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Water-Surface Elevation Frequency Estimates for the Louisiana Coast

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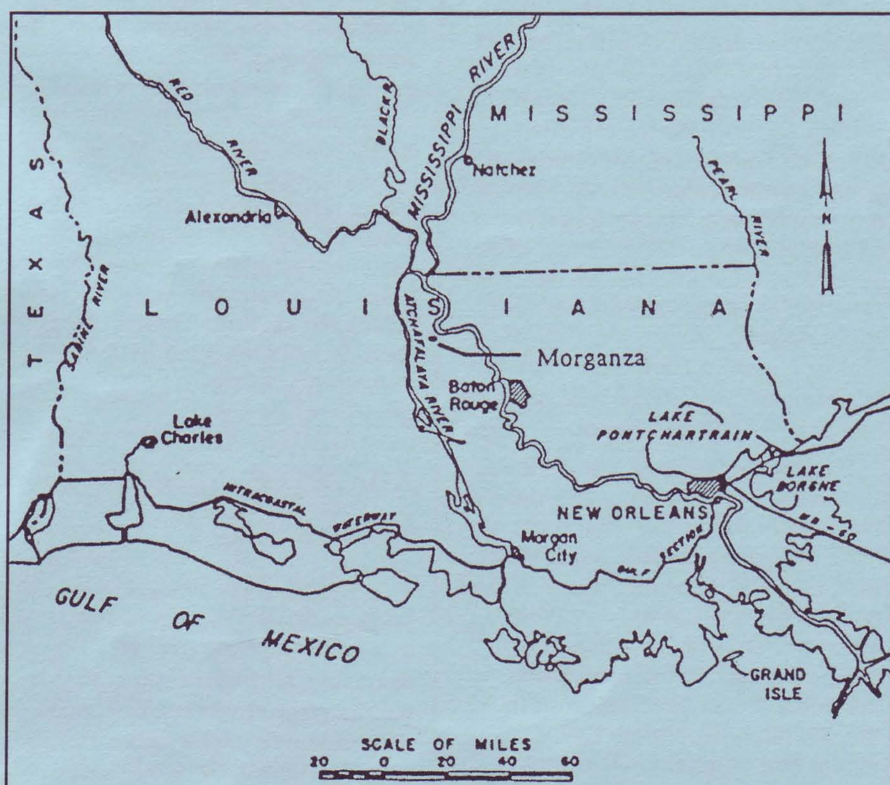

Figure 1. Study area (after U.S. Army Engineer District, New Orleans 1980)

Introduction

The coast of Louisiana (Figure 1) generally consists of low-lying land with extensive marshes and interconnected bayou systems. Historically, this area has been prone to extensive flooding and property damage because of both tropical (hurricanes) and extratropical storms. Over the years, a series of levees and control structures have been constructed to reduce the impact of storms. Recently the U.S. Army Engineer District, New Orleans, embarked on two related studies: (a) the Lake Pontchartrain Study to investigate storm impacts along the open coast of Louisiana, and (b) the Morganza Study on the present and future uses of the area from Morganza to the Gulf of Mexico. Both studies require estimates of stage-frequency relationships at different locations.

The U.S. Army Engineer Waterways Experiment Station (WES) Coastal and Hydraulics Laboratory applied the two-dimensional (2-D) finite-element, long-wave hydrodynamic model ADCIRC-2DDI (Westerink et al. 1992) to the study area. The model was modified to account for wetting and drying of land because of flooding. ADCIRC was calibrated and verified using field data measured at several locations during Hurricanes Betsy (1965) and Andrew (1992). The model-generated surge levels accurately matched the measured data. Subsequently, the model was applied to several historic storms, and computed maximum surges and time series of surges were saved at

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gauge locations of interest. A stage-frequency analysis was performed for the gauge locations using the Empirical Simulation Technique (EST) (Scheffner, Borgman, and Mark 1996). Conceptually, this statistical approach considers storm characteristics as the input to the system and peak surges as the response.

ADCIRC Numerical Model

ADCIRC is a 2-D, depth-averaged model that uses the Generalized Wave-Continuity Equation approach to solve the equations of momentum and continuity. It employs numerical discretizations using the finite element method in space and finite difference method in time. It allows for extreme grid flexibility that permits simultaneous regional/local modeling and is both highly accurate and efficient.

The wet/dry algorithm operates on a fixed grid, with whole individual elements being either wet or dry. Conceptually, a dry element has barriers along all of its sides, and the barriers are removed as the element is flooded. Nodes may be classified as dry, interface, or wet. Interface nodes are connected to both dry and wet elements and are similar to the standard land/water boundary nodes. A no-slip boundary condition is implemented at these nodes. A node dries when the depth falls below a user-specified minimum depth (e.g., 0.91 m (0.3 ft)). However, in order to minimize numerical noise, a node must remain wet for a minimum number of time-steps (e.g., 10 to 20) before it can dry. A similar constraint is imposed for wetting of dry nodes. An interface node is reclassified as a wet node if the water-level gradient and the vector sum of the water-level gradient and the wind stress both favor water transport towards all the dry nodes connected to that interface node. Furthermore, a sufficient quantity of water must reside in the wet elements composing the flood/dry interface. When the interface node is reclassified as wet, all dry nodes connected to that node become interface nodes.

An existing ADCIRC grid of the Gulf of Mexico was modified for the study by adding finer resolution in the study area. The enhanced numerical grid had 25,732 nodes and 50,215 elements. Boundary conditions were clearly posed and away from the project area of interest. In this case, there are two open-water boundaries, one across the Strait of Florida and the other across the Yucatan Channel. Grid refinement extends from the Gulf of Mexico shoreline south of New Orleans to Interstate Highway 10 approximately 96.56 km (60 miles) north. The refined area includes Lake Pontchartrain and Lake Borgne, and Atchafalaya Bay to the west. Minimum nodal spacings are on the order of 61 m (200 ft). The smallest elements are located near Chef Menteur Pass, which connects Lake Borgne with Lake Pontchartrain.

In addition to wind forcing, tidal forcing was used for calibrating and verifying ADCIRC to historic hurricanes. Five tidal constituents (M_2, S_2, K_1, O_1, and P_1) were modeled. For each constituent, amplitude and phase (nodal factor and equilibrium argument) were furnished at the two open boundaries using results of a larger hydrodynamic model that included in its domain the western North Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. In addition, ADCIRC used tidal potential forcing at all grid nodes.

For tropical storms, the National Hurricane Center's hurricane database was used to determine the track and characteristic parameters (eye location, maximum wind speed, forward speed, minimum pressure, etc.) of a historical hurricane as a function of time. This information was used as input to the Planetary Boundary Layer model that computed wind and atmospheric pressure fields on an hourly basis. This information was archived to data files and used as input to ADCIRC. For extratropical storms, wind information (velocity components) was obtained from the U.S. Navy Fleet Numerical Meteorological and Oceanographic Center's database every 6 hr at 2.5-deg latitude-longitude spacing and used as input to ADCIRC, which interpolated the winds to grid nodes as needed in time.

EST Procedure

The EST is a statistical procedure for modeling frequency-of-occurrence relationships for nondeterministic multiparameter systems. In this case, it was used to develop the frequency relationship for the maximum storm surge elevations as a function of storm characteristic parameters. Tropical and extratropical storms were considered separately because of their different characteristics. In applying the EST, multiple statistical simulations are conducted, each having a duration of N years (e.g., $N = 200$), at each of the selected stations where frequency relationships were desired. Because the procedure is repeated multiple times, an average stage-frequency relationship is generated together with the standard deviation that provides a measure of the uncertainty contained in the relationship. This, coupled with the fact that the EST preserves the statistical relationships inherent in the historical data without relying on assumed parametric relationships or assumed parameter independence, makes the method superior to traditional techniques such as the joint-probability method.

ADCIRC Calibration and Verification

ADCIRC was calibrated using water levels for Hurricane Betsy and verified with water levels for Hurricane Andrew because these storms were severe and because extensive field measurements were collected after their occurrence. No separate calibration was performed for extratropical storms. Typically for tropical storms, simulations were started approximately 2 days before the storm made landfall, and the simulation was conducted for 4 days. For extratropical storms, the simulations were performed for

8 days because of the longer duration of these storms. Generally, a time-step of 5 sec was used. In the wet/dry routine, the minimum water depth was set at 0.3 ft, and wet and dry nodes were kept in their respective states for a minimum of 12 time-steps.

Because the primary interest of the study was in the maximum surges at different gauge locations, time series information on surges was saved at 10-min intervals to resolve the maximum computed surges. Also, surges over the entire grid were saved at the same interval, and the solution was examined using visualization software. Maximum computed surges (maximum for the duration of the storm) were determined at all grid nodes, and contours of maximum surge were plotted and examined. Table 1 shows a comparison of computed and observed peak surges at select stations distributed around the project area for calibration and verification. The agreement is excellent, considering the uncertainty in datum levels in this region.

Results

Following calibration and verification, 19 hurricanes and 11 extratropical storms were simulated using ADCIRC, and the results were archived for use in the EST. At each location of interest, 100 statistical simulations of a 200-year sequence of storms were performed. The results were used to develop separate frequency-of-occurrence relationships for tropical and extratropical storms. The two relationships were then combined into one relationship applicable to both storms. As an example, the results obtained for the Rigolets are shown in Figure 2. Even though the procedure and the tools described here were used previously, this study posed special challenges in terms of the complexity of the region, bathymetry and topography, and wetting/drying. These were successfully overcome, and all of the study objectives were met. This was the first WES study to use ADCIRC's new wetting/drying feature that worked very well. Additional details on this study may be found in Vemulakonda et al. (1997).

Table 1. Comparison of Maximum Surges (ft) at Select Stations for Hurricanes Betsy and Andrew

	Betsy		Andrew	
Name	**Obs.**	**Comp.**	**Obs.**	**Comp.**
Pascagoula	5.4	5.0		
Biloxi	7.6	7.7		
Rigolets at US 90	7.0	7.5	3.7	3.8
Causeway/North	5.1	6.0		
Causeway/Midlake	3.5	4.6	4.4	4.2
Blind River	4.2	5.1		
Ruddock	10.2	9.2		
Westend	5.6	5.1	4.1	3.3
Seabrook	4.4	3.5		
Chef Menteur at US 90	9.1	8.3	4.2	4.5
Shell Beach	9.3	7.4	5.3	5.2
Breton Sound			5.3	5.4
Phoenix	8.3	8.7		
Catfish Lake			5.9	5.6
Port Eads	3.0	3.4		
Grand Isle	4.5	4.7	3.9	4.2
Leeville	5.5	6.2	5.8	5.1
Bayou Petite Caillou			8.3*E	7.1
Eugene Island			3.8	3.4

Note: Obs. = Observed; Comp. = Computed; *E = Estimated.

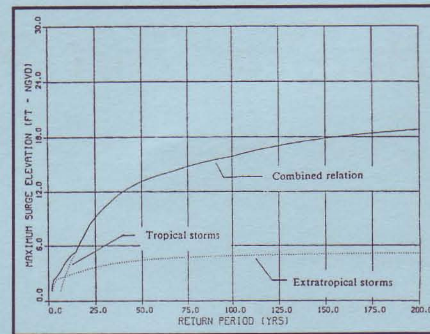

Figure 2. Stage-frequency estimates for the Rigolets at US 90

Acknowledgments

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