Part 1: Ecosystem Services Assessment Model

Introduction

The model integrates water quality and habitat features with shoreline risk through a cross-section of the coastal landscape, from the upland through the subaqueous zone. Each element of the model individually impacts water quality and habitat services, allowing integrated assessment of the ecosystem services provided along a given reach of shoreline. Water quality and habitat functions were modeled separately, because elements may impact the two services independently. Shoreline risk was also modeled separately because it represents a potential threat to the shoreline, not a service provided by the shoreline.

The assessment units were 500 meters in length and of variable width, beginning 90 meters landward of the shoreline and continuing to some distance off-shore as determined by the 2 meter depth contour or 200 meters distance, whichever comes first. They are divided into Upland (90 meters from shoreline), Riparian (30 meters from shoreline), Banks (within the riparian zone), Shoreline, and Subaqueous (channelward of shoreline, variable width).

Each element and its known impacts on water quality and habitat services and shoreline risk are described below. Also included is a brief description of how the element affects the overall score generated by the model. Rankings and calculations associated with the elements are shown in the table. The total value for an assessment unit is a sum of the element values.

The final model scores represent the average of the value of the assessment unit plus half the value of each adjacent unit. This running average method of assessing the shoreline allows for better integration of the effects of adjacent shoreline features and avoids segmentation of the shoreline. In this first iteration of the model, scores are divided into 5 categories that reflect the current level of water quality or habitat functions along a given shoreline. The categories are: Good, High moderate, Moderate, Low moderate and Poor.

Two figures are provided, which show the results of the water quality and habitat models for a stretch of shoreline in Gloucester, Virginia. The range of final scores is shown as different colors along the shoreline.

Model Elements

Upland Landuse

Upland Landuse was estimated from remotely sensed land cover data assessed from the shoreline interface landward 90 meters. For the purposes of the model land cover was compiled into 3 categories: Natural, Agricultural, and Developed. Natural land cover includes wetlands, forest, scrub-shrub, and timbered cover types. Agricultural land cover includes agricultural and grassland cover types. All other cover types were classified as Developed. Land use estimates were taken from the National Land Cover Dataset (RESAC 2000).

Riparian Landuse

Riparian Landuse was estimated from observed data (CCI Shoreline Inventory) assessed from 30 meters landward to the shoreline interface. For the purposes of the model land cover was compiled into 4 categories: Natural, Agricultural, Developed, Industrial/Paved. Natural land cover includes wetlands, forest, scrub-shrub, and timbered cover types. Agricultural land cover includes agricultural and grassland cover types. Industrial/Paved land cover includes large industry and roads/parking lots adjacent to the shoreline interface. All other cover types were classified as Developed.

Forested Buffer

Forested Buffer refers to the presence or absence of a forest fringe in the riparian zone (30 meters landward of the shoreline interface). Forested Buffer presence was a riparian area modifier calculated from a combination of field-observed (CCI Shoreline Inventory) and remotely sensed data (RESAC 2000) and assessed only where combined agricultural or developed cover comprised at least 70% of the assessment unit.

Bank Cover

Bank Cover was estimated from the CCI Shoreline Inventory and refers to either vegetative or structural cover on the bank, defined here as the area of transition between the shoreline and upland. Bank Cover is divided into 3 categories based on percent cover: Bare (< 25%), Partial Cover (25-75%), and Total Cover (> 75%).

Bank Stability

Bank Stability was estimated from the CCI Shoreline Inventory and refers to the amount of erosion on the bank face or bank toe and ranked by severity. Bank Stability is divided into 3 categories based on severity: Stable, Unstable, and Undercut. Stable banks may include banks with minimal or no erosion on the bank face or toe. Unstable banks may include slumping, scarps, or exposed roots on the bank face. Undercut banks may include otherwise stable banks with erosion observed only at the toe.

Shoreline Resources

Shoreline Resources observed in the field were identified by 4 categories: Marsh, Dune, Beach, *Phragmites.* These resources were included in the model score when present but did not reduce the total score when absent. The linear extent of Marsh, Beach, and Phragmites resources were observed in the field and interpreted in the model as a percentage of the linear assessment unit. The extent of Dune features within an assessment unit was determined from remotely sensed data (Hardaway Dune Inventory).

Shoreline Structures

Features added to the shoreline by property owners were recorded as a combination of points or lines. These features include defensive structures, constructed to protect the shoreline from erosion; offshore structures, designed to accumulate sand from longshore transport; and recreational structures, built to enhance recreational use of the water. All features were recorded by presence or absence. Point features include marinas, docks, jetties, breakwaters, and boat ramps. Linear features include bulkheads, riprap, miscellaneous, and debris. All point features were scored as discrete values. All other linear features were scored as a percentage of the linear feature within the assessment unit.

Subaqueous Resources

All subaqueous resources were identified from remotely sensed data (Submerged Aquatic Vegetation (SAV), VIMS; Oysters and Aquaculture, VMRC). For each assessment unit, percentage SAV coverage was calculated between the shoreline interface and the 2 meter depth contour or 200 meters offshore. Presence/absence of Oyster and Aquaculture sites were identified within these same areas.

Fetch

Fetch was calculated using shoreline coverage data from the Department of the Interior's National Wetland Inventory (NWI). GIS arc(s) were created for wetlands intersecting the shoreline. Coordinate geometry (COGO) was used to create short arcs in 16 wind directions (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW). These arcs are then extended to intersect with the bathymetry and shoreline. Directions and distances are then assigned back to the wetland. If two midpoints are measured, the midpoint with the longest fetch is identified and assigned to the wetland. If there are three or more shoreline segments for a single wetland polygon, the maximum fetch and direction for each midpoint is determined. The 16 wind directions are then condensed into four quadrants (NE, SE, SW, NW). The predominant fetch direction is then determined based upon the number of points in each quadrant. The longest fetch is selected from the predominant quadrant and assigned to the wetland. If two or more quadrants have an equal number of points, then the longest fetch is selected from among those quadrants.

The assessment of wetland islands, where a single wetland is completely surrounded by open water, requires a slightly different analysis. A centroid point is established within the wetland. Arcs are created from this point and radiate out in 16 wind directions to intersect with the wetland's perimeter. From each of these intersection points, 16 additional arcs are created and extended to the nearest shoreline and 2m bathymetric contour. The arc with the longest fetch is assigned to the wetland. The direction of the arc with the longest fetch is then used to determine the distance to the 2m contour.

On the Chesapeake Bay and its tributaries, fetches greater than 1,000 m (1 km) are considered unlimited, and form the basis for the scoring system used in this model. Scores are divided into three categories: Long (≤1000m), Short (>1000m), and None.

Bathymetry

NOAA bathymetry data (-2m depth contour) was used to identify the distance from the wetland polygon to the 2m depth contour. Bathymetry was divided into 4 depth categories based on the distance that the 2m depth contour is located from the shoreline: Deep (≤100m), Moderate (>100m and <fetch), Shallow (=fetch), and None (when the wetland polygon is contiguous with the upland shoreline).

Water Quality Model

Upland Landuse

Upland Landuse was considered for the water quality model because upland areas contribute to nonpoint sources pollution through contaminated upland runoff and groundwater. Upland landuses were complied into 3 categories (natural, agricultural, and developed), which reflect general contributions of non-point source pollution. The categories were ranked (1=least important, 2=moderate importance, 3=most important) based on their relative importance for the maintenance of water quality. Natural landuse was given a value of 3 because it includes wetland, scrub-shrub, and forested cover types which are identified as contributing the least excess nutrients while also removing pollutants and retaining sediment from adjacent upland areas. Agricultural landuse was given a value of 2 because it has the potential to retain sediments, however may be associated with excess nutrient inputs. Developed landuse was given a value of 1 because it offers the lowest potential for sediment retention and nutrient removal and may increase contaminated surface runoff. A value was calculated for each assessment unit by adding the relative percentages of each landuse type multiplied by its ranking.

Riparian Landuse

Riparian Landuse was considered for the water quality model because riparian areas provide capacity for mitigating nonpoint source pollution by reducing upland runoff and intercepting groundwater. Landuses were complied into 4 categories (natural, agricultural, industrial/paved, and developed), which reflect the buffering capacity of the riparian lands. In the water quality model, the natural category was given a value of 3 because the vegetation associated with it has high buffering capacity, while the other two categories (developed and agriculture) were given a ranking of 1 because they were considered to have reduced buffering capacity due to lack of vegetation and/or excess nutrient inputs. The fourth category (Industrial) was added to the water quality model and observed by presence/absence. When this category was present, the final score was modified. If the riparian landuse was Industrial and the upland (inland) landuse was greater than 20% developed, then the score for upland landuse went to zero (regardless of the remaining 79% cover). If upland landuse was less than 20% developed, the score was reduced by 1 point. This reflects the lack of buffering value and potential for increased pollution associated with industrial sites. The 20% threshold reflects a conservative estimate based on current understanding of the adverse effects of development on water quality. A value was calculated for each assessment unit by adding the relative percentages of each landuse type multiplied by its ranking.

Forested Buffer

Forested Buffer presence was a riparian area modifier considered for the water quality model since even narrow bands of riparian trees may provide improved ecological services. Buffers were only applied in areas where the Riparian Landuse was less than 30% natural. The presence of a buffer was ranked as a 3 (high buffering capacity) and the absence of a buffer was ranked as 1 (reduced buffering capacity).

Bank Cover

Bank Cover was considered for the water quality model because vegetative cover on a bank helps to stabilize the bank, reducing sediment inputs to the waterway. Bank cover was separated into 3 categories, which reflect general contributions of non-point source pollution. The categories were ranked (1=bare, 2=partial cover, 3=total cover) based on their relative importance for the maintenance of water quality. Total cover was given a value of 3 because vegetation and structures help to prevent erosion and sediment introduction. Partial cover was given a value of 2 because a portion of the bank was unprotected or exposed, resulting in potential for erosion and sediment introduction. Bare banks were given a value of 1 because of their high potential for erosion and sediment introduction. A value was calculated for each assessment unit by adding the relative percentages of each cover category multiplied by its ranking.

Bank Stability

Bank Stability was considered for the water quality model because stable banks are less susceptible to erosion and failure, reducing sediment inputs to the waterway. Bank stability was separated into 3 categories, which reflect general contributions of non-point source pollution. The categories were ranked (1=unstable, 2=undercut, 3=stable) based on their relative importance for the maintenance of water quality. Stable banks were given a value of 3 because a lack of observed erosion suggests low potential for sediment introduction. Undercut banks were given a value of 2 because the minimal toe erosion indicated a moderate potential for sediment introduction. Unstable banks were given a value of 1 because of their high potential for continued erosion and sediment introduction. A value was calculated for each assessment unit by adding the relative percentages of each cover category multiplied by its ranking.

Shoreline Resources

Three resources were considered that provide water quality services in varying degrees: Dunes, Marsh, and *Phragmites*.

Coastal primary sand dunes serve as protective barriers from flooding and erosion resulting in decreased sediment and nutrient inputs. Marshes are transitional areas between upland and sub-aqueous lands that improve water quality and help reduce erosion by filtering groundwater and holding sediment in place. From a water quality perspective, *Phragmites* are highly productive, trapping and binding sediments, intercepting run-off and stabilizing shorelines.

These resources were ranked by their importance to water quality according to their proximity to the shoreline interface and relative opportunity for water quality improvement: Marsh and *Phragmites*=3 and Dune=2. A value was calculated for each assessment unit by adding the relative percentages of each cover category multiplied by its ranking.

Shoreline Structures

Six categories of structures were considered for their potential to impact water quality in varying degrees: Boat ramps, Marinas, Bulkheads, Riprap, Miscellaneous, and Debris (car tires, trash, appliances, etc.). The impact of structures on water quality is variable and may be positive or negative (improve or degrade water quality). Structures that stabilize shorelines (including Miscellaneous and Debris) and reduce erosion may improve water quality and were given a value of 2. Marinas and Boat ramps introduce pollutants associated with boating and therefore were assigned negative values. Presence of a Marina within an assessment unit automatically scored a –3, while boat ramps were scored based on the number of such structures within the assessment unit (public ramps = -2 each; private ramps = -1 each).

In the model, these structures may modify Bank Cover by reducing the overall water quality score if the cover is provided by a manmade structure (Bulkheads, Riprap, Miscellaneous, and Debris) rather than vegetation. This reflects the greater capacity of natural bank cover to impact water quality through the reduction of erosion and interception of runoff and groundwater.

Subaqueous Resources

Three resources were considered to provide water quality services in varying degrees: Submerged Aquatic Vegetation (SAV), Oyster Reefs, and Aquaculture. Both SAV and oysters were once prevalent throughout the Chesapeake Bay and the surrounding watersheds, however they have become increasingly rare. They both have limited capabilities to dampen waves and stabilize nearshore sediments. Oysters also remove pollutants through filtration while SAV may help reduce excess nutrients. These ecosystem services justify a high ranking for these resources. Percent SAV coverage was multiplied by a factor of 6 in the model. Oyster and aquaculture were identified by presence/absence and contributed scores of 3 and 2 respectively which was added to the total model score for each assessment unit.

Habitat Model*

Riparian Landuse

Riparian Landuse was considered for the habitat model because riparian vegetation can provide essential habitat for terrestrial and avian species. Land uses were compiled into 3 categories (natural, agricultural, and developed), which reflect habitat value. In the model, the natural landuse type was given a value of 6 because it provides native or unaltered habitat for terrestrial and avian species. The agricultural landuse type was assigned a value of 4 because it was considered to be in an altered state which may result in reduced availability of suitable habitat. The developed landuse type was assigned a score of 2 because disturbance from development has likely resulted in reduced available habitat. In areas where combined agricultural and development landuse was greater than 50% of the assessment unit, the entire unit was considered developed. This reflects the concept of a minimal threshold of disturbance beyond which habitat is critically compromised. A value was calculated for each assessment unit by adding the relative percentages of each landuse type multiplied by its ranking

Forested Buffer

Forested Buffer presence was a riparian area modifier considered for the habitat model since even narrow bands of riparian trees may provide some habitat. Buffers were only applied in areas where the Riparian Landuse was less than 30% natural. The presence of a buffer was ranked as a 3 because the buffer provides a habitat corridor on otherwise developed land. The absence of a buffer was assigned a rank of 1.

Shoreline Resources

Four resources were considered that provide habitat in varying degrees; the resources are: Dunes, Beaches, Marsh, and *Phragmites*. Coastal primary sand dunes represent transitional areas that bridge marine and terrestrial habitats and provide essential habitat for plants and animals. Beaches interact with primary and secondary sand dunes and serve as habitat for benthic animals and microalgae living on or within the sand. Beaches can also serve as refuge and forage areas for finfish, blue crabs and wading shorebirds. Marshes are transitional areas between upland and subaqueous lands. They provide habitat (food and shelter) for both aquatic and terrestrial animals such as blue crabs, small fish and marsh birds. *Phragmites* marshes grow in a wide range of intertidal and nearshore areas. They generally represent a monotypic community, which limits their habitat value relative to more diverse communities. The non-native variety of *Phragmites* may be highly competitive, displacing native marsh vegetation. In the habitat model, the resources were ranked by their relative habitat value as follows: Dunes=1, Beach and Marsh=3 and *Phragmites*=2.

Shoreline Structures

Seven categories of structures were considered for their potential to impact habitat in varying degrees: Boat ramps, Marinas, Bulkheads, Breakwaters, Miscellaneous, Debris, and Jetties. Generally, structures have an adverse impact on habitat because they displace native environments or interrupt the marine-terrestrial interface. The two exceptions are Breakwaters and Jetties, which involve the placement of stone in the subaqueous zone. These structures may provide attachment surfaces for aquatic animals such as oysters, barnacles, and jingle shells. Jetties and breakwaters were assigned the only positive values (+1) because they provide some habitat value. Boat ramps were given a value of –1 when a single ramp was present and a value of –2 when more than one ramp was present. Marinas were assigned a value of –3. All other structures were assigned a value of –3 multiplied by the linear extent of the feature expressed as a percentage of the assessment unit.

Subaqueous Resources

Two resources were considered to provide habitat in varying degrees; they are Submerged Aquatic Vegetation (SAV) and Oyster Reefs. Both SAV and oysters were once prevalent throughout the Chesapeake Bay and the surrounding watersheds, however they have become increasingly rare. They are important components of the coastal ecosystem, providing critical forage and nursery habitat for a wide variety of estuarine species. These ecosystem services justify a high ranking for these resources. Rankings were positive and relatively high for both categories. Percent SAV coverage was multiplied by a factor of 6 in the model. Oysters were identified by presence/absence and contributed a score of 2, which was added to the total model score for each assessment unit.

*When riparian landuse within an assessment unit was 100% natural and no shoreline structures were present, an additional 10 points was added to the final model score to reflect the diversity of habitat supported by this unaltered landscape condition. It also reflects the relative scarcity of unaltered shorelines along the entire coastline.

Shoreline Risk Model

Fetch

Fetch was used as an element in the model because it influences the wave climate in a given reach. Fetch >1,000 m receive the highest score = 1. Though larger fetches are common, no justification could be provided for weighting greater distances higher. In the shoreline protection model, the highest score (1) represents that tidal wetlands are most valued where they are subject to the greatest potential wave energy. Tidal wetlands located where fetch distances are less than 1,000m receive a moderate value score = 0.5. Our rationale is that fetches <1,000m are less significant and are more easily mitigated.

Bathymetry

Bathymetry data was used in the shoreline protection model because, in addition to fetch, shallow water habitat, water depths < 2m as defined by the US Army Corps of Engineers, can enhance the ability of tidal wetlands to provide shoreline protection by forcing waves to break offshore, thereby dispersing a significant portion of the wave's energy before it reaches the shoreline. Where the distance to the 2m depth contour is less than or equal to 100m, the wetland receives the highest score (1) because the nearshore exerts less wave-reducing influence, and the wetlands are therefore more valuable in providing shoreline protection. Distances greater than 100m are scored progressively lower, to represent the increased ability of nearshore bathymetry to enhance the shoreline protection of tidal wetlands. Therefore, when the distance to the 2m contour is greater than 100m, the nearshore shallow water habitat contributes significantly to wave reduction and the role of the wetland to provide shoreline protection is reduced.

WATER QUALITY ELEMENTS

Shoreline Element	Model Values	Element Rules
Upland Landuse		
natural	3	% landuse * value added to score
agriculture	2	% landuse * value added to score
developed	1	% landuse * value added to score
Riparian Landuse		
natural	3	% landuse * value added to score
agriculture	1	% landuse * value added to score
developed	1	% landuse * value added to score
industrial or paved	0 or -1	Score for upland landuse when present: 0 if developed > 20%, subtract 1 if dev $\leq$ 20%
Forest Buffer		
yes	3	Applied when Ag + Dev RL ≥ 70% of buffer area
no	1	Applied when Ag + Dev RL ≥ 70% of buffer area
Bank Cover		
bare	3	% of unit * value added to score
partial	2	% of unit * value added to score
total	1	% of unit * value added to score
Bank Stability		
stable	3	% of unit * value added to score
undercut	2	% of unit * value added to score
unstable	1	% of unit * value added to score
Shoreline Resources		
dunes	2	% of unit * value added to score
marsh	3	% of unit * value added to score
phragmites	3	% of unit * value added to score
Shoreline Structures		
boat ramp	-1, -2	public= -2, private = -1: all ramps totaled
marina	-3	if present -3 added to score
bulkhead	2	
riprap	2	
miscellaneous	2	Structure modifies bank cover: subtract (% of unit
debris	2	* value) from cover value
Subaqueous Resources		
SAV	3	(% area * 3) added to score
oyster	3	if present +3 added to score
aquaculture	2	if present +2 added to score

HABITAT MODEL ELEMENTS

Shoreline Element	Model Values	Element Rules
Riparian Landuse		
natural	6	When % (Ag+Dev) > 50% = developed
agriculture	4	When % (Ag+Dev) > 50% = developed
developed	2	
industrial or paved	0	
Forest Buffer		
Yes	3	Applied when Ag + Dev RL ≥ 70% of buffer area
No	1	Applied when Ag + Dev RL ≥ 70% of buffer area
Shoreline Resources		
dunes	1	% of unit * value added to score
beach	3	% of unit * value added to score
marsh	3	% of unit * value added to score
phragmites	2	% of unit * value added to score
Shoreline Structures		
boat ramp	-1, -2	One ramp= -1, > one ramp = -2, added to score
marina	-3	If present -3 added to score
bulkhead	-3	% of unit * value added to score
miscellaneous	-3	% of unit * value added to score
debris	-3	% of unit * value added to score
jetty	1	If present +1 added to score
breakwater	1	If present +1 added to score
Subaqueous Resources		
SAV	6	(% area * 6) added to score
oyster	2	if present +2 added to score

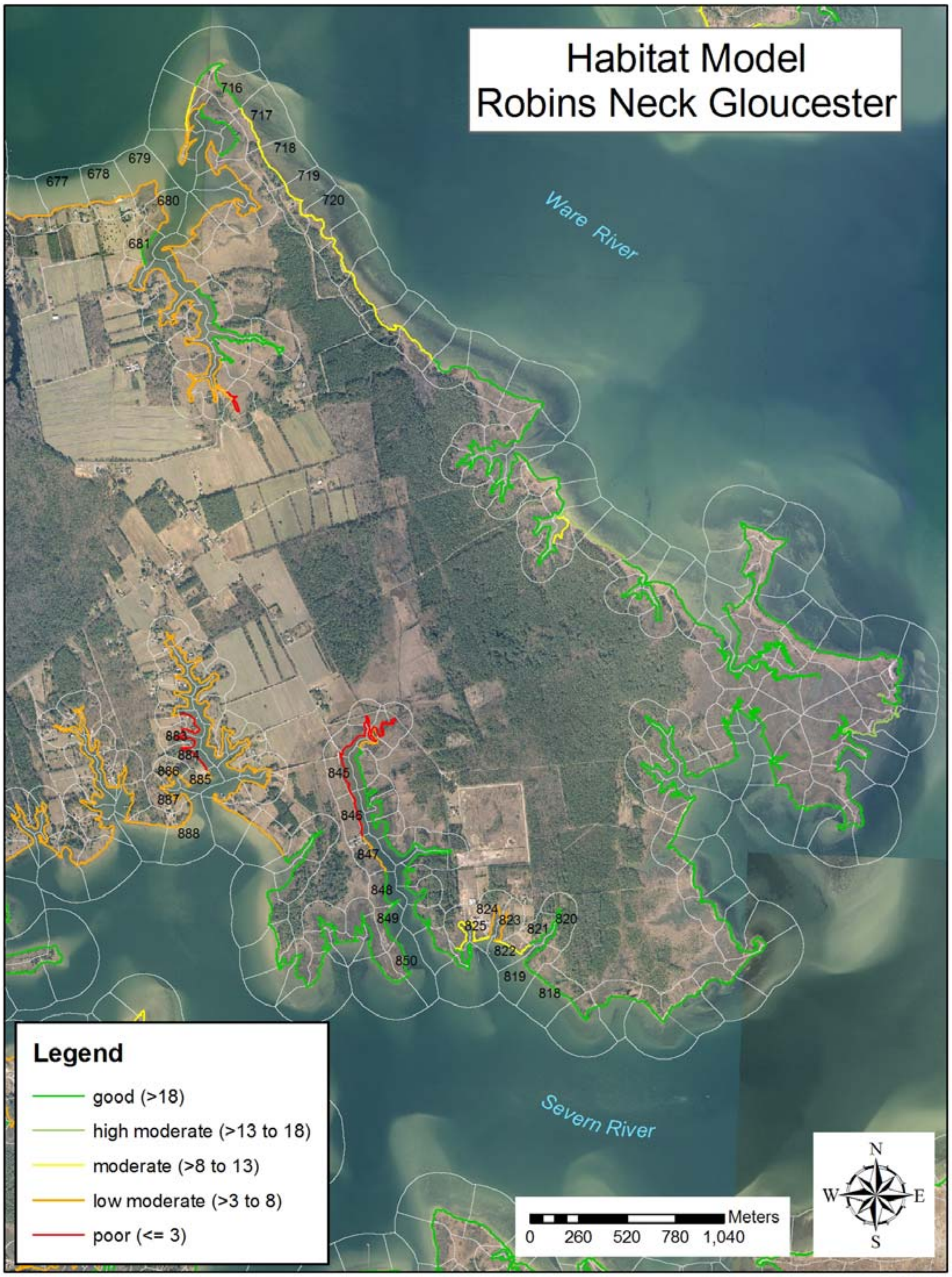
Add 10 points Assessment unit with LU = 100 % natural, no structures

SHORELINE RISK MODEL ELEMENTS

Shoreline Element	Model Values	Element Rules
Bathymetry (Distance to 2 mile contour)		
Deep	1.0	Unit value added to score
Moderate	0.5	Unit value added to score
Shallow	0.25	Unit value added to score
None	0	Unit value added to score
Fetch		
Long	1.0	Unit value added to score
Short	0.5	Unit value added to score
None	0	Unit value added to score


Water Quality Model
Robins Neck Gloucester
Ware River
Severn River
677
678
679
680
718
719
720
883
884
886
885
887
888
845
846
847
848
849
850
824
825
823
821
820
822
819
818
Legend
high moderate (>13 to 18)
moderate (>8 to 13)
low moderate (>3 to 8)
poor (< = 3)
N
W
E
S
Meters
0 270 540 810 1,080

11/10/06



Habitat Model
Robins Neck Gloucester
Ware River
Severn River
716
717
718
719
720
677
678
679
680
681
883
884
885
886
887
888
845
846
847
848
849
850
824
825
823
821
820
822
819
818
Legend
good (>18)
high moderate (>13 to 18)
moderate (>8 to 13)
low moderate (>3 to 8)
poor (<= 3)
Meters
0 260 520 780 1,040
N
W
E
S

11/10/06