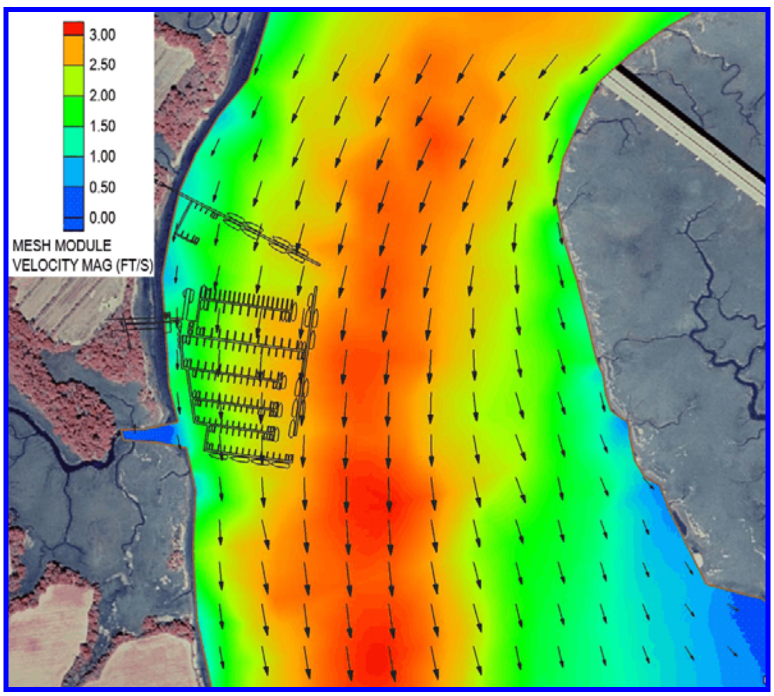
FINAL REPORT

WAVE ANALYSES AND HYDRODYNAMIC/ SEDIMENTATION PROCESSES AT THE PROPOSED DANIEL ISLAND MARINA

WANDO RIVER CHARLESTON SC



Prepared for:

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5.4 Simulation of Extreme Events

Category 3 storm conditions were used to define the extreme conditions at the marina site. It is generally assumed that the receding surge will generate highest velocities just as the ebb tide produces higher velocities than the flood tide. The surge predicted for the 50-year return period (see Section 4.4) was used as the water level estimate at the north end of the model domain. The surge curve was calculated at mid-rising tide. To simulate expected maximum velocities, achieved during ebb flow, the storm surge level curve was transposed on the mid-falling mean tide curve at Charleston.

Six ebb events (A–F) were modeled between maximum water level conditions at the marina site to minimum water level conditions. The events are summarized in Table 5.2. Total tide at the marina basin ranges from a maximum of 10.7 ft NGVD to a minimum of 2.4 ft NGVD during the model runs. Figure 5.14 shows the water levels for each modeled event. Water levels at the southern boundary of the model domain were determined from a linear interpolation of the surface elevation between the marina site and the Charleston harbor entrance. The elevation between the marina site and the southern model boundary ranged from 4.7 ft at maximum surge level at mid tide to 1.1 ft at the minimum total tide level (elevation differences during **normal neap tide** conditions did not exceed 0.2 ft).

TABLE 5.2. Six events over a receding surge estimated with Category 3 storm conditions. The six events define the water level conditions over a falling tide from maximum water level (A) to minimum water level (F). Slope describes the water surface between the upstream project boundary and Charleston Harbor. ΔElevation is the difference in surface elevation between the upstream and downstream project boundaries.

Simulation (Event)	Description	Time (hour)	Tide (ft NGVD)	Surge (ft)	Total Tide (ft NGVD)	Slope ($x10^{-3}$)	Water Level (ft-NGVD)	Δ Elevation (ft)	Discharge ($x10^3$ ft^3/s)
A	Max water level	12.8	1.6	9.1	10.7	0.232	6.0	4.7	600
B	Maximum surge (peak duration)	13.9	0.0	9.1	9.1	0.197	5.1	4.0	530
C	Mid water level	14.8	-1.2	7.8	6.6	0.143	3.7	2.9	400
D	Between mid water level and low tide	15.6	-2.0	6.2	4.2	0.091	2.3	1.9	331
E	Low tide	16.4	-2.4	5.2	2.8	0.061	1.6	1.2	249
F	Minimum water level	17.0	-2.1	4.5	2.4	0.052	1.3	1.1	225

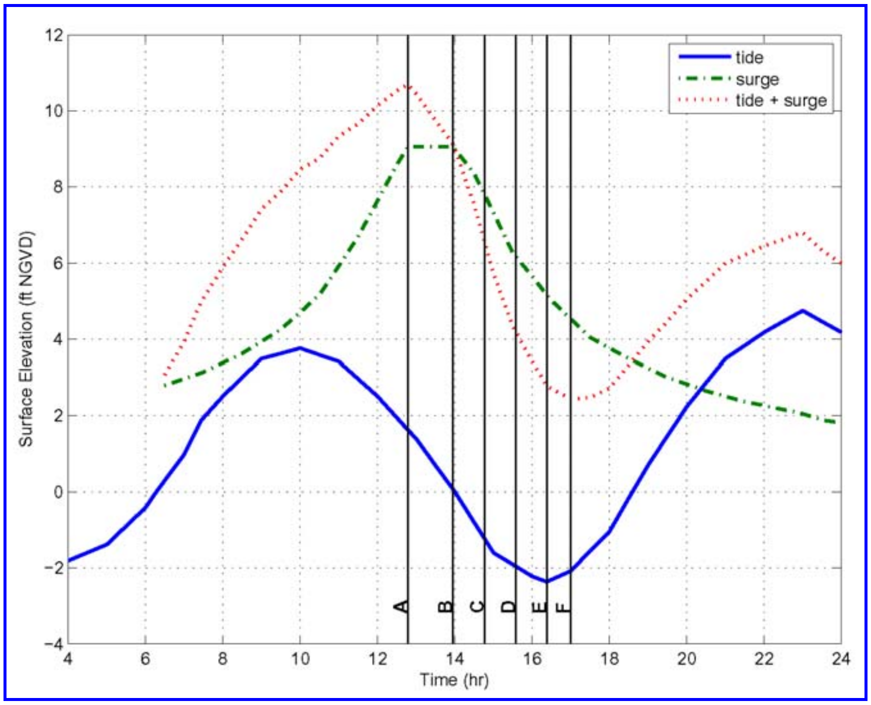


FIGURE 5.14. Six events were used to model Category 3-type flow events (A–F). The difference between the total water level (tide plus surge) and the Charleston Harbor water level (tide) was used to model the elevation head difference in the hydraulic model.

Flow rates were estimated for model input. The flow rates were iterated until the estimated surface elevations at the northern boundary were achieved. Simulations assume that the elevation head difference is the only contributor to initially drive the flow. Wind forces and other forcing factors were not considered for these simulations. Only ebb conditions were chosen because they represent the maximum potential velocities that may occur during the storm surge.

5.4.1 Model Simulations

Simulations of Events A, B, and C were modeled with marsh inundation because the water level at each point in the domain exceeded the marsh elevation of +2.25 ft NGVD. Because RMA2 does not allow for large solution differences at a point between successive model runs, events whose elevations may drop below the high points of the model grid could not be modeled. To alleviate the problem, simulations of Events D, E, and F were modeled assuming no marsh inundation. The resulting low velocities predicted at the boundaries adequately model the currents at those points. Modeled surface elevations are virtually unaffected because the algorithm derives the model conditions by assuming a bed slope at the boundaries.

Model simulations for the extreme events are shown in Figures 5.15 through 5.20.

Event A (Fig 5.15): Velocities are at the peak at mid-falling tide when the storm surge is at its highest elevation. Velocities through the main channel generally exceed 8 ft/s. Within the vicinity of the marina, the velocities are up to 8.9 ft/s and do not fall below 3 ft/s except within 200 ft of the shoreline. Surface elevations range from ~6.0 ft NGVD to ~11 ft NGVD across the regional domain. Within the marina basin, the water surface elevation varies by as much as 0.5 ft.

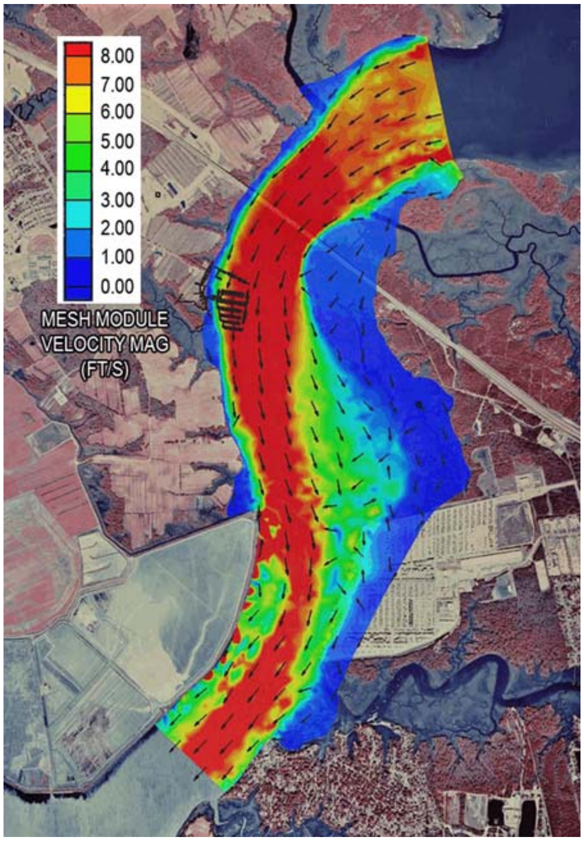
Event B (Fig 5.16): Similar conditions exist in the regional model for Event B as in Event A. The surge is still at its maximum level but the tide has dropped by 1.5 ft. Velocities remain high in the channel (exceeding ~8 ft/s). Velocities also increase at points near the shoreline in the upper and lower sections of the domain. Velocities also remain about 8 ft/s in the marina basin. The elevation difference between the upper and lower boundaries is ~4.0 ft. The marina basin elevations vary by 0.5 ft.

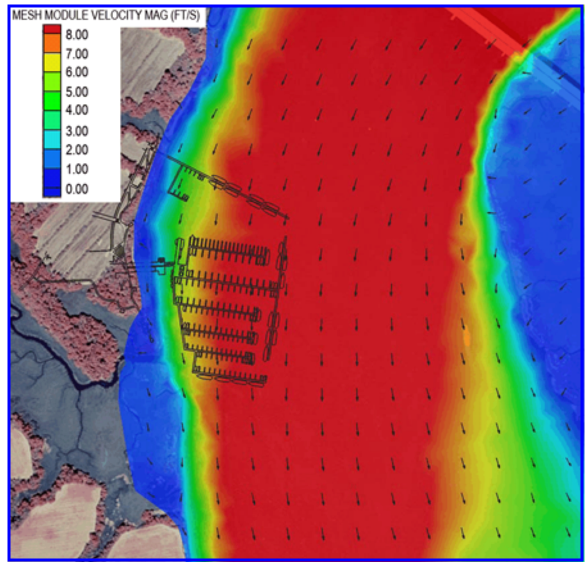
Event C (Fig 5.17): Velocities of 8 ft/s are still evident in the main channel but are lower in the north and south sections of the domain, with the exception of the flow hot sports at the north boundary. Velocities in the marina basin are below 7 ft/s nearly two hours after the peak flow. Surface elevation differences may be ~3.0 ft over the model domain and as much as 0.35 ft within the marina basin.

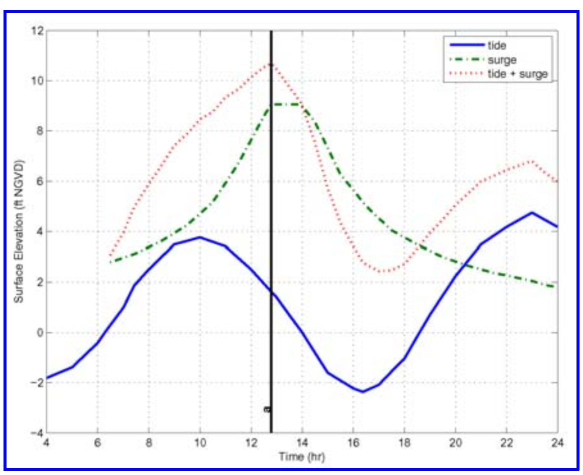
Event D (Fig 5.18): Current velocities are now below 7 ft/s throughout most of the channel. The main channel in the central section remains the fastest section. There is a surface elevation variation of ~2.0 ft over the regional domain where the downstream two thirds of the domain is very flat. As with the other simulations, there is a higher surface gradient in the vicinity of the marina. The surface elevation variation within the marina basin is ~0.35 ft.

Event E (Fig 5.19): Maximum velocities in the regional model are 5–5.5 ft/s and nearly constant along the main channel. Velocities in the marina basin do not exceed 5 ft/s during low tide. Surface elevations over the regional domain vary by 1.2 ft from the lower part to the upper part.

Event F (Fig 5.20): At the minimum water surface elevation (tide + surge), velocities do not exceed 5 ft/s along the channel with the exception of a point along the western bank at the northern border of the domain. The anomaly is likely due to modeled flow at the boundary with high ground. Velocities within the marina basin do not exceed 4.2 ft/s. The water surface varies by ~1.1 ft over the regional domain and by ~1.5 ft within the marina basin.







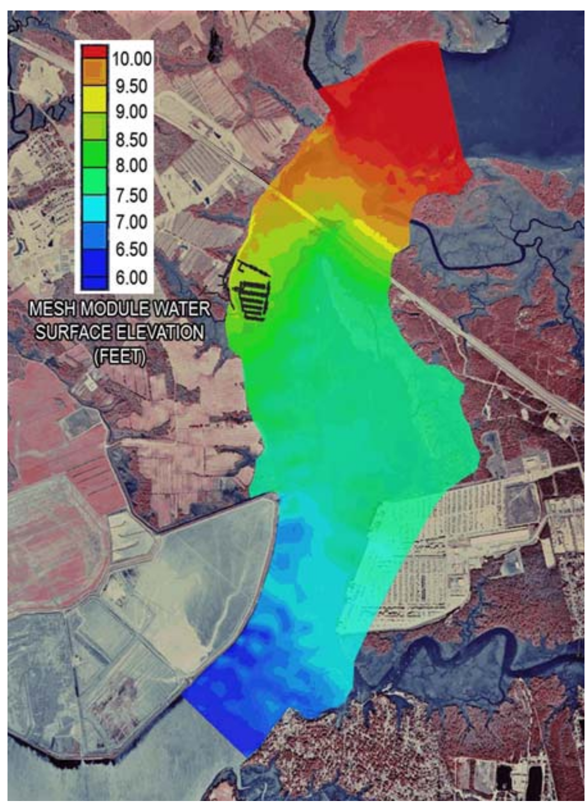
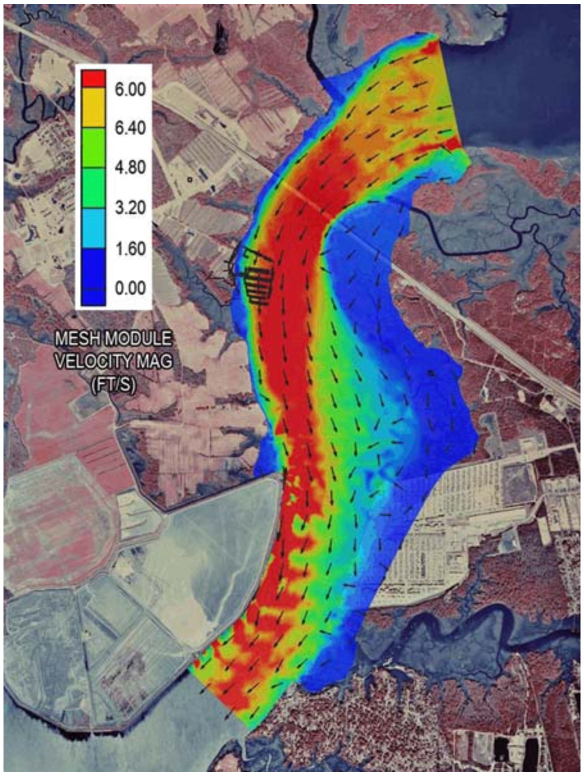
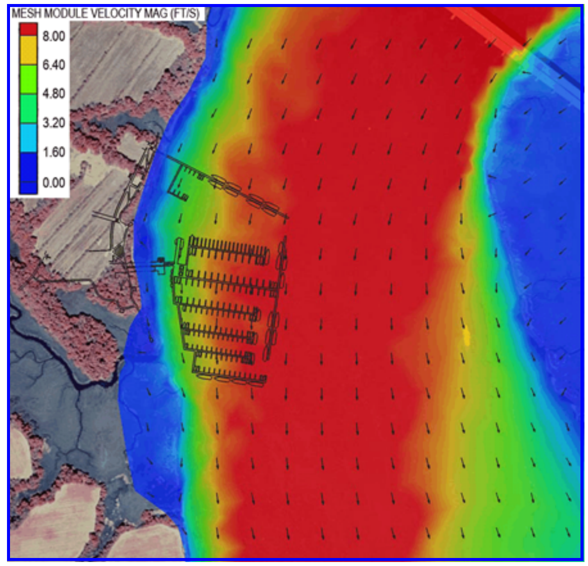
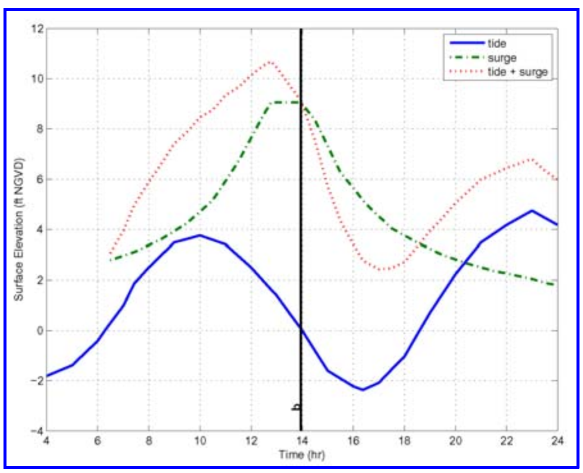


FIGURE 5.15.

Modeled flow at maximum water level (Event A) under Category 3 conditions. Regional velocity (upper left), marina site velocity (upper right), and surface elevation (lower right) for the event which occurred at the maximum surge level at mid falling tide (lower left).







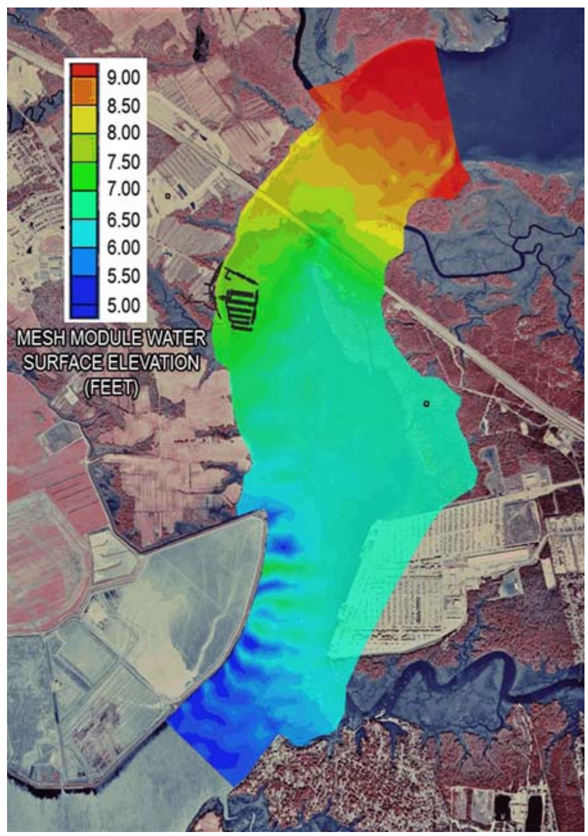
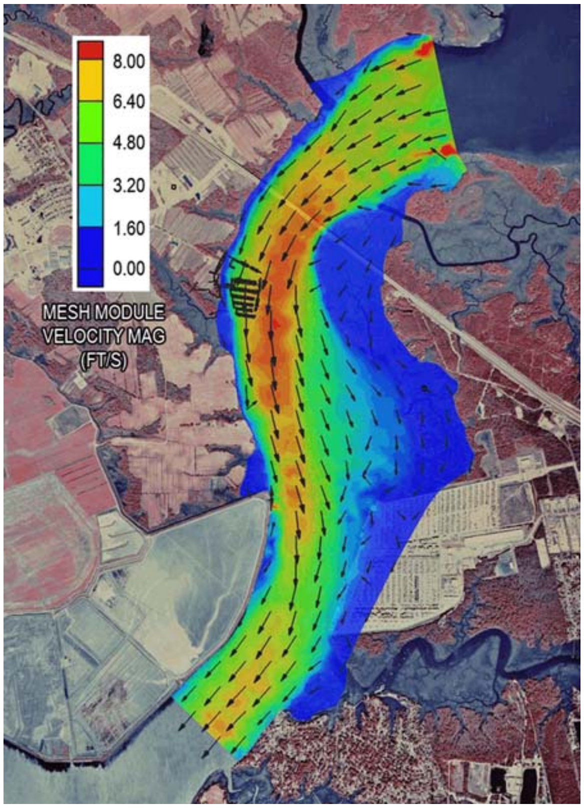
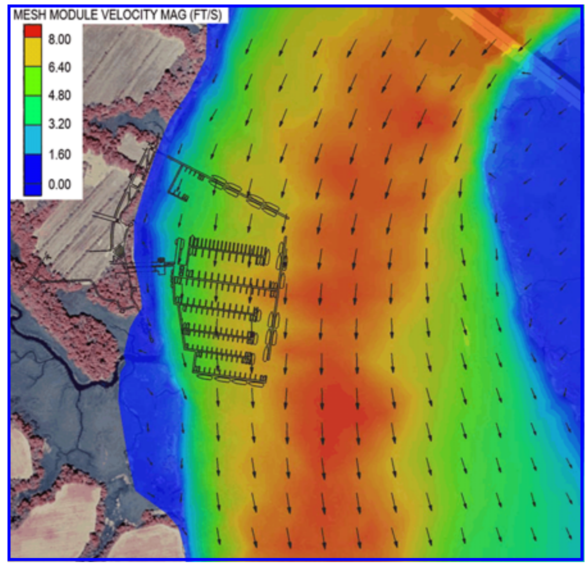


FIGURE 5.16.

Modeled flow at maximum surge at peak duration (Event B) under Category 3 conditions. Regional velocity (upper left), marina site velocity (upper right), and surface elevation (lower right) for the event which occurred at the maximum surge level just after mid falling tide (lower left).





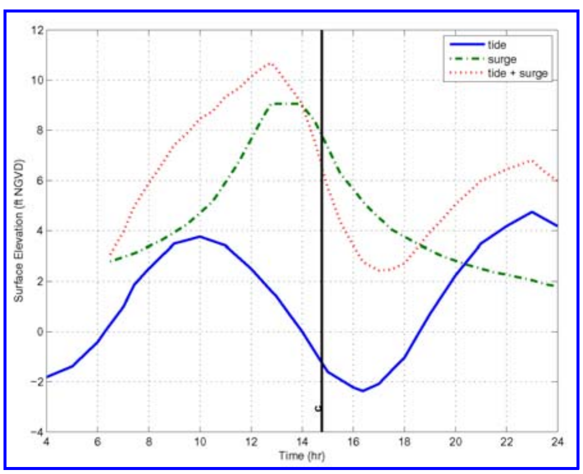
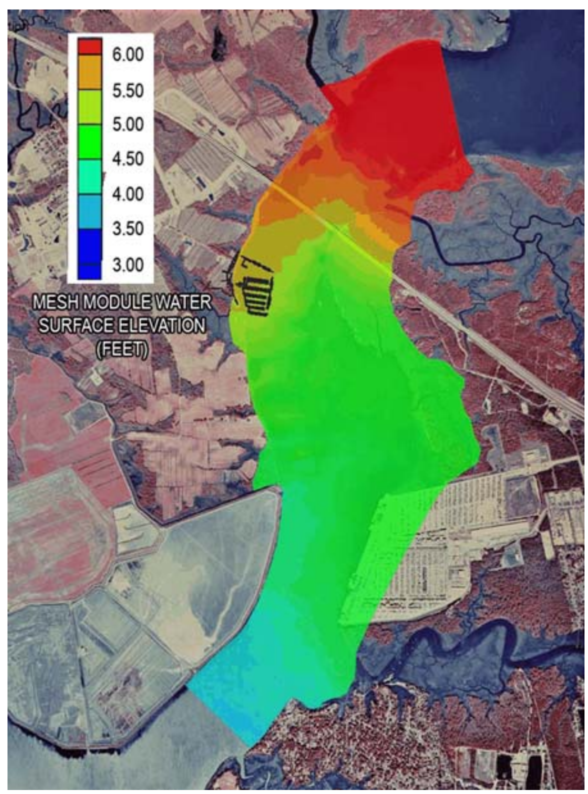
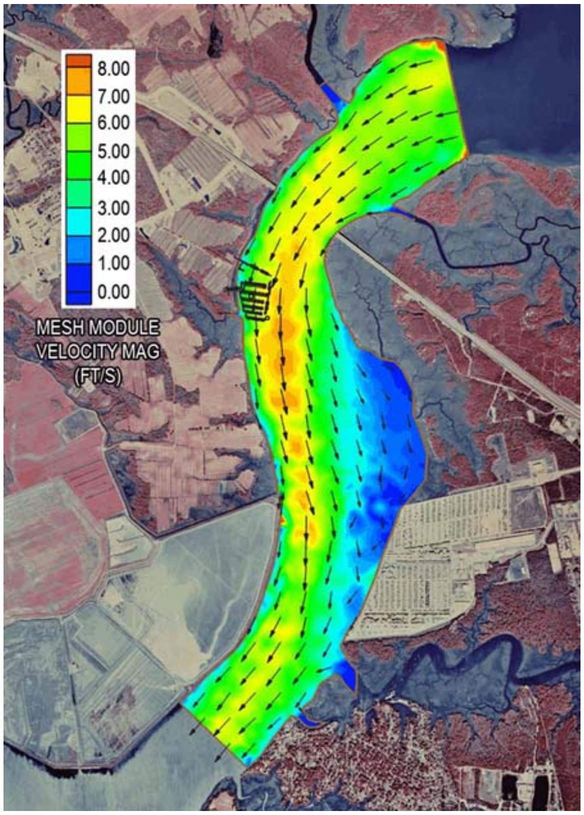
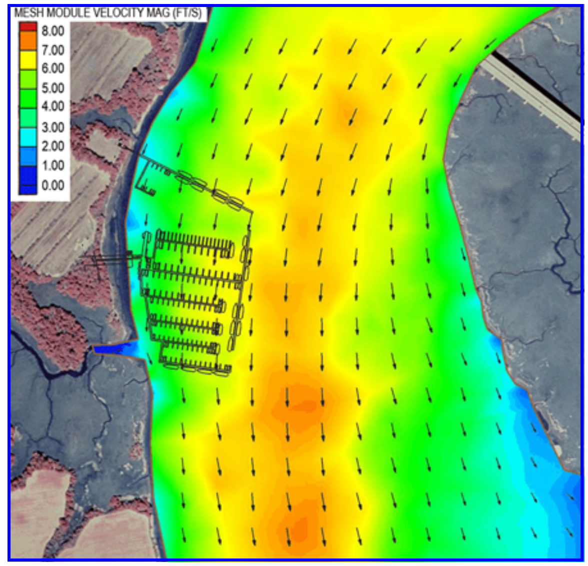


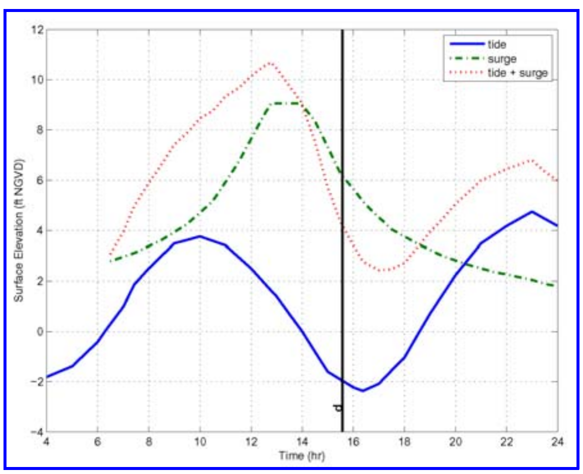
FIGURE 5.17.

Modeled flow at mid total water level (Event C) under Category 3 conditions. Regional velocity (upper left), marina site velocity (upper right), and surface elevation (lower right) for the event which occurred near the beginning of the receding surge (lower left).









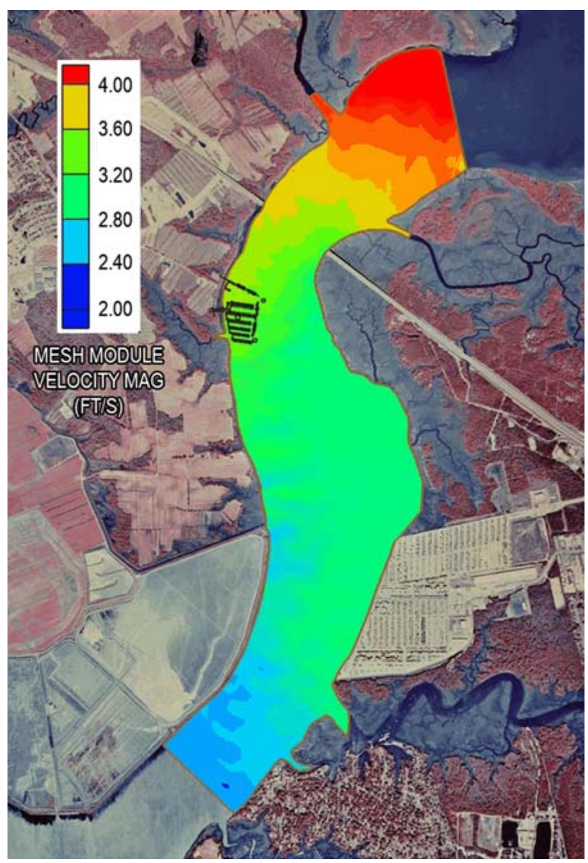
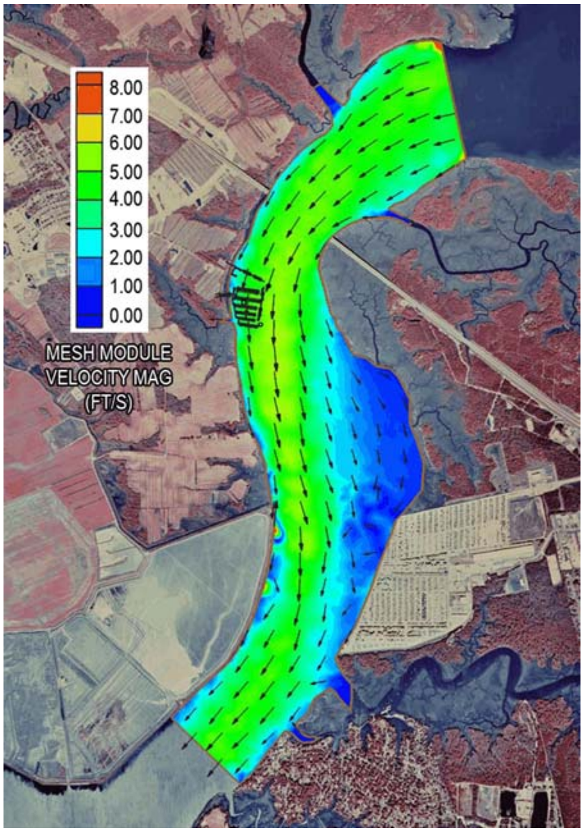
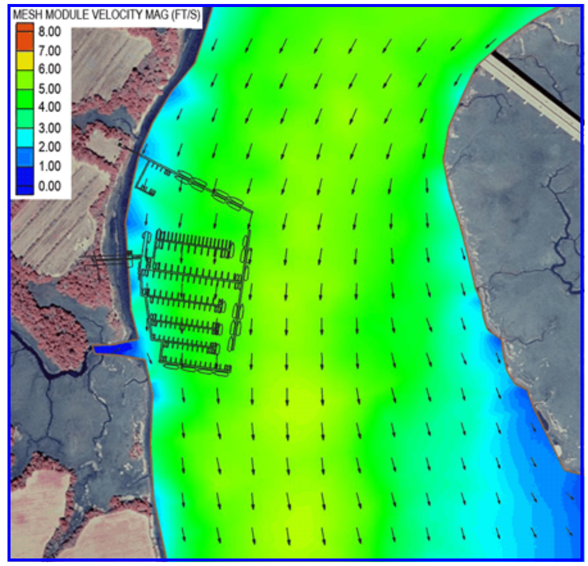
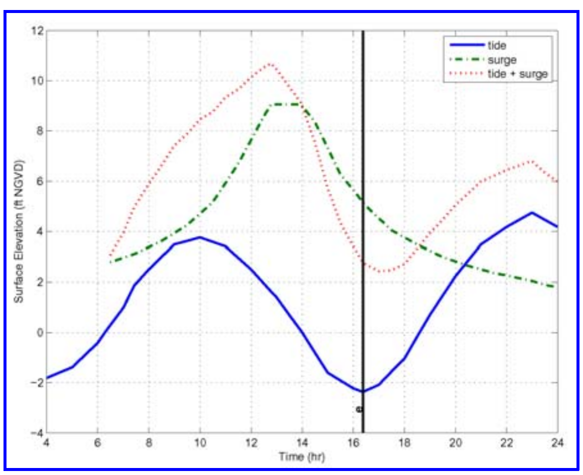


FIGURE 5.18.

Modeled flow for Event D between mid total water level and low tide. Regional velocity (upper left), marina site velocity (upper right), and surface elevation (lower right) for the event which occurred after mid total water level and before low tide (lower left).







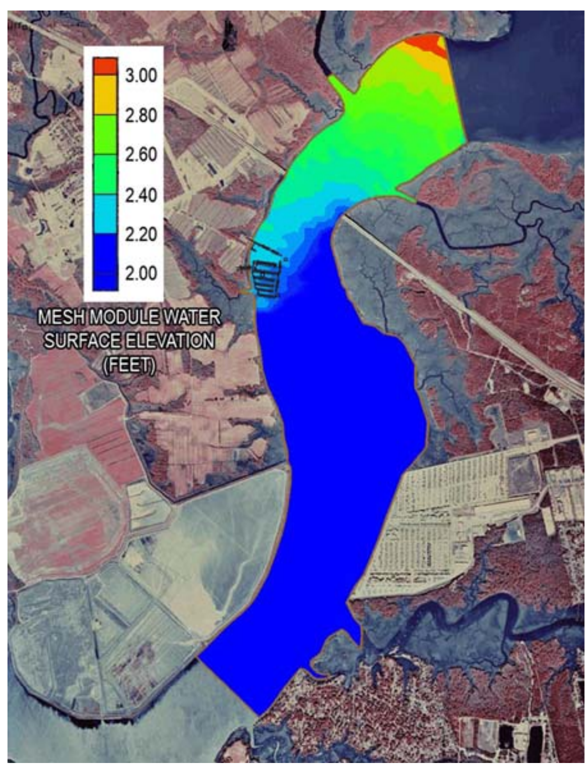
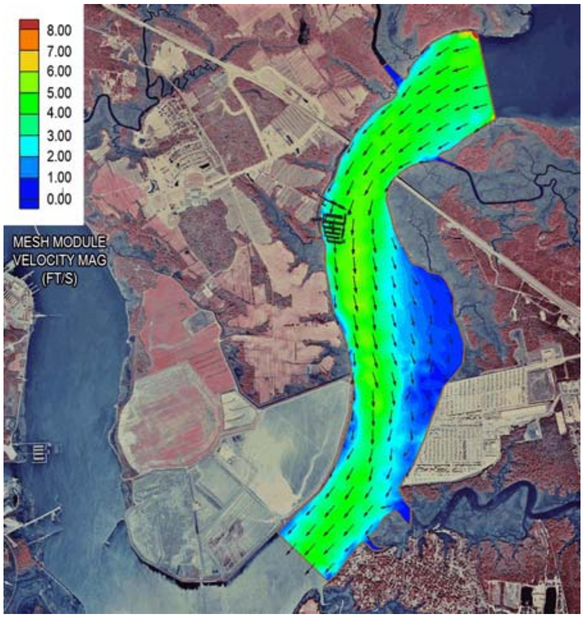
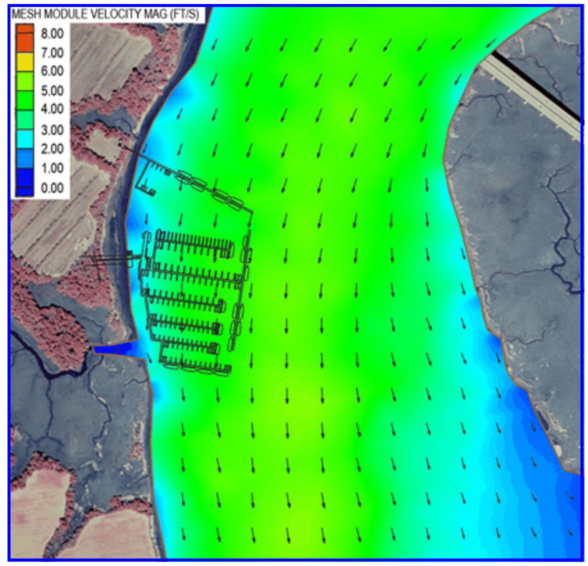
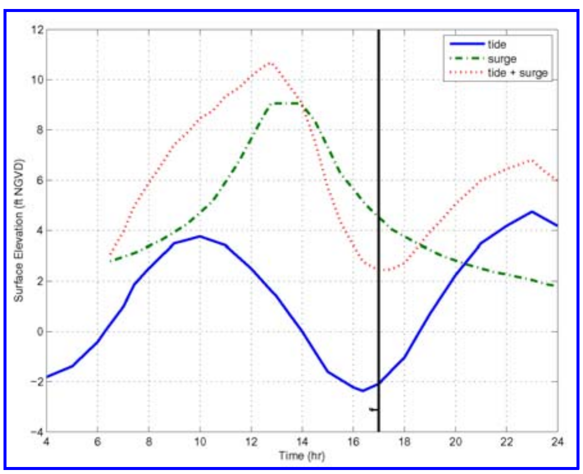


FIGURE 5.19.

Modeled flow at low tide (Event E) under Category 3 conditions. Regional velocity (upper left), marina site velocity (upper right), and surface elevation (lower right) for the event which occurred at low tide in Charleston Harbor (lower left).







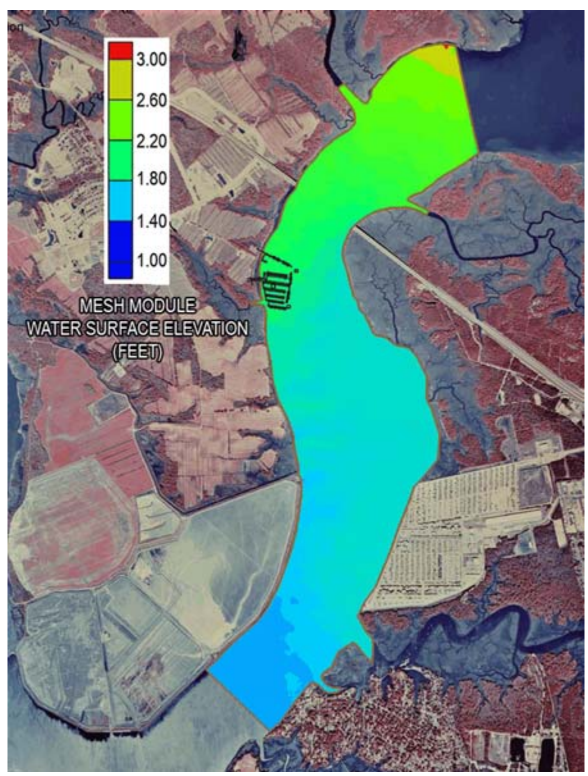


FIGURE 5.20.

Modeled flow at minimum total water level (Event F) under Category 3 conditions. Regional velocity (upper left), marina site velocity (upper right), and surface elevation (lower right) for the event which occurred just after low tide in Charleston Harbor (lower left).

5.4.2 Velocities at Marina

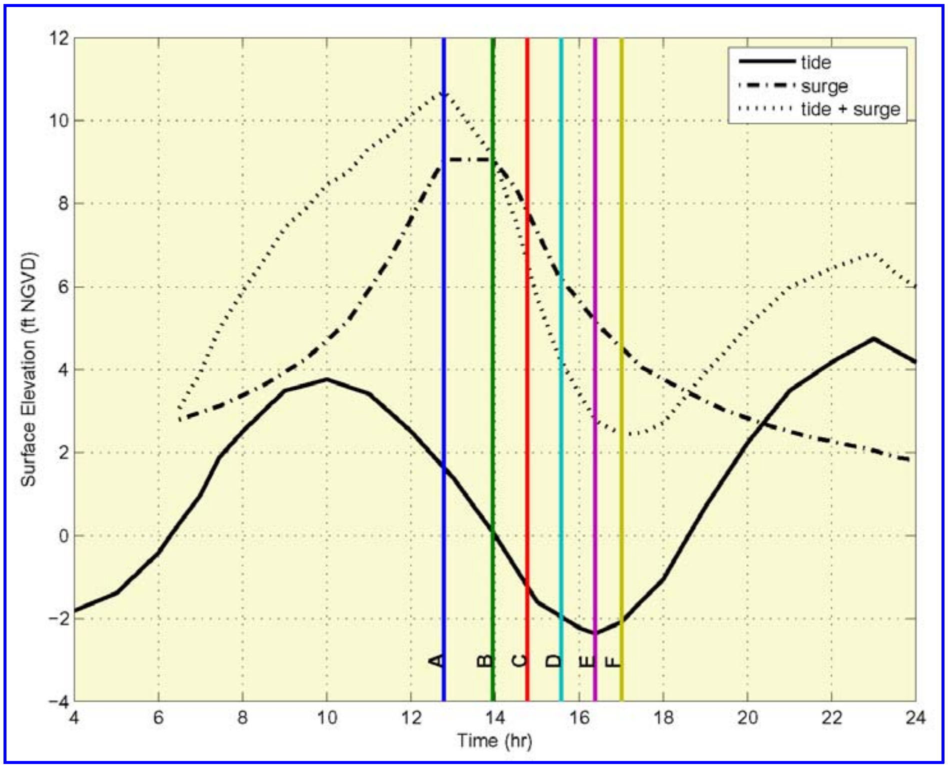
Modeled depth-averaged velocities do not exceed 10 ft/s along the marina cross-section for Events A–F (Fig 5.21). The velocities over the cross-section decrease as the total tide level decreases. The most rapid decrease in cross-section peak velocity occurred from Event B to Event C when the peak velocity decreased by 1.63 ft/s in 0.85 hours, which is a rate of –1.9 ft/s per hour (ft/s/hr). A similar rate of decrease in velocity occurred from Event D to Event C when the rate of change in velocity was –1.7 ft/s/hr. Velocities in the marsh on the eastern side of the river are very low. Simulated velocities for the unconfined flow events (D, E, and F) are relatively high along the marsh boundary.

5.5 Simulation of Spring Tide Conditions

To better understand the relative magnitude of the Category 3 storm velocities, they are compared to spring tide conditions measured on 8 October 2006. The largest difference between TG1 and TG3 was 0.71 ft at mid tide. Low tide occurred 3.3 hours later. For the case of the maximum spring tide ebb velocities (Fig 5.22), the maximum velocities approached 4.5 ft/s in the main channel. Marsh velocities remained near zero (Fig 5.22, upper left). Ebb velocities within the marina basin did not exceed 3.8 ft/s (Fig 5.22, upper right). The water surface level was very flat over the downstream two-thirds of the model domain. The surface gradient gradually increased over the downstream one third (Fig 5.22, lower right).

Figure 5.23 compares the velocities at the marina over three ebb flow conditions: (1) neap tide, (2) spring tide, and (3) Category 3 storm. Velocities are estimated at three points in the marina basin: (1) the interior of the marina, (2) the north marina entrance, and (3) the south marina entrance. (Velocities are estimated assuming no marina structures.) During ebb flows, the south entrance tends to experience higher velocities than the north entrance. The interior point is exposed to about 80 percent of the velocity that is calculated at the entrances. The maximum velocity at the south entrance for Category 3 conditions is over 5 ft/s higher than the peak velocity for spring tide conditions, and 6.5 ft/s higher than for neap tide conditions.

Spring and neap tide velocities diminished predictably with the tide. Under normal conditions (no surge) the ebb velocities return to zero at low tide. This is not the case for velocities under storm surge conditions. The flow takes longer to return to normal. The length of time for the storm surge to return to zero is estimated from the storm surge calculated in Section 4 and shown in Figure 4.4. By linear extrapolation using the tail end of the storm surge curve, the storm surge drops by 0.2 ft per hour and will go to zero about 18 hours after. This time estimate is nearly the same as the Hurricane Hugo duration between peak surge and return to normal tide levels (Garcia et al 1990).



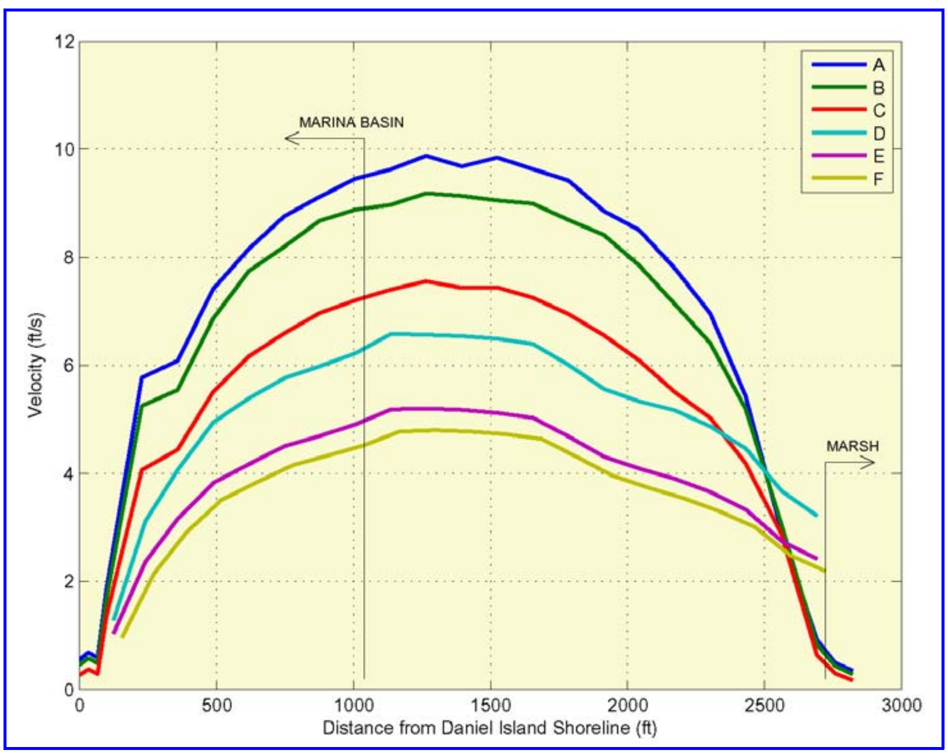
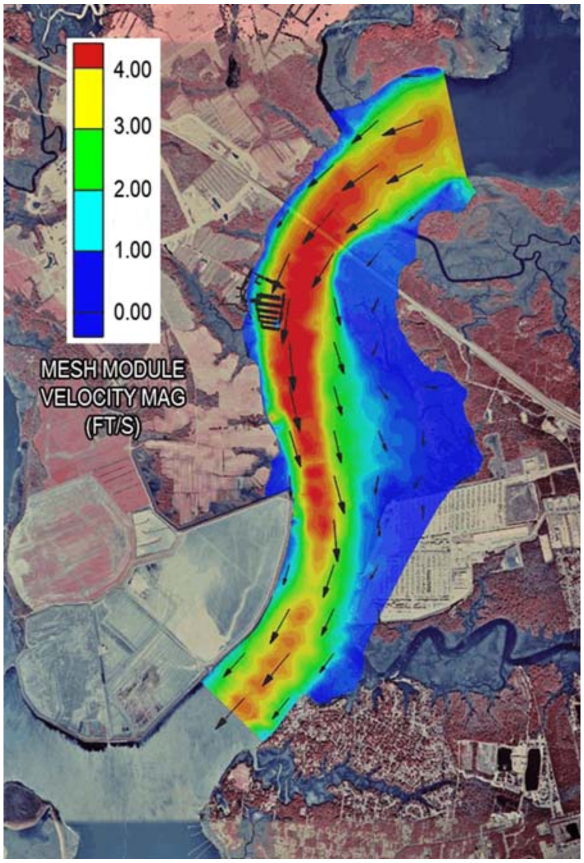
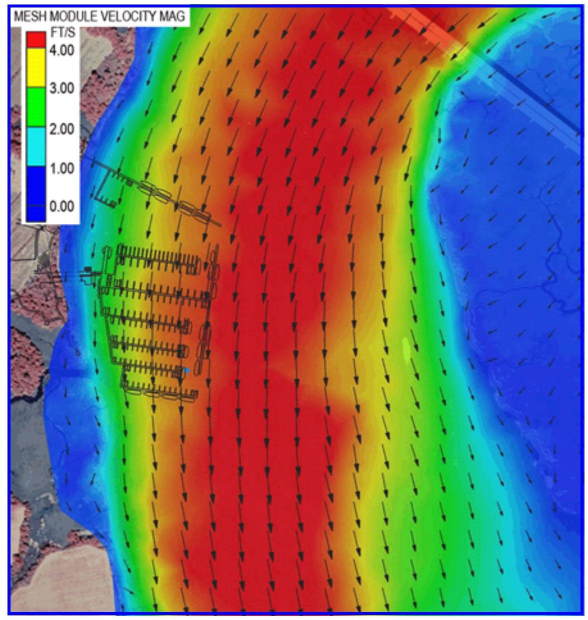
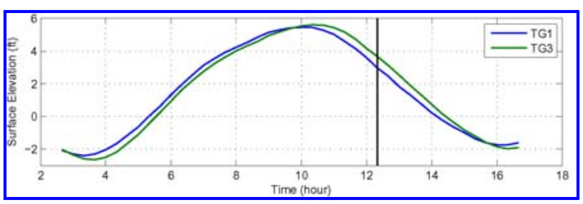


FIGURE 5.21. Modeled depth-averaged ebb velocity across the transect at the proposed marina site (looking north) for the six modeled events under Category 3 storm surge conditions. Peak velocities along the transect occur outside the marina basin near mid channel. Channel peak velocities drop from 9.8 ft/s to ~4.8 ft/s in ~4 hours.







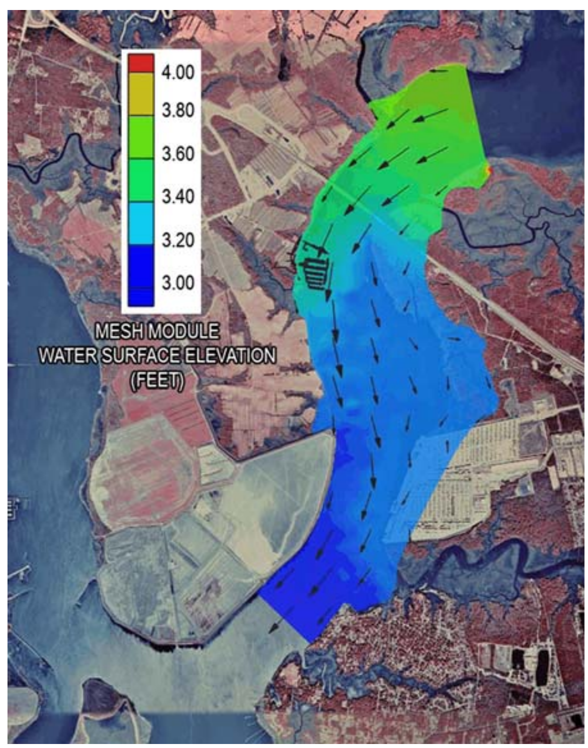
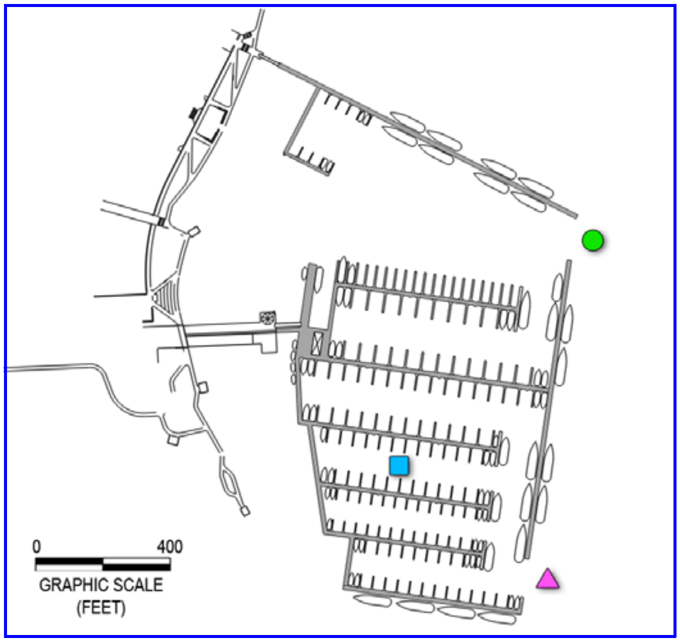


FIGURE 5.22.

Maximum ebb event under normal spring tide conditions. Regional velocity (upper left), marina site velocity (upper right), and surface elevation (lower right).



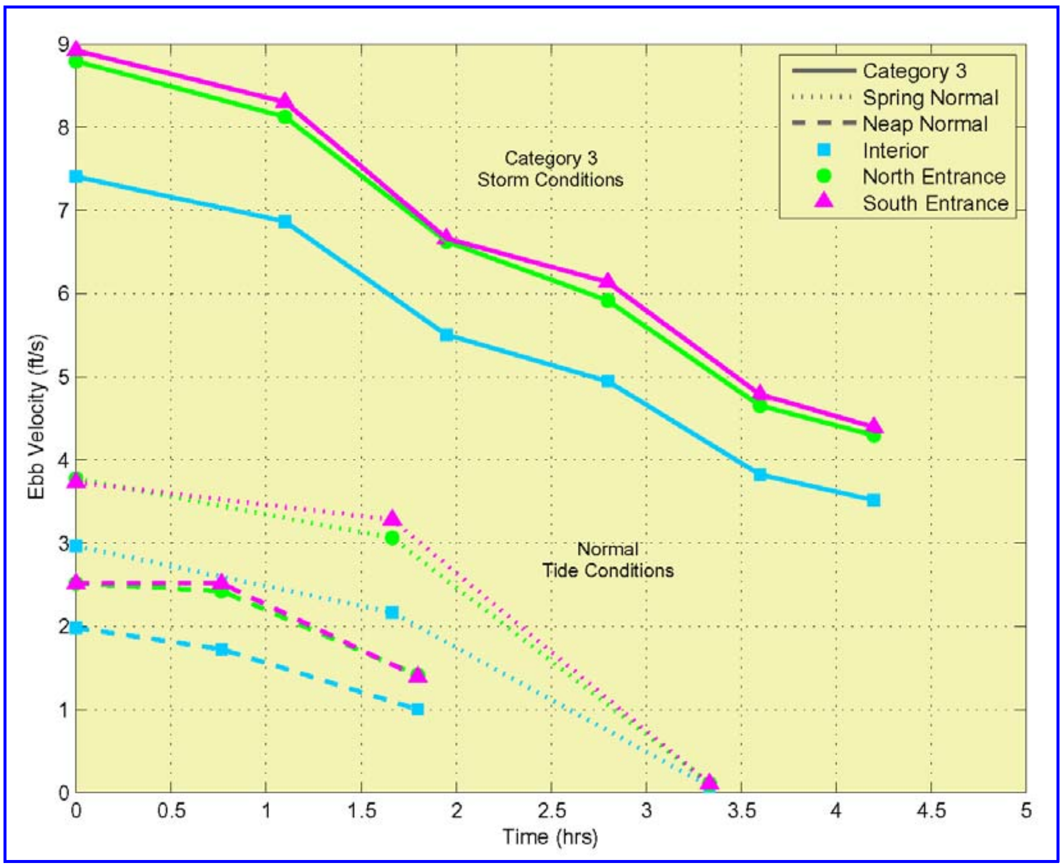


FIGURE 5.23. Ebb velocities at three points at the proposed marina site under Category 3 conditions and normal tide conditions. Velocities were modeled at the entrances of the marina and at a point interior to the marina. Modeled velocities reflect conditions without marina structures in place. **[UPPER]** Preliminary marina site plan by Thomas & Hutton Engineering Company.

5.6 Summary – Flow Modeling

A flow model was developed for the lower Wando River to simulate normal conditions and extreme (Category 3) conditions around the Daniel Island marina site. Model testing and calibration using site-specific measurements of water levels and currents showed excellent correlation and was found to accurately describe the flow field in a 20,000-ft reach encompassing the marina. Under normal tide ranges the model confirmed:

- Higher velocities during spring tides.
- Higher velocities on the **ebb tide**.
- Higher velocities during periods when flows are **confined** (ie, water levels <2.25 ft NGVD which corresponds approximately to the marsh elevation).
- Velocities around the marina entrances are of the order 80-90 percent of the velocities in the center of the channel.
- Velocities within the center of the marina basin are typically about 80 percent of the velocity at the entrances.

Under the normal range of tide conditions, the maximum ebb velocities did not exceed 3.8 ft/s in the marina.

The model was used to stimulate Category 3 storm surge conditions, assuming that the peak velocities would occur as the surge recedes. The basic assumption in the model simulation is that the extreme flow is driven by the gradient (head) between the surge level at the upper limit of the model grid and the normal tide level in the ocean after the storm. This was used to estimate (by interpolation) the water level at the downstream boundary of the model grid. Head differences with the model grid under the assumptions were as much as 5 ft (0.5 ft within the marina basin). The resulting current speeds in the marina (Category 3 conditions) were found to be up to ~8 ft/s. Such conditions have short durations (1-2 hours) and tend to diminish at rates of the order 1.5 to 2 ft/s/hr. The Category 3 flow conditions in the marina have a high degree of uncertainty simply because there are no available water level measurements at multiple stations under hurricane conditions within the Charleston Estuary system.

The modeling for bridge scour analysis by Ayres (2000a,b) indicated average velocities at the I–526 bridge of the order 4.5 ft/s. The present results indicate much higher velocities during major storm surges. Because the methodology and objectives of the Ayres

(2000a,b) study and the present study differ, there is no attempt to compare and contrast the results.

Peak depth-averaged velocities **measured** by CSE at the marina site approached 4 ft/s during a normal tidal cycle (see Figs 3.4c and 3.4d) with a mild water-surface slope. The underlying approach to drive the velocity model with hurricane condition was to assume a water surface slope predicted from standard surge analysis and tide curves. The analysis provides a much steeper water surface for these conditions and resulting velocity magnitudes of >8 ft/s.

CSE believes the basic approach of the present modeling is valid and that the resulting velocities are conservative. Numerous factors could act to attenuate extreme flows (ie, reduce the head differences which drive the discharge). For example, water levels in the Cooper River would follow a similar trend but would likely remain higher for a longer period after passage of a storm (given the large basin area). This would, in effect, hold the water level higher at the mouth of the Wando River (near the downstream model grid) and reduce the hydraulic gradient. Simulations which account for attenuation factors such as this are beyond the scope of the present study. Nevertheless, the predicted flows under Category 3 conditions should offer some guidance to the design engineer regarding potential velocities, which the marina docks and piles may experience during a 50-year design life.