4-2021

Expanding The Use Of Natural And Nature-Based Infrastructure To Enhance Coastal Resiliency

Marcia Berman
Virginia Institute of Marine Science

Pamela Mason
Virginia Institute of Marine Science

Jessica Hendricks
Virginia Institute of Marine Science

Tamia Rudnicky
Virginia Institute of Marine Science

EXPANDING THE USE OF NATURAL AND NATURE-BASED INFRASTRUCTURE TO ENHANCE COASTAL RESILIENCY FINAL PROJECT REPORT (YEAR 3 OF 3)

Submitted to the Virginia Coastal Zone Management Program, Department of Environmental Quality

April, 2021

Marcia Berman, Pamela Mason, Jessica Hendricks, Tamia Rudnicky

VIMS | William & Mary
Virginia Institute of Marine Science

Center for Coastal Resources Management
Virginia Institute of Marine Science

Berman, M., Mason, P., Hendricks, J., & Rudnicky, T. (2021) Expanding The Use of Natural and Nature-Based Infrastructure To Enhance Coastal Resiliency. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/047s-dp84

This project, Task #81 was funded, in part, by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Grant FY19 NA19NOS4190163 of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended.

Contents

Figures and Tables

Executive Summary

For the first year, focus was on upgrades to the shoreline management model. We expanded coding to include recommendations for shorelines that had existing protection structures, including consideration of opportunities to retro-fit conventional structures with living shorelines. The CCRM Fetch model, part of the SMM, was improved to produce more robust outputs. Data on SAV to inform potential ecological conflicts was added to the SMM and significant QA/QC was performed to validate model outputs. Model classes for shoreline management are found in Table 1. The final model is represented in the flow charts illustrated in Appendix 2. Appendix 3 summarizes the treatment options. Revisions and updates to existing data portals (Here) and interactive map tools (AdaptVa Interactive Map) reflect the enhancements made to the model under this grant project. Shape files for the coastal zone covered under this project were delivered to the Virginia Coastal Zone Management Program along with metadata.

In year 2 of this study, the modeled data were used to estimate the potential nutrient reduction benefits that are available to communities who elect to implement living shorelines for resiliency and shoreline erosion control. Table 2 lists the classes of living shoreline BMPs from SMM version 5.1. A sub-class of these meet the criteria for load reduction benefits and are noted. Non-structural living shorelines is a broad class that includes practices that are dominated by vegetation, but can also include fiber logs, oyster shell bags, and vegetation management. To be considered as a BMP that can be assigned for use as nutrient reduction credit, the BMP must include new area of vegetated tidal marsh.

The upgraded Shoreline Management Model (SMM) identifies the preferred shoreline management approach for all of Virginia's coastal waters. The SMM is a geographic information system (GIS) based analytical model that considers readily available remotely sensed and analytical quality-assured bio-physical data to derive a recommendation for place-based shoreline management. Of greatest interest relevant to Virginia's policy on living shorelines, the model identifies where living shoreline practices are suitable.

Recognition of the multiple benefits of living shorelines, from provision of habitat, water quality, erosion control and flood services, to open space and aesthetics has promoted efforts to develop decision support tools to integrate the many benefits to inform decision-making and serve to promote the use of living shorelines as a nature based solution. The SMM output was used to model living shorelines and determine a minimal areal extent of their implementation wherever suitable. The acreage of created tidal marsh was used to apply the Chesapeake Bay Program (CBP) approved shoreline BMP values to calculate the potential load reductions from the living shorelines created marsh. Notably, the estimates are conservative based on the minimal marsh extent and only for shores without existing marsh. As such, the potential load reductions possible via living shorelines marsh creation could be considerably higher. In addition to the potential load reduction credits possible for living shoreline marsh creation, the opportunity to provide flood benefits to coastal buildings, critical facilities, address social vulnerabilities and create habitat continuity were attributed to each living shoreline BMP and used to generate a cumulative ranking for each possible BMP.

The final year of the study conducted a model analysis of potential living shorelines based on co-benefits of water quality, habitat connectivity, flood services and social vulnerability. For each potential living shoreline, an assessment was made as to the provision of each of the services and the cumulated value was used to produce a ranking of relative service provision with three classes.

Coastal resilience is the result of effective management, protection, promotion, and implementation of just actions that engage all sectors of the community to provide for the health and persistence of linked ecological and socio-economic systems. The outcomes of this multi-year project provide information to assess and prioritize use of living shorelines as a nature based solution to support coastal resilience.

Introduction

The vulnerability of coastal communities and the growing risks of coastal infrastructure continue largely due to past and ongoing patterns of development in high risk areas. This project is focused on increasing the use of natural and nature-based features (NNBFs) to increase resilience of coastal communities to flooding caused by extreme weather events. The project effectively addresses two problems:

- The natural capital of coastal communities is generally declining, and is projected to decline at an accelerating rate due to sea level rise and current land use practices.
- The use of NNBFs to sustain or increase resilience in coastal communities is restricted by the many competing needs for limited local resources.

There has been so much attention to the threats and potential consequences of sunny day and storm driven flooding in coastal communities such that no local government official is unaware of the issue. Most also have some general understanding that implementation of nature-based approaches is one option available to lower risks and increase resilience. The problem is that the resources required to implement resilience actions are limited and, in the face of competing interests, it is difficult to rationalize making nature-based approaches a priority. One solution to accelerating the pace of building natural resilience is to find ways to address multiple needs with each action, taking advantage of the co-benefits available from carefully planned projects.

To that end, this project identifies local opportunities to increase community resilience through the use of natural and nature based shoreline enhancements. Specifically, the project identifies where living shorelines can enhance resiliency and offer nutrient reduction benefits as well as offering protection to shoreline undergoing erosion.

The use of living shorelines for erosion control is the preferred method under Virginia law. When originally enacted into law, there was little attention to the co-benefits that living shorelines offer beyond erosion control. The shift in policy at that time was more motivated by ecosystem services associated with habitat enhancement and creation. As communities struggle to address Total Maximum Daily Load (TMDL) requirements, the newly released criteria for nutrient reduction credits associated with marsh restoration elevated the interest in local governments advocating for living shorelines since vegetated living shorelines could earn TMDL credits when constructed for erosion control.

Over three years this study accomplished the following goals:

1) Refined the Shoreline Management Model (SMM) to better predict where living shorelines were appropriate;

2) Used the output of the updated SMM to map where vegetated living shorelines could offer nutrient reduction benefits to communities through credits, and calculated the potential contribution these management practices could have toward reaching community nutrient reduction goals;

3) Developed a protocol for evaluating where these features offer resilience benefits by closing gaps in naturally occurring coastal resilience buffers.

Chapter 1. Applying the Shoreline Management Model (SMM) for Living Shorelines Suitability

The shoreline management model (SMM) started with development of a protocol for converting shoreline management decision trees to a geospatial model. The SMM uses decision tree logic for arriving at a recommended shoreline management approach. These decision trees depict logic pathways that reflect the scientific literature and best professional judgement with regards to shoreline management options, and have been heavily vetted over many years of on the ground site reviews in the field by wetlands scientists at the Center for Coastal Resources Management (CCRM) with input from local wetlands boards. More information on the development of the model is available (Berman et al., 2018) and diagrams are included in Appendix 1.

(See also: CCRM website: Decision Tools).

In 2012, with the change in state policy regarding erosion control and living shorelines, CCRM used GIS and available GIS data through the Virginia Shoreline Inventory, to model the logic represented in the existing decision trees for shorelines which were undefended (Decision Tree Manual) (CCRM, 2010) (Figure 1). This gave state and local managers the first comprehensive perspective on best management practices for tidal shoreline erosion control. Limitations in the model were always noted along some shoreline types; particularly those that have been altered. Included among those, was the ability for the model to accurately predict treatment options along shorelines that were already hardened with traditional erosion control structures.

In Year 1 of this project, the focus was on refining the existing Shoreline Management Model (SMM) to improve the suitability targeting for living shorelines along shorelines that have already been hardened with erosion control structures. The model upgrade to v.5.0 represents a major improvement to the tool, which previously treated all shorelines equally. To better analyze for where resiliency and nutrient reduction credits could be applied through the construction of a living shoreline, the model had to address shoreline hardening and the limitations that existing structures impose on living shoreline applications. The expanded version (5.0) was initially tested on three pilot localities: Westmoreland County, and the cities of Poquoson and Newport News.

Approach

The model improvements incorporated shorelines which were hardened into the predictive model and streamlined the output to a more user-friendly classification. The more robust model (v5.0) was applied to the entire coastal zone of Virginia and used to identify 1) where creation of new natural capital can offer protection to vulnerable shorelines and 2) where existing natural capital currently provides sufficient protection, and may be lost if traditional shoreline protection structures are put in place. Following QA/QC, the model was re-run for all Tidewater localities where the model had been previously run. This accounted for a substantial amount of Virginia's Coastal Zone.

The SMM model upgrade developed under this grant added decision tree logic for shorelines that have been previously defended with bulkheads and revetments (Appendix 1). This required the development of rules to incorporate two different decision trees (one for each conventional shoreline type) into the model. As shorelines with groin fields were already in the earlier model version, the upgraded model provides an output recommendation for all Virginia shoreline whether undefended or not. The Virginia Shoreline Inventory (Inventory) provided the data necessary to determine where shoreline hardening has occurred.

The SMM calls upon a second model, the Fetch Model, as inputs to indicate the potential wave energy climate based on fetch distance from dominant directions. Fetch is used as a surrogate for energy and differentiates among possible living shoreline types according to capacity to withstand anticipated wave energy. For example, in low fetch environments the model would recommend a living shoreline practice that is strictly nature based; such as marsh plantings or fiber logs. In contrast, a breakwater may be recommended if the fetch environment for a site was computed to be high.

A QA/QC process compared outcomes for shoreline management recommendations using the decision trees to modeled output. All shoreline recommendation types, locations with small to large fetch, marsh and beach shorelines and both non-defended and defended scenarios where compared.

Another revision to the model occurred as part of an external project and addressed the potential conflict between placement of shoreline practices in shallow waters where submerged aquatic vegetation (SAV) maybe present. This is most likely in the case of breakwaters with beach nourishment along sandy shorelines. Data from the VIMS SAV mapping Program provided the spatial data necessary to integrate SAV presence into the model update (VIMS SAV website).

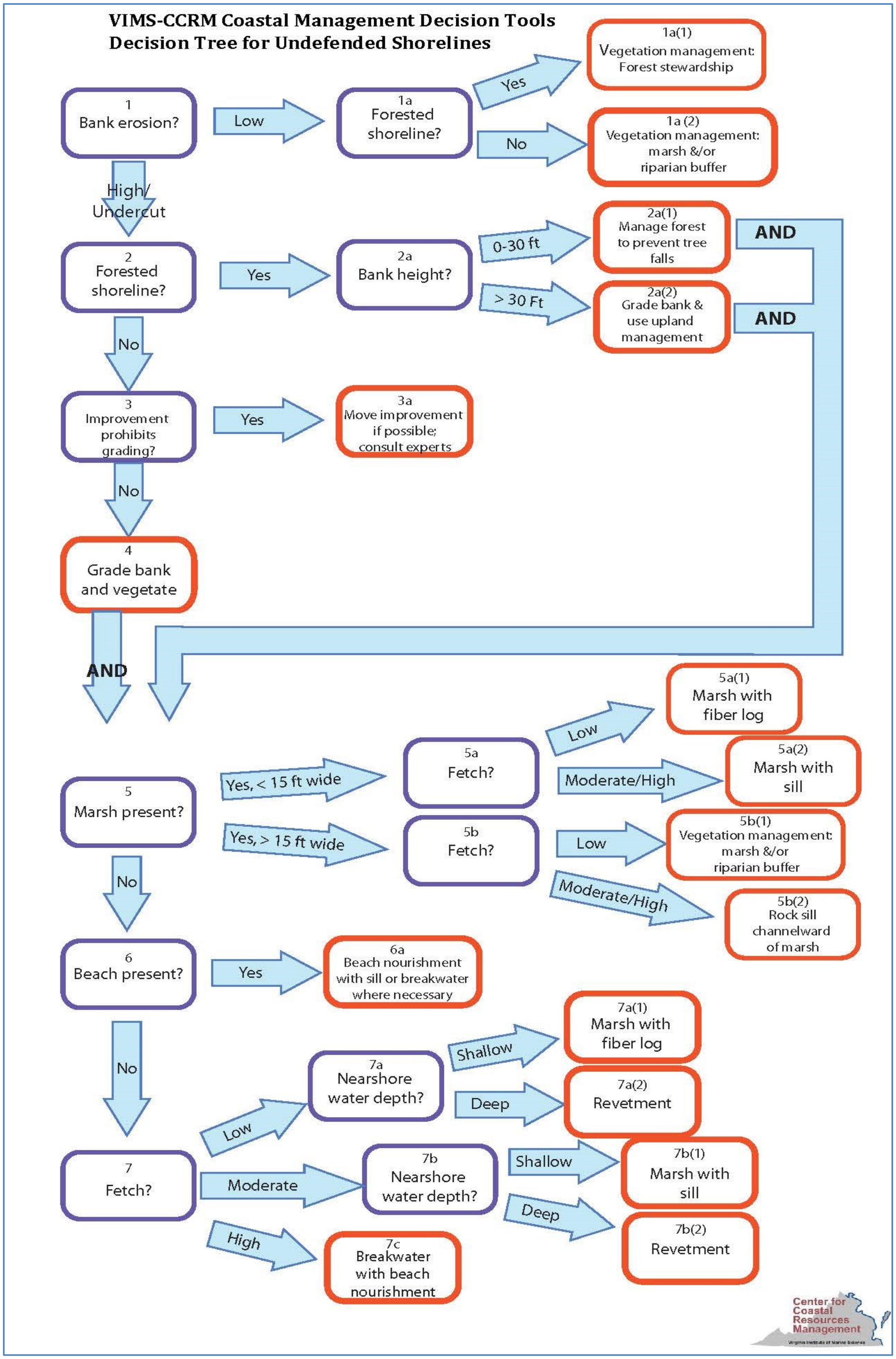


Figure 1 Original Decision Tree for Undefended Shoreline CCRM, 2010

Results

The current model (v5.0) was run for the entire coastal zone and used for the remainder of the project. The modeled on the ground best practices are shown in Table 1. Adjustment in the model coding was made in response to the QA/QC. The final model is represented in the flow charts illustrated in Appendix 2. Appendix 3 summarizes the treatment options.

The model results were posted to the CCRM Comprehensive Coastal Resource Management Portals (CCRMPS) and to ADAPTVA AdaptVa. Shape files for the coastal zone were delivered to the Virginia Coastal Zone Management Program along with metadata.

Table 1. List of classes for on the ground best practices in SMM v5.0.

Shoreline Best Management Practices (V5.0)
Non-structural living shoreline
Plant marsh with sill
Maintain beach or offshore breakwater with beach nourishment
Groin field with beach nourishment
Revetment
Revetment/Bulkhead Toe Revetment

Chapter 2. Co-Benefits of Living Shorelines – Nutrient Reduction Goals

The focus of year 2 was to address the value of nature based features from the perspective of the co-benefits they provide. Specifically, the project is focused on how the creation of nature-based features such as living shorelines garner nutrient reduction credits that can be applied to assist local governments in meeting their TMDL nutrient reduction requirements. The analysis applies the Chesapeake Bay Program (CBP) approved process for crediting nature based solutions to areas where such treatment options could be incorporated into efforts focused on coastal resilience and shoreline protection. The most recent version of the SMM (v.5.1) was used to assess where living shorelines are appropriate along natural/unmanaged shoreline or previously hardened shorelines and where, if implemented according to the model output, would meet the CBP criteria for TMDL credits.

Approach

The SMM (V5.1) delineates where living shoreline treatments are suitable erosion control methods based on current shoreline conditions, as well as where more traditional erosion control structures would work best (i.e. navigationally limited areas where living shorelines are not feasible). The SMM version from year 1, was further modified under a different NOAA funded grant (NOAA Contract No. NA17NOS4510100) and was applied to this project. The newest version (v.5.1) was used to re-assess Virginia shoreline to identify preferred shoreline management approaches (Figure 2).

This model has been run for all of the coastal zone of Virginia. The model identifies different classes of living shoreline, or traditional alternatives that should provide protection along both natural (no erosion control adaptations in place) and modified shorelines (e.g. those existing structures such as bulkheads or revetments). A glossary and description of these classes is found in Appendix 2. structures such as bulkheads or revetments). A glossary and description of these classes is found in Appendix 2.

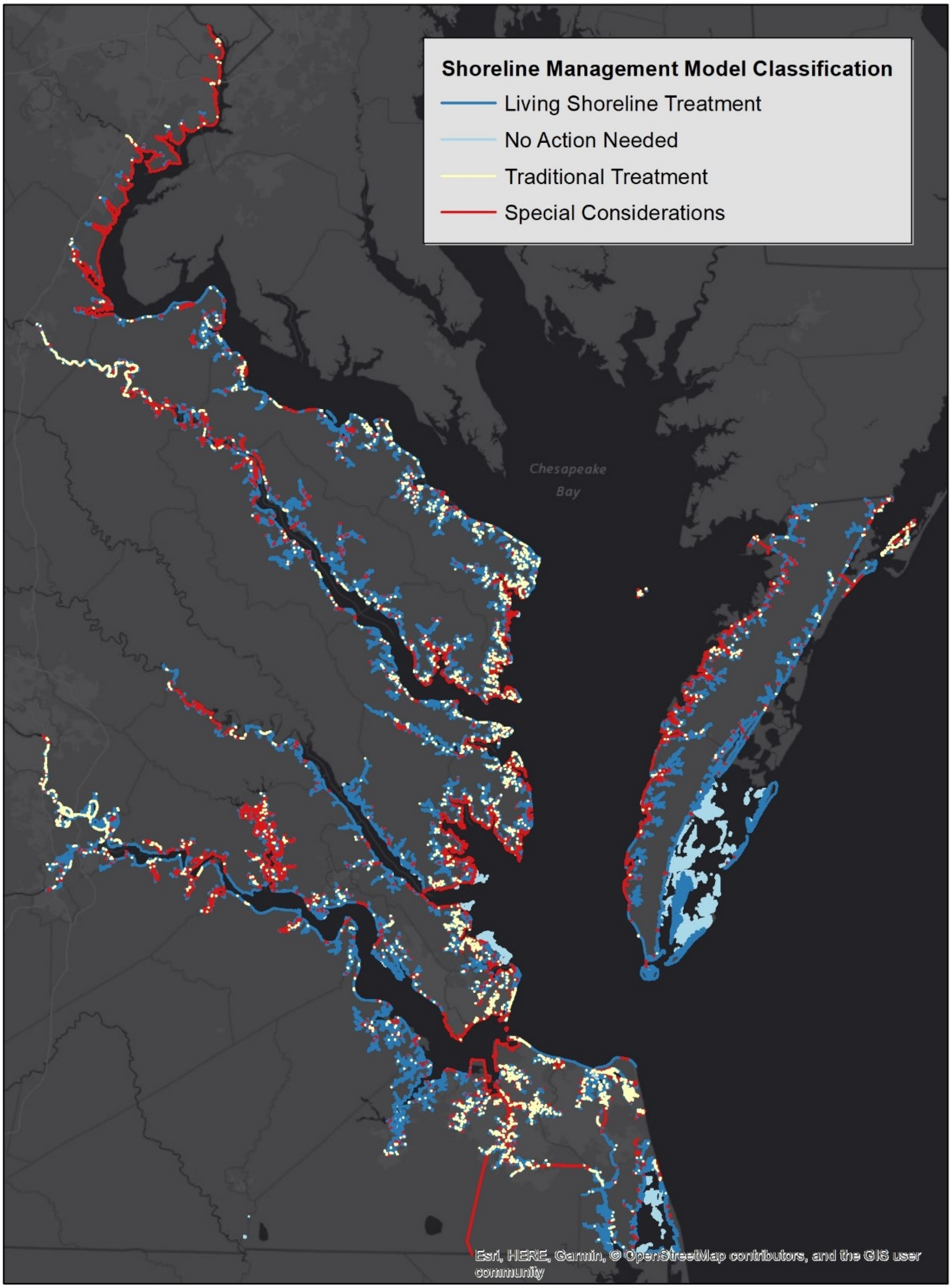


Figure 2. Model Version 5.1 output for Virginia

Where living shorelines were modeled as suitable, the model was used to meet the second project goal which was to apply Chesapeake Bay Programs' nutrient reduction criteria to calculate the TMDL credits these best management practices (BMPs) could bring if these living shorelines were constructed. This project focused on the potential for the past and future implementation of nature and natural-based features, and specifically on the use of tidal vegetated marsh for erosion protection and the co-benefit of water quality improvement. Using vegetated marsh alone, or in combination with a channelward protective structure, are approaches that meet the Commonwealth's definition of living shorelines which are codified as the preferred practice for erosion control. In the SMM output, marsh creation is included in two of the shoreline best management practices; "non-structural living shorelines" or "plant marsh with sill" (Table 2).

Table 2. List of classes for on the ground best practices in SMM v5.1. * denotes classes that meet criteria for load reduction credits

Shoreline Best Management Practices (V5.1)
Non-structural living shoreline*
Plant marsh with sill*
Maintain beach or offshore breakwater with beach nourishment
Groin field with beach nourishment
Revetment
Revetment/Bulkhead Toe Revetment

The Chesapeake Bay Program (CBP) uses loading estimates to quantify expected amounts of nutrients (nitrogen and phosphorus) or sediment loads to water from specific land uses or point sources and makes adjustments based on an estimate of the effectiveness of a best management practice (BMP). BMP Expert Panels are convened to develop the BMP effectiveness estimates and the Water Quality Goal Implementation Team (WQGIT) is responsible for approving the loading rate reductions, and percentage adjustments to these rates, used in the Chesapeake Bay Watershed Model (CBWM). The CBP empaneled a group of shoreline science and management experts to provide a recommendation on nutrient and sediment load reduction efficiencies provided by shoreline management practices. The expert panel process has been codified by the CBP to include generation of a recommendation report and subsequent review, and approval, by the pertinent workgroups and Teams. The panel provided a recommendation based on a scientific literature review and best professional judgement.

Four different protocols are defined for shoreline BMPS:

Protocol 1, "Prevented Sediment" provides an annual mass sediment reduction credit for qualifying shoreline management practices that prevent tidal shoreline erosion that would otherwise be delivered to nearshore/downstream waters. The pollutant loads are reduced for sand content and bank instability (based on the state's assessment).

Protocol 2, "Credit for Denitrification" provides an annual mass nitrogen reduction credit for qualifying shoreline management practices that include vegetation.

Protocol 3, "Credit for Sedimentation" protocol provides an annual mass sediment and phosphorus reduction credit for qualifying shoreline management practices that include vegetation.

Protocol 4 "Credit for Marsh Redfield Ratio" provides one-time nutrient reduction credit for qualifying shoreline management practices that include vegetation.

"Default Rate" provides an annual mass sediment and nutrient reduction credit for qualifying shoreline management practices.

Accounting for load reductions for Protocol 1 based on a GIS model is problematic as it would require detailed and precise bank elevation data and mean value for annual shoreline retreat. This data is not currently available. As such, protocol 1 load reductions are identified as site specific and are currently determined on a project by project basis. However, for calculating load reductions for existing and non-conforming practices, the approved BMP assigns values to nitrogen, phosphorus and sediment reductions based on linear feet. (CBP, 2017). Pollution load reductions under protocols 2 and 3 are credited annually. Recommendations call for a review to verify the BMP is still functioning as intended. Pollution load reductions under protocol 4 are a one-time nutrient reduction credit for practices that include vegetation.

Table 3 shows the approved CBP protocols for nitrogen, phosphorous and sediment reductions of shoreline management BMPs. Nutrient load reduction benefits were attributed to those potential living shoreline sites that included vegetative practices - the creation of marsh.

Table 3. Summary of CBP protocols for nitrogen, phosphorus and sediment reductions of shoreline management BMPs

Protocol	Submitted Unit	Total Nitrogen (lbs per unit)	Total Phosphorus (lbs per unit)	Total Suspended Sediment (lbs per unit)
Prevented Sediment	Linear Feet	Project-Specific*	Project-Specific*	Project-Specific
Denitrification	Acres of re-vegetation	85	NA	NA
Sedimentation	Acres of re-vegetation	NA	5.289	6,959
Redfield Ratio	Acres of re-vegetation	6.83	0.3	NA
Non-conforming/ Existing Practices*	Linear Feet	MD= 0.04756 VA = 0.01218	MD= 0.03362 VA = 0.00861	MD= 164 VA = 42

The geospatial analysis uses the ESRI® software ArcMAP for computation and output. The model's output of location and extent of shoreline management recommendations is geospatially represented as a line along the shoreline. We selected the recommendations for non-structural living shoreline and plant marsh with sill only (Table 2) and converted that shoreline to a polygon by multiplying the alongshore dimension by a constant marsh width of eight (8) feet. With a greater than 50% reduction in wave energy and height (Knutsen et. al., 1982), this width is consistent with the minimal recommended width for marsh creation for erosion abatement. It is also specified as the minimum vegetated marsh area to qualify for the Virginia Living Shoreline Group 2 General Permit for "Certain Living Shoreline Treatments Involving Submerged Lands, Tidal Wetlands Or Coastal Primary Sand Dunes And Beaches". The modeled marsh width is considered to be a minimum recommended width for erosion control, but creation of marshes with greater areal extent would qualify for great load reductions accordingly. The newly computed areas (or polygons in ArcMap) represent the location and minimal amount of vegetation which may be created along that shoreline to reduce erosion.

The analysis was run on shoreline currently unmanaged (i.e. no shoreline armoring present) and shorelines currently defended with structures such as bulkheads and revetments. The analysis excluded shorelines where marsh grass was already present as the criteria considers credit only for "new" marsh creation. However, it is possible to create additional marsh, which can qualify for load reduction credits if the qualifying criteria are met.

The approach applied in this project is to calculate the CBP approved nutrient load reductions for nitrogen, phosphorous and sediment (Table 3) for potential created marsh areas generated through the spatial analysis. The analysis is for two time frames:

- forecasting – looking forward to all possible shoreline where the SMM assigns living shoreline suitability;
- back-casting – for all shoreline hardened between 2009 and 2018 where the CCRM permit database identified the suitability for a living shoreline.

Each potential living shoreline treatment option that includes vegetation is assessed to quantify its added value potential as a TMDL credit to satisfy pollution reduction requirements that must be met by the CBP signatories. The potential credits were calculated for each Tidewater locality and for 8-digit HUC units.

Results

Future Nutrient Reduction Credits from Potential NNBF BMPs

We computed the location and amount of qualifying living shoreline BMPs appropriate for erosion control along the shoreline for each locality. The potential load reduction credits to be achieved if all these BMPs are to be implemented and credited was also calculated. For shorelines currently unmanaged, more than 760 acres of tidal marsh could potentially be created for erosion abatement across all tidewater localities analyzed (Note: King and Queen and King William counties had no data available for the analysis).

Combining all potential nutrient reduction credits analyzed across all localities, Virginia's Tidewater communities could reduce the nitrogen load reduction requirement by 69,907 pounds of nitrogen. An additional 278 acres of marsh could be created along shorelines that have already been defended. This would add an additional 25,499 pounds of nitrogen as credit. Across Tidewater the credits applied for phosphorous reductions would equal 4,255 pounds with an additional 1,552 pounds for hardened shorelines that convert to NNBF.

Table 4. SMM outputs used to calculate potential load reductions. Linear in thousand feet. Green = Included outputs. Yellow= possible marsh creation opportunities.

Tidal Shoreline SMM Preferred BMPs												
Shoreline Type	Special Geo-morphic Feature	Ecological Conflicts	Highly Modified Area	Landuse Manage-ment	No Action Needed	Non-Structural Living Shoreline	Plant Marsh with Sill	Maintain Beach/ Breakwater w/ Beach Fill	Groin Field with Beach Fill	Revet ment	Revet-ment / Bulkhead Toe	Total
Undefended – Marsh	31.2	2,145.3	4,44.8	21.8	8,575.7	23,945.5	2,479.7	168.9	0.00	7.6	0.00	37,820.0
Undefended - No Marsh	44.6	918.0	342.7	93.6	134.3	5,710.9	522.2	1,044.6	0.00	486.7	0.00	9,297.4
Defended - Marsh	1.0	121.6	147.4	5.3	3.9	614.0	187.0	92.0	5.0	50.0	4.0	1,231.0
Defended - No Marsh	3.0	466.0	1,169.0	12.5	0.5	12,453.7	266.8	905.0	92.1	152.0	14.0	4,326.3
Total	80.0	3,650.8	2,10.3	133.1	8,714.4	31,515.8	3,455.6	2,210.5	97.0	696.2	17.7	52,674.5

The load reduction calculations for living shoreline implementation are conservative. Not all of the Virginia localities have been mapped with a SMM recommendation (specifically King and Queen, King William) and certain shoreline settings do not have a shoreline management approach recommendation. Only shoreline with no existing marsh were included to highlight where a living shoreline would restore/ create marsh. The modeled living shorelines have the minimum 8-foot width called for in the Group 2 general permit, but for best performance and in practice, most are much wider and existing marshes could be expanded. Some highly developed, high physical risk or special resource landscapes such as: marinas and canals, infrastructure within 50 feet of the shoreline, along small spit features and in the vicinity of SAV, are excluded from provision of a specific recommendation even though a living shoreline may be feasible in some of these areas. Finally, we did not include breakwaters which commonly include some vegetated area within the project, but for which a standard marsh creation area is not common and dependent upon the project design. Table 4 shows the categories of SMM output used in the calculations and possible additional marsh creation and load reduction opportunities.

The values computed for each locality represent the potential nutrient reduction credits available if vegetative alternatives are put in place everywhere possible. The actual credits will need to be evaluated on a project by project basis. Appendix 3 reports the rates for each locality (A = Currently Unmanaged Shoreline; B = Currently Defended Shoreline). Considering the benefit of vegetated BMP practices to TMDL credits per hydrologic unit, Appendix 3C and 3D also report data for the fifteen (15) different 8-digit hydrologic units within the coastal zone of Virginia.

A cautionary note comes from the CBP expert panel report regarding the forecasting of load reduction credits attributable to all shoreline identified as suitable for vegetated practices. The load reduction values may provide a perverse incentive for shoreline management along shorelines where erosion protection is not warranted. A perverse incentive is an incentive that has an unintended and undesirable result which is contrary to the intentions of its designers. Perverse incentives are a type of negative unintended consequence. From an ecosystem perspective, shoreline management even in the form of preferred natural and nature-based practices, still result in environmental consequences, most notably the prevention of sediment inputs into the waterways. While sediment prevention is an intended consequence from a water quality perspective, the loss of available material necessary for wetland and beach resilience can adversely impact the provision of erosion abatement, flood risk reduction and habitat services. The panel addressed this concern by including a set of qualifying conditions. The qualifying conditions establish living shoreline (nonstructural, hybrid marsh with sill, hybrid beach/dune with breakwater) as the first option when the site is experiencing erosion. The second option is for a revetment or breakwater where a living shoreline is not feasible, and finally bulkhead or seawall where certain land use limitations necessitate the approach (CBP 2017). Nevertheless, given the concern for erosion and the current rate at which erosion control practices are applied for (660/ year), the projection of water quality benefits from vegetated practices provides rationale for their implementation as a preferred practice.

Potential Nutrient Reduction Credits Lost Due to Past Shoreline BMP Decisions

This study also analyzed credits which may have been available to local governments had NNBFs been installed instead of traditional erosion abatement structures. In order to backcast the potential load reductions for existing and non-conforming shoreline practices, permits applications for the years 2009-2018 were reviewed for all the coastal localities in Virginia (CCRM 2019). As the CBP model has already accounted for landuse and BMPs activities up through 2008, we selected those actions that could have received load reduction credits starting in 2009 to presently available data. The analysis called for an extraction of all sites where a traditional bulkhead or revetment was permitted but a non-structural living shoreline or a hybrid marsh planting with sill was recommended through the SMM. The total linear footage of shoreline along which marsh creation was possible was estimated by the project

lengths reported in the permit application (n=306,234 linear feet of shoreline). Table 5 reports the values by locality.

Using the same method above to estimate the amount of marsh that could have been created at each site, the project length was multiplied by a minimal marsh width of 8 feet to calculate the area of possible marsh creation along the shoreline (n=56.24 acres of marsh).

Since the Chesapeake Bay Program's guidance does allow for credits for existing and non-conforming practices such as bulkheads and revetments, the load reduction values for these conventional shoreline practices were calculated using the approved removal rates for these practices. We also calculated the potential load reductions if the projects had been living shorelines. For the Protocol 1 calculation for the living shorelines backcasting, we used the same sediment removal rate as for the non-conforming/ existing and the approved removal rates of 0.00029 pounds of total nitrogen per pound of total suspended solids and 0.000205 pounds of total phosphorus per pound of total suspended solids. Table 6 shows the totals for all conventional hardening approaches with both the "approved" rates for non-conforming/ existing practices and the possible rates if those practices had been living shorelines as identified in the SMM. This is the load reduction the locality lost because NNBFs were not used where appropriate for erosion control abatement, and the number of sites where this occurred. Using the load reduction numbers from Table 3, we projected the potential amount of nutrient reduction credits available to the locality had the preferred NNBF management practice been installed. The importance of this figure is to re-emphasize the co-benefits and value of encouraging the use of NNBFs for erosion control.

Furthermore, while much of tidal shore permitting decisions are made at the local level, the implications for water quality benefits are not necessarily well communicated to decision making boards. Year three of this project plan includes communication to these local units to help build awareness of the co-benefits of NNBFs.

Table 5. Conventional structures permitted where suitable for vegetated practices (Non-structural living shoreline and Plant marsh with sill). In linear Feet.

Locality	LF Approved
Accomack	12533
Charles City	897
Chesapeake	6483
Chesterfield	500
Colonial Heights	26
Essex	3225
Fairfax	357
Gloucester	15244
Hampton	6607
Henrico	168
Hopewell	165
Isle of Wight	1906
James City	2617
King George	1490
Lancaster	31212
Mathews	13525
Middlesex	23093
New Kent	2540
Newport News	1082
Norfolk	19885
Northampton	2537
Northumberland	64893
Poquoson	2813
Portsmouth	4101
Prince George	251
Richmond County	1524
Spotsylvania	325
Stafford	729
Suffolk	4159
Virginia Beach	55124
Westmoreland	16332
York	9891
Total	306234

Table 6. Potential nutrient reduction credit lost from permitted activities 2009-2018

Protocol	Unit of measure	Total N Removal (lbs)	Total P Removal (lbs)	Total SS Removal (lbs)
1. Prevented Sediment	306,234 linear feet	373	2637	12,861,828
2. Denitrification	56.24 acres	4,780	NA	NA
3. Sedimentation	56.24 acres	NA	297	391,374
4. Marsh Redfield Ratio	56.24 acres	384	17	NA
TOTAL Nutrient Credits		5,537	2,951	391,374
Non-conforming /Existing Practices	306,234 linear feet	3,729	2637	12,861,828
Difference		1,808	314	391,374

Outcomes

The implementation of shoreline BMPs can result in significant nutrient and sediment load reduction and in support of Virginia's efforts to achieve the pollutant reductions required by the Bay Total Maximum Daily Load (TMDL). Where property owners are seeking to manage their shoreline to reduce or prevent erosion, they have a range of management options including living shorelines and conventional hardening. Virginia has established public policy to identify living shoreline as the preferred practice and the CBP has approved a pollution load reduction rate for shoreline management practices. While all shoreline management practices may be eligible for load reduction credits, the CBP BMP requires that an eligible site be experiencing current erosions, and use a natural or nature-based vegetative practice unless demonstrated to be infeasible. The BMP load reduction rates for conventional practices are smaller than living shoreline practices because they lack the additional load reduction attributed to the creation of marsh. As such, the co-benefit of water quality improvement, and opportunity for credits, provides additional rational for the preference of NNBF shoreline management approaches over conventional hardening techniques.

Our analysis shows that future implementation of living shorelines at all suitable locations would result in 1,070 miles of living shoreline and the creation of 1,038 acres of tidal marsh. This area of marsh creation could, at least for some time into the future, improve the sustainability of tidal vegetated wetlands in the face of loss to rising seas. The load reductions anticipated from future marsh creation would be about 100,000 pounds nitrogen, 5800 pounds phosphorus annually, plus additional nutrient and sediment load reductions to be calculated on a project-specific basis. Additionally, back-casting the application of living shorelines to suitable locations where conventional hardening was used during the years 2009-2018 found 58 miles of eligible shoreline that would have minimally created 56.3 acres of tidal marsh. This would have also resulted in potential annual reduction of almost 2000 pounds of nitrogen, about 300 pounds of phosphorus and almost 400,000 pounds of sediment (Berman et al 2020).

Chapter 3. Living Shoreline for Building Community Resiliency

While communities continue to gain insight into the general understanding of actions that can lower risks and increase resilience, financial and people resources required to undertake those actions are limited. In the face of competing interests, one solution to accelerating the pace of building resilience is to find ways to address multiple needs with each action. Therefore, the co-benefits of building resilience through nature-based features offer an opportunity for communities to also acquire nutrient reduction benefits, habitat benefits, and other values from carefully planned projects.

Chapters 1 and 2 have focused on two of these co-benefits of living shorelines: erosion control and nutrient reduction credits. The additional co-benefits addressed in the third year of this study are 1) the potential for the living shoreline to abate flood waters and storm surge for buildings, and 2) the potential for a living shoreline project to provide these benefits for socially vulnerable communities.

Under NOAA Grant Number # NA17NOS4730142, NNBFs existing across low-lying areas (areas generally less than 10-feet elevation relative to NAVD88) of coastal Virginia were mapped, a geospatial protocol that relates NNBFs with specific buildings they benefit was developed, and a ranking methodology was designed. The ranking methodology was used to assess the potential for these existing NNBFs to provide multiple benefits for communities, including mitigating tidal flooding impacts for buildings. (Data is served on Adaptva.com)

Year three of this study applied the data and approaches developed for existing NNBFs with the output from the models from year 2 to rank potential living shoreline sites based on the co-benefits they can provide: 1) nutrient reduction, 2) shoreline habitat continuity, 3) flooding mitigation benefits for vulnerable buildings, and, 4) providing these benefits for socially vulnerable communities.

Approach

Potential living shoreline sites that provide erosion and nutrient reduction benefits were identified in year 2 (see Chapter 2 of this report) of this project. In year 3, we ranked these sites based on their potential to provide the most co-benefits for a community by adapting the multi-criteria ranking framework created in the NOAA project (described above). Focusing on sites where living shorelines will address gaps in existing NNBFs and enhance resilience for communities, an overall benefit rank was calculated using four criteria, described below (Table 7).

Nutrient Reduction Potential

This factor incorporates the work completed in year 2 of the project to quantify nutrient reduction benefits of living shorelines. The relative amount of potential water quality benefit is dependent on the size of the potential living shoreline feature (shoreline length suitable for vegetative living shoreline x constant width of 8 ft= polygon area), and thus larger sites receive a higher rank for benefits provided, as described in Table 7.

Habitat Continuity Benefit

Creating living shorelines in locations that are adjacent to existing natural features, and particularly nearby marshes, will enhance and improve connectivity of shoreline habitats. Using NNBFs layers mapped in the NOAA project, we were able to identify those living shoreline locations that have existing adjacent natural features. The highest rank was assigned to those potential living shoreline sites near existing marshes (including tidal marshes, other wetlands, and installed living shoreline projects). As expected, the vast majority (~86%) of potential living shoreline project sites were adjacent to other tidal marshes, wetlands, or existing living shorelines.

Benefits to Local Buildings and Communities

The geospatial approach developed to assess existing NNBFs in the landscape was applied to these potential living shoreline sites. Topographic connections, called 'inundation pathways' (IPs), between tidal shorelines and more than 170,000 buildings lying on lands generally less than 10-feet in elevation (relative to NAVD88) were delineated. These IPs are the lowest areas of the landscape and where storm surge is most likely to flow through as it rises and moves inland toward infrastructure. NNBFs that exist along an IP are therefore inferred to have the most potential to provide flooding mitigation services for the associated building during storm events. As a result, for each NNBF we can count how many IPs intersect it, and use that as a relative measure of the importance of that NNBF in providing benefits to buildings.

For this study, potential living shoreline sites were evaluated based on the number of IPs that they intersect. The number of buildings benefitting from a potential living shoreline project ranged widely from 0 up to 839, though only 25% of these sites benefit 1 or more buildings.

Ranking categories reflect those used for the NOAA project, and are the statistical grouping of results into low, medium, and high categories, as shown in Table 7.

Benefits to Socially Vulnerable Buildings

Utilizing an existing Social Vulnerability Index created by researcher Sarah Stafford at William & Mary and described in Stafford and Abramowitz (2017), potential living shoreline sites were ranked based on their proximity to socially vulnerable communities, as described in Table 7.

The social vulnerability classification is based on census tract data, and considers many criteria to assess the potential for a community to "anticipate, cope with, resist and recover from a physical hazard…[A]s social vulnerability in a population increases, their resiliency to natural hazards decreases." Therefore, the creation of a new living shoreline project in socially vulnerable communities has the potential to improve resilience.

According to application of the social vulnerability classification, approximately half of the potential living shoreline sites were located in communities that were not considered socially vulnerable. Only 3% of projects were located in communities with high social vulnerability. This may reflect the relatively high economic value of waterfront property, but also may be a limitation of the granularity of the data given that the census tracts include non-waterfront property as well.

Table 7. Classification of Benefits of Living Shorelines for Building Community Resiliency

Criteria	Benefits Rank		
	Low (1)	Medium (2)	High (3)
1. Potential to Provide Nutrient Reduction/Water Quality Improvement The potential for the living shoreline project to provide nutrient reduction benefits for Chesapeake Bay waters, based on the size of the BMP polygons. (Fixed width of 8 feet, variable lengths)	Smallest Size (<33 percentile, <0.02 acres)	Medium Size (34-66 percentile, 0.02 - 0.04 acres)	Largest Size (67-100 percentile, 0.04 – 1.4 acres)
2. Potential to Provide Habitat Continuity and Enhancement The potential for the living shoreline to fill existing gaps in natural buffers, based on the type of natural features within 1 meter.	No Adjacent NNBFs	Adjacent Wooded, Scrub-Shrub, Beaches, Dunes	Adjacent Tidal Marsh, other Wetlands, or existing Living Shorelines
3. Potential to Provide Benefits for Vulnerable Buildings The potential for the living shoreline to provide tidal flooding mitigation for buildings in the community, based on the number of building IPs that the project intersects or comes within 1 meter of.	0 Buildings	1 Building	2 or more buildings
4. Potential to Provide Benefits for Socially Vulnerability Communities Communities without the funds to adapt, recover, or respond to a natural hazard are identified. Based on a classification created by Sarah Stafford of William & Mary, calculated by census tract.	Not Socially Vulnerable or Not Included	Moderate Social Vulnerability	High Social Vulnerability

Results

Each of the 19,982 potential living shoreline sites was scored in each of the four criteria, and those scores combined into an overall ranking. The overall ranking is based on the sum of each of the four scores and then statistically grouped into three bins: ‘some benefits’ (low), ‘many benefits' (moderate), or 'the most benefits' (high) potentially provided, and are summarized by locality in Table 8.

Table 8 Areas Suitable for Living Shorelines Ranked, By Locality

Locality	Some Benefits Provided	Many Benefits Provided	Most Benefits Provided	Total
Accomack	455	229	217	901
Alexandria	7			7
Arlington	14			14
Caroline	51	41	4	96
Charles City	63	54	39	156
Chesapeake	243	115	155	513
Chesterfield	124	28	1	153
City of Hopewell	19	9	7	35
Colonial Heights	22	5	1	28
Essex	113	81	57	251
Fairfax	34	2	2	38
Fredericksburg	6	4	5	15
Gloucester	385	202	189	776
Hampton	181	102	158	441
Hanover	8	1		9
Henrico	52	26		78
Isle of Wight	340	117	8	465
James City	252	62	10	324
King George	266	106	4	376
Lancaster	877	785	656	2318
Mathews	363	303	419	1085

Locality	Some Benefits Provided	Many Benefits Provided	Most Benefits Provided	Total
Middlesex	613	394	258	1265
New Kent	68	15	2	85
Newport News	152	40	14	206
Norfolk	168	130	312	610
Northampton	127	130	142	399
Northumberland	2064	1343	660	4067
Petersburg		1	1	2
Poquoson	107	48	74	229
Portsmouth	121	44	83	248
Prince George	95	21	5	121
Prince William	20	7		27
Richmond	91	78	121	290
Richmond (city)	3		10	13
Spotsylvania	7	2		9
Stafford	36	12	2	50
Suffolk	243	77	22	342
Surry	55	42	31	128
Virginia Beach	739	338	577	1654
Westmoreland	432	437	477	1346
Williamsburg	16	2		18
York	461	175	158	794

Rankings of ‘most benefits provided’ (the highest ranking) applied to 4,881 (24%) of the potential living shoreline sites and these were found across Virginia coastal localities. In general, most of the highest-ranking living shoreline sites had both a high habitat continuity rank (92% of high-ranking sites) and a high nutrient reduction rank (79% of high-ranking sites). To the extent that benefit ranking may be incorporated into setting priorities for living shoreline implementation, this equates to the highest priority going to sites that fill or close gaps in NNBF corridors along the shoreline and that are projected to provide the greatest pollution load reduction benefit.

Outcomes

In a complex landscape where environmental, economic, and societal stressors may impede the ability of a community to advance regulated or progressive adaptation measures, data that can help decision makers prioritize resource spending and demonstrate multiple benefits is useful. The outcome of this study presents data that allows planners, managers, and conservationists to identify and highlight where certain on the ground best management practices have the capacity to serve multiple benefits to individuals and the community.

The results inform localities on the ranked co-benefit value of site-specific living shoreline implementation associated with pollution load reduction, flood benefits and habitat service provisions. The deliverables have been integrated into the AdaptVA (http://adaptva.com/) Interactive Map, under the Protection/Restoration Opportunities Tab (Figure 3). Within this layer, each potential living shoreline site can be viewed and an informational popup describes the rankings and site characteristics (Figure 4).

ye

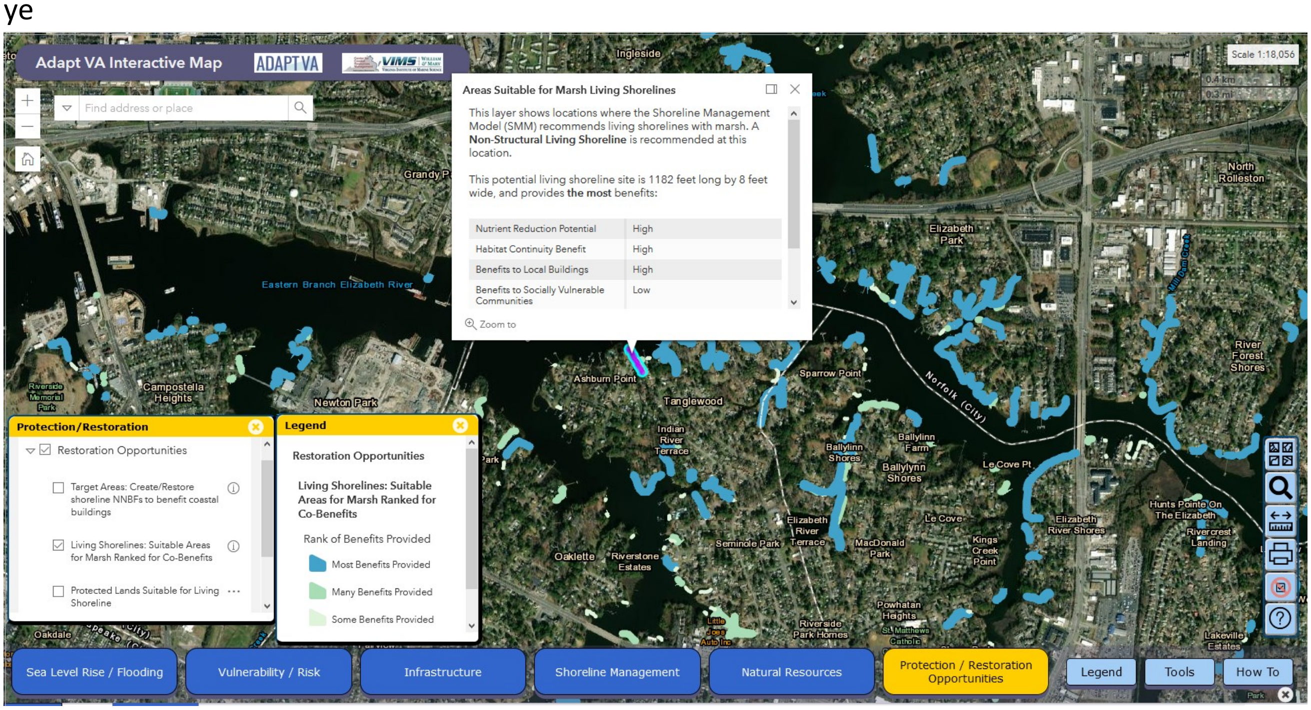


Figure 3. Model results illustrated on the AdaptVA interactive map. Eastern Branch Elizabeth River, Cities of Norfolk and Chesapeake.

Figure 3 demonstrates the data display in the Adaptva interactive viewer. There are shown the ranked potential living shorelines, located within the Protection/ Restoration opportunities tab (highlighted in yellow), the legend (some, many, most benefits) and the popup (Figure 4) showing the benefits ranking. Each living shoreline location (polygon) in the viewer can be "selected" with click to display the detail on the ranking for that BMP. The highlighted living shoreline in Fig. 3 has the attributes shown in Figure 4.

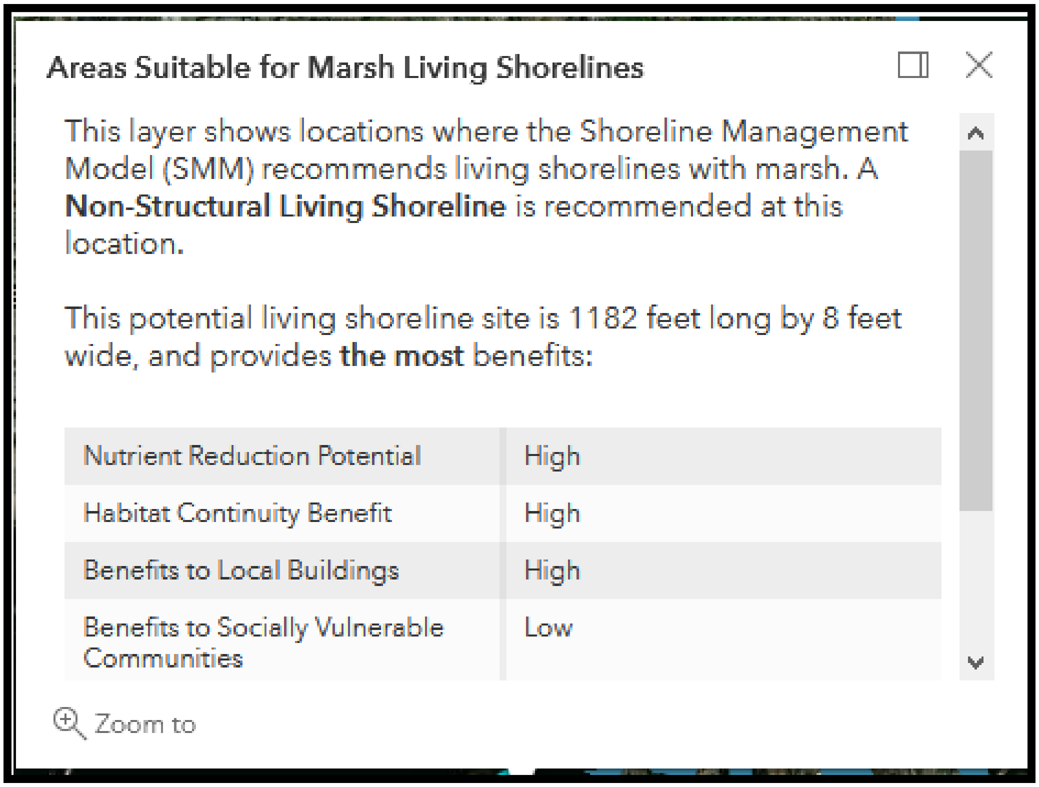


Figure 4. Popup window in AdaptVA reveals the ranked value of the potential living shoreline site for co-benefits.

With ever-growing interest and use of living shorelines and the incentives and assistance provided to promote greater application, the modeled approach and data developed through this multi-year project can be helpful in directing resources in an efficient way, can highlight often overlooked co-benefits that living shorelines can provide to the entire community, and also identify possible opportunities for partnerships in the identified co-benefits. For example, a living shoreline that provides habitat continuity in tidal marsh may be of interest to local non-profits such as Audubon Society, the Department of Wildlife Resources, or others entities focused on habitat restoration. At the same time, identification of suitable locations for living shorelines may be useful for farmers and residential property owners exploring cost-share opportunities through either the Virginia Agricultural Cost Share or the Virginia Conservation Assistance Programs. Including a social vulnerability element in the ranking provides additional points, and a resultant higher value, for living shorelines provision of co-benefits in vulnerable areas. We used a social vulnerability index determined by census track which is produced on a scale that cannot reflect smaller communities or properties. Coastal resilience is the result of effective management, protection, promotion, and implementation of just actions that engage all sectors of the community to provide for the health and persistence of linked ecological and socio-economic systems.

References

Berman, Marcia; Mason, Pamela; and Rudnicky, Tamia. 2018. Expanding the use of natural and nature-based infrastructure to enhance coastal resiliency – Interim Report (Year 1 of 3), Center for Coastal Resources Management, Virginia Institute of Marine Science, William & Mary, pp17.

Berman, M., Mason, P., & Rudnicky, T. (2020) Expanding the use of natural and nature-based infrastructure to enhance coastal resiliency: Forecast and hind-cast load reductions from Living shoreline BMPs: Project Report (Year 2 of 3). Virginia Institute of Marine Science, William & Mary. doi: 10.25773/378t-k497

Center for Coastal Resources Management (CCRM).2019. Center for Coastal Resources Management (CCRM). Shoreline Permit Database. Virginia Institute of Marine Science, William & Mary, Gloucester Point, Virginia.

Center for Coastal Resources Management, 2010. Decision tree for undefended shorelines and those with failed structures, Center for Coastal Resources Management, Virginia Institute of Marine Science, Gloucester Point, Virginia, pp. 33.

Chesapeake Bay Program (CBP). 2017. (Nathan Forand, Kevin DuBois, Jeff Halka, Scott Hardaway, George Janek, Lee Karrh, Eva Koch, Lewis Linker, Pam Mason, Ed Morgereth, Daniel Proctor, Kevin Smith, Bill Stack, Steve Stewart, and Bill Wolinski). Recommendations of the Expert Panel to Define Removal Rates for Shoreline Management Projects. Prepared by S. Drescher and B. Stack, Center for Watershed Protection. Approved by the WQGIT July 13, 2015, with revised credits approved June 26,2017.
https://www.chesapeakebay.net/documents/LONG_SHORELINE_MGMT_EPR_05152018.pdf

Knutsen, P. et al. 1982. Wave damping in *Spartina alterniflora* marshes. Wetlands vol. 2:87-104.

Stafford, S., Abramowitz, J. 2017. An analysis of methods for identifying social vulnerability to climate change and sea level rise: a case study of Hampton Roads, Virginia. Natural Hazards vol. 85:1089–1117. https://doi.org/10.1007/s11069-016-2622-4

APPENDIX 1. Shoreline Management Model (v5.1) Flow Diagrams

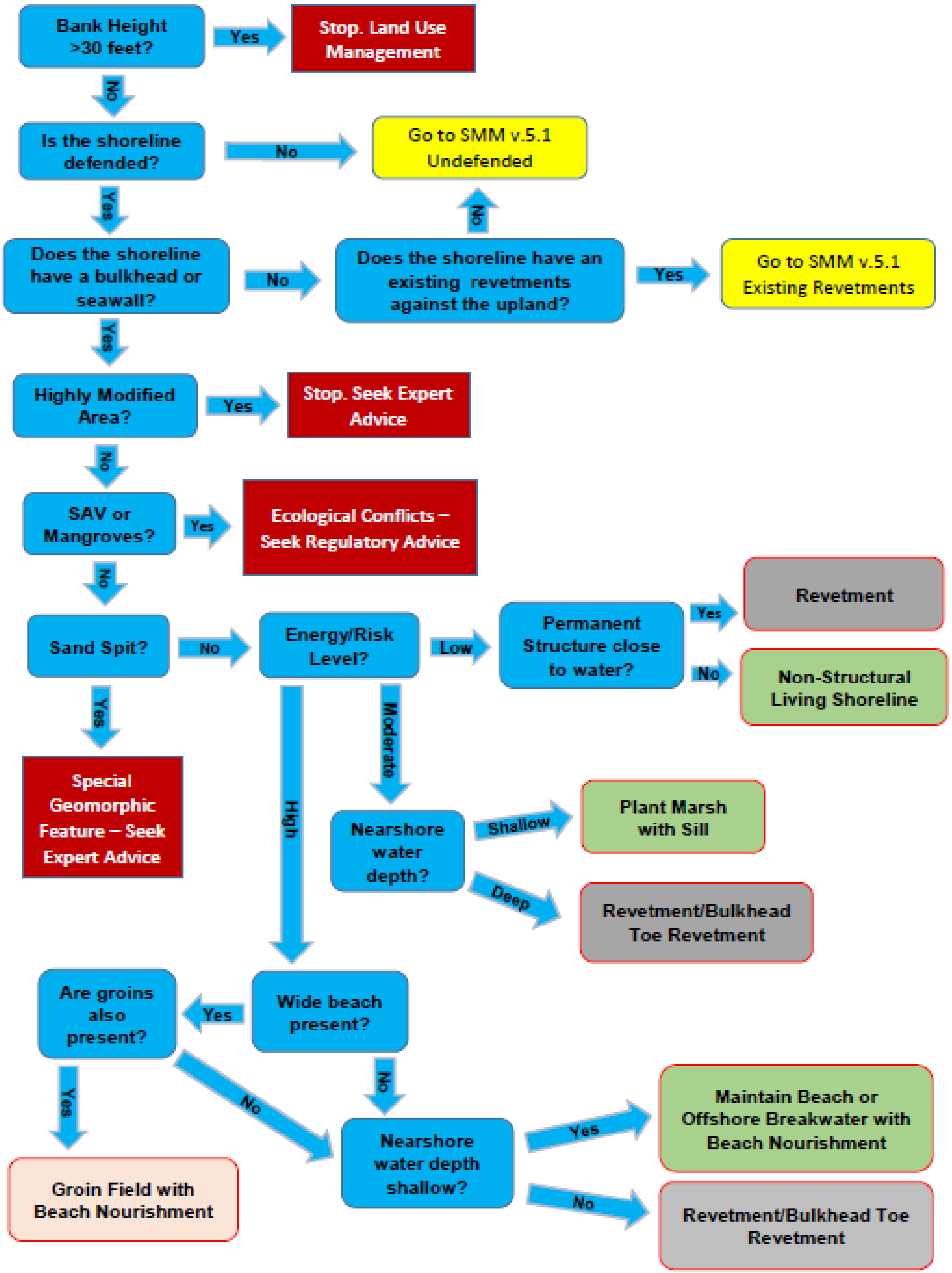
SMM Flow Diagram for Undefended Shoreline

SMM Flow Diagram for Defended Shoreline: Bulkhead

SMM Flow Diagram for Defended Shoreline: Revetment

Shoreline Management Model version 5.1 for Undefended Shoreline

Shoreline Management Model version 5.1 for Defended Shoreline: Bulkhead



Shoreline Management Model version 5.1 for Defended Shoreline: Revetment

APPENDIX 2.

Shoreline Management Model (V5.1): Shoreline Best Management Practices Glossary

Groin Field with Beach Nourishment: Maintain existing wide beach between groins. Remove unnecessary structures at the backshore (e.g. bulkheads) and stabilize the bank with grading and riparian plants. Repair/replace existing groins, add beach nourishment and plant beach vegetation.

Maintain Beach or Offshore Breakwater with Beach Nourishment: If shoreline exceeds 200 feet in length, remove existing shoreline structure, add beach nourishment sand, consider offshore breakwaters or another type of wave attenuation device with beach nourishment; consider adding plantings to the nourished areas. When the shoreline length is less than 200 feet an offshore breakwater may not be practical. In this case, remove failed shoreline structures and repair or construct a revetment as far landward as possible. Consider shoreline enhancement such as creation of vegetated wetlands and/or riparian buffer and/or sandy beach/dune above and immediately channelward of the structure.

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

Plant Marsh with Sill: In moderate energy environments a sill may be required to establish a living shoreline. Remove any existing shoreline structure if present and grade the bank if possible. Stabilize bank with riparian vegetation and plant a marsh with a sill. If the bank cannot be graded, repair existing shoreline structure with a minimal footprint and consider incorporating a marsh with a sill or some other shoreline enhancement (e.g. oyster castles).

Revetment: Remove existing failing or failed shoreline structure, if present. Construct new revetment as far landward as possible; grade the bank and plant vegetation buffers where possible. If grading is not possible, construct or repair existing revetment in the same alignment. A bulkhead should be considered only if previously present and the site is limited by navigation. Consider shoreline enhancement such as creation of vegetated wetlands and/or riparian buffer and/or sandy beach/dune above and immediately channelward of the structure. In high energy settings where shoreline extends more than 200 feet see option for **Offshore Breakwater with Beach Nourishment.**

Revetment/Bulkhead Toe Revetment: If grading is possible, remove the failed bulkhead and replace with a revetment landward of the current bulkhead. When grading not possible, (re)construct bulkhead in the same alignment and/or add a toe revetment. Consider a shoreline enhancement project such as creation of vegetated wetlands and/or riparian buffer and/or sandy beach/dune above and immediately channelward of the structure.

Special Considerations

Ecological Conflicts: Management options for this shoreline may be limited by the presence of Submerged Aquatic Vegetation (SAV) or Mangroves (Florida and Gulf coast shorelines). For Virginia shorelines, seek advice from the Virginia Marine Resources Commission Habitat Management Division http://www.mrc.virginia.gov/. If you live in another state, seek advice from your local marine regulatory agency.

Highly Modified Area: Management options for this shoreline may be limited due to the presence of highly developed upland (e.g. commercial wharfs) or infrastructure directly adjacent to the shoreline (e.g. road) and will depend on the need for and limitations posed by navigation access and erosion control. Seek expert advice on the design of your project.

Land Use Management: Shorelines with tall banks greater than 30 feet limit possible solutions to address bank erosion. Forces other than tidal erosion, such as over-land runoff, upland development, and vegetation management are likely also having effect on bank conditions. Assessment of all factors and modifications to address causes for bank erosion are recommended. This may include changes to vegetation management, implementation of projects to address storm water, relocating buildings, utilities, and other infrastructure. All new construction should be located 100 feet or more from the top of bank. Actions may also include requesting zoning variances for relief from setback and other land use requirements or restrictions that may increase erosion risk. Seek expert advice to inform management options.

No Action Needed: No specific management actions are suitable for shoreline protection, e.g. boat ramps, undeveloped marsh, and barrier islands.

Special Geomorphic Feature: Maintain the natural condition of this shoreline to allow for unimpeded sediment movement and the corresponding response of wetlands, beach and/or dune. If primary structures are present and threatened, seek expert advice on the design of your project.

APPENDIX 3.

Potential Nutrient Reduction Loads from Living Shorelines

A. Estimated load reduction credits for created marsh along unmanaged shoreline by county

Unmanaged Shoreline with Potential Living Shoreline BMP (SMM v.5.1)* - Estimated Nutrient Load Reduction: County Analysis

		Protocol 2: Denitrification	Protocol 3: Sedimentation		Protocol 4: Marsh Redfield Ratio			
County/City	Estimated Acres	Total Nitrogen (lbs)	Total Phosphorus (lbs)	Total Suspended Sediment (lbs)	Total Nitrogen (lbs)	Total Phosphorus (lbs)	Sum of Total Nitrogen (lbs)[1]	Sum of Total Phosphorus (lbs)[2]
Accomack	31.049	2639.131	164.216	216067.167	212.062	9.315	2851.192	173.531
Alexandria	0.156	13.291	0.827	1088.158	1.068	0.047	14.359	0.874
Arlington	0.525	44.604	2.775	3651.785	3.584	0.157	48.188	2.933
Caroline	5.881	499.909	31.106	40927.812	40.169	1.764	540.078	32.870
Charles City	9.837	836.116	52.026	68453.297	67.184	2.951	903.300	54.977
Chesapeake	17.984	1528.630	95.117	125149.826	122.830	5.395	1651.460	100.512
Chesterfield	13.718	1165.993	72.552	95460.573	93.691	4.115	1259.685	76.668
City of Hopewell	3.087	262.366	16.325	21480.044	21.082	0.926	283.448	17.251
Colonial Heights	2.786	236.787	14.734	19385.875	19.027	0.836	255.813	15.569
Essex	16.017	1361.452	84.714	111462.863	109.397	4.805	1470.849	89.519
Fairfax	3.756	319.221	19.863	26134.805	25.650	1.127	344.871	20.990
Fredericksburg	2.485	211.231	13.144	17293.597	16.973	0.746	228.204	13.889
Gloucester	27.077	2301.580	143.212	188431.715	184.939	8.123	2486.519	151.336
Hampton	9.038	768.242	47.803	62896.435	61.731	2.711	829.973	50.514
Hanover	0.821	69.822	4.345	5716.343	5.610	0.246	75.432	4.591
Henrico	5.758	489.393	30.452	40066.867	39.324	1.727	528.717	32.179
Isle of Wight	14.253	1211.532	75.386	99188.865	97.350	4.276	1308.883	79.662
James City	16.176	1374.920	85.552	112565.545	110.479	4.853	1485.399	90.405
King George	21.878	1859.645	115.714	152250.218	149.428	6.563	2009.073	122.277
Lancaster	83.078	7061.643	439.400	578140.883	567.424	24.923	7629.067	464.324
Mathews	30.904	2626.840	163.451	215060.931	211.074	9.271	2837.914	172.722
Middlesex	44.508	3783.180	235.403	309731.166	303.990	13.352	4087.170	248.755
New Kent	5.701	484.598	30.153	39674.287	38.939	1.710	523.536	31.864
Newport News	7.799	662.884	41.247	54270.737	53.265	2.340	716.149	43.587
Norfolk	9.223	783.943	48.780	64181.842	62.992	2.767	846.935	51.547
Northampton	28.132	2391.222	148.790	195770.774	192.142	8.440	2583.364	157.230
Northumberland	155.057	13179.822	820.095	1079039.795	1059.037	46.517	14238.860	866.612
Petersburg	0.237	20.139	1.253	1648.812	1.618	0.071	21.758	1.324
Poquoson	3.798	322.819	20.087	26429.348	25.939	1.139	348.758	21.226
Portsmouth	2.702	229.641	14.289	18800.883	18.452	0.810	248.094	15.100
Prince George	8.657	735.842	45.787	60243.824	59.127	2.597	794.969	48.384
Prince William	0.830	70.522	4.388	5773.647	5.667	0.249	76.188	4.637
Richmond	14.632	1243.756	77.391	101827.059	99.939	4.390	1343.696	81.781
Richmond (city)	3.062	260.309	16.197	21311.656	20.917	0.919	281.226	17.116
Spotsylvania	3.137	266.639	16.591	21829.922	21.425	0.941	288.065	17.532
Stafford	7.025	597.133	37.156	48887.646	47.981	2.108	645.115	39.263
Suffolk	13.687	1163.379	72.390	95246.555	93.481	4.106	1256.860	76.496
Surry	5.844	496.737	30.909	40668.157	39.914	1.753	536.651	32.662
Virginia Beach	51.712	4395.538	273.506	359865.311	353.194	15.514	4748.733	289.020
Westmoreland	54.730	4652.043	289.467	380865.460	373.805	16.419	5025.848	305.885
Williamsburg	0.476	40.428	2.516	3309.855	3.248	0.143	43.676	2.658
York	24.050	2044.213	127.198	167360.950	164.259	7.215	2208.472	134.413
TOTALS	761.260	64707.136	4026.306	5297611.290	5199.409	228.378	69906.545	4254.685

* Shoreline Management Model (SMM) verion 5.1 living shoreline BMPs used for this project are Plant Marsh with Sill and Non-Structural Living Shoreline. Shoreline with these BMPs where excluded from analysis if tidal marsh is present or if the shoreline is adjacent to NWI Palustrine Forest (PFO) or Palustrine Scrub/shrub (PSS) polygons.

[1] Sum of Total Nitrogen = Protocol 2 Total Nitrogen + Protocol 4 Total Nitrogen

[2] Sum of Total Phosphorus = Protocol 3 Total Phosphorus + Protocol 4 Total Phosphorus

B. Estimated load reduction credits for created marsh along currently defended shorelines by county

Defended Shoreline with Potential 278Living Shoreline BMP (SMM v.5.1)* - Estimated Nutrient Load Reduction: County Analysis								
		Protocol 2: Denitrification	Protocol 3: Sedimentation		Protocol 4: Marsh Redfield Ratio			
County/City	Estimated Acres	Total Nitrogen (lbs)	Total Phosphorus (lbs)	Total Suspended Sediment (lbs)	Total Nitrogen (lbs)	Total Phosphorus (lbs)	Sum of Total Nitrogen (lbs)[1]	Sum of Total Phosphorus (lbs)[2]
Accomack	5.792	492.342	30.635	40308.326	39.561	1.738	531.903	32.373
Alexandria	0.045	3.783	0.235	309.698	0.304	0.013	4.087	0.249
Arlington	0.262	22.286	1.387	1824.561	1.791	0.079	24.077	1.465
Caroline	0.352	29.914	1.861	2449.094	2.404	0.106	32.318	1.967
Charles City	1.849	157.129	9.777	12864.243	12.626	0.555	169.755	10.332
Chesapeake	9.398	798.794	49.704	65397.696	64.185	2.819	862.979	52.523
Chesterfield	1.022	86.879	5.406	7112.815	6.981	0.307	93.860	5.713
City of Hopewell	0.252	21.443	1.334	1755.547	1.723	0.076	23.166	1.410
Colonial Heights	0.046	3.952	0.246	323.539	0.318	0.014	4.269	0.260
Essex	4.308	366.174	22.785	29978.871	29.423	1.292	395.597	24.077
Fairfax	0.862	73.255	4.558	5997.446	5.886	0.259	79.141	4.817
Gloucester	8.011	680.919	42.369	55747.278	54.714	2.403	735.633	44.772
Hampton	12.403	1054.260	65.600	86312.920	84.713	3.721	1138.973	69.321
Henrico	0.662	56.287	3.502	4608.243	4.523	0.199	60.810	3.701
Isle of Wight	1.246	105.876	6.588	8668.104	8.507	0.374	114.383	6.962
James City	1.496	127.183	7.914	10412.550	10.220	0.449	137.403	8.363
King George	1.121	95.249	5.927	7798.076	7.654	0.336	102.902	6.263
Lancaster	35.105	2983.886	185.668	244292.478	239.764	10.531	3223.650	196.199
Mathews	9.447	803.002	49.966	65742.212	64.524	2.834	867.525	52.800
Middlesex	14.156	1203.231	74.869	98509.233	96.683	4.247	1299.914	79.116
New Kent	0.839	71.307	4.437	5837.946	5.730	0.252	77.037	4.689
Newport News	2.061	175.203	10.902	14343.984	14.078	0.618	189.281	11.520
Norfolk	22.223	1888.942	117.537	154648.779	151.782	6.667	2040.724	124.203
Northampton	0.933	79.297	4.934	6492.132	6.372	0.280	85.669	5.214
Northumberland	48.928	4158.894	258.781	340491.096	334.179	14.678	4493.073	273.460
Poquoson	4.796	407.625	25.364	33372.510	32.754	1.439	440.379	26.803
Portsmouth	5.710	485.375	30.202	39737.961	39.001	1.713	524.377	31.915
Prince George	1.605	136.423	8.489	11169.035	10.962	0.481	147.385	8.970
Prince William	0.139	11.838	0.737	969.221	0.951	0.042	12.790	0.778
Richmond	1.173	99.666	6.202	8159.699	8.008	0.352	107.674	6.553
Richmond (city)	0.387	32.892	2.047	2692.901	2.643	0.116	35.535	2.163
Spotsylvania	0.054	4.618	0.287	378.053	0.371	0.016	4.989	0.304
Stafford	0.263	22.378	1.392	1832.072	1.798	0.079	24.176	1.471
Suffolk	1.121	95.325	5.931	7804.298	7.660	0.336	102.984	6.268
Surry	1.001	85.109	5.296	6967.944	6.839	0.300	91.948	5.596
Virginia Beach	55.380	4707.299	292.905	385389.333	378.245	16.614	5085.544	309.519
Westmoreland	14.363	1220.855	75.966	99952.106	98.099	4.309	1318.954	80.275
York	8.863	753.328	46.875	61675.396	60.532	2.659	813.860	49.534
TOTALS	277.673	23602.217	1468.613	1932327.395	1896.508	83.302	25498.725	1551.915

* Shoreline Management Model (SMM) verion 5.1 living shoreline BMPs used for this project are Plant Marsh with Sill and Non-Structural Living Shoreline. Shoreline with these BMPs where excluded from analysis if tidal marsh is present or if the shoreline is adjacent to NWI Palustrine Forest (PFO) or Palustrine Scrub/shrub (PSS) polygons.

[1] Sum of Total Nitrogen = Protocol 2 Total Nitrogen + Protocol 4 Total Nitrogen

[2] Sum of Total Phosphorus = Protocol 3 Total Phosphorus + Protocol 4 Total Phosphorus

C. Estimated load reduction credits for created marsh within unmanaged shoreline by 8-digit HUC

Unmanaged Shoreline with Living Shoreline BMP (SMM v.5.1)* - Estimated Nutrient Load Reduction: HUC 8 Analysis

				Protocol 2: Denitrification	Protocol 3: Sedimentation		Protocol 4: Marsh Redfield Ratio			
Hydrologic Unit Code - 8 Digit	HUC 8 Name	Number of Shoreline Segments	Estimated Acres	Total Nitrogen (lbs per acre)	Total Phosphorus (lbs per acre)	Total Suspended Sediment (lbs per acre)	Total Nitrogen (lbs per acre)	Total Phosphorus (lbs per acre)	Sum of Total Nitrogen (lbs per acre)[1]	Sum of Total Phosphorus (lbs per acre)[2]
02040303	Chincoteague	83	3.353	285.005	17.734	23333.509	22.901	1.006	307.906	18.740
02040304	Eastern Lower Delmarva	94	6.626	563.196	35.044	46109.150	45.254	1.988	608.450	37.032
02070010	Middle Potomac-Anacostia-Occoquan	65	4.879	414.673	25.802	33949.522	33.320	1.464	447.993	27.266
02070011	Lower Potomac	2666	124.990	10624.186	661.074	869808.354	853.685	37.497	11477.871	698.571
02080102	Great Wicomico-Piankatank	5091	172.218	14638.543	910.862	1198466.128	1176.250	51.665	15814.793	962.527
02080104	Lower Rappahannock	3030	160.996	13684.687	851.510	1120373.391	1099.605	48.299	14784.292	899.808
02080106	Pamunkey	71	5.156	438.291	27.272	35883.152	35.218	1.547	473.509	28.819
02080107	York	462	21.026	1787.214	111.207	146320.222	143.608	6.308	1930.821	117.515
02080108	Lynnhaven-Poquoson	1708	57.983	4928.586	306.674	403506.236	396.026	17.395	5324.612	324.069
02080110	Tangier	13	0.583	49.591	3.086	4060.066	3.985	0.175	53.576	3.261
02080111	Pokomoke-Western Lower Delmarva	1339	49.281	4188.875	260.647	342945.660	336.588	14.784	4525.463	275.431
02080206	Lower James	1412	80.956	6881.288	428.178	563375.117	552.932	24.287	7434.220	452.465
02080207	Appomattox	105	10.975	932.881	58.047	76375.489	74.960	3.293	1007.840	61.340
02080208	Hampton Roads	1346	47.811	4063.974	252.875	332719.978	326.552	14.343	4390.527	267.218
03010205	Albemarle	263	14.425	1226.146	76.295	100385.316	98.524	4.328	1324.671	80.623

D. Estimated load reduction credits for created marsh along defended shoreline by 8-digit HUC

Defended Shoreline with Living Shoreline BMP (SMM v.5.1)* - Estimated Nutrient Load Reduction: HUC 8 Analysis

				Protocol 2: Denitrification	Protocol 3: Sedimentation		Protocol 4: Marsh Redfield Ratio			
Hydrologic Unit Code - 8 Digit	HUC 8 Name	Number of Shoreline Segments	Estimated Acres	Total Nitrogen (lbs per acre)	Total Phosphorus (lbs per acre)	Total Suspended Sediment (lbs per acre)	Total Nitrogen (lbs per acre)	Total Phosphorus (lbs per acre)	Sum of Total Nitrogen (lbs per acre)[1]	Sum of Total Phosphorus (lbs per acre)[2]
02040303	Chincoteague	90	1.924	163.564	10.178	13391.051	13.143	0.577	176.706	10.755
02040304	Eastern Lower Delmarva	71	1.417	120.414	7.493	9858.336	9.676	0.425	130.089	7.918
02070010	Middle Potomac-Anacostia-Occoquan	38	1.280	108.780	6.769	8905.919	8.741	0.384	117.521	7.153
02070011	Lower Potomac	1192	31.883	2710.029	168.628	221871.634	217.759	9.565	2927.787	178.192
02080102	Great Wicomico-Piankatank	2287	61.902	5261.696	327.401	430778.156	422.793	18.571	5684.489	345.972
02080104	Lower Rappahannock	1270	40.039	3403.289	211.765	278629.270	273.464	12.012	3676.753	223.776
02080106	Pamunkey	12	0.117	9.903	0.616	810.797	0.796	0.035	10.699	0.651
02080107	York	172	4.409	374.744	23.318	30680.501	30.112	1.323	404.856	24.641
02080108	Lynnhaven-Poquoson	1964	65.581	5574.343	346.855	456374.703	447.915	19.674	6022.257	366.529
02080110	Tangier	6	0.147	12.464	0.776	1020.437	1.002	0.044	13.466	0.820
02080111	Pokomoke-Western Lower Delmarva	178	4.058	344.946	21.464	28240.912	27.717	1.217	372.663	22.681
02080206	Lower James	341	11.850	1007.267	62.676	82465.578	80.937	3.555	1088.204	66.231
02080207	Appomattox	19	0.469	39.898	2.483	3266.450	3.206	0.141	43.104	2.623
02080208	Hampton Roads	1581	48.011	4080.903	253.928	334105.964	327.913	14.403	4408.816	268.331
03010205	Albemarle	128	4.588	389.977	24.266	31927.687	31.336	1.376	421.313	25.642