ERDC/CHL TR-14-12

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Inner Harbor Navigation Canal Basin Velocity Analysis

Jennifer N. Tate and Fulton C. Carson

October 2014

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Final report

Prepared for U.S. Army Corps of Engineers
New Orleans District

Abstract

Post Hurricane Katrina, the U.S. Army Engineer District, New Orleans (MVN), constructed a comprehensive system of levees, gates, and drainage structures in the Inner Harbor Navigation Canal (IHNC) basin and the greater New Orleans, Louisiana, area. Two areas of modification are the connection of the IHNC and Lake Pontchartrain at Seabrook and in the Gulf Intracoastal Water Way (GIWW) just east of the Mississippi River Gulf Outlet (MRGO). The structures allow for continued navigation, and the gate structures are designed to remain open during normal tidal conditions with the ability to close during surge events. A water control plan was developed by MVN to guide the closure of these structures based on water surface elevations at specific locations.

The Adaptive Hydraulics (AdH) numerical modeling code was applied to investigate the hydrodynamic impacts associated with various operating rules for the structures, specifically those in and around the Seabrook and GIWW structures. The study is being performed to provide spatially varying velocity and water surface elevation data to determine the anticipated velocities in and around the constructed gate structures under different ambient conditions. MVN will use these data to determine forces that the structures will experience.

The AdH-computed, hydrodynamic model results are analyzed to determine velocity magnitudes and water surface elevations in the area of the IHNC basin structures for several alternative conditions. Results reported include velocity and water surface elevation data at the structures and at other locations requested by the sponsor.

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Preface

The model investigation presented in this report was authorized and funded by the U.S. Army Engineer District, New Orleans (MVN), as part of an effort to support the operation of the completed Hurricane and Storm Damage Risk Reduction System structures. This hydrodynamic modeling study focuses on the Gulf Intracoastal Waterway structures and the Seabrook structures.

The work described herein was performed and the report written by Jennifer Tate and Fulton Carson at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), during the period of December 2013 to March 2014. The work was conducted under the direction of José E. Sánchez, Director of the CHL; Dr. Ty V. Wamsley, Chief of the Flood and Coastal Storm Protection Division, CHL; and Dr. Robert McAdory, Chief of the Estuarine Engineering Branch, CHL.

Dr. Jeffery P. Holland was Director of ERDC. COL Jeffrey Eckstein was Commander and Executive Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
fathoms	1.8288	meters
feet	0.3048	meters
foot-pounds force	1.355818	joules
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
knots	0.5144444	meters per second
microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
slugs	14.59390	kilograms
square feet	0.09290304	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

1 Introduction

Background

Post Hurricane Katrina, the U.S. Army Corps of Engineers (USACE), New Orleans District (MVN), modified the Inner Harbor Navigation Canal (IHNC) basin and the greater New Orleans, Louisiana, area for hurricane protection by placing flood control structures in several locations. This protection was accomplished through the construction of a comprehensive system of levees, gates, and drainage structures.

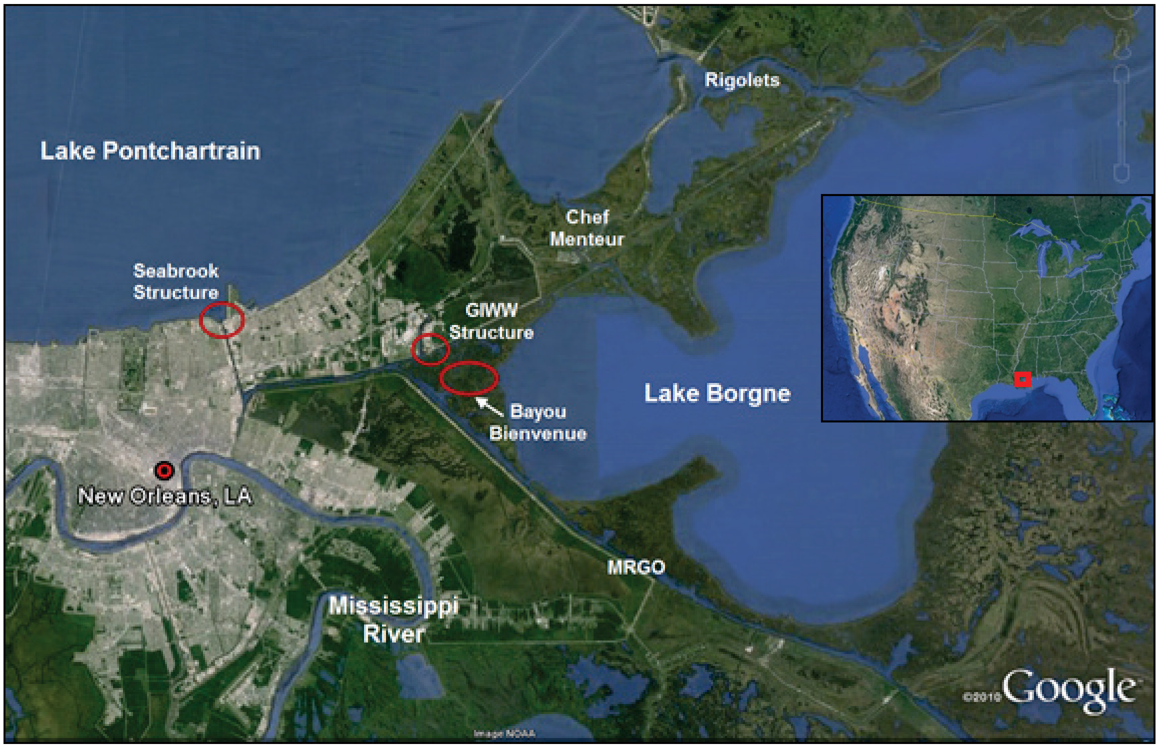
The entire Hurricane and Storm Damage Risk Reduction System (HSDRRS) is composed of multiple closure complexes, 350 miles of floodwalls, and pump stations. Two areas of modification are the connection of the IHNC and Lake Pontchartrain at Seabrook and in the Gulf Intracoastal Water Way (GIWW) just east of the Mississippi River Gulf Outlet (MRGO). The planned structures allow for continued navigation in the IHNC, Bayou Bienvenue, and GIWW. The Seabrook, Bayou Bienvenue, and GIWW gate structures are designed to remain open during normal tidal conditions with the ability to close during surge events. A water control plan was developed by MVN to guide the closure of these structures based on water surface elevations at specific locations; such a plan is needed to ensure safe and efficient structure closure due to velocities and forces on the structures expected under closure conditions (USACE 2013a).

As part of the initial HSDRRS study, MVN requested the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), develop, validate, and perform numerical model simulations in and around several structures. Hydrodynamic results from the Adaptive Hydraulics (AdH) model were applied as input to the Particle Tracking Model (PTM) to analyze the impact of the changes to the Seabrook and GIWW areas on the transport of larval species into Lake Pontchartrain. This work is documented in Tate et al. (2010) and is the starting point for the work presented in this report.

Objective

The study investigates hydrodynamic impacts associated with various closure operating rules for structures located in the IHNC basin, specifically those in and around Seabrook and the GIWW. The Bayou Bienvenue structure is included for its effects on the GIWW structures. Figure 1 shows the project area and locations of interest. The study is being performed to provide spatially varying velocity and water surface elevation data to determine the anticipated velocities in and around the constructed gate structures under different ambient conditions. MVN will use these data to estimate expected forces on the structures.

Figure 1. Project area map; red circles show locations of interest.



The study of velocities in and around the structures began with a Hydrologic Engineering Center (HEC) one-dimensional (1D) model (Gerwick 2013); the effort documented in this report extends that work. The current effort will provide multidimensional analyses for some of the scenarios calculated in the earlier 1D effort.

Approach

The previously developed AdH-based model included Lake Pontchartrain, Lake Borgne, the Mississippi River Gulf Outlet (MRGO), the GIWW, and surrounding areas to the Gulf of Mexico (Tate et al. 2010). For the current effort, the existing model domain is reduced in size in order to apply the requested water surface elevation slopes across the structures being analyzed. The model mesh is also refined in the area of the sector gates so that partial gate closures can be simulated.

AdH simulations were performed to calculate conditions throughout the reduced-size domain for the following:

- specified water surface slope conditions across the GIWW structures
- specified water surface slope conditions across the Seabrook structure in the IHNC area
- hurricane-like conditions throughout the entire domain.

Table 1 lists the simulation alternatives. Water surface elevation values are set at Lake Borgne and Lake Pontchartrain so that the values on the protected and unprotected sides near the structures, as given in the table, are realized for each alternative. The protected side of the structures is the interior of the system (i.e., the western side of the GIWW structures and the southern side of the Seabrook structures).

Table 1. Simulation alternative table.

	Open/Closed/Isaac Conditions				Water Surface Elevation (NAVD88)	
Alternative	Barge Gate	Sector Gate	Bayou Bienvenue	Seabrook Gate Complex	Lake Borgne	Lake Pontchartrain
Basin-4 ft*	closed	open	closed	open	4 ft	1 ft
Basin-5 ft	closed	open	open	open	5 ft	1.5 ft
Seabrook-2 ft	NA	NA	NA	open	2 ft	1 ft
Seabrook-4 ft	NA	NA	NA	50%	4 ft	2 ft
Isaac-1	Isaac	Isaac	Isaac	Isaac	Isaac	Isaac
Isaac-2	closed	open	closed	open	Isaac	Isaac

*ft = feet

The AdH-computed hydrodynamic model results are analyzed to determine velocity magnitudes and water surface elevations in the area of the IHNC basin structures for each alternative condition. Results reported include velocity and water surface elevation plots through the structures and at locations requested by MVN.

2 Hydrodynamic Model Development and Verification

Model code description

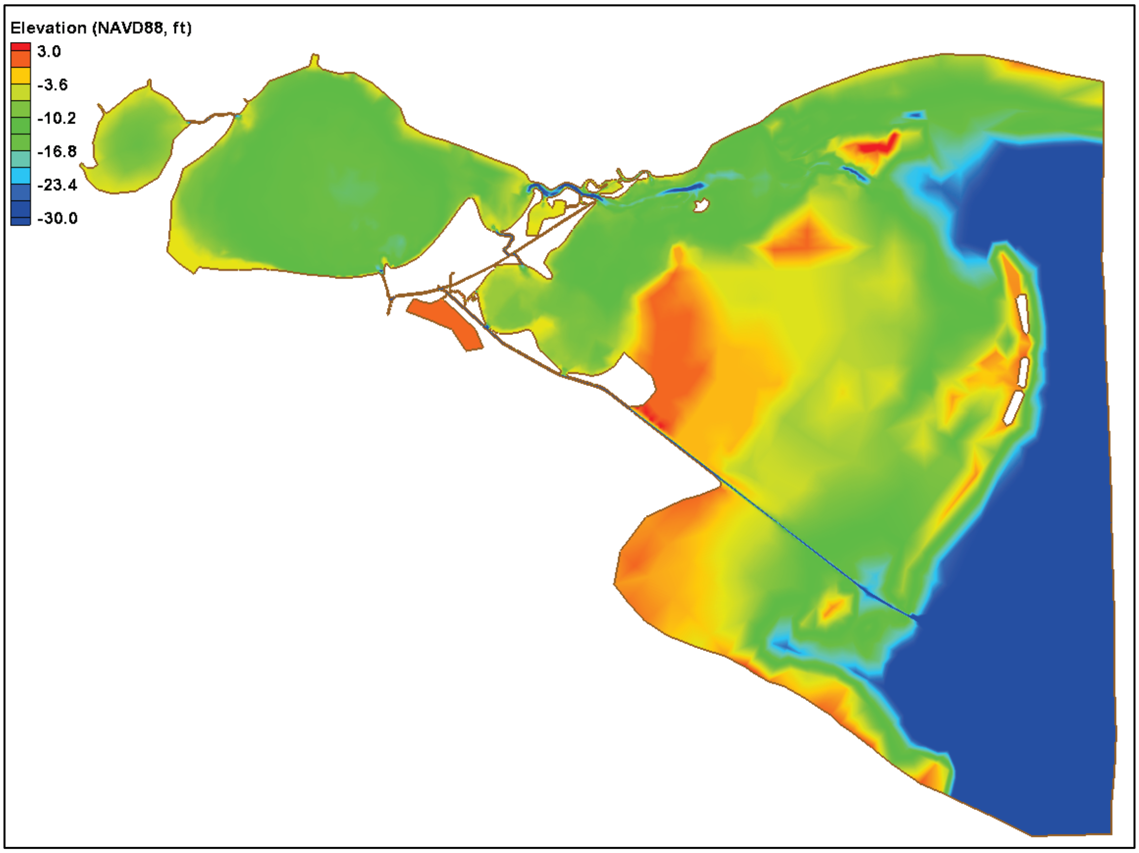
AdH is the numerical model code applied for the simulations in this study. AdH is a finite element code that is capable of simulating three-dimensional Navier Stokes equations, two- and three-dimensional (2D and 3D) shallow water equations, and groundwater equations. It can be used in a serial or multiprocessor mode on personal computers and high performance computing systems. AdH will 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, as well as simulate sediment transport that is coupled to bed and hydrodynamic changes. The ability of AdH to allow the domain to wet and dry within the marsh areas as the tide changes is suitable for shallow marsh environments. This code has been applied to model sediment transport in sections of the Mississippi River, tidal conditions in southern California and San Francisco Bay, and vessel traffic in the Houston Ship Channel, among other sites.

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. In this case, density effects due to salinity or other factors are ignored, and therefore, their effects on the flow are not included in the simulations and results. The omission of salinity impacts is appropriate for this study since the focus is on gate closure during high-water conditions. More details of the 2D shallow water module of AdH and its computational philosophy and equations are available in Berger et al. (2013). AdH version 4.31 was applied for this study to be consistent with simulations on the large domain mesh used in the earlier work and to ensure that this version of the AdH code produces similar results as the original work.

Mesh development

The computational model domain used in the previous study (Tate et al. 2010) is given in Figure 2. The domain covers 4,856 square miles and extends east of the Chandeleur Islands into the Gulf of Mexico, follows the coastline of Mississippi and Louisiana on the north, follows the MRGO on the south, and includes Lake Pontchartrain and Lake Maurepas. The vertical datum for this mesh is NAVD 88 (2004.65), and all units are English. This computational model mesh contains 35,631 elements and 19,719 nodes with elements ranging in area from 1,000 square feet (ft^2) to 100 million ft^2, the largest located in the Gulf of Mexico. This model was compared to field data, and the validation can be reviewed in Tate et al. 2010.

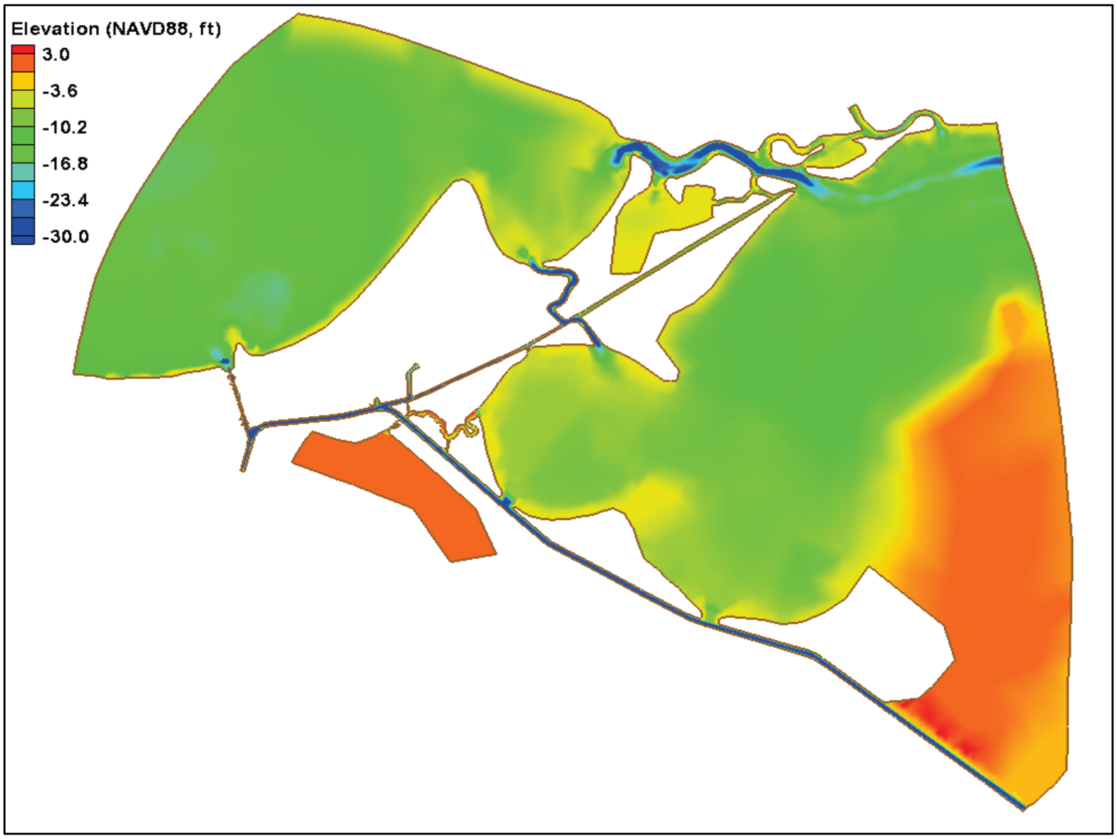
Figure 2. Original model domain.



Reduced-size mesh

The original model domain mesh was reduced in size to include only the sections of the domain necessary for the simulations in this study. Since the boundary conditions for this work are specified to generate specific water surface slopes only, the mesh can be reduced in size and simplified. Figure 3 shows the reduced-size mesh. This domain encompasses only 685 square miles or 14% of the original mesh size, has 30,064 elements with 16,809 nodes, and includes additional resolution in the vicinity of the Seabrook and GIWW structures. All bed properties, such as bed roughness, were maintained from the previous study. The simulation results for this mesh were checked against the large-domain mesh using time-varying boundary conditions since the Hurricane Isaac alternatives are time-varying simulations. This mesh will be used for the Basin and Isaac alternatives.

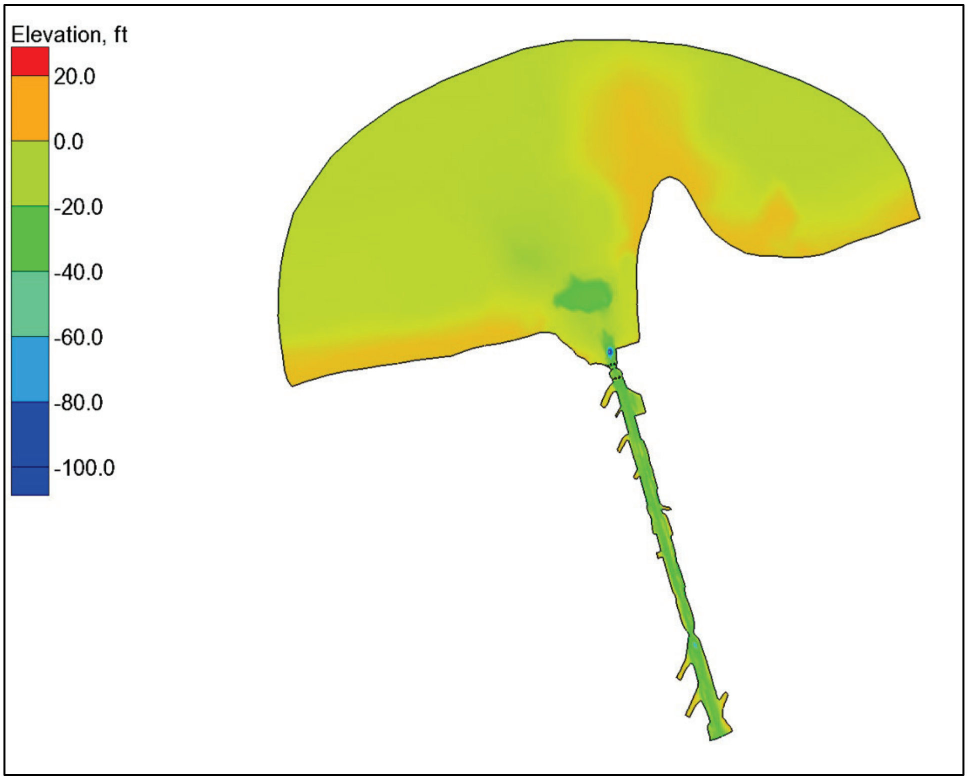
Figure 3. Reduced-size mesh.



Seabrook mesh

The Seabrook alternatives require an even smaller domain than the reduced-size mesh. Figure 4 shows the Seabrook alternative model domain. This mesh contains 5,483 elements and 3,080 nodes, and additional resolution was included in the vicinity of the Seabrook structure. The domain encompasses 6.9 square miles from just north of the IHNC's connection with the GIWW into Lake Pontchartrain. Since the Seabrook alternatives only simulate steady state conditions across the Seabrook structures, a time-varying verification analysis is not required for this mesh domain.

Figure 4. Seabrook alternative model domain.

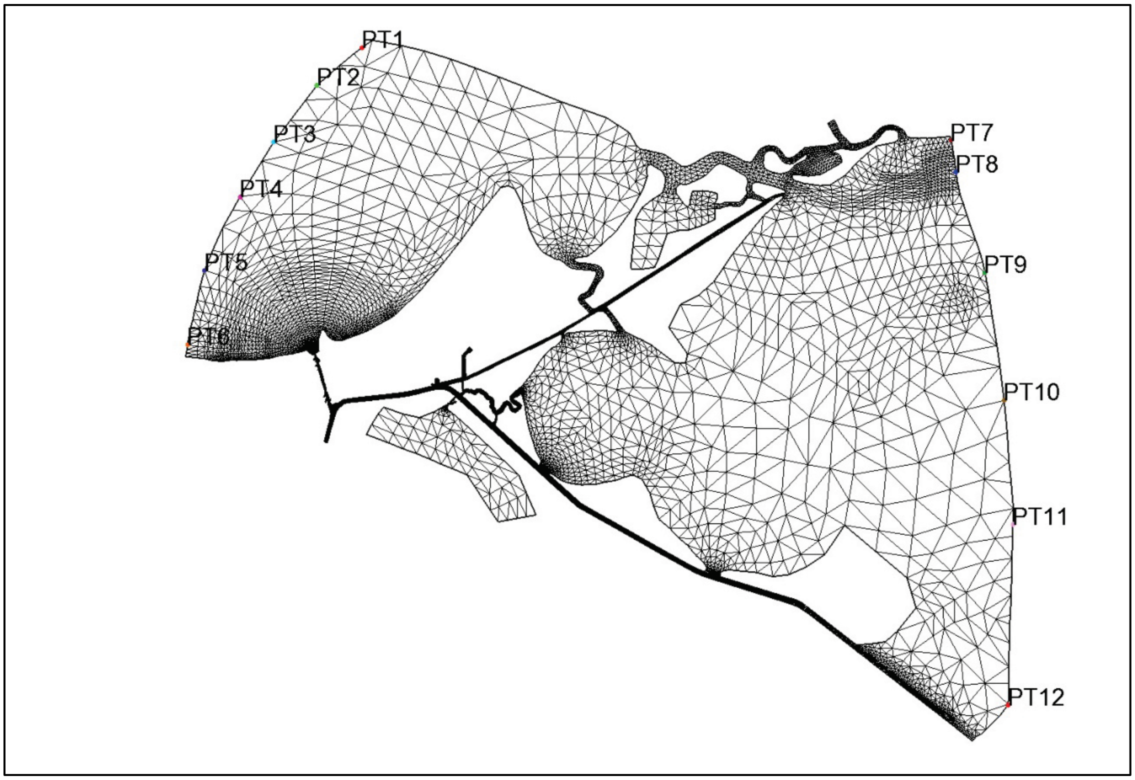


Model validation

Numerical modeling domains must be large enough such that the boundary conditions do not impact the results in the area of interest. To ensure that the reduced-size mesh is not too small, it is simulated using water surface elevations taken from the large-domain mesh at the boundary locations of the reduced-size mesh (i.e., the reduced-size mesh is driven with results from the large mesh). No velocity values were supplied at the reduced-size mesh boundary, so the momentum must be generated within the model domain during the simulation. The results of this simulation serve as a validation if they match the previously validated results obtained from the large domain (Tate et al. 2010).

The boundary conditions for the reduced-size mesh are varied along each boundary according to Figure 5, where each labeled point sets a constant value along a set segment length for each time-step. These conditions are based on results extracted from a simulation using the large-domain mesh. This variation allows for the changing water levels along each boundary without having to supply time-varying data at every element along each boundary edge (Figure 5).

Figure 5. Reduced-size mesh boundary locations.



Nine points within the reduced-size model domain (Figures 6 and 7) are used for comparison to the previously validated model's results to ensure that the reduced size of the mesh does not negatively impact the results. Points 1–7 were selected initially, and points 8 and 9 were added in the center of the GIWW sector gate structure and the center of the Seabrook sector gate structure, respectively.

Figures 8–16 show the comparison of the full-mesh water surface elevation results to the reduced-size mesh results. These results show that the reduced-size mesh is replicating the results from the larger, validated model; therefore, the reduced-size model domain can be used successfully for this study of the Basin and Isaac alternative conditions.

No validation was performed for the Seabrook alternative model domain since time-varying results were not calculated under this study.

Figure 6. Reduced-size mesh comparison locations; circled points are shown in detail in Figure 7.

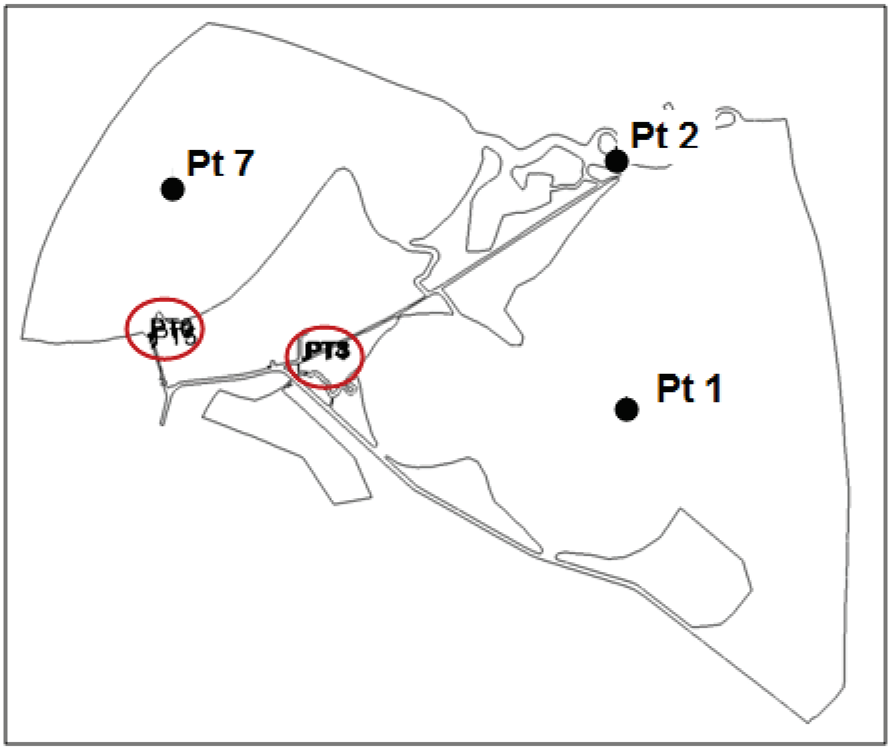


Figure 7. Reduced-size mesh comparison locations at the structures.

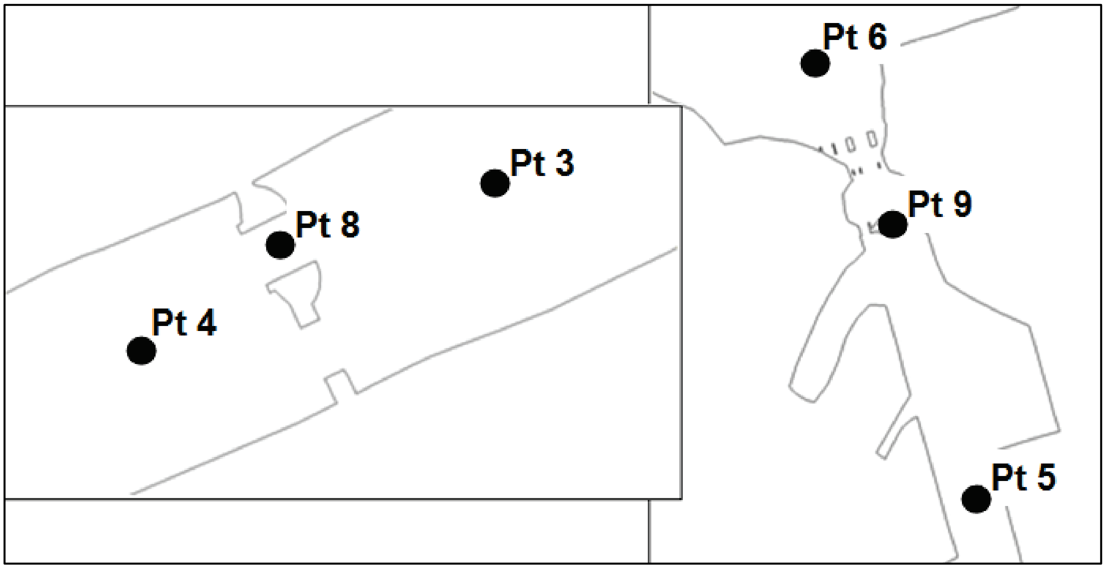


Figure 8. Water surface elevation comparison for large domain and reduced-size domain at point 1.

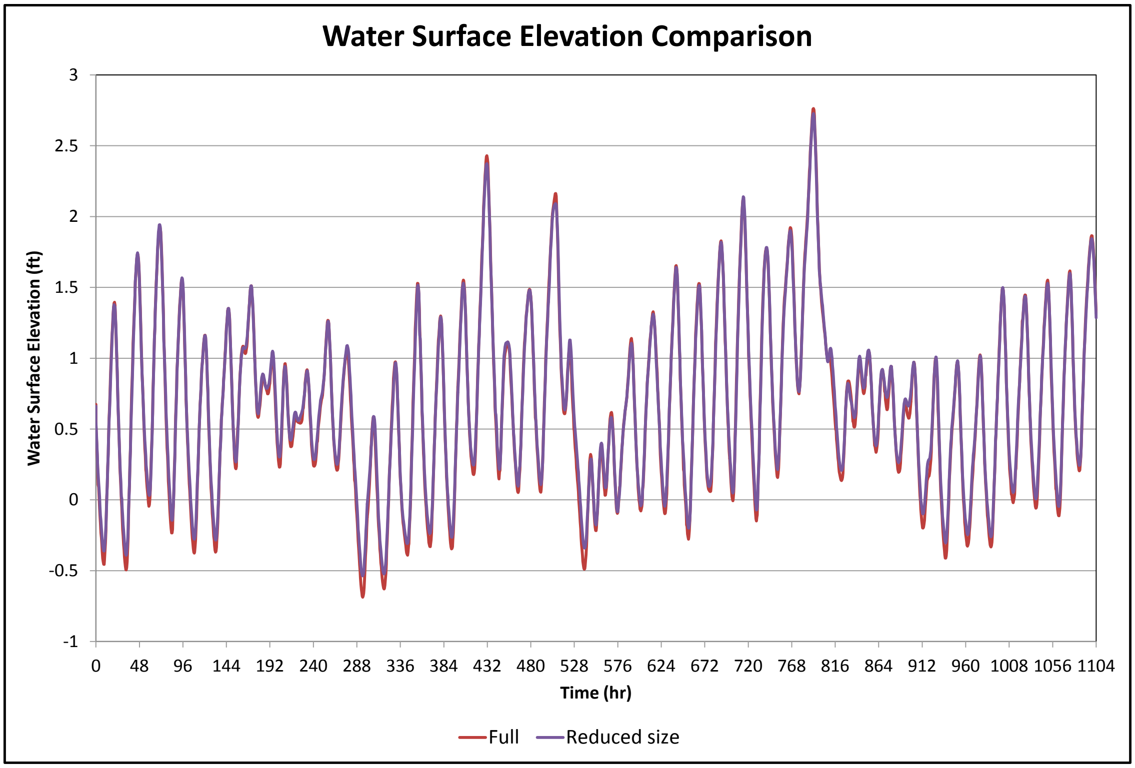


Figure 9. Water surface elevation comparison for large domain and reduced-size domain at point 2.

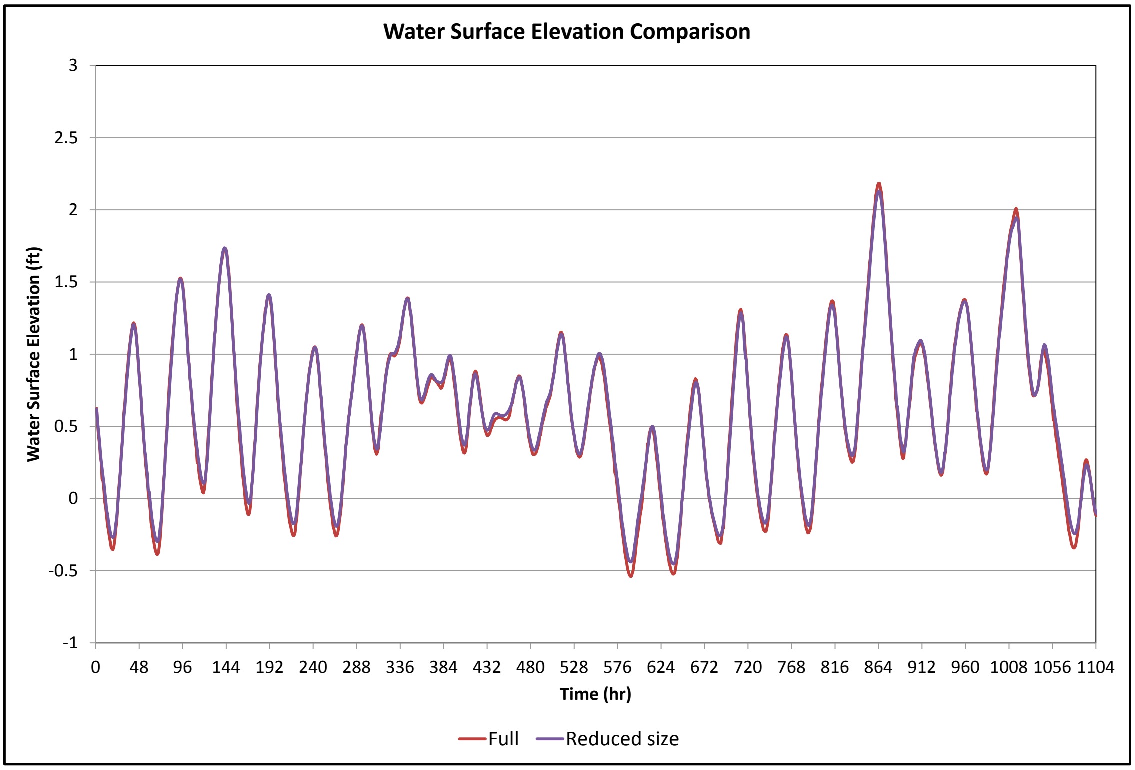


Figure 10. Water surface elevation comparison for large domain and reduced-size domain at point 3.

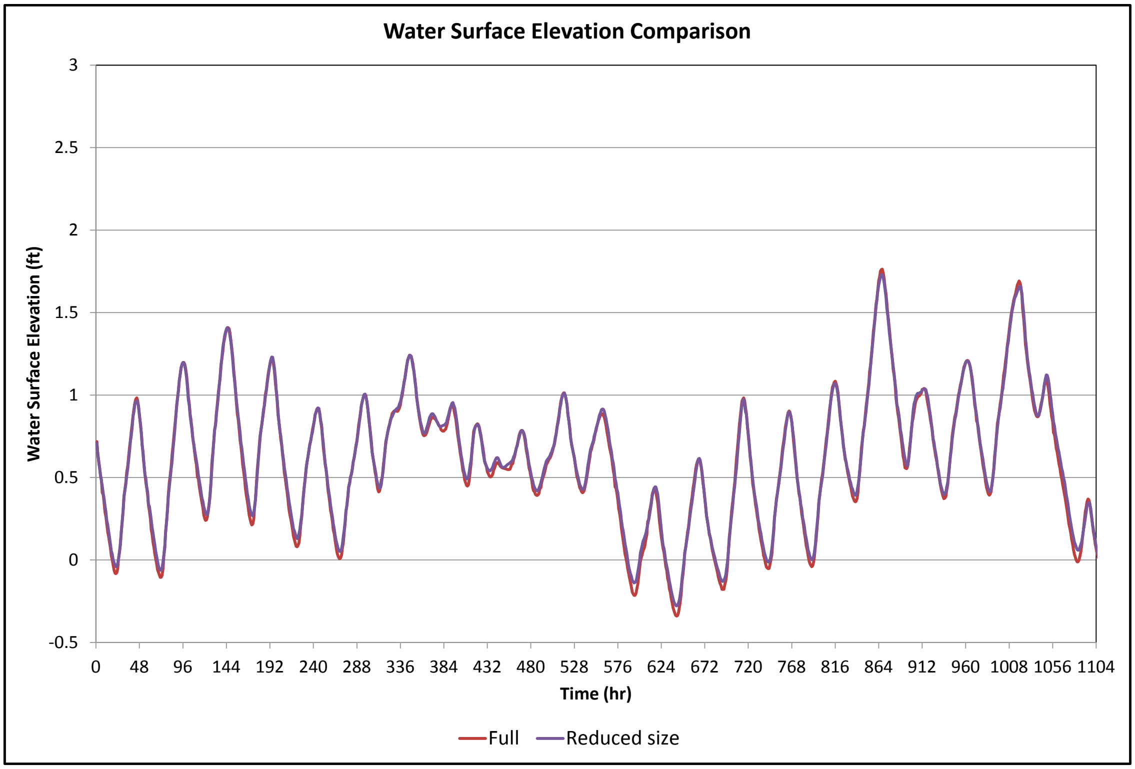


Figure 11. Water surface elevation comparison for large domain and reduced-size domain at point 4.

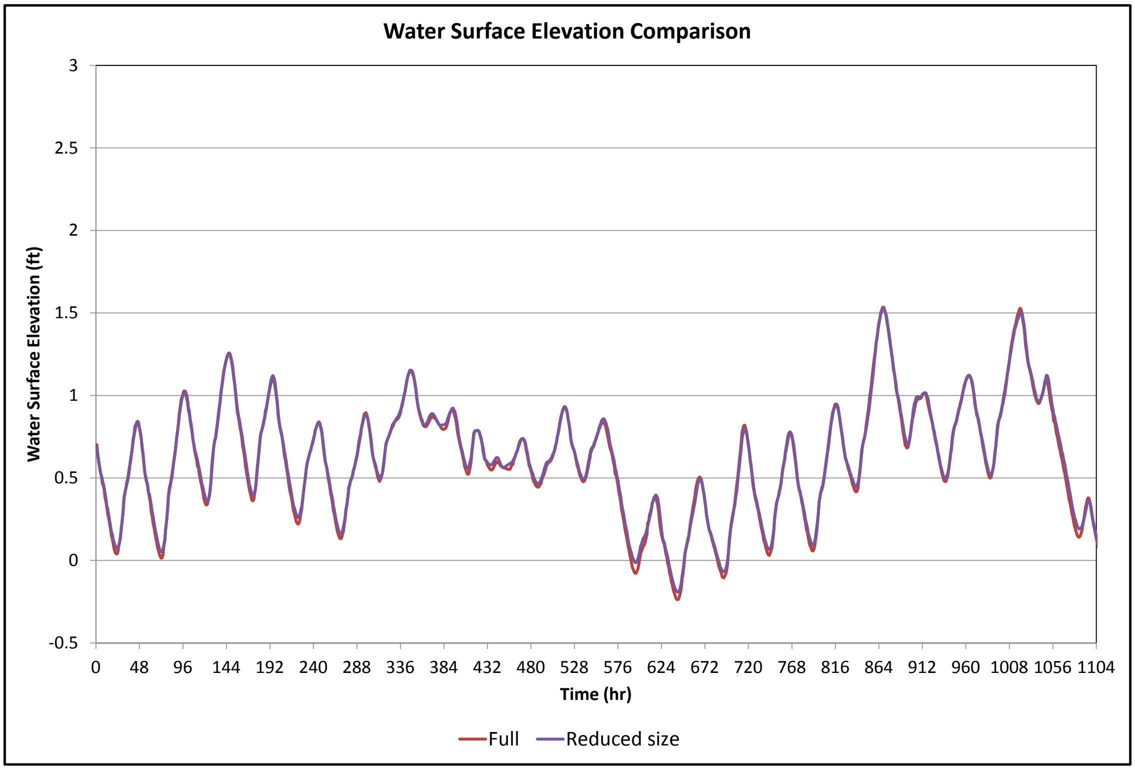


Figure 12. Water surface elevation comparison for large domain and reduced-size domain at point 5.

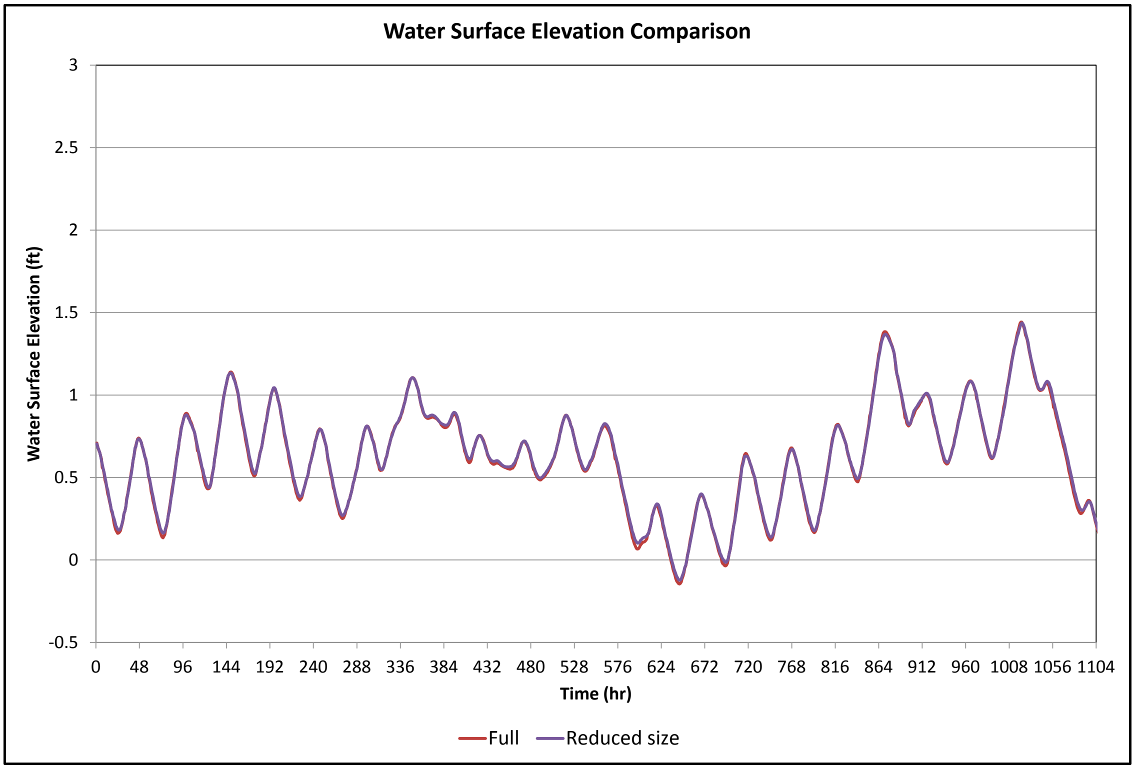


Figure 13. Water surface elevation comparison for large domain and reduced-size domain at point 6.

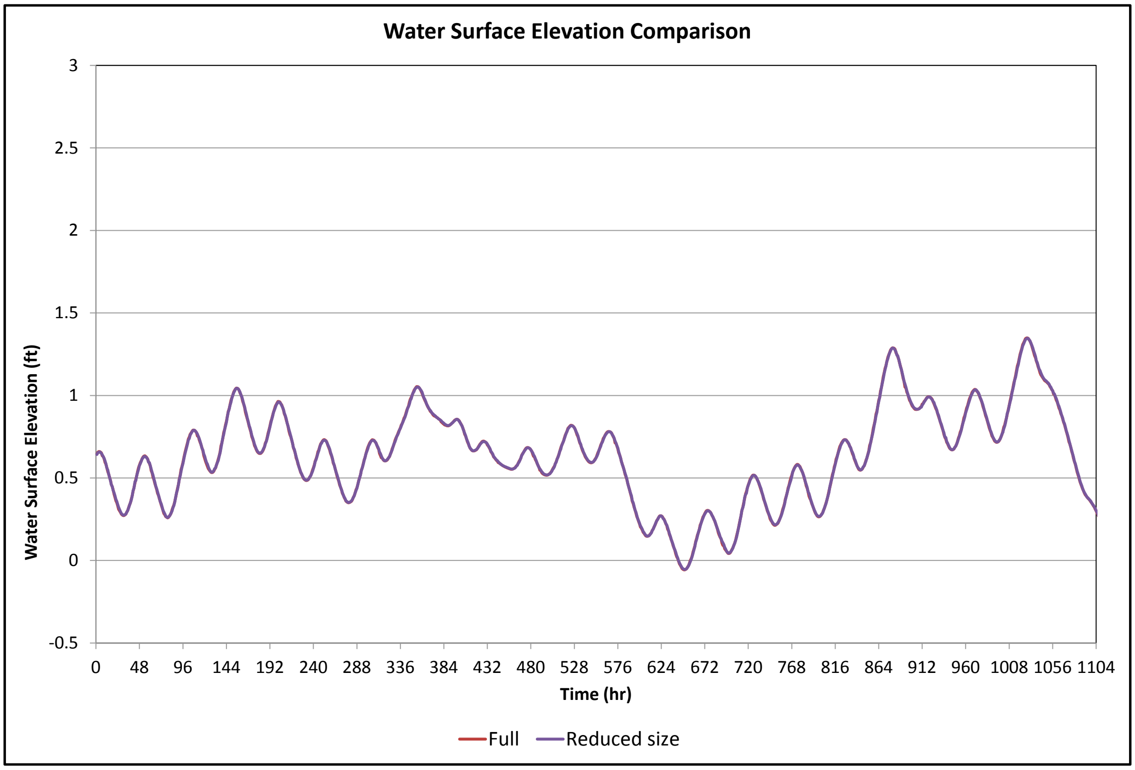


Figure 14. Water surface elevation comparison for large domain and reduced-size domain at point 7.

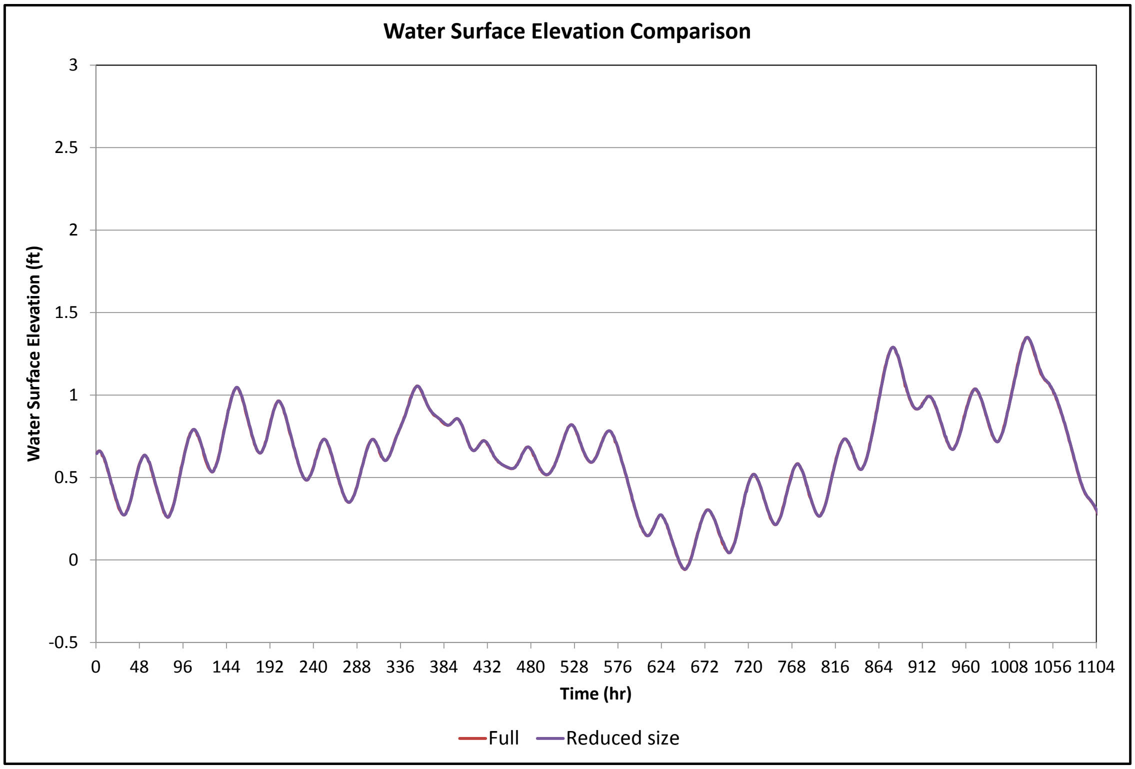


Figure 15. Water surface elevation comparison for large domain and reduced-size domain at point 8.

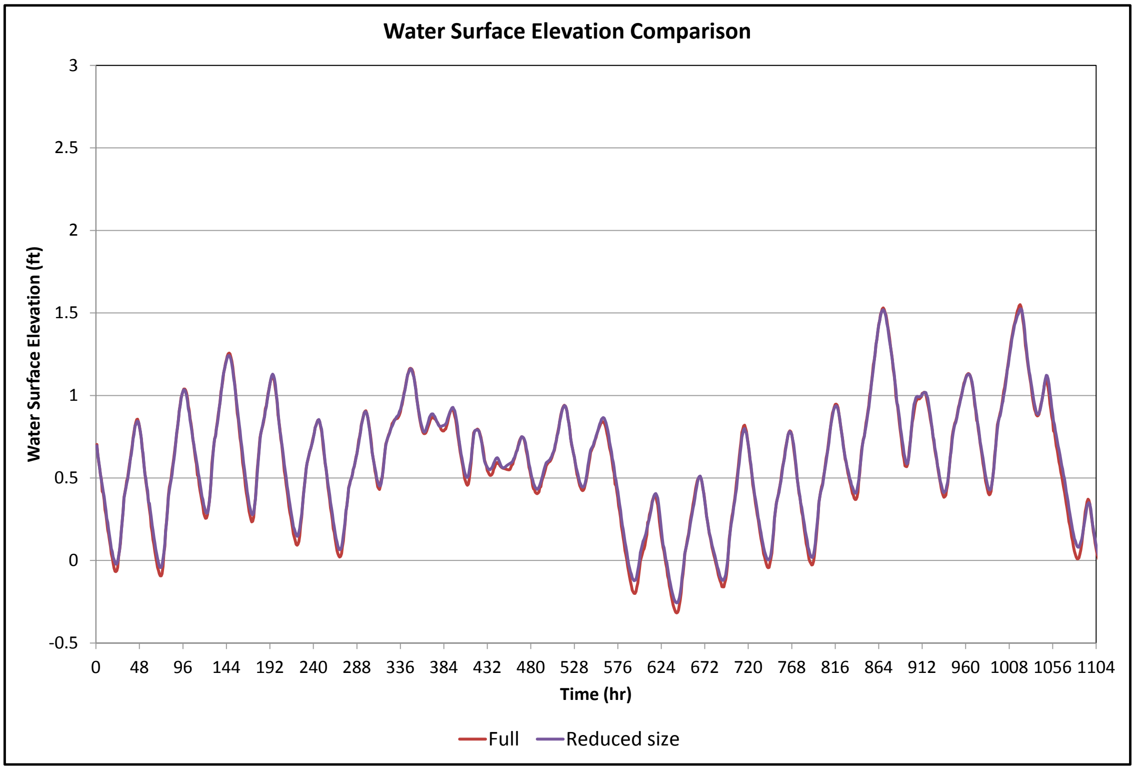
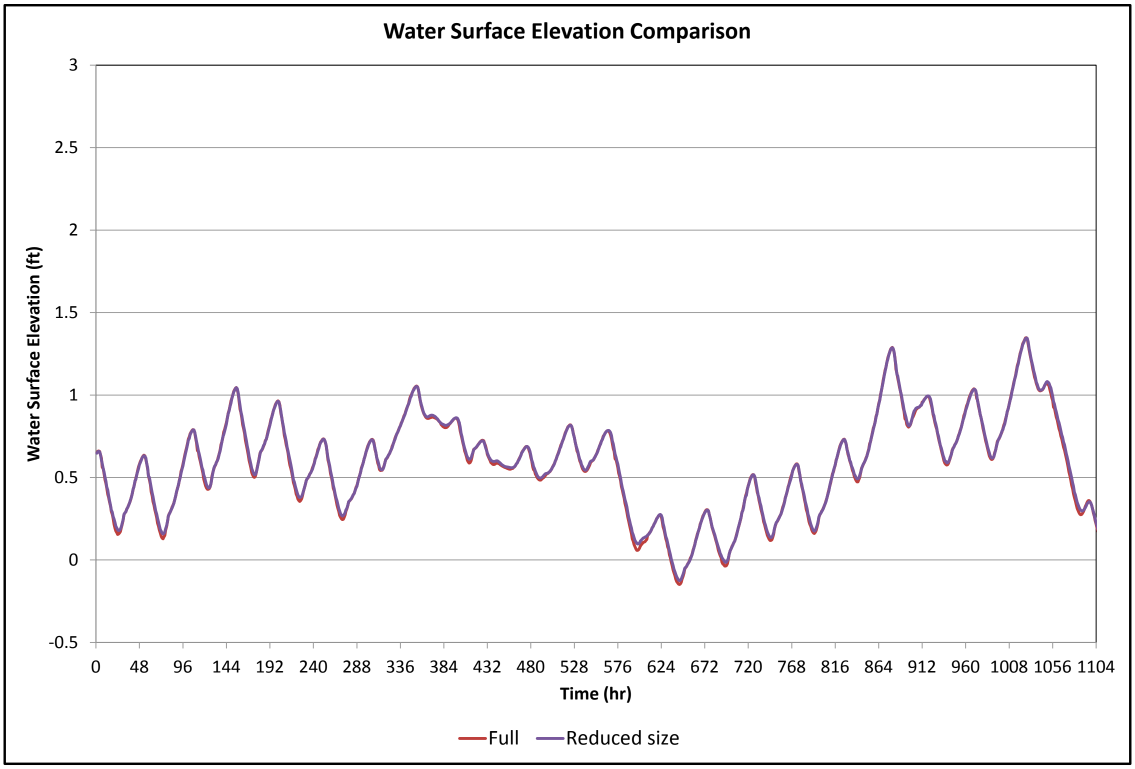


Figure 16. Water surface elevation comparison for large domain and reduced-size domain at point 9.



3 Simulation Alternatives

Six simulation alternatives are defined by MVN for analysis. The analysis table is provided again for reference (Table 2). The alternatives include two (Basin) for analysis of the entire IHNC basin such that the Lake Borgne-side elevation is immediately east of the GIWW sector gate and the Lake Pontchartrain-side elevation is immediately north of the Seabrook sector gate, two (Seabrook) for analysis across only the Seabrook structures such that the Lake Borgne-side elevation is immediately south of the Seabrook sector gate and the Lake Pontchartrain-side elevation is immediately north of the Seabrook sector gate, and two (Isaac) for analysis of the entire IHNC basin under hurricane-like water surface elevation conditions. Each set of alternatives varies due to gate opening combinations or water surface slope across the protected and unprotected side of the domain.

Table 2. Simulation alternative table (repeat).

	Open/Closed/Isaac Conditions				Water Surface Elevation (NAVD88)	
Alternative	Barge Gate	Sector Gate	Bayou Bienvenue	Seabrook Gate Complex	Lake Borgne	Lake Pontchartrain
Basin-4 ft	closed	open	closed	open	4 ft	1 ft
Basin-5 ft	closed	open	open	open	5 ft	1.5 ft
Seabrook-2 ft	NA	NA	NA	open	2 ft	1 ft
Seabrook-4 ft	NA	NA	NA	50%	4 ft	2 ft
Isaac-1	Isaac	Isaac	Isaac	Isaac	Isaac	Isaac
Isaac-2	closed	open	closed	open	Isaac	Isaac

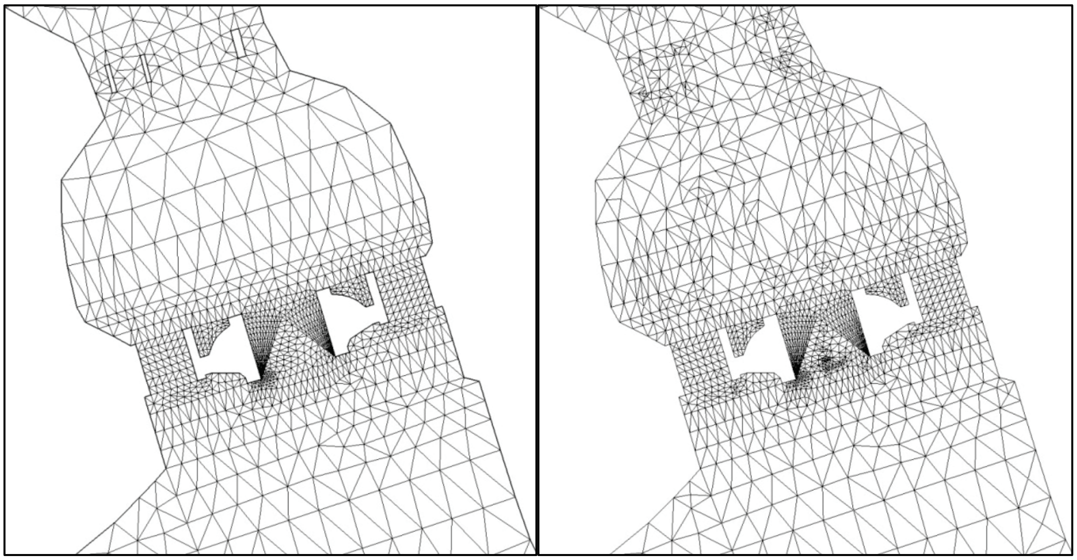
Gate structures are modeled as either 100% open or 100% closed except for the Seabrook-4 ft alternative. This condition models the Seabrook sector gate at 50% open. The sector gates are included in the model mesh such that they can be closed/opened in 10% increments, although not used for the GIWW sector gate conditions. Figure 17 shows the gate locations. The structure closures are modeled by turning mesh elements off in the structure itself such that no computations are made in those elements. The boundary between elements that are on and off is simulated as an infinite vertical wall. The back sides of the gates, when partially open, were modeled as a closed structure such that the entire sector from the hinge point to the gate is turned off.

Figure 17. Gate structures included in the alternative conditions.

The Hurricane Isaac-similar conditions are modeled using data obtained from the ADvanced CIRCulation (ADCIRC) model results of storm surge for the area (USACE 2013b). The water level from the ADCIRC model was pulled at selected locations along the reduced-size model boundary and applied as water level boundary conditions for the AdH simulations. These are 7 day, time-varying conditions that start prior to the storm and continue after the storm has passed the area. The Isaac-1 alternative includes gate conditions as they were operated during the storm such that each structure is closed at the appropriate time in the hydrograph. The Isaac-2 alternative includes set gate conditions for the entire simulation period. Additional details of the Isaac alternative boundary conditions are provided later in this report.

For all simulations, mesh adaption is allowed. AdH adds resolution to a mesh based on user-specified parameters. For these simulations, four levels of adaption (one element can be split into 16 elements) are allowed in the main flow areas of the model domain. By allowing adaption, the mesh can be initially resolved to adequately define the bathymetry. Once the simulation begins, the AdH code will refine the mesh as dictated by the hydrodynamic conditions (and later remove this added resolution if appropriate). This feature is advantageous for capturing eddies and flow details that are often missed when a mesh does not have adequate resolution in an area to properly define the flow conditions. An example of the mesh adaption that occurs for one of the Seabrook conditions is shown in Figure 18.

Figure 18. Mesh adaption around the Seabrook structures (left: original mesh; right: adapted mesh).



4 IHNC Basin Alternative Results

The IHNC basin alternatives model the entire domain area such that systematic impacts can be observed throughout the GIWW and Seabrook areas. These alternatives are simulated with the Seabrook gate complex open, the GIWW barge gate closed, and the GIWW sector gate open. The Basin-4 ft alternative is run with the Bayou Bienvenue structure closed and a 3 ft slope across the basin area (4 ft east of the GIWW structures and 1 ft north of the Seabrook structures). The Basin-5 ft alternative is run with the Bayou Bienvenue structure open and a 3.5 ft slope across the basin area (5 ft east of the GIWW structures and 1.5 ft north of the Seabrook structures).

The model boundary conditions are set up such that the appropriate water surface elevations are obtained at the structures. Bed roughness causes the elevations to drop as the flow propagates into the area of interest and must be accounted for in the boundary conditions. For the Basin-4 ft condition, a value of 5.1 ft is applied at the offshore boundary. For the Basin-5 ft condition, a value of 6.2 ft is applied at the offshore boundary. The inland boundary conditions did not have to be adjusted. These simulations are run to a steady state condition such that the results no longer change in time.

Results from the IHNC Basin simulations are provided as images of velocity patterns around each of the structure areas, water surface and velocity magnitude profiles through each of the sector gates, velocity and water surface point values for each side of the structure areas, and maximum velocity point values in the sector gate structures.

Figure 19 shows the locations of the point values for each of the structure areas. These values are provided in Table 3. The highest velocity in a structure is computed in the GIWW sector gate for the Basin-4 ft alternative. Although this condition is the smaller slope (3.0 ft), the Bayou Bienvenue structure is closed in this alternative, forcing more flow through the GIWW and generating the higher velocity magnitudes. The Basin-5 ft alternative produces high velocities in both the GIWW and Seabrook sector gates due to the 3.5 ft slope across the basin.

Figure 19. Point-analysis locations.

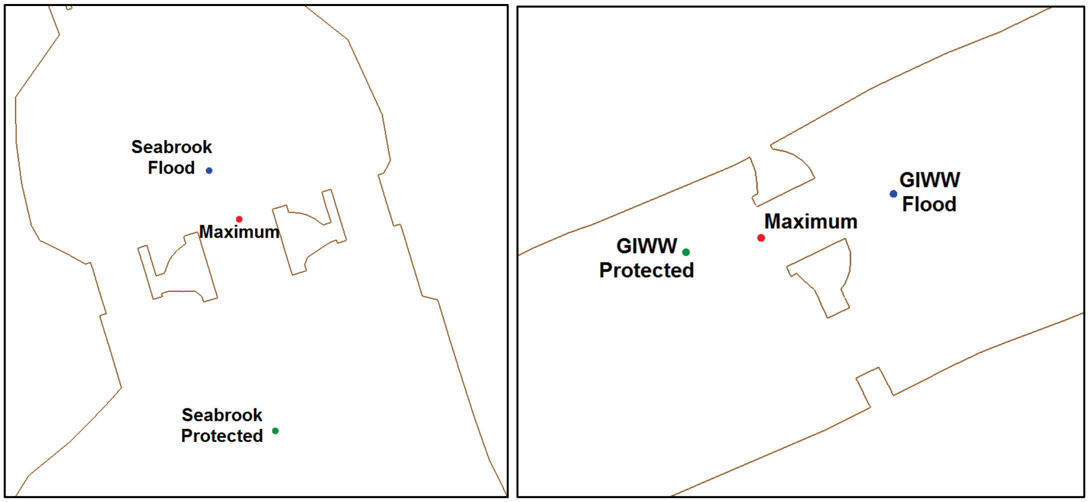


Table 3. Point-value analysis for IHNC Basin alternatives.

Location	Basin-4 ft			Basin-5 ft		
	Water Surface Elevation (ft)	Steady State Velocity (ft/s)*	Maximum Velocity in Structure (ft/s)	Water Surface Elevation (ft)	Steady State Velocity (ft/s)	Maximum Velocity in Structure (ft/s)
GIWW Flood	3.98	2.04	13.45	5.20	1.70	11.01
GIWW Protected	1.98	10.72		3.81	9.02	
Seabrook Protected	1.66	1.53	7.67	2.88	2.28	10.87
Seabrook Flood	1.06	5.63		1.44	9.27	

*ft/s = feet per second

Figures 20 and 21 show the velocity contours and vectors for the Basin-4 ft and Basin-5 ft alternatives, respectively, in the GIWW area. Figures 22 and 23 show the same information for the Seabrook-structure area. The vectors are indicative of direction only (i.e., they are not scaled according to the velocity magnitude; color indicates velocity magnitude). The flow-reversal patterns are easily observed on the exit side of each of the structures as well as the locations of high velocities and their decay patterns. The variation in the velocity magnitudes between the two alternative conditions is evident in the figures. Because of the geometry of the structures, the direction of flow, and the bridge piers to the north of the Seabrook structure, high velocity values extend over a large distance on the protected side of the GIWW structure and on the northern side of the Seabrook structure.

Figure 20. Basin-4 ft velocity in the GIWW- structure area (Bayou Bienvenue closed).

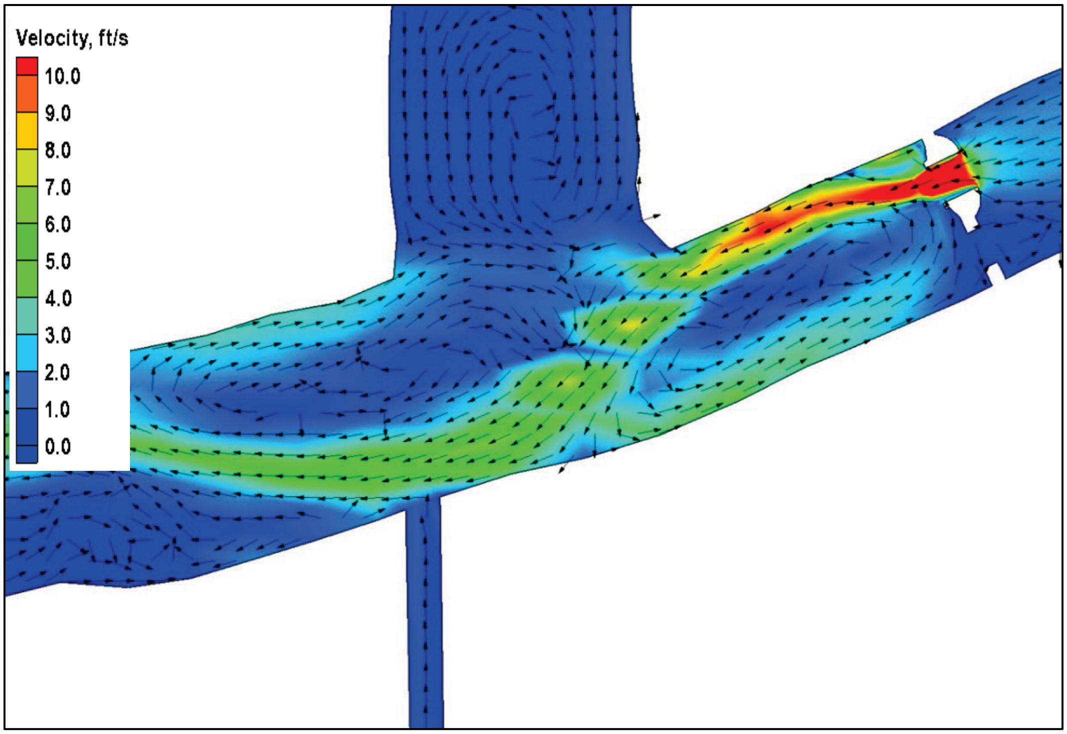


Figure 21. Basin-5 ft velocity in the GIWW-structure area (Bayou Bienvenue open).

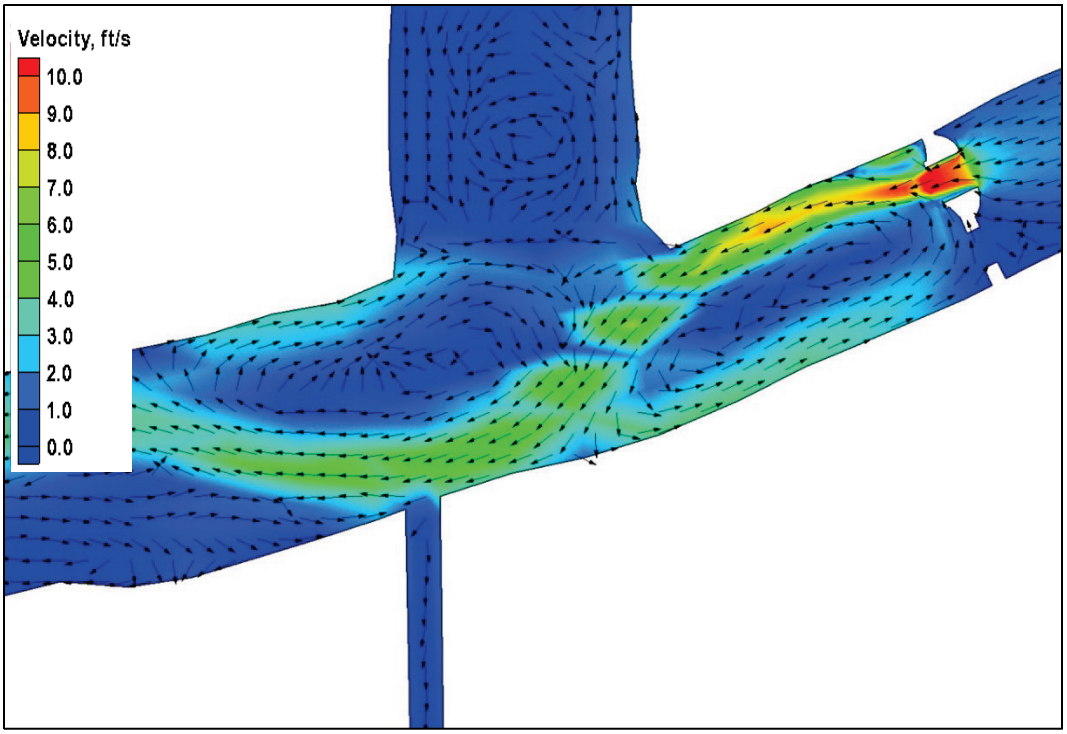


Figure 22. Basin-4 ft velocity in the Seabrook-structure area.

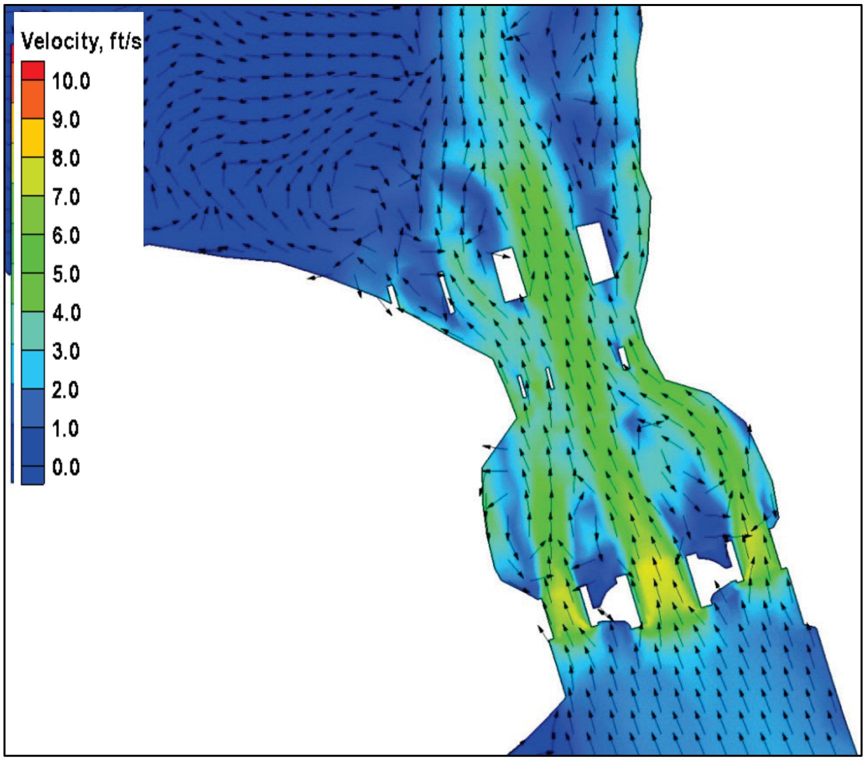
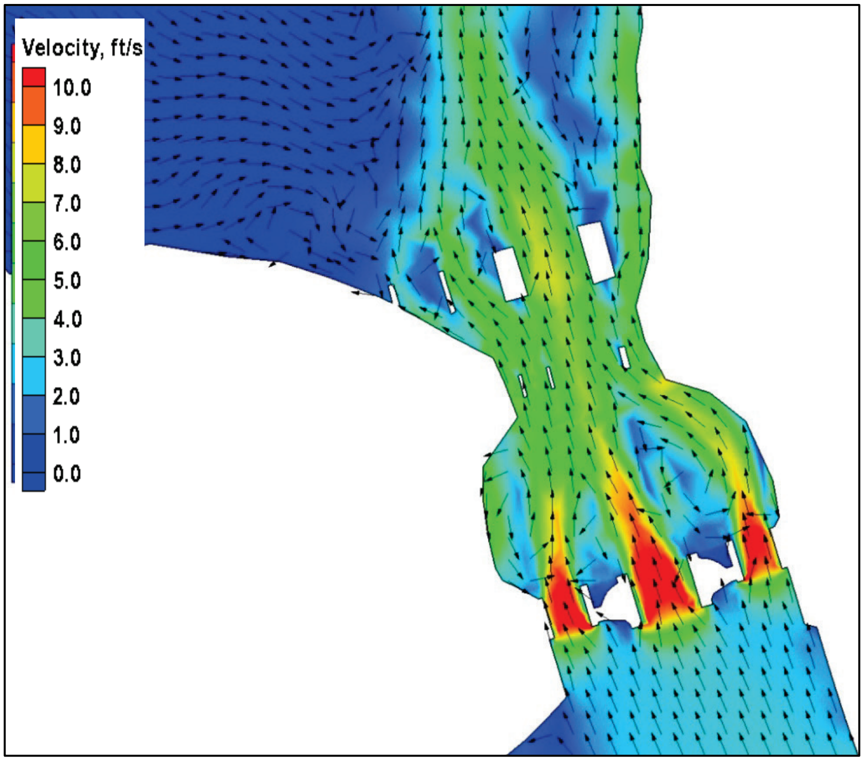


Figure 23. Basin-5 ft velocity in the Seabrook-structure area.



Water surface and velocity magnitude profiles through the GIWW and Seabrook structures at steady state conditions are plotted along the lines shown in Figure 24 for each of the structure areas. The profile values for each alternative, starting on the protected side, at "0", and moving toward the flood side are shown in Figures 25 and 26 for the GIWW area and the Seabrook area, respectively. The solid lines are the water surface elevation profiles with values on the left axis, and the dashed lines are the velocity magnitudes with values on the right axis.

The velocity magnitude profiles mirror the water surface elevation profiles in many ways. The drop in water level, or head, across the structure causes an increase in velocity as known through the conservation of mass and momentum equations. However, the velocity magnitudes reach a similar value on each side of the structure, returning to the same value as prior to entering the structure.

Figure 24. GIWW (left) and Seabrook (right) observation arcs.

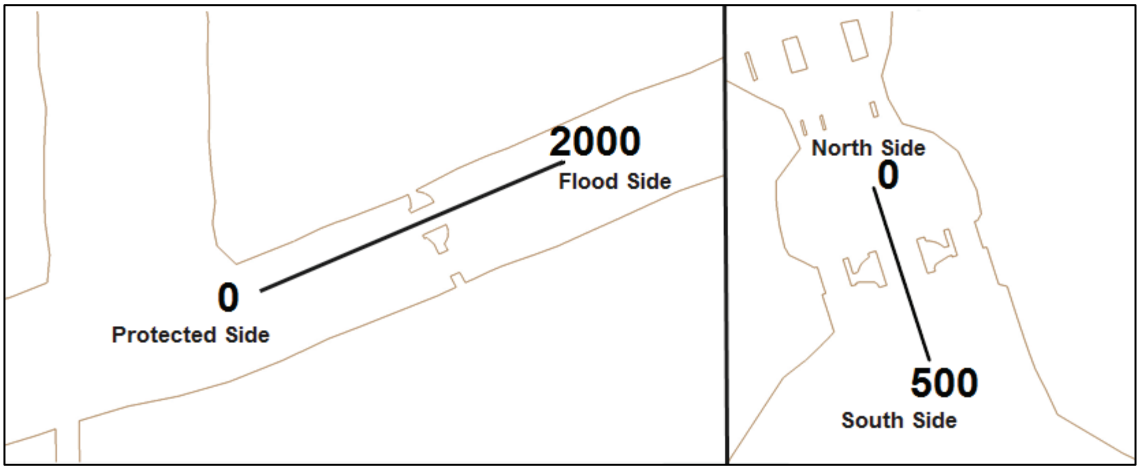


Figure 25. Profiles through the GIWW sector gate for the IHNC Basin alternatives.

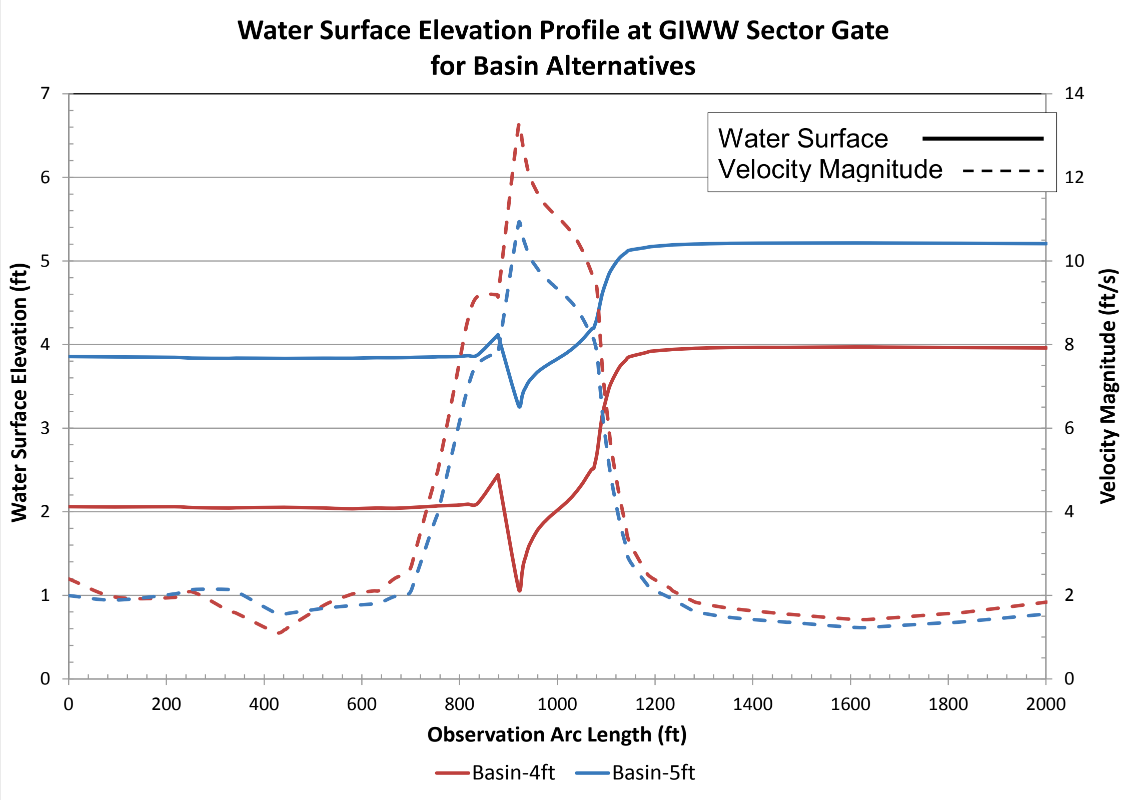
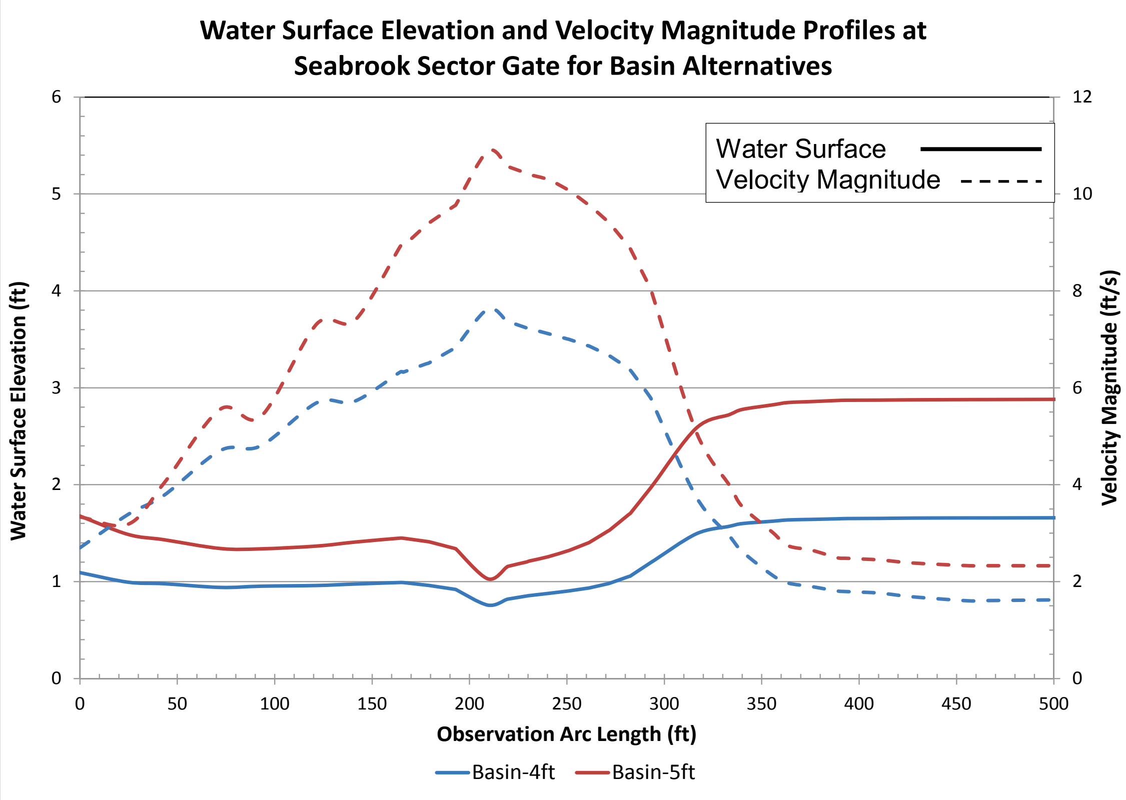


Figure 26. Profiles through the Seabrook sector gate for the IHNC Basin alternatives.



5 Seabrook Alternative Results

The Seabrook alternatives simulate only the IHNC from its connection with the GIWW north through the Seabrook structures into Lake Pontchartrain. The Seabrook-2 ft alternative is run with the 3 structures open and a 1 ft slope across the structures (2 ft south of the Seabrook structures and 1 ft north of the Seabrook structures). The Seabrook-4 ft alternative is run with the Seabrook lift gates closed and the sector gate 50% closed with a 2 ft slope across the structures (4 ft south of the structures and 2 ft north of the Seabrook structures).

The model boundary conditions are set up such that the appropriate water surface elevations are obtained at the structures. Bed roughness causes the elevations to drop as the flow propagates into the area of interest and must be accounted for in the boundary conditions. For the Seabrook-2 ft condition, a value of 2.8 ft is applied at the IHNC (southern)-side boundary. For the Seabrook-4 ft condition, a value of 4.1 ft is applied at the IHNC (southern)-side boundary. The Seabrook-4 ft alternative does not need as large of an adjustment at the boundary due to the 50% closure of the sector gate limiting the flow passage through the structure. The Lake Pontchartrain (northern) boundary conditions did not have to be adjusted. These simulations are run to a steady state condition such that the results no longer change in time.

Results from the Seabrook simulations are provided as images of velocity patterns around the structure areas, water surface and velocity magnitude profiles through the sector gate, velocity and water surface point values for each side of the structure, and maximum velocity point values in the sector gate. Figure 27 shows the locations of the point values of the Seabrook-structure area. The maximum velocity magnitude occurs at different places for the two alternative conditions and is labeled accordingly in the figure. These point analysis values are provided in Table 4.

The highest velocity in the sector gate is computed for the Seabrook-4 ft alternative. This condition simulates the sector gate as 50% closed and the lift gates as 100% closed (Figure 17). The drastic reduction in flow area causes the water surface slope across the structure to rise, which then forces the velocity magnitude to increase through the limited gate opening.

Figure 27. Seabrook point-analysis locations.

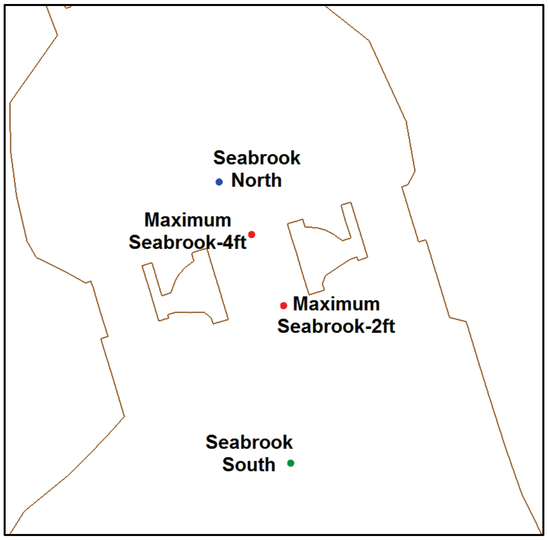


Table 4. Point-value analysis for Seabrook alternatives.

Location	Seabrook-2 ft			Seabrook-4 ft		
	Water Surface Elevation (ft)	Steady State Velocity (ft/s)	Maximum Velocity in Structure (ft/s)	Water Surface Elevation (ft)	Steady State Velocity (ft/s)	Maximum Velocity in Structure (ft/s)
Seabrook South	2.05	1.83	9.64	4.02	0.76	12.05
Seabrook North	0.93	7.57		1.86	8.02	

Figures 28 and 29 show the velocity contours and vectors for the Seabrook-2 ft and Seabrook-4 ft alternatives, respectively. The vectors are indicative of direction only (i.e., they are not scaled according to the velocity magnitude; color indicates velocity magnitude). The flow-reversal patterns are easily observed on the exit side of each of the structures as well as the locations of high velocities and their decay patterns. The variation in the velocity magnitudes between the two alternative conditions is evident in the figures.

Water surface and velocity magnitude profiles through the Seabrook sector gate are plotted along the line shown in Figure 30. The profile values for each alternative, starting on the north side, at “0”, and moving toward the south side, at “500”, are shown in Figure 31. The solid lines are the water surface elevation profiles at steady state conditions with values on the left axis, and the dashed lines are the velocity magnitudes with values on the right axis.

Figure 28. Seabrook-2 ft velocity in the structure area.

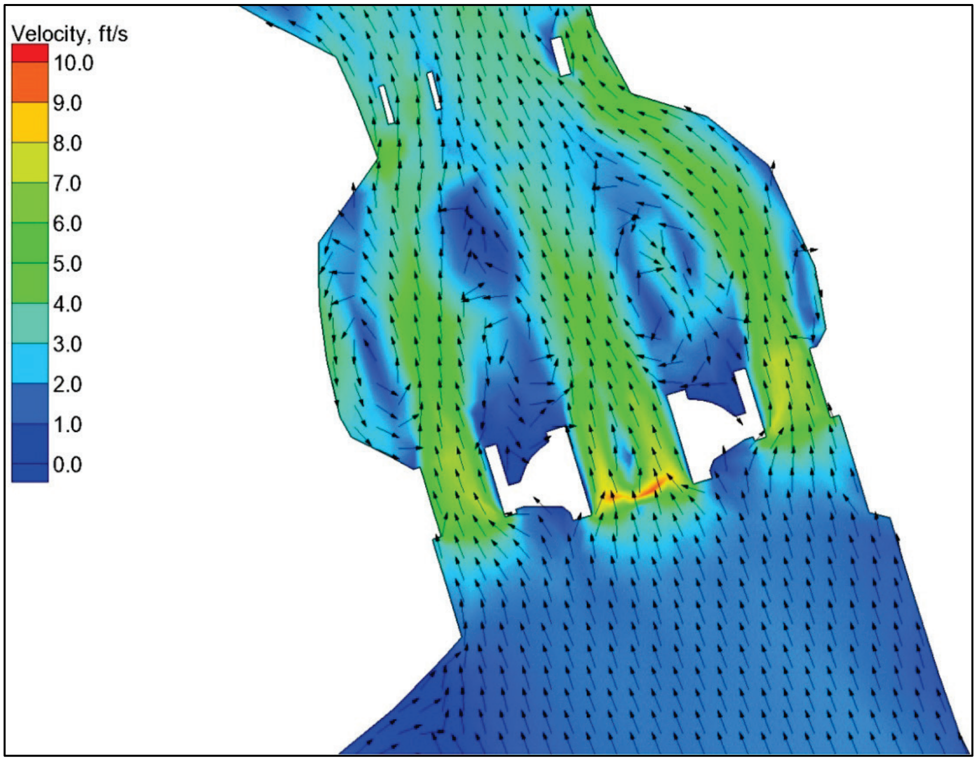


Figure 29. Searbrook-4 ft velocity in the structure area.

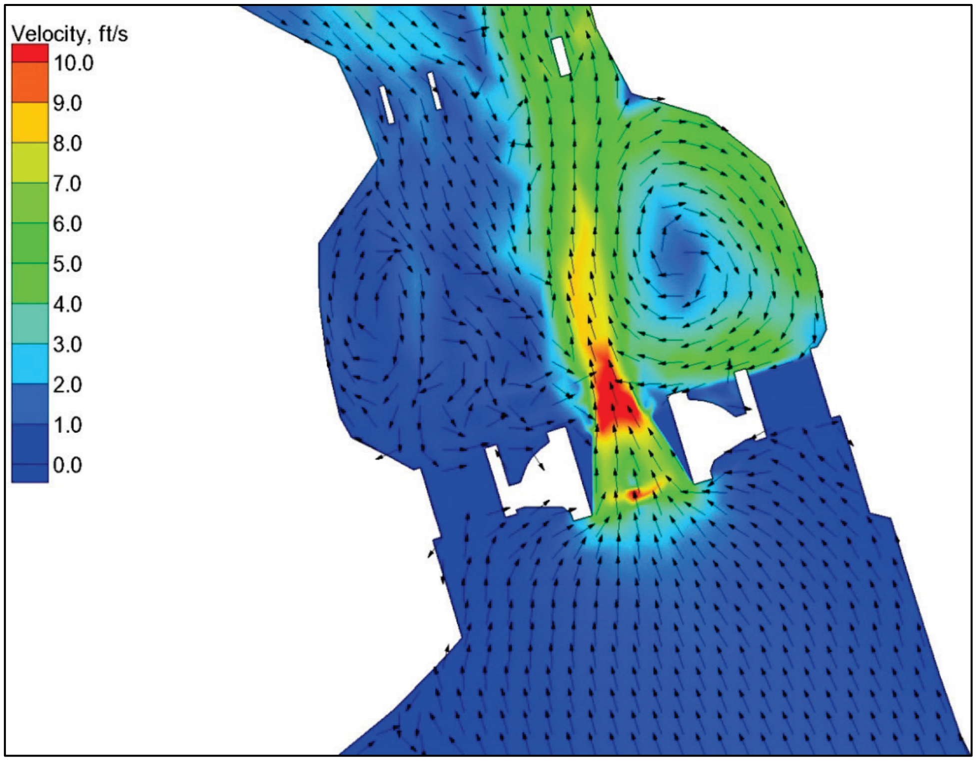


Figure 30. Seabrook observation arc.

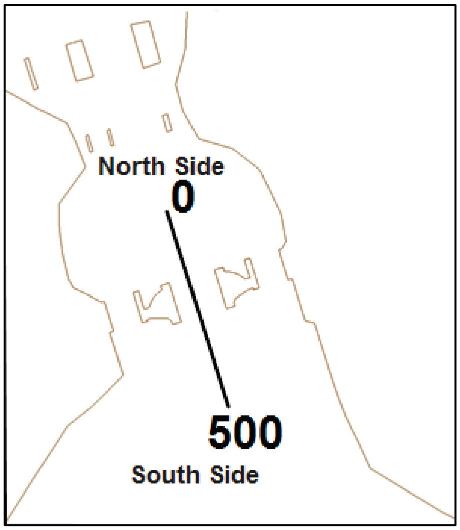
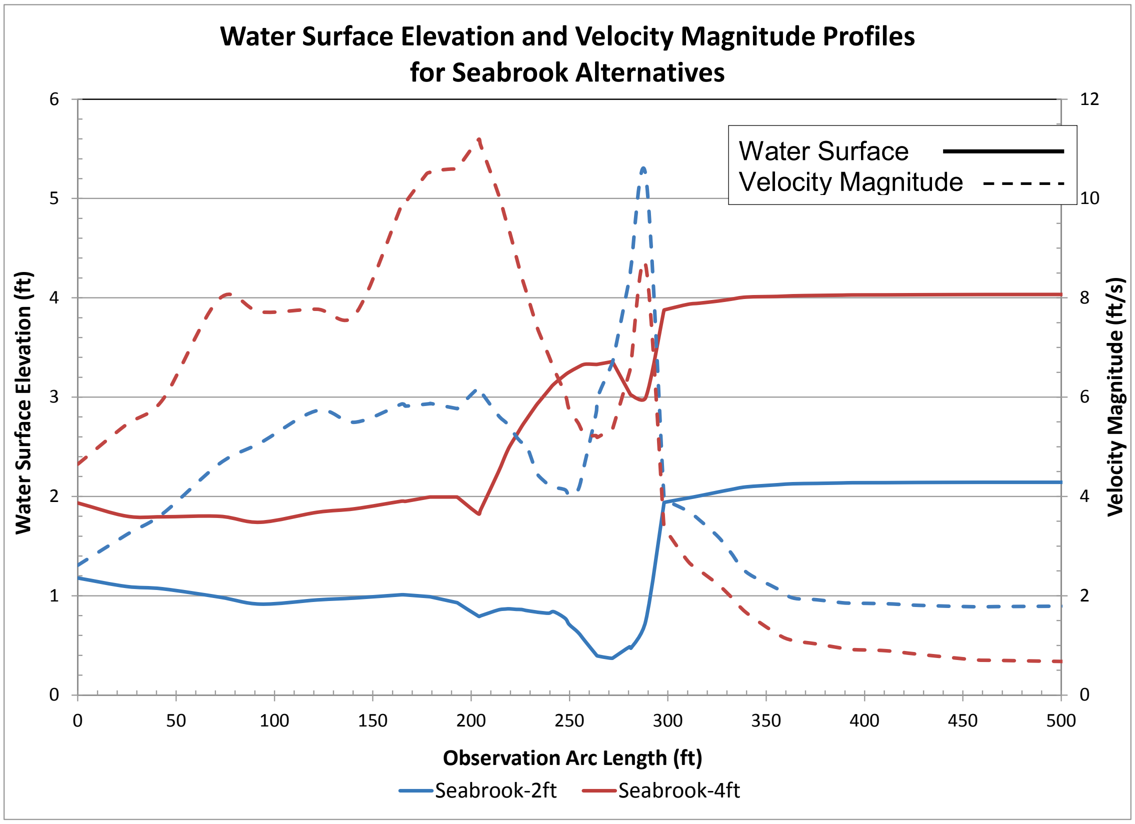
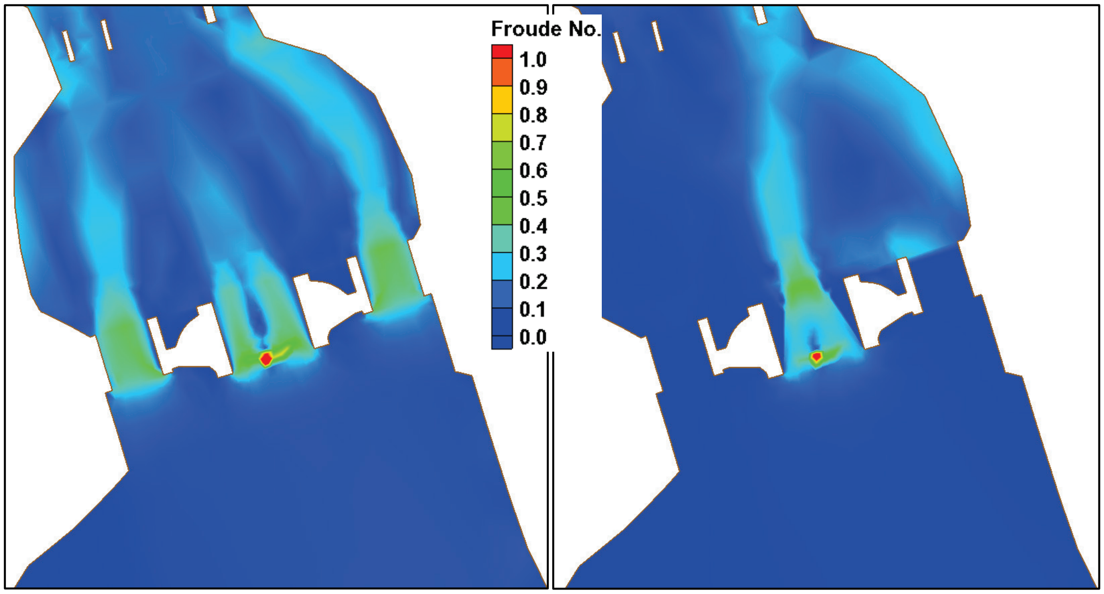


Figure 31. Profiles through the Seabrook sector gate for the Seabrook alternatives.



Similar mirroring effects are observed between the water surface elevation and the velocity magnitude profiles as observed in the Basin alternatives. The effects of the flow direction and the bridge piers to the north of the Seabrook structures generate high velocity values over at least 500 ft on the northern side of the structure. This effect is not unexpected; however, the high velocity magnitudes occurring over a large area should be considered when designing bed and pier scour-protection measures. The shape of the water surface elevation and velocity magnitude profile indicate the presence of a hydraulic jump or flow discontinuity with the sharp drop in the elevation (rise in the velocity) on the southern side of the structure followed by the humped rise and fall of the elevation through the structure. Upon computing the Froude number for these alternatives, the supercritical nature of the flow is verified by values greater than 1.0 on the southern side of the sector gate (Figure 32). Supercritical flow can have implications for local scour as well as water levels and should be considered in operations, particularly if more extreme flow conditions are anticipated.

Figure 32. Froude number for the Seabrook alternative; greater than 1.0 indicates supercritical flow.



6 Hurricane Alternative Results

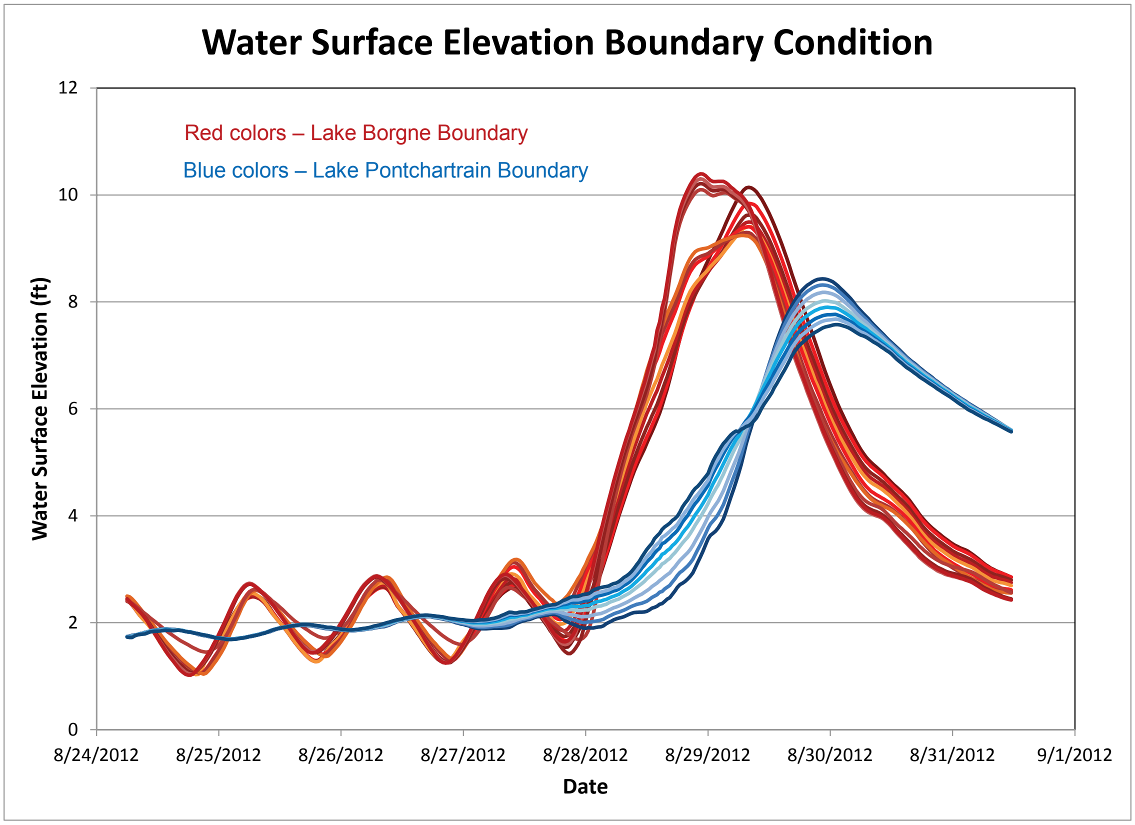
Hurricane Isaac struck coastal Louisiana in the vicinity of New Orleans on 28–29 August 2012. During this storm, the Seabrook, GIWW, and Bayou Bienvenue structures were operated based on previously developed operation plans. The two hurricane alternatives (Isaac) were driven with a water surface elevation hydrograph generated with an ADCIRC simulation of a storm like Hurricane Isaac (USACE 2013a). The Isaac alternatives differ based on gate closures. The Isaac-2 alternative is defined as the GIWW barge gate and the Bayou Bienvenue structure closed and the GIWW sector gate and the three Seabrook gates open. The Isaac-1 alternative is defined as the structures were actually operated during the storm, with gate positions changing over time. In order to model these time-varying closures, the model is stopped at the appropriate time, and the structure is turned off; then the model is started again with the previous time-step results as the initial condition. This method allows for the simulation to represent the time history of the gate closures. The gate closure sequence for the Isaac-1 alternative is provided in Table 5.

Table 5. Gate closure sequence for the Isaac-1 alternative.

Structure	Time/Date Closed
GIWW Barge Gate	Closed pre-event
GIWW Sector Gate	8/28/2012 11:00 CDT
Bayou Bienvenue Lift Gate	8/28/2012 11:00 CDT
Seabrook Sector Gate	8/28/2012 13:30 CDT
Seabrook Lift Gates	8/28/2012 13:30 CDT

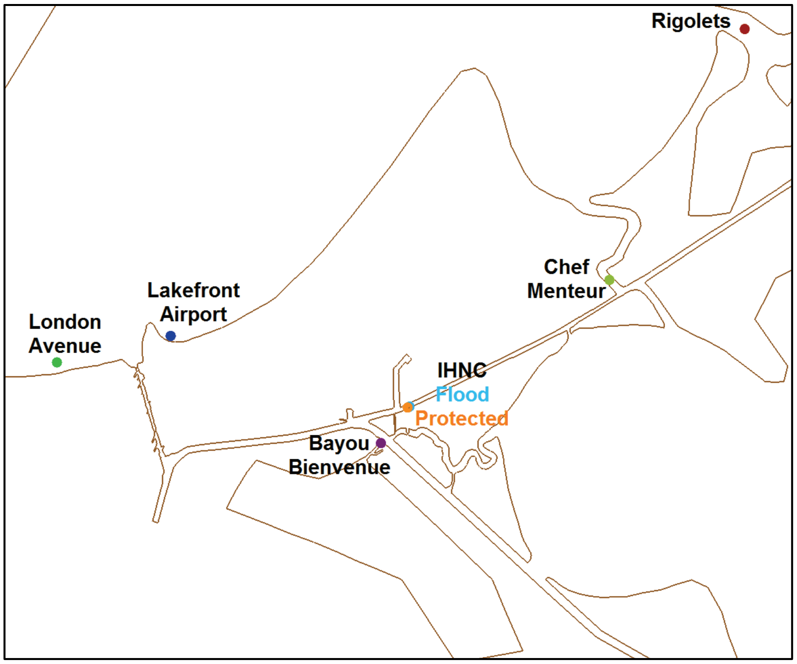
The water surface boundary conditions are obtained from a previously simulated ADCIRC model of a storm surge similar to that from Hurricane Isaac (USACE 2013b). The ADCIRC model was developed to analyze storm surge into the area. The AdH model does not include the hurricane pressure and wind conditions but is driven only by the ADCIRC-computed water levels. The ADCIRC results were extracted at each AdH mesh element along the boundaries (Figure 5). To reduce the number of boundary conditions applied in the AdH model, elements with similar water surface elevations are grouped together such that each element group is given a constant value along its length for each time-step. A total of 20 different water surface elevation data sets are used to produce the boundary condition hydrograph for both model boundaries. This variation allows for the changing water levels along each boundary without having to supply time-varying data at every element along each boundary edge. The ADCIRC model is run in metric units on a Mean Sea Level Datum. The boundary condition data are converted to English units and shifted by 0.5106 ft so that the elevations reference NAVD88, the datum of the AdH model. Figure 33 shows the AdH boundary-condition, water surface elevations. The red-colored series are applied along the Lake Borgne boundary, and the blue-colored series are applied along the boundary in Lake Pontchartrain. The two Hurricane Isaac alternative conditions are simulated with the same boundary conditions. The only difference between the two alternatives is the structure closures.

Figure 33. Water surface elevation, boundary-condition time-series for Hurricane Isaac alternatives.



The Isaac-1 alternative adjusts the gates according to the time of closure during the storm while the Isaac-2 alternative varies from the historic operations. Seven gage locations within the model domain are used for some of the model analyses presented. These locations match locations that exist in the field. Figure 34 shows the location of these points.

Figure 34. Isaac-alternative analysis locations.

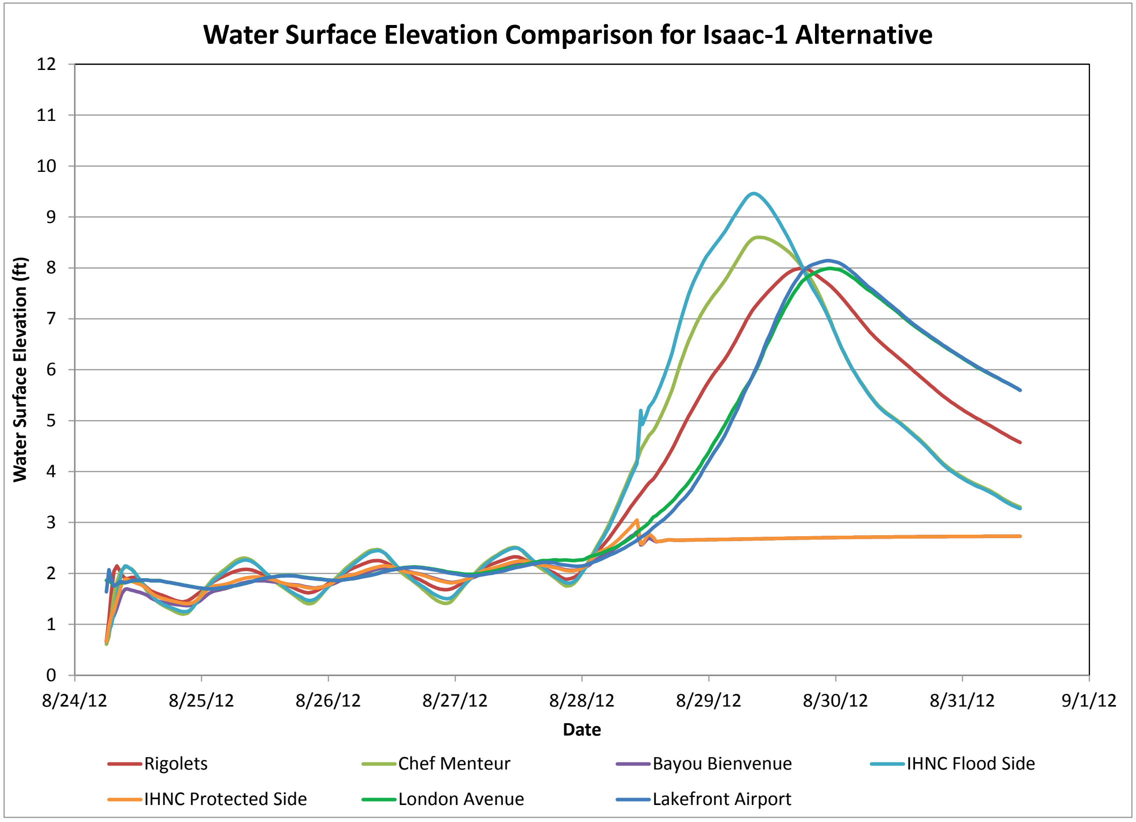


The AdH model is not set up to be a storm-surge model. The overbank areas are not included in the model domain nor are the numerous small channel connections that extend throughout this south Louisiana area. Hurricanes produce very strong and changing wind patterns, but wind is not included in this model set up. For this model, the wind effects are only included in the water level at the boundaries. Therefore, the intent of this modeling was not to simulate actual conditions during Hurricane Isaac but rather to simulate velocities in the project area of interest during a storm with a surge hydrograph similar to Hurricane Isaac.

Isaac-1 results

Figure 35 shows the water surface elevation for the model at the seven gage locations. The gate closures on the GIWW and Bayou Bienvenue are shown in the model by the flat line of the water surface elevation for the protected side of the structures. The greatest elevation is on the flood side of the structures at the IHNC flood and Chef Menteur locations.

Figure 35. Isaac-1 water surface elevation results.



Additional analyses are performed at the locations on either side of the GIWW and Seabrook structures as shown in Figure 36. Figure 37 shows the water surface elevation at each of these locations, and Figure 38 shows the velocity magnitudes. Table 6 gives the maximum-point-value velocity magnitude and water surface elevation on each side of the structures and the maximum velocity magnitude in the structures during the simulation period.

The water levels are highest for the flood side of the GIWW sector gate and the Lake Pontchartrain side of the Seabrook sector gate. The water levels on the protected side (i.e., in the interior of the structure area) remain low throughout the event, as expected. The peak water level on the northern side at Seabrook lags the high levels in the GIWW by approximately 15 hr. As the storm surge recedes, the elevations drop faster on the unprotected side of the GIWW. The levels in Lake Pontchartrain on the unprotected, or northern, side of the Seabrook structures recede slower due to the limited flow pathways with the structures closed.

Figure 36. Point-analysis locations and location of maximum values in the structures.

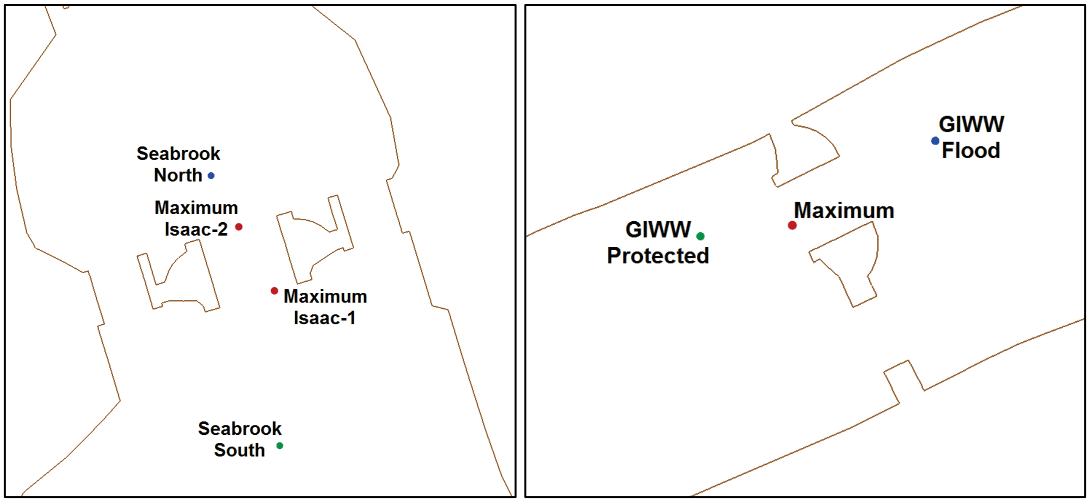


Figure 37. Isaac-1 water surface elevations at the structures.

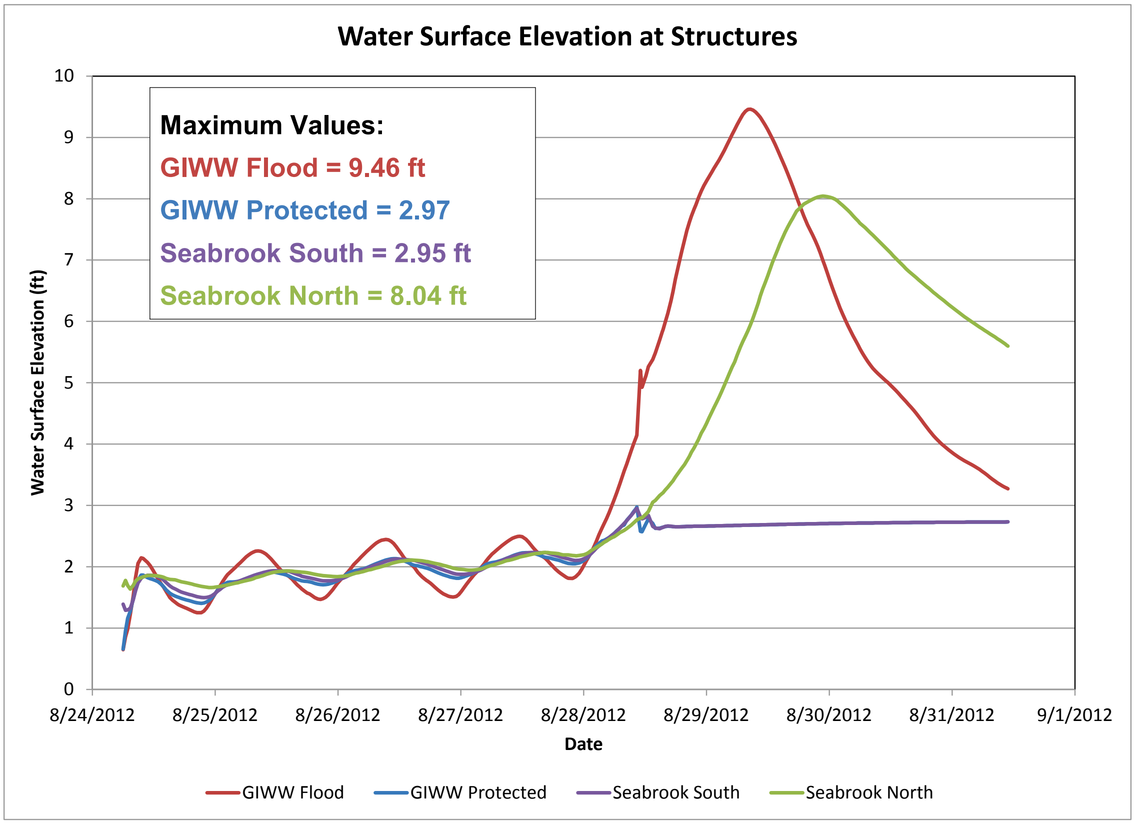


Figure 38. Isaac-1 velocity magnitudes at the structures.

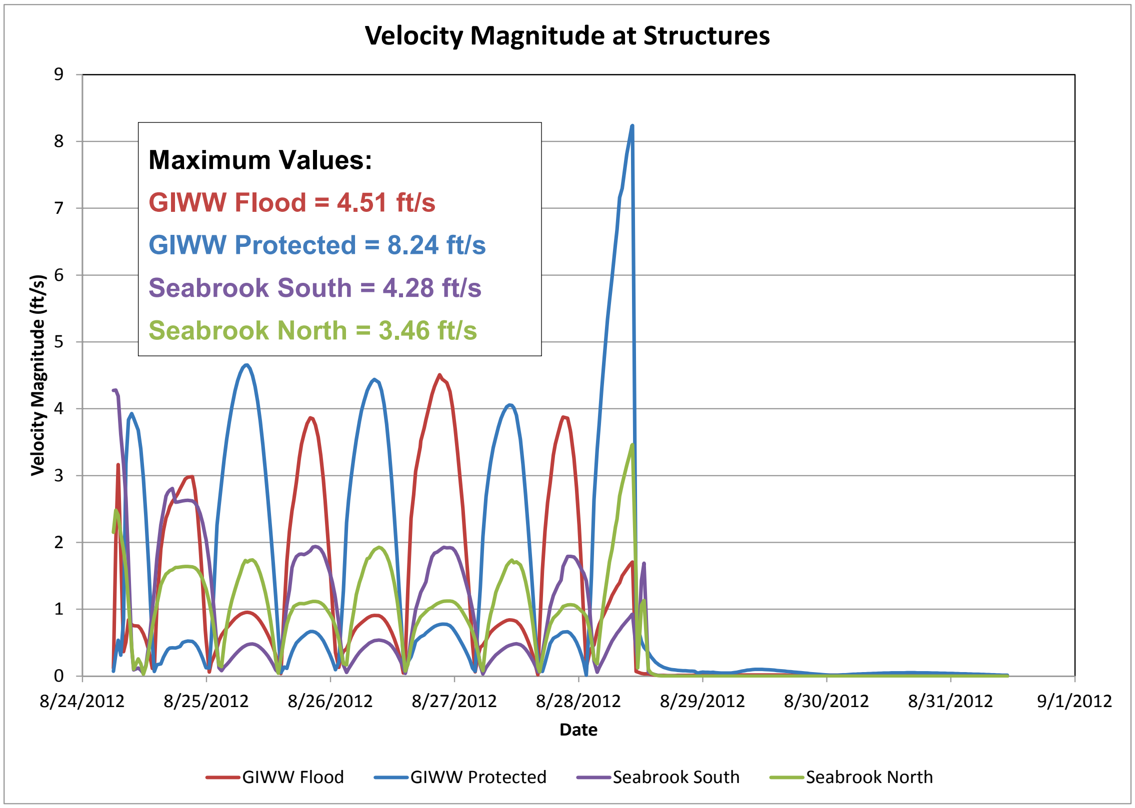


Table 6. Point-value analysis for Isaac-1 alternative.

Location	Isaac-1		
	Water Surface Elevation (ft)	Maximum Velocity (ft/s)	Maximum Velocity in Structure (ft/s)
GIWW Flood	9.46	4.51	17.09
GIWW Protected	3.05	8.24	
Seabrook South	2.95	4.28	5.33
Seabrook North	8.04	3.46	

The velocity magnitudes are generally highest on the GIWW protected side and on the Seabrook north side. The alternating pattern of highs and lows for each side of a structure is due to the change in tidal direction. The overall greatest magnitude is just prior to the closing of the structures, as expected. The velocity magnitudes on the GIWW flood side and Seabrook south side are greatest during the prior tidal fluctuations than at the time of structure closure. Since the GIWW structures are closed prior to the Seabrook structures, there are two spikes in the results at the Seabrook locations—one due to the GIWW closures and the other due to the Seabrook closures. Once the closures are made, the velocity magnitudes reduce to near zero.

Isaac-2 results

The water surface elevation results for the Isaac-2 alternative show that the locations along the unprotected side of the structures experience the highest elevations (Figure 39). The flood side of the GIWW structures and the Chef Menteur elevations are very similar through the peak of the hydrograph. The elevations in the Rigolets peak approximately 0.5 ft below the Chef Menteur, and there is a lag in the timing of this peak value by 9 hr. The locations in Lake Pontchartrain (London Avenue and Lakefront Airport) experience high peak elevations as well, and they are lagged 12 hr from the peak elevation on the flood side of the GIWW structures. Although the GIWW sector gate and the Seabrook structures are open in this alternative, the high surge values cannot easily pass through the limited channel of the GIWW and IHNC. Therefore, the Chef Menteur and Rigolets pathways become important pathways that allow the high-elevation flows to pass into Lake Pontchartrain. The Bayou Bienvenue and IHNC protected-side locations have the lowest peak elevations as expected since they are located on the protected side of the hurricane-protection measures, and flow into this area is limited. As the waters recede, the unprotected side of the structures decays faster than the internal areas. Again, this is expected since the waters that do reach the inner areas of the protection measures have limited pathways out of the area.

Additional analyses are performed at the locations on either side of the GIWW and Seabrook structures (Figure 36). Figure 40 shows the water surface elevation at each of these locations, and Figure 41 shows the velocity magnitudes. Table 7 gives the maximum-point-value velocity magnitude and water surface elevation on each side of the structures and the maximum velocity magnitude in the structures during the simulation period.

The water levels are, again, highest for the flood side of the GIWW sector gate and the Lake Pontchartrain side of the Seabrook sector gate. The water levels in the interior of the structure area remain lower than the peak value but do exceed 7 ft at all locations due to the open structures in the GIWW and IHNC. The peak water level on the northern side at Seabrook lags the high levels in the GIWW by approximately 13 hr. The drawdown of the surge is fastest for the flood side of the GIWW structure but falls at similar rates for the other three locations.

Figure 39. Isaac-2 water surface elevation results.

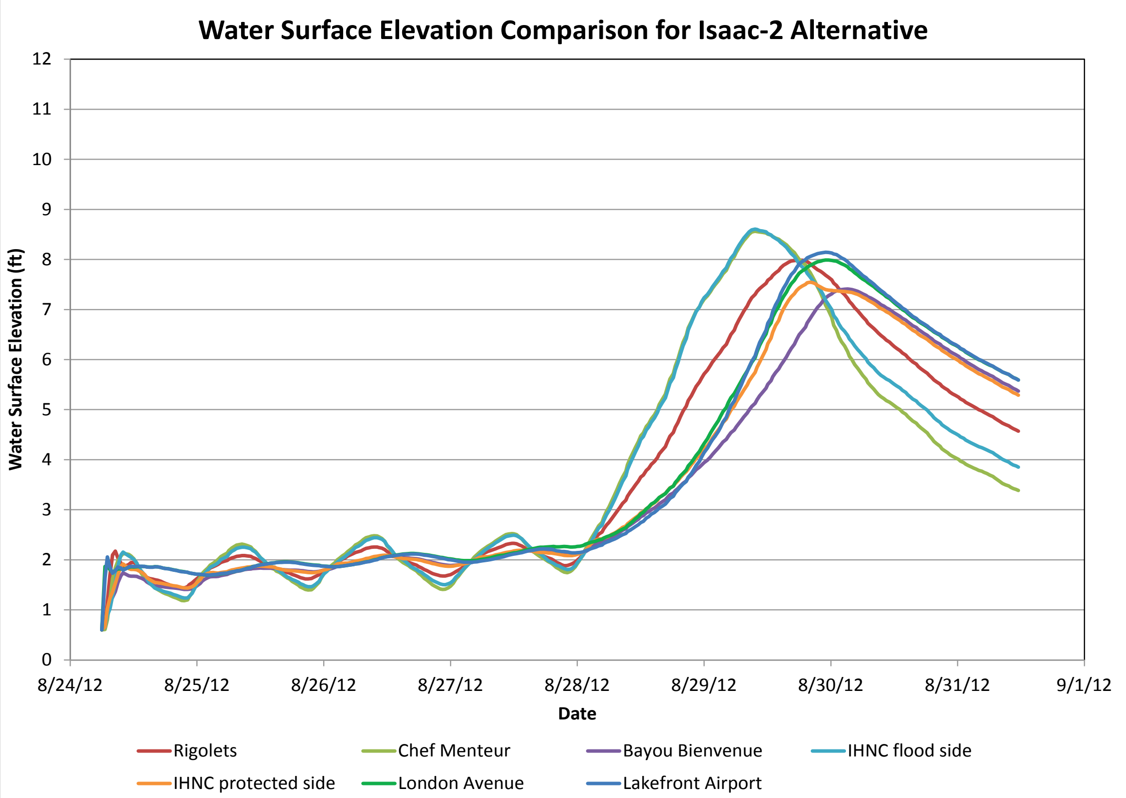


Figure 40. Isaac-2 water surface elevations at the structures.

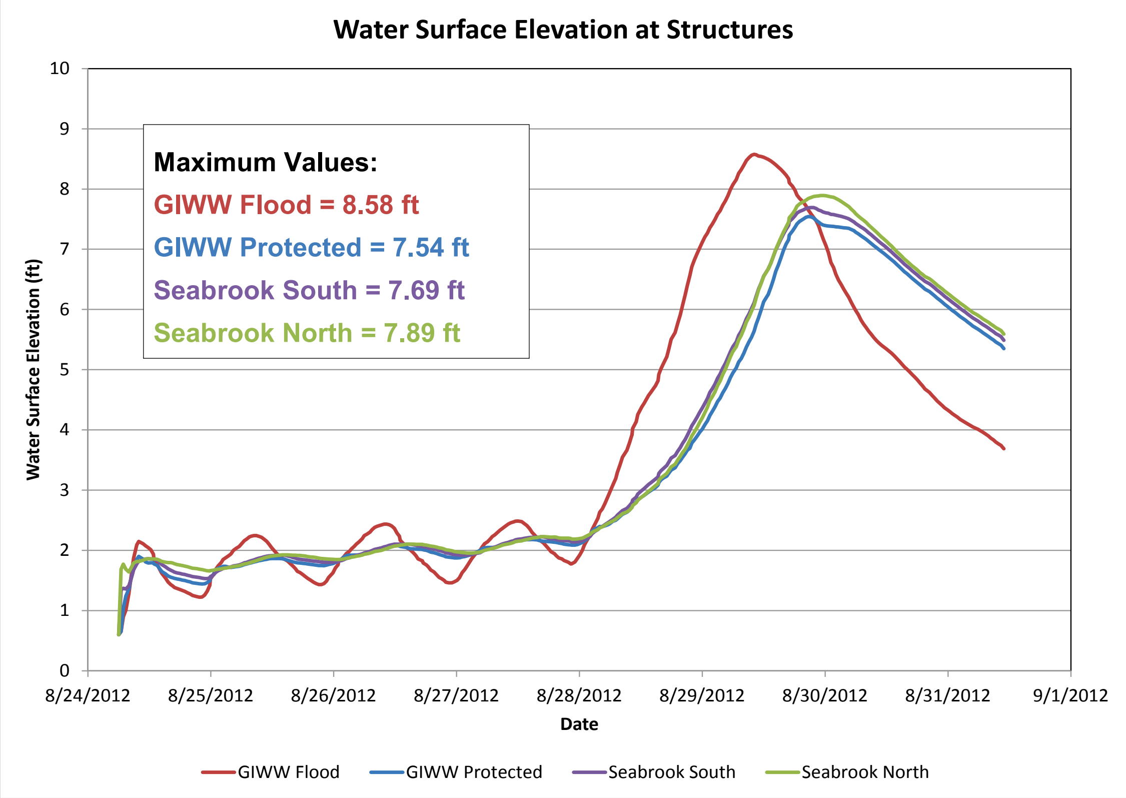


Figure 41. Isaac-2 velocity magnitudes at the structures.

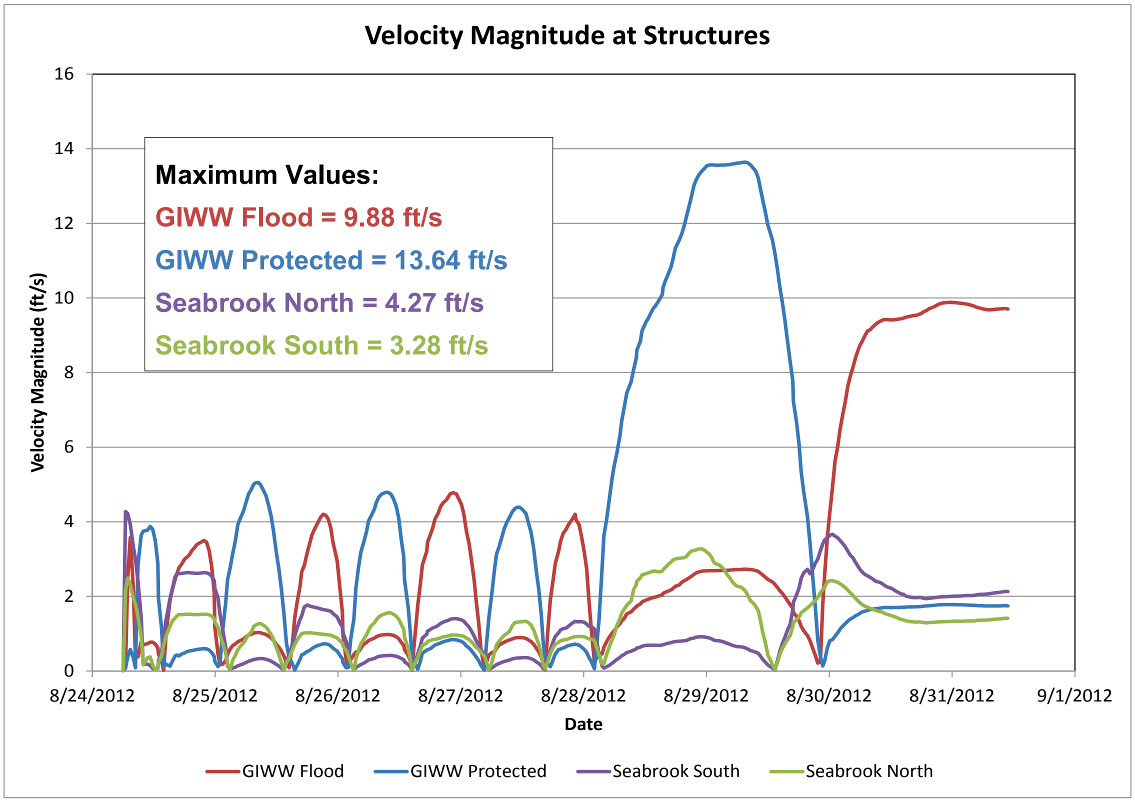


Table 7. Point-value analysis for Isaac-2 alternative.

	Isaac-2		
Location	Water Surface Elevation (ft)	Maximum Velocity (ft/s)	Maximum Velocity in Structure (ft/s)
GIWW Flood	8.58	9.88	10.22
GIWW Protected	7.54	13.64	
Seabrook South	7.69	4.27	4.11
Seabrook North	7.89	33.28	

The velocity magnitudes are highest on the protected side of the GIWW structure due to the increased water levels moving through the constricted opening of the structure as the storm surge moves inland. The alternating tidal direction is seen in the alternating high and low velocity magnitudes at each side of the structures. As the peak of the water levels moves through the structures, the velocity magnitude is high for an extended time period. This same pattern is seen for the opposite side of each structure as the water levels recede.

7 Conclusions

The study is an investigation of the hydrodynamics associated with various closure operating rules for structures located in the IHNC basin, specifically in and around the Seabrook and GIWW structures. The study results provide spatially varying velocity and water surface elevation data such that the sponsor can determine the anticipated velocities in and around the constructed gate structures under different ambient conditions. Six alternative conditions are included in the study and presented in this report.

Water surface elevation variations through the gate structures are common during storm-surge events. The hurricane-protection structures are intended to allow navigation throughout the area and protect life and infrastructure when needed. The timing of the structure closures is important since these structures have design limitations on the hydrodynamic forces under which they can operate.

Of the six alternative conditions included in this study, the highest velocity values (greater than 13 ft/s) are observed in the GIWW sector gate with the GIWW barge gate and Bayou Bienvenue gates closed (Basin-4 ft and Isaac-2 alternatives). However, high velocities are shown at the Seabrook structure (greater than 12 ft/s) for the Seabrook-4 ft alternative. Although peak velocity magnitude is an important parameter for analyzing the forces that will be applied on the structure components during storm events, the duration of such forces is also of importance. The Isaac-2 alternative shows that the high velocity magnitudes can persist for many hours in constricted-flow areas. Maximum point velocity magnitudes in the GIWW sector gate and Seabrook sector gate for all alternatives are given in Table 8.

The Seabrook alternatives produce supercritical flow through the Seabrook sector gate. Supercritical flow is discontinuous, creating a hydraulic jump due to the extremely high velocity magnitudes and depth at the structure. These results indicate that additional care for erosion protection and water-level-impact considerations should be taken at this location.

Table 8. Velocity-magnitude point values in the structures for all alternatives.

Alternative	Maximum Velocity in Structure (ft/s)	
	GIWW Sector Gate	Seabrook Sector Gate
Basin-4 ft	13.45	7.67
Basin-5 ft	11.01	10.87
Seabrook-2 ft	NA	9.64
Seabrook-4 ft	NA	12.05
Isaac-1*	17.09	5.33
Isaac-2*	10.22	4.11

*Isaac-simulation maximum velocity values are not necessarily due to the structure closures (Chapter 6).

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14. ABSTRACT

Post Hurricane Katrina, the U.S. Army Engineer District, New Orleans (MVN), constructed a comprehensive system of levees, gates, and drainage structures in the Inner Harbor Navigation Canal (IHNC) basin and the greater New Orleans, Louisiana, area. Two areas of modification are the connection of the IHNC and Lake Pontchartrain at Seabrook and in the Gulf Intracoastal Water Way (GIWW) just east of the Mississippi River Gulf Outlet (MRGO). The structures allow for continued navigation, and the gate structures are designed to remain open during normal tidal conditions with the ability to close during surge events. A water control plan was developed by MVN to guide the closure of these structures based on water surface elevations at specific locations.

The Adaptive Hydraulics (AdH) numerical modeling code was applied to investigate the hydrodynamic impacts associated with various operating rules for the structures, specifically those in and around the Seabrook and GIWW structures. The study is being performed to provide spatially varying velocity and water surface elevation data to determine the anticipated velocities in and around the constructed gate structures under different ambient conditions. MVN will use these data to determine forces that the structures will experience.

The AdH-computed, hydrodynamic model results are analyzed to determine velocity magnitudes and water surface elevations in the area of the IHNC basin structures for several alternative conditions. Results reported include velocity and water surface elevation data at the structures and at other locations requested by the sponsor.

15. SUBJECT TERMS

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Gulf Intracoastal Waterway
Hydrodynamic modeling
Inner Harbor Navigation Canal
Navigation structures
Seabrook
USACE New Orleans District

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