United States Department of the Interior

FISH AND WILDLIFE SERVICE
176 Croghan Spur Road, Suite 200
Charleston, South Carolina 29407

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March 24, 2004

Colonel Roger A. Gerber
District Engineer
U.S. Army Corps of Engineers
P.O. Box 889
Savannah, GA 31402-0889

Dear Colonel Gerber:

As you know, the Fish and Wildlife Service (Service) has requested the assistance of the U.S. Geological Survey (USGS) in evaluating the hydrodynamic and water quality models for the Savannah Harbor Expansion Study. USGS has completed a review of the report "Calibration of a Hydrodynamic and Water Quality Model (WQMAP) for Savannah Harbor" prepared by Applied Technology and Management (ATM) for the Georgia Ports Authority. USGS scientists from South Carolina, North Carolina and California participated in the review. Copies of the USGS letter and review comments are enclosed.

Based on the review, use of the WQMAP-ATM model to predict impacts of potential Savannah Harbor deepening would not be scientifically defensible. Instead of a physics based vertical mixing sub-model, the WQMAP-ATM model relies on a unique empirical formulation based on field measurements from 1997 and 1999. Therefore, the performance of the model outside of a very narrow range of tides, river flows and the existing geometry would be highly suspect. There is no assurance that the model would correctly function after geometry changes (channel deepening) are made because the model has been adjusted to fit only a narrow set of existing conditions. While the USGS review focused on the vertical mixing problem, other concerns were also identified. These concerns included the backwater calculation to simulate stream flow from Clyo and discrepancies in the stated input flows at Clyo.

The Service cannot support use of the WQMAP-ATM models in their present form. In order to make the hydrodynamic model acceptable, it must incorporate a physics based vertical mixing component that does not rely on empirical adjustments to improve the fit of observed data to model predictions. In addition, the concerns regarding backwater calculation and the stated freshwater inflows at Clyo must be adequately addressed. Subsequent to addressing these identified problems, another thorough review of the model would be required.

We understand that another three-dimensional model, Environmental Fluid Dynamics Code (EFDC), has been applied to Savannah Harbor and has demonstrated that a physics-based turbulence closure model can be successfully applied in the system. We recommend that you evaluate and compare the defensibility and performance of the EFDC model and the WQMAP-ATM model.

The hydrodynamic model is the critical impact assessment tool for the entire harbor expansion project. Most of the other impact assessments will be based on predictions from the model. Therefore, it is imperative that the hydrodynamic model be as reliable as possible and scientifically defensible.

We appreciate the efforts of you and your staff to coordinate this project with the Service. If you have any questions or wish to discuss this issue, please contact Ed EuDaly at 843-727-4707 x 13.

Sincerely,

Timothy N. Hall
Field Supervisor

TNH/EME

United States Department of the Interior

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March 19, 2004

Mr. Ed Eudaly
U.S. Fish and Wildlife Service
Suite 200
176 Croghan Spur Road
Charleston, SC 29407

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Dear Mr. Eudaly,

I have completed my review of the report "Calibration of a Hydrodynamic and Water Quality Model for Savannah Harbor" prepared by Applied Technology and Management (ATM) for the Georgia Ports Authority. The review summary is attached to this letter. The report and its appendices describe the hydrodynamic and water-quality models, their applications to the Savannah Harbor, their calibration, and other supporting documentation of the modeling study. These models will be used to assess impacts from a potential harbor deepening on the freshwater tidal marshes of the Savannah National Wildlife Refuge and the striped bass and sturgeon fisheries. Because of the importance of these models for evaluating the mitigation impacts of a potential deepening, the technical defensibility of the models has been the salient concern of the Federal Agencies. I had assistance in the review of the hydrodynamic model and vertical mixing formulation from Dr. Jerad Bales and Dr. Peter Smith, from our North Carolina and California District Offices, respectively.

The model development and review process has been a long one, and we appreciate the opportunity to participate in this process. The goal of all of the participants has been to produce the best tool for determining future impacts of the Savannah Harbor Expansion Project on Savannah River resources.

Please call me at (803) 750-6140 if you have any questions or need additional information.

Sincerely,

Paul A. Conrads
Hydrologist

Review Comments
On
"Calibration of a Hydrodynamic and Water Quality Model for Savannah Harbor"

prepared by
Applied Technology and Management (ATM)
for the Georgia Ports Authority

A key element of a hydrodynamic and water quality model used for evaluating salinity and dissolved oxygen response to a system alteration is the ability of the model to accurately simulate the transport of water and constituent mass. Proper simulation of mass is fundamental for accurate prediction of salinity intrusion from coastal waters and of the effect oxygen consuming materials on system-wide dissolved oxygen levels. In a system such as the Savannah Harbor that regularly stratifies and de-stratifies, a two- or three-dimensional model must accurately simulate vertical mixing to accurately simulate the transport of mass. Three-dimensional models typically incorporate a physics-based turbulence mixing sub-model. These sub-models are often referred to as turbulence closure models or turbulence energy models. The hydrodynamic model, BFHYDRO, used in the WQMAP modeling package, uses the turbulence energy sub-model (Muin and Spaulding, 1997) to simulate vertical mixing. Another vertical mixing model used in many models is Mellor-Yamada turbulence closure model developed at Princeton University in the 1970's. Because of the importance of the vertical mixing formulation on accurate prediction of Savannah Harbor deepening impacts, this review focused on that particular aspect of the modeling study, although all aspects of the study were reviewed.

The initial application of the BFHYDRO model to the Savannah River was unable to capture the stratification/de-stratification dynamics of the system. Various configurations of the turbulence energy model were tried without satisfactory results. In order to capture the vertical mixing dynamics, ATM developed an empirical scheme to predict vertical mixing. Data from 1997 field measurements were used in the developoment of this algorithm. ATM refers to this vertical mixing sub-model as the "Log Law" model and the BFHYDRO model was modified to incorporate this empirical scheme. This modified version of BFHYDRO was used to determine impacts of deepening in the first Environmental Impact Statement.

For the Log Law model, ATM correlated vertical mixing calculated from velocity data at the GPA 04 station (Fort Jackson) with the water level data from Fort Pulaski. From this correlation, they determined a vertical mixing time series (Dv, vertical diffusivity) for input to the model. The Dv is both temporally and spatially variable, and dependent simulated salinity gradient.

Following are some observations on the Log Law model and its application in the Savannah River:

> The Log Law vertical mixing formulation is not based on the proper physics of the system. Turbulence, which is primarily responsible for vertical mixing, is

largely a function of bottom friction, local velocity, and local depth. A vertical mixing formulation using local friction velocity and depth would be more physically based and likely to perform better than one based on tide range at the downstream boundary.

2. The Log Law vertical mixing formulation assumes that the physics of vertical mixing are the same throughout the entire model domain. It is assumed that local channel geometry, which affects the flow regime, is not a factor in the mixing scheme. The mixing coefficients for this study were derived from the vertical velocity profiles at Fort Jackson (GPA 04). It is unlikely that the physics (flow regime) at GPA 04, which is downstream of the confluence of the Back and Front Rivers and upstream of the divergence between the Savannah River and South Channel, is representative of the vertical mixing throughout the entire model domain, which ranges from tide-dominated reversing flows to purely riverine flows. (A Munk and Anderson type model, discussed in App. Q of the report, that was applied using the model predicted velocities and depths of flows could address these concerns.)

3. There are better methods to spatially vary the Dv time series than using a salinity gradient. Adopting a Munk and Anderson type model (discussed in Appendix Q) and using the model predicted velocities and depths of flows would be more physically based and address concerns identified in Item 2.

4. The assumption in the Log Law model is that freshwater inflow is irrelevant to the vertical mixing. The correlation between Richardson number[1] and tidal range for GPA 04 (Fort Jackson) and GPA 08 (downstream of US Highway 25 Bridge) are 0.63 and 0.33, respectively. The correlation coefficients imply that tidal range explains two-thirds of the variability at GPA 04 and only one-third of the variability at GPA 08 for the flow conditions. The differences in correlation coefficients indicate that there are differences in the physics between the two locations. Other hydrodynamic factors, including streamflow, could explain the two-thirds of the variability at GPA 08 not explained by tidal range.

5. In the correlation analysis referred to in Item 4, Richardson numbers that were greater the 10 were set to 10; the reason for this assumption was not reported. Yet, as shown in figure XX, there were many values greater than 10 for several tidal cycles - especially at GPA 08. Use of all the Richardson numbers from the data set would certainly would have changed the reported correlation coefficients, as well as perhaps invalidating the assumption that tidal range is the only significant factor in vertical mixing in Savannah Harbor.

The implementation of the Log Law model is described in Appendix Q as being a "straightforward" and, in essence, as an additional "boundary condition" for the model. As a boundary condition, the computation of the Dv time series needs to be clearly

[1] Richardson number is a dimensionless number that is the ratio of vertical density stability to destabilizing horizontal shear, or velocity.

described. Unfortunately, the description provided in the report was overly simplified and inadequate for understanding the computation of vertical mixing time series, leading to concerns about using the Log Law model to make predictions for future conditions in Savannah Harbor. Listed below are some questions that were left unanswered in the description and application of the model

6. Appendix Q did not adequately describe the computation of the Dv time series. Equation 5, as it is presented in the report, is not the equation used in the computation of the Dv inputs used for the model calibration and validation. An additional constant was added to the application of Equation 5 that was not described in Appendix Q. Figure 22 shows the curve fit of Equation 5, as reported in Appendix Q, but does not show the final form of the equation used for the application of the model.

7. Appendix Q does not explain that the Dv was computed using two unique sets of coefficients (with the additional constants) and that the higher values of the two computations were used for the final calibration values. Scientific justification for the use of two sets of coefficients and additional constants was not provided. There is no way to know which set of values should be used to make predictions for future conditions, or whether another set of values would be needed.

8. Along with the additional constant added to Equation 5 described in comment 6 and 7, an additional 0.0001 was added to the final time series for both the 1997 and 1999 time series. This constant is not described in the report or appendix.

9. A smooth (no rapid fluctuations with time) Dv time series is desired for the input to the model. The manner in which the time series is smoothed makes a significant difference in the Dv "boundary condition" that is applied, as well as in the resulting salinity predictions. Smoothing the final time series of Dv (using the same three iterations of a running average used for the smoothing of the tidal range) made a significant difference in the Dv time series, especially the first two high mixing periods in 1999. Salinity simulations using the new Dv time series show differences in salinity predictions of approximately 5 to 10 percent at selected stations. A justification of the computation of Dv (smoothing order and the running averages used) was not provided.

10. The 1997 and 1999 data sets cover only a limited range of tidal and streamflow conditions. It appears that the determination of the curve fit coefficients for Equation 5 is highly calibrated to the four or five stratification/de-stratification cycles in1997 and 1999 data sets. Before the vertical mixing scheme can be used to a major modification to the system, the robustness of the scheme needs to be demonstrated on a wider range of hydrologic, tidal, and geometry conditions.

A hindcast analysis to the harbor geometry of 1993 was present in Appendix Q, although the reasons for presenting the hindcast analysis were unclear. Vertical mixing is not discussed in the hindcast analysis so the intent may not have been to validate or confirm the vertical mixing routine. Nevertheless, it was anticipated that the hindcast analysis would be used to demonstrate the robustness of the vertical mixing formulation for simulating salinity intrusion using the harbor geometry prior to the last deepening in 1994.

The premise for ATM's approach to the Log Law vertical mixing formulation was that accurate prediction of salinity intrusion was dependent on simulating the stratification/de-stratification dynamics. A quantitative hindcast analysis should demonstrate the model's ability to simulate the stratification/de-stratification and/or salinity intrusion for a different set of geometry, hydrologic, and tidal conditions. The hindcast analysis did not show the model performance of BFHYDRO using the 1993 geometry, flow, and tidal conditions and salinity time series at the USGS sites. Rather the presented results compared 60-day mean salinity responses between a multivariate analysis of relative deepening impacts and the 1999 calibration model set up using the 1993 geometry. The original multivariate analysis ("Analysis of the Historical Data for the Lower Savannah River Estuary-Draft" 1998), which was the basis of the approach taken for the hindcast analysis, was described as a "qualitative analysis" and not a quantitative analysis of mean salinity impacts due to the previous deepening. The qualitative analysis of relative 60-day mean salinity impacts can not be used as a quantitative analysis demonstrating the skill of a vertical mixing routine to be able to predict salinity intrusions.

BFHYDRO model uses a backwater calculation approach to simulate stream flow from Clyo. The backwater formulation is another modification to the original BFHYDRO code and the description of the formulation is inadequate in the report. It is assumed that the approach simulates river flows as a function of water surface slopes rather than as a function of bottom slopes and water surface slopes. The rationale for the application of a backwater formulation and the implications for the model are not discussed. It is unclear whether the channel geometries for the river had to be distorted to accommodate restrictions of the channel bed elevations; the effects of any distortions on water surface elevations during higher flows, on surface heat and oxygen exchange, and on light penetration in water quality simulations were not discussed.

The report states that the flows at Clyo were increased by ten percent to account for potential increase of flows due to the increase in drainage area between Clyo and Fort Pulaski. As a part of this review, the model input flows for the 1997 and 1999 were compared to the measured flow at Clyo. For 1997, the model input flows are higher than the measured flows at Clyo. For 1999, the model input flows are lower (approximately 10 percent) at the beginning of the simulation period and gradually become equal to the measured flows by the end of the calibration period. The reported sensitivity analysis indicated that salinity predictions are sensitive to the streamflow. It was unclear whether the discrepancies in the adjustment to flow inputs to the model were used as a calibration factor or due to a hydrologic factor that was not explained. For application of the model for impact scenarios, it is unclear how the flows would be adjusted to be consistent with the model calibration and validation.