DRAFT Response to Comments on the Savannah Harbor Hydrodynamic and Salinity Model Acceptance Package: Part IV

Computational Hydraulics and Transport, LLC (CHT) for US Army Engineer and Research Development Center (ERDC) Comments (Billy H. Johnson)

GENERAL RESPONSE:

The comments provided by Dr. Billy Johnson of Computational Hydraulics and Transport (CHT) were by request from the US Army Engineer and Research and Development Center (ERDC). The comments basically address three main issues with the hydrodynamic and salinity model calibration effort and as such the responses will be subdivided into three major areas. In addition, the commenter made a recommendation that the three issues be investigated further which the authors have done and will present here. The original recommendations are presented here for clarity.

"It is recommended that the possible impacts noted … 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."

The three recommendations listed above were investigated and a series of model simulations were run to test the variations suggested. The results of the model simulations are presented in the response sections for each of the three comments.

1. COMMENT: Vertical diffusion effect on salinity

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.

RESPONSE:

To address the recommended investigation associated with this comment, a number of model simulations were completed to test the model sensitivity to vertical diffusion in the lower part of the estuary. The vertical diffusion coefficient for the model is calculated based on tidal energy in the system and is spatially and temporally variable. For the test cases, the calculated vertical dispersion coefficient from the river entrance area at Ft. Pulaski and offshore was essentially increased arbitrarily by a factor of 2, 3, 4, 5, and 6. The model was then run for the calibration period (basically August 1999) using the same setup and input files that were used for the calibration scenario. Table 1-1 gives the case name and the mixing factor for each of the tests performed.

Table 1-1 Summary of increased offshore mixing simulations

Scenario	Description
RRCAL	Baseline – Calibration scenario
VMIX1	3 times the offshore mixing
VMIX2	4 times the offshore mixing
VMIX3	2 times the offshore mixing
VMIX4	5 times the offshore mixing
VMIX5	6 times the offshore mixing

The results of the tests are shown in the Figures below. Figure 1-1 shows a detail of the predicted vs. the observed salinity at station GPA-04 at the surface and bottom for the calibration scenario during the month of August 1999, for reference. Figures 1-2 and 1-3 show the same data for increased vertical mixing offshore cases VMIX3 and VMIX5, respectively. Cases VMIX3 and VMIX5 represent factors of 2 and 6 times the offshore mixing calculated in the calibration case and cover the range of additional mixing tested.

Reviewing Figures 1-1 through 1-3, it can be seen that the mixing does influence the salinity concentrations at GPA-04 but tends to decrease the bottom salinity, resulting in some improvement for scenario VMIX3, but unfortunately without a corresponding increase at the surface, which was the other half of the desired result.

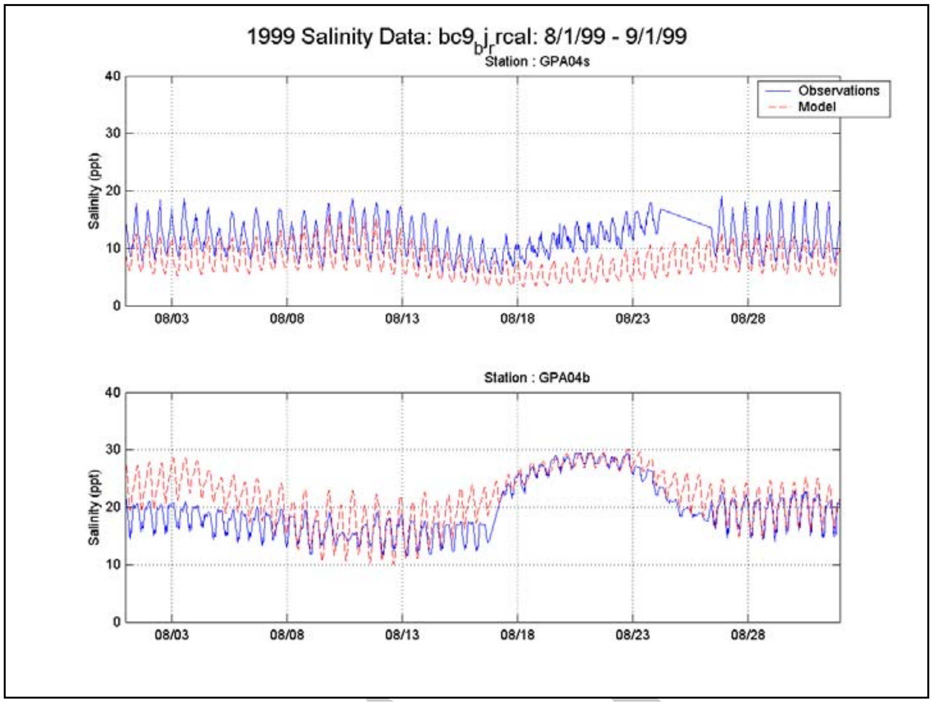

Figure 1-1. 1999 simulated vs. observed surface and bottom salinity at station GPA-04 for the calibration scenario.

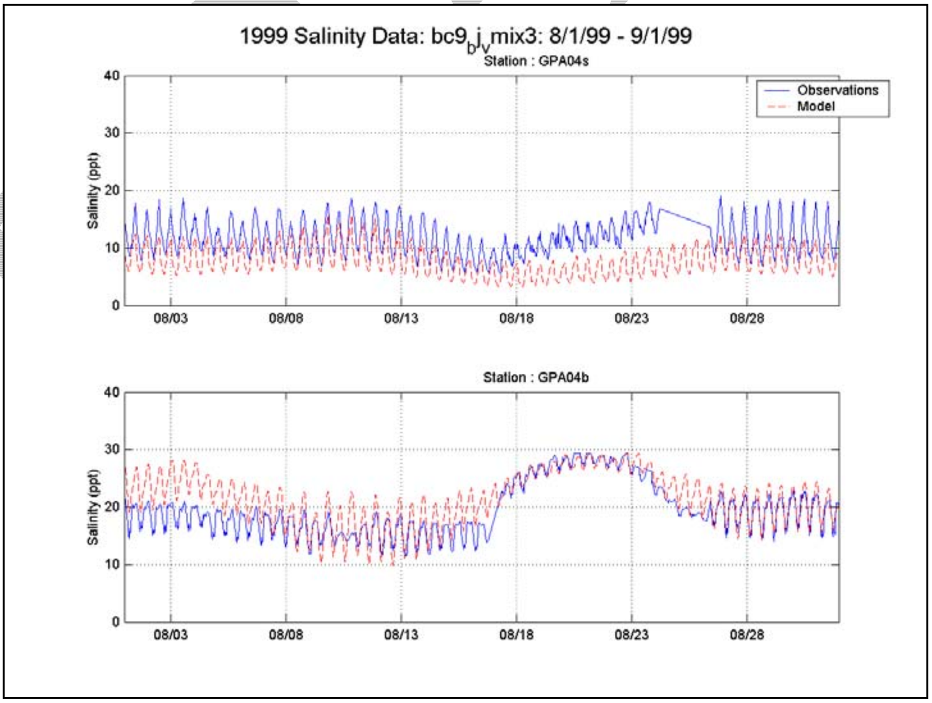

Figure 1-2. 1999 simulated vs. observed surface and bottom salinity at station GPA-04 for increased offshore mixing case VMIX3.

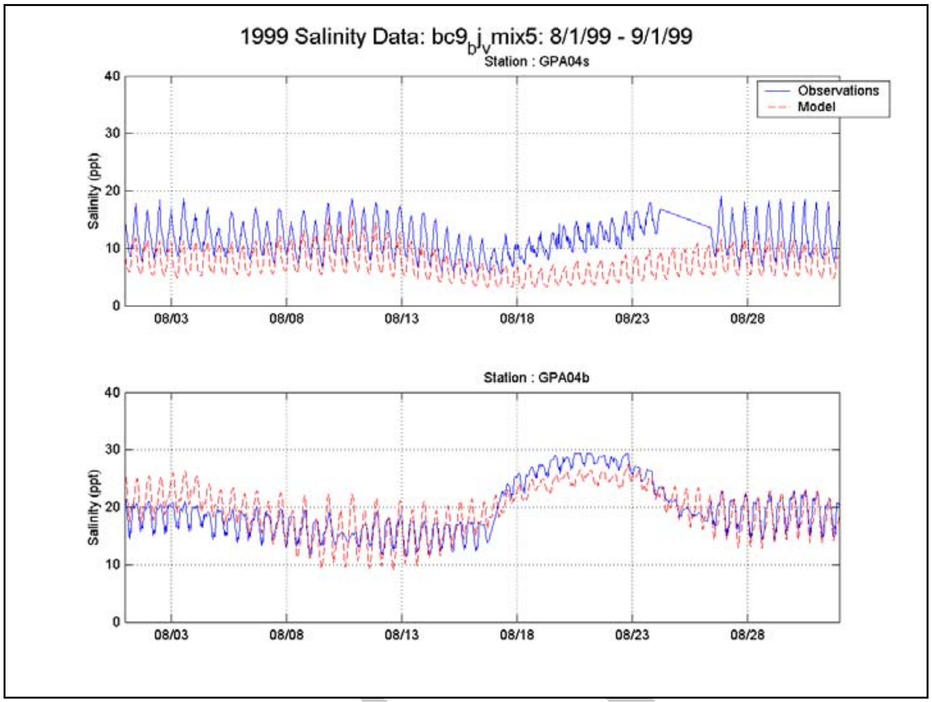

Figure 1-3. 1999 simulated vs. observed surface and bottom salinity at station GPA-04 for increased offshore mixing case VMIX5.

In order to understand the overall influence of the increased offshore mixing a series of statistical comparisons were performed between the observations and the model predictions, as described in the calibration report. As a representative analysis the root mean square error (RMSE) in salinity is presented here. The RMSE of the model predictions for all of the GPA salinity time series stations was calculated and compared to the calibration case to note improvement or decline.

Figures 1-4, 1-5 and 1-6 show the RMSE stations along the Front River bottom, the Front River surface and the Back and Middle Rivers (one depth only for those stations), respectively. As might be inferred from the previous time series plots, the figures indicate that there is a slight improvement in the model predicted salinities along the Front River bottom, but little improvement or actual decline in predictive capability for the Front River surface. The Back and Middle river stations appear to show no significant change at all.

The change in the mean salinity is somewhat different however. The difference in the model predicted and the observed mean salinities is presented in Figures 1-7 and 1-8 for the Front River bottom and the Front River surface, respectively. Here, the change for the increased mixing cases is more dramatic and there is again some improvement in the Front River bottom with no improvement in the surface. No significant change was observed at the Middle and Back River stations.

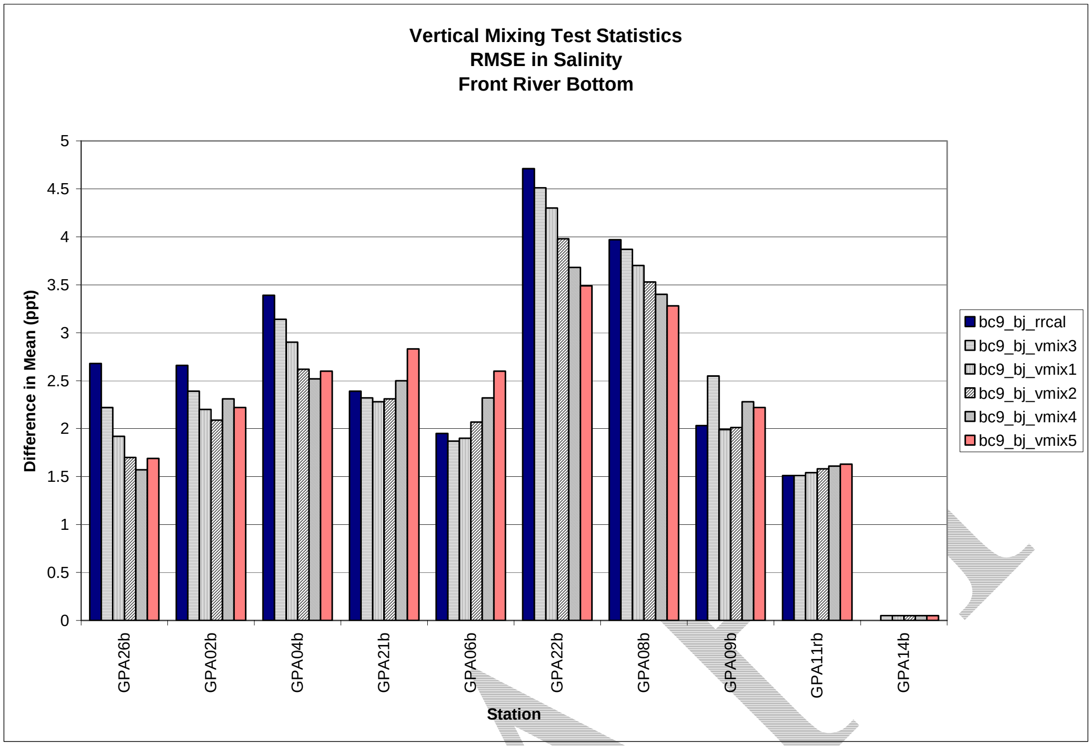

Figure 1-4. Comparison of RMSE in salinity prediction at GPA stations along the Front River bottom for increased vertical mixing tests.

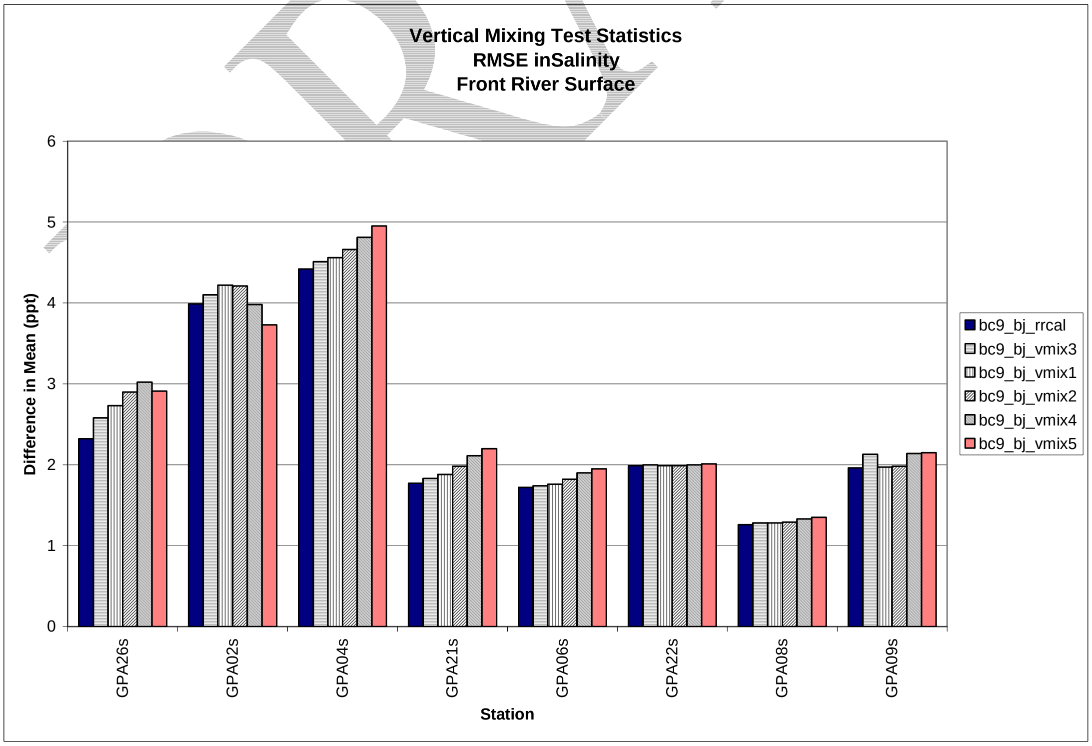

Figure 1-5. Comparison of RMSE in salinity prediction at GPA stations along the Front River surface for increased vertical mixing tests.

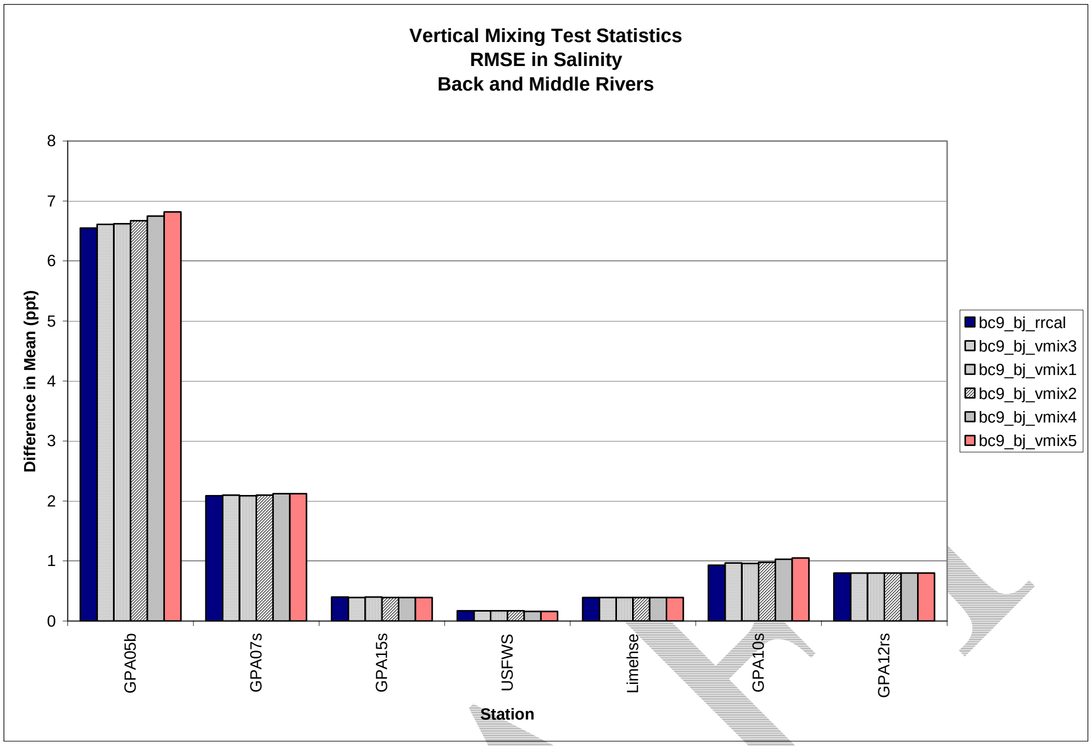

Figure 1-6. Comparison of RMSE in salinity prediction at GPA stations along the Back and Middle Rivers for increased vertical mixing tests.

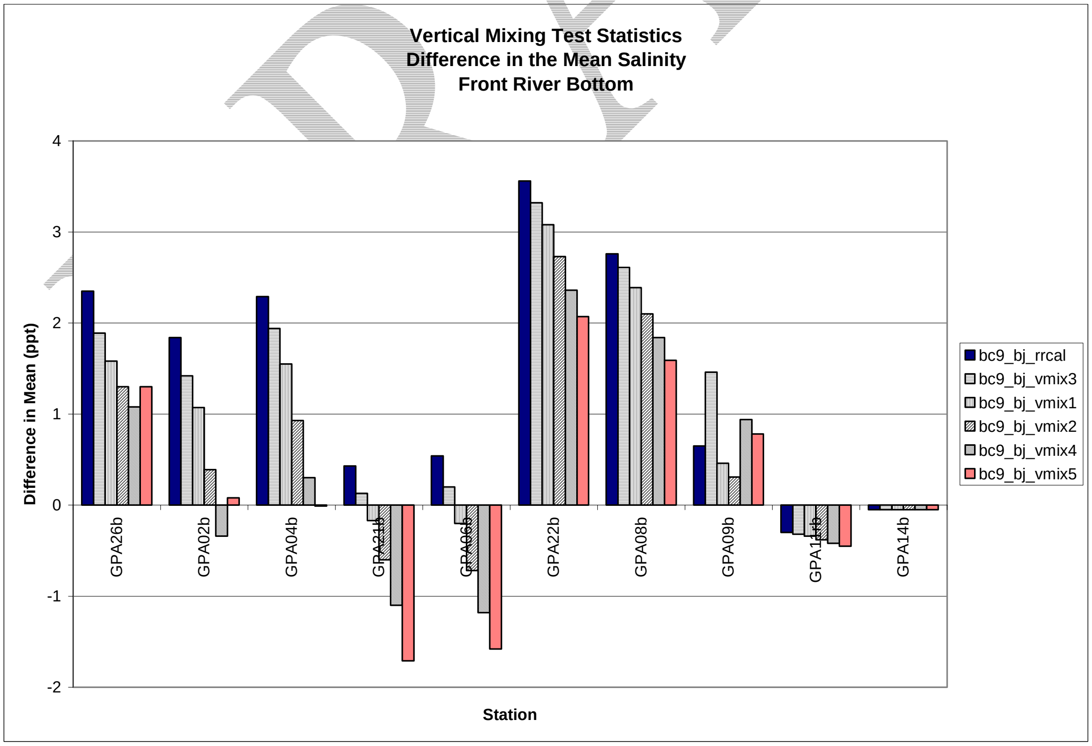

Figure 1-7. Comparison of the difference in mean observed vs. prediction salinity at GPA stations along the Front River bottom for increased vertical mixing tests.

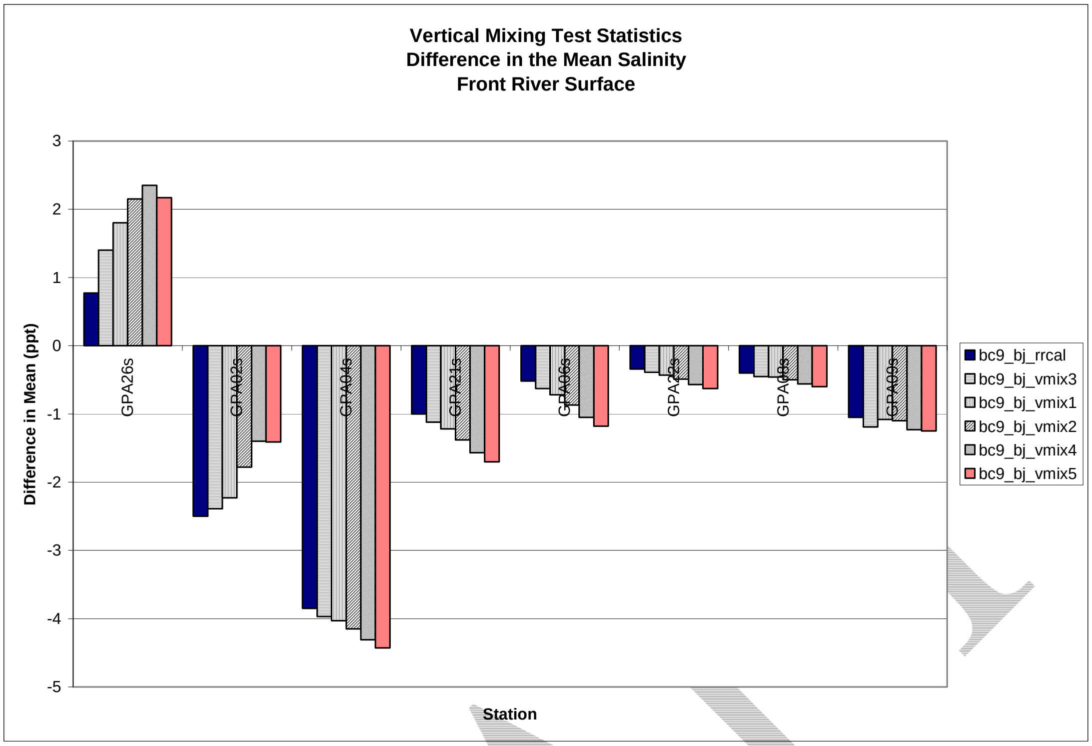

Figure 1-8. **Comparison of the difference in mean observed vs. prediction salinity at GPA stations along the Front River bottom for increased vertical mixing tests.**

2. COMMENT: Flow distribution

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?

RESPONSE:

It appears that the commenter is referring to volume flux plots in the Draft Hydrodynamic and Salinity Model Calibration Report (ATM, 2001). Since the distribution of that report a subsequent Hydrodynamic and Salinity Model Approval Package (ATM, 2002) has been issued which included many improvements to the model predictions. In addition a number of plotting errors have been corrected. In the Draft Hydrodynamic and Salinity Model Calibration Report (ATM, 2001), the simulated volume flux plots were unfortunately in error due to a model output post-processing error. The correct simulated and measured flows are shown in Figure 2-1 for day 269 of 1999. The plot demonstrates that the model accurately replicates the flow rates measured in the field.

The commenter notes that the sum of the flux into Front River and into Back River should be the total flux below the junction. This was evaluated by summing the fluxes over a tidal cycle. For the ebb and flood cycles that correspond to the measured data on day 269, the simulated volume fluxes were summed over the ebb and flood tides. The results are tabulated below:

Tidal Phase	**Volumes (m^3)**					
	GPA-04	**GPA-21**	**BR**	**GPA-21 + BR**	**Difference [GPA-04 minus (GPA-21 + BR)]**	**Difference (%)**
Flood	7.12E+07	4.33E+07	1.85E+07	6.18E+07	9.40E+06	13%
Ebb	8.01E+07	4.62E+07	2.41E+07	7.04E+07	9.78E+06	12%

The 12-13% difference in the gross ebb and flood volume fluxes between upriver and downriver transects are accounted for in the tidal storage area between the transects. The storage area is equal to the surface area of the river between the transects multiplied by the tidal range for that particular ebb or flood tide. The surface area between the transects is approximately 3.22 km^2. The simulated tide ranges over the flood and ebb tides were approximately 2.87 m and 2.84 m, respectively. Therefore, the tidal storage volume between the flow transects is equal to 9.14E+06 m^3. This volume is approximately equal to the difference in the integrated volumes shown in the above table. The remaining discrepancy is less than 1% of the flow volume passing GPA-04. This analysis confirms that the model is conserving volume transport.

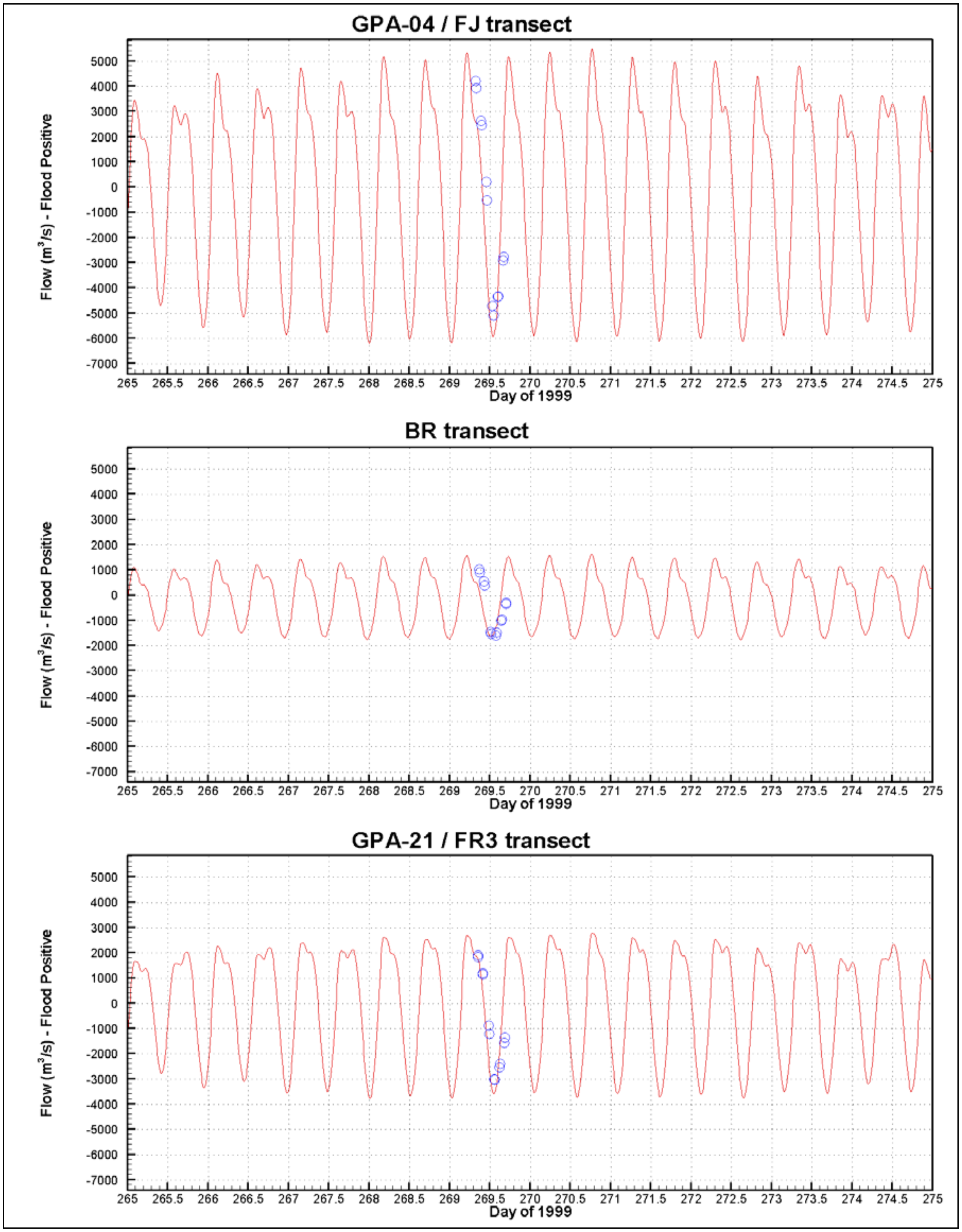

Figure 2-1. Model predicted volume flux comparison to observations.

3. COMMENT: Marsh boundaries and tidal wave characteristics

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.

RESPONSE:

This comment includes evaluations of water surface slope (based mean water levels), tidal wave elevation and current phasing (progressive versus standing wave characteristics) and the effects of marsh boundaries on the above. The response will address each of these topics in order.

The commenter examines the mean water level plots from the Draft Calibration Report and concludes that under-prediction of the mean water level at I-95 may cause poor simulation of the salinity front. Improvements made to the model following the Draft Calibration Report included better simulation of the river slope above Houlihan Bridge. The water levels percentiles shown in Figures 3-1 and 3-2 (taken from the Approval Package, showing the 90th, 50th and 10th percentiles for 1999 and 1997 respectively) show that the model is reproducing the increase in mean water level in the upriver areas.

The commenter compares water surface elevation and currents at Station GPA-06 and concludes that the simulated data show a standing tidal wave whereas the measured data show a progressive wave. The conclusion is based on only the GPA-06 current figure in the Draft Calibration Report, which unfortunately, was in error. The GPA-06 ADCP data had timing error for part of the monitoring study that has since been corrected. The measured data in the other ADCP current plots in the Draft Calibration report for GPA-04 (Figures 7-16a, 7-16b, 8-16a and 8-16b) and GPA-08 (Figures 8-17a and 8-17b) show the maximum currents out of phase with the peak water levels, which indicates that the tidal wave in the estuary is not a progressive wave. Instead, the measured data show that it is closer to a standing wave.

The depth averaged ADCP currents and water surface elevation for GPA-06 is shown in Figure 3-3 (for data collected during the 1999 monitoring study). The 1999 measured data show that the tidal wave is close to a standing wave. The simulated currents (Figure 3-4) show that the model is simulating the phase relationship between water surface elevation and currents reasonably well.

The commenter notes that the peaks of the simulated water surface elevations are flatter than the measured data, which may be caused by excessive marsh storage areas. The commenter also recommended varying the marsh storage area (and other marsh characteristics) to improve the tidal wave characteristics.

To address this comment, several model simulations were performed with varying marsh inputs. A summary of the variations tested for the model simulation is given in Table 3.1 below.

Table 3-1 Summary of marsh simulations

Scenario	Description
1	Baseline – marshes same as Approval Package
2	No marshes
3	50% marsh area
4	Increased marsh friction
5	Decreased marsh elevation

The increased marsh friction simulation increased the Manning’s n friction from 0.03 to 0.14. It was expected that the increased friction would reduce the influence of the marshes on the river hydrodynamics by allowing less water to flood the marshes.

The decreased marsh elevation simulation decreased the front elevation of the marsh from 0.58 m to 0.0 m. It was expected that the decrease of the marsh elevation would increase the influence of the marshes on the river hydrodynamics by allowing the marshes to flood sooner during the tidal cycle.

The simulation results for water surface elevation at GPA-21 are shown in Figure 3-5. The simulation without marshes is significantly worse for the high tide predictions. Decreasing the marsh area by 50% made no significant difference. Increasing the marsh friction is worse for the high tide predictions. Decreasing the marsh elevation resulted in a slight improvement.

The simulation results for depth averaged currents at GPA-06 are shown in Figure 3-6. The simulation without marshes is significantly worse for the ebb tide predictions. Decreasing the marsh area by 50% made no significant difference. Increasing the marsh friction is worse for the ebb tide predictions. Decreasing the marsh elevation resulted over-prediction of the current velocities.

The simulation results for salinity at GPA-06 are shown in Figure 3-7. It can be seen that none of the variations from the baseline marsh configuration resulted in significant overall improvement to the salinity predictions.

The root-mean-square error (RMSE) statistics for the water surface elevation and the salinity are presented in Tables 3-2 and 3-3. The statistics show that the decreased marsh elevation (Scenario 5) will result in a small overall improvement to the water surface elevations. However, the marsh adjustments do not provide an overall improvement in the salinity simulations. Therefore, adjustment of the marsh variables is not necessary for improvement of the model performance beyond the calibration simulation presented in the Approval Package.

Table 3-2 RMSE of WSE for marsh simulations

Station	**Scenario**				
	1	**2**	**3**	**4**	**5**
Ft.Pulaski	0.08	0.08	0.08	0.08	0.07
GPA-02	0.13	0.14	0.13	0.14	0.12
GPA-04	0.21	0.24	0.22	0.23	0.18
GPA-21	0.26	0.29	0.27	0.28	0.23
GPA-06	0.27	0.3	0.27	0.28	0.23
GPA-22	0.31	0.37	0.32	0.34	0.25
GPA-08	0.32	0.38	0.34	0.36	0.25
GPA-09	0.34	0.4	0.35	0.38	0.27
GPA-11	0.45	0.52	0.47	0.5	0.36
GPA-14	0.62	0.71	0.64	0.68	0.51
GPA-16	0.48	0.57	0.5	0.55	0.4
Hardeeville	0.21	0.28	0.22	0.26	0.18
GPA-17	0.28	0.3	0.29	0.28	0.28
GPA-05	0.34	0.38	0.35	0.37	0.3
LucknowCan	0.58	0.69	0.61	0.66	0.42
Broad	0.26	0.3	0.27	0.29	0.22
Houlihan	0.36	0.42	0.37	0.4	0.29
I-95	0.62	0.71	0.64	0.68	0.51
Average	0.34	0.39	0.35	0.38	0.28

Table 3-3 RMSE of salinity for marsh simulations

Station	**Scenario**				
	1	**2**	**3**	**4**	**5**
GPA26b	2.6	2.33	2.55	2.48	2.91
GPA02b	2.64	2.6	2.6	2.63	2.71
GPA04b	3.48	3.6	3.39	3.55	3.17
GPA21b	2.32	2.71	2.38	2.51	2.21
GPA06b	2	1.88	1.94	1.9	2.3
GPA22b	4.68	3.94	4.62	4.2	5.29
GPA08b	4.31	4.24	4.36	4.27	4.23
GPA09b	2.7	2.82	2.73	2.74	2.9
GPA11rb	1.54	1.78	1.53	1.66	1.82
GPA14b	0.05	0.05	0.05	0.05	0.08
GPA26s	2.31	2.28	2.27	2.22	2.43
GPA02s	3.52	5.2	3.79	4.39	3.75
GPA04s	3.7	5.15	3.87	4.75	3.08
GPA21s	1.38	1.68	1.45	1.47	1.63
GPA06s	1.6	1.59	1.62	1.5	1.91
GPA22s	2.08	2.2	2.17	2.1	2.13
GPA08s	1.57	1.62	1.61	1.69	1.59
GPA09s	1.36	1.5	1.33	1.4	1.56
GPA05b	5.89	7.38	5.94	6.94	4.57
GPA07s	1.68	2.01	1.67	1.86	1.42
GPA15s	0.61	0.55	0.62	0.54	1.21
USFWS	0.53	0.15	0.46	0.11	1.29
Limehse	0.28	0.38	0.28	0.35	0.77
GPA10s	0.63	1.14	0.67	0.91	1.02
GPA12rs	1.29	1.51	1.26	1.43	1.29
GPA03b	4.04	5.64	4.18	5.16	3.84
Houlihn	2.57	2.58	2.65	2.58	2.83
Average	2.27	2.54	2.30	2.42	2.37

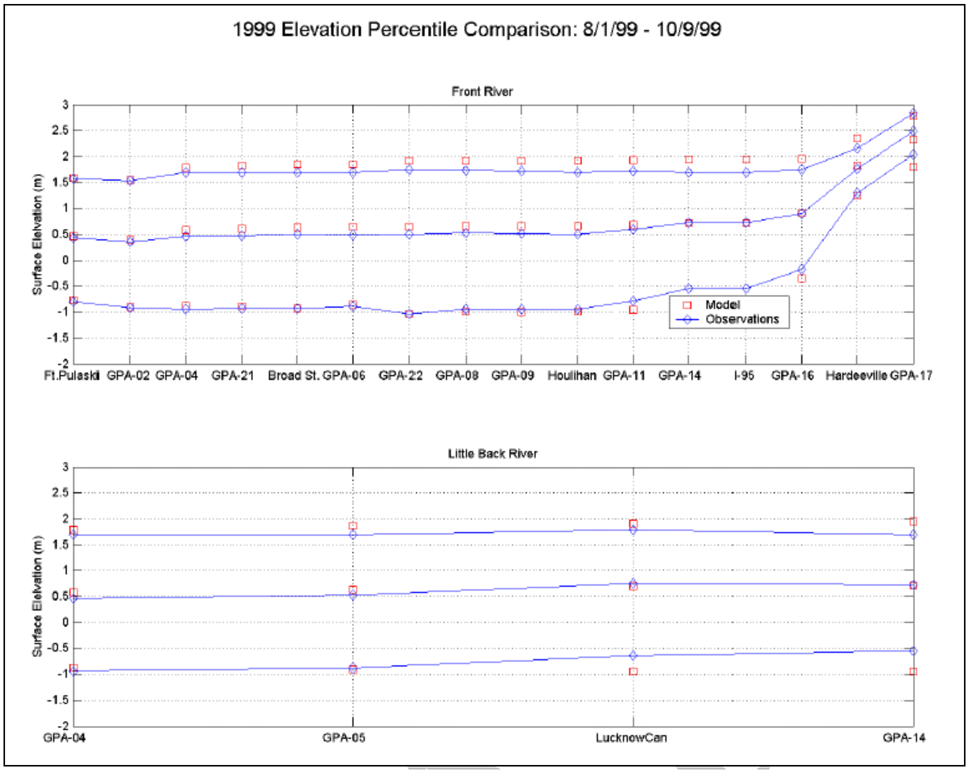

Figure 3-1. Simulated and measured water surface elevation (WSE) percentiles for the 1999 calibration.

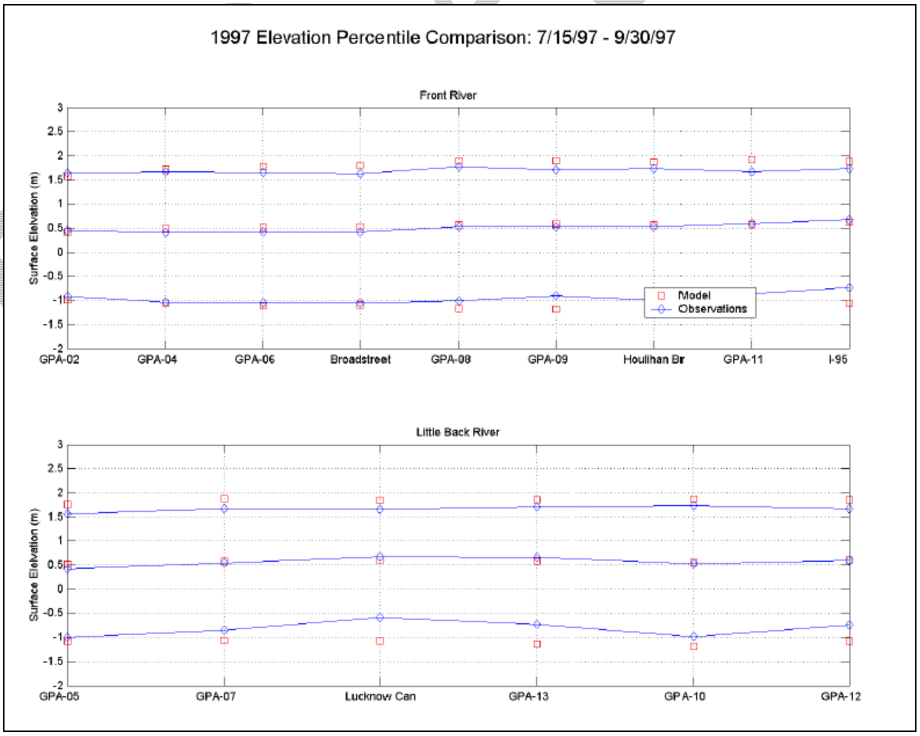

Figure 3-2. Simulated and measured WSE percentiles for the 1997 validation.

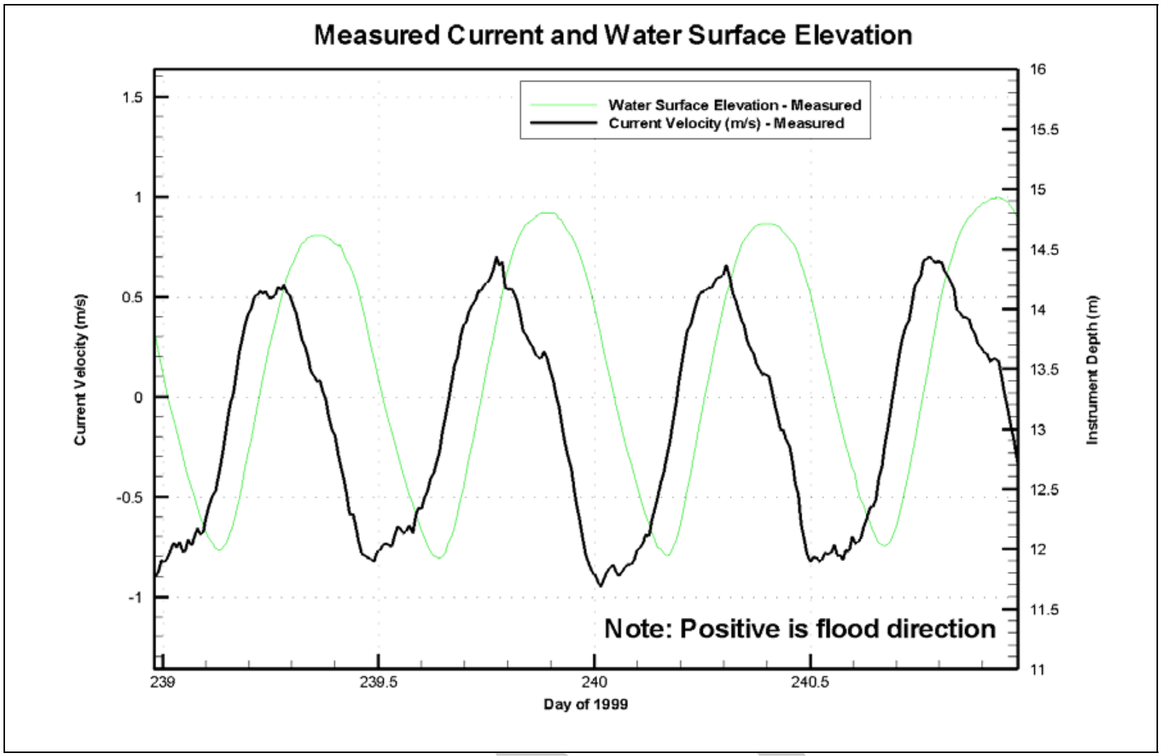

Figure 3-3. Measured depth averaged currents and instrument depth at GPA-06.

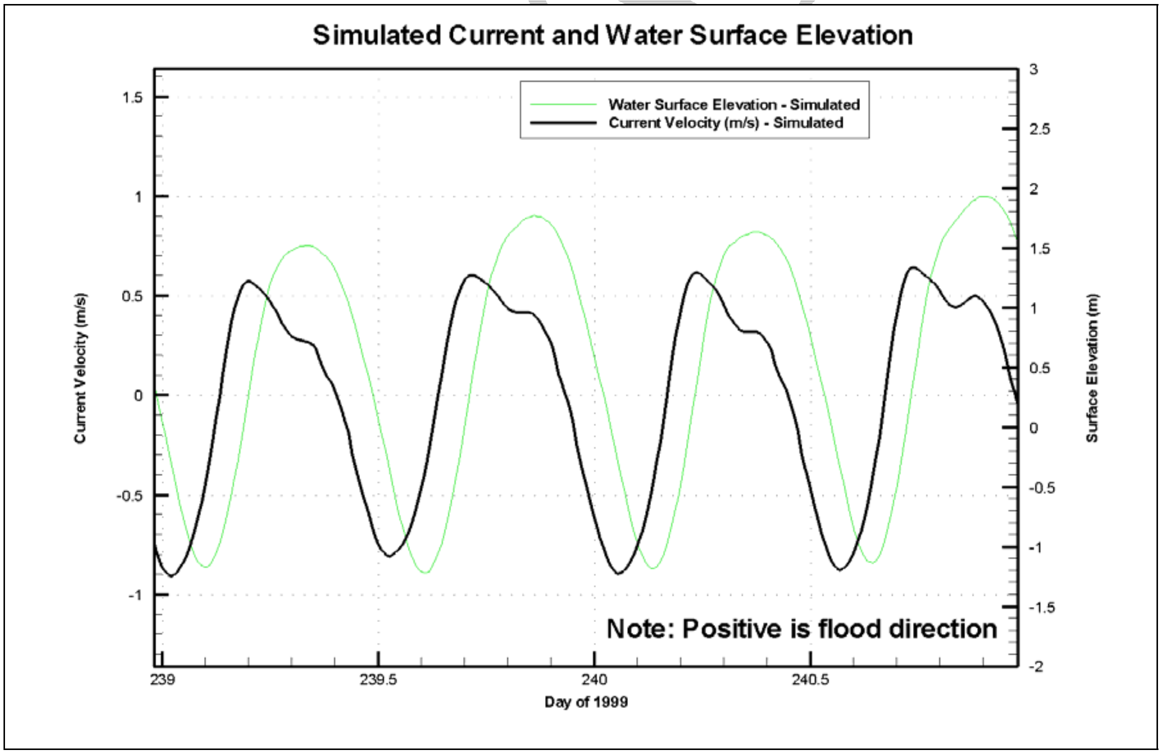

Figure 3-4. Simulated depth averaged currents and WSE at GPA-06.

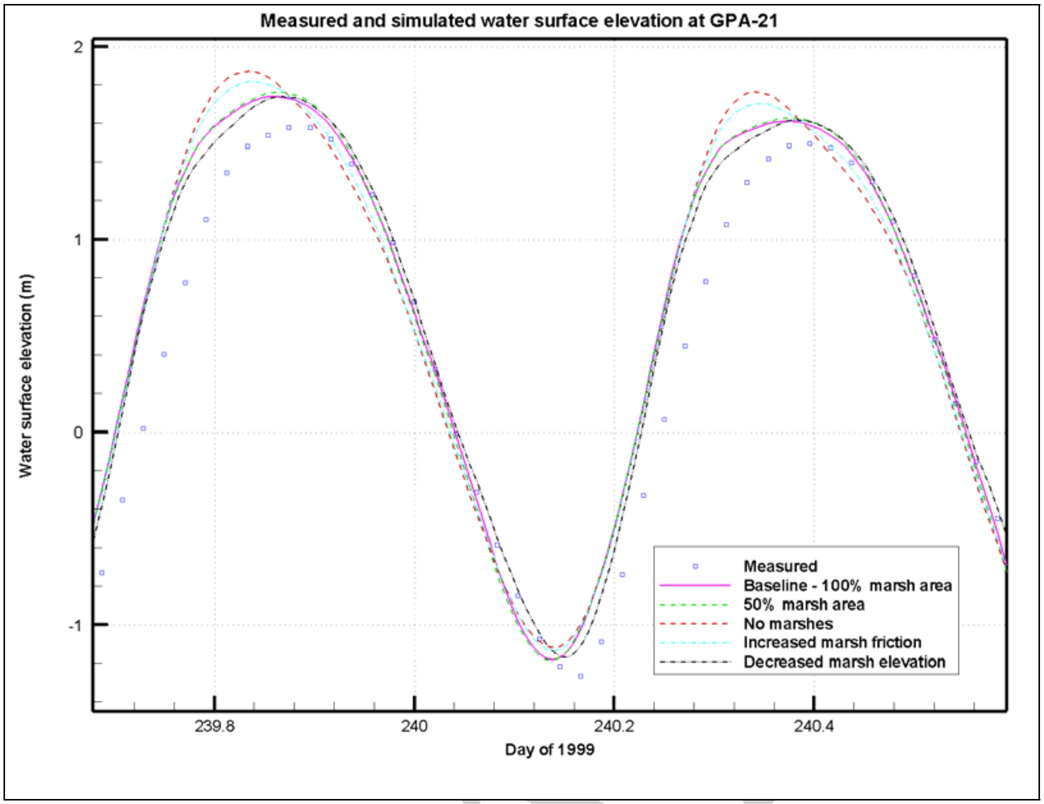

Figure 3-5. Simulated WSE at GPA-21 for marsh runs.

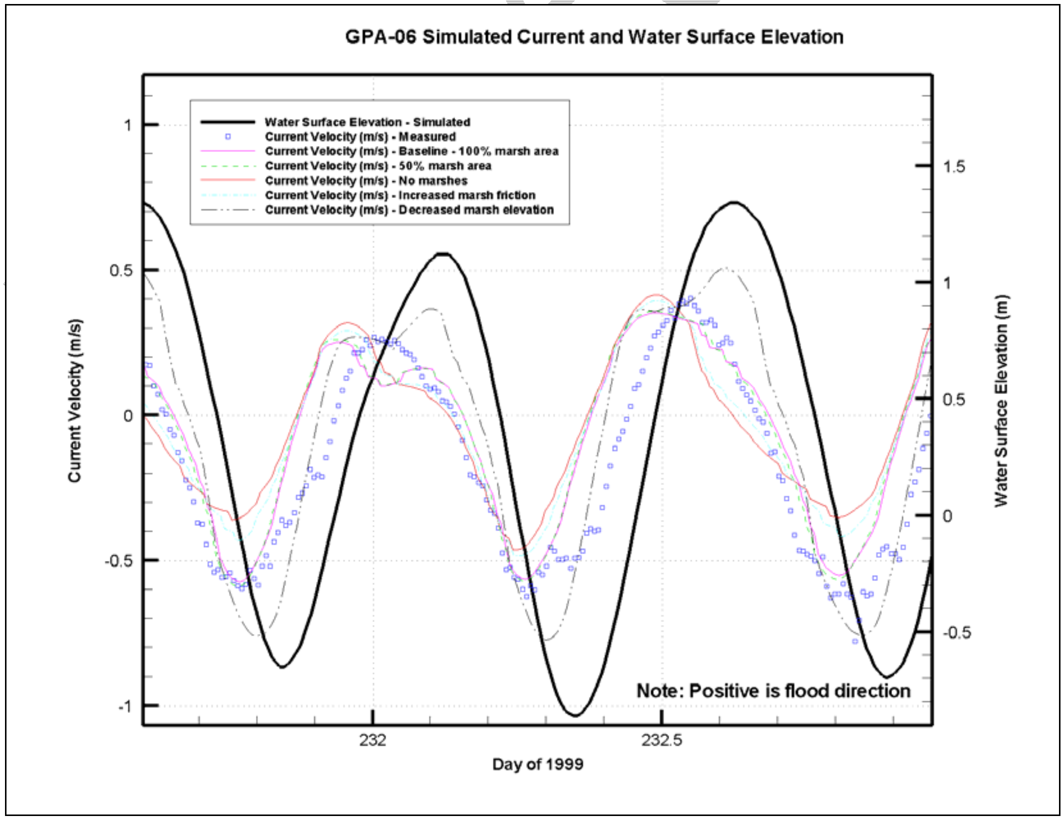

Figure 3-6. Simulated depth averaged currents and WSE at GPA-06 for marsh runs.

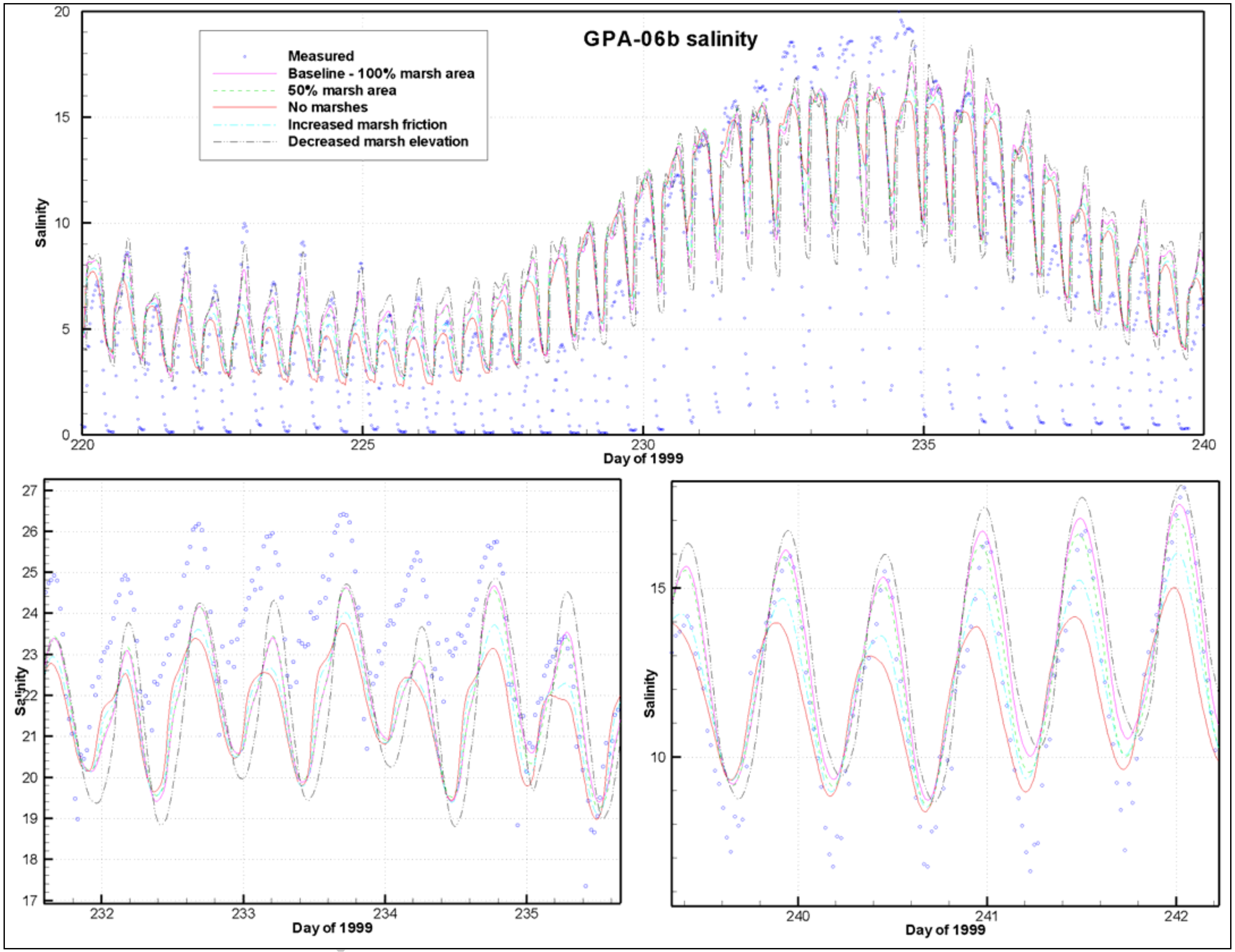

Figure 3-7. Simulated salinity at GPA-06 for marsh runs

RECOMMENDATIONS:

Based on the analyses performed to address the review comments, it is not recommended that additional work be performed at present. The tests showed that although there was marginal improvement in the results for some of the variations tested, overall there was not enough improvement over the calibration simulation to warrant additional investigation.

The calibration of the water quality model is in progress and tests of the hydrodynamics and salinity (H&S) model predicted circulation and transport are being made for that application. If additional insight into the H&S model predictions is gained through the water quality model calibration effort and it is determined that an improvement to the H&S model calibration can be made for the Final Model Calibration Report, the variations that showed incremental improvements noted in the investigation above, will be added to that calibration.