A Comprehensive Modeling System for Mid-Breton Sedimentation Diversion Project (Oral Presentation)

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Abstract

To address the problem of large-scale land loss in coastal Louisiana caused by sediment deprivation, hydrologic alteration, subsidence, sea level rise and saltwater intrusion, 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. Various numerical models were developed to support the development of the diversion design. The models include 1D/2D hydraulic models, 3D hydrodynamic models and CFD models. This paper describes the development of the comprehensive model system to support the diversion design.

Introduction

Background

The MBrSD Project is intended to divert sediment-laden water from the river into Breton Sound to build and sustain land. 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, large sand wave movements, and underwater slope sliding.

Numerical modeling is one of the primary approaches used in support of engineering design and was used to determine the design criteria, to evaluate structure performance, and to assess localized flooding, scour, debris and sedimentation impacts. Several models are utilized for this project due to the complexity of the environment and dynamic forcing mechanisms.

Two primary goals of the modeling system are to develop an understanding of the physical conditions and processes at the study site in conjunction with the field investigations which are described in the other paper (Quan *et al*, 2022) and to evaluate how the existing site conditions and processes will change with the implementation of the proposed project.

Modeling Framework

The model system consists of the six model components: a) a river model (MC01) to primarily provide a boundary condition for the other models and to evaluate the impact of diversions and sea level rise (SLR) on the river water level; b) three-dimensional (3D) numerical models (MC02) with high grid resolution to evaluate structure performance, potential river impacts, and to optimize the design; c) 3D computational fluid dynamic (CFD) model (MC03) to evaluate the performance of structure design with very high grid resolution; d) physical model (MC04) to independently evaluate numerical model findings and support the structure design, as required; e) 2D/3D outfall management (OM) model (MC05) to predict the delta development, and f) a storm surge model (MC06) to evaluate the impact of diversion on flooding in the receiving basin and to generate the design wave and water level conditions within the conveyance channel for design (Baird 2021).

Model Development and Calibration

All these model components were progressively developed with the design phases and the progress of field surveys (Quan *et al*. 2022). The development of each model component, including model calibration and validation is described below:

MC01

The MIKE21 model was used for the river model (MC01) from Baton Rouge to the Gulf of Mexico in the LMR. The MIKE21 model was calibrated and improved throughout the project phases using the water level profiles at gages along the river and currents measured at the project site. Overall, the model performs well with an average root mean squared error of 0.26 ft based on the results at all gages (Figure 1).

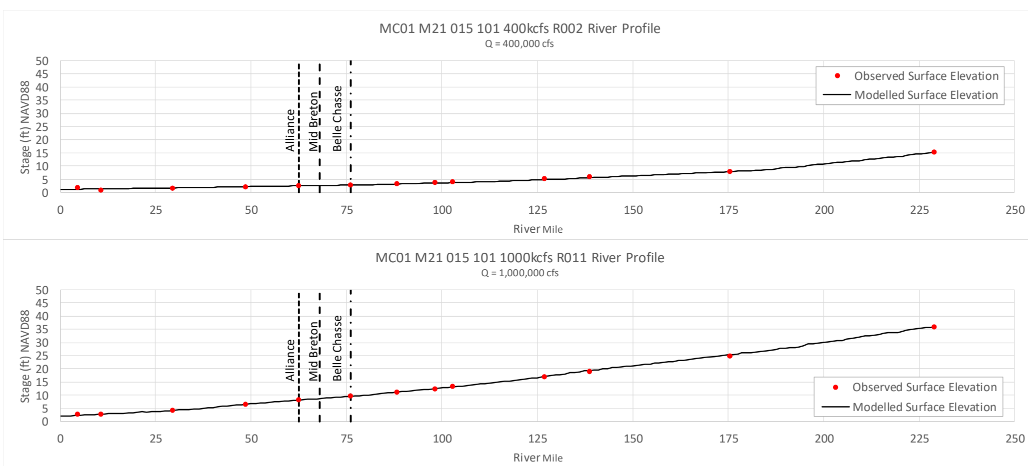

Figure 1. Comparison of water level profile in the river for 400,000 cfs and 1,000,000 cfs

A one-dimensional (1D) and two-dimensional (2D in delta) HEC-RAS model was also developed for internal quality control review. The model domain for the HEC-RAS model is the same as the MIKE21 model. The HEC-RAS model was calibrated and validated against measured water levels along the river under the different river flow conditions. Both HEC-RAS and MIKE21 models reproduced well water levels measured in the LMR.

MC02

MC02 in the model system is a high-resolution 3D model used to simulate hydrodynamics and sediment transport in the river and through the diversion channel. Both MISED (a Baird in-house model) and Delft3D models are used for this model component to better understand the model uncertainty. Both MISED and Delft3D were calibrated and validated against measured currents and suspended sediment concentration in the LMR and were able to reproduce the current speeds, secondary flow, and suspended sediment concentration measured in the field reasonably well (Figure 2).

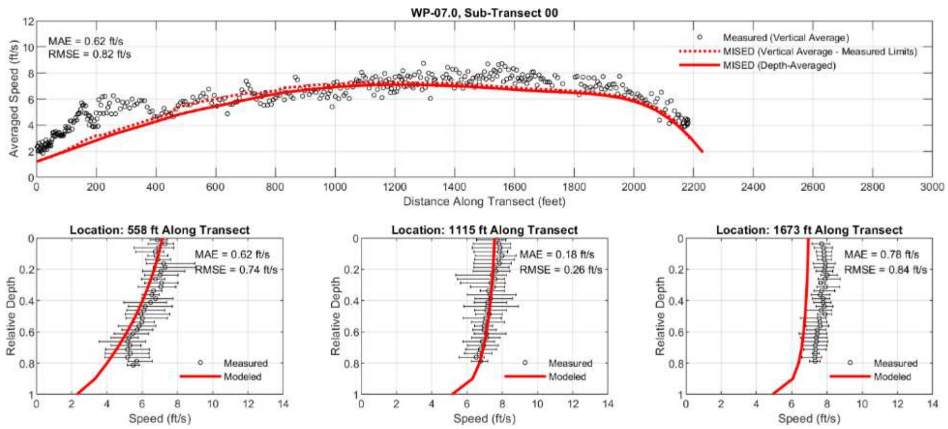

Figure 2. Velocity calibration plot by MISED

More detailed morphological calibration for a longer period was conducted in the 30% design phase. The findings showed both the MISED and Delft3D models cannot simulate the bed forms on the point bar, which are important features in point bar morphodynamics; therefore, the models cannot simulate the fluctuation in bed elevation due to sand wave movement. Therefore, a simplified model, the Box Mass Balance (BMB) model, was developed. The RUNOUT module was built into the BMB to simulate the lateral sediment transport caused by the underwater sliding. The model was calibrated against the measured bed change (Figure 3).

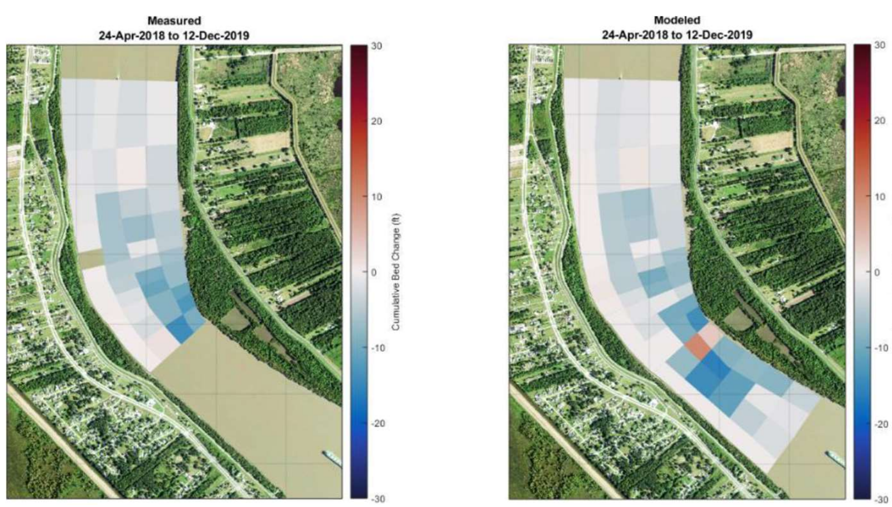

Figure 3. Comparison of measured cumulative bed change (left) with the bed change predicted by the BMB model (right) in the period from April 2018 to December 2019.

MC03

MC03 is a CFD model used to confirm the conveyance capacity estimated by the MC02 models (MISED and Delft3D) and to support the design of the diversion structure components (i.e. intake, gates, conveyance channel, and outfall) to identify any flaws in the design and to provide detailed design criteria (flow speeds and loads). In the 5% design phase, the CFD model was tested by using the FLOW3D model which was selected for this model component. In the 15% design phase, the FLOW3D model was calibrated and validated with the flow measurements from the 2019 events. The model has been used to support the design and provide the boundary conditions for the physical model.

MC04

MC04 is the physical model. Baird provided the support on physical modeling tests in terms of physical model domain determination, quality control review, data supply for open boundary conditions, etc. Two physical models with the horizontal scale of 1:65 and 1:20 were developed by Alden and have been used for gate structure design, riprap stability tests, head loss estimation, and sedimentation dynamics.

MC05

The purpose of MC05 is to estimate the delta development resulting from the diversion design over a 50-year period and the near-field tailwater conditions in Breton Sound to use as a boundary condition in the MC02 and MC03 models. MC05 consists of several coupled models to simulate hydrodynamics, sediment transport, morphodynamics, and vegetation/wetland growth and collapse. 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).

In the 30% phase, the OM-LV model was calibrated and validated against the field data in the receiving basin. Many sensitivity tests were performed to evaluate the Delft3D model performance of hydrodynamic and morphological responses to the vegetation change. Multiple parameters in the LAVegMod model (vegetation model) were tested to understand the ecological response to the diversion.

MC06

MC06 is a storm surge model used to simulate the rise of water levels caused by a storm. The ADCIRC 2D model was used for storm surge simulation and STWAVE was used to generate wave parameters for design. These models have been used to support the design of riprap armoring needs on the Breton Sound side of the project feature and estimate wave loads on the downstream training walls and gates.

Conclusions

A comprehensive modeling system was developed to support the design of the Mid-Breton sediment diversion structure. The different components of the model system have been calibrated and validated with field measurements. The models have been vital to the assessment of design components and are also under continuous improvement through the progression of design phases.

References

Baird. 2021. Mid-Breton Sediment Diversion Project -Hydraulics and Modeling Assessment for 30%

Quan, Rebecca, Qimiao Lu, Matthew Hoy, and Robert Nairn. 2023. "Data Collection and Analysis in Support of the Mid-Breton Sediment Diversion Project." SEDHYD 2023 Conference.