Memo from Modeling Subcommittee Advisory Group

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July 25, 2007

Review of Objectives

The water quality (WQ) model is intended to be a tool for evaluating estuarine water-quality changes in response to alternative management scenarios. The primary reason for incorporating sediment in the water quality model is to improve model estimates of light penetration. Therefore, the model must accurately reflect changes in the field of suspended sediment as it is influenced by circulation, fluvial sources, shoreline erosion, and resuspension of bottom sediment. It is most important to correctly model fine sediment in shallow regions where reduced light penetration affects submerged aquatic vegetation. To achieve the correct timing and concentration of resuspended fine material over spring-neap cycles, during and after floods or storms, through seasonally cycles, and in response to management actions, it is important that the model accurately represents temporal changes in bed composition and erodibility.

Additional benefits of adding sediment dynamics in the WQ model (which may not be realized in this phase of model improvement) include the ability to track resuspension and sequestering of organic and chemical constituents associated with sediment, to link sediment fluxes of nutrients and contaminants to physical sedimentary processes, and to determine changes in bottom characteristics and morphology associated with sediment transport.

Progress

Significant progress toward WQ model goals has been made: the WQ model now has a bed with multiple sediment classes that responds to near-bottom stresses from the combined action of waves and currents. Sediment is conserved in the model, and simple tests indicate that balance between downward settling and upward diffusion has been implemented correctly. Sediment erosion and deposition respond appropriately to the prescribed behavior, and bed algorithms appear to move sediment fractions correctly among layers in the bed. A simple and efficient wind-wave model has been developed, and realistic near-bottom wave-current combined stresses are calculated and used by the sediment-transport model.

Areas Needing Improvement

The sediment-transport component of the water quality is not yet suitable for management purposes. In the current state, the model does not produce useful estimates of the SSC field, it has not been shown to respond correctly to well-understood scenarios, and it has shown no skill at reproducing measured values. The model formulation has been altered in an ad hoc fashion (e.g., attribution of critical shear stress profiles to non-cohesive material; resetting of mass eroded parameter *m*). Model parameters are set with unrealistic values (e.g., settling velocity is too low) or arbitrary values that are not supported by literature or observations (e.g. critical shear stress profiles for sand, time scale for resetting *m*). The number of size classes is too few to represent the diverse sediment of the study area, the initial bed thickness is apparently too thin, and the initial distribution of size classes in the bed is not realistic. The resulting model behavior is neither physically realistic nor well understood. For example, temporal variations in SSC show start-up transients that take more than a year to settle down, chronic erosion occurs near the entrance, and bottom grain size distributions do not seem to be converging toward observed values. The performance of the model, at least based on material presented at the meeting on July 11, 2007 meeting, is very far from suitable.

Recommendations

The sediment model should be based on published and tested parameterizations of physically based sediment dynamics. Physical parameters (sediment size distribution, settling velocity, critical shear stress, etc.) should have realistic values based on observations. Empirical values (resuspension coefficients, mixing rates, time scales) should be set to values within established ranges using available data, and sensitivity of model results to uncertainty in these values should be determined.

In terms of the present model, we have two categories of specific recommendations. In the first category are suggestions for changing parameters and conducting tests to evaluate and improve the performance of the model, either in its current form or after any changes to the algorithms. The second category includes suggestions for changes to sediment-related algorithms, which will require more time and effort, and will necessitate additional calibration, testing, and validation. It is late in the modeling cycle to make fundamental changes, but we feel that at least some of these changes will probably be needed to properly represent the sediment dynamics in Chesapeake Bay

First Category of Recommendations: Parameter Changes and Tests

1) Develop simpler simulations for diagnosing model problems (e.g., the test bed suggested by Carl Cerco as his Sixth Task...this should be a high priority). Perform simple model simulations to qualitatively evaluate model behavior for important situations. For example, the model should be able to correctly reproduce estuarine turbidity maxima and wind-wave resuspension in shallow water without excess erosion or deposition. Simple scenarios will also allow insight into model predictions for less-well understood conditions. For example, according to the model, what is the fate of river-derived material, and what are its effects on light attenuation? What is the fate of material introduced by shoreline erosion? What does the model indicate about the balance of sediment near the mouth? Under what conditions does sediment from the channels impinge on shallow water, and under what conditions does sediment resuspended in shallow water get exported to channels? What is the ultimate fate of fine sediment...is it exported to the ocean or sequestered in depositional areas? Until these processes are

modeled realistically and reliably, there cannot be any confidence in the validity of the model results for making management decisions.

2) Use at least one more noncohesive sediment size class to better represent existing bed distribution. This should be a nearly immobile size class (established using a very high resuspension critical shear stress), and should constitute a high fraction (i.e., > 75%) of the sediment beds in the grid cells near the Bay mouth to insure that the beds in those cells are not completely eroded. Initialize the model with a realistic sediment distribution derived from observations followed by a minimum one-year model spin-up simulation. The resulting sediment bed compositions should be compared with the data to determine if the spun-up bed compositions are reasonably close to the actual compositions in the areas where grain size distribution data are available. Other grain classes (in multiples of four) should be added to represent specific sediment sources (e.g. certain rivers or bank loads) of interest in regulatory scenarios. These classes would normally have associated sediment characteristics identical to the original four classes.

3) Use a thinner surface sediment layer, something on the order of 0.5? cm. Use an equation from the literature to calculate the active layer thickness as a function of D_{50} of the noncohesive sediment in the surface layer.

4) Calculate the mass balance over the entire modeling domain for each sediment size class over a specified period of time. This step is crucial to insure that sediment mass is being adequately conserved and to allow comparisons to previous sediment budgets.

5) Verify that the influx of noncohesive sediment at the Bay mouth is correctly being represented as a function of the flood tidal flow in the model.

6) Retention of fine sediment in the Bay and formation of turbidity maxima will dependent on suspended sediment stratification and thus on settling velocity. The correct value will likely be found within the 60 to 600 micron per sec range being used for testing. If the settling rate to achieve proper stratification results in too much deposition and too low overall concentrations, implement a depositional velocity (much less than water column settling velocity) to calculate depositional flux. Concentration-dependent settling velocities, used successfully in most other cohesive sediment models, might also be implemented in the model to help retain fine material in the Bay during and after large events. Implementing depositional threshold stresses for clay and silt (above which no deposition occurs) would also reduce overall deposition of clay and silt classes. The values of these parameters are slightly less than for $\tau ce1$ and $\tau ce2$ discussed above.

7) Prepare necessary watershed inputs and hydrodynamic model results to allow comparison of the WQ model with recent field measurements, especially observations of sediment resuspension and SSC in shallow regions. Use these comparisons to help set model coefficients and evaluate model skill. It might be useful to make preliminary comparisons using statistical summaries for normal conditions as a guide to model adjustment until complete watershed and hydrodynamic model results become available.

8) Establish quantitative metrics of model skill that are closely related to model objectives and can be evaluated with field data; use these to test model skill and sensitivity to uncertain parameters.

Second Category of Suggestions: Reformulation of the Model Algorithms

1) Incorporate depth varying critical shear stress for resuspension and erosion rate of fine-grained sediment (clay and silt size sediment classes) into the existing bed model. These values should be specified using the Sedflume or other data. (The vertical distribution of critical stress for sand fractions should be removed.) This might be accomplished using the Sanford distribution but with the *m*-parameter either never arbitrarily reset (but continuously updated by eroded and deposited masses) or reset using a very long time constant (months). The upper erosion threshold limit for clay at the bottom of the sediment column should be of the order of 1 Pa or more. At each time step, first calculate erosion threshold for clay ($\tau ce1$) at the bed surface, then if ($\tau ce1 > \tau ce2$ (silt)), $\tau ce2 = \tau ce1$. Repeat for sand. As previously recommended, a good minimum $\tau ce1$ is about 0.05 Pa and a reasonable $\tau ce2$ might be 0.1 to 0.2 Pa.

2) Simulate the formation of a fluff (or unconsolidated) layer of fine-grained sediment when deposition is predicted to occur. Deposition of fine-grained sediment should only occur when the bed shear stress is less than a specified critical shear stress for deposition. The fluff layer should be assigned a very low critical shear stress for resuspension and a low bulk density such that it is usually re-entrained into the water column during the accelerating phase of the subsequent ebb or flood tide. In a depositional area, the fluff layer will dewater with time and eventually become part of the surficial sediment bed layer. This process can be easily represented using an empirical approach as opposed to using a finite-strain consolidation model. This is not hard to represent in a model, but does require keeping track of the time the fluff layer in each cell is present. The bed model should evolve a reasonable bed grain mix and shear strength over several years of simulation and only very limited/special areas should erode away.

3) Implement the algorithms currently in development for the Community Sediment Transport Model. The existing CSTM research code relaxes the porosity and critical shear stress profiles back to initial, specified, equilibrium values using specified time constants. It also implements rules-based transitions between sandy and muddy (cohesive) beds. The existing code should be easy to incorporate in the WQ model because it is similar to the earlier code, but it is still buggy, and it will require a concerted and collaborative effort to make sure it is working correctly.

Finally, evaluate what modeling goals are realistic for the CBP schedule. For the sediment-transport component of the model to be acceptable as a regulatory tool, it must meet high standards. If these cannot be achieved in time, the sediment-transport calculations should not be used in evaluating management scenarios, and alternative approaches will be required.