Model Name: Model Uncertainty Analysis Technical Report

Functional Area: Predictive Models / Uncertainty Analysis

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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Background

Definition of Uncertainty

Within the modeling framework of the 2012 Coastal Master Plan, model uncertainty can be defined as the deviation of model prediction from the actual ecosystem response to a certain proposed project (Habib et al. 2007, 2008). In such context, uncertainty is attributed to two main aspects: (1) uncertainty due to inherent natural variability in the external model drivers that control the dynamics of the ecosystem response, and (2) uncertainties associated with the models utilized within the project-effects analysis of the master plan. The first aspect of uncertainty is addressed in the master plan through a set of scenarios that capture plausible future conditions (e.g., changes in sea level over the next 50 years) and system mechanics (e.g., variable salinity and inundation conditions that may result in the collapse of a marsh area); See Appendix C – Environmental Scenarios for more information. The second aspect of uncertainty (model-related uncertainties) is the focus of this Model Uncertainty Analysis technical report.

Because the 2012 Coastal Master Plan revision includes the development and utilization of new set of predictive models and a planning tool, it is necessary to assess uncertainty associated with these models. In addition to identifying the uncertainties, the uncertainties need to be assessed for the extent to which they affect model accuracy.

Model Uncertainty

Model uncertainty can result from different factors such as: insufficient, inaccurate or unrepresentative input data; lack of knowledge about the physical processes simulated by the model; model structure uncertainty; and algorithmic or numerical uncertainty. Imperfect representation of processes in the model is often referred to as model structural uncertainty. Parameter-induced uncertainty is caused by the imperfect knowledge of the values of the parameters associated with representing and simulating the natural processes. While reducing these different sources of uncertainty is most desirable, it can be a challenging and an unattainable goal given the time and resource constraints during the 2012 Coastal Master Plan. Using more complex models may not always result in uncertainty reduction, especially with the inherent lack of complete knowledge about some of the important natural processes. More complex models usually include more parameters and thus require much more input data at spatial and temporal scales that are probably beyond most existing monitoring systems. Given the complexity of the coastal Louisiana ecosystem and the current data and modeling limitations, it seems more realistic to recognize the models' inherent uncertainties and take them into account while using the model outputs at subsequent stages. Therefore, it is more viable to attempt to describe the variability in the simulated system response as a result of the model-induced uncertainties.

A distribution of various model outputs (e.g, in this case proxies for ecosystem services, such as alligator and spotted sea trout habitat suitability), rather than a fixed single output, is the focus of this Uncertainty Analysis (UA). The approach followed in the UA is based on identifying the most critical model parameters in terms of their effect on the ecosystem response and characterizing the impact of uncertainties in specifying these parameters on a selected set of critical ecosystem services. In this context, the term "parameter" refers to any model terms that control the relationship between model inputs (drivers) and outputs (response). As such, parameters can take the form of simple numerical

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values such as bed roughness and diffusion coefficients. Parameters can also take the form of tabular of graphical relationships (e.g., relationships that control probability of marsh collapse as a function of salinity or tables that control probability of vegetation establishment and death). Parameters can also refer to mathematical formulae such as those that estimate habitat suitability indices as a function of different environmental variables.

Predictive Models in the 2012 Coastal Master Plan

The master plan uses seven linked models (Figure 1) that predict change in the nature of coastal Louisiana under future conditions both with and without the implementation of any new projects. As illustrated in Figure 1, the models provide input to other models and/or produce outputs which themselves support an estimation of the project effects. Each model contains important but uncertain parameters to drive the dynamics of that aspect of the system.

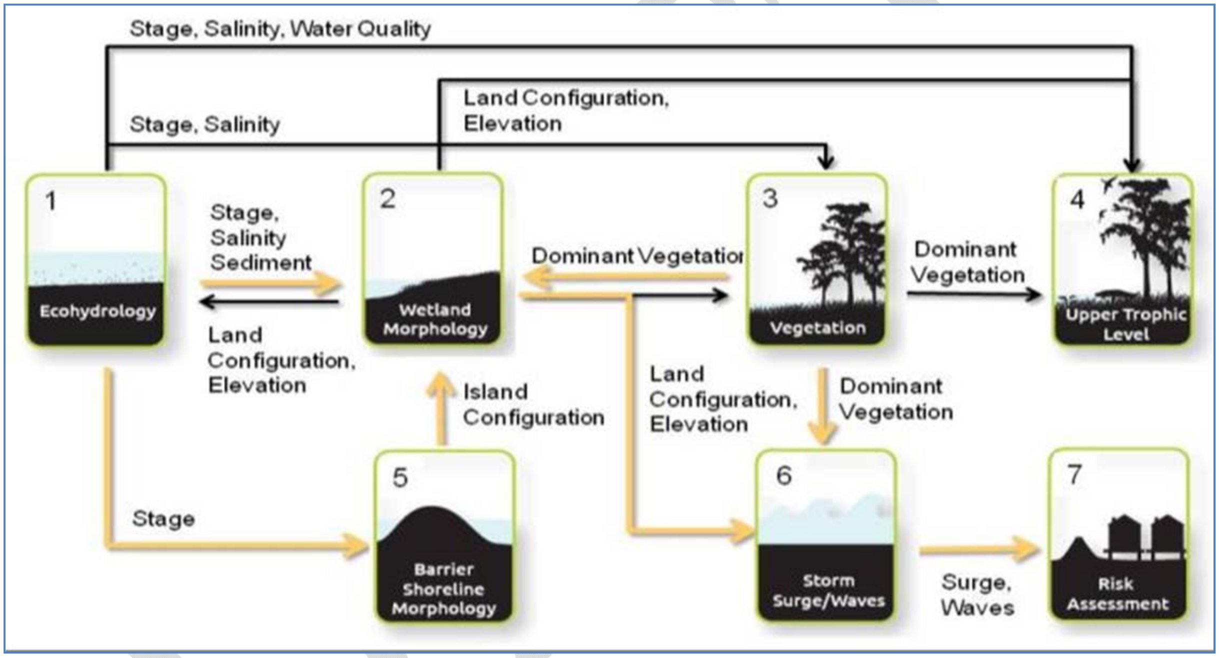

Figure 1: Summary of Linkages Among Inputs, Master Plan Models, and Outputs.

Uncertainty Analysis Approach

Traditionally, an uncertainty analysis is implemented in such a way that uncertainties are propagated in a *"forward"* manner starting from the first model (e.g., Eco-Hydrology model), through the intermediate models (e.g., Wetland Morphology model) and ending with the last model(s) (e.g. Ecosystem Services models (also referred to as Upper Trophic Level models)). While this approach guarantees that all model parameters are thoroughly investigated, it requires an excessively large number of model simulations. Instead of following a "*forward*" approach, this uncertainty analysis effort started from the end of the model chain and *"back-tracked"* the uncertainties. The analysis was driven by the master plan focus on assessing the impact of proposed protection and restoration projects from an ecosystem perspective.

The UA examined a set of ecosystem services proxies (e.g., alligator habitat suitability; henceforth referred to as ecosystem services) that were used to evaluate the effects of restoration and protection projects, and then back-tracked the model uncertainties that are perceived to be most critical for assessing these ecosystem services. This approach, despite not being comprehensive in assessing all sources of uncertainties, focused on a narrower set of model parameters that are perceived to be most critical for the end result of the project-effects modeling in its entirety. The following is a step-by-step description of the overall UA approach:

(1) Selected a set of ecosystem services (e.g., shrimp harvest) that are most indicative in terms of evaluating the effect of proposed protection and restoration projects and their contribution towards the overall goals of the master plan.

(2) Identified the specific model outputs that impact these ecosystem services (e.g., brown shrimp habitat suitability).

(3) Identified which model parameters and/or functional relationships impacted the model outputs identified in *step (2)*. This was performed by using the expert judgment of each modeling team. The selected model parameters were intended to be independent from each other (i.e. uncorrelated) to save on the number of parameters to be examined in later steps and to reduce the number of simulation runs.

(4) For each parameter selected in step (3), the team identified a simple probability distribution (e.g., triangular) specifying the range that the parameter is likely to take. This distribution reflects the degree of uncertainty associated with each parameter. A minimum, a maximum and a most likely value of each parameter are sufficient to define the triangular probability distribution. For other parameters where a most likely value cannot be identified, a uniform distribution was used. These specific values were selected based on literature sources and the expert judgment of the model developers.

(5) Designed a simulation experiment based on limited sampling from the parameter distributions described in step (4). A set of carefully-selected combinations of parameter values were considered such that the parameter combinations produced the widest possible range in the model outputs and the ecosystem services identified in step (1).

(6) Used the results of step (5) to construct empirical probability distributions of the five selected ecosystem services.

(7) The approximate probability distributions constructed in step (6) were used to: (i) assess the impact of model uncertainties on the selected ecosystem services; (ii) make probabilistic inference on whether and how such uncertainties can affect the evaluation of different project alternatives.

This procedure was first performed for the base-case (i.e., future without action) scenario. It is intended to be extended to cover a selected set of project considerations.

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Selection of Critical Ecosystem Services

Based on consultation with the master plan team, the current UA concentrates on the following ecosystem services[1]:

- Alligator Habitat
- Juvenile Brown Shrimp Habitat
- Largemouth Bass Habitat
- Oyster Habitat
- Surge-Wave Attenuation

This set of ecosystem services rely heavily on the primary input data that are provided by the different models in the master plan (Eco-Hydrology, Wetland Morphology, Vegetation). Table 1 indicates the ecosystem services that were selected to be the focus of the Uncertainty Analysis, along with their model inputs and the input sources.

Table 1: Ecosystem services selected by the master plan team to be the focus of the Uncertainty Analysis.

Ecosystem Service	Inputs	Source of Inputs
Alligator	1. V1: % land	Wetland Morphology
	2. V2: water depth	Eco-hydrology/ Wetland Morphology
	3. V3: habitat type	Vegetation
	4. V4: edge	Wetland Morphology
	5. V5: salinity	Eco-hydrology
Brown Shrimp	1. V1: % area covered by marsh vegetation	Vegetation
	2. V2: mean spring salinity (Feb-May)	Eco-hydrology
	3. V3: mean spring water temperature (Feb-May)	Eco-hydrology
Largemouth bass (to represent freshwater fish)	1. V1 - percent water with SAV per 500m^2	Vegetation
	2. V2 - average water temperature for April to August	Eco-hydrology
	3. V3 - maximum yearly salinity for June to August	Eco-hydrology
	4. V6 - % of cell that is permanently dry land per 1km^2	Vegetation
	5. V7 - index value of primary productivity in open waters	Eco-hydrology
Oyster	1. V1: % cultch	Mapped reefs, leases
	2. V2: mean salinity for May-Sep	Eco-hydrology
	3. V3: minimum salinity	Eco-hydrology
	4. V4: annual mean salinity	Eco-hydrology

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[1] CPRA is aware that habitat in and of itself is not a true ecosystem service as it lacks the monetary benefits associated with actual services such as harvest; for the sake of simplifying terminology, these ecosystem service proxies are referred to as ecosystem services throughout this document.

Surge/wave attenuation	1. V1: location relative to perimeter of an area designated for a 100- or 500-year risk reduction	CPRA
	2. V2: % land/water	Wetland Morphology
	3. V3: vegetation type	Vegetation
	4. V4: mean elevation	Wetland Morphology

Identification of model parameters that result in uncertainty

Having selected the five critical Ecosystem Services for the UA, the next step was to identify which model parameters and relationships: (1) affect the selected ecosystem services the most, and (2) are perceived to have an uncertain effect on the model output. This was performed for every predictive model. The following sections provide a detailed discussion of the selected model parameters and relationships. For each selected parameter and identified relationship, the modelers were asked to define a set of possible values that covered a "physically" possible range and reflected the inherent uncertainty in identifying a unique value for the parameter/relationship. These ranges are considered a proxy for a full probability distribution of each parameter. Whenever possible, the modelers were asked to make a statement on whether a direct relationship could be established between the parameter and the final ecosystem response (e.g., a lower range of the parameter leads to less potential of land loss).

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Eco-Hydrology Model

Critical Model Outputs: Several parameters have been identified in the Eco-Hydrology model that have uncertain effects and would therefore cause model outputs to retain this uncertainty. The Eco-Hydrology model was divided into three regions, the Pontchartrain-Barataria Region (PB), the Atchafalaya Region (AA), and the Chenier Plain Region (CP), and uncertainties were analyzed specifically in all three regions. The following table (Table 2) summarizes the outputs of the Eco-Hydrology model identified as being critical inputs for subsequent models and for estimating the five ecosystem services identified above.

Table 2: List of Eco-Hydrology model outputs identified as being critical for subsequent models and ecosystem service calculations. The parameters viewed as having the most uncertain effect for each output are also listed.

Output	Parameter with High Uncertainty	Notes
Stage	Bed Roughness	No direct relationship between this parameter and any of the ecosystem services
	Diffusion Coefficient	Higher diffusion leads to more mixing; however, there is no direct relation between this parameter and the ecosystem services
Salinity	Bed Roughness	Higher roughness leads to more mixing, however, there is no direct connection between this parameter and the ecosystem services
	Diffusion Coefficient	Higher diffusion leads to more mixing; however, there is no

		direct relation between this parameter and the ecosystem services
Sediment/ Accretion	Critical Wind Speed (controls Resuspension rate)	A large value of critical wind speed leads to less Total Suspended Solids (TSS) and thus high potential for land loss
	Base Resuspension Flux (controls Resuspension rate)	Base resuspension flux is a product of sediment bulk density and base resuspension rate; larger values of this parameter lead to lower vertical accretion and thus high potential of land loss
	Krone's Coefficient (controls deposition rate)	A larger value of this coefficient leads to more deposition/accretion and less potential of land loss
	Critical Velocity (controls deposition rate)	A higher velocity leads to more sediment settling and more potential for land building
	Percent Sand/Fines (controls accretion)	A lower value of this parameter leads to less accretion and thus higher potential for land loss
	Reference Settling Velocity	Higher settling velocity means more accretion which leads to more land building
Algae growth	Sediment Denitrification Rate	A larger value results in higher potential of nutrient removal
	Half Saturation Concentration - Nitrogen	The lower the half saturation concentration, the greater the algal growth limitation factor, which can result in more algal growth. The limitation factor is between 0 and 1 and is multiplied by the algal maximum specific growth rate. Thus, the greater the value the greater the growth rate. However, the overall nutrient limitation factor is the minimum of the N and P limitation factors. Algae removes NO3, NH4, and TIP from water; and when algae die, some of the nitrogen & phosphorus is released back into the system. Too much algae leads to depletion of nutrients used for plant life as well as benthic creatures. Too much algae can cause eutrophication and hypoxia, which causes fish kills. Also, algae contributes to turbidity, which doesn't allow enough light to reach the vegetation and species living on/near the bed.
	Half Saturation Concentration - Phosphorus	
	Optimal Light	Algal growth rate is a product of temperature-modulated maximum specific growth rate, and nutrient, light and salinity limitation factors. The light factor varies from 0 to 1 as light varies from 0 to optimal light, then it varies from 1 to 0 as light increases above optimal light. More algal growth leads to more nutrient removal as algae takes nutrients from the water.

Below is an itemized discussion outlining the parameters thought to have uncertain impacts on these outputs in the Eco-Hydrology model. Ranges of parameter values that can be used to analyze the effects of their uncertainty are also presented.

Parameters with uncertain effects on stage and salinity: There are two main parameters that control the stage and salinity model outputs. Selection of specific values of these two parameters is subject to uncertainty.

- Bed roughness
- Diffusion Coefficient

The bed roughness is an estimate of the frictional resistance of a surface for water to pass over. Therefore, the roughness affects the advection, or forward motion, of water from cell to cell. Bed roughness is not a natural feature that can be measured or visually inspected, but it is typically a calibration parameter that has been extensively studied over the years. There are published literature values of recommended bed roughness factors for many different types of vegetation and structural materials. In the CP domain, the roughness was based on the type of cell i.e. canal, water, or marsh. In the AA domain, the roughness was based on the vegetation type. In the PB domain, the roughness was originally based on vegetation type and was then altered to calibrate the model. Table 3 shows the roughness factors used in each region, along with the recommended range of values used to analyze their uncertainty.

Table 3: Roughness Factors for Uncertainty Analysis. No “direct” connection to ecosystem services could be made. In PB region, the actual value used varies by cell (calibrated). These are multiplier factors, however, that ensure roughness “n” doesn’t fall below 0.01 since this represents a hydraulically smooth boundary.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
AA Vegetation Type	**Minimum**	**Intermediate Minimum**	**Most-likely Value**	**Intermediate Maximum**	**Maximum**
Deep Open Water	0.02	0.0275	0.02	0.0425	0.05
Intermediate Open Water	0.02	0.0275	0.03	0.0425	0.05
Shallow Open Water	0.02	0.0275	0.05	0.0425	0.05
Deep Channel	0.02	0.0275	0.03	0.0425	0.05
Intermediate Channel	0.02	0.0275	0.04	0.0425	0.05
Shallow Channel	0.02	0.0275	0.05	0.0425	0.05
Marsh	0.1	0.1375	0.15	0.2125	0.25
Swamp	0.1	0.1375	0.25	0.2125	0.25

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CP Cell Type	Minimum	Intermediate Minimum	Most-likely Value	Intermediate Maximum	Maximum
Canal/Channel	0.02	0.0275	0.025	0.0425	0.05
Marsh	0.05	0.1375	0.08	0.2125	0.25
Open Water	0.02	0.0275	0.025	0.0425	0.05
PB Cell Type (*see Note above*)	**Minimum Factor**	**Intermediate Minimum factor**	**Most-likely Value**	**Intermediate Maximum factor**	**Maximum factor**
All cells	0.3	0.7	1	1.7	2.8

The diffusion coefficient is the second parameter identified as a source of uncertainty for stage and salinity model outputs. Physical diffusion is sometimes included in numerical models to help smooth out shocks and anomalies in the system, which would otherwise cause the model to crash. The AA and CP regions have numerical diffusion due to the UPWIND scheme used in their models; therefore, the physical diffusion coefficient is set to zero. The PB model utilizes the Central Differencing scheme, which does not have as much numerical diffusion and thus a physical diffusion coefficient was introduced. The diffusion coefficient was used primarily as a calibration parameter based on cell stage and therefore, varies for each cell. In order to calibrate the model, a multiplication factor was applied to the diffusion coefficient. Table 4 shows the range of diffusion coefficients used, as well as the recommended range of factors to multiply by for the uncertainty analysis.

Table 4: Diffusion Coefficient multiplier factors for Uncertainty Analysis (values used in model range: 1-1000 m^2/s). No "direct" connection to ecosystem services could be made.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
PB Model	**Minimum Factor**	**Intermediate Minimum Factor**	**Mean Factor**	**Intermediate Maximum Factor**	**Maximum Factor**
All cells	0.5	0.75	1	1.5	2

Parameters with uncertain effects on deposition and accretion: The following parameters are identified as the main source of uncertainty for sediment and accretion model outputs:

- Critical wind speed
- Base resuspension flux
- Krone's coefficient
- Critical velocity
- Percent sand/fines
- Reference settling velocity

The critical wind speed is the minimum speed at which sediment becomes resuspended into the water column. Therefore, it affects the resuspension rate of sediment, which controls the amount of Total Suspended Solids (TSS) and accretion (ACC). The critical wind speed was calibrated to Lake Pontchartrain in the PB model, but is used across all three regions; this could introduce uncertainty into all of the regions, including the PB region, because it includes Barataria as well as Pontchartrain. Table 5 shows

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the critical wind speed used for all regions and the recommended range of values to analyze its uncertainty.

Table 5: Critical Wind Speed Values for Uncertainty Analysis. A larger value leads to less TSS and high potential for land loss.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
Region	**Minimum**	**Intermediate Minimum**	**Most likely Value**	**Intermediate maximum**	**Maximum**
AA	1.5	2	2	3	4
CP	1.5	2	2	3	4
PB	1.5	2	2.77	3	4

The base resuspension flux*:* The base resuspension flux is the product of the bulk density of sediment and the base resuspension rate of sediment, and it is used as a calibration parameter for resuspension. Uncertainty could come from using one sediment bulk density across the entire domain or from the empirical base resuspension rate. Table 6 shows the base resuspension flux parameters used in each region, along with the recommended range of values used to analyze their uncertainty.

Table 6: Critical Re-suspension Flux Values for Uncertainty Analysis. Larger values lead to lower vertical accretion and high potential of land loss.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
Region	**Minimum**	**Intermediate Minimum**	**Most likely Value**	**Intermediate maximum**	**Maximum**
AA	25	37.5	50	62.5	75
CP	25	37.5	50	62.5	75
PB	25	37.5	50	62.5	75

The Krone's coefficient: The Krone's coefficient is an empirical constant used to calculate the deposition rate of sediment. Because it is empirically defined, it has inherent uncertainty. Table 7 shows the Krone's coefficients used in each region, along with the recommended range of values used to analyze their uncertainty.

Table 7: Krone's Coefficient Values for Uncertainty Analysis (Unitless). A larger value leads to more deposition/accretion and less potential of land loss.

Run # (RXX)	**R04**	**R03**	**R00**	**R02**	**R01**
Region	**Minimum**	**Intermediate Minimum**	**Most likely Value**	**Intermediate Maximum**	**Maximum**
AA	0.0003	0.00048	0.0003	0.00083	0.001
CP	0.0003	0.00048	0.001	0.00083	0.001
PB	0.00012	0.00048	0.00012	0.00083	0.001

The critical velocity: The critical velocity was included in the Eco-Hydrology model to limit the amount of sediment deposited in river deltas. For example, at higher velocities, sediment is less likely to settle than at lower velocities. The uncertainty in specifying values for the critical velocity comes from its empirical nature. Because the CP region does not have large rivers, the critical velocity was not included in the

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model. The PB region redistributes the Mississippi River flow instead of including the critical velocity. The AA region does use the critical velocity, and Table 8 shows the value used, as well as the recommended range of values for the uncertainty analysis.

Table 8: Critical Velocities Values for Uncertainty Analysis (m/d). A higher velocity leads to more sediment settling and more potential for land building.

Run # (RXX)	**R04**	**R03**	**R00**	**R02**	**R01**
AA Model	**Minimum**	**Intermediate Minimum**	**Most likely Value**	**Intermediate Maximum**	**Maximum**
All cells	0.8	0.9	1	1.1	1.2

The percent sand: The PB model included the percent sand to establish the settling ability of the sediment load coming from the Mississippi River. The CP and AA regions did not use the percent sand. The uncertainty of the percent sand comes from the lack of field data. In the PB model, the percent sand is calculated as a function of the River discharge and thus varies for each cell. Table shows the range of percent sand values used as well as the recommended range of factors to multiply by for the uncertainty analysis.

Table 9: Percent Sand multiplier factors for Uncertainty Analysis (%). A lower value of this parameter leads to less accretion and thus higher potential for land loss.

Run # (RXX)	**R04**	**R03**	**R00**	**R02**	**R01**
PB Model	**Minimum**	**Intermediate Minimum**	**Most Likely Value**	**Intermediate Maximum**	**Maximum**
All cells	0.25	0.625	1	1.125	1.25

The reference settling velocity: For the AA and CP models, the reference or baseline settling velocity is calculated from the Krone's equation using TSS and the Krone's coefficient mentioned previously. For the PB model, the reference settling velocity is set to a constant and is corrected based on flocculation and salinity effects. The uncertainty of the reference settling velocity is due to its empirical nature. Table shows the reference settling velocity value used, along with the recommended range of values for the uncertainty analysis.

Table 10: Reference Settling Velocity Values for Uncertainty Analysis (m/d). Higher settling velocity leads to more accretion and higher potential for land building.

Run # (RXX)	**R04**	**R03**	**R00**	**R02**	**R01**
PB Model	**Minimum**	**Intermediate Minimum**	**Most Likely Value**	**Intermediate Maximum**	**Maximum**
All cells	8	10	12	14	16

Parameters with uncertain effects on algae: The following parameters are identified as having uncertain effects on modeling the algae output:

- Sediment denitrification rate at 20 °C
- Half saturation concentration of nitrogen
- Half saturation concentration of phosphorus
- Optimal light

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The sediment denitrification rate is a reaction parameter used to determine the amount of nitrate removed from the water by bacteria in the bed sediment at 20 °C. The uncertainty of the denitrification rate comes from its empirical nature. Table shows the denitrification rates used for all three regions, along with the recommended range of values used to analyze their uncertainty.

Table 11: Sediment Denitrification Rates at 20 °C for Uncertainty Analysis (m/d). A larger denitrification rate results in higher potential of nutrient removal.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
Region	**Minimum**	**Intermediate Minimum**	**Most Likely Value**	**Intermediate Maximum**	**Maximum**
AA	0.04	0.045	0.05	0.06	0.07
CP	0.04	0.045	0.05	0.06	0.07
PB	0.04	0.045	0.08	0.065	0.08

The half saturation concentration of nitrogen: The half saturation concentration of nitrogen is the concentration at half of the maximum algal uptake rate. It is used to determine the nutrient limitation factor and the ammonium preference of algae. The uncertainty of the half saturation concentration of nitrogen comes from its estimation for this project area. Table 1 shows the half saturation concentrations of nitrogen used for all three regions, along with the recommended range of values used to analyze their uncertainty. It should be noted that the PB model uses a variation of the half saturation concentration based on Michealis-Menten's minimization theory.

Table 12: Half Saturation Concentrations of Nitrogen for Uncertainty Analysis (mg/L)**.**

Run # (RXX)	**R04**	**R03**	**R00**	**R02**	**R01**
Region	**Minimum**	**Intermediate Minimum**	**Most Likely Value**	**Intermediate Maximum**	**Maximum**
AA	0.005	0.01	0.02	0.035	0.05
CP	0.01	0.055	0.1	0.55	1
PB	0.016	0.018	0.02	0.022	0.024

The half saturation concentration of phosphorus: The half saturation concentration of phosphorus is the concentration at half of the maximum algal uptake rate. It is used to determine the nutrient limitation factor. The uncertainty of the half saturation concentration of phosphorus comes from its estimation for this project area. Table shows the half saturation concentrations of phosphorus used for all three regions, along with the recommended range of values used to analyze their uncertainty. It should be noted that the PB model uses a variation of the half saturation concentration based on Michealis-Menten's minimization theory.

Table 13: Half Saturation Concentrations of Phosphorus for Uncertainty Analysis (mg/L). Lower half saturation concentration results in more algal growth and more nutrient removal.

Run # (RXX)	**R04**	**R03**	**R00**	**R02**	**R01**
Region	**Minimum**	**Intermediate Minimum**	**Most Likely value**	**Intermediate Maximum**	**Maximum**
AA	0.0005	0.00075	0.001	0.0015	0.002
CP	0.0005	0.00275	0.005	0.0275	0.05
PB	0.0024	0.0027	0.003	0.0033	0.0036

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The optimal light: The optimal light is the photosynthetically available radiation (PAR), or light, at which algal growth is optimal. The uncertainty of the optimal light comes from its estimation for this project area. Table shows the optimal light used for all three regions, along with the recommended range of values used to analyze their uncertainty. It should be noted that the PB model uses a sine curve fit for the optimal light and thus uses a range of values for the year.

Table 14: Optimal Light Values for Uncertainty Analysis (Ly/d). PB model uses a sine curve for optimal light and uses a range of values in the year; the sine function should be varied to provide five possible ranges in this region.

Run # (RXX)	**R04**	**R03**	**R00**	**R02**	**R01**
Region	**Minimum**	**Intermediate Minimum**	**Most Likely value**	**Intermediate Maximum**	**Maximum**
AA	200	250	300	350	400
CP	200	250	300	350	400
PB (see Note above)	200	250	225 - 375	350	400

Wetland Morphology Model

The outputs of the Wetland Morphology model are used as direct and indirect inputs into the calculations of many of the ecosystem services in the master plan, including the five ecosystem metrics selected for the model uncertainty analysis. The model outputs are directly input into the calculations of the alligator habitat and the wave/surge attenuation potential. The model outputs are also used by the vegetation model, which feed directly into the ecosystem service models (e.g., Habitat Suitability Indices), and therefore can be considered as indirect inputs into the calculations of the other three ecosystem services (brown shrimp, oyster, and largemouth bass).

Parameters/Relationships with Uncertain Effects Identified for the Uncertainty Analysis: Given the critical role that the Wetland Morphology model plays in determining the outcome of the ecosystem services, it is important to examine the parameters of this model within the scope of the uncertainty analysis. Based on a thorough discussion with the Wetland Morphology model team, two main model parameters were selected to be included in the uncertainty analysis: the marsh collapse thresholds and bulk density (Table 15).

Table 15: Uncertain parameters/relationships in the Wetland Morphology Model selected for the Uncertainty Analysis.

Parameter/relationship with High Uncertainty	**Function**
Marsh collapse thresholds	Collapse probability and land loss potential
Bulk density	Vertical accretion and elevation

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The current version of the Wetland Morphology model has a default (base) table that specifies the bulk density for different basin/marsh types. Bulk density values were determined based on model calibration, whenever field data were available. It also has a default (base) table that specifies the marsh collapse thresholds for different marsh types. These thresholds were determined based on expert opinion. To reflect the uncertainty in specifying the bulk densities and marsh collapse thresholds, four additional sets (or realizations) of such tables were specified. With the base tables, the five sets of tables represent the following uncertain realizations: most-likely (or base), low, medium-low, medium-high, and high. The following figures and tables present a graphical representation of such tables (exact digital values of these tables have been finalized with the Wetland Morphology model team).

Table 16: Marsh Collapse Threshold Values for Uncertainty Analysis

Note: Lower bound of collapse thresholds was assumed to result in high collapse probability, or high land loss potential.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
Marsh Type	**Low land loss potential**	**Medium-low land loss potential**	**Most-likely value**	**Medium-high land loss potential**	**High land loss potential**
Fresh (salinity: 8 week average -growing season)	8.00	7.50	7.00	6.50	6.00
Intermediate (inundation depth, cm)	38.00	36.18	34.36	32.54	30.72
Brackish (inundation depth, cm)	25.56	24.17	22.78	21.39	20.00
Saline (inundation depth, cm)	25.00	22.75	20.50	18.25	16.00
Swamp (salinity: 8 week average -growing season)	7.00	6.25	5.50	4.75	4.00

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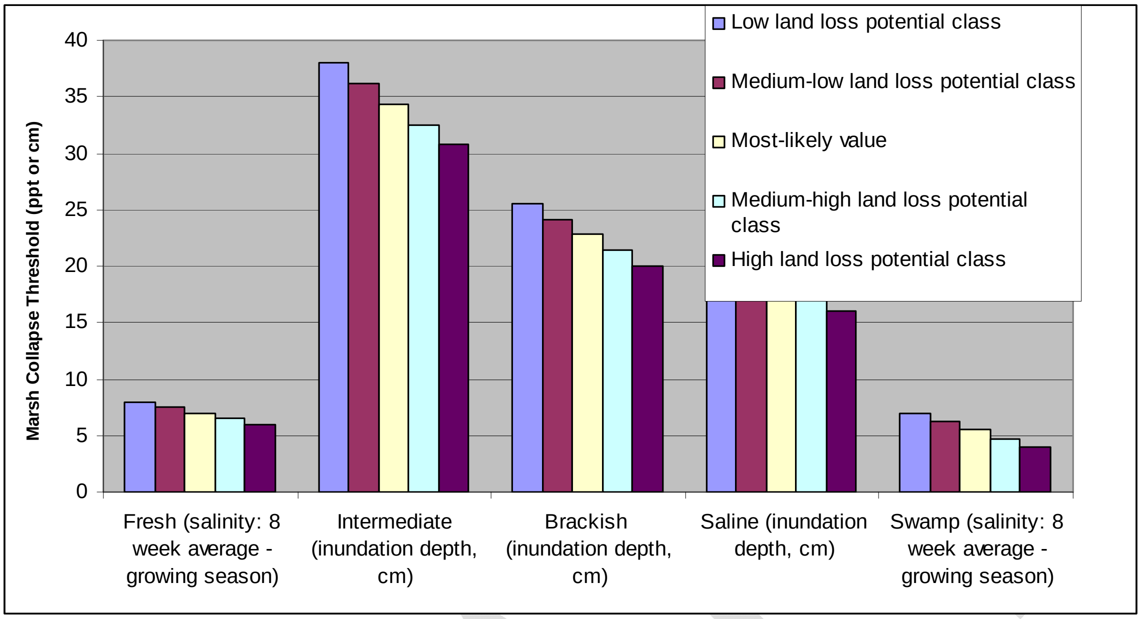

Figure 2: Graphical representation of the marsh collapse threshold uncertainty settings

Table 17: Bulk density Values for Uncertainty Analysis. Note: High Bulk Density leads to lower vertical accretion and, thus lower capability in maintaining surface elevation (or high land loss potential) AT = Atchafalaya, BA = Barataria, BS = Breton Sound, CS = Calcasieu-Sabine, ME = Mermentau, PO= Pontchartrain, TE = Terrebonne, TV = Teche-Vermilion.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
Basin-Marsh Group	**Low land loss potential**	**Medium-low land loss potential**	**Most-likely value**	**Medium-high land loss potential**	**High land loss potential**
ATDelta	0.50	0.79	0.65	1.08	1.37
ATFresh	0.18	0.25	0.25	0.33	0.41
ATInter	0.12	0.36	0.42	0.60	0.84
ATOther	0.13	0.26	0.24	0.39	0.53
ATSwamp	0.17	0.30	0.21	0.43	0.56
BABrack	0.07	0.24	0.15	0.41	0.59
BAFresh	0.03	0.15	0.05	0.28	0.40
BAInter	0.04	0.14	0.08	0.25	0.35
BASalin	0.08	0.27	0.28	0.45	0.64
BSBrack	0.06	0.36	0.23	0.66	0.96
BSSalin	0.23	0.38	0.53	0.53	0.68
CSBrack	0.04	0.30	0.23	0.55	0.80
MEBrack	0.04	0.31	0.38	0.59	0.87

MEFresh	0.02	0.14	0.04	0.25	0.37
MEInter	0.05	0.15	0.19	0.25	0.35
MESalin	0.25	0.33	0.41	0.41	0.49
MRDelta	0.31	0.68	0.46	1.05	1.42
POInter	0.06	0.15	0.11	0.24	0.33
TEBrack	0.05	0.29	0.32	0.53	0.77
TEFresh	0.05	0.16	0.11	0.26	0.37
TEInter	0.04	0.21	0.18	0.38	0.55
TEOther	0.06	0.11	0.10	0.16	0.22
TVBrack	0.08	0.39	0.21	0.70	1.01
TVInter	0.04	0.24	0.16	0.45	0.65
TVSwamp	0.11	0.26	0.36	0.41	0.57

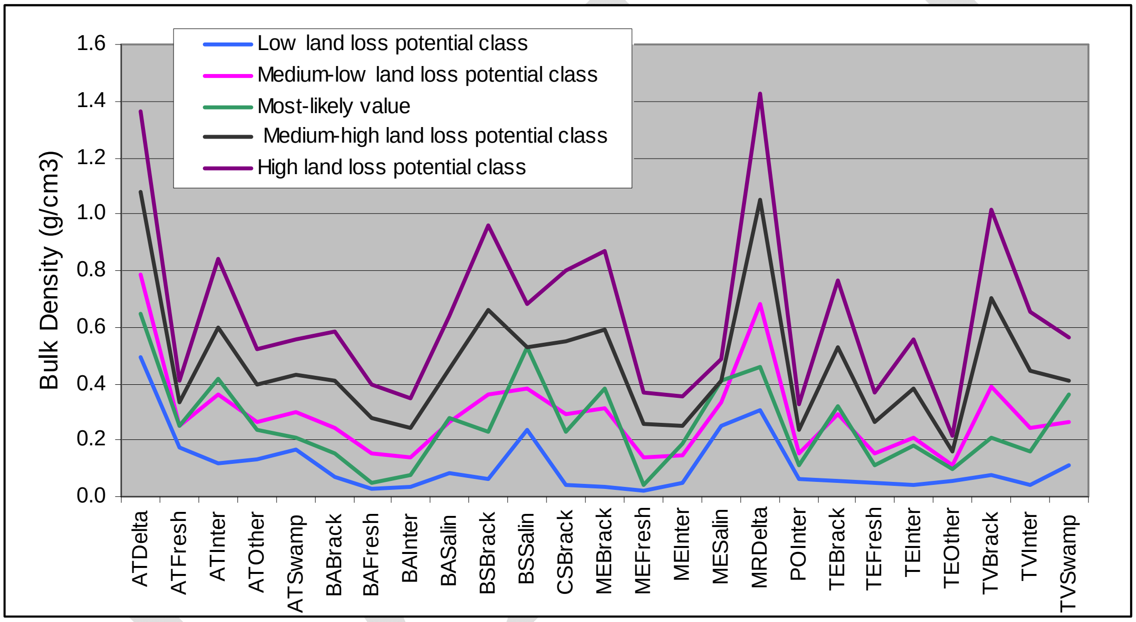

Figure 3: Graphical representation of the bulk density uncertainty settings

Barrier Shoreline Morphology Model

Barrier island and shoreline calculations were based on the Barrier Shoreline Morphology model (also referred to as the Coastal Morphology Model (CMM)), which simulates coastline and inlet evolution in response to physical forcing such as offshore wave climate, sea level rise and storms. The Coastal Morphology model has two components, the inlet morphology model (IMM) and the barrier morphology model (BMM). In addition, the CMM produced output in two spatial sections, the Chandeleur Island Chain and the Terrebonne and Barataria Island Chains.

Parameters/Relationships with High Uncertainty Identified for the Uncertainty Analysis: Based on discussions with the Barrier Shoreline Morphology model team, the following parameters were

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identified and selected for the uncertainty analysis. Tables 18 and 19 provide the different uncertainty settings selected for these parameters.

Parameters in the barrier morphology model (BMM):

- Parameter beta (β) that specifies the sand/mud fraction
- Closure depth (d_c)
- Mean grain diameter (D_{50})

Parameters in the inlet morphology model (IMM):

- Exponent for the gulf coast inlets (a)
- Gulf coast coefficient (k)

Parameters (a) and (k) are used to compute the likely increase in the inlet cross-sectional area based on the Gulf Coast version of the Jarrett-O'Brien relationship given by $A = kP^a$ where P is the maximum annual tidal prism.

Table 18: Barrier Morphology Model (BMM) Values for Uncertainty Analysis.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
parameter	**Minimum impact**	**Intermediate Minimum impact**	**Most likely Value**	**Intermediate maximum impact**	**Maximum impact**
beta	0.05	0.01	0.0225	0.1	0.17
dc_Caminada (m)	-10	-15	-12.5	-8.5	-7.5
dc_R2S (m)	-6	-10	-8	-5	-4
dc_Chan (m)	-8	-15	-11	-6.5	-5

Table 19: Inlet morphology model (IMM) Values for Uncertainty Analysis.

Run # (RXX)	**R01**	**R02**	**R00**	**R03**	**R04**
parameter	**Minimum impact**	**Intermediate Minimum impact**	**Most likely Value**	**Intermediate maximum impact**	**Maximum impact**
alpha ('a')	0.73	0.83	0.86	0.93	0.99
kappa ('k')	0.000297	0.000324	0.000351	0.000384	0.000416

Vegetation Model

The purpose of the Vegetation model is to forecast changes in vegetation distribution/composition based on changes in elevation, water level, and salinity. The output of the vegetation model (% of each vegetation class in each cell) is used as a direct input to many of the Ecosystem Service models, including four of the five selected selected for the uncertainty analysis (alligator, brown shrimp, largemouth bass, and surge/wave attenuation).

Parameters/Relationships with High Uncertainty Identified for the Uncertainty Analysis: Given the critical role played by the Vegetation model in determining the outcome of many ecosystem services, it

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is important to examine the parameters of this model within the scope of the uncertainty analysis. Based on a thorough discussion with the Vegetation model team lead, the parameters/relationships with the greatest uncertainty within the Vegetation model are the establishment and probability of death tables, see Table 20. The establishment tables are used to decide on how a certain vegetation class is established on a bare-ground cell. The probability of death tables (one table for each vegetation class) determine the probability of death of a certain vegetation class in a certain cell. Both sets of tables (establishment and death) are functions of combinations of two variables: mean annual salinity and water level variability. The dependency of establishment and probability of death on water level variability and salinity combinations is estimated from published data and is also based on available data from Coastwide Reference Monitoring System (CRMS) stations. While the establishment/death dependence on salinity is fairly reliable, the dependence of establishment-death on water level variability is less certain. Therefore, the rules and logic that control the dependence of the establishment (Figure 4) and death probabilities on water level variability (Figure 5) will be varied in this analysis. The current version of the Vegetation model has a set of default (base) tables that include: an establishment-salinity-water variability table, and probability of death tables for different vegetation classes. For the purposes of the uncertainty analysis, four additional sets (or realizations) of such tables were established to reflect the uncertainties in the dependencies of establishment/death probabilities on the water level variability and salinity conditions. With the base tables, the five sets of tables represent the following uncertain realizations: most-likely (or base), low, medium-low, medium-high, and high. The following figures present a graphical representation of such tables (exact digital values of these tables have been finalized with the Vegetation model team).

Table 20: Parameters/Relationships with High Uncertainty in the Vegetation Model Selected for the Uncertainty Analysis.

Parameter/relationship with High Uncertainty	**Function**
Establishment table	Specifies conditions of salinity and water level variability that lead to establishment of certain
Probability of death tables (one table for each of the 21 vegetation classes)	Specifies conditions of salinity and water level variability that lead to "death" of each vegetation class

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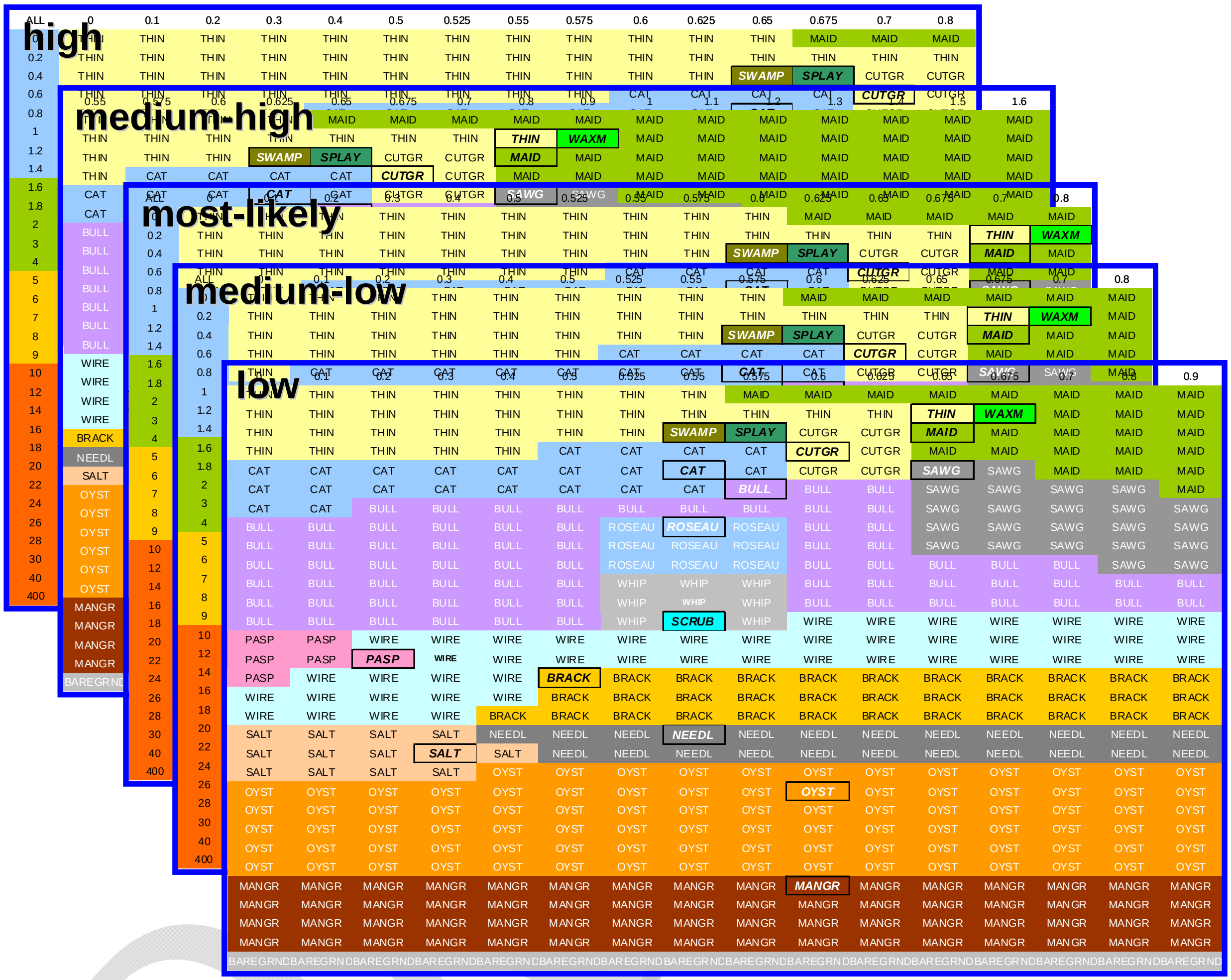

0	0.1	0.2	0.3	0.4	0.5	0.525	0.55	0.575	0.6	0.625	0.65	0.675	0.7	0.8	0.9
THIN	THIN	THIN	THIN	THIN	THIN	THIN	THIN	MAID	MAID	MAID	MAID	MAID	MAID	MAID	MAID
THIN	THIN	THIN	THIN	THIN	THIN	THIN	THIN	THIN	THIN	THIN	**THIN**	**WAXM**	MAID	MAID	MAID
THIN	THIN	THIN	THIN	THIN	THIN	THIN	**SWAMP**	**SPLAY**	CUTGR	CUTGR	**MAID**	MAID	MAID	MAID	MAID
THIN	THIN	THIN	THIN	THIN	CAT	CAT	CAT	CAT	**CUTGR**	CUTGR	MAID	MAID	MAID	MAID	MAID
CAT	CAT	CAT	CAT	CAT	CAT	CAT	**CAT**	CAT	CUTGR	CUTGR	**SAWG**	SAWG	MAID	MAID	MAID
CAT	CAT	CAT	CAT	CAT	CAT	CAT	CAT	**BULL**	BULL	BULL	SAWG	SAWG	SAWG	SAWG	MAID
CAT	CAT	BULL	BULL	BULL	BULL	BULL	BULL	BULL	BULL	BULL	SAWG	SAWG	SAWG	SAWG	SAWG
BULL	BULL	BULL	BULL	BULL	BULL	ROSEAU	**ROSEAU**	ROSEAU	BULL	BULL	SAWG	SAWG	SAWG	SAWG	SAWG
BULL	BULL	BULL	BULL	BULL	BULL	ROSEAU	ROSEAU	ROSEAU	BULL	BULL	SAWG	SAWG	SAWG	SAWG	SAWG
BULL	BULL	BULL	BULL	BULL	BULL	ROSEAU	ROSEAU	ROSEAU	BULL	BULL	BULL	BULL	BULL	SAWG	SAWG
BULL	BULL	BULL	BULL	BULL	BULL	WHIP	WHIP	WHIP	BULL	BULL	BULL	BULL	BULL	BULL	BULL
BULL	BULL	BULL	BULL	BULL	BULL	WHIP	WHIP	WHIP	BULL	BULL	BULL	BULL	BULL	BULL	BULL
BULL	BULL	BULL	BULL	BULL	BULL	WHIP	**SCRUB**	WHIP	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE
PASP	PASP	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE
PASP	PASP	**PASP**	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE	WIRE
PASP	WIRE	WIRE	WIRE	WIRE	**BRACK**	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK
WIRE	WIRE	WIRE	WIRE	WIRE	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK
WIRE	WIRE	WIRE	WIRE	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK	BRACK
SALT	SALT	SALT	SALT	NEEDL	NEEDL	NEEDL	**NEEDL**	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL
SALT	SALT	SALT	**SALT**	SALT	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL	NEEDL
SALT	SALT	SALT	SALT	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST
OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	**OYST**	OYST	OYST	OYST	OYST	OYST	OYST
OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST	OYST
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MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	**MANGR**	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR
MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR
MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR
MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR	MANGR
BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND	BAREGRND

Figure 4: Representation of five possible realizations reflecting uncertainties in the establishment table in the Vegetation model.

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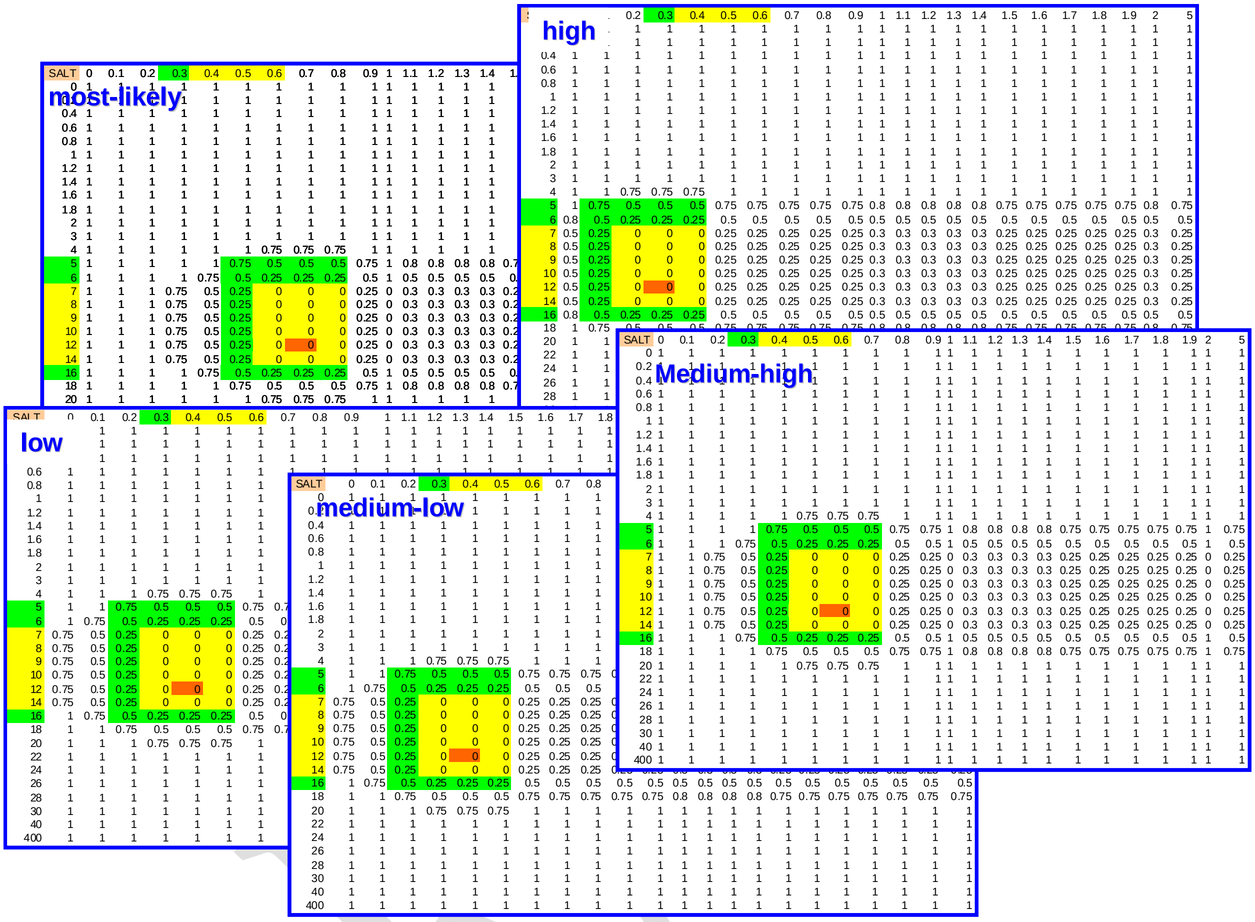


Figure 5: Representation of five possible realizations reflecting uncertainties in the probability of death tables in the Vegetation model (shown for one class of vegetation, saltgrass; other sets of tables were derived for all 21 vegetation classes).

Ecosystem Services Models

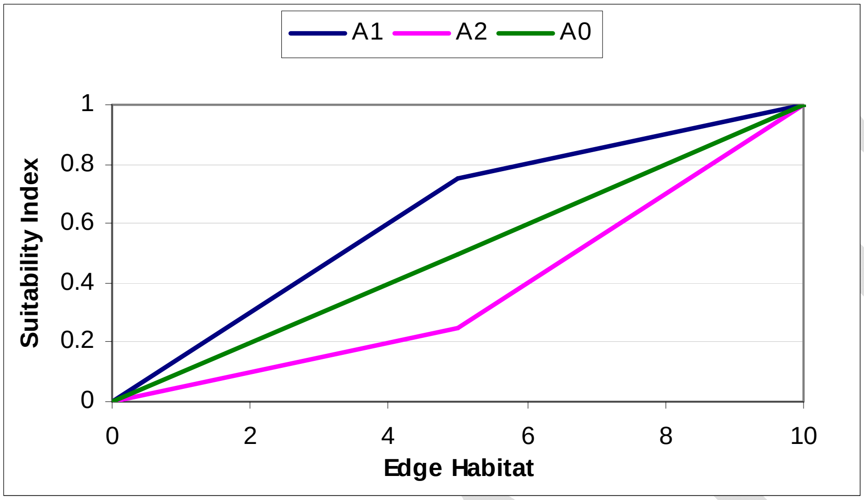
As previously discussed, the current UA study concentrates on five ecosystem services: Alligator Habitat, Juvenile Brown Shrimp Habitat, Largemouth Bass Habitat, Oyster Habitat, and Surge-Wave Attenuation. These services are calculated using a set of Habitat Suitability Indices and Ecosystem Service (ESS) Models. The Alligator Habitat, Juvenile Brown Shrimp Habitat, Largemouth Bass Habitat, and Oyster Habitat models include a set of rules that determine the habitat suitability index value as a function of input variables that are provided by the earlier models (e.g. Eco-Hydrology, Wetland Morphology, Vegetation, etc.). The Surge-Wave Attenuation model includes a set of rules that determine the potential of the landscape to provide surge-wave attenuation. Table 21 lists these five models and indicates which specific inputs and decision rules are being assessed for uncertainty.

Table 21: List of Input Variables and Decision Rules of the Five Ecosystem Services Included in the Uncertainty Analysis.

Ecosystem service	Input/decision rule	Included in uncertainty analysis	Source of inputs
Alligator	1. V1: % land		Wetland morphology
	2. V2: water depth	Yes	Eco-hydrology
	3. V3: habitat type		Vegetation
	4. V4: edge	Yes	Wetland morphology
	5. V5: salinity	Yes	Eco-hydrology
Brown shrimp	1. V1: % area covered by marsh vegetation	Yes (by using same weights for V1 & V3)	Vegetation
	2. V2: mean spring salinity (Feb-May)		Eco-hydrology
	3. V3: mean spring water temperature (Feb-May)	Yes	Eco-hydrology
Freshwater fisheries (largemouth bass)	1. V1 - percent water with SAV per 500m^2	Yes	Vegetation
	2. V2 - average water temperature for April-August		Eco-hydrology
	3. V3 - maximum yearly salinity for June to August		Eco-hydrology
	4. V6 - % of cell that is permanently dry land per 1km^2	Yes	Vegetation
	5. V7 - index value of primary productivity in open waters		Eco-hydrology
Oyster	1. V1: % cultch	Yes	Mapped reefs, leases
	2. V2: mean salinity for May-Sep		Eco-hydrology
	3. V3: minimum salinity		Eco-hydrology
	4. V4: annual mean salinity		Eco-hydrology
Surge/wave attenuation	1. V1: location relative to perimeter of an area designated for a 100- or 500-year risk reduction	Yes	
	2. V2: % land/water		Wetland morphology
	3. V3: vegetation type		Vegetation
	4. V4: mean elevation	Yes	Wetland morphology

Alligator Habitat

The alligator model has a total of five variables and decision rules that determine the Habitat Suitability Index. Based on Table 21, and according to discussions with the model team, three of these variables are included in the uncertainty analysis (water depth, edge, and salinity). These variables and decision rules were selected because of their high impact on the habitat quality and the potential uncertainties associated with specifying their decision rules. The following is a representation of how the three decision rules are varied within the uncertainty analysis.



	A_0	A_1	A_2
V_2 (Water Depth)	SI = 0 V2<-0.3 & V2>0 SI=V2/0.15+2 -0.3<V2<-0.15 SI=V2/(-0.15) -0.15<V2<0	SI=0 V2<-0.3 SI=V2/0.1+3. -0.3<V2<-0.2 SI=V2/(-0.1) -0.1<V2<0 SI=1 -0.2<V2<-0.1 SI=0 V2>0	SI = 0 V2<-0.3 SI=V2/0.08+3.75 -0.3<V2<-0.22 SI=V2/(-0.08) -0.08<V2<0 SI=1 -0.22<V2<-0.08 SI=0 V2>0
V_4 (Edge)	SI=0 V4<0 SI=0.1V4 0<V4<10 SI=1 V4 >10	SI=0 V4<0 SI=0.05V4 0<V4<5 SI=0.15V4-0.5 5<V4<10 SI=1 V4 >10	SI=0 V4<0 SI=0.15V4 0<V4<5 SI=0.05V4+0.5 5<V4<10 SI=1 V4 >10
V_5 (Salinity)	SI=1-0.1V5 0<V5<10 SI=0 V5>10	SI=1-0.091V5 0<V5<11 SI=0 V5>11	SI=1-0.0833V5 0<V5<12 SI=0 V5>12

Brown Shrimp (juvenile) Habitat

The brown shrimp model has a total of three variables and decision rules that determine the Habitat Suitability Index. Based on Table 21, and according to discussions with the brown shrimp model team, the mean water spring temperature variable and its decision rule are included in the uncertainty analysis. In addition, the HSI formula used to combine the three SI's is varied to give more equal weights to the vegetation (SI_1) and mean spring temperature (SI_3). The following is a representation of how these decision rules are varied within the uncertainty analysis.

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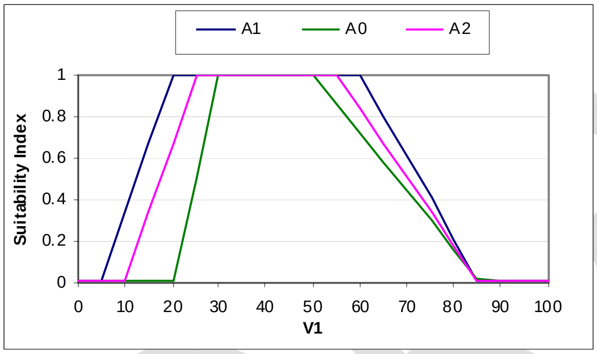
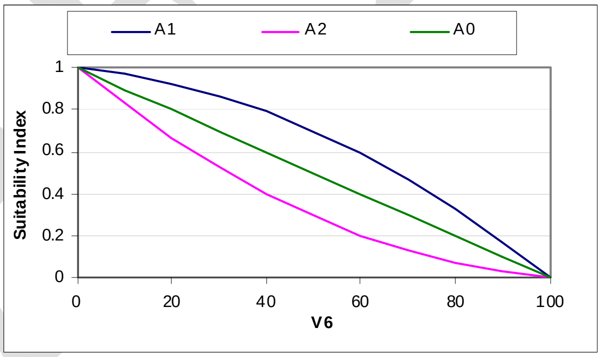
	A_0	A_1	A_2
V_3 (Mean Spring water temperature)	SI = 0 V3<10 SI=0.1V3-1 10<V3<20 SI=1 20<V3<30 SI=-0.1V3+4 30<V3>40 SI=0 V3>40	SI = 0 V3<10 SI=0.0677V3-0.667 10<V3<25 SI=1 25<V3<30 SI=-0.1V3+4 30<V3>40 SI=0 V3>40	SI = 0 V3<10 SI=0.0833V3-0.833 10<V3<22 SI=1 22<V3<30 SI=-0.1V3+4 30<V3>40 SI=0 V3>40
Overall HSI	$HSI=(SI_1^{2} x SI_2 x SI_3)^{1/4}$	$HSI=(SI_1 x SI_2 x SI_3)^{1/3}$	$HSI=(SI_1^{2} x SI_2 x SI_3^{2})^{1/5}$

Largemouth Bass Habitat

The largemouth bass model has a total of six variables and decision rules that determine the Habitat Suitability Index (HSI). Based on Table 21, and according to discussions with the model team, three of these variables and their decision rules are included in the uncertainty analysis (percent emergent vegetation per 500m^2, and % of cell that is permanently dry land per 1km^2). The following is a representation of how these decision rules are varied within the uncertainty analysis.





	A_0	A_1	A_2
V_1(Mean Spring water temperature)	SI = 0.01 V1<20 SI=0.05V1-0.05 20<V1<30 SI=1 30<V1<50 SI= -0.028V1+2.4 50<V1>85 SI=0.01 V1>85	SI = 0.01 V1<5 SI=0.066V1-0.32 5<V1<20 SI=1 20<V1<60 SI= -0.0396V1+3.376 60<V1<85 SI=0.01 V1>85	SI = 0.01 V1<10 SI=0.066V1-0.65 10<V1<25 SI=1 25<V1<55 SI= -0.033V1+2.815 55<V1<85 SI=0.01 V1>85
V6 ([1 - (% open water + % emergent vegetation)]*100)	SI = 1-0.01*V6 0< V6 < 100	SI= -0.007*V6+1 0< V6 <50 SI= -0.013*V6+1.3 50< V6 <100	SI= -0.013*V6+1 0< V6 <50 SI= -0.007*V6+1.3 50< V6 <100

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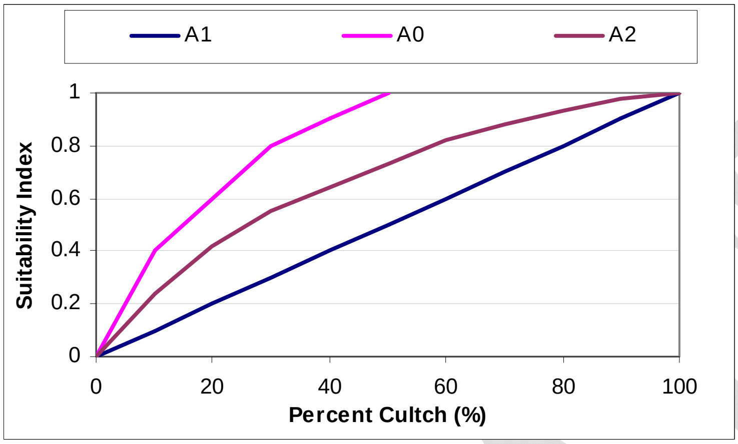
Oyster Habitat

The oyster model has a total of four variables and decision rules that determine the Habitat Suitability Index. Based on Table 21, and according to discussions with the oyster model team, the percent cultch variable and its decision rule are included in the uncertainty analysis. The following is a representation of how the percent cultch decision rule is varied within the uncertainty analysis.



	A_0	A_1	A_2
V_1 (Percent Cultch)	SI = 0 V1<0	SI = 0 V1<=0	SI = 0 V1<=0
	SI = 0.04 V1 0<V1<10	SI=0.01V1 0<=V1<=100	SI=0.021V1 0<=V1<=20
	SI = 0.2 + 0.02 V1 10<V1<30	SI=1 V1>=100	SI=0.22+0.01V1 20<=V1<60
	SI = 0.5 + 0.01 V1 0<V1<50		SI=0.55+0.0045V1 60<=V1<=100
	SI=1 V1>50		SI=1 V1>=100

Surge/Wave Attenuation, Potential for

The surge-wave attenuation potential model has a total of four variables and decision rules that determine the Suitability Index. Based on Table 21, and according to discussions with the ecosystem service model team, two of these variables and their decision rules are included in the uncertainty analysis (V1: location relative to perimeter of an area designated for a 100- or 500-year risk reduction, and V4: mean elevation). The following is a graphical/tabular representation of how these decision rules are varied within the uncertainty analysis.

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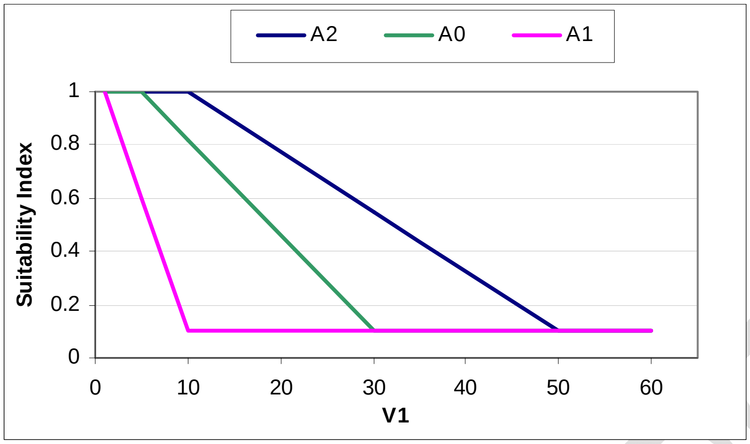

	A_0	A_1	A_2
V_1 (Cell Distance from an Area Designated for a 100 or 500 yr Level of Risk Reduction)	SI = 1 V1<5 SI=(-0.036V1)+1.18 5<V1<30 SI=0.1 V1>30	SI = 1 V1<1 SI=1-0.1(V1-1) 1<V1<10 SI=0.1 V1>10	SI = 1 V1<10 SI=1-0.0025(V1-10) 10<V1<50 SI=0.1 V1>50
V_4 (Land Elevation)	SI = 1.0 V4 > 1.0 SI = 0.7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

Design of Sampling Experiment

The previous sections described the selection of (1) a set of ecosystem services that are critical for the master plan objectives, (2) a set of model parameters and relationships that have the most effect on the selected ecosystem services, yet are perceived to have potentially high uncertainty on model output, and (3) a set of possible parameter/relation values that reflect the uncertainty in these parameters/relationships. These parameter values and ranges represent a proxy for the full probability distributions. Next, a simulation experiment composed of multiple model runs was designed (Table 22) based on limited sampling from the parameter distributions identified above. The design was based on a set of carefully selected combinations of parameter values such that the parameter combinations produce the widest possible range in the model outputs and the five previously identified ecosystem service metrics. The design takes into account the "computational cost" associated with each model. For example, the Eco-Hydrology and Wetland Morphology models are fairly expensive computationally and involve extensive effort for data handling and pre- and post-processing. Therefore, only few UA runs for these models were conducted (Table 22). The Vegetation model can accommodate more runs and as such more parameter combinations were possible. The Ecosystem Service model calculations are computationally inexpensive, and therefore a larger number of parameter combinations were made

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(Table 22). The design shown in Table 22 results in a total of 27 runs (last row in the table) for each of the five ecosystem services selected earlier.

Table 22: Configurations of uncertainty analysis runs (realizations, Rxx) for the Vegetation model (R00 to R08) and UTL/ESS models (R11-R38) based on the incoming uncertainty runs (R00 to R04) from the Eco-Hydrology and Wetland Morphology models.

Model UA Settings	**Low-Impact**	**Medium-low impact**	**Base case**	**Medium-high impact**	**High-impact**	**Low-Impact**	**Medium-low impact**	**Base case**	**Medium-high impact**
Eco-Hydro & Wetland Morph UA Runs (*)	**R01**	**R02**	**R00**	**R03**	**R04**	**R01**	**R02**	**R03**	**R04**
Vegetation Model UA Settings	**Low-tables**	**Medium-low tables**	**Base Tables**	**Medium-high tables**	**High-tables**	**High-tables**	**Medium-high tables**	**Medium-low tables**	**Low-tables**
Vegetation Model UA Runs	**R01**	**R02**	**R00**	**R03**	**R04**	**R05**	**R06**	**R07**	**R08**
Ecosystem Services UA Settings	**3 Alternative Rules for each uncertain Variable (Base, Alt-1 & Alt-2)**								
Ecosystem Services UA Runs	**R11, R21, R31**	**R12, R22, R32**	**R10, R20, R30**	**R13, R23, R33**	**R14, R24, R34**	**R15, R25, R35**	**R16, R26, R36**	**R17, R27, R37**	**R18, R28, R38**

(*) see Tables 2-16 for specification of model parameters in each run (R00-R04)
(**) see Figures 4 and 5 for details on the 5 possible uncertain tables in the Vegetation model
(***) see Section on Ecosystem Services calculations for specification of the three alternative rules A0, A1 and A2

Current Status and Next Steps

The modeling teams have finished performing all the UA runs identified in Table 22 above. This included 5 runs (R00-R04) for the Eco-Hydrology model, Wetland Morphology, and Barrier Shoreline Morphology models and 9 runs (R00-R08) for the Vegetation model. A computer program that allows automatic multiple runs for the Ecosystem Service models was developed. This computer program was used to perform the 27 runs (R10-R38) defined above in Table 22. The output of these runs is being analyzed using a statistical analysis. In this analysis, the results from the multiple runs described above is being used to study the variability and uncertainty in the predictions of the ecosystem services due to the incoming uncertainties in the model parameters. Empirically-based probability distributions of the ecosystem services are being constructed and used to analyze the uncertainty in the predicted ecosystem services and make various types of inferences such as: (i) assess the impact of model uncertainties on the selected ecosystem services and (ii) make probabilistic statements on whether and how such uncertainties can affect the evaluation of different project alternatives.

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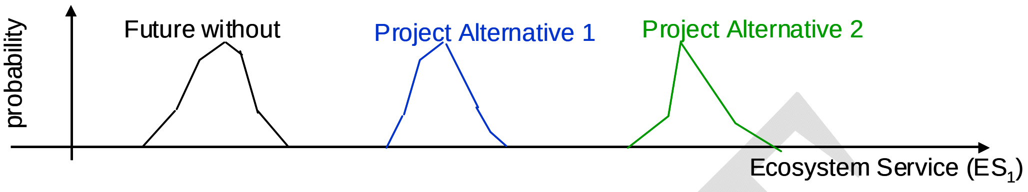
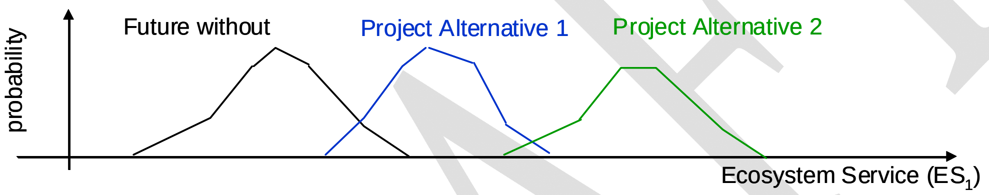
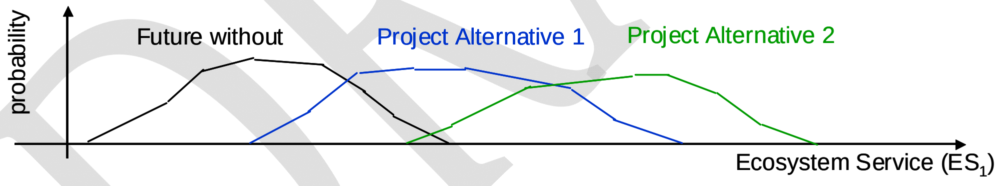
The following "hypothetical" examples provide a rough representation of the kind of analyses and statistical interpretation that will be performed on results from the UA runs. Analysis based on actual results from the multiple UA model runs is pending and will be presented in the final report.



Uncertainties are negligible and don't cause any ambiguities in judging the performance of certain projects in comparison to the future/without case. Project 1 and Project 2 offer higher levels of ecosystem service (ES1), and Project 2 is clearly more favorable than Project 1



Uncertainties are significant but not large enough to cause ambiguities in judging the performance of certain projects in comparison to the future/without case. Project 1 and Project 2 offer higher levels of ecosystem service (ES1), and Project 2 is clearly more favorable than Project 1



- Uncertainties are large enough to lead to ambiguities in judging the performance of certain projects in comparison to future/without case. While "on average" both projects seem more favorable than future/without case, the model-induced uncertainties are too wide to the point that they mask the differences between the different cases. Similarly, Project 2 seem on average more favorable than Project 1 but because of the parameter-induced uncertainties, the favorable performance of Project 2 cannot be established with sufficient confidence.

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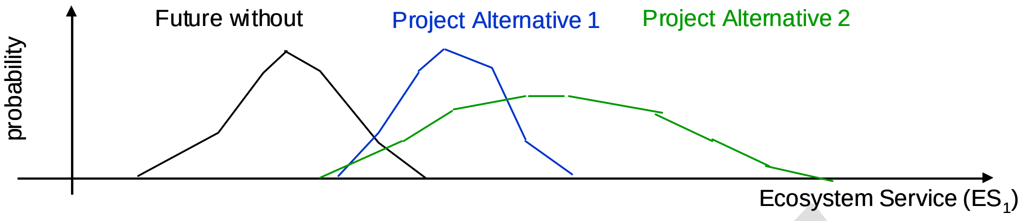
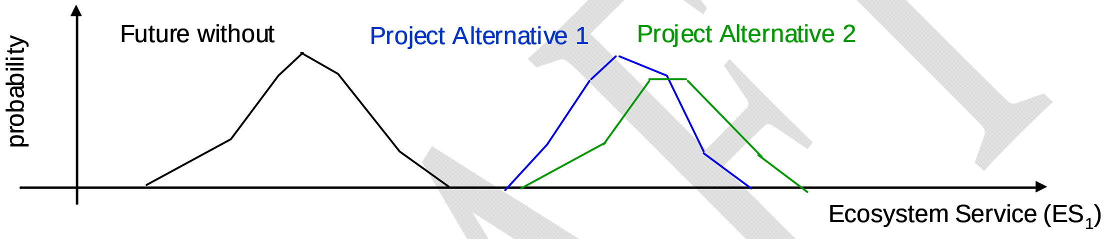


Project 1 and 2 offer better ecosystem service values over future/without case. While Project 2 seems more favorable than Project 1, Project 1 may still be selected because the uncertainty associated with Project 2 is too wide. Even though Project 1 has an average ES1 that is larger than that of Project 1, Project 2 is more vulnerable/sensitive to model parameter-induced uncertainties than Project 1.



Project 1 and 2 offer better ecosystem service values over future/without case. While Project 2 seems more favorable than Project 1, it is difficult to clearly decide on which project to select since their model-induced uncertainties cause their performance to overlap significantly. Model-induced uncertainties lead to significant ambiguities in distinguishing between two different projects.

Finally, the master plan team is considering performing additional uncertainty analysis on the area of land gained/lost as a criterion for analysis of proposed restoration and protection projects.

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