4. MODEL VERIFICATION

As noted in Section 3, the two models being used have been verified by application to other waterbodies and comparing results to measured data. Of course, as is always the case, verification may be in the eye of the beholder. In the following, verifications of the models as used in the Apalachicola area will be discussed.

4.1 Verification of CAFE-1

4.1.1 Field Data

Two primary types of data were obtained from the field: (1) tidal information at various points in the bay and (2) water velocity measurements. In addition, the wind velocity was measured several times during the data collection process.

Most of the field data to be discussed in this report were gathered from September 15 through September 26, 1980, and from November 7 through November 9, 1980.

4.1.1.1 Tide Recordings. Tide gages were place at each of the four ocean boundaries: East Pass, Sikes Cut, West Pass, and Indian Pass. The tides recorded at these gages were used as input boundary information to the model.

In addition, tide gages were installed at two internal points in the bay (points A and B in Figure 4.1). The recordings from these two tide gates were used as a comparison with the model results. Figure 4.2 shows a tide gage and recorder in place on a private dock at Indian Pass. A sample recording of the tide at East Pass is shown in Figure 4.3.

Additional tidal information was obtained from NOAA.
Figure 4.1. Location of Verification Points in Apalachicola Bay.
Figure 4.2. Tide Gage and Recorder in Place at Indian Pass.
Figure 4.3. Sample Recording from Tide Gage at East Pass.
4.1.1.2 Velocity Measurements. All velocity measurements were taken from a boat using a V "Arkansas" Ott Meter (see Figures 4.4 and 4.5). Logarithmic velocity profiles were assumed, so the velocity readings to be compared with the model output were taken at 36.8% of the total depth from the bottom (which is the location of the spatial mean velocity for a logarithmic velocity profile). Velocities were also recorded at other depths so that velocity profiles could be plotted and the assumption of logarithmic velocity profile checked.

At points C and D (Figure 4.1) measurements were taken at short intervals for periods of about four hours. These values were used as a comparison with the model results. Velocity profiles were also measured at several other points in the bay.

Flow direction was measured with a compass after hoisting the Ott Meter to an elevation where it could be seen (see Figure 4.6). It is assumed that the flow direction is the same at all depths below the water surface.

4.1.2 Model Input for Verification Runs

4.1.2.1 Grid Configuration. The finite element grid shown in Figure 3.1 was used for all of the computer runs to be discussed in this report. It contains 281 nodes and 439 elements.

This particular grid was chosen after experimentation with several grids because of its many desirable characteristics. First, the element size is small enough to provide an accurate representation of the bay. Second, most of the triangles are approximately equilateral and there is no rapid change in element size. This is of particular importance because rapid change in element size as well as irregular triangles, tends to produce instabilities which cannot be predicted by quantifiable stability criteria as discussed earlier.
Figure 4.4. Ott Propeller Meter Used for Velocity Measurements in Apalachicola Bay.
Figure 4.6. Observation of Direction of Water Flow.
The remaining reasons for choosing this grid are related to the cost of running the model. This cost is roughly proportional to the number of elements and inversely proportional to the timestep.

The timestep was chosen to be 60 seconds in accordance with the earlier discussed stability criteria. In addition, the output from CAFE-I is used as input to a water quality model and 60 seconds is a convenient interval for transferring this information.

4.1.2.2 Turbulent Eddy Viscosity Coefficients. As stated earlier, internal stresses from turbulence and velocity shear are represented in the model in the form of Equation (3.9). Since there is no way to actually measure these stresses, the literature review provided reasonable values for the eddy viscosity coefficients. The values currently being used are the following:

\[ E_{xx} = 40.0 \text{ m}^3\text{s}^{-1} \]
\[ E_{yy} = 40.0 \text{ m}^3\text{s}^{-1} \]
\[ E_{xy} = 20.0 \text{ m}^2\text{s}^{-1} \]

The sensitivity of the model to these coefficients was not known. A single computer run was made with each of these values cut in half. The resultant change in velocities was only about 1-2%. The turbulent eddy viscosity coefficients are parameters that can be easily manipulated by the operator for the purpose of calibrating the model. Therefore, a more detailed study on the effects of making larger changes in these parameters may easily be undertaken if necessary.
4.1.2.3 Manning's n. The first set of computer runs was made with n = 0.045. This value was calculated in accordance with the method proposed by Christensen (1975) from a few scattered velocity profiles obtained in the field. From the velocity profiles that were logarithmic (surprisingly few of them were not), an average of the n values was taken. This average was input as a constant value for the entire bay.

Since the first set of runs yielded velocities that were too small, a second set of runs was made with n equal to a constant 0.030 throughout the bay. The result of this change will be discussed in more detail in the next section.

It is also possible to input varying values of Manning's n throughout the bay. Although this is more time consuming than simply supplying a constant value, it is the only way to account for differences in bottom friction at various locations. This type of input can be used as a final step in "fine-tuning" the model.

4.1.2.4 River Flow. Although river flow is a physical characteristic of the bay, the exact river discharges are not known for the periods during which data was taken. However, average monthly flows for the Apalachicola River (1961 - 1976) were available from the U.S.G.S. so these values were used (see Table 4.1 and Figure 1.7). Fortunately, errors in the river flow do not significantly affect the overall hydrodynamics of the bay, because the river flow constitutes a very small part of the total amount of water entering the bay. This is illustrated in the following calculation showing the ratio of river flow ($Q = 705 \text{ m}^3\text{s}^{-1}$ for the Apalachicola River) during a half tidal cycle to a mean tidal prism height of 0.5 m:

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean Discharge (m^3/s)</th>
<th>Ratio to Mean Annual Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>387</td>
<td>.55</td>
</tr>
<tr>
<td>N</td>
<td>391</td>
<td>.56</td>
</tr>
<tr>
<td>D</td>
<td>617</td>
<td>.88</td>
</tr>
<tr>
<td>J</td>
<td>985</td>
<td>1.40</td>
</tr>
<tr>
<td>F</td>
<td>1131</td>
<td>1.60</td>
</tr>
<tr>
<td>M</td>
<td>1209</td>
<td>1.72</td>
</tr>
<tr>
<td>A</td>
<td>1082</td>
<td>1.54</td>
</tr>
<tr>
<td>M</td>
<td>687</td>
<td>.97</td>
</tr>
<tr>
<td>J</td>
<td>580</td>
<td>.82</td>
</tr>
<tr>
<td>J</td>
<td>505</td>
<td>.71</td>
</tr>
<tr>
<td>A</td>
<td>496</td>
<td>.70</td>
</tr>
<tr>
<td>S</td>
<td>392</td>
<td>.56</td>
</tr>
</tbody>
</table>

Mean Annual Discharge: 705 \(m^3/s\) 
Ratio to Mean Annual Discharge: 1.00

These values correspond to the hydrograph given in Figure 1.7.
\[
(100\%) \cdot \frac{(705 \text{ m}^3\text{s}^{-1}) (60 \text{ s} \text{ min}^{-1}) (60 \text{ min} \text{ h}^{-1}) (6.21 \text{ h})}{(550 \text{ km}^2) (0.5 \text{ m}) (1,000,000 \text{ m}^2 \text{ km}^{-2})} = 5.7\%
\]

4.1.2.5 Wind Velocity. The model does not provide for the input of time-varying wind velocity, so average velocities were used. For the run used as a comparison with the internal water surface fluctuations:

wind velocity = 2.24 m s\(^{-1}\) (5 mph) at 207° clockwise from North

For the two runs used as comparisons with water velocities:

wind velocity = 2.24 m s\(^{-1}\) (5 mph) at 0° clockwise from North

4.1.2.6 Tide Information at Boundaries. The tidal curves at the boundaries are input to the model as a set of amplitudes and times. The model then approximates the tides as a series of sinusoidal curves. It is important that the first half tide curve input to the model is one of increasing water elevation (i.e., from low tide to high tide) since the initial depths in the model are at MLW.

Complete tidal information at all boundaries was available for the run used as a comparison with the internal water surface fluctuations. However, for the two runs used as comparisons with the water velocities, only partial boundary data was available. (Tide gages were only set-up at East Pass and Indian River Pass when the velocity data were gathered.) Correction factors for both amplitude and time lag were established from the complete set of curves and used to estimate the tidal curves at West Pass and Sikes Cut for the remaining runs from the information at East Pass.

4.1.2.7 Depths at MLW. The depths input at each node were obtained from a Navigational Chart published by NOAA. The depths input at West Pass
and Sikes Cut are slightly lower than the actual values, because the latter causes instabilities in the model with the 60 second time step. Using a time step small enough to permit the input of actual depths would make the cost of running the model prohibitive. To compensate for the smaller depths, larger than actual widths were input so that the cross-sectional area of the outlets remained the same.

4.1.3 Comparison of Model Results with Field Data

Figures 4.7 and 4.8 show field measurements and model results for the water surface fluctuations at two points, B and A, in the bay. Computer results are shown for \( n = 0.045 \) and \( n = 0.030 \). At point B, both computer runs are extremely close to the range and phase lag of the actual curve. The change in Manning's \( n \) produced only about a 5 percent change in the tidal range and almost no difference in the phase lag. This is important to note, since the same change induced a much larger difference in velocities. The difference between the range of the computer run with \( n = 0.030 \) and the actual measured range is only about 7 percent.

At point A, there is almost exact correlation between the range of the \( n = 0.030 \) computer run and the range of the recorded curve. However, there appears to be a slight phase lag difference between the two (about 10 percent).

Similar correlations between measured and computed velocity and velocity orientation are obtained with the model. Figure 4.9 shows the comparison at point C as an example. Observed and computed values of the vertically averaged velocities at points A through B show similar satisfactory agreement. The predicted model velocities are often lower than the observed velocities. However, Wang (1978) reports that a comparison of current velocities measured by portable current
Figure 4.7. Water Surface Elevation vs Time at Point B in Apalachicola Bay.
Figure 4.8. Water Surface Elevation vs Time at Point A in Apalachicola Bay.
Figure 4.9. Comparison of Observed and Computed Velocity Direction as Function of Time at Point C.
meters from boats with those measured by recording current meters mounted on fixed structures showed that the former tend to be inflated due to wave motion. Hence, the agreement between observed and model predicted velocities may be even better than the observations indicate.

4.1.4 Comparison with Wang's Verification

Figures 4.10 and 4.11 show field and preliminary model results obtained by Wang (1978) using the CAFE-1 model at Biscayne Bay. Wang considers his results to be good for an initial computer run with no adjustments. All of the results for Apalachicola Bay discussed in the previous section fall well within the errors illustrated in the two figures. Therefore, it may be assumed that CAFE-1 correctly predicts the principal physical processes in Apalachicola Bay. However, further refinement is still possible as more detailed data in specific areas are obtained.

4.1.5 Further Calibration

Because of the large change in velocities occurring when n was decreased from 0.045 to 0.030, it was estimated that further decreasing n to 0.015 would cause the model to output velocities of magnitudes approximately equal to those measured in the field. However, use of n = 0.015 results stability problems, presumably because the larger velocities produced violated the stability criterion. Since the instabilities occurred early in the run (about halfway through the first tidal cycle), it is possible that the velocities causing the stability problems are produced only as a result of the "cold-start" (i.e., all initial velocities and water surface elevations set equal to zero). Assuming that the steady-state velocities are smaller in magnitude than these initial velocities, it may be possible to eliminate the instabilities by inputting initial
Figure 4.10. Surface Displacement Verification by Wang for a Model of Biscayne Bay Using CAFE-1 (Wang, 1978b).

Figure 4.11. Hodograph Comparison by Wang for a Model of Biscayne Bay Using Cafe-1 (Wang, 1978b).
values for the velocities and water-surface elevations. These values can be estimated by using the model output from past runs. Although it will take some time to input these values initially, this change will probably decrease computer cost because less computer time will be required for the model to reach a steady-state. (The model is currently being run for three to five tidal cycles before the final information is output).

4.2 **Verification of DISPER-1**

The verification of a transport model can take many forms. Field data can be obtained for releases of a dye or other tracer from the river mouth or other sources. In an estuary of this size, the problems with such measurements can be simply too great in terms of time and manpower. A reasonable alternative is to model some naturally occurring substance which can be monitored by point samples through the bay, rather than following a tracer cloud. The best choice is salinity. While large amounts of salinity data exist on the bay, unfortunately concurrent tidal and velocity data are rarely available. Therefore, additional data was obtained for this study.

4.2.1 **Field Data for Quality Verification**

The specific set of salinity data to be treated here was taken in September, 1980, by a field crew from the Hydraulic Laboratory at the University of Florida and analyzed in Gainesville. The data are reported in Table 4.2.

A review of the data in Table 4.2 indicates both spatial and temporal variation of salinity; see, for example, the values at East Pass at two different times. Notice also some apparent small anomalies in the data which evidently reflect measurement error, symptomatic of difficulties of sampling in such an environment. It is also interesting that samples 22 to 26 at East Pass are inverted from that expected, indicating possible
Table 4.2. Salinities in Apalachicola Bay, September 1980. Observed by Hydraulic Laboratory, University of Florida.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Approximate Location</th>
<th>Salinity ppt</th>
<th>Date, Time of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Apalachicola River Mouth</td>
<td>1.6&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-18-80, 1010</td>
</tr>
<tr>
<td>2</td>
<td>Apalachicola River Mouth</td>
<td>21.2</td>
<td>9-18-80, 1010</td>
</tr>
<tr>
<td>3</td>
<td>Center of Bay</td>
<td>30.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-18-80, 1100</td>
</tr>
<tr>
<td>4</td>
<td>Center of Bay</td>
<td>30.0</td>
<td>9-18-80, 1100</td>
</tr>
<tr>
<td>5</td>
<td>Center of Bay</td>
<td>31.6</td>
<td>9-18-80, 1100</td>
</tr>
<tr>
<td>6</td>
<td>Center of Bay</td>
<td>28.8</td>
<td>9-18-80, 1100</td>
</tr>
<tr>
<td>7</td>
<td>Center of Bay</td>
<td>31.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-18-80, 1100</td>
</tr>
<tr>
<td>8</td>
<td>West Pass</td>
<td>33.2&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-18-80, 1630</td>
</tr>
<tr>
<td>9</td>
<td>West Pass</td>
<td>34.0</td>
<td>9-18-80, 1630</td>
</tr>
<tr>
<td>10</td>
<td>West Pass</td>
<td>29.2</td>
<td>9-18-80, 1630</td>
</tr>
<tr>
<td>11</td>
<td>West Pass</td>
<td>33.8</td>
<td>9-18-80, 1630</td>
</tr>
<tr>
<td>12</td>
<td>West Pass</td>
<td>32.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-18-80, 1630</td>
</tr>
<tr>
<td>13</td>
<td>Sikes Cut</td>
<td>29.8&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-18-80, 1730</td>
</tr>
<tr>
<td>14</td>
<td>Sikes Cut</td>
<td>30.0</td>
<td>9-18-80, 1730</td>
</tr>
<tr>
<td>15</td>
<td>Sikes Cut</td>
<td>31.8</td>
<td>9-18-80, 1730</td>
</tr>
<tr>
<td>16</td>
<td>Sikes Cut</td>
<td>32.0</td>
<td>9-18-80, 1730</td>
</tr>
<tr>
<td>17</td>
<td>Sikes Cut</td>
<td>33.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-18-80, 1730</td>
</tr>
<tr>
<td>18</td>
<td>East Pass</td>
<td>35.0&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-19-80, 1140</td>
</tr>
<tr>
<td>19</td>
<td>East Pass</td>
<td>35.0</td>
<td>9-19-80, 1140</td>
</tr>
<tr>
<td>20</td>
<td>East Pass</td>
<td>34.4</td>
<td>9-19-80, 1140</td>
</tr>
<tr>
<td>21</td>
<td>East Pass</td>
<td>34.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-19-80, 1140</td>
</tr>
<tr>
<td>22</td>
<td>East Pass</td>
<td>36.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-26-80, 1500</td>
</tr>
<tr>
<td>23</td>
<td>East Pass</td>
<td>35.8</td>
<td>9-26-80, 1500</td>
</tr>
<tr>
<td>24</td>
<td>East Pass</td>
<td>38.2</td>
<td>9-26-80, 1500</td>
</tr>
<tr>
<td>25</td>
<td>East Pass</td>
<td>44.3</td>
<td>9-26-80, 1500</td>
</tr>
<tr>
<td>26</td>
<td>East Pass</td>
<td>43.5&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-26-80, 1500</td>
</tr>
<tr>
<td>27</td>
<td>New River</td>
<td>28.7</td>
<td>9-26-80, 1600</td>
</tr>
<tr>
<td>28</td>
<td>South Span-Causeway</td>
<td>34.9&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-26-80, 1820</td>
</tr>
</tbody>
</table>

<sup>s</sup> = surface  
<sup>b</sup> = bottom
Table 4.2 - continued.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Approximate Location</th>
<th>Salinity ppt</th>
<th>Date, Time of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>South Span-Causeway</td>
<td>36.1</td>
<td>9-26-80, 1820</td>
</tr>
<tr>
<td>30</td>
<td>South Span-Causeway</td>
<td>35.0</td>
<td>9-26-80, 1820</td>
</tr>
<tr>
<td>31</td>
<td>South Span-Causeway</td>
<td>37.8</td>
<td>9-26-80, 1820</td>
</tr>
<tr>
<td>32</td>
<td>South Span-Causeway</td>
<td>35.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-26-80, 1820</td>
</tr>
<tr>
<td>33</td>
<td>South Span-Causeway</td>
<td>37.5&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-26-80, 1820</td>
</tr>
<tr>
<td>34</td>
<td>North Span</td>
<td>30.4&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-27-80, 1150</td>
</tr>
<tr>
<td>35</td>
<td>North Span</td>
<td>34.4</td>
<td>9-27-80, 1150</td>
</tr>
<tr>
<td>36</td>
<td>North Span</td>
<td>34.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-27-80, 1150</td>
</tr>
<tr>
<td>37</td>
<td>St. George Sound</td>
<td>38.4&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-27-80, 1300</td>
</tr>
<tr>
<td>38</td>
<td>St. George Sound</td>
<td>37.4</td>
<td>9-27-80, 1300</td>
</tr>
<tr>
<td>39</td>
<td>St. George Sound</td>
<td>37.8</td>
<td>9-27-80, 1300</td>
</tr>
<tr>
<td>40</td>
<td>St. George Sound</td>
<td>38.6</td>
<td>9-27-80, 1300</td>
</tr>
<tr>
<td>41</td>
<td>St. George Sound</td>
<td>41.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-27-80, 1300</td>
</tr>
<tr>
<td>42</td>
<td>St. Vincent Sound</td>
<td>25.0&lt;sup&gt;s&lt;/sup&gt;</td>
<td>9-28-80, 1200</td>
</tr>
<tr>
<td>43</td>
<td>St. Vincent Sound</td>
<td>22.6</td>
<td>9-28-80, 1200</td>
</tr>
<tr>
<td>44</td>
<td>St. Vincent Sound</td>
<td>24.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9-28-80, 1200</td>
</tr>
</tbody>
</table>

<sup>s</sup> = surface  
<sup>b</sup> = bottom
upwelling or local disturbances. This sort of variability should be recalled when assessing model agreement with the data. It should further be noted that the model, being two-dimensional, yields a depth-averaged concentration value.

4.2.2 Model Input for Verification Runs

Due to the time span in salinity measurements, typical tides and winds for that period were specified for a CAFE run to form hydrodynamic input to DISPER. While this of course may lead to some inadequacies in the simulation, it was perceived as a good test, for uncertainty in these model parameters often exists. The 439 element, 281 node general grid shown in Figure 3.1 was used again for the simulation. Salinities of 36 ppt were specified at the external passes and inlets, with 10 ppt and 5 ppt at appropriate elements for the river mouth. River flow was taken at 337 m$^3$s$^{-1}$ during this period, based on USGS records.

Some oscillations of concentrations were observed in the early simulation. As noted earlier, both the spatial increment, $\Delta x$, and the time increment, $\Delta t$, bear on this problem. Changing $\Delta x$ means a change in the grid, locating critical areas and then refining the grid there.

Oscillations in the results caused some experimentation with the dispersion coefficient, $D_{ij}$, resulting in specifying input values which typically yield maximum values of $D_{ij}$ of 150-300 m$^2$s$^{-1}$ in the bay.

These values are within the range of reported values for estuaries. Further accuracy considerations resulted in selection of a time step, $\Delta t$, of 60 seconds. These steps were chosen first in the verification process as they represent reasonable options for the typical user.
4.2.3 Results of DISPER-1 Verification Runs

Results of one verification run are shown in Figure 4.12. Values shown in the elements are salinities in parts per thousand. It can be seen by comparison with Table 4.2 that there is reasonable agreement with measured values in the East and West Pass regions, in St. Vincent Sound, and in the East Bay - East Point region where the freshwater input from the Apalachicola River is so important. There are, however, some regions where values are too low, especially near the causeway island and slightly east of that region.

There are several possible explanations for these low values in the regions noted. First, it should be observed that the figures shows a synoptic view of the bay, i.e., at a single time, while the observations in Table 4.2 were taken over a range of times and therefore occur at different parts of the tidal cycle. What is more important, however, is the fact that measurements spanned such a long time that varying wind, tides, and other conditions can significantly influence bay behavior. The run pictured here is based on a constant wind speed and direction. In addition, no attempts have been made to fine-tune CAFE results by varying Manning's n across the bay and other such steps which might help resolve some localized errors.

It appears that verification is easier against data taken synoptically, such as in enhanced LANDSAT photographs. Comparison of predicted and observed shapes and extents of plumes, i.e., pattern recognition, can provide a good assessment of model performance. Graham, Hill and Christensen (1978) and Hill and Graham (1980) reported on use of such data for this verification.

In conclusion, it can be stated that an attempt at model verification with no fine-tuning yielded acceptable results over much of the bay.
Figure 4.12. Salinity Run for Apalachicola Bay Using DISPER-1.
However, some changes in element arrangement would be necessary to remove some locally low values near the causeway island.

4.3 Satellite Verification of DISPER-1

Use of LANDSAT imagery computer enhanced for surface water color may be utilized for verification of the DISPER-1 model, since surface water color and water quality (e.g., acidity expressed by pH) may be related. Since the satellite images only reveal what is going on in the upper inches of the water column, it may be difficult to let the images relate to the vertically averaged water quality. However, the general pattern of the dispersion of a pollutant at the surface may be observed and compared to the print-out of the DISPER-1 model. Assuming a well-mixed bay, the surface water quality should indeed be indicative of the vertically average quality parameter.

Verification by such pattern recognition from LANDSAT images has given surprisingly good results.

Figure 4.13 shows an example of the color enhanced pictures used. Note the red colored water in East Bay and at Carrabelle. This color indicates low pH water. The pattern shown in Figure 4.13 is in almost perfect agreement with computer printouts. The plume at Sikes Cut is also noteworthy. Also this phenomenon may be reproduced by the model.
Figure 4.13. Computer Enhanced LANDSAT Image Showing Water Quality Patterns in Apalachicola Bay.
5. THE ATLAS. SELECTION OF CONDITIONS FOR A TYPICAL YEAR

To illustrate more clearly behavior in the bay, model solutions demonstrating variation through a typical year were sought. The objective is to provide an overview of possible behavior, with the expectation that specific problems will still require running the model for conditions appropriate to those problems. The material generated for the average year is presented in the form of an atlas at the end of this report.

There are several sets of physical parameters to be selected to provide a view of bay behavior. Major ones include the following:

1) Tides - amplitude and phase lag.
2) River flows.
3) Wind speed and direction.
4) Source location and loading.

To provide a reasonable view of expected bay behavior and yet keep the size of this report reasonable, it was decided to produce runs for each month, or twelve in all. Therefore, parameter values selected should be expected to represent monthly average values.

5.1 River Flows

The average monthly river flows shown in Table 4.1 were used for the CAFE-I simulations.

5.2 Tides

Tidal data was obtained from the National Ocean Survey for the five-year period from 1975-1980. Tide tables and the tidal data discussed in Section 4.1.1.1 were used to estimate expected tidal height variations from points of measured values to other boundary points and time (phase) lag between tidal peaks.
The tide at Apalachicola is considered diurnal, in that two highs or two lows may occur on the same day with different amplitudes. This is clearly indicated in Figure 4.3. There are difficulties and uncertainties associated with selecting a "typical" tide pattern for each month of the form in Figure 4.3. In addition, the runs of interest, and many problems of practical interest, occur over several tidal cycles. This tends to average out the influence of tidal amplitude variation. Therefore, given the objective of providing an overview of bay behavior, it was decided to simply use mean tidal amplitudes to drive the model, with a respecting sinusoidal tide specified. This should reproduce the general structure well, although there may be small local differences at individual times within a tidal cycle.

A review of the tidal data from 1975-1980 showed mean tidal ranges at the Apalachicola gage rather close to one foot for all months. The lowest value obtained was 0.86 ft and the highest 1.10 ft. No consistent trend appeared by month, at least for the five years reviewed. It was therefore decided to simply use a single value of 1.0 ft (or a tidal amplitude of 0.50 ft = 0.155 m). Review of tide tables and UF measured data then led to the tides at the bay boundaries, as shown in Table 5.1.

<table>
<thead>
<tr>
<th>Location</th>
<th>Tidal amplitude, m</th>
<th>Phase lag, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Pass</td>
<td>0.23</td>
<td>0</td>
</tr>
<tr>
<td>Sikes Cut</td>
<td>0.19</td>
<td>2520</td>
</tr>
<tr>
<td>West Pass</td>
<td>0.13</td>
<td>3780</td>
</tr>
<tr>
<td>Indian Pass</td>
<td>0.10</td>
<td>5400</td>
</tr>
</tbody>
</table>
Again, these values are taken as typical and should not be interpreted as representing any specific case.

5.3 Winds

Wind is an extremely important factor in bay behavior. Wind data from 1975 through early 1981 was obtained from the Apalachicola office of the National Weather Service in the form of monthly summaries of Local Climatological Data, with wind speed and direction reported at three-hour intervals, as well as daily and monthly average speeds and directions. A review of the data led to selection of the monthly average wind values shown in Table 5.2.

Table 5.2. Monthly Average Values of Wind Speed and Direction Used in Model Runs.

<table>
<thead>
<tr>
<th>Location</th>
<th>Wind Speed, mi/hr</th>
<th>Wind direction, deg. from N^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>8.4</td>
<td>030</td>
</tr>
<tr>
<td>February</td>
<td>8.2</td>
<td>073</td>
</tr>
<tr>
<td>March</td>
<td>8.4</td>
<td>186</td>
</tr>
<tr>
<td>April</td>
<td>7.9</td>
<td>192</td>
</tr>
<tr>
<td>May</td>
<td>7.4</td>
<td>182</td>
</tr>
<tr>
<td>June</td>
<td>7.0</td>
<td>197</td>
</tr>
<tr>
<td>July</td>
<td>6.3</td>
<td>217</td>
</tr>
<tr>
<td>August</td>
<td>6.1</td>
<td>130</td>
</tr>
<tr>
<td>September</td>
<td>6.7</td>
<td>110</td>
</tr>
<tr>
<td>October</td>
<td>7.15</td>
<td>063</td>
</tr>
<tr>
<td>November</td>
<td>7.3</td>
<td>078</td>
</tr>
<tr>
<td>December</td>
<td>7.4</td>
<td>045</td>
</tr>
</tbody>
</table>

a: For example, 090 is a wind from the East, 180 from the South, etc.
Variation in wind speed shown in Table 5.2 seems less significant than direction. Note the tendency of the wind to be from slightly west of south during March-July, but more like easterly to northeasterly during the rest of the year.

5.4 Generated Results

The model CAFE-1 is run with the grid shown in Figure 4.7 for each of the twelve months, utilizing river flows from Table 4.1, tidal information from Table 5.1 (the same for all months), and the wind data from Table 5.2. The results will be presented as views of the velocity field throughout a tidal cycle and the net velocity field over a cycle. Output from CAFE-1 runs for each of the twelve months will then be used to drive a DISPER-1 run representing a continuous discharge concentration of 100 units (ppm, eg.) in the river water.

The results from the conservative pollutant can be scaled directly to salinity by assuming an average salinity at the river mouth of 7.5 ppt (typical) with 36 ppt at the ocean boundary. Then any reported concentration can be converted to salinity by

\[ s = 36 - 0.285 \cdot c \]  \hspace{1cm} (5.1)

in which \( c \) = concentration projected by model
\( s \) = salinity in ppt

Full results are presented in the attached Atlas in 204 maps depicting hydrodynamics as well as water quality during the "average" year.
6. DETERMINATION OF POLLUTANT CONCENTRATION (AND SALINITY) AT AN ARBITRARY LOCATION FOR OTHER RIVER CONCENTRATIONS AND OCEAN CONCENTRATIONS

The computer prepared maps, given in the atlas showing the distribution of conservative pollutant concentrations \( c \) in the Apalachicola Bay, are based on the river concentration \( c_R = 100 \) (e.g., ppm) and the ocean (Gulf of Mexico) concentration \( c_O = 0 \).

Pollutant concentrations, \( c_1 \), corresponding to other river and ocean concentrations may be found from these maps by use of a simple conversion formula to be established in the following.

Since the \( c \) distribution, shown in the maps and schematically in the upper part of Figure 6.1, is a solution to the differential equations governing the migration of conservative pollutants in the Apalachicola Bay, it is easily proven that the concentration \( c_1 \) given by the linear expression

\[
c_1 = a \ c + b
\]  \hspace{1cm} (6.1)

also must be a solution. In Equation (6.1) \( a \) and \( b \) are constants.

A special case of Equation (6.1) is

\[
c_1 = c \ \frac{c_R - c_O}{100} + c_O
\]  \hspace{1cm} (6.2)

in which \( c_R \) and \( c_O \) are arbitrary pollutant concentrations in the river and ocean, respectively.

This equation satisfies the boundary conditions

\[
c_1 = c \text{ for } c_R = 100 \text{ and } c_O = 0 \text{ corresponding to the original } c\text{-mapping.}
\]
Figure 6.1. Schematic Maps Showing Boundary Conditions Used in Concentration Conversion Formulas.
\[ c_1 = c_0 \text{ for } c = 0 \]
\[ c_1 = c_0 \text{ for } c_R = c_0 \]
and \[ c_1 = c_R \text{ for } c_o = 100 \]

Equation (6.2) will therefore give the pollutant concentration at any point where \( c \), based on \( c_R = 100 \) and \( c_o = 0 \), is known when the river and ocean pollutant levels are known. The maps presented in the attached atlas will therefore, when combined with Equation (6.2), yield the vertical average of the pollutant concentration at any location in the bay and at any time during the tidal cycle for any values of \( c_R \) and \( c_o \).

In the same way the maps may be used to predict the salinity at any point and at any time during the average tidal cycle.

The equation
\[ s = (1 - \frac{c}{100}) s_o \quad (6.3) \]
in which \( s \) = the salinity at \((x,y)\) at time \( t \) and \( s_o \) = salinity of the Gulf of Mexico waters is of the same form as Equation (6.1). \( s \) is therefore a solution to the equations governing the water quality of the bay. Since it furthermore satisfies the boundary conditions
\[ s = 0 \text{ for } c = 100 \]
and \[ s = s_o \text{ for } c = 0 \]
it must represent the bay's salinity distribution. These boundary conditions are indicated in the lower part of Figure 6.1.
7. ACKNOWLEDGEMENTS

The work presented in this report is a result of numerical modeling research being performed by the University of Florida's Hydraulic Laboratory, sponsored by the National Oceanic and Atmospheric Administration, Office of Sea Grant, Department of Commerce, under Grant #NA86AA-D-00038, Project #R/EM-13, and by the Engineering and Industrial Experiment Station of the University of Florida. Support from the U.S. Army Corps of Engineers, Mobile District, is also acknowledged.
8. LIST OF SYMBOLS

The symbols used in this report are defined where they first appear in the text and in the following list of symbols.

\( a \) = dimensionless constant

\( b \) = dimensionless constant

\( c \) = vertically averaged pollutant concentration at point \((x,y)\), at time \(t\) corresponding to \(c_R = 100\). Note in Section 3 \(c\) stands for the vertically integrated concentration while the vertically averaged concentration there is denoted \(\bar{c}\)

\( c_1 \) = vertically averaged pollutant concentration at point \((x,y)\) at time \(t\) corresponding to \(c_R = 100\)

\( c_0 \) = vertically averaged pollutant concentration in Gulf of Mexico and entrances to the bay

\( c_R \) = pollutant concentration of river water entering the bay

\( C_F \) = dimensionless friction coefficient

\( D \) = average estuary depth

\( D_{ij} \) = dispersion coefficient

\( D_{xx}, D_{xy}, D_{yy} \) = dispersion coefficients

\( E_{ij}^* \) = dimensionless turbulent eddy viscosity coefficients

\( E_{ij} \) = turbulent eddy viscosity coefficients

\( f \) = Coriolis parameter

\( F_{xx}, F_{xy}, F_{yy} \) = internal specific stress terms (stress/density)

\( g = 9.806 \text{ m s}^{-2} \) = acceleration due to gravity

\( h \) = water depth below mean low water (MLW) at point \((x,y)\)

\( H = h + \eta = \text{total depth at point } (x,y) \text{ at time } t \)

\( H_0 \) = refer to grid location giving critical \(\Delta t\) - value

\( k \) = Nikuradse's equivalent sand roughness

\( L \) = estuary length

\( M_x, M_y \) = momentum addition per unit horizontal area
\[ n = \text{Manning's } n = k^{1/6}/(8.25\sqrt{g}) \text{ (metric)} \]

\[ p = \text{pressure} \]

\[ p^b = \text{pressure at the bottom} \]

\[ p^s = \text{pressure at the water surface} \]

\[ P = \text{tidal prism} \]

\[ P_o = \text{sources and sinks of mass} \]

\[ q_x, q_y = \text{discharge per unit width in } x-\text{ and } y-\text{direction, respectively} \]

\[ q_I = \text{volume addition rate} \]

\[ Q = \text{river discharge} \]

\[ R = \text{tidal range} \]

\[ s = \text{salinity at point } (x,y) \text{ at time } t \]

\[ s_o = \text{salinity in Gulf of Mexico at entrances to the bay} \]

\[ t = \text{time} \]

\[ T = \text{tidal period} = 12.42 \text{ hr} \]

\[ \hat{u} = \text{expected velocity} \]

\[ (u,v) = \text{vertically averaged velocity components in the } x-\text{ and } y-\text{direction, respectively, at point } (x,y) \text{ at time } t \]

\[ U_{10} = \text{air velocity at } 10 \text{ m above the water surface in } m/s^{-1} \]

\[ x,y = \text{horizontal Cartesian coordinates} \]

\[ z = \text{vertical coordinate} \]

**Greek Letters**

\[ \alpha = \text{dimensionless coefficient} \]

\[ \Delta x = \text{characteristic grid length} \]

\[ \Delta t = \text{time increment} \]

\[ \Delta x_0 = \text{refer to grid location giving critical } \Delta t - \text{value} \]

\[ \eta = \text{elevation of water surface above mean low water (MLW)} \]

\[ \hat{\eta} = \text{expected tidal range} \]
\( \rho \) = density of water
\( \rho_{\text{air}} \) = density of air
\( \rho_0 \) = reference value of \( \rho \)
\( \rho_1, \rho_2 \) = characteristic extreme densities
\( \tau^b \) = bottom shear stress
\( \tau^s \) = surface shear stress
\( \omega_{\text{earth}} \) = angular velocity of earth = \( 2\pi / (24 \cdot 3600) \)
9. REFERENCES


