# A Reconnaissance Modeling Study of Two-dimensional Tidal Circulation and Sediment Bed Change in the Vicinity of the Cape Fear River Navigation Channel, NC


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## Introduction

The objective of this study was to apply the latest two-dimensional, vertically-integrated version of the ADCIRC circulation model and the ADBED bed change model to study tidal circulation and accompanying bed change in the area surrounding the mouth of the Cape Fear River, NC. This research effort, in support of the U.S. Army Corps of Engineers (USACE) Coastal Inlets Research Program (CIRP), provides an initial investigation of possible circulation and sedimentation consequences of a USACE channel re-alignment project scheduled to begin during the fall of 2000.

Specific tasks to be accomplished in this project were:

*Task 1*: Build a finite element grid extending from roughly Cape Lookout, NC, to Cape Romain, SC, that provides resolution on the order of 100m in the immediate vicinity of Cape Fear and the Cape Fear River Navigation Channel. Bathymetry for this grid will be obtained from the NOS bathymetric soundings database and supplemented in the vicinity of the Cape Fear River with data to be provided by the USACE.

*Task 2*: Calibrate the ADCIRC circulation model for this grid using open water boundary conditions from a large scale tidal database (e.g., the ADCIRC Western North Atlantic Tidal Database) and observed tidal constituents in the Cape Fear River reported by NOS (Welch and Parker, 1979) and/or as provided by the USACE.

*Task 3*: Compare tidal circulation near the mouth of the Cape Fear River for the present dredged channel configuration and the proposed channel re-alignment.

*Task 4*: Use results from the tidal circulation model as input to the ADBED bed change model. This represents the first field scale use of the ADBED model and therefore we are interested in assessing the model's viability for identifying areas of potential erosion and deposition. We consider this in the context of the present channel configuration and the proposed channel re-alignment.

## Results

*Task1: Develop Finite Element Grid*:

The finite element grid constructed to depict pre-dredge conditions of the Cape Fear River Estuary is shown in Figure 1. The model domain includes a single offshore boundary, a mainland boundary, and several islands, which characterize the plan-view configuration of the estuary. Near the mouth of the estuary, each element side represents a distance of approximately 150 meters, (Fig. 2). The final grid consists of 12811 nodes and 24,154 elements.

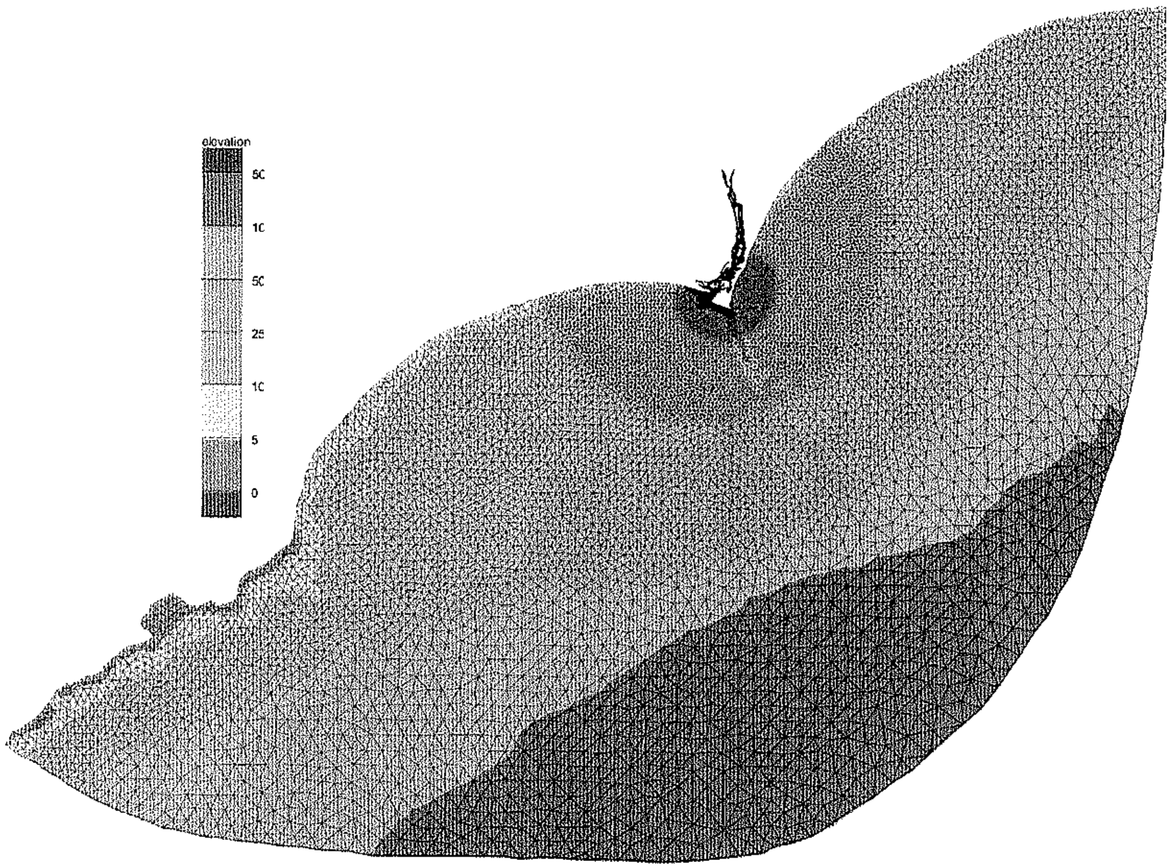



Figure 1. Model domain for the Cape Fear River Estuary

Mainland boundary locations were obtained from the NOAA Medium Resolution Digital Vector Shoreline database (http://crusty.er.usgs.gov/coast/getcoast.html). Details of shoals and islands within the estuary were determined from the NOAA United States East Coast NC Cape Fear River Chart 11537 (1999). Bathymetry was obtained from the National Ocean Survey sounding database (NOAA, 1995). At the time of the grid development no further bathymetric data was available.

*Task 2: ADCIRC Model Calibration*

Tides obtained from the ADCIRC Western North Atlantic Tidal Database were used to drive the model. Tidal amplitudes and phases for the M2, S2, N2, K1, and O1 tidal constituents were designated at each open-water boundary node. For calibration, the tidal amplitudes were then adjusted (Table 1) to reflect measured values near the mouth of the estuary as reported by NOS (Welch and Parker, 1979). No changes were deemed necessary to model boundary condition phases.

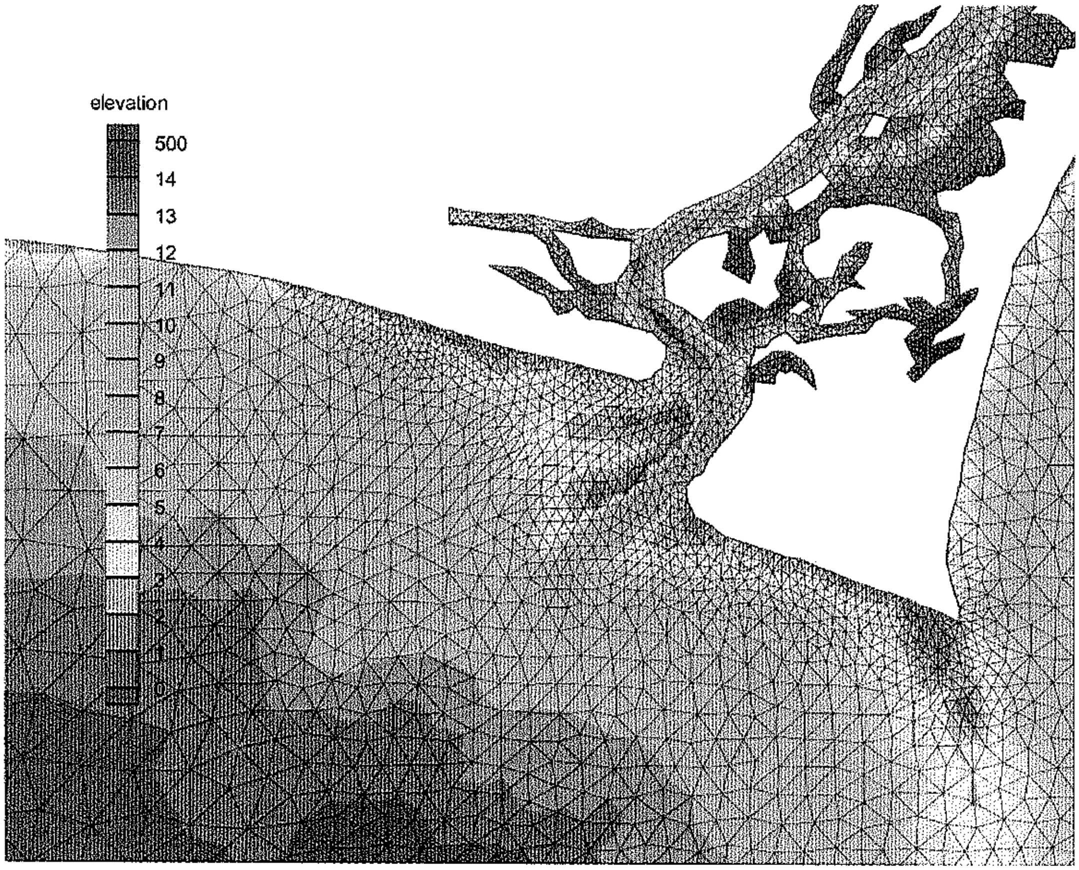



Figure 2. Entrance of the Cape Fear Estuary, present conditions

The calibration process is further illustrated in Figures 3, 4, and 5. ADCIRC was run for a forty-day simulation period with-wetting and-drying included. Amplitudes and phases for the M2, S2, N2, K1, O1, M4, and M6 tidal constituents were determined from harmonic analysis of elevation solutions at specified locations (Fig. 3). Results were then compared to observed values (Welch and Parker, 1979) for differing frictional coefficients (Fig 4,5). Other parameters of the calibrated model are summarized in Table 2.

Table 1. Adjustments to Tidal Amplitudes on Open-water Boundary Nodes.

| Tidal Constituent | Amplitude Reduction |
|---|---|
| M2 | 7.6% |
| O1 | 9.2% |
| K1 | 13.8% |
| N2 | 12.0% |
| S2 | 7.7% |

*Percentage values for amplitudes represent reductions relative to values of the ADCIRC Western North Atlantic Tidal Database.

Table 2. ADCIRC Calibration Run Parameters.

| Parameter | Value |
|---|---|
| Runtime | 40days |
| Time step | 10sec |
| Bottom Friction Coefficient | 0.005 (dimensionless) |
| Lateral Eddy Viscosity Coefficient | 0 ($m^2$/sec) |
| Number of Forcing Frequencies on Open-water Boundary | 5 |

Calibration results suggest that for a bottom friction coefficient value of 0.005 modeled and measured amplitudes and phases are in relatively close agreement (Table 3), especially near the entrance of the estuary. In general the model over-predicts tidal amplitudes in the upper region of the estuary. Differences between model output and reported values upstream may be associated with river discharge, the propagation of tides through the Intracoastal Waterway at Myrtle Sound, somewhat coarse grid resolution in the upper estuary, the use of a reflecting boundary condition at the upper end of the estuary and bathymetric changes that have occurred since the observational study was conducted (1976).

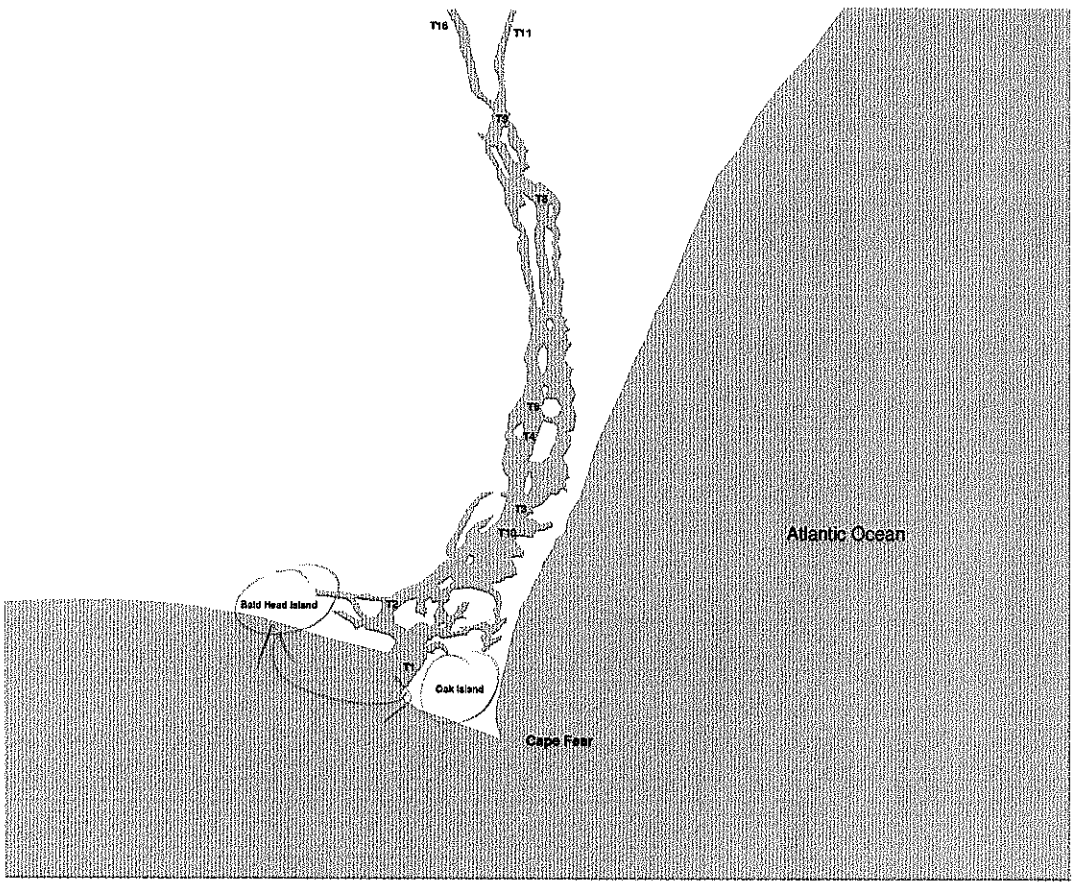



Figure 3. Location of elevation stations

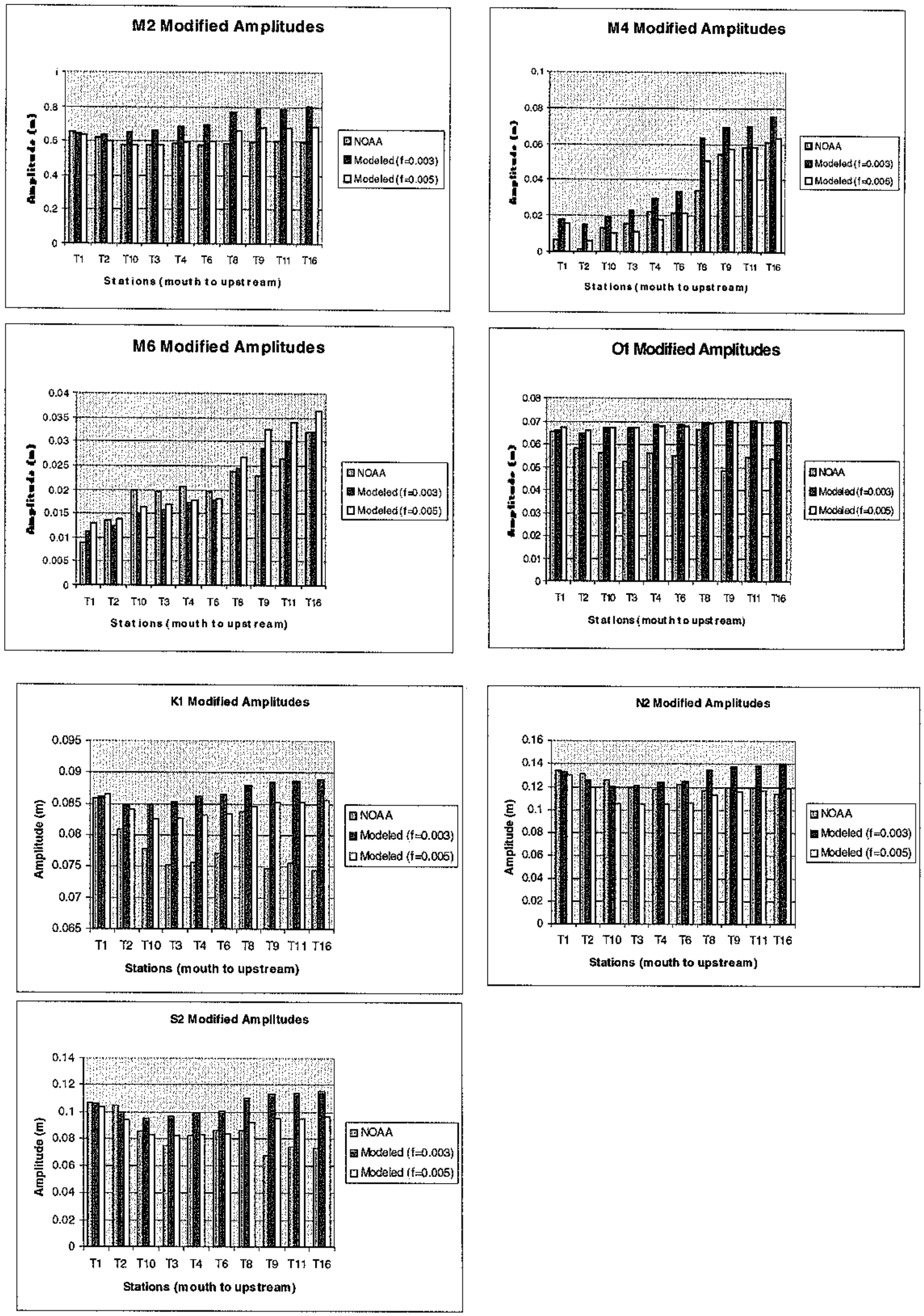



Figure 4. Observed tidal amplitudes and model results for varying frictional coefficients

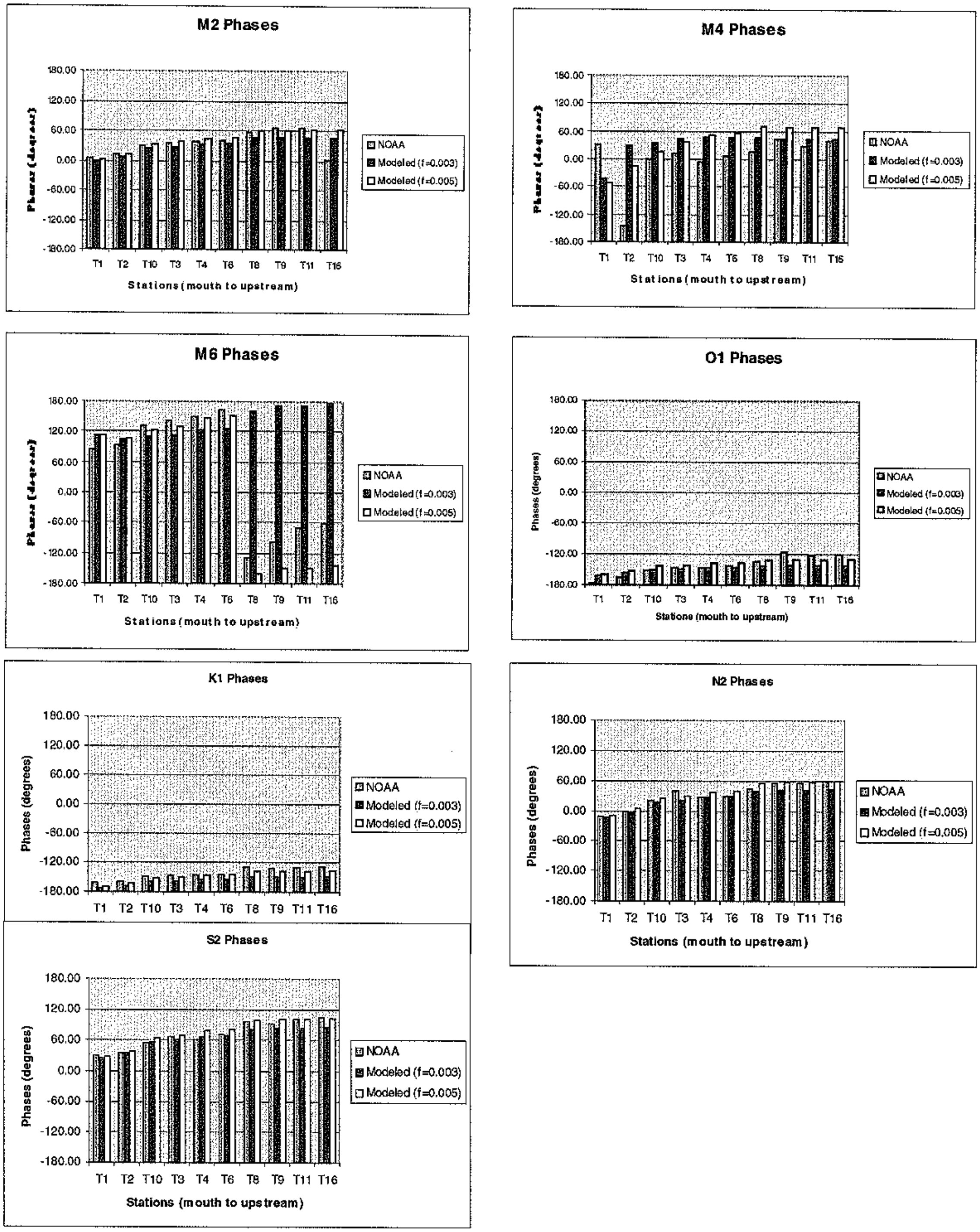



Figure 5. Observed tidal phases and model results for varying frictional coefficients

| Constituent | RMS for Amplitudes (m) | RMS for Phases (degrees) |
|---|---|---|
| M2 | 0.0523 | 5.0 |
| M4 | 0.0067 | 61.0 |
| M6 | 0.0047 | 41.5 |
| O1 | 0.0128 | 10 |
| K1 | 0.0072 | 5.8 |
| N2 | 0.0119 | 7.6 |
| S2 | 0.0141 | 8.6 |

Table 3. Root Mean Square Error for the calibrated model

*Task 3: Hydrodynamic effects of channel re-alignment.*

In order to consider how deepening and relocation of the shipping channel may affect flow near the entrance of the estuary, an ADCIRC simulation depicting the new channel location was run, Figure 6. Shoals were extended to represent filling of the old channel. Pre- and post-- realignment comparison simulations were run for a period of eight days with forcing by the dominant M2 constituent only. All other parameters remained the same as those of the calibrated model.

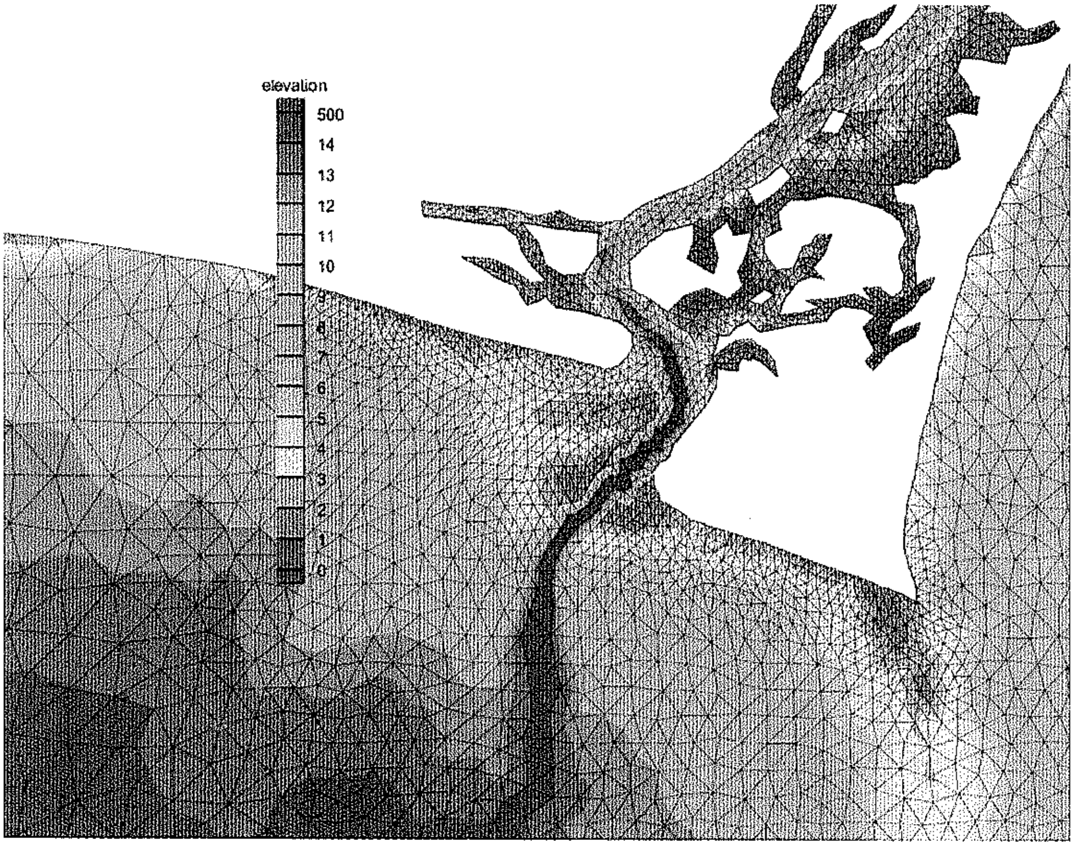
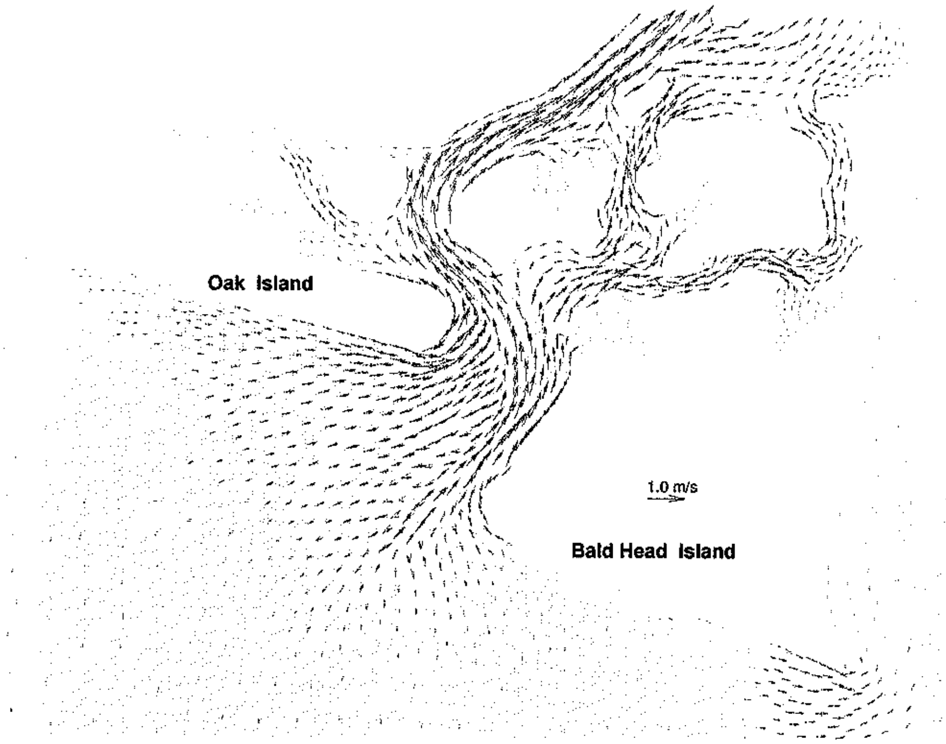



Figure 6. Planned deepening and realignment of the shipping channel at the entrance of the Cape Fear

For pre- and post-dredge conditions, modeled tidal amplitudes and phases for the Steady, M2, M4, and M6 constituents obtained from harmonic analysis of elevation solutions at the observation stations are compared (Table 4). In addition, current velocities at the entrance of the estuary for pre- and post-dredge conditions are shown in Figure 7. These results suggest little change in the water levels throughout the estuary and velocities in the vicinity of the estuary entrance.

Table 4. Modeled amplitudes and phases for pre- and post-dredge conditions.

| Station | Constituent | Original Channel Modeled Amplitude (m) | Modeled Phase (degrees) | New Channel Modeled Amplitude (m) | Modeled Phase (degrees) |
|---|---|---|---|---|---|
| T1 | STEADY | 4.52E-05 | 0.00 | -1.56E-03 | 0.00 |
| | M2 | 6.74E-01 | 1.54 | 6.84E-01 | 0.43 |
| | M4 | 1.82E-02 | -63.08 | 1.72E-02 | -59.87 |
| | M6 | 1.56E-02 | 109.50 | 1.59E-02 | 117.08 |
| T2 | STEADY | -5.76E-03 | 0.00 | -9.31E-03 | 0.00 |
| | M2 | 6.36E-01 | 12.84 | 6.50E-01 | 11.05 |
| | M4 | 5.47E-03 | -46.11 | 4.11E-03 | -11.33 |
| | M6 | 1.77E-02 | 102.75 | 1.66E-02 | 109.34 |
| T10 | STEADY | 1.38E-02 | 0.00 | 1.21E-02 | 0.00 |
| | M2 | 6.04E-01 | 33.86 | 6.15E-01 | 32.35 |
| | M4 | 1.07E-02 | 2.77 | 1.03E-02 | 8.72 |
| | M6 | 2.12E-02 | 119.57 | 2.00E-02 | 120.18 |
| T3 | STEADY | 1.43E-02 | 0.00 | 1.27E-02 | 0.00 |
| | M2 | 6.08E-01 | 37.28 | 6.18E-01 | 35.80 |
| | M4 | 1.12E-02 | 28.14 | 1.13E-02 | 33.60 |
| | M6 | 2.18E-02 | 125.65 | 2.07E-02 | 125.59 |
| T4 | STEADY | 1.88E-02 | 0.00 | 1.75E-02 | 0.00 |
| | M2 | 6.23E-01 | 45.13 | 6.33E-01 | 43.75 |
| | M4 | 1.90E-02 | 49.47 | 1.91E-02 | 51.15 |
| | M6 | 2.30E-02 | 142.66 | 2.21E-02 | 141.39 |
| T6 | STEADY | 1.98E-02 | 0.00 | 1.86E-02 | 0.00 |
| | M2 | 6.30E-01 | 47.79 | 6.40E-01 | 46.45 |
| | M4 | 2.35E-02 | 53.60 | 2.35E-02 | 54.27 |
| | M6 | 2.36E-02 | 149.72 | 2.29E-02 | 148.04 |
| T8 | STEADY | 1.81E-02 | 0.00 | 1.72E-02 | 0.00 |
| | M2 | 6.90E-01 | 60.72 | 7.00E-01 | 59.53 |
| | M4 | 5.86E-02 | 67.69 | 5.83E-02 | 66.60 |
| | M6 | 3.48E-02 | -161.46 | 3.42E-02 | -165.61 |
| T9 | STEADY | 2.14E-02 | 0.00 | 2.07E-02 | 0.00 |
| | M2 | 7.10E-01 | 62.45 | 7.20E-01 | 61.29 |
| | M4 | 6.63E-02 | 65.62 | 6.59E-02 | 64.29 |
| | M6 | 4.25E-02 | -150.47 | 4.17E-02 | -154.72 |
| T11 | STEADY | 2.18E-02 | 0.00 | 2.11E-02 | 0.00 |
| | M2 | 7.13E-01 | 62.53 | 7.23E-01 | 61.37 |
| | M4 | 6.74E-02 | 65.41 | 6.69E-02 | 64.18 |
| | M6 | 4.45E-02 | -149.93 | 4.37E-02 | -154.36 |
| T16 | STEADY | 2.04E-02 | 0.00 | 1.96E-02 | 0.00 |
| | M2 | 7.23E-01 | 63.71 | 7.33E-01 | 62.56 |
| | M4 | 7.41E-02 | 64.72 | 7.36E-02 | 63.27 |
| | M6 | 4.78E-02 | -144.40 | 4.68E-02 | -148.72 |



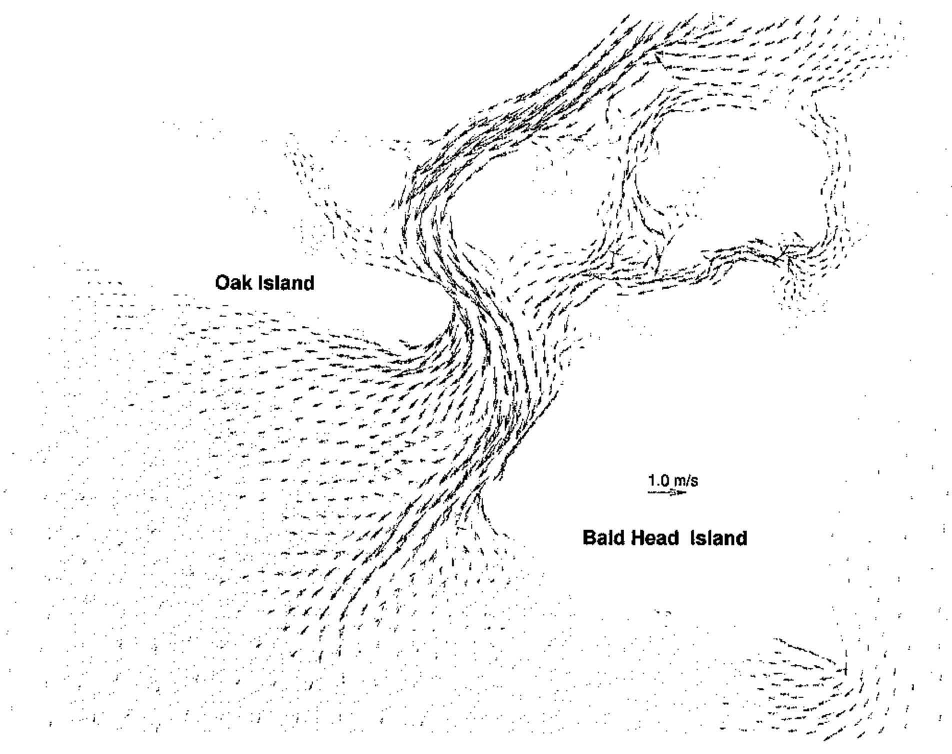




Figure 7. Velocity vectors for pre-dredge (green) and post-dredge (red) conditions after 54 hours (top) and 96 hours (bottom) of simulation.

*Task 4: Preliminary runs with the ADCIRC bed change model (ADBED)*

Eight-day simulations of ADBED were run using the flow fields obtained from the pre-dredge simulations of ADCIRC and those obtained from the post-dredge simulations of ADCIRC. Resynthesized M2, M4, M6, and Steady tidal constituents from the calibrated ADCIRC model were used to drive ADBED. Other parameters used in the simulations are summarized in Table 5.

Table 5. Parameter values for ADBED simulations.

| Parameter | Value |
|---|---|
| Runtime | 8 days |
| Timestep | 10 sec |
| Diffusivity Type | Constant |
| Diffusion coefficient | 0, 0.01 $m^2s^{-1}$ |
| Minimum Depth | 1.1 m |
| Drag Coefficient | 0.0025 |
| Grain Diameter | 0.00025 m |
| Sediment Flux formulation | Ackers and White |

Differences between elevation solutions at the beginning of Day 1 and end of Day 8 are shown in Figure 8 for the case of a horizontal diffusion coefficient of zero. In general the solutions are quite noisy, presumably due to the use of a central-difference equivalent numerical scheme in ADBED which has no numerical damping. There is the possibility of enhanced erosion in the post-dredge channel along the northwestern shore of Bald Head Island, however, given the numerical noise in the solution, these results are highly suspect.

In an attempt to damp the numerical noise in the ADBED solution, a small amount of diffusion was added using a non-zero, spatially constant, horizontal diffusion coefficient (0.01 $m^2s^{-1}$). Figure 9 presents the difference between elevation solutions at the beginning of Day 1 and the end of Day 8 for the pre-dredge grid. Despite the low diffusion coefficient, the solution is very diffusive and suggests the occurrence of erosion in all of the channels and accretion on the banks. In general we were unable to identify a value for the diffusion coefficient that simultaneously damped the numerical noise and didn't cause the solution to appear overly diffusive. ADBED also has the capability for a spatially variable, streamwise oriented diffusion coefficient. Preliminary runs using this feature did not show significant improvement from the spatially constant diffusion coefficient, however, this should be explored further.

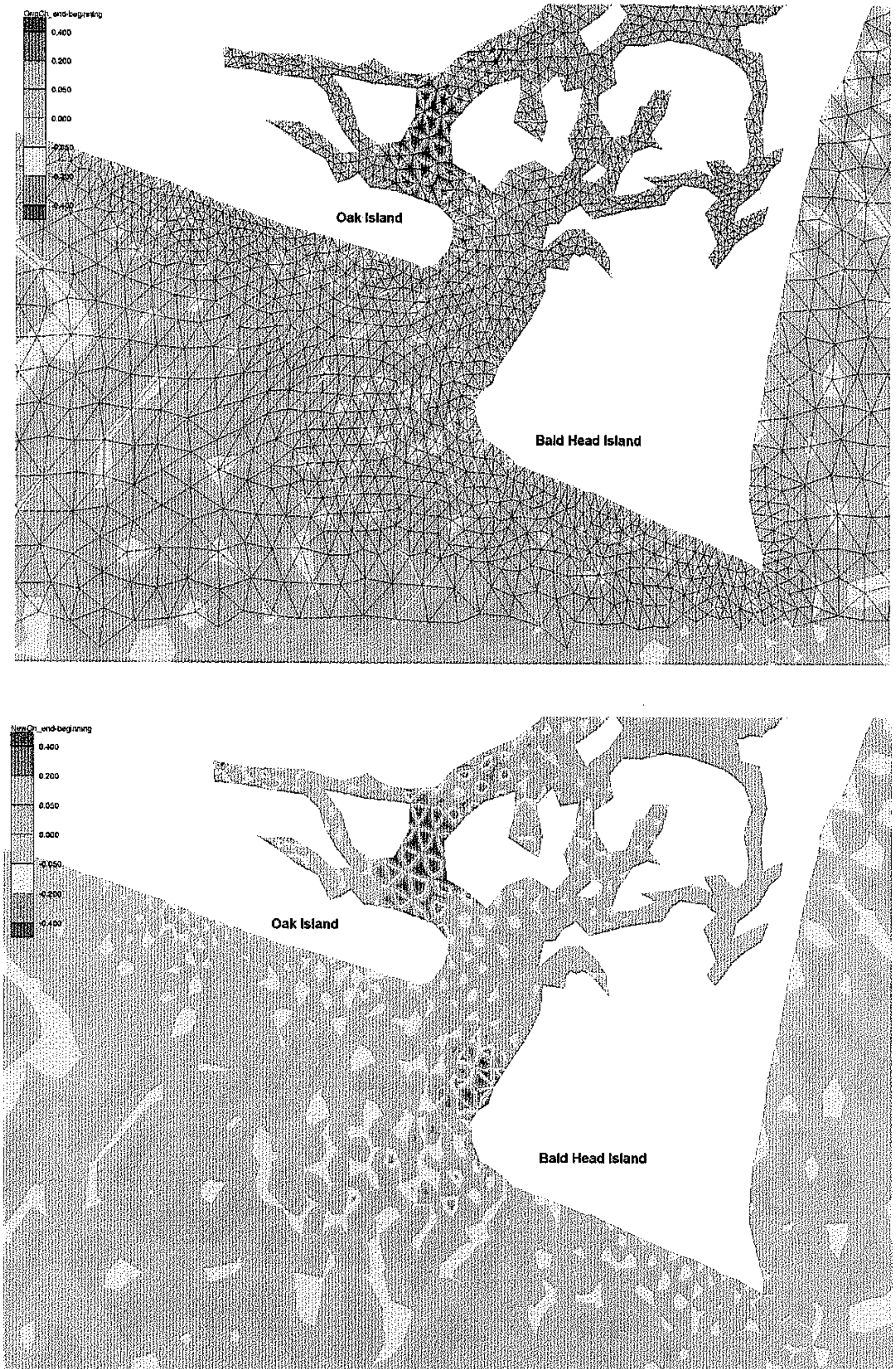



Figure 8. ADBED predicted bed change after 8 days of model simulation for the pre-dredge (top) and post-dredge (bottom) configuration.

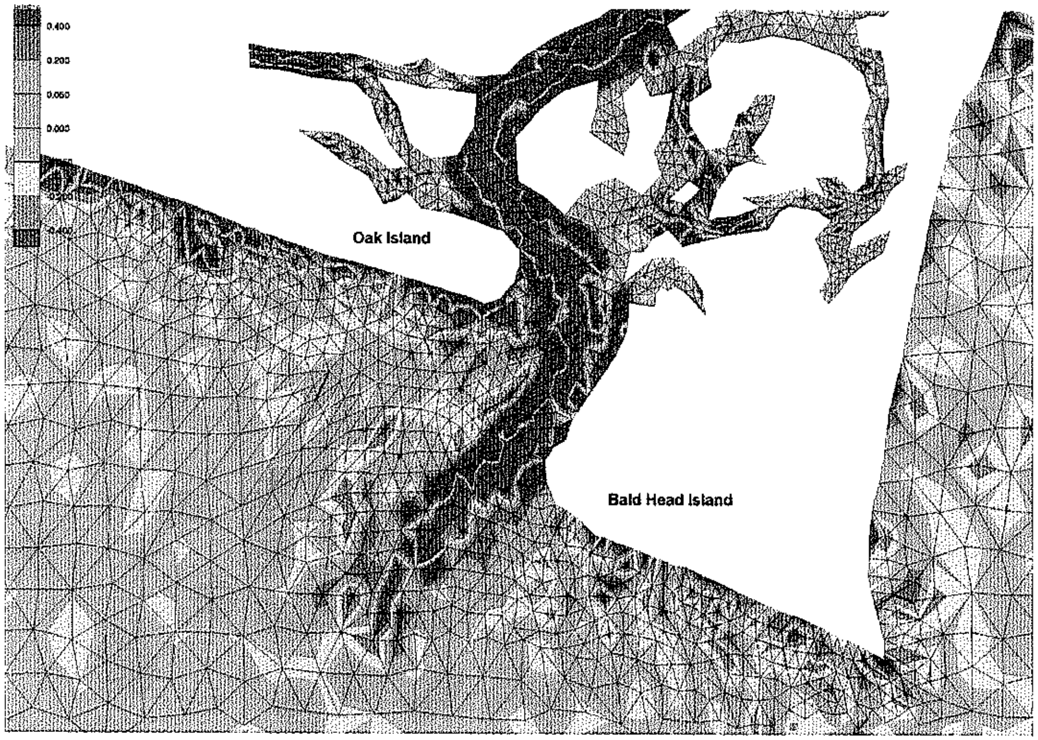



Figure 9. ADBED predicted bed change after 8 days of model simulation for the pre-dredge configuration using a spatially horizontal diffusion coefficient of 0.01 $m^2s^{-1}$.

*Conclusions*

ADCIRC has been set up and a reasonable calibration (as compared to data from a 1976 NOS study) obtained for forcing by five astronomical tidal constituents. Proposed channel modifications had minimal impact on water level inside the estuary and only slight impact on currents near the mouth of the estuary. Simulations with the new ADBED model generally exhibited unsatisfactory numerical behavior suggesting that the use of a more sophisticated numerical technique may be necessary.

*Recommendations*

Follow up modeling studies at this location should consider the use of a more refined grid, radiation boundary conditions at the upstream end, river discharge, updated bathymetry and more recent field studies to construct a more accurate representation of the hydrodynamic field. Furthermore, additional work is clearly warranted with the ADBED transport model, either in terms of identifying a better streamwise diffusion operator or in reformulating the model in such a way that local mass conservation is ensured and upwinding is employed.

References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