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Development of Three-Dimensional Wetting and Drying Algorithm for the Geophysical Scale Transport Multi-Block Hydrodynamic Sediment and Water Quality Transport Modeling System (GSMB)

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INTRODUCTION: The Environmental Laboratory (EL) and the Coastal and Hydraulics Laboratory (CHL) have jointly completed a number of large-scale hydrodynamic, sediment and water quality transport studies. EL and CHL have successfully executed these studies utilizing the Geophysical Scale Transport Modeling System (GSMB). The model framework of GSMB is composed of multiple process models as shown in Figure 1. Figure 1 shows that the United States Army Corps of Engineers (USACE) accepted wave, hydrodynamic, sediment and water quality transport models are directly and indirectly linked within the GSMB framework.

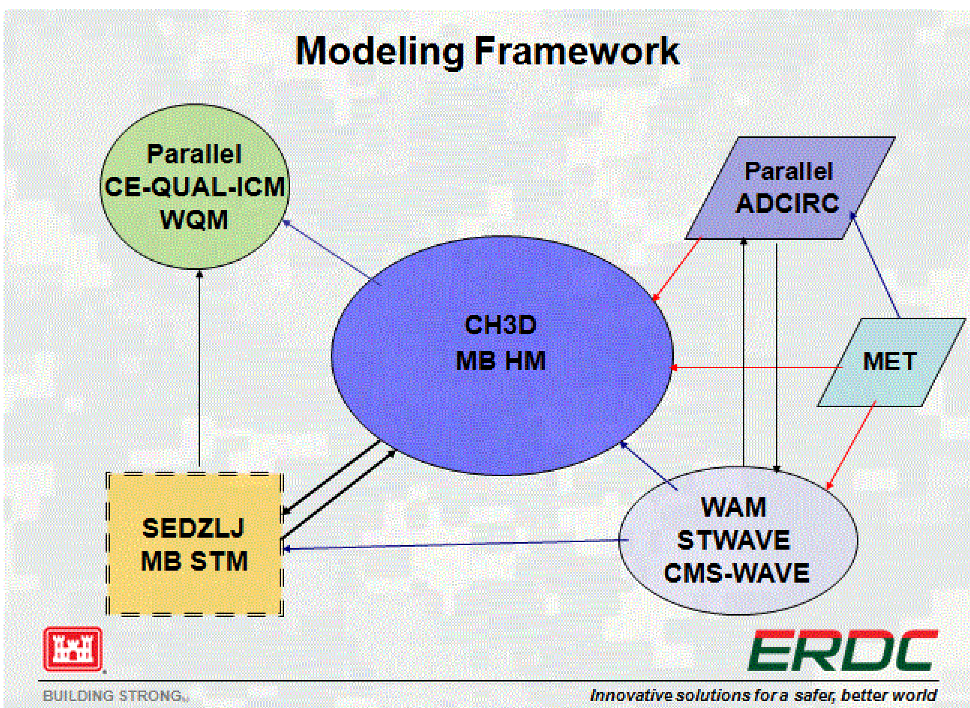

Figure 1. Multi-Block Geophysical Scale Transport Modeling System

The components of GSMB are the two-dimensional (2D) deep-water wave action model (WAM) (Komen *et al*. 1994, Jensen *et al*. 2012), data from meteorological model (MET) (*e.g.*, Saha *et al*. 2010 - *http://journals.ametsoc.org/doi/pdf/10.1175/2010BAMS3001.1*), shallow water wave models (STWAVE) (Smith *et al.* 1999), Coastal Modeling System wave (CMS-WAVE) (Lin *et al*. 2008), the large-scale, unstructured two-dimensional Advanced Circulation (2D ADCIRC) hydrodynamic model (*http://www.adcirc.org*), and the regional scale models, Curvilinear Hydrodynamics in three dimensions-Multi-Block (CH3D-MB) (Luong and Chapman 2009), which is the multi-block (MB) version of Curvilinear Hydrodynamics in three-dimensions-Waterways Experiments Station (CH3D-WES) (Chapman *et al*. 1996, Chapman *et al*. 2009), MB CH3D-SEDZLJ sediment transport model (Hayter *et al*. 2012), and CE-QUAL Management - ICM water quality model (Bunch *et al*. 2003, Cerco and Cole 1994).

Task 1 of the DOER project, "Modeling Transport in Wetting/Drying and Vegetated Regions," is to implement and test three-dimensional (3D) wetting and drying (W/D) within GSMB. This technical note describes the methods and results of Task 1. The original W/D routines were restricted to a single vertical layer or depth-averaged simulations. In order to retain the required 3D or multi-layer capability of MB-CH3D, a multi-block version with variable block layers was developed (Chapman and Luong 2009). This approach requires a combination of grid decomposition, MB, and Message Passing Interface (MPI) communication (Snir *et al*. 1998). The MB single layer W/D has demonstrated itself as an effective tool in hyper-tide environments, such as Cook Inlet, Alaska (Hayter *et al.* 2012). The code modifications, implementation, and testing of a fully 3D W/D are described in the following sections of this technical note.

Wetting and Drying Concept and Development. The basic concept of the W/D within CH3D is to enforce a zero flux on cell edges or faces associated with a dry edge. When properly implemented, definition of the modified Alternating Direction Implicit (ADI) matrix coefficients in the X and Y directions allow a stable and volume conserving solution of the water surface elevation and depth-averaged velocities. The following sections of this technical note describe the approach taken to develop the W/D capability. It is required that the users of this version are sufficiently knowledgeable of the original input and subroutine structure of CH3D as presented in Chapman *et al*. (1996).

In order to implement W/D capability within CH3D, a number of parameters had to be modified or defined, and significant rewrites of subroutines were required. The parameter, IWD, was defined and read from the input file, BLK#.inp, to distinguish between W/D (IWD = 1) and non W/D (IWD = 0) blocks. The number symbol defines the input file associated with the individual block number. Hydrodynamic code modifications were implemented in MAIN and CH3DM2, and new W/D subroutines CH3DIHW, CH3DIHW2, CH3DDPW, CH2XADIW, and CH2YADIW were developed.

The grid initialization routine, MAIN, was modified to check the value of IWD in each block and call CH3DIHW and CH3DIHW2 for W/D blocks. In order to take advantage of the existing boundary indicator arrays, NS and MS, the parameter HADD was redefined to be the additional depth added to the HS array within CH3DIHW and required to flag active W/D cells above mean tide level (MTL) as initially wet, or the W/D cell switch IWDS is set to one. Following the call to CH3DII, CH3DIHW2 is called, HADD subtracted from HS, and IWDS is set to zero where HS is less than or equal to a minimum depth, HMINW (RSPAC(7) in MAIN.INP).

The time-stepping routine, CH3DM2, was modified to check the value of IWD in each block and call the appropriate W/D (IWD = 1) and non W/D (IWD = 0) subroutines. An initial call to subroutine CH3DDPW for W/D blocks places the W/D cell face flags, IXWD, and IYWD to one for wet cell faces and zero for dry cell faces. A cell face is defined as dry when the edge depth AHUU or AHVV is less than HMIN, which has been previously described. When all four cell faces become dry, the W/D cell flag, IWDS, is set to zero; otherwise, IWDS is one. The W/D flags are set prior to each call to CH2DXADIW and CH2DYADIW to ensure the correct computation of the ADI continuity and momentum equations coefficients. In addition, the bottom drag coefficient used in CH2DXADIW, CH2DYADIW, and CH3DXYZWD3 is modified so that it increases linearly with depth for depths less than RSPAC(9) at a rate of RSPAC(10), which are specified in MAIN.INP.

Further modification of subroutine CH3DDPW assisted in the implementation of the wetting and drying capability in 3D, in which the dry edge velocities throughout the water column were set to zero. An additional modification to subroutine CH3DXYZWD restricted vertical computations to cells where the water column depth exceeded a minimum value of HMINW.

The W/D cell and cell face flags are used in the transport routines, CH3DSAGW3U and CH3DTEGWU, to disable salinity and temperature cell updates, or flux across individual cell faces. To allow transport across individual flow faces, the salinity and temperature transport routines were rewritten in the form of updated flux based edge transport routines, CH3DSAGW3 and CCH3DTEGW3. As in the 3D vertical hydrodynamic computations, transport is restricted to cells where the water column depth exceeds a minimum value of HMINWD (RSPAC(8), specified in MAIN.INP).

Initial testing of the W/D algorithm was performed by simulating flow in a flume composed of a single computational block or grid that was two-cells wide, 60 cells in length, and that used a five-layer sigma stretched vertical grid. Grid size was 200m wide by 200m long. Flume dimensions were 400m wide and 12,000m long. An open boundary at the east end of the flume was driven by a sinusoidal tide of 2m amplitude in a 12.42- hour period, representing an M2 tide. Grid orientations of 0.0, 45.0, and 90.0 degrees, with respect to east, were developed. The objective of these simulations was to demonstrate mass conservation for water and salinity at the wetting/drying interface over the duration of multiple tidal cycles. Additional test grids were developed to validate the code modifications over a range of tidal amplitudes, boundary depths, grid resolutions, and bottom slopes. Figures 2 and 3 show the East oriented grid and bathymetry with a boundary depth (i.e., mean depth of water at the open water boundary of the model domain) of 6.0m and bottom slope of 0.00065, respectively.

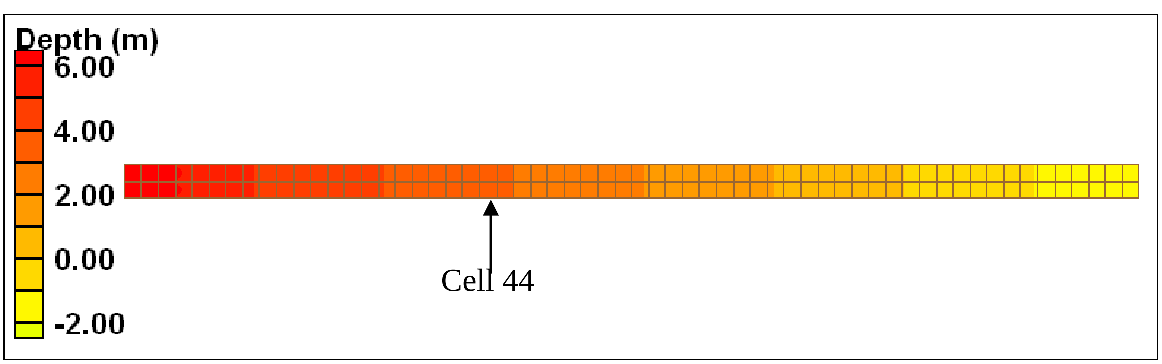

Figure 2. East Oriented Grid Bathymetry.

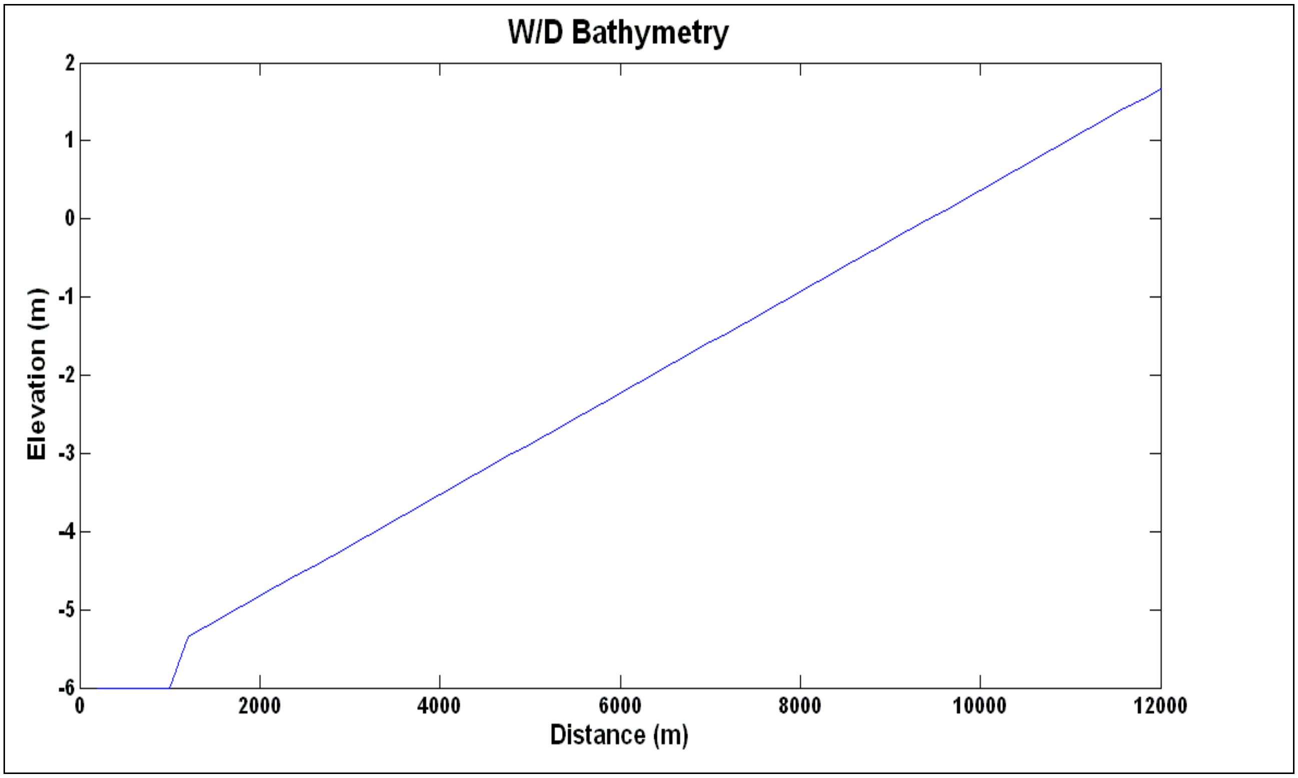

Figure 3. Sloping Grid Bathymetry.

Figures 4–7 show the water column depths and salinity distributions at hours 45 and 75 of the W/D simulation, respectively. Figures 6 and 7 illustrate that the salinity concentration remains at 30 psu, thus demonstrating mass conservation.

Figures 8 and 9 display time series of the vertical velocity distribution within the five-layer water column at Cell 44 (Figure 2). The boundary layer effect is clearly evident in Figure 9 where the magnitude of the velocity increases with increased layer number, i.e., from the bottom (first) layer to the top (fifth) layer, over the two-hour period shown in this figure. The abrupt plateau in the time series (Figure 8) indicates the transition from dry to wet and then back to dry. Figures 10-12 show, respectively, velocity profile at Cell 44 (Figure 2) during flood (t=25 hrs), ebb (t=26.5 hrs), and low water slack when the cell is dry (t = 27.5 hrs).

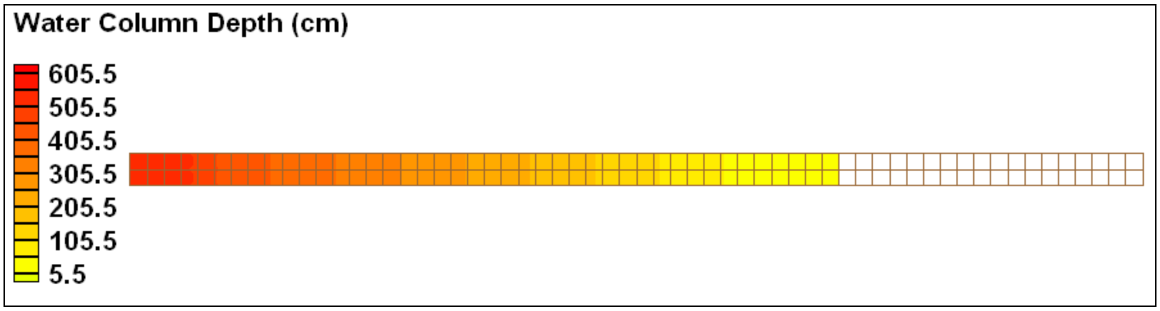

Figure 4. Water Column Depth - Hour 45.

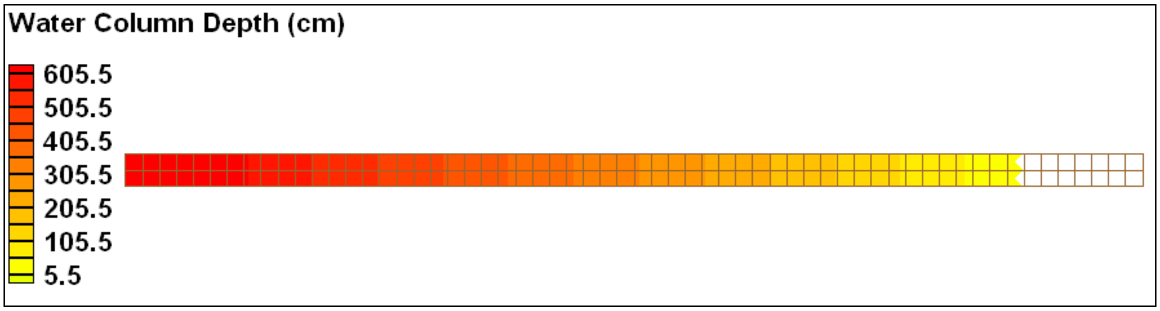

Figure 5. Water Column Depth – Hour 75.

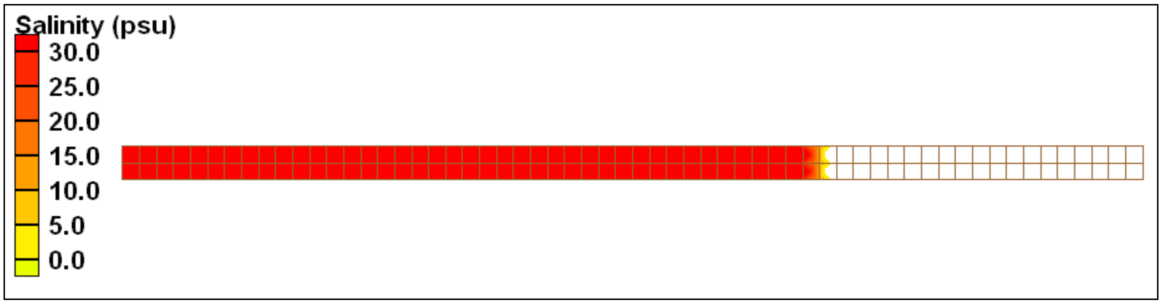

Figure 6. Salinity Distribution - Hour 45.

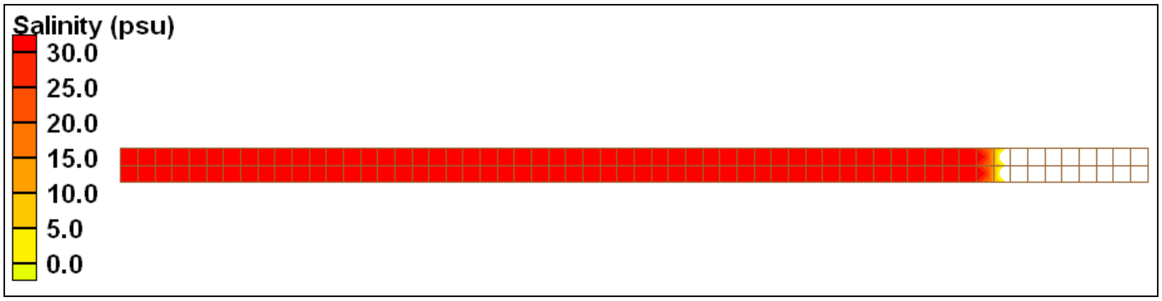

Figure 7. Salinity Distribution - Hour 75.

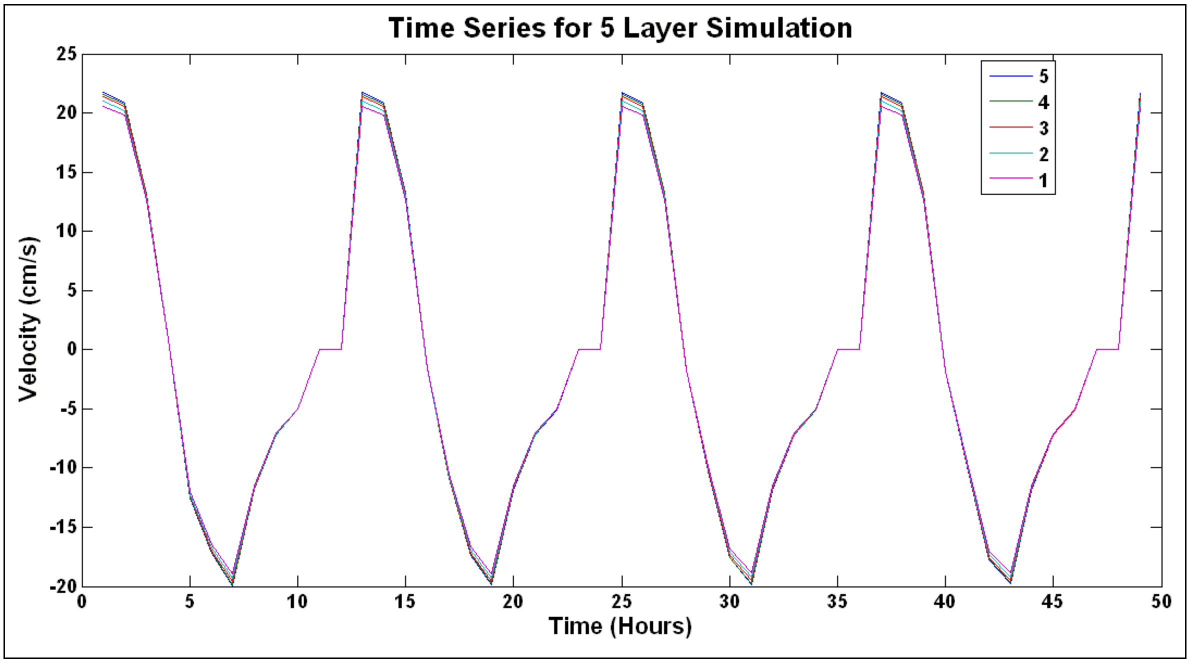

Figure 8. Vertical Velocity Distribution Time Series, Cell 44.

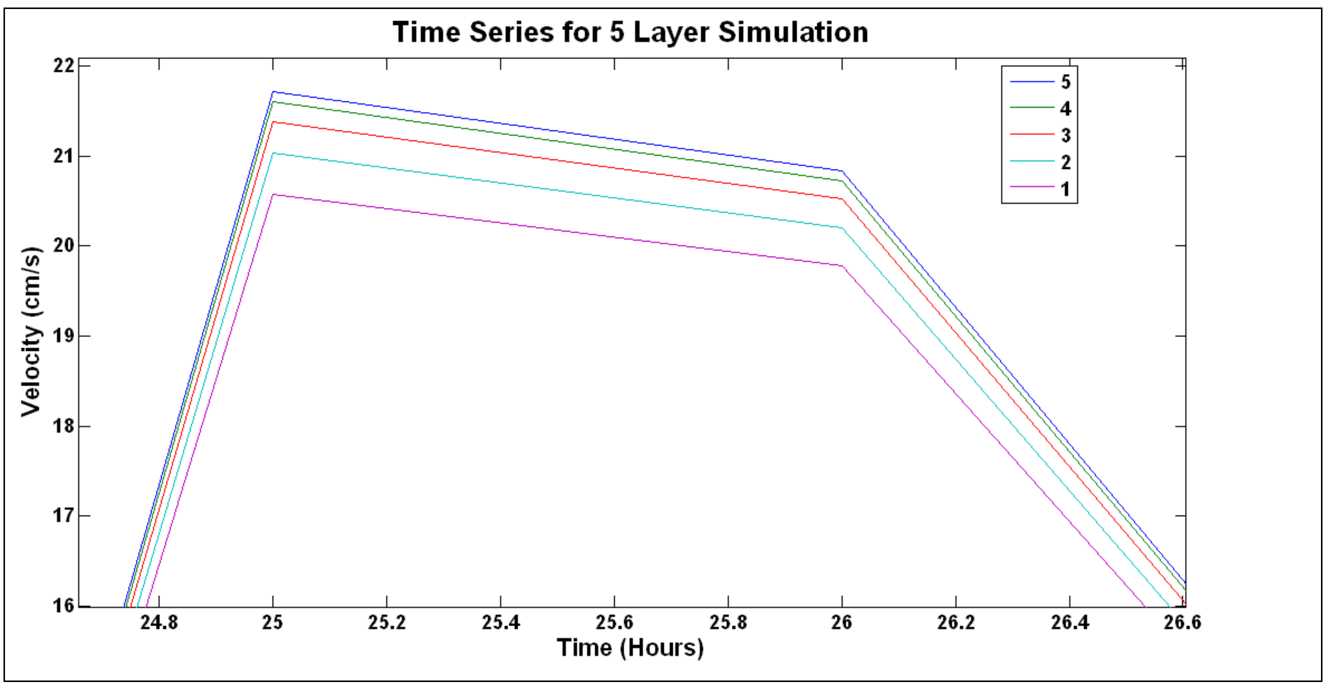

Figure 9. Vertical Velocity Distribution Time Series, Cell 44.

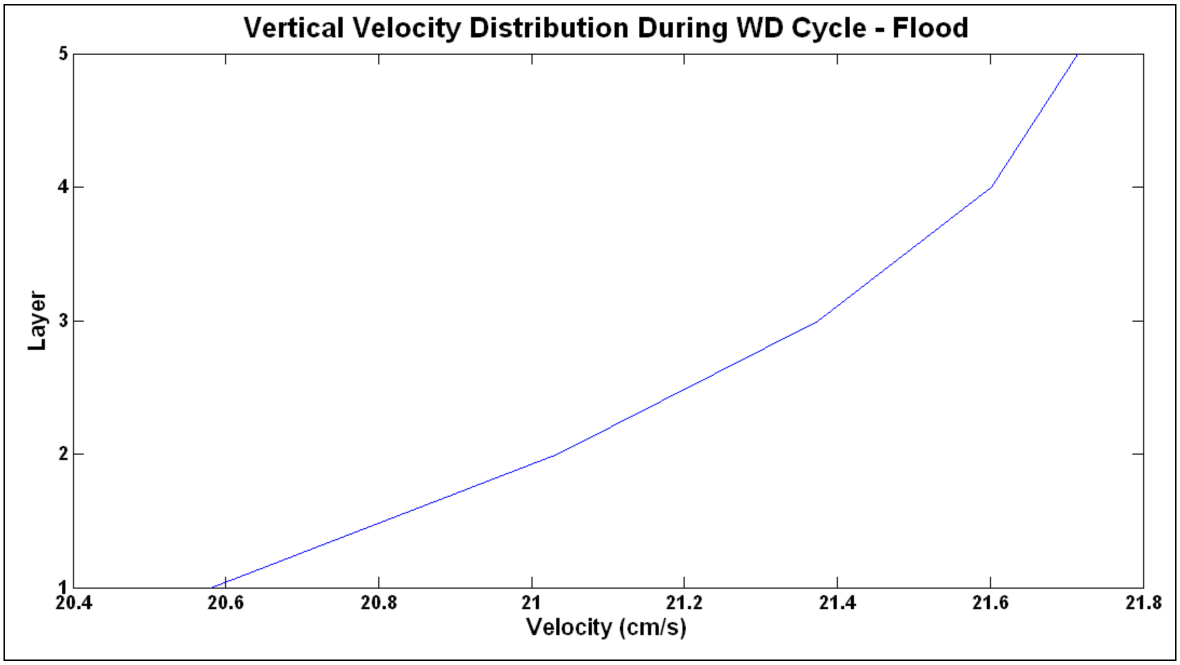

Figure 10. Vertical Velocity Distribution- Flood, Cell 44.

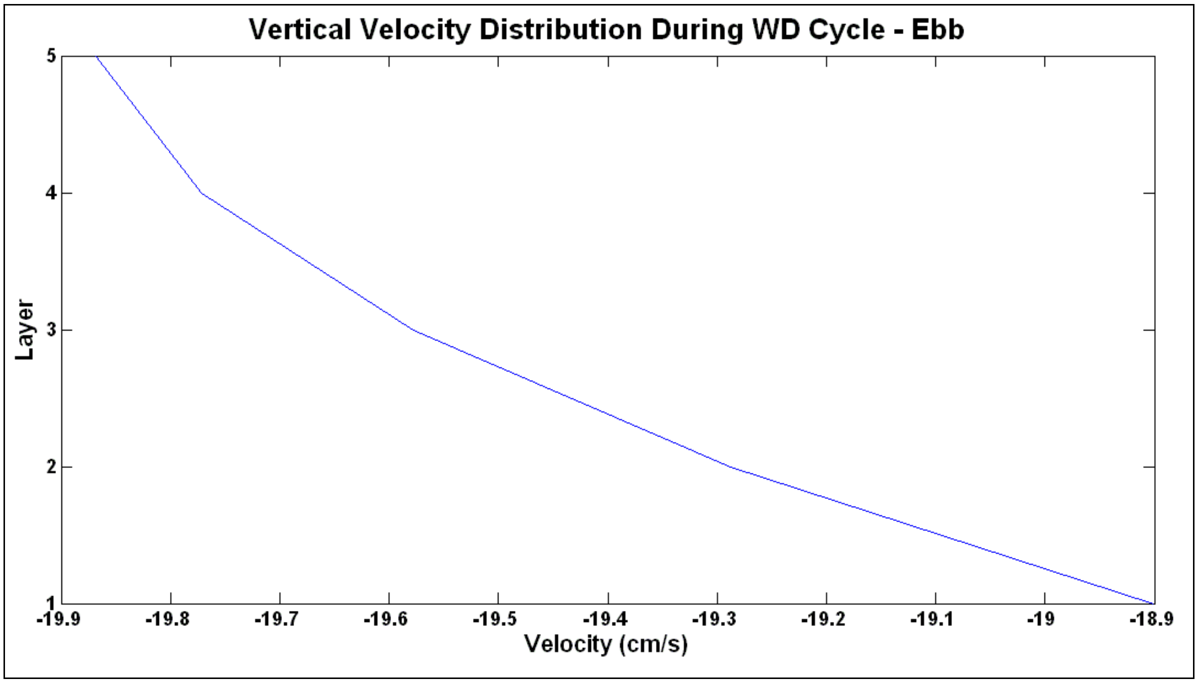

Figure 11. Vertical Velocity Distribution- Ebb, Cell 44.

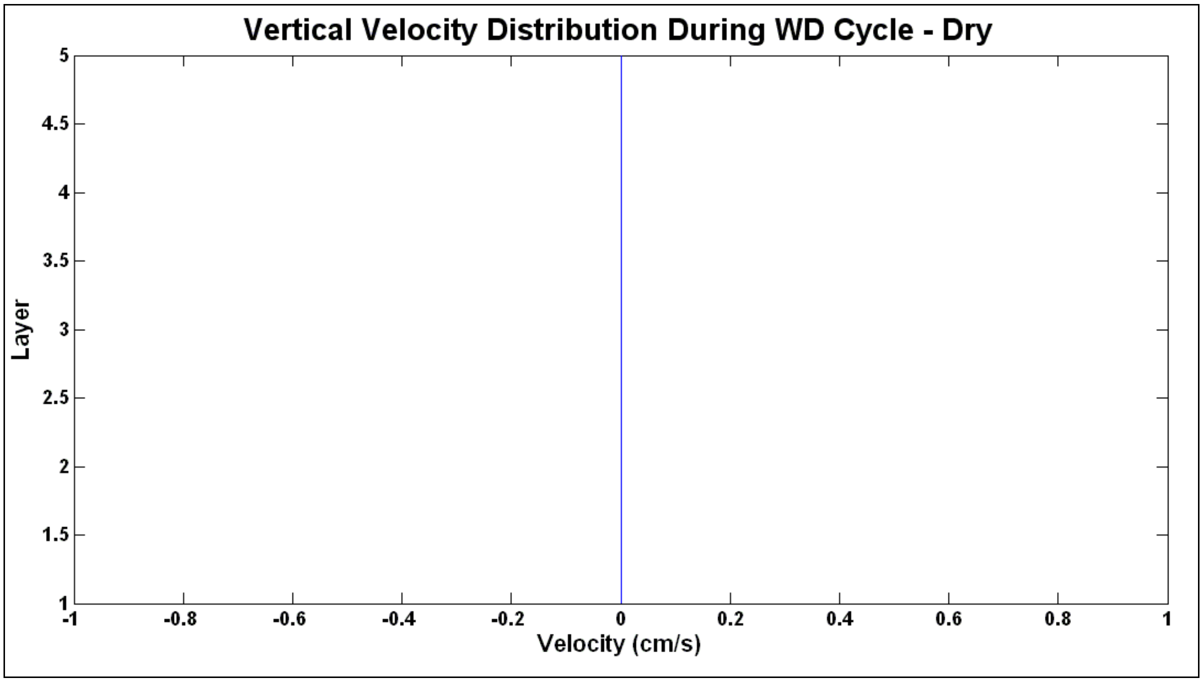

Figure 12. Vertical Velocity Distribution- Dry, Cell 44.

SUMMARY: Three-dimensional wetting and drying has been successfully implemented with the hydrodynamic and salinity transport modules of GSMB. Next, vegetative resistance will be implemented within the hydrodynamic module, followed by 3D wetting and drying in the sediment transport module.

Additional information: This technical note was previously published as ERDC TN-DOER-L but has been revised to reflect the correct series. This technical note should be cited as follows:

Chapman, R., P. Luong, S. Kim, and E. Hayter. 2021. *Development of Three-Dimensional Wetting and Drying Algorithm for the Geophysical Scale Transport Multi-Block Hydrodynamic Sediment and Water Quality Transport Modeling System (GSMB)*. ERDC/TN DOER-D23. Vicksburg, MS: US Army Engineer Research and Development Center.

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