LONG TERM MORPHOLOGIC MODELLING OF DELTA DEVELOPMENT IN BRETON SOUND RESULTING FROM A PROPOSED DIVERSION STRUCTURE

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BACKGROUND

Sediment deprivation, hydrologic alteration, subsidence, sea level rise, and saltwater intrusion have been causing significant land loss in coastal Louisiana. Breton Sound combined with the nearby Barataria Bay, and Mississippi River Delta have lost approximately 1800 square kilometers (or 447,000 acres) of land, representing one of the highest land loss rates in the world since the 1930s when the Mississippi River was leveed. To address this problem, the Coastal Protection and Restoration Authority (CPRA) initiated several sediment diversion projects in the Lower Mississippi River (LMR). The Mid-Breton Sediment Diversion (MBrSD) project is one of the costal restoration projects proposed to restore natural processes in Breton Sound, which can strategically re-establish hydrologic flows, carry land-building sediments, nourish marshes and sustain land.

The MBrSD Project is intended to divert sediment-laden water from the river into Breton Sound to build and sustain land (project location shown in Figure 1). The proposed diversion is located at Jesuit Bend which is at approximately River Mile 68 in the LMR. The bend has a large point bar on the east side at Will's Point to which the proposed intake is to be connected. The hydraulic, sediment transport, and morphology dynamics in the bend are complex and feature strong secondary flows and large sand wave movements.

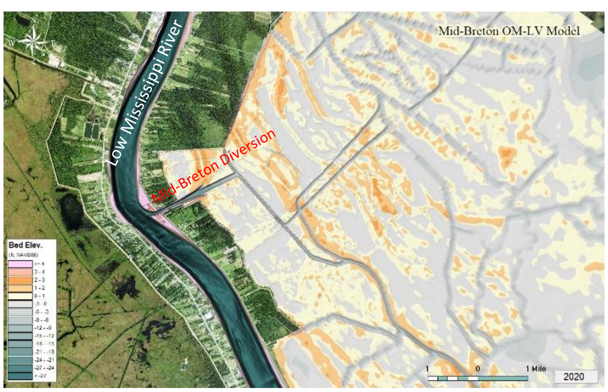

Figure 1 - Location of Mid-Breton Sediment Diversion Project with the Existing Bathymetry

Baird has provided hydrologic and hydraulic support to the engineering design for the Mid-Breton Sediment Diversion Project. The designed conveyance capacity is expected to reach 50,000 cfs for a river flow of 1,000,000 cfs. This paper focuses on prediction of delta development resulting from the proposed diversion project using a coupled modeling system to simulate hydrodynamics, sediment transport, morphodynamics, and vegetation/wetland growth and collapse in 50-year engineering life. Inclusion of vegetation dynamics in the model is necessary to appropriately evaluate the delta development in the receiving basin since it impacts hydrodynamics, sediment transport, and morphologic evolution including vertical accumulation of particulate organic matter (POM). These processes ultimately affect the diversion performance in terms of conveyance capacity and sediment delivery. The objective of the model development is to evaluate the long-term morphologic development caused by the diversion in Breton Sound over 50 years.

MODEL DEVELOPMENT

The model is primarily a coupling of the Delft3D Outfall Management (OM) model and a vegetation/wetland model (LaVegMod.DM, Visser et al. 2013), hereafter referred to as the OM-LV model. The coupled model consists of four model components and many linkages for data exchange between components (see Figure 2).

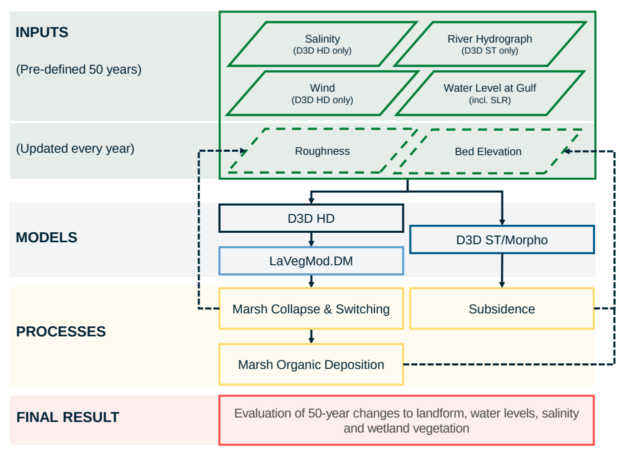

Figure 2 - The OM-LV Model Framework and Data Flows

The Delft3D hydrodynamic (HD) model is used to simulate water levels, currents, and salinity driven by the diverted flow, tides, winds, and sea level rise. The model generates input data such as inundation state and salinity level in vegetation growth seasons for the LaVegMod.DM model. Due to the difference in time scale and driving forces, the HD model is separate from the OM model to speed up the simulation.

The Delft3D OM model is used to simulate sediment transport and bed change in the receiving basin associated with the diversion. The morphological acceleration technique is applied to speed up the simulation. The output of bed change is used to build the bathymetry in the receiving basin for the next model year.

The LAVegMod.DM model is used to simulate the growth of vegetation in the receiving basin. The output of vegetation coverage and its associated physical characteristics are used to modify bed roughness which is used as input for the Delft3D HD and OM models.

The Wetland Morph model is used to simulate marsh organic deposition and marsh collapse and switching. The output of marsh organic deposition is integrated with the bed change simulated by the OM model to construct the bathymetry for the next model year. The output of marsh collapse and switching is used to modify the vegetation coverage and bed roughness.

The OM-LV model works with two systems (primary and secondary) operating in parallel using multiple personal computers. The primary system controls the OM model and vegetation models (LaVegMod.DM, Marsh Collapse, and POM Accretion). The secondary system controls the Delft3D HD simulations. The two systems communicate to feed information back and forth on an annual basis since the hydro-statistics from the Delft3d HD model runs are required for the LaVegMod.DM model, and the updated bathymetry from the models operating on the primary system is then required for the next year's Delft3D HD runs. An overview of the OM-LV model parallelism is shown in Figure 3.

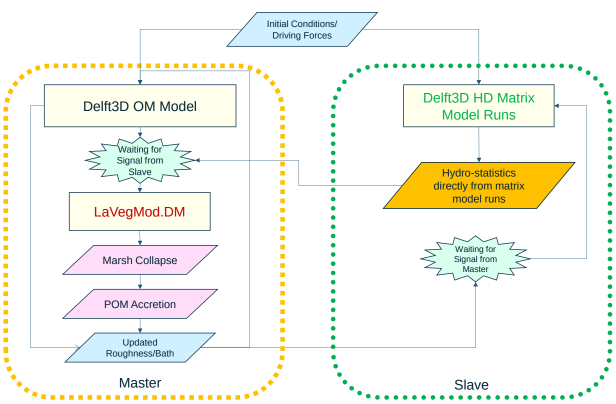

Figure 3 - Parallelism of the OM-LV Coupled Model Using Multiple Computers

MORPHOLOGY

The morphological component of the OM-LV model is a curvilinear grid Delft3D model covering Breton Sound, the proposed diversion structure, and part of the Lower Mississippi River. Morphological acceleration (referred to as Morfac in the Delft3D model) is applied to reduce computational time, varying from values of 40-80 based on river flows. Lower Morfac values are used for large flow conditions, and the higher Morfac values are selected for low flow conditions. Nine sediment classes are used in the model, ranging from clay to sand, and multiple sediment types are used to define both the Mississippi River and Breton Sound bed sediment with the erodibility data derived from flume testing of sediment cores. Subsidence and sea level rise (SLR) are also considered in the morphological simulation. The rate of sea level rise was provided by CPRA, which equates to 0.50 m and 1.5 m of sea level rise by 2050 and 2100, respectively, with the 1992 sea level as the baseline. In addition, a series of 14 extensive field survey campaigns have been conducted over three years to support model development and calibration, including ADCP surveys, iso-kinetic water sampling of suspended sediment concentration, bed sediment grab samples, multibeam hydrographic surveys, and boreholes in Breton Sound.

Vegetation impacts in the morphology model are considered using the trachytope functionality of Delft3D. The Baptist 2 method in Delft3D (Baptist, 2005) was applied to increase the bottom roughness to indirectly account for the flow resistance caused by the presence of vegetation. Additionally, a negative source term to the momentum equation is included to account for the drag forces caused by vegetation. It is important to include the vegetation impacts to model the morphologic change more accurately.

HYDRODYNAMICS

The hydrodynamic simulations use a matrix approach to increase computational efficiency. It works by running 'short bursts' of hydrodynamic runs with an array of driving forces including river inflows, winds, and tides that cover the full range of tide variation for the year. This model also includes SLR. The results of the shorter HD runs are interpolated between to obtain a representation of the full-year time series which are used to generate the yearly hydro-statistics. These include the annual average water depth, annual standard deviation of stage height, mean annual salinity, and locations where salinity levels surpass a threshold value. This information is passed back to the LaVegMod.DM model which simulates vegetation growth.

VEGETATION

The vegetation growth and wetland morphological component of the OM-LV coupled model consists of three parts: LaVegmod.DM, marsh collapse, and POM deposition. The LaVegmod.DM is a vegetation growth model created as part of a suite of modeling tools for the 2012 Coastal Master Plan (Peyronnin et al. 2013). The model is spatially explicit and predicts changes in the composition of vegetation at a grid cell over time in response to the changes caused by the diversion such as water depth and salinity (Visser et al., 2013). Seven different vegetation types are included: fresh, intermediate, brackish, and saline marsh types. The resulting vegetation change is then modified to consider the possibility of marsh collapse caused by inundation stress and salinity. Lastly, the POM module adjusts the mass of the sediment layer and updates bathymetry by estimating POM accretion. The resulting vegetation coverage and bathymetry is then applied to the next year morphology and hydrodynamic Delft3D runs.

50-year OM-LV model runs were performed by using the hydrograph measured at Belle Chasse in the LMR from 1968 to 2018. Time series of incoming sediment load from the LMR was developed and used as the boundary conditions for sediment transport simulation. The model results were generated every year over 50 years. The outputs include predicted bed elevations, top layer sediment fraction, and vegetation fraction.

RESULTS & DISCUSSION

The OM-LV model was used to evaluate the performance of the sediment diversion in terms of conveyance capacity and sediment delivery to support design. Over the 50 years, the vegetation in the floodplain near the diversion transforms as delta distributaries are developed shaping the landscape and sediment transport pathways. These pathways result in some areas having land gain (such as natural levees along the new and developing distributaries), raising the elevation sufficiently to host vegetation whereas others become submerged. Vegetation coverage in Breton Sound after 50 years of model simulation is shown in Figure 4.

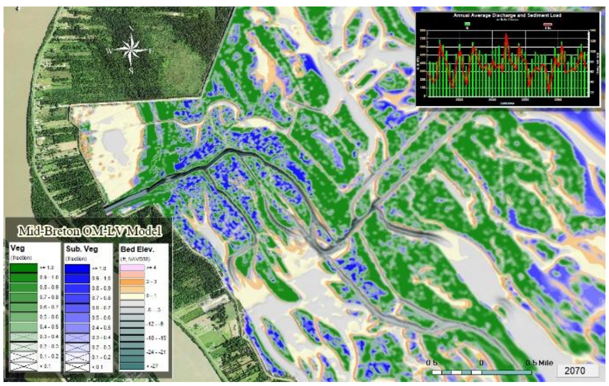

Figure 4 – Predicted Vegetation in Breton Sound After 50 Years of the Operation of the Sediment Diversion. Green Colors from Transparent Light to Dark Indicates the Fraction of Vegetation from 0% to 100%. The Blue Colors from Transparent Light to Dark Indicate the Fraction of Submerged Vegetation from 0% to 100%

The predicted bed elevation at the end of 50 years is shown in Figure 5. The comparison to the existing bathymetry as shown in Figure 1 reveals the bed changes. The main morphological changes include two distributary channel developments to the southeast of the diversion, the main one merging with the Oak River channel. These distributaries also connect to an existing channel to the south of the diversion, intersecting the Oak River channel and running northeast. These two main channels, one running south and the other intersecting a channel running northeast, act as the two main distributaries pathways for flow and sediment coming from the diversion.

Lastly, the depositional location of sand, silt and clay is shown in Figure 6. Clay is distributed the furthest from the diversion, reaching all the way to the ocean boundary of the model, whereas the sand is deposited within 4.8 kilometers of the diversion and the silt within 40.2 kilometers. About 82% of diverted sediment was trapped in the model domain while about 55% of diverted sediment contributed to the delta development.

In conclusion, the OM-LV model is used to simulate the delta development in the Breton Sound as a result of the MBrSD Project. Model results indicate that the diversion will contribute to land gain to combat the effects of subsidence and sea level rise. Sensitivity testing was completed to evaluate uncertainty associated with the model projections due to several factors, including future hydrograph and sediment load in the LMR, soil characteristics and erodibility parameters, vegetation parameters such as stem height, density and drag coefficient, and the rate of sea level rise.

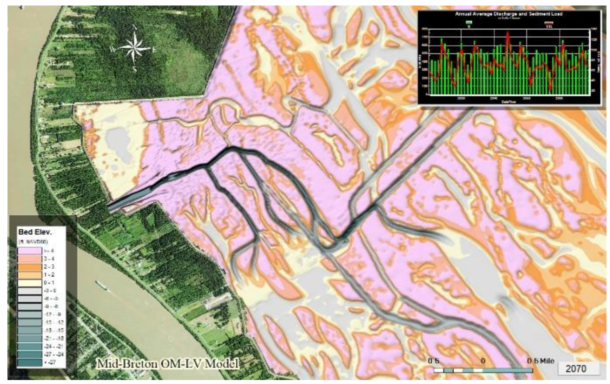

Figure 5 – Predicted Bed Elevation and Delta Distributary Development in Breton Sound after 50 Years of the Operation of the Sediment Diversion

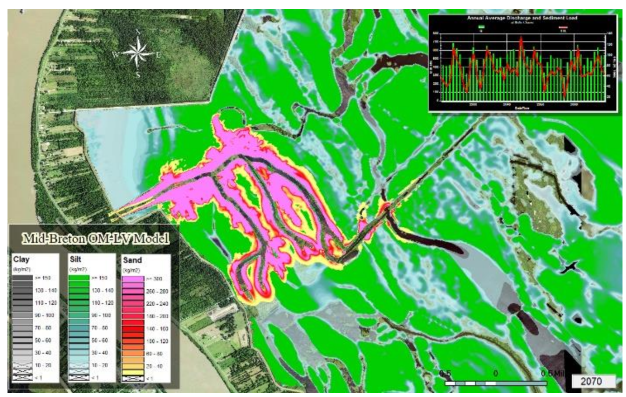

Figure 6 – Deposition Location of Sand, Silt, and Clay in Breton Sound after 50 Years of the Operation of the Sediment Diversion

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