Two-Dimensional Subgrid Sediment Transport Modeling with HEC-RAS

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Abstract

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) and Hydrologic Modeling System (HEC-HMS) share a two-dimensional (2D) flow solver which utilizes a subgrid modeling approach. The subgrid approach incorporates terrain information from the subgrid scale into the computations and significantly improves the model accuracy when the computational grid cells are larger than terrain resolution (Casulli 2009; Casulli and Stelling 2011). This feature allows the model to use relatively coarse computational grids while reducing computational times and maintaining an accurate solution (Sánchez et al. 2017).

This paper presents recent and ongoing developments in 2D sediment transport modeling within HEC-RAS. The flow is solved with either a shallow water equation or diffusion wave equation solver. Both solvers utilize Finite Volume Methods on an unstructured mesh with subgrid bathymetry. The 2D sediment model solves for total-load sediment transport with a finite volume advection-diffusion solver. Key model features include multi-sized sediment transport, variable particle density, variable bed density, hiding and exposure corrections, bed slope corrections, various transport potential formulas, various subgrid erosion and deposition formulations, sheet and splash erosion, simulation of non-erodible surfaces, and avalanching. HEC-RAS also updates the 2D mesh at subgrid scales based on simulated morphological change. The 2D morphodynamic subgrid modeling approach is similar to that used by HEC-RAS in one-dimensional (1D) simulations, but resolves many 2D specific processes including wetting and drying, bed roughness, erosion, deposition, bed composition and layering, at a subgrid level.

The approach presented here is different from previous 2D morphodynamics approaches developed by Volp et al. (2016) and Volp (2017) in that there is no high-resolution grid utilized and all of the sediment computations are done directly on subgrid property tables. The present approach utilizes both high-resolution and low-resolution property tables for simulating hydrodynamics and morphodynamics, respectively. The presented dual subgrid resolution approach allows for a great deal of flexibility in defining the subgrid resolution for simulating morphodynamics at different locations making the method very efficient computationally. A key feature of the subgrid method is that the subgrid property tables in the sediment model handle partially wet grid cells. This allows for consistent treatment of the wet and dry boundary.

This paper will present a short overview of the modeling features and capabilities. The model performance will be demonstrated with results from example verification and validation test cases as well as example applications.

Approach

The subgrid approach for hydrodynamics is largely based on the methods developed by (Casulli (2009) and Casulli and Stelling (2011). The approach consists of utilizing lookup property tables for various hydraulic variables at cells and faces. Figure 1 shows a schematic of a computational cell in which the bed elevations have been binned into discrete elevations. This produces a piece-wise constant elevation vs. area curve and a piece-wise linear elevation vs volume curve.

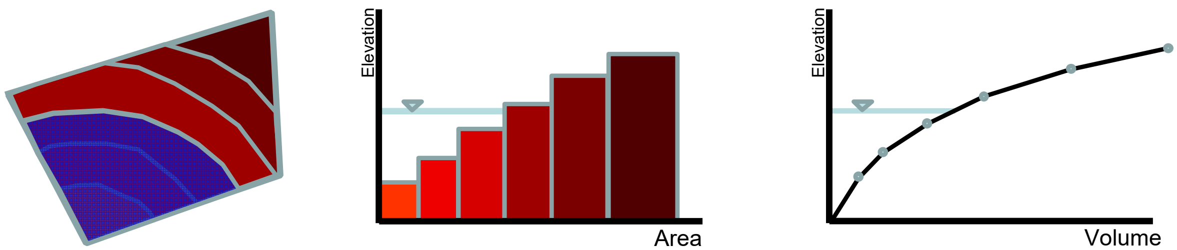

Figure 1. Schematic illustrating the subgrid concept for a computational cell.

Volp et al. (2016) presented a subgrid approach for morphodynamic modeling which utilizes a coarse grid for the hydrodynamics and a fine grid for the morphodynamics. However, since the entirety of the morphodynamic computations are done on the fine grid, it may be actually considered more a dual mesh approach with physics-based interpolation methods from the coarse grid to the fine grid for water levels and current velocities. Volp (2017) presented a subgrid approach in which the suspended-load is solved on the coarse grid but the bed-load transport and bed elevations are still computed on the high-resolution grid. Therefore, this sediment transport approach may be considered as only partially subgrid. The approach presented here is different in that there is no high-resolution grid utilized and all of the sediment computations are done directly on subgrid property tables. This method is very efficient computationally but is obviously is not as spatially explicit as the methods proposed by Volp et al. (2016) and Volp (2017).

In the present approach each computational cell has two sets of curves for the horizontal wetted area and water volume as a function of elevation. In addition, each face also has two sets of curves for the wetted horizontal length and vertical wetted area as a function of elevation. These curves are referred to as the subgrid curves. These sets of curves are relatively high-resolution and are utilized by the flow model in order to capture the effects of the subgrid bathymetry on the water storage and conveyance. The high-resolution (hydraulic) curves are obtained from a detailed terrain model, while the coarse (sediment) curves are derived from the hydraulic curves. In theory it is possible to utilize the same high-resolution curves for both hydraulic and sediment, but this would make the computational time and memory requirements for the sediment transport calculations prohibitively expensive. This is the reason why a second set of relatively coarse curves are utilized by the sediment transport model to compute the subgrid bed change, sorting and bed layering. It also allows for flexibility in defining the subgrid resolution for different parts of the domain depending on the objectives of a project. Figure 2 shows an example of the process of creating the coarse resolution area vs elevation curve utilized for sediment from the high resolution area vs elevation curve utilized for hydrodynamics. The hydraulic model utilizes 6 subareas, whereas the sediment model utilizes only 3. Figure 3 shows the process of modifying the two sets of curves as a function of bed change. Careful attention is placed to conserving mass and also keeping track of wet and dry bed erosion/deposition rates.

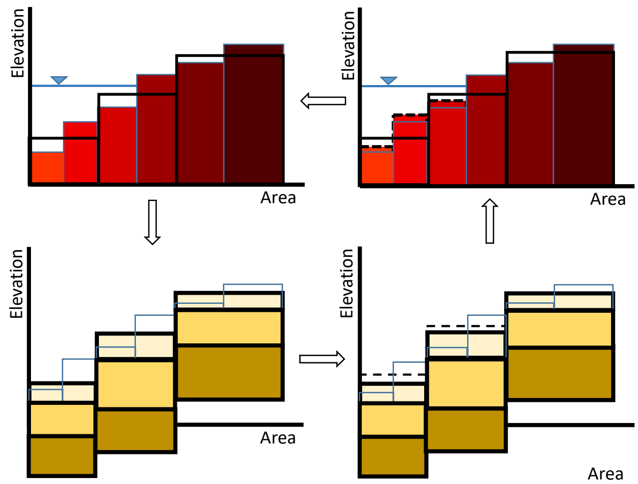

Figure 2. Schematic representing computation of bed change.

Results

The validation case presented is the West Fargo Diversion channel, ND (see Figure 3). The diversion consists of a 6.8-mile channel, which flows north from the City of West Fargo, ND. The bed material consists of mostly fine silts and clays. The 2D sediment transport model was setup for the diversion using only one cell across the channel in order to demonstrate the ability of modifying the subgrid bathymetry and hydraulic property tables. The model was run for approximately 13 years from 1992 (time of construction) to 2005.

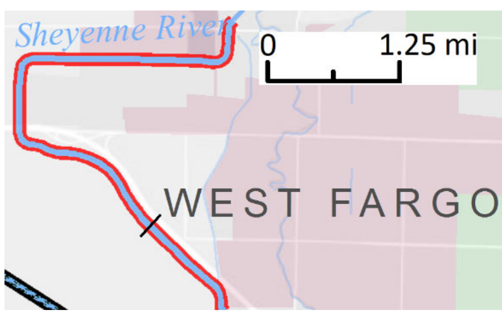

Figure 3. Map of the West Fargo Diversion Channel.

As an example result, Figures 4 shows the computed final subcell bed elevation and bed change at the approximate location indicated by a black line in Figure 3. The left panel shows the computed bed elevations vs horizontal area for the hydrodynamic (red) and sediment (blue) models. A fixed number of 10 subareas was used for the sediment model. Figure 5 shows the computed cross-sectional bed elevations and bed change. The model was able to reproduce the observed erosion in the pilot channel and deposition in the overbanks but under-predicted the bed change in general (Figures 4 and 5).

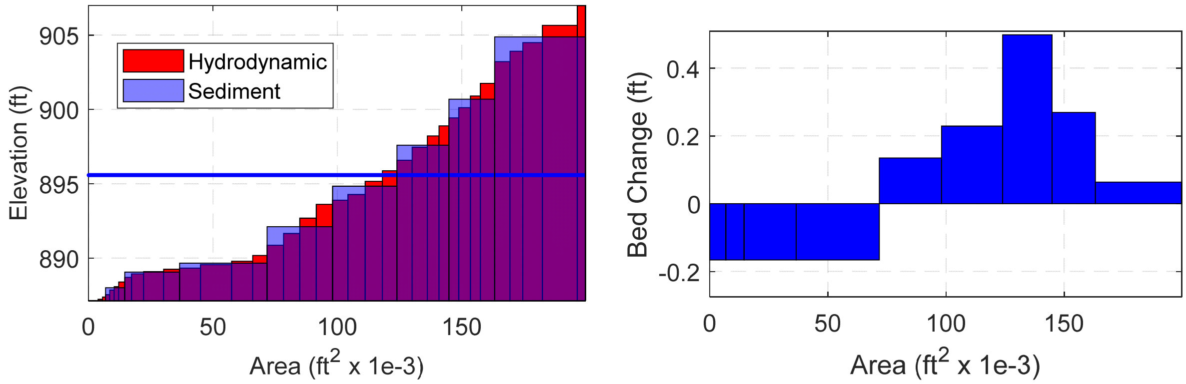

Figure 4. Example subcell bed elevations and bed change after approximately 12.8 years of simulation for the West Fargo Diversion Channel, North Dakota.

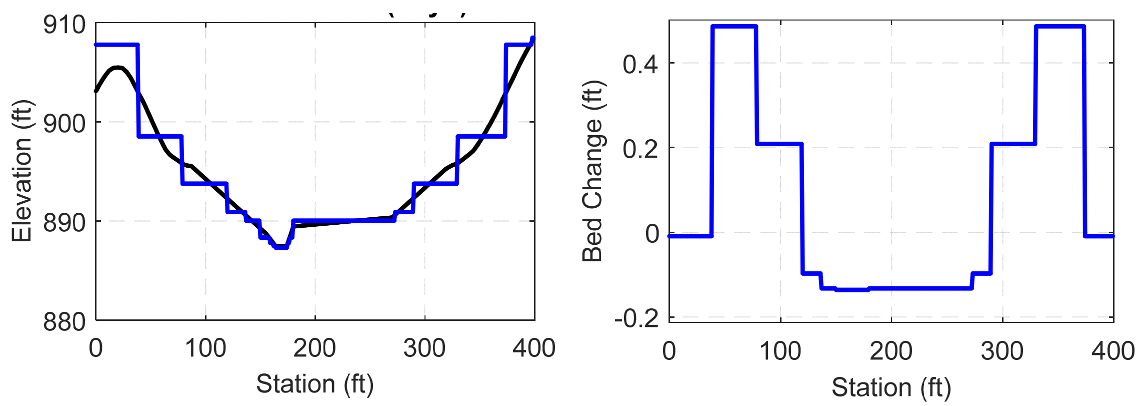

Figure 5. Example subface bed elevations and bed change after approximately 12.8 years of simulation for the West Fargo Diversion Canal, North Dakota.

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