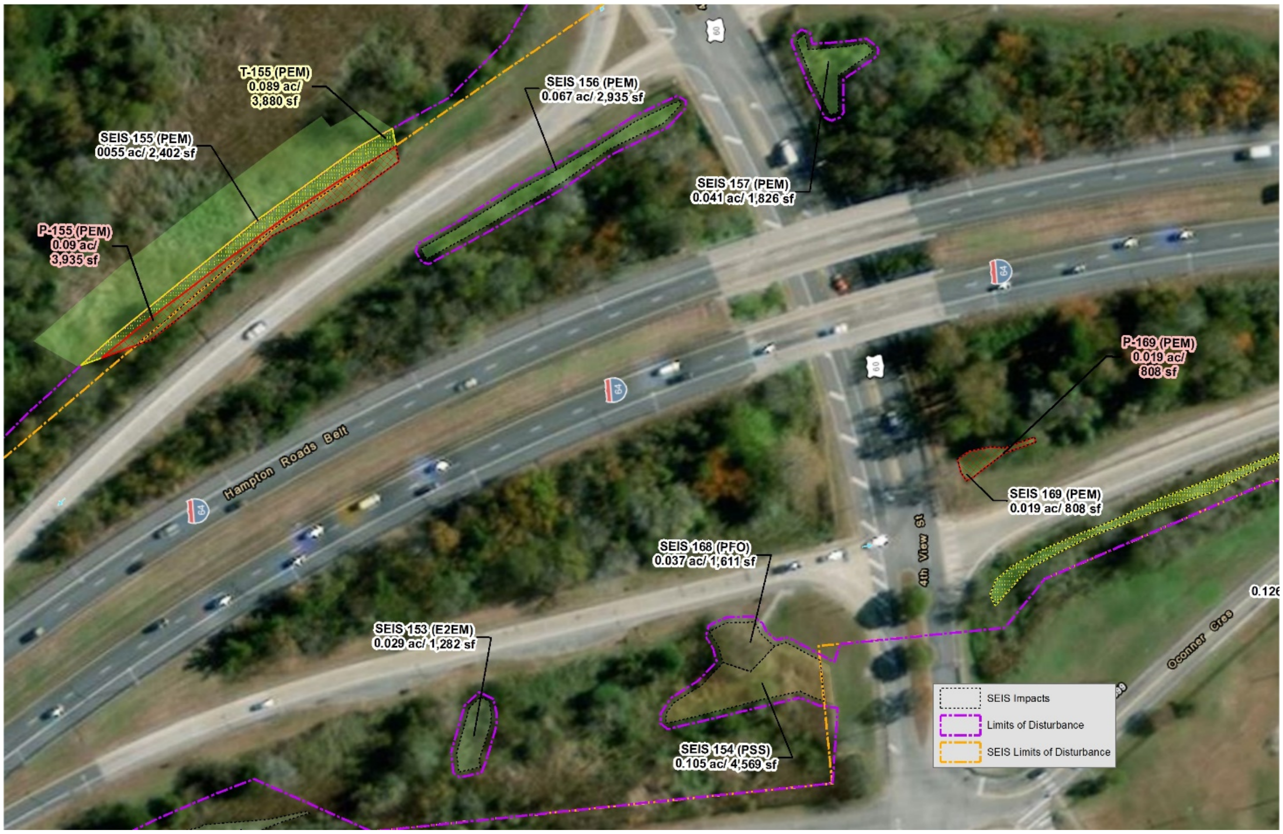
The existing Willoughby Bay Bridge structure will be modified by widening existing structures to the outside in both directions to accommodate new travel lanes, shoulders and new sound walls. Outfall impact near the west shore of the bay has been removed, eliminating 0.01 acres of impacts to open water.

No dredging is required in Willoughby Bay. Additionally, no major demolition is needed in Willoughby Bay as the existing bridge piles will be rehabilitated instead of replaced.

P.3.3.3 4TH VIEW INTERCHANGE

The cut/fill line has been moved closer to the road which will minimize impacts to wetlands. Impacts have been reduced from 0.05 acre to 0.01 acre (148-PEM, 149-E2EM, and 150-E1OW) along the eastbound lanes, and an 80 square feet impact (125-E2EM) has been removed from the westbound lanes. Additionally, five wetlands (SEIS-153 [E2EM], SEIS-154 [PSS], SEIS-156 [PEM], SEIS-157 [PEM], SEIS-168- [PFO]) totaling 0.279 acre have been avoided (Sheets 26-27 of Attachment G-1). Silt fence will be placed around these wetlands during construction so they will not be impacted (Figure P-5).

Figure P-5: 4th View Interchange



Between 4th View and Bay Ave, impacts to 0.135 acre PFO (SEIS-166), 0.027 acre PEM (SEIS-167), and 0.081 acre PFO (SEIS-174) have been avoided totaling 0.243 acre (Sheets 27-28 of Attachment G-1.

P.3.3.4 BAY AVENUE/OASTES CREEK

The LOD has been pulled in along the westbound lanes so there is just enough space (40-foot width) for pile rehabilitation on the existing bridge. Impacts outside of the SEIS LOD on the eastbound side will be limited to temporary trestles in place for longer than 6 months, which will be removed at project completion.

No dredging or barges are required for Oastes Creek, and no major demolition is needed for Oastes Creek since the piles will be rehabilitated on the existing bridge. Construction access through wetlands for pile rehabilitation will use temporary matting to provide the least amount of impact possible. The temporary construction methods are discussed further in Attachment P-2.

P.3.3.5 MASON CREEK

Similar to Bay Avenue, the LOD has been reduced along the westbound lanes to the minimum construction access area required (40-foot width) for pile rehabilitation. Impacts outside of the SEIS LOD on the eastbound side will be limited to temporary trestles in place for longer than 5 months, which will be removed at project completion. South of Mason Creek, wetland SEIS-214 (PUB - 0.55 acre), SEIS-257 (PUB- 0.01 acre) and SEIS-220 (PEM- 0.02 acre) have been avoided as the LOD was shifted closer to the road. No dredging, barges, or demolition is required for Mason Creek. As with Oastes Creek, construction access through wetlands for pile rehabilitation will use temporary matting to provide the least amount of impact possible. The temporary construction methods are discussed further in Attachment P-2.

P.3.3.6 GRANBY STREET / I-564 INTERCHANGE

Since the SEIS, impacts to the wetlands near I-564 have been minimized and avoided with adjustments to the project alignment. Along the westbound lanes, permanent impacts to 0.31 acre of SEIS-265 (PUB) were avoided and permanent impacts to SEIS-266 (PEM) were minimized from 0.05 acre to 0.01 acre. Along the eastbound lanes and ramp, permanent impacts to 0.13 acre of SEIS-264 (PEM) were reduced to less than 0.01 acre, and permanent impacts to SEIS-261 (PEM) were avoided. In the cloverleaf, impacts to 260 and 262 (PUBs) totaling 0.09 acre, as well as SEIS-259 and SEIS-263 (PEMs) totaling 0.04 acre were avoided. Wetlands SEIS-258 (PUB), SEIS-261 (PEM), SEIS-264 (PEM), and SEIS-265 (PUB) will be only temporarily impacted for access and will be returned to pre-construction condition at project completion (Figure P-6).

Figure P-6: I-56 Interchange

P.3.4 CONCLUSION:

The impact reductions discussed in this document represent avoidance and minimization achieved through modification of construction methods and design refinements and include:

1. avoidance of approximately 60 acres of dredging (along 6,300 feet) and 1,200,000 cubic yards of dredged material disposal by using a bored tunnel design versus immersed tube tunnel;
2. avoidance of approximately 1.28 acres (20 acres reduced to 18.72 acres) of wetlands by increasing island shoreline slopes to 5% (to reduce island expansion footprints) and refining the roadway alignment.
3. avoidance of approximately 1.8 acres of non-tidal wetlands and 1.3 acres of tidal wetlands through refinement of the roadway typical section to move the cut/fill line closer to the existing interstate at various locations along the project corridor,
4. use of temporary construction trestles instead of traditional stone or earthen causeways to minimize impacts to over 11 acres of vegetated wetlands and avoid the need to dredge temporary construction access channels in shallow water (< 4-6 feet mean low water); and,
5. elimination of 40 linear feet of permanent stream impacts.

Unavoidable permanent impacts will be compensated to ensure no net loss of wetlands or waters as discussed in Attachment P-2.

P.3.5 REFERENCES

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ATTACHMENT 1 – HCA

DOCUMENT HISTORY

Issue Date	Description	By	Revision
September 18, 2019	Revised for consistency with Revision 1 of the Appendix G – Impact Tables	R. Wilk	1

TABLE OF CONTENTS

TABLES

FIGURES

P.1 INTRODUCTION

The Commonwealth of Virginia does not provide compensatory mitigation guidance for aquatic habitats within jurisdictional Waters of U.S. (WOUS) other than vegetated intertidal and nontidal wetlands and other waters. That is, there is no guidance for non-vegetated intertidal and vegetated and non-vegetated subtidal waters and wetlands. The Habitat Condition Analysis (HCA) method is commonly used to determine the net loss or gain of aquatic habitat function or value within the project limits. The HCA is a semi-quantitative approach, similar to the National Oceanic and Atmospheric Administration (NOAA) Habitat Equivalency Analysis (NOAA 2000), to determine the appropriate compensation for loss or conversion of subaqueous lands and shallow water habitat (EA 2017). HCAs have been performed for other projects within the Chesapeake Bay watershed to assess habitat value in relation to out-of-kind mitigation, including the Parallel Thimble Shoals Tunnel Project for the Chesapeake Bay Bridge Tunnel (EA, 2017) and the Downtown/Midtown/MLK Tunnel Project (Elizabeth River, Portsmouth, Virginia) (EA 2012).

The impact of the Hampton Roads Bridge Tunnel (HRBT) expansion project on intertidal and subtidal estuarine habitat within the James River has been assessed. The compensation strategy for impacts to aquatic habitat resulting from implementation of the HRBT expansion project will be based on the HCA. Since the pre-and post-scores are negligibly different, proposed compensation was based on the amount of subaqueous bottom converted to upland. Pre- and post-scores are integral in showing the biological success or failure of a site. A pre-construction score can provide framework for what a post-construction habitat should resemble. The purpose of this document is to present the methods developed for the HCA, present pre- and post- habitat conditions expressed as habitat units, and to inform the decision making process to compensate for impacts to aquatic habitat.

P1.1 METHODS

This HCA assigns habitat types to subaqueous and non-vegetated habitats based on the September 19, 2017 and October 18, 2018 Preliminary Jurisdictional Determination (PJD) (NAO-1994-01166), the 2018 Baseline Benthic Survey of the project area (Wong et al. 2018), and available bathymetric survey data. It also uses studies conducted for the HRBT expansion project, as well as other existing data, to score the condition of the habitat within the project area. For both pre-construction and post-construction conditions, scores assigned for each individual factor within each habitat type are used to calculate an average habitat condition score for each habitat type. Pre-construction habitat units are subtracted from post-construction habitat units to determine the relative change in habitat condition/value. A positive number or a zero value indicates either an expected net improvement in habitat function or no change, respectively. A negative number indicates a net loss in habitat function.

The analytical process consists of the following steps:

1. Determine habitat types within the project area
2. Develop condition factor categories and scores to qualitatively assess habitat conditions within the HRBT project footprint

3. Estimate the pre-construction habitat conditions by:
    a. Using GIS to estimate the acreage of each habitat type based on the results of the wetland delineation, 2018 Baseline Benthic Survey and bathymetry.
    b. For each habitat type, score the pre-construction habitat conditions based on the habitat factors
4. Estimate the post-construction habitat conditions by:
    a. Use GIS to estimate the acreage of each habitat type based on the results of the wetland delineation, 2018 Baseline Benthic Survey and bathymetry
    b. For each habitat type, score the post construction habitat conditions based on the same habitat factors as the pre-construction conditions.
5. Calculate pre- and post-construction habitat units (multiply habitat scores by habitat acreage).
6. Compare pre- and post-construction habitat units to determine net gain or loss of habitat function/value (i.e., subtract the pre-construction habitat units from the post-construction habitat units).

P.1.1.1 HABITAT TYPES IN THE PROJECT AREA

The HRBT Project Area was subdivided by categories based on the wetland delineation, 2018 Baseline Benthic Survey, and water depth for the pre-construction analysis as follows:

- Upland (existing non-aquatic habitat and former aquatic habitat converted to upland)
- Intertidal rock substrate (above mean lower low water (MLLW); below mean higher high water (MHHW) tidal datums)
- Intertidal sand substrate (above MLLW; below MHHW tidal datums)
- Shallow Water (MLW – 6.6 ft. deep) (potential to support SAV and shellfish resources) (Cowardin et al. 1979; VIMS 2017, 2018)
- Mid-Depth (6.6 to 15 ft. deep) (potential to support shellfish resources) (CBP 2004, USACE 2012, VIMS 2018)
- Deep Open Water (15 to 30 ft. deep)
- Deeper Open Water(30 to 45 ft. deep)
- Deepest Open Water (greater than 45 ft. deep)

Habitat condition factors were identified based on the known or presumed attributes (i.e., estuarine/coastal ecology literature) of the existing habitats and environmental conditions within the project area. The condition factors (indicators) identified for the HRBT HCA analysis include:

- Water Quality
- Submerged Aquatic Vegetation (SAV)
- Shellfish Resources
- Epibenthic Habitat
- Benthic Community
- Fish
- Protected Species Habitat

P.1.1.2 HABITAT CONDITION FACTOR SCORING APPROACH

P.1.1.2.1 PRE-CONSTRUCTION HABITAT CONDITION FACTOR SCORING APPROACH

Habitat conditions are scored based on a factor scale of 0-5, with 5 being of the highest quality and 0 being upland/ non-aquatic habitat.

***Water Quality**:* Water quality scores were based on dissolved oxygen levels and attainment of open-water water quality goals (from the Chesapeake Bay Program, CBP). CBP water quality data was available from 2014-2019. Virginia Estuarine and Coastal Observing System (VECOS) real-time and historic (2005 present) water quality data was also available for the project area. Using an approach similar to previous HCAs developed in the lower Chesapeake Bay region, scores among depth strata (habitat categories described above) were based on the percentage of values below CBP target values ("restoration goals"). Under pre-construction conditions, all HRBT project areas achieved 100% attainment of water quality goals, both pre- and post-construction, and are therefore assigned a score of "5"(1-5).

***Submerged Aquatic Vegetation (SAV)**:* Historic and recent SAV distribution maps were sourced from the Natural Resources Technical Appendix to the EIS (VDOT 2016) and via the Virginia Institute of Marine Science's interactive online mapper (Orth et al. 2017). Similar to previous HCAs conducted in the region, SAV scoring considered water depth, historic presence of SAV, and present-day SAV distribution within the project area. A depth range of <6.6 ft. was established for SAV-supporting conditions (Cowardin et al 1979, Orth et al. 2017), which is consistent with previous HCAs. Shallow water sites within the project area that currently support stable SAV beds are assigned a score of "5." Areas which historically supported SAV but presently do not are assigned a score of "3." Existing areas >6.6 ft. are assigned a value of "1"; however, if an area >6.6 ft. was reliably documented (via historical maps, survey reports, etc.) to have supported SAV historically, a score of "3" would be assigned. Existing shallow unvegetated habitats <6.6 ft. lacking any historical records of SAV are assigned a value of "2." Score of "4" can occur if sparse vegetation is present <6.6 ft. in depth.

***Shellfish Resources**:* Shellfish habitat was scored based on recent (2018) and historic (2001-2002) hard clam survey results (VIMS 2018), supplemented with information on the blue crab and other shellfish species distribution (e.g., oysters) obtained from the Natural Resources Technical Appendix of the EIS (VDOT 2016). Hampton Roads has long supported a hard clam fishery. Prior to 2018, the last comprehensive survey of hard clam resources in Virginia (which included the HRBT study area) was completed by VIMS in 2001 and 2002. Presently, clams are absent from a 45-acre parcel surveyed in the vicinity of Willoughby Spit. A total of 67,854 clams are estimated to occupy a186-acre parcel surveyed in the vicinity of HRBT South, and a total of 439,731 clams are estimated to be present on a 362-acre parcel in the vicinity of HRBT North. These values generally represent an average density of <1 clam per square meter (VIMS 2018). These values are seen as low, while high average densities range just over 3 clams per square meter (Mann et al., 2005). Furthermore, along with relatively low densities of market-size clams, the size distributions of the population surveyed were markedly skewed towards older individuals, with relatively few juveniles present, indicating poor clam recruitment in the vicinity of the HRBT project (VIMS 2018). Limited recent oyster recruitment was observed at HRBT North. However, there is no evidence of a widespread occurrence of oysters throughout the project area surveyed (VIMS 2018). Throughout most of the HRBT project area, bottom substrates were well-oxygenated and well-sorted, ranging from sand-to-sand-mud mixes (VIMS 2018). However, south of Willoughby Spit, sediments were characterized as mud-shell mixes or anoxic, poorly sorted muds. In general, throughout the lower Chesapeake Bay region, areas with water depths greater than approximately 20 ft. are often considered unsuitable for oyster recruitment/development, due to the likelihood of seasonal hypoxia at greater depths (CBP 2004, USACE 2012). Historically, prior to the onset of chronic/seasonal hypoxia in the Bay (during the latter half of the 20th Century), oysters were abundant and exhibited successful recruitment at up to approximately 30 ft. depths (Boynton et al. 1995, Kemp et al. 2005). As indicated above (Water Quality), all HRBT project areas (including those up to and exceeding 30 ft. in depth) achieved 100% attainment of Water Quality goals under pre-construction conditions. Based on existing water quality conditions, as well as historical depth distributions, areas >30 ft. in depth are considered unsuitable for the development of hard clam and oyster populations and are assigned a score of "1." Areas <30 ft. (intertidal, shallow water, and mid-depth) that presently support extensive, viable hard clam or oyster resources are assigned a score of "5." Areas <30 ft. (intertidal, shallow water, and mid-depth) that presently support low-density hard clam or oyster resources are assigned a score of "4." Areas <30 ft. that historically supported shellfish resources (e.g., hard clam and/or oyster), but presently do not, are assigned a score of "3." Areas <30 ft. with no historical records of hard clams or oysters are assigned a score of "2."

Epibenthic Habitat*:* Epibenthic habitat scores are based on the type of habitat present in a particular depth zone/project area and the ability of that habitat to provide the necessary hard substrate to support epifauna communities. A site-specific epibenthic habitat survey of the project area conducted in 2018 provides community composition and secondary production estimates for various hard bottom habitat types present throughout the study area (Wong et al. 2018). The rocky intertidal zone was dominated by barnacles and amphipods, and the inner tip of the north portal island exhibited high density and biomass of oysters and mussels. The rocky subtidal zone was covered by a dense canopy of algae that provided habitat for numerous species of amphipods. Sponges, anemones, amphipods, gastropods, and bryozoans were common in the rocky subtidal. Based on the results of the 2018 epibenthic survey, intertidal sand habitat within the project area is assigned a score of "3" for epibenthic habitat suitability, and shallow water sand habitat is assigned a score of "2." Existing intertidal and subtidal rock habitat are assigned scores of "5" and "4," respectively. Predominantly silt/clay would earn a value of "1".

Benthic Community*:* Benthic community scores are based on the type of habitat present in a particular depth zone/project area and ability of that habitat to provide the necessary soft substrate (sand, silt, mud) to support infaunal communities. A site-specific benthic community survey of the project area conducted in 2018 provides community composition and secondary production estimates for infaunal assemblages present throughout the study area (Wong et al. 2018). Soft bottom substrate in the project area was dominated by polychaetes and amphipods, with oligochaetes especially abundant in coarser sediments. High densities of polychaetes were recorded along the south bridge and inner (bridge side) tip of the south portal island. Benthic community scoring is based on Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) values calculated as part of a site-specific benthic community survey (Weisberg et al. 1997, Wong et al. 2018). Where data is available (i.e., among the 38 benthic survey stations which occur within the project impact area boundaries), the site-specific B-IBI values are used directly (i.e. not inferred) as the scoring for this attribute, since IBI and HCA scoring is on the same scale (1-5) with the exception that the HCA has a "0" score for upland habitats. Among the 48 sites sampled during the 2018 survey, 32 sites met CBP Benthic Restoration Goals and 16 failed the goals, with B-IBI scores ranging from 1.3 to 4.0. Of the 16 sites that failed, eight were classified as marginal (score of 2.6 – 3.0), three were classified as degraded (score of 2.0 – 2.6), and five were classified as severely degraded (score of 2.0 or less). Sites were classified as "degraded" or "severely degraded" because of low abundance and biomass overall, low abundance of deep-deposit feeding organisms, low abundance of pollution-sensitive organisms, and/or high biomass of pollution-indicative organisms. Where site-specific B-IBI data are not available (i.e., project areas not assessed during the 2018 benthic community survey), scores were inferred based on conditions observed in similar areas/depth zones. Intertidal and subtidal rock habitat was not included in the 2018 B-IBI analysis; however, these areas were surveyed for general community attributes and for estimation of secondary production. Rocky intertidal and subtidal areas in the vicinity of the project are assumed to provide minimally suitable substrate for benthic infauna (vs. epifauna) and are assigned a score of "1." Existing upland (non-aquatic) habitats are assigned a score of "0."

***Fish**:* Four sub-criteria were assessed to evaluate the overall fish community/resources in the project area - General Fish Community; Anadromous Fish Populations; Essential Fish Habitat (EFH); and designated Habitats of Particular Concern (HAPCs). Each of these four sub-criteria is scored separately, and then an average score is developed in the matrix analysis. Information sources for the HRBT HCA included available data from regional trawl surveys (Tuckey and Fabrizio 2013, 2014, 2015, 2016, and 2017), EFH/HAPC mapping resources (NOAA-NMFS) from the EFH consultations already conducted/underway for various HRBT project components (Hampton Roads Connector Partners 2019), and information provided in the Natural Resources Technical Appendix of the EIS (VDOT 2016).

> *General Fish Community:* The Lower James River is an important nursery for many commercial and recreational species including spot, Atlantic croaker, Atlantic menhaden, weakfish, striped bass, black seabass, and summer flounder (Schloesser and Fabrizio 2016, 2019, Tuckey and Fabrizio 2017). These species and their various life stages (juveniles, adults) are widely distributed throughout the lower James River, thus a score of "4" was assigned to the general fish community sub-component across all subtidal habitat types/depth strata >6.6 ft. in depth. A "5" was unlikely to be attained due to a slight disparity in diversity and abundance of species in all seasons. Shallow Water Habitat (<6.6 ft. depth) may be limiting for some estuarine fish (Ruiz et al. 1993), notably, large, predatory or open water species, and is therefore assigned a score of "3." Existing Intertidal sand habitat, only available as a forage/refuge area for use by fish when flooded, is assigned a score of "2." Existing rocky intertidal habitat is assigned a score of "1" as this substrate type may be represent less suitable, or sub-optimal foraging habitat for demersal fish such as summer flounder, windowpane flounder, and similar species (Grimes et al. 1989, NOAA 2018). Upland (non-aquatic) habitat was assigned a score of "0."

> *Anadromous Fish Population:* The lower James River is an important migratory corridor for several anadromous fish species including alewife, blueback herring, American shad, hickory shad, striped bass, and white perch (Aunins and Olney 2009, Grant and Olney 1991, Hilton et al.

2017, Kerr and Secor 2012, Olney and Maki 2002, Sadler et al. 2017, Tuckey and Fabrizio 2017). Based on this information, the anadromous fish sub-criteria was assigned a score of “3” for all open-water (subtidal) habitats. Intertidal habitats are less suitable/available as migration corridors for anadromous species due to tidal fluctuations and are assigned a score of “2.” Existing (pre-construction) upland habitats are assigned a score of “0”. A “5” was not documented because it is not certain they are present during migration season; or suitable spawning habitat is present, and they were not documented spawning in project area. A “4” was not documented because it is not certain that opportunistic spawning is present in the project area. A “1” was not documented because anadromous fish are present.

Essential Fish Habitat (EFH): Many EFH-designated species are known to use the southern portion of the Chesapeake Bay and the lower James River. These include Atlantic butterfish, Atlantic herring, Atlantic sharpnose shark, Black sea bass, bluefish, clearnose skate, cobia, king mackerel, little skate, red drum, red hake, sand tiger shark, sandbar shark, scup, Spanish mackerel, summer flounder, windowpane flounder, and winter skate, all of which are known to use the area in the vicinity of the HRBT project as habitat as adults/spawning adults (NOAA 2018). A subset of this species list may occur in the project area as early life stages (eggs, larvae, juveniles). Based on the presence of EFH for various species within the HRBT project area, the EFH sub-criterion was assigned a score of “5” for all depth ranges (excluding intertidal criterion and shallow water) within the project area under existing (pre-construction) conditions. Table 1-P describes the reasoning behind this determination for the entire project site.

Habitats of Particular Concern (HAPC): A single EFH species, sandbar shark, is listed as a HAPC species within the HRBT project area. Based on the potential presence of sandbar shark HAPC within the project area, the HAPC sub-criterion was assigned a score of “3” for suitable depth ranges where at least one life stage of sandbar is mapped. Suitable depth ranges include inshore shallow coastal waters, including bays, harbors, and estuaries; typically in waters 5-180 ft (2-55 m); also offshore, occasionally to 600-810 ft (183-247 m). The HAPC sub-criterion was assigned a score of “4” for suitable depth ranges for this species (shallow water, mid-depth) within the project area where at least two life stages are indicated as potential occurrences under existing (pre-construction) conditions OR where mapped HAPC is indicated for all life stages, but sand substrate is not present (or substrate type is unknown). Suitable depth ranges with preferred sand substrate (and mapped HAPC for all life stages of sandbar shark) are scored a “5.” Project areas with no mapped HAPC for sandbar shark were assigned a score of “1.” Project areas with mapped HAPC, but where existing depths are unsuitable (>15 ft.) were assigned a score of “2.”

Protected Species Habitat: Protected species habitat is scored based on information on protected species occurrence/distribution obtained primarily from the Natural Resources Technical Appendix of the EIS (VDOT 2016). Scoring was developed for the following sub-criteria: Suitability for Whales and Dolphins; Use by Seals; Suitability for Sea Turtles; and Suitability for Atlantic sturgeon. Like the Fish category, each of these four sub-criteria is scored separately, and then an average score is developed in the matrix analysis.

Whales and Dolphins: In general, whales do not occupy preferred habitat within the Chesapeake Bay, but are known to travel into the lower Chesapeake Bay as seasonal transients, straying from nearby Atlantic Ocean migratory corridors during the cooler months (Blaylock 1985, Barco and Swingle 2014). Bottlenose dolphin are also known to occupy the open waters within the Chesapeake Bay region, including the Hampton Roads area, on a seasonal basis (primarily during cooler months) (Blaylock 1985, Barco and Swingle 2014, Barco et al 1999). Under existing (pre-construction) conditions, Upland, Intertidal and Shallow Water habitats are assigned a score of "0" as these areas are not available to marine mammals as habitat. Mid-Depth (or deeper) areas are recognized as potential habitat for dolphins on a seasonal basis, and are assigned a score of "3" for this sub-criterion.

Seals: Seals (primarily harbor seals) are seasonally present in the lower Chesapeake Bay during the colder months and may occur as transients within the HRBT Project Area (Barco and Swingle 2014, Mayfield 2016). Their presence in deeper, open water environments as well as the potential for nearshore and/or intertidal areas to provide resting habitat merits consideration of open waters and shorelines in the vicinity of the HRBT project areas as potential seasonal habitat. Under existing (pre-construction) conditions, Upland habitats are assigned a score of "2" as under certain configurations, these areas may provide suitable "haul-out" or resting areas for seals on a seasonal basis, as can Shallow-Water and Mid-Depth areas. Similarly, intertidal rock and sand habitat may also provide resting areas for seals on a seasonal basis in the project area and are assigned a score of "3" for this sub-criterion.

Sea Turtles: Sea turtles are seasonally present in the lower Chesapeake Bay region, including the Hampton Roads area (Barco and Lockhart 2015, Swingle et al. 2017, VIMS 2019). Species known to occur in the HRBT study area include the Kemp's ridley, leatherback, loggerhead, and green sea turtles. The leatherback sea turtles are known to occur throughout the lower and middle reaches of Chesapeake Bay; however, they do not nest in Virginia. Kemp's ridley sea turtle is the smallest and rarest of all sea turtles; juveniles comprise a majority of this species' occurrences within the Chesapeake Bay, including the Hampton Roads region (Barco and Lockhart 2015, VIMS 2019). Green sea turtles (primarily juveniles) occur throughout the lower Chesapeake Bay during the late summer and early fall (Barco and Lockhart 2015, VIMS 2019). The loggerhead sea turtle is the most common sea turtle in Chesapeake Bay, including the Hampton Roads region, occurring from May to November. This species has been reported to nest on the barrier beach islands off the Eastern Shore and/or near the Back Bay Wildlife Refuge (Barco and Lockart 2015, VIMS 2019). No nesting beaches occur within the vicinity of the HRBT project area. While the HRBT project area does not include nesting or juvenile rearing habitat for these species, their presence in deeper, open water environments merits consideration of open waters in the vicinity of the HRBT project areas as potential seasonal habitat. Under existing (pre-construction) conditions, Upland and Intertidal habitats are assigned a score of "0" as these areas do not support sea turtles in the HRBT project area. Shallow-Water and Mid-Depth areas are recognized as potential foraging habitat for sea turtles on a seasonal basis, and are assigned a score of "1" and "2," respectively, for this sub-criterion.

Atlantic Sturgeon: The federally-listed Atlantic sturgeon is known to occur in the general vicinity of the project area; however, the HRBT project area does not represent important staging or feeding habitats for either juvenile or adult life stages of this species (Balazik and Garman 2018). Residence times by individual adult and juvenile sturgeon within the project area are brief, on the order of hours, rather than days or weeks, as documented upstream from the study area in known spawning areas. However, the HRBT project area is included within the only pathway for sturgeon movements between the Bay and the James River. During late fall and early winter, sturgeon may spend very brief periods (typically 1-2 hours) within the HRBT project area (Balazik and Garman 2018). Under existing (pre-construction) conditions, Upland and Intertidal habitats are assigned a score of "0." Shallow-Water and Mid-Depth areas are recognized as only providing very limited foraging habitat for sturgeon on a seasonal basis, and are assigned a score of "1" for this sub-criterion.

P.1.1.2.2 POST-CONSTRUCTION HABITAT CONDITION FACTOR SCORING APPROACH

Project construction activities which only result in temporary impacts (e.g., temporary reductions in water quality/clarity, temporary structures, excavated or filled areas which would be later back-filled or dredged to pre-construction conditions) do not result in a change of score for any of the criteria. The post-construction scores generally follow the criteria listed in the pre-construction scores. Below describes how conversion of habitat will be scored that may differ from the pre-construction scoring.

Water Quality: Following construction, water quality in the project area is not expected to undergo a permanent change from pre-construction conditions, as no major alterations in tidal flushing and hydrodynamics are predicted to occur as a result of project implementation. Thus, post-construction scores for water quality are the same as pre-construction scores for areas converted to Shallow Water, or Mid-Depth, with the exception of areas converted to non-aquatic (upland) habitat – these were scored as "0."

Submerged Aquatic Vegetation: Post-construction, conversions to Shallow Water habitat (<6.6 ft.) are assigned a value of "2" because those areas have potential to be suitable for SAV. Post-construction conversion of existing shallows to deeper habitats merits a score of "1." Shallow Water areas converted to upland habitat are assigned a score of "0."

Shellfish Resources: Post-construction areas converted from Intertidal, Shallow Water, Mid-Depth, or Deep Open Water conditions to upland (non-aquatic) habitat during construction are scored as "0."

Epibenthic Habitat: For post-construction analyses, conversion of any aquatic habitats to an upland (non-aquatic) substrate will be assigned a score of "0". Conversion of Intertidal or Shallow Water rock habitat to sand habitat >6.6 ft. depth is assigned a score of "2." Conversion of Intertidal or Shallow Water rock or sand substrate to rock substrate >6.6 ft. depth and/or permanent conversion of aquatic habitat (sand substrate) >6.6 ft. depth to rock substrate >6.6 ft. depth is assigned a score of "4." Conversion of sand substrate <6.6 ft. depth to rock substrate <6.6 ft. depth and/or permanent conversion of aquatic habitat (rock or sand substrate) >6.6 ft. depth to rock substrate <6.6 ft. depth is assigned a score of "5."

Benthic Community: Benthic communities within the project area are expected to quickly recolonize disturbed areas following project construction; however recovery rates are known to vary based on several factors, including the duration and initial timing of the impact(s); temperature/latitude, water quality/hydrodynamics, sedimentation post-construction patterns and the life history characteristics of re-colonizing fauna (Newell et al. 1998). Thus, areas converted to Shallow Water or Mid-Depth habitat are assigned a habitat score of 3.5, assuming they will, over time, provide for the development of benthic communities capable of meeting CBP Restoration Goals. As with epibenthic habitat, conversion to non-aquatic (upland) substrate results in a score of "0."

Fish: In general, it was assumed that estuarine fish assemblages in the vicinity of the project area would generally not be affected by project implementation because most pelagic and demersal fish move freely throughout the Lower James River and are not restricted to habitats within the project area (thereby avoiding temporary impacts such as underwater noise, turbidity increases, and temporary substrate disturbance) (Schloesser and Fabrizio 2016, 2019, Tuckey and Fabrizio 2013, 2014, 2015, 2016, 2017). Potential impacts would be temporary since displaced fish would quickly return to the project areas following cessation of construction activity. Thus, scoring of the pre- and post-construction conditions for this sub-criterion is largely comparable.

General: Permanent conversion of any aquatic habitats to Upland (non-aquatic) habitat as a result of project implementation scored a "0" for the areas affected. Similarly, permanent conversion of Shallow Water or deeper aquatic habitats to Intertidal sand and rock habitat as a result of project implementation is scored "2" and "1" for the areas affected, respectively, as fish would only be able to access these habitats when tidally inundated, and rock substrate may represent less suitable, or sub-optimal foraging habitat for demersal fish species such as summer flounder, windowpane flounder, and similar species (Grimes et al. 1989, NOAA 2018) Conversion of Uplands, Intertidal or Mid-Depth aquatic habitat to Shallow Water habitat is assigned a score of "3." Conversion of Uplands, Intertidal or Shallow Water habitat to Mid-Depth aquatic habitat is assigned a score of "4." As described for the pre-construction scoring, a "5" was unlikely to be attained due to a slight disparity in diversity and abundance of species in all seasons.

Anadromous: Permanent conversion of any aquatic habitats to upland (non-aquatic) habitat as a result of project implementation is scored a "0" for the areas affected. Similarly, permanent conversion of any open water subtidal habitat to intertidal habitat as a result of project implementation is assigned a score of "2" for the areas affected because intertidal habitats are less suitable/available as migration corridors for anadromous species due to tidal fluctuations.

EFH: Should any habitat conversions to Shallow Water (<6.6 ft. depth) take place as a result of project implementation, these affected areas would be assigned a score of "2" as certain EFH species would be unlikely to occur in shallow subtidal waters, except as occasional transients (primarily juveniles). Similarly, habitat conversions from areas >6.6 ft. depth to Intertidal sand substrate would be assigned a score of "2." Habitat conversions from >6.6 depth to Intertidal rock substrate would be assigned a score of "1," as these areas may represent less suitable, or sub-optimal foraging habitat for demersal EFH species such as summer flounder, windowpane flounder, and similar species (Grimes et al. 1989, NOAA 2018). Habitat conversions from any depth to Upland (non-aquatic) habitat would be assigned a score of “0” for the EFH sub-criterion.

*HAP*C: Post-construction habitat conversions (either from Upland or Intertidal to Shallow Water or Mid-Depth) are assigned a “4,” assuming these areas would provide suitable habitat for at least two life stages of sandbar shark. Post-construction habitat conversions from deep (or deeper) water habitats (>15 ft.) to Mid-Depth or Shallow Water conditions also merit a score of “4”. Habitat conversions from any depth to Upland (non-aquatic) habitat would be assigned a score of “0” for the HAPC sub-criterion.

Protected Species Habitat: It was assumed that the protected species in the vicinity of the project area would generally not be affected by temporary construction activities as they are able to move freely through the Lower James River (thereby avoiding temporary impacts such as underwater noise, turbidity increases, and temporary substrate disturbance). Thus, an average scoring of the pre- and post-construction conditions for this sub-criterion is generally comparable, with the exception of permanent habitat conversion impacts, as follows:

Whales and Dolphins: Under post-construction conditions, conversion of Mid-Depth habitats to Upland habitat would merit a score of “0.” Conversion of Mid-Depth habitats to Shallow Water habitat would merit a score of “1” due to lack of habitat presence. Conversion of Upland, Intertidal or Shallow Water habitat to Mid-Depth habitat as a result of construction activity would merit a score of “3” due to the conversion of habitat to transient use.

Seals: Under post-construction conditions, conversion of Intertidal or deeper habitats to Upland habitat suitable as resting areas would merit a score of “2” due to conversion of potential habitat to transient use. However, aquatic habitat be converted to Uplands containing structures of other features deemed unsuitable to provide resting areas for seals would be scored as “0.” Conversion of Upland, Intertidal or Shallow Water habitat to Mid-Depth habitat would also merit a score of “2”, as transient use may be provided.

Sea Turtles: Under post-construction conditions, conversion of Shallow Water or deeper habitats to Upland habitat would merit a score of “0.”

Atlantic Sturgeon: Under post-construction conditions, conversion of Shallow Water or deeper habitats to Upland habitat would merit a score of “0.”

Table 1-P provides a brief description of the habitat scores.

P.1.1.3 CALCULATION OF TOTAL PRE- AND POST-CONSTRUCTION HCA SCORES AND HABITAT UNITS

Average HCA scores for each category/area of habitat present in the project area prior to construction and post-construction are calculated as follows:

(Epibenthos + Water Quality + SAV + Benthic Community + Shellfish + Fish + Protected Species) ÷ Number of Condition Factors = Habitat Condition Factor Score

The average score is then multiplied by the by the area of habitat (acres) to provide a final habitat unit value for each habitat type.

Average Score x Acreage = Habitat Units

The final habitat units for each habitat type are summed to create a total score (total habitat units) for the pre-construction and post-construction conditions.

P.1.1.4 COMPARISON OF PRE- AND POST-CONSTRUCTION HABITAT UNITS

The total number of pre-construction habitat units is subtracted from the total number of post-construction habitat units to determine the relative change as a result of the project. A positive number or a zero value indicates either a net improvement or no change, respectively. A negative number indicates a net loss and that mitigation may need to be considered to offset losses. However, since this analysis is semi-quantitative, a minor difference in final habitat unit values may be viewed as an inconsequential change in habitat functional capacity throughout the project area.

P1.2 RESULTS

The HCA analysis for the existing (pre-construction) conditions in the HRBT project area resulted in a total of 58.96 habitat units (Table 2-P). The post-construction condition yielded 17.90 habitat units (Table 3-P). This is a net loss of 41.01 habitat units as a result of project implementation. The vast majority (98%) of project-related impacts occur at 3 areas, the North Trestle (Figure 1-P) and the North (Figure 2-P) and South islands (Figure 3-P), primarily as a result of conversion of mid-depth and deep open water habitat to 14.12 acres of uplands. This conversion provides virtually no habitat value to aquatic organisms with the exception of potential basking/ haul out habitat for seals that may occur seasonally in the vicinity of the project area. In addition, 0.70 acre of intertidal sand habitat will be lost, while intertidal rock habitat will increase from 0.70 acre to 0.99 acre. Shallow-water habitat, which supports SAV and shellfish resources in the vicinity of the study area, will increase from 1.24 to 2.21 acres, offsetting a portion of the loss in function attributed to the conversion of mid-depth and deeper open water to uplands/intertidal rock habitat. The remaining habitat loss/ conversions occur throughout the project area at Oastes Creek (Figure 4-P), Willoughby Bay- West Shore (Figure 5-P), Fourth View Street (Figure 6-P), and First View Street (Figure 7-P).

Based on this analysis, and under current regulatory policy, compensatory mitigation will be needed to offset overall projected loss in habitat function associated with project construction.

P1.3 RECOMMENDATIONS

Results of the HCA assessment indicated a functional loss of 41.01 habitat units associated with construction of the HRBT project. As most of the habitat unit loss is due to conversion to upland and the pre and post construction scoring was very similar for remaining habitat, we propose to only mitigate for the conversion to upland. The assessment used available data on estuarine ecological indicators for the geographic region of the project. It also used conservative assumptions for the habitat condition scoring to ensure that the pre-construction score was not biased low and that the post-construction assessment was not biased high. As the permit process continues, the project sponsors should coordinate closely with the federal and state regulatory and advisory agencies on an equitable and practicable compensation plan. Elements of the plan may include out-of-kind mitigation options such as purchase of regional mitigation bank credits or purchase of credits within an in-lieu fee program [e.g., TNC's Virginia Aquatic Resources Trust Fund (VARTF) (TNC 2009) or the Elizabeth River Project's Living River Restoration Trust (LRRT], should the number of available regional mitigation credits be insufficient to offset functional loss, or should the mitigation habitat types available through regional banks be deemed inappropriate for estuarine shallow and open water habitat compensation.

Tables

Table 1-P. Habitat Condition Scores

Habitat Condition Scores

Indicator or Feature	0	1	2	3	4	5
Water Quality (based on CBP and VECOS data)	Non aquatic habitat	Poor water quality; dissolved oxygen (DO) meets restoration goal up to 50% of the time.	Seasonally low DO; DO meets restoration goal 51 to 75% of the time.	DO usually supports aquatic life year round; DO meets restoration goal 76 to 90% of the time.	DO supports aquatic life year-round; stable foraging habitat; DO meets restoration goal 91 to 99% of the time.	DO supportive of aquatic life; DO meets restoration goal 100% of the time (HRBT pre-construction condition)
Shellfish Resources (based on data in VIMS 2018 clam survey)	Non aquatic habitat	No shellfish habitat (0 live clams m^2); depth >30 ft. and substrate does not support bivalves.	Isolated patches of potential shellfish habitat; No existing or historic shellfish beds; depth <30 ft.	Existing shellfish beds limited or absent (<1 live clams m^2); historic record of shellfish beds; depth <30 ft.	Some/moderate shellfish habitat (1-2 live clams m^2); known moderately productive existing shellfish beds/reefs; depth <30 ft.	Extensive shellfish habitat (2-3 live clams m^2); known highly productive existing shellfish beds/reefs; depth <30 ft.
SAV (based on 2013-2017 VIMS SAV data)	Non aquatic habitat	No suitable SAV habitat present; depth >6.6 ft.	No SAV present; no historic record of SAV; depth <6.6 ft.	No SAV present; depth <6.6 ft.; historic presence of SAV in area documented.	Sparse SAV present; depth <6.6 ft.	Stable SAV population present; depth $\leq$6.6 ft.
Epibenthic Habitat (based on Versar 2018 epibenthic survey and VIMS 2018 clam survey)	Non aquatic habitat	Predominantly silt/clay substrate conditions, habitat does not support epibenthic organisms.	Predominantly soft bottom (sand) substrate in depths of >6.6 ft; limited hard surface for epibenthic organisms.	Predominantly soft bottom substrate in depths of <6.6 ft; some hard surface for epibenthic organisms (e.g., gravel).	Predominantly rock substrate >6.6 ft; majority of the area provides hard substrate for epibenthic organisms.	Predominantly rock substrate <6.6 ft; Varied substrate sizes that provide extensive/diverse habitat for epibenthic organisms.
Benthic Community (based on Versar 2018 benthic survey)	Non aquatic habitat	Severely degraded benthic community; Benthic Index of Biotic Integrity (B-IBI) score of <2.0; poor abundance and diversity of species; populations present only seasonally.	Degraded community; B-IBI score of 2.0 – 2.5; low abundance and diversity of species. Areas encompassing Deepest Water not included in 2018 benthic survey are scored as 2.25 to reflect seasonal DO impairments expected to control benthic community structure at those depths.	Fair community; B-IBI score of 2.6 – 2.9; to account for potential (seasonal) DO reduction, a score of 2.75 is assigned to Deeper Water areas not included in the 2018 benthic survey.	Good community; B-IBI score of 3.0 – 4.0; moderate to high diversity and abundance; populations present year-round.	Excellent community; B-IBI score of 4.1 – 5.0; high diversity and abundance; stable community present year-round.

Habitat Condition Scores

Indicator or Feature	0	1	2	3	4	5
Fish	Non aquatic habitat	General: few or no fish present; present species are irregular transients; habitat does not support fish populations.	General: poor diversity; relatively high abundance of one species; poor habitat for fish populations; population is marginally sustainable.	General: moderate diversity and abundance of species; adequate habitat for fish populations.	General: moderate to high diversity of species; high abundance of several species; good habitat for fish populations; stable fish population.	General: high diversity and abundance of species in all seasons; excellent habitat for fish populations; stable fish population at carrying capacity for available habitat.
	Non aquatic habitat	Anadromous: none present.	Anadromous: historic use; no known current activity.	Anadromous: present during migration season; no known spawning habitat in project area.	Anadromous: present during migration season; opportunistic spawning documented in project area.	Anadromous: present during migration season; suitable spawning habitat present, documented spawning in project area.
	Non aquatic habitat	EFH: no EFH species present.	EFH: transient EFH species.	EFH: seasonal use by EFH species.	EFH: use by transient/ seasonal EFH species in most seasons.	EFH: EFH species present.
	Non aquatic habitat	HAPC: no sandbar shark HAPC present.	HAPC: mapped sandbar shark HAPC present, but depths unsuitable (>15 ft.).	HAPC: mapped HAPC present for at least one life stage of sandbar shark.	HAPC: mapped sandbar shark HAPC present in Shallow Water and Mid-Depth Areas (at least two life stages); OR mapped HAPC for all life stages, but substrate type other than sand (e.g., mud, rock), or unknown.	HAPC: mapped sandbar shark HAPC present in Shallow Water and Mid-Depth Areas (all life stages), with preferred sand substrate, documented sandbar sharks in project area.

Habitat Condition Scores

Indicator or Feature	0	1	2	3	4	5
Protected Species	Whales/ Dolphins: non- aquatic habitat. Seals: non-aquatic habitat, no haul-out areas. Sea Turtles: non-aquatic habitat. Atlantic Sturgeon: non-aquatic habitat.	Whales/ Dolphins: habitat not present. Seals: suitable habitat not present. Sea Turtles: suitable habitat not present. Atlantic Sturgeon: suitable habitat not present.	Whales/ Dolphins: transient use. Seals: transient/occasional use of Shallow and/or Mid-Depth areas as potential foraging habitat; resting or "haul-out" areas present. Sea Turtles: transient/occasional use. Atlantic Sturgeon: transient use.	Whales/ Dolphins: seasonal use. Seals: seasonal use; a variety of water depths available as potential habitat. Sea Turtles: seasonal use. Atlantic Sturgeon: seasonal use.	Whales/ Dolphins: species present year-round. Seals: species present all year-round. Sea Turtles: year-round use. Atlantic Sturgeon: species present all year-round.	Whales/ Dolphins: species present year-round; breeding grounds present. Seals: breeding grounds and species present. Sea Turtles: year-round use; beach/nesting habitat and species present. Atlantic Sturgeon: spawning habitat and species present.

Table 2-P. Pre-Construction Habitat Impact Factor Scores and Habitat Units

Pre-Construction Habitat Impact Factor Scores and Habitat Units

	Habitat Type	Area (acres)	Epibenthic Habitat	Water Quality	Shellfish Resources	SAV	Benthos	Fish	Protected Species	Average Score	Existing Habitat Unit (Average Score x Acres)
1	Upland	0	0	0	0	0	0	0	0.5	0.07	0.00
2	Intertidal Rock	0.70	5	5	4	0	1	1.25	1	2.46	1.73
3	Intertidal Sand	0.70	3	5	4	0	3	2	0.75	2.54	1.78
4	Intertidal Mud	0	1	5	4	0	2	1.5	0.75	2.04	0.00
5	Shallow Water	1.25	2	5	4	3	2.8	3.25	1	3.01	3.73
6	Mid-Depth	13.41	2	5	4	1	3.1	4.25	2	3.05	40.90
7	Deep Open Water	3.99	2	5	1	1	3.1	3.75	2.75	2.66	10.60
8	Deeper Open Water	0.08	2	5	1	1	3.1	3.75	3	2.69	0.22
9	Deepest Open Water	0	2	5	1	1	2.25	3.75	3	2.57	0.00
										Habitat Units	**58.96**

Table 3-P. Post-Construction Habitat Impact Factor Scores and Habitat Units

Post-Construction Habitat Impact Factor Scores and Habitat Units

	Habitat Type	Area (acres)	Epibenthic Habitat	Water Quality	Shellfish Resources	SAV	Benthos	Fish	Protected Species	Average Score	Existing Habitat Units (Average Score x Acres)
1	**Upland**	14.12	0	0	0	0	0	0	0.5	0.07	1.01
2	**Intertidal Rock**	0.99	5	5	4	0	1	1.25	1	2.46	2.44
3	**Intertidal Sand**	0	3	5	4	0	3	2	0.75	2.54	0.00
4	**Intertidal Mud**	0	1	5	4	0	2.75	1.5	0.75	2.14	0.00
5	**Shallow Water**	2.21	2	5	4	3	3	3.25	1	3.04	6.71
6	**Mid-Depth**	0.98	2	5	4	1	3	4.25	2	3.04	2.98
7	**Deep Open Water**	1.82	2	5	1	1	3	3.75	2.75	2.61	4.81
8	**Deeper Open Water**	0	2	5	1	1	2.75	3.75	3	2.64	0.00
9	**Deepest Open Water**	0	2	5	1	1	2.25	3.75	3	2.57	0.00
										Habitat Units	**17.95**

Figures

Figure 1-P. Habitat Conversion - North Trestle

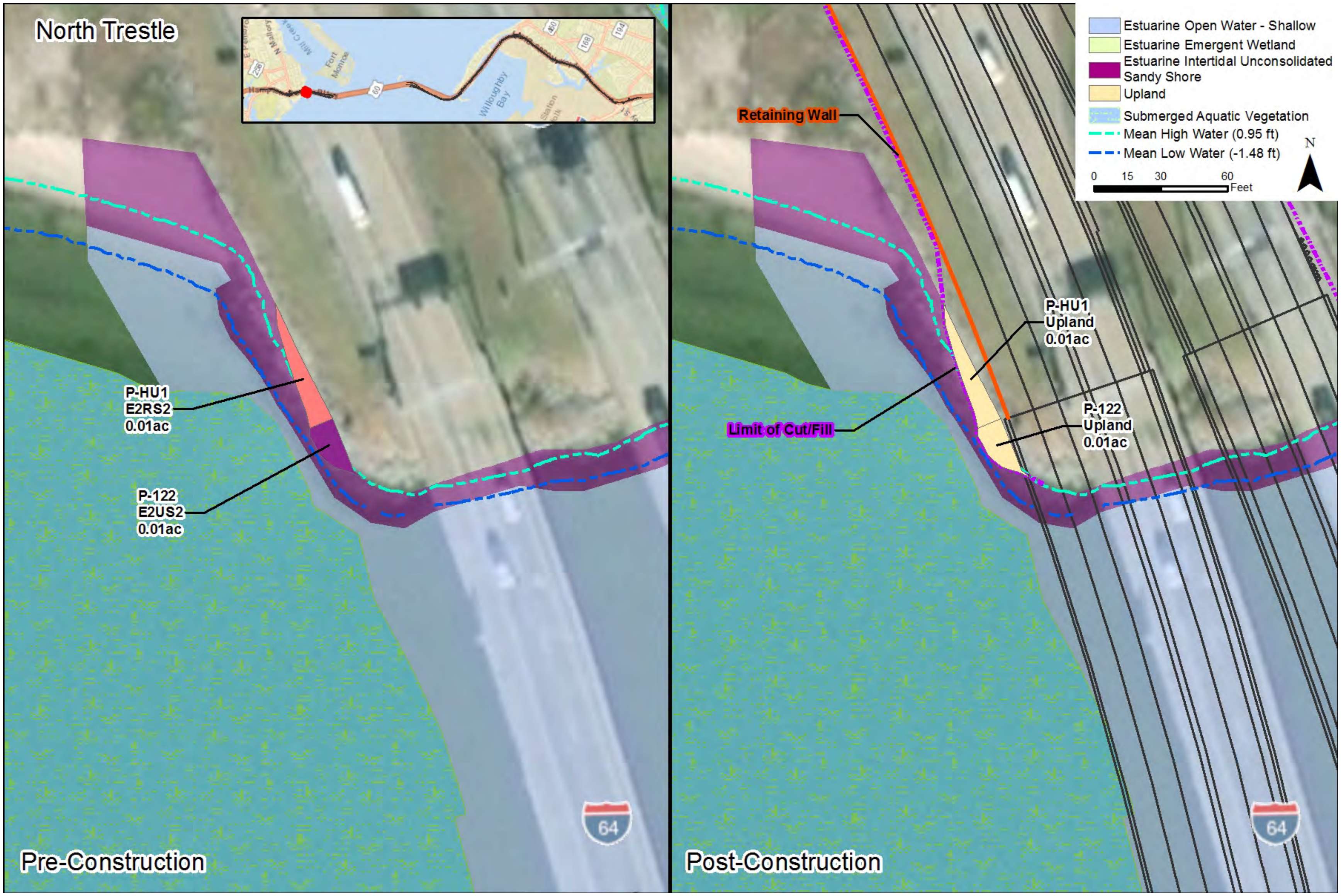


Figure 2-P. Habitat Conversion - North Island

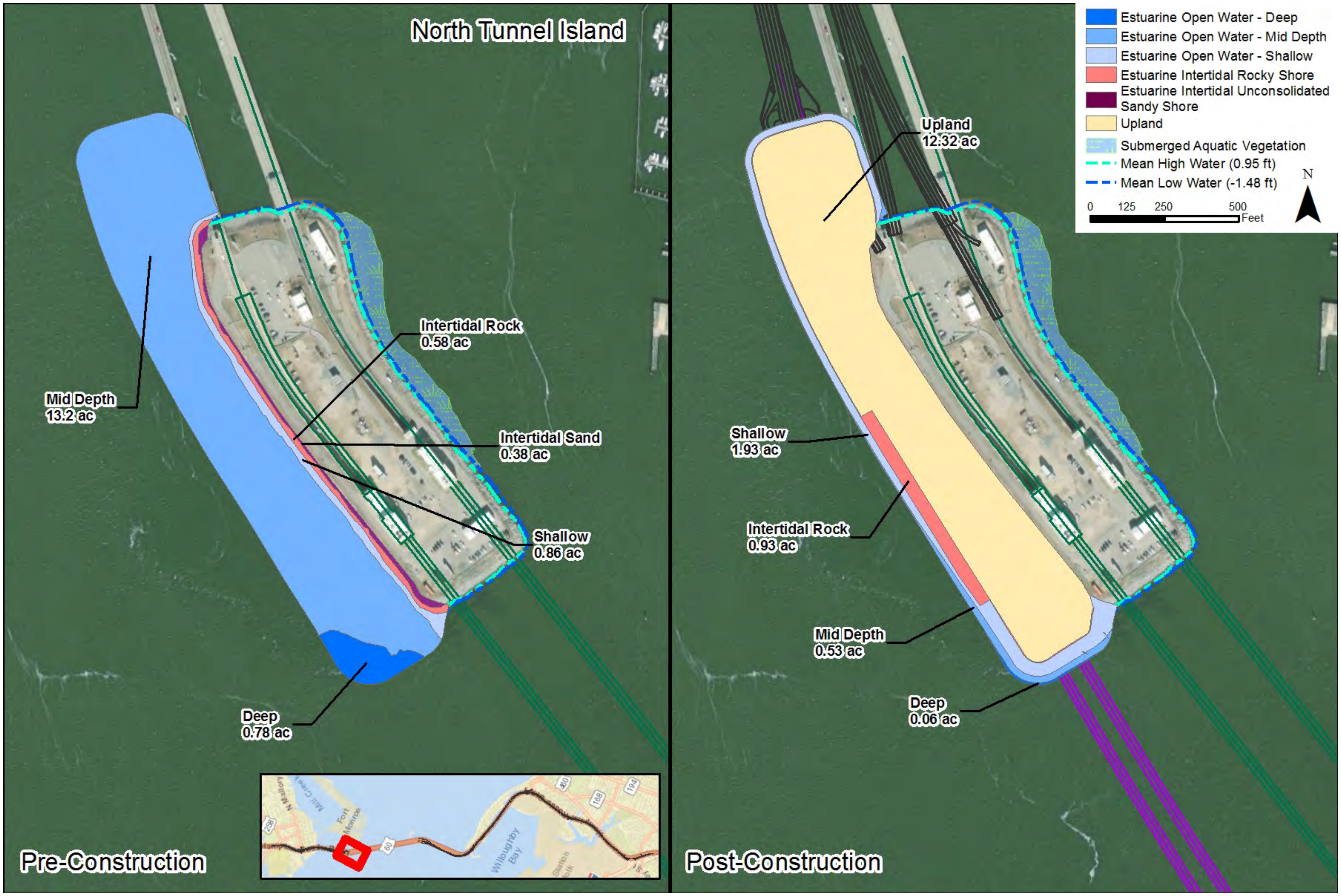


Figure 3-P. Habitat Conversion - South Island

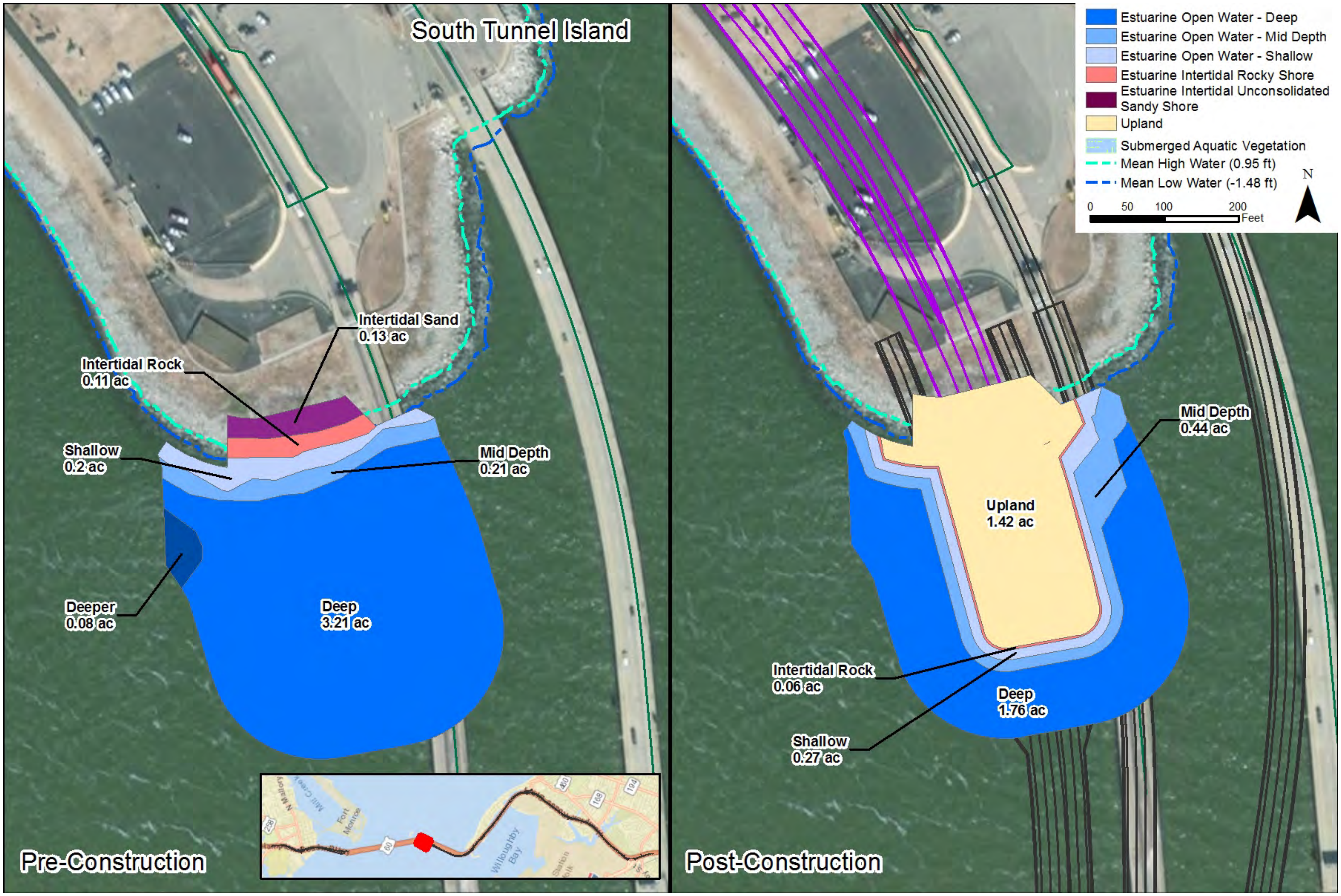


Figure 4-P. Habitat Conversion - Oastes Creek

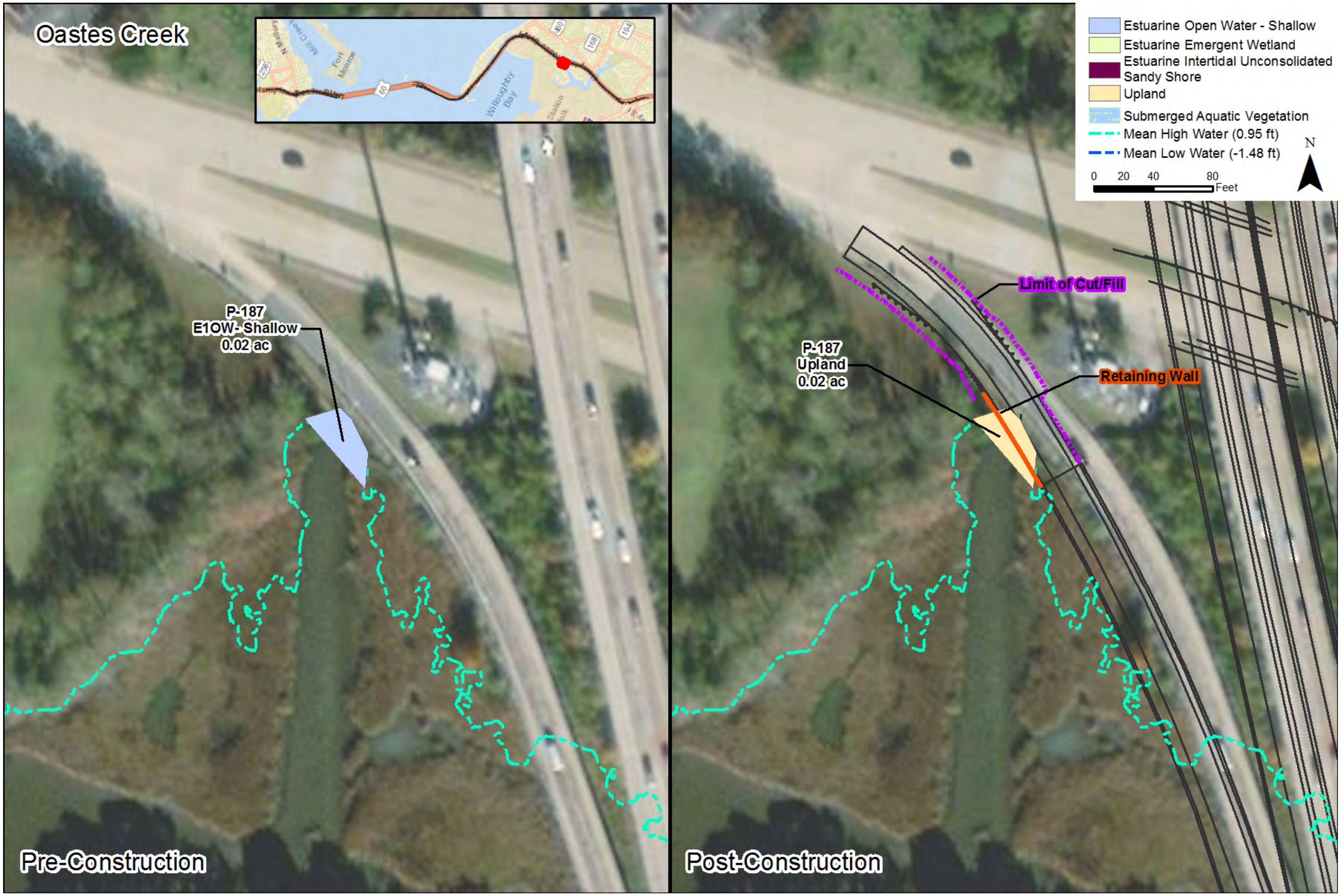


Figure 5-P. Habitat Conversion - Willoughby Bay, West Shore

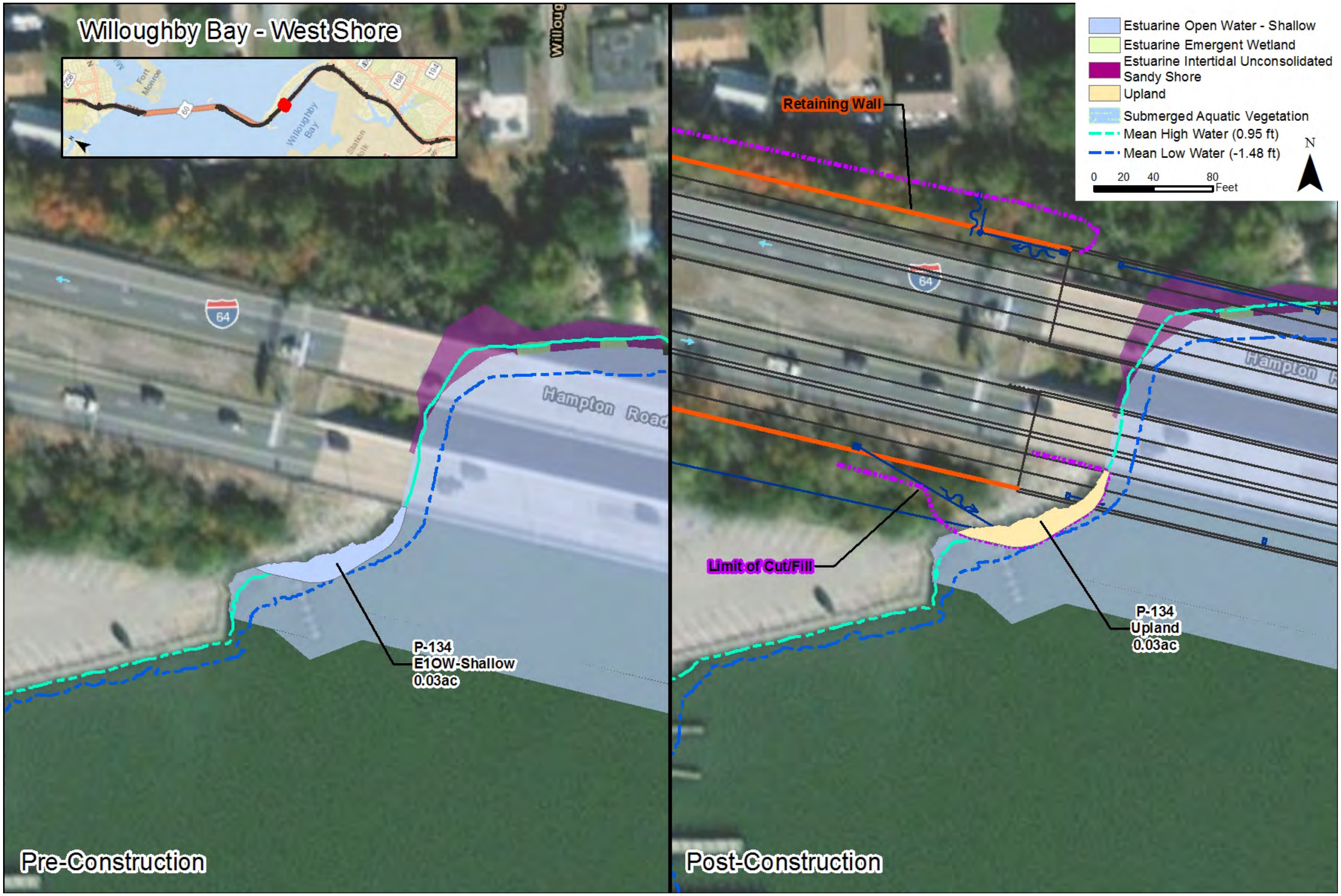


Figure 6-P. Habitat Conversion - Fourth View Street

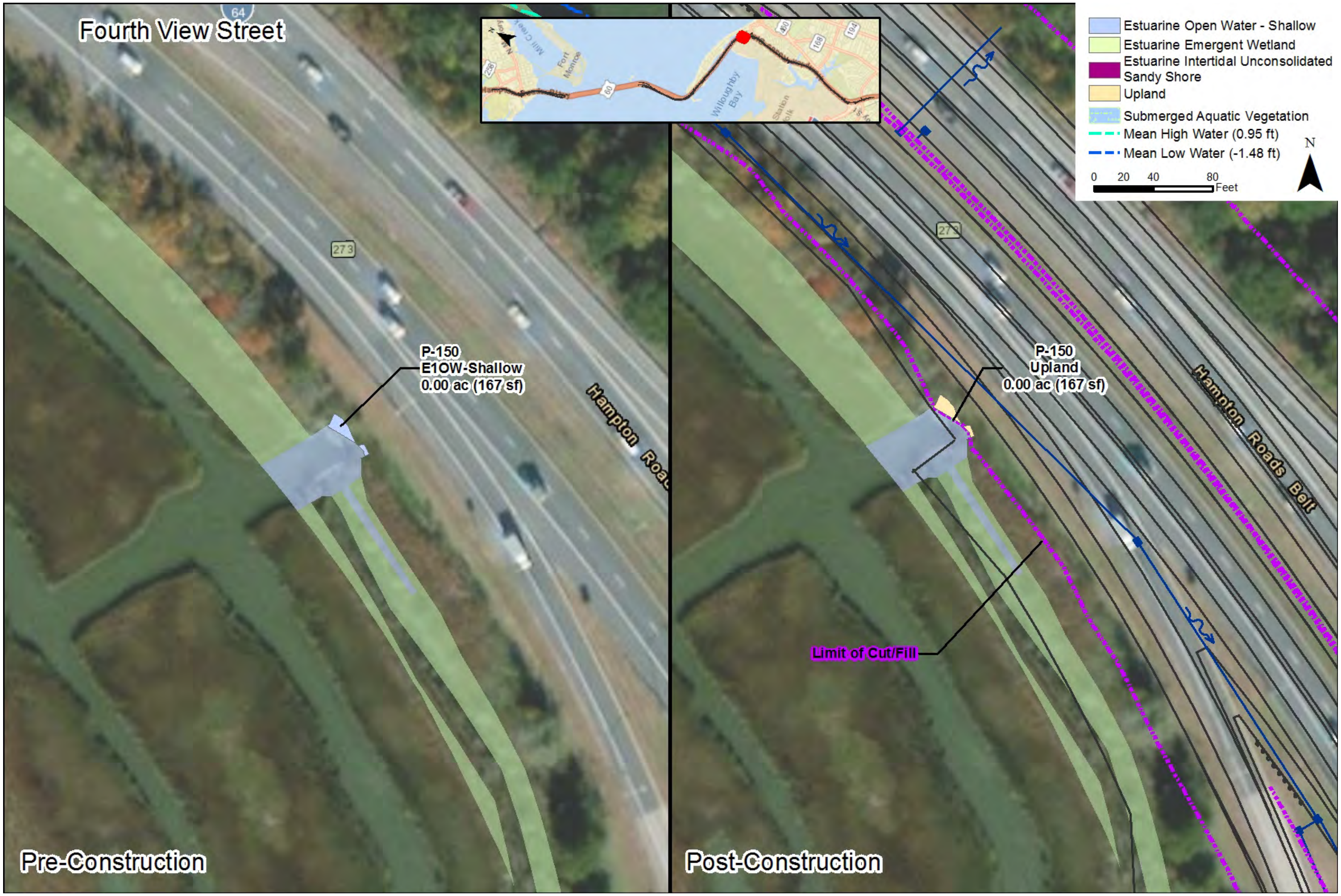
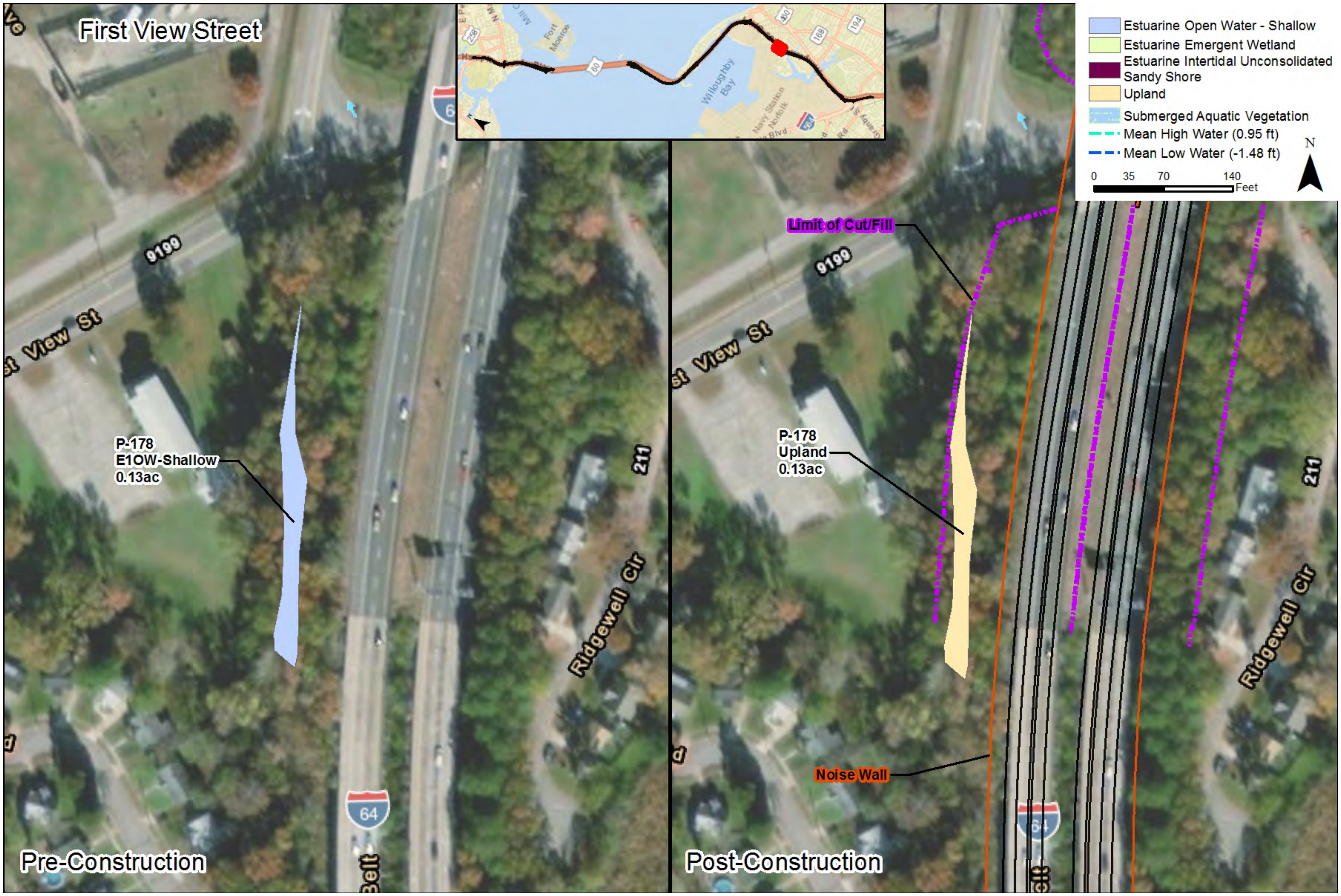


Figure 7-P. Habitat Conversion - First View Street



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ATTACHMENT 2 – MITIGATION PLAN

DOCUMENT HISTORY

Issue Date	Description	By	Revision
September 18, 2019	Revised for consistency with Revision 1 of the Appendix G – Impact Tables	R. Wilk	1

TABLE OF CONTENTS

Tables

P.1 COMPENSATORY MITIGATION PLAN

This compensatory mitigation plan has been developed in accordance with applicable state and federal mitigation policies and generally accepted practices in Virginia by the regulatory agencies. Compensatory mitigation options were considered and prioritized pursuant to the April 10, 2008 final federal regulations entitled “Compensatory Mitigation for Losses of Aquatic Resources; Final Rule” (USACE regulation 33 CFR Parts 325 and 332 and EPA regulation 40 CFR Part 230; “Final Rule”).

As stated in the Final Rule:

> *For impacts authorized under section 404, compensatory mitigation is not considered until after all appropriate and practicable steps have been taken to first avoid and then minimize adverse impacts to the aquatic ecosystem pursuant to 40 CFR part 230 (i.e., the Clean Water Act Section 404(b)(1) Guidelines).*

Typically, required compensatory mitigation should be located within the same watershed as the impact site and should be located where it is most likely to successfully replace the lost functions and services of impacted aquatic resources, taking into account such watershed scale features as aquatic habitat diversity, habitat connectivity, relationships to hydrologic sources (including the availability of water rights), trends in land use, ecological benefits, and compatibility with adjacent land uses. The Final Rule emphasizes a watershed approach to compensatory mitigation and presents the following “preference hierarchy” for compensatory mitigation (in order of preference):

- Mitigation Banking
- In-Lieu Fee Mitigation
- Permittee-Responsible Mitigation

This compensatory mitigation plan uses the Final Rule’s preferred hierarchy as the guiding principal objective by proposing a combination of mitigation methods to compensate for the unavoidable impacts resulting from the Project.

P.1.1 PROPOSED COMPENSATION

Compensation will be provided for impacts to wetland and waters resulting from permanent cut/fill, permanent shading, extended temporary shading lasting more than six months (from temporary work trestles), and permanent conversion. Temporary impacts to impacts lasting less than six months and extended temporary impacts greater than six months to non-vegetated wetlands will be restored to preexisting conditions after construction completion, thus no compensatory mitigation is proposed.

P.1.1.1 STREAMS

The Project will not permanently impact streams but will result in 27 linear feet of temporary impacts to a single perennial stream. The temporarily impacted stream will be restored to original elevations and contours and the banks will be seeded or planted with the same vegetative cover type originally present along the banks, including supplemental erosion control grasses, if necessary. No compensatory mitigation is proposed for temporary impacts to streams. Virginia Water Protection Permit Program (VWPPP) Regulations state: Compensatory mitigation for open water impacts may be required to protect state waters and fish and wildlife resources from significant impairment, as appropriate. Compensation shall not be required for permanent or temporary impacts to open waters that are identified as palustrine by the Cowardin classification method, but compensation may be required when such open waters are located in areas of karst topography in Virginia and are formed by the natural solution of limestone. (9VAC25-210-116) The VWPP Regulations define “open water” as an area that, during a year with normal patterns of precipitation, has standing water for sufficient duration to establish an ordinary high water mark. The term “open water” includes lakes and ponds but does not include ephemeral waters, stream beds, or wetlands. (9VAC25-210-10. Definitions) Cowardin et al. (1979) do not include the term “palustrine open water” as a formal classification type; however, they do acknowledge that: The Palustrine System was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie, which are found throughout the United States. It also includes small, shallow, or permanent or intermittent water bodies often called ponds. The palustrine unconsolidated bottom wetlands being impacted by the Project are equivalent to palustrine ”open water” referenced in the VWPPP Regulations; therefore, no compensation is proposed for impacts to palustrine unconsolidated bottom wetlands.

P.1.1.2 OTHER WATERS OF THE US

Permanent impacts to other waters of the US include 0.110 acres of palustrine unconsolidated bottom. The Project will also result in temporary impacts to 0.254 acres of palustrine unconsolidated bottom. The majority of the Project’s PUB impacts are to ditches that were constructed along roads for the purpose of conveying stormwater from the road surface. The Project has been designed to adequately convey all water in and around the road and is, therefore, compensating for any impact to the primary function of the ditches, which is to convey water. No compensatory mitigation is proposed for impacts to PUB wetlands.

Virginia Water Protection Permit Program (VWPPP) Regulations state:

Compensatory mitigation for open water impacts may be required to protect state waters and fish and wildlife resources from significant impairment, as appropriate. ***Compensation shall not be required for permanent or temporary impacts to open waters that are identified as palustrine by the Cowardin classification method****, but compensation may be required when such open waters are located in areas of karst topography in Virginia and are formed by the natural solution of limestone. (9VAC25-210-116. Compensation)*

The VWPPP Regulations define “open water” as:

….an area that, during a year with normal patterns of precipitation, has standing water for sufficient duration to establish an ordinary high water mark. The term "open water" includes lakes and ponds but does not include ephemeral waters, stream beds, or wetlands. (9VAC25-210-10. Definitions)

Cowardin *et al*. (1979) do not include the term “palustrine open water” as a formal classification type; however, they do acknowledge that:

The Palustrine System was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie, which are found throughout the United States. It also includes the small, shallow, permanent or intermittent water bodies often called ponds.

The palustrine unconsolidated bottom wetlands being impacted by the Project are equivalent to palustrine “open water” referenced in the VWPPP Regulations; therefore, no compensation is proposed for impacts to palustrine unconsolidated bottom wetlands

P.1.1.3 VEGETATED WETLANDS

P.1.1.3.1 SUMMARY OF IMPACTS AND CREDITS REQUIRED

Compensation will be provided for impacts to wetlands resulting from permanent cut/fill, permanent shading, extended temporary shading lasting more than six months (from temporary work trestles), and permanent conversion. Compensation for permanent impacts to vegetated wetlands will be achieved through the purchase of wetland credits from approved mitigation banks using generally-accepted ratios. Impact acreages, compensation ratios, and proposed compensation are summarized in Table P-1 below.

Table P-1: Summary of Credits Required for Permanent Impacts to Nontidal and Tidal Vegetated Wetlands

Impact Type	Compensation Ratio	Impact Area (AC)	Credits Required
Nontidal			
PFO Cut/Fill	2:1	0.123	0.246
PFO Permanent Conversion	1:1	0.009	0.009
PSS Cut/Fill	1.5:1	0.252	0.378
PSS Shading	1:1	0.112	0.112
PEM Cut/Fill	1:1	0.260	0.260
PEM Shading	1:1	0.006	0.006
Nontidal Total		**0.762**	**1.011**
Tidal			
E2SS Cut/Fill	1.5:1	0.084	0.126
E2SS Cut/Fill Mallory Street Mitigation Site	3:1	0.051	0.153
E2SS Shading Mallory Street Mitigation Site	2:1	0.056	0.112
E2EM Cut/Fill/Piles	1:1	0.131	0.131
E2EM Shading	1:1	1.911	1.911
E2EM Cut/Fill Mallory Street Mitigation Site	2:1	0.037	0.074
E2EM Shading Mallory Street Mitigation Site	2:1	0.088	0.176
Tidal Total		**2.358**	**2.683**

P.1.1.3.2 PROPOSED COMPENSATION FOR IMPACTS TO VEGETATED WETLANDS

HRCP proposes to compensate for permanent impacts to 0.762 total acres of nontidal vegetated wetlands (PFO, PSS, and PEM) through the application of 1.011 nontidal vegetated wetland credits previously purchased by VDOT from the Great Dismal Swamp Restoration Bank - Lewis Farm Mitigation Bank (Table P-1).

HRCP proposes to compensate for permanent impacts (which includes temporary impacts greater than six months) to 2.358 acres of tidal vegetated wetland (ESS and EEM) impacts through the purchase of 2.683 tidal vegetated wetland credits from approved mitigation banks and “advance release credits” from the Living River Restoration Trust (LRRT) in the Hampton Roads sub-basin (HUC 02080208). Table P-2 summarizes the tidal vegetated wetland credits that are currently available or that will be available prior to the anticipated construction start date for the Project. Based on the current availability of tidal vegetated wetland credits for purchase in the Hampton Roads sub-basin, it is anticipated that successful mitigation for tidal vegetated wetland impacts will be achieved. A letter of credit availability is provided.

Table P-2: Available Tidal Vegetated Wetland Credits

Bank	Credits Available	Date Available
Chesapeake Land Development Banks (Libertyville, New Mill Creek Mitigation Bank, Steek Street Mitigation Bank)	2 AC	Current
Chesapeake Land Development Banks (Libertyville, New Mill Creek Mitigation Bank, Steek Street Mitigation Bank)	3 AC	August 30, 2019
Chesapeake Land Development Banks (Libertyville, New Mill Creek Mitigation Bank, Steek Street Mitigation Bank)	5 AC	June 2020
LRRT Advanced Credits	2 AC	Current
Total Credits Available (Updated 06/28/2019)	4 AC	---
Additional Credits Available by June 2020	8 AC	---

The Project will also result in temporary impacts (for trestles and construction access) to a total of 3.291 acres of vegetated wetlands, which includes 0.450 acres of nontidal vegetated wetlands (PFO, PSS, and PEM) and 2.841 acres of tidal vegetated wetlands (EFO, ESS, and EEM) (see Appendix G, Attachment G-2). Where practicable, the existing natural root mat, stumps, and herbaceous vegetation will be used as a base for any temporary access routes, however no grubbing will occur. Woody vegetation will be cut at or above the ground level. Geotextile fabric will be placed on the existing surface and BMPs will be used for all wetland crossings such as temporary ground protection wooden mats, prefabricated equipment pads, or washed free-draining aggregate placed on geotextile fabric. All mats, aggregate, and fabric will be removed after construction is complete. Temporarily impacted wetlands will be restored to preconstruction elevations once construction is completed and compacted soil will be loosened by ripping or other approved methods. During the permitting process, HRCP will coordinate with regulatory agencies to develop practices acceptable for restoration of temporarily impacted vegetated wetlands. Compensatory mitigation is not proposed for temporary wetland impacts.

P.1.1.4 NON-VEGETATED AQUATIC MITIGATION

The Commonwealth of Virginia does not provide compensatory mitigation guidance for aquatic habitats within jurisdictional waters of U.S. other than vegetated intertidal and nontidal wetlands and waters. Thus, there is no guidance for non-vegetated intertidal and vegetated and non-vegetated subtidal waters. The vast majority of the impacts from the project are to non-vegetated subtidal areas through the expansion of the north and south islands (14.12 acres to uplands, see Attachment 1 Table P-2).

P.1.1.4.1 HABITAT CONDITION ASSESSMENT

To quantify the net loss or gain of aquatic habitat functions and values that may result from the Project, a Habitat Condition Assessment (HCA) was performed (see Attachment 1 of this appendix). The HCA method is a semi-quantitative approach, based on the National Oceanic and Atmospheric Administration (NOAA) Habitat Equivalency Analysis (NOAA 2000). HCAs have been performed for other projects within the Chesapeake Bay watershed to assess habitat value and to aid in determining compensatory mitigation (EA 2017). The HCA expresses habitat functions and values in terms of Habitat Units which are the product of habitat score multiplied by acreage.

The HCA found that impacts (conversion of aquatic habitat or loss of habitat) to tidal subaqueous and non-vegetated wetlands would result in a net loss of approximately 41 Habitat Units; however, the vast majority of this reduction (over 90%) was due to loss of habitat from conversion to uplands necessary for the expansion of the north and south islands. The remaining impacts are from various fills or conversions from road widening, trestle widening and other construction activities. When comparing average habitat scores pre- and post-construction, it was found that all other conversions of aquatic resources to another aquatic resource did not result in large changes of functions and values. These results suggest that a loss of functions and values only results if tidal subaqueous and non-vegetated wetlands are converted to uplands and that all other conversion impacts are self-mitigating. These conversions are self-mitigating because there was not a substantive change in function or value so the overall habitat conditions remained largely unchanged from pre-construction conditions. Consequently, HRCP is proposing to compensate for the conversion of tidal subaqueous and non-vegetated wetlands to uplands (14.12 acres).

P.1.1.4.2 PROPOSED COMPENSATION FOR TIDAL AND SUB-TIDAL SUBAQUEOUS HABITATS CONVERTED TO UPLAND

HRCP is proposing to compensate for conversion of 14.12 acres of inter-tidal and sub-tidal subaqueous habitats to uplands by purchasing 14.12 subaqueous advance release credits from the Living River Restoration Trust (LRRT). LRRT is currently the only source of subaqueous bottom credits in the watershed.

Currently, the LRRT has 10 subaqueous advance release credits available. According to the LRRT's Mitigation Banking Instrument (MBI), the Interagency Review Team (IRT) may approve additional advance release credits to meet current market demand in the watershed. HRCP will request that LRRT initiate coordination with the IRT to secure 4.12 additional advance release credits. In HRCP's opinion, LRRT's subaqueous credits provide the closest to "in-kind" compensation compared to other options in the watershed.

P.1.1.5 SUBMERGED AQUATIC VEGETATION MITIGATION

The project will permanently impact a relatively small area (6.25 square feet) of submerged aquatic vegetation (SAV) for one 30-inch pile placement (see Attachment G-1, Sheet 5). Additionally, the Project will result in 0.401 acres of extended temporary shading impacts to SAV from pile-supported temporary work trestles that will remain in place for longer than six months (see Appendix G, Impact ET-SAV on Impact Sheet 5). As explained in Appendix G, the DEQ shading formula was used to calculate shading impacts. Impact WT-SAV (0.146 acres) is the area underneath the temporary work trestle and adjacent to Impact ET-SAV that will not experience shading per the DEQ shading formula. There will be no shading impacts to SAV from the permanent trestles. In coordination with permitting agencies, it was determined that compensating for both permanent and extended temporary impacts greater than six months to SAV beds at a 1:1 ratio would provide suitable replacement of lost functions and values. There are no "in-kind" commercially available mitigation credits available for SAV in the watershed; therefore, HRCP explored two options for SAV compensation: the purchase of advance release oyster credits from LRRT and providing funding for SAV restoration through the Virginia Institute of Marine Science (VIMS). LRRT currently has 2 advance release oyster credits for restoration of oyster reefs in the watershed.

VIMS is actively working to restore SAV through plantings of SAV seed and transplants. VIMS has restored over 6,000 acres of SAV on the seaside of Virginia (VIMS 2019) (outside of the Project watershed); however, restoration efforts in the Chesapeake Bay have been less successful. Efforts to restore eelgrass in the Chesapeake Bay by transplanting have failed to significantly increase its overall abundance in most locations. Early success in restoring eelgrass to the lower York and James Rivers via seed has also not persisted long term. SAV restoration in the Chesapeake Bay is problematic due in large part to high levels of turbidity that result from suspended solids that are carried into the Bay from multiple riverine sources. High turbidity results in a bias for successful SAV establishment in shallower waters where SAV is susceptible to higher temperatures and an associated increase in mortality. Bayraktarov et al (2016) found that sea grass restoration efforts worldwide had a survival rate of just 38% after 2 years.

One key criterion for improving the success of SAV restoration is improving water quality. The establishment of water-clarity goals to reduce sediment and nutrient inputs from upland sources, tidal shorelines, tidal resuspension, and estuarine processes facilitate seagrass restoration and recovery (VIMS 2019). Mann (2000) studied the interaction of oysters and SAV and found that, on a large scale, the presence of multiple reef systems with vertical relief in otherwise open bodies of water, like much of the Chesapeake Bay, reduces fetch and, therefore, wind-driven resuspension of particulate material in the water column. The presence of fringing reefs also reduces sediment input from shoreline erosion. At a smaller scale, filter feeding by oysters reduces water column loads of sediment and plankton, thereby increasing light penetration and increasing SAV growth. Mann (2000) concluded that a critical reduction in sediment load promoted SAV growth resulting in an oyster-SAV positive feedback interaction loop. Cerco and Noel (2005) also found that, in shallow regions, oyster removal of solids from the water column enhances adjacent SAV beds.

Because of the low success rate of SAV restoration in the Chesapeake Bay and the overall indirect benefit to SAV success from oyster reefs, it is HRCPs opinion that oyster reef restoration would provide the best replacement of lost functions and value from SAV impacts. Additionally, because SAV restoration through VIMS would be considered permittee responsible mitigation, the purchase of advance release credits from LRRT would be consistent with the mitigation hierarchy of the 2008 Final Mitigation Rule. Therefore, HRCP is proposing to compensate for impacts to 0.40 acres of SAV beds through the purchase of 0.40 currently available advance release oyster credits from LRRT.

P.1.2 CLAM MITIGATION

A benthic survey was performed for the HRBT Expansion project by Versar in 2018. Three transects within the proposed North Island expansion area and two transects near the proposed south island expansion were evaluated for the density of bivalves. The results are summarized in Table P-3.

Table P-3: Benthic Survey Results

Location	Average of Abundance (# per m^2)	Average of Biomass (ADFW)
North Island	118.41	0.11
South Island	130.64	0.30
Grand Total	**123.56**	**0.19**

Clam habitat will be mitigated at 1.3:1 with the purchase of chowder clams for placement on public clam grounds by the VMRC per conversations and meetings with the VMRC. HRCP is currently working with VIMS to finalize the clam mitigation activities to adequately compensate for clam impacts. HRCP would not conduct long-term monitoring of the clam sites and HRCP would assume that the clam compensation requirement would be satisfied upon purchase of the clam chowders.

P.1.3 DREDGING IMPACTS

Limited dredging will occur along the southern extent of the existing bridge between the South Island and Willoughby Spit in areas that are too shallow to allow access for construction vessels. Dredging of 7.896 acres will occur to estuarine open water near the south trestle. Dredging in the estuarine sandy shore zone will be limited to the minimum depth necessary to remove debris which will be 1-2 feet deep. There will also be dredging within the island expansion footprints.

Impacts of dredging to benthic communities in the Chesapeake Bay have been observed to be mostly short-term. A literature review states there would be no significant impacts to benthic infauna from dredging operations due to the natural resilience of species found in areas subject to strong tidal flushing such as the Chesapeake Bay (Sullivan and Hancock 1977; Dauer 1985; Nichols et al. 1990; USDOT 1994). Stern and Stickle (1978) found the benthic community can recover in as little as 28 days according to the findings of McCauley et al. (1977).

Newell et al. (1998) considers recovery to be around 80% of the diversity and abundance as the reference site. Initial colonization after dredging is by opportunistic species like aquatic worms, which transitions to a mixed diversity of both opportunistic and habitat-selective species until finally plateauing with predominately habitat-selective species. Dredging can be expected to reduce species diversity by 30–70% and the number of individuals (abundance) by 40–90%. However, recolonization proceeds rapidly, with only 6 months until re-establishment to a similar condition as the control. In shallow water and estuarine conditions, where the community is likely dominated by opportunistic species, recovery to the original species composition may be very rapid. In the stable environmental conditions of deeper waters, the replacement of the initial colonizers, like opportunistic species, in the transitional community following complex biological interactions between habitat-selective species may take several years" (Newell et al. 1998). A comprehensive study by Wilber and Clarke (2007) observed dredging across the United States and found that certain conditions dictate the rate of benthic community recovery time. They studied five (5) sites in the U.S. (one of which being the Delaware Bay) pre and post channel dredge that recorded benthic recovery (equal to that of an un-impacted reference site) anywhere from 1 to 6 months. The Delaware Bay recorded a recovery time just greater than 5 months. No long-term impacts to infaunal community were reported (Wilber and Clarke 2007).

Since the proposed dredging for the project is relatively shallow it is expected that the benthic communities will recover quickly based on the existing scientific data. Since the benthic communities are expected to return to pre-dredged conditions in a fairly short time period, no compensatory mitigation is proposed for dredging impacts.

P.1.4 TRESTLE PILES

A total of 1,453 permanent piles (9,082 square feet) will be placed to support the new trestles throughout the project. As part of the demolition of the existing trestles, 1,774 piles (12,346 square feet) will be removed. The piles will be removed by cutting the piles two to three feet below the mudline and placed onto barges for disposal. This constitutes a reduction of 321 piles. The area where the old piles are removed is expected return to the surrounding conditions upon removal. Since the new construction results in an overall reduction of piles and impact from the existing structures, the piles placed by the project will not require mitigation.

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ATTACHMENT 3 – BENTHIC REPORT

HAMPTON ROADS BRIDGE-TUNNEL EXPANSION
BASELINE BENTHIC SURVEY

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VERSAR

FOREWORD

This report provides baseline data to characterize the benthic community and sediment composition within and adjacent to the proposed area of disturbance prior to construction activities associated with the expansion of the Hampton Roads Bridge Tunnel. Versar conducted and/or managed all field operations, sample collection, and laboratory analysis. The project and report were managed by David A. Wong, and completed with the assistance of the following staff: Suzanne Arcuri, Amanda Bromilow, Patrick Donovan, Maggie Glaudemans, Roberto Llanso, Kevin McGuckin, Don Strebel, and Danielle Zaveta. Versar was assisted in the field by Crofton Industries who conducted the technical diving portion of the rocky shore surveys. Cove Corporation assisted with taxonomic identification and verifications.

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EXECUTIVE SUMMARY

The Hampton Roads Bridge-Tunnel (HRBT) Expansion Project, known as Alternative A, is an effort to reduce congestion at the tunnel by widening the Interstate 64 corridor through Hampton and Norfolk, Virginia, from four to six lanes. To determine the potential impacts of bridge-tunnel construction on the surrounding marine environment, the natural conditions of the area need to be established. Baseline surveys in the project area were conducted in September and October 2017 to characterize the natural background condition of the benthic macroinvertebrate community within and adjacent to the proposed area of disturbance. The surveys consisted of soft-bottom transects along the existing bridge and disturbance area surrounding the HRBT portal islands, and rocky intertidal and subtidal transects perpendicular to the portal islands.

A total of 48 sites in 12 transects and the cove at Fort Wool was sampled using a Young-modified van Veen grab, and an additional 48 sites in 12 transects were sampled using a coring device in the intertidal habitat and quadrats in the subtidal habitat. Soft-bottom samples were processed for benthic macroinvertebrates, grain size, and organic carbon content, and rocky shore samples were processed for algal biomass and benthic macroinvertebrates. Water quality measurements of temperature, salinity, conductivity, dissolved oxygen, dissolved oxygen saturation, and pH were taken near the surface and near the bottom of the water column.

The surveys yielded a total of 184 taxa in the soft-bottom, 62 taxa in the rocky intertidal, and 117 taxa in the rocky subtidal, a majority of which could be identified to species level. Water quality was homogeneous throughout the project area, with salinity in the polyhaline range and dissolved oxygen near saturation. Sediments were mostly fine and medium sands with various amounts of coarse sand and gravel, and low organic carbon content. In the Fort Wool cove, sediments were fine and very fine sands with various amounts of silt and clay.

The soft-bottom was numerically dominated by the reef-forming polychaete *Sabellaria vulgaris* and amphipods, and oligochaetes were abundant in coarser sediment. High densities of *Sabellaria* were recorded along the south bridge and inner (bridge side) tip of the south portal island. Biomass dominants were the sand lancelet *Branchiostoma caribaeum*, *Sabellaria vulgaris*, and the decapod *Eurypanopeus depressus.* The soft-bottom macrobenthos met the Chesapeake Bay Benthic Community Restoration Goals in 32 sites, and failed the goals in 16 sites. Of the 16 sites that failed, eight were classified as marginal, three as degraded, and five as severely degraded by the Benthic Index of Biotic Integrity.

The rocky intertidal was numerically dominated by barnacles (*Chthamalus fragilis*) and amphipods, and the inner tip of the north portal island exhibited high density and biomass of oysters and mussels. The rocky subtidal was covered by a dense canopy of algae that provided habitat for numerous species of amphipods. Sponges and bryozoans were common in the rocky subtidal, and the amphipod *Caprella penantis* was very abundant. Anemones (*Diadumene leucolena*), oysters, amphipods (*Caprella penantis*), and gastropods (*Mitrella ocellata*) were biomass dominants. Diversity and dominance measures were similar in the soft-bottom and rocky subtidal. In the rocky intertidal, diversity was lower and dominance higher.

Annual secondary production of macrobenthos, estimated by Brey's empirical model, was on average highest in the rocky intertidal (mean = 156.0 g AFDW m^{-2}), including one site with very high oyster and mussel production (578.5 g AFDW m^{-2}), and lowest in the soft-bottom (mean = 15.7 g AFDW m^{-2}). Annual secondary production in the rocky subtidal was high (mean = 86.2 g AFDW m^{-2}) and within the range of production of shoreline stabilization structures reported for other studies.

Total macrobenthic production was 3.7x higher for the soft-bottom than for the rocky shore when scaled to the footprint of the inventory area. Thus, the reef area represented by the portal islands will be unable to compensate for production loss in the surrounding soft-bottom benthic community, if the footprint of the disturbance area is of the same magnitude as the footprint of the inventory area.

TABLE OF CONTENTS

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VERSAR

LIST OF TABLES

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LIST OF FIGURES

Figure No. **Page**

1.0 INTRODUCTION

The Hampton Roads Bridge-Tunnel (HRBT) Expansion Project, known as Alternative A, is an effort to reduce congestion at the tunnel by widening the Interstate 64 corridor through Hampton and Norfolk, Virginia, from four to six lanes. To determine the potential impacts of bridge-tunnel construction on the surrounding marine environment, the natural conditions of the area need to be established. The purpose of this study was to characterize the benthic community and sediment composition within and adjacent to the proposed area of disturbance. In addition, to understand the potential enhancement value of the portal island rock habitat for mitigation purposes, estimates of secondary production are provided. Data from the benthic surveys will be used as a baseline for future ecological impact evaluations of the HRBT Expansion Project.

2.0 METHODS

2.1 Soft-Bottom Survey

<u>Sampling Design</u>

A survey of the soft-bottom benthos in the project area was conducted in September 2017. A total of 48 sites was sampled, with 14 sites located along the existing bridge and 34 sites located within the proposed disturbance area surrounding the HRBT portal islands (Figure 1a). Sample sites surrounding the northern (Figure 1b) and southern (Figure 1c) portal islands were located along transects radiating out from the islands. Four additional sites were selected at random in the cove formed by the southern portal island and Fort Wool (Sites 25-28, Figure 1c). All sampling locations were given final approval by VDOT. Site coordinates are presented in Appendix A.

<u>Field Procedures</u>

Benthic sampling was conducted September 13-14, 2017, from Versar's research vessel R/V *Integrity*. In the field, sampling sites were identified using an onboard Global Positioning System (GPS). Once on station, position coordinates were marked and stored on the GPS and recorded on field datasheets. Sampling of the benthic invertebrates was limited to soft-bottom substrates. If the benthic grab encountered hard substrate (rocks, consolidated sand), samples were taken at alternative locations nearby until a valid soft-sediment sample was obtained. This was done because benthic sampling gears usually cannot penetrate hard substrates.

Water quality parameters were measured at the surface and bottom (~0.5 m from the seafloor) of the water column at each sample site. A Yellow Springs Instrument EXO2 data sonde was used to measure dissolved oxygen concentration (DO), salinity, conductivity, temperature, and pH. Time and water depth were also recorded from the vessel's electronic depth finder.

Benthic samples were collected using a Ted Young-modified van Veen grab sampler with a surface sampling area of 0.044 m^2 and a maximum substrate penetration depth of 10 cm. Separate samples were collected for benthic macroinvertebrates and sediment analysis (one of each per site). Benthic samples were sieved in the field through a 0.5-mm mesh screen. Organisms retained on the screen were transferred to labeled 1-gallon plastic jars and preserved in a 10% solution of buffered formaldehyde stained with Rose Bengal. Sediment samples for grain size and organic carbon content analysis were subsampled by removing the top 2 cm of sediment into labeled 8-oz plastic bags. Bags were kept on ice in the dark while in the field, and subsequently frozen in the laboratory pending analysis.

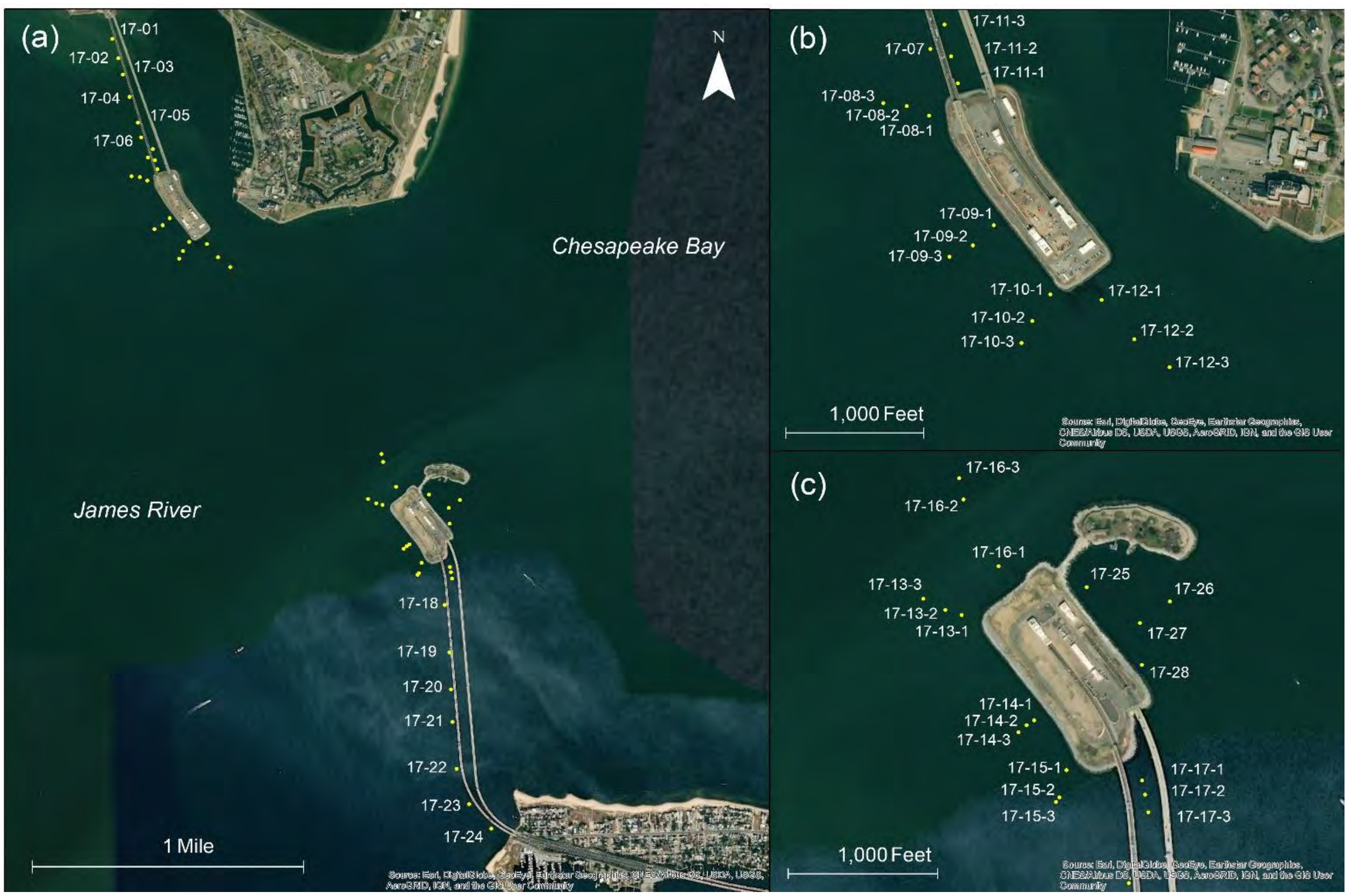

Figure 1. Map of the Soft-Bottom Benthic Survey in the Hampton Roads Bridge-Tunnel Project Area. Sampling sites were positioned along the bridge trestle (a), and transects at the northern (b) and southern (c) portal islands

2.2 Rocky Shore Survey

Sampling Design

The intertidal and subtidal rocks of the portal islands were sampled in October 2017. A reconnaissance dive survey was conducted ahead of sampling on August 16, 2017, to identify representative sites for the benthic survey. Professional divers from Crofton Industries captured video of the substrate at 10 potential survey stations to assess the distribution and abundance of epifaunal growth on the rocky substrate surrounding the portal islands. The video was also used to determine the most efficient strategy for collecting samples.

Versar and VDOT established 12 sampling locations based on the reconnaissance dive survey (Figure 2). At each location, a transect was created from the mean high water (MHW) mark down to the interface where the rocks met the soft bottom. A marker float was anchored at this interface, and the length of the transect was estimated using a laser rangefinder. Three subtidal sites were then marked with weighted floats at equal intervals along the transect. An intertidal site was also marked randomly and sampled at each transect. A total of 48 samples (12 transects x 4 levels) was collected from the rocks. Site coordinates are presented in Appendix A.

Field Procedures

Benthic sampling was conducted October 2-4, 2017, with the help of Crofton Industries divers. In the field, the boats were anchored perpendicular to shore at the sampling locations, and transects and sampling sites were marked. Versar scientists provided guidance to the dive team during the sampling to ensure an understanding of and compliance with the survey design and methods.

Intertidal samples were collected by scraping organisms off the surface of a randomly selected point at the sampling site (Figure 3a). A 15.2-cm (6 in) diameter PVC pipe was used to mark a sampling area (182 cm^2) on the rock surface (Figure 3b). A metal scraper was then used to remove the organisms within the marked area (Figure 3c). All biological material was collected in a labeled cloth bag.

For subtidal samples, the diver located the sampling site following the marker float line to the weight on the seafloor. A 30-cm square PVC quadrat (900 cm^2 surface sampling area) was positioned on the seafloor with the bottom-left corner next to the weight to mark the sampling area. All foliage within the quadrat was removed by hand and placed in a labeled cloth bag (Figure 4). Remaining organisms were then scraped from the rocks using a metal scraper (Figure 5). A custom-made PVC suction sampler with an attached bag was used to collect material while scraping to minimize the loss of sample (Figure 6). Sample bags were secured and brought to the surface after each dive.

Upon retrieval, sample bags were placed in a 5-gallon bucket filled with ambient seawater. Bags were then transferred to a 0.15% propylene phenoxytol (POP) solution, a common relaxing agent used to aid in taxonomy. After approximately 30 minutes in the POP solution, bags were placed in 1-gallon bottles and preserved in an 8-10% buffered formalin solution.

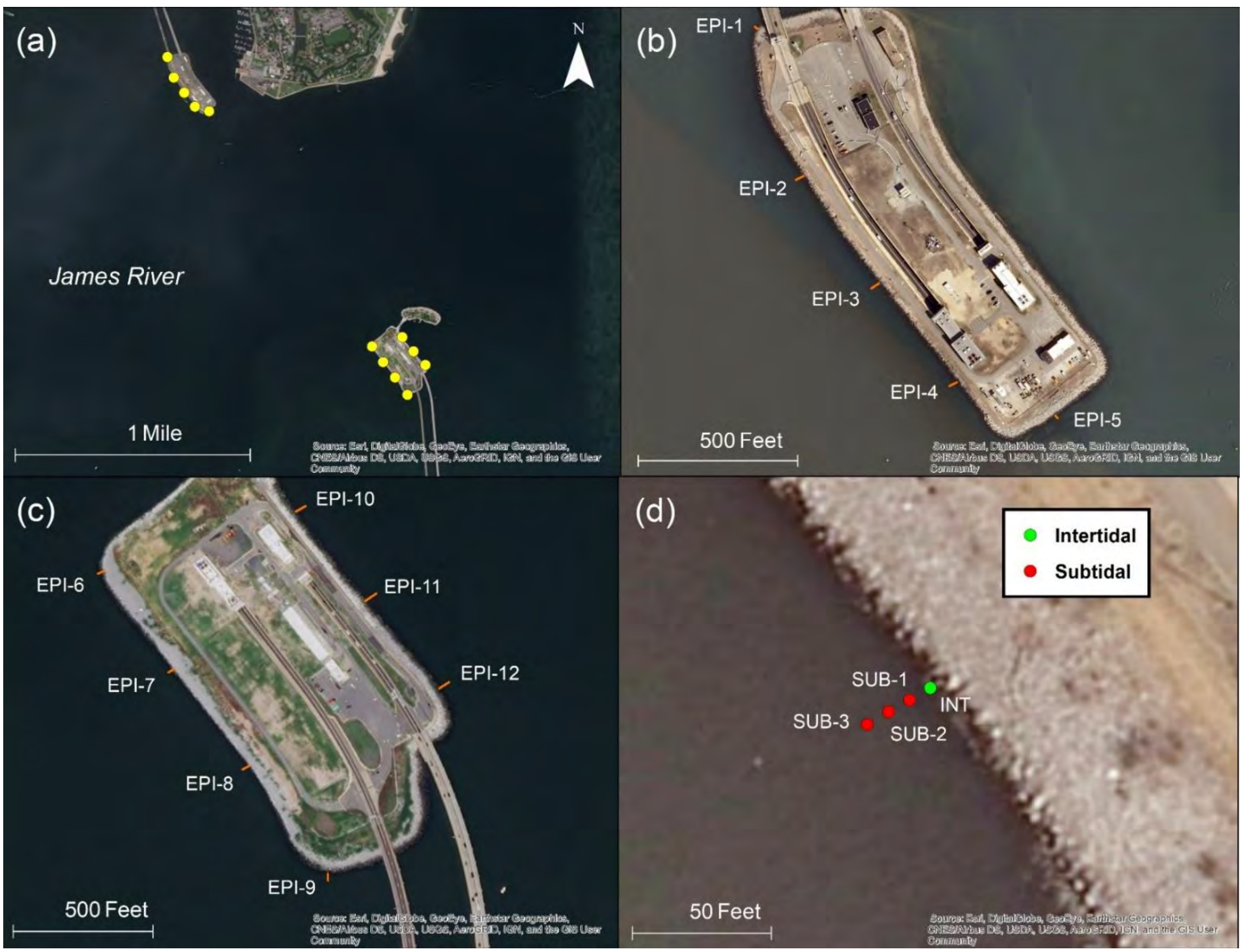

Figure 2. Sites were positioned in transects perpendicular to the portal islands (a), with five transects in the northern portal island (b), seven transects in the southern portal island (c), and four sites per transect (d)

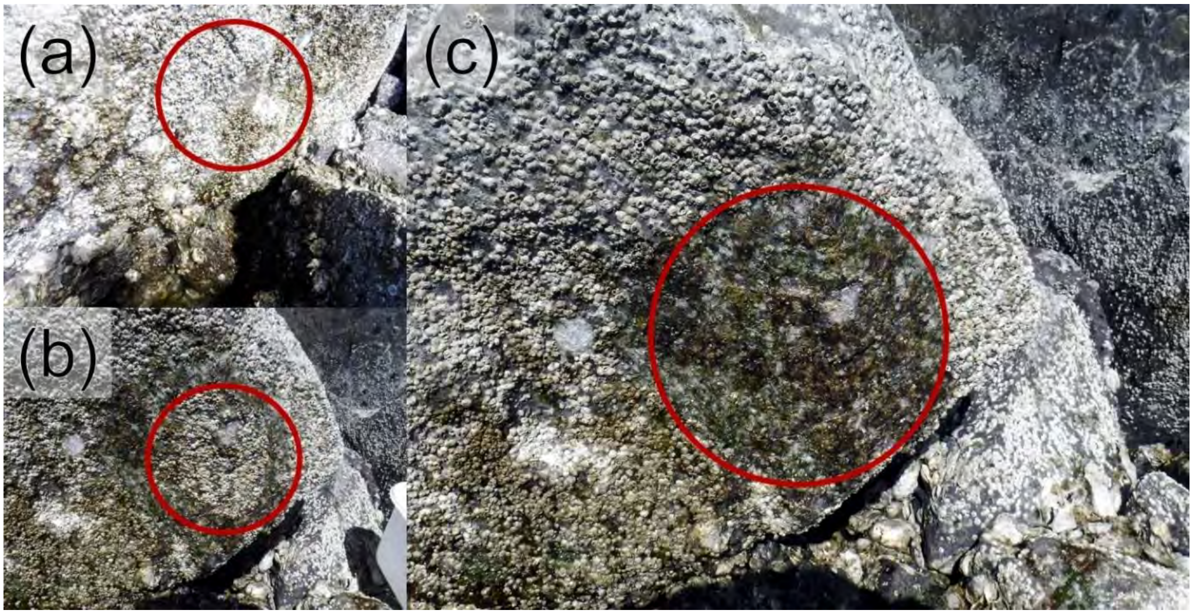

Figure 3. The intertidal was sampled by selecting a point at random (a), marking a circular area with the aid of a 6-inch PVC pipe (b), and removing all the biological material (barnacles in this case) within the sampling area. Red circles indicate the sampling area

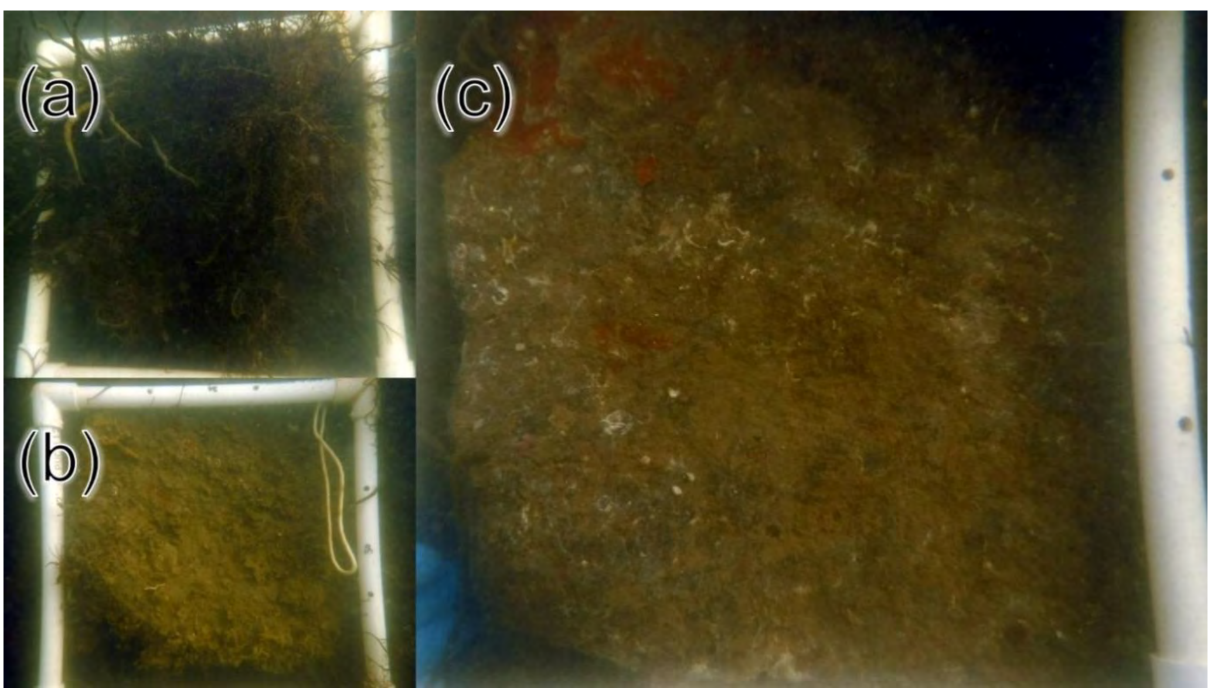

Figure 4. Images of the Sampling Process at a Subtidal Site with Abundant Foliose Growth. Soft growth within a 30 X 30 cm quadrat (a) was first removed by hand to expose the encrusted rock surface (b). The rock was then scraped, and the remaining

biological material collected with the aid of a suction sampler until the rocky surface was exposed (c)

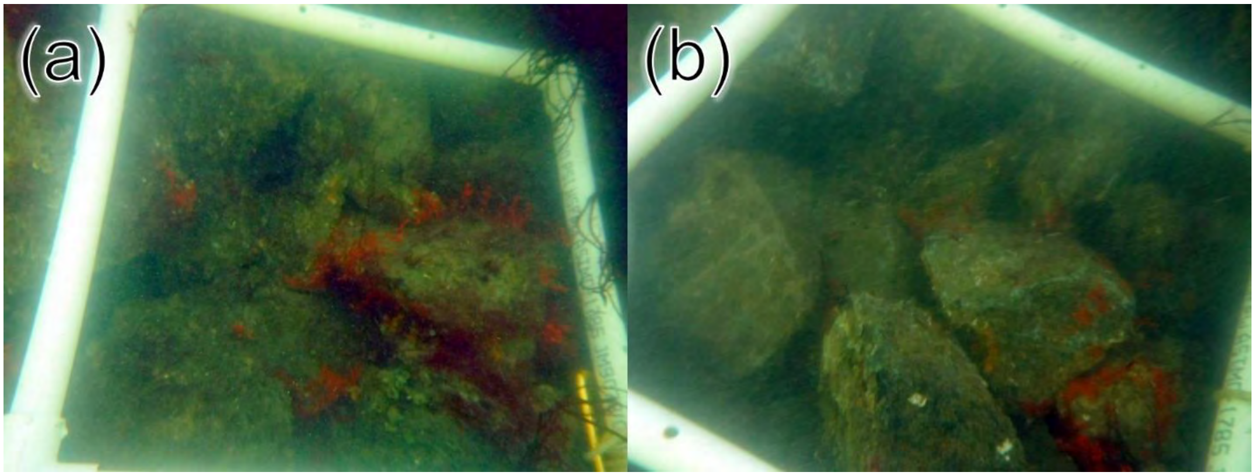

Figure 5. Images of the Sampling Process at a Subtidal Site with Little Foliose Growth. Shown is the epifaunal growth before (a) and after (b) the rocks were scraped

Figure 6. The Custom Suction Sampler Used to Sample the Rocky Shore of the Portal Islands

2.3 Laboratory Procedures

Soft-Bottom Benthos

Benthic macroinvertebrates were sorted from the samples using professional-grade dissecting microscopes. All organisms were identified to the lowest practical taxon, usually species, and counted. Organisms greater than 2 cm in length were recorded separately as an indication of benthic community health. Organisms that could not be identified to species due to early life stage or poor condition were identified to genus or higher-taxonomic level, and excluded from species counts if there was a lower-level taxon reported in the sample for the same group. For example, amphipods in the family *Caprellidae* were identified at the genus (*Caprella* spp.) and species level, with three species reported (*Caprella penantis, Paracaprella tenuis*, and *Caprella equilibra*). Therefore, the generic level designation *Caprella* spp. was excluded from species counts in a sample if any of the species within the group were reported in the same sample.

Ten percent of the samples were re-sorted and identified for quality assurance/quality control (QA/QC), following Versar's standard laboratory operating procedures.

Biomass was determined for each taxon by drying individuals grouped by taxon at 60° C, weighing, ashing at 500° C for 4 hours, and re-weighing. This procedure allows for the calculation of ash-free dry weight (carbon content).

Rocky Shore Benthos

Rocky shore samples were rinsed over a 250-μm sieve using tap water and the foliose material (e.g., algae) was separated and stored in plastic bags for later processing. The remaining sample was transferred from the sieve to petri dishes and sorted from the detritus into major taxa (e.g., barnacles, crustaceans, molluscs) using professional-grade dissecting microscopes. Some large samples were subsampled to reduce processing time. Subsampling was conducted by spreading the sample evenly across a gridded tray and then randomly selecting a pre-determined number of grid cells to process. After sorting, organisms were identified to the lowest practical taxon, usually species, and counted. Colonial organisms that cannot be counted (e.g., sponges, hydroids, bryozoans) were reported as presence/absence.

Biomass (ash-free dry weight) was determined for each taxon following the same procedure used for soft-bottom benthic samples, except that the biomass of colonial encrusting organisms (cheilostomate bryozoans and some hydroids) could not be determined as these organisms cannot be separated from the surfaces on which they live (e.g., bivalve shells). Foliose organisms were kept in major taxonomic groups (algae, sponges, hydroids, bryozoans) and their wet weight was measured to determine relative biomass of soft growth.

Sediment

Grain size analysis was performed according to methods described in Folk (1974) and Holme & McIntyre (1971). The fine fraction of the sediment (particles < 63 μm) was separated from the sand and gravel fraction (particles > 63 μm) by wet sieving, followed by pipetting and weighing to obtain percent silt-clay. The sand and gravel fraction was oven-dried and sieved over nested mesh metal wire screens (U.S. Standard Sieves No. 5, 10, 18, 35, 60, 120, and 230) to obtain percent sand-size categories in the Wentworth grade scale. Total organic carbon (TOC) was determined for each sample by loss on ignition.

2.4 Data Analysis

Database

All field and laboratory data were entered into a Microsoft Access database and double checked against hard copies of the field and laboratory processing sheets as part of the QA/QC process for data entry.

Benthic Community Structure

Benthic macroinvertebrate data were analyzed to identify patterns in species abundance, composition, and biomass distribution among the soft-bottom sites and portal island rocky shore sites. Sites were examined individually and grouped into North Bridge, South Bridge, South Cove, and by transect.

Species diversity was measured by the Shannon-Wiener H' (Shannon 1948) and Simpson D indices:

$$H' = -\sum_{i=1}^{s} p_i * \log_2(p_i)$$

$$D = \Sigma\ p_i^2$$

where s is the number of species and p_i is the proportion of the i^{th} species abundance in the sample. Species richness was measured according to the formula given by Margalef (1958):

$$SR = s\text{-}1/\log_e N$$

where s is the number of species in a sample and N is the total number of individuals. Evenness, a measure of how evenly the abundance is distributed among the species, was computed according to Pielou (1966):

$$J' = H' / \log_2 s$$

Numerical dominance was calculated by computing the percent abundance contribution of the top two most abundant species to the total abundance of the sample.

Benthic Index of Biotic Integrity

Analysis of the soft-bottom benthos was performed in the context of the Chesapeake Bay Program Benthic Community Restoration Goals which use the Benthic Index of Biotic Integrity (B-IBI) to measure goal attainment. The polyhaline habitat (bottom salinity >18) restoration goals (Weisberg et al. 1997) were applied to each site.

The B-IBI is a multiple-attribute index developed to identify the degree to which a benthic assemblage meets the Chesapeake Bay Program Benthic Community Restoration Goals. The restoration goals are quantitative thresholds based on reference data distributions (Weisberg et al. 1997). The B-IBI provides a means for comparing the relative condition of benthic invertebrate assemblages across different habitats. It also provides a validated mechanism for integrating several benthic community attributes indicative of "health" into a single number that measures overall benthic community condition.

The B-IBI is scaled from 1 to 5, and sites with values of 3 or more are considered to meet the restoration goals. The index is calculated by scoring each of several attributes as either 5, 3, or 1 depending on whether the value of the attribute approximates, deviates slightly from, or deviates strongly from values at the best reference sites in similar habitats, and then averaging these scores across attributes. The criteria for assigning these scores are numeric and habitat-dependent.

Benthic community condition was classified into four levels based on the B-IBI. Values less than or equal to 2.0 were classified as severely degraded; values from 2.0 to 2.6 were classified as degraded; values between 2.6 and 3.0 were classified as marginal, and values of 3.0 or more were classified as meeting the goals.

Secondary Production

Secondary production (P) was estimated from biomass (B) using Brey's (2001) equation, which relates P/B ratios to mean body mass per individual (w, kJ), sample depth (D, m), and temperature (T, °K):

$$\text{Log}_{10}(P/B) = 7.947 - 2.294 * \log_{10}(w) - (2409.856*1/T) + (0.186*1/D) + (0.194*\textit{Subtid}) + (0.180*\textit{InfEpi}) + (0.277*\textit{MoEpi}) + (0.174*\textit{Tax1}) - (0.188*\textit{Tax2}) + (0.330*\textit{Tax3}) + (582.851*\log_{10}w*1/T).$$

Subtid is a dummy variable that increases the P/B ratio if the organism is found in a subtidal habitat (depth >1 m), whereas *InfEpi* and *MoEpi* are set to 1 if the organism is infaunal or motile epifaunal, respectively, also resulting in an increase in the P/B ratio. *Tax1*, *Tax2*, and *Tax3* are dummy variables that identify specific effects on P/B associated with membership in different taxonomic groups, and are set to 1 if the organism is (1) annelid or crustacean, (2) echinoderm, or (3) insect, respectively, and 0 if otherwise (Brey 2001). w was estimated for each species by dividing the AFDW per sample by the total number of individuals of the species to obtain an average mass per individual (g C). This value was then converted to kJ units using taxonomic group specific conversion factors provided in Brey (2001). Species-level mass values in combination with the depth and temperature recorded for the sample were used to calculate $\log_{10}$-transformed P/B ratios. The ratios were then converted back to the arithmetic scale and multiplied to the mean standing crop biomass (per m^2) to obtain an estimate of production per unit area and time for each species. Standing crop values were assumed to be representative of one year of benthic community biomass, so that production could be expressed in terms of g C m^{-2} yr^{-1}. Total community production for a given site was the summation of all the taxa specific production values.

The method used in this study to estimate secondary production employs similar parameters to that described in Steimle et al. (2002) and used in Burton's study of out-of-kind mitigation success of an artificial reef in Delaware Bay (Burton et al. 2002). Brey's (2001) method, however, offers several advantages, such as that P/B ratios are calculated from the sample biomass data. Brey's method was applied to Chesapeake Bay and found to produce reasonable estimates of secondary production consistent with previous studies (Dauer et al. 2011). An evaluation of production estimation methods also found Brey's method as providing the most satisfactory results among empirical models that were tested and compared to field estimates (Dolbeth et al. 2005).

Colonial organisms (sponges, bryozoans, hydroids) and algae were not included in the production estimates because they cannot be counted as individuals. Also, some colonial organisms, such as encrusting bryozoans, cannot be easily separated from the surfaces on which they grow. Although production will be underestimated by excluding these groups, this was assumed to have little effect on forage value estimates, because few fish feed on these taxa, and, among the megabenthos, only crabs incidentally feed on colonial organisms (Steimle et al. 2002). Typically, colonial organisms are preyed upon by epibionts, such as amphipods and isopods, and these taxa were incorporated in production estimates.

To compare rocky shore secondary production to the surrounding soft-bottom secondary production, average production estimates per unit area were extrapolated to the area covered by the rocky intertidal and subtidal zones, and to the footprint of the inventory area surrounding the portal islands and the bridge expansion areas. The footprint of the inventory area was provided by VDOT.

The boundaries of the project area were defined through a Geographic Information System (GIS) analysis by incorporating field-collected GPS points with a Topobathymetric Lidar Digital Elevation Model (DEM) provided by the National Oceanic and Atmospheric Admin-istration (NOAA) Office of Coastal Management. Topobathymetric digital data for the study area were downloaded from NOAA's Data Access Viewer (https://coast.noaa.gov/ dataviewer/#/lidar/ search/) and overlaid with the inventory corridor shapefile provided by VDOT, and Virginia Base Mapping Program's high-resolution aerial photography (http://garden.gis.vt.edu/arcgis/ rest/ services). The mean high-water line was identified in the GIS from the aerial photography. The mean tidal range (0.74 m) at the Sewells Point, VA, tide station (Station ID: 8638610), located directly southwest of the study area, was then used to determine the intertidal zone in the study area. By finding the elevation of the high-water mark in the DEM, and reclassifying the DEM with the mean tidal range, the rocky intertidal zone of the portal islands was determined. This area was converted to a polygon in the GIS.

The rocky subtidal zone was determined by buffering the intertidal zone in GIS by the average distance measured in the field at each transect, from the mean low-water mark to the boundary between the rocks and the soft-bottom. The resulting polygon was joined to the intertidal polygon and the two areas were used to eliminate area of the inventory corridor using the 'Erase' function in GIS. The final step consisted of removing the areas which represented the portal islands to provide the soft-bottom study area. The soft-bottom layer was split into individual production areas using GPS points collected in the field at sampling transects.

3.0 RESULTS AND DISCUSSION

3.1 Soft-Bottom Benthos

Water Quality

Summary bottom water quality is presented in Table 1. Sites have been grouped by transect, from north to south, so that north island transects are t1-t5, starting with sites 17-11-01 through 17-11-03, and south island transects are t6-t10. North bridge, south bridge, and south cove sites are grouped separately. The individual-site surface and water quality data are presented in Appendix B.

Water depth ranged between 1.2 m and 9.5 m (Appendix B). The average depth of the transects increased from the north bridge to the outer tip of the north island (t5, Table 1). In the south island, it was deepest again at the tips of the island (t6 and t9, Table 1).

Bottom water characteristics were homogeneous throughout the project area (Table 1, Appendix B). Salinity was in the polyhaline range (20.9-22.9), and dissolved oxygen was high (6.8-7.7 mg/L), near saturation, during the two sampling dates in September. Salinity and dissolved oxygen at the surface of the water column were very similar to the bottom readings, indicating absence of water column density stratification in the project area, and no low dissolved oxygen problems. Bottom water temperature varied little (21.9-23.2 °C) and was only slightly higher at the surface (21.8-27.5 °C). pH was homogeneous, in the 7.8-8.0 range, surface to bottom.

Sediment Characteristics

Sediment characteristics for the individual sites are presented in Table 2. Transects are also shown in Table 2, but data have not been averaged because there were significant differences among sites. Sediments were mostly fine sands (mean = 36.2%) and medium sands (mean = 24.2%), with various amounts of coarse material (Table 2). Generally, the coarseness of the material increased from north to south. The south island (t6 – t10) and south bridge had, on average, a higher percentage of medium and coarse sand. There was also a larger spread in particle diameter at these sites, indicating moderately to poorly sorted sediments and a variable water current regime. South cove sediments were fine and very fine sands with various amounts of silt and clay. Some sites had a large percentage of gravel (pebble and granule), especially the outer most site of the outer tip of the north island (t5, Table 2) and sites near the inner tip of the south island (t10).

Total organic carbon was generally low (mean = 0.65%) and was highest at the south cove (Table 2). As expected for most sedimentary habitats, there was a relationship between grain size (percent silt-clay) and the organic carbon content of the sediment (r^2= 0.78).

Benthic Community Structure

One hundred eighty-four taxa were identified in the soft-bottom benthic samples. Of these, 146 taxa were identified to species level and 38 were identified to a taxonomic level higher than species (genus, family, etc.). Appendix C provides a list of taxa and Appendix D provides the macroinvertebrate abundance and biomass data for each sampling site.

Eight species accounted for 60% of the total abundance. The reef-forming polychaete worm *Sabellaria vulgaris* accounted for 80,542 individuals and 34% of total abundance; the amphipod *Unciola serrata* accounted for 15,859 individuals and 7% of total abundance; and oligochaetes (Oligochaeta spp.) accounted for 10,338 individuals and 4% of total abundance. The next five taxa, the sand lancelet *Branchiostoma caribaeum*, tube-building phoronids (*Phoronis* spp.), the polychaete *Polycirrus eximius*, the amphipod *Batea cathariniensis*, and the bivalve *Nucula proxima*, each accounted for 3-4% of total abundance. Thus, the polychaete *Sabellaria vulgaris* was numerically dominant in the soft-bottom of the project area. Although oligochaetes were abundant, they only occurred in large numbers at five sites.

Nine species accounted for 60% of the total biomass. The sand lancelet, *Branchiostoma caribaeum*, accounted for 29.7 g AFDW and 23% of total biomass; the polychaete *Sabellaria vulgaris* accounted for 11.4 g AFDW and 9% of total biomass; and the mud crab *Eurypanopeus depressus* accounted for 9.4 g AFDW and 7% of total biomass. The next six species, the polychaetes *Arabella iricolor* and *Polycirrus eximius*, the bivalves *Nucula proxima* and *Tagelus divisus* (razor clam), and the gastropods *Nassarius vibex* and *Costoanachis avara*, each accounted for 3-5% of total biomass. The sand lancelet, therefore, emerges as the biomass dominant species in the soft-bottom of the project area.

In terms of species composition, the soft-bottom survey identified 76 taxa of polychaete annelids; 45 taxa of crustaceans, of which 23 were amphipods; and 43 taxa of molluscs, of which 19 were gastropods and 24 were bivalves. The remaining taxa were nemerteans (7 taxa), echinoderms (3 taxa), anemones (2 taxa), turbellarians (2 taxa), oligochaete annelids (unidentified), and one taxon each of Pycnogonida, Phoronida, Hemichordata, Ascidiacea, and Cephalochordata.

Figure 7 summarizes the composition of the soft-bottom macrobenthic community by transect. This figure captures the major groups contributing to total abundance, with polychaetes, amphipods, bivalves, and gastropods accounting for 50-97% of the abundance at any one transect. Polychaetes were abundant in all transects but comprised the largest percentage of the community in t3, t6, and t10. At these transects, amphipods also comprised a large percentage of the community. Transects t6 and t10 were at the outer and inner tips of the south island, where sediments were coarser.

Figure 8 summarizes numerical density of macroinvertebrates by transect. Total abundance (Figure 8a) was higher in the south bridge than in the north bridge, and was highest in t9. The higher abundance in t1, t5, t9, and t10 was due to high densities of the polychaete *Sabellaria vulgaris*, ranging from 2,600 individuals per m^2 in t1 to 22,000 individuals per m^2 in t9, but note the large error bars indicating variability among sites.

Total epifauna (Figure 8b) and total Polychaeta (Figure 8d) predominately reflect the distribution of *Sabellaria*. Oligochaeta (Figure 8e) were abundant in south island transects, and the south bridge. Generally, these sites had coarser sediment and a higher proportion of gravel, which provided habitat for interstitial organisms such as the Oligochaeta.

Among the amphipods (Figure 8f), several species associated with *Sabellaria* reef habitat were abundant. These amphipod species were *Bata cathariniensis*, *Unciola serrata*, and *Elasmopus levis*. Finally, bivalves (Figure 8g) and gastropods (Figure 8h) occurred throughout the project area, but gastropods exhibited higher abundance in transects at the inner tip of the islands (t1, t2, t9, and t10). These sites were dominated by small grastropods in the family Columbellidae (dovesnails).

Figure 9 summarizes biomass density of macroinvertebrates by transect. The dominant species by weight, the sand lancelet *Branchiostoma caribaeum*, occurred throughout the project area except in the south cove. It exhibited highest biomass in the south bridge transect, contributing to the high biomass exhibited in SB (Figure 9a, c). The next dominant species by weight, the polychaete *Sabellaria vulgaris*, contributed to most of the biomass in t9 and t10 (Figure 9a, d). In general, the biomass density of macroinvertebrates followed the same distribution patterns across transects as the abundance density.

Diversity

Diversity and dominance measures of the soft-bottom macrobenthos are shown in Figure 10. Number of species (range =12-45) was highest in t9, t10 and SC, and lowest in t4. Along the bridges, about the same number of species were found in NB and SB (Figure 10a). Shannon diversity (max. possible unbounded, range = 1.6-4.6) was highest in the north island in t1, t2, and t3, and lowest in t6 (Figure 10b). Simpson diversity (max. possible = 1, range = 0.3-0.9) was, on average, high across transects, and exhibited the same pattern as Shannon diversity (Figure 10c). Margalef species richness (max. possible unbounded, range = 1.6-5.0) was highest in t1, t2, t3, t9, t10, and SC, and lowest in t4 and t6. Along the bridges, Margalef species richness was similar in NB and SB (Figure 10d). Percent dominance (max. possible = 100%, range = 21-83%) showed the opposite pattern than Shannon diversity (Figure 10e); it was highest in t9 and t10 where the highest densities of *Sabellaria vulgaris* were found, and showed considerable variability among sites within transects. Lastly, evenness followed the same pattern and direction as Shannon diversity (Figure 10f).

Benthic Index of Biotic Integrity

For each of the soft-bottom survey sites, index metrics, B-IBI values, and the corresponding benthic community condition are presented in Table 3 and Figures 11 and 12.

Of the 48 sites, 32 sites met the Benthic Community Restoration Goals and 16 failed the goals (Table 3). Of the 16 sites that failed, eight were classified as marginal, three were classified as degraded, and five were classified as severely degraded (Table 3).

Sites that failed the goals as degraded or severely degraded were located along the north bridge (three sites), t4 (two sites), and one site each in t5, t9, and south bridge (Figures 11 and 12).

Sites classified as severely degraded failed the B-IBI because of low abundance and biomass below thresholds (scoring 1), insufficient abundance of deep-deposit feeding organisms, insufficient abundance of pollution-sensitive organisms, and/or excess biomass of pollution-indicative organisms (Table 3). Sites classified as degraded also failed the B-IBI because of low abundance and biomass, insufficient abundance of pollution-sensitive organisms, and insufficient abundance of deep-deposit feeding organisms (Table 3).

3.2 Rocky Shore Benthos

Benthic Community Structure

Portal island rocky intertidal and rocky subtidal habitats differed in species composition, abundance, and biomass. Therefore, summaries for these two habitats are presented separately.

Intertidal

Sixty-two taxa were identified in the intertidal benthic samples. Of these, 51 taxa were identified to species level and 11 taxa were identified to a taxonomic level higher than species. The intertidal was numerically dominated by barnacles and amphipods.

Four species accounted for 76% of the total abundance. Barnacles (*Chthamalus fragilis* and unidentifiable juveniles) accounted for 206,727 individuals and 40% of total abundance. The next three species were amphipods. *Monocorophium insidiosum* accounted for 97,032 individuals and 19% of total abundance; *Ampithoe valida* accounted for 59,041 individuals and 11% of total abundance; and *Jassa marmorata* accounted for 34,482 individuals and 7% of total abundance.

Three species accounted for 96% of the total biomass. The Eastern Oyster, *Crassostrea virginica*, accounted for 845.2 g AFDW and 66% of total biomass; barnacles accounted for 305.5 g AFDW and 24% of total biomass; and the Ribbed Mussel, *Geukensia demissa*, accounted for 81.0 g AFDW and 6% of total biomass. Although oysters and mussels were biomass dominants in the intertidal zone, their distribution was limited to a few sites (see below).

In terms of species composition, the intertidal survey identified 28 taxa of crustaceans and 15 taxa of polychaete annelids. The remaining taxa were gastropods (8 taxa), bivalves (4 taxa), turbellarians (2 taxa), insect larvae (2 taxa), and one taxon each of Cnidaria (anemones), nemerteans, and Pycnogonida (sea spiders).

Figure 13 summarizes the composition of the intertidal macrobenthic community by transect. Bivalves (oysters and mussels) were numerically dominant in the inner tip of the north island at t1. Otherwise, amphipods and barnacles (Cirripedia) comprised the largest percentage of the community, but their relative contribution differed among transects (Figure 13).

Figure 14 summarizes numerical density of intertidal macroinvertebrates by transect. Throughout these panels, infaunal and epifaunal organisms are shown separately. Benthic macroinvertebrates were classified as infauna or epifauna based on their predominant living mode. However, many species that live in sediments (infauna) are also found on hard substrata occupying crevices, in sediments deposited within crevices, or on the three-dimensional structure created by other organisms such algae and mussels. Classification of species into infauna and epifauna allows for the comparison of portal island rock surfaces to surrounding soft-sediments for similar types of organisms.

Total abundance (Figure 14a) was variable, but higher in t3 and t11. The higher abundance in these two transects was due to high densities of epifaunal amphipods. This is reflected in Figure 14b (total epifauna) and Figure 14f (Amphipoda). The higher abundance of total infauna in transects t5, t6, and t12 was due to elevated densities of insect larvae (Diptera), predominately in the family Chironomidae (Figure 14c, h). Large densities of bivalves, mostly oysters but also mussels, were found in t1 (Figure 14e), as noted above. Barnacles (Cirripedia) were abundant in most transects, but absent from t1 (Figure 14g).

Figure 15 summarizes the biomass density of intertidal macroinvertebrates by transect. In general, the biomass density of macroinvertebrates followed the same distributional patterns across transects as the abundance density. The most salient point is the high biomass of oysters in t1 (Figure 15a, b, e).

Subtidal

One hundred seventeen taxa were identified in the subtidal benthic samples. Of these, 92 taxa were identified to species level and 25 taxa were identified to a taxonomic level higher than species.

The subtidal rock surfaces of the portal islands were covered by a dense canopy of algae that provided habitat for numerous species of epibionts, predominately amphipods. Sponges (*Microciona prolifera* and *Halichondria bowerbanki*) and bryozoans were also common and hosts of amphipods and polychaetes. Oysters and mussels, although less common, provided three-dimensional habitat for colonial organisms such as hydroids and encrusting bryozoans.

Seven species accounted for 71% of the total abundance. Caprellid amphipods (skeleton shrimps, mostly *Caprella penantis*) were very abundant on algae and accounted for 1,204,332 individuals and 50% of total abundance. The reef-forming polychaete *Sabellaria vulgaris* accounted for 117,000 individuals and 5% of total abundance. The next five taxa, Corophiidae, the amphipods *Elasmopus levis* and *Ericthonious brasiliensis*, the isopod *Erichsonella filiformis*, and the sabellid polychaete *Fabricinuda trilobata*, each accounted for 3-4% of total abundance.

Seven species accounted for 76% of the total biomass. Dominants by weight were the anemone *Diadumene leucolena*, accounting for 150.2 g AFDW and 26% of total biomass; the Eastern Oyster, *Crassostrea virginica*, accounting for 94.1 g AFDW and 16% of total biomass; and the amphipod *Caprella penantis*, accounting for 68.8 g AFDW and 12% of total biomass. The columbellid gastropod *Mitrela ocellata* accounted for 50 g AFDW and 9% of total biomass. The next three species, the isopod *Erichsonella filiformis*, and the polychaetes *Hydroides dianthus* and *Sabellaria vulgaris*, each accounted for 4-5% of total biomass.

In terms of species composition, the subtidal survey identified 39 taxa of crustaceans, 35 taxa of polychaete annelids, and 20 taxa of gastropods. The remaining taxa were bivalves (9 taxa), nemerteans (4 taxa), Pycnogonidae (3 taxa), turbellarians (2 taxa), ascidians (2 taxa), oligochaete annelids (unidentified), and one taxon each of Cnidaria (anemones) and Diptera (insect larvae). The foliose fraction of samples consisted of green and red algae, hydroids, sponges, and bryozoans.

Figure 16 summarizes composition of the subtidal macrobenthic community by transect. The subtidal community was homogeneous among the samples in terms of species composition, with amphipods and polychaetes accounting for most of the abundance at any one transect. Amphipods were common in all transects but comprised the largest percentage of the community in t2, t6, and t12 (Figure 16).

Figure 17 summarizes numerical density of subtidal macroinvertebrates by transect. Total abundance (Figure 17a) was higher in t2, t6, and t12, but note the large error bars indicating substantial variability among the samples of these transects. The higher abundance in these transects was due to epifaunal amphipods, primarily caprellid amphipods. The distribution of epifauna (Figure 17b) and Amphipoda (Figure 17e) primarily reflected the distribution of caprellids and other epibiont amphipods. Polychaetes (Figure 17d), isopods (Figure 17f), gastropods (Figure 17g) and anemones (Figure 17h) occurred throughout the rocky subtidal habitat, but their numbers varied considerably among transects and among samples.

Figure 18 summarizes biomass density of subtidal macroinvertebrates by transect. Biomass was higher at t1 and t2, and this was primarily due to polychaetes, amphipods, and anemones (Figure 16a, d, e, h). As with abundance, there was considerable variability in biomass density among transects, and among samples within transects, as indicated by the large error bars.

Diversity

Intertidal

Diversity and dominance measures of the intertidal macrobenthos are shown in Figure 19. Number of species (range = 6-29) was highest in t4 and lowest in t7 and t12. Shannon diversity (range = 0.8-3.5) was highest in t8 and lowest in t7 and t12 (Figure 19b). Simpson diversity (range = 0.3-0.9) exhibited a similar pattern to that of Shannon diversity (Figure 19c). Margalef species richness (range =0.5-2.6) was highest int4 and lowest in t6 and t12 (Figure 19d). Percent dominance (range = 50-98%) was generally high, above 50%, indicating that the intertidal community was dominated by 1-2 species (Figure 19e). Evenness (range = 0.3-0.8) was generally low and followed the same pattern and direction as Shannon diversity (Figure 19f).

Subtidal

Diversity and dominance measures of the subtidal macrobenthos are shown in Figure 20. Overall, diversity indices were higher, and dominance values lower, in the subtidal than in the intertidal, indicating a more homogeneous benthic community in the rocky subtidal. Number of species (range = 23-48) was relatively homogeneous across transects, with an average of 34.5 species per transect. Shannon diversity (range = 1.6-4.7) was highest in t7 and lowest in t12. Simpson diversity (range = 0.6-0.9) was similar to Shannon diversity (Figure 20b,c). Margalef species richness (range = 2.0-4.4) was highest in t7 and lowest in t10 (Figure 20d). Lastly, percent dominance (range =22-95%) and evenness (range = 0.3-0.9) were moderate in most transects and followed a similar pattern and direction to that of Shannon diversity (Figure 20e, f).

3.3 Secondary Production

Standing crop and secondary production estimates of macrobenthos for individual sites are provided in Table 4. Wet weight biomass is presented in Table 5.

Secondary production varied among sites, with some sites exhibiting 2-3 times the production of the average site, and a few sites exhibiting more than 3 times the production of the average site. Per unit area, rocky shore production was on average higher than soft-bottom production. The annual mean production of soft-bottom sites was 15.7 g AFDW m^{-2}. The annual mean production of the rocky intertidal was 156.0 g AFDW m^{-2}, but this included one site (t1) with very high production of bivalves (578.5 g AFDW m^{-2} yr^{-1}). Excluding t1, the annual mean production of the rocky intertidal was 117.6 g AFDW m^{-2}. The annual mean production of the rocky subtidal was 86.2 g AFDW m^{-2}. Thus, rocky intertidal production was 1.4x and 7.5x higher than rocky subtidal and soft-bottom production, respectively, excluding t1. Secondary production values by transect are provided in Figure 21, and ranges for the individual sites are provided in Figures 22 and 23.

The estimates of secondary production calculated in this study are comparable to those estimated for other estuaries (Wong et al. 2011). A North Carolina oyster reef shoreline studied by Wong et al. (2011) had the highest secondary production of any of the habitats sampled, with a mean annual value of 467.3 g AFDW m^{-2} calculated using the same empirical model used in this study. Annual secondary production of the macrobenthos on shoreline stabilization structures, such as bulkheads, was also high, ranging from 36 to 131.4 g AFDW m^{-2} yr^{-1}, depending on estimation method.

Total secondary production for regions (soft-bottom inventory area, portal island intertidal, portal island subtidal) was calculated by splitting each region into individual production areas to account for differing productivity. Individual production areas were made for the north bridge, south bridge, north island, south island, south cove, a soft-bottom south island special area encompassing transects t9 and t10, and the rocky intertidal t1 (Figures 24 and 25). Area measurements, mean production, and total production are presented in Table 6.

South bridge total production was 6x higher than north bridge total production (Table 6), in part because of higher mean productivity in south bridge sites, where *Sabellaria* reefs were present, and in part because of the larger area encompassed by the south bridge inventory area. Total soft-bottom macrobenthic production in the south island was also higher than total soft-bottom macrobenthic production in the north island, due to high production at t9 and t10 (the South Island Special Area, Figure 25). Excluding this area, the north island exhibited higher soft-bottom productivity (Table 6). In the rocky shore, total production was highest in the south island rocky subtidal, due to the larger area assessed around this island.

Even though the per unit mean production of the soft-bottom macrobenthos was lower than the per unit mean production of the rocky shore macrobenthos, when scaled to the inventory area, total macrobenthic production was 3.7x higher for the soft-bottom than for the rocky shore (Table 6). Thus, the reef area represented by the portal islands will be unable to compensate for production loss in the surrounding soft-bottom benthic community if the footprint of the disturbance area is of the same magnitude as the footprint of the inventory area. For a different disturbance area, Table 6 can be used to calculate net loss or net gain in macrobenthic production. In addition to secondary production, other components of ecosystem health should be addressed, such as the potential degradation of areas with good benthic community condition, as measured by the B-IBI in this study.

Table 1. Bottom Water Characteristics (Mean) for Sites Grouped by Transect. NB = North Bridge, SB = South Bridge, SC = South Cove

Site	Transect	Depth (m)	Salinity (psu)	Conductivity (mS/cm)	DO (mg/L)	DO Sat (%)	Temp (°C)	pH
17-01–17-07	NB	2.4	21.0	33.5	7.0	91.9	22.7	7.9
17-11, 1-3	t1	2.8	21.2	33.8	6.9	90.1	22.6	7.9
17-08, 1-3	t2	3.8	21.4	34.1	6.8	88.9	22.6	7.9
17-09, 1-3	t3	4.4	22.0	34.9	7.1	93.7	22.7	7.9
17-10, 1-3	t4	5.6	21.9	34.8	7.5	97.9	22.7	8.0
17-12, 1-3	t5	6.5	21.9	34.7	7.6	100.1	22.6	8.0
17-16, 1-3	t6	6.7	21.9	34.8	6.8	89.6	22.7	7.9
17-13, 1-3	t7	3.2	21.5	34.2	6.8	89.5	22.8	7.9
17-14, 1-3	t8	4.0	21.5	34.2	6.8	89.4	22.9	7.9
17-15, 1-3	t9	9.5	21.3	33.9	6.8	90.0	22.9	7.9
17-17, 1-3	t10	6.3	21.6	34.4	6.9	90.8	22.9	7.9
17-18–17-24	SB	2.4	21.5	34.2	6.9	89.9	22.5	7.9
17-25–17-28	SC	4.9	22.2	35.2	7.5	99.1	22.7	8.0

Table 2. Grain Size Fractions (Wentworth Grade Scale) and Total Organic Carbon (TOC) Content of Sediments (Percent)

Site	Transect	Pebble	Granule	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt-clay	TOC
17-01	NB	0.0	0.0	0.1	1.3	14.6	75.4	6.5	2.2	0.43
17-02		0.0	0.0	0.0	0.7	35.7	59.4	2.4	1.8	0.44
17-03		0.0	0.0	0.0	1.4	48.8	44.8	3.1	1.8	0.40
17-04		0.0	0.0	0.2	0.3	7.5	37.2	48.3	6.5	0.59
17-05		0.0	0.1	0.1	0.1	0.9	53.5	38.6	6.8	0.68
17-06		0.0	0.1	0.0	0.0	0.6	47.3	47.6	4.3	0.63
17-07		0.0	0.0	0.0	0.1	0.8	56.0	38.9	4.2	0.51
17-11-1	t1	2.9	1.8	3.8	13.9	25.2	40.6	6.8	5.0	0.60
17-11-2		0.3	0.0	0.0	0.3	1.5	69.7	24.1	4.1	0.73
17-11-3		0.0	0.0	0.0	0.2	2.9	76.8	16.2	3.9	0.59
17-08-1	t2	0.0	0.0	0.1	0.2	0.9	48.8	37.5	12.5	0.98
17-08-2		0.0	0.0	0.0	0.0	0.3	20.5	62.0	17.2	1.16
17-08-3		0.0	0.0	0.0	0.1	0.2	34.4	52.7	12.7	1.02
17-09-1	t3	0.0	0.0	0.9	4.5	15.0	69.4	5.3	4.8	0.56
17-09-2		0.0	0.2	0.0	0.2	2.9	82.7	9.1	4.9	0.47
17-09-3		0.0	1.0	5.9	15.9	22.3	38.6	10.7	5.6	0.39
17-10-1	t4	1.7	2.2	5.2	16.7	36.9	28.8	5.3	3.4	0.81
17-10-2		0.0	0.0	0.0	0.1	7.4	86.3	3.8	2.4	0.29
17-10-3		0.0	0.1	0.0	0.1	13.4	81.6	3.1	1.6	0.44
17-12-1	t5	0.0	0.0	0.1	0.1	0.7	83.9	11.4	3.9	0.54
17-12-2		0.3	0.3	0.2	0.6	2.5	79.5	10.4	6.1	0.49
17-12-3		3.5	13.5	21.0	25.7	18.4	11.7	2.6	3.5	0.43
17-16-1	t6	0.4	2.7	10.2	37.5	36.8	5.7	1.7	4.9	0.45
17-16-2		1.2	1.6	9.1	36.2	43.0	5.1	1.0	2.8	0.58
17-16-3		0.2	0.8	4.0	17.2	47.0	17.7	6.1	7.2	0.65
17-13-1	t7	2.1	1.2	6.1	27.0	39.9	11.2	7.2	5.4	0.47
17-13-2		0.4	0.1	0.4	5.9	23.1	39.9	21.4	8.8	0.75
17-13-3		0.0	0.7	3.8	17.2	39.7	29.0	4.4	5.2	0.61

Table 2. Continued

Site	Transect	Pebble	Granule	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt-clay	TOC
17-14-1	t8	0.0	0.6	2.6	16.6	61.9	11.7	3.0	3.7	0.53
17-14-2		2.6	2.4	6.0	19.8	51.1	9.6	4.1	4.4	0.34
17-14-3		3.6	1.0	5.5	22.7	42.0	16.1	5.1	3.9	0.38
17-15-1	t9	0.0	0.4	2.5	18.1	55.4	12.4	2.3	8.9	0.47
17-15-2		0.5	1.4	5.9	31.8	43.8	10.7	1.9	3.9	0.41
17-15-3		2.8	1.6	2.8	13.7	27.2	16.9	8.5	26.6	1.03
17-17-1	t10	0.3	0.8	0.8	9.1	71.8	13.2	1.3	2.7	0.58
17-17-2		12.2	2.4	2.2	4.6	22.4	17.8	14.9	23.4	0.99
17-17-3		1.6	1.8	1.6	2.9	17.2	22.6	7.3	44.9	1.63
17-18	SB	32.0	2.8	1.9	1.8	22.1	32.1	3.6	3.9	0.74
17-19		0.7	0.3	1.3	4.1	61.6	29.0	0.7	2.2	0.21
17-20		0.0	0.1	0.3	1.5	46.9	48.2	0.9	2.2	0.34
17-21		0.0	0.2	2.4	9.7	50.2	35.4	1.1	1.1	0.25
17-22		1.6	9.9	20.2	21.2	32.9	12.6	0.5	1.2	0.15
17-23		0.2	2.2	9.9	15.7	34.9	31.2	4.3	1.5	0.38
17-24		0.0	0.2	0.8	2.0	5.1	24.6	58.5	8.8	1.08
17-25	SC	0.0	0.0	0.1	0.3	0.6	2.2	49.7	47.0	1.84
17-26		0.0	0.1	0.2	0.4	6.8	38.5	39.2	14.8	0.90
17-27		0.0	0.7	0.1	0.1	0.4	10.3	62.7	25.7	1.28
17-28		0.6	1.3	4.0	29.5	17.1	6.8	33.5	7.2	1.03

VERSAR

Table 3. B-IBI Metrics, B-IBI Values, and Benthic Community Condition at Soft-Bottom Survey Sites in the Hampton Roads Bridge-Tunnel Project Area
Abun = abundance (#/m2), Bms = biomass (g AFDW m^{-2}), Poll-ind = pollution-indicative (%), Poll-sen = pollution sensitive (%), Carn-Om = carnivore and omnivores (%)

Site	Transect	Abun	Bms	Shannon-Wiener	Poll-ind Bms	Poll-sen Bms	Poll-sen Abun	Deep-dep Abun	Carn-Omm Abun	Abun Score	Bms Score	Shannon Score	Poll-ind Bms Score	Poll-sen Bms Score	Poll-sen Abun Score	Deep-dep Abun Score	Carn-Om Abun Score	B-IBI Value	Community Condition
17-01	NB	977	0.14	3.42	19.84	58.73	58.14	11.63	32.56	1	1	3	1	.	3	3	.	2	Sev. Degraded
17-02		909	0.32	2.92	1.43	27.96	62.50	5.00	22.50	1	1	3	5	.	3	1	.	2.3	Degraded
17-03		1522	1.14	2.87	1.59	8.75	58.21	7.46	22.39	3	3	3	5	.	5	1	.	3.3	Meets Goal
17-04		1772	1.14	4.30	6.29	36.86	42.31	16.67	19.23	3	3	5	3	.	3	3	.	3.3	Meets Goal
17-05		1931	1.99	3.82	0.80	34.93	48.24	4.71	18.82	3	3	5	5	.	3	1	.	3.3	Meets Goal
17-06		2227	1.94	3.21	1.99	55.85	58.16	7.14	17.35	3	3	3	5	.	5	1	.	3.3	Meets Goal
17-07		909	0.97	3.55	25.53	12.30	35.00	0.00	20.00	1	1	5	1	.	3	1	.	2	Sev. Degraded
17-11-1	t1	2590	2.07	4.42	0.77	8.42	12.28	14.91	26.32	3	3	5	5	.	1	3	.	3.3	Meets Goal
17-11-2		954	1.31	3.35	0.00	34.49	28.57	4.76	11.90	1	3	3	5	.	3	1	.	2.7	Marginal
17-11-3		1113	0.48	3.60	0.00	16.43	51.02	8.16	28.57	1	1	5	5	.	3	1	.	2.7	Marginal
17-08-1	t2	2567	1.65	4.22	3.85	23.44	34.51	13.27	15.93	3	3	5	5	.	3	3	.	3.7	Meets Goal
17-08-2		3499	1.71	4.04	11.16	32.40	38.96	8.44	15.58	5	3	5	3	.	3	1	.	3.3	Meets Goal
17-08-3		3522	1.88	3.76	8.20	22.06	35.48	11.61	11.61	5	3	5	3	.	3	3	.	3.7	Meets Goal
17-09-1	t3	1500	0.73	3.81	1.25	5.31	7.58	21.21	6.06	1	1	5	5	.	1	3	.	2.7	Marginal
17-09-2		1204	0.28	4.20	0.81	24.80	35.85	22.64	15.09	1	1	5	5	.	3	3	.	3	Meets Goal
17-09-3		2227	1.98	4.19	0.46	57.45	41.84	13.27	17.35	3	3	5	5	.	3	3	.	3.7	Meets Goal
17-10-1	t4	2726	2.40	2.76	0.19	8.63	6.67	48.33	12.50	3	3	3	5	.	1	5	.	3.3	Meets Goal
17-10-2		523	1.00	3.26	0.00	89.40	17.39	0.00	0.00	1	1	3	5	.	1	1	.	2	Sev. Degraded
17-10-3		750	0.80	3.33	44.38	0.57	6.06	3.03	3.03	1	1	3	1	.	1	1	.	1.3	Sev. Degraded
17-12-1	t5	1022	0.79	3.80	6.07	16.04	15.56	11.11	15.56	1	1	5	3	.	1	3	.	2.3	Degraded
17-12-2		1477	0.67	3.81	5.57	11.49	12.31	30.77	7.69	1	1	5	3	.	1	5	.	2.7	Marginal
17-12-3		4589	3.88	3.44	0.00	10.02	2.48	18.81	27.72	5	3	3	5	.	1	3	.	3.3	Meets Goal
17-16-1	t6	4680	3.00	3.39	0.00	0.15	0.49	26.21	36.89	5	3	3	5	.	1	5	.	3.7	Meets Goal
17-16-2		1227	0.96	3.06	0.00	13.21	9.26	29.63	5.56	1	1	3	5	.	1	5	.	2.7	Marginal
17-16-3		5362	1.44	1.43	0.00	2.84	1.27	86.86	3.81	3	3	1	5	.	1	5	.	3	Meets Goal
17-13-1	t7	2022	1.82	3.56	6.62	8.74	14.61	20.22	19.10	3	3	5	3	.	1	3	.	3	Meets Goal
17-13-2		1568	0.63	3.26	1.79	53.05	33.33	4.35	11.59	3	1	3	5	.	3	1	.	2.7	Marginal
17-13-3		1454	1.26	3.62	0.00	6.95	10.94	28.13	10.94	1	3	5	5	.	1	5	.	3.3	Meets Goal
17-14-1	t8	2045	0.96	3.21	0.00	3.77	4.44	24.44	13.33	3	1	3	5	.	1	3	.	2.7	Marginal
17-14-2		3931	1.73	3.58	0.00	3.54	6.36	45.09	13.87	5	3	5	5	.	1	5	.	4	Meets Goal
17-14-3		1772	1.43	3.48	0.00	8.74	16.67	24.36	20.51	3	3	3	5	.	1	3	.	3	Meets Goal
17-15-1	t9	15177	5.14	2.60	0.00	12.36	1.65	5.39	13.77	1	5	1	5	.	1	1	.	2.3	Degraded
17-15-2		4317	3.74	3.28	0.00	3.40	1.05	15.79	13.68	5	3	3	5	.	1	3	.	3.3	Meets Goal
17-15-3		3272	1.81	3.96	0.38	16.19	6.94	15.97	27.08	5	3	5	5	.	1	3	.	3.7	Meets Goal
17-17-1	t10	2840	2.43	3.64	0.00	0.19	0.80	12.80	20.80	3	3	5	5	.	1	3	.	3.3	Meets Goal
17-17-2		3953	3.06	3.28	0.00	0.19	1.15	13.79	22.99	5	3	3	5	.	1	3	.	3.3	Meets Goal
17-17-3		4612	7.16	2.98	0.03	33.64	4.93	13.79	20.20	3	5	3	5	3	.	.	1	3.3	Meets Goal
17-18	SB	4612	4.20	2.89	0.27	21.98	4.93	25.62	7.39	5	3	3	5	.	1	5	.	3.7	Meets Goal
17-19		1863	1.78	3.52	1.40	0.13	2.44	13.41	23.17	3	3	5	5	.	1	3	.	3.3	Meets Goal
17-20		750	0.81	2.97	1.69	5.62	24.24	6.06	6.06	1	1	3	5	.	1	1	.	2	Sev. Degraded
17-21		2204	2.34	3.19	1.26	0.19	3.09	18.56	3.09	3	3	3	5	.	1	3	.	3	Meets Goal
17-22		1908	3.33	3.19	0.07	4.44	21.43	19.05	7.14	3	3	3	5	.	1	3	.	3	Meets Goal
17-23		2522	4.95	2.76	0.92	3.08	24.32	8.11	3.60	3	3	3	5	.	1	1	.	2.7	Marginal
17-24		2045	1.54	3.85	0.00	21.37	53.33	16.67	17.78	3	3	5	5	.	5	3	.	4	Meets Goal
17-25	SC	4090	2.38	3.72	5.16	34.46	21.67	29.44	13.33	3	3	5	3	3	.	.	1	3	Meets Goal
17-26		3249	2.50	3.83	5.71	40.82	27.97	16.08	13.29	5	3	5	3	.	3	3	.	3.7	Meets Goal
17-27		3022	4.89	4.10	2.46	23.85	26.32	18.05	15.79	5	3	5	5	.	3	3	.	4	Meets Goal
17-28		3590	0.49	3.07	1.84	44.83	26.58	48.73	19.62	5	1	3	5	.	3	5	.	3.7	Meets Goal