RESPONSE TO QUESTIONS REGARDING THE SAVANNAH HYDRODYNAMIC AND SALINITY MODEL VERTICAL MIXING METHODOLOGY

Several questions were raised by members of the Savannah MTRG regarding the vertical mixing methodology implemented in the BFHYDRO hydrodynamics and salinity transport model. The questions appear to follow two basic tracks; first, is the formulation acceptable and does it calculate appropriate values for the vertical mixing; and second, with this formulation is the model capable of predicting the changes in the system response, associated with a channel deepening? It is felt that the majority of the questions have arisen due to an incomplete understanding of the vertical mixing methodology as well a as a concern regarding the model's predictive capabilities.

The following response discusses the questions regarding the mixing theory, presents a detailed description of how the theory is implemented and addresses the model capability to perform a deepening analysis.

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Preamble

I have been reading one of your papers (Mendelsohn et al. "A Hydrodynamic Model Calibration Study of the Savannah River Estuary with an Examination of Factors Affecting Salinity Intrusion"). Here are my questions:

Eq.2, $D_v = D_o \, g(Ri)$ [2]

Eq.3, $g(Ri) = (1 + \beta \, Ri)^{-m}$ [3]

From Fig. 8, you may see

$Ri = - r * Range$

Then, Eq. 3 becomes

$g = (1 + \gamma * Range)^{-m}$

where $\gamma = \beta * (-r)$

Thus, from Eq. 2,

$\log(D_v) = \log(D_o) - m * \log(1 + \gamma * Range)$

Is this the way you drive

Eq.5 $\log(D_v) = \delta + \phi * Range$ [5]

Question (1) If so, δ is controlled by D_o which represents neutral diffusion. One may argue that neutral diffusion is more or less function of tidal energy (a good proxy is tidal range) but not D_v. One may argue that Richardson number is not only the function of tidal energy but also the freshwater inflow and offshore salinity. I am not quite sure how you can justify (or put a limit on) the dominant role of tidal energy over hydrology shown in Fig 8 which is based on 1997 summer (and I think this represents less influence of hydrology). Is there any way you can demonstrate that your method is working well or has a certain limit on application over a range of hydrology and tidal energy conditions?

ATM Response:
While it is true that the Richardson number is probably dependent on both the upstream river flow as well as the tidal energy, preliminary analyses of the salinity, tides and river flow clearly showed that the tidal energy is the dominant factor in the stratification/de-stratification cycle in the estuary. The stratification/de-stratification cycle is the controlling factor for circulation and salinity intrusion in the estuary, while river flow rate appears only to produce deviations on the pattern.

In addition, a variety of hydrologic conditions were exhibited during the 1997 summer season, with flow rates ranging from approximately 5,000 – 11,000 cfs. This is not the full range of flows experienced in the Savannah River but a large range, more than doubling in size from the low flow to the high flow conditions. The model predictions for the 1997 clearly show the reproduction of the stratification and collapse.

Finally, the same formulation implemented for the 1997 simulations was used for the recent 1999 simulations with very good results. The only difference between the two applications was the input tide range, where the time varying range for 1999 from the Ft. Pulaski gage was used for the 1999 simulations. A description of how the time varying tide range is determined is included in the response to the next question.

Question (2) In your response to us given early, you said the diffusivity is varying spatially and temporally. I guess you have spatially varying delta and phi from Eq. 5 when you applied your model to the Savannah River. Is this right? If so, did you estimate the coefficients for measured stations and make interpolation in between? How about time variation? I think you make D_v time-varying controlled by tidal range? How do you determine a time varying tidal range? Or, are you using a fixed value for a tidal range?

ATM Response:
The values for delta and phi in Eqn. 5 do not vary spatially. The coefficients, phi and delta were determined during the initial calibration and have been retained through all subsequent work. The two values were determined in the manner described in the paper cited above, and were selected such that the Log Law calculated D_v closely matched the

gradient Richardson number calculated values for data recorded at GPA-04. The final selected values for phi and delta were tuned through the calibration effort.

The spatial variation occurs as a result of scaling according the local gradient Richardson number. At each horizontal cell location, the local density gradient is calculated for each layer in the water column. A vertical profile of mixing is then calculated by scaling the input tidal range calculated mixing ass follows:

$D_v(x,y,z) = D_v\ (\text{input}) * \{[\delta\rho/\delta z\_max(x,y) - \delta\rho/\delta z\ (x,y,z)] / \delta\rho/\delta z\ s\_max(x,y)\}$

The temporal variation of D_v is calculated based on an instantaneous (but slowly varying) tide range input. The tide range is determined hourly (basically looks like a series of steps as the range varies tide to tide) over the entire simulation period and subsequently smoothed into a gradually varying tidal range curve. The hourly range values are then input into Equation 5 to calculate the vertical mixing.

The vertical mixing numbers are read into the model for the appropriate time and scaled locally (horizontally and vertically) by the local gradient Richardson number as described above. This second step of scaling the mixing to the Richardson number was an innovation added after the original paper cited above.

Question (3) Eddy viscosity (A_v) was also mentioned in the paper but not much detail was given. Are you using the same method for eddy viscosity as diffusivity? By definition, eddy diffusivity and eddy viscosity are related through Prandtl number. Are you using the Prandtl number to relate D_v to A_v?

ATM Response:
The eddy viscosity is also calculated in the same manner, and is indeed related to the diffusivity via the Prandtl number.

Question (4) In addition, a question has been raised as to whether the Savannah Hydrodynamic and Salinity transport model system could adequately predict the impacts due to the deepening of the channel in the Savannah River Estuary.

ATM Response:
There are two ways in which the model will respond to a deepening simulation. First, in a direct physical sense, the model gridded bathymetry will be different after a deepening, which will affect every term in the conservation equations. For example, with the increased depth the cross-sectional area will also increase, slowing currents through the area. The depth increase will also affect the baroclinic pressure terms, increasing the pressure gradient along the bottom of the deepened channel.

Second, the vertical mixing term itself will be affected by the increased depth by decreasing the vertical gradients of density as discussed in the answer to Question 2 above. As the depth increases, the gradient is decreased for similar vertical differences of density, which subsequently scales the vertical mixing proportionately.

Finally, a hindcast of a the channel deepening project in the 1993-1994 time period was simulated after the initial model calibration to the 1997 data set. The results are written up in the Savannah River Teir I, EIS (ATM 1998). The results clearly indicated that the model was capable of predicting changes due to a channel deepening, closely predicting the increased intrusion of the 0.5ppt salinity contour after the dredging. For the simulations, no alterations were made to the vertical mixing scheme, the only variation being the gridded bathymetry.