A Hydrodynamic Model of Mobile Bay, Alabama

Vladimir J. Alarcon
Geosystems Research Institute-Northern Gulf Institute
Mississippi State University
2 Research Blvd
Starkville, MS 39759

William H. McAnally
Department of Civil Engineering
Mississippi State University
235 Walker Engineering Building
Mississippi State, MS 39762

Wali Aziz
Computational Simulation and Design Center
Mississippi State University
Box 9627
Mississippi State, MS 39762, USA

and

John H. Cartwright
Geosystems Research Institute-Northern Gulf Institute
Mississippi State University
2 Research Blvd
Starkville, MS 39759

ABSTRACT

This paper presents a hydrodynamic model of Mobile Bay developed using the Adaptive Hydraulic Modeling system (ADH), the Hydrological Simulation Program FORTRAN (HSPF), and the Mesh Generation and Refinement Tool (MGRT), to simulate water surface elevations in Mobile Bay, Alabama. The computational grid was created using MGRT and NOAA’s coastline and bathymetric data. HSPF provided stream flow time series for establishing fresh water boundary conditions. NOAA’s tidal stations in the region were used for establishing ocean boundary conditions and for calibrating the model. ADH was used for the actual hydrodynamic calculations. The existing parallel ADH code (developed at USACE-ERDC) was compiled in a 384-node computer cluster and an exploration of the optimum number of processors for the model’s runs was performed. With the parallelized code, speed-ups of up to 21 were obtained. The hydrodynamic calibration of the Mobile Bay hydrodynamic model was greatly eased with the parallelized ADH version. The Surface Water Modeling System (SMS) was used for partial pre-processing (add bathymetry data to mesh) and visualization of the results. Calculated and observed water depths were consistent ($r^2 > 0.75$).

Keywords: Mobile Bay, Hydrodynamics, ADH, HSPF, MGRT, modeling.

1. INTRODUCTION

This research is part of on-going research activities at the Mississippi State University’s Northern Gulf Institute. One of the goals of those research efforts, it is to develop and demonstrate the use of advanced spatial technology and high performance computing in the prediction of hydrodynamics and surface water quality in the region.

This paper presents updated results on the modeling of Mobile Bay hydrodynamics. The Adaptive Hydraulic Modeling (ADH) system was used to explore several alternatives of hydrodynamic models of Mobile Bay. Meshes created with the Mesh Generation Tool (MGRT) were enriched with bathymetry data from NOAA data centers. The resulting ADH model application was fed with output data from Hydrological Simulation Program FORTRAN (HSPF) watershed models of upland catchments that drain waters into the bay. Tidal data form NOAA stations were used to establish ocean boundary conditions and to calibrate the model for water surface elevation.

2. METHODS

2.1. Study area

The study area in this research is Mobile Bay, Alabama, (see Figure 1). Although the actual hydrodynamic model is focused on the bay, the non-point source portion of
this study (i.e., the hydrological model) encompasses the entire Mobile River watershed and several other smaller watersheds that surround Mobile Bay. Those watersheds are shown in Figure 2.

Figure 1. Study area: Mobile Bay, AL (after [1]).

Figure 2. Upland and coastal watersheds draining waters to Mobile Bay (after [2]).

Mobile Bay is located in the Gulf of Mexico, in the state of Alabama. The Mobile River is the most important contributor to the bay with an average stream flow of approximately 2000 cubic meter per second. Several other smaller rivers also drain waters into the bay with much lower stream flow input. Mobile Bay is the fourth largest estuary in the United States. It covers approximately 1,000 km² with an average water depth of 3 m.

2.2. Computational Models
Hydrological modeling of the Mobile River watershed and several watersheds surrounding Mobile Bay was performed using the Hydrological Simulation Program Fortran (HSPF). HSPF is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The model uses continuous precipitation and other meteorological/water-quality records to compute stream-flow hydrographs. The generation of the stream flow time series that were input into the hydrodynamic model that was used in this research is fully detailed in [2].

The modeling and simulation of the Mobile Bay hydrodynamics is performed using the Adaptive Hydraulics (ADH) modeling system. ADH is a software package that can describe both saturated and unsaturated groundwater, overland flow, 3D Navier-Stokes, and 3D Shallow Water problems in addition to the 2D shallow water problems [5].

The ADH model is designed to work in conjunction with the Surface Water Modeling System (SMS), which is a Windows application for building ADH application models, running simulations, and visualizing results [5]. In this research, however, SMS was used mostly for visualization of results since its interaction with the parallelized Linux version was not possible during pre-processing.

2.3 Parallelization
The parallelized ADH source code (provided by [6]), was compiled in an IBM x335 Linux Super-cluster (384 processors 3.066GHz Xeon, 192 nodes, 480 Gigabytes of RAM). The provided code had already been parallelized for computer clusters at USACE-ERDC. In this research, the make files were modified to adapt the source code to the local cluster. The Mobile Bay ADH model application was run for several time windows: 100, 1000, 3600, 7200, 86400, and 172800 seconds. Several numbers of processors were tried sequentially and processing times were recorded. For optimum comparison of processing time, the 7200 seconds simulation was chosen (greater simulation times would require extensive waiting time when the parallel ADH application is run in 2, 4 and 8 processors).
2.4 Ocean boundary data and hydrodynamic calibration
Ocean boundary conditions were established with measured tidal data at Dauphin Island Station for a two day time period beginning 3/7/2009, 11:42:00 AM. Tidal data from other stations (Coast Guard, State Docks, and Weeksbay) were also downloaded from the NOAA-Tides-Online database for calibrating the resulting hydrodynamic model. Figure 3 shows the geographical location of the stations.

![Figure 3. Geographical location of tidal data stations used for setting-up and calibrating the Mobile Bay hydrodynamic model.](image)

3. RESULTS

3.1 Grid generation
The resulting computational grid consisted in 27578 triangular elements, 14259 nodes. All nodes were provided with bathymetric elevations referenced to the local tidal datum (Mean Lowest Low Water, MLLW), averaged over a 19 year tidal epoch. Horizontal datum was defined as the North American Datum 1983. The Universal Transverse Mercator (UTM, zone 16N) coordinate system was used throughout. The computational grid and bathymetry are shown in Figure 4.

![Figure 4. Computational grid and bathymetry used for the Mobile Bay hydrodynamic model.](image)

3.2 Parallelization
The ADH application was run in a dual-core PC (2.16 GHz, 2 GB RAM), and an IBM x335 Linux Supercluster with 384 processors (3.066GHz Xeon), 192 nodes, 480 Gigabytes of RAM. The runs in the cluster were performed to locate the optimum number of processors (corresponding to the highest speed up) for the ADH application to Mobile Bay. Table 1 and Figure 5 show results of the exploration.

<table>
<thead>
<tr>
<th># of Proc.</th>
<th>Cluster processing time (sec)</th>
<th>Simulation time (sec)</th>
<th>PC process time (sec)</th>
<th>Speed-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>29669.4</td>
<td>7200</td>
<td>5517</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>2107.8</td>
<td>7200</td>
<td>5517</td>
<td>2.6</td>
</tr>
<tr>
<td>16</td>
<td>516.9</td>
<td>7200</td>
<td>5517</td>
<td>10.7</td>
</tr>
<tr>
<td>32</td>
<td>254.2</td>
<td>7200</td>
<td>5517</td>
<td>21.7</td>
</tr>
<tr>
<td>64</td>
<td>6633.6</td>
<td>7200</td>
<td>5517</td>
<td>0.8</td>
</tr>
</tbody>
</table>

As shown in Table 1 and Figure 3, the optimum number of processors for this particular application of ADH to
Mobile Bay is 32. The speedup is defined as \( Sp = \frac{T_1}{T_p} \), where: \( p \) is the number processors, \( T_1 \) is the execution time of the sequential ADH algorithm, \( T_p \) is the execution time of the parallel algorithm with \( p \) processors. For this particular exploration: \( Sp = 21.7 \). Figure 5 shows the optimization of number of processors.

![Figure 5](image)

**Figure 5.** Comparison of sequential and parallel processing times. Optimum number of processors is 32.

### 3.3 Hydrodynamic modeling

![Figure 6](image)

**Figure 6.** Visualization of water velocity vectors and water depths at 4:12 hr simulation time.

Figure 6 shows a view of the simulation results (provided by SMS) at 4 hours and 12 minutes of simulation time. Water velocity vectors with magnitudes in the range of 0.1 and 1 m/s are visualized. Simulated water velocities ranged within 0 to 4.95 m/s but visualizing all velocity vectors would have produced a very dense arrangement of indistinguishable vectors. In Figure 6, vectors sizes are scaled according to their magnitude.

![Figure 7](image)

**Figure 7.** Calibration of the ADH model application to Mobile Bay.

Once the ADH model application to Mobile Bay was set up and running times were optimized using the computer cluster, the model was calibrated (i.e., tuned) to produce a hydrodynamic model capable of replicating measured tidal data. Model parameters (wall and bed roughness) were sequentially varied to achieve good approximations of predicted tides to observed tides at Coast Guard, State Docks, and Weeksbay tidal stations. Water depth was used as the variable to be compared. Calibration results are shown in Figures 7 and 8.

Scatter plots of measured versus simulated water depths are shown in Figure 8. Coefficients of determination greater than 0.75 were calculated, showing a good fit between measured and simulated water depths.
Figure 7. Comparison of calculated and observed water depths at the State Docks and Coast Guard tidal stations. R² values greater than 0.75 were calculated.

4. CONCLUSIONS

The hydrodynamic model of Mobile Bay is shown to produce water depths values consistent with measured data at tidal stations distributed throughout the bay. The compilation and use of the existing parallel version of the ADH code is also shown to be very effective, producing speed-up values of up to 21.7. The loose-link between the Hydrological Simulation Program FORTRAN (HSPF) and the Adaptive Hydraulic Modeling (ADH) system was effectively used to provide fresh boundary conditions at the upland stream inlets to Mobile Bay.

5. REFERENCES


