A SENSITIVITY ANALYSIS FOR A TIDALLY-INFLUENCED RIVERINE SYSTEM

by

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ABSTRACT

Optimal parameter input values are essential in producing the most accurate results for any given model. This is especially true when attempting to capture the physics of a complex estuarine and riverine system. Two very important variables in any two-dimensional hydrodynamic study are the bottom friction and horizontal eddy viscosity. This study attempts to optimize these two parameters by performing a sensitivity analysis in a region that has been difficult to model in the past.

This project centers on the Waccamaw River and Atlantic Intracoastal Waterway (AIW) region in South Carolina. This estuarine and riverine system is strongly influenced by the astronomical tide, but also has significant freshwater inflows from adjoining rivers discharging into the system. This particular area is very susceptible to flooding, discharge coming downstream from North Carolina as well as storm surge entering from the downstream entrance to the Atlantic Ocean, Winyah Bay. Since this system is so complex, the National Weather Service’s Southeast River Forecast Center (SERFC) has had difficulties estimating past flood events. The results from this study are an initial step towards providing the SERFC with accurate downstream boundary conditions for their hydrodynamic model to increase the accuracy of their flood predictions.

A previously existing finite element mesh of the study region is extensively modified to add the entire Waccamaw River and AIW system. Element sizes are on the order of 20 to 100 meters in the estuarine and riverine system to allow for horizontal
circulations patterns to evolve if present. By increasing the resolution and adding the latest bathymetry to the previous mesh of this area, the geometry and physics of the system can be accounted for much better than before.

The model is solved with a two-dimensional depth-integrated, finite element coastal circulation code that solves the nonlinear shallow water equations, ADCIRC-2DDI. ADCIRC-2DDI incorporates a hybrid bottom friction function that allows the bottom stress to be proportional to the bathymetric depth to allow for a better representation of the bottom friction in shallow water. The model is forced with seven main tidal constituents at the open ocean boundary: \( M_2, M_4, M_6, N_2, O_1, S_2, \) and \( K_2 \). Results are initially compared to historic tide gage records near the coast to determine model accuracy. An optimal range of values can then be determined for the bottom friction and horizontal eddy viscosity through a sensitivity analysis of these parameters.
ACKNOWLEDGEMENTS

I would like to thank the many people who inspired me to pursue my goal of becoming a successful engineer and adult: First, I would like to thank Dr. Scott C. Hagen for his guidance and mentoring throughout my entire experience at UCF; Dr. Gour-Tsyh (George) Yeh and Dr. John D. Dietz for serving on my committee; All my teachers that I have had throughout my educational career who have provided me with motivation and the facility to learn from them; D Michael Parrish for his help with FORTRAN and his thorough proofreading of my manuscript; Members of the Compaq Water Resources Simulations Lab, who made the atmosphere in the lab an enjoyable one; Reggina Garza, Wylie Quillian and members of the Southeast River Forecast Center for providing insight into the FLDWAV model.

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CHAPTER 1 – INTRODUCTION

The focus of this study will be on a riverine system that is strongly influenced by the astronomical tide, the Waccamaw River and Atlantic Intracoastal Waterway, in South Carolina. The primary objective is to determine appropriate horizontal eddy viscosity and bottom friction values in order to allow accurate modeling of the tidal and riverine flow dynamics in the study area. A two-dimensional hydrodynamic model representing the coastal area of northern South Carolina and the Waccamaw River is used for this purpose. Implementation of this model, combined with knowledge of the range of parameter values, will improve tide and flood predictions along the coast of northern South Carolina and within the Waccamaw River basin along with helping similar modeling efforts in this region.

The Waccamaw River drains the coastal areas of southern North Carolina and northern South Carolina. The river leaves Lake Waccamaw in North Carolina and flows southward through Conway, South Carolina. From there, it flows southward to a confluence with the Atlantic Intracoastal Waterway (AIW) near Enterprise Landing, South Carolina, through Winyah Bay, and into the Atlantic Ocean (Figure 1-1). Several rivers form a confluence with the Waccamaw River, including the Pee Dee River, the Little Pee Dee River, the Black River and the Sampit River. These adjoining rivers provide a significant amount of freshwater inflow to the Waccamaw River, thus affecting the dynamics in the river. The study area includes all of the Waccamaw River and AIW
estuarine system upstream to Conway, South Carolina. This riverine system is strongly tidally influenced, with a tidal signal present as far as 60 river miles from Winyah Bay.

Previous studies (Bennett, 1999; Hagen and Bennett, 1999; Hagen et al., 2002) included only a small portion of the AIW and focused solely on capturing the flow dynamics at the coastline. This project extends the previous analyses by incorporating freshwater inflows and by including the entire Waccamaw River and AIW upstream to Conway, South Carolina. As a result, the flow dynamics of the riverine and estuarine systems, not just the coastal waters, can be captured.

Figure 1-1: Waccamaw River study region
The National Weather Service’s Southeast River Forecast Center (SERFC) is in charge of providing flood forecasts for all rivers in the southeastern United States. The Waccamaw River has historically been a trouble spot for the SERFC, due to its large basin area and the number of tributaries. The SERFC uses a hydrodynamic model, FLDWAV (pronounced “flood wave”), to provide a real-time forecast of water surface elevations of rivers in its forecast area. FLDWAV is a finite difference model that solves the Saint-Venant equations of one-dimensional unsteady flow (National Weather Service Hydrologic Laboratory - River Mechanics, 2001). This model is fairly accurate, however, it needs an accurate, time-dependent tidal boundary condition to be able to properly forecast tidally influenced rivers. This study will provide an accurate estimate of the downstream tidal boundary conditions at Hagley’s Landing, S.C. and Nixon’s Crossroads, S.C., which can be applied to the FLDWAV model (Figure 1-2).

This study focuses on a sensitivity analysis of two parameters: horizontal eddy viscosity and bottom friction. Three freshwater inflow scenarios (low, medium and high) are incorporated in order to determine corresponding ranges of values for each of the two parameters. Ideally, the range of values of the parameters would be applicable for any flow event in the riverine system. In the sensitivity analysis, the values of each parameter are adjusted to determine the optimal values for the domain and selected flow scenario. This sensitivity analysis produces the best combination of eddy viscosity and bottom friction for each riverine flow scenario.
Figure 1-2: Schematic of FLDWAV Model
In previous studies, these parameters did not affect the accuracy of the results as much as they do in the present simulations because the former model domain did not include the riverine system and was focused on the offshore hydrodynamics. This is due to the relatively deeper water and simpler geometry of the area when the Waccamaw River and AIW is not included. In the deep water, the friction factor does not influence the propagation of the flow as much as it does in shallow water. Also, in order for an eddy or eddies to form, not only must the eddy viscosity parameter be in the appropriate range, but the shoreline and topography must be sufficiently irregular to allow formation of eddies. Further, the level of resolution must be sufficient to capture eddy formation. Since the entire riverine and estuarine system is included and because of the meandering nature of the river, combined with the shallow bathymetry of the river, the bottom friction and eddy viscosity parameters become more important in this study than in the previous studies.

Simulations are performed with a two-dimensional, finite element code for coastal and ocean circulation, ADCIRC-2DDI (Advanced Circulation Model for Oceanic, Coastal, and Estuarine Waters—Two Dimensional Depth Integrated option). ADCIRC-2DDI is a computer program that solves depth integrated, time dependent free surface circulation and transport problems. ADCIRC-2DDI solves the depth-integrated continuity equation in the Generalized Wave-Continuity form in conjunction with the momentum equations in order to obtain the water surface elevation and velocities in the latitudinal and longitudinal directions. Elevation boundary conditions are applied at the open ocean boundary in the form of tidal constituent forcings. The values for these tidal
constituents are obtained from a larger Western North Atlantic tidal model. The initial model results are validated by comparing the simulated water surface elevations to tidal constituent data at various locations in the near-shore region of the coastline. After validating the model, a successful sensitivity analysis can be performed.
CHAPTER 2 – LITERATURE REVIEW

Introduction of the Tides and Tidal Theory

Early scientists had various hypotheses about the driving mechanisms of the tides. Galileo attributed the tides to the rotation of the earth, Newton described the tides as being produced by a tide-generating force and Bernoulli attributed the tides to a gravitational force (Dronkers, 1964). In 1897, Sir George Howard Darwin presented a series of lectures and eventually a book (Darwin, 1962) that expanded on the works of Galileo, Newton and Bernoulli. These lectures contained a history of tidal theory and explained the tides as resulting from the gravitational attractions of the sun and moon. Darwin was the first to decompose the tide into harmonic constituents based on the moon and sun’s orbits.

Throughout time, the tides have played an important role in many activities that occur near the coast. Everything from commercial travel, naval battles, devastating pollutant spills to storm surge is affected by the tides. Commercial oceanic transportation depends on the tides, especially in areas where the tidal range is very high. Some large vessels have to time their entrance to an inlet or port to coincide with the high tide or risk grounding the vessel (MacMillan, 1966). Historically, several naval battles have depended on (or failed because of) the tides (Guth, 2001). If there is some type of contaminant spill, containment efforts usually center on where the pollutant will travel with the tide (Sengupta, Lee & Miller, 1978). When a hurricane or tropical system is
nearing landfall, the tide is a major factor in determining the amount of inundation from the storm surge.

Therefore, having accurate estimates of the tidal cycle is very important. Until the advent of digital computers, seafaring people had to rely on tide tables that were calculated from observations. Some of these tide tables were passed on from generation to generation as heirlooms. However, with the advancement of technology, today tides can be predicted or generated at any location in the world within a fairly reasonable degree of accuracy.

**Numerical Modeling of the Tides**

In the mid-20th century, people began to use digital computers to model the tides. Early models were one-dimensional steady-state models that were severely hampered by computer speed at that time. As computers increased in computational ability, models could become more complex, expanding to 2-D and 3-D and acquiring the ability to incorporate such processes as sediment transport, surface wave interaction and water quality parameters such as nutrients, light and seagrass (Cheng & Smith, 1989; Westerink & Gray, 1991; Sheng, 1997). As model accuracy increased, the amount of complexity increased as well. Presently, most models are either a depth-averaged two-dimensional (2D) model or a three-dimensional (3D) model. Two-dimensional depth-averaged models are generally preferred due to their computational efficiency (Luetttich, Westerink & Scheffner 1992). However, if the vertical density stratification cannot be neglected, or
transport mechanics are desired, a 3D model needs to be applied. With either of these models, computing time can be a limiting factor. Therefore, several models allow for parallel computation by clusters, several computers connected in a network. ADCIRC uses a form of parallel computing called domain decomposition, this allows the model input to be decomposed into smaller parts and solved simultaneously (i.e. in parallel) to allow for a magnitude of speedup that is nearly equal to the number of processors.

Several studies (Boericke & Hogan, 1977; Gomez-Reyes, 1989; Grenier & Luettich, 1995; Lee & Jung, 1999, Cobb & Blain, 1999) have centered on attempting to find the optimal parameter value so that a particular model may produce the most accurate results. Many of these studies center on the bottom friction or eddy viscosity parameter and how they affect the tidal signal. One drawback from this approach is the bottom friction or eddy viscosity is ‘tuned’ to match the results instead of the physical characteristics of the river itself. This can cause the bottom friction or eddy viscosity values to be unrealistic by not being within a typical range of values determined from the actual characteristics of the river (bed material, slope, flow, etc.). But, tidal studies that attempt to optimize the eddy viscosity or bottom friction within a reasonable range, while at the same time incorporating a freshwater inflow, are scarce.

**Tides and Freshwater Flow Interaction**

With rivers that are directly connected to the ocean, variations can be seen in the water surface depending on the tides and amount of freshwater inflow. Records show
that an increase in riverine discharge damps the tidal signal if the riverine and tidal flows are opposing each other and reduces the velocity of the tidal current while raising the water level (Vongvisessomjai & Rojanakamthorn, 1989). The water level rise is due to an overall increase in water volume, and subsequently, when a high tide is superimposed onto a very high inflow discharge, the possibility of overtopping the banks (i.e. flooding) is high.

Some of the first to analyze the overall aspect of the interaction between these two dynamics were Einstein and Fuchs (1955). They made a survey of past and present calculation methods used for the prediction of tide stage and discharge in canals and estuaries. The purpose of their work was to determine if one method worked better than the others. Einstein and Fuchs determined that the problem of tidal flow combined with a steady inflow was extremely complex and could not be solved easily. Many of the methods presented used varying assumptions to simplify the model and in most cases were not accurate. In general, Einstein and Fuchs showed that many of the past methods used in assessing a situation of combined tidal flow and riverine inflow were incorrect or didn’t describe the physics adequately.

J. J. Dronkers followed in 1964 with a book entitled *Tidal Computation in River and Coastal Waters*. This book provided insight into solving practical problems involving tides in shallow water. Dronkers discusses using physical hydraulic models and numerical computer models to simulate the system. He also discusses the specific problem of a tidal wave on a river that is influenced by a freshwater run-off some distance upstream from the mouth of the river. At a specific distance upstream, called the
limit of flood flow, the tidal flow characteristics change due to the inflow. Upstream of
the limit of flood flow, only ebb flow occurs due to the opposing inflow. He also defines
the time period of near zero current at a specific point as being slack or still water.
Downstream from the limit of flood flow, two slack waters occur, one during flood flow
and one during ebb flow. At approximately the location of the limit of flood flow, only
one slack water occurs and upstream of the limit of flood flow, the current is always in
the seaward direction. Dronkers also noted that a high run-off will damp the tides more
than a low run-off and that the tidal wave will propagate further upstream during a low
inflow. He also states that a river with a greater bottom slope will damp the tides
(assuming inflow stays constant) because the increase of velocity of the inflow will
increase and the water depth will be lower. Both of these factors will contribute to a
stronger distortion of the main tide and will allow the overtides to increase.

**Bottom Friction**

The bottom friction term can take on several different forms. The way that the
bottom friction is formulated in the governing equations significantly impacts the
contribution of the bottom stress to the overall tidal signal. In general, most 2-D models
use either a standard quadratic bottom friction formulation or a Manning’s type friction
formulation, both a function of the depth-averaged velocity. The form of the quadratic
formulation of bottom stress that is used can vary from model to model, but they all use a
form that incorporates the resultant of the depth-averaged velocity and a drag coefficient.

One generic form of the quadratic formulation is:

\[
\tau = C \rho \sqrt{U^2 + V^2}
\]  \hspace{1cm} (2-1)

where

\( C = \) drag coefficient
\( \rho = \) reference density
\( U, V = \) depth-averaged velocities

Other models use a slightly different quadratic bottom stress formulation:

\[
\tau_s = \frac{C_f (U^2 + V^2)^{1/2}}{H}
\]  \hspace{1cm} (2-2)

where

\( C_f = \) drag coefficient
\( H = \) total bathymetric depth of water column
\( U, V = \) depth-averaged velocities

When a Manning’s type of friction law is applied, the Manning’s bottom friction coefficient is correlated to the overall bottom friction through the Chezy equation.

\[
C = \sqrt{\frac{g}{C_b}} = \frac{R^{\frac{1}{n}}}{n}
\]  \hspace{1cm} (2-3)
where

\( R = \) hydraulic radius

\( C_b = \) drag coefficient

\( g = \) acceleration due to gravity

For most models, calibration of the model is primarily achieved by adjusting the friction factor. However, in some three-dimensional models, the internal friction in the vertical direction can prove to be just as important. When attempting to select a bottom friction value, many authors suggest beginning with a value of 0.0025 for the drag coefficient in quadratic formulations. Depending on the bottom profile and other contributing physical factors, the bottom friction drag coefficient can vary from 0.009 to 0.0015. Table 2-1 summarizes the bottom friction values used in several tidal studies reported in journal articles and presented at various conferences. The author, value, location of model domain and model used are all noted.

Cobb and Blain (1999) used the ADCIRC-2DDI model to perform a sensitivity analysis of the bottom friction and eddy viscosity in a shallow, nearshore location. A result of their study was to determine the sensitivity of the model to its nonlinear processes in order to determine the effect on nearshore circulation. The model was simulated using a constant alongshore current and bathymetry and used two different slopes of the nearshore bottom surface. One interesting result was that as the combination of the bottom friction and eddy viscosity that produced the observed circulation patterns only occurred when both variables were at the lower end of the study.
limits. Cobb and Blain hypothesized that this was because a decrease in the diffusion and
dissipative effects prevented the system from relaxing into a steady state and
subsequently allowed unsteady circulation patterns to form. At the upper end of the
study limits, the currents were damped significantly. Discussion regarding the eddy
viscosity variable will follow in the next section.

Since the addition of a freshwater inflow some distance upstream from the mouth
of the river introduces a more complex flow pattern, the bottom friction value plays a
different role. Ideally, the bottom friction coefficient that is determined would be
appropriate for studies that: 1) Include both tides and inflow 2) Include only inflows or
3) Include only tides. This requires a more intense sensitivity analysis in order to
determine what friction factor is most suitable for both the freshwater inflow and the tidal
signal together. Table 2-2 summarizes various tidal studies that include a freshwater
inflow in a manner similar to that of Table 2-1.
<table>
<thead>
<tr>
<th>Investigator(s)</th>
<th>Bottom Friction Coefficient</th>
<th>Location of Model Domain</th>
<th>Model Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boericke &amp; Hogan (1977)</td>
<td>0.02 (^1)</td>
<td>Lower Hudson River, N.Y.</td>
<td>User-Developed</td>
</tr>
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<td>Le Provost et al. (1981)</td>
<td>0.0025</td>
<td>English Channel</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Kim et al. (1989)</td>
<td>0.0028</td>
<td>Chesapeake Bay</td>
<td>CH3D</td>
</tr>
<tr>
<td>Spaulding &amp; Liang (1989)</td>
<td>0.0036</td>
<td>Mt. Hope Bay, R.I.</td>
<td>User-Developed</td>
</tr>
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<td>Suscy et al. (1989)</td>
<td>0.0023</td>
<td>Gulf of Maine</td>
<td>POM</td>
</tr>
<tr>
<td>Weisman et al. (1989)</td>
<td>0.02, 0.014 (^1,2)</td>
<td>Great Sound, N.J.</td>
<td>HYDTID</td>
</tr>
<tr>
<td>Vemulakonda &amp; Butler (1989)</td>
<td>0.02 (^1)</td>
<td>Long Beach Harbor, Calif.</td>
<td>CH3D</td>
</tr>
<tr>
<td>Vongvisessomjai &amp; Rojanakamthorn (1989)</td>
<td>0.028</td>
<td>Chao Phraya River, Thailand</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Kolar &amp; Gray (1990)</td>
<td>0.0001</td>
<td>Artificial Brood stock Pond</td>
<td>FLEET</td>
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<tr>
<td>Chen &amp; Lee (1991)</td>
<td>0.035-0.045 (^3)</td>
<td>Lower Green Bay Estuary System, Wisc.</td>
<td>User-Developed</td>
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<td>Westerink et al. (1992)</td>
<td>0.03 (^1)</td>
<td>Gulf of Mexico</td>
<td>ADCIRC</td>
</tr>
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<td>Grenier et al. (1993)</td>
<td>0.009</td>
<td>Bight of Abaco, Bahamas</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Mark &amp; Scheffner (1993)</td>
<td>0.003</td>
<td>Delaware</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Ziegler et al. (1993)</td>
<td>0.0028</td>
<td>Tar-Pamlico River, N.C.</td>
<td>SIMSYS 2D</td>
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<td>Kolar et al. (1994)</td>
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<td>Western North Atlantic</td>
<td>ADCIRC</td>
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<td>Grenier &amp; Luettich (1995)</td>
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<td>ADCIRC</td>
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<td>Soliman (1995)</td>
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<td>Suez Canal</td>
<td>User-Developed</td>
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<td>Tomasson &amp; Eliasson (1995)</td>
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<td>Northern Atlantic Ocean</td>
<td>AQUASEA</td>
</tr>
<tr>
<td>Blain (1997)</td>
<td>0.0015</td>
<td>Arabian Gulf</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Foreman &amp; Cummings (1997)</td>
<td>0.01 (^1)</td>
<td>Vancouver Island</td>
<td>QUODDY4</td>
</tr>
<tr>
<td>Luettich et al. (1997)</td>
<td>0.0025</td>
<td>Beaufort Inlet, N.C.</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Martin &amp; Shelden (1997)</td>
<td>0.02 (^1)</td>
<td>Johor, Malaysia</td>
<td>RMA-2</td>
</tr>
<tr>
<td>Militello &amp; Kraus (1997)</td>
<td>0.025 (^1)</td>
<td>Matagorda Bay, Texas</td>
<td>M2D</td>
</tr>
<tr>
<td>O'Connor et al. (1997)</td>
<td>0.0025</td>
<td>East and West Coasts of Florida</td>
<td>POM</td>
</tr>
<tr>
<td>Signell et al. (1997)</td>
<td>0.003</td>
<td>Long Island Sound, N.Y.</td>
<td>ECOM</td>
</tr>
<tr>
<td>Spaulding et al. (1997)</td>
<td>0.0035</td>
<td>Greenwich Bay, R.I.</td>
<td>User-Developed</td>
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<td>Vincent et al. (1997)</td>
<td>0.0025</td>
<td>Tampa Bay, Fla.</td>
<td>ECOM</td>
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<tr>
<td>Hagen &amp; Bennett (1999)</td>
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<td>South Carolina</td>
<td>ADCIRC</td>
</tr>
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<td>Hench &amp; Luettich (1999)</td>
<td>0.0025</td>
<td>Beaufort Inlet, N.C.</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Investigator(s)</td>
<td>Bottom Friction Coefficient</td>
<td>Location of Model Domain</td>
<td>Model Used</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------</td>
<td>-------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Lee &amp; Jung (1999)</td>
<td>0.0038</td>
<td>Yellow and East China Seas</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Luick &amp; Henry (2000)</td>
<td>0.0025</td>
<td>Southern Pacific Ocean -- Tongan Region</td>
<td>Walters (1986)</td>
</tr>
<tr>
<td>Cobb &amp; Blain (2001)</td>
<td>0.0025</td>
<td>Artificial Ideal Inlet</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Baumeister &amp; Manson (2001)</td>
<td>0.0027</td>
<td>Hudson River, N.Y.</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Luettich et al. (2002)</td>
<td>0.0025</td>
<td>Albemarle–Pamlico Estuarine System, N.C.</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Wilson et al. (2002)</td>
<td>0.011</td>
<td>Artificial Channel</td>
<td>TELEMAC-2D</td>
</tr>
</tbody>
</table>

1 Investigator used a Manning’s value, as shown in Equation 2-3
2 0.02 used at flood tide; 0.014 used at ebb tide
3 Range of values used for various regions in domain

---

Table 2-2

Bottom Friction Values from Various Tidal Studies with Freshwater Inflows

<table>
<thead>
<tr>
<th>Investigator(s)</th>
<th>Bottom Friction Coefficient</th>
<th>Location of Model Domain</th>
<th>Model Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spaulding et al. (1989)</td>
<td>0.0036</td>
<td>Mt. Hope Bay, RI</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Teeter (1989)</td>
<td>0.021</td>
<td>New Bedford Estuary, MA</td>
<td>RMA-2</td>
</tr>
<tr>
<td>Gomez-Reyes (1989)</td>
<td>0.0002</td>
<td>Peconic Bay, NY</td>
<td>Isaji &amp; Spaulding Developed Model</td>
</tr>
<tr>
<td>Blumberg et al. (1989)</td>
<td>0.021</td>
<td>Jamaica Bay, NY</td>
<td>ECOM-3D</td>
</tr>
<tr>
<td>Evans et al. (1989)</td>
<td>0.0017, 0.0014</td>
<td>Bristol Channel, UK</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Park &amp; Kuo (1993)</td>
<td>0.0181</td>
<td>Rappahannock River, Western Chesapeake Bay</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Huang &amp; Spaulding (1993)</td>
<td>0.002</td>
<td>Mt. Hope Bay &amp; Lower Taunton River, RI</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Schuepfer et al. (1999)</td>
<td>0.0251</td>
<td>Long Island Sound, NY</td>
<td>RMA-10</td>
</tr>
<tr>
<td>Veeramony &amp; Blain (2001)</td>
<td>0.0025</td>
<td>Mississippi Sound Inlet</td>
<td>ADCIRC</td>
</tr>
</tbody>
</table>

1 Investigator used a Manning’s value, as shown in Equation 2-1
3 0.0017 was used at spring tide; 0.0014 was used at neap tide
Eddy Viscosity

Eddy viscosity is the internal friction acting on an individual fluid particle; it acts both vertically and horizontally. In ADCIRC-2DDI and other 2D depth-averaged models, the vertical component of the eddy viscosity is neglected. In the 3D tidal models, the vertical eddy viscosity can prove to be a largely influential factor in vertical circulation and transport. Since the model used for this study is of the 2D depth-averaged type, the vertical eddy viscosity will not be discussed.

There are several ways to describe the horizontal eddy viscosity in the governing equations. The majority of models using some variation of the shallow water equations include the horizontal eddy viscosity in the momentum terms. In many of the 2D models, the optimization of the eddy viscosity parameter is not needed due to the large domain, large bathymetric depths and coarse discretization of the domain. However, in order to effectively simulate the formation of time-dependent circulation patterns in regions where the flow area is small, the discretization is sufficient and the bathymetric features (abrupt changes in depth) can promote the formation of horizontal circulation patterns, eddy viscosity plays a more important role. Cobb and Blain (1999) showed the importance of the horizontal eddy viscosity when attempting to capture nearshore nonlinear circulation, or eddies. As the value decreased, the model allowed the time-dependent circulation pattern to appear.

The disparities between different model formulations regarding the horizontal eddy viscosity are far greater than the variations between model formulations of bottom friction. Several formulations exist, it can be described as a simplified eddy viscosity
formulation (Kolar and Gray, 1990), other models may use a Smagorinsky horizontal mixing coefficient or just neglect the horizontal eddy viscosity altogether.

Many studies using ADCIRC-2DDI use a zero value for the horizontal eddy viscosity parameter; a reason for this might be that the model domain is quite large and horizontal circulation patterns cannot be captured due to a coarse discretization of the domain. If the element size is too coarse, the horizontal circulation can be contained in a single element. Therefore, for the horizontal eddy viscosity parameter to show circulation, the model discretization must be at a high enough level so several elements can describe the area of a large-scale eddy. Table 2-3 summarizes several studies with respect to eddy viscosity, where the discretization is sufficient to capture large-scale eddies. For comparativeness, only studies that have used ADCIRC-2DDI’s version of the simplified eddy viscosity model are included. A detailed description of the Kolar and Gray eddy viscosity formulation used in ADCIRC-2DDI is presented in the next chapter.
<table>
<thead>
<tr>
<th>Investigator(s)</th>
<th>Coefficient of Eddy Viscosity (m²/s)</th>
<th>Location of Model Domain</th>
<th>Model Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blumberg et al. (1989)</td>
<td>3.0</td>
<td>Jamaica Bay, NY</td>
<td>ECOM-3D</td>
</tr>
<tr>
<td>Gomez-Reyes (1989)</td>
<td>0.75</td>
<td>Peconic Bays Estuary, NY</td>
<td>Isaji &amp; Spaulding Model</td>
</tr>
<tr>
<td>Vemulakonda &amp; Butler (1989)</td>
<td>20.0</td>
<td>Long Beach Harbor, CA</td>
<td>CH3D</td>
</tr>
<tr>
<td>Spaulding &amp; Liang (1989)</td>
<td>15.0</td>
<td>Mt. Hope Bay, RI</td>
<td>User-Developed</td>
</tr>
<tr>
<td>Teeter (1989)</td>
<td>5.0</td>
<td>New Bedford Estuary, MA</td>
<td>RMA-2</td>
</tr>
<tr>
<td>Sheng et al. (1993)</td>
<td>1.0</td>
<td>Indian River Lagoon, FL</td>
<td>CH3D</td>
</tr>
<tr>
<td>Ziegler et al. (1993)</td>
<td>10.0</td>
<td>Tar-Pamlico River, NC</td>
<td>SIMSYS 2D</td>
</tr>
<tr>
<td>Luettich et al. (1997)</td>
<td>2.0</td>
<td>Beaufort Inlet, NC</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Hench &amp; Luettich (1999)</td>
<td>7.0</td>
<td>Beaufort Inlet, NC</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Cobb &amp; Blain (2001)</td>
<td>1.0</td>
<td>Artificial Inlet</td>
<td>ADCIRC</td>
</tr>
<tr>
<td>Veeramony &amp; Blain (2001)</td>
<td>1.0</td>
<td>Mississippi Sound Inlet</td>
<td>ADCIRC</td>
</tr>
</tbody>
</table>
CHAPTER 3 – MODEL FORMULATION

The model used for the simulations in this study is a two-dimensional, depth-integrated, finite-element code for coastal and ocean circulation, ADCIRC-2DDI (Advanced Circulation Model for Oceanic, Coastal, and Estuarine Waters—Two Dimensional Depth Integrated option; Westerink, Blain, Luettich and Scheffner, 1994) is a system of computer codes that solve depth integrated, time dependent free surface circulation and transport problems. The model solves the fully nonlinear shallow water equations and includes nonlinear convective terms. This model assumes hydrostatic pressure, incompressibility, and the Boussinesq approximation and has been discretized in space using the finite element (FE) method and in time using the finite difference (FD) method. ADCIRC-2DDI solves the depth-integrated continuity equation in the Generalized Wave-Continuity Equation formulation (GWCE) in conjunction with the momentum equations to obtain the water surface elevation and velocities in the latitudinal and longitudinal directions. Elevation boundary conditions are applied at the open ocean boundary in the form of tidal forcing terms.
Governing Equations

For spherical coordinates, ADCIRC-2DDI solves the non-conservative momentum equations in the latitudinal (λ) and longitudinal (φ) directions along with the continuity equation in the Generalized Wave-Continuity formulation (Westerink, Blain, Luettich and Scheffner, 1994). The spherical equations are solved by first mapping them into a rectilinear coordinate system using the Carte Parallélogrammatique Projection (CPP). This makes the projected form of the spherical equations very similar to the Cartesian form. In non-conservative form, the vertically integrated momentum equation in the latitudinal direction is:

$$
\frac{\partial U}{\partial t} + \frac{1}{R \cos \phi} \frac{\partial U}{\partial \lambda} + \frac{1}{R} V \frac{\partial U}{\partial \phi} - \left( \frac{\tan \phi}{R} U + f \right) V = $$

$$
- \frac{1}{R \cos \phi} \frac{\partial}{\partial \lambda} \left[ \frac{p_z}{\rho_o} + g (\zeta - \alpha \eta) \right] + \frac{1}{H} M_\lambda + \frac{\tau_{\lambda \lambda}}{\rho_o H} - \tau_U \tag{3-1}
$$

In the longitudinal direction, it is:

$$
\frac{\partial V}{\partial t} + \frac{1}{R \cos \phi} \frac{\partial V}{\partial \lambda} + \frac{1}{R} V \frac{\partial V}{\partial \phi} + \left( \frac{\tan \phi}{R} U + f \right) U = $$

$$
- \frac{1}{R \partial \phi} \frac{\partial}{\partial \phi} \left[ \frac{p_z}{\rho_o} + g (\zeta - \alpha \eta) \right] + \frac{1}{H} M_\phi + \frac{\tau_{\phi \phi}}{\rho_o H} - \tau_V \tag{3-2}
$$
where

\( \lambda, \phi \) = degrees longitude and latitude, respectively

\( U, V \) = depth averaged horizontal velocities

\( H \) = total water column, \( h + \zeta \)

\( h \) = bathymetric depth, relative to mean sea level

\( \zeta \) = free surface elevation, relative to mean sea level

\( R \) = radius of the Earth

\( f = 2\Omega \sin \phi \) = Coriolis parameter

where \( \Omega = \) angular speed of the Earth

\( p_s \) = atmospheric pressure at the free surface

\( \rho_o \) = reference density of water

\( g \) = acceleration due to gravity

\( \alpha \) = earth elasticity factor

\( R \) = radius of the Earth

\[
M_{\lambda} = \frac{E_{h_z}}{R^2} \left[ \frac{1}{\cos^2 \phi} \frac{\partial^2 UH}{\partial \lambda^2} + \frac{\partial^2 UH}{\partial \phi^2} \right] = \text{depth-integrated momentum dispersion, longitudinal direction}
\]

\[
M_\phi = \frac{E_{h_z}}{R^2} \left[ \frac{1}{\cos^2 \phi} \frac{\partial^2 VH}{\partial \lambda^2} + \frac{\partial^2 VH}{\partial \phi^2} \right] = \text{depth-integrated momentum dispersion, latitudinal direction}
\]

\( E_{h_z} \) = horizontal eddy viscosity
\( \tau_{s, \lambda}, \tau_{s, \phi} = \text{applied free surface stress, } \lambda \text{ direction and } \phi \text{ direction} \)

\( \tau_s = \text{bottom stress} \)

\( \eta = \text{Newtonian tide potential}^* \)

The Generalized Wave-Continuity Equation, in spherical coordinates (Kolar, Gray, Westerink and Luettich, 1994) is:

\[
\begin{aligned}
\frac{\partial^2 \zeta}{\partial t^2} &+ \tau_0 \frac{\partial \zeta}{\partial t} - \frac{1}{R \cos \phi} \frac{\partial}{\partial \lambda} \left[ \frac{1}{R \cos \phi} \left( \frac{\partial UUH}{\partial \lambda} + \frac{\partial UVH \cos \phi}{\partial \phi} \right) \right] - \left( \frac{\tan \phi}{R} U + f \right) VH \\
&- \frac{H}{R \cos \phi} \frac{\partial}{\partial \lambda} \left[ \frac{p_s}{\rho_0} + g(\zeta - \alpha \eta) \right] + \frac{E_{h_2}}{R \cos \phi} \frac{\partial^2 \zeta}{\partial \lambda^2} + \tau_{s, \lambda} \left( \tau_s - \tau_0 \right) UH \\
&- \frac{1}{R} \frac{\partial}{\partial \phi} \left[ \frac{1}{R \cos \phi} \left( \frac{\partial HUV}{\partial \lambda} + \frac{\partial HVV \cos \phi}{\partial \phi} \right) \right] + \left( \frac{\tan \phi}{R} U + f \right) UH - \frac{H}{R \cos \phi} \frac{\partial}{\partial \phi} \left[ \frac{p_s}{\rho_0} + g(\zeta - \alpha \eta) \right] \\
&+ \frac{E_{h_2}}{R} \frac{\partial^2 \zeta}{\partial \phi^2} + \tau_{s, \phi} \left( \tau_s - \tau_0 \right) VH \\
&- \frac{\tan \phi}{R} \left( \frac{\partial VH}{\partial t} + \tau_0 VH \right) = 0
\end{aligned}
\]

\( ^* \) The Newtonian tidal potential is defined as:

\( \eta(\lambda, \phi, t) = \sum_{n, j} \alpha_n C_n f_n (t_0) L_j (\phi) \cos \left[ \frac{2\pi (t - t_0)}{T_{j_n} + j \lambda + \nu_{j_n} (t_0)} \right] \)

and is not implemented in this study due to the relatively small size of the model domain.
ADCIRC-2DDI expresses the bottom friction as:

\[ \tau_{nx} = U \tau_s \quad \text{and} \quad \tau_{ny} = V \tau_s \]

This friction value can have three different forms: a linear, quadratic, or hybrid function of the depth-averaged velocity. The linear version is recommended for model testing, or if using ADCIRC-2DDI in linear mode. For most applications, a quadratic or hybrid function is recommended. Both use the quadratic bottom friction equation, but the hybrid bottom friction formulation allows the bottom friction coefficient, \( C_f \), to change with respect to the bathymetric depth. For this study, the hybrid bottom friction function is used. This form is more accurate in shallow water and when wetting and drying of elements are allowed. The quadratic bottom friction equation that is used with the hybrid bottom friction formulation is defined as:

\[ \tau_s = \frac{C_f(U^2 + V^2)^{1/2}}{H} \]  \hspace{1cm} (3-4)

with the hybrid bottom friction, the bottom friction coefficient is defined as:

\[ C_f = C_{f_{\text{min}}} \left[ 1 + \left( \frac{H_{\text{break}}}{H} \right)^\theta \right]^{\frac{\lambda}{\theta}} \]  \hspace{1cm} (3-5)

where

\( C_{f_{\text{min}}} = \) minimum friction factor that is approached in deep water when the hybrid bottom friction function reverts to the quadratic bottom friction function

\( H_{\text{break}} = \) break depth to determine if hybrid function will act like a quadratic function or increase with depth similar to a Manning’s type friction
\( \theta \) = dimensionless parameter that determines how rapidly the hybrid function approaches its upper and lower limits.

\( \lambda \) = dimensionless parameter that describes how quickly the friction factor increases as water depth decreases.

The parameters \( C_{f\min}, H_{\text{break}}, \theta \) and \( \lambda \) are read in as model inputs. With the hybrid bottom friction relationship, the value of \( \tau_\ast \) in the governing equations changes with respect to bathymetric depth. As bathymetric depth approaches zero, the friction factor becomes \( C_{f\min} \left( \frac{H_{\text{break}}}{H} \right)^{\lambda} \). As the depth approaches infinity, the friction factor approaches \( C_{f\min} \). The variable \( \theta \) determines how rapidly \( C_f \) approaches its deep water and shallow water limits and \( \lambda \) determines how quickly the friction factor increases with decreasing water depth. If \( \lambda \) is set to 1/3, the increase behaves similar to a Manning’s type bottom friction law. The hybrid friction formulation works well with the Waccamaw River and AIW due to the rather shallow bathymetric depths upstream in the model. Model developers recommend values for \( \theta \) and \( \lambda \) of 10 and 1/3, respectively. Table 3-1 shows the progression of the bottom friction coefficient from a larger, Manning’s type in shallow water (bottom friction increases as water depth decreases) to the minimum bottom friction value (quadratic) with different values of the break depth \( H_{\text{break}} \) and bathymetric depth. Figure 3-1 shows this same progression graphically. Notice as the depth increases, a smaller \( H_{\text{break}} \) value reaches the minimum value quicker, while a larger \( H_{\text{break}} \) allows for a smoother transition between the Manning’s type and quadratic type.
Table 3-1

Variation in $C_f$ with Bathymetric Depth and $H_{\text{break}}$; $C_{f\text{ min}} = 0.0025$, $\theta = 10$ and $\lambda = 1/3$

<table>
<thead>
<tr>
<th>Bathymetric Depth (m)</th>
<th>H_{\text{break}}</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.00256</td>
<td>0.00250</td>
<td>0.00250</td>
<td>0.00250</td>
<td>0.00250</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.00427</td>
<td>0.00256</td>
<td>0.00250</td>
<td>0.00250</td>
<td>0.00250</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.00539</td>
<td>0.00315</td>
<td>0.00256</td>
<td>0.00250</td>
<td>0.00250</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.00617</td>
<td>0.00361</td>
<td>0.00286</td>
<td>0.00256</td>
<td>0.00250</td>
</tr>
</tbody>
</table>

\[
C_f = C_{f\text{ min}} \left[ 1 + \left( \frac{H_{\text{break}}}{H} \right)^{\theta} \right]^{\lambda} \theta
\]

$C_{f\text{ min}} = 0.0025$; $\theta = 10$; $\lambda = 1/3$

Figure 3-1: Variation in $C_f$ with bathymetric depth for various values of H-Break
Eddy Viscosity

The eddy viscosity term that will be optimized in this study is found in the depth-integrated momentum dispersion terms in the momentum equations and in the GWCE. The viscosity model used in ADCIRC is similar to Kolar and Gray (1990). In the spherical momentum equations, the momentum dispersion terms, $M_\lambda$ and $M_\phi$ are:

$$
M_\lambda = \frac{E_{h_2}}{R^2} \left[ \frac{1}{\cos^2 \phi} \frac{\partial^2 UH}{\partial \lambda^2} + \frac{\partial^2 UH}{\partial \phi^2} \right] \tag{3-6}
$$

$$
M_\phi = \frac{E_{h_2}}{R^2} \left[ \frac{1}{\cos^2 \phi} \frac{\partial^2 VH}{\partial \lambda^2} + \frac{\partial^2 VH}{\partial \phi^2} \right] \tag{3-7}
$$

where

$E_{h_2} =$ horizontal eddy viscosity (ft$^2$/s or m$^2$/s)

By adjusting the horizontal eddy viscosity term, the model can properly account for momentum transfer between adjacent fluid particles.

The horizontal eddy viscosity term is also found in the GWCE in the term:

$$
\frac{E_{h_2}}{R \cos \phi} \frac{\partial^2 \zeta}{\partial \lambda \partial t} \quad \& \quad \frac{E_{h_2}}{R} \frac{\partial^2 \zeta}{\partial \phi \partial t} \tag{3-8}
$$

By adjusting the horizontal eddy viscosity term, variations in the deviation from mean sea level, $\zeta$, and the $\lambda$ and $\phi$ direction velocities, can be seen spatially and temporally.
CHAPTER 4 – MODEL DISCRETIZATION

The primary region of focus for this study is the Waccamaw River and the Atlantic Intracoastal Waterway (AIW). Theoretically, a model domain could be developed that only included the aforementioned water bodies with boundary conditions being applied at the mouth of Winyah Bay. However, a number of previous studies have shown that there are several advantages of extending the domain to include the deep ocean (Westerink, Muccino and Luettich, 1990). These advantages include (Kolar, Gray, Westerink and Luettich, 1994): 1) Use of astronomical tidal forcings obtained from larger global ocean models that are accurate in deep ocean regions, 2) The nonlinear waves in the deep ocean are not important because the nonlinear waves generated in the deep ocean are canceled by out of phase reflection when on the continental slope, 3) Due to the large bathymetric depth in the deep ocean, element sizes can be larger, allowing a simpler geometry.

After taking into account these advantages, the open-ocean boundary is extended seaward. A semi-circular arc is used to define the open ocean boundary, with endpoints at Hilton Head Island, South Carolina and Cape Fear, North Carolina (see Figure 4-1). This arc extends nearly 60 miles into the Atlantic Ocean to allow the open-ocean boundary to be in the deep ocean.

A finite element mesh representing this region was developed previously, but it included neither the upstream portion of the Waccamaw nor the AIW. This mesh uses
triangular elements in order to properly represent the irregularities of the study boundary. To this initial mesh, called the SC mesh (see Figure 4-2), the entire Waccamaw River, AIW and the Shallotte Inlet and Little River Inlet areas are added. Digitized shoreline data representing these sections is obtained from the NGDC Coastline Extractor at http://rimmer.ngdc.noaa.gov/coast/. The basis of this data is the NOAA/NOS Medium Resolution Digital Vector Shoreline in a 1:70,000 scale. This data is obtained by digitizing NOAA Nautical Charts and it is available for the entire United States.

After appending the digitized boundaries to the existing mesh, nodes are placed within the boundary to allow triangulation of the nodes into elements. After these nodes are placed and using the grid editing software ACE/gredit 5.0 (http://www.ccalar.ogi.edu/~pturner/gredit/), a finite element mesh is created that included the Waccamaw River upstream to Conway, S.C. and the AIW and surrounding inlets. This new mesh, called the SC-Waccamaw mesh (see Figure 4-3), had approximately 55,000 more nodes and 95,000 more elements than the SC mesh, representing an increase of greater then 600% each (see Table 4-1). This large increase is due to addition of the Waccamaw River and AIW, along with the small element size needed in these regions. Plus, the Winyah Bay region taken from the original SC mesh is extensively modified in order to have a smooth transition between the larger elements in the Bay and the smaller elements upstream (see Figures 4-4 and 4-5).

The FLDWAV model requires designated cross-sections at various distances downstream from each upstream boundary condition in order to describe the riverine and estuarine system. The basic cross-sectional shapes at each location are obtained from the
SERFC, and are based upon previous studies in this region. However, to preserve the geometry of the riverine and estuarine system between the two models and because the bathymetric data in the SC-Waccamaw mesh is the best available, the bathymetry in FLDWAV is modified to match the bathymetry in the SC-Waccamaw mesh. This required a detailed analysis of where the FLDWAV cross-sections are on the SC-Waccamaw mesh and adjusting the channel inverts in FLDWAV as needed.
Table 4-1
Comparison of SC-Waccamaw Mesh and SC Mesh

<table>
<thead>
<tr>
<th></th>
<th>SC-Waccamaw Mesh</th>
<th>SC Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Nodes</td>
<td>64896</td>
<td>10379</td>
</tr>
<tr>
<td>Number of Elements</td>
<td>114915</td>
<td>19023</td>
</tr>
</tbody>
</table>

Figure 4-1: Location of mesh with respect to the State of South Carolina
Figure 4-2: Original SC Mesh with largest and smallest element sizes
Figure 4-3: SC-Waccamaw Mesh with largest and smallest element sizes

≈ 15 km
Figure 4-4: Winyah Bay region from original SC Mesh with element sizes

Figure 4-5: Winyah Bay region from SC-Waccamaw Mesh with element sizes
Spatial Discretization and Bathymetry

Having the proper element size is essential in order for the model to correctly simulate the physics of fluid flow. This is particularly true for the formation of an eddy or eddies. If an element is too large, the eddy might be contained solely inside the element. Therefore, the node-to-node spacing has to be small enough so that several elements can capture the area of an eddy. Since the optimization of the eddy viscosity parameter and to a lesser degree eddy formation are desired results of this study, the element sizes have to be of an optimal size in areas where the riverine system has a potential to form large scale eddies. These areas include: areas near strong freshwater inflow locations, the regions surrounding an inlet or groin, a drastic change in river geometry (bend) and similar locations.

To assure the physics and non-linear interactions of the riverine and estuarine system are properly captured, the closest representation of the actual geometry of the system must be incorporated into the model. The cross-sections that represented the actual riverine system in the SC-Waccamaw mesh must contain enough nodes to properly describe the cross-sectional shape. Any number of nodes can be used to describe the geometry of the river, however, a larger number of nodes is preferred as opposed to a minimum number of nodes. This is due to the fact that if a cross-section only contains three nodes across, the shape of the cross-section is limited to a triangular form. With four nodes across, the shape is constrained to being of a trapezoidal type. Therefore, the number of nodes that describe the cross-section must be great enough to describe the
irregularities of the riverine and estuarine system. Figures 4-6 and 4-7 show an actual
cross-section location and shape in the SC-Waccamaw mesh and what this cross-section
would look like with only three or four nodes across. Clearly, to assure that the majority
of the bathymetric features are captured in the SC-Waccamaw mesh, node-to-node
spacing and element sizes have to be small.
Figure 4-6: Location of actual cross-section on SC-Waccamaw Mesh

Figure 4-7: Shape of actual cross-section in SC-Waccamaw Mesh
Figure 4-8: Actual cross-section with triangular cross-section

Figure 4-9: Actual cross-section with trapezoidal cross-section
When performing any hydrodynamic study, having the correct bathymetry is an important factor in obtaining good results. For this particular study, bathymetric values are obtained from several sources. The majority of the deep ocean bathymetry (extending from the coastline outward) was already incorporated into the original SC Mesh. Therefore, no modifications are needed in the deep ocean for the SC-Waccamaw Mesh (see Figure 4-10). However, in all areas that are either added or modified, bathymetric values need to be integrated into the mesh. In ADCIRC-2DDI, the bathymetry is considered to be positive if it is a depth below mean sea level and negative if it is above mean sea level.

The vast majority of the bathymetric data from the Winyah Bay region upstream is obtained from the National Geophysical Data Center (NGDC) Coastal Relief CD-ROM Volume 2. The NGDC has produced a gridded database that merges the USGS 3-arc-second digital elevation maps (DEM) with a vast collection of hydrographic sounding data, collected by the National Ocean Service (NOS) and various academic institutions. Five CD-ROMs are currently available covering the United States’ East and Gulf coasts. Volume 2 encompasses the Southeastern Atlantic coast between latitudes 31 and 40 (see Figure 4-11). The data is output at a 3-second arc to allow for the maximum number of bathymetric points. To assure that the datum of the SC mesh and SC-Waccamaw mesh matched, the datum is chosen to be mean sea level. The data from the Coastal Relief CD accounted for the bathymetry in all areas upstream of Winyah Bay except the AIW.
Figure 4-10: SC-Waccamaw mesh bathymetry
Since there is no available data for the AIW, some assumptions had to be made concerning the bathymetry. First, since the AIW is a manmade channel that is regularly dredged in order to maintain its depth for navigational purposes, a single depth value is assumed for the entire AIW. Second, during a site visit to the Waccamaw River in 2001, the bathymetric depth of the AIW is generally between 4 to 6 meters for the entire run of the waterway. Depth is determined by an acoustic depth finder installed on the research vessel used. Therefore, a bathymetric depth of 5 meters is assumed for all areas of the Atlantic Intracoastal Waterway.

Figure 4-11: Coverage of NGDC Coastal Relief CD-ROM-Volume 2
In order, to implement these bathymetric values, separate “bathymetric patches” are developed to use in interpolating the depths onto the SC-Waccamaw mesh. In the grid editing software, ACE/gredit 5.0, there is a function that allows interpolation from a “background mesh” onto an “edit mesh.” So, several bathymetric patches, extending from the Winyah Bay region up to the Little River Inlet region, are constructed using the NGDC Coastal Relief data or the 5-meter assumed depth. The bathymetric points are read in as nodes along with the digitized boundary, and subsequently triangulated in order to produce a small bathymetric patch. Next, bathymetric values for nodes of the SC-Waccamaw mesh are interpolated from the bathymetric patches. ACE/gredit 5.0 interpolates the depths linearly along an element side between two nodes of different depths. Therefore, even if the patch and original mesh’s nodes don’t line up exactly, a good approximation of the bathymetric depth is still maintained.

Figures 4-13 through 4-19 show the node-to-node spacing and bathymetry of selected regions (Figure 4-12) on the SC-Waccamaw mesh. Figure 4-13 shows the Winyah Bay region, with the nodal spacing and bathymetry noted. This region has a very complex bathymetry, especially when entering the Bay itself. A large tidal flat and distinct channel can be observed just upstream from the entrance to Winyah Bay. The element sizes have a large range in this area, with the smallest occurring in the small channel on the southernmost end of the Bay and the largest elements are found out in the ocean.

A section of the southern Atlantic Intracoastal Waterway is shown in Figure 4-14. The bathymetry in this region clearly shows a channel that is relatively uniform on both
sides. The node-to-node spacing of the elements is between 25 and 50 meters, allowing for several elements to comprise the cross-sectional shape of this region. There is an average of approximately 10 to 12 elements that make up the cross-sectional profile of the estuarine system in this region.

Figure 4-15 shows the confluence of the Waccamaw River and the Atlantic Intracoastal Waterway. In this area, a proper representation of the bathymetry is extremely important. Since this area has a combination of freshwater inflows coming from the northern end and a tidal wave coming from the other ends, it is important to not have the geometry cause a damming effect. Any type of damming effect in this region can cause the velocities to get very large and cause model instability, especially with the larger inflows. The majority of the riverine system in this area is made up of four elements across the channel, representing a node-to-node spacing of 20 to 40 meters.

The Waccamaw River is presented in Figure 4-16. The irregularities of the river geometry can be seen in these figures, with significant meandering occurring with the river. The bathymetry mimics the actual bathymetry to a good degree, showing the deeper, naturally scoured areas around bends that should be present. The river is generally made up of four elements in this region, with a node-to-node spacing ranging from 20 to 40 meters.

A typical section of the Atlantic Intracoastal Waterway is shown in Figure 4-17. The majority of the AIW upstream from the confluence is a straight, dredged channel. Since no bathymetric data is available for this reach of the model, the 5-meter constant depth channel that is implemented in the bathymetry can be seen. The majority of the
elements in this area have a node-to-node spacing of 20 to 30 meters and the river is fairly uniform, usually being made up of four elements.

One of the two northern inlets, Shallotte Inlet, is shown in Figure 4-18. Shallotte Inlet is a fairly complex inlet, servicing several residential areas to the northeast. The bathymetry in this region clearly shows a channel implemented for boats and other marine vessels. Manmade groins can be seen that help preserve the depth of this channel for local residents and commercial vessels. The node-to-node spacing in this area ranges from 30 meters in the AIW region, to as large as 500 meters out in the ocean.

The other inlet on the north end of the model domain is called the Little River Inlet and is shown in Figure 4-19. The bathymetry in this inlet ranges from 5 to 9 meter, with the 5-meter depths generally occurring in the AIW region. Node to node spacing in this region is between 30 meters in the AIW to greater than 600 meters in the ocean.
Figure 4-12: Locations of detailed insets in SC-Waccamaw Mesh
Figure 4-13: Winyah Bay. a) Mesh detail with node-to-node spacing; (b) Bathymetry
Figure 4-14: Southern Atlantic Intracoastal Waterway. a) Mesh detail with average node-to-node spacing; b) Bathymetry
Figure 4-15: Confluence of Waccamaw River and AIW. a) Mesh detail with average node-to-node spacing; b) Bathymetry
Figure 4-16: Waccamaw River. a) Mesh detail with average node-to-node spacing; b) Bathymetry
Figure 4-17: Atlantic Intracoastal Waterway. a) Mesh detail with average node-to-node spacing; b) Bathymetry
Figure 4-18: Little River Inlet. a) Mesh detail with node-to-node spacing; b) Bathymetry
Figure 4-19: Shallotte Inlet. a) Mesh detail with node-to-node spacing; b) Bathymetry
CHAPTER 5 – AVAILABLE HYDRODYNAMIC DATA

In riverine and estuarine studies, having accurate data is essential to producing correct model results and verifying the model. Depending on the type of study, several types of data are needed. Water quantity studies usually need streamflow and stage data to allow setup and verification of the model. Coastal circulation models need tidal constituent data to verify they are producing the correct tidal signal near shore. The present study not only needs tidal constituent data to verify the model but hydrodynamic data to allow for a proper representation of the contributing rivers to the riverine and estuarine system.

In order to verify that the ADCIRC model is correctly simulating the tidal signal at the near-shore boundary of the coast, tidal constituent data is obtained for NOS tidal stations in the domain (see Figure 5-1). There are four stations in the study region, however, only two of them lie within the model domain. Therefore, only the Springmaid Pier, S.C. and Charleston, S.C. stations will be used to verify the model results. The data obtained consists of the amplitude and phase of the 37 constituents (see Table 5-1) that together make up the complete tidal signal in the Atlantic Ocean. The amplitudes and phases acquired from the NOS are compared to the amplitudes and phases produced by the ADCIRC model in order to confirm the simulation results.

The complete tidal signal in any ocean can be calculated by adding the amplitude of each constituent at every time interval within the cycle. There are five constituents that comprise approximately 95% of the total amplitude produced when summing up all
37 constituents in this region. Figure 5-2 shows these five constituents and the signal that results from summing up these values at each interval. The ADCIRC model will be forced with seven constituents (see Table 5-2) at the open ocean boundary: the five constituents shown in Figure 5-2 along with the shallow water overtides of the M_2 constituent. Overtides are constituents that have a speed that is an exact multiple of the speed of one of the fundamental constituents (principal lunar, M_2 and principal solar, S_2). They are due to wave dispersion of the main constituents when they encounter shallower water (and speed up) and generally affect the velocity of the tidal wave more than the amplitude. Only the shallow water overtides of the M_2 are included because it is much more dominant than the S_2 in this region. The values for these seven forcing constituents at the open ocean boundary are obtained from a larger model that includes the entire Western North Atlantic (see Figure 5-3). By using this larger model, values of each constituent’s amplitude and phase can be obtained for every forcing node.
Table 5-1

Atlantic Ocean Tidal Constituents

<table>
<thead>
<tr>
<th>Constituent Name</th>
<th>Definition</th>
<th>Period (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M₂</td>
<td>Principal lunar semidiurnal constituent</td>
<td>12.42</td>
</tr>
<tr>
<td>S₂</td>
<td>Principal solar semidiurnal constituent</td>
<td>12.00</td>
</tr>
<tr>
<td>N₂</td>
<td>Larger lunar elliptic semidiurnal constituent</td>
<td>12.66</td>
</tr>
<tr>
<td>K₁</td>
<td>Lunar diurnal constituent</td>
<td>23.93</td>
</tr>
<tr>
<td>M₄</td>
<td>Shallow water overtides of principal lunar constituent</td>
<td>6.21</td>
</tr>
<tr>
<td>O₁</td>
<td>Lunar diurnal constituent</td>
<td>25.82</td>
</tr>
<tr>
<td>M₆</td>
<td>Shallow water overtides of principal lunar constituent</td>
<td>4.14</td>
</tr>
<tr>
<td>MK₃</td>
<td>Shallow water terdiurnal</td>
<td>8.18</td>
</tr>
<tr>
<td>S₄</td>
<td>Shallow water overtides of principal solar constituent</td>
<td>6.00</td>
</tr>
<tr>
<td>MN₄</td>
<td>Shallow water quarter diurnal constituent</td>
<td>6.27</td>
</tr>
<tr>
<td>NU₂</td>
<td>Larger lunar evectional constituent</td>
<td>12.63</td>
</tr>
<tr>
<td>S₆</td>
<td>Shallow water overtides of principal solar constituent</td>
<td>4.00</td>
</tr>
<tr>
<td>MU₂</td>
<td>Variational constituent</td>
<td>12.87</td>
</tr>
<tr>
<td>2N₂</td>
<td>Lunar elliptical semidiurnal second order constituent</td>
<td>12.91</td>
</tr>
<tr>
<td>OO₁</td>
<td>Lunar diurnal</td>
<td>22.31</td>
</tr>
<tr>
<td>LAM₂</td>
<td>Smaller lunar evectional constituent</td>
<td>12.22</td>
</tr>
<tr>
<td>S₁</td>
<td>Solar diurnal</td>
<td>24.00</td>
</tr>
<tr>
<td>M₁</td>
<td>Smaller lunar elliptic diurnal constituent</td>
<td>24.83</td>
</tr>
<tr>
<td>J₁</td>
<td>Smaller lunar elliptic diurnal constituent</td>
<td>23.10</td>
</tr>
<tr>
<td>MM</td>
<td>Lunar monthly constituent</td>
<td>661.31</td>
</tr>
<tr>
<td>SSA</td>
<td>Solar semiannual constituent</td>
<td>4382.91</td>
</tr>
<tr>
<td>SA</td>
<td>Solar annual constituent</td>
<td>8765.82</td>
</tr>
<tr>
<td>MSF</td>
<td>Lunisolar synodic fortnightly constituent</td>
<td>354.37</td>
</tr>
<tr>
<td>MF</td>
<td>Lunisolar fortnightly constituent</td>
<td>327.86</td>
</tr>
<tr>
<td>RHO</td>
<td>Larger lunar evectional diurnal constituent</td>
<td>26.72</td>
</tr>
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<td>Q₁</td>
<td>Larger lunar elliptic diurnal constituent</td>
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</tr>
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<td>T₂</td>
<td>Larger solar elliptic constituent</td>
<td>12.02</td>
</tr>
<tr>
<td>Constituent Name</td>
<td>Definition</td>
<td>Period (hours)</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>$R_2$</td>
<td>Smaller solar elliptic constituent</td>
<td>11.98</td>
</tr>
<tr>
<td>$2Q_1$</td>
<td>Larger elliptic diurnal</td>
<td>28.01</td>
</tr>
<tr>
<td>$P_1$</td>
<td>Solar diurnal constituent</td>
<td>24.07</td>
</tr>
<tr>
<td>$2SM_2$</td>
<td>Shallow water semidiurnal constituent</td>
<td>11.61</td>
</tr>
<tr>
<td>$M_3$</td>
<td>Lunar terdiurnal constituent</td>
<td>8.28</td>
</tr>
<tr>
<td>$L_2$</td>
<td>Smaller lunar elliptic semidiurnal constituent</td>
<td>12.19</td>
</tr>
<tr>
<td>$2MK_3$</td>
<td>Shallow water terdiurnal constituent</td>
<td>8.39</td>
</tr>
<tr>
<td>$K_2$</td>
<td>Lunisolar semidiurnal constituent</td>
<td>11.97</td>
</tr>
<tr>
<td>$M_8$</td>
<td>Shallow water eighth diurnal constituent</td>
<td>3.11</td>
</tr>
<tr>
<td>$MS_4$</td>
<td>Shallow water quarter diurnal constituent</td>
<td>6.10</td>
</tr>
</tbody>
</table>

Figure 5-1: National Ocean Service tidal stations in study region
Table 5-2

Amplitudes and Phases of Main Tidal Constituents at Selected NOS Tidal Stations

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Charleston, South Carolina</th>
<th>Springmaid Pier, South Carolina</th>
</tr>
</thead>
<tbody>
<tr>
<td>M₂</td>
<td>Amplitude (m) Phase (°)</td>
<td>Amplitude (m) Phase (°)</td>
</tr>
<tr>
<td>0.783</td>
<td>10.4</td>
<td>0.751</td>
</tr>
<tr>
<td>N₂</td>
<td>0.172 354.9</td>
<td>0.173</td>
</tr>
<tr>
<td>S₂</td>
<td>0.119 36.1</td>
<td>0.126</td>
</tr>
<tr>
<td>K₁</td>
<td>0.105 199.7</td>
<td>0.103</td>
</tr>
<tr>
<td>O₁</td>
<td>0.079 203.4</td>
<td>0.076</td>
</tr>
<tr>
<td>M₄</td>
<td>0.033 209.6</td>
<td>0.007</td>
</tr>
<tr>
<td>M₆</td>
<td>0.006 135.3</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Resynthesized tidal signal with major constituents

Figure 5-2: Re-synthesized tidal signal with the five major constituents
Figure 5-3: Western North Atlantic domain with SC-Waccamaw domain
In order to describe the physics of the river correctly, lateral and local inflows need to be added to the SC-Waccamaw model. These inflows are obtained from the SERFC through the USGS. The SERFC converted these flows to one hour or six hour time interval format from 24-hour daily mean values. This allows rivers that have a confluence and discharge into the Waccamaw to be properly represented by lateral inflows into the ADCIRC model domain. These rivers can be represented by three lateral inflow locations (see Figures 5-4, 5-5 and Table 5-3). The southernmost contributing river is not included as an inflow because it is outside the region of interest for the SERFC and the corresponding gage record contains bad data.

Figure 5-4: Contributing rivers to Waccamaw River and locations of lateral inflows
Table 5-3

Locations of Lateral Inflows to Waccamaw River and Time Period of Measurement

<table>
<thead>
<tr>
<th>Lateral Inflow Location</th>
<th>Time Period of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pee Dee River at Pee Dee, SC</td>
<td>Oct. 1, 1938 to Present</td>
</tr>
<tr>
<td>Lynches River at Effingham, SC</td>
<td>Oct. 1, 1929 to Present</td>
</tr>
<tr>
<td>Little Pee Dee River at Galivant's Ferry, SC</td>
<td>Jan. 1, 1942 to Present</td>
</tr>
</tbody>
</table>

Figure 5-5: Locations of freshwater inflows with respect to SC-Waccamaw mesh
The local flows represent all runoff from contributing basins discharging into the Waccamaw River system. These local flows are produced by the SERFC’s National Weather Service’s River Forecast System (NWSRFS), which is a software suite that utilizes several models. This particular data set was produced by first delineating the local drainage basin and estimating a six-hour unit hydrograph for the region. Next, the historical mean aerial precipitation (MAP) for each local area is calculated. Finally, the SERFC ran the NWSRFS software to calculate discharge by running the MAP through the Sacramento Soil Moisture Accounting (SAC-SMA) program and the unit hydrograph operation. SAC-SMA is a model that attempts to parameterize soil moisture characteristics to allow for an effective simulation of runoff. Two contributing basins are considered for this project: Longs, S.C. to Conway, S.C. and Conway to Bucksport, S.C. Only the Conway to Bucksport local flow is in the area defined by the SC-Waccamaw mesh; the Longs to Conway local flow is represented in the FLDWAV model.

The USGS is an excellent source for streamflow and stage data for any riverine system in the United States. Seven gages are stationed along the Waccamaw River and AIW (see Figure 5-6). These gage locations generally provide mean daily streamflow and mean daily stage values via the Internet. However, the SERFC was able to contact the USGS and obtain 15-minute time step data for all the gage locations along the river system. However, the gages located at AIW at HWY 544 near Socastee and Sampit River at Georgetown did not contain streamflow or stage data for any of the time frames associated with the flow scenarios. Therefore, these gages are omitted from the simulations. This data will allow the simulation results from ADCIRC to be verified at
almost any time step and provided a better view of the dynamics of the riverine and estuarine system.

Low, medium and high flow scenarios were chosen to allow proper optimization of the bottom friction and eddy viscosity parameters for any flow encountered by the riverine system. 60-day time frames were chosen by the SERFC (Garza, 2002) to define each flow condition (see Table 5-4). The high flow scenario is based on the flows created by the runoff from Hurricane Floyd in 1998. The medium event is based on a 10-year storm. The low flow event is based on a typical annual event. After isolating each time frame at every gaging station (Figures 5-7 to 5-9), the average value for the entire time frame could be determined to input into the ADCIRC simulation (see Table 5-5). Since a constant inflow value is desired, the average is chosen to allow for a proper representation of the entire scenario. Incomplete data is found in parts of the Waccamaw River upstream of Conway gage location, therefore this station is omitted from Figures 5-7 to 5-9 and an average value had to be selected from the data available.
Table 5-4

Time Frames for Selected Flow Scenarios

<table>
<thead>
<tr>
<th></th>
<th>High Flow</th>
<th>Medium Flow</th>
<th>Low Flow</th>
</tr>
</thead>
</table>

Figure 5-6: Locations of UGSG gaging stations along the Waccamaw River and AIW

- Waccamaw River at Conway
- AIW at HWY 9 at Nixon’s Crossroads
- AIW at HWY 544 near Socastee
- Waccamaw River at Bucksport
- Waccamaw River at Hagley Landing
- Sampit River at Georgetown
Table 5-5

Average Flow Values at Specified Locations for all Flow Scenarios

<table>
<thead>
<tr>
<th>Inflow Location</th>
<th>High Flow Scenario (m$^3$/s)</th>
<th>Medium Flow Scenario (m$^3$/s)</th>
<th>Low Flow Scenario (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conway, SC to Confluence of Waccamaw River and AIW— Local Runoff</td>
<td>15.0</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Little Pee Dee River— Lateral Inflow</td>
<td>360.0</td>
<td>257.0</td>
<td>73.0</td>
</tr>
<tr>
<td>Pee Dee River -- Lateral Inflow</td>
<td>757.0</td>
<td>503.0</td>
<td>175.0</td>
</tr>
<tr>
<td>Lynches River – Lateral Inflow</td>
<td>133.0</td>
<td>100.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Waccamaw River North of Conway – Lateral Inflow</td>
<td>367.0</td>
<td>137.0</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Figure 5-7: High flow scenario
Figure 5-8: Medium flow scenario

Figure 5-9: Low flow scenario
CHAPTER 6 – MODEL PARAMETERS

The following parameters and functions are constant for all ADCIRC-2DDI simulations performed in the present study. The simulation begins from a cold start. The coordinate system is set to spherical. The bottom friction term selection parameter is set to operate with the hybrid formulation. The tidal potential option is turned off. Gravity is set to 9.81 m/s² to specify metric units. NOLIFA is set to 2, enabling wetting and drying of elements. The GWCE weighting factor, \( \tau_0 \), is set to \(-0.01\), a recommended value. \( \tau_0 \) is a parameter that weights the relative contribution of the primitive and wave portions of the GWCE; if \( \tau_0 = 0 \), the GWCE is a pure wave equation, if \( \tau_0 > 1 \), the GWCE becomes a pure primitive continuity equation. All runs had a 15-day ramp with a 20-day total simulation length. The hybrid bottom friction parameters, \( \text{H}_{\text{break}} \), \( \theta \), and \( \lambda \), are set to 1, 10 and 1/3, respectively, to coincide with recommended values. Seven tidal constituents are forced at the open ocean boundary, \( \text{K}_1 \), \( \text{O}_1 \), \( \text{N}_2 \), \( \text{S}_2 \), \( \text{M}_2 \), \( \text{M}_4 \) and \( \text{M}_6 \).

The time step in ADCIRC is dependent on the Courant number. ADCIRC developers suggest that to maintain numerical stability and produce accurate results, the Courant number should not exceed 1.0 (Westerink, Blain, Luettich, & Scheffner, 1994). The Courant number is defined as:

\[
C_s = \frac{\sqrt{gh} \Delta t}{\Delta x}
\]  

(6-1)

where
g = acceleration due to gravity  
h = nodal depth  
\( \Delta t \) = time step (seconds)  
\( \Delta x \) = nodal spacing  

With each flow scenario, the increase (or decrease) in the flow rate will affect the total volume of water in the system. Following the continuity equation, higher flow rates will make the water surface elevation increase due the larger volume of water in the river, causing numerical instability if the same time step is used for all scenarios. Therefore, each flow scenario uses a different \( \Delta t \) value (see Table 6-1).

To perform a sensitivity analysis of a certain parameter, the accompanying parameters must be kept constant in order to isolate the effects of the desired parameter. In order to analyze each parameter separately, a base value had to be chosen for both the bottom friction and eddy viscosity. For all eddy viscosity runs, the bottom friction is set constant at 0.0025. With the bottom friction sensitivity analysis, the eddy viscosity is set at 5.0 m\(^2\)/s.

Four values of each parameter are chosen initially in order to determine the effects of each parameter. After the initial run with four variations in value of each parameter using the low flow scenario, the range is narrowed to three values for the remaining flow scenarios. The range is from 0.0025 to 0.025. Lower values of the bottom friction were attempted, but were unstable due to the time step used for the simulations (see Appendix E). Table 6-2 lists the values of bottom friction and eddy viscosity that are chosen for the sensitivity analysis.
Table 6-1

Time Steps for Selected Flow Scenarios

<table>
<thead>
<tr>
<th>Flow Scenario</th>
<th>Time Step (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1.20</td>
</tr>
<tr>
<td>Medium</td>
<td>0.85</td>
</tr>
<tr>
<td>High</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Table 6-2

Parameter Values Chosen for Each Flow Scenario to use in Sensitivity Analysis
(Constant Bottom Friction = 0.0025; Constant Eddy Viscosity = 5.0 m²/s)

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<tr>
<th>Low Flow Scenario</th>
<th>Medium Flow Scenario</th>
<th>High Flow Scenario</th>
</tr>
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<td>Eddy Viscosity (m²/s)</td>
<td>Bottom Friction</td>
<td>Eddy Viscosity (m²/s)</td>
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In order to apply the freshwater inflows from contributing rivers, a single non-forcing frequency flow has to be added to the input file. This non-forcing frequency has the same format as a forcing frequency on the open ocean, except the equilibrium argument and nodal factor associated with it are the same as a steady state forcing.
function. The flow values have to be entered for each corresponding node that is defined in the grid and boundary information file to have a non-zero normal flow associated with it. For each non-zero normal flow node, the flow value has to be entered as a flow per unit width. With these normal flows, ADCIRC establishes a flow per unit width value at the node and interpolates over the element side and uses the value as a flux condition.

Simulations are performed with a twelve-node cluster of Compaq alpha machines with a CPU bus speed of 600 MHz. Computing times varied, depending on the time step. The average computing time for a 20-day run is as follows: for low flow ($\Delta t=1.2$), approximately 20 hours; for medium flow ($\Delta t=0.85$), approximately 28 hours and for high flow ($\Delta t=0.65$), approximately 39 hours.
CHAPTER 7 – MODEL SIMULATION RESULTS AND DISCUSSION

Tidal Results

Before a sensitivity analysis can be performed with the model, it is necessary to determine if the model is simulating the tides at the shoreline accurately. In order to determine this, two different types of comparisons are used. The first is to compare amplitude differences in each individual constituent; the second is to compare phases of the constituents. The five primary constituents that make up the majority of the signal amplitude are used: M2, N2, S2, K1 and O1. The amplitude difference is computed by:

\[ \frac{A_{\text{HISTORICAL}} - A_{\text{MODEL}}}{A_{\text{HISTORICAL}}} \times 100\% \]  

(7-1)

The phase error is determined by taking the absolute difference between the historical phases and the model phases. Tables 7-1 and 7-2 present these comparisons, while Figures 7-1 and 7-2 show these comparisons graphically.

The Springmaid Pier tidal gage location is the closest to the riverine system under investigation, therefore making this gage the most important in validating the model for the sensitivity analysis. At this location, the worst amplitude and phase errors occur in the O1 constituent. All other errors are less than 4.5% for amplitudes and under 7° for phases. By examining the graphical view of the comparison, the model does a very good job of simulating the tides at this location.
At Charleston, the results are not as good as the Springmaid Pier location. The amplitudes and phase errors are much larger, especially with the M\textsubscript{2} constituent. This is the dominant constituent in this region, and the errors in this constituent effect the overall error of the total signal to a large extent. One reason for the high amount of error at this location could be the large number of freshwater inflows located near this area. Since the region under focus is the Waccamaw River and AIW, no inflows are added to this area since it would not affect the results in the riverine system. The addition of inflows in this region could significantly alter the amplitude and phase at this location in future simulations.
Table 7-1

Comparison of Historical vs. Simulated Tidal Constituents at Springmaid Pier, S.C.

<table>
<thead>
<tr>
<th>Tidal Constituent</th>
<th>Historical</th>
<th>Model</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude (m)</td>
<td>Phase (°)</td>
<td>Amplitude (m)</td>
</tr>
<tr>
<td>M₂</td>
<td>0.751</td>
<td>357.7</td>
<td>0.723</td>
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<td>N₂</td>
<td>0.173</td>
<td>337.9</td>
<td>0.166</td>
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<tr>
<td>S₂</td>
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<td>18.8</td>
<td>0.126</td>
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<tr>
<td>K₁</td>
<td>0.103</td>
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<tr>
<td>O₁</td>
<td>0.080</td>
<td>173.3</td>
<td>0.070</td>
</tr>
</tbody>
</table>

Figure 7-1: Graphical comparison of historical vs. simulated tidal signal at Springmaid Pier, S.C.
Table 7-2

Comparison of Historical vs. Simulated Tidal Constituents at Charleston, S.C.

<table>
<thead>
<tr>
<th>Tidal Constituent</th>
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<th>Model</th>
<th>Error</th>
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<td>Amplitude (m)</td>
<td>Phase (°)</td>
<td>Amplitude (m)</td>
</tr>
<tr>
<td>M₂</td>
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<tr>
<td>N₂</td>
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<td>354.9</td>
<td>0.162</td>
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<tr>
<td>S₂</td>
<td>0.119</td>
<td>36.1</td>
<td>0.126</td>
</tr>
<tr>
<td>K₁</td>
<td>0.105</td>
<td>199.7</td>
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<tr>
<td>O₁</td>
<td>0.079</td>
<td>203.4</td>
<td>0.069</td>
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</tbody>
</table>

Figure 7-2: Graphical comparison of historical vs. simulated tidal signal at Charleston, S.C.
Visible Eddy Formation and Velocities

Along with determining the appropriate range of bottom friction and eddy viscosity values, determining if the computational mesh had proper resolution to capture large scale eddies is also motivation for this study. Several locations are analyzed for each flow scenario to see if there is any large scale eddies present. However, there is presently no data to confirm or discredit eddy formation and location in this domain. Areas near inflow locations and inlet regions are the areas chosen. The presence of an eddy is established by analyzing the global velocity vectors at each location for two tidal cycles at the end of the simulation. Viewing the velocities at different time steps also proved useful to visibly see where the freshwater inflows are propagating.

After analyzing several locations, the only clear eddy that could be seen is located at the Winyah Bay region. Due to the large amount of inflow being transported down the river and the large tidal signal at this location, several eddies are visibly present, both at ebb tide and at flood tide. Presently, there is no data to confirm that these eddies form in this region. Figures 7-3 through 7-8 show ebb and flood tides with each flow scenario. Figures 7-9 through 7-11 show these eddies for each flow scenario.

Other areas of interest are locations near freshwater inflows. Analyses of these locations are used to see how the tide interacted with the inflow and if the inflow is being transported downstream properly. The two largest inflows are the Pee Dee and the Little Pee Dee Rivers, therefore only these are concentrated on. Figures 7-12 and 7-13 show the Pee Dee River inflow location. It is clear that during flood tide, the inflow effects the
tidal signal greatly, causing slack water to exist just downstream of the inflow itself.

During ebb tide, the velocity is much larger due to the combined effect of the ebb tide and the inflow. But, when the inflow value gets larger, the flow dynamics are controlled by the inflow at this location making the figures difficult to see and inconclusive. Therefore, only the low flow scenario is shown with these snapshots.

The other area of interest is the Little Pee Dee inflow location (see Figures 7-14 and 7-15). It is located on a bend that has a confluence with the Waccamaw River. Depending on the flow scenario, at flood tide, the inflow is either suppressed by the tide or decreased. Since this inflow is quite large with the medium and high flow scenarios, the flow dynamics are governed solely by the inflow at this location. Similar to the Pee Dee River location, only the low flow scenario is shown due to the inconclusiveness of the snapshots of the larger flow scenarios.
Figure 7-3: Winyah Bay flood tide at low flow

Figure 7-4: Winyah Bay ebb tide at low flow
Figure 7-5: Winyah Bay flood tide at medium flow

Figure 7-6: Winyah Bay ebb tide at medium flow
Figure 7-7: Winyah Bay flood tide at high flow

Figure 7-8: Winyah Bay ebb tide at high flow
Figure 7-9: Winyah Bay eddy formation at low flow

Figure 7-10: Winyah Bay eddy formation at medium flow
Figure 7-11: Winyah Bay eddy formation at high flow
Figure 7-12: Pee Dee River at ebb tide with low flow

Figure 7-13: Pee Dee River at flood tide with low flow
Figure 7-14: Little Pee Dee River at ebb tide with low flow

Figure 7-15: Little Pee Dee River at flood tide with low flow
Sensitivity Analysis

Since the tides are captured at the shoreline with reasonable accuracy, a sensitivity analysis in the riverine and estuarine system can be performed. The sensitivity analysis simulations are performed with all flow scenarios, using a minimum of three variations in each parameter. The model output is analyzed for the last two days of the simulation time period (days 18 through 20), allowing for two complete tidal cycles to be included.

Elevations and velocities are output at several gaging stations along the Waccamaw River and AIW to determine the importance of each variable at various locations within the system. The stations chosen are: Waccamaw River at Conway, S.C.; Bucksport, S.C.; Hagley’s Landing, S.C.; and Nixon’s Crossroads, S.C. (see locations on Figure 5-6). Each station is important to the analysis: Conway is directly downstream of the farthest upstream freshwater inflow location (Waccamaw River upstream of Conway) and is a good location to see the effect of the bottom friction on the tidal signal; Bucksport is important because it is very near the confluence of the Waccamaw River and AIW and near the location of a lateral inflow (Conway to Confluence local flow); Hagley’s Landing is just downstream of the largest inflow (Pee Dee River) and has a strong tidal signal due to it’s close proximity to the ocean, it is also a downstream boundary condition location for FLDWAV; Nixon’s Crossroads is in the AIW and is also a downstream boundary condition location for FLDWAV. Each location will be analyzed independently for each flow scenario.
The variations in the bottom friction and H-Break at Conway alter the tidal signal dramatically (see Figures 7-16 to 7-19). An increase in the bottom friction damps the tidal signal until the signal is absent and only the inflow is present. At 0.0025, a distinct tidal signal is shown at Conway; at 0.025, one order of magnitude higher, the tidal signal is nonexistent. Physically, this makes sense because the Conway location is so far upstream from the Atlantic Ocean (approximately 55 miles). Increasing the bottom friction impedes the progression of the tidal wave upstream; also an increase in the bottom friction effects the interaction of the tidal signal and the freshwater inflow. Both of these factors are highly influential to the propagation of a tidal wave up a riverine system. When increasing the bottom friction, a large change is shown in the total water surface elevation at Conway. The difference between the largest bottom friction and smallest bottom friction value is nearly one meter in stage height. This is largely due to the bottom stress decreasing the velocity of the inflow, therefore increasing the elevation, as stated in the continuity equation.

Similar patterns are seen in both the medium flow (see Figure 7-17) and high flow scenarios (see Figure 7-18). However, one difference between individual flow scenarios is when the inflow value increases, the total water volume in the system rises, causing the water surface elevation to increase. Also, an increase in flow significantly damps out the tide at this upstream location. This means that at medium to high flows, the Waccamaw
River does not have a significant tidal influence near Conway and is dominated by the freshwater inflows in the area.

Compared to the bottom friction, the model is insensitive to the eddy viscosity parameter at this location (see Figure 7-20). However, the model showed more sensitivity at the Conway location to the eddy viscosity than at other locations downstream. This is probably due to the cumulative effect of the horizontal eddy viscosity from downstream regions. All flow scenarios showed similar patterns in the sensitivity of the model to variations in horizontal eddy viscosity. Therefore, only one figure is shown to illustrate this lack of sensitivity. This could be due to the computational mesh not being resolved enough to capture large scale eddies, or that for this particular domain, the bottom friction is much more important due to the addition of the freshwater inflows.
Figure 7-16: Bottom friction sensitivity analysis at Conway, S.C. for low flow
Figure 7-17: Bottom friction sensitivity analysis at Conway, S.C. for medium flow
Figure 7-18: Bottom friction sensitivity analysis at Conway, S.C. for high flow
Figure 7-19: H-Break sensitivity analysis at Conway, S.C.
Figure 7-20: Horizontal eddy viscosity sensitivity analysis at Conway, S.C.
Bucksport, S.C.

With the bottom friction, the Bucksport location showed a similar relationship to the Conway location (see Figures 7-21 to 7-23). As the bottom friction value increased, the influence of the tide decreased and total stage height increased. However, due to Bucksport being significantly closer to the ocean (approximately 35 miles), the tidal influence is more pronounced at this location. Also, the H-Break parameter exhibited a similar sensitivity at this location to the Conway location (see Figure 7-24).

With an increase in inflow, the tidal signal is significantly damped. With medium flow (see Figure 7-22) and high flow (see Figure 7-23) the tide is visible with a bottom friction of 0.0025, but is severely damped when the bottom friction is increased. With the higher bottom friction values, there is not much tidal influence in this region for any flow scenario. This could be due to the large amount of inflow downstream of this location suppressing the tide at some point.

The horizontal eddy viscosity did not show much sensitivity at this location (see Figure 7-25). Initially, it was thought that the eddy viscosity would be important at this location due to the close proximity of this location to the confluence of the Waccamaw River and AIW. However, this is not the case. The only minor variation between eddy viscosity values is seen at ebb tide, which might have to do with the lateral inflows upstream adding to the total flow at ebb tide along with the cumulative effects downstream of the eddy viscosity. This same pattern existed for all inflow scenarios.
Figure 7-21: Bottom friction sensitivity analysis at Bucksport, S.C. for low flow
Figure 7-22: Bottom friction sensitivity analysis at Bucksport, S.C. for medium flow
Figure 7-23: Bottom friction sensitivity analysis at Bucksport, S.C. for high flow
Figure 7-24: H-Break sensitivity analysis at Bucksport, S.C.
Figure 7-25: Horizontal eddy viscosity sensitivity analysis at Bucksport, S.C.
Hagley’s Landing showed an interesting response to the variations with the bottom friction (see Figures 7-26 to 7-28). For all values of bottom friction, the flood tide amplitude stayed near the same value. But, as the bottom friction value increased, the ebb tide amplitude increased. This could be due to the reaction of freshwater inflow and tides that Dronkers (1964) discussed. With any particular location and value of freshwater inflow, there exists a point somewhere upstream from the ocean where the influence of the flood tide ends and there exists only ebb tide. Dronkers called this location the limit of flood flow. Possibly, the location of the limit of flood flow for this riverine and estuarine system could be very near Hagley’s Landing.

Due to the close proximity of Hagley’s Landing to the ocean (approximately 20 miles), the influence of the tide is greater than the overall effect of the freshwater inflows. However, the largest difference of the amplitude of the flood tide with regard to bottom friction occurred at high flow (see Figure 7-28), which could be due to the large amount of inflow just upstream from Hagley’s Landing. Minimal sensitivity is seen with the H-Break parameter at this location (see Figure 7-29).

With Hagley’s Landing being so close to the Atlantic Ocean, no sensitivity is observed in the horizontal eddy viscosity (see Figure 7-30) at any flow condition. Because of its close proximity to the ocean, the cumulative effects of eddy viscosity seen at Conway and Bucksport are negligible at Hagley’s Landing.
Figure 7-26: Bottom friction sensitivity analysis at Hagley’s Landing, S.C. for low flow
Figure 7-27: Bottom friction sensitivity analysis at Hagley’s Landing, S.C. for medium flow
Figure 7-28: Bottom friction sensitivity analysis at Hagley’s Landing, S.C. for high flow
Figure 7-29: H-Break sensitivity analysis at Hagley’s Landing, S.C.
Figure 7-30: Horizontal eddy viscosity sensitivity analysis at Hagley’s Landing, S.C.
The station at Nixon’s Crossroads is located in the Atlantic Intracoastal Waterway. Due to the AIW being regularly dredged to maintain a minimum depth for vessels to travel, the effects of bottom friction are not significant (see Figures 7-31 to 7-33). Also, since the majority of the freshwater inflow travels down the Waccamaw River, the freshwater inflows have a minor influence on the flow at this location. However, with the higher flows (see Figures 7-32 and 7-33), there does exist a backwater effect that causes some of the inflow to travel up the AIW via the Waccamaw River at the confluence. This helps explain why there is some difference between the bottom friction values for the various flow scenarios. The main effect of the bottom friction to the flow dynamics at this location is the phase of the tide. With a higher bottom friction, the phase increases slightly. Minimal sensitivity is seen with the H-Break parameter at Nixon’s Crossroads (see Figure 7-34).

The horizontal eddy viscosity showed minimal model sensitivity at this location (see Figure 7-35). Since the AIW is a straight channel, it is difficult for any large-scale or small-scale eddies to form due to the regularity of the geometry. Therefore, no downstream cumulative effects are seen at this location.
Figure 7-31: Bottom friction sensitivity analysis at Nixon’s Crossroads, S.C. for low flow
Figure 7-32: Bottom friction sensitivity analysis at Nixon’s Crossroads, S.C. for medium flow
Figure 7-33: Bottom friction sensitivity analysis at Nixon’s Crossroads, S.C. for high flow
Figure 7-34: H-Break sensitivity analysis at Nixon’s Crossroads, S.C.
Figure 7-35: Horizontal eddy viscosity sensitivity analysis at Nixon’s Crossroads, S.C.
CHAPTER 8 – CONCLUSIONS

This study provided an initial estimate of the sensitivity of the ADCIRC model to the bottom friction and eddy viscosity parameters in the Waccamaw River and AIW estuarine and riverine system. Also, preliminary attempts to capture the complete physics of the riverine system were performed by adding several lateral and local freshwater inflow locations and by using the best bathymetric data available. The results of this study will be influential to future work in this and similar areas regarding tidal dynamics and flood routing.

Significant model sensitivity can be seen with variations in the bottom friction value, the H-Break parameter and the freshwater inflow value. Since the results of all bottom friction values used in this study were different, future work should attempt to verify the accuracy of the results shown in this study. Comparing the results to historical data at these locations will determine which of these values is the most correct, or to help narrow the range of values. Also, performing a more rigorous sensitivity analysis on the H-Break parameter in the hybrid bottom friction formulation would aid in future simulations in this area. At present, a range of 0.0025-0.0075 is recommended in this region.

The ADCIRC model is less sensitive to the horizontal eddy viscosity parameter than the bottom friction with this study. A limitation of this present study is only one mesh resolution was used. By using a coarser or more resolved mesh, the amount of parameter sensitivity in this study could be significantly different.
In this study, the difference seen in the model results with various values of the eddy viscosity parameter is small compared to the bottom friction. Therefore, a horizontal eddy viscosity value of 5.0 is recommended. Future work could prove that the computational mesh is not resolved enough to capture eddies in this region, requiring more resolution or that the formation of eddies is not as important in this area as other parameters.

The bottom friction and eddy viscosity parameters are more sensitive at some locations than others. Therefore to match up with historical records in future work in this area, researchers may concentrate on tuning these values at specific locations in an attempt to produce the most accurate results.

Future work will need to be addressed in several ways to improve this study. The model results need to be compared to historical data to determine if the range of parameter values is applicable. Adding freshwater inflows in all applicable locations might increase the accuracy of the tidal results at Charleston, S.C. Increasing the mesh resolution in the Winyah Bay and Waccamaw River region might help to further determine if the eddy viscosity parameter is sensitive. Decreasing or increasing the mesh resolution will help to determine the effect of mesh resolution of the sensitivities of these parameters. Routing a time-dependent hydrograph of the flow scenario instead of a constant value might help establish the physics of the system better.

It would be helpful for the ADCIRC-2DDI to be able to use a spatially varying bottom friction. A bottom friction that is a spatially varying Manning’s type, would allow specific values to be set for different flow conditions and bed materials.
The materials presented herein represent an initial step to producing correct downstream boundary conditions for the SERFC for their flood predictions. Also, they show significant model sensitivity to certain parameters and range of recommended values.
APPENDIX A

ADCIRC INPUT FILE

FINITE ELEMENT MESH
This mesh has all local and lateral inflows added and has the latest bathymetry (4/23/03)

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828
817

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50810
51327

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<td>! ending node for Pee Dee inflow</td>
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<td>! land boundary 5 (no flow) number of nodes and type</td>
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115
54906  ! ending node for land boundary 5 (no flow)
5 2    ! Lynches River Inflow-number of nodes and type
54906  ! beginning node for Lynches River inflow
54907
54904
54905
54902  ! ending node for Lynches River inflow
1524 0 ! land boundary 6 (no flow) number of nodes and type
54902  ! beginning node for land boundary 6
54903
54900
54901

::

LINES DELETED

::

880
874  ! ending node for land boundary 6
36 1 ! beginning of 20 islands
2920
2953
3013
3047

::

LINES DELETED

::

1745
1673
APPENDIX B

ADCIRC PARAMETER INPUT FILE

LOW FLOW
STEADY/K1/O1/N2/S2/M2/M4/M6/Low  ! 32 CHARACTER ALPHANUMERIC RUN DESCRIPTION
SC-Conway-LOWQ-Tides-20d ! 24 CHARACTER ALPHANUMERIC RUN IDENTIFICATION
1 ! NFOVER - NONFATAL ERROR OVERRIDE OPTION
1 ! NABOUT - ABBREVIATED OUTPUT OPTION PARAMETER
0 ! NSCREEN - UNIT 6 OUTPUT OPTION PARAMETER
0 ! IHOT - HOT START PARAMETER
2 ! ICS - COORDINATE SYSTEM SELECTION PARAMETER
0 ! IM - MODEL TYPE (0 INDICATES STANDARD 2DDI MODEL)
2 ! NOLIBF - BOTTOM FRICTION TERM SELECTION PARAMETER
2 ! NOLIFA - FINITE AMPLITUDE TERM SELECTION PARAMETER
1 ! NOLICA - SPATIAL DERIVATIVE CONVECTIVE TERM SELECTION PARAMETER
1 ! NOLICAT - TIME DERIVATIVE CONVECTIVE TERM SELECTION PARAMETER
0 ! NWP - VARIABLE BOTTOM FRICTION AND LATERAL VISCOSITY OPTION PARAMETER
1 ! NCOR - VARIABLE CORIOLIS IN SPACE OPTION PARAMETER
0 ! NTIP - TIDAL POTENTIAL OPTION PARAMETER
0 ! NWS - WIND STRESS AND BAROMETRIC PRESSURE OPTION PARAMETER
1 ! NRAMP - RAMP FUNCTION OPTION
9.81 ! G - ACCELERATION DUE TO GRAVITY - DETERMINES UNITS
-0.01 ! TAU0 - WEIGHTING FACTOR IN GWCE
1.2 ! DT - TIME STEP (IN SECONDS)
0.0 ! STATIM - STARTING TIME (IN DAYS)
0.0 ! REFTIM - REFERENCE TIME (IN DAYS)
20.0 ! RNDAY - TOTAL LENGTH OF SIMULATION (IN DAYS)
15.0 ! DRAMP - DURATION OF RAMP FUNCTION (IN DAYS)
0.35 0.30 0.35 ! TIME WEIGHTING FACTORS FOR THE GWCE EQUATION
0.25 5 5 0.05 ! H0-MINIMUM CUTOFF DEPTH, NODEDROMIN, NODEWETRMP, VELMIN
265.5 29.0 ! SLAM0, SFEA0 - CENTER OF CPP PROJECTION (NOT USED IF ICS=1, NTIP=0, NCOR=0)
0.0025 1.0 10 0.3333333 ! FFACTOR, HBREAK, FTHETA, FGAMMA
5.00 ! ESL - LATERAL EDDY VISCOSITY COEFFICIENT; IGNORED IF NWP =1
0.0 ! CORI - CORIOLIS PARAMETER - IGNORED IF NCOR = 1
0 ! NTIF - NUMBER OF TIDAL POTENTIAL CONSTITUENTS BEING FORCED
8 ! NBFR - TOTAL NUMBER OF FORCING FREQUENCIES ON OPEN BOUNDARIES
STEADY ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 1
0.000000000000000 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 1
K1 ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 2
0.000072921165921 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 2
O1 ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 3
0.000067597751162 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 3
N2 ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 4
0.000137879700000 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 4
S2 ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 5
0.000145444119418 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 5
M2 ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 6
0.000140518917083 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 6
M4 ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 7
0.000281037834166 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 7
M6 ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 8
0.00041556751249 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 8
STEADY ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 1
0.19196E-02 0.000 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 1 AT FIRST NODE
0.18488E-02 0.000
0.17777E-02 0.000

LINES DELETED

118
N2            ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 4
0.20080E+00  349.483 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 4 AT FIRST NODE
0.20070E+00  349.389
0.20060E+00  349.303
0.20051E+00  349.237

LINES DELETED

S2            ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 5
0.15960E+00  18.899 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 5 AT FIRST NODE
0.15952E+00  18.807
0.15943E+00  18.724
0.15936E+00  18.658

LINES DELETED

M2            ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 6
0.88290E+00  359.856 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 6 AT FIRST NODE
0.88233E+00  359.806
0.88181E+00  359.760

LINES DELETED

M4            ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 7
0.19039E-01  275.053 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 7 AT FIRST NODE
0.18520E-01  275.841
0.18055E-01  276.613
0.17708E-01  277.254

LINES DELETED

M6            ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 8
0.11321E-01  37.818 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 8 AT FIRST NODE
0.11360E-01  37.433
0.11404E-01  37.067

LINES DELETED

45.0 ! ANGINN - INNER ANGLE THRESHOLD
1 ! NFFR - NUMBER OF FREQUENCIES IN SPECIFIED NORMAL FLOW B.C. (INFLOWS)
STEADYFLOW ! ALPHA DESCRIPTOR FOR INFLOW
0.000000000000000 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR INFLOW NO. 1
STEADYFLOW ! ALPHA DESCRIPTOR FOR INFLOW
0.9430  0.000 ! q VALUES AT EACH NODE (3) OF U/S CONWAY WACCA RVR INFLOW-LISTED CCW

119
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1 0.0 20.0 1000 ! NOUTE,TOUTSE,TOUTFE,NSPOOL:ELEV STATION OUTPUT INFO (UNIT 61)
23 ! TOTAL NUMBER OF ELEVATION RECORDING STATIONS
-79.9231 32.7818 ! Charleston, SC (Cooper River Entrance)
-78.9183 33.6550 ! Springmaid Pier, SC
-79.093966 33.648889 ! Waccamaw River @ Bucksport, SC
-79.043889 33.829722 ! Waccamaw River @ Conway, SC
-79.181683 33.436743 ! Waccamaw River @ Hagley's Landing, SC
-78.656111 33.851389 ! AIW @ Nixon's Crossroads, SC
-79.004823 33.686529 ! AIW @ HWY 544 @ Socastee, SC
-79.281698 33.346890 ! Sampit River @ Georgetown, SC

LINES DELETED

1 0.0 20.0 1000 ! NOUTE,TOUTSV,TOUTFV,NSPOOLV:VEL. STATION OUTPUT INFO (UNIT 62)
23 ! TOTAL NUMBER OF VELOCITY RECORDING STATIONS
-79.9231 32.7818 ! Charleston, SC (Cooper River Entrance)
-78.9183 33.6550 ! Springmaid Pier, SC
-79.093966 33.648889 ! Waccamaw River @ Bucksport, SC
-79.043889 33.829722 ! Waccamaw River @ Conway, SC
-79.181683 33.436743 ! Waccamaw River @ Hagley's Landing, SC
-78.656111 33.851389 ! AIW @ Nixon's Crossroads, SC
-79.004823 33.686529 ! AIW @ HWY 544 @ Socastee, SC
-79.281698 33.346890 ! Sampit River @ Georgetown, SC
1 18.95 20.0 1000 ! NOUTGE,TOUTSGE,TOUTFGE,NSPOOLGE:GLOBAL ELEV OUTPUT (UNIT 63)
1 18.95 20.0 1000 ! NOUTGV,TOUTSGV,TOUTFGV,NSPOOLGV:GLOBAL VEL OUTPUT (UNIT 64)
22 ! NHARFR - NUMBER OF CONSTITUENTS TO BE INCLUDED IN THE HARMONIC ANALYSIS
STEADY                 ! HAFNAM - ALPHA DESCRIPTOR FOR CONSTITUENT NAME
0.000000000000000 1.0 0.0     ! HAFREQ, HAFF, HAFACE
MN
0.00002639203022 1.0 0.0
SM
0.00004925201824 1.0 0.0
O1
0.000067597744151 1.0 0.0
K1
0.00007292158358 1.0 0.0
MNS2
0.000132954497662 1.0 0.0
2MS2
0.000135593700684 1.0 0.0
O1
0.000137879699487 1.0 0.0
M2
0.000140518902509 1.0 0.0
2MN2
0.000143158105531 1.0 0.0
S2
0.000145444104333 1.0 0.0
2SM2
0.000150369306157 1.0 0.0
MN4
0.000278398601995 1.0 0.0
M4
0.000281037805017 1.0 0.0
MS4
0.000285693006842 1.0 0.0
2MN6
0.000418917504504 1.0 0.0
M6
0.000421556707526 1.0 0.0
MSN6
0.000423842706328 1.0 0.0
M8
0.000562075610035 1.0 0.0
M10
0.000702594512543 1.0 0.0
K2
0.000145842317201 1.0 0.0
Q1
0.000146955854129 1.0 0.0
15.00 20.00 250 0.0 ! THAS,THAF,NHAINC,FMV - HARMONIC ANALYSIS PARAMETERS
0 0 0 0 ! NHASE,NHASV,NHAGE,NHAGV - CONTROL HARMONIC ANALYSIS AND OUTPUT TO UNITS
51,52,53,54
1 36000 ! NHSTART,NHSINC - HOT START FILE GENERATION PARAMETERS
1 0 2.98E-5 25 ! ITITER, ISLDIA, CONVCR, ITMAX - ALGEBRAIC SOLUTION PARAMETERS
12 ! MNPROC
APPENDIX C

ADCIRC PARAMETER INPUT FILE

MEDIUM FLOW
STEADY/K1/O1/N2/S2/M2/M4/M6/MED  ! 32 CHARACTER ALPHANUMERIC RUN DESCRIPTION
SC-Conway-MEDQ-Tides-20d! 24 CHARACTER ALPHANUMERIC RUN IDENTIFICATION
1  ! NFOVER - NONFATAL ERROR OVERRIDE OPTION
1  ! NABOUT - ABREVIATED OUTPUT OPTION PARAMETER
0  ! NSCREEN - UNIT 6 OUTPUT OPTION PARAMETER
0  ! IHOT - HOT START PARAMETER
2  ! ICS - COORDINATE SYSTEM SELECTION PARAMETER
0  ! IM - MODEL TYPE (0 INDICATES STANDARD 2DDI MODEL)
2  ! NOLIBF - BOTTOM FRICTION TERM SELECTION PARAMETER
2  ! NOLIFA - FINITE AMPLITUDE TERM SELECTION PARAMETER
1  ! NOLICA - SPATIAL DERIVATIVE CONVECTIVE TERM SELECTION PARAMETER
1  ! NOLICAT - TIME DERIVATIVE CONVECTIVE TERM SELECTION PARAMETER
0  ! NWP - VARIABLE BOTTOM FRICTION AND LATERAL VISCOSITY OPTION PARAMETER
1  ! NCOR - VARIABLE CORIOLIS IN SPACE OPTION PARAMETER
0  ! NTIP - TIDAL POTENTIAL OPTION PARAMETER
0  ! NWS - WIND STRESS AND BAROMETRIC PRESSURE OPTION PARAMETER
1  ! NRAMP - RAMP FUNCTION OPTION
9.81  ! G - ACCELERATION DUE TO GRAVITY - DETERMINES UNITS
-0.01  ! TAU0 - WEIGHTING FACTOR IN GWCE
0.85  ! DT - TIME STEP (IN SECONDS)
0.0  ! STATIM - STARTING TIME (IN DAYS)
0.0  ! REFTIM - REFERENCE TIME (IN DAYS)
20.0  ! RNDAY - TOTAL LENGTH OF SIMULATION (IN DAYS)
15.0  ! DRAMP - DURATION OF RAMP FUNCTION (IN DAYS)
0.35  ! TIME WEIGHTING FACTORS FOR THE GWCE EQUATION
0.25 5 5 0.05  ! H0-MINIMUM CUTOFF DEPTH, NODEDRYMIN, NODEWETRMP, VELMIN
265.5 29.0  ! SLAM0, SFEA0 - CENTER OF CPP PROJECTION (NOT USED IF ICS=1, NTIP=0, NCOR=0)
0.0025 1.0 10 0.3333333  ! FFACOR, HBREAK, FTHETA, FGAMMA
5.00  ! ESL - LATERAL EDDY VISCOSITY COEFFICIENT; IGNORED IF NWP =1
0.0  ! CORI - CORIOLIS PARAMETER - IGNORED IF NCOR = 1
0  ! NTIF - NUMBER OF TIDAL POTENTIAL CONSTITUENTS BEING FORCED
8  ! NBFR - TOTAL NUMBER OF FORCING FREQUENCIES ON OPEN BOUNDARIES
STEADY  ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 1
0.000000000000000 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 1
K1  ! ALPHA DESCRIPTOR FOR CONSTITUENT No. 2
0.000072921165921 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 2
O1  ! ALPHA DESCRIPTOR FOR CONSTITUENT No. 3
0.000067597751162 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 3
N2  ! ALPHA DESCRIPTOR FOR CONSTITUENT No. 4
0.000137879700000 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 4
S2  ! ALPHA DESCRIPTOR FOR CONSTITUENT No. 5
0.000145444119418 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 5
M2  ! ALPHA DESCRIPTOR FOR CONSTITUENT No. 6
0.000149518917083 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 6
M4  ! ALPHA DESCRIPTOR FOR CONSTITUENT No. 7
0.000281037834166 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 7
M6  ! ALPHA DESCRIPTOR FOR CONSTITUENT No. 8
0.000421556751249 1.000 0.000  ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR Const. No. 8
STEADY  ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 1
0.19196E-02 0.000  ! BNDRY FORCING DATA FOR CONSTITUENT NO. 1 AT FIRST NODE
0.18488E-02 0.000
0.17777E-02 0.000
0.17096E-02 0.000
K1 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 2
0.11117E+00  190.794 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 2 AT FIRST NODE
0.11118E+00  190.750
0.11118E+00  190.712
0.11118E+00  190.682

O1 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 3
0.82243E-01  202.436 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 3 AT FIRST NODE
0.82247E-01  202.417
0.82249E-01  202.399
0.82248E-01  202.385

N2 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 4
0.20080E+00  349.483 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 4 AT FIRST NODE
0.20070E+00  349.389
0.20060E+00  349.303
0.20051E+00  349.237

S2 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 5
0.15960E+00  18.899 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 5 AT FIRST NODE
0.15952E+00  18.807
0.15943E+00  18.724
0.15936E+00  18.658

M2 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 6
0.88290E+00  359.856 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 6 AT FIRST NODE
0.88233E+00  359.806
0.88181E+00  359.760
0.88141E+00  359.723

124
M4 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 7
0.19039E-01 275.053 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 7 AT FIRST NODE
0.18520E-01 275.841
0.18055E-01 276.613
0.17708E-01 277.254

LINES DELETED

M6 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 8
0.11321E-01 37.818 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 8 AT FIRST NODE
0.11360E-01 37.433
0.11404E-01 37.067
0.11463E-01 36.732

LINES DELETED

45.0 ! ANGINN - INNER ANGLE THRESHOLD
1 ! NFFR - NUMBER OF FREQUENCIES IN SPECIFIED NORMAL FLOW B.C. (INFLOWS)
STEADYFLOW ! ALPHA DESCRIPTOR FOR INFLOW NO. 1
0.000000000000000 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR INFLOW NO. 1
STEADYFLOW ! ALPHA DESCRIPTOR FOR INFLOW NO. 1
2.5849 0.000 ! q VALUES AT EACH NODE (3) OF U/S CONWAY WACCAMAW INFLOW--LISTED CCW
2.5849 0.000
2.5949 0.000
0.1709 0.000 ! q VALUES AT EACH NODE (3) OF CONWAY 2 CONF LOCAL INFLOW--LISTED CCW
0.1709 0.000
0.1709 0.000
1.3967 0.000 ! q VALUES AT EACH NODE (9) OF LITTLE PEE DEE RIVER INFLOW--LISTED CCW
1.3967 0.000
1.3967 0.000
1.3967 0.000
1.3967 0.000
1.3967 0.000
1.3967 0.000
1.3967 0.000
1.3967 0.000
1.6767 0.000 ! q VALUES AT EACH NODE (9) OF PEE DEE RIVER INFLOW--LISTED CCW
1.6767 0.000
1.6767 0.000
1.6767 0.000
1.6767 0.000
1.6767 0.000
1.6767 0.000
1.6767 0.000
1.6767 0.000
0.3289 0.000 ! q VALUES AT EACH NODE (5) OF LYNCHES RIVER INFLOW--LISTED CCW
0.3289 0.000
0.3289 0.000
0.3289 0.000
0.3289 0.000
1 0.0 20.0 1000 ! ROUTE.TOUTSE.TOUTFE.NSPOOLE.ELEV STATION OUTPUT INFO (UNIT 61)
23 ! TOTAL NUMBER OF ELEVATION RECORDING STATIONS
-79.9231  32.7818  ! Charleston, SC (Cooper River Entrance)
-78.9183  33.6550  ! Springmaid Pier, SC
-79.09366 33.64889  ! Waccamaw River @ Bucksport, SC
-79.043889 33.829722 ! Waccamaw River @ Conway, SC
-79.181683 33.436743 ! Waccamaw River @ Hagley's Landing, SC
-78.656111 33.851389 ! AIW @ Nixon's Crossroads, SC
-79.004823 33.686529 ! AIW @ HWY 544 @ Socastee, SC
-79.294722 33.356111 ! Sampit River @ Georgetown, SC

**LINES DELETED**

1  0.0  20.0  1000 ! NOUTV,TOUTSV,TOUTFV,NSPOOLV:VEL. STATION OUTPUT INFO (UNIT 62)
23 ! TOTAL NUMBER OF VELOCITY RECORDING STATIONS
-79.9231  32.7818  ! Charleston, SC (Cooper River Entrance)
-78.9183  33.6550  ! Springmaid Pier, SC
-79.09366 33.64889  ! Waccamaw River @ Bucksport, SC
-79.043889 33.829722 ! Waccamaw River @ Conway, SC
-79.181683 33.436743 ! Waccamaw River @ Hagley's Landing, SC
-78.656111 33.851389 ! AIW @ Nixon's Crossroads, SC
-79.004823 33.686529 ! AIW @ HWY 544 @ Socastee, SC
-79.281698 33.346890 ! Sampit River @ Georgetown, SC

**LINES DELETED**

1 18.975  20.0  1000 ! NOUTGE,TOUTSGE,TOUTFGE,NSPOOLGE:GLOBAL ELEV OUTPUT (UNIT 63)
1 18.975  20.0  1000 ! NOUTGV,TOUTSGV,TOUTFGV,NSPOOLGV:GLOBAL VEL. OUTPUT (UNIT 64)
22 ! NHARFR - NUMBER OF CONSTITUENTS TO BE INCLUDED IN THE HARMONIC ANALYSIS
STEADY     ! HAFNAM - ALPHA DESCRIPTOR FOR CONSTITUENT NAME
0.000000000000000 1.0 0.0     ! HAFREQ, HAFF, HAFACE
MN
0.000002639203022 1.0 0.0
SM
0.00004925201824 1.0 0.0
O1
0.000067597744151 1.0 0.0
K1
0.000072921158358 1.0 0.0
MNS2
0.000132954497662 1.0 0.0
2MS2
0.000135593700684 1.0 0.0
N2
0.000137879699487 1.0 0.0
M2
0.000140518902509 1.0 0.0
2MN2
0.000143158105531 1.0 0.0
S2
0.000145444404333 1.0 0.0
2SM2
0.000150369306157 1.0 0.0
MN4
0.000278398601995 1.0 0.0
M4
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MS4
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M6
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M8
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M10
0.000702594512543 1.0 0.0
K2
0.000145842317201 1.0 0.0
Q1
0.000064958541129 1.0 0.0
15.00 20.00 250 0.0 ! THAS,THAF,NHAINC,F MV - HARMONIC ANALYSIS PARAMETERS
0 0 0 0 ! NHASE,NHASV,NHAGE,NHAGV - CONTROL HARMONIC ANALYSIS AND OUTPUT TO UNITS
51,52,53,54
1 36000 ! NHSTAR,NHSINC - HOT START FILE GENERATION PARAMETERS
1 0 2.98E-5 25 ! ITITER, ISLDIA, CONVCR, ITMAX - ALGEBRAIC SOLUTION PARAMETERS
12 ! MNPROC
APPENDIX D

ADCIRC PARAMETER INPUT FILE

HIGH FLOW
STEADY/K1/O1/N2/S2/M4/M6/HIGH    ! 32 CHARACTER ALPHANUMERIC RUN DESCRIPTION
SC-Conway-HIQ-Tides-20d! 24 CHARACTER ALPHANUMERIC RUN IDENTIFICATION
 1  ! NFOVER - NONFATAL ERROR OVERRIDE OPTION
 1  ! NABOUT - ABBREVIATED OUTPUT OPTION PARAMETER
 0  ! NSCREEN - UNIT 6 OUTPUT OPTION PARAMETER
 0  ! IHOT - HOT START PARAMETER
 2  ! ICS - COORDINATE SYSTEM SELECTION PARAMETER
 0  ! IM - MODEL TYPE (0 INDICATES STANDARD 2DDI MODEL)
 2  ! NOLBF - BOTTOM FRICITION TERM SELECTION PARAMETER
 2  ! NOLIFA - FINITE AMPLITUDE TERM SELECTION PARAMETER
 1  ! NOLICA - SPATIAL DERIVATIVE CONVECTIVE TERM SELECTION PARAMETER
 1  ! NOLICAT - TIME DERIVATIVE CONVECTIVE TERM SELECTION PARAMETER
 0  ! NWP - VARIABLE BOTTOM FRICTION AND LATERAL VISCOSITY OPTION PARAMETER
 0  ! NCOR - VARIABLE CORIOLIS IN SPACE OPTION PARAMETER
 0  ! NWS - WIND STRESS AND BAROMETRIC PRESSURE OPTION PARAMETER
 1  ! NRAMP - RAMP FUNCTION OPTION
 9.81 ! G - ACCELERATION DUE TO GRAVITY - DETERMINES UNITS
-0.01 ! TAU0 - WEIGHTING FACTOR IN GWCE
0.65 ! DT - TIME STEP (IN SECONDS)
0.0   ! STATIM - STARTING TIME (IN DAYS)
0.0   ! REFTIM - REFERENCE TIME (IN DAYS)
20.0  ! RNDAY - TOTAL LENGTH OF SIMULATION (IN DAYS)
15.0  ! DRAMP - DURATION OF RAMP FUNCTION (IN DAYS)
0.35 0.30 0.35 ! TIME WEIGHTING FACTORS FOR THE GWCE EQUATION
2.25 5 5 0.05 ! H0 - MINIMUM CUTOFF DEPTH, NODEDRYMN, NODEWETRMP, VELMIN
265.5 29.0 ! SLAM0,SFEA0 - CENTER OF CPP PROJECTION (NOT USED IF ICS=1, NTIP=0, NCOR=0)
0.0025 1.0 10 0.3333333 ! FFACTOR, HBREAK, FTHETA, FGAMMA
5.00 ! ESL - LATERAL EDDY VISCOSITY COEFFICIENT; IGNORED IF NWP =1
0.0  ! CORI - CORIOLIS PARAMETER - IGNORED IF NCOR = 1
0  ! NTIF - NUMBER OF TIDAL POTENTIAL CONSTITUENTS BEING FORCED
8  ! NBFR - TOTAL NUMBER OF FORCING FREQUENCIES ON OPEN BOUNDARIES
STEADY    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 1
0.0000000000000000 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 1
K1    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 2
0.000072921165921 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 2
O1    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 3
0.000067597751162 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 3
M2    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 4
0.0001378797000000 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 4
S2    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 5
0.000145444119418 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 5
M2    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 6
0.000140518917083 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 6
M4    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 7
0.000281037834166 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 7
M6    ! ALPHA DESCRIPTOR FOR CONSTITUENT NO. 8
0.000421556751249 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR CONST. NO. 8
STEADY    ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 1
0.19196E-02 0.000 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 1 AT FIRST NODE
0.18488E-02 0.000
0.17777E-02 0.000
0.17096E-02 0.000

;
K1 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 2
0.11117E+00 190.794 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 2 AT FIRST NODE
0.11118E+00 190.750
0.11118E+00 190.712
0.11118E+00 190.682

O1 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 3
0.82243E-01 202.436 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 3 AT FIRST NODE
0.82247E-01 202.417
0.82249E-01 202.399
0.82248E-01 202.385

N2 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 4
0.20080E+00 349.483 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 4 AT FIRST NODE
0.20070E+00 349.389
0.20060E+00 349.303
0.20051E+00 349.237

S2 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 5
0.15960E+00 18.899 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 5 AT FIRST NODE
0.15952E+00 18.807
0.15943E+00 18.724
0.15936E+00 18.658

M2 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 6
0.88290E+00 359.856 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 6 AT FIRST NODE
0.88233E+00 359.806
0.88181E+00 359.760
0.88141E+00 359.723

130
M4 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 7
0.19039E-01 275.053 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 7 AT FIRST NODE
0.18520E-01 275.841
0.18055E-01 276.613
0.17708E-01 277.254

LINES DELETED

M6 ! ALPHA NUMERIC DESCRIPTION OF OPEN BOUNDARY FORCING DATA SET 8
0.11321E-01 37.818 ! BNDRY FORCING DATA FOR CONSTITUENT NO. 8 AT FIRST NODE
0.11360E-01 37.433
0.11404E-01 37.067
0.11463E-01 36.732

LINES DELETED

45.0 ! ANGINN - INNER ANGLE THRESHOLD
1 ! NFFR - NUMBER OF FREQUENCIES IN SPECIFIED NORMAL FLOW B.C. (INFLOWS)
STEADYFLOW ! ALPHA DESCRIPTOR FOR INFLOW
0.000000000000000 1.000 0.000 ! CONST. FREQ., NODAL FACTOR, EQUIL. ARG. FOR INFLOW NO. 1
STEADYFLOW ! ALPHA DESCRIPTOR FOR INFLOW
6.9245 0.000 ! q VALUES AT EACH NODE (3) OF U/S CONWAY WACCAMAW INFLOW--LISTED CCW
6.9245 0.000
6.9245 0.000
0.2564 0.000 ! q VALUES AT EACH NODE (3) OF CONWAY 2 CONF LOCAL INFLOW--LISTED CCW
0.2564 0.000
0.2564 0.000
1.9565 0.000 ! q VALUES AT EACH NODE (9) OF LITTLE PEE DEE RIVER INFLOW--LISTED CCW
1.9565 0.000
1.9565 0.000
1.9565 0.000
1.9565 0.000
1.9565 0.000
1.9565 0.000
1.9565 0.000
1.9565 0.000
2.5233 0.000 ! q VALUES AT EACH NODE (9) OF PEE DEE RIVER INFLOW--LISTED CCW
2.5233 0.000
2.5233 0.000
2.5233 0.000
2.5233 0.000
2.5233 0.000
2.5233 0.000
2.5233 0.000
2.5233 0.000
2.5233 0.000
0.4375 0.000 ! q VALUES AT EACH NODE (5) OF LYNCHES RIVER INFLOW--LISTED CCW
0.4375 0.000
0.4375 0.000
0.4375 0.000
0.4375 0.000
1.0 0 20.0 1000 ! NOUTE, TOUTSE, TOUTFE, NSPOOLE: ELEV STATION OUTPUT INFO (UNIT 61)
23 ! TOTAL NUMBER OF ELEVATION RECORDING STATIONS
-79.231  32.7818  ! Charleston, SC (Cooper River Entrance)
-78.9183  33.6550  ! Springmaid Pier, SC
-79.09366  33.648889  ! Waccamaw River @ Bucksport, SC
-79.043889  33.829722  ! Waccamaw River @ Conway, SC
-79.181683  33.436743  ! Waccamaw River @ Hagley’s Landing, SC
-78.656111  33.851389  ! AIW @ Nixon's Crossroads, SC
-79.004823  33.686529  ! AIW @ HWY 544 @ Socastee, SC
-79.281698  33.346890  ! Sampit River @ Georgetown, SC

1 0.0 20.0 1000 ! NOUTV,TOUTSV,TOUTFV,NSPOOLV:VEL. STATION OUTPUT INFO (UNIT 62)
23 ! TOTAL NUMBER OF VELOCITY RECORDING STATIONS
-79.9231  32.7818  ! Charleston, SC (Cooper River Entrance)
-78.9183  33.6550  ! Springmaid Pier, SC
-79.09366  33.648889  ! Waccamaw River @ Bucksport, SC
-79.043889  33.829722  ! Waccamaw River @ Conway, SC
-79.181683  33.436743  ! Waccamaw River @ Hagley’s Landing, SC
-78.656111  33.851389  ! AIW @ Nixon's Crossroads, SC
-79.004823  33.686529  ! AIW @ HWY 544 @ Socastee, SC
-79.281698  33.346890  ! Sampit River @ Georgetown, SC

1 18.975  20.0  1000 ! NOUTGE,TOUTSGE,TOUTFGE,NSPOOLGE:GLOBAL ELEV OUTPUT INFO (UNIT 63)
1 18.975  20.0  1000 ! NOUTGV,TOUTSGV,TOUTFGV,NSPOOLGV:GLOBAL VEL. OUTPUT INFO (UNIT 64)
22 ! NHARFR - NUMBER OF CONSTITUENTS TO BE INCLUDED IN THE HARMONIC ANALYSIS
STEADY  ! HAFNAM - ALPHA DESCRIPTOR FOR CONSTITUENT NAME
0.000000000000000 1.0 0.0  ! HAFREQ, HAFF, HAFACE
MN
0.000002639203022 1.0 0.0
SM
0.00000492501824 1.0 0.0
O1
0.000067597744151 1.0 0.0
K1
0.000072921158358 1.0 0.0
MNS2
0.000132954497662 1.0 0.0
2MS2
0.000135593700684 1.0 0.0
N2
0.000137879699487 1.0 0.0
M2
0.000140518902509 1.0 0.0
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0.000143158105531 1.0 0.0
S2
0.000145444104333 1.0 0.0
2SM2
0.000150369306157 1.0 0.0
MN4
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2MN6
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0.000702594512543 1.0 0.0
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0.000145842317201 1.0 0.0
Q1
0.000064958541129 1.0 0.0
15.00 20.00 250 0.0 'THAS,THAF,NHAINC,FMV - HARMONIC ANALYSIS PARAMETERS
0 0 0 0 !NHASE,NHASV,NHAGE,NHAGV - CONTROL HARMONIC ANALYSIS AND OUTPUT TO UNITS
51,52,53,54
1 36000 !NHSTAR,NHSINC - HOT START FILE GENERATION PARAMETERS
1 0 2.98E-5 25 !ITITER, ISLDIA, CONVCR, ITMAX - ALGEBRAIC SOLUTION PARAMETERS
12 !MNPROC
APPENDIX E

TABLE OF RUNS PERFORMED
<table>
<thead>
<tr>
<th>Run #</th>
<th>( \Delta t ) (sec.)</th>
<th>Flow Scenario</th>
<th>Eddy Viscosity</th>
<th>Ramp (days)</th>
<th>Bottom Friction</th>
<th>Complete without Crash?</th>
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LIST OF REFERENCES


