THE GEO PROJECT
GEOSPATIAL EDUCATION & OUTREACH

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TECHNICAL REPORT
NO. 5098

THE APPLICATION OF A LIVING SHORELINE SITE SUITABILITY MODEL TO ST. LOUIS BAY, MISSISSIPPI, USA

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JULY 2022

This work was supported through funding by the National Oceanic and Atmospheric Administration Regional Geospatial Modeling Grant, Award # NA19NOS4730207.

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The Geospatial Education and Outreach Project (GEO Project) is a collaborative effort among the Geosystems Research Institute (GRI), the Northern Gulf Institute (a NOAA Cooperative Institute), and the Mississippi State University Extension Service. The purpose of the project is to serve as the primary source for geospatial education and technical information for Mississippi.

THE APPLICATION OF A LIVING SHORELINE SITE SUITABILITY MODEL TO ST. LOUIS BAY, MISSISSIPPI, USA

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INTRODUCTION

Coastal managers often use armoring, or the use of physical structures such as bulkheads, revetments, and sea walls, to protect shorelines from coastal erosion. Soft stabilization practices that incorporate vegetation, known as living shorelines, can more effectively and economically prevent shoreline erosion in some cases, with the added ecological benefits of maintaining a connection between riparian, intertidal, and subaqueous areas and creating habitat for marine and estuarine organisms (Currin et al. 2010, Bilkovic 2016, SAGE 2016). Many local factors affect suitability of a living shoreline management practice, chiefly wave energy and potential and existing vegetation. Living shoreline management practices succeed where wave energy, bank height, and water depth are relatively low and vegetation is present or possible. Living shoreline site suitability models use geospatial technology and data to rapidly assess suitability for living shorelines at state and county landscape scales. This paper describes the use of one such shoreline management model to evaluate St. Louis Bay, Mississippi.

BACKGROUND

Shoreline erosion on the Mississippi coast has traditionally been addressed with physical structures such as bulkheads or revetments. Although typically viewed by contractors as the easiest and simplest solutions, hardened structures have drawbacks. They sever the land-water interface, leading to a reduction in habitat for important estuarine and marine wildlife species. They can lead to scouring of land underneath the structure, which increases water depth, thereby increasing wave energy, which can lead to structural failure. Living shorelines are a low-impact alternative to traditional hardened methods of addressing shoreline erosion. Living shorelines use vegetation and low slope profiles to mimic natural processes and increase habitat for economically important fisheries. They improve water quality by filtering pollutants from stormwater runoff, enhance marine recreation and tourism opportunities, and can be less expensive to maintain over time (Arkema et al. 2017, Bilkovic et al. 2016, SAGE 2015).

Written guides and digital decision support tools for landowners considering living shorelines are publicly available. The Mississippi-Alabama Sea Grant Consortium (2022) hosts catalogs of shoreline management resources developed for each of the Gulf states. The Virginia Institute of Marine Science (2022) offers an online decision support tool that generates a shoreline erosion control strategy based on user responses to a set of questions. Efforts to "scale up" the logic supporting these decisions to large landscapes through geospatial technology have produced various shoreline management models at state and county scales. The model applied in this project processes input datasets using decision tree logic to categorize shoreline segments into management recommendation classes such as "no action needed," "living shoreline," and "hardened structure" (Virginia Institute of Marine Science 2022). Other models prioritize landscape features to generate index scores of suitability for living shorelines specifically (Balasubramanyam & Howard 2019, Carey 2013, Dowel 2019, Maine Geological Survey 2021, Zilberman 2022). The models generally agree that wave energy and vegetation (potential or existing) are the most important factors influencing suitability and use a variety of approaches for assessing those features. Other landscape features assessed include erosion trends, the existence of roads and built structures, and contribution to a connected ecological network.

This project used the Virginia Institute of Marine Science Shoreline Management Model (VIMS SMM v5.1, Center for Coastal Resources Management 2022) to evaluate the shoreline of St. Louis Bay, located in Harrison and Hancock Counties on the Mississippi Gulf Coast. The main bay consists of about 4327 ha (16.7 square miles) of shallow water, fed by the Jourdan River from the west and by Wolf River and Bayou Portage from the east. The VIMS SMM v5.1 was used because it has been applied in every US state in the Northern Gulf of Mexico except for Mississippi (Center for Coastal Resources Management 2022) and because it is developed in the widely-used ESRI ModelBuilder application and easily shared as an ArcGIS toolbox.

METHODS

The VIMS SMM v5.1 model processes information in the attribute table of a vector shoreline data layer and generates management recommendations based on combinations of features described in the table. An illustrated Handbook, included in the zipped file that contains the model, describes data preprocessing steps and includes a conceptual diagram of the decision tree logic used. The Handbook also describes how the input shoreline vector attribute table is processed in the Model Builder environment to generate the output management recommendations. Four input datasets are needed: a vector shoreline polyline, aerial imagery, near-shore land elevation, and bathymetry (near shore water depth). An additional layer mapping submerged aquatic vegetation (SAV) is recommended but not necessary for a successful model run. This project generated a shoreline vector polyline from a digital elevation model (DEM) derived from Mississippi Coastal LiDAR collected in 2015 by the Mississippi Department of Environmental Quality (MDEQ), available from the Mississippi Automated Resource Information System (MARIS) and from the National Oceanic and Atmospheric Administration's (NOAA) Digital Coast data portal. The same DEM was used to obtain bank height data. The high-resolution imagery (MARIS 2022) was obtained from the Mississippi Digital Earth Model, which uses data collected by MDEQ and made publicly available through the MARIS portal. Bathymetric data were obtained from NOAA's National Centers for Environmental Information (NCEI THREDDS Data Server 2017). Location data for SAV were not available for the project area.

Building an attribute table that the model can process requires segmenting and coding attributes into multiple copies of the vector shoreline before all copies are combined into a single layer. The following subsections describe processes for segmenting and coding the attributes of the multiple individual layer copies.

Vector shoreline base layer

The vector shoreline used in this project was created from a LiDAR-derived DEM created by the Mississippi Department of Environmental Quality (MDEQ) from data collected in 2015. The DEM was clipped to St. Louis Bay and projected to NAD 1983 (2011) State Plane Mississippi East. The raster layer was reclassified into above and below zero values from which land and water polygons were derived. The steps used to refine the polygons to generate a reasonable shoreline are described in the GRI Technical Report "A Vector Shoreline Extraction Methodology" (Gray et al. 2022). The process for deriving the shoreline polyline from the DEM used the NOAA Composite Shoreline (NOAA Shoreline Website 2016) to establish a shoreline "neighborhood" to mask elevation values equal to the shoreline but not in proximity to it. A topology validation procedure was run on the vector shoreline to correct for the following errors: must not overlap, must not intersect, must not have dangles, must not self-overlap, and must not self-intersect.

Riparian Land Use/Land Cover, Beaches, and Marsh

The vector shoreline was segmented and coded according to the following Land Use/Land Cover classes (*indicates a class expected by the model):

Bare	Extensive marsh*	Marsh	Residential
Beach	Forested	Marsh island*	Scrub-shrub
Commercial*	Industrial*	Paved*	

The class "Marsh" was used for marsh patches less than 30 feet wide. Since the model does not recognize this land use class, these segments were processed for a shoreline management recommendation based on other features such as bathymetry and exposure to wave energy. The

“Extensive marsh” and “Marsh island” classes automatically send those segments to a “no action needed” class, since these classes describe the management goal in the context of the model logic.

The Handbook instructs users to code information about beaches and marsh in separate copies of the vector shoreline. For most features, segmenting and coding are less confusing when applied to a “clean” line. For this project, beach and marsh classes (specifically beach, wide beach, marsh, extensive marsh, and marsh island) were coded in the LULC field first, then those values were used to generate values for new beach and marsh fields in the same shapefile data layer. In this way, the close inspection of imagery needed to identify these features was executed once instead of the suggested three times.

Bank Height, roads, and permanent structures

The model assumes that a 3:1 bank slope is necessary for a successful living shoreline management practice. This layer identifies areas where the desired slope cannot be achieved due to either a high bank or the presence of roads and permanent structures near the shore. The model expects bank height to be expressed in ranges of 0-5, 5-30, and > 30 feet occurring within 25 feet of the shoreline. The user then creates a buffer with the width determined by the max value (5, 30, and 40 assigned as a placeholder for the > 30 class) in the height class ranges and the linear distance required to allow a 3:1 slope (i.e., height x three plus 20 feet to buffer the construction project). The run distance values calculated by the formula are recorded in a new field and used as an input distance to the buffer tool, generating a shoreline buffer with variable width based on bank height. The imagery is visually analyzed to identify roads and permanent structures within that variable buffer, and the vector shoreline is segmented and coded accordingly. In the model run, shoreline segments with > 30-foot bank height are automatically assigned to a “seek expert advice” recommendation class. The digital elevation dataset used for this project identified no > 30-foot elevation values within 35 feet of shore, and values of > 10 were rare. Bins of 0-5, 5-10, and > 10, with max height values of 5, 10, and 15, were therefore used to classify near-shore elevation and generate the variable buffer.

Bathymetry, near-shore water depth

Shallow water is more suitable for living shorelines because it corresponds with low wave energy and potential for emergent vegetation. Bathymetric data were obtained from NOAA’s National Centers for Environmental Information (NCEI THREDDS data Server 2022). The zero-elevation values indicated in this dataset do not correspond well with the vector shoreline. In many areas, particularly in the northern reaches of the bay, the vector shoreline lies 200-300 feet outside the extent of the bathymetry dataset, probably due to the fact that near-shore water depths are very shallow (< 1 meter) throughout the bay and its tributaries (Figure 1).

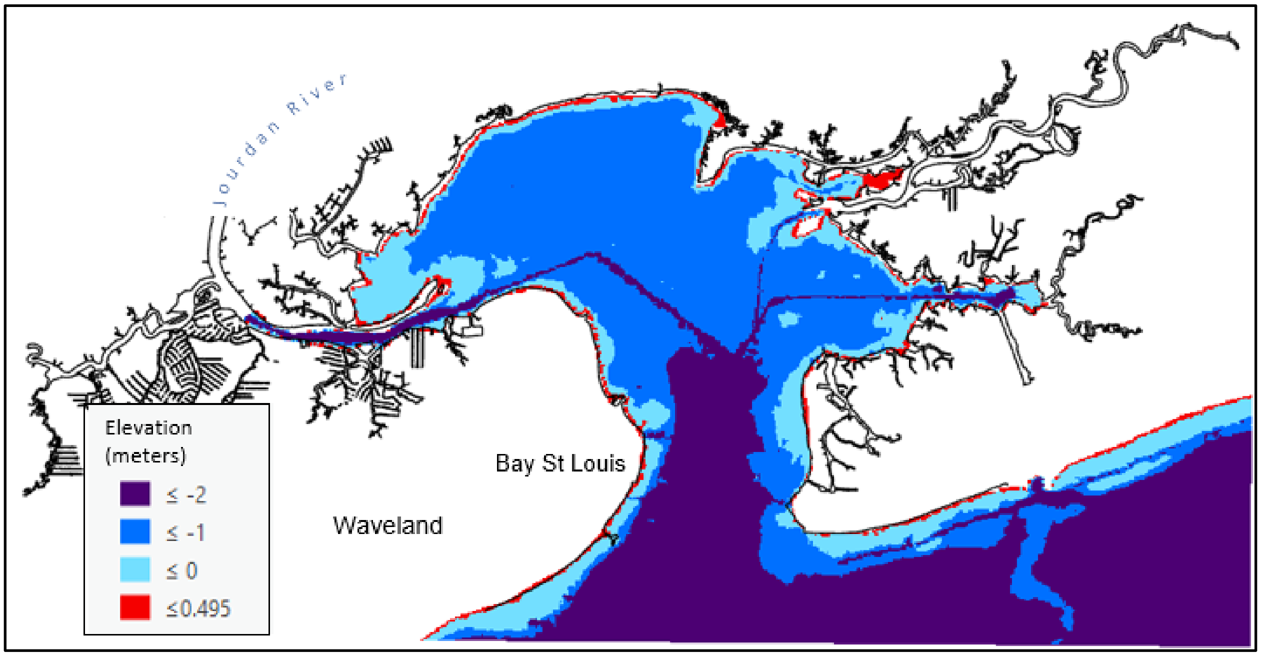

Figure 1: Bathymetry raster data. Red indicates above zero elevation values. Light blue indicates water depth less than or equal to one meter.

A polygon was created from all values <-1, the polygon was buffered ten meters, and an intersection of the buffer with the shoreline was used to indicate shoreline segments associated with deep water. Less than three miles were indicated, which is less than 1% of the total shoreline. Most of the near-shore deep water is on the south bank of the Jourdan River northwest of the cities of Waveland and Bay St. Louis.

Canals, public boat ramps, sand spits, SAV

Canals, public boat ramps, and sand spits are classified by the model as requiring outside expert review to determine the preferred erosion control option. Canals were defined for this project as those narrow water bodies that appear to be developed and maintained on both sides of the channel, excluding channels that appear to be maintained on one bank only with the opposite bank supporting natural vegetation such as marsh, scrub-shrub, or forest. Extensive canals exist northwest of the cities of Waveland and Bay St. Louis along the Jourdan River on the west side of the bay. Public boat ramp locations were identified through publicly available sources and confirmed with imagery. No sandspits were observed. The presence of these features was confirmed by visual inspection of imagery and coded into line segments in three new fields using header names and text field values provided by the Handbook. Lacking SAV information, a field with the heading ‘SAV’ was created and populated with null values.

Shoreline protection structures

The model expects values of “Bulkhead,” “Riprap,” “Revetment,” “Marina,” and “Wharf” in a field headed ‘Structure’ to differentiate defended and undefended shore. Bulkheads are most common and typically are found in residential areas. These structures often occur with areas of marsh separating them from the open water. Since the vector shoreline is designated as the marsh-water edge (following the practice used by the NOAA Composite) rather than the shoreline protection structure, a threshold distance of 30 meters from shore was used to determine which structures would be inventoried. Google Maps includes an off-nadir oblique view option, which was useful in the identification of bulkheads. Bulkheads are often obscured by the presence of boardwalks. Not every boardwalk installed at the water’s edge has a bulkhead underneath it. Although the presence of a bulkhead can be inferred by the presence of a hard edge separating land and water, only those that were explicitly evident in the image were noted. Since canals are automatically assigned to a “highly modified area: no action needed” class in the model output, areas consisting entirely of canals were not reviewed for the presence of shoreline protection structures.

Exposure to wave energy (Fetch) and tributary designation

Fetch is the distance across open water to the opposite shore and is used by the model as a proxy for exposure to wave energy. The model expects values of Low, Moderate, and High representing fetch distances of less than a half-mile, one-half to two miles, and greater than two miles. Estimations of exposure were obtained by visually inspecting the scaled map image (Figure 2) along with a scaled conceptual diagram of the fetch threshold (Figure 3). The mouth of the bay, where US-90 crosses, is approximately two miles across. None of the major tributaries are more than a half-mile wide. Therefore, most of the main bay is in the High class, and the tributaries and tidal creeks are all classed as Low. A designation of the next highest value class is based on open water extending beyond the threshold value in a hypothesized region designated by two rays originating from a point on shore at an angle of 22.5 degrees (Figure 3).

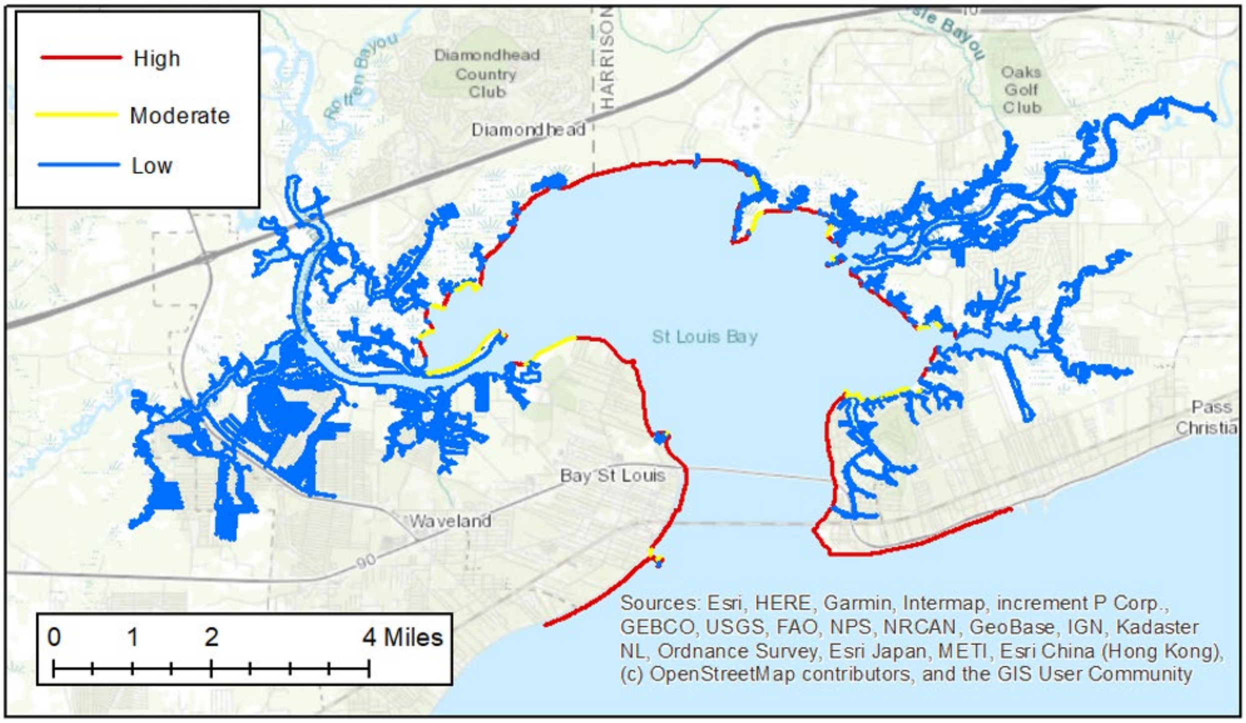

Figure 2: Exposure to wave energy (fetch) in St Louis Bay.

The Handbook instructs users to code the exposure values in a field named 'Exposure,' but doing so causes the model to fail when it attempts to create a new field of the same name. To prevent this, the values were coded in a field called 'Expos' and the script in the corresponding processing box in the model was modified to accommodate the change.

The model uses a tributary designation layer to force tidal creeks into a low wave exposure category. Creeks are low-energy environments, but configuration, sinuosity, and proximity to major tributaries and bays can cause some shoreline segments to meet the condition illustrated in Figure 3 and therefore be erroneously placed in a higher class.

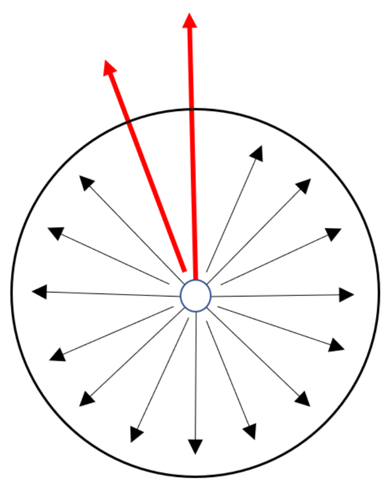

Figure 3: Conceptual diagram of a fetch threshold. The center circle is a point on shore. The outer circle is the threshold. To obtain a higher class of exposure, two rays 22.5 degrees apart must cross open water beyond the threshold distance.

In the tributary designation layer, the model searches for only the "Tidal creek" text value to ensure classification as low exposure. This project also assigned "Major tributary" and "Bay" classes, to comprehensively classify the entire shoreline. The vector shoreline was buffered 500 meters and the buffer polygon was then split by Gestalt interpretation, or quick-decision parsing of the "major" tributaries, smaller tidal creeks, and the main bay, based on the general pattern (Figure 4).

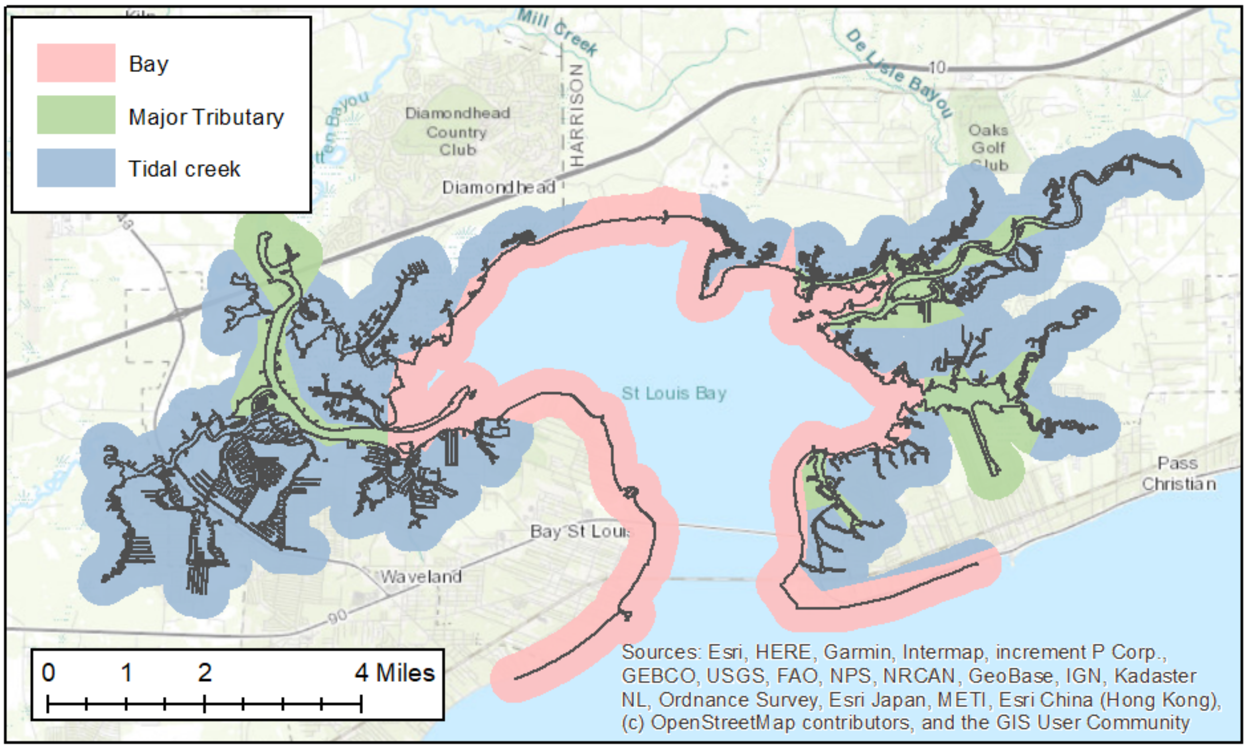

Figure 4: Polygon buffer used for tributary designation.

Combining layers and model run

All copies of the vector shoreline are combined using the "Identity" tool. The Riparian Land Use layer was designated as the input layer and all other layers were converted to polygons by buffering them by 0.1 meters. The identity tool imports the segment breaks and attribute fields from the polygon (Identity) features to the input file and is applied iteratively, the output of each computation being used as input for the next as the process cycles through all the polygon layers. This process combines all the information in the multiple copies of the vector shoreline into a single layer containing all the fields required by the model in the attribute table (Table 1).

Table 1: Field names and expected values for the attribute table of the input vector polyline.

Field Name	Field Definition	Expected Text Values	Source, Process
RiparianLU	Riparian Land Use	Expected by model: Commercial, Industrial, Military or Government, Paved, Marsh Island, Extensive Marsh, Detached Marsh. Other values used: Bare, Beach, Forested, Grass, Marsh, Park, Residential, Scrub-shrub	High-resolution county mosaic images from MDEM/MARIS, visual inspection
Beach	Beach	No, Yes	
WideBeach	Wide beach	<Null>, Yes	
canal	Canal	<Null>, Canal	
PublicRamp	Public Boat Ramp	<Null>, Yes	
SandSpit	Sand Spit	<Null>, Yes	
bnk_height	Bank Height	0-5, 5-30, > 30. These values are not appropriate for the flat landscape of St Louis Bay. We used 0-5, 5-10, 10-15, and 15-20.	2015 LiDAR-derived DEM from MDEQ. Buffer width = (max BH x 3)+20
roads	Roads	<Null>, Roads	Overlay buffer (width driven by bank height) over high-resolution county mosaic images from MARIS, visual inspection
PermStruc	Permanent Structures	<Null>, Permanent Structure	
bathymetry	Bathymetry, Near shore water depth	Deep, Shallow	NOAA/NCEI Mississippi Sound Regional Bathymetry. Polygon from values <-1, intersection with shoreline
Structure	Shoreline Protection Structure	Bulkhead, Riprap, Revetment, Marina, Wharf	Imagery, including "3D" bird's-eye view in Google Earth
offshorest	Offshore Protection Structure	Breakwater, Groin, Marsh Toe	
defended	Defended	<Null>, Yes	
Expos*	Exposure (Fetch)	Low, Moderate, High	Scaled symbol of threshold distance applied to map surface
SAV	Submerged Aquatic Vegetation	<Null>, Yes	No data available for St. Louis Bay
marsh_all	Tidal Marsh	Marsh present, Marsh Island, No	Coded according to values in RiparianLU field
tribs	Tributary Designation	Expected by model: Tidal Creek. Other values used: Major tributary, Bay	500 m buffer of shoreline, split buffer polygon based on general channel size (no threshold metric)

*The name of the field 'Exposure' was changed to prevent an error in the model run, see main text for details

Unnecessary FID fields generated automatically during the Identity runs were removed by dissolving based on the desired fields. Segments less than a meter in length were eliminated by combining them with longer adjacent segments. The topology was validated on the vector layer to confirm no rule violations for dangles, intersects, and overlaps. In addition to the input vector shoreline, the model requires a scratch geodatabase directory location and the directory location (file path) of the definitions table in the toolbox. The model can only be run in ArcMap (this project used v10.8). Valid output will have no null values in the recommendation class field. If these occur, or if the model fails to complete, the cause is most likely formatting in the field names or the text values in the fields.

RESULTS

The vector shoreline used in this project describes 596 km (370 miles) of shoreline. Of that, the model identifies 17% (102 km, 64 miles) as appropriate for a living shoreline management practice (Table 2, Figure 5). The largest class, “No Action Needed,” is associated with “Extensive Marsh” and “Marsh Island,” the largest land use classes. “Highly Modified Area. Seek Expert Advice” is recommended for 30% (183 km, 114 miles) of the shoreline. This corresponds to similar amounts for canals in the land use classification. These results indicate that opportunities for living shoreline management practices are generally restricted to sites situated on unmodified tributaries and creeks.

*Table 2: Recommendation class linear amounts. *Indicates living shoreline.*

Management Class	km	miles	percent
Groin Field with Beach Nourishment*	0.40	0.25	0.07
Highly Modified Area. Seek expert advice.	182.73	113.54	30.65
Maintain Beach or Offshore Breakwater with Beach Nourishment*	16.58	10.30	2.78
No Action Needed	305.07	189.56	51.18
Non-Structural Living Shoreline*	83.50	51.89	14.01
Plant Marsh with Sill*	2.00	1.24	0.33
Revetment	5.31	3.30	0.89
Revetment/Bulkhead Toe Revetment	0.51	0.31	0.08

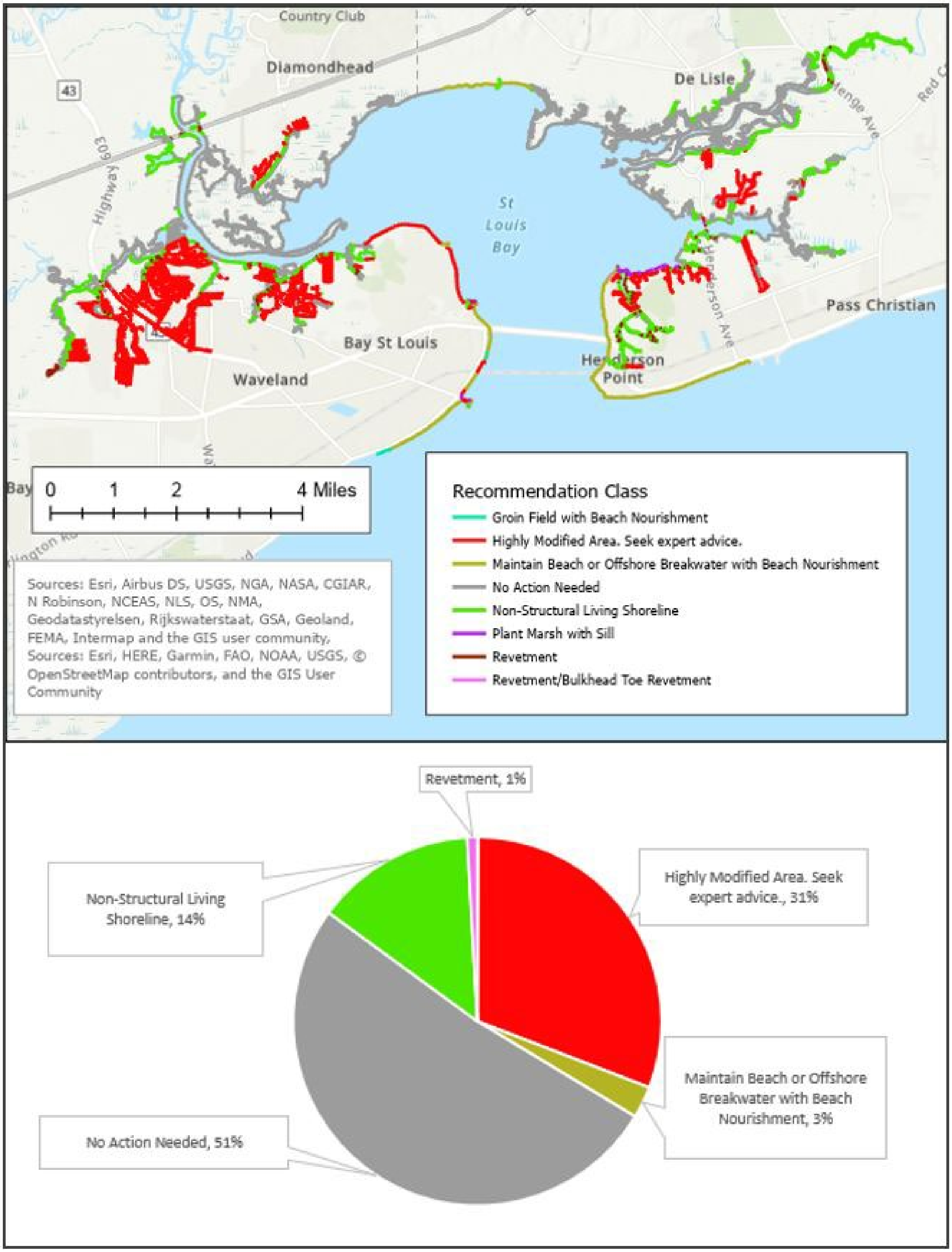

Figure 5: Recommendation classes for St. Louis Bay. Pie graph displays values greater than or equal to 1%.

The Riparian Land Use map (Figure 6) indicates that about half the shoreline (52%) is marsh. This may be an overestimation, given that the vector shoreline was generated from a contour derived from LiDAR data, which delineates marsh patches in more detail than is generally reasonable for a vector shoreline. Ninety-nine percent of the marsh identified in the Land Use layer is classified as either “Extensive marsh” or “Marsh island,” resulting in the automatic “no action needed” recommendation for those segments.

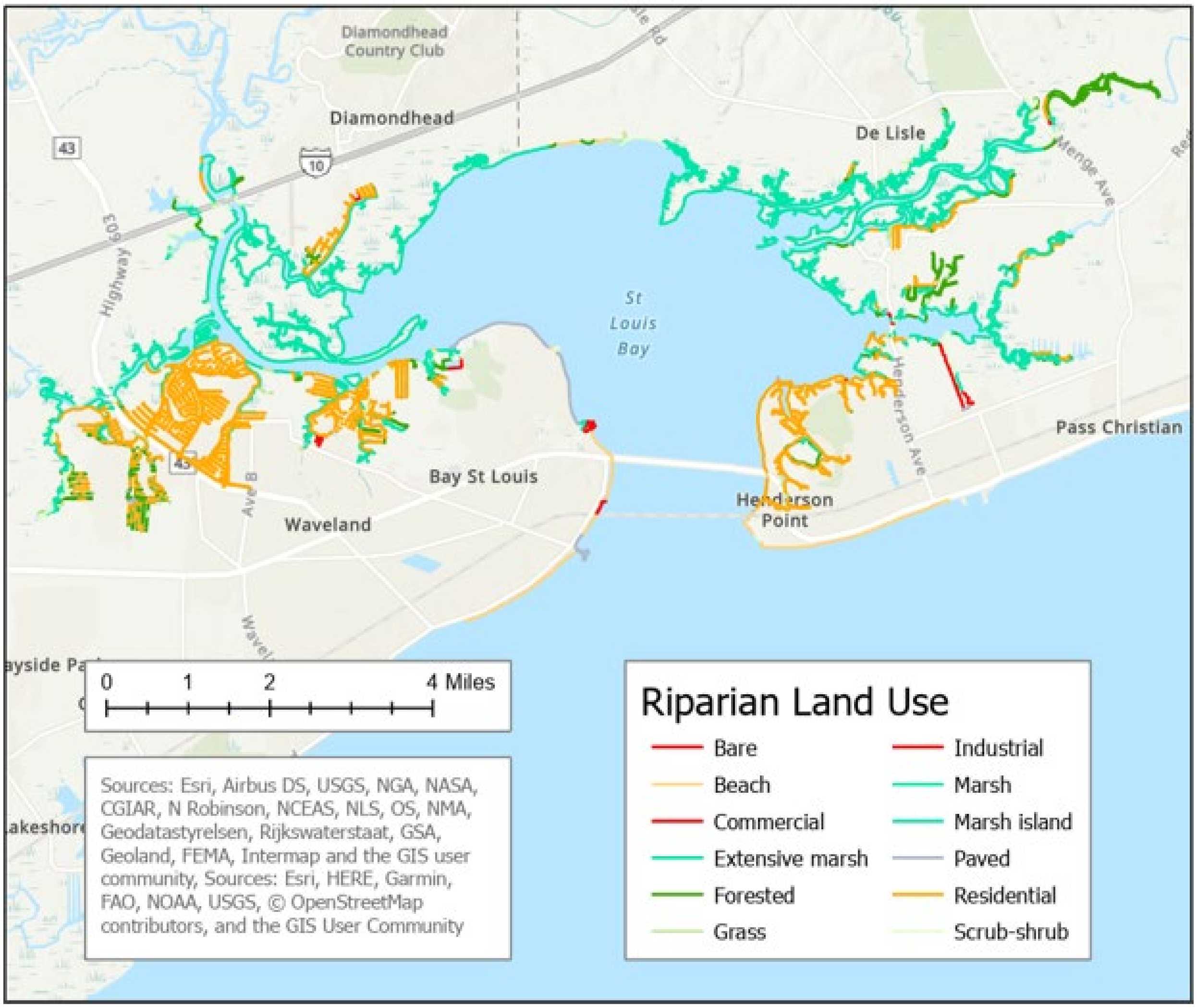

Figure 6a: Riparian land use classes for St. Louis Bay.

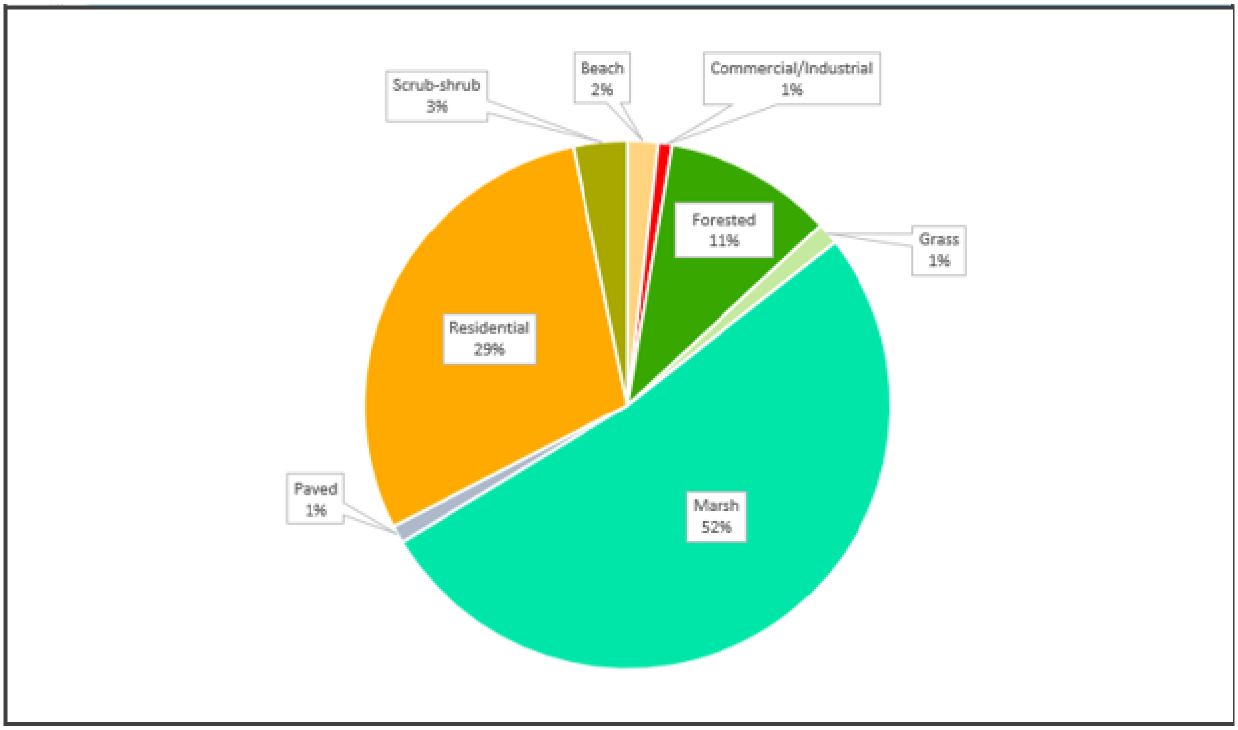

Figure 7b: Pie graph showing riparian land use classes for St. Louis Bay greater than or equal to 1%.

LIMITATIONS AND FUTURE DIRECTIONS

The Virginia Institute of Marine Science Shoreline Management Model (VIMS SMM v5.1) has been adapted for use in Texas, Louisiana, Alabama, and Florida (Center for Coastal Resources Management 2022). It was designed initially to support management action in response to a request for some erosion abatement technique and to inform property owners and marine contractors of alternative practices for shoreline stabilization (Berman and Rudnicky 2008). It shares one limitation common to all such models: it is only as good as the decision logic employed and the geospatial input data. In other words, it can't take into consideration factors and landscape features it can't see. It is intended to guide decisions across multiple sites, based on a limited set of features assumed to affect suitability in the same way across the land. It is not intended to replace on-site consultation and observation.

Because it addresses shoreline stabilization in the context of site-level management actions, it does not address improvement in ecosystem services by the prioritization of an ecologically connected network. In other words, it does not prioritize candidate sites by size or proximity to ecologically functioning estuarine environments. On the other hand, both the input and output layers generated in the VIMS SMM v5.1 process can provide valuable input to a regional-scale analysis of the connectivity and functioning of local ecosystems.

The wave-energy model is a stand-alone component of VIMS SMM v5.1 and was not addressed in this project. Future directions for incorporating wave energy into shoreline management modeling include the use of data loggers to measure wave energy directly, vessel traffic data collected by the U.S. Coast Guard's Automatic Identification System (DIGITALCOAST 2021), proximity to boat ramps (Carey 2013), and models that account for wind direction (Rohwerder et al. 2012) or wind speed (Bezore et al. 2022).

CONCLUSIONS

The Virginia Institute of Marine Science Shoreline Management Model (VIMS SMM v5.1) was applied to St. Louis Bay, Mississippi. The model output shows that opportunities for implementing a living shoreline management practice are limited to only 17% of the shoreline. Most of the shoreline is characterized by one of two conditions making living shorelines impractical: either so highly modified that the practice is not feasible (31%), or occupied by marsh (52%), essentially the condition living shoreline management practices are intended to create. This model shows potential for regional land planners and coastal managers to rapidly assess suitability for living shoreline and other low-impact shore stabilization practices across large landscapes. Preparation of the input vector shoreline layers prior to processing is labor-intensive, but the logic of the model is clear and transparent, and the process is repeatable. As geospatial datasets are updated to reflect changing conditions, repeated model runs based on new inputs can provide coastal managers with better information about the configuration and spatial pattern of the opportunity for living shoreline management practices. The model operates in accordance with the priorities of individual site-specific land managers faced with a range of options, including traditional armoring techniques, to mitigate shoreline erosion. The model has potential to be adapted and expanded to include priorities relevant to ecosystem services and sociopolitical planning priorities, or – as an initial phase qualitative assessment classifying land units into management categories – could produce an important input into a multi-criteria prioritization scheme.

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