Model Name: Landscape Change and Relative Elevation Sub-models

Functional Area: Wetland Morphology

Model Proponents: Coastal Protection and Restoration Authority

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1. *Background*

a. Purpose of Model

Predicting future conditions for the entire coastal Louisiana landscape requires the formulation of a comprehensive modeling approach. The 2012 Coastal Master Plan (master plan) utilized output from a suite of predictive models developed by teams representing Wetland Morphology, Eco-Hydrology, Barrier Shoreline Morphology, Vegetation, Ecosystem Services (e.g., upper trophic levels), Storm Surge and Waves, and Risk Assessment to evaluate the performance of potential coastal protection and restoration projects over the next 50 years. This report describes the Wetland Morphology model which is comprised of landscape change and relative elevation sub-models. The sub-models described herein are built upon landscape change desktop models that were used to predict the effects of restoration alternatives for the Louisiana Coastal Area (LCA; U.S. Army Corps of Engineers, 2004) and Coastal Protection and Restoration Authority (CPRA) master plan (CPRA, 2007) efforts. Previous desktop models (Visser et al., 2003a, 2008) relied heavily on: (1) historical land loss trends to project into the future, (2) empirical relationships between land loss and distance to freshwater input, and (3) landscape analogs of delta progradation. These models assume that the processes that caused loss in the past will be operating in the future.

The motivation to modify the existing landscape change models and develop a new relative elevation model was driven by the requirement to model two scenarios of future conditions, based on a suite of environmental uncertainties (see Appendix C – Environmental Uncertainties). Two of the critical uncertainties captured in the scenarios that greatly influence the outcome of a landscape change model are sea level rise and subsidence. Incorporation of these uncertainties dictated the need for two sub-models to track changes both horizontally (land and water change) and vertically (elevation) across the landscape. Comprehensive coast wide field data collected under the Coastal Wetlands Planning, Protection and Restoration Act's (CWPPRA) Coastwide Reference Monitoring System (CRMS, http://www.lacoast.gov/crms2/Home.aspx) , and recent updated digital elevation and satellite imagery, provided sufficient data to develop the models.

Understanding the potential effects of sea level rise, subsidence and other stressors on coastal ecosystems and the extent to which protection and restoration can positively mitigate those factors, are important questions to policy makers, resource managers, scientists, and the general public. Assessing, to the extent that the science allows, where coastal wetland landscapes are stable and sustainable, where they are susceptible to loss, and where protection and restoration measures can slow or reverse trends of loss, can inform decision-makers and the public on where to invest in the future. The landscape change and relative elevation sub-models provide projections of wetland and water acreage, landscape configuration, vertical accretion and elevation under varying scenarios of accelerated sea level rise, subsidence and protection and restoration projects from 2010 to 2060. The benefits of these planning models are that they can effectively and efficiently conduct a large number of model runs that evaluate future with action versus future without action (FWOA) under a variety of future conditions.

b. Model Description and Depiction

The Wetland Morphology model was developed to predict coastal Louisiana wetland morphologic dynamics in a changing environment (e.g., global warming, eustatic sea- level rise [ESLR], land subsidence, freshwater and mineral sediment supply reductions). The model consists of relative elevation and landscape change sub-models that are developed based upon the best available data and our most recent understanding of the role of coastal biophysical processes including land loss, land gain, marsh collapse, sediment transport, sediment deposition, sediment retention, vertical accretion, organic matter production, sea level rise (SLR), and subsidence on shaping coastal morphology.

The relative elevation sub-model determines coastal wetland surface elevation change in response to both natural factors (e.g., land subsidence, sea level rise) and human activities (e.g., restoration activities, wetland management alternatives) by examining the roles of both organic matter and inorganic sediments on wetland vertical accretion and surface elevation (Twilley and Nyman, 2005). Mineral sediment contribution is estimated by a sediment model provided from the Eco-Hydrology model. Sediment accumulation is assumed to represent the long-term net available sediment input (i.e., deposition - erosion/resuspension) in the system. Organic matter contributions to vertical accretion are determined by mineral sediment accumulation, soil bulk density (BD), and percentage of organic matter content (OM%). Organic matter content is estimated by a curvilinear relationship between OM% and BD (See Section 2 "Technical Quality" for details) observed using monitoring data from CRMS. In this sub-model, vertical accretion rate is estimated by dividing sediment accumulation (mineral and organic) by BD (See Section 2 "Technical Quality" for model equations). For a given amount of sediment accumulation, the variation in BD values determines the degree of uncertainty in estimating vertical accretion rates. Therefore, representative BD and OM% have to be examined and applied due to the non-equilibrium nature of BD and OM% with depth in the wetland soils of coastal Louisiana. We define the representative BD and OM% as the values of BD and OM% that are capable of describing long-term (multi-decadal) vertical accretion rates in soil. In other words, the simulated vertical accretion rates should match closely with the observed rates while using the representative BD and OM% values in model simulation. Representative BD and OM% were obtained for different combinations of hydrologic basins and vegetation types through calibration using coast wide long-term sediment accumulation and vertical accretion field data collected from the Louisiana Coastal Area Science and Technology (LCA S&T) Program during 2006-2007 in addition to soil data collected from CRMS during 2006-2008. Wetland vertical accretion rates were compared with eustatic sea level rise (ESLR) and subsidence rates (ESLR + subsidence = Relative SLR) to determine the wetland surface elevation balance (elevation deficit if accretion < RSLR). The surface elevation balance is used to examine and predict the changes in the soil organic carbon (SOC) storage within a certain depth (e.g., 1 m) and SOC sequestration potential (so called potential because elevation change is not necessarily representing the real change in the depth of soil layers under RSLR and protection and restoration projects) (Zhong and Xu, 2009; DeLaune and White, 2011). The current version of the relative elevation sub-model takes into account the influence of different vegetation community types on accretionary rates by switching BD and OM% values when vegetation types change. The model does not explicitly and directly take into account the influence of wetland plant growth and below-ground soil processes, such as soil compaction and organic matter decomposition, on vertical accretion due to data limitations and limited scientific understanding regarding the relative influences of above- and below-ground biophysical processes on vertical accretion in all vegetation communities in coastal Louisiana. Nevertheless, the ultimate long-term effects of these below-ground soil processes are considered in the sub-model through an observed empirical relationship between mineral and organic matter accumulation, although it is not a mechanistic model.

The landscape change sub-model is capable of predicting coast wide land and water area and landscape configuration (fragmentation and connection) under different scenarios of ESLR, subsidence and protection and restoration projects by considering the influences of coastal processes such as sediment transport, deposition, hurricanes/storms, vegetation community productivity and distribution, tidal and freshwater induced inundation, and saltwater intrusion. The landscape change sub-model predicts coast wide wetland morphologic dynamics by incorporating decadal land change trends (Couvillion et al., 2011); exploring probabilities of marsh collapse (vegetated area converted into open water) given changes in inundation (depth) and salinity regime by building upon productivity-stressor relationships described in Visser et al. (2003b); updating landscape topography and bathymetry by incorporating the relative elevation sub-model (See details in relative elevation sub-model); redistributing the box-level sediment accumulation from the Eco-Hydrology model at a fine resolution (i.e., 30m grid cell size) based on a coast wide stream network, elevation, source of sediment and distribution probability; and coupling with coast wide Eco-Hydrology and Vegetation models. This sub-model is limited by the inability to describe salinity, water stage and sediment accumulation at fine resolutions and the inability to accurately estimate sediment accumulation over space contributed by hurricanes and storms.

c. Contribution to Planning Effort

Long-term protection and restoration planning requires forecasts of landscape changes associated with changes in environmental drivers at the systems scale. The Wetland Morphology model accommodates flexibility in its design by being spatially-explicit, scalable (i.e., 30m, 500m, or larger; 0 to 50-year time-step), and modular, such that it can be linked under a geospatial framework to any other model. It is also adaptable to be updated as new scientific understanding or new datasets are available. The Wetland Morphology model is dependent upon input data from the Eco-Hydrology model, so if higher resolution and fidelity hydrodynamic models are available, a more robust Wetland Morphology model can be developed. This would enable an assessment of effects of planned activities, such as re-engineering the Mississippi River for a tighter linkage between freshwater and sediment delivery processes and resulting landscape change and elevation dynamics, by providing enhanced assessments of diversions and other land building features (e.g., Allison and Meselhe, 2010; Boustany, 2010; Winer, 2011). Simulation results could also provide information for risk and benefit assessment for adaptive management.

d. Description of Input Data

The Wetland Morphology model is driven by salinity, water level (stage) and sediment accumulation input data provided by the Eco-Hydrology model and plant community distribution data for selection of representative BD and OM% from the Vegetation model. The relative elevation and landscape change sub-models utilize spatial data at a 30m resolution and also compiled data at 500m resolution. These data are compiled across the entire Louisiana coastal domain from the Texas border in the west to the Mississippi border in the east, and a 10-m elevation contour to the north and a 20-m bathymetric contour to the south. A summary of the input datasets are identified in Table 1. Eco-Hydrology model's sediment accumulation, water level and salinity for each box (irregular shape, polygons, spatially

Table 1. Input datasets supporting the Wetland Morphology model.

Input	**Scale**	**Source**
Historical Land Loss Rate	30m	Satellite imagery; Couvillion et al. (2011)
Wetland Area	30m	Satellite imagery; Couvillion et al. (2011)
Landscape Fragmentation	500m	Satellite imagery; McGarigal and Marks (1995)
Sediment Accumulation	Variable box	Eco-Hydrology model
Salinity	Variable box	Eco-Hydrology model
Water Level	Variable box	Eco-Hydrology model
Vegetation Type	30m/500m	Satellite imagery; Vegetation model
Bathymetry	Point soundings	Krigged interpolation of AdCirc grid
Topography	Points	LIDAR; Gaps filled with artificial neural network
Land Subsidence	Variable box	Literature; Professional judgment of expert panel (provided by master plan team)
Eustatic sea level	Coast wide	Literature (provided by master plan team)

lumped model) are in Excel format. These tabular data at box level were converted and interpolated/redistributed into grid format (30m and 500m) using ArcGIS's ArcToolbox or other programming languages (e.g., Python and Fortran). The Vegetation model output was post-processed to obtain major vegetation types (e.g., Deltaic, Freshwater, Intermediate, Brackish, Saline marshes, Swamp and Other including upland forest) from over 20 community classes using FORTRAN, Python and ArcToolbox tools.

The spatial data that are utilized as input data for the Wetland Morphology model include: historical land change rates (1984-2010), wetland area, landscape fragmentation (edge), elevation (topographic and bathymetric data), land subsidence and eustatic sea level rise. Other datasets that were used in the derivation, calibration and validation of algorithms include distance to water bodies, average band 5 reflectance (Landsat TM), bulk density, OM%, percentage of organic carbon, percentage of mineral matter (these data were collected at varying depths [0 to 24 cm for CRMS data and 0 to 50 cm for LCA data]), vertical accretion, salinity, inundation, marsh type, land use and land cover, and Normalized Difference Vegetation Index (NDVI) data. The Wetland Morphology model simulates landscape and elevation change from 2010 to 2060 with a 5-year time step. Simulated salinity, water level and sediment from the Eco-Hydrology model are updated at a 5-year interval while vegetation types simulated by the Vegetation model are updated at a 25-year interval. Output from the Wetland Morphology model is provided to other model teams at a 5-year interval. The initial conditions to run the model are based on 2010 coastal landscape data.

e. Description of Output Data

The Wetland Morphology model produces spatial patterns of landscape composition (land and water area), fragmentation (patch edge), soil vertical accretion rates, soil surface elevation, projection of SOC storage and sequestration for the period 2010-2060 under changing ESLR and subsidence at a 30m (aggregated into 500m for Vegetation and Ecosystem Services models) spatial resolution, and a 5-year interval temporal resolution across coastal Louisiana. The spatial outputs are saved in raster format (with file extensions as .img, .asc) and can be viewed using GIS/remote sensing software (e.g., ArcGIS and ERDAS IMAGINE), and animated using multimedia software such as EverVIEW after converting the raster data into a Network Common Data Form (NetCDF) (Conzelmann and Romanach, 2010). Specifically, there are six output items at each five year interval during 2010-2060:

(1) Land and water areas (square km)
(2) Percent of land (in a 500m by 500m grid cell)
(3) Landscape fragmentation metrics (percentage of patch edge)
(4) Soil vertical accretion rate (cm/yr)
(5) Surface elevation (in meters NAVD 88, can also be relative to mean sea level)
(6) Soil organic carbon (storage over the upper 1 m of soil in tC/500m grid cell and sequestration potential in tC/ha/yr)

The outputs are generated for 381 projects that are assembled into 50 model groupings (symbolized by G) in order to expedite modeling run times. CPRA used expert judgment to group projects with no predicted interactions. Additionally, two future scenarios are modeled to address uncertainties (Table 2). Below are examples of model outputs (percentage of land, percentage of edge, surface elevation and SOC storage) under "future-without-action” (FWOA = G01) and two “future-with-project” (FWP) restoration groupings (G02 and G09) that can be visualized using EverVIEW (Figures 1A to 1E for G02; and Figures 1F to 1J for G09).

Table 2. Description of the future scenarios used in the Wetland Morphology model simulations.

Uncertainty	**Moderate**	**Less Optimistic**
Sea level Rise	0.3m over 50 yrs	0.5m over 50 yrs
Subsidence	Spatially Variable	Spatially Variable
Storm Intensity	+10% of current	+20% of current
Storm Frequency	Current	+3% of current
River Discharge / Sediment Load	Current	-5% of current
River Nutrient Concentration	-12% of current	Current
Rainfall	Percent of historic mean	Percent of historic mean
Evapotranspiration	Current	+0.4SD
Marsh Collapse Threshold	Mid-range of salinity/inundation values	Lower 0.25 end of the salinity/inundation values

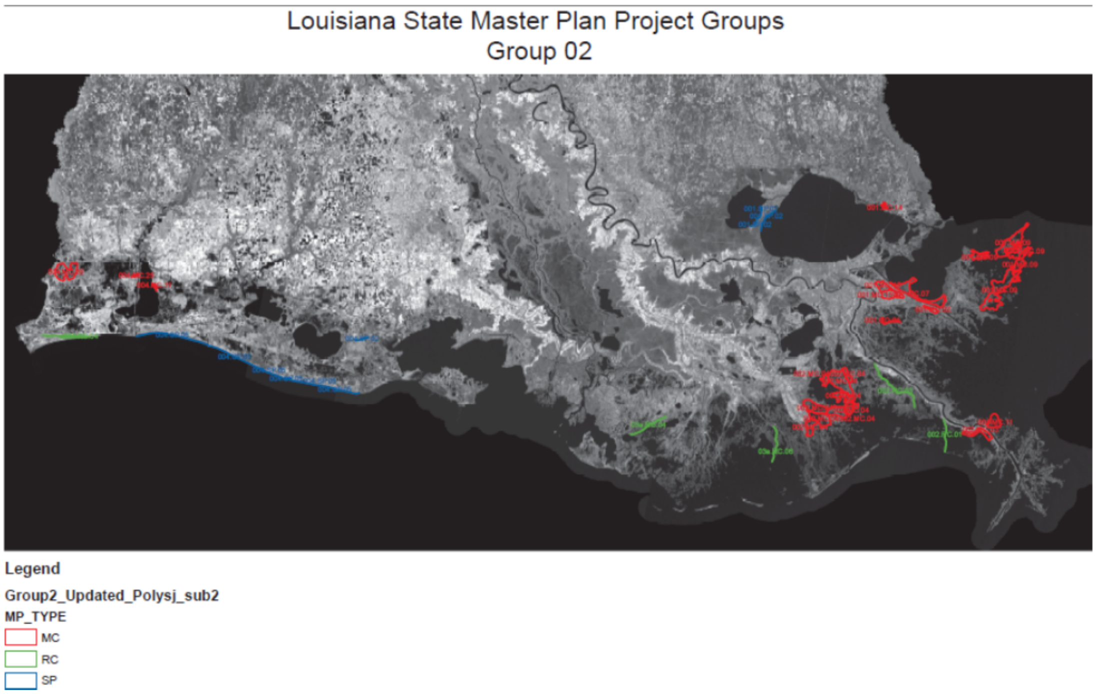


Figure 1A. Map of project Group 02 consisting of marsh creation (MC) in red, ridge restoration (RC) in green, and shoreline protection (SP) in blue across coastal Louisiana.

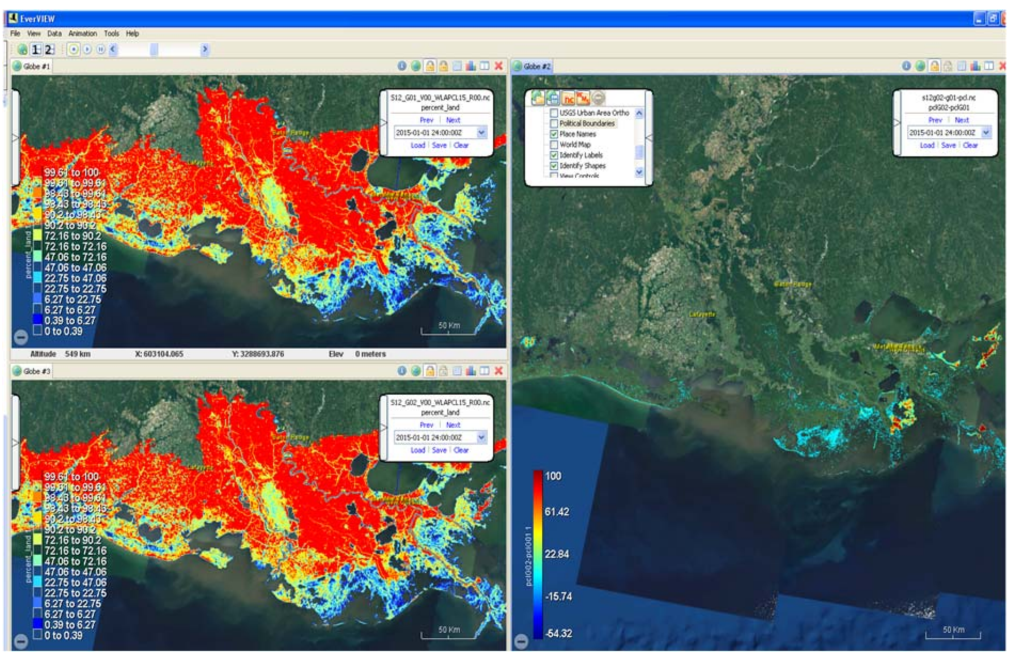


Figure 1B. Example of outputs for percentage land (PCL) across coastal Louisiana using EverVIEW: left panel shows land percentage without restoration action (G01) (upper) and with restoration projects (G02) (lower); right panel shows the difference in land percentage between G02 and G01.

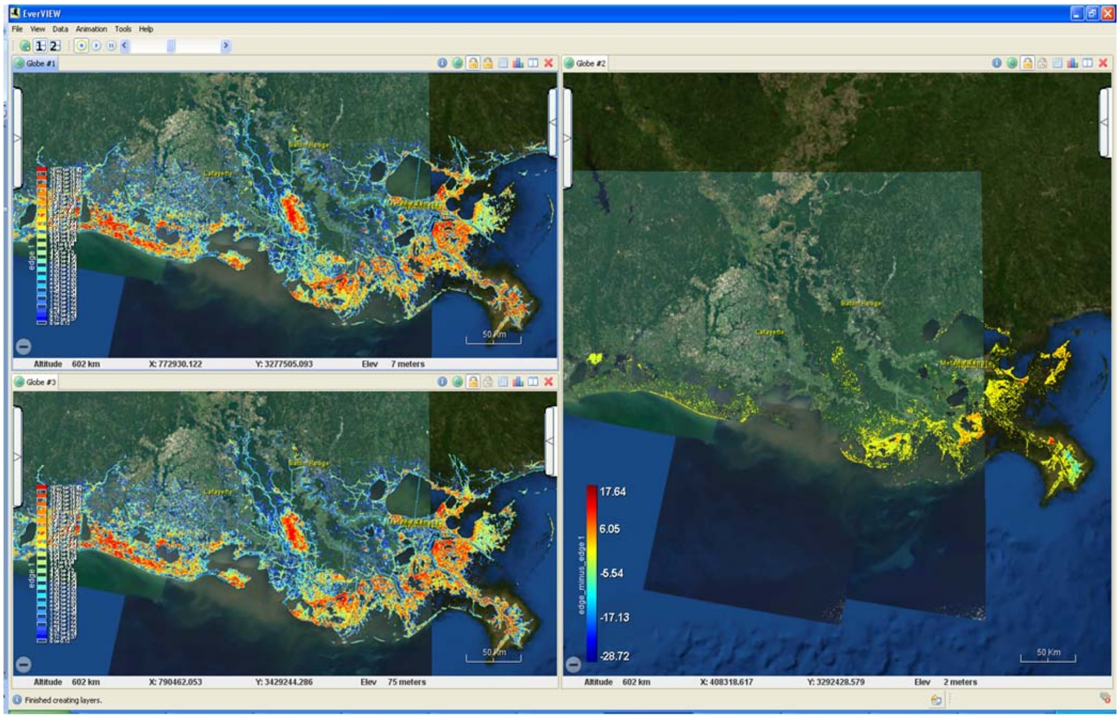


Figure 1C. Example of outputs for edge (%) across coastal Louisiana using EverVIEW: left panel shows edge (%) without restoration action (G01) (upper) and with restoration projects (G02) (lower); right panel shows the difference in edge (%) between G02 and G01.

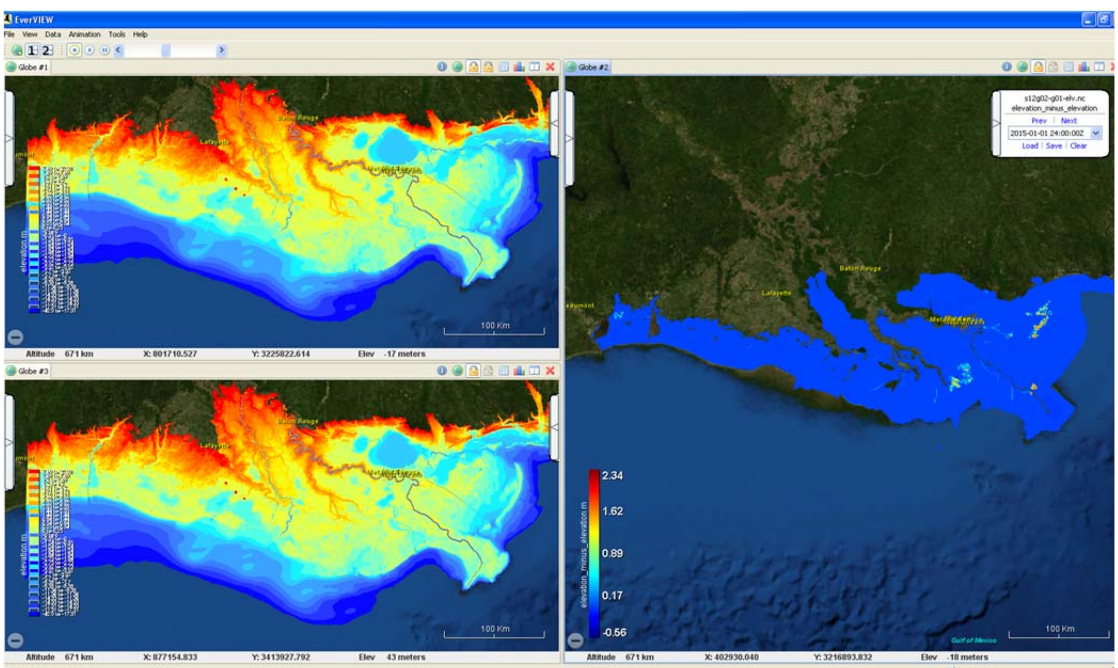


Figure 1D. Example of outputs for surface elevation (m, NAVD88) across coastal Louisiana using EverVIEW: left panel shows surface elevation without restoration action (G01) (upper) and with restoration projects (G02) (lower); right panel shows the difference in surface elevation between G02 and G01.

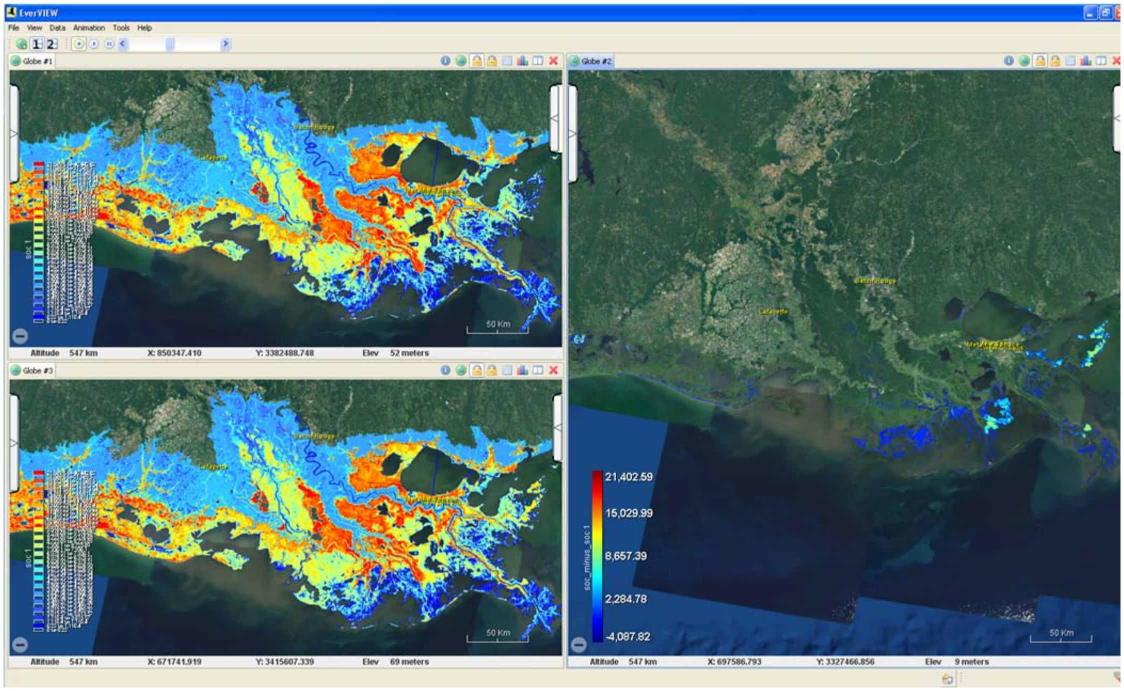


Figure 1E. Example of outputs for soil organic carbon (SOC) storage in upper 1-m of soil (metric tons per 500m grid cell) across coastal Louisiana using EverVIEW: left panel shows SOC storage without restoration action (G01) (upper) and with restoration projects (G02) (lower); right panel shows the difference in SOC storage between G02 and G01.

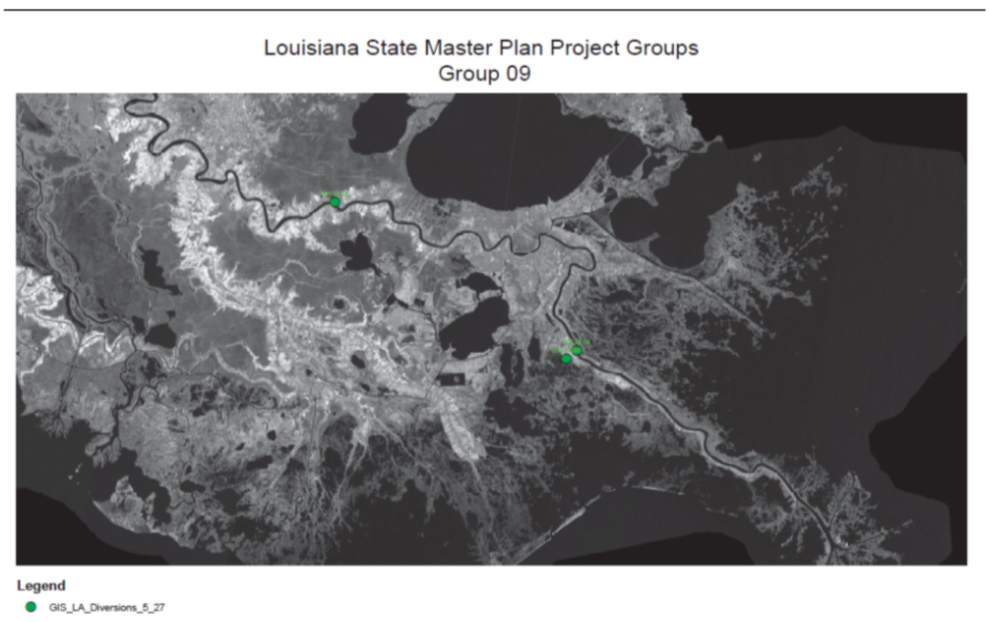


Figure 1F. Map of project Group 09 consisting of East Maurepas Diversion (25,000 cfs) and Mid-Barataria Diversion (250,000 cfs) across Pontchartrain and Barataria Basins.

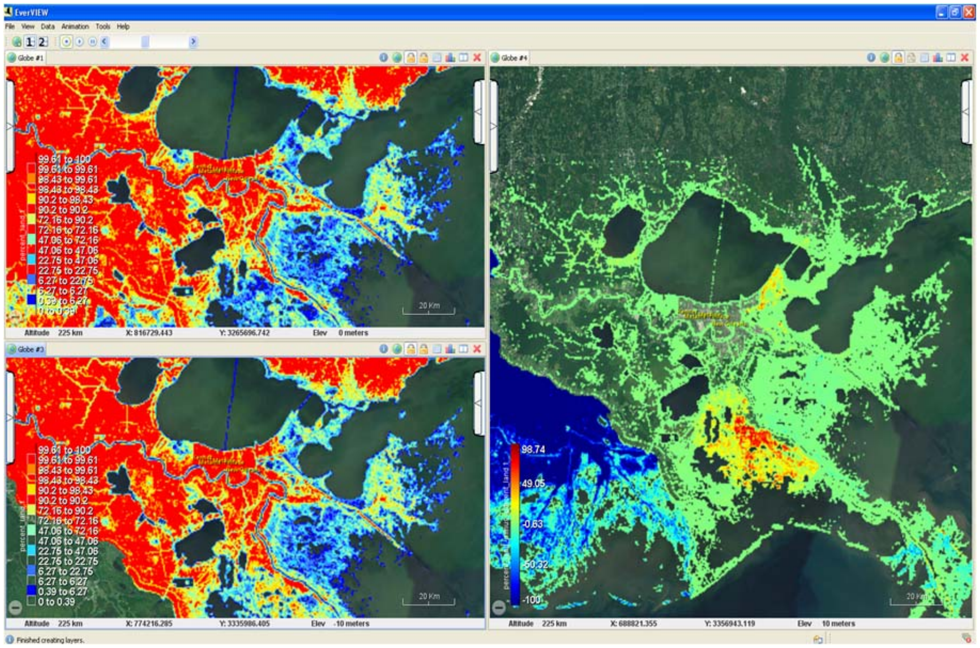


Figure 1G. Example of outputs for percentage land (PCL) across Pontchartrain and Barataria basins using EverVIEW: left panel shows land percentage without restoration action (G01) (upper) and with diversions (G09) (lower); right panel shows the difference in land percentage between G09 and G01.

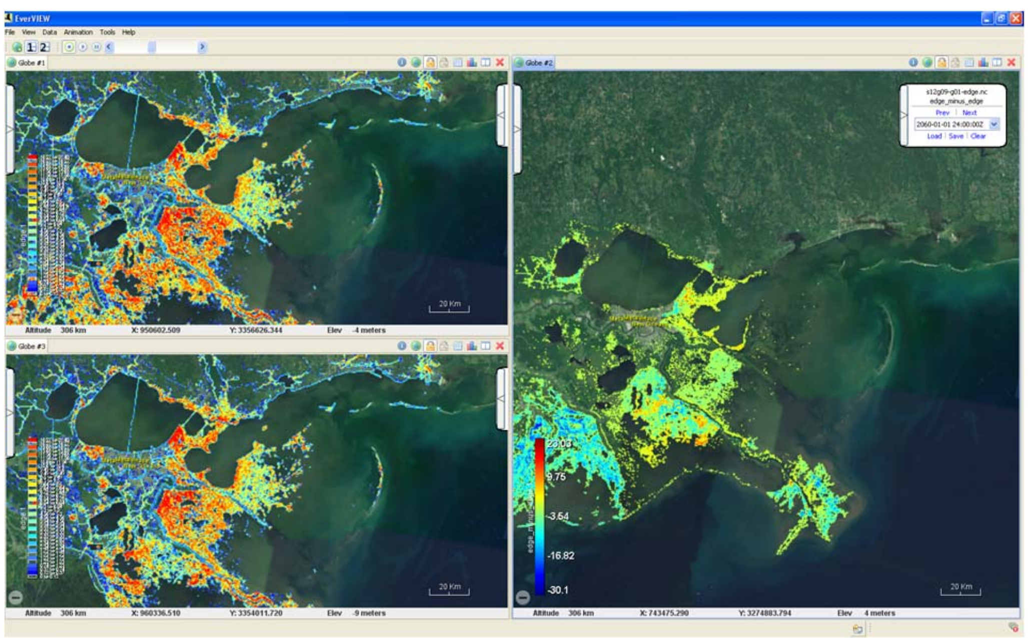


Figure 1H. Example of outputs for edge (%) across Pontchartrain and Barataria Basins using EverVIEW: left panel shows edge (%) without restoration action (G01) (upper) and with diversions (G09) (lower); right panel shows the difference in edge (%) between G09 and G01.

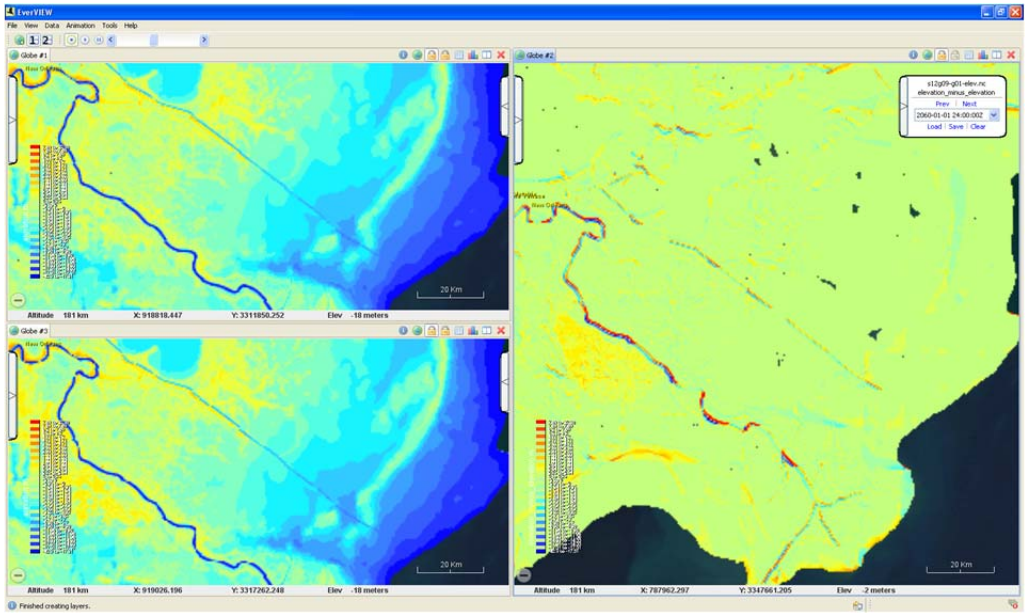


Figure 1I. Example outputs for surface elevation (m, NAVD88) in Barataria Basin showing influence of Mid-Barataria Diversion (250,000 cfs) using EverVIEW: left panel shows surface elevation without restoration action (G01) (upper) and with diversions (G09) (lower); right panel shows the difference in surface elevation between G09 and G01.

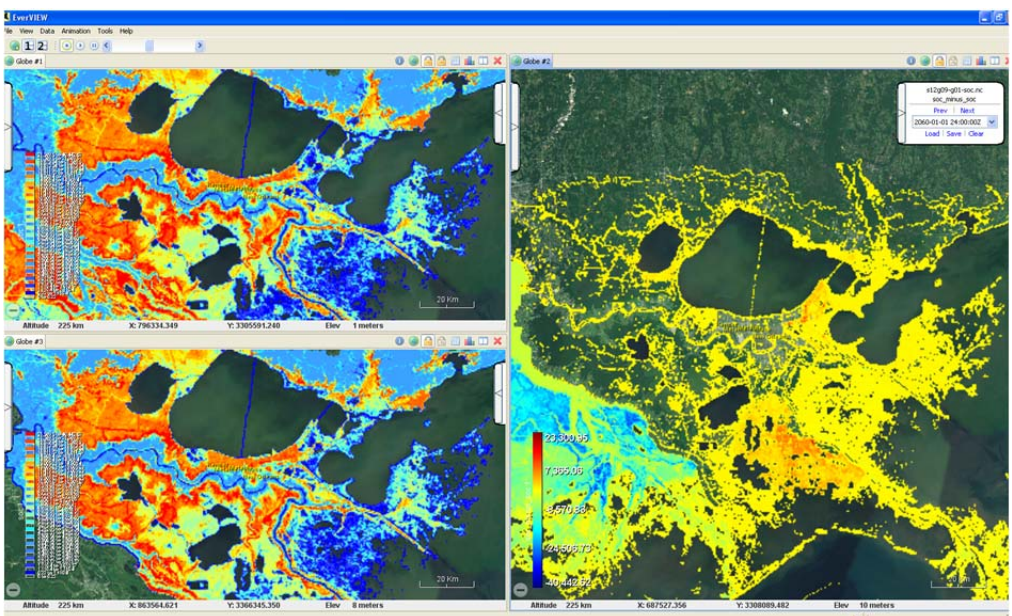


Figure 1J. Example outputs for soil organic carbon (SOC) storage in upper 1-m of soil (metric tons per 500m grid cell) across Pontchartrain and Barataria Basins using EverVIEW: left panel shows SOC storage without restoration action (G01) (upper one) and with diversions (G09) (lower one); right panel shows the difference in SOC storage between G09 and G01.

We conducted post-simulation analyses on model outputs to examine landscape change, relative elevation dynamics, and SOC storage and sequestration potential under different combinations of sea level rise, subsidence and restoration activities. The analyses can be performed at local, project, basin and coast wide scales. To illustrate, Table 3 summarizes the analysis results of simulated basin-scale percent of land, percent of edge, surface elevation and SOC storage under future without action (G01), and FWP restoration project groupings (G02 and G09) conditions with moderate sea level rise and subsidence scenarios (see Appendix C – Environmental Scenarios for details). In terms of percent of land, restoration projects in G02 have the potential to increase land in the 500m grid cells in proximity to marsh creation project areas (e.g., Pontchartrain, Breton Sound, Barataria, Calcasieu/Sabine), and may influence percent of land adjacent to shoreline protection and ridge restoration (e.g., Terrebonne, Atchafalaya, Teche/Vermilion and Mermentau). Additionally, the East Maurepas Diversion (25,000 cfs) and Mid-Barataria Diversion (250,000 cfs) (G09) tend to increase the percent of land for Pontchartrain and Barataria basins, whereas basins without diversion influences continue to lose land. The amount of SOC storage (1 meter depth, per 500m grid cell) within basins mimics what was found in the percent of land results. G02 projects are likely to increase SOC storage for Pontchartrain, Breton Sound, Barataria, and Calcasieu/Sabine basins, and have little influence on Terrebonne, Atchafalaya, Teche/Vermilion and Mermentau basins. Diversion projects in G09 are likely to increase SOC storage in Pontchartrain and Barataria basins. Additionally, it should be noted that restoration projects in G02 and G09 tend to have little or no basin-wide influence in terms of surface elevation although we do see a localized increase in surface elevation within project areas (e.g., a 5-cm increase under diversion [G09] compared to the FWOA [G01] in Barataria Basin [Table 3]). Furthermore, restoration projects may increase or decrease percent of edge when assessed at a basin scale; therefore, a project scale analysis is needed for a better understanding of influences on habitat utilization.

The impacts of coastal restoration projects over time can also be examined by plotting time series of simulation results. Here we used the Large-scale Barataria Marsh Creation (G03, Figure 2A) and the Upper Breton Diversion (250,000 cfs capacity) (G20, Figure 2B) as examples of such analysis. Within marsh creation project areas (total area is approximately 216 km^2) in Barataria Basin, the average percentage of land, surface elevation and SOC storage are all improved with marsh creation (FWP) even under a less optimistic scenario compared with that without marsh creation efforts (FWOA) (a, c, and d in Figure 2C). The simulated percentage of edge tends to be stable around 6% over the course of the simulation period under FWOA-moderate scenario condition (b in Figure 2C). However, under FWP, simulated percent of edge is very low (~0.8%) after the initial contiguous marsh platform construction, and increases throughout the 50 year simulation under both moderate and less optimistic scenarios (b in Figure 2C).

Table 3. Simulated percentage of land, percentage of edge, surface elevation and SOC storage in a 500m x 500m grid cell under "future-without-action" (G01) and "future-with-project" (G02 and G09) restoration conditions with moderate sea level rise and subsidence scenarios.

	G01		G02		G09	
Basin	**MEAN**	**STD**	**MEAN**	**STD**	**MEAN**	**STD**
		Percent of Land				
Pontchartrain	24.19	38.86	25.86	39.71	24.43	39.07
Breton Sound	14.06	23.79	14.81	24.43	13.65	23.39
Mississippi River Delta	5.24	12.14	4.23	11.05	3.18	9.55
Barataria	40.40	44.19	42.66	44.34	43.71	44.87
Terrebonne	40.47	41.98	40.64	41.98		
Atchafalaya	42.43	46.46	42.43	46.46		
Teche/Vermilion	40.13	43.67	40.14	43.68		
Mermentau	50.82	40.72	50.88	40.71		
Calcasieu/Sabine	47.32	39.86	48.08	40.03		
		Percent of Edge				
Pontchartrain	1.39	3.28	1.44	3.38	1.38	3.35
Breton Sound	3.83	5.64	3.93	5.68	3.57	5.32
Mississippi River Delta	2.80	5.10	2.26	4.34	1.77	3.76
Barataria	2.28	4.16	2.40	4.34	2.03	3.83
Terrebonne	3.25	4.78	3.27	4.79		
Atchafalaya	0.88	1.98	0.89	1.98		
Teche/Vermilion	2.14	3.90	2.14	3.90		
Mermentau	4.45	5.67	4.47	5.67		
Calcasieu/Sabine	4.54	5.54	4.51	5.52		
		Elevation (m, NAVD88)				
Pontchartrain	-2.02	2.21	-2.01	2.21	-2.03	2.23
Breton Sound	-1.18	1.73	-1.17	1.73	-1.19	1.74
Mississippi River Delta	-3.22	4.08	-3.24	4.07	-3.23	4.05
Barataria	-1.67	3.97	-1.66	3.97	-1.62	3.94
Terrebonne	-0.76	1.52	-0.76	1.52		
Atchafalaya	-0.69	1.56	-0.69	1.57		
Teche/Vermilion	-0.69	1.47	-0.69	1.47		
Mermentau	-0.80	1.73	-0.80	1.73		
Calcasieu/Sabine	-0.77	1.89	-0.77	1.89		
		total SOC (tC/grid cell)				
Pontchartrain	3333	5953	3507	5991	3364	5985
Breton Sound	1671	3180	1750	3231	1623	3111
Mississippi River Delta	430	969	350	885	267	768
Barataria	5657	7251	5884	7215	5989	7236
Terrebonne	5496	6829	5517	6830		
Atchafalaya	4974	5776	4974	5776		
Teche/Vermilion	4833	5624	4834	5625		
Mermentau	7846	6815	7855	6815		
Calcasieu/Sabine	8569	8039	8711	8072		

Note: Model results are averages between 2055 and 2060. MEAN = basin-wide average, and STD = Standard deviation for the basin, both were derived using zonal statistics in ArcGIS.

Figure 2A. Map of Large-Scale Marsh Creation Projects (G03) in Barataria Basin (~ 216 km^2).

Figure 2B. Map of upper, mid, and lower basin zones in Breton Sound Basin. The impacts of the Upper Breton Diversion (G20) are evaluated using model simulations based on these three zones.

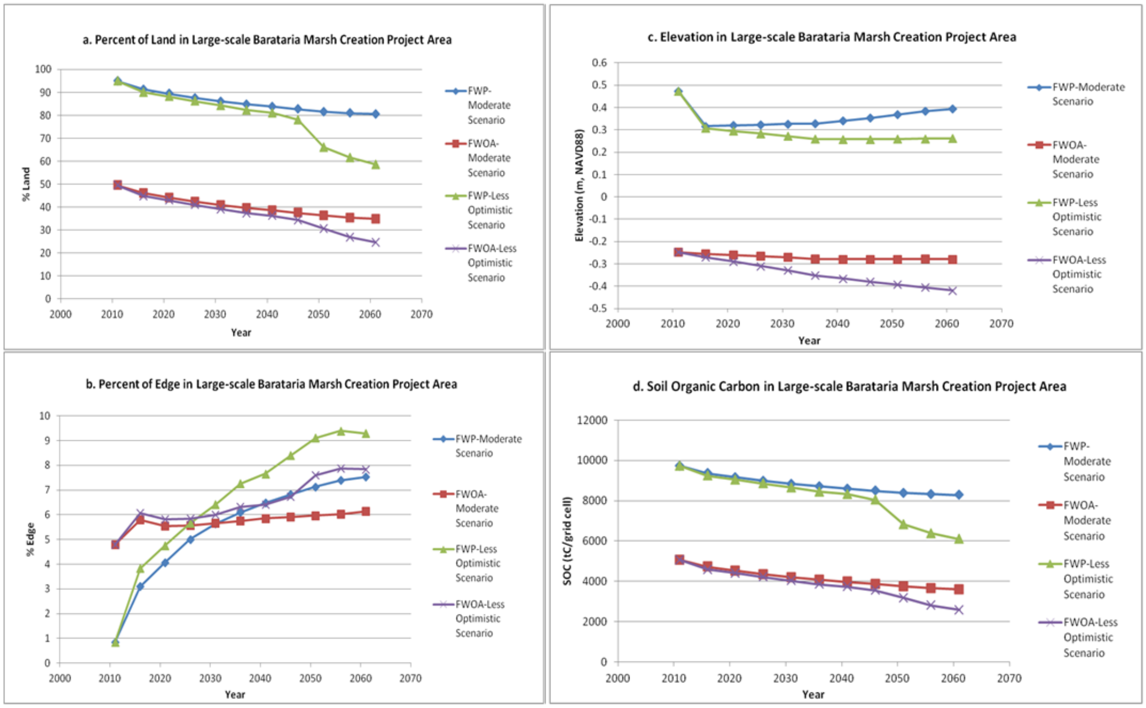


Figure 2C. (a) Simulated percentage of land, (b) percentage of edge, (c) surface elevation, and (d) soil organic carbon storage in upper 1-m of soil at project area (~216 km^2) in Barataria Basin with (FWP) and without (FWOA) the Large-scale Marsh Creation (G03) under moderate and less optimistic scenarios. Note that the initial values for the four variables are different between FWP and FWOA conditions. It is assumed that restoration projects are fully constructed at 0+1 day for FWP conditions.

Impacts of the Upper Breton Diversion (G20) on estuary morphology vary in space and time. Distance to the Upper Breton Diversion (250,000 cfs) determines to a large degree the diversion influence in terms of the average percentage of land, percentage of edge, surface elevation and SOC storage. Under both moderate and less optimistic scenarios, if there was no diversion (FWOA), simulated percentage of land would decline from ~60% to ~40%, ~48% to 25%, and ~20% to 10% for upper, mid, and lower basins, respectively. With G20 diversion operations implemented (FWP), percent of land could be increased for the upper basin and stabilized in the mid basin (a and e in Figure 2D). As a result of the increase in percentage of land, the percentage of edge would decrease with diversion from ~ 5.5% to ~2.6% (moderate scenario) and 3.3% (less optimistic scenario) in the upper basin in contrast to the increase in percentage of edge without diversion due to the continuous loss of land (b and f in Figure 2D). Under both moderate and less optimistic scenarios, the Upper Breton Diversion could increase marsh surface elevation from ~0.1 m to >0.5m and ~0.3 m (NAVD88) at upper and mid basin, respectively, in contrast to the declining trend of elevation without diversion (c and g in Figure 2D). Simulated values of SOC storage in the upper 1-m of soil would show similar patterns as percentage of land (d and h in Figure 2D). It should be noted that Upper Breton Diversion appears not to be affected by percentage of land, percentage of edge, surface elevation and SOC storage in the lower basin (a to h in Figure 2D).

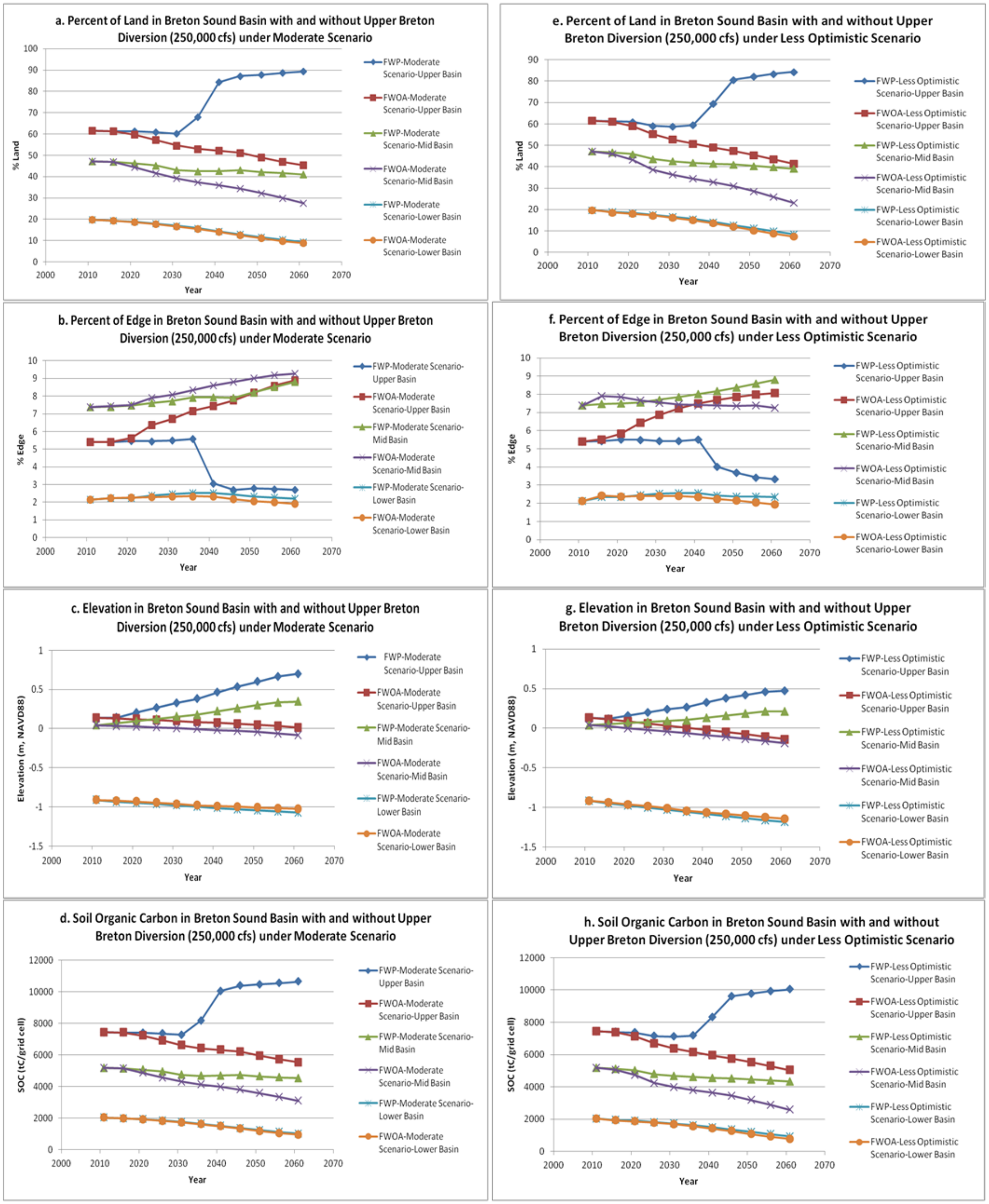


Figure 2D. (a) Simulated percent of land, (b) percentage of edge, (c) surface elevation, and (d) soil organic carbon storage in upper 1-m of soil at upper, mid, and lower estuary in Breton Sound Basin with and without the Upper Breton Diversion (250,000 cfs) under moderate (a-d) and less optimistic scenarios (e-h).

We can also assess and compare the impacts of multiple project groups over the 50-year simulation at the same time. Tables 4A and 4B contain simulated land area totals across coastal Louisiana for the FWOA condition (G01) and multiple restoration project groups (G02-G08) during 2020-2060 under moderate and less optimistic scenarios. Over the course of the 50-year simulation, G01 results in an overall decrease in wetland area of 2,053.5 km^2 under the moderate scenario and 4,702.6 km^2 under the less optimistic scenario. This example illustrates that all restoration project groups would still experience a net loss of land area over the projection period; however, all restoration efforts (G02-08) constitute a reduction in the net land loss that is forecasted to occur in the FWOA condition (G01). As expected, model results forecast higher wetland loss under less optimistic scenarios (Table 4B) than under moderate scenarios (Table 4A).

Table 4A. Simulated land area totals (km^2) by basin for a "future-without-action (FWOA)" condition (G01) and multiple restoration project grouping (G02-G08) during 2020-2060 under moderate scenario.

Basin	G01	G02	G03	G04	G05	G06	G07	G08
				2020				
Pontchartrain	2260.27	2423.04	2263.71	2262.03	2296.49	2291.35	2288.48	2284.65
Breton Sound	605.35	630.73	607.00	612.65	685.24	685.51	611.53	673.81
Mississippi River Delta	277.33	276.00	279.72	270.24	276.00	278.73	283.35	276.04
Barataria	2618.41	2753.96	2781.36	2619.37	2753.75	2618.92	2619.46	2649.29
Terrebonne	3137.63	3138.34	3296.33	3429.98	3188.15	3279.36	3139.41	3137.77
Atchafalaya Delta	596.13	596.06	596.26	596.14	596.14	598.45	596.33	596.82
Teche/Vermilion	1221.80	1221.99	1226.61	1230.96	1228.36	1223.92	1239.74	1266.20
Mermentau	1947.25	1949.62	1948.44	1943.56	2010.28	1960.31	1987.24	1966.29
Calcasieu/Sabine	1519.28	1541.42	1597.06	1532.46	1583.07	1520.78	1526.93	1640.78
Coast wide Total	**14183.45**	**14531.16**	**14596.49**	**14497.38**	**14617.47**	**14457.33**	**14292.47**	**14491.66**
				2030				
Pontchartrain	2184.78	2345.47	2187.33	2184.62	2218.60	2213.77	2211.00	2207.20
Breton Sound	535.21	558.46	537.95	550.46	612.13	612.27	539.08	601.88
Mississippi River Delta	251.85	242.08	246.29	236.02	242.02	244.79	249.43	242.22
Barataria	2511.67	2639.55	2666.83	2512.52	2641.31	2510.83	2509.41	2541.14
Terrebonne	3038.15	3039.33	3196.07	3333.97	3089.60	3174.55	3039.92	3038.27
Atchafalaya Delta	623.64	623.67	623.43	623.63	623.65	624.32	623.84	624.10
Teche/Vermilion	1206.77	1206.99	1211.43	1213.79	1211.21	1208.32	1225.46	1250.25
Mermentau	1818.08	1820.46	1822.25	1819.45	1892.04	1833.88	1858.20	1839.79
Calcasieu/Sabine	1448.50	1472.97	1529.54	1462.48	1525.77	1449.56	1454.26	1571.30
Coast wide Total	**13618.66**	**13948.98**	**14021.11**	**13936.95**	**14056.33**	**13872.30**	**13710.59**	**13916.15**
				2040				
Pontchartrain	2140.11	2300.88	2143.06	2140.07	2173.20	2169.12	2166.32	2162.59
Breton Sound	476.83	501.64	483.67	513.63	554.90	554.68	483.01	545.85
Mississippi River Delta	234.54	216.96	220.68	209.34	216.91	219.77	223.16	217.25
Barataria	2415.95	2543.84	2573.83	2417.35	2547.31	2415.28	2413.87	2445.64
Terrebonne	2997.12	2998.84	3150.20	3292.24	3048.44	3134.44	2998.87	2997.24
Atchafalaya Delta	657.90	657.93	657.80	657.89	657.91	658.32	658.09	658.30
Teche/Vermilion	1207.22	1207.44	1211.68	1214.18	1211.40	1208.71	1225.72	1248.97
Mermentau	1820.77	1823.12	1825.29	1821.71	1899.88	1837.77	1861.57	1843.76
Calcasieu/Sabine	1442.31	1466.43	1523.56	1456.14	1520.08	1443.57	1448.86	1565.16
Coast wide Total	**13392.76**	**13717.06**	**13789.75**	**13722.55**	**13830.04**	**13641.66**	**13479.47**	**13684.76**
				2050				
Pontchartrain	2103.05	2263.85	2106.26	2102.99	2135.62	2132.10	2129.30	2125.57
Breton Sound	408.15	433.82	417.21	471.35	487.44	487.02	415.21	478.30
Mississippi River Delta	173.85	141.51	145.06	131.31	141.33	144.69	147.84	142.48
Barataria	2315.81	2445.06	2477.24	2317.91	2449.56	2316.13	2314.78	2346.58
Terrebonne	2878.82	2892.05	3039.15	3183.12	2945.90	3035.38	2887.66	2878.93
Atchafalaya Delta	675.59	675.57	675.53	675.59	675.61	676.00	675.79	675.99
Teche/Vermilion	1201.48	1201.73	1205.86	1208.75	1205.81	1202.96	1219.93	1243.90
Mermentau	1813.33	1815.60	1818.70	1809.47	1899.15	1841.48	1854.50	1847.86
Calcasieu/Sabine	1419.60	1443.52	1503.28	1433.05	1498.64	1421.84	1429.67	1543.51
Coast wide Total	**12989.69**	**13312.72**	**13388.28**	**13333.54**	**13439.07**	**13257.59**	**13074.68**	**13283.12**
				2060				
Pontchartrain	2075.26	2236.11	2078.74	2075.11	2107.67	2104.35	2101.53	2097.78
Breton Sound	343.03	363.28	353.02	426.86	422.61	422.26	350.27	413.97
Mississippi River Delta	114.03	92.23	97.46	75.13	92.06	94.99	98.76	93.43
Barataria	2251.74	2381.18	2416.11	2254.46	2385.97	2252.06	2250.76	2282.57
Terrebonne	2765.02	2778.46	2900.63	3049.06	2835.65	2919.00	2766.80	2765.09
Atchafalaya Delta	691.31	691.32	691.18	691.30	691.33	691.69	691.51	691.73
Teche/Vermilion	1195.90	1196.18	1200.18	1203.64	1201.03	1197.35	1214.43	1238.94
Mermentau	1802.96	1805.31	1805.51	1799.37	1889.56	1828.71	1844.20	1835.01
Calcasieu/Sabine	1407.50	1431.27	1491.65	1420.86	1486.85	1409.83	1419.85	1531.46
Coast wide Total	**12646.74**	**12975.34**	**13034.48**	**12995.80**	**13112.73**	**12920.22**	**12738.11**	**12949.98**

Table 4B. Simulated land area totals (sq.km) by basin for a "future-without-action (FWOA)" condition (G01) and multiple restoration project grouping (G02-G08) during 2020-2060 under less optimistic scenario.

Basin	G01	G02	G03	G04	G05	G06	G07	G08
			2020					
Pontchartrain	2218.36	2379.14	2220.66	2217.76	2252.68	2247.53	2244.77	2240.83
Breton Sound	590.77	615.33	591.79	597.37	669.29	669.78	596.08	658.44
Mississippi River Delta	266.52	264.35	266.88	263.04	264.34	267.08	271.69	264.41
Barataria	2588.86	2724.38	2752.26	2588.18	2721.83	2589.18	2587.75	2619.50
Terrebonne	3054.03	3055.70	3217.38	3356.17	3109.18	3194.72	3055.83	3054.18
Atchafalaya Delta	592.97	592.91	593.17	592.97	592.98	595.30	593.17	593.65
Teche/Vermilion	1201.05	1201.65	1206.23	1209.37	1207.33	1203.22	1220.42	1246.25
Mermentau	1842.54	1845.34	1845.64	1844.12	1904.16	1853.43	1883.63	1859.49
Calcasieu/Sabine	1447.92	1471.64	1534.31	1461.33	1529.66	1449.42	1455.15	1570.32
Coast wide Total	**13803.03**	**14150.44**	**14228.32**	**14130.31**	**14251.45**	**14069.66**	**13908.49**	**14107.07**
			2030					
Pontchartrain	2128.77	2287.67	2129.87	2125.86	2160.89	2156.01	2153.21	2149.24
Breton Sound	506.08	507.67	505.68	518.42	580.01	580.72	507.03	546.86
Mississippi River Delta	170.27	150.72	153.93	146.46	150.66	153.47	156.79	150.88
Barataria	2468.37	2596.35	2624.21	2467.01	2598.15	2467.69	2466.15	2497.90
Terrebonne	2865.17	2879.75	3019.40	3186.33	2941.99	3043.84	2866.94	2865.25
Atchafalaya Delta	618.10	618.05	617.87	618.05	618.27	618.98	618.30	618.60
Teche/Vermilion	1178.99	1179.20	1183.85	1185.04	1186.07	1180.30	1198.61	1224.71
Mermentau	1615.49	1618.32	1619.54	1582.55	1689.66	1628.90	1657.49	1634.90
Calcasieu/Sabine	1329.44	1355.09	1424.79	1343.01	1429.16	1332.58	1341.06	1464.86
Coast wide Total	**12880.67**	**13192.82**	**13279.14**	**13172.74**	**13354.86**	**13162.48**	**12965.58**	**13153.20**
			2040					
Pontchartrain	2074.55	2229.10	2077.09	2073.20	2106.58	2101.68	2097.46	2095.20
Breton Sound	440.36	443.25	442.14	473.91	515.77	516.35	442.66	482.28
Mississippi River Delta	83.84	79.26	83.04	77.40	79.24	81.99	85.30	79.35
Barataria	2364.76	2491.01	2477.60	2362.66	2423.38	2362.37	2360.91	2369.72
Terrebonne	2791.15	2808.02	2918.44	3092.44	2871.11	2945.82	2792.93	2791.23
Atchafalaya Delta	650.35	650.38	650.14	650.28	650.52	650.95	650.55	650.74
Teche/Vermilion	1172.61	1173.08	1177.24	1180.00	1183.25	1174.28	1192.63	1219.52
Mermentau	1591.73	1594.62	1596.22	1557.24	1670.39	1604.18	1634.24	1610.74
Calcasieu/Sabine	1297.65	1324.18	1396.05	1310.94	1405.55	1302.84	1312.12	1433.82
Coast wide Total	**12466.99**	**12792.90**	**12817.96**	**12778.08**	**12905.79**	**12740.45**	**12568.79**	**12732.60**
			2050					
Pontchartrain	2021.98	2176.46	2023.32	2019.11	2053.56	2047.65	2032.52	2042.38
Breton Sound	369.36	373.62	372.90	430.60	444.51	441.39	373.18	412.28
Mississippi River Delta	72.19	71.73	75.64	70.83	71.73	74.46	77.74	71.74
Barataria	2229.73	2233.38	2313.41	2221.90	2262.07	2221.21	2219.86	2219.70
Terrebonne	2353.71	2461.47	2374.99	2510.11	2472.97	2525.91	2356.77	2353.63
Atchafalaya Delta	659.90	660.95	659.65	660.96	661.08	661.65	660.09	660.29
Teche/Vermilion	1073.42	1074.65	1077.71	1086.43	1113.19	1074.79	1101.03	1122.50
Mermentau	1328.31	1363.77	1366.91	1246.58	1402.08	1396.27	1405.39	1401.15
Calcasieu/Sabine	1015.93	1044.09	1134.49	1015.34	1090.01	1020.16	1042.85	1136.82
Coast wide Total	**11124.52**	**11460.12**	**11399.04**	**11261.87**	**11571.20**	**11463.48**	**11269.42**	**11420.50**
			2060					
Pontchartrain	1962.52	2116.78	1964.18	1959.36	1993.50	1987.44	1975.24	1982.42
Breton Sound	297.06	301.48	301.02	377.98	372.59	369.44	301.07	340.10
Mississippi River Delta	70.50	70.18	74.18	69.33	70.18	72.90	76.19	70.18
Barataria	2078.84	2068.11	2154.10	2065.69	2087.41	2064.39	2063.24	2063.16
Terrebonne	2033.75	2124.88	2059.55	2104.29	2133.47	2250.41	2036.83	2033.47
Atchafalaya Delta	666.28	665.84	665.95	665.71	665.89	667.60	666.49	665.92
Teche/Vermilion	969.17	970.81	975.93	985.28	1029.28	971.66	1002.34	1017.47
Mermentau	1133.47	1139.68	1145.69	1138.24	1218.10	1209.25	1284.00	1228.14
Calcasieu/Sabine	859.91	887.88	944.93	859.84	924.47	864.12	882.51	957.01
Coast wide Total	**10071.49**	**10345.63**	**10285.53**	**10225.72**	**10494.88**	**10457.21**	**10287.90**	**10357.87**

f. Statement on the capabilities and limitations of the model

The relative elevation and landscape change sub-models are capable of discriminating the relative influences of different project groupings from a FWOA condition. These sub-models are designed to conduct assessments across the entire coastal Louisiana domain; therefore, data (information) to drive the modeling effort are needed to be available across all coastal vegetation communities. This constraint was primary in the decision to utilize a relative elevation model rather than a sediment cohort model (e.g., Kairis and Rybczyk, 2010). The sediment cohort model needs detailed information on above and below ground productivity and decomposition processes, which is currently unavailable for all marsh types. The major capabilities and limitations of the sub-models are listed below.

Capabilities:

1) Forecasting land gain or loss under ESLR, subsidence and wetland management activities;
2) Locating collapsing marsh areas (e.g., vegetated areas converting to open water) if ESLR and subsidence sufficiently exceed soil vertical accretion and trigger marsh collapse;
3) Describing spatial fragmentation of coastal Louisiana landscape (e.g., land/water patch, edge density, connectivity);
4) Forecasting spatial and temporal patterns of soil vertical accretion at different hydrologic basins and vegetation community settings under different levels of contributions of both mineral matter and organic matter;
5) Predicting soil surface elevation and its change in space and time under different scenarios of ESLR, subsidence and restoration activities;
6) Describing soil organic carbon storage and sequestration (accreted and potential) under different scenarios of ESLR, subsidence and restoration project groupings; and
7) Changing sedimentation rates as a function of changing elevation.

Limitations:

1) Effectively address how much sediment is delivered to the marsh surface, how much remains in open water, and how much is exported at resolutions finer than the box scale;
2) Reflect the spatial variation in sediment accumulation brought by hurricanes/storms of different categories;
3) Explicitly reflect the contribution of organic matter to vertical accretion through simulations of below-ground ecological processes;
4) Estimate vertical soil loss depth by erosive forces (e.g., wind/wave at marsh open water interface) and by biological factors (e.g., vegetation mortality);
5) Determine the relative influence of heavy materials versus fine materials on accretion rates (e.g., sand in sediment from diversions and dredged material); and
6) Examine the positive feedback between vegetation and marsh vertical accretion at finer temporal resolution than a 25-year interval (e.g., a 5-year interval or annual time step).

Therefore, future Wetland Morphology modeling requires the implementation of process-based spatial models that include ecological feedbacks (See Section 2 "Technical Quality" for details on model improvements).

g. Description of model development process including documentation on testing conducted (Alpha and Beta tests)

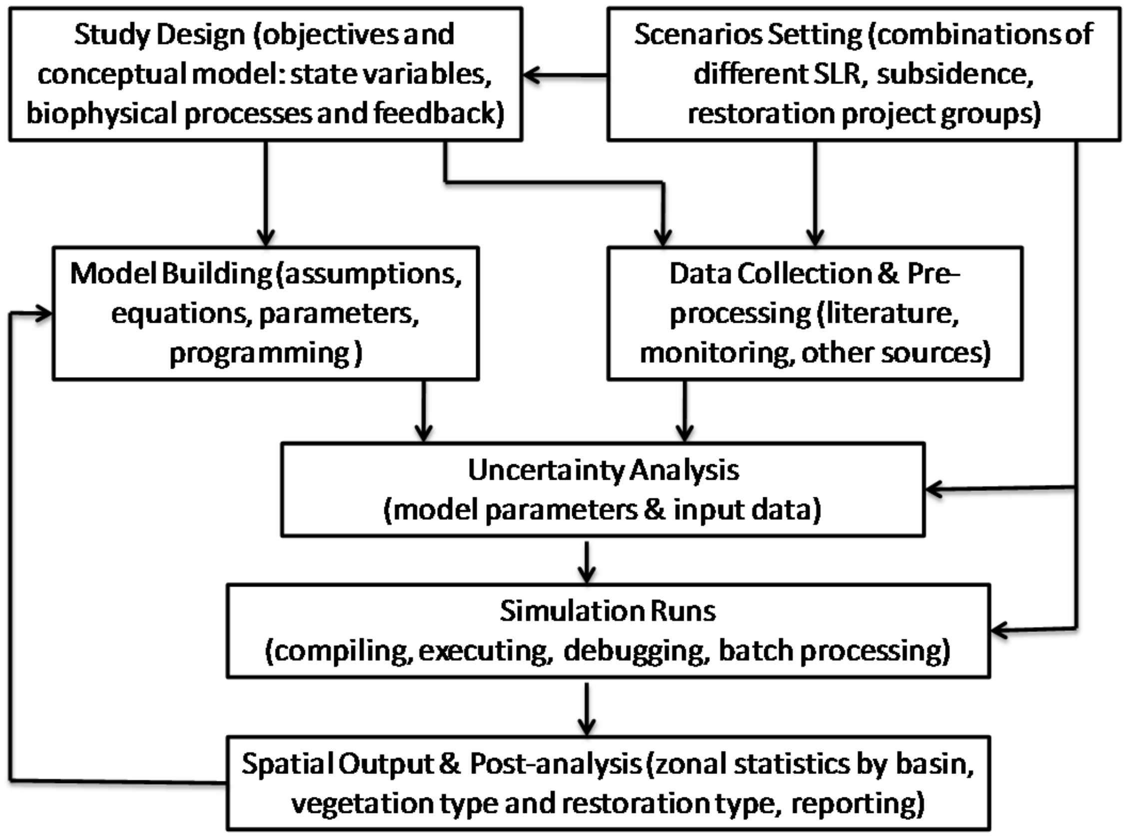


Figure 3. The flowchart of Wetland Morphology model development and simulations.

General technical steps in model development are illustrated in Figure 3. Additionally, the model building team pursued the following routine:

1) Data/models/algorithms were proposed by team members based on master plan modeling objectives and timeline;
2) Entire team discussed rationale and appropriateness of models/algorithms;
3) Input datasets were compiled and/or developed by USGS personnel and reviewed by other team members for completeness and appropriateness;
4) Test run/preliminary results of algorithms conducted by USGS personnel were provided to other team members to review/comment prior to any master plan FWOP and project runs;
5) Entire team provided feedback on data/time limitations and input data quality from the Eco-Hydrology model;
6) Entire team made decision on final data/models/algorithms;
7) Internal review of results of final data/models/algorithms conducted by USGS personnel (Greg Steyer, Brady Couvillion, and Hongqing Wang); and
8) External review of data/models/algorithms and results conducted by the full model development team and the external review team. External reviewers focused on process and logic of model. Model inputs from the Eco-Hydrology model and outputs from the land change and relative elevation models were reviewed for Groups 1, 2, 9 and 17 for the

moderate scenario using EverVIEW. Each reviewer submitted written comments on inputs or outputs that seem unreasonable (e.g., outside the bounds of expectation based on professional understanding or existing literature) and comments were tracked and responded to.

Names and affiliations of the reviewers who performed Step 8 are presented below:

- External Reviewers: Guerry Holm, Brian Perez, (CH2M Hill), Camille Stagg (USGS-NWRC), Ty Wamsley (USACE-ERDC), and Gregg Snedden (USGS-NWRC).
- Marsh Collapse Expert Panel: Jim Morris (University of South Carolina), Irv Mendelssohn (Louisiana State University), Charles Sasser (Louisiana State University), Karen McKee (USGS-NWRC), and Gary Shaffer (Southeastern Louisiana University).
- Team Lead Feedback: Eco-Hydrology (sediment load and salinity values in some compartments); Joseph Suhayda (hurricane sedimentation); Jenneke Visser and Andy Nyman (marsh collapse thresholds and vegetation base map).

Steps #1 - 6 were taken at a frequency of ~ bi-weekly at the beginning of the project, later on at a frequency of ~ 3-week to monthly basis. Step #8 (external reviews) was taken whenever the Steps #1-7 were finished and needed external review (occurred throughout project timeline).

2. *Technical Quality*

a. Theory

Coastal wetlands are thought of as net sinks for greenhouse gases and sequester a significant amount of carbon within soils (Smith et al., 1983; Chumura et al., 2003; Laffoley and Grimsditch, 2009; Mcleod et al. 2011). However, a recent study found that coastal Louisiana lost wetlands coastal wetlands at a rate of 16.57 mi^2 per year from 1932 to 2010 (Couvillion et al., 2011). Meanwhile, although the average global sea level rise (SLR) is approximately 3.1 mm/yr (range 2.4-3.8) over 1993 - 2003 (Intergovernmental Panel on Climate Change [IPCC], 2007), a higher land subsidence rate (10-15 mm/yr in Mississippi Delta Plain) is estimated for most of the deteriorating marshes along the coastal Louisiana (Törnqvist et al., 2006). Therefore, the benefits (e.g., reduction in wetland loss and improvement of soil carbon sequestration) of future wetland restoration projects should be evaluated based on predicted landscape response to the combination of rising sea level and high subsidence.

Coastal landscape dynamics (horizontal dimension) and elevation (vertical dimension) are influenced by physical and ecological processes and their interactions (Nyman et al., 1993; Rybcyzk et al., 1998; Reyes et al., 2000; DeLaune et al., 2003; Day et al., 2011). In coastal Louisiana, human activities and natural events have contributed to wetland loss (land mass gone from both horizontal and vertical dimensions) through reduction in sediment supply from the Mississippi River (Day et al., 2000; Blum and Roberts, 2009), changed hydrology due to natural (e.g., sea level rise, salt water intrusion) and anthropogenic factors (e.g., construction of levees, road, canals) (Day et al., 2000), wind/wave induced erosion (Chen and Zhao, 2011) and many other interacting factors such as land subsidence (e.g., Törnqvist et al., 2006) (Figure 4).

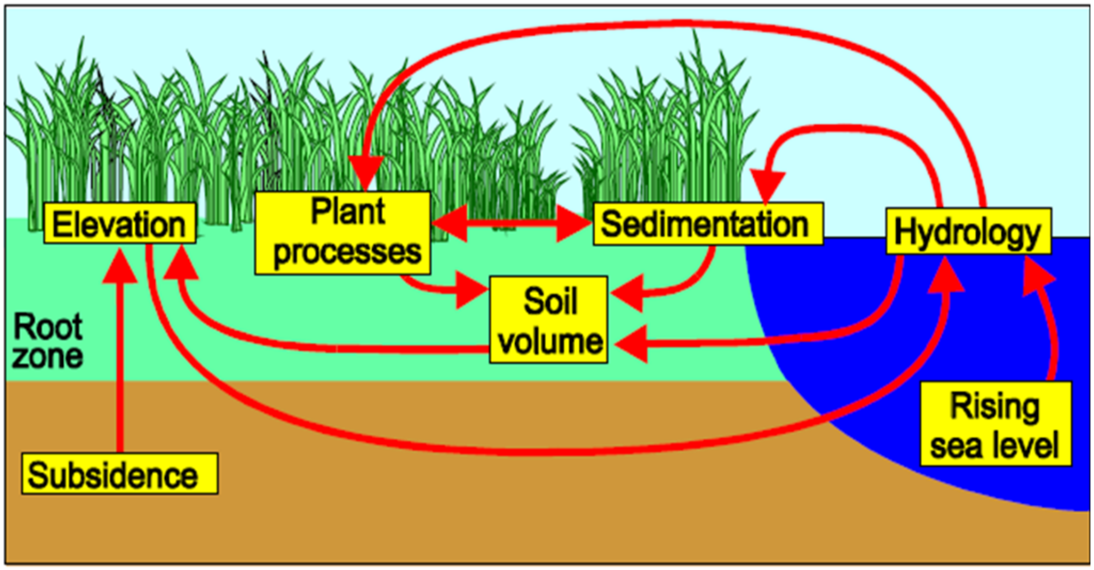


Figure 4. The conceptual model of coastal landscape and elevation influenced by physical, ecological processes and their interaction (source: USGS, 1997).

Previous efforts in modeling landscape change across coastal Louisiana, conducted under the Coastal Louisiana Ecosystem Assessment and Restoration Program (CLEAR) (Twilley et al., 2008), have enhanced our understanding of spatial variability in landscape processes and modeling of such dynamics. The CLEAR Nourishment Module (Visser et al., 2003a; Kemp et al., 2004) and Landscape Change model (Visser et al., 2008) used a combination of empirical relationships and landscape analogs to reflect the complex processes controlling land change in coastal Louisiana. The models were originally developed in support of the Louisiana Coastal Area (e.g., Visser et al., 2003a; Kemp et al., 2004). They were subsequently refined and used to support the State of Louisiana Coastal Protection and Restoration Authority to assess a 50-year future landscape under the Preliminary Draft Master Plan (PDMP) and a future under No Increased Action (NIA) in 2007 (Visser et al., 2008). These models were limited by the assumption that historic loss rates detected from remote sensing and field measurements would remain unchanged into the future (Barras et al., 2003) unless reduced due to restoration actions (within a broad distance from diversion structure or river mouth) or salinity reduction by hydrologic modification in Chenier Plain (Visser et al., 2003a). This assumption was sufficient for the LCA and PDMP efforts because the models did not have to take into account future changes associated with climate change and rising sea levels.

Field and remote sensed data limitations prevented the previous landscape change models from considering the causal mechanisms of land loss, and prohibited the development of coast wide elevation predictions. The current effort requires the projection of possible landscapes under variable estimates of particular processes, such as RSLR (Table 2). This then necessitated the ability to forecast land loss as a result of particular processes, rather than merely projecting past trends. This was done by incorporating important uncertainties concerning the conditions under which wetlands are projected to be lost in the future (See Section 2c “Analytical requirements” for details).

Surface elevation change is one of the important components of coastal landscape change detection that cannot be ignored. The surface elevation change determines the sustainability of coastal wetlands under future climate change, sea level rise, subsidence and management of freshwater and sediment inputs. In coastal Louisiana, relative surface elevation models have been developed for specific locations in coastal Louisiana by Chmura et al. (1992), Callaway et al. (1996), Rybczyk et al. (1998), and Rybczyk and Cahoon (2002). However, efforts in expanding the elevation model to a larger geographical area (e.g., basin and coast wide scales) were prohibited by limited data available for model initialization, calibration and validation such as below-ground production (root-to-shoot ratio), root distribution with depth, decomposition rates, bulk density profiles, and compaction coefficients for different hydrologic and ecological settings across the coast. In the current effort, coast wide monitoring data from CRMS-wetlands and other current research on soil accumulation, bulk density, organic matter, vegetation distribution, plant cover, height, salinity and flooding have made it possible to develop a coast wide elevation model according to the processes and non-linear feedback mechanisms involved in elevation dynamics. Additionally, in the elevation model, sediment accumulated from mineral sources and organic matter contributions to vertical accretion are both accounted for. More importantly, the impacts of subsidence and future sea level rise on elevation change can be explicitly examined in elevation change forecasting. By comparing vertical accretion with rates of global sea level rise and subsidence (or RSLR), elevation surplus (accretion > RSLR) or deficit (accretion < RSLR) can be determined (Nyman et al., 1994; 1999; Rybczyk and Cahoon, 2002).

The concept of elevation deficits, where relative sea level rise exceeds the ability of coastal wetlands to maintain their elevation in the tidal frame (Nyman et al., 1994; Rybczyk and Cahoon, 2002), has long been recognized as a contributing factor in Louisiana coastal land loss. While field measurements in many locations have supported the accretion deficit concept, the way in which marshes respond to deficits has rarely been directly measured in the field (Webb and Mendelssohn, 1996). Laboratory experiments show changes in vegetation growth under increased flooding regimes and indicate that the nature and magnitude of the plant response varies among species (Spaulding and Hester, 2007; Willis and Hester, 2004). Considerable data exists for *Spartina alterniflora* marshes, both from Louisiana and other coastal states, but the response of other plants common in Louisiana are less well understood.

To predict the effects of future elevation deficits on coastal wetlands, it is also important to consider the interactive effects of increased inundation and changes in salinity that may be associated with rising sea level. The stresses induced by increased salinity and inundation/submergence is a major reason for vegetation death, a mechanism that is responsible for marsh collapse and one of the important mechanisms for wetland loss (DeLaune et al., 1987; DeLaune et al., 1994; Nyman et al., 1993; 1994). There are numerous field and laboratory studies of plant responses to changes in salinity, but comprehensive information on the full range of responses and thresholds of Louisiana wetland vegetation to changes in inundation and/or salinity are not available. The Habitat Switching model developed for the Louisiana Coastal Area study was based on literature compilation of existing information on salinity and inundation thresholds (Visser et al., 2003b). This study was informative because it established for each marsh type salinity and inundation conditions under which one would expect minimum productivity. Those minimum productivity values served as a starting point for establishing collapse thresholds, where plants are no longer viable. Most of the literature in Visser et al. (2003b) focused on laboratory studies, so for the 2012 Coastal Master Plan, we combined existing field data (collected under CRMS) with remote sensing applications to establish a marsh collapse threshold (See Section 2c"Analytical requirements" for details).

By working with the Eco-Hydrology, Vegetation and Barrier Shoreline Modeling teams, we developed a coast-wide Wetland Morphology model (landscape change and relative elevation sub-models) that predicts changes in landscape, surface elevation and soil carbon sequestration potential under different scenarios of sea level rise, subsidence and restoration projects in support of the State of Louisiana's coastal planning efforts (Figure 5).

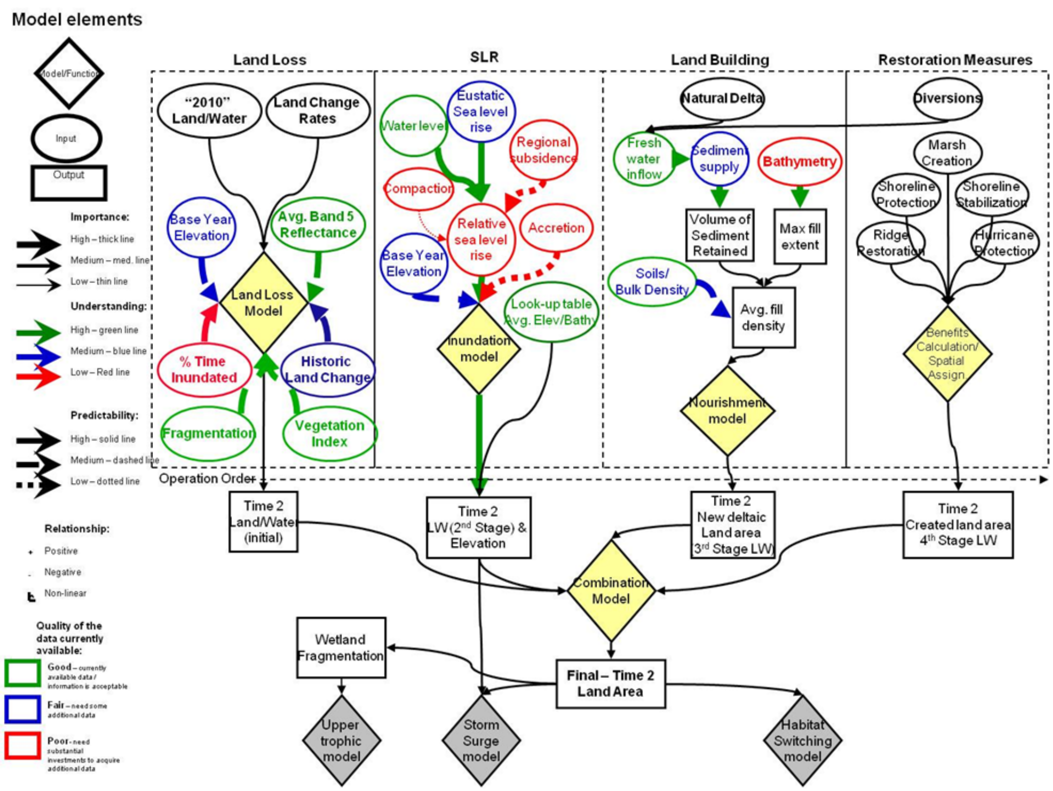


Figure 5. The flow diagram of morph-dynamics under sea level rise, subsidence and ecosystem restoration efforts across coastal Louisiana used in Wetland Morphology model.

There are four components in the landscape change sub-model: (1) land loss, (2) SLR and elevation deficit-induced marsh collapse, (3) land building, and (4) restoration measures (Figure 5). The procedures in processing these four components are described below:

1. Land loss projection: Wetland loss is projected in space by applying the historical land loss rate into an algorithm which distributes loss across the landscape with consideration to a weight surface that was determined by multiple criteria (i.e., spatial layers of elevation [NAVD88], distance to water body, land cover, historical land loss trend, percent time inundated, fragmentation, average band 5 reflectance from Landsat satellite imagery, and average peak biomass from NDVI).

2. SLR-Inundation and marsh collapse detection: Inundation depth in space was determined by comparing surface elevation with ESLR, subsidence, vertical accretion, and water level from the Eco-Hydrology model. Inundation depth, together with salinity from the Eco-Hydrology model

was used to establish marsh collapse thresholds that were determined by previous research, field studies, remote sensing analyses and recommendations by an expert panel.

3. Land building: Land building in space was estimated by simulating vertical accretion using the relative elevation sub-model (See details in relative elevation sub-model section below) using simulated sediment supply from the Eco-Hydrology model to calculate accretion and comparing the updated surface elevation to mean water level (MWL). The coarse resolution (box level) sediment supply from the Eco-Hydrology model was redistributed across the landscape at finer resolutions by applying a sedimentation redistribution weighting surface (30m grid size) to the sediment load from the model (See Section 2c.3 "Sediment redistribution" for details.) First, total sediment amount (grams) in an Eco-Hydrology model box over the 5-year period is calculated by the product of sediment load ($g/m^2/yr$) (provided by Eco-hydro team), the box area (m^2) and distributed every 5 years. Then the sediment load (grams) is estimated at a 30m resolution per grid cell (i.e., 30m X 30m = 900 m^2) by multiplying the total sediment amount by the redistribution weighting surface. Vertical accretion for each of the 30m by 30m grid cell is then calculated using the relative elevation sub-model. Finally, the updated surface elevation can be compared with the updated MWL (= previous time step MWL + ESLR) for land building (gain) or marsh collapse (loss) determination given the vegetation type requirements (e.g., salinity tolerance) using the marsh collapse approach (See Section 2c.2 "Marsh collapse threshold" for details). For example, if a landscape feature is "Land" and vegetation type is "Swamp forest", under the conditions that: (1) mean salinity is less than 5.5 ppt; or (2) mean salinity is greater than 5.5 ppt but new elevation is larger than the updated maximum water level, there is no conversion of land to water; however, under the condition that mean salinity is greater than 5.5 ppt and new elevation is less than the updated maximum water level, marsh collapse would occur (i.e., the assumed land is converted into open water within the 5-year period being modeled). On the other hand, if the landscape feature is "Open water", under the condition that new elevation is less than the updated mean water level, there is no land gain" whereas. In contrast, if new elevation is larger than the updated mean water level, then the area would convert from open water to land. The complete model diagrams and scripts (separated for different restoration groupings) can be found in Attachment C of this report for all conditions of marsh collapse and land gain determination for various vegetation types.

4. Restoration measures: Different types of restoration projects such as marsh creation, freshwater and sediment diversion, shoreline stabilization, shoreline protection, ridge restoration and hurricane projection with targets on land building/filling volume and elevation were provided by the CPRA in project groupings. The Eco-Hydrology model estimated salinity, water level and sediment supply for the areas affected by restoration measures and provided output to the Wetland Morphology team.

Additionally, the CPRA requested an estimate of the ecosystem service, soil organic carbon (SOC) storage. This was estimated in the upper 1-m of soil under different scenarios of RSLR and restoration project groupings using updated information on soil bulk density, organic matter and percentage of land from the Wetland Morphology model simulations. Thus the change in SOC storage and sequestration potential under different groups of restoration projects could be compared (details in SOC section).

The relative elevation sub-model (also called the pre-compaction relative elevation model) is based on the assumption that soil bulk density and organic matter content reach equilibrium with depth, thus an approximate constant value for both BD and OM% can be selected at the depth just before the completion of soil compaction (Figure 6). However, in coastal Louisiana wetlands, such equilibrium of soil bulk density and organic matter is rarely reached due to dynamics of physical and ecological processes under natural and human activities (Markewich et al., 2007). Figure 7 shows soil bulk density and organic matter content change with depth substantially even at the top 30 cm at Old Oyster Bayou, Louisiana. Therefore, representative values of BD and OM% should be selected in order for the pre-compaction relative elevation model to reasonably describe the vertical accretion. If a smaller BD than the "true" or observed BD over a long time is used, vertical accretion would be over-estimated. On the contrary, if a larger BD than the "true" or observed BD is used, vertical accretion would be under-estimated.

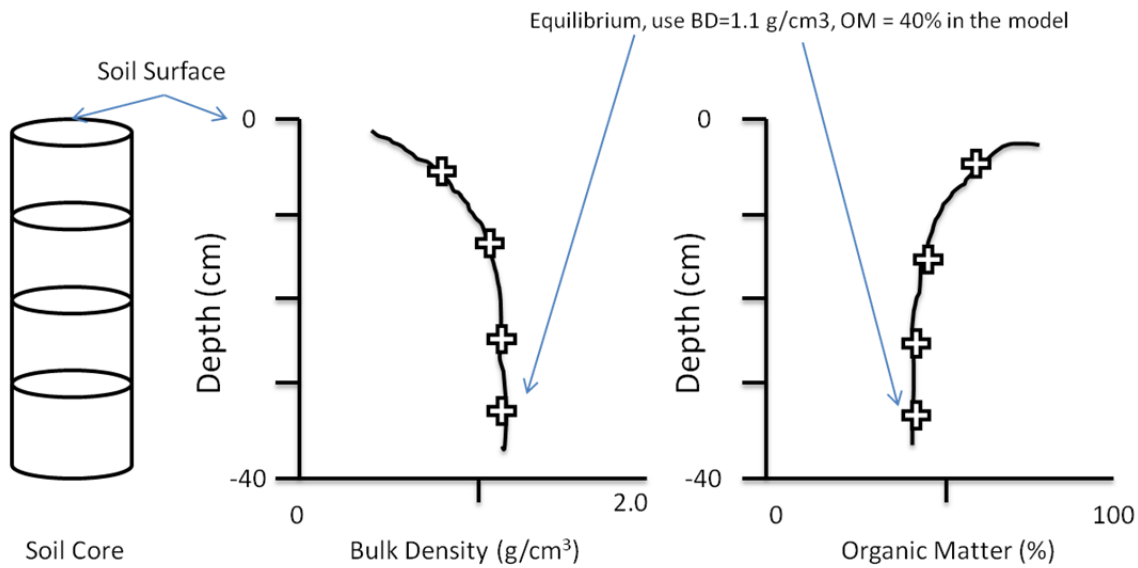
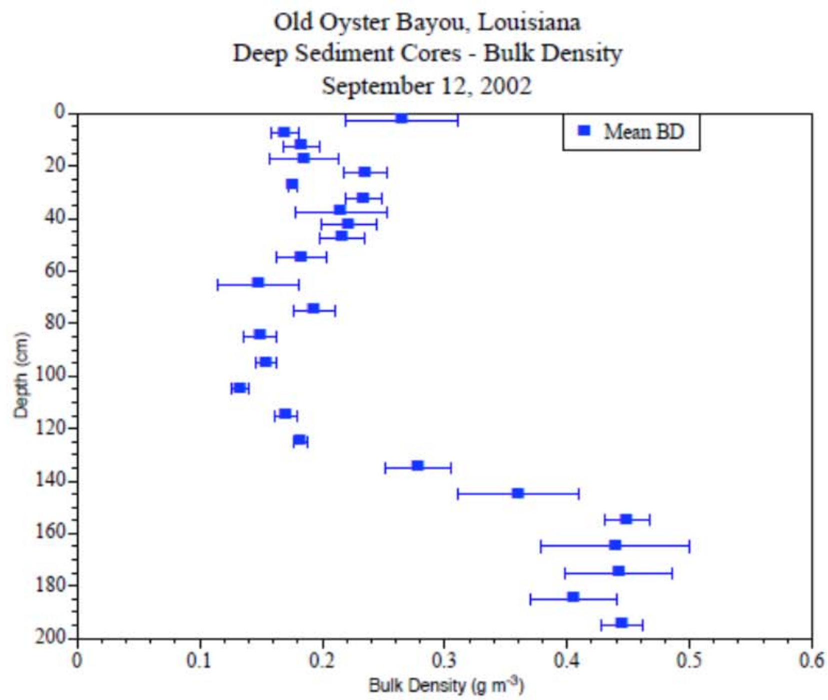


Figure 6. Sketch of the pre-compaction relative elevation model.



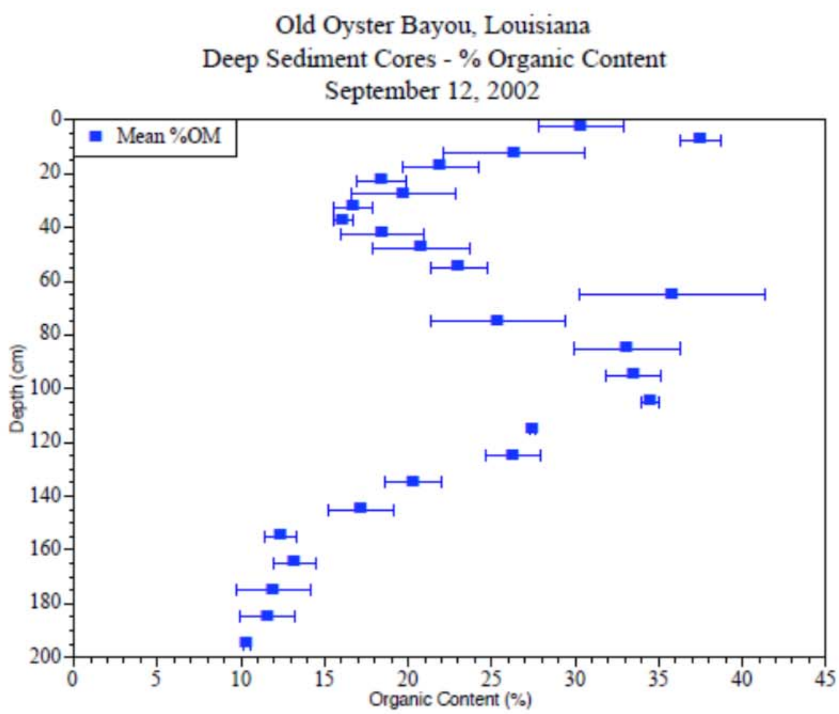


Figure 7. Soil bulk density (a) and organic matter content profile (b) to a depth of 2 meters at Old Oyster Bayou, Louisiana. Samples were collected on September 12, 2002 (data source: Brian Perez, and Guerry Holm of CH2M HILL).

The relative elevation sub-model can be described by the following equations:

$$H = (Q_{sed} + Q_{org})/(10{,}000*BD) \qquad \textbf{(Equ. 1)}$$

Where H = the rate of vertical accretion (cm/yr); Q_{sed} = mineral sediment accumulation rates ($g/m^2/yr$), Q_{org} = organic matter accumulation rates ($g/m^2/yr$); the constant 10,000 is a conversion factor from cm^2 to m^2; and BD = soil bulk density (g/cm^3).

$$Q_{org} = Q_{sed}*F_{org}/F_{min} \qquad \textbf{(Equ. 2)}$$

Where Q_{org} and Q_{sed} are as defined for Equation 1 above; F_{org} is the fraction of organic matter mass in total soil mass at equilibrium**,** which is equivalent to organic matter content (OM%) divided by 100; and F_{min} is the fraction of inorganic matter mass in total soil mass ($1 – F_{org}$). This equation was established based upon examinations of field data on long-term accumulation of organic matter and mineral material from CRMS and LCA S&T (Piazza et al., 2011). The assumptions are: (1) long-term organic matter accumulation can be derived from long-term mineral material accumulation; and (2) there would be no organic matter accumulation when mineral material accumulation is zero. It describes the positive nonlinear relationship between organic and inorganic matter accumulations with varying percent soil organic matter (SOM%). Under similar SOM% conditions, the higher mineral material accumulates, the higher organic matter will accumulate due to the increased availability of mineral for soil formation. On the other hand, under similar mineral material accumulation conditions, the higher the SOM%, the higher organic matter accumulates due to increased root system trapping, reduced water velocity, enhanced settling and increased sediment deposition (Temmerman et al., 2005; Li and Yang, 2009; Mudd et al., 2010). This equation tends to underestimate organic accumulation by approximately 14% when tested using data from Nyman et al. (1993).

$$\Delta E = H – ESLR – S \qquad \textbf{(Equ. 3)}$$

Where ΔE = surface elevation change (cm/yr); H is as defined in Equation 1 above; ESLR is the rate of eustatic sea level rise (cm/yr); and S is the rate of subsidence (cm/yr).

<u>SOC calculation equations:</u>

1. SOC storage over 1-m depth of soil:

ASOC (cell) = (BD * OM%/2.2)*100cm*25ha*%Land **(Equ. 4)**

Where ASOC = soil organic carbon total amount (metric tonnes per grid cell); BD is as defined in Equation 1; OM% is organic matter content, and %Land is land percentage in the 500m grid cell from the landscape change sub-model**.**

2. SOC sequestration potential from elevation change:

ΔSOC (cell) = (BD * OM%/2.2)* ΔE **(Equ. 5)**

Where ΔSOC = SOC sequestration potential due to elevation change (tC/ha/yr).

3. SOC and SOM conversion factor:

We modified the Van Bemmelen factor (1.724) (Schumacher, 2002; Zhong and Wu, 2009; Pribyl, 2010) to convert SOM to SOC for coastal Louisiana wetlands based on the new relationship between SOM% and SOC% (mass-based) we developed from soil data (Piazza et al. 2011):

SOC% = 0.4541*SOM% (or Percent of historic mean **SOM%=2.2*SOC%) (Equ. 6)**

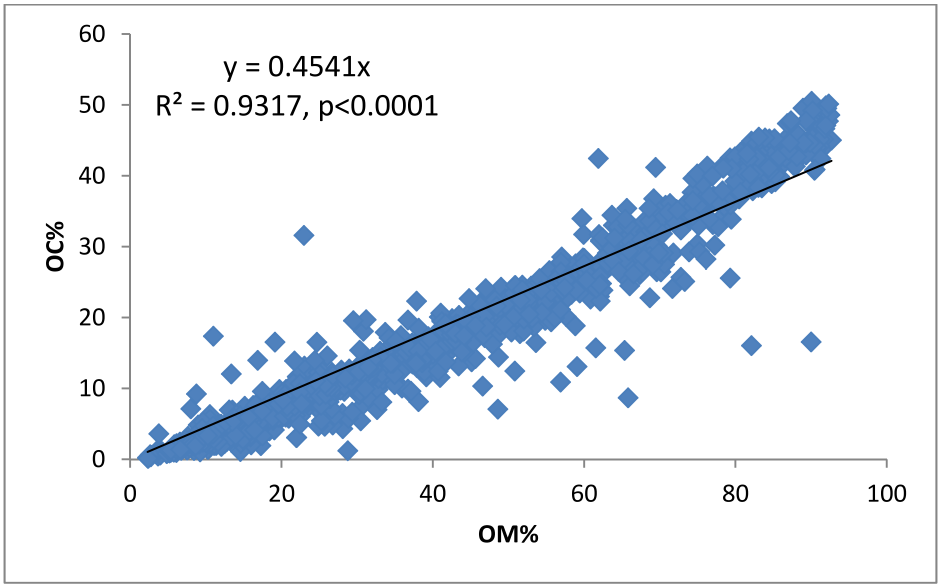


Figure 8. The relationship between organic carbon content (OC%) and organic matter content (OM%) in soils of coastal Louisiana wetlands that is derived from Louisiana Coastal Area Science & Technology soil data (to a depth of ~50cm over 30 sites, and 47 cores during 2006-2007) across the entire coast (sample size n = 1,142).

Figure 8 indicates that in coastal Louisiana wetland soils, the organic matter contains approximately 45.4% organic carbon, not the 58% organic carbon described by Hatton et al. (1983) which was primarily based on terrestrial soil data, and did not reflect the situation of Louisiana coastal soils. Therefore, the converting factor should be 2.2 (1/0.4541) instead of 1.724 (1/0.58).

b. Description of system being represented by the model

The spatial domain of the Wetland Morphology model is defined as coastal Louisiana, bounded by the Texas border in the west and Mississippi border in the east; and 10-m elevation contour to the north and 20-m bathymetric contour to the south (Figure 14). Coastal Louisiana covers diverse landscape features including forest (upland, swamp, mangrove), marsh (freshwater, intermediate, brackish, saline), mudflats, water bodies (bay, river, tributary, bayou, pond, lake, navigation channel), roads, levees, spoil banks and other man-made features. The coastal Louisiana landscape is ever-changing, with significant wetland losses and limited land gains as influenced by natural processes and human interventions (Twilley et al., 2008; Couvillion et al., 2011). Through the previous studies on landscape change detection (e.g., the Louisiana Coastal Area (LCA), the Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) Program and this effort), major natural and anthropogenic factors contributing to wetland loss have been identified to form our conceptual understanding applied in the current version of the Wetland Morphology model (Figure 5). Key coastal factors considered in the Wetland Morphology model and are either directly or indirectly coupled with the Eco-Hydrology model and Vegetation model include climate change induced sea level rise, land subsidence, hurricane/storm surge, saltwater intrusion, flooding, and vegetation community dynamics (e.g., Nyman et al., 1994; Reed et al., 2009; Piazza et al., 2011). The anthropogenic factors include construction of navigation channels, levees, spoil banks along the Mississippi River and some tributaries, subsurface fluid withdraws, water resource management (e.g., impounding), and restoration activities (e.g., river and sediment diversion, marsh creation, shoreline protection) (e.g., Knaus and Van Gent, 1989; Cahoon, 1994; Bryant and Chabreck, 1998; Edwards and Proffitt, 2003; McCorquodale et al., 2004; Cahoon et al., 2011). These factors (or processes) interact closely to determine landscape change across coastal Louisiana (Tables 5, 6). For example, extraction of oil and gas has contributed greatly to land subsidence, together with sea level rise, causing salt water intrusion into inner wetland areas and increased inundation duration in low-lying areas (Day et al., 2000). The stresses induced by increased salinity and inundation/submergence can lead to changes in vegetation community types or wetland loss through marsh collapse following vegetation death. This is studied in the model by exploring marsh collapse thresholds for different vegetation types under various salinity and inundation combinations (Table 7). Reduced sediment supplies from the Mississippi River and construction of roads, levees, canals and channels has resulted in reduction of sediment transport, delivery, and deposition onto wetland surfaces. Sediment delivery and accumulation needed to build or maintain wetlands has been examined in the Wetland Morphology model through coupling with the Eco-Hydrology model (See Section 2c.3 "Sediment redistribution" for details). Wetlands need sufficient vertical accretion to offset the rates of SLR and subsidence in order to maintain surface elevation over time. Knowing that wetland vertical accretion comes from both mineral and organic matter (Nyman et al., 2006) and that contributions of organic and mineral matter to vertical accretion could vary spatially and temporally (Craft et al., 1993; 1997; Turner et al., 2004), the Wetland Morphology model reflected variations of soil bulk density and organic matter content among different hydrologic basins and vegetation types.

The Wetland Morphology model does not capture organic matter contributions to vertical accretion from vegetation productivity. The Vegetation modeling team determined that there was insufficient data and literature across all vegetation types to support inclusion in the modeling effort; therefore, this part of the system is not included in the model. Additionally, other factors that influence vegetation productivity, such as nutrients, are not represented by the model. Data and time limitations also precluded the inclusion of spatially-explicit sediment contributions due to storms and hurricanes.

c. Analytical requirements

During the development of the Wetland Morphology model, analytical requirements for both the landscape and relative elevation sub-models were identified as following:

- Land loss probability weight surface
- Marsh collapse thresholds
- Sediment redistribution surface
- Representative soil bulk density and organic matter through calibration
- Soil organic carbon sequestration calculation

1. Multiple criteria of land loss weighting surface

Multiple criteria approaches (MCA) are commonly used to assess the relative weight of multiple criteria (Belton and Stewart, 2001). One of the most widely used MCA approaches is the Analytical Hierarchy Process (AHP), which provides a consistent way of converting pairwise comparisons into a relative priority for each criterion (Millet and Wedley, 2002). In this modeling effort, we needed to investigate multiple geo-spatial criteria and determine qualitatively which of these criteria are more important in predicting land loss. The criteria utilized in our pairwise comparison are important landscape characteristics that are influential in understanding potential land loss (Table 5).

A survey was distributed to 25 coastal scientists and resource managers in Louisiana and each participant was asked to fill out the matrix shown in Table 6. Each participant was instructed to select the most important criteria in terms of its influence on land loss/gain processes for each of the paired comparisons. In the corresponding cell of the matrix, the letter of the criterion that was determined to be most important was selected. If both criteria are of equal importance, then both letters were included in the corresponding cell. The results from one of the participants are shown in Table 6.

We received 17 responses to the survey and, from these responses we compiled a ranking and assigned weights by the number of cells containing the flagged letter. To illustrate, based on the example in Table 6, the ranking and weighting equation would be 100 = 7A+0B+1C+7D+5E+3F+4G+3H. The consolidated weighting equation and percent weights from all the results were provided back to all respondents for further discussion and iterative refinement until there was a consensus by all respondents. The final weightings utilized in the model are:

Elevation = 17.8%
Distance to Water = 6.9%
Land Cover = 7.1%
Historic Loss Trend = 14.1%
Percent Time Inundated = 16.6%
Fragmentation = 15.9%
Average Band5 = 9.9%
Vegetation Index = 11.7%

Table 5. Multiple criteria and their meaning in weight surface determination.

Elevation	Height in m NAVD88. In areas for which no LIDAR is available, neural network approach used to project elevation of area
Distance to Water	Each cell's straight line Euclidean distance to water
Land Cover	Northern Gulf of Mexico land cover classification; similar to NOAA C-CAP with greater number of wetland types
Historic Loss Trend	Moving window averaging of land change rates in percentage per year
% Time Inundated	Percentage of time the cell is classified as water as derived from Band 5 reflectance of cloud free Landsat images between 1983 and 2009
Fragmentation	Indication of extent of marsh breakup; six categories of fragmentation including perforated, patch, edge, and 3 sizes of core
Avg Band 5 Reflectance	Indication of wetness; average band 5 reflectance of cloud-free Landsat images between 1983 and 2009

Vegetation Index	Indication of health and vigor; average peak biomass normalized vegetation index as derived from MODIS and Landsat composite 2000-2009

The weighting approach is an improvement over previous land loss/gain projections which primarily projected historic land loss trends into the future. Utilizing a multi-criteria approach, and an iterative review by respondents knowledgeable of factors contributing to land loss/gain, both subjective and objective evaluation measures and group decision-making through consensus were incorporated.

Table 6. Criteria matrix used to conduct pairwise comparison. Values in matrix are an example **from one participant from the survey.**

		Elevation	DistWater	LandCover	HistoricLossTrend	PercentTimeInun	Fragmentation	AvgBand5	VegIndex
		A	B	C	D	E	F	G	H
Elevation	A		A	A	AD	A	A	A	A
DistWater	B			C	D	E	F	G	H
LandCover	C				D	E	F	G	H
HistoricLossTrend	D					D	D	D	D
PercentTimeInun	E						EF	E	E
Fragmentation	F							G	H
AvgBand5	G								G
VegIndex	H								

2. Marsh collapse threshold

The basic approach of establishing a marsh collapse threshold is to extend the relationship between inundation and vegetation productivity to allow prediction of conditions under which the plants are not viable. A great deal of land change data exists delineating which areas have been lost during the 1984-2010 observation period. These remotely sensed (RS) data (Couvillion et al., 2011) characterize loss at a resolution of 30-meter, and individual pixels of loss were examined for depth of inundation, vegetation vigor, elevation and vegetation type, shortly prior to the loss. Those characteristics for loss pixels were compared via multivariate statistics to pixels which were retained. This method determined unique combinations of characteristics exhibited by pixels which were lost and was used to extend the relationships between inundation and productivity towards intercepts, where productivity is effectively zero.

Table 7. The marsh collapse thresholds for different vegetation types across coastal Louisiana.

Marsh Type	Threshold Range	Rationale and Justification
Fresh	Salinity: 6-8 ppt (8 week average – growing season	Expert Panel (pers. comm.)
Intermediate	Inundation: Proposed as 32-38cm (CRMS), 30.7to 35.7 (RS)	30.7-38.0 cm depth (per supporting documentation below)

Brackish	Inundation: Proposed as 25-20cm (CRMS), 20.1-25.6 (RS)	20.0-25.6 cm depth (per supporting documentation below)
Saline	Inundation: Proposed as 16-18cm (CRMS), 16.9-23.5 cm (RS)	16.0-23.5 cm depth (per supporting documentation below)
Swamp	Salinity: 4-7 ppt (8 week average – growing season)	Gary Shaffer (per. com.)

Note: CRMS= Coast wide Reference Monitoring System; RS = Remote Sensing.

This method required the creation of select data layers which approximate past conditions and which focus on periods for which other land loss factors (e.g., droughts, hurricanes) are thought to be minimal. CRMS data from 2007-2008 served as training data to improve the development of data layers from previous periods. Once the marsh collapse thresholds were determined by the Wetland Morphology team, an Advisory Panel was assembled by the CPRA to provide expert opinion on the approach and values (see Appendix C – Environmental Scenarios). The final marsh collapse thresholds for different vegetation types were determined as shown in Table 7 using the full range of values derived from CRMS and remote sensing data. The following section describes in detail how these marsh collapse thresholds were determined.

<u>1. Relationship between wetland productivity and inundation and salinity regimes</u>
Much of the available information on relationships between vegetation productivity and both inundation and salinity was assembled for the CLEAR modeling effort which supported the LCA comprehensive planning effort (Visser et al. 2003b). Using the estimated relationships between vegetation productivity, inundation and salinity that were described in the document, we focused on salinity and inundation conditions within each marsh type that contributed to conditions supporting 25% or less of maximum productivity as a starting point for establishing thresholds. The following inundation and salinity regime thresholds were established for each vegetation class: (1) swamp: >4ppt salinity and 80% inundation; (2) fresh marsh: >6ppt salinity and 90% inundation; (3) intermediate marsh: >14ppt and 100% inundation; (4) brackish marsh: >20ppt and 70% inundation; and (5) saline marsh: >40ppt and 90% inundation.

The current need was to predict the conditions under which productivity is effectively zero (e.g., the plants are no longer viable) to aid in the predictions of potential land loss. Two additional datasets that supported the determination of these thresholds were field data from CRMS and remotely sensed data from satellite imagery.

2. Field data: Wetland vegetation and elevation relationships from CRMS sites by habitat type
Figures 9A-C represent herbaceous cover values from 2007, 2008, and 2009 with respect to the each site's elevation. They are summarized by intermediate, brackish, and saline marsh types. Fresh marsh is not represented because it is assumed that fresh marsh would not experience a marsh collapse strictly based on inundation effects associated with increasing sea level. This assumption was supported by the expert panel and is based on vast acreage of robust fresh marsh in coastal Louisiana that exists under conditions of 100% inundation. As a guidepost, in Figures 9A-C, the dashed red vertical line represents an approximate mean sea level (assuming NAVD88 is approximately 30 cm below MSL; this is known to vary). The dashed slanted line extends to approximately 30 cm below MSL. What may be most important here is that the preponderance of herbaceous marshes occur above +0.5 ft NAVD88 (15 cm below MSL). This pattern becomes more obvious with increasing salinity—fewer sites reside below the +0.5 ft NAVD88 threshold.

It is clear that a strong linear relationship does not exist with elevation and plant cover across the breadth of the data. However, in thinking about marsh collapse thresholds, it may be useful to consider the lower bound on elevations at which these marshes occur. The blue and green lines in Figures 9A-C represent the lowest range of inundation where herbaceous vegetation cover still exists.

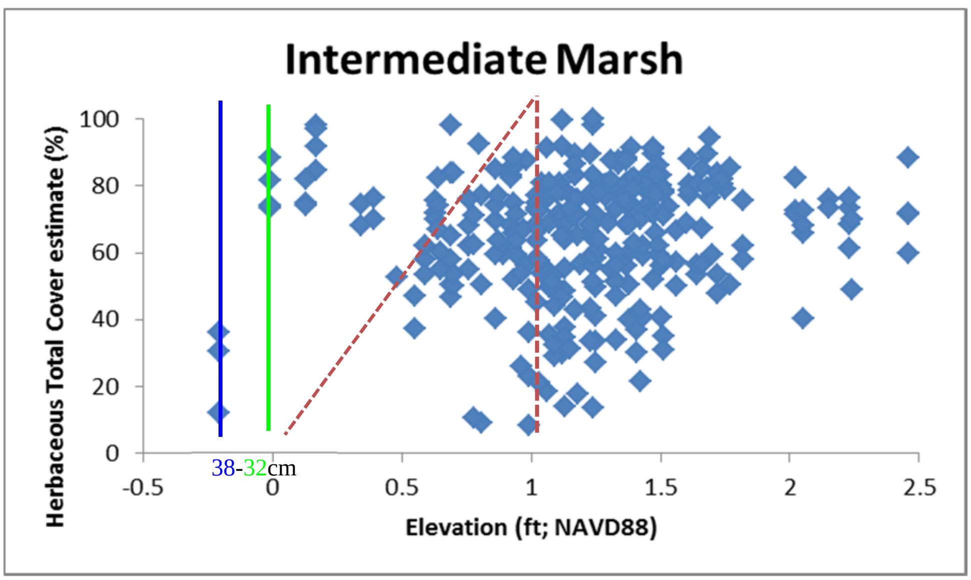


Figure 9-a. Herbaceous Total Cover (%) for 2007, 2008, and 2009 vs. site elevation at intermediate CRMS sites in coastal LA. As a guidepost, the dashed red vertical line represents an approximate mean sea level (assuming NAVD88 is approximately 30 cm below MSL; this is known to vary). The green and blue vertical lines illustrate the lowest bound of vegetation cover. Data were compiled by CH2M Hill.

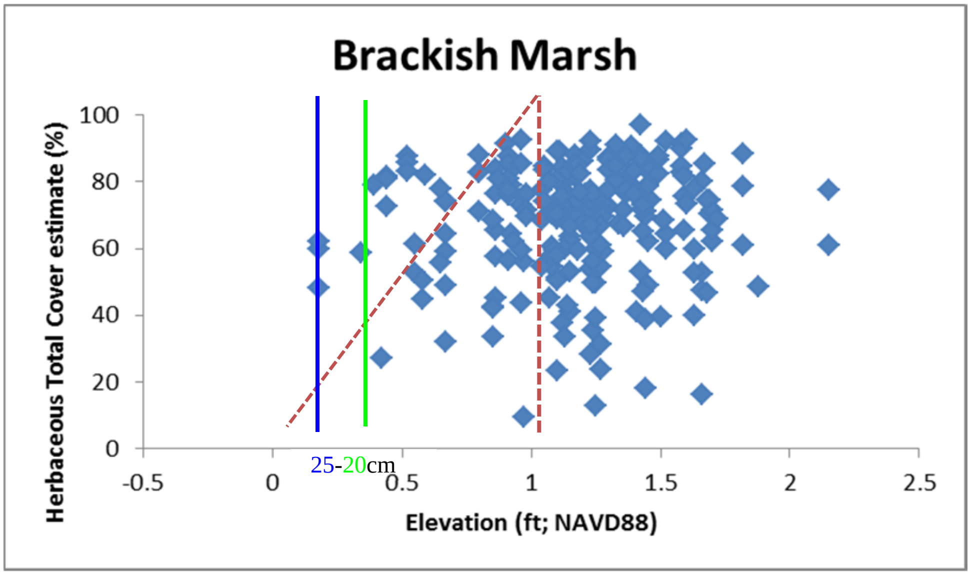


Figure 9-b. Herbaceous Total Cover (%) for 2007, 2008, and 2009 vs. site elevation at brackish CRMS sites in coastal LA. As a guidepost, the dashed red vertical line represents an approximate mean sea level (assuming NAVD88 is approximately 30 cm below MSL; this is known to vary). The green and blue vertical lines illustrate the lowest bound of vegetation cover. Data were compiled by CH2M Hill.

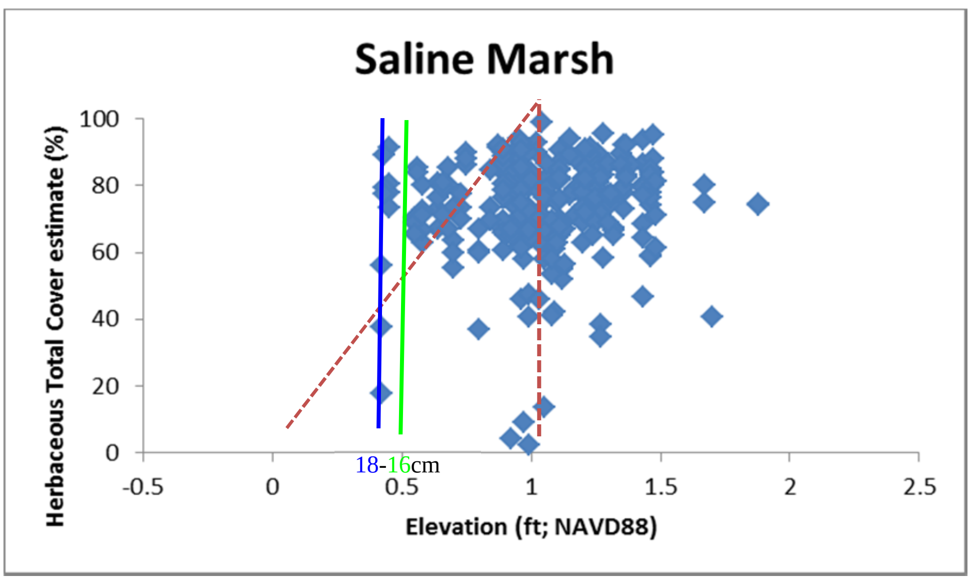


Figure 9-c. Herbaceous Total Cover (%) for 2007, 2008, and 2009 vs. site elevation at saline CRMS sites in coastal LA. As a guidepost, the dashed red vertical line represents an approximate mean sea level (assuming NAVD88 is approximately 30 cm below MSL; this is known to vary). The green and blue vertical lines illustrate the lowest bound of vegetation cover. Data were compiled by CH2M Hill.

3. Remote sensing approach

In addition to our examination of field-data, we also investigated vegetation relationships utilizing remote sensed data. The relationships presented here have been informed by satellite and geospatial data derived from multiple dates and sources. Remotely sensed data from various sources including MODIS, Landsat TM, and LIDAR sensors, collected between 2000 and 2009 were used and proved helpful in determining conditions at which marshes cease to occur. These remotely-sensed data were used in combination with field data pertaining to mean water level, and groups of pixels were examined with respect to depth of inundation and vegetation vigor. These data were used to extend the relationships between inundation and productivity toward intercepts, where productivity is effectively zero. CRMS data from 2007-2008 served as important training data sources to much of this investigation. The following sections outline the specific datasets and methodologies utilized in this examination.

The Normalized Difference Vegetation Index (NDVI), which is an index to detect live, green plant canopies, has been used in many ecosystems to establish relationships with vegetation productivity, leaf area index, fraction of radiation intercepted, and canopy cover and has allowed for the detection of seasonal phenologies and possible stressors that influence these phenologies (Gamon et al. ,1995; Rundquist, 2002; Filella et al., 2004; Pettorelli et al., 2005). The NDVI is a ratio that exploits varying absorption and reflection characteristics of red and near-infrared (NIR) wavelengths of light:

$$\boldsymbol{NDVI = \frac{(NIR - RED\ VIS)}{(NIR + RED\ VIS)}} \qquad \textbf{(Equ. 7)}$$

Previous investigations have studied the seasonal patterns in NDVI value by habitat type in coastal Louisiana (Steyer, 2008). The data presented in Figure 10 show that in nearly all habitat types and regions of the coast, NDVI values typically reach a peak in August. It is generally accepted that this peak corresponds to peak biomass. Therefore, average NDVI values were calculated for the month of August, and this dataset was used to approximate vegetation productivity for future investigations.

Figure 11 shows a composite of NDVI values from multiple sensors (MODIS and Landsat TM) during the month of August. Average values were calculated from imagery collected by both of these sensors during the months of August for multiple years (2000-2009). Higher NDVI values (shown in dark green) indicate healthy, dense vegetation while lower NDVI values (shown in red) indicate lower vegetation density or vigor. NDVI is commonly used as a surrogate for vegetation biomass or productivity.

NDVI values can be very useful in determining thresholds between vegetated and non-vegetated areas. Figure 12 below illustrates the drastic difference in NDVI values as one moves along a transect from vegetated marshes into open water. Although the NDVI formula (Equation 7) results in a theoretical range from -1 to +1, actual values never reach those extremes. Typically even the most dense and vigorous vegetation observed will have a maximum NDVI value of approximately +0.9, and complete open water can be represented by NDVI values anywhere from a value of +0.2 to an absolute minimum of approximately -0.5. The general range for these marshes is approximately +0.35 in saline marshes to a high of approximately +0.7 in fresh marsh.

A land use land cover (LULC) dataset was utilized to isolate groups of pixels by basin and marsh type. First, statistics were calculated for NDVI values by marsh type for intermediate, brackish, and saline marsh in coastal Louisiana. Fresh marsh is omitted from this analysis since the Wetland Morphology team and expert panel decided a marsh collapse threshold based upon inundation was not necessary for fresh marsh. Those marshes would first have to convert to another marsh type as determined by the Vegetation model before the model would reflect loss due to inundation/SLR. Marsh collapse in fresh marsh can also be salinity driven.

The statistics of NDVI values were then summarized by marsh type for the entire Louisiana coast. Example histograms of NDVI values are shown in Figures 13 (a-c).

The red line in Figures 13 (a-c) represents the mean NDVI value for that marsh type. The green and blue lines represent 1.5 and 2 standard deviations lower than the mean respectively. These values were selected as the Wetland Morphology team believes a reasonable marsh collapse threshold may be represented somewhere within this range. As marshes almost never occur beyond these limits, these values may be a reasonable and defendable means of setting a range in the remotely sensed data in which marsh collapse may be likely to occur.

One of the benefits of remotely sensed data is that the sample size is greatly increased compared to the field data. While there may not be enough field samples to calculate appropriate statistics for a given basin/marsh type combination, sampling is usually sufficient with the number of remotely sensed data. Using remotely sensed data, the number of samples can reach hundreds of thousands, or even millions, as each pixel provides a value. Mean and standard deviation (SD) statistics were calculated for each basin and marsh type and are summarized in Table 7. It is important to note that even with remotely sensed data, some basin/marsh type combinations can still have a low number of samples and may not be fully representative of the system. An example of this occurring would be the Atchafalaya Delta basin, which has intermediate, brackish and saline marsh types represented with NDVI values even though the Atchafalaya Delta Basin is composed almost entirely of fresh marsh.

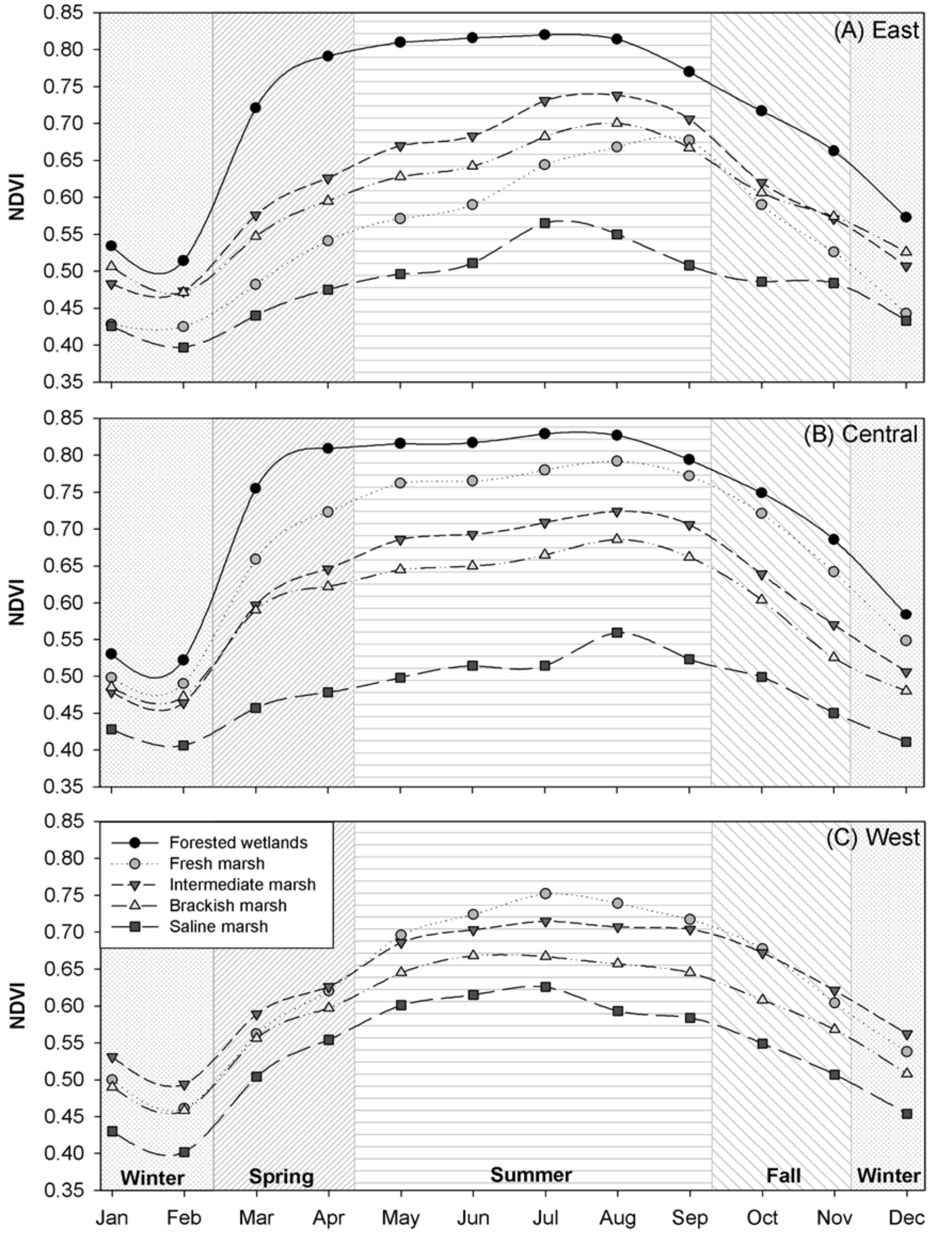


Figure 10. Seasonal trends of mean values in the Normalized Difference Vegetation Index (NDVI) by habitat type and regions within coastal Louisiana: (A) East, (B) Central, and (C) West.

Figure 11. A preliminary data layer of the average peak biomass conditions as estimated by the Normalized Difference Vegetation Index for the northern Gulf of Mexico.

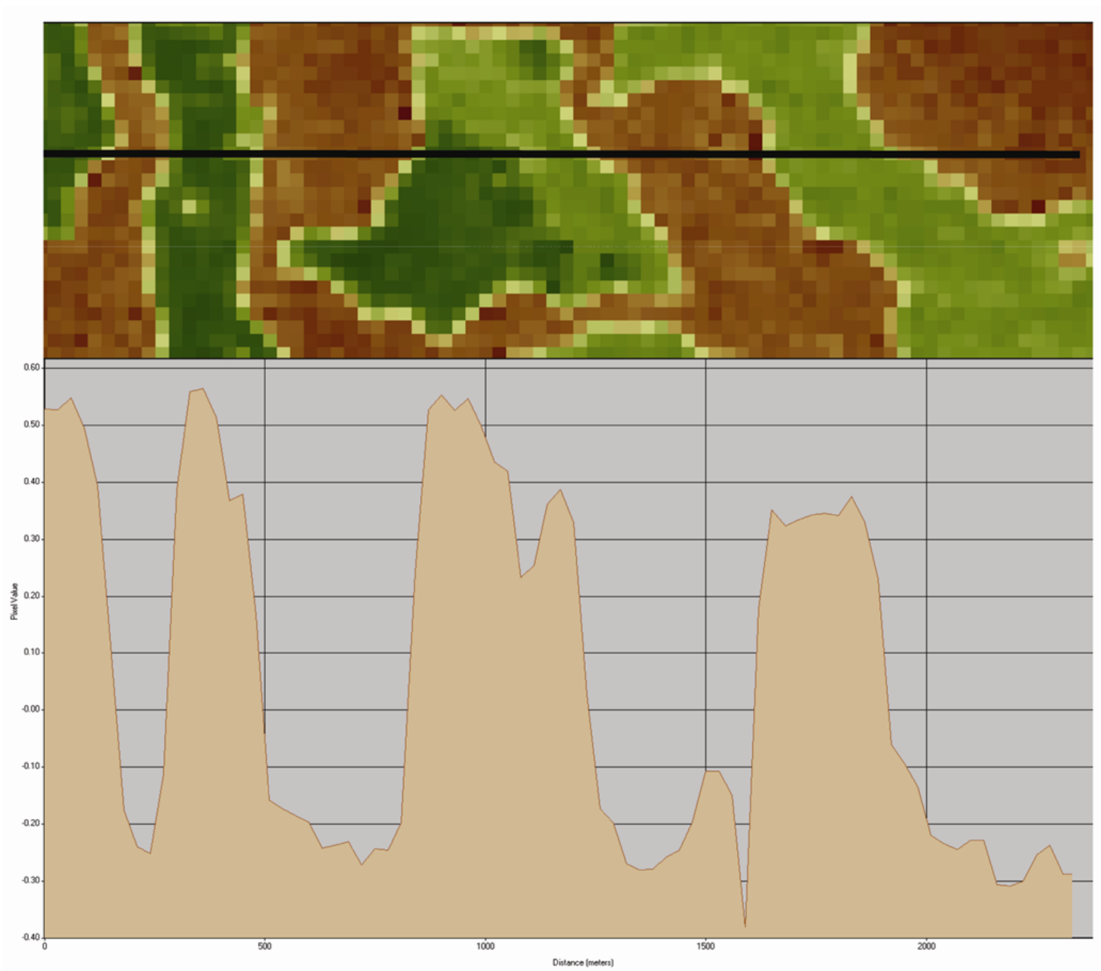


Figure 12. An illustration of NDVI values across a transect (represented by a black line) of marshes and ponds in Breton Sound Basin.

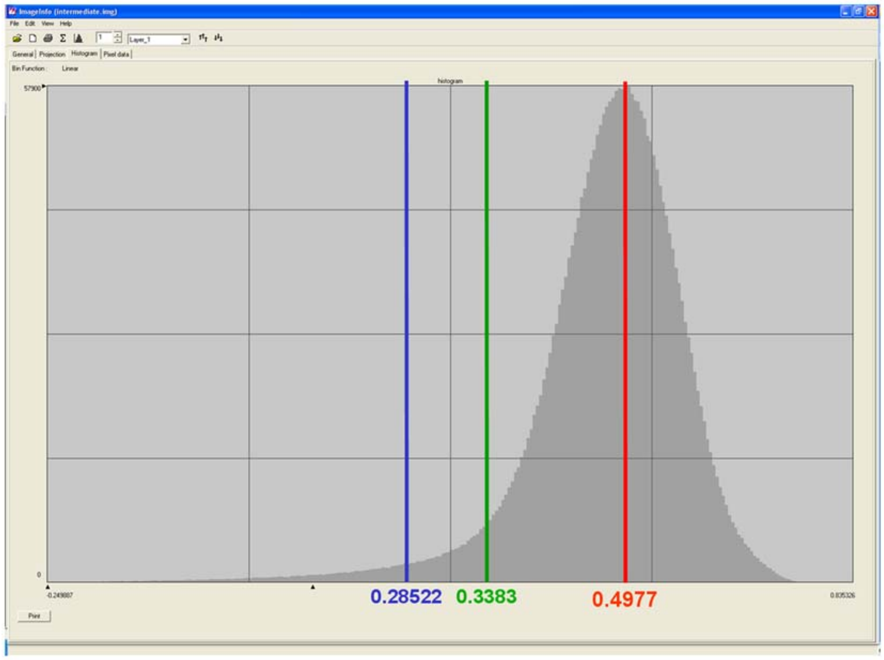


Figure 13A. Example histogram of peak biomass (August) NDVI values for existing intermediate marsh in Barataria Basin. The red line represents mean NDVI value and the green and blue line represent 1.5 and 2 standard deviations lower than the mean, respectively.

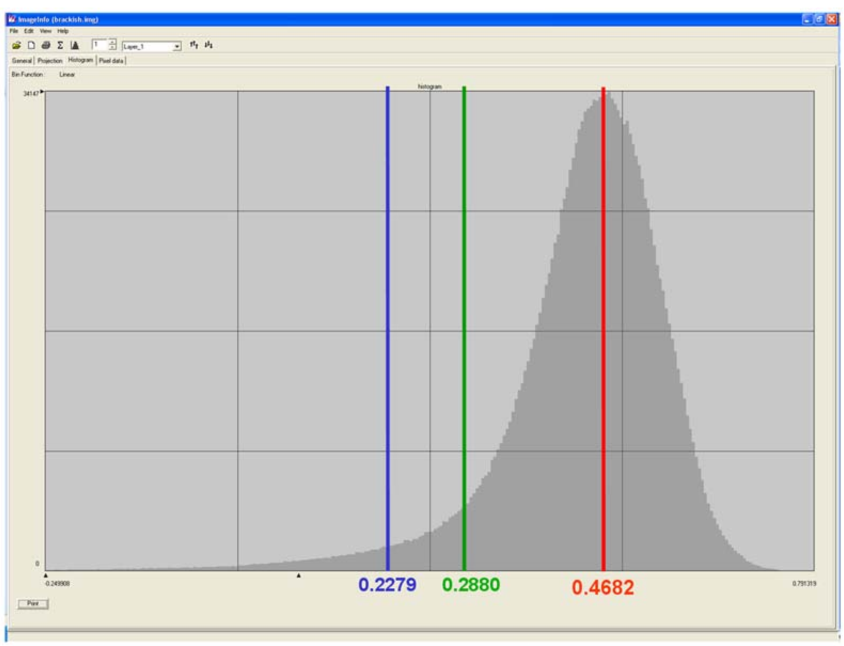


Figure 13B. Example histogram of peak biomass (August) NDVI values for existing brackish marsh in Barataria Basin. The red line represents mean NDVI value and the green and blue line represent 1.5 and 2 standard deviations lower than the mean, respectively.

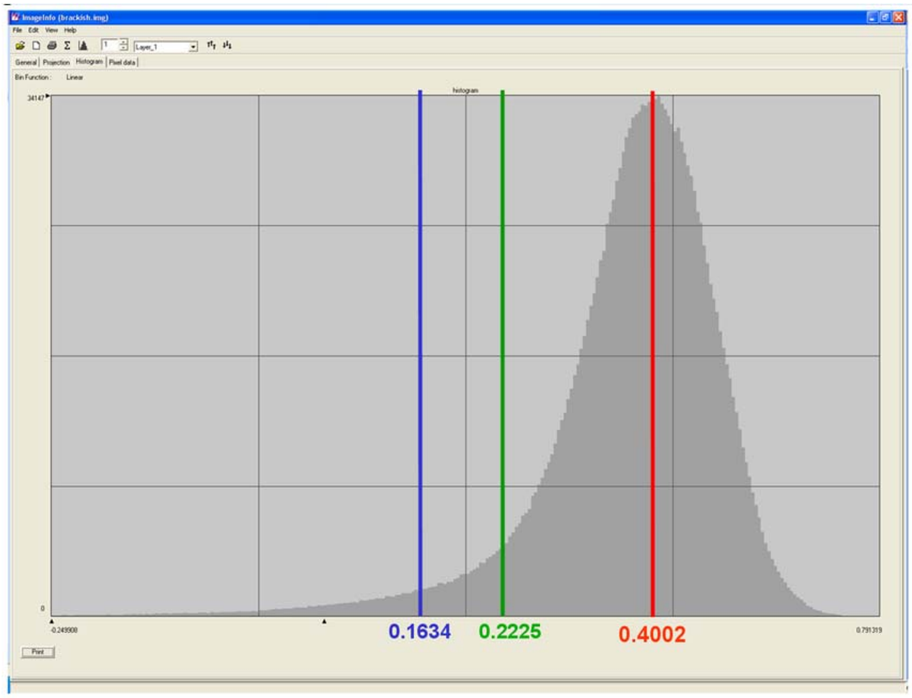


Figure 13C. Example histogram of peak biomass (August) NDVI values for existing saline marsh in Barataria Basin. The red line represents mean NDVI value and the green and blue line represent 1.5 and 2 standard deviations lower than the mean, respectively.

Once we were able to determine the distribution of biomass values (as represented by NDVI), we then turned our focus to the datasets which would be used to quantify inundation. As inundation frequency and duration can be more difficult to characterize from remotely sensed data (cloud cover and sensor return frequency often do not support the temporal frequency necessary to estimate these parameters), inundation depth was selected as the primary candidate for evaluation of marsh collapse thresholds.

Elevation Data

An estimation of inundation depth first requires high quality topography data. Ideally, LIDAR data are used for this purpose; however, recent LIDAR flown in Louisiana excluded many of the unpopulated marsh regions thus leaving holes in the data. These holes can be patched using digital elevation model (DEMs) data from the National Elevation Dataset (NED); however, NED data is coarse in resolution, low accuracy, and is somewhat outdated. In an effort to blend the best of what was available, a model was utilized that incorporated multi-temporal imagery, LIDAR, land cover data, and NED data to predict elevation values in areas lacking LIDAR. The resulting dataset has an accuracy of 10 cm to 15 cm when compared to the original LIDAR. This predicted dataset serves as a strong resource of data until future LIDAR can be flown. The results of this compilation represent the best available topography data for the study area (Figure 14).

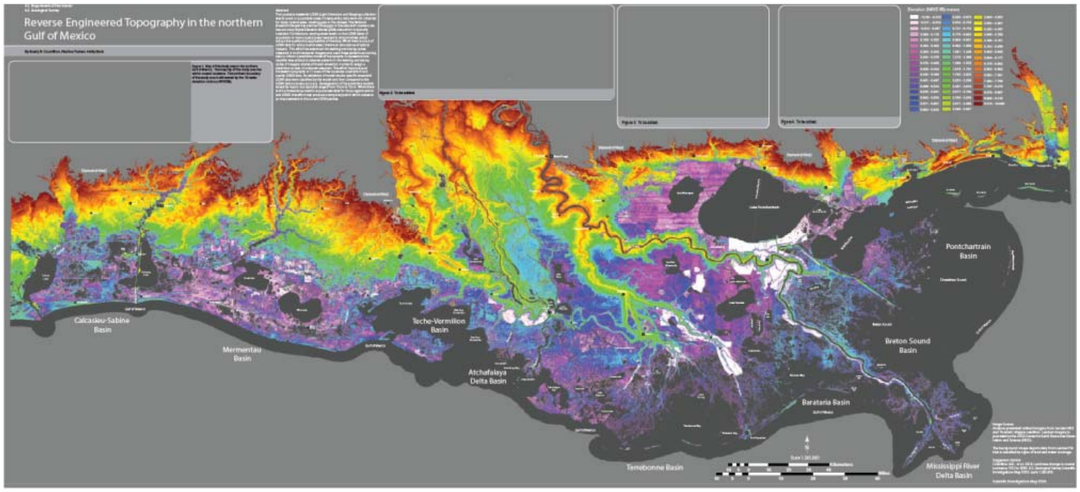


Figure 14. A preliminary data layer of the topography for the northern Gulf of Mexico.

Mean Water Level Data

The second component necessary to calculate inundation depth is an estimate of water levels. Mean water levels were calculated from data acquired at over 200 CRMS stations. The mean water levels were extrapolated across polygons covering all of coastal Louisiana during the 2008-2009 period. Polygons delineating similar hydrologic areas in coastal Louisiana were utilized and average MWL values were calculated for each polygon if at least 3 CRMS sites were contained within that polygon. If less than 3 points were available for an area, the mean water levels were extrapolated using ordinary kriging with first order trend removal and the average of that dataset was utilized for given polygons. Kriging is a geo-statistical technique to interpolate the value of a field (i.e., mean water level in this case) at unknown locations from observations of its value at nearby locations.

Mean water levels in water bodies for which there was no nearby CRMS data were approximated using the average elevation of the nearest land pixel. (This typically only occurred in fresh marsh/swamp in the Atchafalaya Basin, as there are no CRMS sites in the upper Atchafalaya Basin). The datasets were mosaiced together to form one cohesive dataset shown in Figure 15.

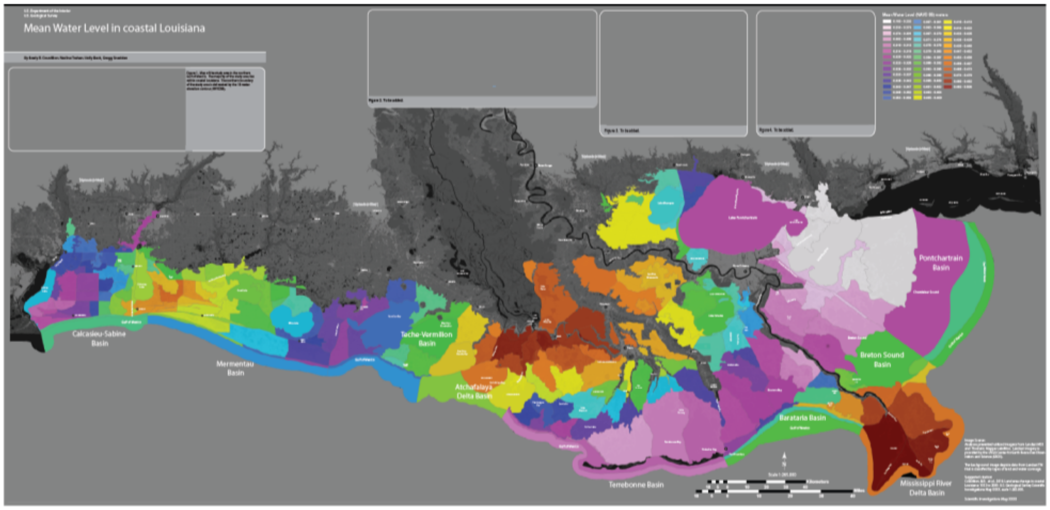


Figure 15. A preliminary data layer of mean water level in coastal Louisiana.

Elevation Relative to Mean Water Level (MWL)
Elevation relative to MWL was calculated by subtracting the mean water levels throughout coastal Louisiana from the elevation dataset. The term "Elevation relative to MWL" is utilized as values can be positive, and positive "depths" are not intuitive. Positive values represent areas which are not flooded at MWL, while negative values are areas which are estimated to be flooded at MWL.

Sampling Data Points
As the total number of samples of 30m pixels for the entire coast in the 3 marsh types of interest were approximately 15.7 million pixels, we determined that only a subset of those pixels was necessary for further evaluation. A sampling tool was used to create a random 10% sample of data for each zone. This tool selected points based on a stratified manner, attempting to subset points representative of the range of NDVI values seen throughout that zone. The variables of "Elevation relative to MWL" and NDVI were collected at each point.

Resulting data were graphed in SigmaPlot. NDVI trendline intercepts were calculated by analyzing histograms for each marsh zone (intermediate, brackish, and saline). Means and standard deviations were calculated. Standard deviations (1.5 and 2) below the mean NDVI were calculated and plotted on the graphs (represented by the green and blue lines respectively in Figures 16A-C). Data for each zone were graphed and a cubic regression line was created.

The marsh collapse uncertainty range values were found by locating the intercept of the regression line with the 1.5 and 2 SD lines. These values are thought to represent the depth in centimeters where marsh collapse is probable. The plots shown in Figures 16A-C represent these investigations for each of the three marsh types under consideration. In all three cases, the range identified by the standard deviation thresholds of the NDVI data seem to intercept the line at a dip which may represent a depth of inundation beyond which marsh typically does not occur.

The final marsh collapse thresholds for different vegetation types were determined as shown in Table 7 using the full range of values derived from the LCA Habitat Switcher model (Visser et al., 2003b), CRMS data, and remote sensing data. All three data sources closely correspond providing a reasonable range of conditions where we would expect a marsh collapse to occur.

3. Sediment redistribution

The sediment accumulation distribution surface is a component of the Wetland Morphology model that determines where sediment is most likely to accumulate and contribute to accretion based on weighted input variables influencing sedimentation. Originally this model was designed to incorporate separate weight surfaces for land and water. Sediment loads to the marsh and the open water were not provided, so a combined weight surface had to be developed.

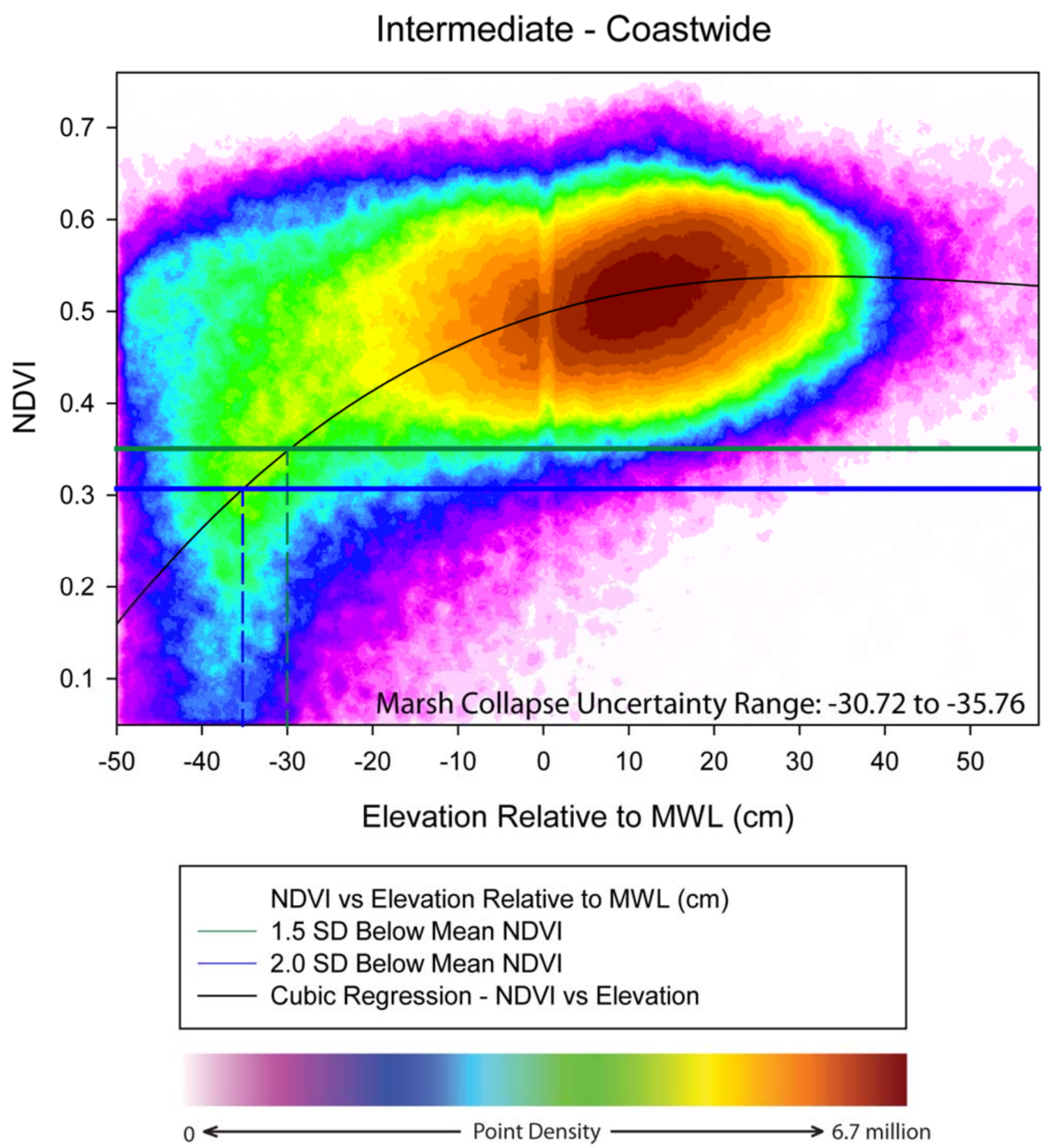


Figure 16A. Coast-wide plot of peak biomass (August) NDVI values for existing intermediate marsh vs elevation relative to MWL. The range for a potential marsh collapse threshold identified by the remotely sensed methodology for intermediate marsh (30.7 to 35.8 cm) is close to that identified by the CRMS field data (32 to 38cm). This could be a source of validation for the ranges identified by the two investigations.

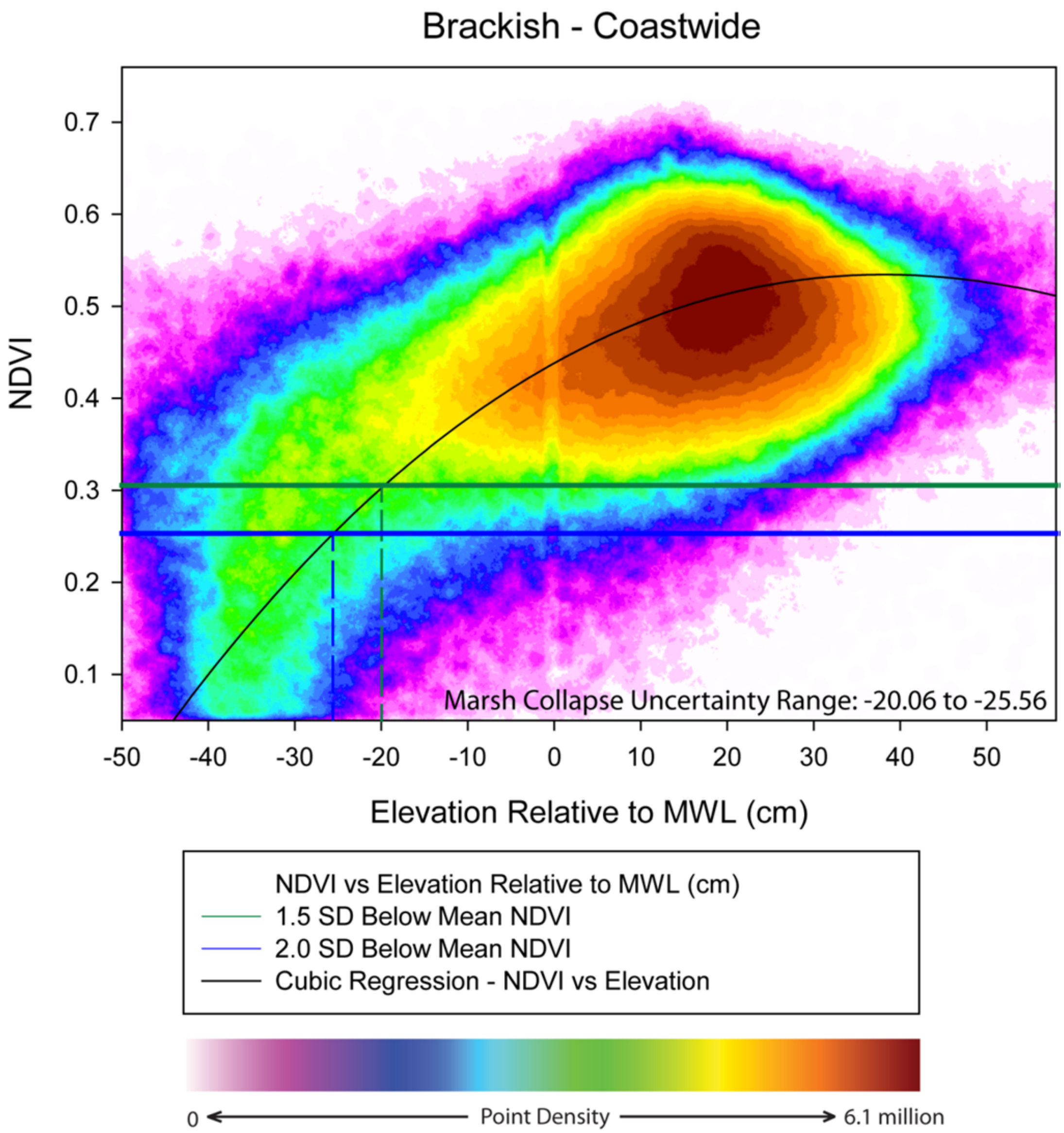


Figure 16B. Coast-wide plot of peak biomass (August) NDVI values for existing brackish marsh vs elevation relative to MWL. The range for a potential marsh collapse threshold identified by the remotely sensed methodology for brackish marsh (20.1 to 25.6 cm) is also close to that identified by the CRMS field data (20 to 25cm). This could be a source of validation for the ranges identified by the two investigations.

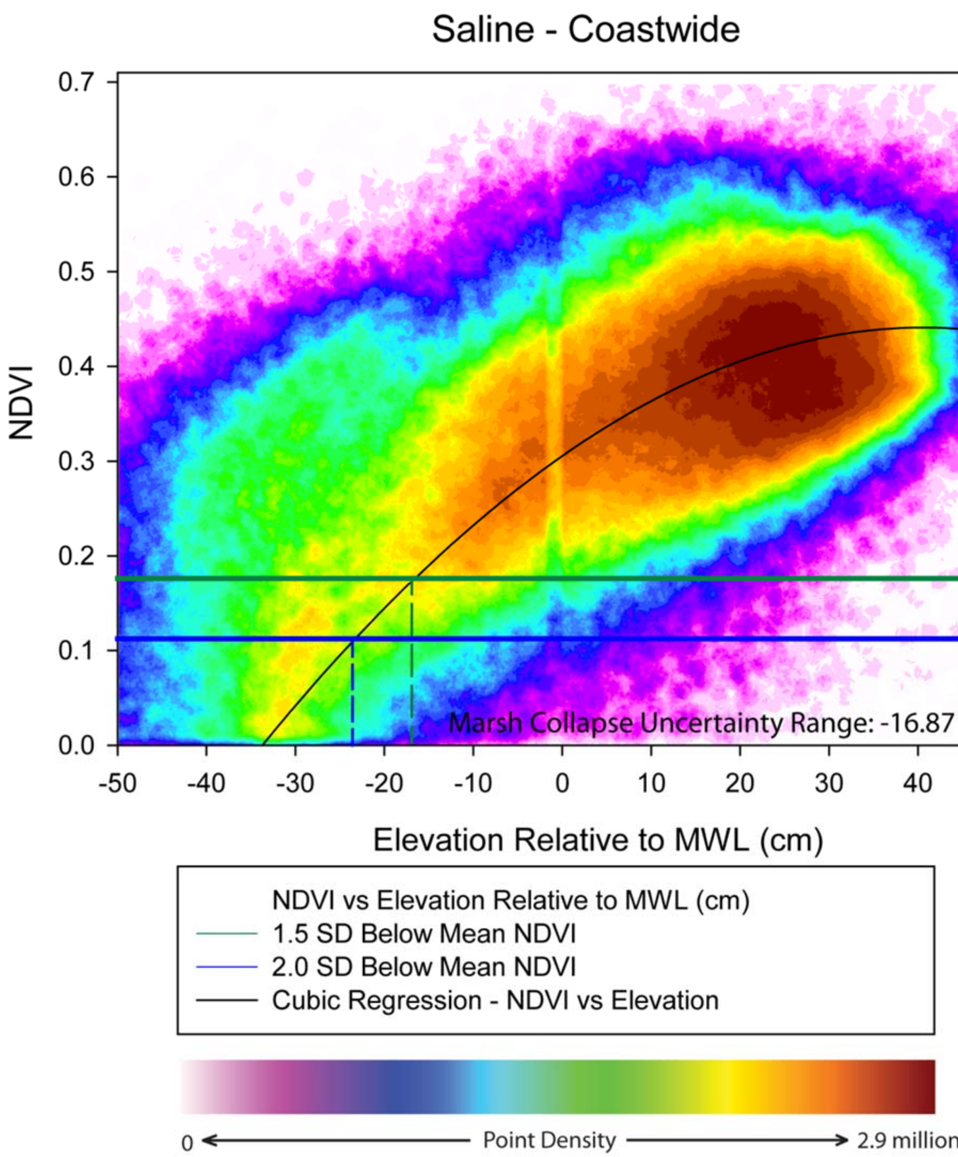


Figure 16C. Coast-wide plot of peak biomass (August) NDVI values for existing saline marsh vs elevation relative to MWL. The range for a potential marsh collapse threshold identified by the remotely sensed methodology for saline marsh (16.9 to 23.5 cm) is a larger than that identified by the CRMS field data (16 to 18cm).

The sedimentation surface was developed by first determining weighting variables. This was accomplished by first isolating the variables available as candidates. As principal determinants of potential sedimentation accretion, geospatial parameters related to hydroperiod, vegetation and the availability of sediments provide useful indicators. Available geospatial datasets representing such variables include elevation, Landsat band 5 (as spectral reflectance is related to ground wetness), frequency of inundation, NDVI (spectral index equation related to vegetation health, density, height, wetness) and land cover type. Final weighting variables utilized as input to the sedimentation weight surface on land include elevation, distance to source, slope, inundation frequency and land cover type. Input variables to sedimentation in open water bodies include elevation, slope, turbidity, distance to source, and distance to existing land. In cases where a hypothetical diversion is to be modeled, the point where the water is to-be-released becomes a source, and distance to the diversion plays a large role in the sediment distribution weight surface.

Historical land gain and loss rates are utilized to determine the relationships between each of the variables and the likelihood for a 30m raster cell to accumulate sediment. This historical land change dataset (Couvillion et al., 2011) was used to identify the ordering of values in terms of weighting future sediment distribution. Historical land change rates estimated from Couvillion et al. (2011) were classified into 100 quantile classes to provide zones of similar change rates. The mean of each variable per land change class was then calculated and graphed to determine relationships between each of the variables and the change classes. Note that each of the variables manifests a relationship with historical land gain/loss in which values either increase or decrease until a threshold is reached at 0 land change rate, then reverses. This reveals the influence of elevation and associated inundation frequency and depth, which are manifested in Landsat band 5 and NDVI reflectance values. Datasets for each of the variables were then sorted in the order of increasing land gain and assigned new values from 1-100 representing increasing weight on the likelihood of sedimentation. Since land cover is a qualitative variable, the relationship between this dataset and historical land change rates was classified in the opposite manner (i.e., the mean change rate was calculated for each land cover zone). The zones were sorted by increasing weight and similarly assigned new values.

The reclassified variable datasets were then combined according to weights assigned by a pairwise comparison. The values were then reversed to shift them from representing likelihood of sedimentation to cost, or resistance to sedimentation. This cost surface provided the input for an ArcGIS path distance function applied to distribute sediment from stream sources across the landscape. The Path Distance tool calculates the least accumulative cost distance of each cell to its nearest source, accounting for horizontal and vertical costs (using bathytopo as input) as well as the input variable cost surface. The output, representing a negative relationship with likelihood for sedimentation, was reversed to once again represent a positively classified weight surface.

Weights are calculated directly for sedimentation in water bodies based on a linear relationship between the variables and sedimentation, with increasing elevation, turbidity, flow accumulation and slope representing increasing likelihood of sedimentation. Respectively, these variables represent the assumptions that sedimentation is likely to increase with decreasing depth, increasing sediment in the water column, increasing slope along shorelines and increasing flow carrying higher sediment loads.

The weight surfaces are designed not to decide whether or not an area gets any sediment at all, but rather the percentage of the total sediment for each box an area receives. This is to say that, unless an area is restricted from receiving any sediment at all via logical constraints (such as a high elevation area which is never inundated), all remaining areas within a box will receive some sediment. The proportion of the total sediment each area receives is determined by the weight surface.

Sediment inputs from the Eco-Hydrology model are calculated as average $g/m^2/yr$ per hydro box. (In the Chenier Plain-CP and Atchafalaya-AA Eco-Hydrology models, values vary by year, so an average is calculated; the Pontchartrain Basin-PB Eco-Hydrology model provides has the same values for all years). Average sediment input ($g/m^2/yr$) is then translated into a total load for each box by multiplying by the total area of the box. This then gives us total grams per year, per hydro box. These total loads are then multiplied by the weight surface. This converts total sediment input per box into a raster representing $g/m^2/yr$ of sediment likely to be accumulated in each cell. These sediment loads then feed the relative elevation sub-model to estimate surface elevation change.

It should be noted that this surface plays no role in deciding the total sediment load, and by definition will put only as much sediment into each box as the Eco-Hydrology model output dictates. The Wetland Morphology model was originally set up to utilize sediment loads which would go to the marsh, and sediment loads which would go to the water bodies. This is because the only way to appropriately decide how much goes onto land versus how much goes into the water is with a hydrologic model, but not by weight surfaces. Separate loads were unavailable from the Eco-Hydrology team, so an assumption was made that sediment loads would be equally available to both marsh and water. In general though, the average loads in most of CP and PB were not high enough to support base accretion rates (based on historical accretion) on just the land portion, so a hurricane sediment load (assumed to be 1,000 $g/m^2/yr$) was delivered to each Eco-Hydrology box based on previous research (Nyman et al., 1995; Turner et al., 2006). Hurricanes may deposit mineral materials on marsh soils that are approximately 4 to 11 times the average annual vertical accretion rate (Nyman et al., 1995). Hurricanes Katrina and Rita in 2005 deposited an average of 22,300 g/m^2 (range: 0- 286,000 g/m^2) at 169 sites across coastal Louisiana (Turner et al., 2006). Nevertheless, Nyman et al. (1995) estimated that long-term hurricane sedimentation in Louisiana averages only 0.24 cm/yr given 460 km of coastline, a hurricane frequency of 0.41/yr (from data in Hsu & Blanchard, 1993), an affected area of 60 km, and an average 4.5 cm of sediment per hurricane. The average bulk density of hurricane deposited material is ~0.4 g/cm^3 (Nyman et al., 1995; Turner et al., 2006); therefore, the long-term hurricane sediment rate is estimated at approximately 0.1 $g/cm^2/yr$ or 1,000 $g/m^2/yr$. Additionally, sedimentation could only occur if maximum stage exceeds elevation.

4. Representative soil bulk density and organic matter through calibration

As stated in the "Theory" section (Section 2a), the pre-compaction relative elevation sub-model requires BD/OM% to reach equilibrium with depth; therefore, BD/OM% equilibrium state is utilized in the model. Since available datasets suggest most of the wetlands along coastal Louisiana are not in an equilibrium state (e.g., the relatively large change in soil bulk density with depth), the bulk density and percentage of organic matter model inputs are required to be calibrated. The calibrated bulk density and percentage of organic matter, using both the short-term feldspar marker horizon technique and long-term ^{137}Cs-dating technique from CWPPRA's CRMS and soil data from Piazza et al. (2011), are considered representative values for a total of 50 observed landscape groups (from 9 hydrologic basins and 7 vegetation types). The representative BD and OM% are capable of describing the long-term (multi-decadal) vertical accretion rates in soil. When vegetation types change as a result of hydrologic, salinity and nutrients from the Eco-Hydrology model, soil bulk density and percentage of organic matter values will also change according to the new vegetation type.

The final representative soil bulk density and organic matter content for different basin and vegetation combination groups through calibration used in the pre-compaction relative elevation sub-model are summarized in Table 8. The specific calibration procedures are described as follows:

4.1 Calibration from long-term ^{137}Cs dated data

Observed long-term sediment accumulation and vertical accretion rates based on ^{137}Cs dating technique were available for soil cores that were collected across coastal Louisiana during 2006-2007 in a study supported by the Louisiana Coastal Area Science & Technology Program (LCA S&T program) (Piazza et al., 2011). There were 30 study sites with 47 soil cores having sediment accumulation and vertical accretion data. These soil cores cover 9 groups of basin and vegetation type combinations that were used in BD/OM% calibration.

We estimated vertical accretion rates for the sites in each of the 9 basin-vegetation groups from a range of BD values (e.g., 0.02 to 1.50 g/cm^3). Once a BD value (e.g., 0.02 g/cm^3) from the BD range was determined and extrapolated to all sites in a basin-vegetation group, we used the relationship between OM% and BD (Equation 8, Figure 17) that was developed using CRMS soil data collected during 2006-2008 to estimate group-level OM%. Previous studies examining the relationship between BD and OM% across coastal Louisiana produced similar results (Hatton et al., 1983; Gosselink et al., 1984). Organic accumulation rate at each basin-vegetation group was calculated from the observed site-specific sediment accumulation rate and group-level OM% using Equation 2 in the "Theory" section (Section 2a). Thus the vertical accretion rate for each site was estimated from the site-specific sediment and organic accumulation rates, and the assigned group-level BD/OM values using Equation 1 in the "Theory" section (Section 2a).

$$\mathbf{OM\% = 100.2e^{(-4.7828*BD)}} \qquad \textbf{(Equ. 8)}$$

The estimated vertical accretion rates (H_{sim}) at the sites in a basin-vegetation group were then compared with the observed accretion rates (H_{obs}) to calculate the Root Mean Square Error (RMSE) using Equation 9. The program estimated vertical accretion rates and calculated RMSE under the same BD/OM% set for all 9 basin-vegetation groups.

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{1}^{n}(H_{obs} - H_{sim})^2}{n}} \qquad \textbf{(Equ. 9)}$$

Next, the program was run using BD values in the range of 0.02 to 1.5 g/cm^3 and at an interval of 0.02 g/cm^3 to get the RMSE for all BD/OM% sets. Then the BD/OM combination with the minimum RMSE for a basin-vegetation group was treated as the “representative BD/OM”. Finally, relative error (RE, in %) for each basin-vegetation group and overall RE for all groups is calculated for the calibration.

$$\mathbf{RE} = \frac{\sum_{i=1}^{n}\{H_{sim}/H_{obs} - 1\}}{n} \qquad \textbf{(Equ. 10)}$$

Table 8. Final calibrated values of bulk density and organic matter content for different groups of basin and vegetation type combinations for the relative elevation sub-model.

Basin	Deltaic	Freshwater	Intermediate	Brackish	Saline	Swamp	Other
			Bulk density (g/cm3)				
Calcasieu/Sabine		0.08[c]	0.13[c]	0.23[a]	0.4[c]		0.24[d]
Mermentau		0.04[a]	0.19[b]	0.38[a]	0.41[b]		0.24[d]
Teche/Vermilion		0.25[d]	0.16[b]	0.21[b]	0.53[c]	0.36[b]	0.24[d]
Atchafalaya	0.65[b]	0.25[b]	0.42[b]	0.21[d]		0.21[b]	0.24[d]
Terrebonne		0.11[b]	0.18[a]	0.32[a]	0.32[c]	0.33[c]	0.10[b]
Barataria		0.05[a]	0.08[b]	0.15[b]	0.28[a]	0.41[c]	0.10[d]
Mississippi River Delta	0.46[b]	0.05[d]		0.23[d]	0.75[c]		0.10[d]
Breton Sound		0.05[d]	0.11[d]	0.23[a]	0.53[a]		0.10[d]
Pontchartrain		0.05[d]	0.11[b]	0.23[c]	0.44[c]	0.30[c]	0.10[d]
			Organic Matter (%)				
Calcasieu/Sabine		61[c]	58[c]	33[a]	19[c]		32[d]
Mermentau		82[a]	40[b]	16[a]	14[b]		32[d]
Teche/Vermilion		30[d]	47[b]	37[b]	14[c]	18[b]	32[d]
Atchafalaya	7[b]	30[b]	13[b]	37[d]		37[b]	32[b]
Terrebonne		59[b]	42[a]	22[a]	25[c]	48[c]	62[b]
Barataria		79[a]	68[b]	49[a]	26[a]	38[c]	62[d]
Mississippi River Delta	11[b]	79[d]		33[d]	9[c]		62[d]
Breton Sound		79[d]	59[d]	33[a]	8[a]		62[d]
Pontchartrain		79[d]	59[b]	35[c]	19[c]	41[c]	62[d]

Note: a= calibrated from LCA S&T data; b=calibrated from CRMS data; c=assumed equal to CRMS 0-24 cm average; d=assumed the same as the type in the nearby basin.

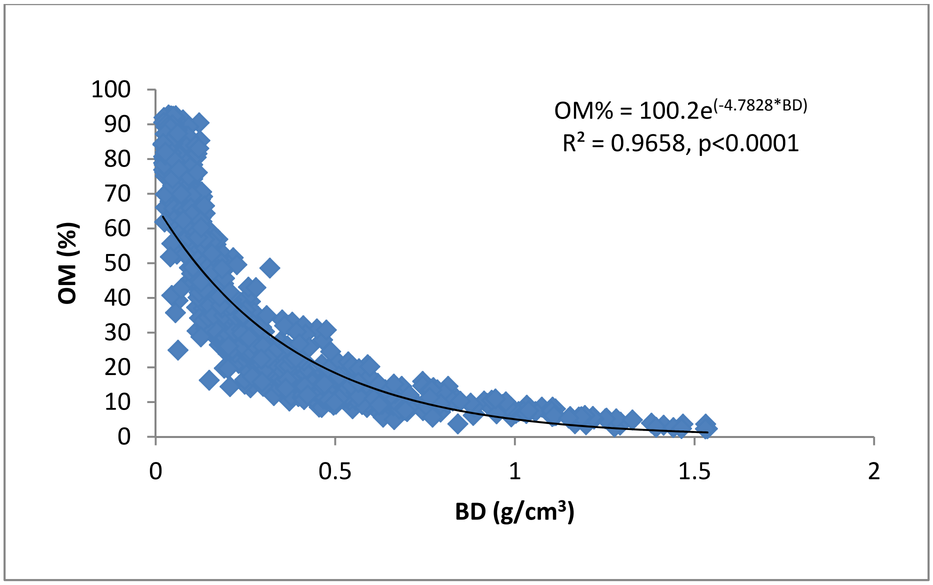


Figure 17. Relationship between soil organic matter content and soil bulk density derived from CRMS soil data (2007-2009) (sample size n = 1,130).

4.2 Calibration from CRMS soil and feldspar marker data

There are 50 groups of hydrologic basin and vegetation type combinations across coastal Louisiana detected from initial vegetation distribution map compiled by the Wetland Morphology model team (See Table 8 for specific groups). Representative BD/OM% through calibration using long-term soil core data from LCA S&T could be derived for only 9 such groups. Therefore, we used CRMS soil and feldspar data that represent short-term (normally < 2 years) sediment accumulation and accretion in order to derive representative BD/OM% values for more basin-vegetation groups. Because the pre-compaction relative elevation model requires long-term (multi-decadal) sediment accumulation rates to estimate long-term vertical accretion, the sediment accumulation and vertical accretion from CRMS soil and feldspar data needed to be converted into long-term rates (Beckett, 2009; Kolker et al., 2009). The LCA S&T provided both long-term and short-term sediment accumulation and vertical accretion data through 15 pairs of sites (one historical research site with ^{137}Cs dating since 1963 and one CRMS monitoring site with feldspar marker data) (Figure 18; Piazza et al., 2011). As such, we were able to use LCA S&T data to examine the relationships between long-term and short-terms rates in sediment accumulation and vertical accretion.

First, we obtained top layer (0-4 cm) BD/OM% from soil data for each CRMS site. We selected 0-4 cm top layer to estimate short-term sediment accumulation because Louisiana coast wide long-term accretion rates are normally less than 2 cm/yr (Jarvis, 2011) and feldspar marker data are normally measured within 2 years (Folse et al., 2008). Therefore, the top 4 cm layer should represent the recent year's sediment accumulation (not mixed with deeper soil/sediment).

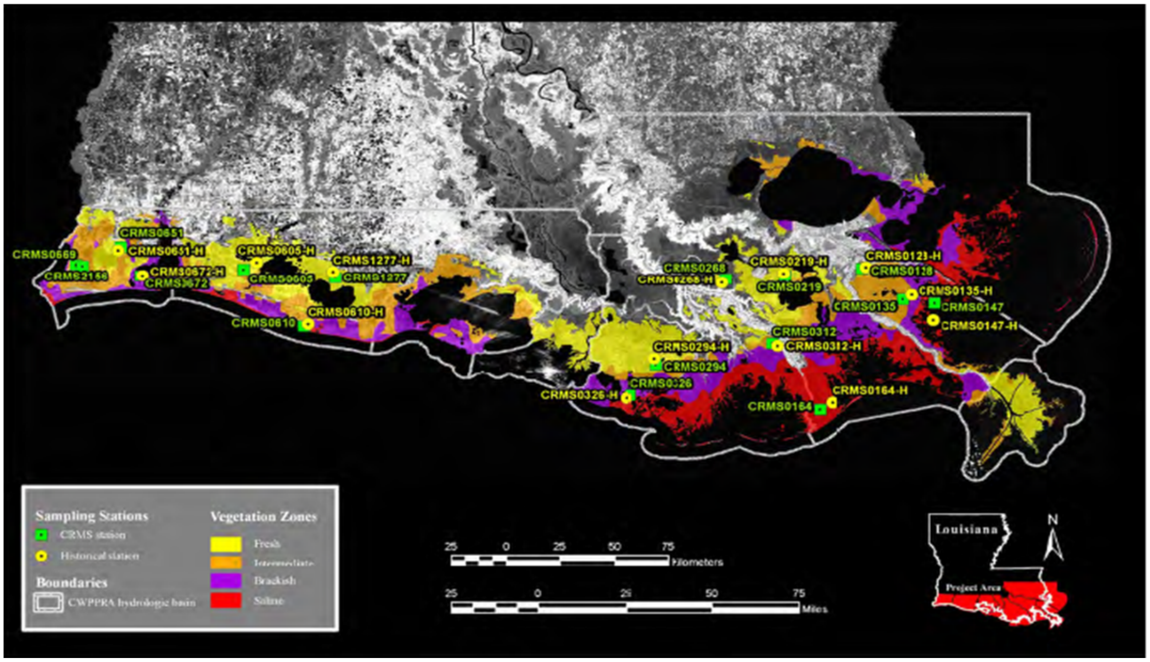


Figure 18. Location map of soil sampling of paired sites across coastal Louisiana through LCA S&T program (source: Piazza et al., 2011).

We estimated short-term sediment accumulation rate (SEDIN(st)) from feldspar-based short-term accretion rate measurements (H(st)) using the following method (refer to Hatton et al., 1983; Nyman et al., 2006):

SEDIN(st) = BD(0-4cm) * H(st)*(1-OM%/100) **(Equ. 11)**

Then we converted the short-term sediment accumulation rate to a long-term rate (SEDIN(lt)) by the relationship derived from LCA S&T data (Figure 19):

SEDIN(lt) = 0.2557* SEDIN(st) + 214.52 **(Equ. 12)**

Next, we needed to estimate long-term ^{137}Cs-based vertical accretion rates (H(lt)) from CRMS feldspar-based short-term accretion rates (H(st) based on the relationship derived from LCA S&T data (Figure 20):

H(lt)/H(st) = -1.2368* Elevation (m, NAVD88) +1.0391 **(Equ. 13)**

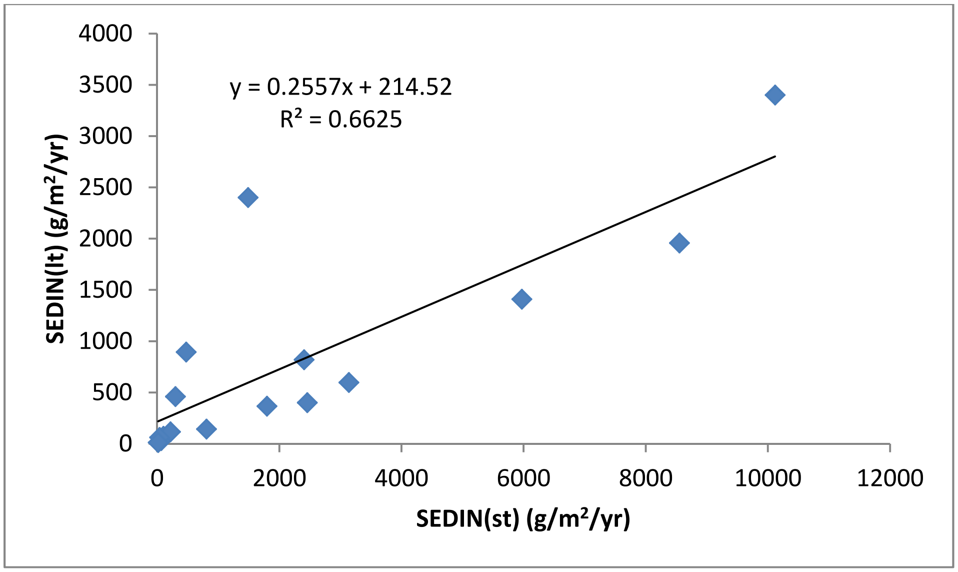


Figure 19. Relationship between long-term and short-term sediment accumulation across coastal Louisiana using LCA S&T and CRMS data (sample size n = 13).

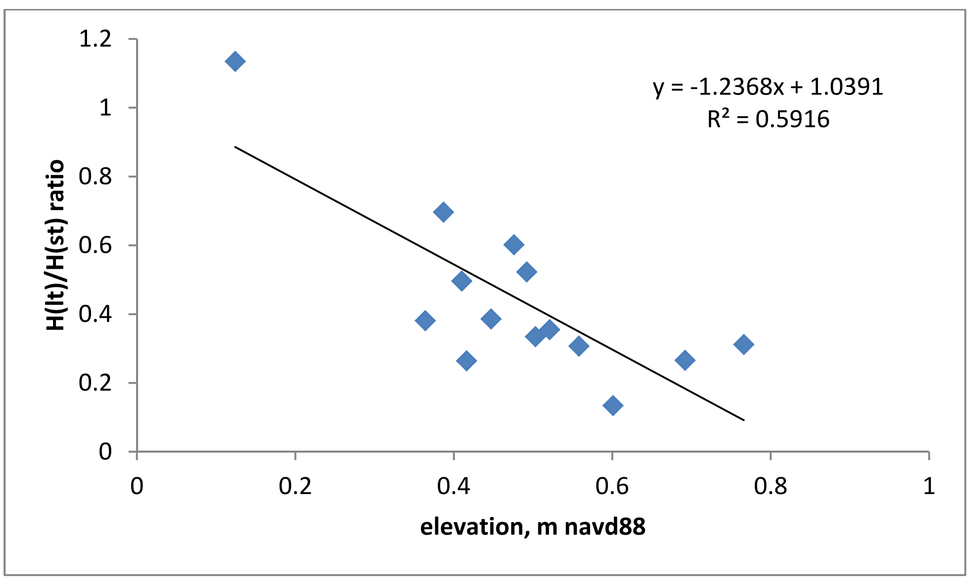


Figure 20. Relationship between the ratio of long-term and short-term vertical accretion and elevation across coastal Louisiana using LCA S&T and CRMS data (sample size n = 14).

This process allowed us to determine long-term vertical accretion rates for CRMS sites. We estimated long-term sediment accumulation and vertical accretion rates for ~340 CRMS sites for calibration. Sites with estimated long-term accretion rates over 2.26 cm/yr were not included. There were 249 CRMS sites with estimated long-term sediment accumulation and vertical accretion rates that were used in calibration (170 sites) and validation (79 sites). Then we followed the methods described in the Section 2c.4.1 "Calibration from long-term ^{137}Cs dated data" to derive representative BD/OM% values for a total of 25 basin-vegetation groups.

4.3. Rules in determining representative BD/OM values for the remaining basin-vegetation groups:
From the LCA S&T and CRMS databases, we were able to calibrate BD/OM% for 25 of a total of 50 observed basin-vegetation groups. Therefore, representative BD/OM% values for the remaining 25 groups needed to be determined by checking if CRMS 0 to 24 cm averaged BD values were available for these remaining groups. If data were available, we assigned the 0 to 24 cm averaged BD as the representative BD for those groups. If CRMS 0 to 24 cm averaged BD from unavailable, we used the BD/OM% values from the same vegetation type in the nearest basin with similar soil characteristics.

d. Assumptions

Relative elevation sub-model

- Sub-model relies on representative soil cores for establishing pre-compaction bulk density values by marsh type by region because the non-equilibrium state of bulk density and organic matter with depth.
- If a basin-vegetation type combination does not have a calibrated BD/OM%, then the 0 to 24 cm average BD/OM% values from CRMS for that group (if available) are assumed to be representative, or (if not available), the calibrated BD/OM values from nearby basin/marsh type with similar sediment input and vertical accretion characteristics are used.
- The upper limit of vertical accretion was assumed to be 2.26 cm/yr based on historical field observations across coastal Louisiana (Rybczyk and Cahoon, 2002).

Landscape change sub-model

- Loss Patterns
    - With the exception of loss related to SLR and hurricanes, the model assumes that the loss related to all other factors will continue at rates similar to those observed during the 1984-2010 time period. Extraction of hurricane-related losses was achieved by bracketing the hurricane events temporally. It is important to note that although the Wetland Morphology model was developed with the ability to incorporate variable storm frequency and intensity, time constraints forced an assumption of storms continuing at rates similar to those observed during the observation period. Extraction of losses related to RSLR was achieved by hindcasting elevation change in the model and comparing inundation based loss to observed loss.
    - With the exception of loss related to SLR and hurricanes, land loss is assumed to take place in a linear fashion.
- Incorporation of Project Effects
    - Assumes project goals provided to Wetland Morphology team can be met.
- Hurricane sediment load: assumes 1,000 $g/m^2/yr$ sediment load delivered to each Eco-Hydrology box based on previous research (Nyman et al., 1995)

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

Model inputs were tested to see if they are imported correctly by the model by comparing with the original data to ensure they are exactly the same (for both tabular and spatial input data). Model equations implemented in the model were also checked with Excel and hand calculations to ensure computations are exactly the same (in some cases very small differences resulting from rounding errors were considered acceptable). Model outputs are reviewed by both internal and external experienced reviewers.

3. *System Quality*

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

Landscape change sub-model: ERDAS IMAGINE Model Maker, ESRI ArcGIS Model Builder and Python scripting languages were used due to their capabilities in handling large and computationally-intensive spatial datasets. Model developers had previous experience in applying these modeling tools in coastal landscape change detection, land building and land loss estimates.

Relative elevation sub-model: FORTRAN 90/95 was used in coding due to its capability and efficiency in scientific calculation. SAS/MatLab, Excel, VBA, and Python were used in pre-and post-simulation-processing. Model developers had previous modeling experiences in applying these tools in landscape ecosystem modeling at regional scales.

b. Proof that the programming was done correctly

Model scripts were reviewed internally within the Wetland Morphology model team to make sure no coding errors existed. Model executions were debugged to ensure no system errors during compiling and executing by the model developers. Model calibration and validation were reviewed first by model programmers, then by internal team members and finally by external reviewers to make sure there were no logical errors.

c. Availability of software and hardware required by model

Landscape change sub-model: Written in ERDAS IMAGINE Model Maker platform and also Python scripting language for Windows XP (32 and 64 bit). Required software include ERDAS IMAGINE, ESRI ArcGIS (ArcMAP, ArcCatalogy, ArcToolbox), PythonWin, Excel, etc. Hardware includes hard drive for large spatial data storing, uploading and downloading, and media device for supporting movie making (for visualizing and animating model output).

Relative elevation sub-model: Intel Visual Fortran Compiler Professional 11 under Microsoft Visual Studio 2008 for Windows XP (64 bit). ESRI ArcGIS (ArcMAP, ArcCatalogy, ArcToolbox), PythonWin, Excel, R, VBA, etc.

d. Description of process used to test and validate model

There are four levels of Wetland Morphology model testing and validation.

1. <u>Test of the reasonability of the pre-compaction relative elevation model.</u>

The pre-compaction relative elevation model (See Equations 1-3 in Section 2 "Technical Quality") describes long-term soil vertical accretion rates from mineral and organic matter accumulations and soil bulk density. Accumulation of organic matter is estimated from mineral sediment and organic matter. Therefore, the first level of model testing is to see if this inorganic-matter-based model can reasonably predict the observed vertical accretion rates. We used data from Nyman et al. (1993) collected at 15 sites in Terrebonne Parish brackish and saline marsh to compare simulated vertical accretion rates with observed rates. It was found that the pre-compaction relative elevation model is capable of describing field observed vertical accretion rates with a relative error of 14% (Figure 21).

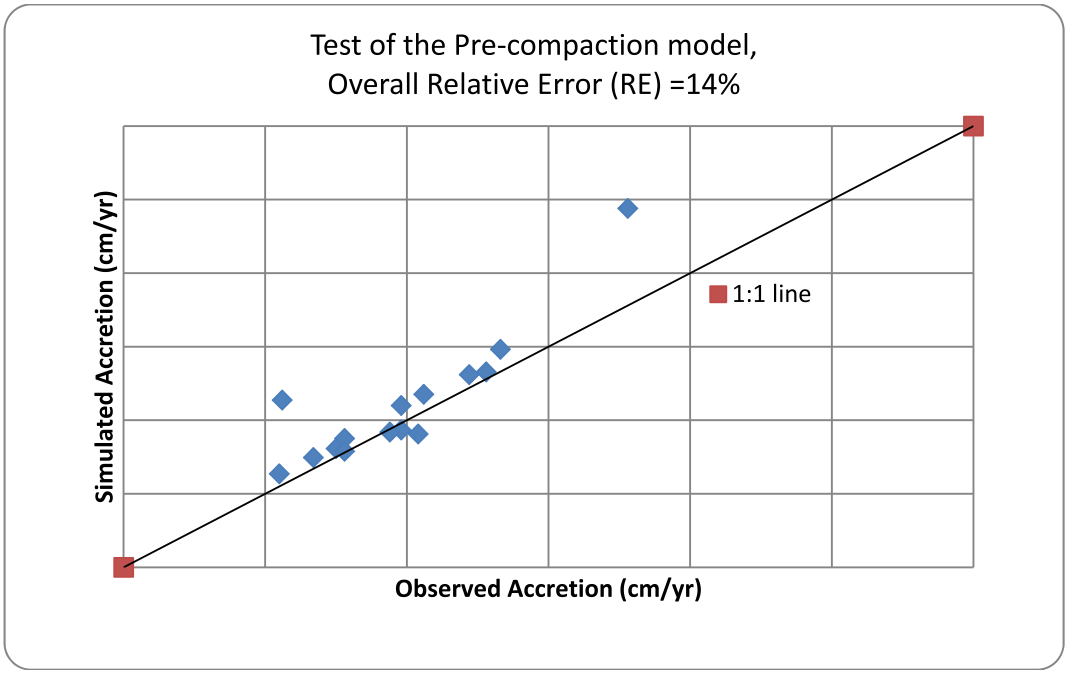


Figure 21. Test of the pre-compaction relative elevation model on vertical accretion rates using field data from an independent research study (Nyman et al., 1993).

2. <u>Test of the relationship between long-term and short-term sediment accumulation rates.</u> During the calibration process, short-term accretion data from CRMS during 2006-2008 were used to obtain representative soil bulk density and organic matter content for different groups of hydrologic basins and vegetation types across coastal Louisiana. Because of the limited long-term mineral sediment accumulation and vertical accretion data from the LCA S&T Program (only 9 of the 50 basin-vegetation type groups), we used CRMS short-term accretion data and estimated mineral accumulation after converting into corresponding long-term rates to derive additional representative BD/OM values. The relationship between long-term (e.g., ^{137}Cs-based) and short-term (feldspar marker-based) mineral accumulation rates (in g/m^2/yr) (See Equation 12) was tested by comparing estimated long-term sediment accumulation rates with 18 observed rates collected from Breton Sound freshwater and intermediate marsh sites by DeLaune et al. (2003). The relative error is 61% (Figure 22) indicating the relationship between long-term and short-term sediment accumulation across coastal Louisiana produces moderate accuracy in estimating long-term sediment rates from short-term feldspar marker measurements. This test also indicates the spatial heterogeneity in sediment transport, deposition and erosion across the coast owning to the impacts of the complex natural and anthropogenic disturbances on sediment distribution and accumulation (Nyman et al., 1993; Turner et al., 2006; Day et al., 2011).

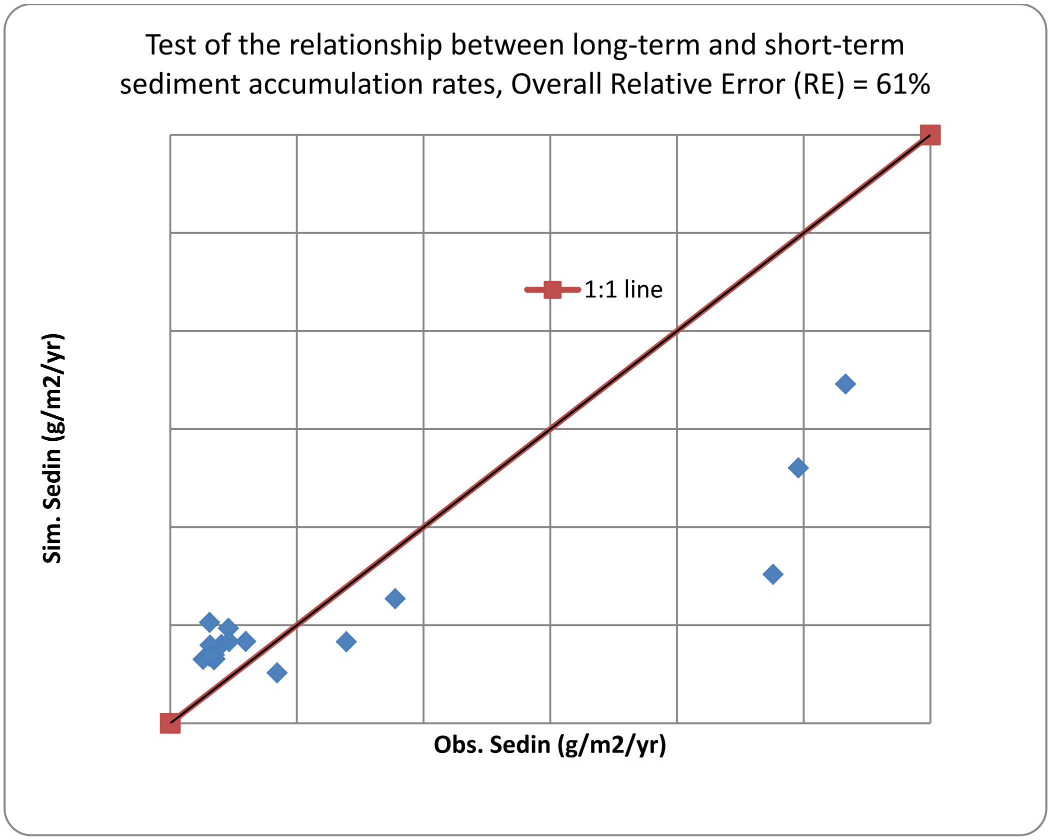


Figure 22. Test of the relationship between long-term and short-term sediment accumulation rates using data from DeLaune et al. (2003).

3. Validate the pre-compaction relative elevation sub-model.

After calibrating BD/OM% by obtaining representative BD/OM% values for 50 basin and vegetation type combinations, we also conducted validation of the relative elevation model by using another set of CRMS data (not used in calibration, a total of 79 sites that were classified into 14 basin-vegetation groups) with derived long-term sediment accumulation and vertical accretion rates. The relative elevation sub-model tends to underestimate the observed vertical accretion rates (relative error = -22%, Figure 23). This can also be attributed to the relationship in estimating long-term sediment rates from short-term feldspar marker measurements.

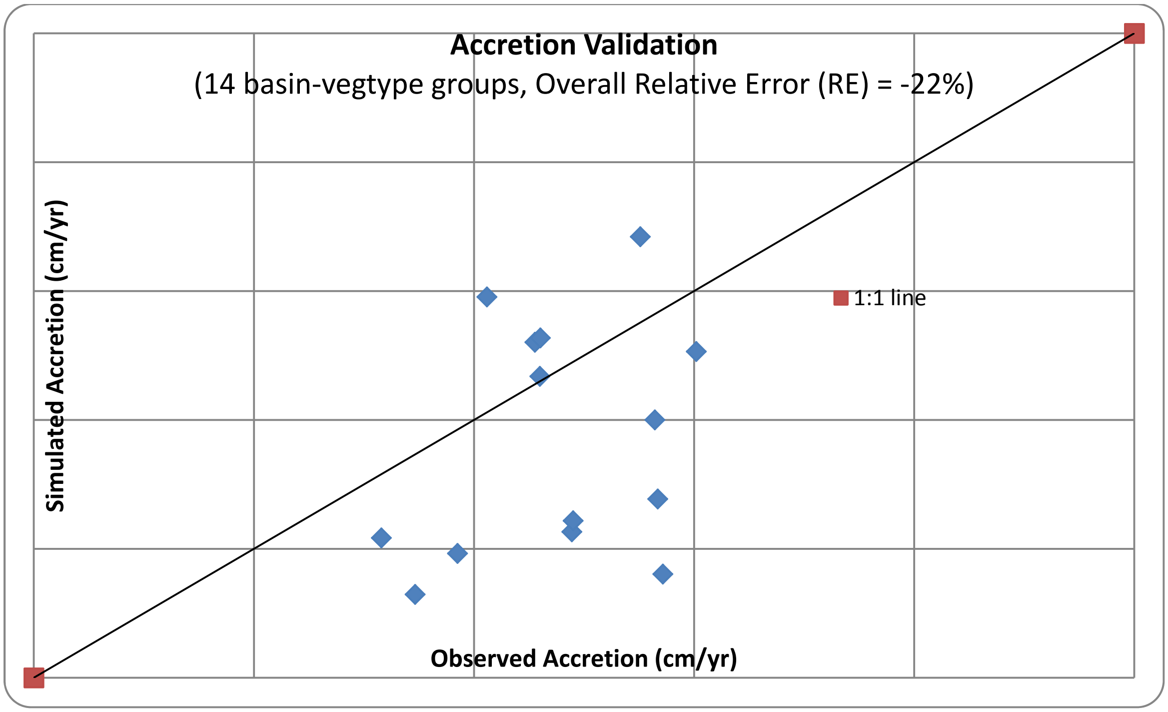


Figure 23. Validation result of the Pre-compaction elevation model using an independent set of CRMS data.

4. <u>Validating model through comparing predicted vertical accretion rates with literature at basin and coast wide levels.</u>
Model testing and validation stated above used observed sediment accumulation and representative BD/OM% to see if the model is capable of producing vertical accretion rates that are close to observed accretion rates at individual CRMS sites. The Wetland Morphology model is also fully validated after incorporating inputs of sediment accumulation rates, salinity and water level from the Eco-Hydrology model team, changed vegetation distribution from the Vegetation model team, and changed elevation along barrier islands from the Barrier Shoreline model team as well as adjusting sediment accumulation brought by hurricanes. We compared model simulated vertical accretion rates with literature values at basin and coast wide scales (Table 9). For most basins, simulated accretion rates are within the range of observed values from literature except for Calcasieu/Sabine Basin where the model tends to underestimate accretion rates. This may be due to less sediment being transported and available for deposition as compared with other basins in the Chenier Plain.

Table 9. Comparison of simulated vertical accretion rates to observed rates from literature at basin and coast wide **scales.**

Basin	Modeled Accretion (cm/yr) Mean	Modeled Accretion (cm/yr) SD	Accretion Range from Literature (cm/yr)	Source
Pontchartrain	0.67	0.51	NA	NA
Breton Sound	0.87	0.47	0.42 - 1.72	DeLaune et al., 2003
Mississippi River Delta	0.73	0.3	NA	NA
Barataria	0.89	0.51	0.59 - 1.40	Hatton et al., 1983; DeLaune et al., 1989
Terrebonne	0.66	0.46	0.07 - 0.99	DeLaune et al., 1989; Nyman et al., 1993
Atchafalaya	1.6	1.03	?? - 2.06	Day et al., 2011
Teche/Vermilion	0.58	0.54	0.29 - 0.70	Bryant & Chabreck, 1998
Mermentau	0.54	0.34	0.12 - 0.98	Cahoon, 1994; Bryant & Chabreck, 1998
Calcasieu/Sabine	0.28	0.22	0.36 -0.90	DeLaune et al., 1989; Bryant & Chabreck, 1998; Steyer, 2008
			0.25 - 1.78	Nyman & DeLaune, 1999
			0.46 - 0.76	Piazza et al., 2011
LA Coast wide	0.69	0.55	0.59 - 0.98	Nyman et al., 2006

Note: Simulated values shown are averages for 2010-2015 time period for a "future-without-action" scenario (Group 01).

e. Discussion of the ability to import data into other software analysis tools (interoperability issue)

The Wetland Morphology model (landscape change and elevation change sub-models) is an integral component of the 2012 Coastal Master Plan modeling system. Our morphology model imports simulated sediment accumulation, water levels and salinity from the Eco-Hydrology model. It also imports simulated vegetation distribution under different scenarios from the Vegetation model to determine vertical accretion, marsh collapse, and change in BD/OM% with different basin-vegetation type groups. On the other hand, our simulated landscape fragmentation, land/water area, elevation change and associated SOC storage in upper 1-meter of soil and SOC sequestration outputs are used as inputs in the Eco-Hydrology model (percentage of land, surface elevation), Vegetation model (initial vegetation distribution, percentage of land, surface elevation), Storm Surge/Wave model (surface elevation), Ecosystem Service models (edge and SOC storage). All wetland morphology outputs are made available in multiple formats and resolutions. These formats include tabular formats (such as .dbf file) and raster formats (such as .img file) which are recognized by nearly all spatial software programs and can easily be converted to many other formats (such as .tif, and .asc files). Wetland Morphology outputs are also provided as net.cdf files and can be visualized in EverVIEW (See examples in Section 1e "Description of Output Data" Section).

4. Usability

a. Availability of input data necessary to support the model

Spatial domain (boundary): GIS data sources from federal (e.g., USGS NWRC spatial database), and state providers (e.g., LSU's Atlas: The Louisiana Statewide GIS: http://atlas.lsu.edu/).

Initial elevation (topo/bathy): Federal and State sources: (e.g., USGS DEM, USGS Topobathy at http://topotools.cr.usgs.gov/Topobathy_viewer/, LIDAR DEM from LSU's Atlas: The Louisiana Statewide GIS).

Initial vegetation map: USFWS NWI, USGS NWRC vegetation mapping database (Sasser et al. 2008); USGS Land Use and Land Cover.

Land area change in coastal Louisiana: USGS NWRC land area change detection team (Couvillion et al., 2011).

Sediment input: regional hydrodynamic and sediment transport modeling (From Eco-Hydrology team).

SLR: IPCC, USGS, USACE, NOAA (From CPRA).

Subsidence: USGS, LA state, University of New Orleans (From CPRA, expert panel).

BD/OM% for basin-vegetation groups: CRMS datasets posted on website, Piazza et al. (2011), and USDA SURRGO soil database (Zhong and Xu, 2011).

b. Formatting of output in an understandable manner

The outputs from the Wetland Morphology model including spatial patterns of land/water distribution, land/water percentage, fragmentation (e.g., edge distribution), land loss area, soil vertical accretion, surface elevation, and SOC inventory, storage and sequestration. These outputs are in spatial format (.img, .asc, esri grids, NetCDF, etc.) at various spatial resolutions (e.g., 30m and 500m) and are produced at a 5-year interval over 50 years (2010-2060). Users can visualize intuitively the spatial and temporal outputs using GIS and associated visualization tools (e.g., movie-making tools to see time-series of the outputs). Users can use Spatial Analysis and Zonal Statistics from ArcToolbox in ESRI ArcGIS, ERDAS IMAGINE or other RS/GIS tools to examine spatial patterns and dynamic changes of simulated ecosystem properties (landscape, vertical accretion, elevation, and SOC inventory (i.e., total carbon in a grid cell) and sequestration potential) across coastal landscape among different regional settings (e.g., by hydrologic basins, by vegetation types or the combination of basin and vegetation types).

c. Usefulness of results to support project analysis

The Wetland Morphology model was designed at the system-scale as a planning tool to look at relative differences between protection and restoration alternatives. As such, this model is best able to detect influences of large marsh creation and sediment diversion projects, and less able to discern influences of smaller ridge restoration and shoreline protection projects. The model results can be applicable to other similar restoration types when scaled accordingly (i.e., relative to freshwater and sediment input of restoration measures), when fully considering conditions of receiving area, and when assumptions are understood and considered.

d. Ability to export results into project reports

The output formats of the Wetland Morphology model include maps (similar to Figures 1, 2), tables (similar to Tables 3, 4) and graphs that can show trends over time of FWOA compared to FWP groupings. The maps and figures can be saved in various forms such as jpegs and bitmaps, and tables can be saved as text or excel files and can be exported into project reports.

e. Training availability

USGS NWRC Wetland Morphology modeling team can provide training (workshop for groups or individual-based) to users upon request and availability. Training contents include model assumptions, equations, scripting, data requirements/preparation, pre-processing, execution of simulations, debugging, and post-processing of outputs.

f. Users documentation availability and whether it is user friendly and complete

User manuals (model instruction documents) are provided with the landscape and elevation sub-model package including source codes, input datasets, and output examples. Users can run the model with their boundary, vegetation map, SLR/subsidence setting, sediment accumulation, salinity and stage data to examine how landscape and elevation will change in the future under different SLR, subsidence and management alternatives. Advanced users can even test model sensitivity to parameters such as representative soil bulk density and OC-OM% conversion factor (e.g., 0.45-0.58) for their research/management purpose by adjusting open source model codes.

g. Technical support availability

Technical support for the Wetland Morphology model is available from USGS NWRC Coastal Restoration Assessment Branch (CRAB), Branch Chief: Dr. Gregory D. Steyer at *steyerg@usgs.gov*. Readme instructions for each sub-model are provided with model package. Questions/issues with applications of the model can be answered via personal contact, telecommunication, and internet communication. If official technical support and funding are made available, users' forum and training workshops can also be conducted.

h. Software/hardware platform availability to all or most users

Landscape change sub-model: ERDAS IMAGINE and ArcGIS for Windows XP are required to run the landscape change sub-model. Pre-compaction relative elevation sub-model: Intel Visual Fortran Compiler Professional 11, Microsoft Visual Studio 2008 for Windows XP are required and available to most computer programmers.

i. Accessibility of the model

The Wetland Morphology landscape change sub-model code was written in ERDAS IMAGINE Model Maker, Python and ESRI ArcGIS tools, with associated scripting. Model diagram (links and operations among spatial data layers) and source codes for both sub-models are available to interested users (See Attachment B). The pre-compaction relative elevation sub-model of the Wetland Morphology model was written in FORTRAN 90/95. The wetland morphology sub-models were run using PC workstation computers at USGS NWRC-CRAB with ERDAS IMAGINE 9.3 installed and Intel Visual Fortran Compiler Professional 11 under Microsoft Visual Studio 2008 platform. Users can compile, link and execute the program to simulate landscape change, landscape fragmentation, surface elevation change, and SOC storage and sequestration potential across coastal Louisiana at 30m or 500m resolutions. The sub-models are capable of batch simulating landscape change, vertical accretion, surface elevation change and SOC storage and sequestration potential under different combinations of scenarios of SLR and subsidence, and restoration project grouping. Post-modeling processing tools are also available, including batch mode zonal statistical analysis for each output file and merging all the zonal statistics results (.dbf) into one Excel (.xls) file after batch converting .dbf into .xls formats. Zonal statistics can be obtained for basins and vegetation types across coastal Louisiana.

j. Transparency of model and how it allows for easy verification of calculations and outputs

The landscape and relative elevation sub-models, developed by the Wetland Morphology modeling team, were written in spatial modeling script (ERDAS IMAGINE Model Maker), Python and Fortran language. In the programming codes, input data, state variables, numerical equations for calculations and output format and destinations are explained intuitively and in an easily-understood format. Given the installation of ERDAS IMAGINE, ArcGIS and Fortran compiler on user's computer, any user can run these sub-models effectively including preparing input data and post-processing simulation results. For example, users can run any designed scenarios of SLR, subsidence and grouping of restoration projects, and summarize land/water fractions, land loss area, vertical accretion, elevation change and changes in SOC inventory and sequestration over 50 years with a time step of 5 years. This can be done according to different basins, vegetation types or combinations of basin and vegetation types.

Calculations and outputs are verified at three levels: (1) individual programmer, (2) developer team, and (3) external reviewers. At programmer level, each sub-model was verified by checking input data to see if they were read correctly by comparing model exported input data with original data; calculations were verified by other platform such as Excel Spreadsheet for sample sites; model outputs (land/water areas, vertical accretion and elevation, SOC sequestration) were verified by comparing site-specific or basin-specific, or vegetation specific observed values. For example, calculations of vertical accretion and SOC sequestration (the equations and model parameters) in the pre-compaction relative elevation model were verified by using historical data (^{137}Cs data on sediment accumulation and vertical accretion) derived values based on basin and marsh type combinations and we found that the simulated vertical accretion and SOC sequestration values are within observed data ranges. At developer level, each sub-model (input data, codes, equations and output) was checked by a modeler other than the programmer of that sub-model. At the external reviewer level, the output (in form of static and animated maps and statistical summary tables in media, Excel, PowerPoint, etc.) of model simulations of landscape change, elevation change, and SOC storage and sequestration change were reviewed and corrected by these knowledgeable reviewers. Model codes were revised and model reruns were performed iteratively for improvement of the model.

5. Sources of model uncertainty

The sources of model uncertainty for the Wetland Morphology model are identified as follows:

a. Marsh collapse thresholds: The range of inundation values determined by 1.5 to 2 standard deviations from the remote sensing approach tends to be lower than that from an assessment of CRMS data on the relationship between vegetation health/cover and inundation depth. A larger range in inundation depths was used for the marsh collapse threshold and incorporated into the landscape change simulations, thus capturing a range of the potential uncertainty associated with inundation effects on marsh collapse.

b. Representative soil bulk density and organic matter content: Representative soil bulk density and organic matter content of some basin/marsh groups could not be derived from the calibration process due to either no available field data or sample sizes less than 3 (See Section 2c.4 "Representative soil bulk density and organic matter through calibration" for details). These groups (a total of 25) include: (1) freshwater, intermediate, saline, and other in Calcasieu/Sabine Basin; (2) other in Mermentau Basin; (3) freshwater, saline, and other in

Teche/Vermilion Basin; (4) brackish in Atchafalaya Basin; (5) saline and swamp in Terrebonne Basin; (6) swamp and other in Barataria Basin; (7) freshwater, brackish, saline, and other in Mississippi River Delta Basin; (8) freshwater, intermediate, and other in Breton Sound Basin; and (9) freshwater, brackish, saline, swamp, and other in Pontchartrain Basin. The representative BD/OM% values are assumed to be the same as the same vegetation type in the nearby basin (depending on Chenier Plain or Deltaic Plain).

c. **Multiple criteria of land loss weighting surface**: We used eight criteria to determine the potential of land in a grid cell to be lost: (1) elevation (NAVD88), (2) distance to water body, (3) land cover, (4) historical land loss trend, (5) percent time inundated, (6) fragmentation, (7) average band 5 reflectance of Landsat satellite imagery, and (8) average peak biomass from NDVI. The weights of these criteria are determined by expert opinion based on their influence on land loss/gain processes. It is anticipated that the weights of the criteria are somewhat subjective and could possibly vary with the inclusion of additional expert opinion.

d. **Probability surface for sediment redistribution at a finer resolution**: We developed an algorithm to distribute sediment from the coarse resolution Eco-Hydrology model boxes into grid cells (e.g., 500m resolution) for the landscape change and relative elevation sub-models. The probability surface is determined by elevation, distance to source, tidal amplitude, inundation frequency and land cover type. This probability surface determines how the percentage of total sediment in each Eco-Hydrology box is deposited in the 500m grid cells within each box by multiplying the total sediment in the box by the redistribution probability surface. The current version of the algorithm did not take into account change in the redistribution probability surface due to water flow/stage, inundation depth and duration.

   In addition, the model accuracy depends greatly on sediment accumulation from the Eco-Hydrology model. The Eco-Hydrology model typically predicted lower sediment accumulations than what is noted in historical observed data, especially in the Mississippi Deltaic Region, while higher sediment values were predicted than what is observed in the Wax Lake Outlet and Atchafalaya Basin regions (e.g., Holm et al., 2000; Hupp et al., 2008).

e. **Topographic/bathymetric data:** The ±15cm vertical accuracy in marsh surface elevation data is the greatest data uncertainty in the model. It could significantly affect inundation frequency and depth, saltwater intrusion inland along the coast, sediment load from the Eco-Hydrology model, land loss rate via the marsh collapse threshold, vegetation spatial distribution, accretion and surface elevation change, and soil organic carbon sequestration.

f. **Spatial pattern and magnitude of land subsidence**: There are large uncertainties in land subsidence rates across coastal Louisiana landscape due to limited data availability and methodology differences in field measurements.

g. **Organic matter contribution to vertical accretion:** We used the relationship between organic and inorganic matter accumulations as described in Equation 2. In the relative elevation sub-model, organic matter accumulation is assumed to be determined by mineral matter accumulation. However, a study by Turner et al. (2001) indicated that the accumulation of organic matter appears to control inorganic accumulation, not the reverse, and there tends to be a minimum organic matter accumulation of approximately 220 g/m^2/yr for tidal marsh to survive SLR. Nyman et al. (2006) also found that accretion varied with organic accumulation rather than mineral sedimentation across a wide range of conditions in coastal Louisiana, including stable marshes where soil contained 80% mineral matter. Therefore, the variations in organic matter accumulation and its contribution to vertical accretion for different vegetation types at different hydrologic conditions should be examined by investigating root/rhizome growth and soil organic matter decomposition under restoration activities with scenarios of SLR and subsidence.

6. Suggested model improvements

a. Sediment accumulation

The detection of spatial variability in land building, vertical accretion/elevation change and soil organic carbon storage and sequestration potential at a finer spatial resolution (e.g., 500m grid cell) is limited by the sediment accumulation input that is estimated from the Eco-Hydrology model at a coarse resolution (i.e., box level, about 400 boxes for entire coastal Louisiana landscape). Coastal Louisiana is characterized by spatially variable, unsteady, non-uniform and shallow water flow, and application of the principles of continuity and momentum are needed to model the water flow, sediment transport/deposition/accumulation and other biophysical processes at fine resolutions. Thus, regional hydrodynamic, sediment transport and accumulation modeling at a finer resolution (e.g., 500m resolution with more than 300,000 grid cells to cover the coastal Louisiana, or varying mesh size of 2D hydrodynamic models) for coastal Louisiana is desired for improving sediment simulations. Additionally, variable hurricane/storm induced sedimentation across the landscape (e.g., Reed et al., 2009) should be considered to improve the estimates of sediment load for land building and soil formation. One possible and realistic approach may be the link between circulation/storm surge modeling from the Storm Surge/Wave model and estimates of sediment deposition from hurricanes/storms from previous studies (e.g., Nyman et al., 1995; Turner et al., 2006).

b. Wetland plant productivity

The current Wetland Morphology model identifies the contribution of organic matter to sediment accumulation by estimating organic matter accumulation from an empirical relationship with mineral matter accumulation. The spatial variation in organic matter accumulation has been considered across different groups of hydrologic basin and vegetation type combinations, but not at the within-group level at which below-ground processes especially root/rhizome growth tend to vary significantly with soil biogeochemical characteristics. Wetland plant productivity data are needed to improve the model structure towards biophysical-processes especially when examining wetland productivity dynamics under climate change such as elevated atmospheric CO_2 concentration, and changed patterns in air temperature and rainfall (e.g., Langley et al., 2009). In addition, wetland plant productivity data can help to refine marsh collapse thresholds for detecting landscape change. The marsh collapse advisory panel recommended establishing marsh organs in all of the Louisiana wetland types to assist in establishing the relationship between marsh collapse and plant productivity that is affected by changes in salinity and inundation.

c. Representative soil bulk density and organic matter content

Soil bulk density and organic matter (including soil organic carbon) data from deeper cores (at least 50cm depth) are needed to better describe long-term (decadal) soil formation and vertical accretion. These cores need to include combinations of hydrologic basin and vegetation types that were not available for this stage of the modeling effort (e.g., among the 50 potential combinations of basin and vegetation types, only 25 combinations have field data for calibrated BD and OM%). These cores should also be accounted for to evaluate the role of natural (e.g., hurricanes/storms) and human influences (e.g., impoundment, river diversion, marsh creation). Such data would help to calibrate the representative BD/OM values in the surface elevation sub-model and improve vertical accretion/elevation change estimates.

Additionally, ^{137}Cs cores should be taken at all CRMS sites (current version of the model uses data from only 15 CRMS sites with long-term sediment and vertical accretion data using ^{137}Cs dating) across coastal Louisiana to better determine sediment accumulation rates and to establish more robust relationships between short-term sediment accumulation and vertical accretion and their long-term counterparts.

d. Coastal erosion and coastline retreat

Wetland morphology across coastal Louisiana is not controlled solely by depositional (both mineral and organic) processes on the marsh platform, but also by the interactions with channel networks, vegetation, and erosional processes. Sea level rise could promote an increase in water depth and deposition rates on marsh platforms, but the expanding tidal prism could also tend to promote increased erosion and expansion of channel networks, thereby reducing marsh area and causing more marsh loss and coastline retreat. Therefore, consideration of marsh/water interface erosion (e.g., hydrodynamic-driven and vegetation-influenced evolution of the channel network) and spatially variable vegetation-influenced accretion on the marsh platform should help to improve the accuracy of Wetland Morphology modeling.

7. Quality review

It is clear from both pure science and practice perspectives that models cannot reflect exactly what happened, is happening or will happen in reality. Moreover, even accurate predictions using models do not mean that a model is correct. We have implemented quality review procedures to ensure that the morphology model has been developed in a scientifically sound manner and that the simulation results provided are reasonable (See Figure 3). Specifically we have addressed the following aspects:

1) Model theory

The Wetland Morphology model was developed based on our current understanding of hydrodynamic, sediment transport, deposition, vegetation community distribution, plant growth, marsh collapse, vertical accretion, soil formation, elevation dynamics, SLR, land subsidence, anthropogenic influences (i.e., restoration activities) and their interaction across the landscape of coastal wetlands. These physical and ecological processes have been identified as the major controlling factors on wetland loss and land gain observed across coastal Louisiana by numerous past and ongoing studies and have been included in our model design (state variables, forcing functions and feedback pathways, Figure 5 in "Technical quality" Section for details on model structure). We have also analyzed recent datasets to improve upon our existing knowledge. For example, the soil organic carbon (SOC) to soil organic matter (SOM) conversion factor was redefined from 1.724 to 2.22 based on CRMS 2006-2009 collected data for describing SOC storage and sequestration. We are comfortable that the Wetland Morphology model is appropriate and relevant in terms of addressing impacts of protection and restoration projects under multiple scenarios of SLR and subsidence on the landscape and elevation change across coastal Louisiana. We also realize that we do not have sufficient knowledge about some processes involved in shaping coastal wetland landscapes and determining soil formation across coastal Louisiana. When sufficient data was not available to establish relationships between these processes and wetland morphology, we used relevant and reasonable assumptions based on existing field observations in coastal Louisiana or from other wetlands research. These assumptions were involved in the determination of the land loss weighting surface, sediment redistribution weight surface, hurricane sedimentation, and maximum stage limits on sediment delivery (See Section 2d "Assumptions" for details). These assumptions as well as the relationships developed between short-term and long-term sediment accumulation rates and vertical accretion rates used for soil bulk density calibration were proposed, discussed and reviewed by internal and external reviewers and the technical advisory panel.

2) Mathematical representation and computer coding/scripting
The translations of theory into mathematical representations are realized by equations and assignments in the Wetland Morphology model such as the vertical accretion equations and marsh collapse assignments on different vegetation types (See Section 2 "Technical quality" for details). These mathematical representations are empirical relationships derived from observations from previous research in coastal Louisiana and other coastal wetlands. The transcription of the mathematical representation into computer codes or scripts were done by modelers of the Wetland Morphology team using reliable, widely used commercial software such as ERDAS IMAGINE Model Maker and Intel FORTRAN compiler. All representations were reviewed by both internal and external reviewers.

3) Parameter uncertainty
Parameter uncertainty is one important factor affecting model performance and thus model quality. We addressed this issue by selecting marsh collapse and soil bulk density as the two major model parameters in the uncertainty analysis (See Section 8 "Uncertainty analysis" below for details). Moreover, we calibrated the soil bulk density to determine the representative bulk density and organic matter for different hydrologic and vegetation types across the coastal Louisiana landscape for the pre-compaction model. We also examined the most plausible marsh collapse thresholds for different vegetation types by using well-distributed, QA/QC'd field data collected from CRMS and LCA S&T programs and linking those data with remote sensing estimates under different salinity and inundation regimes.

4) Testing and validation
We have tested and validated the Wetland Morphology model using field data from previous research, CRMS and LCA S&T programs. These tests and validation indicated that the Wetland Morphology model is capable of broadly describing the landscape and elevation dynamics across coastal Louisiana (See Section 3d "Description of processes used to test and validate model" for details). This process was reviewed by internal and external reviewers who are experienced in coastal morphology and controlling processes.

5) Reasonability of simulation results and findings
We provided simulation results to both internal and external reviewers as well as other modeling teams (e.g., the Eco-Hydrology model, Vegetation model and Ecosystem Services model). Unrealistic and suspicious results were checked and model re-runs were conducted after finding the sources (e.g., errors from coding, scripts, parameters, restoration project

feature descriptors, conversions of input from other model teams) of the errors. Simulations were conducted and assessed until reasonable results and findings could be interpreted.

8. Uncertainty analysis

Marsh collapse threshold and soil bulk density (BD) are the two of the more sensitive parameters regarding predictions of landscape change and vertical accretion/surface elevation in the Wetland Morphology model. These were selected for inclusion in the Model Uncertainty Analysis by CPRA.

Marsh/peat collapse due to plant dieback caused by prolonged inundation and salt water intrusion was found to be the primary mechanism of wetland loss in coastal Louisiana (DeLaune et al., 1994; Day et al., 2011). Marsh collapse threshold is closely related with plant productivity especially below-ground productivity; therefore, lower thresholds tend to be seen in wetlands with lower plant growth (DeLaune et al., 1994; Turner et al., 2004; Langley et al., 2009; Day et al., 2011). Marsh collapse thresholds for different vegetation types across coastal Louisiana were determined based on plant tolerance to salinity regime (for freshwater marsh and swamp forest) and inundation depth (for intermediate, brackish and saline marshes) (refer to "Technical Quality" Section for details). The ranges of these thresholds were found from empirical relationships between plant productivity and salinity regime and inundation depth established from field observations (e.g., CRMS data) and field-data-trained remote sensing investigations. In the model simulations, middle values in the ranges were used as the thresholds for different vegetation types (Table 10). The other four values in the uncertainty analysis were selected evenly from the ranges (Table 10). Lower bound of collapse threshold was assumed to result in high collapse probability, or high land loss potential. It should be noted that marsh collapse defined in the Wetland Morphology model did not include vegetation collapse due to high-energy events (e.g., hurricanes, storm surge, waves, currents) that would induce severe soil/sediment erosion especially along the marsh edges, or interface between marsh and water bodies (e.g., DeLaune et al., 1989; Nyman et al., 1994; Fearnley, 2008; Chen and Zhao, 2011).

Soil bulk density varies in space and time across coastal Louisiana. The BD ranges for peat and mineral soils of different basin-vegetation groups were determined from CRMS soil core data. Coast wide BD ranges between 0.02-1.43 g/cm^3 (Table 11). The highest BD values (1.42 g/cm^3) were found in the Mississippi River Delta Basin and in the Atchafalaya Basin. The lowest BD value (0.02 g/cm^3) was found in freshwater marsh sites within Mermentau Basin. Besides the most-likely BD values (also the model-used BD values) that are based on model calibration (See Section 2 "Technical Quality" for details on vertical accretion calibration), the other four land-loss potential BD values used in the model were selected evenly from the observed ranges of each basin-vegetation group. Thus, the most-likely BD values are not necessarily in the middle of the ranges. In a practical context, three values higher than calibrated/model-used BD could give us scenarios when restoration projects (e.g., sediment slurry addition) increase BD values, and also examine how landscape/elevation will respond to changing environmental conditions (e.g., water, salinity, sediment and nutrient) associated with freshwater and sediment diversions.

Table 10. Settings for marsh collapse threshold uncertainty runs in the Wetland Morphology model.

Vegetation Type	Model Used Value	Lower land loss potential class	Medium land loss potential class	High land loss potential class	Very high land loss potential class
Fresh (salinity: 8 week average -growing season)	7.00	8.00	7.50	6.50	6.00
Intermediate (inundation depth, cm)	34.36	38.00	36.18	32.54	30.72
Brackish (inundation depth, cm)	22.78	25.56	24.17	21.39	20.00
Saline (inundation depth, cm)	20.50	25.00	22.75	18.25	16.00
Swamp (salinity: 8 week average - growing season)	5.50	7.00	6.25	4.75	4.00

In the current Wetland Morphology model, we did not adjust/switch BD values for wetland areas that are impacted by restoration projects due to the limited BD measurements and the diversity of restoration-influenced areas. But, there is a tendency for BD to increase with restoration (e.g., marsh creation, dredge spill, sediment slurry, and river and sediment diversion (Table 12). Additionally, BD changes with time and this temporal variation in BD can be seen from BD-depth plots especially for saline, brackish marsh, or wetland areas that are impacted heavily by restoration activities and experience a change/switch in plant community types.

Table 11. Settings for soil bulk density uncertainty runs in the Wetland Morphology model.

Basin-Vegetation Group	Model Used Value	Low land loss potential class	Medium land loss potential class	High land loss potential class	Very high land loss potential class
Pontchartrain - Intermediate Marsh	0.11	0.06	0.15	0.24	0.33
Breton Sound - Brackish Marsh	0.23	0.06	0.36	0.66	0.96
Breton Sound - Saline Marsh	0.53	0.23	0.38	0.53	0.68
Mississippi River Delta - Deltaic	0.46	0.31	0.68	1.05	1.42
Barataria - Freshwater Marsh	0.05	0.03	0.15	0.28	0.40
Barataria - Intermediate Marsh	0.08	0.04	0.14	0.25	0.35
Barataria - Brackish Marsh	0.15	0.07	0.24	0.41	0.59
Barataria - Saline Marsh	0.28	0.08	0.27	0.45	0.64
Terrebonne - Freshwater Marsh	0.11	0.05	0.16	0.26	0.37
Terrebonne - Intermediate Marsh	0.18	0.04	0.21	0.38	0.55
Terrebonne - Brackish Marsh	0.32	0.05	0.29	0.53	0.77
Terrebonne - Other	0.10	0.06	0.11	0.16	0.22
Atchafalaya - Deltaic	0.65	0.50	0.79	1.08	1.37
Atchafalaya - Freshwater Marsh	0.25	0.18	0.25	0.33	0.41
Atchafalaya - Intermediate Marsh	0.42	0.12	0.36	0.60	0.84
Atchafalaya - Swamp	0.21	0.17	0.30	0.43	0.56
Atchafalaya - Other	0.24	0.13	0.26	0.39	0.53
Teche/Vermilion - Intermediate Marsh	0.16	0.04	0.24	0.45	0.65
Teche/Vermilion - Brackish Marsh	0.21	0.08	0.39	0.70	1.01
Teche/Vermilion - Swamp	0.36	0.11	0.26	0.41	0.57
Mermentau - Freshwater Marsh	0.04	0.02	0.14	0.25	0.37
Mermentau - Intermediate Marsh	0.19	0.05	0.15	0.25	0.35
Mermentau - Brackish Marsh	0.38	0.04	0.31	0.59	0.87
Mermentau - Saline Marsh	0.41	0.25	0.33	0.41	0.49
Calcasieu/Sabin - Brackish Marsh	0.23	0.04	0.30	0.55	0.80

Note:

1. Model used values are based on calibration.
2. High BD leads to lower vertical accretion, thus lower capability in maintaining surface elevation (or high land loss potential)

Table 12. The ranges of soil bulk density measurements from different restoration projects.

Restoration Type	Vegetation Type	BD (g/cm3)	Source
Diversion	Freshwater/brackish Marsh	0.07-0.39	DeLaune et al., 2003
Marsh Creation	salt marsh	1.15-1.45	Fearnley, 2008
Dredge spoil addition	salt marsh	0.5-1.2	Edwards & Profftt, 2003
Dredged material	salt marsh	0.55-0.61	Ford et al., 1999
Sediment Slurry	salt marsh	0.86-1.18	Stagg & Mendelssohn, 2010

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Attachment A: Input Datasets

1. ***Field data on soil bulk density and organic matter content (top 4 cm layer) and vertical accretion using feldspar mark at CRMS sites that were used to derive long-term rates of sediment accumulation and vertical accretion at these sites.***

Table A1. Measured soil bulk density, organic matter at top 4 cm layer and vertical accretion (feldspar mark) at CRMS sites.

Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)	Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)
			Atchafalaya Basin				
CRMS0461	0.55	11.96	3.38	CRMS4016	0.16	26.67	1.78
CRMS0463	0.26	15.76	4.55	CRMS4779	0.08	45.24	1.25
CRMS0464	0.22	19.28	2.39	CRMS4808	0.15	42.51	5.32
CRMS0465	0.84	6.28	2.50	CRMS4809	0.14	34.53	4.26
CRMS0479	0.54	8.73	7.91	CRMS4900	0.25	20.13	3.17
CRMS0482	0.09	44.94	2.65	CRMS4938	0.19	31.65	4.56
CRMS2568	0.23	25.69	3.24	CRMS6038	0.16	29.68	4.63
CRMS4014	0.26	23.39	2.35				
			Barataria Basin				
CRMS0163	0.43	9.74	3.53	CRMS0251	0.17	27.54	2.81
CRMS0164	0.23	27.72	1.89	CRMS0253	0.29	25.54	2.79
CRMS0171	0.49	8.18	4.42	CRMS0260	0.20	37.28	1.84
CRMS0172	0.40	13.99	2.08	CRMS0261	0.32	30.21	3.14
CRMS0173	0.27	21.70	1.71	CRMS0263	0.21	31.20	3.35
CRMS0174	0.30	19.53	4.15	CRMS0268	0.05	77.67	0.39
CRMS0175	0.26	25.18	2.65	CRMS0272	0.34	20.71	5.84
CRMS0176	0.25	22.49	5.53	CRMS0273	0.07	81.42	1.22
CRMS0178	0.67	9.51	2.66	CRMS0276	0.23	37.37	3.13
CRMS0179	0.46	18.93	0.90	CRMS0278	0.06	79.38	1.91
CRMS0181	0.46	14.77	5.34	CRMS0282	0.15	38.32	2.81
CRMS0184	0.03	84.21	2.91	CRMS2991	0.04	92.43	1.22
CRMS0188	0.06	80.78	0.87	CRMS3054	0.13	40.33	2.45
CRMS0189	0.05	90.09	1.38	CRMS3136	0.09	60.91	2.22
CRMS0190	0.08	76.03	0.81	CRMS3166	0.04	70.75	2.30
CRMS0192	0.06	89.14	0.78	CRMS3169	0.27	18.44	8.15
CRMS0194	0.32	36.74	0.98	CRMS3565	0.16	33.93	1.84
CRMS0197	0.33	36.11	0.63	CRMS3601	0.18	33.26	2.85
CRMS0206	0.06	93.29	0.00	CRMS3617	0.24	15.60	4.35
CRMS0209	0.27	24.45	2.62	CRMS3680	0.16	40.00	2.39
CRMS0211	0.06	90.68	1.74	CRMS3985	0.07	62.71	1.78
CRMS0217	0.22	41.04	1.86	CRMS4103	0.12	58.63	2.24
CRMS0219	0.05	82.72	0.83	CRMS4218	0.20	34.15	6.60
CRMS0220	0.15	40.85	3.63	CRMS4245	0.15	35.41	1.77
CRMS0224	0.27	21.94	1.25	CRMS4529	0.38	14.54	2.47
CRMS0225	0.15	40.99	2.66	CRMS4690	0.26	25.98	2.89
CRMS0226	0.27	19.67	1.56	CRMS5116	0.30	25.58	1.92
CRMS0232	0.29	18.20	1.87	CRMS5672	0.12	77.24	2.54
CRMS0237	0.14	24.16	2.51	CRMS6303	0.23	36.03	1.83
CRMS0248	0.39	29.19	3.21				
			Breton Sound Basin				
CRMS0115	0.25	39.51	0.26	CRMS0132	0.17	42.21	3.42
CRMS0117	0.14	30.65	3.98	CRMS0135	0.46	13.58	1.49
CRMS0118	0.42	14.87	5.55	CRMS0136	0.37	25.41	1.49
CRMS0119	0.52	16.11	2.88	CRMS0139	0.53	10.95	4.43
CRMS0120	0.22	33.65	0.75	CRMS0146	0.31	19.76	4.04
CRMS0121	0.18	25.47	5.57	CRMS0147	0.62	9.37	1.51
CRMS0125	0.17	45.63	0.95	CRMS0148	0.75	9.74	1.45
CRMS0128	0.15	30.87	2.37	CRMS2614	0.57	8.61	5.10
CRMS0129	0.60	12.53	2.00				

Table A1. Measured soil bulk density, organic matter at top 4 cm layer and vertical accretion (feldspar mark) at CRMS sites. --Continued.

Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)	Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)
			Calcasieu/Sabine Basin				
CRMS0635	0.07	55.80	1.23	CRMS0682	0.34	13.63	1.37
CRMS0638	0.09	46.17	1.38	CRMS0683	0.05	74.36	1.00
CRMS0639	0.15	27.15	3.68	CRMS0684	0.18	34.46	1.59
CRMS0641	0.11	42.51	0.54	CRMS0685	0.52	11.33	1.26
CRMS0642	0.13	43.08	3.67	CRMS0687	0.30	19.99	2.29
CRMS0644	0.28	18.74	1.48	CRMS0694	0.07	62.91	2.71
CRMS0645	0.12	52.78	1.05	CRMS1205	0.11	45.55	0.94
CRMS0647	0.17	17.71	1.70	CRMS1738	0.18	26.61	1.20
CRMS0648	0.14	30.60	1.72	CRMS1743	0.09	43.95	1.16
CRMS0650	0.05	66.28	1.96	CRMS1838	0.16	27.22	1.86
CRMS0651	0.06	56.09	1.14	CRMS1858	0.25	14.66	1.28
CRMS0655	0.24	15.60	2.01	CRMS2154	0.12	34.41	1.25
CRMS0656	0.23	20.77	1.17	CRMS2156	0.07	51.28	0.67
CRMS0658	0.08	46.98	1.56	CRMS2166	0.07	57.02	1.77
CRMS0660	0.09	68.46	0.52	CRMS2189	0.13	32.84	1.43
CRMS0663	0.06	52.49	4.32	CRMS2219	0.35	16.11	1.34
CRMS0669	0.08	69.12	3.13	CRMS2334	0.16	46.95	1.62
CRMS0672	0.28	16.11	1.02	CRMS2418	0.16	28.33	0.70
CRMS0677	0.06	53.56	1.03	CRMS6301	0.40	11.88	1.24
			Mermentau Basin				
CRMS0553	0.06	56.13	1.37	CRMS0604	0.21	25.79	1.19
CRMS0554	0.20	46.55	0.97	CRMS0605	0.11	39.83	0.70
CRMS0556	0.04	85.83	2.05	CRMS0608	0.45	14.78	0.77
CRMS0557	0.04	80.59	0.62	CRMS0609	0.39	13.54	1.69
CRMS0562	0.13	36.53	1.31	CRMS0610	0.45	12.79	2.60
CRMS0565	0.05	66.46	0.72	CRMS0614	0.17	37.28	2.35
CRMS0568	0.39	16.57	1.50	CRMS0615	0.40	17.82	0.96
CRMS0570	0.11	63.97	3.76	CRMS0616	0.13	49.95	2.00
CRMS0571	0.03	85.73	2.67	CRMS0618	0.20	37.73	0.94
CRMS0574	0.09	55.70	1.71	CRMS0619	0.05	87.94	3.17
CRMS0575	0.05	80.62	0.73	CRMS0622	0.26	19.18	1.77
CRMS0576	0.27	13.01	1.54	CRMS0623	0.30	15.92	3.23
CRMS0580	0.14	48.91	2.04	CRMS0624	0.06	50.10	0.94
CRMS0581	0.60	14.86	3.54	CRMS0626	0.45	10.22	1.84
CRMS0583	0.12	32.22	1.24	CRMS0630	0.08	50.44	1.76
CRMS0584	0.44	11.68	1.88	CRMS0632	0.25	21.60	0.52
CRMS0587	0.34	16.05	1.09	CRMS0633	0.36	18.53	1.90
CRMS0588	0.09	55.77	1.54	CRMS1130	0.08	50.25	3.06
CRMS0589	0.39	18.24	1.18	CRMS1277	0.03	89.05	0.54
CRMS0590	0.18	24.59	4.93	CRMS1409	0.10	49.46	1.48
CRMS0595	0.07	61.66	2.88	CRMS1413	0.15	28.51	0.68
CRMS0599	0.38	12.35	1.60	CRMS1446	0.13	33.50	2.33
CRMS0600	0.50	14.15	3.81	CRMS2493	0.11	37.64	0.82
CRMS0603	0.07	76.41	2.00				
			Mississippi River Delta Basin				
CRMS0154	0.64	8.81	7.83	CRMS0161	0.37	12.13	4.71
CRMS0156	0.88	7.16	8.79	CRMS2608	0.66	5.18	5.01
CRMS0157	0.63	10.10	3.06	CRMS2634	0.74	5.35	7.73
CRMS0159	0.93	5.34	3.92	CRMS4626	0.59	10.92	5.39

Table A1. **Measured soil bulk density, organic matter at top 4 cm layer and vertical accretion (feldspar mark) at CRMS sites.** --Continued.

Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)	Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)
			Pontchartrain Basin				
CRMS0002	0.15	18.64	2.28	CRMS3641	0.08	37.57	1.08
CRMS0003	0.71	5.23	2.34	CRMS3650	0.25	12.78	2.81
CRMS0006	0.21	21.17	3.46	CRMS3664	0.27	27.67	0.99
CRMS0008	0.05	85.78	2.87	CRMS3667	0.14	42.65	2.13
CRMS0030	0.16	26.66	3.05	CRMS3784	0.48	8.78	2.49
CRMS0033	0.10	62.07	1.58	CRMS3913	0.08	54.70	6.38
CRMS0034	0.12	49.44	1.13	CRMS4094	0.13	40.99	0.97
CRMS0038	0.15	33.55	1.41	CRMS4107	0.05	57.49	2.29
CRMS0039	0.11	82.41	0.93	CRMS4406	0.15	30.50	2.08
CRMS0046	0.28	18.65	7.02	CRMS4407	0.10	51.03	0.61
CRMS0047	0.10	61.88	1.60	CRMS4548	0.61	10.98	1.65
CRMS0056	0.15	47.23	2.65	CRMS4551	0.45	14.96	3.14
CRMS0059	0.11	47.57	3.04	CRMS4557	0.26	24.28	3.15
CRMS0061	0.19	28.03	1.21	CRMS4572	0.46	15.68	2.10
CRMS0063	0.08	74.22	2.17	CRMS4596	0.77	5.68	2.48
CRMS0097	0.12	79.55	1.31	CRMS5167	0.17	48.46	1.89
CRMS0103	0.13	45.75	0.76	CRMS5255	0.21	24.31	1.60
CRMS0108	0.23	23.14	3.05	CRMS5267	0.21	29.70	3.55
CRMS1024	0.41	16.53	2.97	CRMS5373	0.11	73.28	1.58
CRMS1069	0.98	3.46	2.88	CRMS5414	0.11	58.76	2.33
CRMS2830	0.22	28.97	1.92	CRMS5452	0.08	52.04	4.37
CRMS2854	0.10	56.90	3.67	CRMS5845	0.17	42.57	3.06
CRMS3626	0.13	32.25	1.40	CRMS6209	0.09	53.26	0.46
CRMS3639	0.17	30.15	0.89	CRMS6299	0.17	29.97	1.56
			Terrebonne Basin				
CRMS0290	0.05	74.34	2.17	CRMS0371	0.09	60.61	2.94
CRMS0292	0.38	21.17	3.12	CRMS0374	0.45	17.22	2.12
CRMS0293	0.44	28.04	1.42	CRMS0376	0.39	11.26	2.33
CRMS0294	0.16	44.25	1.97	CRMS0377	0.36	20.18	2.39
CRMS0296	0.08	80.96	1.84	CRMS0381	0.11	64.37	1.41
CRMS0301	0.20	38.67	5.44	CRMS0382	0.06	68.88	1.81
CRMS0302	0.50	10.24	4.76	CRMS0383	0.34	16.34	2.33
CRMS0303	0.45	12.81	1.99	CRMS0385	0.13	63.27	0.56
CRMS0305	0.24	26.05	2.72	CRMS0386	0.18	52.88	2.16
CRMS0307	0.29	28.79	3.15	CRMS0387	0.14	42.86	1.22
CRMS0309	0.33	18.22	1.75	CRMS0392	0.10	63.41	5.47
CRMS0310	0.22	27.33	2.22	CRMS0394	0.16	45.19	1.89
CRMS0311	0.32	25.83	1.87	CRMS0395	0.15	41.19	2.00
CRMS0312	0.06	82.95	0.95	CRMS0396	0.25	26.85	1.22
CRMS0315	0.23	30.63	3.81	CRMS0397	0.18	41.34	2.73
CRMS0318	0.26	20.66	2.53	CRMS0398	0.19	31.52	2.68
CRMS0319	0.22	26.42	1.58	CRMS0399	0.28	21.49	1.15
CRMS0322	0.29	28.10	0.98	CRMS0400	0.07	49.04	3.65
CRMS0324	0.76	15.52	4.69	CRMS0403	0.08	88.66	4.29
CRMS0326	0.35	22.96	0.56	CRMS0409	0.17	41.68	3.64
CRMS0327	0.13	45.37	2.94	CRMS0411	0.06	72.98	4.94
CRMS0329	0.11	34.57	5.64	CRMS0416	0.13	50.67	1.17
CRMS0331	0.09	62.84	1.31	CRMS0421	0.43	15.24	4.71
CRMS0332	0.73	6.77	1.87	CRMS0434	0.18	24.81	3.90

Table A1. **Measured soil bulk density, organic matter at top 4 cm layer and vertical accretion (feldspar mark) at CRMS sites.** --Continued.

Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)	Site	Bulk Density (g/cm3)	Organic Matter (%)	Vertical Accretion (cm/yr)
			Terrebonne Basin				
CRMS0335	0.32	17.58	3.29	CRMS0978	0.18	42.03	2.83
CRMS0336	0.43	18.46	2.34	CRMS2785	0.06	81.97	2.99
CRMS0337	0.32	13.97	6.11	CRMS2825	0.14	46.37	2.60
CRMS0338	0.29	25.43	8.34	CRMS2862	0.07	81.83	2.93
CRMS0341	0.40	15.42	2.79	CRMS2881	0.04	83.36	2.60
CRMS0345	0.43	11.90	4.12	CRMS2887	0.06	69.84	4.07
CRMS0347	0.48	13.22	5.66	CRMS3296	0.23	33.67	2.13
CRMS0354	0.21	30.24	1.77	CRMS4045	0.20	34.39	2.39
CRMS0355	0.26	19.44	6.08	CRMS4455	0.25	21.33	1.95
CRMS0367	0.11	52.53	2.81	CRMS5035	0.17	50.37	4.16
CRMS0369	0.31	26.80	2.11	CRMS5770	0.17	62.83	2.93
			Teche/Vermilion Basin				
CRMS0488	0.06	65.74	2.59	CRMS0524	0.27	33.38	2.15
CRMS0489	0.31	20.99	2.66	CRMS0527	0.64	10.74	1.87
CRMS0490	0.08	58.11	1.97	CRMS0529	0.09	46.57	3.34
CRMS0493	0.22	36.67	5.16	CRMS0530	0.38	10.01	1.92
CRMS0494	0.38	13.35	3.26	CRMS0532	0.31	22.08	1.77
CRMS0496	0.40	28.85	2.58	CRMS0535	0.31	16.03	1.81
CRMS0498	0.29	17.60	2.30	CRMS0536	0.28	16.15	2.19
CRMS0499	0.26	24.17	1.95	CRMS0541	0.66	9.51	1.97
CRMS0501	0.15	45.29	2.91	CRMS0543	0.18	26.48	1.20
CRMS0504	0.23	18.28	1.11	CRMS0544	0.07	41.76	3.54
CRMS0507	0.20	24.82	4.89	CRMS0545	0.10	41.61	2.78
CRMS0508	0.12	49.45	2.27	CRMS0547	0.38	21.81	2.27
CRMS0511	0.28	24.17	0.41	CRMS0549	0.28	21.80	2.47
CRMS0513	0.07	67.18	1.17	CRMS0550	0.50	15.64	2.44
CRMS0514	0.33	17.12	1.05	CRMS0551	0.20	65.69	0.51
CRMS0517	0.34	13.37	2.29	CRMS0552	0.27	20.18	2.02
CRMS0520	0.26	26.03	3.24	CRMS1650	0.26	20.27	2.02
CRMS0522	0.29	23.21	2.08	CRMS2041	0.28	13.72	1.43
CRMS0523	0.22	30.00	1.79				

2. ***Estimated long-term rates of sediment accumulation and vertical accretion at CRMS sites that were used in the calibration of soil bulk density and organic matter content.***

Table A2. Estimated long-term sediment accumulation and vertical accretion rates at CRMS sites.

Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)	Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)
		Atchafalaya Freshwater Marsh			
CRMS4014	1396	0.66	CRMS4016	749	0.73
		Atchafalaya Intermediate Marsh			
CRMS0461	4426	1.66	CRMS0464	1298	0.85
CRMS0482	551	1.53	CRMS0465	5254	0.92
		Atchafalaya Other			
CRMS4779	355	0.45	CRMS4938	1755	1.02
CRMS4808	1387	1.13	CRMS6038	1574	0.42
CRMS4809	1188	1.10			
		Atchafalaya Swamp			
CRMS2568	1610	1.58	CRMS4900	1852	0.36
		Barataria Brackish Marsh			
CRMS0190	256	0.39	CRMS3565	712	0.96
CRMS0225	831	1.18	CRMS3601	1105	1.19
CRMS0248	2502	2.15	CRMS3617	2497	1.87
CRMS0253	1737	1.47	CRMS3680	800	0.77
CRMS0260	805	0.73	CRMS4103	491	1.44
CRMS0261	2010	1.68	CRMS4245	654	1.19
CRMS0263	1453	1.43	CRMS6303	913	1.03
CRMS0276	1369	1.52			
		Barataria Freshwater Marsh			
CRMS0163	3750	2.13	CRMS0219	232	0.47
CRMS0175	1548	1.04	CRMS0273	255	0.66
CRMS0192	227	0.33	CRMS2991	223	0.41
CRMS0211	241	0.86	CRMS3136	414	1.19
		Barataria Intermediate Marsh			
CRMS0188	240	0.48	CRMS3054	712	1.12
CRMS0189	231	0.92	CRMS3166	289	1.44
CRMS0278	278	1.19	CRMS3985	333	1.14
		Barataria Saline Marsh			
CRMS0164	1017	0.75	CRMS0224	890	0.41
CRMS0171	5337	1.57	CRMS0226	1082	0.79
CRMS0172	2063	0.42	CRMS0232	1334	0.87
CRMS0173	1126	0.56	CRMS0237	896	0.94
CRMS0174	2807	1.54	CRMS0251	1118	1.27
CRMS0179	1073	0.33	CRMS0272	4203	1.86
CRMS0181	5568	2.04	CRMS0282	879	0.59
CRMS0209	1581	0.96	CRMS4529	2265	0.82
CRMS0220	1038	1.62	CRMS4690	1619	1.30
		Barataria Swamp			
CRMS0184	250	1.23	CRMS5672	387	1.06
CRMS0217	823	0.87			
		Breton Sound Brackish Marsh			
CRMS0117	1203	1.01	CRMS0128	843	0.43
CRMS0118	5331	2.10	CRMS0132	1058	2.03
CRMS0120	495	0.23	CRMS0135	1742	0.79
CRMS0125	435	0.40	CRMS0146	2813	1.27

Table A2. Estimated long-term sediment accumulation and vertical accretion rates at CRMS sites. -- continued.

Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)	Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)
Breton Sound Saline Marsh					
CRMS0119	3450	0.82	CRMS0147	2401	0.79
CRMS0129	2915	0.38			
Calcasieu/Sabine Brackish Marsh					
CRMS0635	307	0.52	CRMS0682	1250	0.27
CRMS0638	379	0.66	CRMS0683	250	0.57
CRMS0639	1244	1.57	CRMS0684	694	1.14
CRMS0641	301	0.47	CRMS1205	358	0.77
CRMS0642	908	0.93	CRMS1738	613	0.76
CRMS0644	1083	0.73	CRMS1743	365	0.41
CRMS0645	366	0.56	CRMS1838	758	1.15
CRMS0648	632	0.21	CRMS1858	923	0.45
CRMS0651	291	0.40	CRMS2156	270	0.29
CRMS0658	384	0.59	CRMS2166	344	1.00
CRMS0669	421	0.93	CRMS2189	543	0.22
CRMS0672	830	0.60	CRMS2334	559	1.45
CRMS0677	284	0.60	CRMS2418	424	0.34
Calcasieu/Sabine Freshwater Marsh					
CRMS2219	1228	0.68	CRMS0650	299	0.70
Calcasieu/Sabine Intermediate Marsh					
CRMS0694	394	1.26			
Calcasieu/Sabine Saline Marsh					
CRMS0655	1268	1.24	CRMS0687	1619	1.67
CRMS0685	1689	0.76	CRMS6301	1334	1.10
Mermentau Brackish Marsh					
CRMS0554	479	0.50	CRMS0609	1683	1.13
CRMS0562	485	0.92	CRMS0610	2802	0.24
CRMS0571	244	0.58	CRMS0615	1017	0.62
CRMS0574	395	0.99	CRMS0616	547	0.73
CRMS0576	1130	0.79	CRMS0618	519	0.36
CRMS0580	597	1.04	CRMS0622	1151	1.23
CRMS0583	465	0.75	CRMS0623	2274	1.65
CRMS0584	2094	0.98	CRMS0624	291	0.67
CRMS0587	1004	0.96	CRMS0626	2126	1.11
CRMS0588	371	0.75	CRMS0632	474	0.29
CRMS0603	303	0.82	CRMS0633	1653	1.08
CRMS0605	336	0.62	CRMS2493	363	0.34
CRMS0608	961	0.71			
Mermentau Freshwater Marsh					
CRMS0614	856	0.24	CRMS1130	539	2.03
CRMS0556	244	1.31	CRMS1277	219	0.26
CRMS0557	227	0.25	CRMS1413	397	0.47
CRMS0604	680	0.59	CRMS1446	730	1.26
CRMS0630	393	1.26			

Table A2. Estimated long-term sediment accumulation and vertical accretion rates at CRMS sites. -- continued.

Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)	Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)
		Mermentau Intermediate Marsh			
CRMS0553	311	0.73	CRMS0568	1451	1.01
CRMS0565	243	0.50	CRMS1409	400	0.62
		Mermentau Saline Marsh			
CRMS0589	1168	0.62	CRMS0600	4427	1.01
CRMS0599	1591	0.87			
		Mississippi River Deltaic			
CRMS0157	4676	1.48	CRMS0161	4094	1.72
CRMS0159	9011	1.72			
		Pontchartrain Brackish Marsh			
CRMS0002	926	1.75	CRMS3667	641	1.96
CRMS2830	994	0.54	CRMS4094	404	0.81
CRMS3626	538	1.11	CRMS4406	782	1.78
CRMS3641	353	0.36	CRMS4407	294	0.46
CRMS3650	1783	1.83	CRMS6299	700	1.19
		Pontchartrain Intermediate Marsh			
CRMS6209	263	0.34	CRMS0034	394	0.80
CRMS0033	363	1.04	CRMS0103	352	0.58
		Pontchartrain Saline Marsh			
CRMS0003	4264	1.13	CRMS4548	2500	0.83
CRMS0108	1575	1.55	CRMS4551	3283	1.71
CRMS1024	2838	1.29	CRMS4557	1821	1.14
CRMS1069	7157	1.26	CRMS4572	2308	0.97
CRMS3784	3024	2.13	CRMS4596	4825	1.30
		Pontchartrain Swamp			
CRMS0008	270	1.66	CRMS0063	334	2.02
CRMS0038	565	1.07	CRMS0097	299	0.81
CRMS0039	259	0.26	CRMS5167	647	1.14
CRMS0047	371	1.28	CRMS5255	853	1.55
CRMS0056	751	1.38	CRMS5373	330	1.64
CRMS0059	663	2.01	CRMS5414	477	1.95
CRMS0061	645	1.06			
		Terrebonne Brackish Marsh			
CRMS0293	1366	0.74	CRMS0394	648	1.31
CRMS0305	1449	1.48	CRMS0395	665	1.64
CRMS0309	1435	1.00	CRMS0396	783	0.70
CRMS0312	241	0.43	CRMS0397	939	1.56
CRMS0326	595	0.28	CRMS0398	1120	1.46
CRMS0331	322	0.71	CRMS0399	863	0.47
CRMS0332	3450	0.78	CRMS0416	406	0.71
CRMS0354	890	1.27	CRMS0434	1590	2.16
CRMS0369	1427	1.09	CRMS2825	702	1.56
CRMS0385	283	0.24	CRMS2887	403	1.37
CRMS0386	692	1.25	CRMS4045	1018	1.43
CRMS0387	463	0.64			
		Terrebonne Freshwater Marsh			
CRMS0376	2278	1.59	CRMS0409	1118	1.06
CRMS0335	2409	1.59	CRMS0411	419	1.03
CRMS0381	356	0.59	CRMS2881	263	0.99

Table A2. Estimated long-term sediment accumulation and vertical accretion rates at CRMS sites. -- continued.

Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)	Site	Long-term Sediment Accumulation (g/m2/yr)	Long-term Vertical Accretion (cm/yr)
		Terrebonne Intermediate Marsh			
CRMS0290	291	0.85	CRMS0371	471	1.56
CRMS0294	674	0.82	CRMS2785	302	1.18
CRMS0296	286	0.80	CRMS2862	305	0.67
CRMS0327	762	1.29			
		Terrebonne Other			
CRMS0367	579	1.47	CRMS0382	301	0.72
		Terrebonne Saline Marsh			
CRMS0292	2602	1.74	CRMS0336	2326	1.37
CRMS0303	2211	0.96	CRMS0341	2646	1.89
CRMS0307	1895	1.83	CRMS0374	2219	1.10
CRMS0310	1137	1.25	CRMS0377	1974	1.56
CRMS0311	1360	0.62	CRMS0383	1912	1.77
CRMS0318	1533	1.52	CRMS0978	957	1.48
CRMS0319	879	0.94	CRMS3296	1057	0.96
CRMS0322	735	0.74	CRMS4455	1182	0.89
		Terrebonne Swamp			
CRMS0324	7883	1.22	CRMS5770	698	0.54
CRMS5035	1094	2.03			
		Teche/Vermilion Brackish Marsh			
CRMS0494	2935	1.61	CRMS0524	1201	0.74
CRMS0498	1619	0.87	CRMS0529	625	1.38
CRMS0499	1211	0.95	CRMS0530	1909	0.95
CRMS0501	825	1.36	CRMS0532	1296	0.39
CRMS0504	747	0.63	CRMS0535	1419	0.85
CRMS0508	567	0.44	CRMS0536	1544	0.86
CRMS0511	442	0.35	CRMS0541	3216	0.51
CRMS0520	1831	1.35	CRMS0552	1315	1.35
CRMS0522	1385	1.35	CRMS1650	1284	1.05
CRMS0523	932	0.66	CRMS2041	1106	0.33
		Teche/Vermilion Intermediate Marsh			
CRMS0493	2024	2.00	CRMS0544	584	0.55
CRMS0496	2093	1.09	CRMS0545	630	1.11
CRMS0517	1923	0.71	CRMS0550	2862	1.07
CRMS0543	630	0.58			
		Teche/Vermilion Saline Marsh			
CRMS0527	2936	0.66			
		Teche/Vermilion Swamp			
CRMS0513	283	0.42	CRMS0547	1936	0.62

Note: Long-term rates of mineral sediment accumulation, organic matter and vertical accretion derived from 137Cs data collected from LCA S&T Task II) can be found in Piazza et al. 2011).
Note: Plots of soil bulk density and organic matter content with depth at each CRMS site can be provided upon request.

Attachment B: Model codes (Relative Elevation Model)

B1: Pre-compaction Elevation Model for Coastal Louisiana (Batch version, FOTRAN 90/95)

```
PROGRAM PREM

! Batch version of the Pre-compaction Relative Elevation model (PREM) for coastal Louisiana
! Model Team: Wetland Morphology
!
! This program is for batch processing multiple Scenario (SLR + subsidence)-Grouping (resotration
projects) cases

implicit none
integer ::ncols,nrows,i,j,m,k,cellsize,nodata,basins(1000,1000),vegtypes(1000,1000), filenum,
sgnum,loopnum
integer::basinnum,periodnum,numbasins,numvegtypes,bmcode,om(10,10),yr,numyr,startyr,lastyr,s,outn
um, outnum2
integer::j1,j2,j3,j4,j5,fyr,simyr
integer::ierror, ierror1,ierror2,ierror3,ierror4,ierror5,ierror6

character(len=12)::chancols,chanrows,chaxllcorner,chayllcorner,chacellsize,chanodata
character(len=50)::filename,fn2,fnout, scenario,group,subfilename,subfn2
character(len=28)::nfnout1, nfnout2, nfnout3,nfnout4, nfnout5
character(len=8)::outsg(300)
character(len=4)::ci

real(kind=4)::xllcorner,yllcorner,dem(1000,1000),sedins(5,1000,1000),insedins(50,1000,1000)
real(kind=4)::subsidence(1000,1000),newinsedins(50,1000,1000),eslrlow(5),eslrmed(5),eslrhigh(5),bd(10,
10)
real(kind=4)::orgins(1000,1000),inorgins(50,1000,1000),accrate(50,1000,1000),elev(50,1000,1000)
real(kind=4)::sedins2(1000,1000),sedins3(1000,1000),sedins4(1000,1000),sedins5(1000,1000),eslr(5)
real(kind=4)::soc(50,1000,1000),dsoc(50,1000,1000),asoc(50,1000,1000),delev(50,1000,1000)
real(kind=4)::subslow(1000,1000),subsmed(1000,1000),subshig(1000,1000)


! ================== Part I: Read in data
=====================================================
! Read in unchanged files
! read in ESLR rates under low, medium and high scenarios (from OCPR management team)
open(100,file='ESLRall.txt',status='old', form='formatted',iostat=ierror1)
if(ierror1 /= 0) then
 print*, "failed to open ESLR file"
 stop
 end if

read(100,*) !read in header
!Read in ESLR for different periods to account for acceleration, also in mm/yr, need to convert to cm/yr
do m = 1, 5 !period for ELSR
 read(100, 790) periodnum, eslrlow(m),eslrmed(m),eslrhigh(m)
end do
```

```
 790 format(I8,3(F8.2))
 close(100)

!Read in subsidence rates under low, medium and high scenarios (from OCPR management team)
open(110,file='subfilelist.txt', status='old', form='formatted')
do s =601, 603 !three subsidence spatial data layers
 read(110,800) subfilename
 write(subfn2,800) subfilename
 800 format(A17)

 open(s,file=subfn2,status='old', form='formatted',iostat=ierror2)
 if(ierror2 /= 0) then
  print*, "failed to open Subsidence file"
  stop
  end if

 read(s,*) chancols,ncols
 read(s,*) chanrows,nrows
 read(s,*) chaxllcorner,xllcorner
 read(s,*) chayllcorner,yllcorner
 read(s,*) chacellsize,cellsize
 read(s,*) chanodata,nodata

 !Read in Subsidence rates (in mm/yr) need to convert to cm/yr
 if(s==601) then
  do i=1,nrows
   read(s,*) (subslow(i,j),j=1,ncols)
  end do

 else if(s==602) then
  do i=1,nrows
   read(s,*) (subsmed(i,j),j=1,ncols)
  end do

 else
  do i=1,nrows
   read(s,*) (subshig(i,j),j=1,ncols)
  end do

 end if ! end of readin different subsidence files
 close(s)

end do ! end of 3 sub files

!Read in topo/bath file
open(120,file='bathy0.asc',status='old', form='formatted',iostat=ierror3)
if(ierror3 /= 0) then
  print*, "failed to open the TOPO/Bathy file"
  stop
  end if

!Read in Regions grid
```

```
open(130,file='basins.asc',status='old', form='formatted',iostat=ierror4)
 if(ierror4 /= 0) then
  print*, "failed to open the Basins file"
  stop
  end if

!Read in vegetation types (from VEG team)
open(140,file='veg0.asc',status='old', form='formatted',iostat=ierror5)
if(ierror5 /= 0) then
  print*, "failed to open vegetation type file"
  stop
  end if

!Read header lines
read(120,*) chancols,ncols
read(120,*) chanrows,nrows
read(120,*) chaxllcorner,xllcorner
read(120,*) chayllcorner,yllcorner
read(120,*) chacellsize,cellsize
read(120,*) chanodata,nodata

read(130,*) chancols,ncols
read(130,*) chanrows,nrows
read(130,*) chaxllcorner,xllcorner
read(130,*) chayllcorner,yllcorner
read(130,*) chacellsize,cellsize
read(130,*) chanodata,nodata

read(140,*) chancols,ncols
read(140,*) chanrows,nrows
read(140,*) chaxllcorner,xllcorner
read(140,*) chayllcorner,yllcorner
read(140,*) chacellsize,cellsize
read(140,*) chanodata,nodata

! read the data
do i=1,nrows
   read(120,*) (dem(i,j),j=1,ncols) ! in meters
   read(130,*) (basins(i,j),j=1,ncols)
   read(140,*) (vegtypes(i,j),j=1,ncols)
end do
close(120)
close(130)
close(140)

!Read in calibrated BD/OM for each basin-marsh types (total 9basin* 8vegtypes = 72 groups)
open(150,file='bdomnew2.txt',status='old', form='formatted',iostat=ierror6)
if(ierror6 /= 0) then
  print*, "failed to open BD/OM file"
  stop
  end if
```

```
 read(150,*) !read in header
 numbasins   = 9
 numvegtypes = 8
!Read in BD/OM data for each basin/marsh types (total 72  groups), bd in g/cm3, om in %
 do i = 1, numbasins
  do j =1, numvegtypes
   read(150, 810) bmcode, bd(i,j), om(i,j)
  end do
 end do

 810 format(I10,2x,F8.2, 2x, I8)
 close(150)


!====================  Please change # of files in your inputfiles.txt for SEDIN files
====================
filenum = 50
sgnum = filenum/5 !scenario-group number
!=========================================================================================
====================

open(200,file='filenamenoext2.txt',status='old', form='formatted')
open(210,file='check.txt')

loopnum = 1000
outnum  = 0
do m = 1, sgnum !File loop starts!Note: 1)read files, 2) calculations, 3) outputs are all within this loop
******

 do k = 1, 5 !five period with 5 year interval (update sedin every 5 years)
  loopnum = loopnum + 1
  outnum = outnum + 1

  read(200,820) filename ! readin the name of the .asc files without .asc
  write(fn2,830) filename ! assign the filename with .asc for readin raw data

 820 format(A33)
 830 format(A33,'.asc')

 scenario = filename(1:3)
 group = filename(5:7)

 outsg(outnum) = filename(1:8) !for output filenames with different scenarios and groups

 !Decide what ESLR values to use
 if(trim(scenario)=='s11') then
  eslr(k) = eslrlow(k)
 else if(trim(scenario)=='s12') then
  eslr(k) = eslrmed(k)
 else
  eslr(k) = eslrhigh(k)
 end if
```

```
  write(210,840) scenario, outsg(outnum)
 !7300 format(A3, 2x, F8.3)
 840 format(A3, 2x, A8)

 !Determine which subsidence data to use
 do i=1,nrows
  do j = 1, ncols

   if(trim(scenario)=='s11') then
     subsidence(i,j) = subslow(i,j)
   else if(trim(scenario)=='s12') then
     subsidence(i,j) = subsmed(i,j)
   else
     subsidence(i,j) = subshig(i,j)
   end if

  end do
 end do


!Open sedin data from .asc files
 open(loopnum,file=fn2,  status='old', form='formatted',iostat=ierror)
  if(ierror /= 0) then
  print*, "failed to open the SEDIN ascii 1st part file"
  stop
 end if

 !Read header lines
 read(loopnum,*) chancols,ncols
 read(loopnum,*) chanrows,nrows
 read(loopnum,*) chaxllcorner,xllcorner
 read(loopnum,*) chayllcorner,yllcorner
 read(loopnum,*) chacellsize,cellsize
 read(loopnum,*) chanodata,nodata

 !Read the SEDIN data
 do i=1,nrows
  read(loopnum,*) (sedins(k,i,j),j=1,ncols) ! sedin
 end do

end do ! end of k (five periods)



! ======================== Part II: Calculations  Under each Scenario-Group case
=======================================

startyr  = 2010
lastyr   = 2035
 numyr   = lastyr - startyr !25 yrs

 do yr = 1, numyr
```

```
 do i=1,nrows
  do j =1, ncols

   !Only calculate for cells that are have Basin and Vegtype values not as -9999
   if(basins(i,j)/= -9999.AND.vegtypes(i,j)/= -9999) then
    elev(1,i,j) = dem(i,j)*100.0 !convert from meters to cm, NAVD88 HQ:has to use lower bound=1, not 0
as elev(0,i,j)

    ! Calculate Orgain input: ORGIN g/m2/yr
    if(yr <= 5) then
     insedins(yr,i,j) = sedins(1,i,j)
    else if(yr>5.AND.yr<=10) then
     insedins(yr,i,j) = sedins(2,i,j)
    else if(yr>10.AND.yr<=15) then
     insedins(yr,i,j) = sedins(3,i,j)
    else if(yr>15.AND.yr<=20) then
     insedins(yr,i,j) = sedins(4,i,j)
    else
     insedins(yr,i,j) = sedins(5,i,j)
    end if

     !Added 06222011: adding 1000 g/m2/yr from storm-related sediment accumulation throughout the
coast.
     !if insedins <0 e.g., CP, then add 1000 (newsedin = insedins + 1000), if newsedin >0, then estimate
Orgain from newsedin, if newsedin < 0, then =0
     !if insedins > 0 adding 1000 to (sedin + orgain), not estimating Orgain anymore.
     if(insedins(yr,i,j)<0.) then
      newinsedins(yr,i,j) = insedins(yr,i,j)+ 1000.
      if(newinsedins(yr,i,j)>0.) then
       inorgins(yr,i,j) = newinsedins(yr,i,j)* (om(basins(i,j),vegtypes(i,j))/100.0)/(1-(om(basins(i,j),
vegtypes(i,j))/100.0))

      else
       newinsedins(yr,i,j)= 0.
       !inorgins(yr,i,j) = newinsedins(yr,i,j)* (om(basins(i,j), vegtypes(i,j))/100.0)/(1-(om(basins(i,j),
vegtypes(i,j))/100.0))
       inorgins(yr,i,j) = 0.
      end if
      ! Calculate Accretion rates, cm/yr
      accrate(yr,i,j) = (1.0/10000.0)*(newinsedins(yr,i,j) + inorgins(yr,i,j))/bd(basins(i,j), vegtypes(i,j))

     else !insedins(yr,i,j)>0. as in AA and PB
      ! Calculate organic inputs from sedin
      newinsedins(yr,i,j) = insedins(yr,i,j)
      inorgins(yr,i,j) = newinsedins(yr,i,j)* (om(basins(i,j), vegtypes(i,j))/100.0)/(1-(om(basins(i,j),
vegtypes(i,j))/100.0))
      ! Calculate Accretion rates, cm/yr
      accrate(yr,i,j) = (1.0/10000.0)*(newinsedins(yr,i,j) + inorgins(yr,i,j)+1000.)/bd(basins(i,j),
vegtypes(i,j))

     end if
```

```
      ! Define the max. vertical accretion rate (cm/yr) based on field observation of long-term accretion
rate, 2.26 cm/yr (Rybcyzk, 2002)
      if(accrate(yr,i,j)> 2.26) then
        accrate(yr,i,j) = 2.26
      end if

      !Calculate accreted SOC or sequestred SOC (asoc) tC/ha/yr, below dsoc is based on elevation change
depth on potential of SOC gain/loss
       asoc(yr,i,j) = accrate(yr,i,j)*(bd(basins(i,j), vegtypes(i,j))*om(basins(i,j), vegtypes(i,j))/2.2) ! in tC/ha/yr

      ! Calculate Elevation
      ! For baseline scenario: low ESLR, low subsidence rate
      if(yr <= 5) then
       elev(yr+1,i,j)= elev(yr,i,j) + accrate(yr,i,j) - (eslr(1) + subsidence(i,j))/10. ! convert from mm to cm
      else if(yr > 5.AND.yr <= 10) then
       elev(yr+1,i,j)= elev(yr,i,j) + accrate(yr,i,j) - (eslr(2) + subsidence(i,j))/10.
      else if(yr > 10.AND.yr <= 15) then
       elev(yr+1,i,j)= elev(yr,i,j) + accrate(yr,i,j) - (eslr(3) + subsidence(i,j))/10.
      else if(yr > 15.AND.yr <= 20) then
       elev(yr+1,i,j)= elev(yr,i,j) + accrate(yr,i,j) - (eslr(4) + subsidence(i,j))/10.
      else
       elev(yr+1,i,j)= elev(yr,i,j) + accrate(yr,i,j) - (eslr(5) + subsidence(i,j))/10.
      end if
      ! calculating SOC use the new OM-OC factor: 2.2
       !soc(yr+1,i,j) = elev(yr+1,i,j)*(bd(basins(i,j), vegtypes(i,j))*om(basins(i,j), vegtypes(i,j))/2.2) ! in tC/ha

      ! if yr = 5, 10, 15, 20, 25, then calculate change in elevation and soc
       if(mod(yr*5,numyr)==0) then
         !dsoc(yr+1,i,j)  = soc(yr+1,i,j)- soc(yr+1-5,i,j) !tC/ha/5yr
         delev(yr+1,i,j) = (1./5.)*(elev(yr+1,i,j)- elev(yr+1-5,i,j)) !cm/yr
         dsoc(yr+1,i,j) = delev(yr+1,i,j)*(bd(basins(i,j), vegtypes(i,j))*om(basins(i,j), vegtypes(i,j))/2.2)
!tC/ha/yr
       else
         dsoc(yr+1,i,j)  = -9999
         delev(yr+1,i,j) = -9999
       end if

     ! no -9999 grid cells to calculate elevation
     else
       elev(yr+1, i,j)   = -9999
       soc(yr+1, i,j)    = -9999
       dsoc(yr+1, i,j)   = -9999
       delev(yr+1, i,j)  = -9999
       accrate(yr,i,j)   = -9999
       asoc(yr, i,j)     = -9999

     end if ! no -9999 grid cells to calculate elevation


     end do ! nclos
    end do  ! nrows
```

```
   end do !yr

end do ! end of m (number of scenario-group)

!  ====================================== Part III: Outputs
=============================================

outnum2 = 0
do m = 1, sgnum !File loop starts! scenario-group cases ============================

  yr = 0 ! used for output calculation results for each 500m cell
  do simyr = 2015, 2035,5
    yr = yr + 1
    fyr = 5* yr ! for count 5, 10, 15, 20, 25 years in calculations
   outnum2 = outnum2 + 1 ! for output filenames for that partiticular Scenario-Grouping
   j1 = simyr+(m-1)*35
   j2 = simyr+(m-1)*35 + 10000
   j3 = simyr+(m-1)*35 + 20000
   j4 = simyr+(m-1)*35 + 30000
   j5 = simyr+(m-1)*35 + 40000

    write(ci,905) simyr
    ! for output filenames
    nfnout1 = outsg(outnum2)//'V00_WLAelev_'//ci//'.asc' ! for elevation
    nfnout2 = outsg(outnum2)//'V00_WLAdelE_'//ci//'.asc' ! for change in elevation
    nfnout3 = outsg(outnum2)//'V00_WLAvacc_'//ci//'.asc' ! for vertical accretion
    nfnout4 = outsg(outnum2)//'V00_WLAdsoc_'//ci//'.asc' ! for SOC change by elevation change
    nfnout5 = outsg(outnum2)//'V00_WLAasoc_'//ci//'.asc' ! for SOC change by vertical accretion

    ! write the header lines for output files
    open(j1,file = nfnout1)
    write(j1,910) chancols,ncols
    write(j1,910) chanrows,nrows
    write(j1,920) chaxllcorner,xllcorner
    write(j1,920) chayllcorner,yllcorner
    write(j1,930) chacellsize,cellsize
    write(j1,940) chanodata,nodata

    open(j2,file = nfnout2)
    write(j2,910) chancols,ncols
    write(j2,910) chanrows,nrows
    write(j2,920) chaxllcorner,xllcorner
    write(j2,920) chayllcorner,yllcorner
    write(j2,930) chacellsize,cellsize
    write(j2,940) chanodata,nodata

    open(j3,file = nfnout3)
    write(j3,910) chancols,ncols
    write(j3,910) chanrows,nrows
    write(j3,920) chaxllcorner,xllcorner
    write(j3,920) chayllcorner,yllcorner
```

```
   write(j3,930) chacellsize,cellsize
   write(j3,940) chanodata,nodata

   open(j4,file = nfnout4)
   write(j4,910) chancols,ncols
   write(j4,910) chanrows,nrows
   write(j4,920) chaxllcorner,xllcorner
   write(j4,920) chayllcorner,yllcorner
   write(j4,930) chacellsize,cellsize
   write(j4,940) chanodata,nodata

   open(j5,file = nfnout5)
   write(j5,910) chancols,ncols
   write(j5,910) chanrows,nrows
   write(j5,920) chaxllcorner,xllcorner
   write(j5,920) chayllcorner,yllcorner
   write(j5,930) chacellsize,cellsize
   write(j5,940) chanodata,nodata

 905 format(I4)
 910 format(A5, 5x, I13)
 920 format(A9,F14.1)
 930 format(A8,I16)
 940 format(A12,I12)

 !write out the values for the parameters

   do i=1,nrows
     write(j1,950) (elev(fyr+1,i,j),j=1,ncols)
     write(j2,950) (delev(fyr+1,i,j),j=1,ncols) !deltaElev yr5-yr0
     write(j3,950) (accrate(fyr,i,j),j=1,ncols)
     write(j4,950) (dsoc(fyr+1,i,j),j=1,ncols) !deltaSOC yr5-yr0
     write(j5,950) (asoc(fyr,i,j),j=1,ncols) !accreted SOC at yr5

 950 format(999(F9.2))
   end do ! end of nrows


 end do ! end of simyr


end do ! end of m (number of scenario-group)
**************************************************************************


END PROGRAM PREM ! Simulations are finished.
```

B2: Program for processing Vegetation Team outputs for PREM (Batch mode, FORTRAN 90/95)

```
PROGRAM VEGCODE

! Batch version of processing vegetatino team outputs for Pre-compaction Relative Elevation model
(PREM) for coastal Louisiana
! Model Team: Wetland Morphology
!
! This program is used to convert veg team outputs (% of each 23 community classes for a 500m cell)
!     to 1) max%=dominant class, 2) regroup them into 8 classes: deltaic, fresh, intermediate, brackish
!     saline, swamp, water, other (upland forests etc.)
!     Deltaic type is only for AT and MR (not for other basins), reason is below (from Greg Steyer)
!     Deltaic is primarily a geomorphic classification with vegetation as an indicator, so no Deltaic
!     classes should be found in the Chenier Plain (CS, ME, TV).
!
! Note: Basin ID: 1=AT 2=BA 3=BS 4=CS 5=ME 6=MR 7=PO 8=TV 9=TE
!      Veg ID: 1=Deltaic 2=Fresh 3=Swamp 4=Intermediate 5=Brackish 6=Saline 7=Other 8=Water
!

implicit none
integer::ncols,nrows,i,j,cellsize,nodata,scellid(1100,1100),filenum,k,m,ierror,ierror2,basins(1100,1100)
integer::numcellid,numcomtypes,cellid(172250),comtype(400000),vegtype(400000),finalvegtype(1100,11
00)
character(len=40)::chancols,chanrows,chaxllcorner,chayllcorner,chacellsize,chanodata,filename,fn2,fnout
real(kind=4)::xllcorner,yllcorner,maxpct,compct(400000,25),smaxpct(400000)

!Define number of files that are needed to read, and open the .txt file with list of the .asc+ files
!      (e.g., S11_G05_V00_VLAVEG35.asc+) from veg output
!====================  Please change # of files in your inputfiles.txt ====================
filenum = 48
!==================================================================================
====

open(200,file='inputfiles.txt',status='old', form='formatted')
!open(700,file='check.txt')

!Read in Regions grid
open(210,file='newbasins.asc',status='old', form='formatted',iostat=ierror2)
 if(ierror2 /= 0) then
 print*, "failed to open the Basins file"
 stop
 end if

! read header lines
read(210,*) chancols,ncols
read(210,*) chanrows,nrows
read(210,*) chaxllcorner,xllcorner
read(210,*) chayllcorner,yllcorner
read(210,*) chacellsize,cellsize
read(210,*) chanodata,nodata

do i=1,nrows
```

```
  read(210,*) (basins(i,j),j=1,ncols)
end do


! ================================   Main program  =========================
do k = 1, filenum !File loop starts!

  read(200,800) filename ! readin the name of the .asc+ files without .asc+
  !write(700,800) filename
  write(fn2,810) filename ! assign the filename with .asc+ for readin raw data
  !write(700,810) fn2

  800 format(A20)
  810 format(A20,'.asc+')

 !Part I: Read in raw data ----------------------------------------
 !Open raw data from .asc+ files
  open(k,file=fn2,  status='old', form='formatted',iostat=ierror)
   if(ierror /= 0) then
   print*, "failed to open the veg ascii 1st part file"
   stop
  end if

  !Read header lines of ascgrid
  read(k,*) chancols,ncols
  read(k,*) chanrows,nrows
  read(k,*) chaxllcorner,xllcorner
  read(k,*) chayllcorner,yllcorner
  read(k,*) chacellsize,cellsize
  read(k,*) chanodata,nodata

  !Read the ascgrid cellid data
  do i=1,nrows
   read(k,*) (scellid(i,j),j=1,ncols) ! cellID in space
  end do

 !Read in ASC+ 2nd part: Table for % of each community class in a 500m cell
 !header of table
  read(k,*)

 !Read in 23 veg type %
  numcellid = 172240
  numcomtypes = 23

  do i = 1, numcellid

   read(k,*)
cellid(i),compct(i,1),compct(i,2),compct(i,3),compct(i,4),compct(i,5),compct(i,6),compct(i,7),compct(i,8),co
mpct(i,9),compct(i,10),&

&compct(i,11),compct(i,12),compct(i,13),compct(i,14),compct(i,15),compct(i,16),compct(i,17),compct(i,18
),compct(i,19),compct(i,20),&
```

```
  &compct(i,21),compct(i,22),compct(i,23)
!   Note: 23 community type codes from Veg team:1=BAREGRND 2=SPLAY 3=WAXM 4=CUTGR 5=MAID
6=THIN 7=SWAMP 8=CAT 9=SAWG 10=BULL 11=ROSEAU 12=WHIP
!         13=SCRUB 14=WIRE 15=PASP 16=BRACK 17=NEEDL 18=SALT 19=OYST 20=MANGR 21=WATER
22=SAV 23=NOTMOD
 end do

 close(k)

 !Part II: Reclassification of veg into 7 types used in PREM -----------------------
 do i = 1, numcellid
  maxpct = 0.

  do j =1, numcomtypes

   if(compct(i,j)>maxpct) then
    maxpct = compct(i,j)
    smaxpct(cellid(i)) = maxpct

    comtype(cellid(i)) = j

    if(j==2) then
     vegtype(cellid(i))= 51 ! Delta Splay
    else if(j==11) then
     vegtype(cellid(i))= 52 ! Roseau cane

    else if(j==3.or.j==4.or.j==5.or.j==6.or.j==8.or.j==9) then
     vegtype(cellid(i))= 2
    else if(j==7) then
     vegtype(cellid(i)) = 3
    else if(j==10.or.j==12.or.j==13) then
     vegtype(cellid(i))= 4
    else if(j==14.or.j==15.or.j==16) then
     vegtype(cellid(i)) = 5
    else if(j==17.or.j==18.or.j==19.or.j==20) then
     vegtype(cellid(i)) = 6
    else if(j==21.or.j==22) then !WATER & SAV recalssified as Water
     vegtype(cellid(i))= 8
    else
     vegtype(cellid(i)) = 7 !most BAREGRND, NOTMOD (types in Brady's veg 41 classes but not modeled in
Scott's model
    end if

   end if  !end of deciding maxpct

  end do ! end of #community type, j
 end do ! end of #cellid, i


 !Assign final veg type codes to each 500m cell
 do i=1,nrows
  do j =1, ncols
```

```
  if(scellid(i,j)/= -9999) then !within veg team's boundary

   if(vegtype(scellid(i,j))==51) then
    if(basins(i,j)==1.or.basins(i,j)==6) then !AT/MR
      finalvegtype(i,j)=1
    else
      finalvegtype(i,j)=2
    end if

   else if(vegtype(scellid(i,j))==52) then
    if(basins(i,j)==1.or.basins(i,j)==6) then !AT/MR
      finalvegtype(i,j)=1
    else
      finalvegtype(i,j)=4
    end if

   else ! other types
     finalvegtype(i,j) = vegtype(scellid(i,j))

   end if



  else ! outsinde veg team's boundary
   finalvegtype(i,j) = -9999
  end if  !


 end do  ! end of # of columns
end do    ! end of # of rows

!Part III: Prepare output filenames adding _4fill.asc  ------------------------
write(fnout,820) filename
820 format(A20,'_4fill.asc')

m = k+300
!Open files for output after reclassification
open(m,file =fnout, form='formatted')
 !write out header first for veg2 (Year 203602060) ascii
 write(m,910) chancols,ncols
 write(m,910) chanrows,nrows
 write(m,920) chaxllcorner,xllcorner
 write(m,920) chayllcorner,yllcorner
 write(m,930) chacellsize,cellsize
 write(m,940) chanodata,nodata

910 format(A5, 5x, I13)
920 format(A9,F14.1)
930 format(A8,I16)
940 format(A12,I12)
```

```
  ! Write out final veg type codes
  do i=1,nrows

    write(m,900) (finalvegtype(i,j),j=1,ncols)

  end do ! nrows

  900 format(999(I6))

  close(m)

end do ! end k (file loop)

END PROGRAM VEGCODE ! Simulations are finished.
```

B3: Program for calibrating soil bulk density (BD) using CRMS and LCA data (FORTRAN90/95)

```
PROGRAM calBD

! Calibrating of BD for the Pre-compaction Relative Elevation model (PREM) for coastal Louisiana
! Model Team: Wetland Morphology
!
! This program is for calibrating BD for different groups of basin/vegetation type combinations
! Calibration datasets from CRMS data and LCA S&T Task II

implicit none
integer :: group, groupnum,smpsize(50),i,bdcnt(50),totsize
integer::ierror1,ierror2,sizegroup
character(len=12)::bmgroup(50), site(50,250)
real(kind=4)::sedin(50,250),obsacc(50,250),bd,om(50),minrmse(50),sumdif2(50,250),dif2(50,250),
bestsimacc(50,250)
real(kind=4)::minfrac(50),organin(50,250),simacc(50,250),rmse(50,250),bestbd(50),bestom(50),simaccreti
onrate
real(kind=4)::totsumdif, absdif(200,2500), sumabsdif(200), mare(200),nonabsdif(200,2500),
sumnonabsdif(200), re(200),totmare
real(kind=4)::totalmare, totalre, avemare, avere

sizegroup = 33 !for crms

!Read in sample size for each basin-marsh group (total 12 groups from LCA Task II cores
!OPEN(11,file='lca_newveg_size.txt',status='old', form='formatted',iostat=ierror1)
OPEN(11,file='crms_rsveg_size3.txt',status='old', form='formatted',iostat=ierror1)
if(ierror1 /= 0) then
 print*, "failed to open newveg_size.txt file"
 stop
 end if
read(11,*)

 do group = 1, sizegroup
  read(11,100) groupnum, smpsize(group)

 end do
```

```
 100 format(I10, I10)

!Read in SEDIN g/m2/yr and observed vertical accretion rate (cm/yr)

OPEN(12,file='crms_rsveg_sedinobsacc3.txt',status='old', form='formatted',iostat=ierror2)

if(ierror2 /= 0) then
 print*, "failed to open lca_newveg_sedinobsacc.txt file"
 stop
 end if

read(12,*)

!Open a file for checking readins
open(21,file ='out_crms_calbdom_final3.txt', form='formatted')
write(21,*) 'group, basinmarsh, simcnt,rmse,bestbd,bestom'

open(23,file ='out_crms_bestBDOM_simACC_final3.txt', form='formatted')
write(23,*) 'group, basinmarsh, bestbd, bestom'
write(23,*) 'site,bestsimacc,obsacc'

open(25,file ='out_crms_bestBDOM_error_final3.txt', form='formatted')
write(25,*) ' group, bmgroup(group),mare(group),re(group)'

do group = 1, sizegroup
 do i = 1, smpsize(group)
  read(12, 102) groupnum,bmgroup(group), site(group,i), sedin(group,i), obsacc(group,i)
 end do
end do
102 format(I10, 2(A10),F10.0,F10.2)


! Main program
 do group = 1, sizegroup

  bdcnt(group) = 0
  minrmse(group) = 100.

  do bd = 0.04, 1.5, 0.01 ! Bulk density from smallest to largest in the region

   bdcnt(group) = bdcnt(group) + 1
   sumdif2(group,bdcnt(group)) = 0.

   do i = 1, smpsize(group)

     call bdom(sedin(group,i),bd,simaccretionrate)
     simacc(group,i) = simaccretionrate

    dif2(group,bdcnt(group))=(obsacc(group,i) - simacc(group,i))**2
    sumdif2(group,bdcnt(group)) = sumdif2(group,bdcnt(group)) + dif2(group,bdcnt(group))

   end do ! sample size within a group
```

```
    rmse(group, bdcnt(group)) = sqrt(sumdif2(group,bdcnt(group))/smpsize(group))

    if( rmse(group, bdcnt(group)) < minrmse(group)) then

      minrmse(group) = rmse(group, bdcnt(group))
      bestbd(group) = bd
      bestom(group) = 100.2*exp(-4.7828*bestbd(group))

    endif

  end do ! tested BD range

   write(21,200) group, bmgroup(group), bdcnt(group),minrmse(group),bestbd(group),bestom(group)
  200 format(10x,I5, A15,I5,3(F10.4))


 end do ! groups

!Write out best BD/OM corresponding simulated and observed vertical accretion rates for plot

 totalmare = 0
 totalre  = 0
 do group = 1, sizegroup
  write(23,*) group, bmgroup(group), bestbd(group), bestom(group)

  do i = 1, smpsize(group)
   call bdom(sedin(group,i),bestbd(group),simaccretionrate)
   bestsimacc(group,i) = simaccretionrate
   write(23, 202) site(group,i),bestsimacc(group,i),obsacc(group,i)
   ! calculate mean absolute relative error (MARE)
   absdif(group,i) = abs(bestsimacc(group,i)/obsacc(group,i)-1)
   nonabsdif(group,i) = bestsimacc(group,i)/obsacc(group,i)-1

   sumabsdif(group) = sumabsdif(group) + absdif(group,i)
   sumnonabsdif(group) = sumnonabsdif(group) + nonabsdif(group,i)

   202 format(A15,2(F10.2))

  end do !sample size in a group

    mare(group) = sumabsdif(group)/smpsize(group)
    re(group) = sumnonabsdif(group)/smpsize(group)
    totalmare = totalmare + mare(group)
    totalre = totalre + re(group)

   write(25,204) group, bmgroup(group),mare(group),re(group)
  204 format(I10,A15,2F10.2)

 enddo !# of groups

  avemare = 100*totalmare/sizegroup
  avere   = 100*totalre/sizegroup
```

```
 write(25,*) 'ave MARE% =',avemare,'ave RE%=', avere

end program calBD


! ====================  Subroutine ========================
subroutine bdom(insed,inbd,simaccretion)
 implicit none
 real::insed,inbd,ompct,minfraction,inorgan,simaccretion

 ompct = 100.2*exp(-4.7828*inbd)
 if(ompct >100.) then
 ompct = 99.9
 endif

 minfraction = 1-ompct/100.
 inorgan = insed*ompct/100./minfraction
 simaccretion = (insed+inorgan)/10000./inbd

end subroutine bdom
```

Attachment C: Model codes (Landscape Change Sub-model)

Marsh Collapse (loss) and land building (gain) "If, then" statements (Example from moderate scenario)**:**

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Forested Wetland AND Mean Salinity(t2)<=5.5ppt) THEN Do not flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Forested Wetland AND Mean Salinity(t2)>5.5ppt AND Mean Water Level (t2)<Elev(t2)) THEN Do not flag for loss ,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Forested Wetland AND Mean Salinity(t2)>5.5ppt AND Mean Water Level (t2)>=Elev(t2)) THEN flag for loss ,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Fresh Marsh AND Mean Salinity(t2)<=7.0ppt) THEN Do not flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Fresh Marsh AND Mean Salinity(t2)>7.0ppt AND Mean Water Level (t2)<Elev(t2)) THEN Do not flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Fresh Marsh AND Mean Salinity(t2)>7.0ppt AND Mean Water Level (t2) >=Elev(t2)) THEN flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Intermediate Marsh AND (Mean Water Level (t2)-0.3436m)<=Elev(t2)) THEN Do not flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Intermediate Marsh AND (Mean Water Level (t2)-0.3436m)>Elev(t2)) THEN flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Brackish Marsh AND (Mean Water Level (t2)-0.2278m)<=Elev(t2)) THEN Do not flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Brackish Marsh AND (Mean Water Level (t2)-0.2278m)>Elev(t2)) THEN flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Saline Marsh AND (Mean Water Level (t2)-0.2050m)<=Elev(t2)) THEN Do not flag for loss,

(IF Land_Water_Flag(t2)==Land AND Vegetation_Type(t2)==Saline Marsh AND (Mean Water Level (t2)-0.2050m)>Elev(t2)) THEN flag for loss,

(IF Land_Water_Flag(t2)==Water AND Elev(t2)<=Mean Water Level (t2))THEN Do not flag for gain

(IF Land_Water_Flag(t2)==Water AND Elev(t2)>Mean Water Level (t2))THEN Flag for gain