MULTIDIMENSIONAL MODELING OF THE LOWER MISSISSIPPI RIVER

Ehab A. Meselhe, Associate Professor, Director, Center for Louisiana Inland Water Studies (CLIWS), University of Louisiana at Lafayette (ULL), Meselhe@louisiana.edu, 337-482-0613; Emad Habib, Assistant Professor, CLIWS, ULL, Habib@louisiana.edu; Alonso G. Griborio, Post-Doctoral Research Fellow, CLIWS, ULL, agg2377@louisiana.edu; Shankar Gautam, Research Associate , CLIWS, ULL, gautam@louisiana.edu; John A. McCorquodale, Chair Professor, Department of Civil Engineering, University of New Orleans, jmccorqu@uno.edu; Ioannis Y. Georgiou, Assistant Research Professor, Pontchartrain Institute for Environmental Sciences, University of New Orleans, igeorgio@uno.edu

Abstract

The Mississippi River (MR) is a major natural, economic, and industrial resource for the United States. Historically the MR was a major source of sediment, freshwater and nutrients to the entire Louisiana coast. However, since the installation of the MR flood protection levees, Louisiana's coastal wetlands have been deprived of practically all the sediment (about 220 million tons annually) that the river is transporting to the Gulf of Mexico (GOM). Therefore, alternative solutions to recover or re-direct portion of this massive amount of valuable sediment to benefit Louisiana's coast are currently being considered. In order for such effort to be successful, the impact of restoration projects on the River and on the surrounding wetland and water bodies should be considered. The project reported herein focuses on the supply side, namely, the River itself. Thus, the specific project goal was to develop a detailed and accurate numerical model for the portion of the Lower MR stretching from Tarbert Landing (TL) to Venice. The development of such a tool is a complicated and laborious task. It is being accomplished by using a suite of models with different spatial dimensions, i.e., 1-, 2- and 3-D; different methodologies; and different grid resolutions. After completion, the model will provide detailed information on the spatial and temporal patterns of the river's hydrodynamics, salinity, sediment and water quality parameters. Four numerical modeling systems with different methodologies were considered for the selection process, namely TELEMAC, H3D, ADCIRC, and ECOMSED. A thorough evaluation of these models was conducted using the Detroit River as a test case. Two models were selected, (1) H3D due to its accuracy and computational efficiency, and (2) TELEMAC due to its accuracy and flexibility to capture complex geometries. Additional criteria for selection were the ability to address stratification (thermal, propagation of salt wedge) and selected water quality parameters. Both models also employed the ability to simulate conservative and non-conservative tracers, sediment transport and basic water quality parameters. A one-dimensional model (using the MIKE 11 software) was also setup and calibrated for the MR from TL to Venice. The 1-D model along with the TELEMAC-2D model is being used to route water and sediment from Tarbert Landing to Bonnet Carré, and to other river locations. The entire year of 2003 was selected as calibration period. The comparisons between observed and predicted stages and discharges show a very good agreement. The root mean square errors (RMSE) for stages data at different locations range between 0.02 and 0.24 m, with a coefficient of efficiency between 0.98 and 1.00. Two dimensional and three dimensional models have been set up and calibrated for the River section from TL to Bayou Sara. The -2D and -3D TELEMAC model predictions are in very good agreement with observed water levels and ADCP discharge measurements. RMSEs are lower than 0.15 m and 1200 m^3/s for water levels and discharge, respectively. Two finite element grids were created, one from TL to Bonnet

Carré (BC) and the other from BC to the Gulf of Mexico. Models have been set up for these grids and are currently being evaluated. The H3D model is currently being set up, using a curvilinear-orthogonal grid for the lower section of the River between the Bonnet Carré spillway and the Gulf of Mexico; however results will not be presented in this paper.

INTRODUCTION AND BACKGROUND

There are many 1-D and 2-D models developed which have been successfully used for modeling the hydrodynamics for rivers. However, these models are limited when strong secondary current exist. In order to accurately predict the flow and sediment transport in regions where large pressure gradients are present, it is necessary to use fully non-hydrostatic hydrodynamic models. In recent years, several 3-D models have been developed, including some that incorporate sediment transport with mobile bed capabilities.

Ye and McCorquodale (1997a) developed a 3-D hydrodynamic and sediment transport model for the St. Clair River. The model, which is based on the model presented by Ye and McCorquodale (1997b, 1998a, 1998b), solves the equations of motion in curvilinear coordinates. The model was calibrated using Acoustic Doppler Current Profiler (ADCP) data from the Ontario Ministry of Environment (MOE) and the Detroit District Corps of Engineers. The sediment module was verified with data from bed sediment depth monitors and sediment traps. The 3-D model presented in Meselhe and Sotiropoulos (2000), Meselhe et al. (2000), and Meselhe and Odgaard (1998) is a high-resolution near-field model validated by three-dimensional velocity measurements both in the field and laboratory. The model solved the RANS equations and used the two-equation k-ε model for turbulence closure, applied on boundary fitted curvilinear coordinates. The model showed good ability to reproduce secondary motion. However these models are often limited to steady-state applications and are computationally extensive, therefore rendering their use inappropriate for large-scale and long-term simulations.

Another 3-D model is the Estuarine Coastal and Ocean Model (ECOM-SED) which originated from the Princeton Ocean Model (POM) and coupled hydrodynamic and wave models. For cohesive sediment, it accounts for the resuspension, aggregation and deposition. For noncohesive sediments, it uses van Rijn's sediment model (1984) for resuspension, Cheng's (1997) model for deposition and Karim and Holly's (1986) model for bed armoring process. Wang (2004) used CCHE3D for the simulation of the old river complex to study the three discharging channels that discharge excessive flow from Mississippi River to Atchafalaya River in the case of flooding. They modeled sediment transport in those channels to predict the effects to the Mississippi river main channel. The US Army Corps of Engineers applied CH3D to investigate maintenance dredging quantities for the channel alignment studies on the lower Atchafalaya River. The model can simulate the locations and quantities of sediment depositions. In this paper, the 3-D fully unsteady (hydrostatic and non-hydrostatic) numerical model, H3D (Stronach et al., 1993) is used to investigate the hydrodynamics and subsequent sediment transport of the lower Mississippi River from Braithewaite to West Pointe a la Hache.

MODEL DEVELOPMENT

Setup

The authors set up a 1-D model for the Mississippi River from Tarbert Landing to Venice. This 1-D model was developed using the Danish Hydraulic Institute's (DHI) product MIKE 11, and is being used along with a 2-D model (TELEMAC-) for routing water and sediment from Tarbert Landing to the Bonnet Carré spillway, and to other river locations as needed. This methodology was implemented to ultimately provide boundary conditions for the 3-D model developed for the lower portion of the River between the Bonnet Carré spillway and Venice. These models are also intended to be executed independently as needed to provide water levels and potential sediment quantities near a possible diversion structure for planning purposes; however, for detailed bed scour and deposition quantities, a 3-D model is more suitable. The 1-D MIKE 11 model consisted of cross sections spaced at approximately 500-ft intervals for the entire reach, which spans 300 miles. Each cross section was developed by re-sampling the original 50 m resolution river bathymetry. Two boundary conditions were implemented: 1. discharge was forced upstream water level downstream, and 2. water level was forced for both upstream and downstream. Results from the calibration from both boundary conditions are shown in the calibration section. Figure 1 shows the reach for MIKE 11 and two typical cross sections.

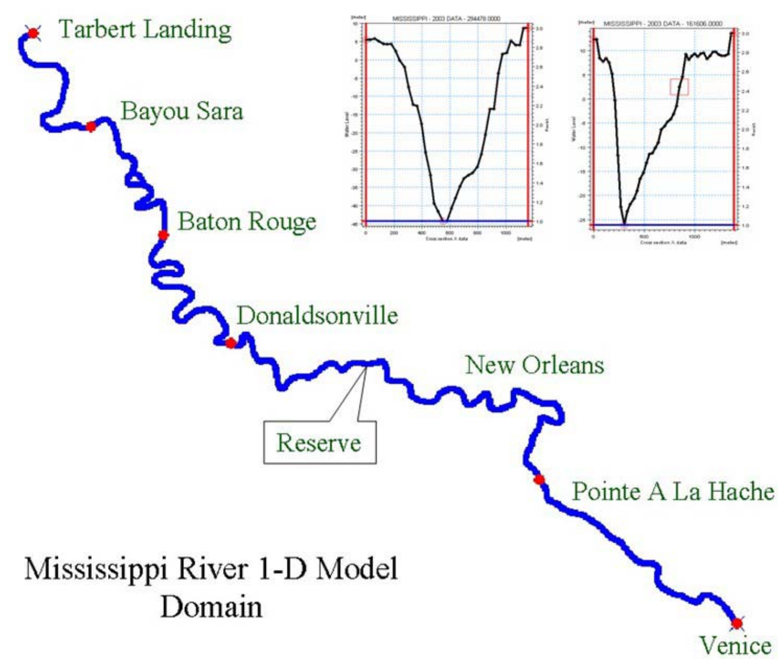

Figure 1 Computational domain for MIKE 11.

The sediment transport module for 1-D model was also activated to route sediment volumes to the other 2-D and 3-D models. Historical sieve analysis of the bed material conducted in the lower portion of the Mississippi River shows the river to be dominated by fine sand. Therefore one class of sediment is initially assumed in this study with the grain size d_{50} chosen to be 0.15 mm.

The 2-D model computational grid extends from Tarbert landing to the Bonnet Carre spillway, with typical in-channel and floodplain grid resolutions of 33 and 1000 meter, respectively. For testing and calibration, a smaller section was used where focused ADCP studies were conducted. The domain for this section was generated from Tarbert Landing to Bayou Sara, which is approximately 41 miles. Figure 2 (left) shows a plan view of the location of the application and Figure 2 (right) shows a segment of the unstructured computational domain in detail.

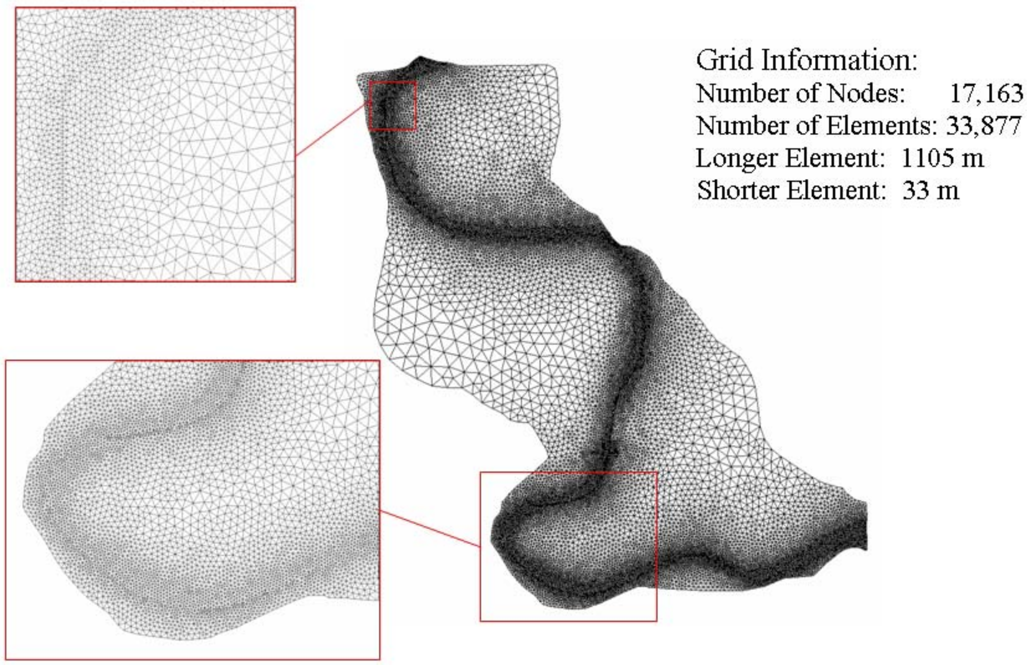

Figure 2 Mississippi River from Tarbert Landing to Bayou Sara.

Model Calibration and Validation

1-D Model

The entire year of 2003 was selected as calibration period. Measured water levels at Tarbert Landing and Venice were used as the upstream and downstream boundary conditions, respectively. The bed roughness was the main calibration parameter. It should be noted that the bed roughness was spatially variable, and was allowed to change with respect to flow velocity.

Comparisons between observed and predicted water levels and discharges are presented in Tables 1 and 2. Table 1 shows the model performance in predicting water levels at different locations, and Table 2 shows the comparison between observed and predicted discharges at Tarbert Landing. The results presented in these Tables indicate that the 1-D model is a useful tool for routing water to downstream locations.

Table 1 Model performance in predicting water levels.

Location	RMSE (m)	Efficiency
Mississippi River at Red River Landing	0.0416	1.000
Mississippi River at Bayou Sara	0.1184	0.998
Mississippi River at Baton Rouge	0.1802	0.995
Mississippi River at Bonnet Carre	0.132	0.990
Mississippi River at New Orleans (Carrollton)	0.117	0.986
Mississippi River Near Braithwaite	0.229	0.951
Mississippi River at Alliance	0.150	0.932
Mississippi River at West Pointe A La Hache	0.064	0.981

Table 2 Model performance in predicting discharge at Tarbert Landing.

Average Observed Discharge (cms)	Average Simulated Discharge (cms)	RMSE (cms)	RMSE (%)	Efficiency	Peak Error (%)
13,820	14,527	1,056	7.64	0.972	4.46

The model results were also compared with the Acoustic Doppler Current Profiler (ADCP) measurements taken at St. Francisville in 2003, close to the Bayou Sara bend (see Figure 3). Figure 4 shows that there is good agreement between ADCP measurements and simulated discharge at low flows, but considerable differences are noticed at high flows. The main reason for the discrepancy is that at high flow, over-bank flow bypasses the ADCP measurement location.

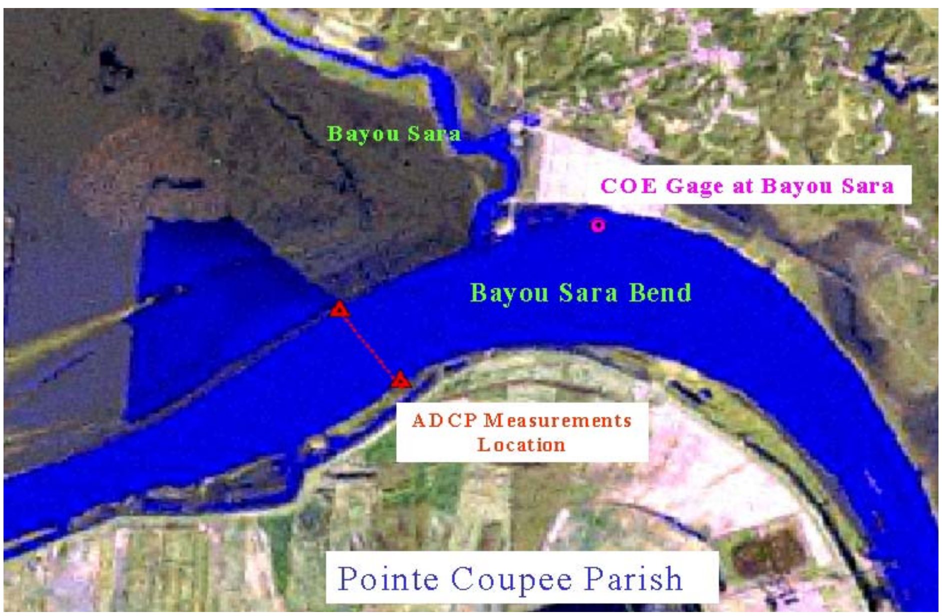

Figure 3 Location of ADCP measurements at St. Francisville.

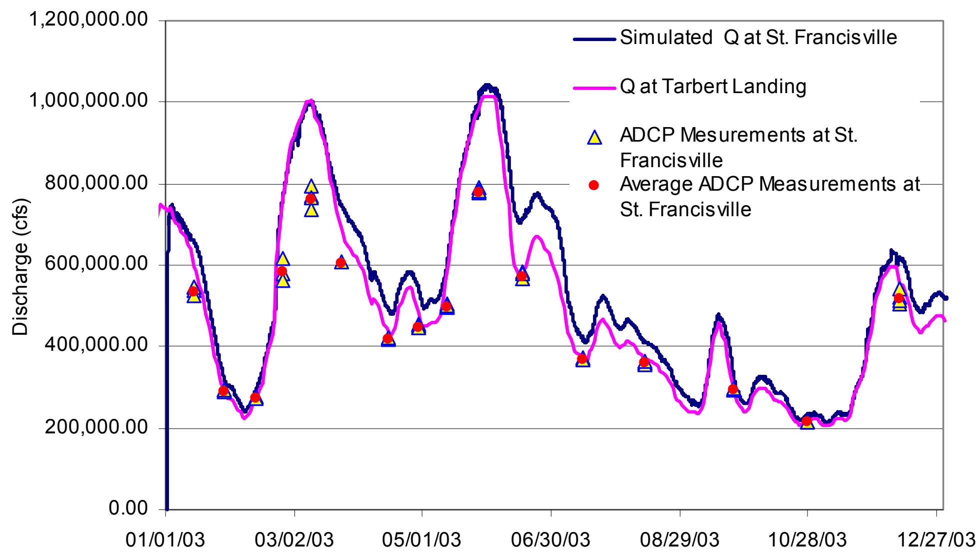

Figure 4 1-D Simulated and measured discharge at St. Francisville.

2-D Model

The 2-D simulations were performed using the TELEMAC-2D modeling system. Figure 5 shows the comparison between observed and simulated stages at the Red River gage location, and Figure 6 shows the comparison between the predicted discharge and the ADCP measurements at St. Francisville. The TELEMAC model predictions are in very good agreement with observed water levels and ADCP discharge measurements. Root-mean-square-errors (RMSEs) are lower than 0.15 m and 1200 m^3/s for stage and discharge, respectively. The 2-D model runs indicate that at high-flows there is a significant over-bank flow that bypasses the ADCP measurement location.

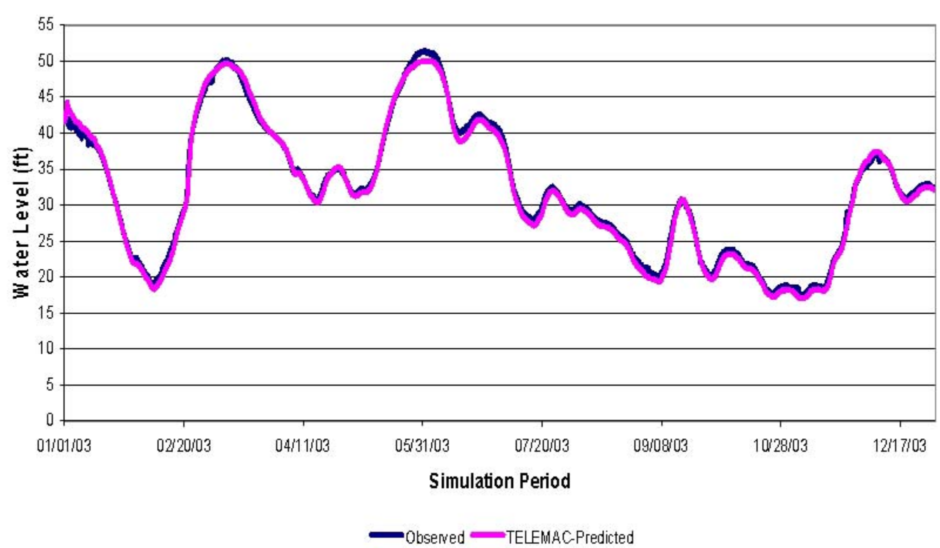

Figure 5 Observed versus predicted water levels at Red River using TELEMAC-2D.

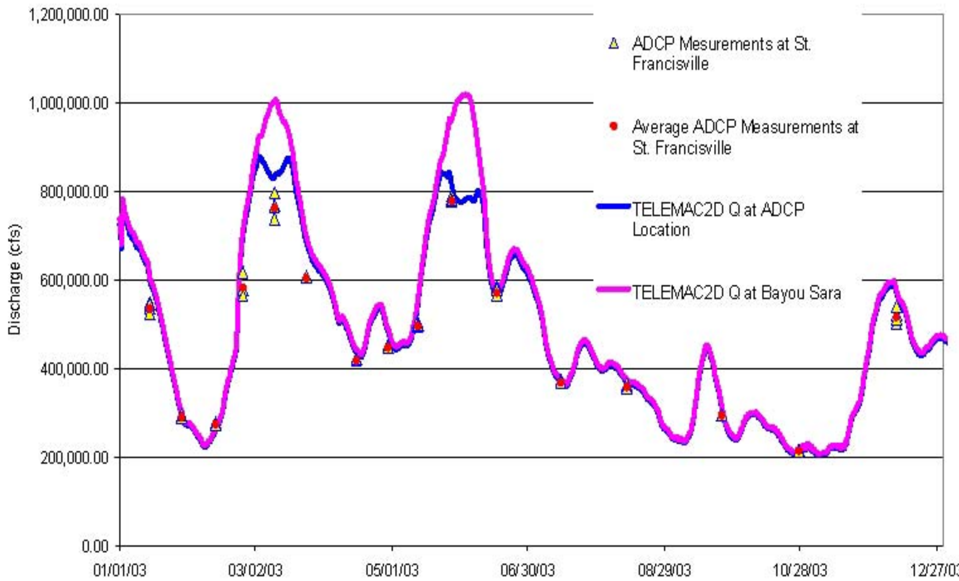

Figure 6 2-D Simulated and measured discharge at St. Francisville.

CONCLUSIONS

A 1-D model for the Mississippi River from Tarbert Landing to Venice was setup and calibrated. Statistical analyses performed on the model results indicate that this model is a useful tool for routing water to downstream locations as desired. Two and three dimensional models have been set up and calibrated for different portions of the rivers. The models show a good agreement between observed and predicted water levels and discharges. A 3-D model with a curvilinear-orthogonal grid (from Bonnet Carré to Venice), H3D, is currently also being calibrated for sediment transport. Initial results indicate fair agreement with respect to deposition and erosion patterns. Spatially varying roughness and the ability of the model to handle and transport multiple size classes is being investigated. Overall, the models have demonstrated that they can deliver a forecast of information related to discharge, water level, and sediment to the entire reach of the river from Tarbert Landing to Venice. This suite of one, two and three dimensional models can serve as a valuable tool for planning restoration efforts along the river, with delivery of information in a timely manner.

ACKNOWLEDGMENTS

The authors would like to thank the Governors Office of Coastal Activities, Louisiana (GOCA) for providing funding for this project. The appreciation is extended to the CLEAR program, and the Louisiana Oil Spill Program for providing supplemental support. Finally, the authors would like to share their appreciation to the New Orleans District Army Corps of Engineers and the US Geological Survey for sharing field data and other observations in the lower Mississippi River.

REFERENCES

Ye, J. and McCorquodale, J.A. (1997a). "3-D Hydrodynamic and Mass Transport Model of the St. Clair River Near Sarnia". A Component Report of the Application of Computer Modelling and Biomonitoring Tools to Assist in Decision Making for the St. Clair River Area of Concern. Great Lake Institute for Environmental Research, Windsor, ON N9B 3P4.

Ye, J. and McCorquodale, J.A. (1997b). "Three-dimensional Numerical Modelling of Mass Transport in Curved Channels," Canadian Journal of Civil Engineering, 24, pp 471-479.

Ye, J. and McCorquodale, J.A. (1998a), "Simulation of Curved Open Channel Flows by a 3-D Hydrodynamic Model," Journal of Hydraulic Engineering, ASCE, 124 (7).

Ye, J. and McCorquodale, J.A. (1998b), "A 3-D Hydrodynamic Model in Curvilinear Coordinates with Collocated Grid," International Journal of Numerical Methods in Fluids, 28, pp 1109 – 1134.

Meselhe E.A. and Sotiropoulos F. (2000), "Three Dimensional Numerical Model for Open Channels with Free Surface Variations," Journal of Hydraulic Research, IAHR, 38 (2).

Meselhe E.A., Weber L.A., Odgaard A.J., and Johnson T (2000), "Numerical Modeling for Fish Diversion Studies," Journal of Hydraulic Engineering, ASCE, 126 (5).

Meselhe E.A., and Odgaard A.J. (1998) "Three-Dimensional Numerical Flow Model for Fish Diversion Studies at Wanapum Dam," Journal of Hydraulic Engineering, ASCE, 124 (12).

van Rijn, L.C. (1984), "Sediment Transport Part II. Suspended Load Transport," Journal of Hydraulic Engineering, ASCE, 110, pp 1613-1641.

Cheng, N.S., (1997), "Simplified settling velocity formula for sediment particle," Journal of Hydraulic Engineering, ASCE, 123(2), pp149-152.

Karim, M.F. and F.M. Holly, Jr. (1986), "Armoring and sorting simulation in alluvial rivers," Journal of Hydraulic Engineering, ASCE, 112, pp 705-715.

Wang, S. (2004). Capabilities of CCHE3D hydrodynamic and transport model: application.

Stronach, J.A., Backhaus, J.O., and Murty, T.S. (1993), "An update on the numerical simulation of the waters between Vancouver Island and the mainland: the GF8 model", Oceanography and Marine Biology Annual Review, 31, pp 1-86.