Model Name: Surge/Wave Attenuation Potential

Functional Area: Ecosystem Service

Model Proponents: Coastal Protection and Restoration Authority

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Please note this is a working-draft document currently undergoing review and revision. The final version will be posted in March 2012 along with the final version of the 2012 Coastal Master Plan.

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1. *Background*

a. Purpose of Model

The Storm Surge/Wave Attenuation Potential Model was based on the concept of habitat suitability index (HSI) models. Through internal discussion among the model developers, the efforts to model storm surge/wave attenuation were focused on populated areas.

b. Model Description and Depiction

The Surge/Wave Attenuation Potential Suitability Index (SI) is intended to consider the potential effect of a project in attenuating storm surge/waves that would otherwise impact populated areas. It is based on 500 x 500m model grid cells and calculated on a 5 year time step. The model combines location from areas designated for 100 or 500yr level protection, percent land, vegetation type, and elevation inputs to produce a suitability index for surge/wave attenuation potential ranging from 0.0 to 1.0.

c. Contribution to Planning Effort

The model provides a prediction of storm surge/wave attenuation in coastal Louisiana for a 50-year time horizon.

d. Description of Input Data

Data used as input are distance from an area designated for 100 or 500yr level protection (km), percent land, vegetation type, and elevation (m). The distance variable is calculated using GIS shapefiles. Percent land and elevation are output from the Wetland Morphology Model and vegetation type is an output of the Vegetation Model.

e. Description of Output Data

The output data is a suitability index ranging from 0.0 to 1.0 that represents the potential of a 500 x 500m model grid cell to attenuate storm surge/ wave height.   A value of 1.0 indicates the greatest potential for storm surge and wave attenuation.

f. Statement on the capabilities and limitations of the model

The model is capable of determining the potential of a model grid cell to attenuate storm surge/wave height in relation to populated areas in order to evaluate the differences between proposed projects.

The model is limited by its focus on predicting attenuation potential around populated areas. It is not intended to predict surge/wave attenuation for all wetland areas, or be a comprehensive quantitative model. It is meant to be a broad planning-level model that predicts areas of the landscape that may provide potential storm surge / wave attenuation under various future conditions.

g. Description of model development process including documentation on testing conducted

The model focuses on storm surge/wave attenuation for populated areas. Therefore, a distance factor was applied to the model with wetlands closer to populated areas given higher scores. The work of Loder et al. (2009) indicated the importance of both percent land and elevation to attenuation. The role of vegetation was based on Manning's *n* values for vegetation. Each of these factors were developed as individual suitability indices and combined arithmetically and geometrically to give a surge/wave attenuation potential suitability index.

2. *Technical Quality*

a. Theory

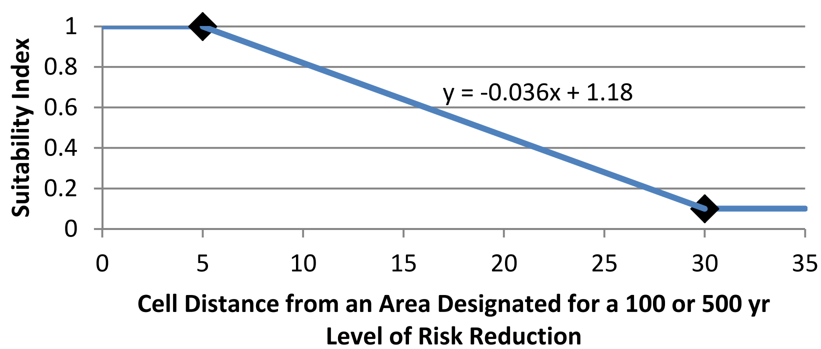
This model was developed in a similar style to habitat suitability indices. The following factors are included in the Surge/Wave Attenuation Potential SI Model:

SI_1 - Suitability Index for Location

Because of the need to protect communities that have been designated for 100 or 500 year level of risk reduction, wetland regions closest to these areas are a top priority since they are the last line of natural defense. This variable was based on the distance of a model grid cell from that of an area designated for a 100 or 500 year level of risk reduction. The distance from perimeter was used to more realistically model the area of protection. Model grid cells that are within 5km of a designated area receive an SI of 1.0, and areas 30km and further have an SI of 0.1. It is assumed that there is a linear relationship between suitability and distance from a designated areas' perimeter. A linear trend line was fitted between the thresholds of 5 and 30km distance, and the resulting equation is $SI_1 = (-0.036 * V_1) + 1.18$.

V_1 = Distance from an area designated for 100 or 500yr level protection (km)

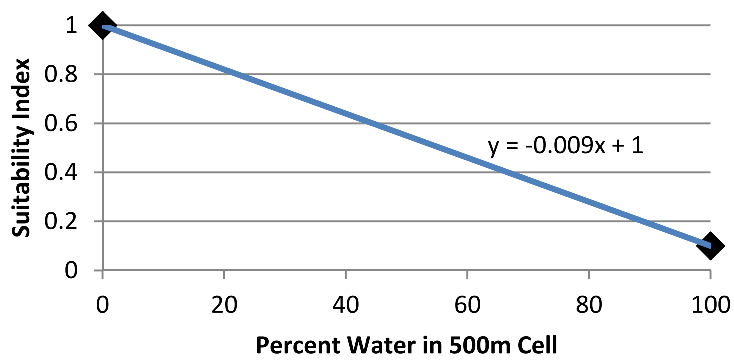
$SI_1 =$	1.0	for $V_1 < 5.0$
	$(-0.036 * V_1) + 1.18$	for $5.0 \leq V_1 < 30$
	0.1	for $V_1 \geq 30$



SI_2 - Suitability Index for Percent Land

The work of Loder et al. (2009) shows that marsh continuity influences the volume of surge within marsh areas, but that the effect varies depending on the surge level/storm type. Based on these findings, areas that contain no water are best for surge/wave height attenuation and have an SI of 1.0. Areas that do not contain land are less desirable, and are given an SI of 0.1 since depth of water has an effect on surge/wave height. All other %land (PCL) were modeled on a linear trend with the equation $SI_2 = (-0.009 * V_2) + 1.0$. This linear relationship with change in landscape features at the 500m cell scale is consistent with Loder et al. general findings.

$SI_2 =$	1.0	for $V_2 = 0.0$
	$(-0.009 * V_2) + 1.0$	for $0.0 < V_2 < 100$
	0.1	for $V_2 = 100$



SI_3 - Suitability Index for Vegetation Type

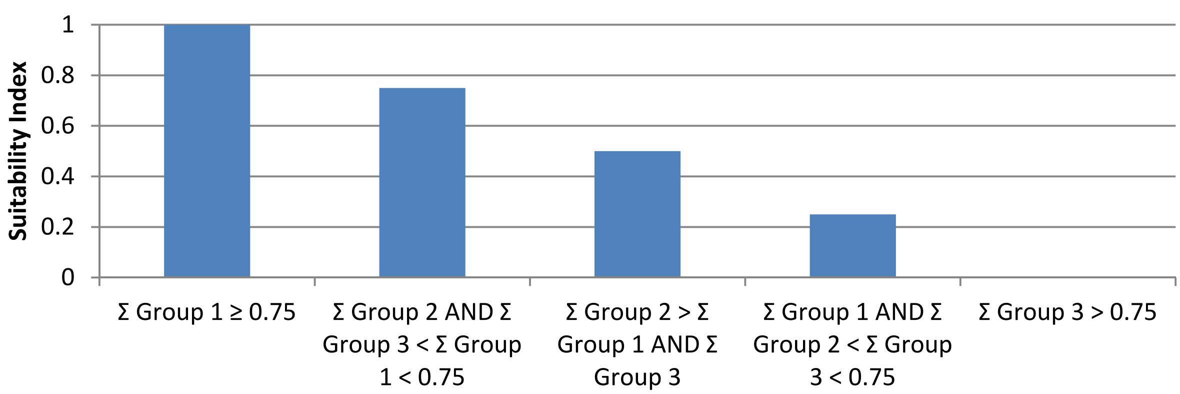
Several habitat types and individual species common to south Louisiana were included in the modeling effort to account for the effects of differing vegetation types (see Table 1). The types are grouped according to their value for increasing friction. Manning's *n* values for vegetation rate dense woods and brush above grasses and bare bottom. Information on percent cover of the land cover types for each 500m cell is provided by the Vegetation Model. Total percent coverage for each group is used for the calculations. An SI of 1.0 is assigned to conditions where forested vegetation is greater than 75% of the cell. When forested vegetation is less than 75% of the cell, but it is still the dominant cell vegetation type, then an SI of 0.75 is given. An SI of 0.5 is given for cells that have herbaceous vegetation as the dominant type. The condition of water being the dominant habitat type, but less than 75% of the cell, earns an SI of 0.25. When water is greater than 75% of a cell the SI value is 0.0.

SI_3 = 1.0 for Forested ≥ 0.75
0.75 for Herbaceous AND Water < Forested ≤ 0.75
0.5 for Herbaceous > Forested AND Water
0.25 for Forested AND Herbaceous < Water < 0.75
0.0 for Water ≥ 0.75

Table 1: Habitat types and individual species included in modeling effort

Forested	Herbaceous	Water
Wax Myrtle (*Morella cerifera*) **Black Mangrove** (*Avicennia germinans*) **Swamp Forest** (composed of *Taxodium distichum* and *Nyssa aquatic*) **Shrub-scrub** (composed of *Iva frutescens* and *Baccharis halmifolia*) **Non-Swamp Forested**	**Cut-grass** (*Zizaniopsis miliacea*) **Maidencane** (*Panicum hemitomon*) **Cattail** (*Typha domingensis*) **Sawgrass** (*Cladium jamaicense*) **Bulltongue** (*Sagittaria lancifolia*)	**Open Water** (Open water without SAV)

	Roseau cane (*Phragmites australis*) **Bullwhip** (*Schoenoplectus californicus*) **Wiregrass** (*Spartina patens*) **Paspalum** (*Paspalum vaginatum*) **Needlegrass** (*Juncus roemerianus*) **Delta Splay** (*Sagittaria latifolia*, *Schoenoplectus deltarum* and *Colocasia esculenta*) **Thin-mat** (*Eleocharis baldwinii*, *Hydrocotyle umbellata*, *Bidens laevis*) **Brackish Marsh** (*Spartina patens*, *Distichlis spicata* and *Spartina alterniflora*) **SAV** (Open water with SAV)	



SI_4 - Suitability Index for Elevation (m)
Loder et al. (2009) described how surge/wave attenuation can be influenced by elevation. It was noted that surge/wave height was decreased due to increasing water depth or land height. However at intermediate elevations, surge/wave height was increased. In the model, each cell is identified as being in one of six classes based on the estimated elevation of the land (m)/depth of the water (negative elevation) in the cell:

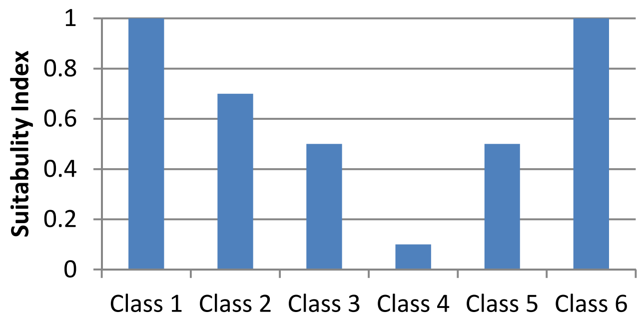
Class 1: Elevation greater than 1m; SI = 1.0
Class 2: Elevation between 1 m and 0.5m; SI = 0.7
Class 3: Elevation between 0.5m and -0.5m; SI = 0.5
Class 4: Elevation between -0.5m and –1m; SI = 0.1

Class 5: Elevation between -1m and -2m; SI = 0.5
Class 6: Elevation less than -2m; SI = 1.0

The pattern of change reflects information developed by Loder et al. (2009) generalized to reflect an array of different surge levels.

V_4 = Elevation (m)

SI_4 =	1.0	for $V_4 > 1.0$
	0.7	for $1.0 \leq V_4 < 0.5$
	0.5	for $0.5 \leq V_4 < -0.5$
	0.1	for $-0.5 \leq V_4 < -1.0$
	0.5	for $-1.0 \leq V_4 \leq -2.0$
	1.0	for $V_4 < -2.0$



Surge/Wave Attenuation Potential SI
The calculation of the Surge/Wave Attenuation Potential SI is a geometric mean of the distance of the wetland from an area designated for 100 or 500yr level of protection and the arithmetic mean of percent land, vegetation type, and elevation. The geometric mean is used because the distance of the wetland and some combination of the other three variables are essential to this process. An arithmetic mean is used for the other variables since it is the combination of the three that is essential to estimating this suitability index.

Surge/Wave Attenuation Potential SI = $(SI_1 * ((SI_2 + SI_3 + SI_4) / 3))^{1/2}$

Surge/Wave Attenuation Potential (use this equation only if a cell is all NOTMOD for vegetation class) = $(SI_1 * ((SI_2 + SI_4) / 2))^{1/2}$
NOTMOD refers to areas that were not modeled by the Vegetation Model (e.g., uplands).

b. Description of system being represented by the model
Communities located in coastal zones have depended on wetlands as natural protection from the damaging effects of storm surge and wave height because of the potential of vegetation to attenuate surge/waves. While this potential is not debated, it is a complex issue. Both Wamsley et al. (2010) and Koch et al. (2009) agree that the physical characteristics of the marsh (bathymetry, structures, plant density and location, species, etc.) have an important effect on surge/wave attenuation. As a result, this suitability index considers the potential effect of a project in attenuating storm surge and waves that would otherwise impact populated areas.

This model simulates the effects of distance from areas designated for 100 or 500yr level protection, percent land, vegetation type, and elevation on habitat ability to attenuate storm surge/wave height in relation to populated areas. Each factor is defined as its own suitability index and all of the factors are combined as a surge/wave attenuation potential suitability index through arithmetic and geometric means.

c. Analytical requirements

In order to adequately investigate storm surge/wave attenuation potential in relation to populated areas, several key factors were identified: location, percent land, vegetation type, and elevation. These key factors were all included in the modeling effort, and combined depending on their importance to describing surge/wave attenuation potential. The calculation of the Surge/Wave Attenuation Potential SI is a geometric mean of the distance of the wetland from an area designated for 100 or 500yr level of protection and the arithmetic mean of percent land, vegetation type, and elevation. The geometric mean is used because the distance of the wetland and some combination of the other three variables are essential to this process. An arithmetic mean is used for the other variables since it is the combination of the three that is essential to estimating this suitability index.

d. Assumptions

The Surge/Wave Attenuation Potential SI Model is based on the assumption that the service provided is greater for vegetated land (as compared to open water) that is closer to population centers (as compared to more distant) and that has a higher elevation. Additionally, the Surge/Wave Attenuation Potential Suitability Index assumes elevation, % water and vegetation type are compensatory, e.g., a small area of high land within a cell that increases mean elevation offsets open water within the cell, but that if high land is distant from the area needing high levels of protection the index has a low but non-zero value.

e. Identification of formulas used in the model and proof that the computations are appropriate and done correctly

The model decision rules that were coded are provided in section 2.a. above. Quality review was performed by both the model coders and CPRA to ensure formulas and computations were correct.

3. System Quality

a. Description and rationale for selection of supporting software tool/programming language and hardware platform

Building on the ecological modeling application development performed for the Everglades modeling community, Java was used as the programming language inside the Eclipse RCP environment which supports plug-in software development. This approach facilitated the construction of software suites which execute the specific decision rules provided by subject matter experts allowing an end-user to choose which of the ecosystem services models to run.

b. Proof that the programming was done correctly

All software products are the result of multiple programmers working in concert. As part of the code development process, code classes are either team developed which ensures multiple individuals real-time code review or when individually coded are spot checked prior to production builds and exports.

c. **Availability of software and hardware required by model**
The choice of Java as the development platform ensures the broadest execution platform. These software suites can run on desktops with the following operating systems: Windows XP, 7 (32 and 64 bit), Apple OSX (32 and 64 bit), Linux. Furthermore, these Java executables could be easily re-compiled to run on Windows or Linux Application Servers.

d. **Description of process used to test and validate model**
These models were tested prior to production release with fabricated data built according to the data descriptions provided by the various teams. The absence of "real" data made pre-production testing far less effective than it could have been had there been high quality test data.

Ideally, model outputs would be validated by comparing the model predictions to observations made in the field but that is not possible with this model. The second best validation is based upon comparison of modeled predictions to what is expected given the known inputs. The s latter approach was followed and used known spatial patterns and temporal patterns to predict patterns in storm surge/wave attenuation.

e. **Discussion of the ability to import data into other software analysis tools (interoperability issue)**
Being standards compliant with international modeling data standards ensures rather broad interoperability. Unidata actively supports netCDF read/write libraries for C++, Java, C# and Fortran programming languages across multiple operating systems. Additionally, netCDF is natively consumable by commercial software product such as ESRI ArcMAP and MatLab. Furthermore, the Everglades Joint Ecologic Modeling community has backed a USGS software development effort resulting in EverVIEW which brings an open-source visualization platform solution to the complex realm of binary modeling data.

4. *Usability*

a. **Availability of input data necessary to support the model**
The input files required to run this model are available through the CPRA.

b. **Formatting of output in an understandable manner**
The output data is a suitability index ranging from 0.0 to 1.0 that represents the surge-wave attenuation of a 500 x 500m model grid cell. The output files are in netCDF format and can be viewed using EverVIEW or ArcGIS. A value of 1.0 represents the best potential for storm surge/wave attenuation.

c. **Usefulness of results to support project analysis**
In general, this model responds to projects which would result in increases or decreases in surge/wave attenuation as well as projects that are within a certain distance from population centers. Therefore, projects such as marsh creation or diversions that build land near such locations would drive changes in model results for a particular area.

d. Ability to export results into project reports
The model output is in netCDF format, which provides both a graphical and tabular representation of the model results that can be incorporated into reports. Model outputs can also be imported into ESRI ArcMap.

e. Training availability
Training for model usage can be provided through CPRA.

f. Users documentation availability and whether it is user friendly and complete
There are currently no user's guides or technical manuals to support the model; however, the model does have a help screen that explains how to convert model inputs into the necessary format as well as which files are necessary to run the model.

g. Technical support availability
Access to technical support can be provided through CPRA.

h. Software/hardware platform availability to all or most users
The ecosystem services modeling suite, being coded in Java, will run on most operating systems.

i. Accessibility of the model
Access to model and associated installation and execution files can be provided through CPRA.

j. Transparency of model and how it allows for easy verification of calculations and outputs
Model decision rules are documented in section 2a. Model HSI values must be between zero and one.

5. Sources of model uncertainty
All relationships in this model are sources of potential uncertainty.

6. Suggested model improvements
The model could be improved by performing additional research or data collection on the relationship of the variables in the suitability indices. In addition, the model could potentially be improved by the adding other contributing variables.

7. Quality review
Specific QR procedures for the Storm Surge/Wave Attenuation Model to support the 2012 Coastal Master Plan included comparing modeled predictions with expected outcomes given the known inputs. The modeling team used known spatial patterns and temporal patterns in input to predict patterns in storm surge/wave attenuation. The model is intended as a broad planning-level model that predicts areas where storm surge/wave attenuation is theoretically possible.

8. Uncertainty analysis
This model was selected for inclusion in the 2012 Coastal Master Plan model uncertainty analysis (See Appendix D-27). Two variables, cell distance from an area designated for a 100yr or 500yr level of risk reduction and land elevation were selected as the most likely to impact model outputs. Three alternative rules were determined for each of these variables, requiring that 27 model runs be

completed. The output of those runs will be used to construct empirically-based probability distributions and to analyze the uncertainty in the model outputs for the ecosystem service. The variation of the decision rules for the two selected variables are listed in Table 2.

Table 2: Variations of Decision Rules used to perform the uncertainty analysis for the Surge-Wave Attenuation Model

	A_0	A_1	A_2
V_1 (Cell Distance from an Area Designated for a 100 or 500 yr Level of Risk Reduction)	SI = 1 V1<5 SI=(-0.036V1)+1.18 5<V1<30 SI=0.1 V1>30	SI = 1 V1<1 SI=1-0.1(V1-1) 1<V1<10 SI=0.1 V1>10	SI = 1 V1<10 SI=1-0.0025(V1-10) 10<V1<50 SI=0.1 V1>50
V_4 (Land Elevation)	SI = 1.0 V4 > 1.0 SI = 0.7 V4 > 0.5 & V4 <= 1.0 SI = 0.5 V4<=0.5 & V4 > -0.5 SI = 0.1 V4<=-0.5 & V4 > -1.0 SI = 0.5 V4 <=-1.0 & V4 >= -2.0 SI = 1.0 V4 < -2.0	SI = 1.0 V4 > 1.5 SI = 0.7 V4 > 0.1& V4 <= 1.5 SI = 0.5 V4 <= 0.1& V4 > -0.3 SI = 0.1 V4 <= -0.3& V4 > -1.5 SI = 0.5 V4 <= -1.5 & V4 >= -3.0 SI = 1.0 V4 < -3.0	SI = 1.0 V4 > 0.3 SI = V4 + 0.7 -0.6 < V4 < 0.3 SI = 0.1 V4 < -0.6

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