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Coastal and Hydraulics Laboratory

US Army Corps
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Brunswick Harbor Numerical Model

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Abstract

The Brunswick area consists of many acres of estuarine and marsh environments. The US Army Corps of Engineers District, Savannah, requested that the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, develop a validated Adaptive Hydraulics model and assist in using it to perform hydrodynamic modeling of proposed navigation channel modifications. The modeling results are necessary to provide data for ship simulation. The model setup and validation are presented here.

Contents

Figures and Tables

Figures

Tables

Preface

The model investigation presented in this report was authorized and funded by the US Army Corps of Engineers, Savannah District, under Project P2 465055, Funding Account Code K6219288, AMSCO Code 465055, MIPR W33SJG92845079.

The work was performed at the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL), Vicksburg, MS. Direct supervision was provided by Dr. Cary A. Talbot, Chief, Flood and Storm Protection Division, and Mr. David P. May, Chief, River and Estuarine Engineering Branch.

At the time of publication of this report, Mr. Keith Flowers was Deputy Director, ERDC-CHL, and Dr. Ty V. Wamsley was Director.

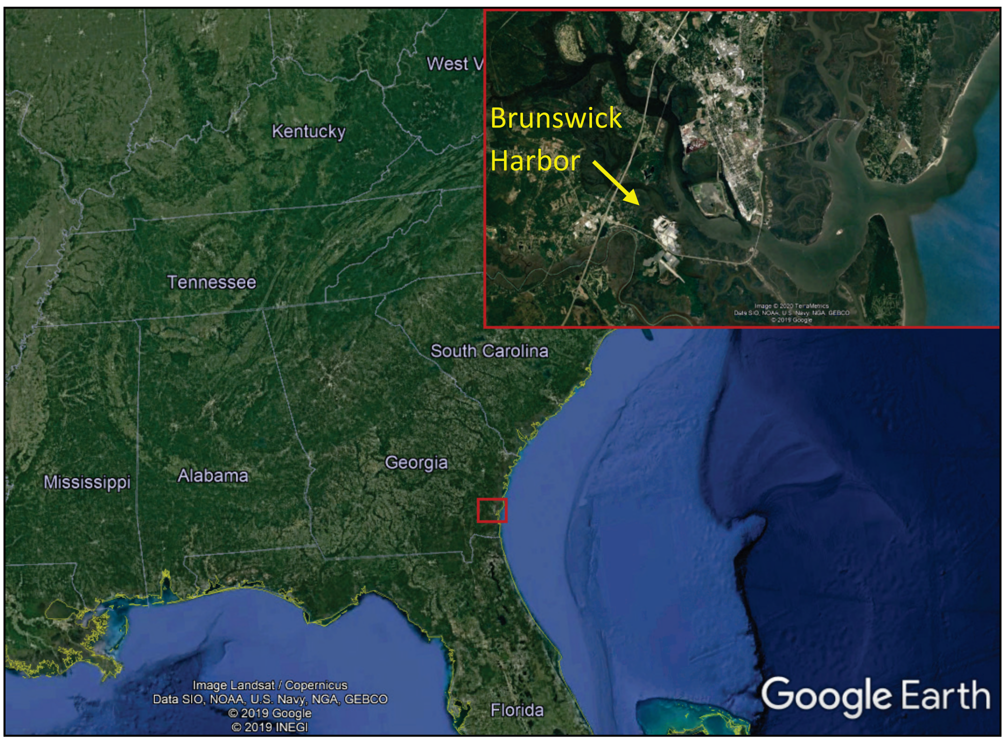
COL Teresa Schlosser was Commander of ERDC, and Dr. David W. Pittman was Director.

1 Introduction

1.1 Background

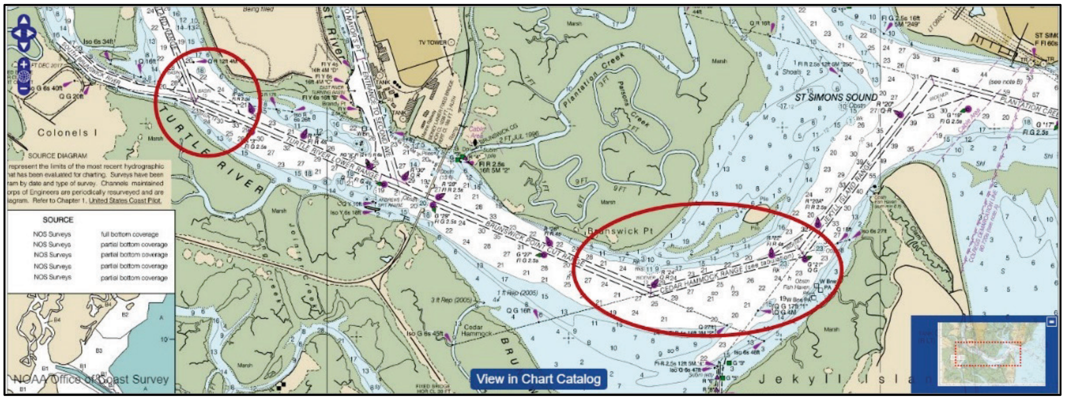
Brunswick Navigation Channel and Harbor is used primarily for the import of new vehicles by Roll On – Roll Off (Ro/Ro) ships. Additionally, cargo ships transport wood and agricultural products through the Brunswick channels. The harbor is located on the southeast Georgia coast of the United States (Figure 1).

Figure 1. Brunswick harbor location map.



A physical model of shoaling in the area was documented in 1981 (Letter and McAnally 1981). Recently, studies of dredge material disposal use and bird habitat have been performed by the US Army Engineer Research and Development Center (ERDC), Environmental Laboratory (Guilfoyle and Fischer 2011). However, there is no documentation of recent studies of the navigation in the channels and harbor area. Cargo vessels continuously grow in size, straining the navigation channels they use to reach port. The Brunswick Harbor area receives large Ro/Ro ships transporting new vehicles. These vessels are required to make a sharp turn after entering the channel and then turn to back into the port (Figure 2). Simulating these maneuvers through a modeling effort will allow ship pilots to determine appropriate conditions for transit of various vessel characteristics.

Figure 2. Areas of proposed channel modification (circled).



1.2 Objective

Ship pilots have brought up concerns about the ease of transit in some reaches of the navigation channel. The Savannah district of the United States Army Corps of Engineers (USACE) requested that the ERDC Coastal and Hydraulics Laboratory (CHL) build and validate a hydrodynamic model of the area and assist district engineers in running the model for proposed channel modifications. The modeling results are necessary for ship simulation testing at the ERDC Ship-Tow Simulator. The model setup and validation are documented.

1.3 Approach

A two-dimensional (2D) Adaptive Hydraulics (AdH) model was developed and validated for simulation of hydrodynamics — water surface elevation and velocity. The model was validated to available field data for all parameters and then utilized to test project alternatives. A field data collection effort was performed in July 2019 to collect discharge/velocity data at several locations.

Chapter 2 discusses the model development and boundary condition definitions for the hydrodynamic model. Chapter 3 documents the model-to-field data comparisons for water surface elevation, velocity, and discharge. Chapter 4 provides the conclusions of this numerical model investigation.

2 Model Development

A numerical model was developed to analyze potential modifications of the Brunswick Navigation Channel. The model was developed such that the natural driving forces of the system are included — winds, tides, and friction effects. The model results are compared to field data collected during the simulation period to ensure an accurate representation of the conditions in the navigation channel.

2.1 Numerical code

AdH is the numerical model code applied for the simulations in this study (Savant et al. 2014; Savant and Berger 2015). AdH is a finite element code that is capable of simulating three-dimensional (3D) Navier-Stokes equations, 2D and 3D shallow water equations, and groundwater equations. AdH can be used in a serial or multiprocessor mode on personal computers and high-performance computing systems. AdH can refine the domain mesh in areas where more resolution is needed at certain times due to changes in the flow conditions and then remove the added resolution when it is no longer needed to minimize computational burden. The code also includes automatic time-step adaption, as needed. AdH can simulate the transport of conservative constituents such as dye clouds and sediment transport when used with SEDLIB, which is coupled to bed and hydrodynamic changes. This code has been applied to model riverine flow (Bell et al. 2017; Clifton et al. 2017) estuarine circulation (Tate et al. 2009; McAlpin et al. 2013), and sediment transport (Sharp et al. 2013; Heath et al. 2015; Letter et al. 2015).

For this study, the 2D shallow water module of AdH is applied for all simulations. This code solves for depth and depth-averaged velocity throughout the model domain (more details of the 2D shallow water module of AdH and its computational philosophy and equations are available in Savant et al. [2014] and Savant and Berger [2015]). AdH version 4.6 was applied for this study.

2.2 Mesh development

The model domain was determined using aerial images and bathymetric/topographic data for the area. The Surface Water Modeling System was used to generate a 2D surface mesh and define material regions for applying specific model features, such as bed roughness. The domain is defined horizontally in Universal Transverse Mercator, zone 17 coordinates with units of meters. Vertically, it is based on NAVD88 units of meters. All data applied to the model are adjusted to this datum and coordinate system.

Bathymetry data for the model were obtained from several sources: sponsor-collected hydrographic surveys (Figure 3), the National Elevation Dataset (NED) (Figure 4) and the Coastal Relief Model (CRM) (Figure 5). These data sets were combined such that the latest data were made a priority as well as data collected at finer resolution. The 2D AdH code can include areas that wet/dry; therefore, elevations were included that do not remain wet during the simulation period.

Figure 3. USACE-collected bathymetry.

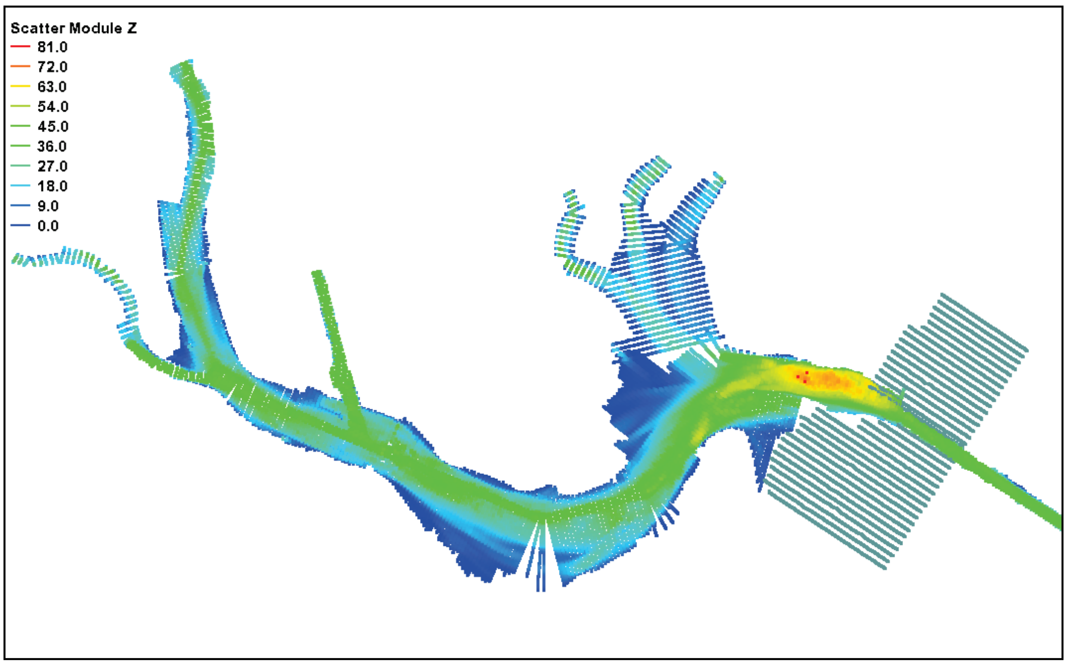


Figure 4. NED topography.

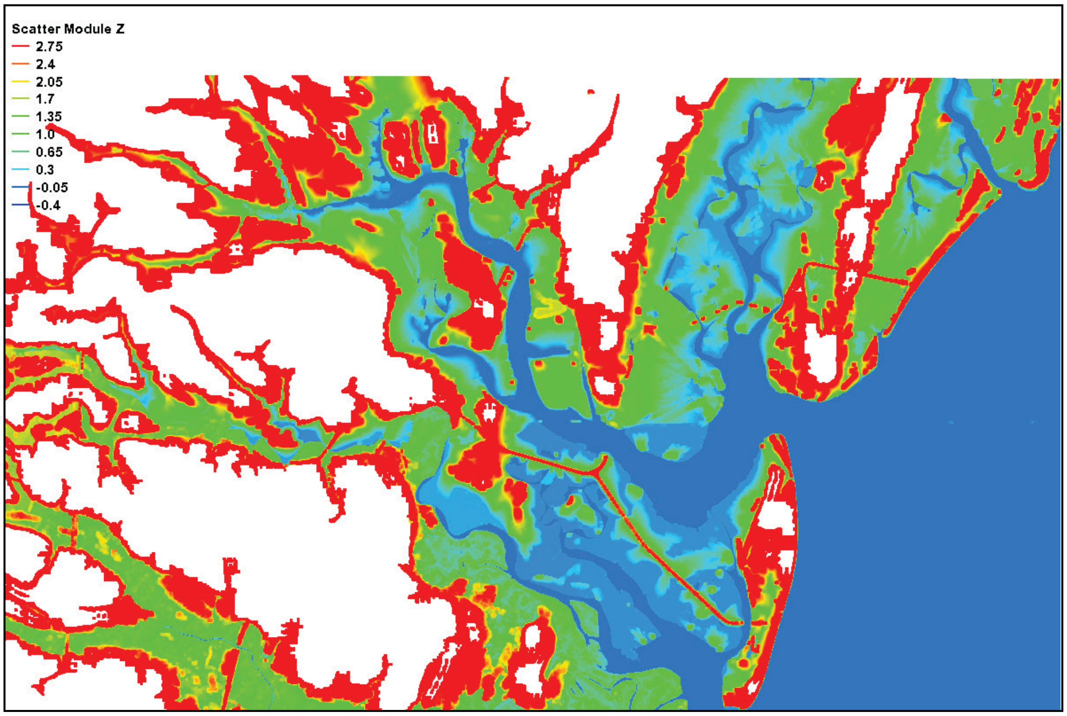
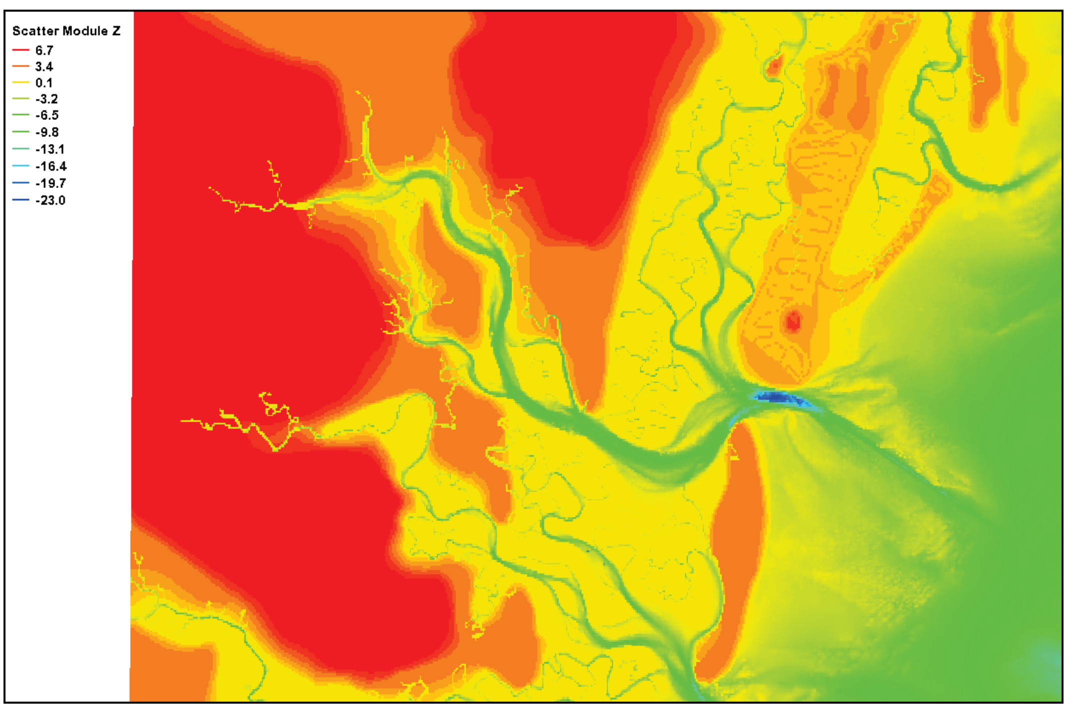
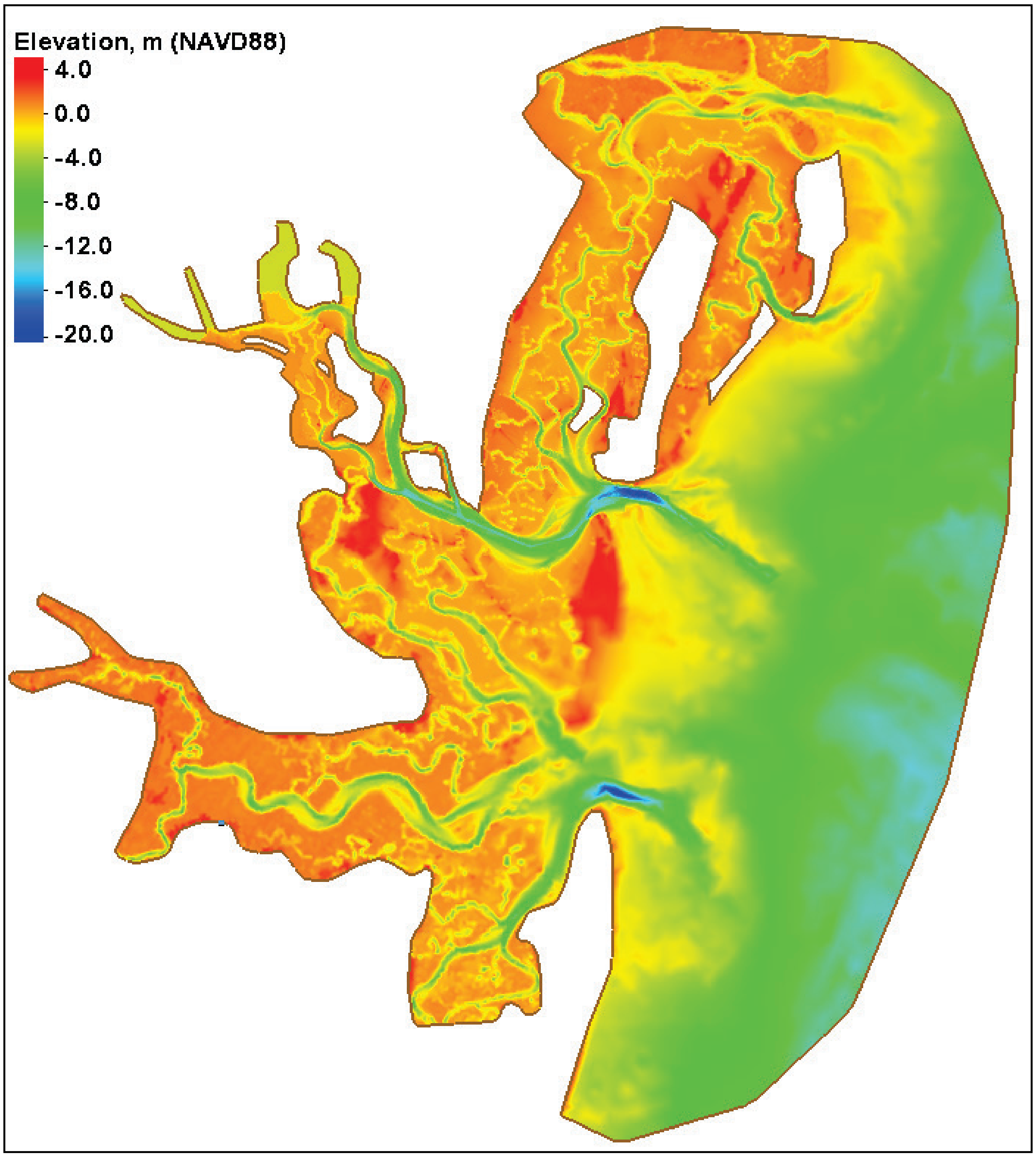


Figure 5. CRM bathymetry/topography.



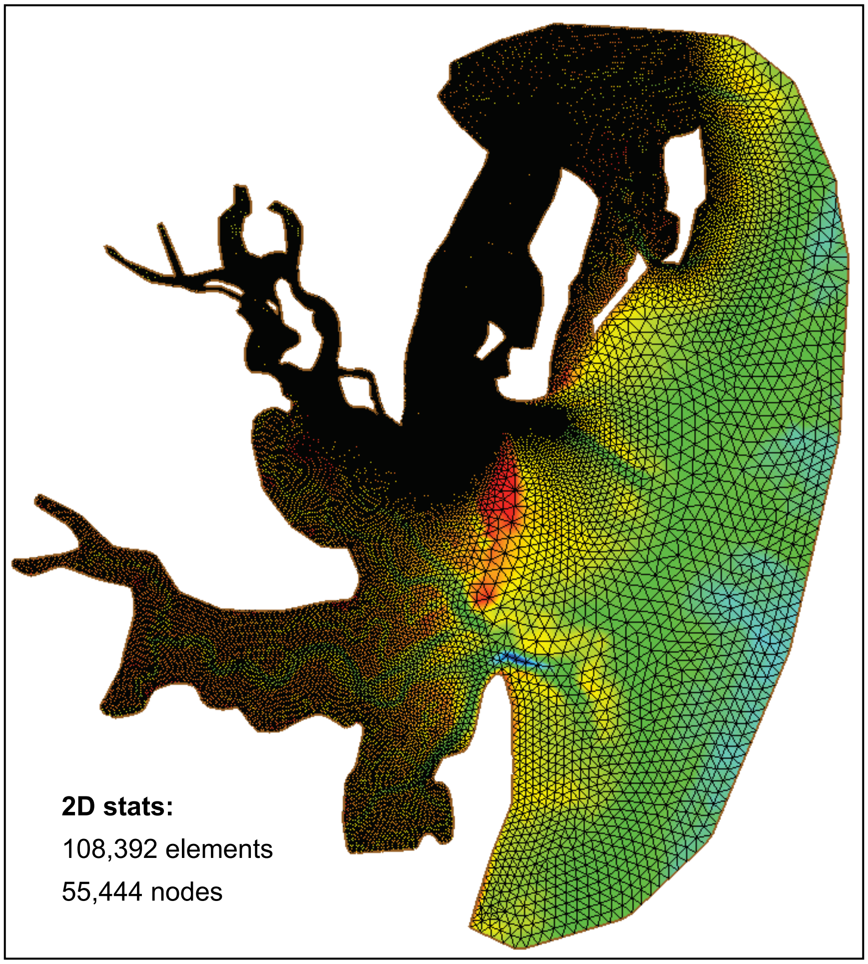
The model domain extents were based on aerial images and indicators of channel connectivity. This region is extremely marshy making accurate inclusion of tidal storage necessary to correctly represent the tidal exchange and velocity patterns. Sensitivity testing was performed on the domain size to ensure that the full area of influence was accounted for in the model. Figure 6 shows the model domain and bathymetry.

Figure 6. Model domain bathymetry.



The model domain includes approximately 620 mi^2,[1,2] extending 36.75 mi along the southern Georgia, Atlantic Ocean coastline. The 2D mesh contains 108,392 elements and 55,444 nodes. Figure 7 shows the horizontal mesh resolution for the model domain with a close-up image of the Brunswick Navigation Channel in Figure 8. Resolution is finest in the small wetland channels to accurately capture the conveyance of flow in these areas. Finer resolution is also seen in areas where geometric features need to be defined accurately, such as in the navigation channel.

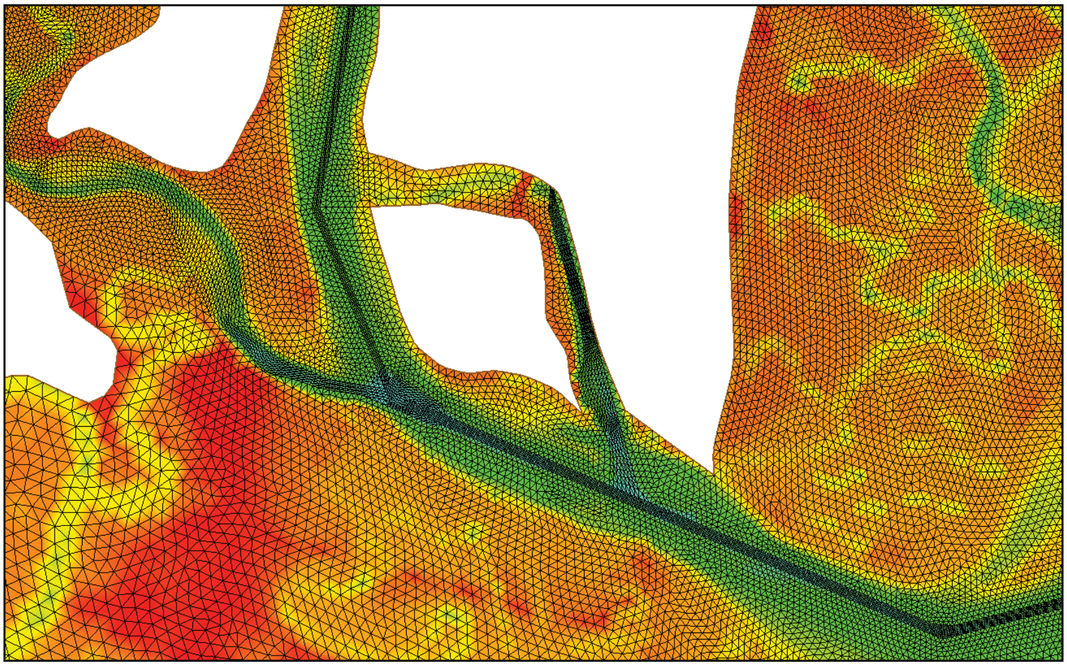
Figure 7. Mesh resolution.



[1] For a full list of the spelled-out forms of the units of measure used in this document, please refer to US Government Publishing Office Style Manual, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

[2] For a full list of the unit conversions used in this document, please refer to US Government Publishing Office Style Manual, 31st ed. (Washington, DC: US Government Publishing Office 2016), 345-7, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Figure 8. Brunswick Navigation Channel mesh resolution.



2.3 Boundary conditions

The boundary conditions for this study are set up in the typical manner for a numerical model study of this kind. Tidal water surface elevations are applied at the ocean boundary. Winds are included throughout the model domain. Since this area is predominantly a tidal storage region, riverine flow is extremely small and therefore not included in this model. The field data collection effort occurred in mid-July 2019; therefore, the model simulates the period 8–20 July 2019. The ship simulation will use steady state periods of maximum flood and ebb conditions that occurred during the simulation period. Note that this is not the peak period of maximum spring tide for this area. The typical maximum peak tide range is approximately 1.5 m higher than the maximum tide range during this simulation period. The velocity magnitudes will be larger during the maximum peak tide range period. This difference should be considered when performing ship simulation as the vessels will, at times, experience larger velocity magnitudes than those being tested with these results.

2.3.1 Tidal boundary condition

The tidal boundary condition was created using the US Geological Survey (USGS) gage at St. Simons Island at the inlet of the Brunswick River (Figure 9). Since this location is not at the model boundary, adjustments to the water level time series are made to account for any phase or amplitude changes that occur as the tide travels from the boundary to the gage location. For this model, the St. Simons Island elevation was shifted in time -0.5 hr and reduced in amplitude by 1.2% (Figure 10). The boundary tide elevation for the full simulation period is given in Figure 11.

Figure 9. St. Simons Island tide gage location.

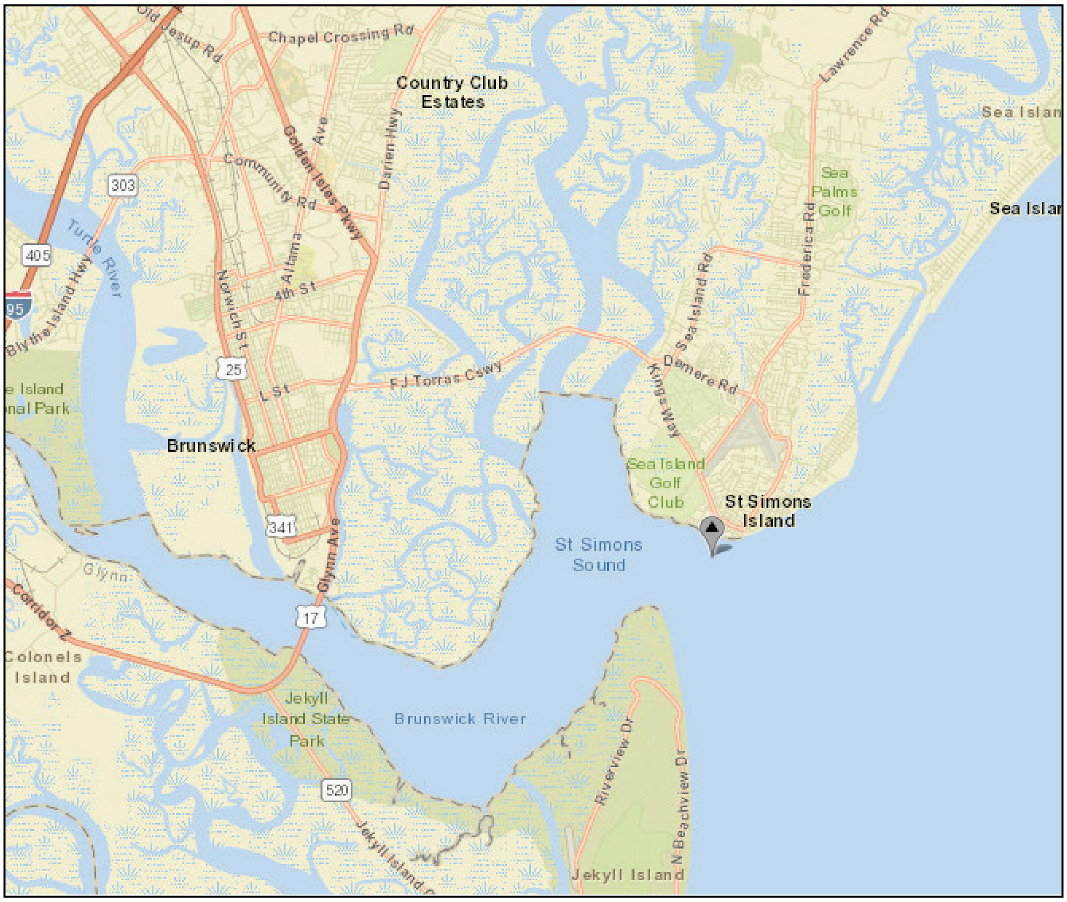


Figure 10. St. Simons Island data adjustment for tide boundary condition (0 hr = 1/1/2019).

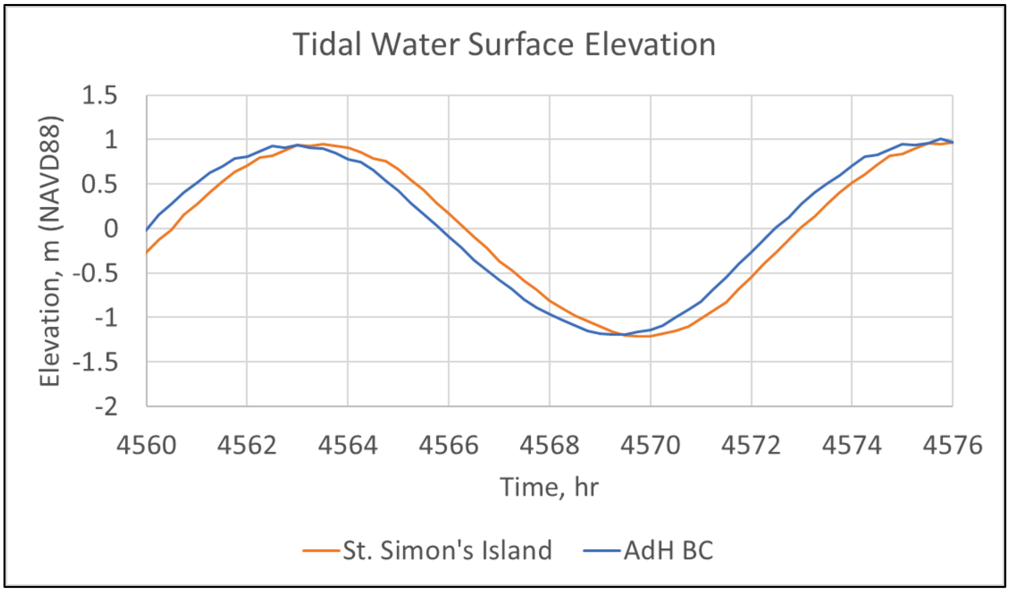
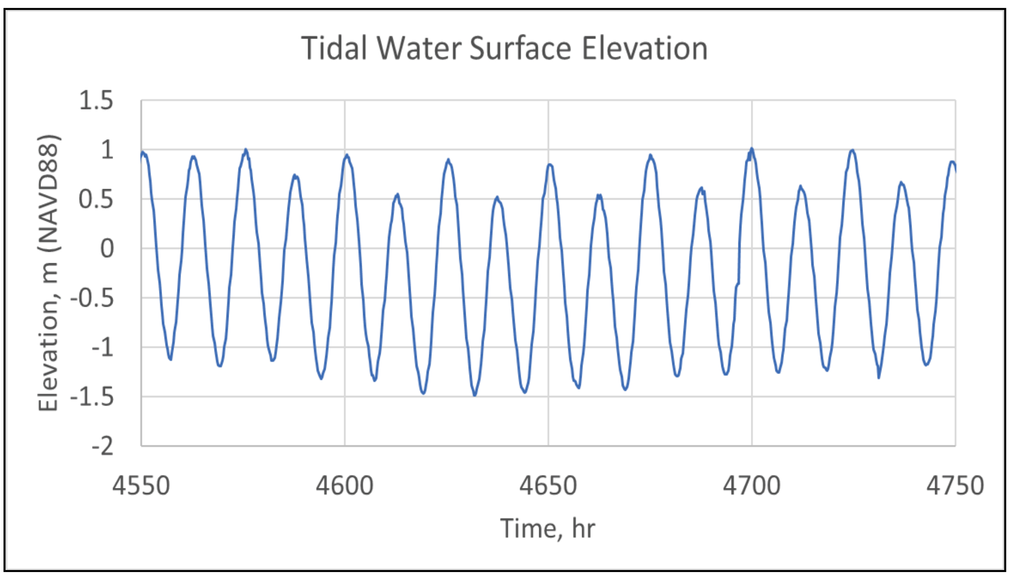


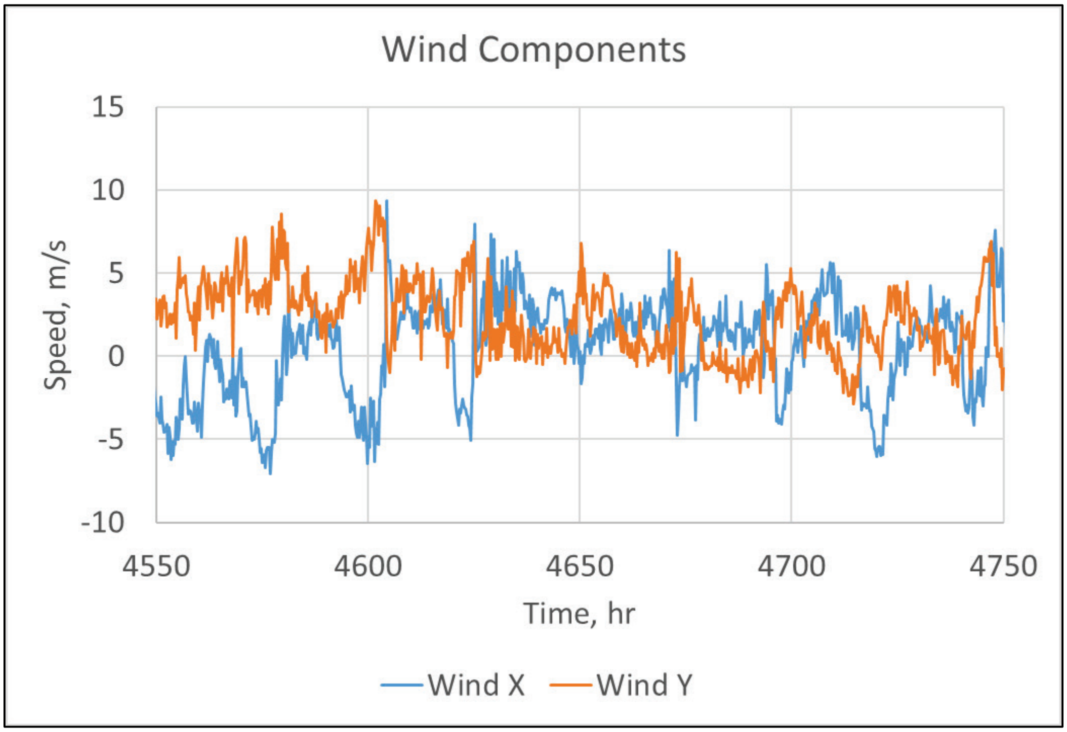
Figure 11. Model boundary tide elevation (0 hr = 1/1/2019).



2.3.2 Meteorological input (wind)

Wind data were available from the USGS collection site at St. Simons Island (Figure 9). The wind speed and direction were converted to Cartesian components. This process included shifting the direction from meteorological format. Figure 12 shows the Cartesian wind speed components with direction converted to “blowing toward” measured counter-clockwise from east.

Figure 12. St. Simons Island wind speed components.



The AdH code can use supplied wind stress components or wind speed and direction to compute the wind stress internally. In this model, the Wu formulation (Wu 1982) is used in the ocean and inlet areas – the deeper areas of the domain. The Teeter formulation (Teeter 2002) is used in the shallow wetland areas.

2.3.3 AdH model parameters

The parameters used by AdH to achieve the validated model (discussed in the following sections) are provided in Table 1. This table provides the specific values used for various model properties such as convergence, eddy viscosity, and time step. The values can vary by location as defined in Figure 13, although in this model only the wind formulation and bed roughness were varied by material as shown in Table 2.

Table 1. Model parameters.

Parameter		Value
Estimated Eddy Viscosity Coefficient		0.5 (Isotropic)
Wetting/Drying Tolerance		1.5 m
Time Stepping		First-order
Time-Step Maximum		300 s
Convergence	Residual Norm	0.001
	Increment Norm	0.01

Figure 13. Material designations.

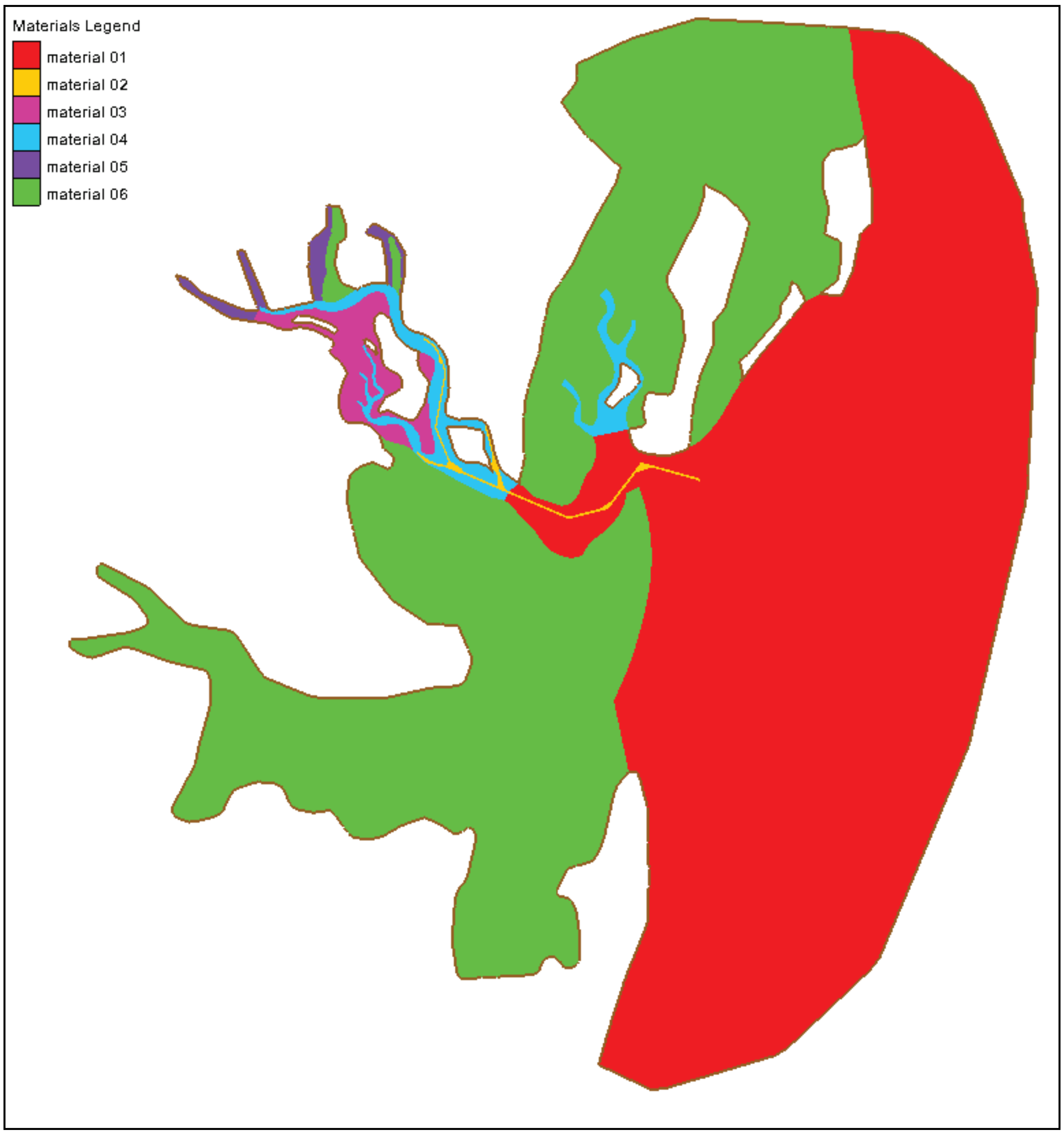


Table 2. Material parameters.

#	Friction Type	Value	Wind Formulation
1	Equivalent Roughness Height	0.0035 m	Wu (1982)
2	Equivalent Roughness Height	0.005 m	Wu (1982)
3	Equivalent Roughness Height	0.006 m	Teeter (2002)
4	Equivalent Roughness Height	0.006 m	Wu (1982)
5	OFF		
6	Equivalent Roughness Height	0.006 m	Teeter (2002)

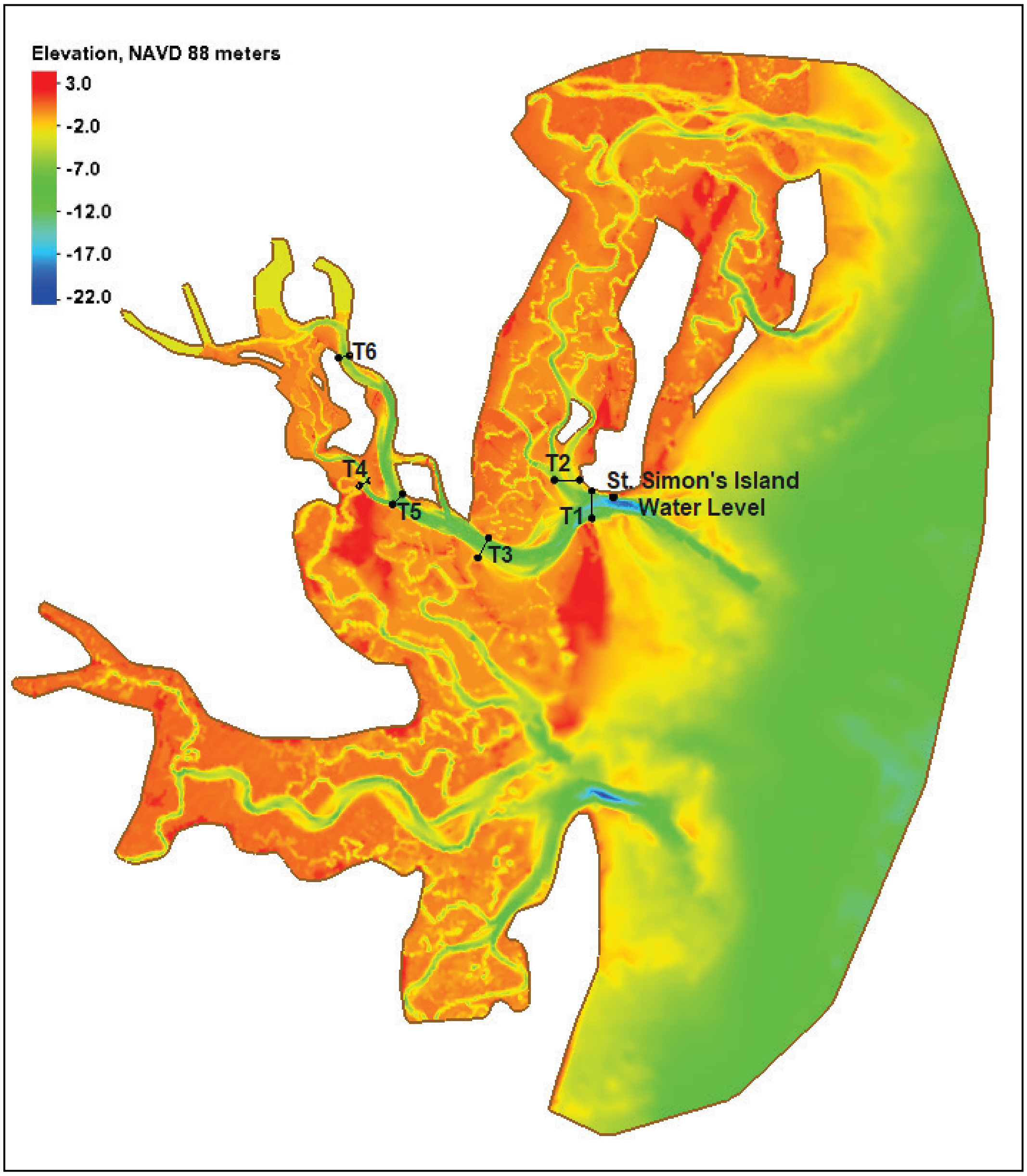
3 Model/Field Comparison

The model is calibrated/validated by comparing to measured field data from July 2019. This is a limited validation effort such that the model is suitable for ship simulation. A more detailed validation period is necessary to utilize this model for a wider range of conditions and parameters. The model domain extents, mesh resolution, bed roughness, and tidal boundary shift were adjusted, within a physically reasonable range, to get the best match to the field data — from the CHL data collection effort and from publicly accessible data websites.

3.1 Field data collection

CHL performed a 13-hr field data collection effort in July 2019 at six transects to collect discharge and velocity measurements from the inlet to locations upstream. Figure 14 shows the location of the transects within the model domain.

Figure 14. Field data collection transects.



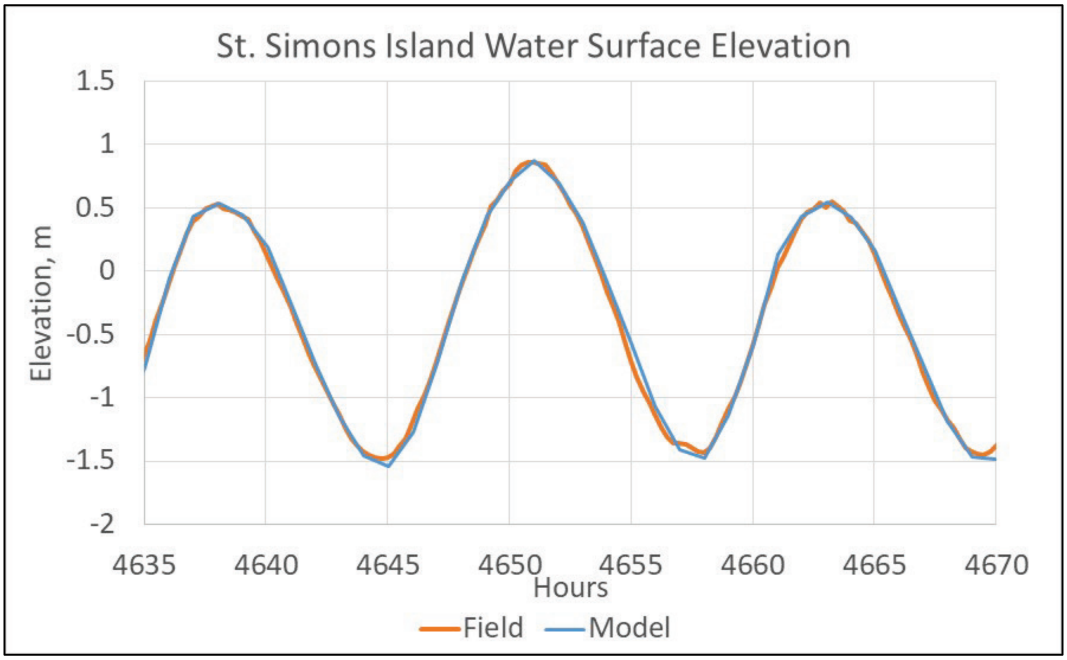
3.2 Hydrodynamic comparisons

The model results are compared to water surface elevation at St. Simons Island and discharge at several locations during the 2019 data collection period.

3.2.1 Water surface elevation

As noted previously, the tidal boundary water surface elevation was adjusted to match the elevation at St. Simons Island as shown in Figure 15.

Figure 15. Water surface elevation comparison at St. Simons Island.



3.2.2 Discharge

Discharge comparisons are made at the six transects that were included in the CHL field data collection. Figure 16 through Figure 21 show the time history discharge (positive: flood; negative: ebb) for these locations. The discharge compares well overall. There is some disagreement in the time of arrival of the peak flood at transects 2 and 4. These areas are impacted greatly by shallow backwater flow which may not be defined with enough detail as necessary to correctly reproduce the timing. The model is low on the discharge range at transect 5 and low on the ebb magnitude at transects 4 and 6. Given the good agreement of the model at transect 3, additional connectivity or roughness features in the inland area of the channel may exist beyond what could be defined in the model. Even with these differences, the model is reproducing the dynamics of the field and is suitable to for use in ship simulation analysis.

Figure 16. Discharge comparison at transect 1.

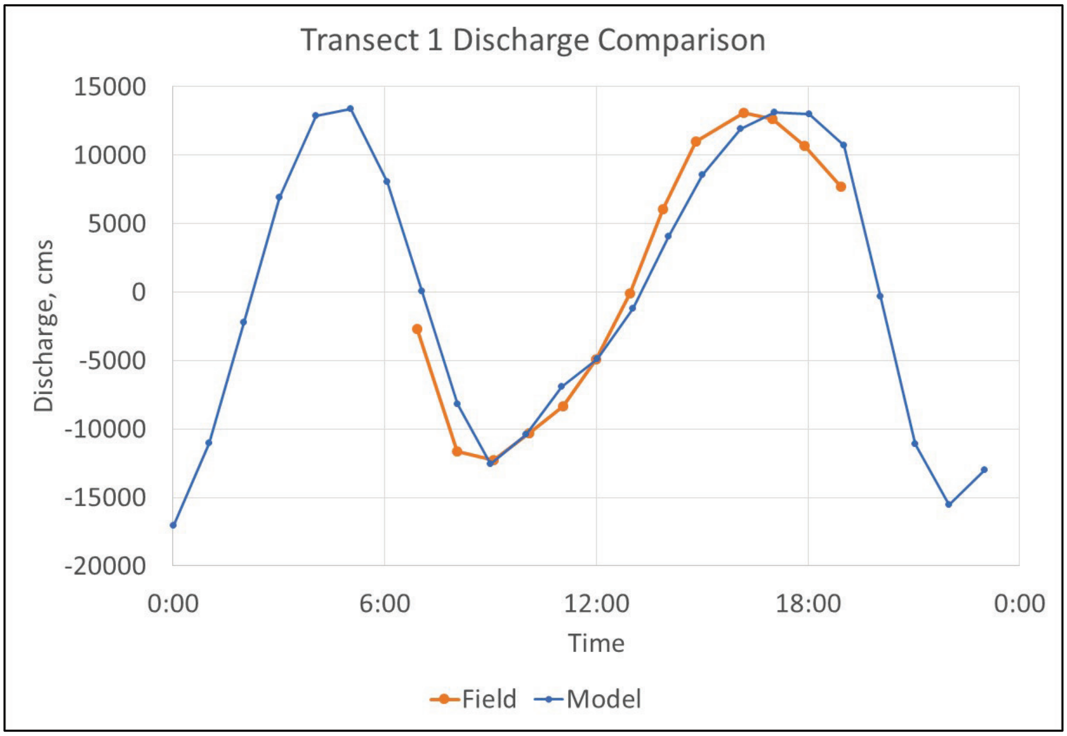


Figure 17. Discharge comparison at transect 2.

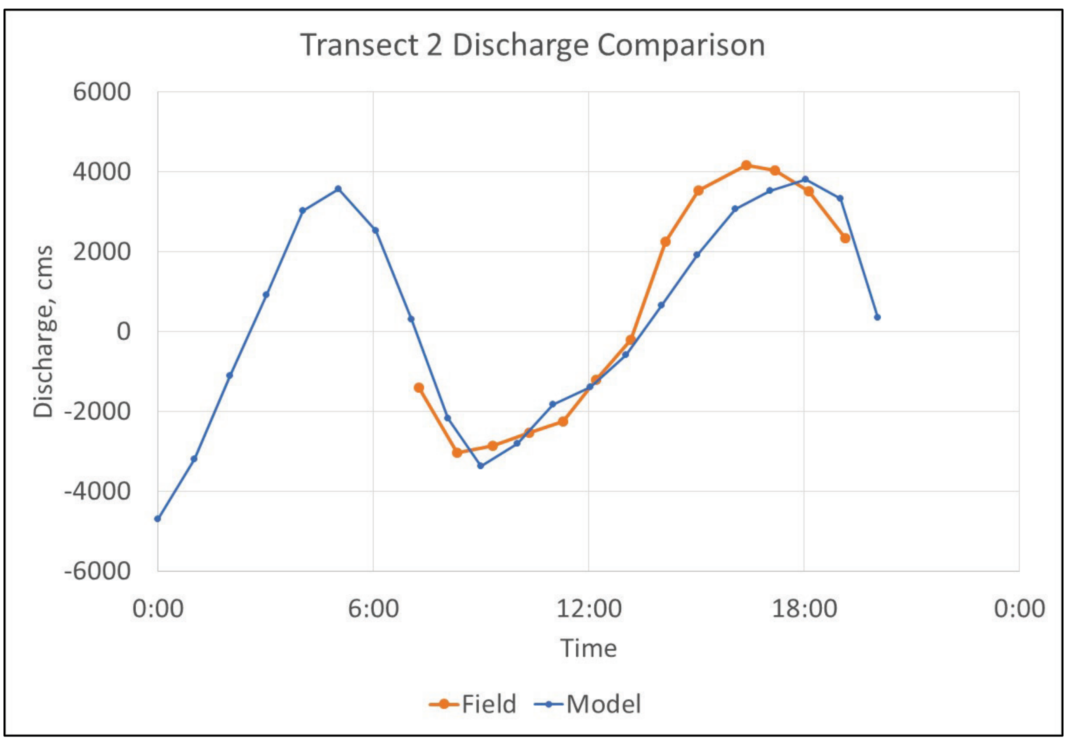


Figure 18. Discharge comparison at transect 3.

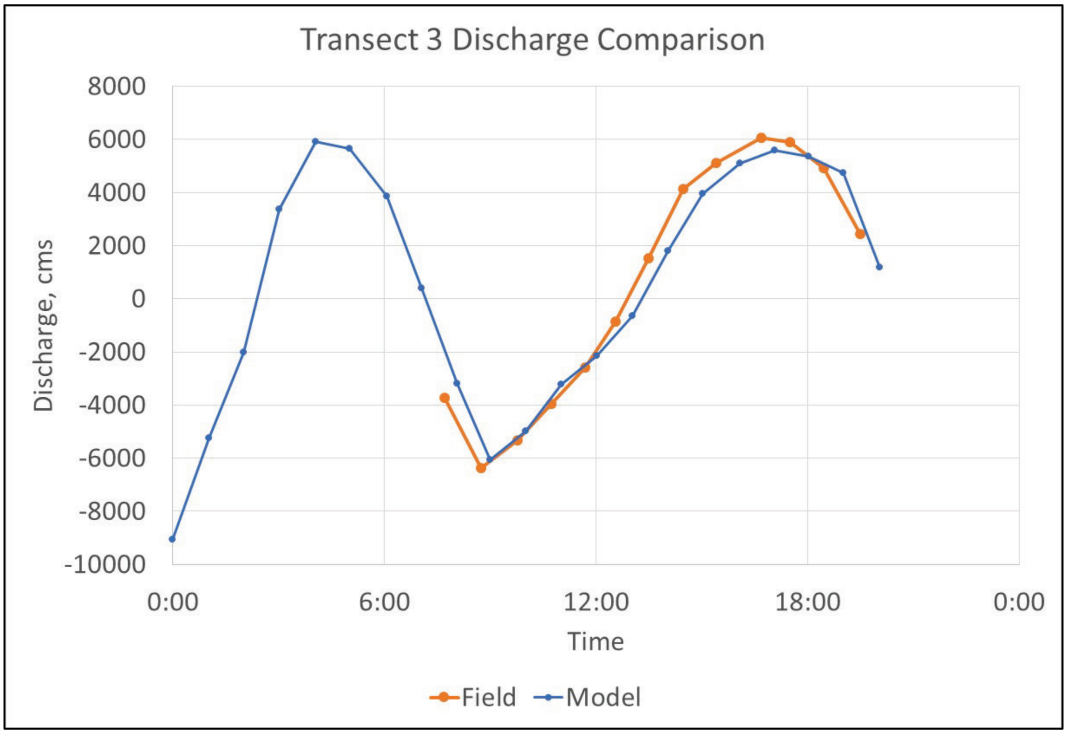


Figure 19. Discharge comparison at transect 4.

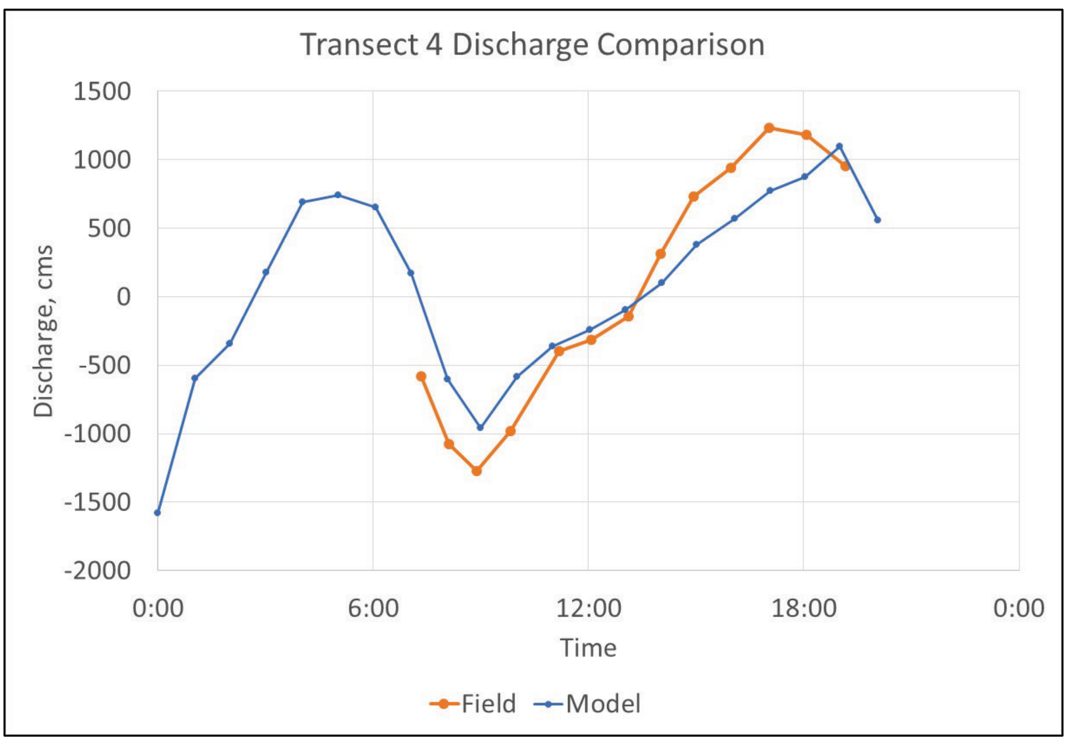


Figure 20. Discharge comparison at transect 5.

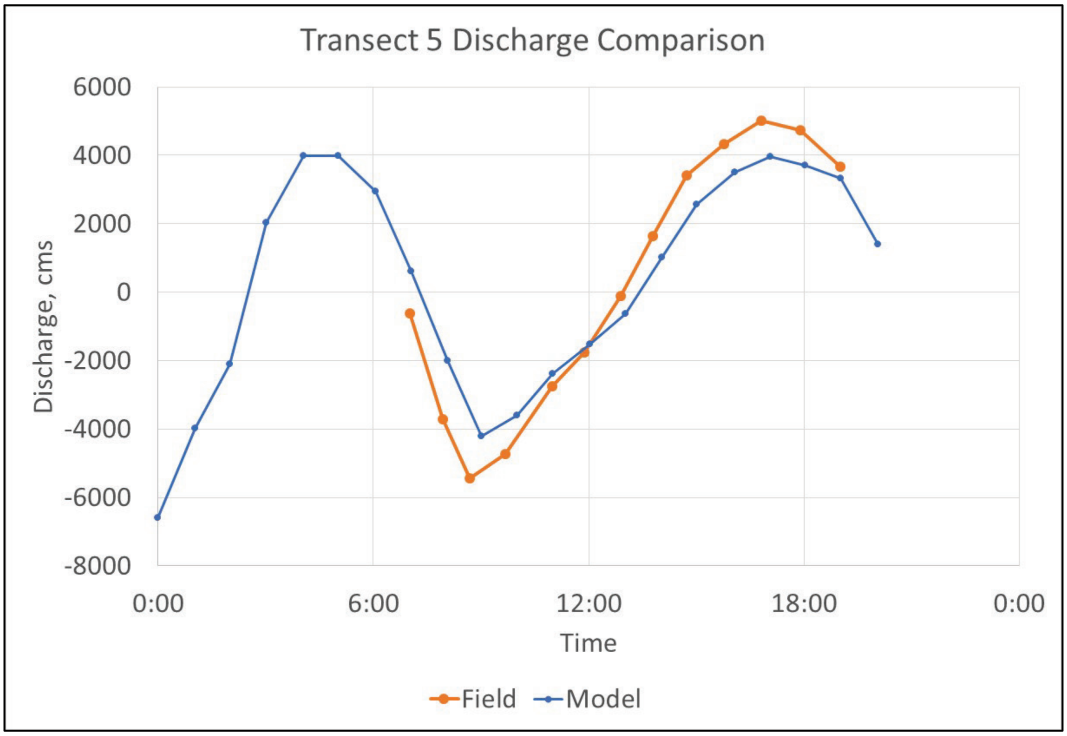
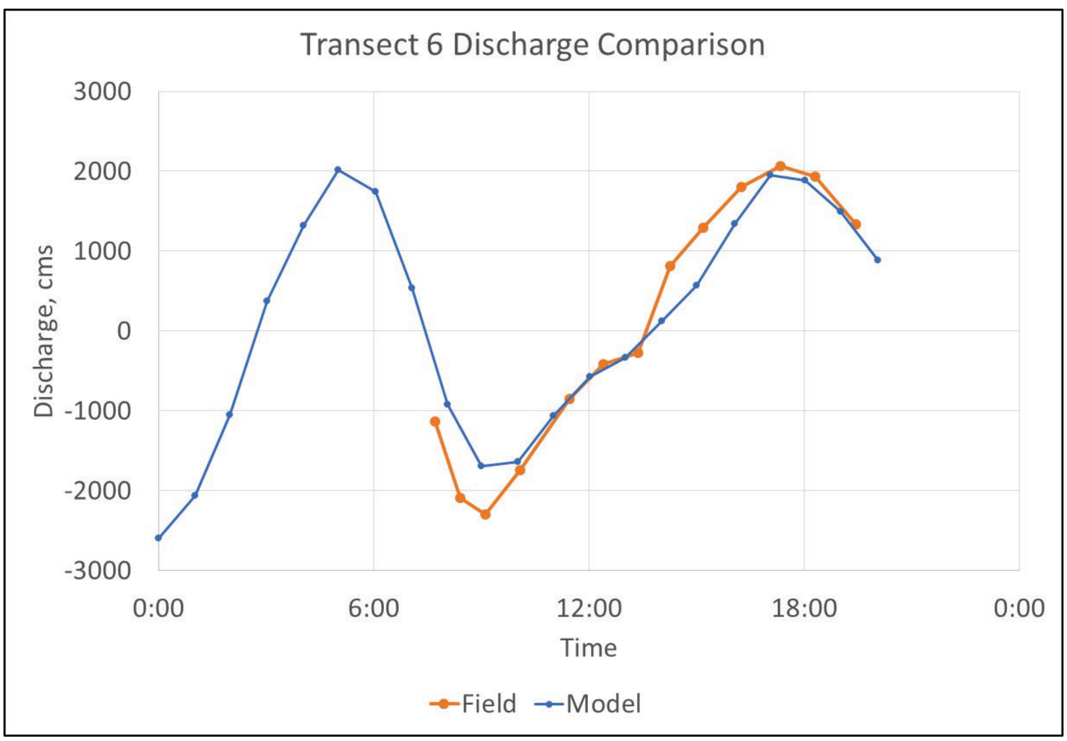


Figure 21. Discharge comparison at transect 6.



3.2.3 Velocity

The velocity magnitude and directions used to compute the field discharge are compared to the model at specific times to determine if the model is reproducing the field velocity patterns. For ship simulation, a single flood and ebb time solution is used, making an accurate representation of the velocity pattern a critical validation step since the velocity direction impacts how the vessel moves in the flow field. Figure 22 through Figure 33 show the flood and ebb velocity comparisons for the six transects. The field-collected velocity direction is shown by the red arrows and the model-computed direction by the black arrows. The vectors are scaled to magnitude. The contours show model velocity magnitude between 0 and 3 m/s.

Figure 22. Transect 1 flood direction velocity.

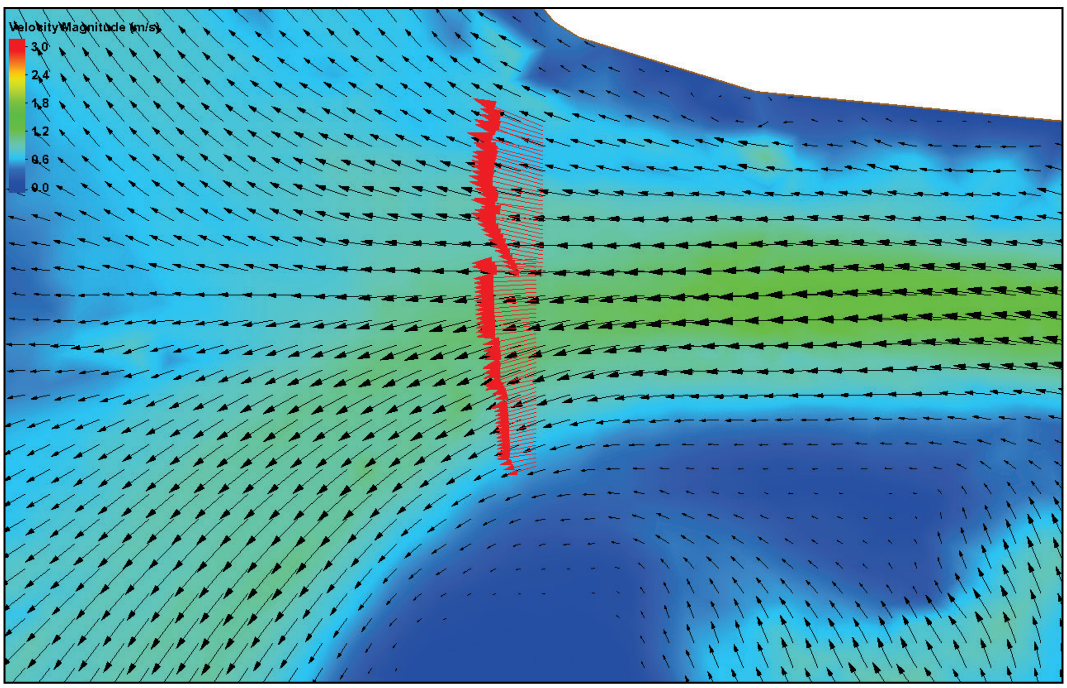


Figure 23. Transect 1 ebb direction velocity.

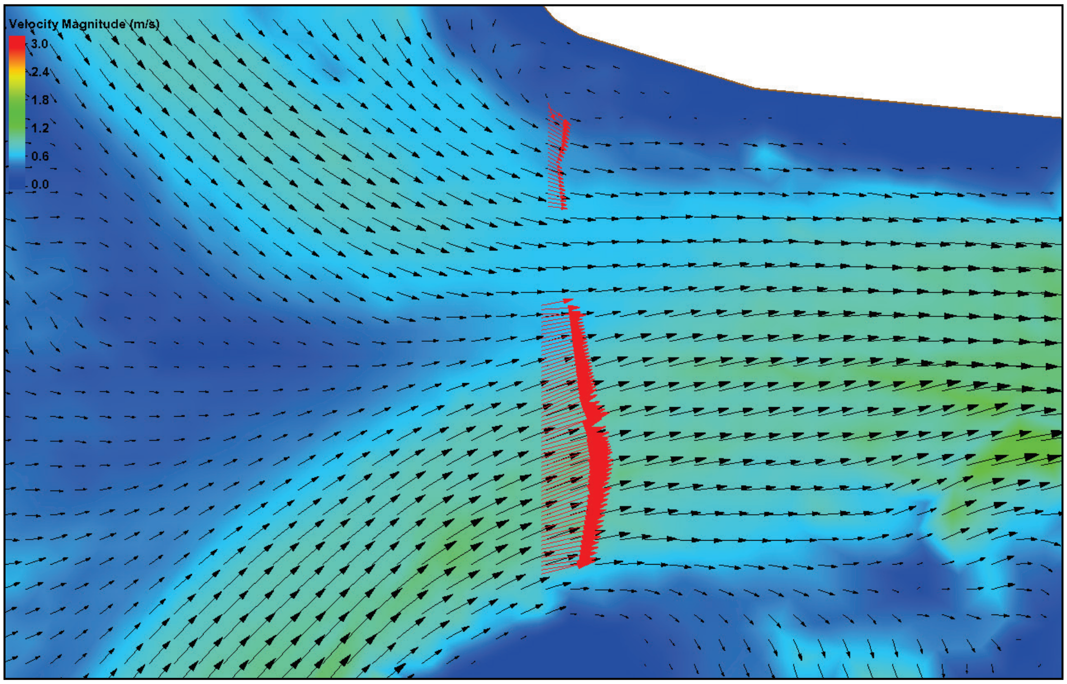


Figure 24. Transect 2 flood direction velocity.

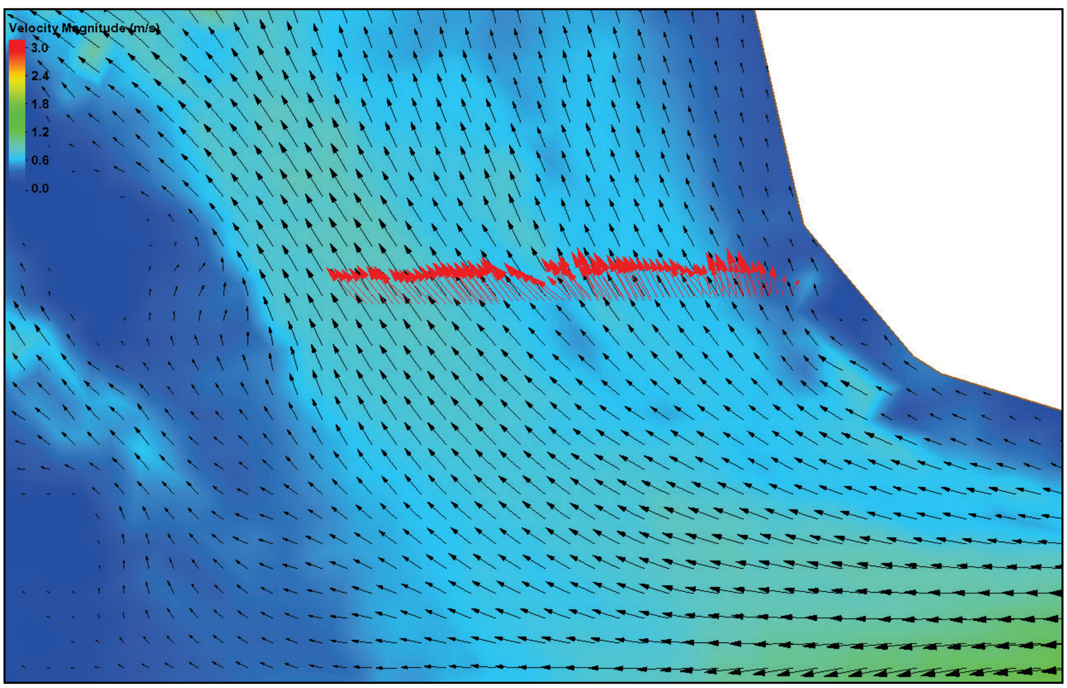


Figure 25. Transect 2 ebb direction velocity.

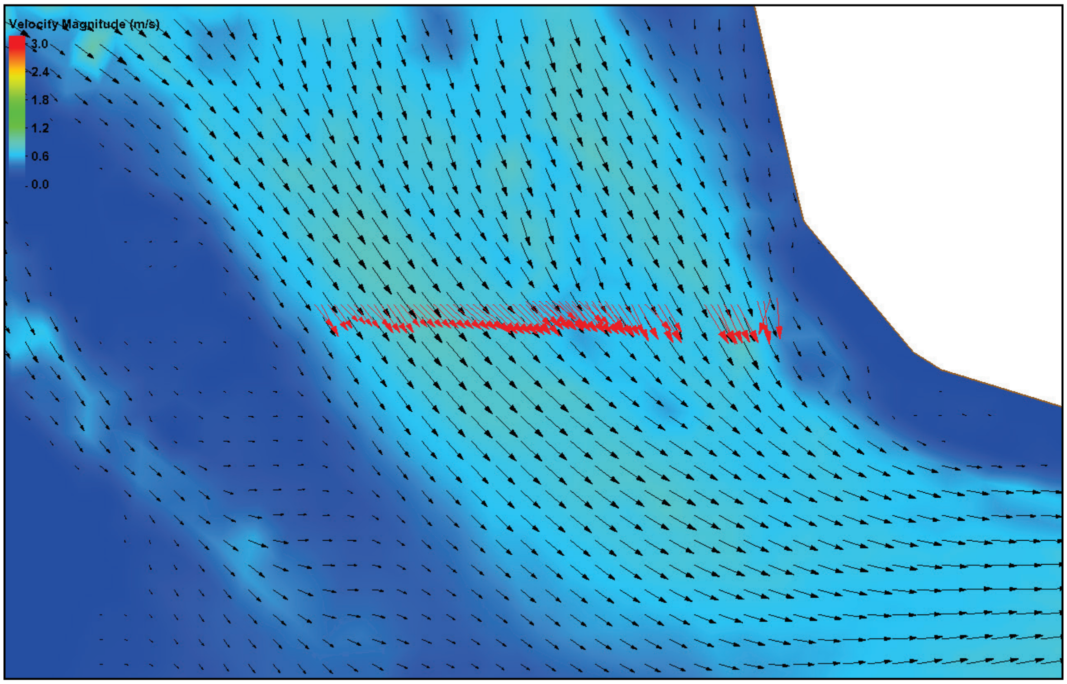


Figure 26. Transect 3 flood direction velocity.

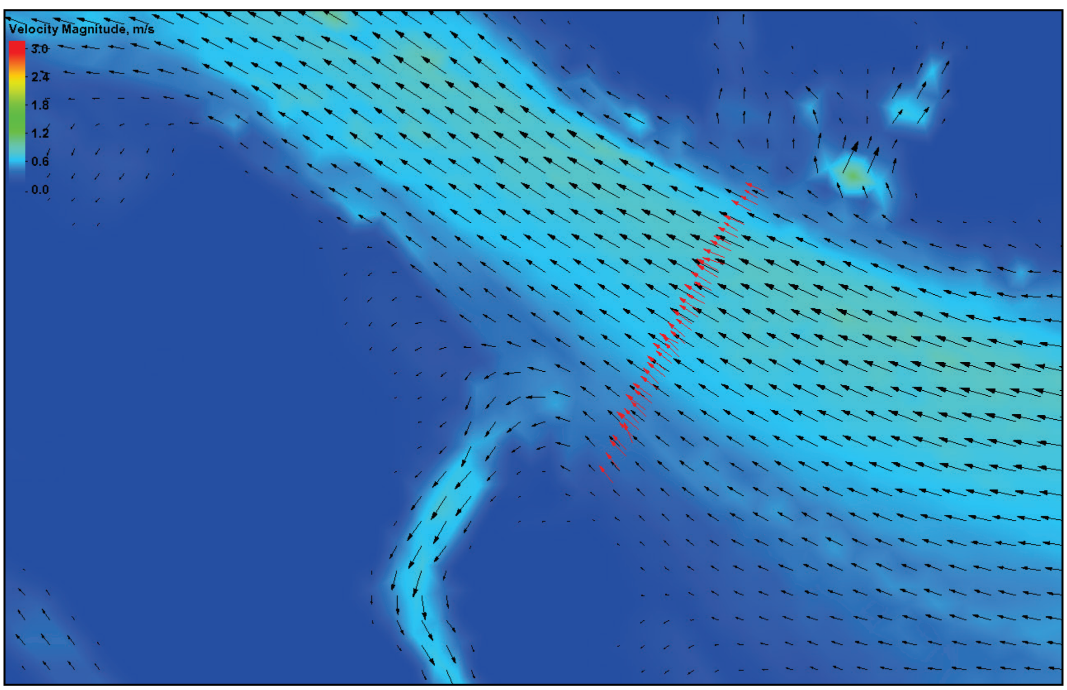


Figure 27. Transect 3 ebb direction velocity.

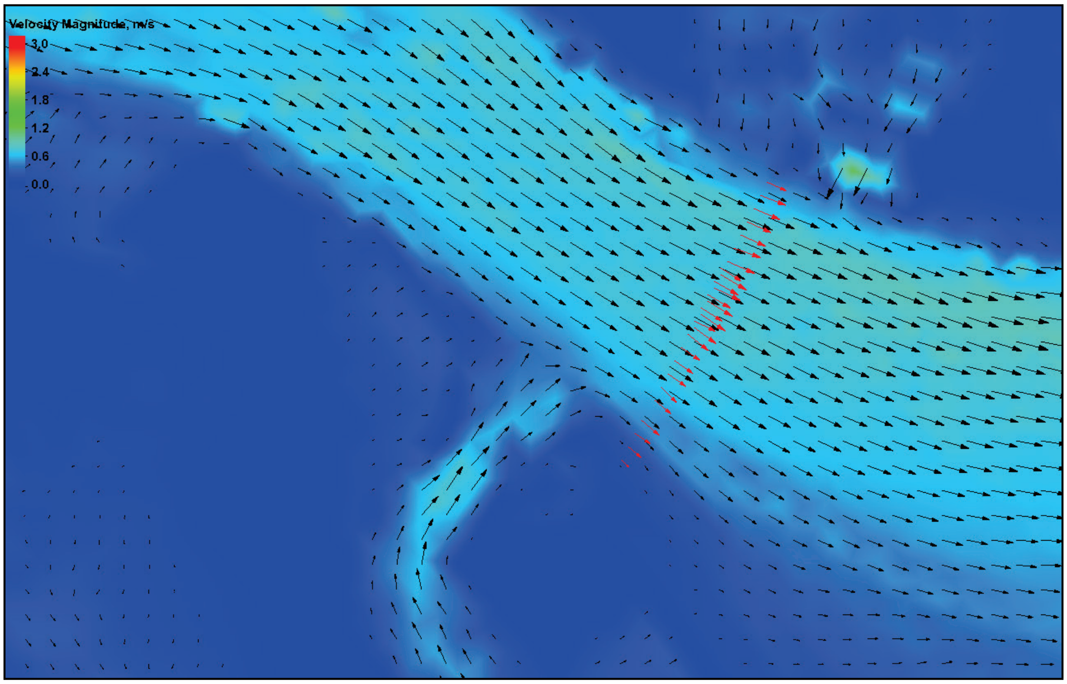


Figure 28. Transect 4 flood direction velocity.

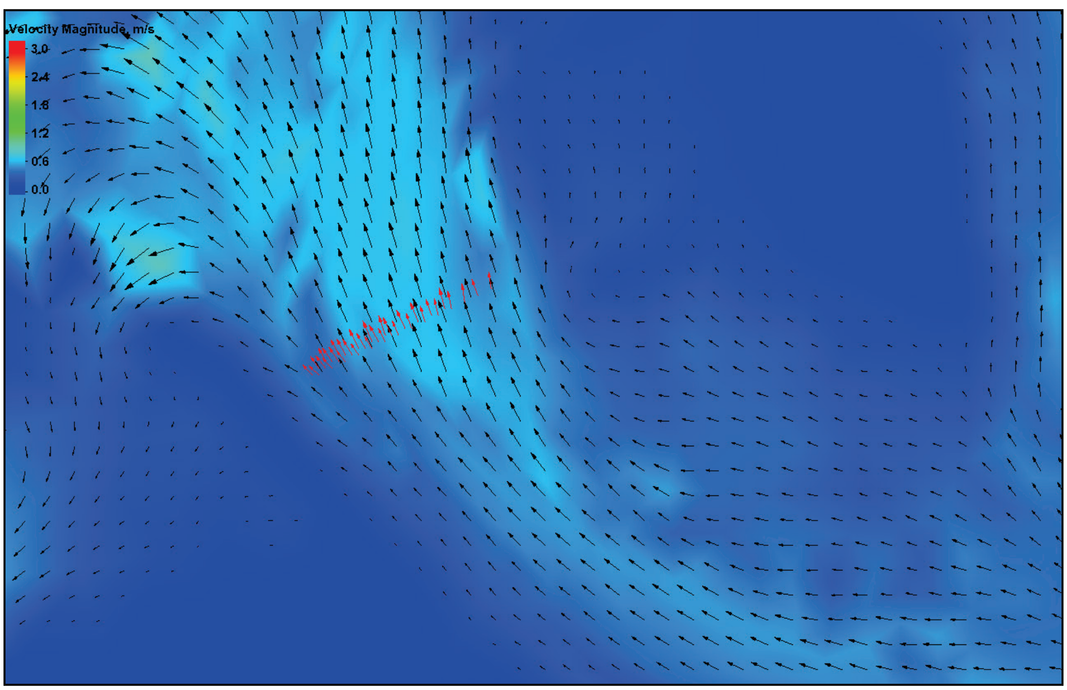


Figure 29. Transect 4 ebb direction velocity.

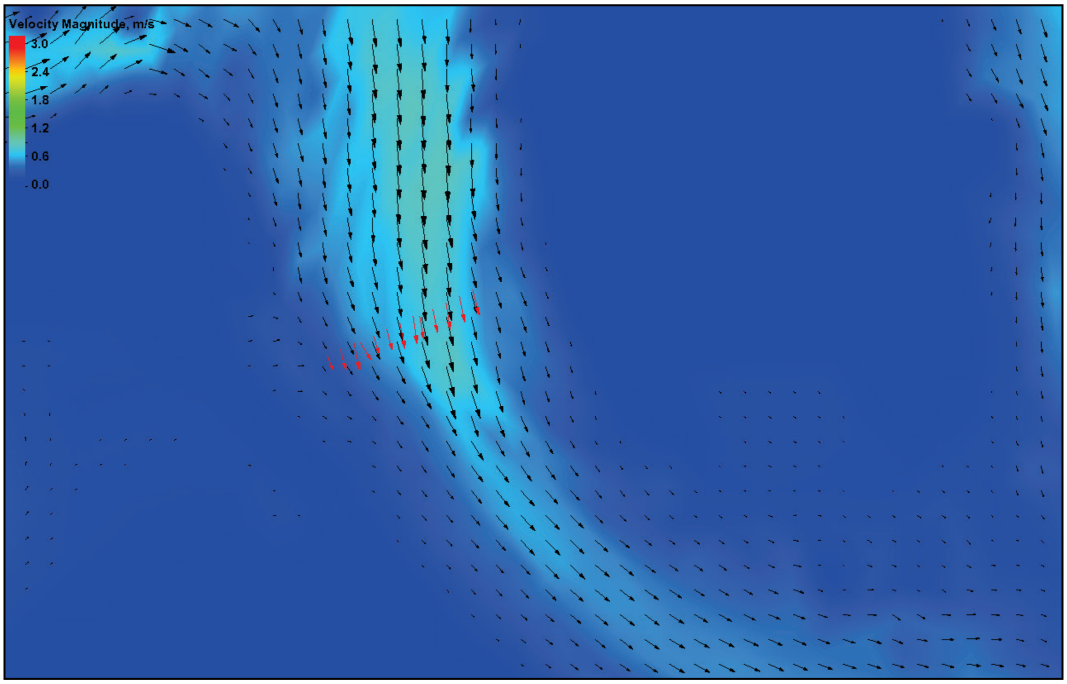


Figure 30. Transect 5 flood direction velocity.

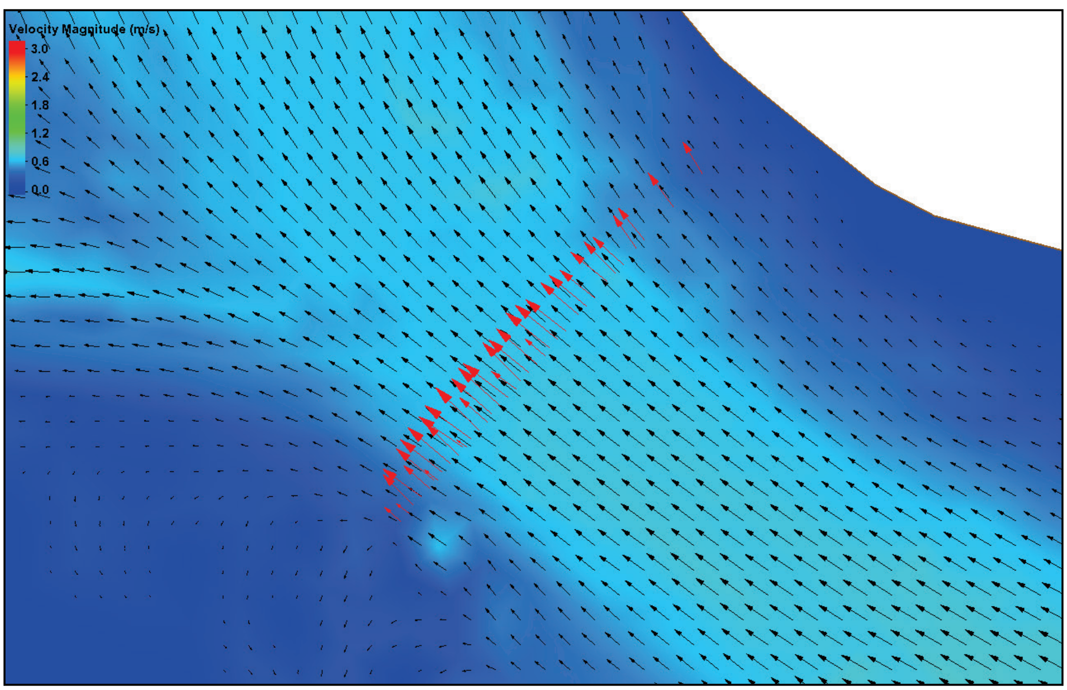


Figure 31. Transect 5 ebb direction velocity.

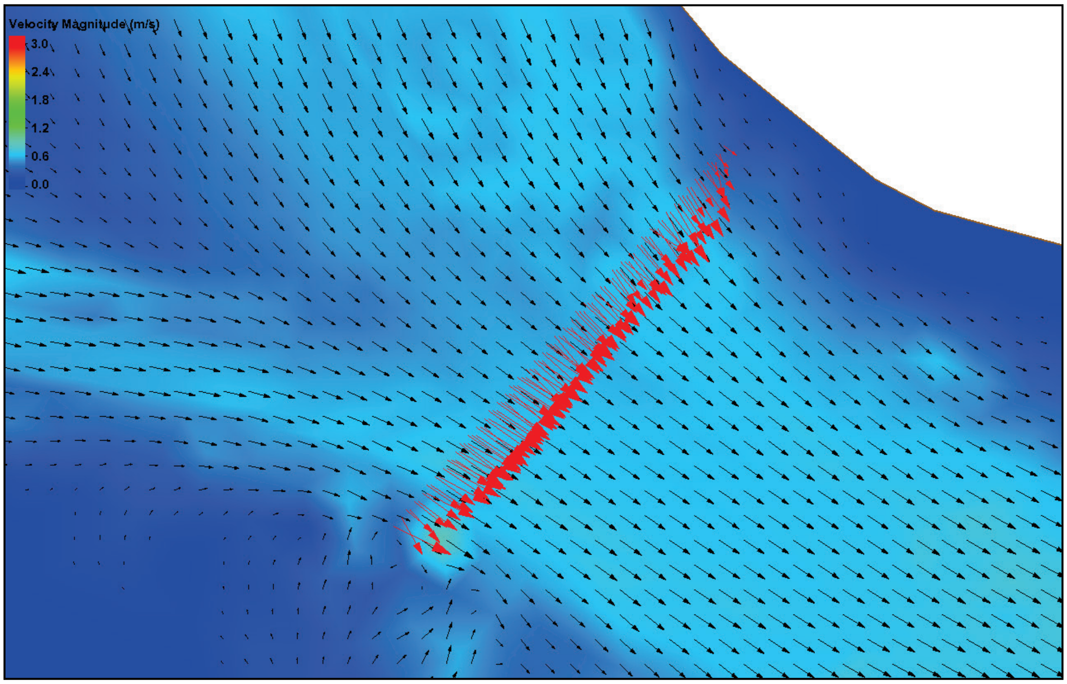


Figure 32. Transect 6 flood direction velocity.

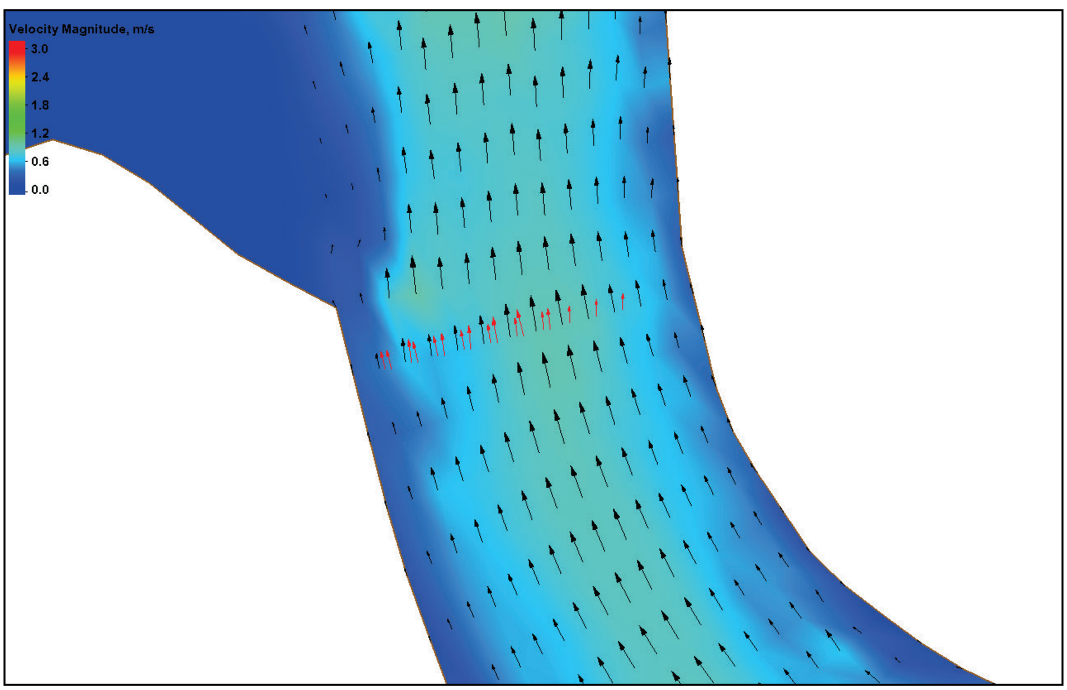
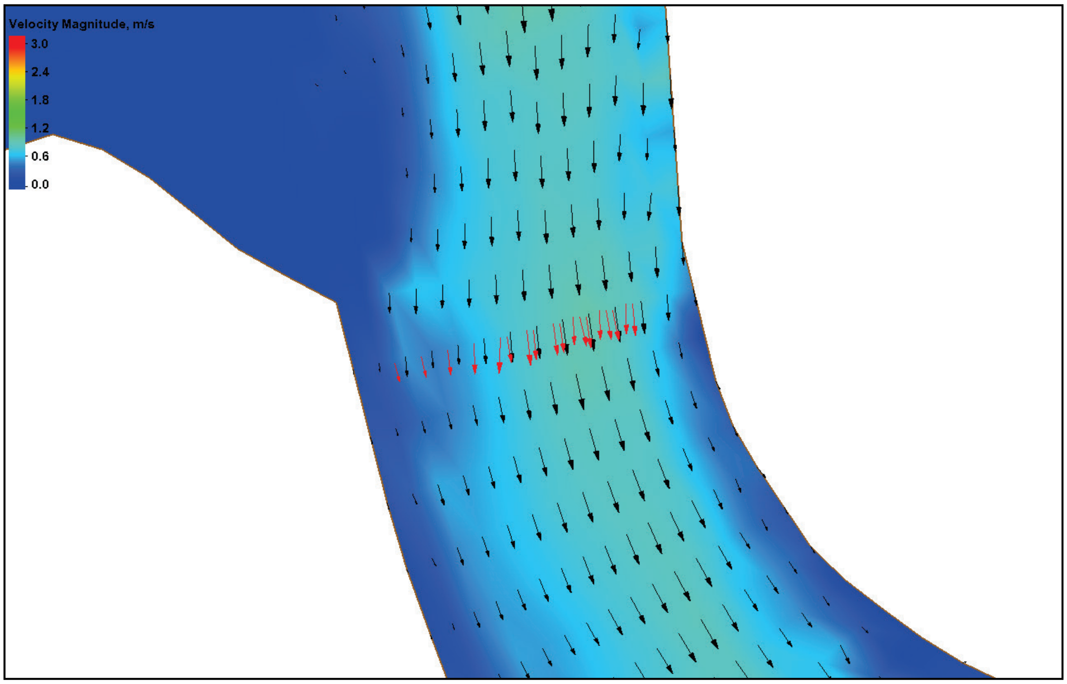


Figure 33. Transect 6 ebb direction velocity.



4 Conclusions

A 2D AdH model was developed and compared to field data for use in ship simulation at ERDC. The model was built to include all areas impacting the Brunswick navigation channel and driven with tides and winds. Bed roughness and tidal storage were adjusted during the model/field comparison. Water surface elevation, discharge, and velocity were used to ensure the model adequately represented the field conditions. Ship simulation uses a single time solution for flood and ebb, making velocity patterns critical to accurate field representation.

The model compares well to the various field datasets. However, the calibration/validation effort was limited by the available data. Although the model is suitable for ship simulation, using it to simulate a longer time period and a range of conditions will require additional data for model/field comparison.

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14. ABSTRACT
The Brunswick area consists of many acres of estuarine and marsh environments. The US Army Corps of Engineers District, Savannah, requested that the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, develop a validated Adaptive Hydraulics model and assist in using it to perform hydrodynamic modeling of proposed navigation channel modifications. The modeling results are necessary to provide data for ship simulation. The model setup and validation are presented here.

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