COMMENTS ON “HYDRODYNAMIC AND SALINITY MODEL APPROVAL PACKAGE” BY APPLIED TECHNOLOGY & MANAGEMENT, INC

Introduction

The comments below are offered as a result of a request by the US Army Engineer and Research Development Center (ERDC) for Computational Hydraulics and Transport, LLC (CHT) to review the referenced numerical modeling effort. These comments are provided by Dr. Billy H. Johnson of CHT

The request by ERDC for a review of the modeling effort was primarily due to the belief that with model modifications the simulation of the salinity in the estuary during the validation period of Aug – Oct 1999 could be improved. Thus, the review was focused on that particular aspect of the modeling effort. It is hoped that the recommendations provided will help to accomplish the goal of improved salinity computations.

The Savannah Estuary is a complex system containing several interconnected channels, as well as substantial marsh areas that alternate between being flooded and dry as the tide floods and ebbs. Modeling such a system is a difficult task, and ATM is to be commended for the job that they have done. After low pass filtering of the computed and observed validation results, they appear to match fairly well. However, an inspection of the time series plots of the salinity throughout the system reveals that the dynamics of salinity transport on a tidal time scale are poorly modeled. The comments below are an attempt to explain why this might be happening and to suggest things to try in the modeling to alleviate the problem.

Comments

Figure 1 shows the locations of several salinity stations. An inspection of the salinity plot at Ft Jackson (Figure 2) shows that the model computes bottom salinities that are too high and surface salinities that are too low. In a previous laterally-averaged modeling effort of the Savannah Estuary by Johnson, Trawle, and Kee (1989), it was concluded that the vertical diffusion of salt in the ocean part of the grid needed to be increased over that in the estuary. If the turbulence closure scheme is modified to result in increased vertical diffusion in the ocean part of the current 3D model, the computed salinity profile moving into the estuary will likely match the field data better. However, accomplishing this will not result in a significant improvement of the model being able to capture the tidal dynamics of salinity transport.

The second comment relates to the distribution of flow near Ft Jackson. ADCP measurements were made at the locations shown in Figure 3. From Figures 4-5, it can be seen that the field data for volume flux below the junction of Front River and Back River matches model results quite well. However, it can be seen that model results are totally erroneous for volume flux into Back River. The sum of the flux into Front River and into Back River should be the total flux below the junction. It is hard to believe that the numerical model could remain stable based on the results shown in Figures 4-5. These results need explaining. Are the Transect BR results displayed correctly?

An inspection of Figures 6-9 clearly illustrates the salinity problem noted above, i.e., salinity transport during a tidal cycle isn’t reproduced well by the model. In an attempt to explain this, attention has been directed on how well the model reproduces the mean water surface level and on the impact of the representation of the marshes in the model.

Figure 10 shows the location of Broad Street and the I 95 Bridge. Figure 11 shows that the mean water surface level at Ft Pulaski is reproduced well. However, at the Broad Street Station on Front River, the computed mean water surface is slightly higher than the observed (see Figure 12). At the I 95 bridge, Figure 13 shows that the computed mean water surface level is significantly lower that the observed. Therefore, from the I 95 Bridge to Broad Street, the computed mean water surface slope is much lower than the observed slope. The major reasons for the discrepancy in the water surface slope are likely related to friction, freshwater inflow, and / or the treatment of marsh storage. It is assumed that the freshwater inflow is correct.

The impact of the small computed water surface slope likely results in a computed salinity front that isn’t nearly as sharp as the observed salinity front. This is illustrated in Figure 6, which shows that at Station GPA-08 the observed salinity ranges from 20 ppt to zero over the tidal cycle, whereas, the computed salinity on flood is far less (13 ppt) and never reaches zero on ebb. However, as discussed below, the treatment of the marsh areas may also be contributing to this.

Marshes in the system are treated as storage areas in the numerical model. As can be seen from the model grid (Figure 14), there are several small tributaries that are connected to the main channels in the system. Marsh storage cells are attached to the end of these tributaries. As the water surface rises, both water volume and salt are moved into the storage cells, whereas, as the water surface falls, the water and salt are released into the small tributary channels and then transported back into the main channels, e.g., Front, Middle, and Back Rivers.

The tide moves into the system at Ft Pulaski as a progressive wave. Since the Savannah River continues up stream, with the tidal influence completely diminished by the time the upstream model boundary is reached at Clyo, the tide continues to propagate up the system as a progressive wave. If the estuary system had upstream boundaries that resulted in wave reflections, one could expect to see standing waves in the system. A characteristic of a progressive wave is that the water surface elevation and the water velocity are in phase, i.e., the current reaches its maximum absolute values when the water surface is highest or lowest. However, the water surface elevation and the velocity are 90 degrees out of phase for a standing wave (see Figure 15 from Dyer 1977).

Figure 16 shows that the observed tide at GPA-06 is indeed a progressive wave since the elevation and current are in phase. Note, however, that the computed tide closely resembles a standing wave with the elevation and current out of phase. In addition, it can be seen that the computed water surface elevation has a flatter peak than the observed, indicating that the total amount of marsh area in the model may be too large. Also note that the observed ebb velocity is higher than the computed ebb velocity. This is likely related to either the discrepancy in the mean water surface slope, the movement of water into and out of the marshes and/or an error in the freshwater input to the model.

An obvious question is why the model computes standing wave characteristics, whereas, the observed tide clearly has progressive wave characteristics. Since wave reflections can result in the production of standing waves in an estuary, the answer must be that there are sufficient reflections caused by the storage cells at the end of the small tributaries to result in the computed tide more closely becoming a standing wave rather than continuing as a progressive wave.

In addition to the difference in phasing between the water surface elevation and the water current for a progressive wave versus a standing wave, the phasing of the salinity is different (see Figure 15). For a progressive wave, the maximum salinity occurs near when the current reverses and the water surface crosses its mean level. However, for a standing wave, the maximum salinity is almost in phase with the water surface elevation. With the manner in which marshes are treated in the current model, this could have a significant impact on the computation of salinity transport in the main channels. For example, with a standing wave model, as the water surface rises and water moves into the marsh cells, a higher salinity is attached to the water moving into the marsh than what would be attached to the water moving into the marsh with a progressive wave. The impact of this would be to reduce the main channel salinity on flood, but to increase it on ebb. This behavior is observed in Figures 6-7.

Recommendations

It is recommended that the possible impacts noted above be investigated. The first recommendation is to determine the reason for the volume imbalance between the Front and Back Rivers. The second recommendation is to investigate increasing the vertical diffusion coefficient in the ocean part of the grid to better match the salinity profile as the tide moves into the estuary. The third recommendation is to make several model runs with different storage cell surface areas until the model computes a progressive tidal wave rather than a standing wave. The impact of variable marsh surface area (and thus volume) on the salinity in the main channel and on the mean water surface slope should be determined during these model runs.

Bibliography

Johnson, B. H., Trawle, M. J., and Kee, P. G. 1989. “A Numerical Model Study of the Effect of Channel Deepening on Shoaling and Salinity Intrusion in the Savannah Estuary”, Technical Report HL-89-26, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dyer, K. R. 1977. Estuaries: a Physical Introduction, Johns Wiley & sons, New York, NY.