HEC-RAS 2D Sediment User Manual

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1 Introduction

The Corp's Hydrologic Engineering Center River Analysis System (HEC-RAS) is designed to simulate one-dimensional (1D) steady, unsteady flow. The latest release of HEC-RAS V6.0 also simulates unsteady two-dimensional horizontal (2D) sediment transport, and bed change, sorting, and layering. Sediment transport is computed with a non-equilibrium total-load formulation. The total-load transport equation is solved with implicit Finite-Volume methods on the same unstructured polygonal mesh as the flow solver. Sediment transport is coupled to the flow model at the time step level. One powerful feature of the 2D flow solvers is that they use the subgrid topographic variations directly into the model thus improving the accuracy of the solution and permitting the use of relatively coarse meshes resulting in reduced computational times. The sediment transport model is designed to work within the subgrid framework of the flow model, and computes subgrid erosion and deposition rates, bed elevations, gradations, and bed layering.

This document discusses how to utilize the 2D sediment user-interface, the model input and output, and how-to setup and run a 2D sediment transport model in HEC-RAS. The document is intended as supplemental to the 1D Sediment Users Manual as many concepts and features are covered in detail in that document. Most of the 1D sediment capabilities are supported in 2D sediment and many new features have been added to 2D sediment which are not available yet in 1D sediment. Some of the new sediment features include variable density bed sorting and layering model, flocculation, consolidation, hiding and exposure effects, multiple new transport potential formula. However, as a beta release, there are still several computational and user-interface limitations and known issues including the inability to hot-start sediment, the inability to couple 1D and 2D sediment, the inability to modify terrains based on computed bed change, inability to visualize subgrid output directly in HEC-RAS, the inability to specify avalanching parameters in the user-interface, and the inability to specify subsidense in 2D areas. Lastly, the 2D sediment transport feature in HEC-RAS V6.0 is a beta feature and should not be used for design purposes.

1.1 Report Documentation Page

US Army Corps
of Engineers
Hydrologic Engineering Center

1.1.1 HEC-RAS River Analysis System

1.1.1.1 **Two-Dimensional Sediment Transport User Manual**

1.1.1.1.1 Version 6.1.0
September 2021

Approved for Public Release. Distribution Unlimited

<table>
<tr><td colspan="3">REPORT DOCUMENTATION PAGE</td><td>Form Approved</td></tr>
<tr><td colspan="4">Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the date needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</td></tr>
<tr><td>1. AGENCY USE ONLY (Leave blank)</td><td>2. REPORT DATE
September 2021</td><td colspan="2">3. REPORT TYPE AND DATES COVERED
Computer Program Documentation</td></tr>
<tr><td colspan="3">4. TITLE AND SUBTITLE
HEC-RAS Two-Dimensional Sediment User Manual</td><td rowspan="2">5. FUNDING NUMBERS</td></tr>
<tr><td colspan="3">6. AUTHOR(S)
Alejandro Sanchez</td></tr>
<tr><td colspan="3">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US ARMY CORPS OF ENGINEERS
HYDROLOGIC ENGINEERING CENTER (HEC)
609 Second Street
Davis, CA 95616-4687</td><td>8. PERFORMING ORGANIZATION REPORT NUMBER
CPD-69</td></tr>
<tr><td colspan="3">9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</td><td>10. SPONSORING / MONITORING AGENCY REPORT NUMBER</td></tr>
<tr><td colspan="4">11. SUPPLEMENTARY NOTES</td></tr>
<tr><td colspan="3">12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release. Distribution is unlimited.</td><td>12b. DISTRIBUTION CODE</td></tr>
</table>

<table>
<tr><td colspan="4">13. ABSTRACT (Maximum 200 words)</td></tr>
<tr><td colspan="3" rowspan="2">14. SUBJECT TERMS
water surface profiles, river hydraulics, steady and unsteady flow, One-dimensional and two-dimensional sediment transport, computer program</td><td>15. NUMBER OF PAGES</td></tr>
<tr><td>16. PRICE CODE</td></tr>
<tr><td>17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED</td><td>18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED</td><td>19. SECURITY CLASSIFICATION OF ABSTRACT
UNCLASSIFIED</td><td>20. LIMITATION OF ABSTRACT
UNLIMITED</td></tr>
</table>

1.1.2 HEC-RAS River Analysis System

1.1.3 Two-Dimensional Sediment Transport User Manual

1.1.3.1 Version 6.1.0 September 2021

U.S. Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil[1]

1.1.3.2 River Analysis System, HEC-RAS

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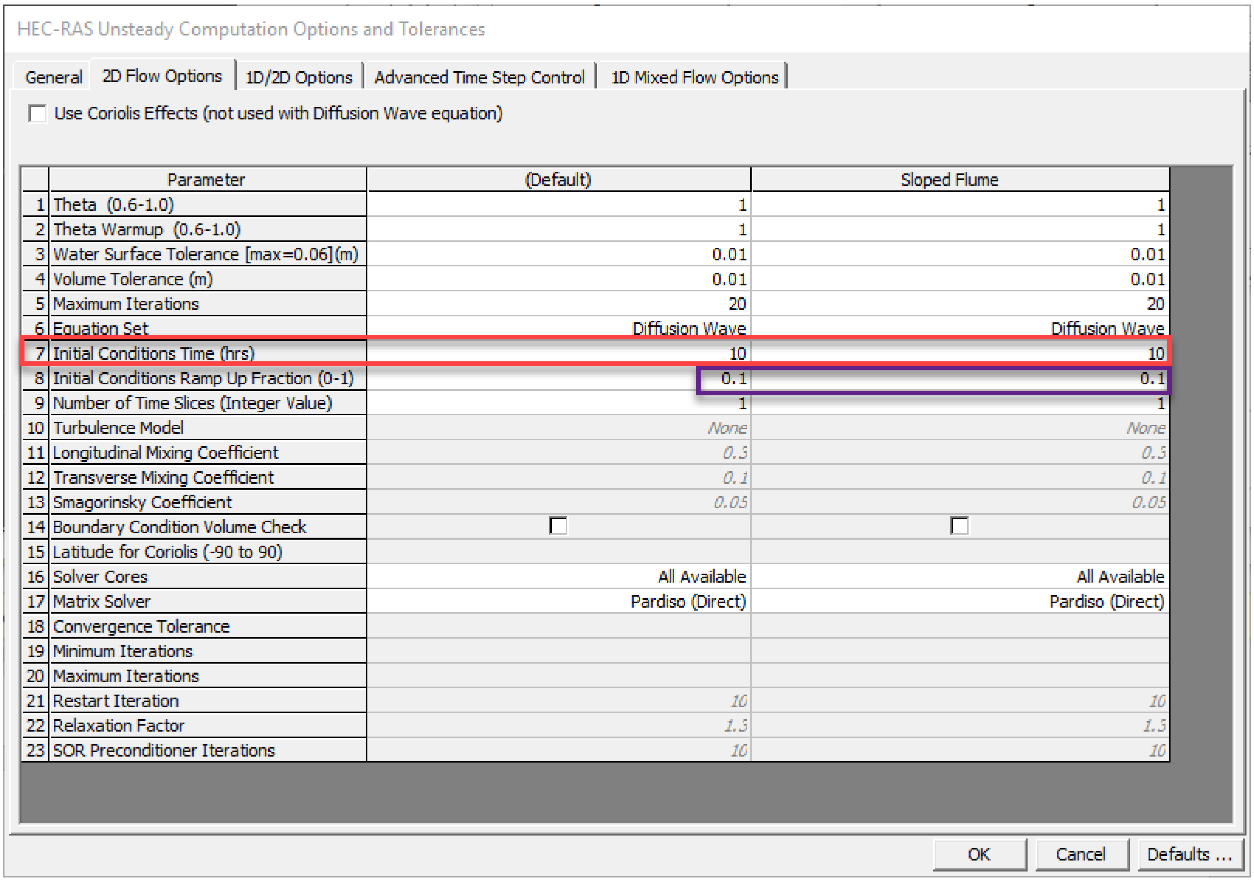
2 Hydraulic Best Practices for a 2D Sediment Model

Sediment models are often more sensitive to hydraulic modeling choices than fixed bed models. Adding sediment to a hydraulic model that runs and generates reasonable results often exposes model problems hidden by the robustness of the hydraulic equations or approximations that were sufficient for hydraulic analysis but not for sediment modeling. Sediment modelers should consult the 2D hydraulics manuals to help them construct an excellent, calibrated hydraulic model before they move on to a sediment simulation. However, this section summarizes several of the hydraulic modeling best practices (and most common mistakes) that will propagate into strong or poor sediment results.

2.1 Hydraulic Warm Up

<u>One of the most important hydraulic parameters for sediment modeling is the **hydraulic warm-up period**</u>. Unless the prototype starts dry and pushes a wetting front through the domain, it is essential to use a hydraulic warm up period for the a 2D sediment model. A hydraulic model can often pass through a wetting phase at the beginning of a simulation without affecting the final results (this is not best practice but can produce acceptable results in some cases). If the sediment model runs without a warmup period, it will scour as the wetting front initialized the model and bias the result.
HEC-RAS will only run hydraulics during the first half of the warmup period, and then will add sediment warm up during the second half. Choose a warmup period that wets the mesh fully during the first half. HEC-RAS does not populate a warmup period by default. Define this parameter by slecting *OptionsComputational Options and Tolerances…* and selecting the **2D Flow Options** tab.
Define the **Initial Contidions Time (hrs)** and the **Ramp Up Fraction** (the portion of the Initial Conditions Time the model will take to gradually get up to the full warm up flows – often 0.1). Run the hydraulic model (without sediment) to make sure this time is sufficient to reach an initial steady-state flow condition.



	Parameter	(Default)	Sloped Flume
1	Theta (0.6-1.0)	1	1
2	Theta Warmup (0.6-1.0)	1	1
3	Water Surface Tolerance [max=0.06](m)	0.01	0.01
4	Volume Tolerance (m)	0.01	0.01
5	Maximum Iterations	20	20
6	Equation Set	Diffusion Wave	Diffusion Wave
7	Initial Conditions Time (hrs)	10	10
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9	Number of Time Slices (Integer Value)	1	1
10	Turbulence Model	None	None
11	Longitudinal Mixing Coefficient	0.3	0.3
12	Transverse Mixing Coefficient	0.1	0.1
13	Smagorinsky Coefficient	0.05	0.05
14	Boundary Condition Volume Check	☐	☐
15	Latitude for Coriolis (-90 to 90)		
16	Solver Cores	All Available	All Available
17	Matrix Solver	Pardiso (Direct)	Pardiso (Direct)
18	Convergence Tolerance		
19	Minimum Iterations		
20	Maximum Iterations		
21	Restart Iteration	10	10
22	Relaxation Factor	1.3	1.3
23	SOR Preconditioner Iterations	10	10

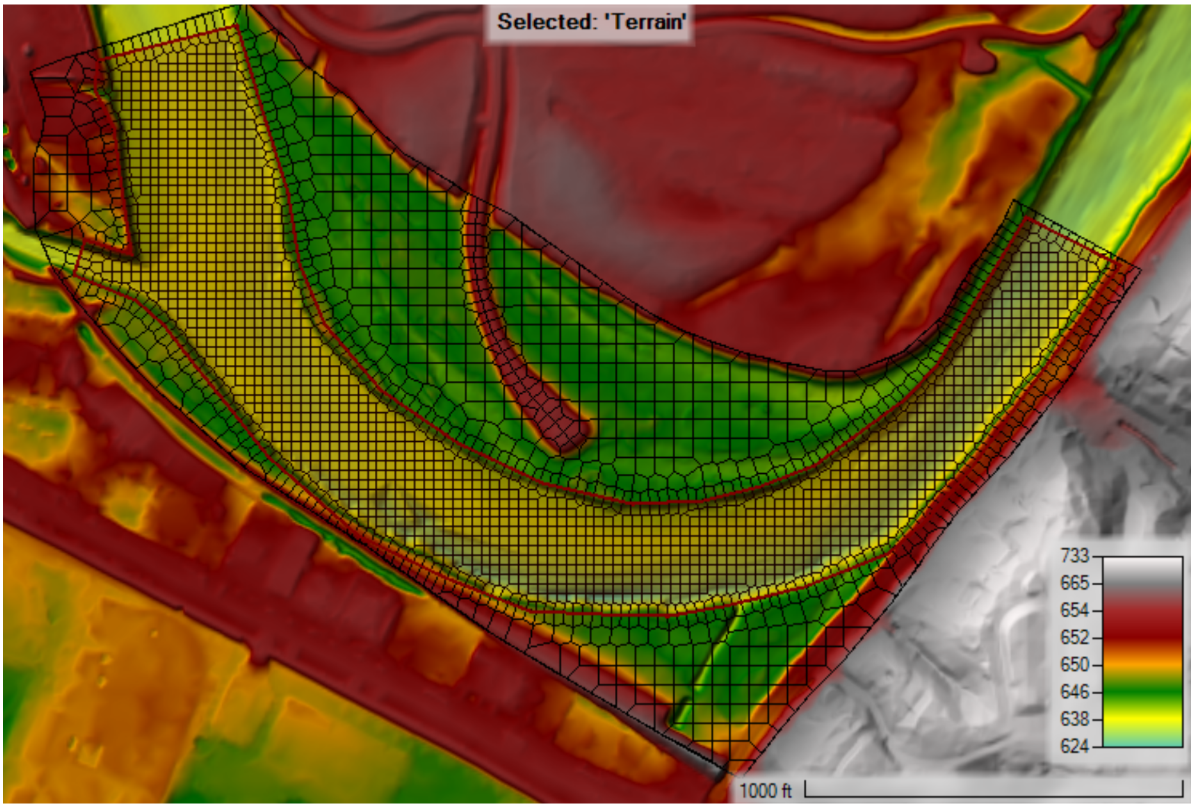
Figure 1. HEC-RAS Unsteady Computation Options and Tolerances editor.

2.2 Mesh Quality

Although HEC-RAS can compute on highly irregular meshes, poor mesh quality will decrease the accuracy of the numerical solution and can lead to poor convergence and numerical instabilities. Mesh quality affects both the flow and sediment, but it is especially important when simulating sediment transport. Generating a mesh is an iterative process and may require running simulations in order to identify problem areas or areas which require their resolution adjusted in order to resolve the flow or sediment transport.

2.2.1 Mesh Alignment

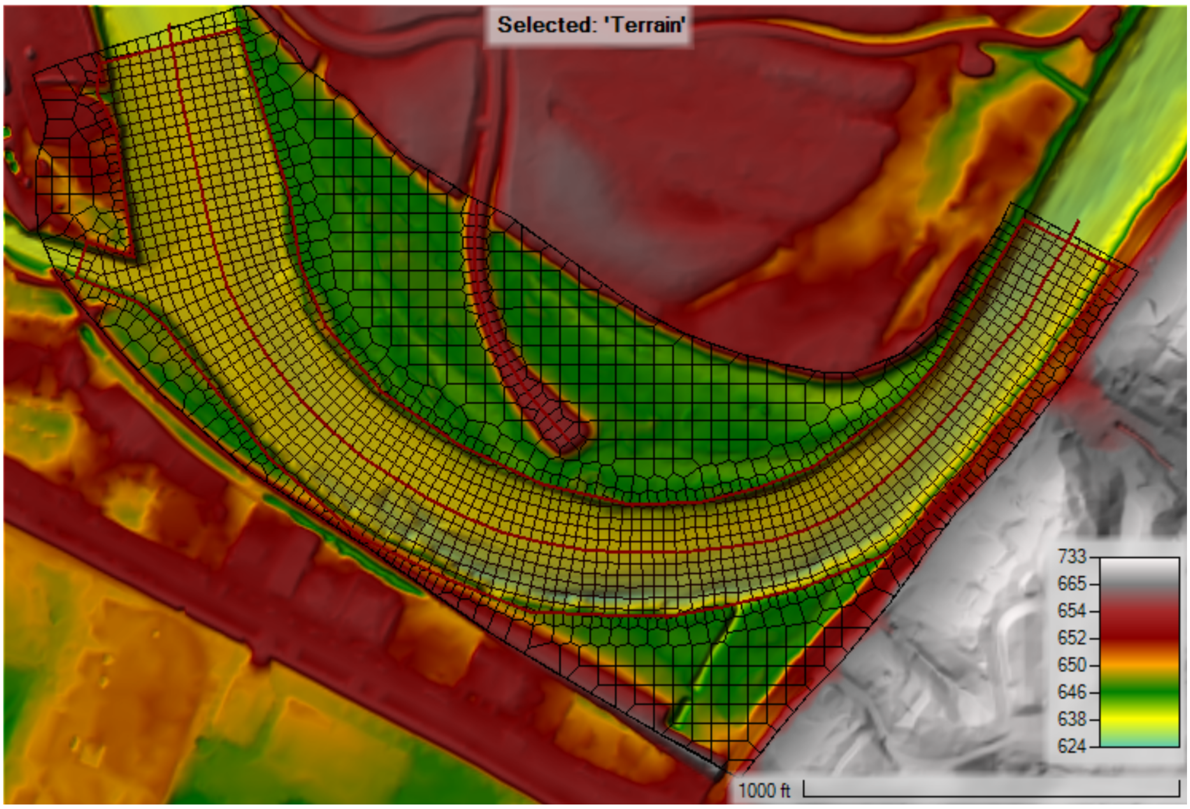
With 2D flow and sediment transport, the HEC-RAS will produce better results if the mesh is oriented or aligned with the flow. This reduces numerical diffusion and improved computational accuracy. In the example below, a refinement region is used to increase the spatial resolution (25 ft) within the channel. The refinement region allows for a more resolution within the channel while maintaining coarse resolution outside of the channel, thus reducing the total number of computational cells and computational costs. The refinement region also also aligns the channel banks which also improves the model results. However, the issue with this approach is the that the cells are not aligned with the flow producing more numerical diffusion. In addition, the regions in between the square or rectangular cells within the refinement polygon and the boundaries of the refinement polygon can have relatively irregular cells and relatively poor mesh quality.



1 Example of a computational mesh with a simple refinement regions within the channel.

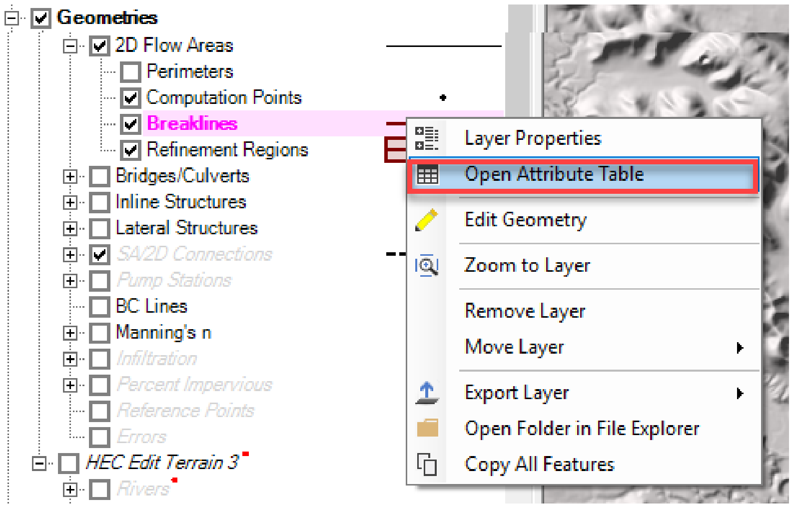
2.2.2 Aligning the Mesh with a Breakline

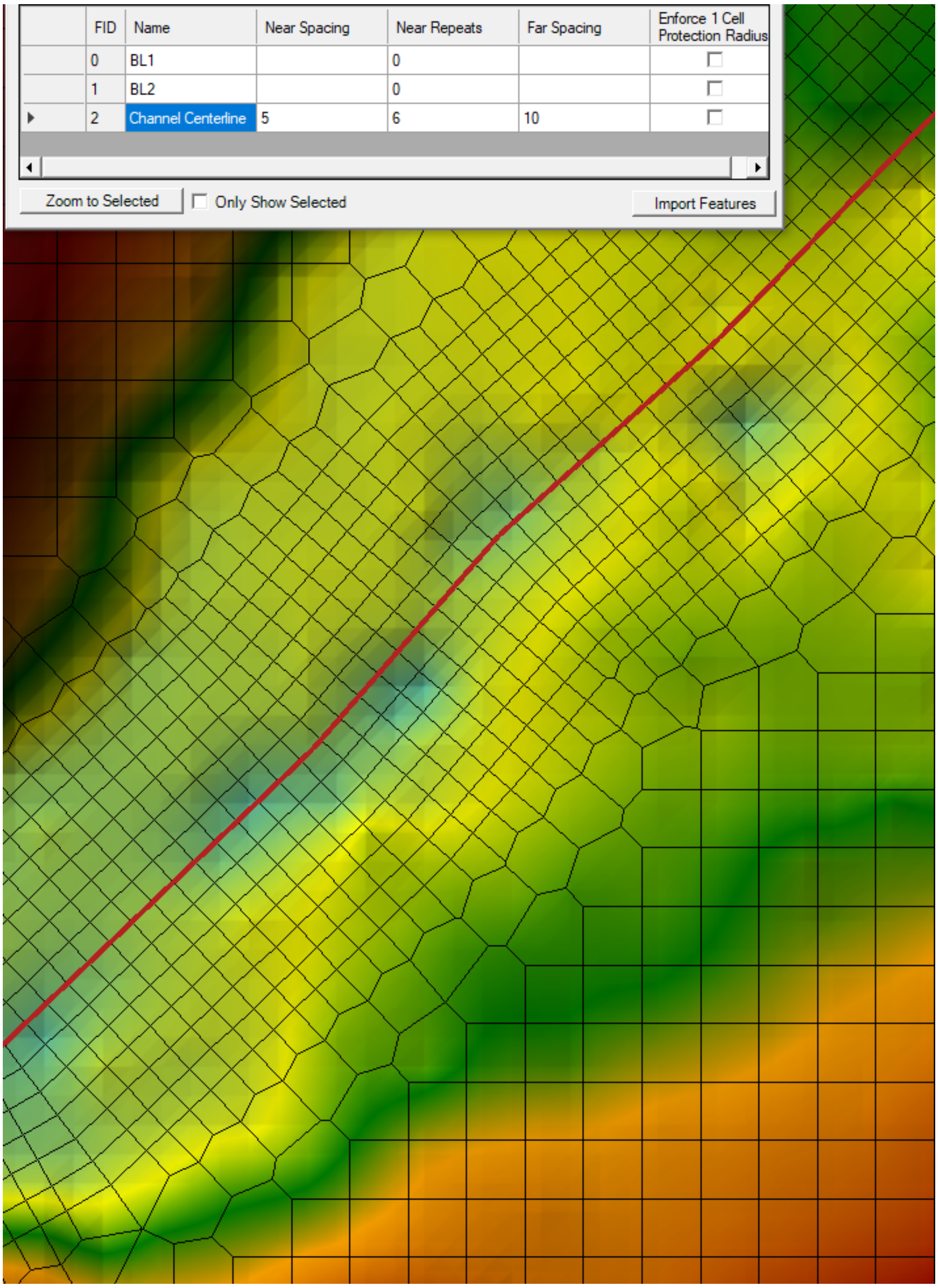
To improve the mesh alignment with the flow, a break line is inserted along the centerline of the channel as shown in the figure below. The breakline is added with 6 repeat points and a 30-ft spacing.



2 Example computational mesh with cells in the channel aligned with the direction of flow.

To "repeat points" right click on the break line in the RASMapper Tree and select **Open Attribute Table**.



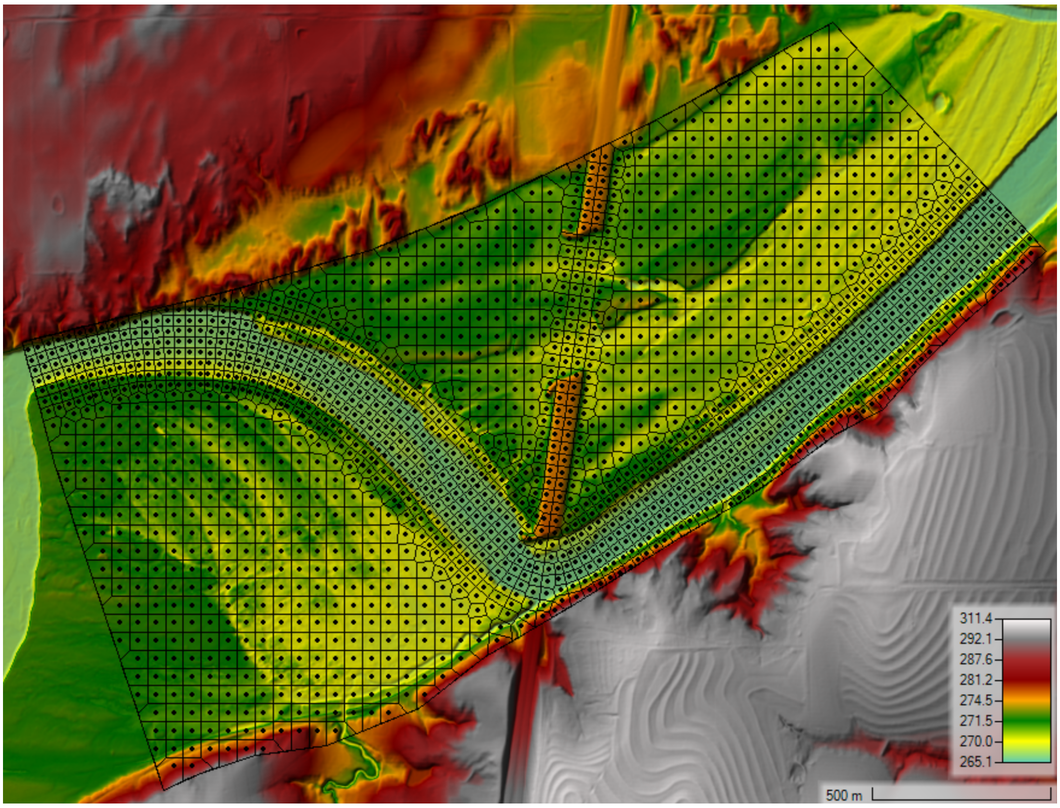


Then specify the size of the aligned cell and the number of repetitions. Enforcing the protection radius can cause awkward transitions between the aligned mesh and the original, orthogonal mesh. It is often useful *not* to enforce the 1 cell protection radius unless the channel is bounded by a levee or other high ground you need to resolve precisely.

When using breaklines around bends, the inside of the bend can have computational points which are very close to each other. Similarly, the outside of bends have points spread too far apart. This areas may need manual adjustment by inserting and removing points where necessary.

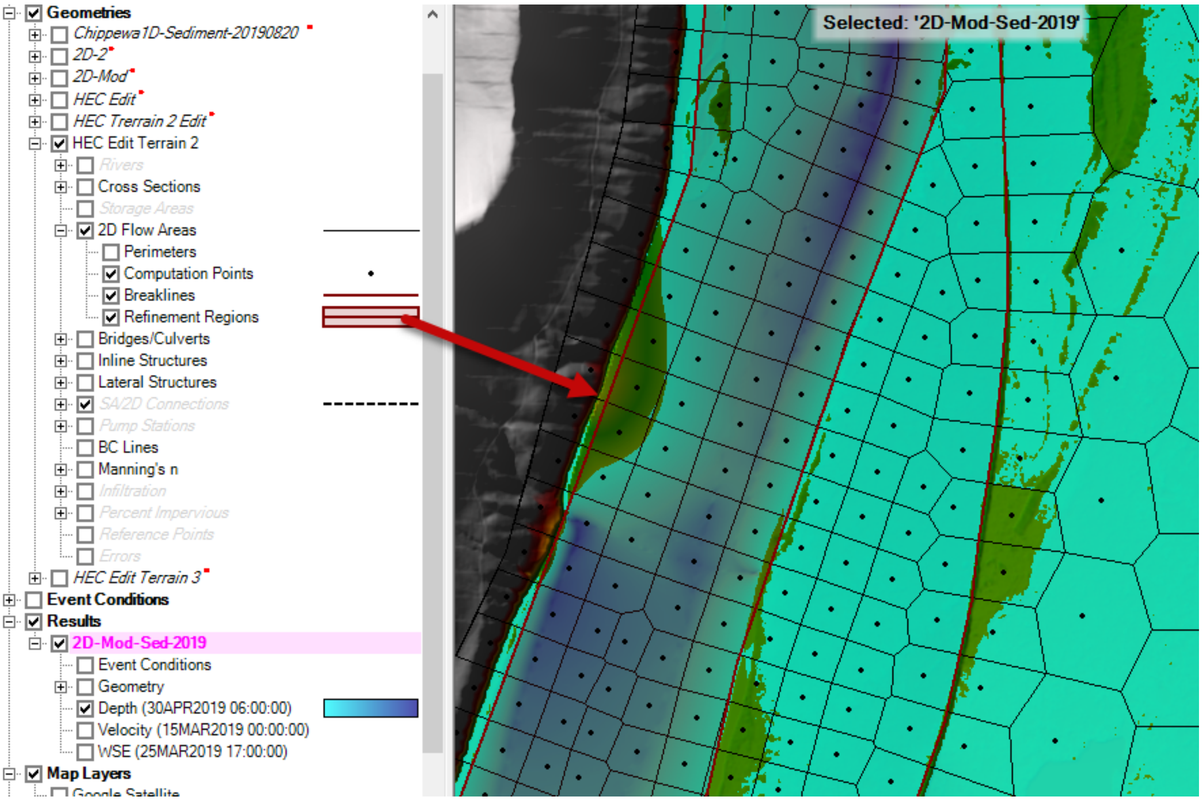
When editing the mesh manually, it is often useful to turn on and off the computational edges and terrain in order to identify gaps in spatial resolution, to identify small edges, and to align edges with the terrain features and principle flow direction.

An example of how the corrected mesh with improved transitions areas is shown in the figure below.



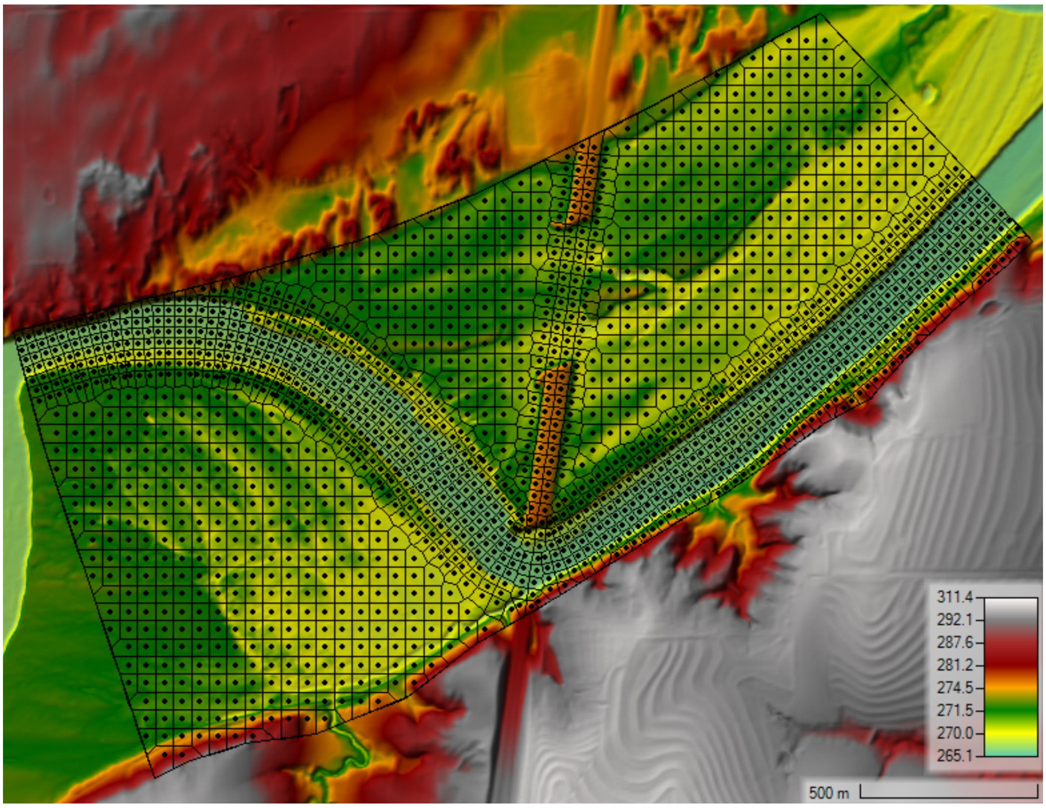
2.2.3 Aligning the Mesh with a Refinement Region

Refinement Regions aligned in the direction of flow can also align cells with the flow direction, however, these will often require some manual editing after enforcing the refinement. Refinement regions can be more detailed or have the same cell spacing as the surrounding mesh.

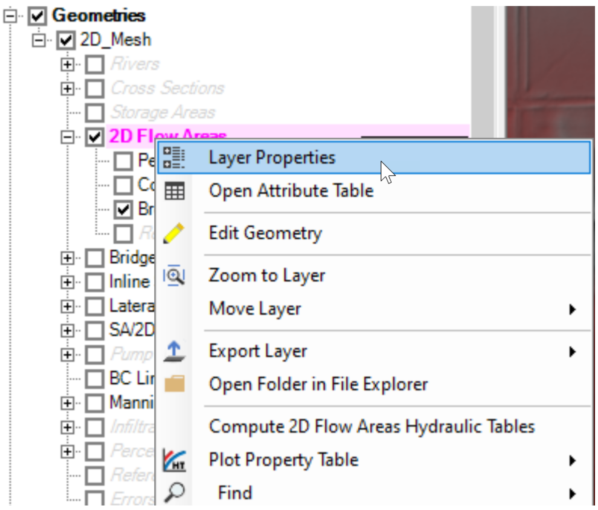


2.2.4 Identifying Poor Transition Areas and Adding Computational Points Manually

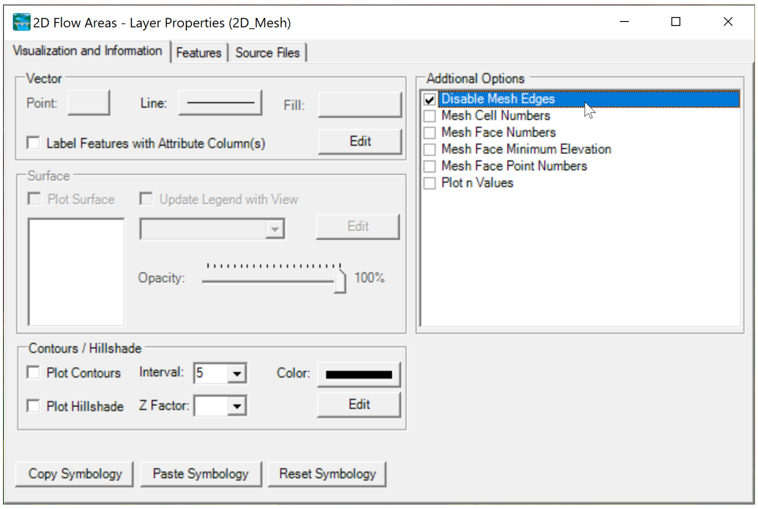
When creating a computational mesh, often the transition areas near refinement reaches or breaklines have spatial resolutions which are coarser than the the neighboring areas. Below is an example of a computational mesh which was generated by adding two breaklines; one following the channel centerline, and one following a roadway embankment.



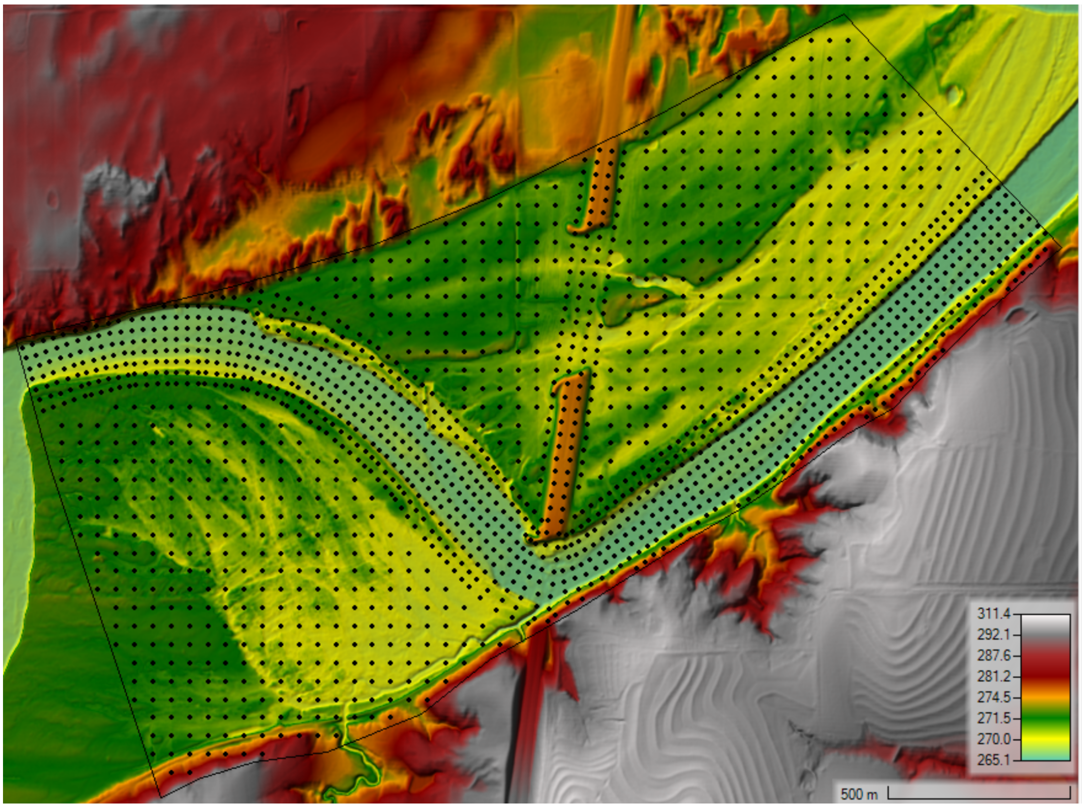
At first glance the computational looks reasonable. However, the transition areas between the breaklines and coarser parts of the mesh have some problem areas which can be easily identified by turning on the computational points and turning off the edges (faces). The mesh edges can be done by right-clicking on the **2D Flow Area** and selecting **Layer Properties** as shown in the figure below.



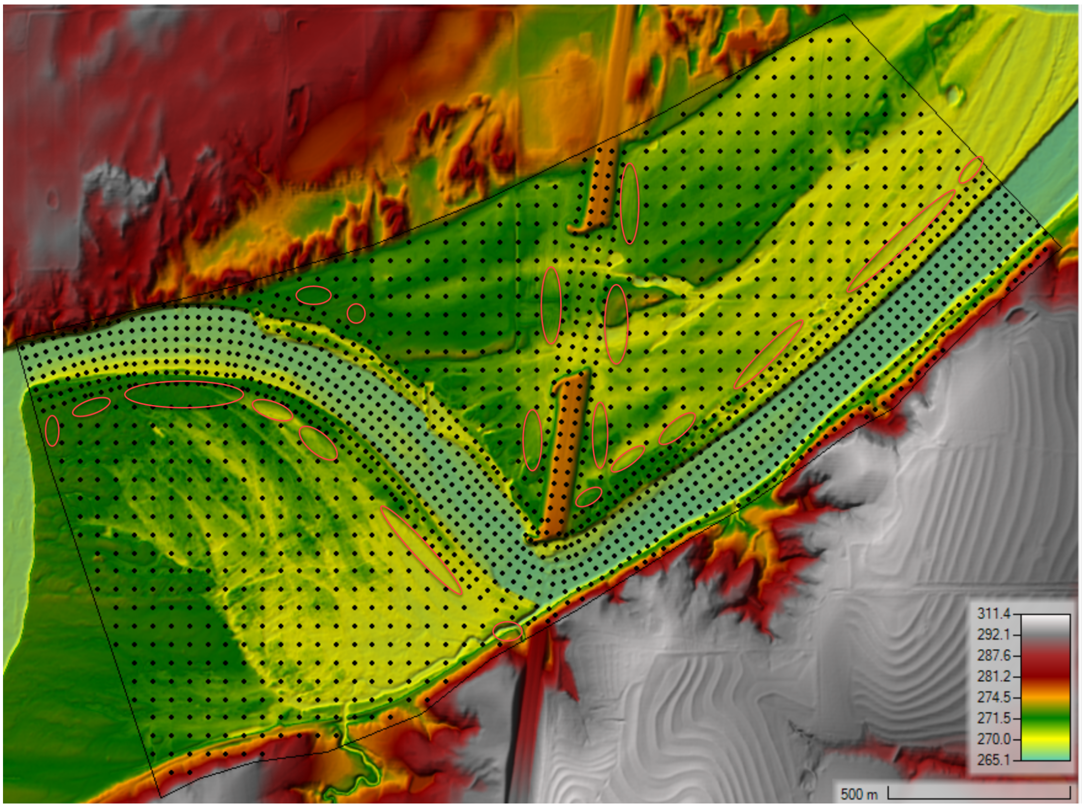
This will open the **2D Flow Areas - Layer Properties** editor. In the section **Additional Options** select the option **Disable Mesh Edges.**



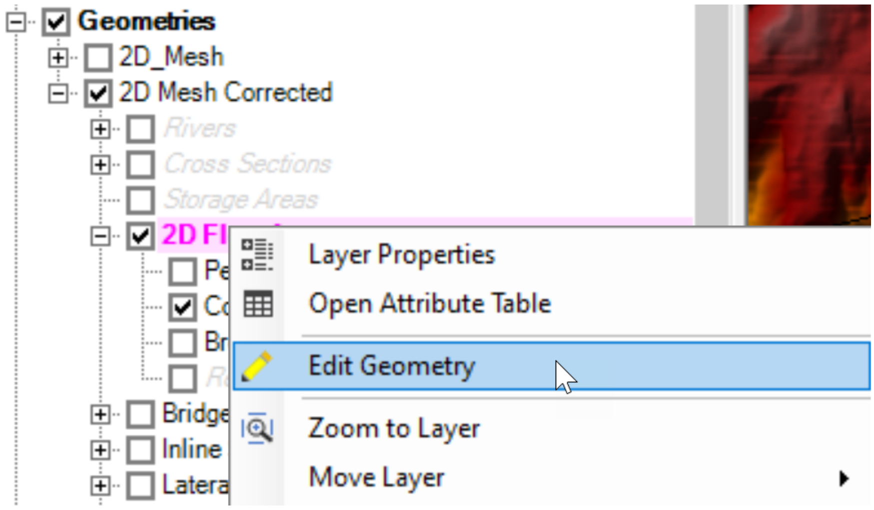
Once the **Computational Points** are turned on the **Mesh Edges** turned off, the computational mesh should look like this:



The poor transition areas are identified as holes in the computational points. These areas are highlighted with ellipses in the figure below.



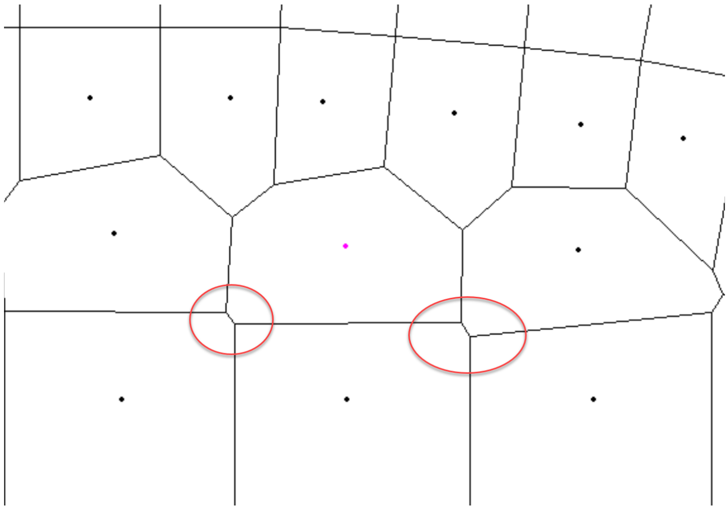
The best way to fill in the "holes" in the computational points is to edit the mesh and add points manually. This is done by right-clicking on the mesh and selecting **Edit Geometry** as shown in the figure below.



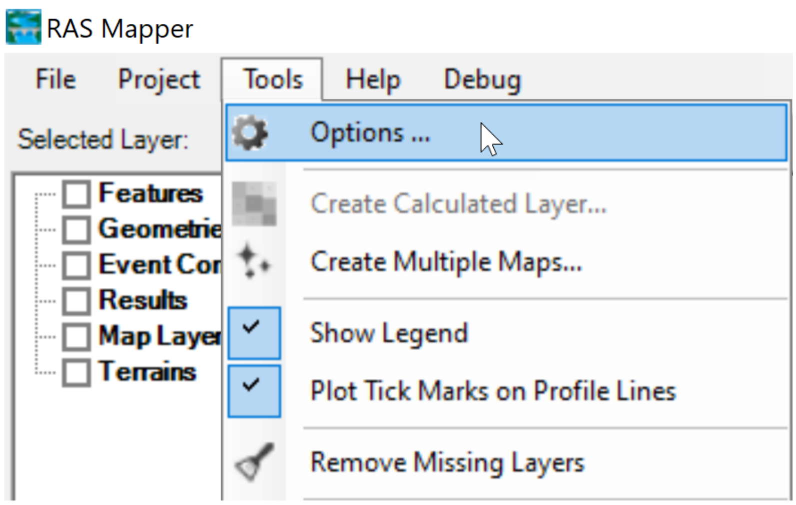
Next, add and move existing **Computational Points** so that the there are smooth transitions in resolution and there are no gaps in resolution.

2.2.5 Small Cell Faces

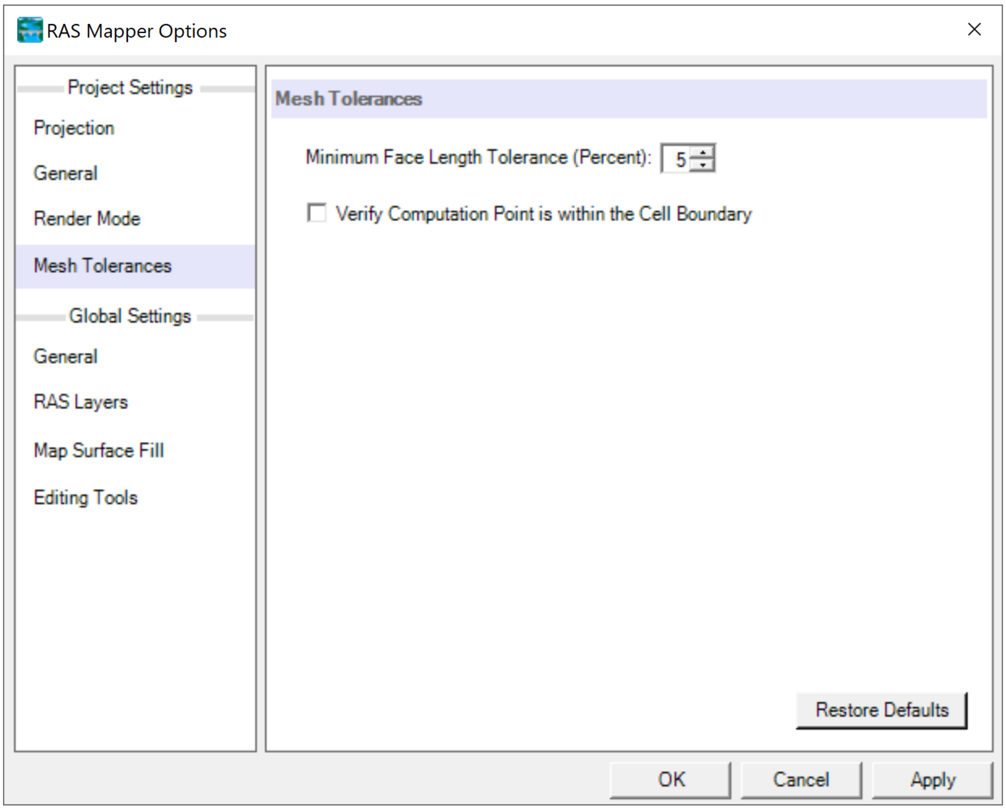
The HEC-RAS mesh generator has a tolerance for the Minimum Face Length. The Tolerance is the minimum face length specified as a percentage of the distance between neighboring computational points. The default value in versions 6.1 and earlier is 5%. This value is relatively small for sediment simulations and can lead to reduced stability and also increases the computational time and memory. The figure below shows an example of small faces produces by a **Minimum Face Length Tolerance** of 5%.



Small faces can be reduced by either manually nudging computational points or by increasing the **Minimum Face Length Tolerance**. The value can be changed in RAS Mapper **Options** editor (see figure below on how to open editor).

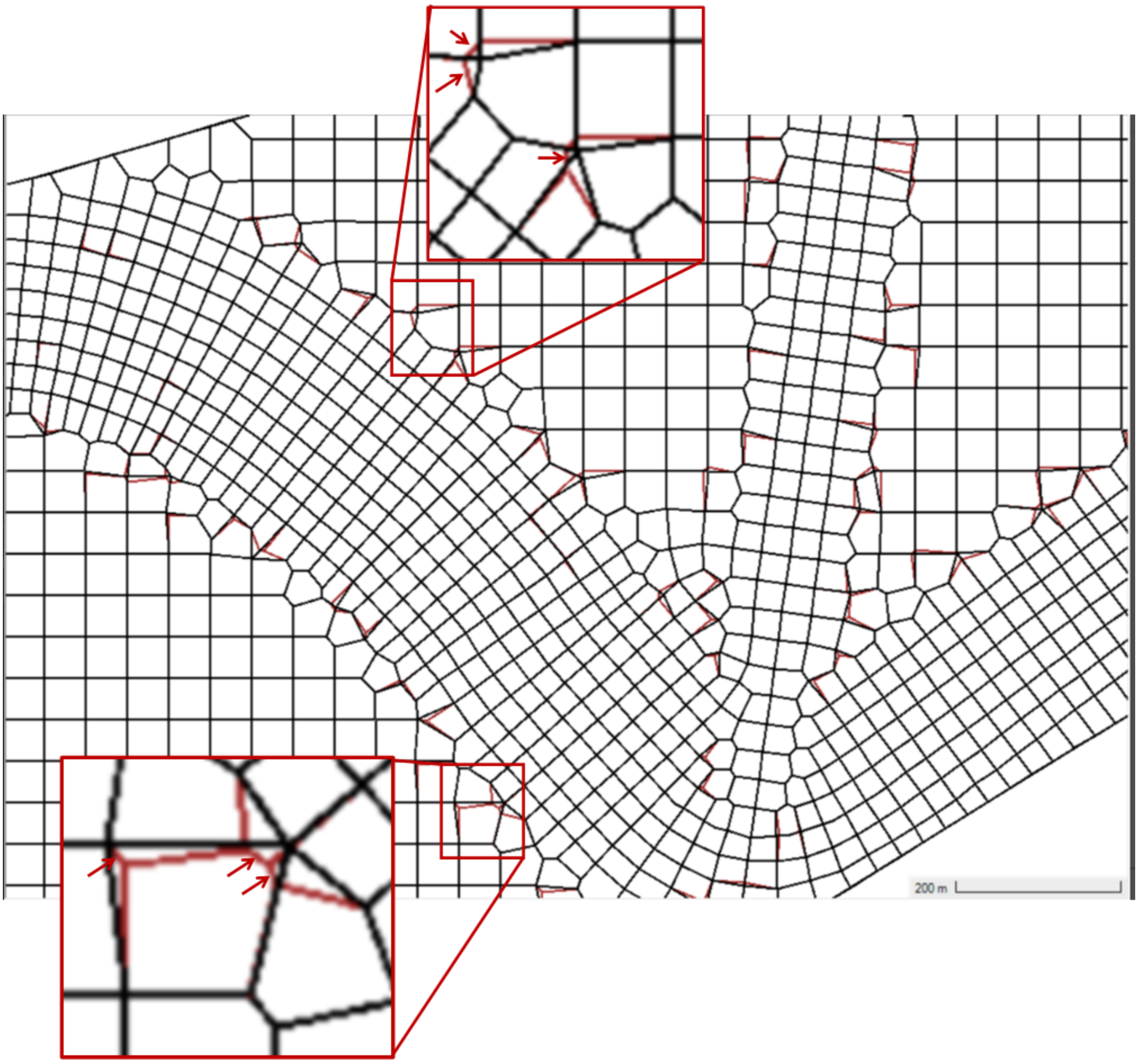


The **Minimum Face Length Tolerance** is found in the **Mesh Tolerances** section of the **Options** editor (see figure below).



For 2D sediment simulations, a **Minimum Face Length Tolerance** of about 15 to 25% has been found to work well.

An example is shown in figure below where the red mesh correspond to a **Minimum Face Length Tolerance** of 5% and the black mesh corresponds to **Minimum Face Length Tolerance** of 20%.

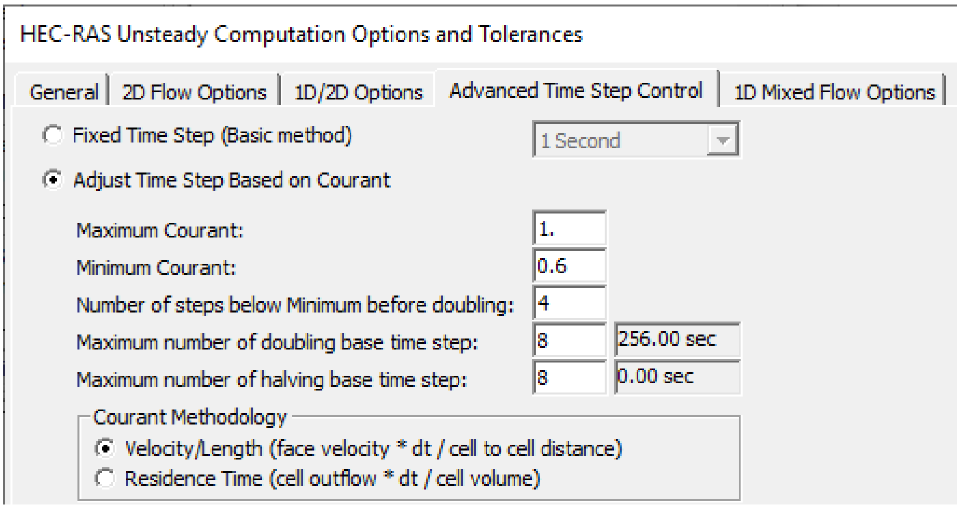


2.3 Selecting a Time Step

2.3.1 Fixed vs Adaptive Time steps

The time step is the most common issue with 2D sediment models that do not run.

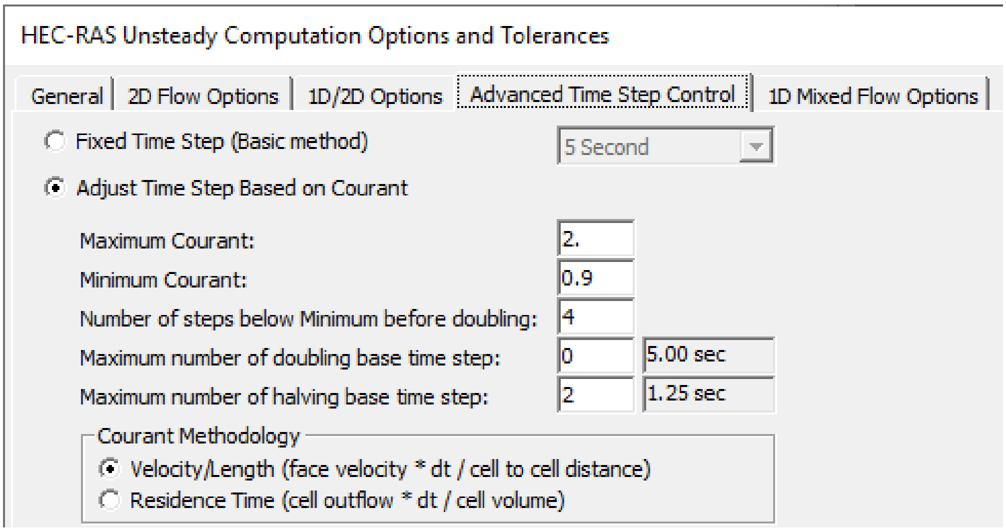
Modelers usually try to run the 2D sediment model with time steps that are too large. By default, the hydraulic and sediment time steps are equal unless the user enters a Sediment Computation Multiplier larger than 1 (more on this later). There are two options for selecting a time step for the hydraulic model in HEC-RAS. The first is a fixed time step. This option uses a constant time step throughout the simulation. This option is useful for simple datasets including laboratory or analytical test cases. For most real-life cases, the user will want to use the second time step option which is the adaptive time step. In this method, the time step is adjusted so that the Courant number is always within a user-specified range. The **Advanced Time Step Control** under the **Unsteady Computation Options and Tolerances** includes options for adaptive time steps that will change during the simulation. The option to **Adjust Time Step Based on Courant** is the most widely used and is becoming standard practice for 2D modeling. Define a maximum and minimum Courant condition and then the maximum halving or doubling steps allowed from the base time step, and the model will compute the appropriate time step throughout the model



Modeling Note: The Computational Efficiency of Small Time Steps

It seems intuitive that smaller time steps generate larger run times. However, HEC-RAS will iterate on each solution until it reaches an acceptable tolerance. Iteration is computationally expensive and smaller time steps often iterate less. Therefore, selecting a smaller time step will often reduce the number of iterations, leading to less additional run time than users often expect. In rare cases, a smaller run time can actually speed the model up by more-than-compensating for the additional time steps by neutralizing iterations.

* The Implicit Finite Volume solver in HEC-RAS 1D and 2D is not Courant limited. So the Courant Condition is more of a stability guideline and time-step selection support, than the hard limit it can be in other, explicit, solvers. Therefore, modelers sometimes set their max Courant condition closer to 2, without introducing computational issues or instabilities.



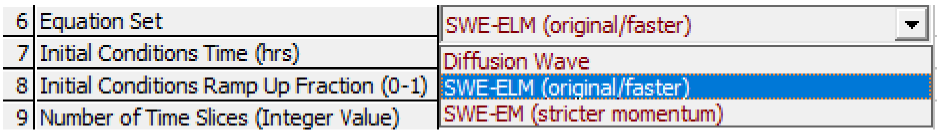
It is important to mention that the current adaptive time step method does not consider any sediment processes such as bed change in computing the time step. These will be added to HEC-RAS in future versions through additional criteria.

2.3.2 Sediment Computation Multiplier

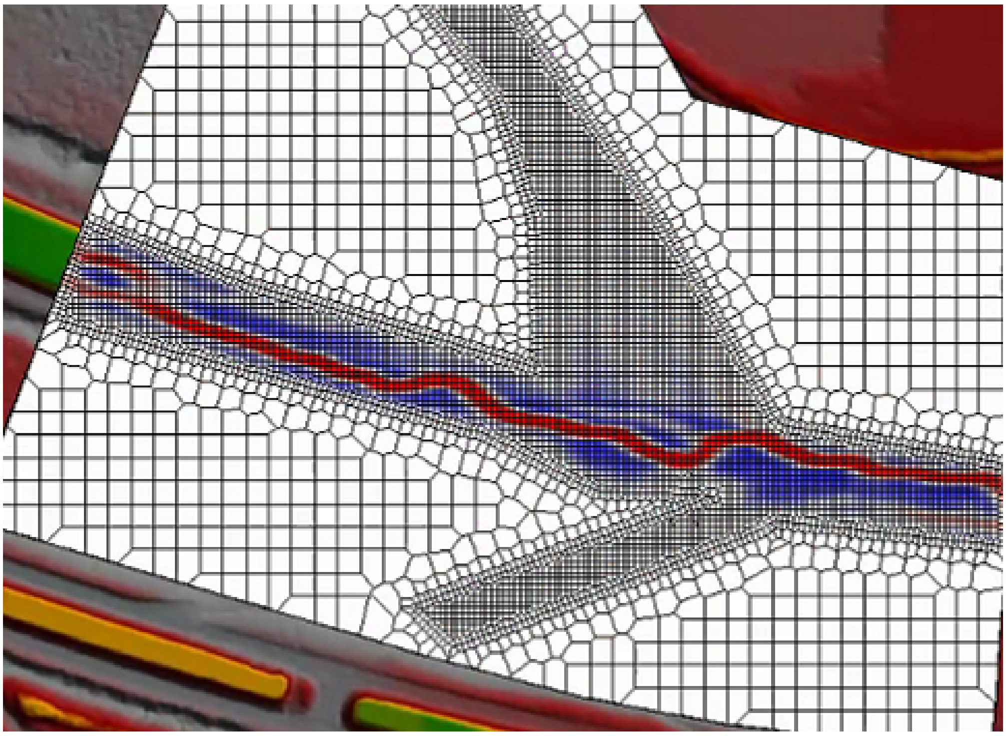
As briefly mentioned above, the user can specify a Sediment Computation Multiplier which determines the number of hydraulic time steps computed within a sediment time step. The sediment Computation Multiplier can often be used to significantly reduce model run times without significantly affected model results. For more information on the Sediment Computation Multiplier see Sediment Computation Options and Tolerances (see page 78).

2.4 Diffusion Wave Scour Pattern

Two-dimensional sediment transport usually does not perform well with the Diffusion Wave equation.



2D sediment runtimes can be get long, so it can be attractive to select the Diffusion Wave equation to try to reduce the runtime. However, 2D, Diffusion-Wave, sediment models often develop a distinctive pattern, eroding a deep sub-channel and depositing in the rest of the channel. This is not a credible result. Most 2D sediment transport models should be run with one of the Shallow Water Flow Equations (SWE).



3 Distinctive sub-channel erosion common in diffusion wave 2D sediment models (red is erosion, blue is deposition). This is a numerical aritfact of the interaction of the Diffusion Wave hydraulics with the transport algorithms. Switch to SWE.

3 Sediment Data

2D sediment transport models in HEC-RAS require four files: an unsteady flow file, a geometry file, a sediment file, and a plan file to tie them together. Sediment data should be specified after the geometry. Some mandatory sediment parameters are specified spatially and thus require knowledge of the geometry. If the geometry changes, the sediment data may need updates before it can run.
Sediment results are very sensitive to hydraulic results (e.g. roughness parameters and ineffective flow areas). An HEC-RAS sediment model will not be robust or reliable if it is not built on a well constructed hydraulic geometry (USACE, 1993, Thomas and Cheng, 2008). Before adding sediment data, test the hydraulic model over the expected range of flows using the HEC-RAS Unsteady Flow Analysis option, calibrating the bottom roughness and if necessary, the turbulence coefficients. It is recommended to identify hydraulics model problems before adding the bed change complexity. Only add sediment data after crafting a careful, robust, hydraulic model.

This document focuses on the 2D sediment data. However, many of the 2D sediment parameters and data inputs are the same as 1D. To enter sediment data, select **Sediment Data** from the **Edit** menu or press the sediment data icon. The sediment data editor will appear as depicted in figure below. The sediment data editor has four tabs: **Initial Conditions and Transport Parameters,** Sediment **Boundary Conditions**, the **USDA-ARS Bank Stability and Toe Erosion Model (BSTEM),** and **2D Bed Gradations**. The first two and last tabs are mandatory for 2D simulations. The third (BSTEM) is only for bank process computations and is not required for a sediment transport model.

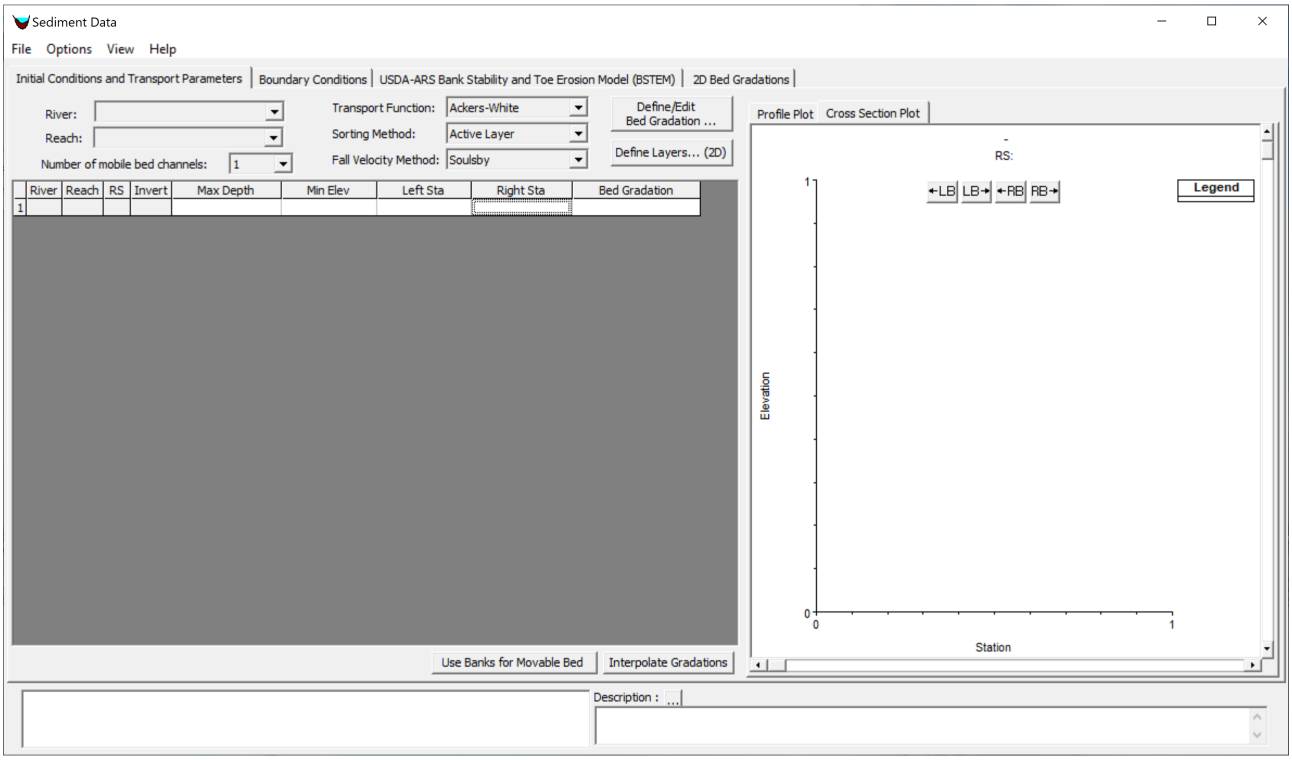


Figure 1. Sediment Data editor.

- Initial Conditions, Bed Materials, and Transport Parameters (see page 32)

3.1 Initial Conditions, Bed Materials, and Transport Parameters

The **Initial Conditions and Transport Parameters** is the first tab in the **Sediment Data** editor and opens by default when the editor launches. From this editor the user can specify the transport function, sorting method, fall velocity method for the entire model. It is also used to specify sediment data for 1D cross-sections. However, if the model does not include cross-sections, then that information may be left empty.

3.1.1 Transport Function

Select a **Transport Function** from the drop-down box near the top of the editor. HEC-RAS 6.0 includes the following eleven transport functions:

1. Ackers and White (Ackers and White 1973; Day 1980; Proffitt and Sutherland 1983)
2. England and Hansen (Engelund-Hansen 1967)
3. Laursen-Copeland formula (Laursen 1968)
4. Meyer-Peter and Müller (1948)
5. Toffaleti (1968)
6. MPM-Toffaleti (Meyer-Peter and Müller 1948; Toffaleti 1968)
7. Yang (sand and gravel eqns.)
8. Wilcock and Crowe (2003)
9. Soulsby-van Rijn (Soulsby 1997)
10. van Rijn (1984a,b; 2007a,b)
11. Wu et al. (2000)

Modeling Note – Transport Function Sensitivity: Sediment transport functions simulate non-linear transport processes and produce very different results. Model results are very sensitive to selected function. Carefully review the range of assumptions, hydraulic conditions, and grain sizes for which each method was developed. Select the method developed under conditions that most closely represent the system of interest and calibrate results to actual bed change.

Note: Transport Function Sensitivity

Sediment transport functions simulate non-linear transport processes and produce very different results. Model results are very sensitive to selected function. Carefully review the range of assumptions, hydraulic conditions, and grain sizes for which each method was developed. Select the method developed under conditions that most closely represent the system of interest and calibrate results to actual bed change.

3.1.2 Sorting Method

Transport functions compute transport potential without accounting for availability. The bed **Sorting Method** (sometimes called the mixing or armoring method) keeps track of the bed gradation which HEC-RAS uses to compute grain-class specific transport capacities and can also simulate armoring processes which regulate supply. The **Sorting Method** drop down menu in the **Sediment Data** editor only applies to 1D sediment transport. The 2D sediment transport model always uses a method similar to the **Active Layer** method for 1D except that it can have any arbitrary number of layers. The active layer thickness is set equal to the D90 by default or a factor of the D90.

Note: Sorting Method Model Sensitivity

Sediment transport results can be as sensitive to the sorting method parameters selected as the transport function.

3.1.3 Fall Velocity Methods

The same sediment fall velocity formulas are available for 2D and 1D sediment transport. The options include:

1. Rubey (1933)
2. Toffaleti (1968)
3. Van Rijn (1993)
4. Report 12 (Default method in HEC-6)
5. Dietrich (1982)
6. Soulsby (1997)
7. Wu and Wang (2006)

The fall velocity formula used to compute free particle settling velocity for both cohesive and noncohesive sediments. Depending on the concentration and whether the user has selected flocculation, cohesive sediments may also settle as flocs. Hindered settling of noncohesive particles may also be simulated if selected by the user. In general, the fall velocity formula should not used as a model calibration parameter for morphology change, since the results are not very sensitive to the formula. Preference for the formulas is generally based on the transport formula used, the range of grain classes, and/or the parameters utilized by the fall velocity formulas. For example, the Wu and Wang formula takes into account the particle shape.

3.1.4 Bed Gradations

Bed gradations are specified in the same manner as for 1D models. Instead of requiring users to input gradations for each cell individually, HEC-RAS uses a **Bed Gradation Template** concept similar to that in the Channel Modification Editor. **Sediment Bed Material Types** are defined in a **Sediment Bed Material Layer** in RAS Mapper. The **Sediment Bed Material Types** are regions defined as polygons in RAS Mapper in a **Sediment Bed Material Layer**. The polygons can be overlapping to override regions. **Sediment Bed Material Layer Types** are the associated to **Bed Gradation Templates**, **Non-erodible Surfaces**, or **Bed Layer Groups** within the **2D Bed Gradations (Beta)** tab of the **Sediment Data** editor. **Bed Layer Groups** consist of one or more bed layers. Each layer is assigned a **Bed Gradation Template** or a **Non-erodible Surface**. The connectivity between these elements utilized for specifying the sediment bed material are described in the schematic below.

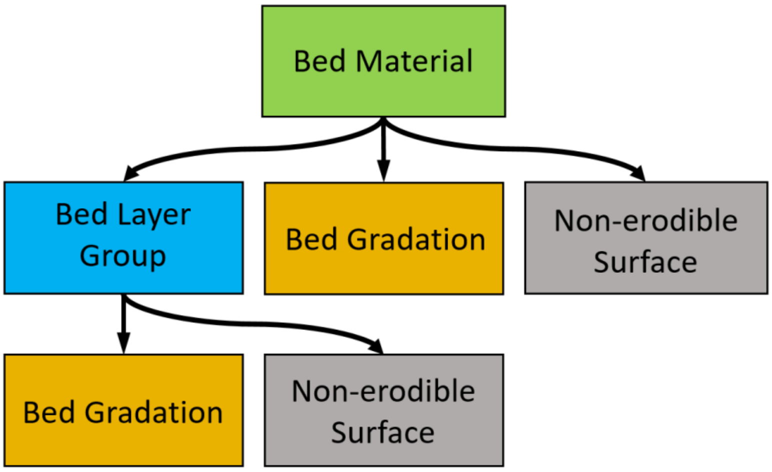


Figure 1. Bed Gradation Template editor.

Non-erodible surfaces are surfaces such as bedrock or structures which cannot be eroded. Non-erodible surfaces may be associated with a **Sediment Bed Material** are specified within a **Bed Layer Group**. Non-erodible surfaces are specified at computational cells and are not enforces at computational faces.

3.1.4.1 Defining Bed Material Layers in RAS Mapper

Users will associate bed gradations, layer groups, or non-erodible surfaces with **Sediment Bed Material Layers** defined in RAS Mapper. In order to define gradations in the sediment editor, you must define **Sediment Bed Material Layers** in Mapper first.
Sediment Bed Material Layers are independent of specific model geometries or terrains. Like **n-value Layers** or **Land Cover Layers** (see 2D Hydraulic Manuals). Create new **Sediment Bed Material Layers** by right clicking on the Map Layer node in RAS Mapper.
To Define Bed Material Layers, follow these five steps:

1. Create a New/Empty RAS Layer

2. Import or Draw Polygons in the Created RAS Layer
3. Give the Polygon Classifications Sediment Material Names that will show up in the Sediment Editor
4. Go to Manage Geometry Associations and associate the Bed Material Layers with geometry files
5. Associate each Bed Material Classification with a bed gradation, bed layers, or define it as a non-erodible surface, in the 2D sediment editor.

Defining these bed material layers have two main workflows, which are not mutually exclusive. Users will generally import a pre-existing shape file or draw overlapping polygons. Often users will do both, importing a base bed material shape file, but then drawing in channel features, sand bars, and/or non-erodible features on top of them as new layers.

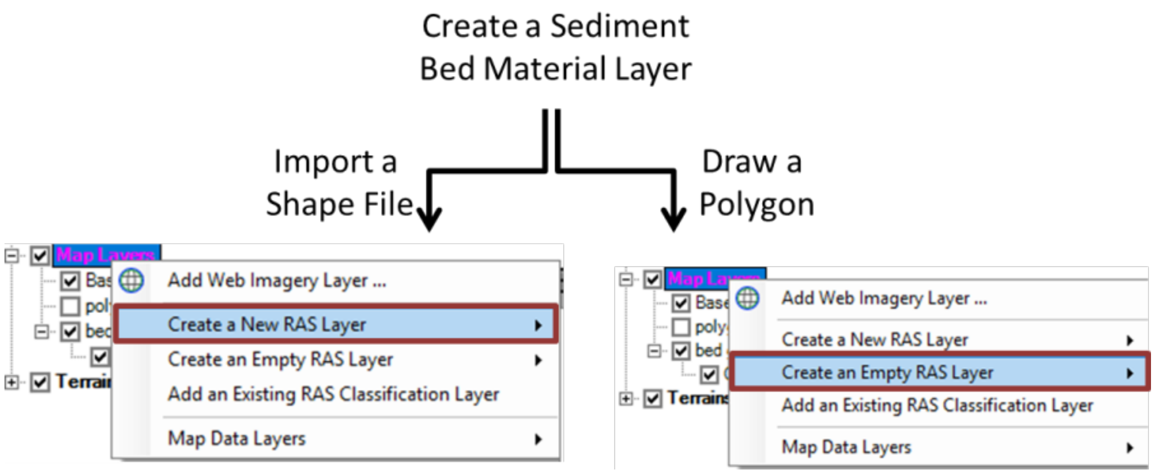


Figure 2. Crating a Bed Material Layer in RAS Mapper.

The Sediment Bed Material Layer will show up under the **Map Layers** tree in RAS Mapper.

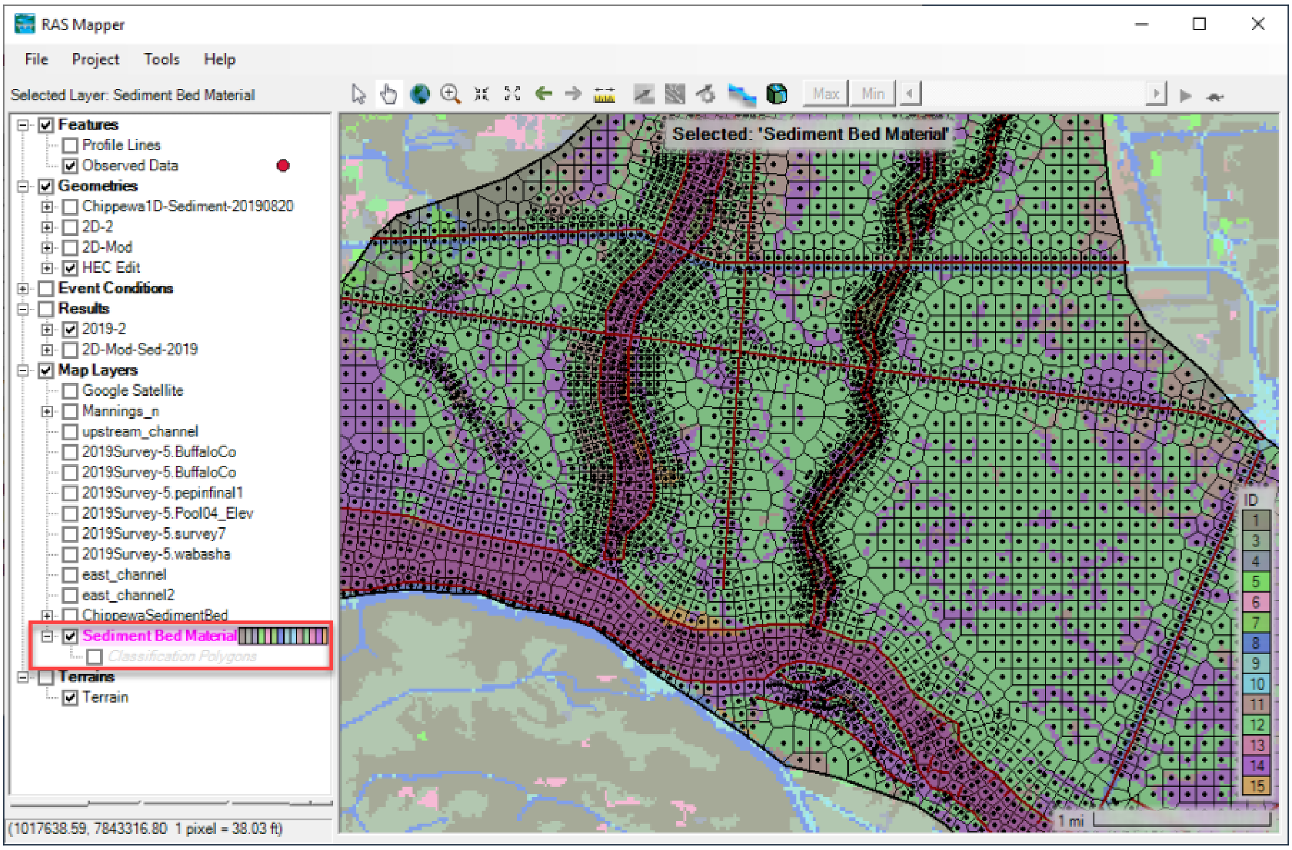
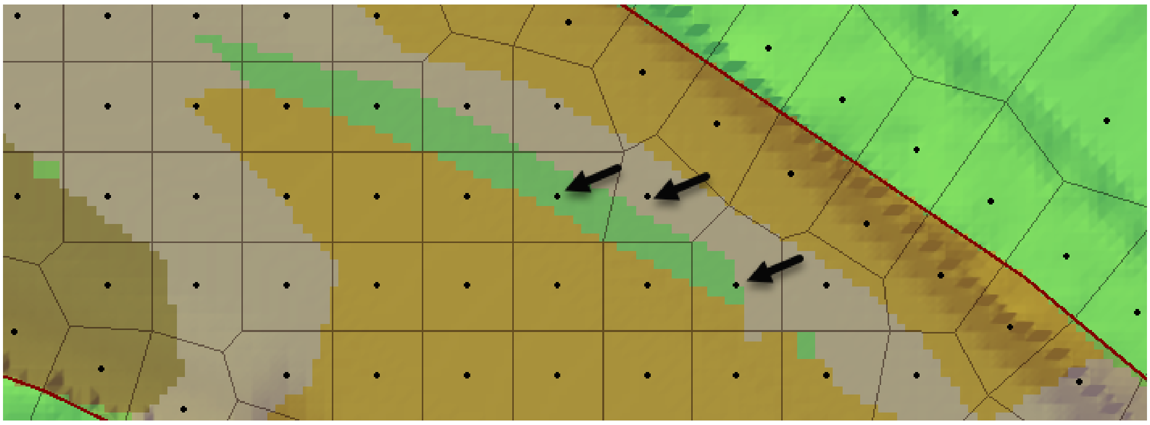


Figure 3. Sediment Bed Material Layer underlying a 2D mesh and in the RAS Mapper tree under Map Layers.

Whether you create your **Sediment Bed Material Layer** by importing a shape file, creating polygons, or both, there are two additional steps before the bed materials are ready for the sediment model.

Modeling Note - HEC-RAS Uses the Gradation at the Cell Computation Point

Sediment Bed Material Layers can be more detailed than the mesh. If a 2D cell includes multiple sediment bed material layers, HEC-RAS uses the material type associated with the computation point.



RAS Mapper will create a **Classification Polygons** node under your map layer and will add a feature to the geo-referenced database for each polygon you import or create. You will have to give each of these polygons a (preferably descriptive) name which will show up in the sediment editor, where you will associate the polygon(s) that share this classification with a **Bed Material** or **Bed Layer Group**.

Name the layer classifications by right clicking on the **Classification Polygons** node (in editable mode) and selecting **Layer Properties.** Then select the **Features** tab and give each of the Layer Classifications a Name that will show up in the Sediment Data editor.

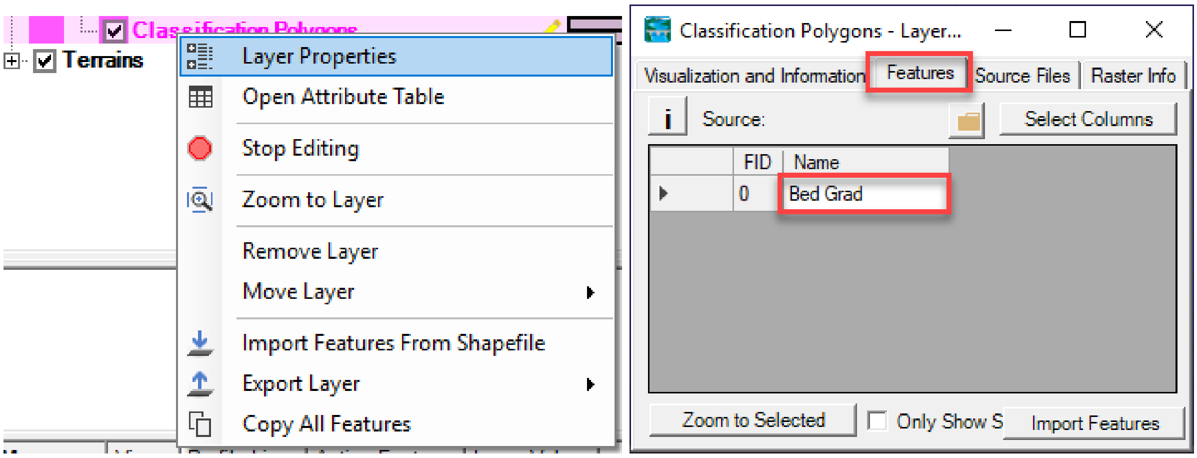
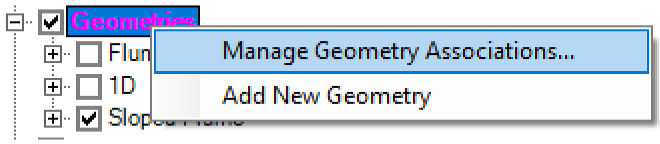


Figure 4. Give the layer classifications names that will show up in the sediment editor under Layer Properties.

When the **Sediment Bed Material Layer** and Classifications are complete, **Stop Editing** and save.
Before these layers and classifications become available in the Sediment Data editor, however, they must be associated with a geometry file. Just like n-values, Land Cover, and Terrains must be associated with a geometry file, **Sediment Bed Material Layer Groups** must be matched to one-or-more geometries to connect the Mapper classifications to the other files in HEC-RAS.
Right Click on the **Geometries** node in RAS Mapper and Select **Manage Geometry Associations…**



Select the **Sediment Bed Material Layer** that goes with each **Geometry**.

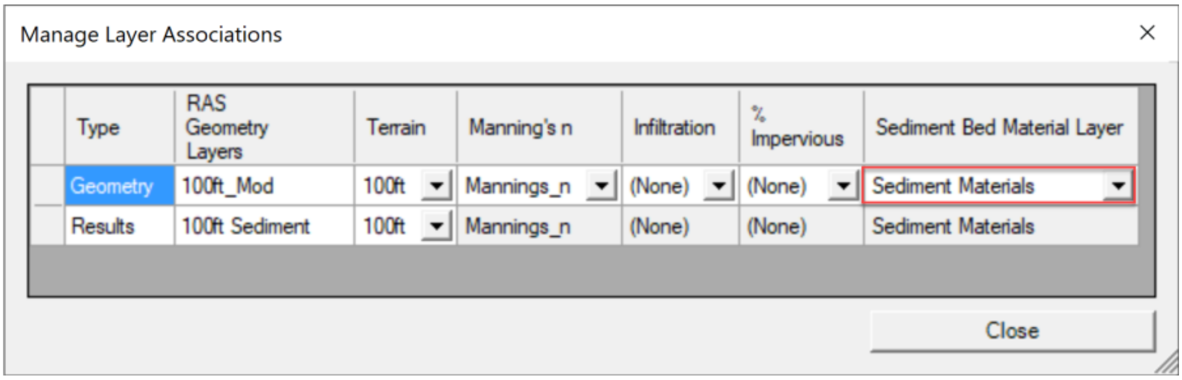


Figure 5. RAS Mapper Manage Layer Associations editor.

It is worth noting, that this associates the Bed Gradation Layers with the geometry, not the sediment file. Sediment files depend on geometry files for some of their data structures (e.g. cross sections in 1D). The sediment file will inherit the bed gradation layers and classifications from the active geometry file. These layer classifications will become available in the **2D Sediment** tab of the Sediment Data Editor (see the 2D gradation selection section (see page 42)).

3.1.4.2 Bed Gradation Templates

Bed Gradation Templates contain the sediment grain class sizes, grain fractions by weight, and optionally bulk cohesive parameters. Users define sediment **Bed Gradations Templates** in a database with no spatial data. They can be considered simply as a database of different sediment types. In many applications, **Bed Gradation Templates** will correspond to individual bed samples taken in the project. Templates are created and edited by pressing the **Define/Edit Bed Gradation** button, which will launch the dialog depicted in the figure below.

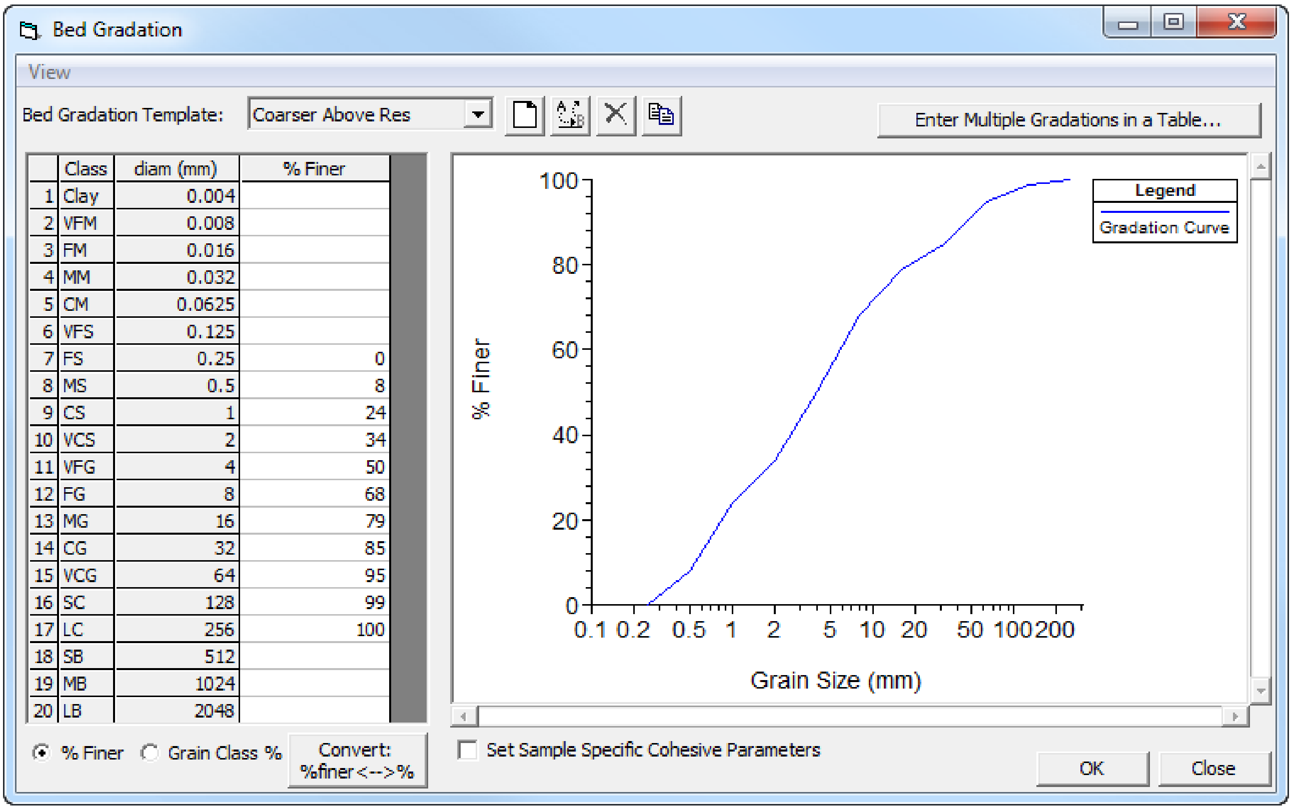


Figure 6. Bed Gradation Template editor.

Multiple bed gradations may be entered for 2D sediment models in the same as for 1D sediment models.

To create a **Bed Gradation Template**, first create a new bed gradation template by selecting the **New Bed Gradation Sample** button: and entering a name for the sample. (Alternatively, data for several different samples can be entered at once by clicking on the Enter Multiple Gradations in a Table... button and entering the data in the **Multiple Bed Gradation Table**.

The gradation of the bed sample can be input in either of two forms by toggling between the radio buttons at the bottom of the form:

• **% Finer**: % Finer defines the sample using as a cumulative bed gradation curve with percent finer defined by the upper bound of each grain class. The diameter listed for each grain class is the upper bound of that grain class and values should be entered as percent values. (e.g. since this is specified in Percent Finer, 50% should be input as 50 and NOT as 0.5)

• **Grain Class Fraction/Weight**: the sample fraction of each grain class is specified. These values will be normalized so values do not have to add up to one or 100% and can be input as simple masses if preferred. (e.g. if 20% of the sample is fine sand, input the value 0.2 or 20 as long as the rest follow that convention). The upper and lower bound grain diameter is associated with each grain class to delineate the range of the class.

3.1.4.3 Bed Layer Groups

User specified **Bed Layer Groups** allow the user to specify vertical bed layers with different bed gradations and different bulk properties. **Bed Layer Groups** are specified by selecting the button 

in the main **Sediment Data** editor which will open the **Define Gradation Layers** editor (see the figure below).

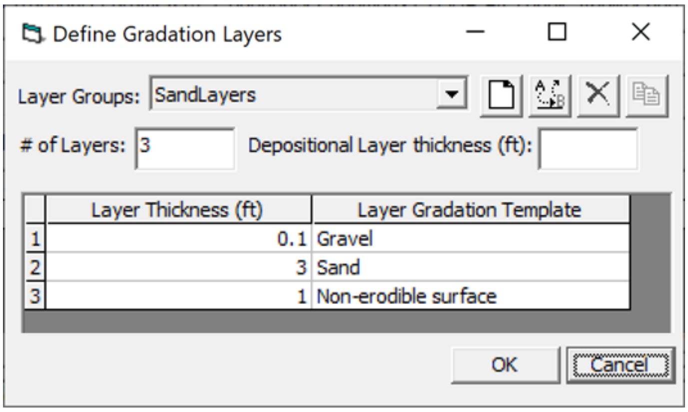


Figure 7. Example of a Bed Layer Group definition in the Define Gradation Layers editor.

In HEC-RAS 2D sediment transport, the depositional layer thickness is not utilized. The parameter is only utilized for 1D sediment transport.
The layer thickness specified for non-erodible surfaces is not actually used. Bed gradations are specified for each computational cell. Faces do not have bed gradations and only bed elevations. All subareas within a cell have the same **Sediment Bed Material**. Therefore, if a **Bed Layer Groups** is assigned to a cell, the bed layers will be at different elevations for the different subareas. For example, the figure below shows a computational which has been assigned a **Bed Layer Group** three layers. In the example below, the cell has three subareas. The bed layers have the same thickness in each subarea but start at a different elevation.

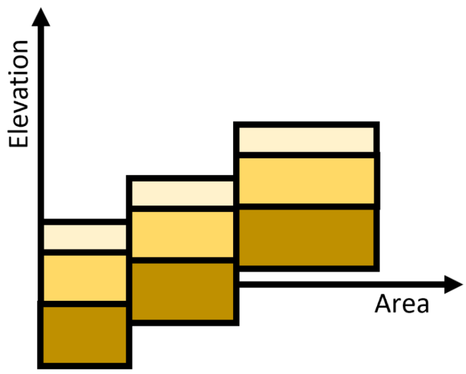


Figure 8. Example of a Bed Layer Group assigned to a computational cell.

3.2 Associated Bed Gradation Templates with Bed Material Layers

Once the user has created **Bed Gradation Templates**, and a **Sediment Bed Materials Layer** in RAS Mapper these can be associated in the **2D Bed Gradations (Beta)** tab of the **Sediment Data** editor.

After user defines the sediment **Bed Gradation Templates,** they are available in a drop-down pick list under the **Bed Gradation** column of the **Sediment Data** grid. Clicking on a cell of the Bed Gradation column generates a drop down list of the defined bed sample templates. A single bed sample is frequently associated with multiple **Sediment Bed Material Layers**. Therefore, once selected; a sample can be easily copied into multiple cells by placing the mouse pointer over the bottom right corner of the selected cell and dragging vertically.
The drop-down list always includes all of the user specified bed gradations and layer groups as well as a **non-erodible** option. If the **Bed Material Layer** represents a hard surface, engineered element (e.g. bank protection, wing wall, bed rock, or river engineering element), selecting the non-erodible option will allow the model to deposit on top of them, but not erode below the starting terrain surface.

A simple example of a dataset is shown below which only has one **Bed Material Type** and one **Bed Gradation**. Simple datasets like this are most easily created by starting with an empty **Sediment Bed Materials Layer** in **RAS Mapper** and creating polygons for different regions of different bed composition. Each polygon corresponds to a Bed Material Type and can then be associated with a **Gradation** in the **2D Bed Gradations** tab of the **Sediment Data** editor.

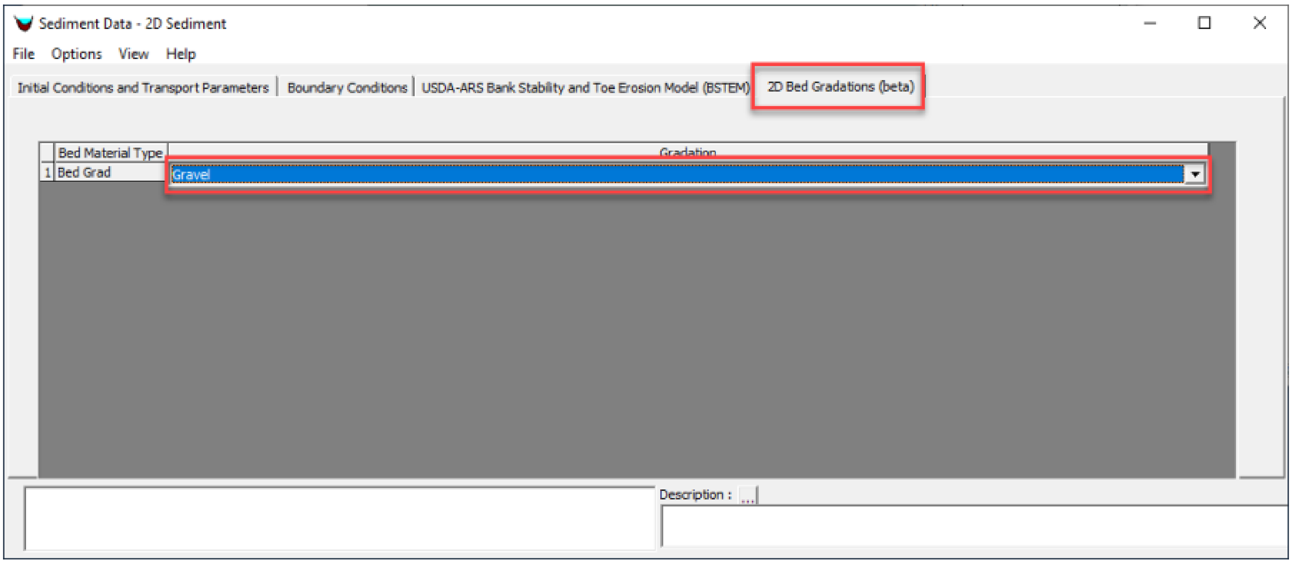


Figure 1. Simple, single gradation, 2D sediment specification with one Bed Gradation associated with one Bed Material Type.

A more complicated dataset is shown in the figure below for which the **Sediment Bed Material Layer** was created by importing a shape file. The shape file defines the polygon types in RAS Mapper with integers, that show up under **Bed Material Type**. The user then defined and associated bed gradations with these **Sediment Bed Material** classifications. Users can rename these imported polygons under the *Layer Properties-->Features* menu of the RAS Mapper Layer.

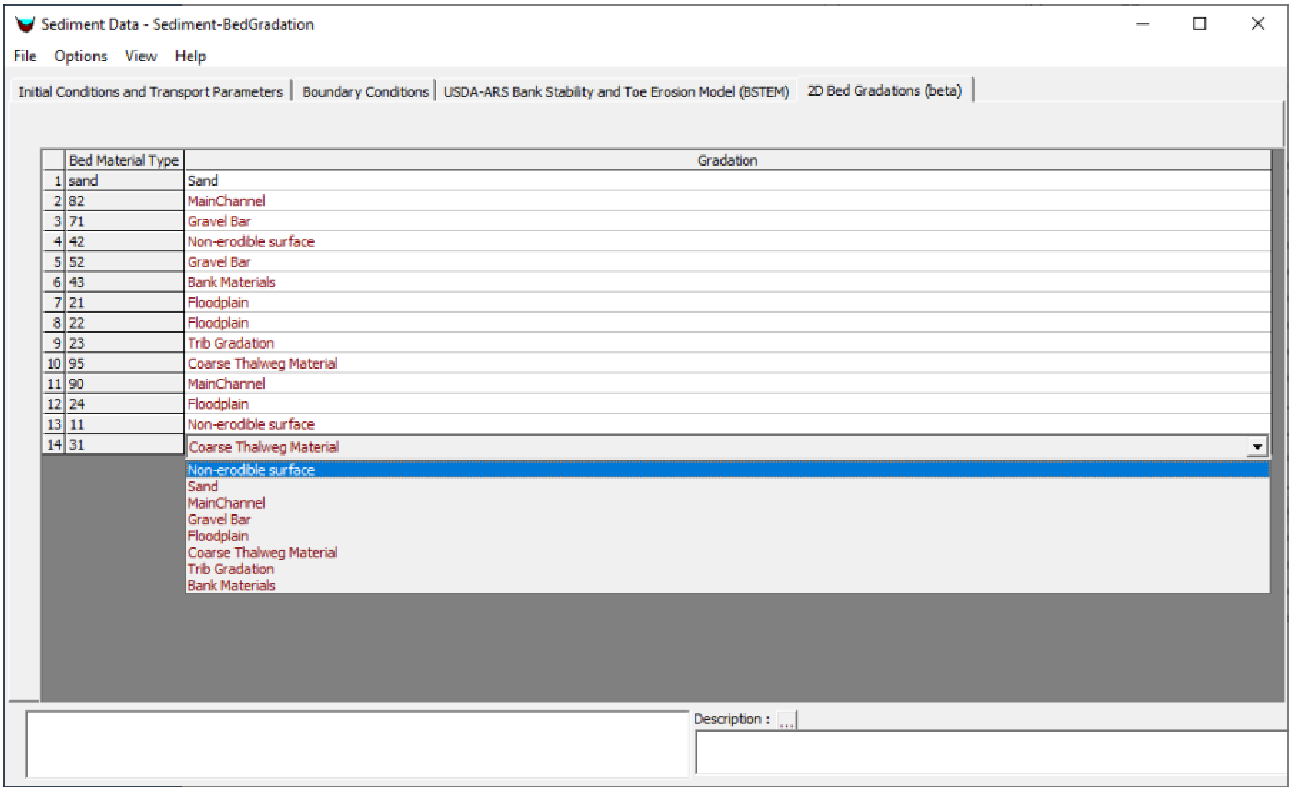


Figure 2. More detailed bed material specification, where the Bed Material Layer was imported from a shape file.

3.3 Sediment Boundary Conditions

The second tab on the **Sediment Data** editor defines sediment boundary conditions (see figure below). The editor automatically lists external model boundaries. HEC-RAS requires a boundary condition at all external boundaries. If any external boundary (i.e. boundary condition line) is left unspecified, then an equilibrium sediment load boundary condition is assumed. The types of boundary conditions which may be specified in a 2D sediment model are:

1. Rating curve
2. Sediment load series
3. Equilibrium load
4. Clear water (no sediment)
5. Capacity Ratio

The other boundary condition options available from the interface (which are mosty associated with 1D flow splits) are not allowed at 2D sediment transport boundaries. Only inflow sediment boundary conditions are required. When the model computes flow out of the domain the sediment can simply leave the domain. At 2D boundaries that where flux is always out of the domain, users can select the equilibrium boundary condition may or simply leave the sediment boundary condition empty. Any boundary condition lines left empty are assigned an **Equilibrium Load** boundary condition. This is necessary so a boundary condition type is available if the flow were to reverse direction even locally during the simulation.

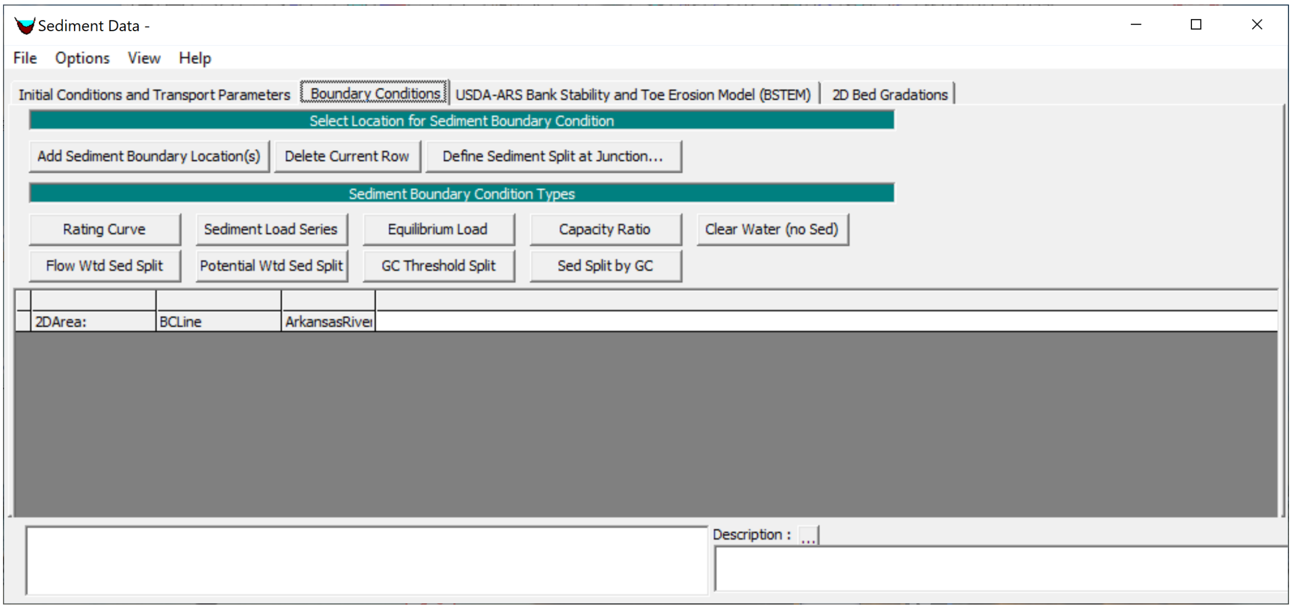


Figure 1. **Boundary Conditions** tab in the **Sediment Data** editor.

3.3.1 Rating Curve

The rating curve specifies the sediment load in tons/day or sediment concentration in mg/l as a function of flow discharge. The fractional composition of the incoming sediment load is specified for each grain class. The fractional loads are then specified to each cell using the cell sediment capacity as a weighting function. For 2D sediment transport, the user has the option to no specify the fractional bed-load composition. In this case, the cell sediment capacities (equilibrium concentrations) are used to compute the fractional sediment loads at each cell. This option is useful when the rating curve sediment gradations are not known.

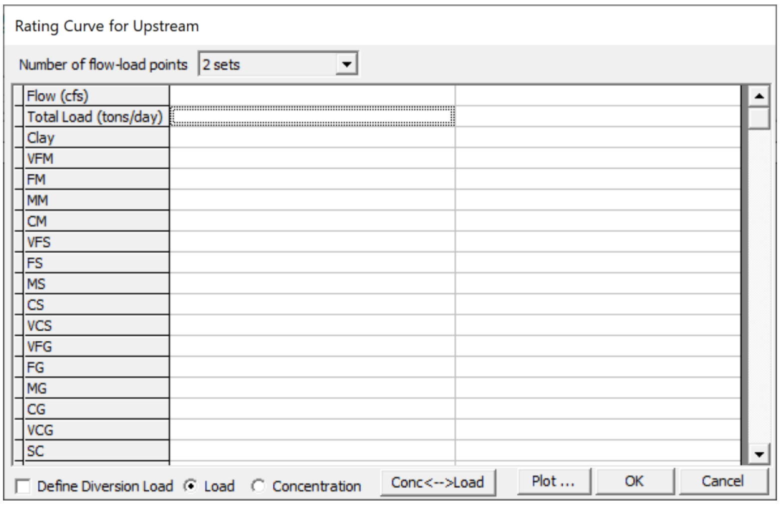


Figure 2. **Sediment Rating Curve** editor.

3.3.2 Sediment Load Series

The **Sediment Load Series** boundary condition specifies the sediment load in tons per time increment (see figure below). The sediment gradation may be specified with a **Gradation Rating Curve** or if this data is left empty, the gradation is determined by weighting the local (cell) equilibrium sediment loads. The **Gradation Rating Curve** specifies the gradation of the inflow sediment as a function of total load in tons/day. It is important to keep in mind that any grain specified in the gradation curve is automatically added to the computed grain classes.

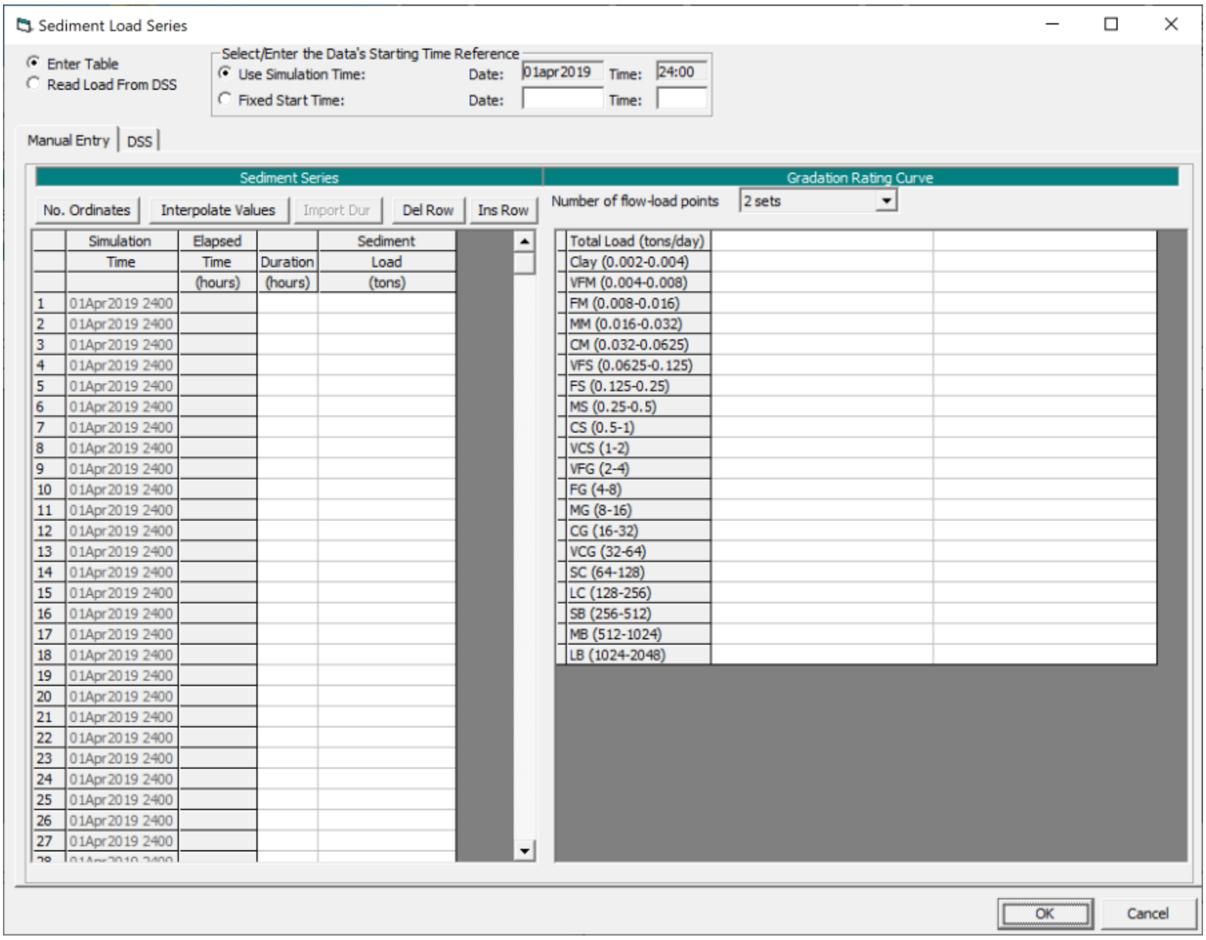


Figure 3. **Sediment Load Series** editor.

3.3.3 Equilibrium Load

The **Equilibrium Load** boundary condition specifies the inflow sediment load as the equilibrium sediment load. The equilibrium sediment load is computed as the equilibrium sediment concentrations at the boundary cells times the face flows. This approximation essentially assumes a zero-gradient concentration normal to the boundary. The equilibrium boundary condition should be used whenever data is not available or when first setting up a model in order to quickly get simulation results or to compare results from other boundary condition types which may be suspect.

3.3.4 Clear Water

The **Clear Water** boundary condition specifies a zero load/concentration at the boundary. This boundary is not very commonly used except for very specific situations.

3.3.5 Capacity Ratio

The **Capacity Ratio** boundary condition specifies a load/concentration at the boundary which is a ratio of the equilibrium load/concentration. This boundary condition is a generalization of the equilibrium boundary condition and is useful for over-loading or under-loading a boundary when there is not much sediment data available.

3.3.6 Unsteady Temperature

Temperature is the only data the unsteady flow editor required for sediment transport analyses. Specify temperature for an unsteady sediment transport model in the **Unsteady Flow Editor**. Select the **Water Temperature (for Unsteady Sediment)…** option from the **Options** menu (see figure below).

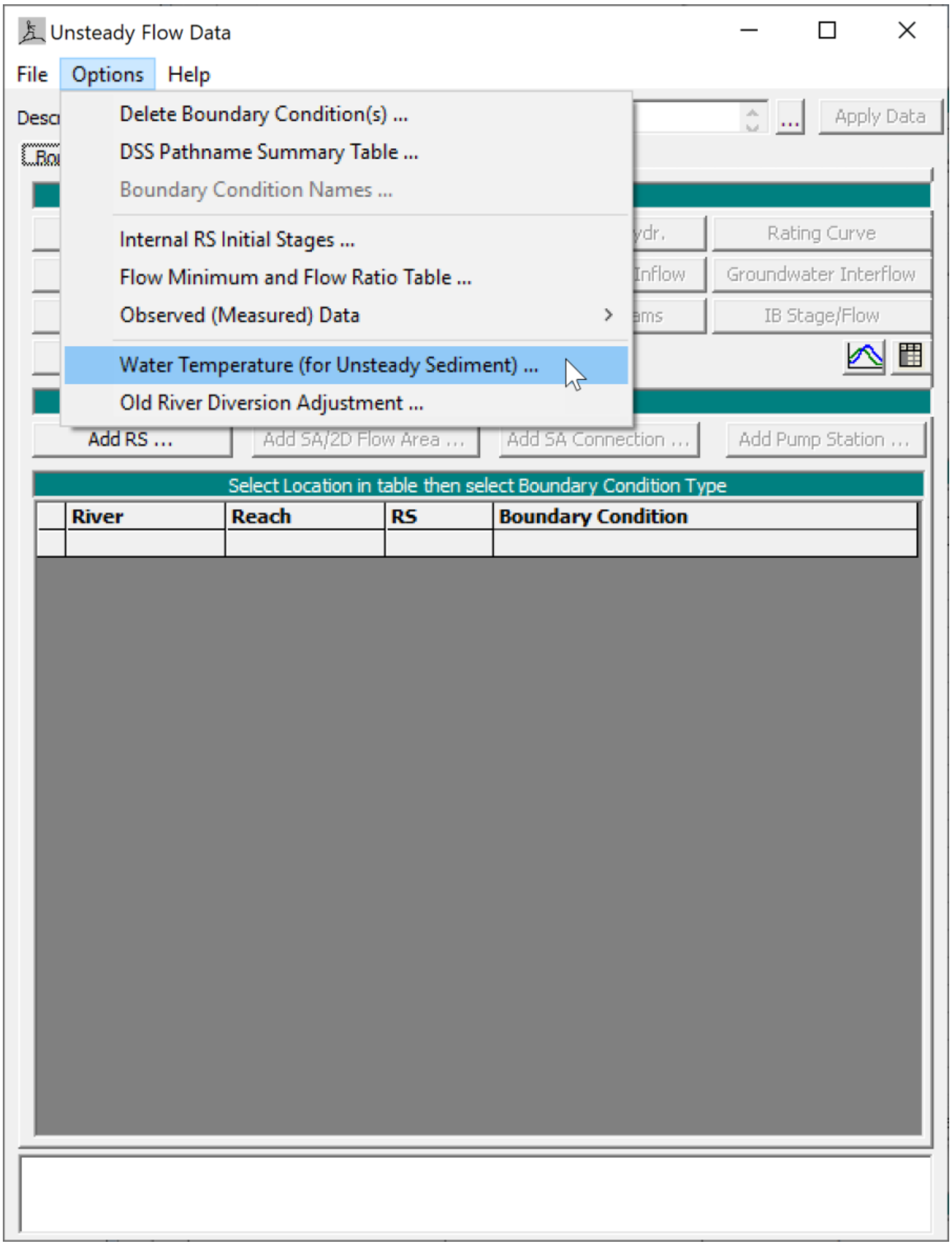


Figure 4. Opening the **Unsteady Temperature** editor from the **Unsteady Flow Data** editor.

The **Unsteady Temperature** time series editor, is similar to the unsteady flow and stage editors (see figure below). In the absence of temperature data in the unsteady flow file, HEC-RAS will assume 55.4ºF. The water temperature is used to compute the water kinematic and dynamic viscosities, and the water density which are then used by the sediment transport model.

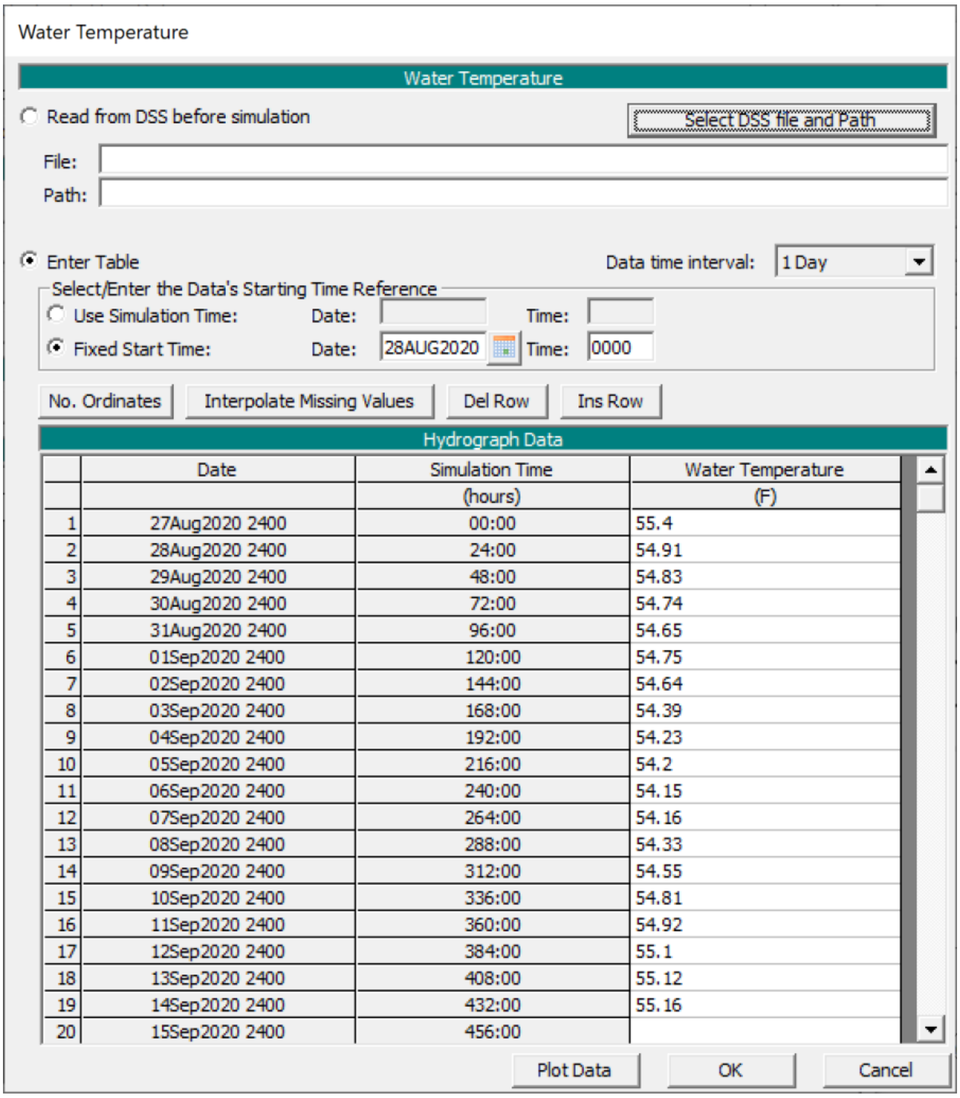


Figure 5. Specifying a temperature time series.

3.4 User-Defined Grain Classes

HEC-RAS divides the sediment material into multiple grain classes. Default grain classes sub-divide the range of transportable material, (0.002 mm to 2048 mm) into 20 grain classes or bins, each including adjacent, non-overlapping fractions of the grain size spectrum. Default grain classes follow a standard log base 2 scale where the upper bound of each class is twice its lower bound, the upper bound of the smaller, adjacent class. The gain class represents all particles they contain with a single, representative grain size. HEC-RAS uses the geometric mean of the grain class to represent the grain size for each bin. Grain boundaries (and labels) are editable.
The user may change the size range for the grain classes by going to the Sediment Data editor and selecting **Options** | **User Defined Grain Classes…** (see figure below).

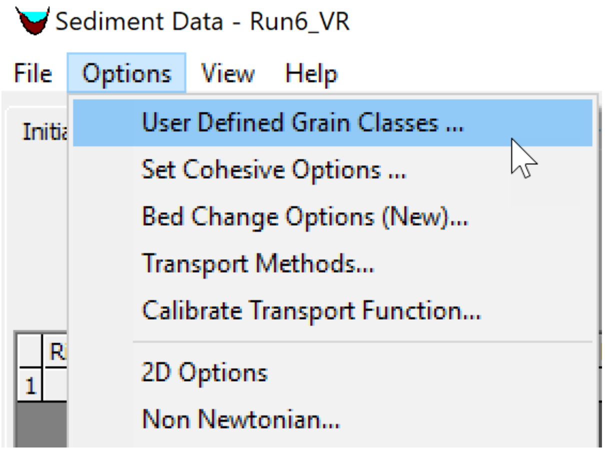
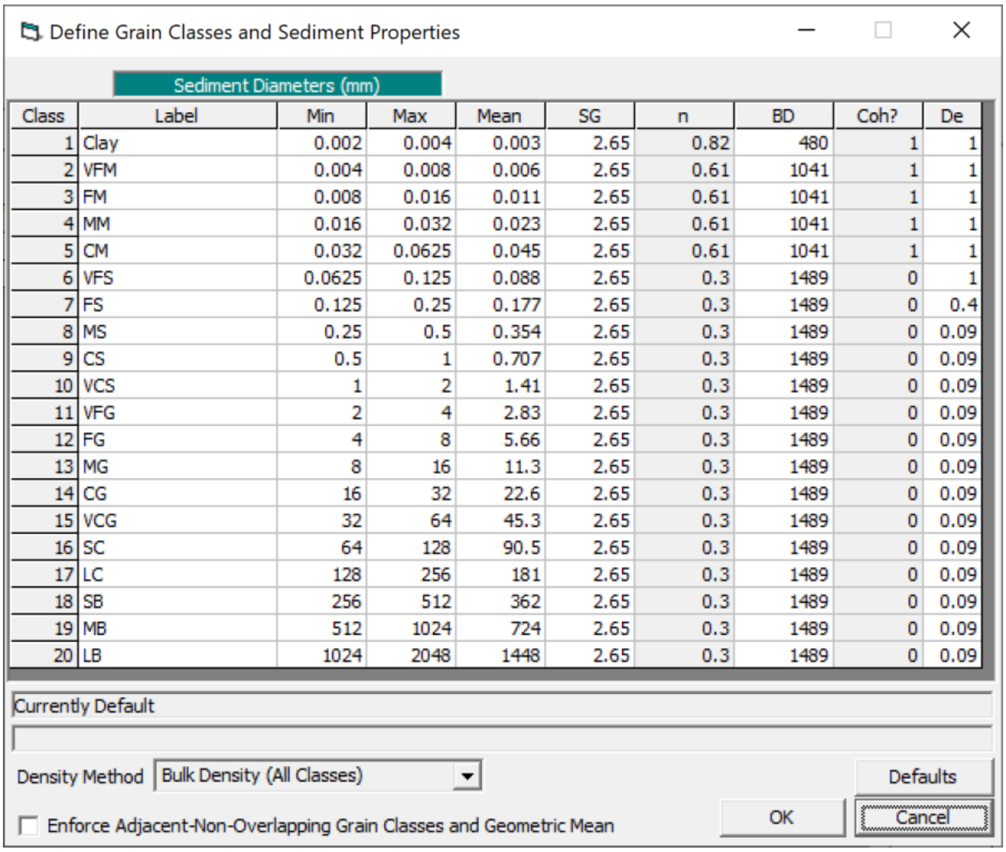


Figure 1. Opening the User Defined Grain Classes editor from the Sediment Data editor.

In the **User Defined Grain Classes** editor (see figure below), the user may change the diameter limits, names of the grain classes, and sediment properties including the Specific Gravity (SG), Porosity, dry Bulk Density (BD). The label (name) for each grain class may be changed in the table. The labels are used in the sediment output to identify variables associated with each grain class such as fractional concentrations and particle fall velocities. It is important to note that for 2D sediment transport, not all the grain-classes in the **User Defined Grain Classes** editor are actually used by the model. Only the grain classes which exist in the **Sediment Bed Gradations** and/or the sediment boundary conditions are used. This saves computational time and memory since only the grain classes which exist in the 2D domains are used. Therefore, the number of grain classes in 1D and 2D sediment may be different.



Class	Label	Min	Max	Mean	SG	n	BD	Coh?	De
		Sediment Diameters (mm)							
1	Clay	0.002	0.004	0.003	2.65	0.82	480	1	1
2	VFM	0.004	0.008	0.006	2.65	0.61	1041	1	1
3	FM	0.008	0.016	0.011	2.65	0.61	1041	1	1
4	MM	0.016	0.032	0.023	2.65	0.61	1041	1	1
5	CM	0.032	0.0625	0.045	2.65	0.61	1041	1	1
6	VFS	0.0625	0.125	0.088	2.65	0.3	1489	0	1
7	FS	0.125	0.25	0.177	2.65	0.3	1489	0	0.4
8	MS	0.25	0.5	0.354	2.65	0.3	1489	0	0.09
9	CS	0.5	1	0.707	2.65	0.3	1489	0	0.09
10	VCS	1	2	1.41	2.65	0.3	1489	0	0.09
11	VFG	2	4	2.83	2.65	0.3	1489	0	0.09
12	FG	4	8	5.66	2.65	0.3	1489	0	0.09
13	MG	8	16	11.3	2.65	0.3	1489	0	0.09
14	CG	16	32	22.6	2.65	0.3	1489	0	0.09
15	VCG	32	64	45.3	2.65	0.3	1489	0	0.09
16	SC	64	128	90.5	2.65	0.3	1489	0	0.09
17	LC	128	256	181	2.65	0.3	1489	0	0.09
18	SB	256	512	362	2.65	0.3	1489	0	0.09
19	MB	512	1024	724	2.65	0.3	1489	0	0.09
20	LB	1024	2048	1448	2.65	0.3	1489	0	0.09

Figure 2. User Defined Grain Classes editor.

The grain size classes can be viewed as analogous so the grid resolution. When initially setting The table below shows typical specific gravity ranges for different common minerals and rocks.

Table 1. Specific gravity ranges for different minerals and rocks.

Material	Specific Gravity
Quartz	2.6 – 2.7
Limestone	2.6 – 2.8
Basalt	2.7 – 2.9
Magnetite	3.2 – 3.5
Coal	1.3 – 1.5

The grain specific gravity should not be used as calibration parameter. It is a parameter of the sediment particles and should be specified as accurately as possible. However, in general the results are generally not very sensitive to the specific gravity for natural sediments in rivers.

3.4.1 Density Methods

The **Density Method** refers to the methods used to specify the grain class dry density/porosity/unit weight:

1. Bulk Density (All Classes)
2. Porosity (All Classes)
3. UW-Cohesive/Porosity-Cohesionless

The default **Density** Method is **Bulked Density** (**BD**). To specify a different **Density Method**, the user may select one of the options in the drop down menu as shown in the figure below.

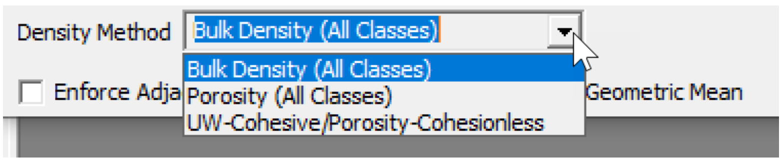


Figure 3. Selecting the Density Method in the Define Grain Classes and Sediment Properties editor.

Depending on the choice selected the appropriate columns will be enabled or grayed out in the **User-defined Grain Classes** editor. If the **Bulk Density** method is selected the **BD** (for dry bulk density) column is enabled. The program computes a grain class porosity from the specific gravity (column labeled **SG**) which may not be the same as the values in the grayed-out porosity (column labeled **n**). If the **Porosity (All Classes)** method is selected, the specific gravity and porosity columns are enabled. The program internally computed a dry bulk density from the specific gravity and porosity, which may not be the same as that which is displayed in the editor. The last option is the **UW-cohesive/Porosity-Cohesionless** method. In this method the dry bulk density is specified for cohesive grain classes, and the porosity is specified for the cohesionless (noncohesive) grain classes.

The treatment of the dry bulk density in HEC-RAS 2D sediment is different from that of HEC-RAS 1D. In 2D the bulk density is treated as a property of the sediment mixture and there is not always a one-to-one relationship between the grain class fractions and the bulk density. This is necessary to simulate processes such as packing and consolidation.

If all the utilized grain class (cohesive and noncohesive) have the same bulk density and consolidation is not enabled, a constant bulk density is assumed, which significantly simplifies the computations. If the specified bulk densities or porosities for the noncohesive grain classes are variable, a variable bed density model is utilized with the bed porosities calculated from the Colby (1963) formula. The variable bed density model is more computationally expensive because it requires several more calculations and steps during the simulation. If the dry densities or porosities are left empty, then the Wooster et al. (2008) porosity formula is utilized based on the sediment sorting. Dry densities generally vary between 300 to 1,600 kg/m^3.

3.5 Cohesive Options

Most of the sediment transport equations were developed with sand and/or gravel data. Therefore, most silt and all clay particles are outside of the range of applicability of the sediment transport functions implemented in HEC-RAS. In most systems, these particles are *wash load,* material only found in the bed in trace amounts, because transport capacity always exceeds supply. Some modelers will just ignore fines as *throughput load*, arguing that if fines never interact with the bed in the model reach, the model is insensitive to them and they add unnecessary complexity and parameters to the model. However, sometimes fines must be modeled explicitly. In reservoirs and other backwater or low energy zones, silt and clay can deposit and clay lined channels, both natural and engineered, can erode, causing local and downstream problems.

Fine sediment transport is further complicated by electrostatic and electrochemical forces. These particles are not just outside of the empirical range of the equations, but they often erode and deposit by fundamentally different processes. These forces cause fine particles, particularly clay, to flocculate and "stick" to the bed surface, so that fine erosion and deposition are often not primarily functions of sediment size. These processes make fine deposition and erosion fundamentally different than the cohesionless sand and gravel transport.

In HEC-RAS, the cohesive options can be set by selecting **Set Cohesive Options...** under **Options** menu of the **Sediment Data** editor (see figure below).

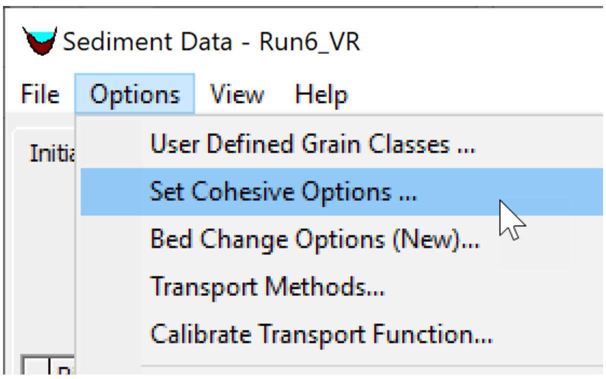


Figure 1. Opening the Cohesive Options editor from the Sediment Data editor.

The **Cohesive Options** editor is shown in the figure below. The editor allows the user to select how the erosion is computed for cohesive sediments.

3.5.1 Erosion Parameters

HEC-RAS includes three cohesive erosion methods; applying the standard transport equations, or two different implementations of the Krone and Partheniades approach. In HEC-RAS 2D sediment transport, the **HEC 6T Capacity Method** is not available. When utilizing the 2D sediment transport model, it is generally not recommended to use the transport functions for the cohesive grain classes, especially clay. If the cohesive grain classes represent a very small fraction of the bed gradation, then it is better to simply remove them from the bed gradation then it is better to model them as cohesive.

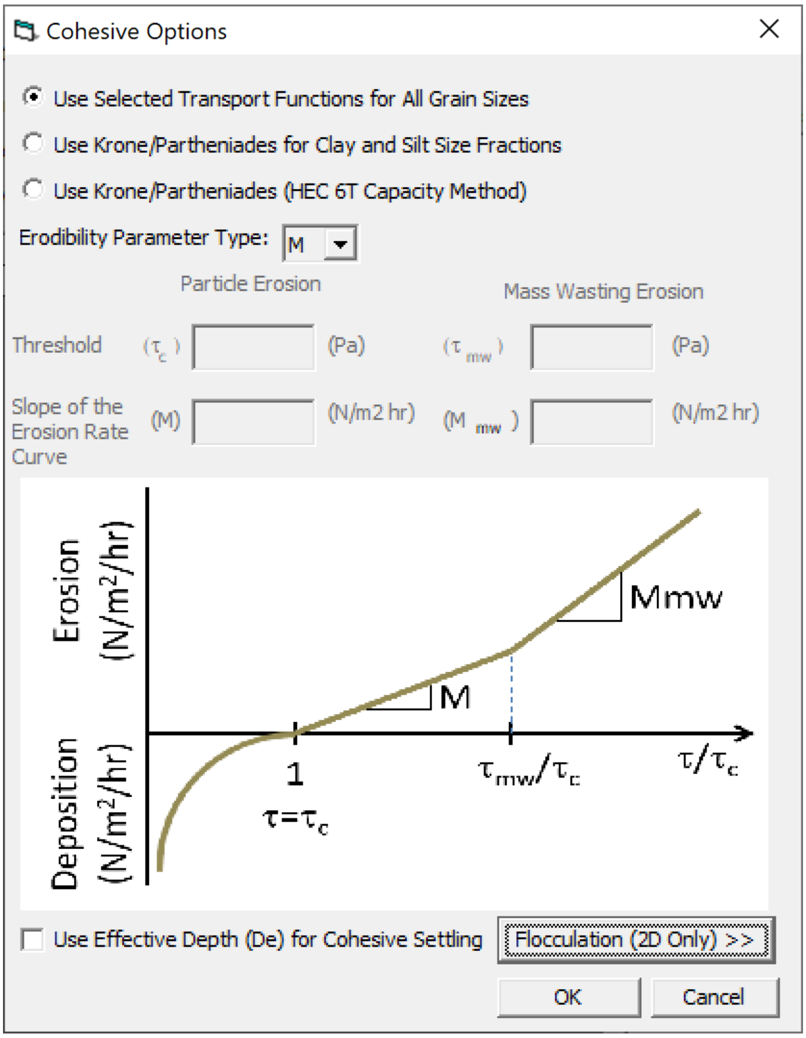


Figure 2. Cohesive Options editor.

The treatment of cohesive sediments and mixtures of cohesive and noncohesive sediments is slightly different for HEC-RAS 1D and 2D. HEC-RAS 1D considers the smallest five grain classes 'fine sediment'. HEC-RAS 1D applies the same cohesive erosion method selected to these grain classes. By default, the first five grain classes are the clay and silt classes, and are all finer than 0.0625 mm. However, if the user edits the diameters sizes for these, the cohesive erosion methods will still apply to the first five grain classes, regardless of their size. HEC-RAS 2D has diameter thresholds that determine whether a grain class forms flocs and behaves cohesively on the bed. The reason for having these separate thresholds is to allow for the erosion to be calculated with the user-selected transport function while still allowing fine grain classes to form flocs. The upper threshold for grain classes to form flocs is 0.0625 mm. The size tolerance for grain

classes are behave cohesively on the bed is either set to 0.0 mm if the **Use Selected Transport Functions for All Grain Sizes** option is selected or 0.0625 mm if the Krone/Partheniades formulas are selected.
In HEC-RAS 1D if more than 20% of the active layer is cohesive, then the model considers the sediment active layer as cohesive and computes the erosion for all grain classes using the cohesive method. However, in 2D the erosion of mixed cohesive/noncohesive sediments is computed
Ariathurai (1974) parameterized Partheniades (1962) results into a formula with an erosion rate coefficient M and critical shear for erosion τc. M and τc include the stochastic nature of both the sediment bed composition and surface and the bed shear stress. The critical shear for erosion is usually in the range of 0.2 to 0.8 Pa, while M is usually in the range widely from 0.01 to 50 Pa/hr (Winterwerp and van Kesteren 2004). Dahl et al. (2018) obtained good results in simulating the lower Mississippi river using τc = 0.02 lb/ft^2, τmw = 0.04 lb/ft^2, M = 0.05 $lb/ft^2/hr$, and M = 0.03 $lb/ft^2/hr$.

3.5.2 Flocculation

The settling velocity of cohesive particles is computed using a flocculation settling velocity. The flocculation settling velocity takes into account the formation and destruction of flocs as a function of the sediment concentration. HEC-RAS has two methods for estimating the settling velocity of flocs (see figure below). The first is the method of Hwang (1989). The method represents the settling velocity as 4 separate zones: (1) free settling, (2) flocculation, (3) hindered settling, and (4) negligible settling. The method requires 4 empirical coefficients.

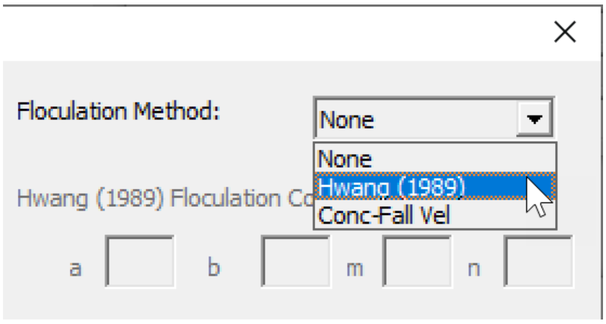


Figure 3. Selecting the Hwang (1989) floc settling velocity formula.

Example coefficient values for the Hwang (1989) formula are shown in the table below.

Table 1. Example coefficient values for the Hwang (1989) formula from literature.

Reference	**Location**	a	b	m	n
Krone (1962)	San Francisco Bay, CA	0.048	25.0	1.00	0.40
Owen (1970)	Severn River, UK	0.100	10.0	1.30	1.0
Nichols (1984)	James River, VA	0.039	3.8	1.32	1.52
Hwang (1989)	Lake Okeechobee, FL	0.080	3.5	1.88	1.65

Costa (1989)	Hangzhou Bay, China	0.100	6.20	1.60	1.20
Marván (2001)	Ortega River, FL	0.160	4.50	1.95	1.70
Ganju (2001)	Loxahatchee River, FL	0.19	5.80	1.80	1.80

The second method available to estimate the floc settling velocity is a user-specified **Flocculation Curve**. The **Flocculation Curve** defines the settling velocity as a function of the suspended sediment concentration. An example of a user-specified flocculation curve is shown in the figure below. The free-particle settling velocity is used when it is higher than the user-specified fall velocity for concentrations less than the concentration at the peak settling velocity. When the concentration is high than the maximum concentration specified in the flocculation curve, the settling velocity corresponding to the maximum concentration is used.

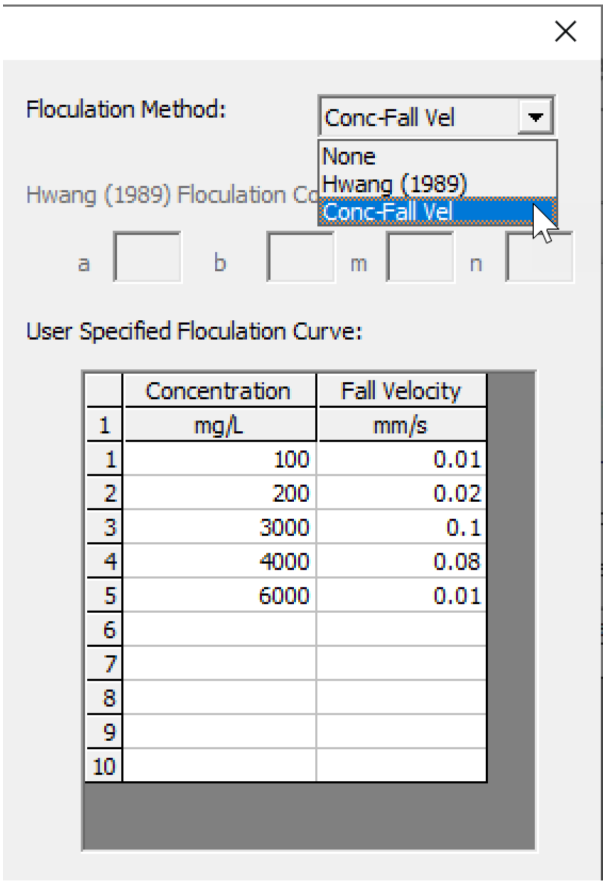


Figure 4. Specifying a floc settling velocity as a function of suspended sediment concentration.

In addition to taking into account the sediment concentration, HEC-RAS corrects the floc settling velocity for the water temperature by applying a correction which is a function of the water dynamic viscosity. This assumes that the user-specified curve and the coefficients in the Hwang method correspond to a standard water temperature of 55.4°F.

3.5.3 Consolidation

Consolidation curves are developed for a specific bed material. Since HEC-RAS only allows the user to specify one consolidation curve, a representative consolidation curve is used for the all of the modeling domain. It is assumed that the consolidation curve was developed for cohesive sediments. Until more than one consolidation curve is added to HEC-RAS a simple correction is computed to account for the presence of noncohesive sediments which can significantly affect the consolidation curve.

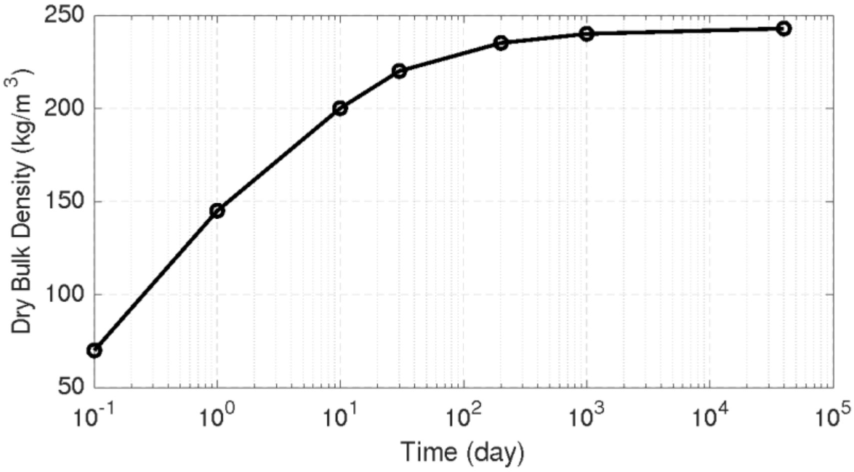


Figure 5. Example consolidation curve of dry bulk density as a function of time.

3.5.4 Kd vs M

HEC-RAS uses two different version of the excess shear equation for cohesive erosion: the dimensional (*Kd*) form and the "dimensionless" (*M*) form.

3.5.4.1 The Dimensional Form (*Kd*)

In the dimensional form of the excess shear equation, the erosion coefficient (Kd) is the ratio of the erosion rate to the excess shear stress (e.g. the difference between the bed shear stress and the critical shear stress). It is the slope of the shear-erodibility relationship, normalized by the shear stress.

This is called the "dimensional" form, because the excess shear term has shear stress units, giving the erodibility coefficient units (Mass/Force-time) that are not entirely intuitive.

What are the units of k_d

$$E = k_d(\tau_b - \tau_c)$$

$$\frac{Mass}{Area * time} \quad \frac{Mass}{Force * time} \quad \frac{Force}{Area}$$

3.5.4.2 The Dimensionless Form (*M*)

The alternate form of the excess shear equation normalizes the excess shear component by the critical shear stress, making it unitless. This makes the equation a little less intuitive but gives the erodibility coefficient (M) the same units as the erosion rate, which makes this parameter more intuitive and easier to communicate.

What are the units of *M*

$$E = M \frac{(\tau_b - \tau_c)}{\tau_c}$$

$$\frac{Mass}{Area * time} \qquad \frac{Mass}{Area * time} \qquad (Unitless)$$

3.5.4.3 Relationship Between *M* and *Kd*

You can convert between the dimensional and dimensionless forms of this equation by multiplying or dividing by τ_c / τ_c such that:

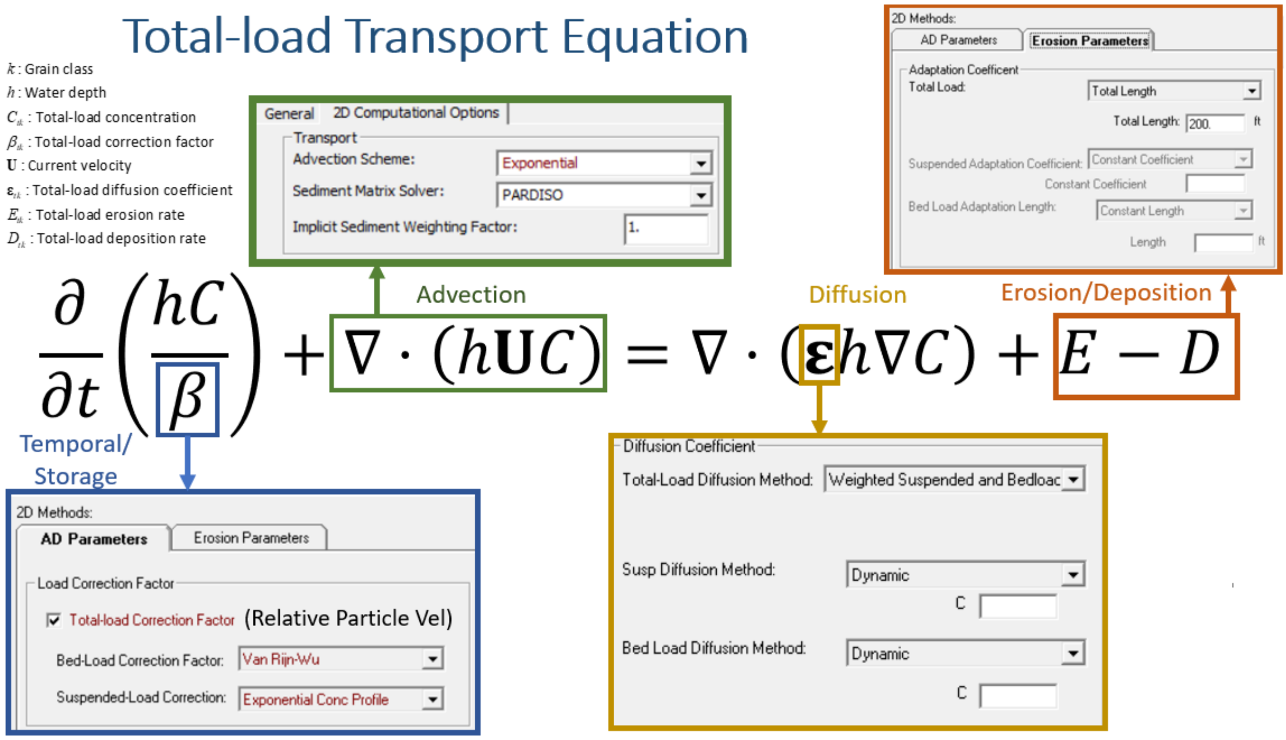
$$E = k_d(\tau_b - \tau_c) * \left(\frac{\tau_c}{\tau_c}\right) = \overbrace{k_d\,\tau_c}^{M} \frac{(\tau_b - \tau_c)}{\tau_c}$$

Therefore, you can convert between *M* and *Kd* by multiplying or dividing by the critical shear stress:

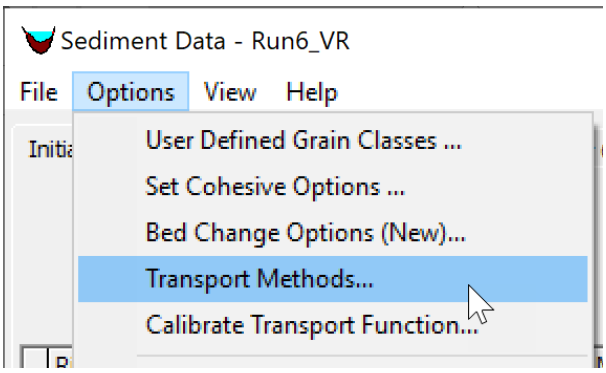
$$M = k_d\,\tau_c \qquad\qquad k_d = \frac{M}{\tau_c}$$

3.6 Transport Methods

The Transport Methods give you several parameters to influence the Advection-Diffusion sediment transport equation:



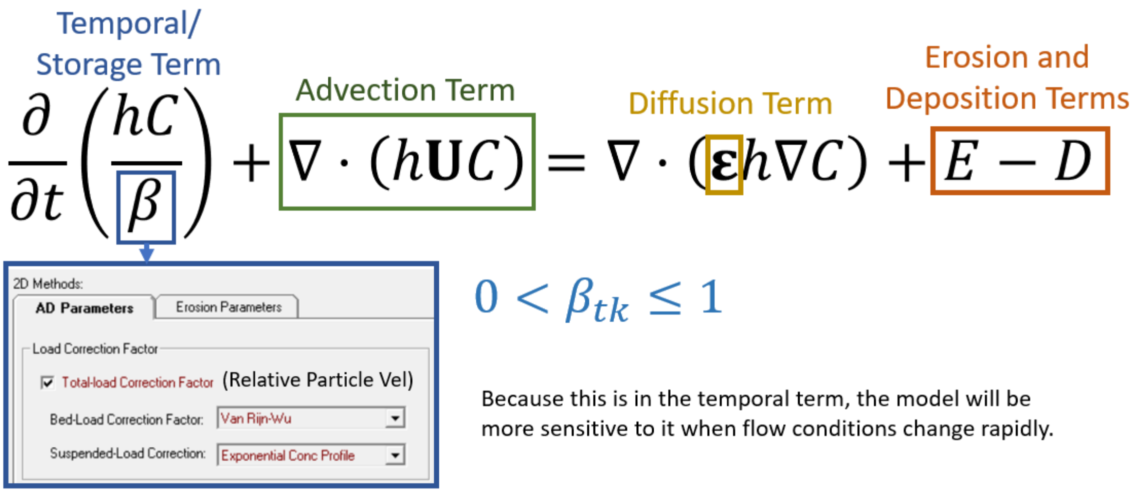
The **Transport Methods** editor is where the user may select the parameters and values for several transport-related variables. These include the Load Correction Factor, Diffusion Coefficient, and adaptation parameters. To open the **Transport Methods** editor, open the **Sediment Data** editor, and select open the **Options** menu and select **Transport Methods…** (see figure below).



4 Open the Transport Methods in from the Options menu of the Sediment Data editor.

3.6.1 Load Correction Factor (Relative Particle Velocity)

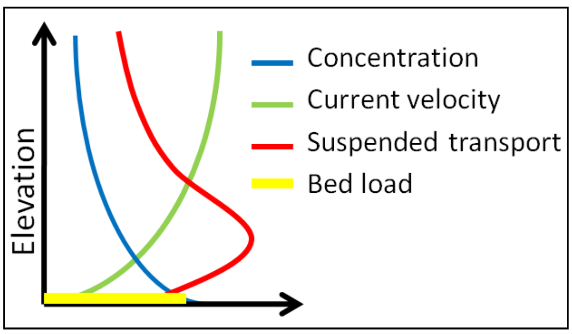
The load correction factor (beta) is - essentially - the relative velocity of the sediment particles. The **value varies from 0 to 1**, as a fraction of the flow velocity (e.g. beta=1 means that the sediment moves at the velocity of flown whild beta=0.1 means that the water velocity is 10X the sediment velocity).



Modeling Note: Particle Velocity Range and Sensitivity

This term influence results more if concentrations are changing dynamically. Slow changing systems or quasi-steady models will not be sensitive to this parameter.
Because β is a relative velocity, it should not be more than 1 or less than 0 (because sediment does not generally travel faster than water or in the opposite direction).

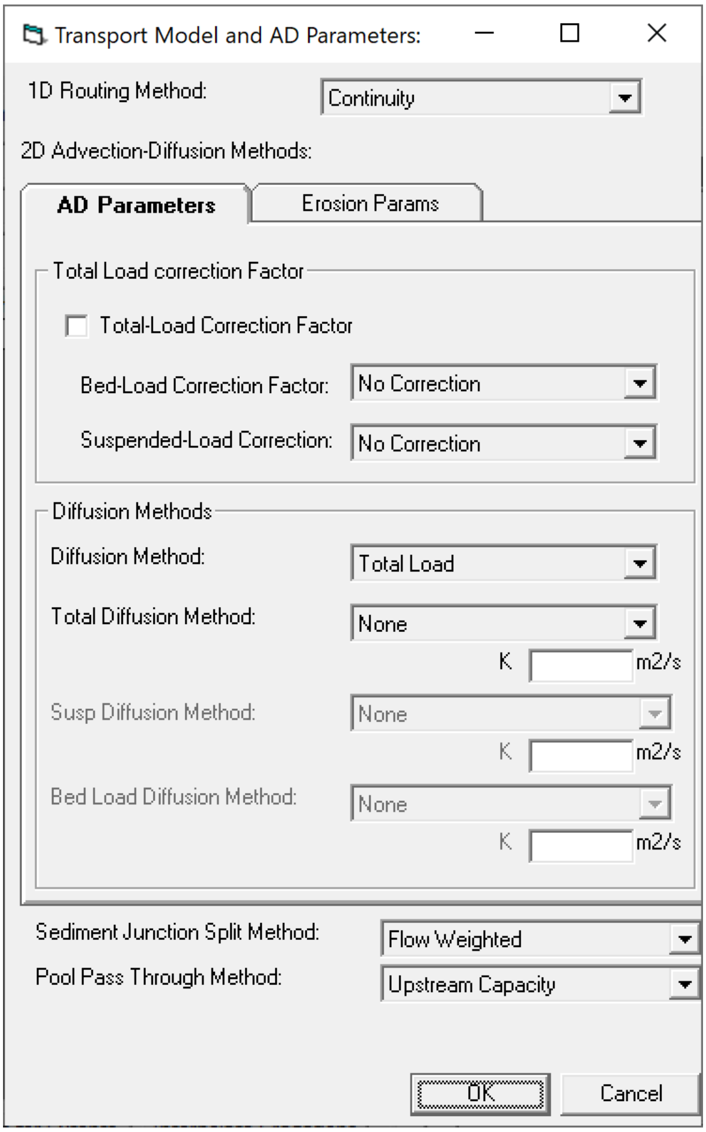
HEC-RAS 2D sediment transport has the option to approximate the current velocity and concentration profiles with approximate semi-analytical profiles, as well as to utilize an empirical formula for the bed-load velocity (see figure below). If these options are enabled, a load correction factor is included in the temporal term of the transport equation (i.e. advection-diffusion equation). The load correction factor accounts for non-uniform vertical profiles of the concentration and current velocity as well as the bed-load velocity. Since most of the sediment concentration is typical near the bed where the current velocities are slower, the load correction factor is generally less than one and produces a temporal lag between the flow and the sediment concentrations.



5 Schematic of sediment and current velocity profiles.

The load correction factor options are specified in the **Transport Model and AD Parameters** editor which can be accessed by opening the **Sediment Data** editor and selecting the menu **Options** and selecting **Transport Methods…**

The load correction factor options are specified within the section **Total-Load Correction Factor** section of the first tab of editor called **AD Parameters**. By default, HEC-RAS does not compute any load correction factors. To turn on the load correction factor the user may check the box labeled **Total-load Correction Factor**. One this checkbox is selected the user should select the methods used to compute the bed and suspended-load correction factors.

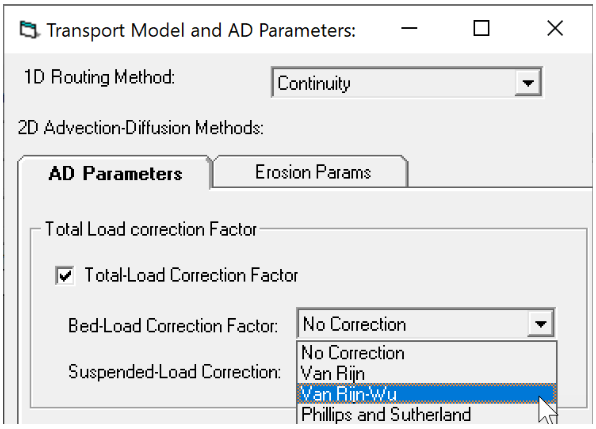


Setting the Total-load correction factor options in the Transport Model editor.

The bed-load correction factor method selects the formula for computing the bed-load velocity. The available bed-load velocity formulas are:

1. No correction
2. Van Rijn
3. Van Rijn-Wu
4. Phillips and Sutherland

Selecting **No Correction** assumes the bed-load velocity is equal to the depth-averaged velocity (β=1). The van Rijn and van Rijn-Wu are similar formulas. The only difference is that the van Rijn-Wu formula has coefficients that have been recalibrated with a larger dataset of measurements.



Setting the bed-load correction factor options in the Transport Model editor.

The suspended load correction factor methods select vertical sediment concentration profile. The three options are:

1. No correction
2. Rouse sediment concentration profile
3. Exponential sediment concentration profile

When selecting the Rouse and Exponential sediment concentration profiles, it is assumed that the current velocity follows a logarithmic profile. If **No Correction** is selected, the suspended-load correction factor is set to one.

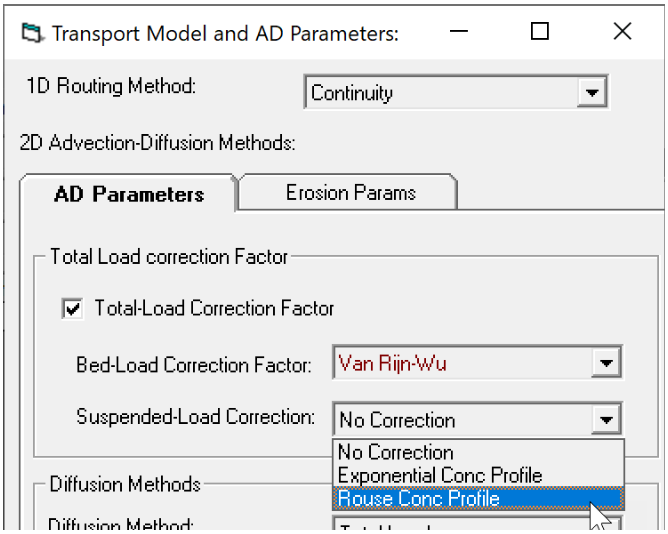


Figure 5. Setting the suspended-load correction factor method in the Transport Model editor.

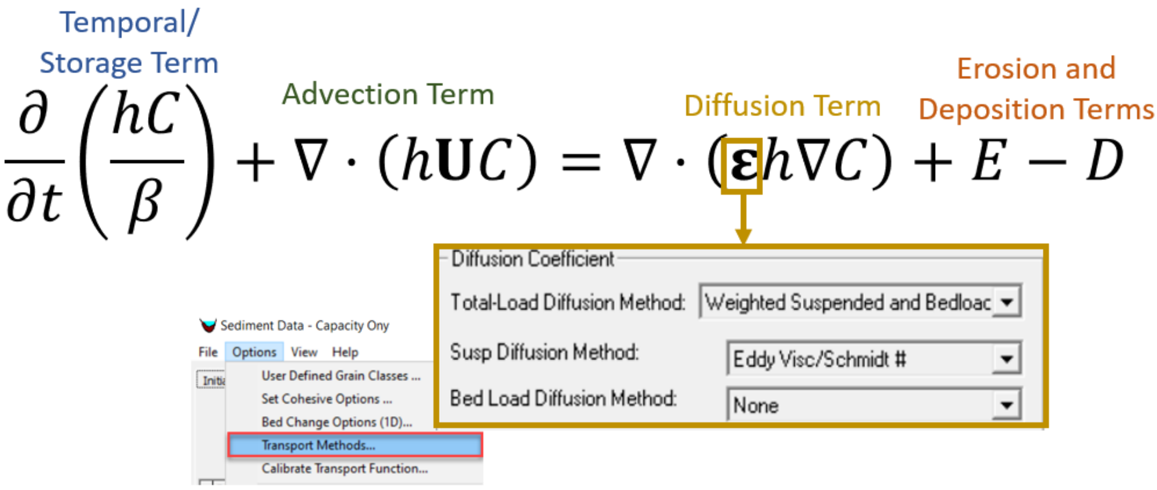
Generally, for practical applications there is not enough data to calibrate the bed and suspended-load correction factors. Their use is a compromise between accuracy and computational time which are both relatively minor. In general, the morphology change is much more sensitive to other parameters and options such as the transport function and adaptation parameters than the load correction factors.

3.6.2 Diffusion Coefficient

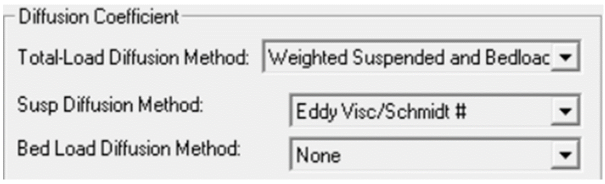
Diffusion in the transport equation includes a diffusion coefficient that you can parameterize. By default this is zero, computing no diffusion. HEC-RAS computes the horizontal diffusion coefficients with two methods:

1. Constant total-load diffusion coefficient
2. Weighted bed-load and suspended-load diffusion coefficients

Some of these methods require empirical parameters, while others use equations based on hydraulic results.



Modeling Note: Bed Load Diffusion is Usually Small and Can be Can be Ignored



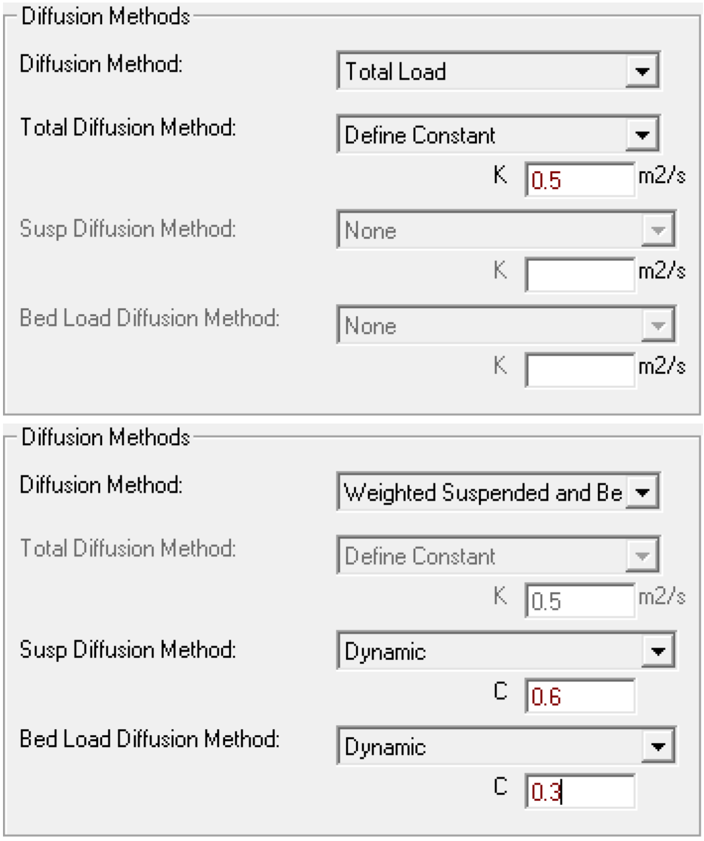
If you partition the suspended and bed load diffusion methods, selecting **Eddy Visc/Schmidt #** for suspended and **None** for bed load is a good place to start (that does not require an empirical parameter) because the suspended diffusion is usually much more significant than bed load..

Horizontal turbulent mixing and dispersion is modeled in HEC-RAS with a Fickian diffusion model. Turning on horizontal mixing is important in simulations with high resolution and sharp variations in sediment concentration capacities and concentrations, and when using high-resolution advection schemes. When the computational grid is relatively coarse or when using a first-order advection scheme the numerical diffusion may be so large that adding horizontal mixing is unnecessary. In general, sediment diffusion should not be used in combination with the Diffusion Wave Equation (DWE), since this can result and overly diffusive results.

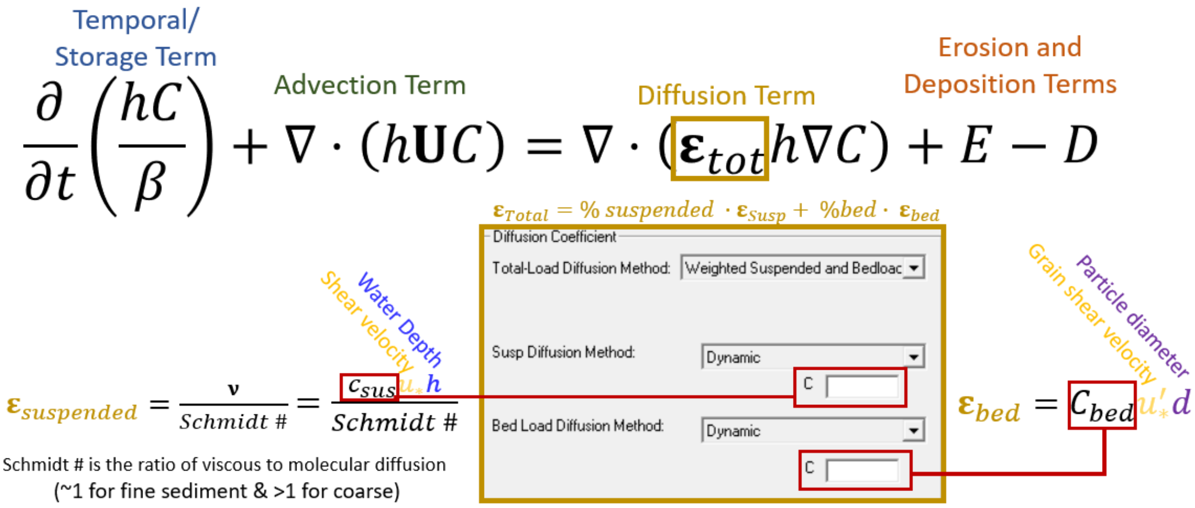
HEC-RAS computes the horizontal diffusion coefficients with two methods. The options and parameters are in the **AD Parameters** tab of the **Transport Model and AD Parameters** editor which can be opened from the

Sediment Data editor under **Options** and selecting **Transport Methods...** HEC-RAS has two options for the total-load diffusion coefficient.

The default in HEC-RAS is for total-load diffusion of zero (i.e. no horizontal diffusion).



Constant total-load diffusion coefficient (left) weighted bed and suspended load coefficients (right).



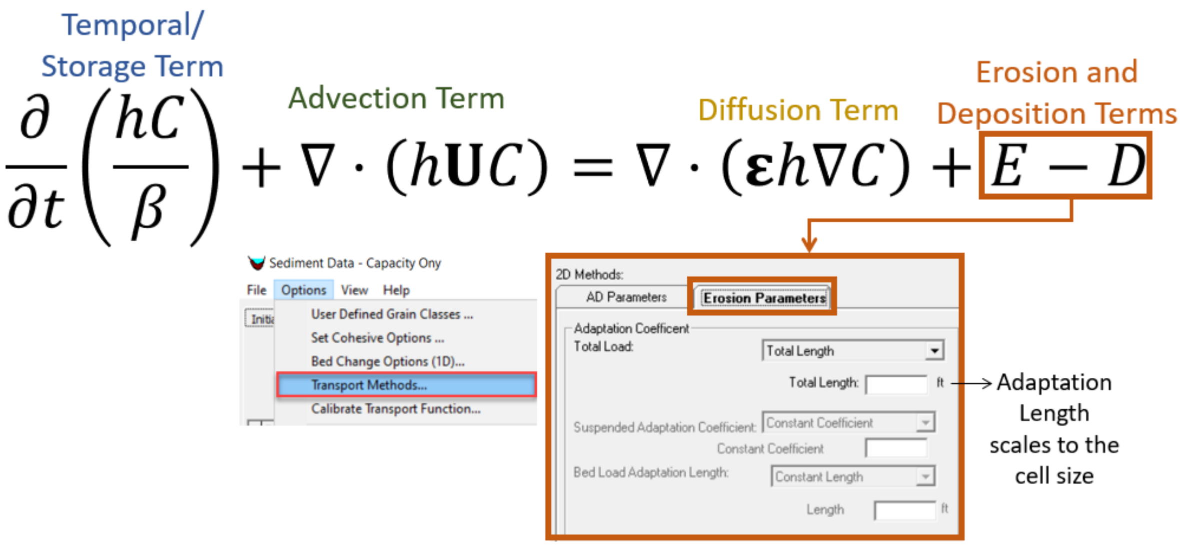
Modeling Note: Suspended Load Diffusion is Larger than Bed Load

Note: The equations for suspended and bed load diffusion coefficients are very similar (Cu*h/~1 vs Cu*'d - see above), except one includes the water depth and the other the particle diameter. Suspended diffusion is, therefore, orders of magnitude larger than bedload diffusion.

3.6.3 Erosion Parameters

The **Erosion Parameters** tab of the **Transport Model and AD Parameters** editor contains the settings for the noncohesive sediment transport erosion formulation. The total-load sediment erosion is computed as a function of the total-load adaptation coefficient. In HEC-RAS there are two methods for computing total-load adaptation coefficient:

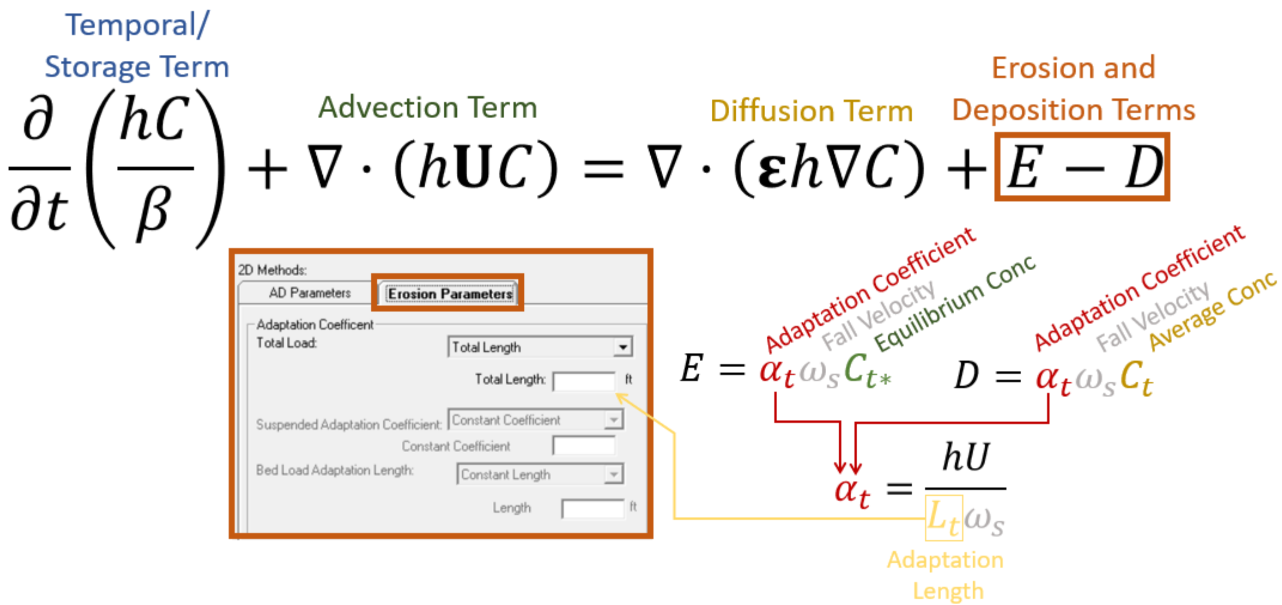
1. Total-load length
2. Weighted bed-load and suspended-load adaptation coefficients



Modeling Note: Estimating Adaptation Length

This is an important parameter. A good initial estimate for the adaptation length is ~1-2X the cell size. Runs with smaller adaptation lengths will erode and deposit more than while models with larger adaptation lengths. Larger adaptation lengths will smooth results.

The total-load adaptation length computes the total-load adaptation length as a function of the unit discharge and sediment fall velocity (see figure below). The total-load adaptation length is the simplest and most computationally efficient of the two options.



Modeling Note: Adaptation Coefficient and Adaption Length

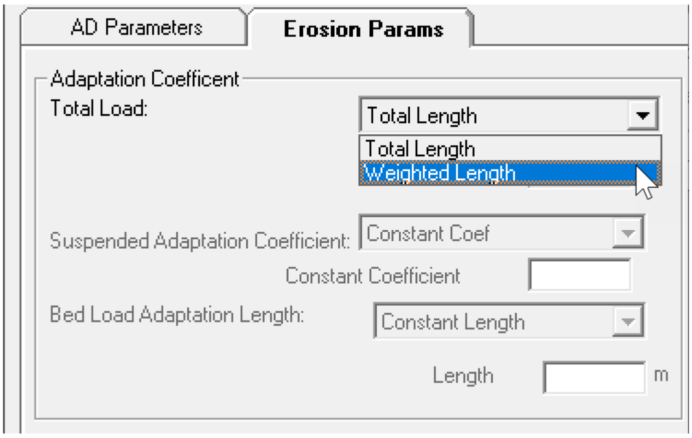
In the Wu (2000) approach erosion and deposition are directly related to the same Adaptation Coefficient (α_t) to compute erosion and deposition.

Both are inversely related to the Adaptation Length (L_t)

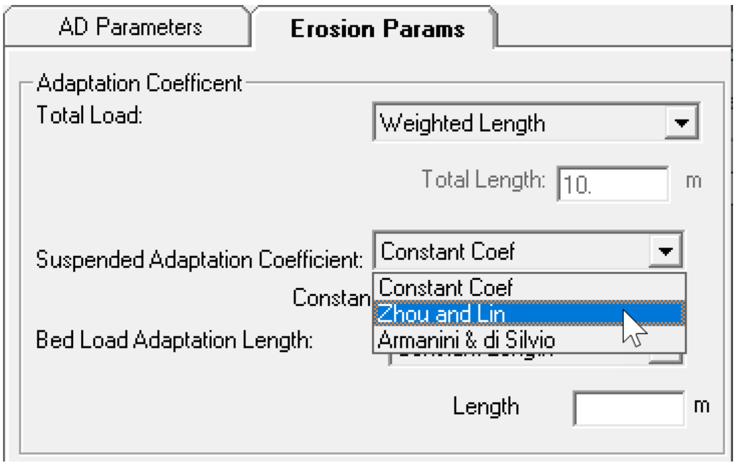
Erosion is a function of the equilibrium concentration C_{t*} which comes from the transport function (e.g. Wu or van Rijn)

Deposition is a function of the average concentration in the cell C_t

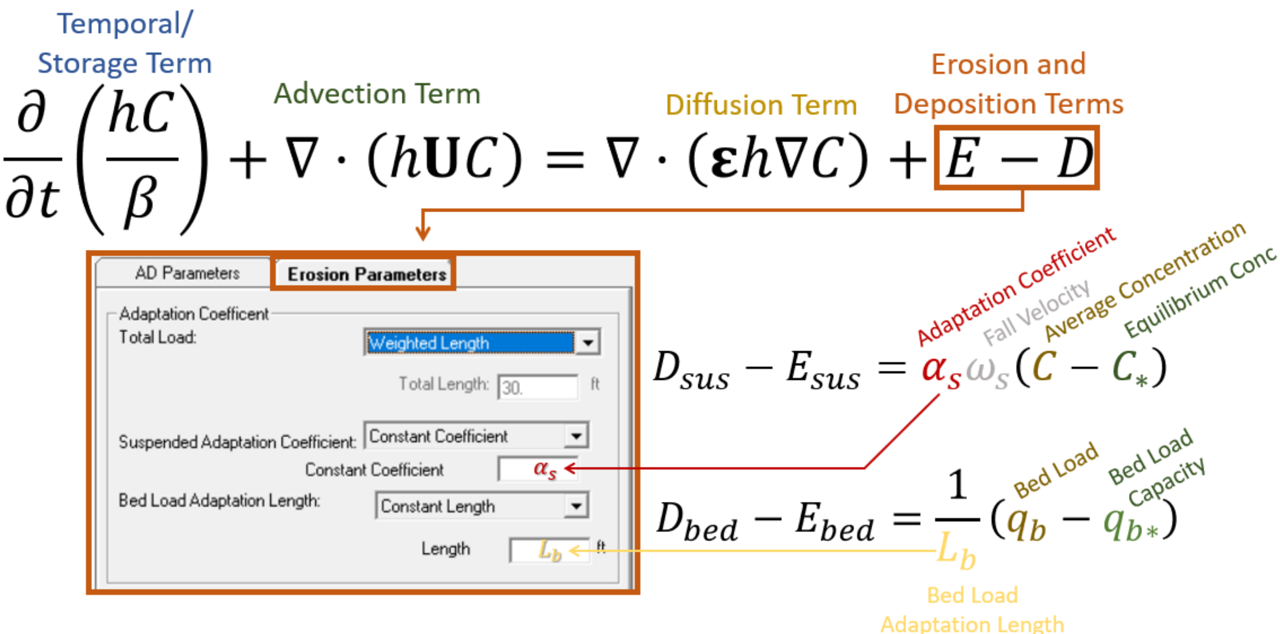
The weighted bed-load and suspended adaptation coefficients requires specifying methods for the bed-load and suspended-load adaptation coefficients and computing the fraction of suspended sediments. However, it is the most physically accurate method.



If you select a weighted total-load adaptation length you will specify separate suspended and bed load parameters.



Specifying a suspended-load adaptation coefficient.



When first setting up a sediment transport model, it is recommended to use a constant total load adaptation length for simplicity. Once the user has a stable model producing reasonable results, it is recommended to perform a sensitivity of the adaptation length by adjusting the adaptation length. In many cases, the results are not found to be sensitive. This is usually for relatively coarse grid simulations under mild to moderate forcing. However, if the results are found to be sensitive to the adaptation length then more tests are necessary in determining to optimal adaptation method and parameters.

2D Sediment Parameter Quick Start Guide

A printable document that identifies the adjustable parameters and recommendations on ranges, sensitivities, and starting points.

3.7 Transport Function Calibration and Modification

The **Transport Function Calibration and Modification** editor allows the user to scale or calibrate different transport formula in various ways. It is opened from the **Sediment Data** editor by opening the **Options** menu and selecting **Calibrate Transport Function** (see figure below).

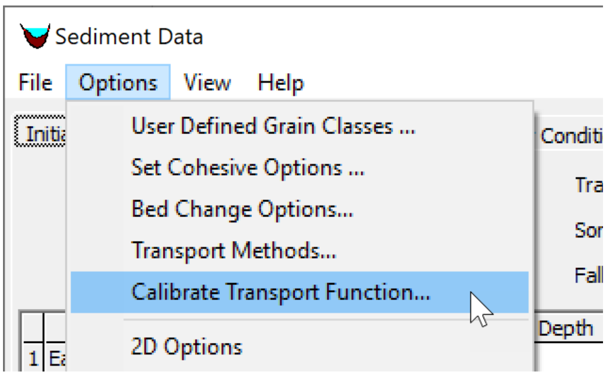


Figure1. Opening the Transport Function Calibration and Modification editor from the Sediment Data editor.

The preferred method for calibrating the transport function is by means of the scaling factors. The total-load scaling factor is applied the same to all the transport functions. The mobility factor multiplies by the threshold for incipient motion (albeit a critical shear, reference shear, or Shields number). Therefore, a mobility factor larger than 1 reduces the mobility of a sediment. The option is also available to calibrate specific coefficients and exponents of several transport formula.

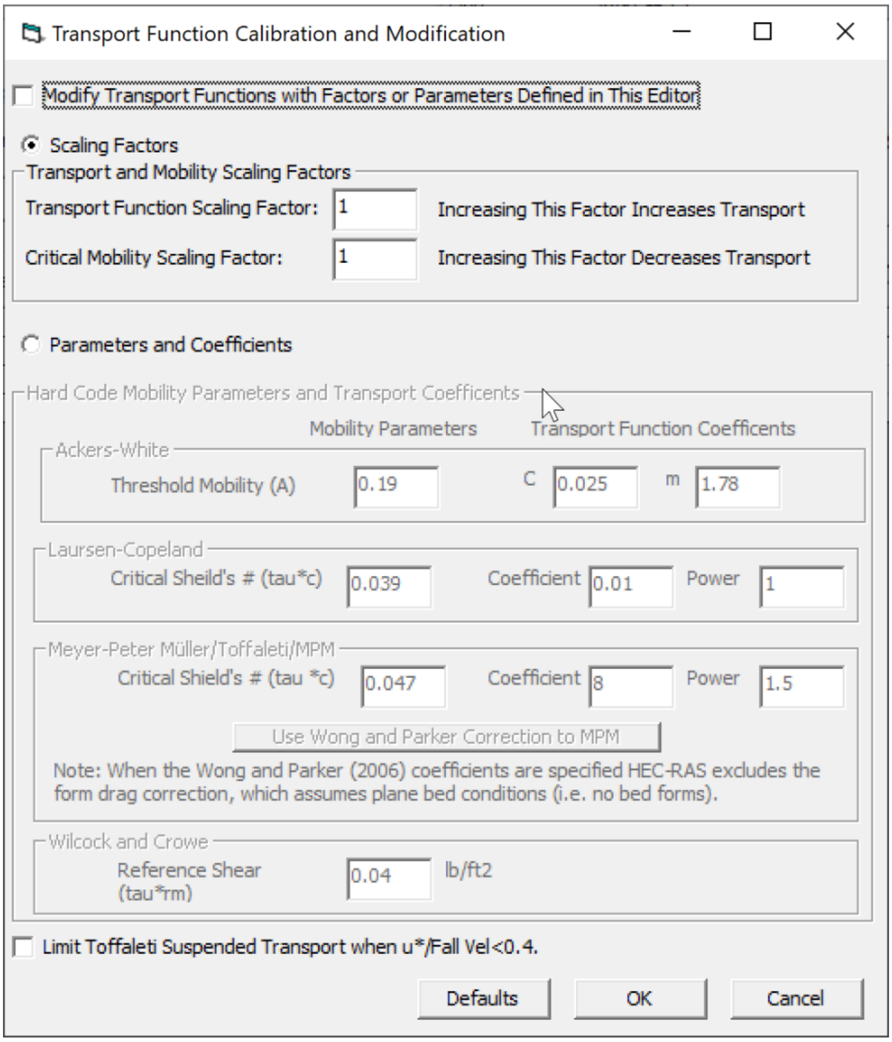


Figure 2. Transport Function Calibration and Modification editor.

3.8 2D Options

There are several sediment transport options which are only available in 2D. The goal is for both 1D and 2D sediment transport to have the same options but for now the 2D only options have been places in a single editor called **2D Options** which is available from the **Sediment Data** editor under the **Options** menu (see figure below).

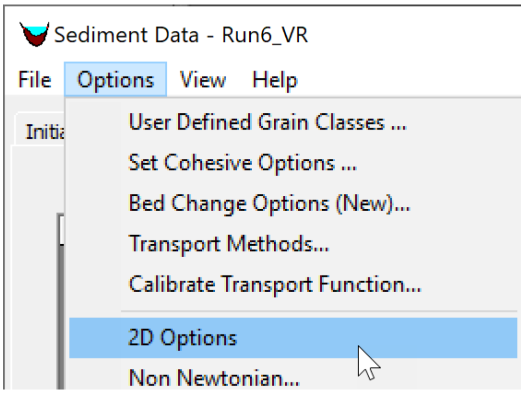


Figure 1. Opening the 2D Options editor from the Sediment Data editor.

The 2D Sediment Options editor is shown in the figure below. The editor is used to specify the options for sheet and splash erosion, the morphologic acceleration factor, the base bed-slope coefficient, and hindered settling.

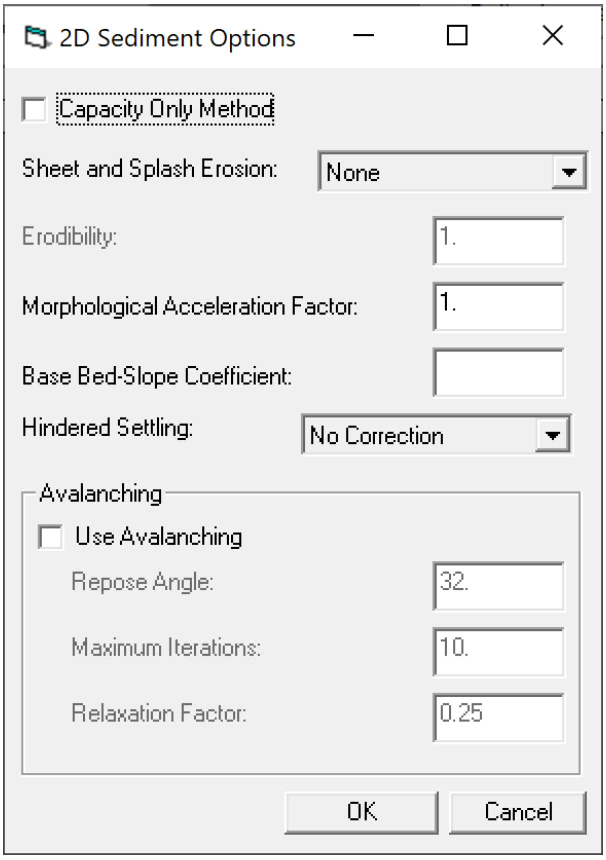


Figure 2. 2D Options editor.

3.8.1 Capacity Only Method

In HEC-RAS Version 6.2 the **Capacity Only Method** was introduced. If the **Capacity Only Method** is checked on, the model computes only the sediment transport capacity (i.e. equilibrium concentrations) for all grain classes and does not solve the transport, bed sorting, and bed layering equations. The transport rates are computed with the sediment capacity. The **Capacity Only Method** runs much faster because it does not solve transport, bed sorting, and bed layering equations for each grain class. This makes the method very useful for screening sediment transport functions and estimating initial sediment bed gradations and sediment boundary conditions.

3.8.2 Sheet and Splash Erosion

The first option available in the editor is the **Sheet and Splash Erosion**. The 2D sediment transport model has the option to use the Wei et al. (2009). The formulation has an erodibility coefficient which for simplicity is set to a single value in HEC-RAS. The units of the erodibility coefficient are $kg \cdot m^{-3.644} \cdot s^{0.644}$. Wei et al. (2009) reported values for the sheet and splash erosion coefficient between 1124 and 2555 $kg \cdot m^{-3.644} \cdot s^{0.644}$ for 3 grassland rangeland plots in Arizona (all variables in the International System of Units). However, its value can vary by orders of magnitude for different soil types and cover characteristics.

3.8.3 Morphologic Acceleration Factor

The **Morphologic Acceleration Factor** can turn off the bed change or - as the name implies - accelerate the bed change. The factor is directly multiplied by the mass bed exchange rates at every time step. A value of zero will turn off the bed elevation and bed composition change.

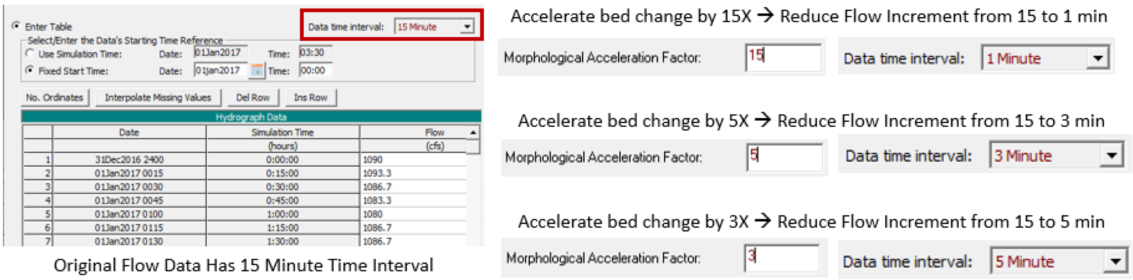
The **Morphologic Acceleration Factor** can be utilized in several ways. It can turn off bed change (Morph Acceleration = 0). This saves computational time and is useful for idealized situations are when debugging a problem with a sediment model. The "Concentration Only" computational mode provides the same capability now, however, and is a more direct method for fixed-bed sediment modeling.

The **Morphologic Acceleration Factor** is usually a scaling factor for bed change change. The factor can be simulate a time period which represents the morphological change of a time period equal to the simulation period times the **Morphologic Acceleration Factor**. This approach is commonly used in coastal applications with tidal boundary conditions. As an example, a 5-year simulation can be run with **Morphologic Acceleration Factor** of 20 to simulate 100 years of change, which greatly reduces the computational time. However, it should be noted that this approach changes the order of events (i.e. storms and tidal forcing with respect to morphological features) which can have a negative impact on the accuracy of the approach.

Lastly, the **Morphologic Acceleration Factor** can speed-up run time. This approach is more appropriate in river applications or when simulating single events or sequences of events. As an example, a 20-day simulation can be reduced to 2 days by setting the **Morphologic Acceleration Factor** to 10. In this approach you also must speed up the boundary conditions by the same factor. However, do not speed-up the time so much that the hydrodynamics change substantially and thereby the morphological change.

Changing the Boundary Condition Time Step with the Morphological Acceleration Factor

It is useful to choose a Morphological Acceleration Factor that is easily divisible by the time step. For example, if a boundary condition data increment is 15 minutes, selecting Morphological Acceleration Factors of 3, 5, or, 15 makes it easier to adjust these data to accommodate the temporal dilation. See these three examples below:



Original Flow Data Has 15 Minute Time Interval

The **Morphologic Acceleration Factor** should be used with caution as it can lead to misleading results or instabilities. The best practice for using the factor is to test the validity of the factor by doing a full or partial length of a simulation with the factor and without it and compare the results. If the results agree reasonably well, then longer or alterative simulations can usually be done with the **Morphologic Acceleration Factor** thus saving time. It is generally not recommended to use a factor larger than 30 to 50, and values between but not equal to 0 and 1. The **Morphologic Acceleration Factor** can be verified by reducing its value (e.g. by a factor of 2) while also increasing the simulation time by the same factor and verifying the simulation results do not significantly change.

Since, the **Morphologic Acceleration Factor** is applied to the bed exchange rates, the approach does not change total-load transport rates or concentrations. In addition, the approach is not locally mass conservative but approximately globally conservative.

Finally, it is important to emphasis that the **Morphologic Acceleration Factor** should NOT be used as a calibration parameter. It should be used carefully and validated to make sure the results are not sensitive to the **Morphologic Acceleration Factor**. When used carefully the **Morphologic Acceleration Factor** can be a powerful and useful tool in numerical studies.

3.8.4 Base Bed-Slope Coefficient

The **Base Bed-Slope Coefficient** specifies the maximum value of the bed-slope coefficient. The coefficient is then reduced based on the skin and critical shear stresses. As the ratio between the skin and critical shear stress increases bed-load particles are less influenced by the bed slope. The coefficient is used to compute an additional sediment flux in the downslope direction which is a function of the bed slope, the bedload, and the bed-slope coefficient. For further details on the formulation, the user is referred to the HEC-RAS 2D Sediment Technical Reference manual (HEC 2020). The **Base Bed-Slope Coefficient** typically has a value between 0.1 and 1. Increasing the coefficient has the effect of smoothing the bathymetry. Measured bed change can be used to calibrate the base bed-slope coefficient. However, its effect is significantly less than the transport formula, transport scaling factors and mobility scaling factor. The **Base Bed-Slope Coefficient** will tend to improve model stability by smoothing out small scale instabilities. However, if the value is too large the numerical scheme can become unstable. In these situations the user can either reduce the computational time step or reduce the value of the **Base Bed-Slope Coefficient**.

Modeling Note: Base Bed-Slope Coefficient Range

The Base Bed-Slope Coefficient generally varies from 0.1 to 0.5 and higher values tend to smooth results.

3.8.5 Hindered Settling

Hindered settling is the condition in which the settling velocity of particles or flocs is reduced due to a high concentration of particles. Hindered settling is primarily produced by particle collisions and the upward water flow equal to the downward sediment volume flux. Hindered settling occurs to both cohesive and noncohesive particles. However, the hindered settling correction described here only applies to noncohesive particles. The hindered settling of cohesive particles is accounted for in the floc settling method. Currently, the 2D sediment has the option to use the Richardson and Zaki (1954) formula for hindered settling (see figure below). For simplicity the exponent in the Richardson and Zaki (1954) is set to 4.0 and cannot be modified in the user interface.

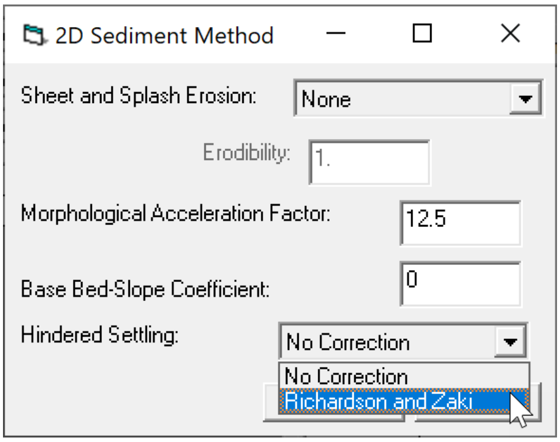


Figure 3. Setting the hindered settling method to the Richardson and Zaki (1954) method.

The figure below shows the ratio of the hindered settling velocity ω_{sd} and free settling velocity ω_{sd0} as a function of the total sediment concentration by volume following Richardson and Zaki (1954).

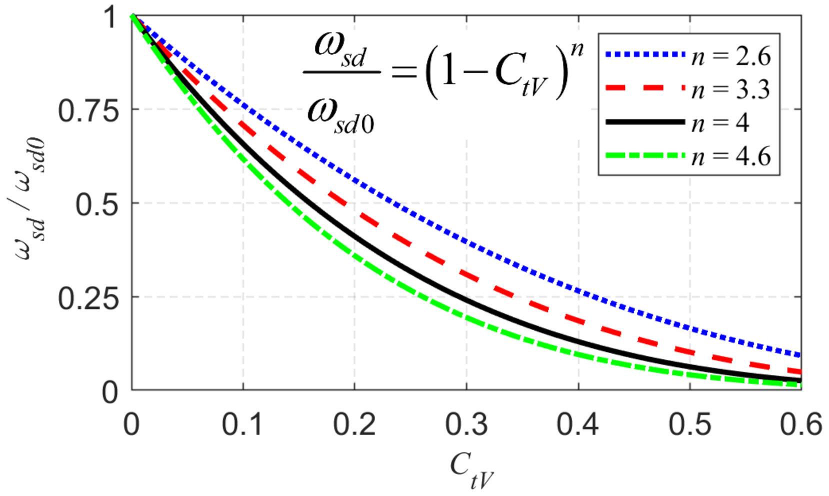


Figure 4. Richardson and Zaki (1954) hindered settling velocity formula.

3.8.6 Avalanching

HEC-RAS Version 6.2 and newer support the option to simulate sediment sliding or avalanching. This option is limits the bed slope to the angle of repose. A single angle of repose is utilized for both wet and dry cells. The angle of repose can vary from about 30° to nearly vertical for cohesive beds. Avalanching is computed with an iterative relaxation approach which has two parameters: (1) the maximum number of iterations, and (2) a relaxation factor. The recommended range for the maximum number of iterations is between 5 to 20. The range for the relaxation parameter is typically between 0.1 and 0.3. The angle of repose, maximum number of iterations, and relaxation factor are specified in the **Avalanching** section of the 2D Options menu.

3.9 Bed Mixing Options

The **Bed Mixing Options** editor contains both 1D and 2D sediment bed mixing options and other parameters. The editor is opened from the **Sediment Data** editor by going to the **Options** menu and selecting **Bed Mixing Options …** (see figure below).

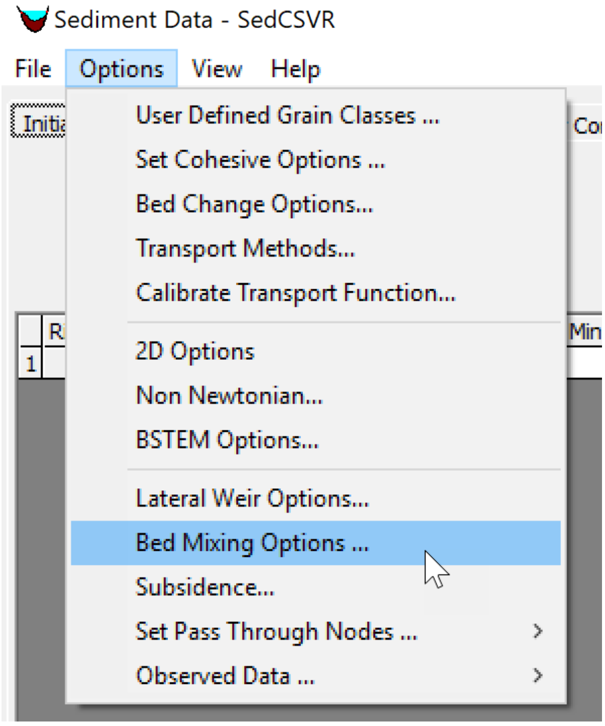


Figure 1. Accessing the Bed Mixing Options editor from the Sediment Data editor.

An example of the **Bed Mixing Options** editor is shown in the figure below. The sections which are applicable to 2D sediment are **Hiding Functions** and **Active Layer Options.**

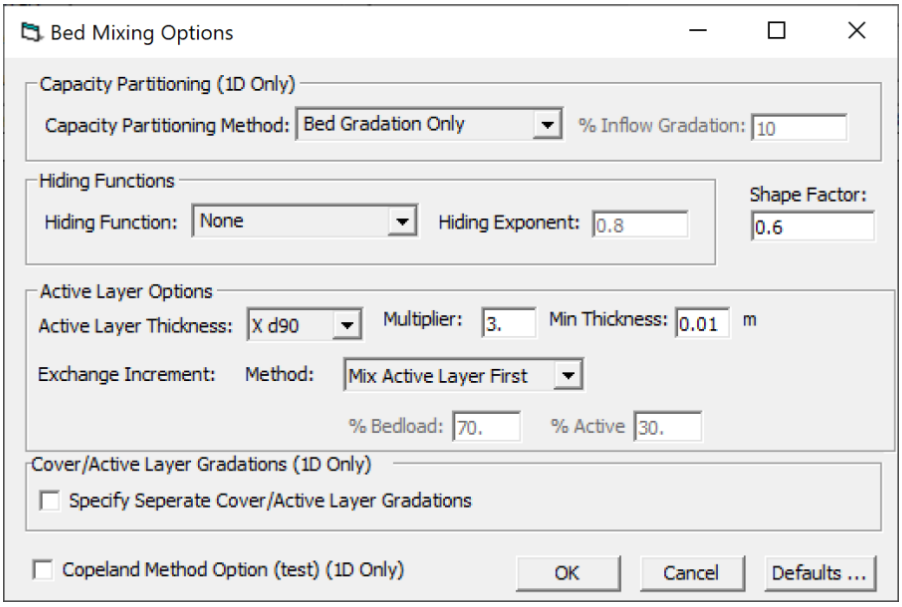


Figure 2. Bed Mixing Options editor.

3.9.1 Hiding Functions

In non-uniformly sized sediment beds, smaller particles are hidden from the flow and physically trapped by larger particles whereas larger particles are more exposed to the flow and less impeded to move freely. The hiding (and exposure) function computes a correction to the incipient motion variable such as a shear stress or velocity to account for the hiding and exposure of particles. The hiding functions available in HEC-RAS are:

1. None (no correction)
2. Ashida and Michiue (1971)
3. Day (1980)
4. Egiazaroff (1965)
5. Hayashi et al. (1980)
6. Parker et al. (1982)
7. Proffitt and Sutherland (1983)
8. Wilcock and Crowe (2003)
9. Wu et al. (2000)

The hiding and exposure function can have a big impact on the results. Some of the hiding and exposure functions were developed for in conjunction with specific transport potential functions. For example, the Wu et al. (2000) hiding function was developed for use with bed- and suspended-load transport potential functions published in the same paper. Similarly, the Day (1980) and Proffitt and Sutherland (1983) hiding function where developed specifically for the Ackers and White (1973) transport potential formula. Lastly the Wilcock and Crowe (2003) hiding function was developed specifically for the Wicock and Crowe formula (Wilcock 2001; Wilcock and Crowe 2003).

3.9.2 Active Layer Options

Within the **Active Layer Options** section of the **Bed Mixing Options** editor are the input options controlling the active layer thickness and the Exchange Increment Method. The exchange increment is not utilized in the HEC-RAS 2D sediment transport model.

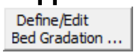
3.9.2.1 Active Layer Thickness

There are two methods for computing the active layer thickness: (1) **d90**, and (2) **X d90**. The methods are selected within the **Active Layer Options** section of the **Bed Mixing Options** editor. The option **d90** , the active layer is set to the 90th percentile diameter of the active times a user-specified multiplier. If the multiplier is set to 1, then the two methods produce the same results. In future versions, the method **d90** will be dropped in favor of the **X d90** method with a multiplier for simplicity. The

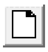
3.9.2.2 Minimum Active Layer Thickness

The option is provided to specify a minimum active layer thickness within the **Active Layer Options** section of the **Bed Mixing Options** editor. This option is useful when simulating very fine material as the active layer thickness can become unreasonably small. Increasing the minimum active layer thickness may also reduce instability problems when the active layer gradation is changing very quickly.

3.10 Bed Gradations

Instead of specifying the sediment size distribution and potentially the cohesive sediment properties at every 2D computational cell (and cell subarea), HEC-RAS uses a template concept similar to that of the **Channel Modification Editor**. In HEC-RAS a **Bed Gradation Template** describes the grain size distribution and cohesive sediment properties of a sediment mixture. **Bed Gradation Template** are first defined in a database and then associated to **Sediment Bed Materials** which are specified at each computational cell within **RAS Mapper**. The **Bed Gradation** editor, is opened from the **Sediment Data** editor by clicking on the button 

. An example grain size distribution in the **Bed Gradation** editor is shown in the figure below.

To create a new **Bed Gradation** the user may click on the "New" button  . Give it a name (e.g. "Nonuniform"). Enter the gradation information as shown in the figure below.

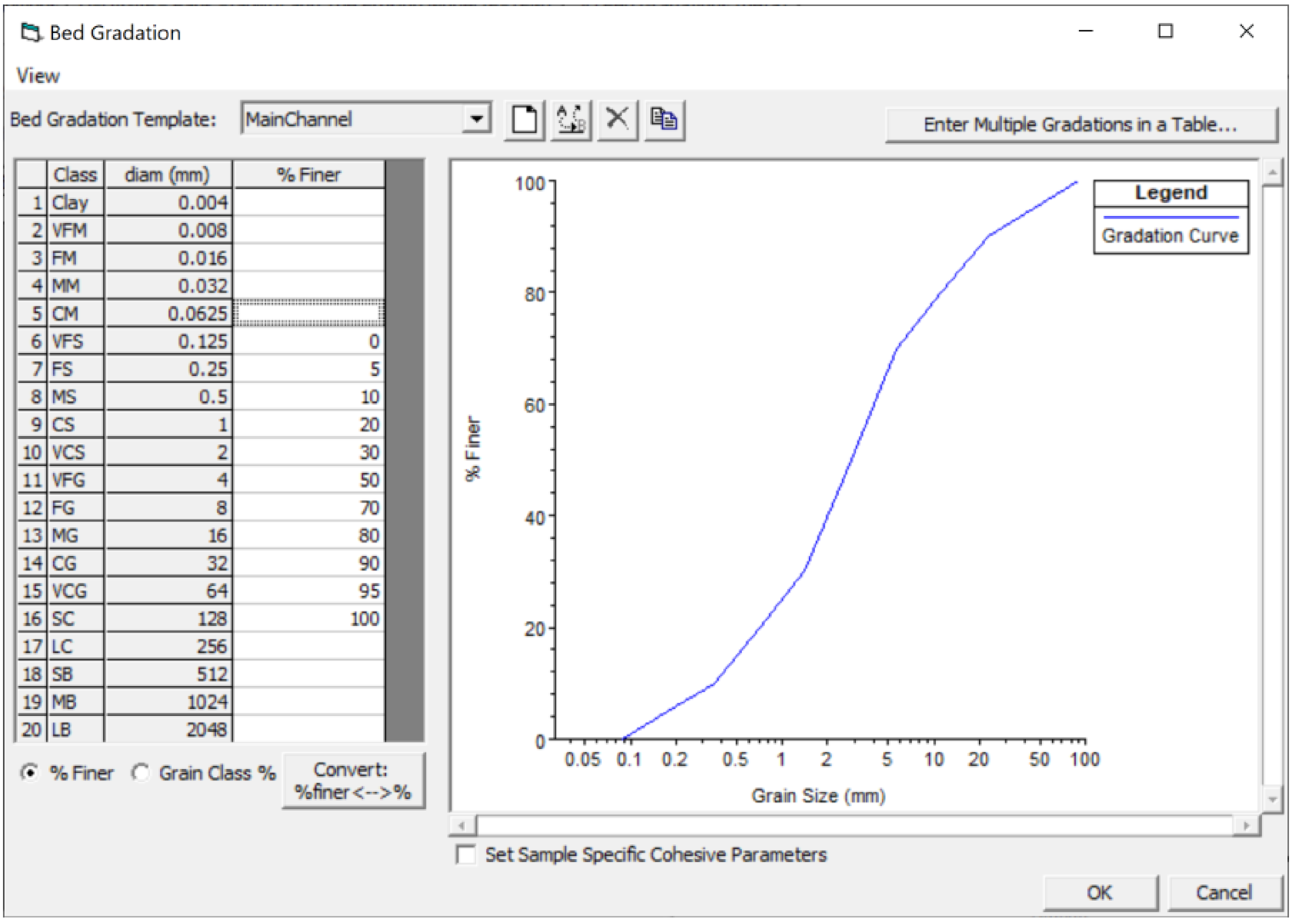
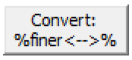


Figure 1. Bed Gradation editor with an example grain size distribution.

The user may enter the size distribution as percent finer values or grain class percent values. The current mode is indicated by the radio buttons under the table on the left side of the editor names **% Finer** and **Grain Class %**. The user may also convert the values in the table from one mode to the other by clicking on the button 

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The 2D sediment transport model will only compute grain classes which are utilized in the initial bed gradations or any boundary conditions. This reduces the computational costs and speeds up the model. Consequently, it is important for the user to be mindful of how many grain classes are utilized in the input.

For example, HEC-RAS has 5 cohesive grain classes. Except for the particle fall velocity, all the cohesive grain classes are treated the same, therefore using 5 cohesive grain classes or just 1 will have little impact on the results but a big impact on the computational costs.
Optionally, HEC-RAS allows users to associate bulk bed properties with bed gradations. More specifically, the sediment cohesive properties can be specified for each bed gradation. This option is activated by selecting the checkbox at the bottom of the **Bed Gradation** editor labeled **Set Sample Specific Cohesive Parameters** (see figure below).

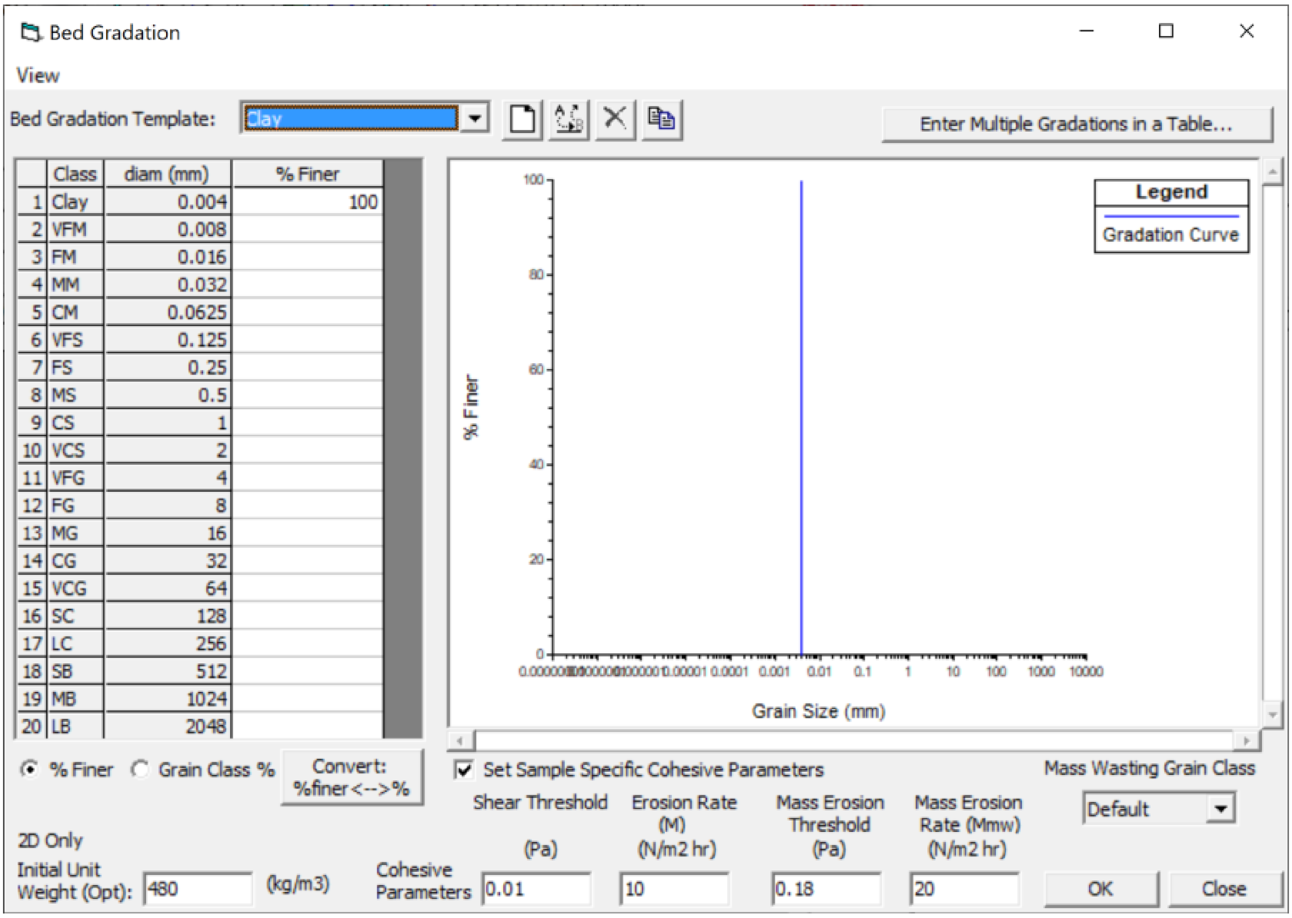


Figure 2. Setting sample specific cohesive parameters in the Bed Gradation editor.

4 Sediment Computation Options and Tolerances

The sediment transport user-specified computational options, parameters, tolerances, and methods are set in the **Sediment Computation Options and Tolerances** editor. To open the editor, open the **Unsteady Flow Analysis** editor and select the **Options** menu and click on the menu item **Sediment Computation Options and Tolerances** (see figure below).

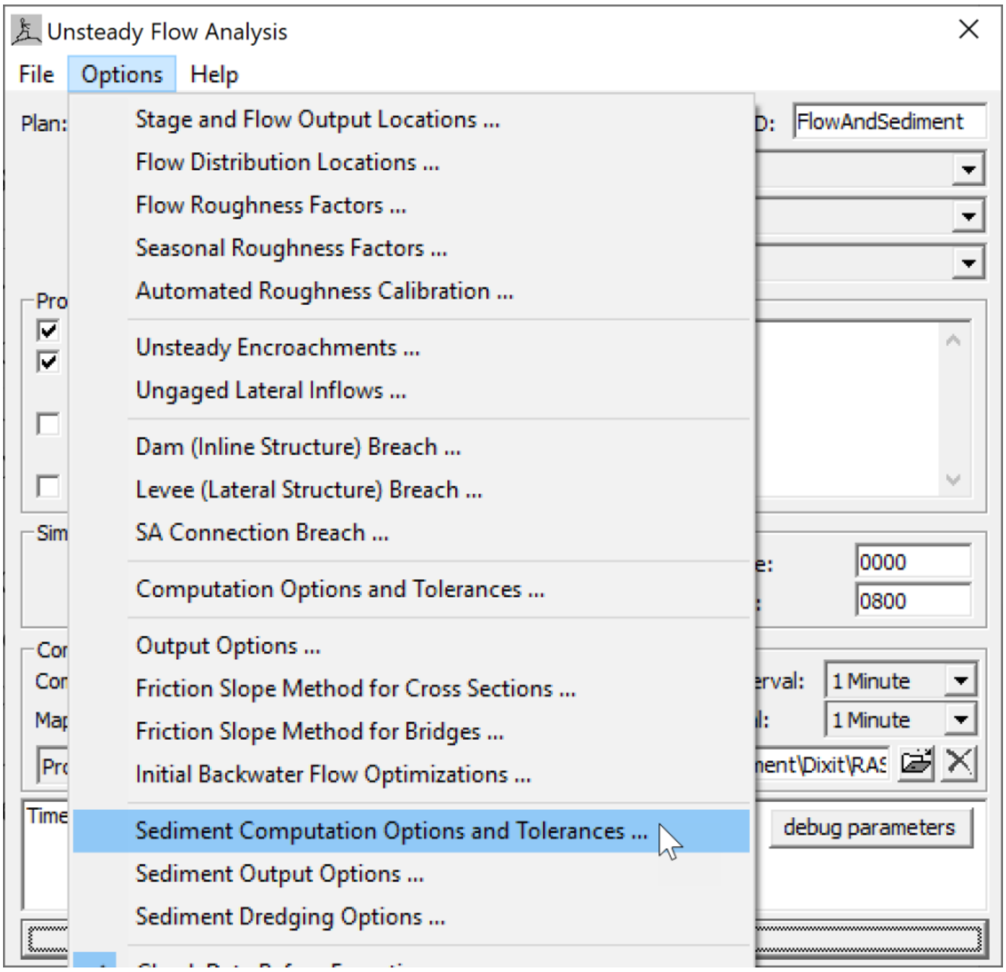


Figure 1. Bed Gradation editor with an example grain size distribution.

The **Sediment Computation Options and Tolerances** editor has two tabs: **General** and **2D Computational Options**. These tabs are described in the sections below.

- General Options and Tolerances (see page 78)
- 2D Computational Options (see page 80)

4.1 General Options and Tolerances

4.1.1 Computational Options

The **General** tab of the **Sediment Computation Options and Tolerances** editor contains the 1D computational options but also includes some options which the 1D and 2D sediment models share (see figure below). The 2D sediment transport model uses the **Bed Roughness Predictor**, the **Computation Multiplier** and **Warmup Periods**.

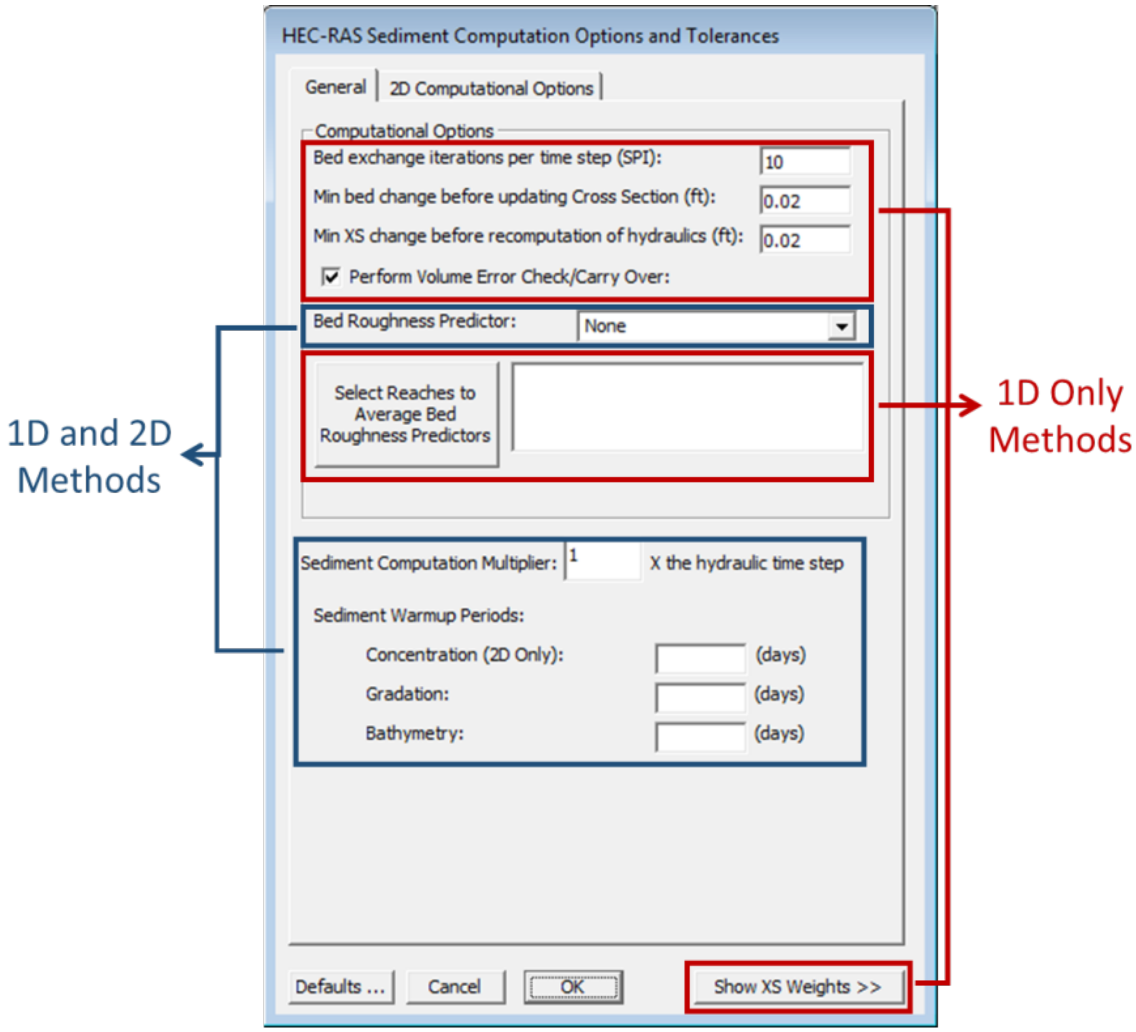


Figure 1. General tab of the Sediment Computation Options and Tolerances editor.

4.1.2 Bed Roughness Predictor

The **Bed Roughness Predictor** computes bed roughness dynamically based on the hydrodynamics and bed materials. The sediment transport model and hydraulic models use the computed roughness, then update it based on the new hydraulics and bed materials. The 1D model allows users to define sub-reaches to apply the bed roughness predictor, but the 2D model will apply the selected algorithm to the all wet cells. When using bed-roughness predictor it is recommended to also output the cell bed roughness's and evaluate the computed bed roughness to maker sure results are realistic. The **Bed Roughness Predictor** is specified in the **General** Tab of the **Sediment Computation Options and Tolerances** editor.

The **Bed Roughness Predictor** options include three methods:

1. Limerinos
2. Brownlie
3. Van Rijn

4.1.2.1 Limerinos

The Limerinos (1970) formula is a relatively simple equation based on the d_{84} and hydraulic radius, with no consideration for bed form mechanics. Therefore, it should be applied mainly to coarse, gravel and cobble systems where the grain roughness is the primary source of channel roughness.

4.1.2.2 Brownlie

Brownlie (1983) computed bed roughness based on bed form mechanics in large rivers. In particular, he tried to capture the non-linear drop in roughness when bed form dominated transport shifts from lower to higher regimes (EM 4000). Brownlie, evaluates the bed form regime based on hydraulic parameters, grain size, and the gradational distribution, then applies separate equations for low and high regime transport.

4.1.2.3 Van Rijn

The Van Rijn (1984) bed roughness formula is based on flume and field data. Van Rijn computes bed form dimensions from flow and sediment parameters and converts these into equivalent bed roughness. This method was designed to compute bed roughness in both dune and plane bed regimes.

4.1.3 Sediment Computation Multiplier

The **Sediment Computation Multiplier** is used to compute sediment computations at a larger time step than the hydraulic computations. The **Sediment Computation Multiplier** is an integer which defines the number of hydraulic time steps before computing a sediment time step. A 2D sediment time step calculation can be significantly more computationally expensive than the hydraulic time, especially if there are many grain classes. It is important to note that the actual number of hydraulic time steps between sediment time steps may differ from the **Sediment Computation Multiplier** at certain times during the simulation in order for the model to synchronize time steps with output intervals. When the multiplier is utilized, the face flows and areas are averaged during the sediment time step. The parameter must be used with caution since it can reduce the model accuracy or produce instabilities. Typical values that work well are in the range of 5 to 20. Testing should be be done to confirm that the the parameter does not significantly affect the computed results. The **Sediment Computation Multiplier** has a default value of 1 meaning the sediment and hydraulics are computed at the same computational time step. The **Sediment Computation Multiplier** is specified in the **General** Tab of the **Sediment Computation Options and Tolerances** editor.

4.1.4 Warmup Method

HEC-RAS applies sediment warmup period slightly differently in 1D and 2D sediment transport. The 1D model adds the warmup period to the simulation, as an additional (negative) time period computed before the simulation starts. In 2D the warmup period is considered as part of the simulation time period.
The 2D model also computes three sediment warmup periods, in sequence (after the hydraulic warmup). First, HEC-RAS computes equilibrium concentrations in each cell based on the first specified flow or stage for the first time step at each hydraulic boundary, the boundary sediment fluxes, and the bed gradations. The Concentration warmup is only available in 2D sediment transport, and avoids the initial erosion associated with starting a model with clear water throughout the domain.

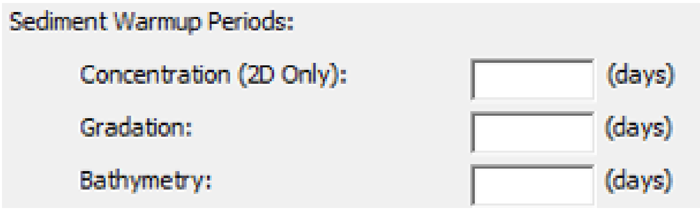


Figure 2. Specifying the warmup periods for 2D simulations.

After the concentration warmup, the 2D model warms up the bed gradations. Starting with the cell concentrations at the end of the concentration warmup, HEC-RAS will run the unsteady, 2D, sediment model with constant flow, stage, and sediment boundary conditions (those associated with the first time step in the simulation window). During the gradation warmup, HEC-RAS will *not* adjust the bed, the elevation-volume curves for the cells, or the elevation-area curves of the cell faces. It will only adjust the bed gradations, allowing them to fine or (more often) coarsen in response to the flow field. The 2D sediment model will also begin to develop vertical gradational stratigraphy in this warmup period, even bed layers were not initially specified.

After the Gradation warmup, the 2D model will warmup the bathymetry. In this warmup period, the model will still hold they hydraulic and sediment boundary conditions constant, but will allow the bed elevations, and the elevation-volume/elevation-area curves to adjust in response to transport. This phase will tend to fill local depressions, scour local raised areas, plane out bed forms, highlight problems with the terrain, and, generally smooth the terrain.

4.2 2D Computational Options

The **2D Computational Options** tab of the **Sediment Computation Options and Tolerances** editor contains the computational options which are utilized for 2D sediment transport (see figure below). The editor has options and parameters related to the subgrid erosion and deposition calculation methods, the advection scheme used in the transport solver, the matrix solver, outer loop convergence tolerances, the bed layer parameters, and subgrid options.

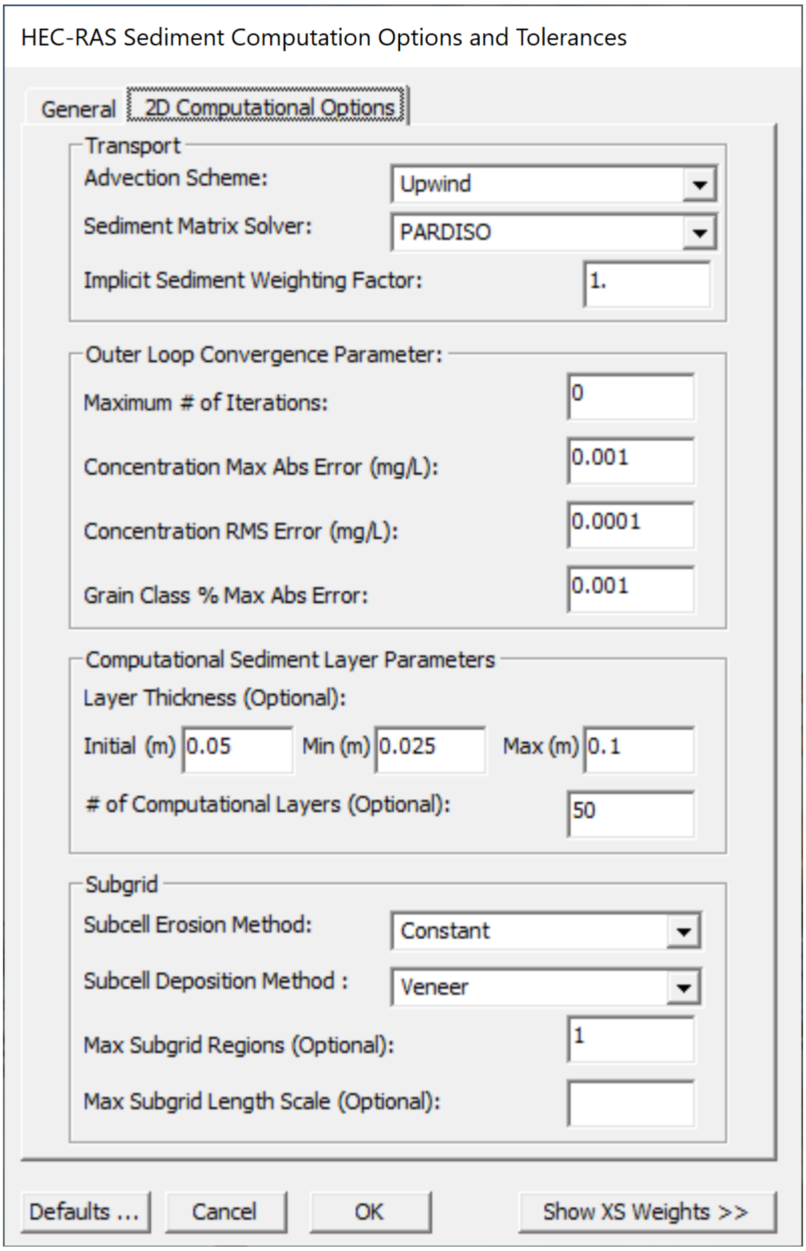


Figure 1. Specifying the warmup method for 2D simulations.

4.2.1 Subgrid Erosion and Deposition Methods

One of the key features of HEC-RAS 2D is the subgrid modeling. HEC-RAS 2D sediment has several methods for computing the subgrid erosion and deposition with different levels of complexity and computational requirements.

The erosion rate is computed as the erosion potential times the bed availability (grain fractions). Therefore, if the subgrid bed gradations vary, the subgrid erosion rates will also vary. However, the subgrid erosion potential may be calculated with one of four methods available (see table below).

Table 1. Summary of subcell erosion potential approaches.

Method	Depth-Weighting	Bed Properties	Hydraulics
Constant	None	Cell Wet-Average	Cell Wet-Average
Variable Bed	None	Subcell	Cell Wet-Average
Full Subgrid	None	Subcell	Subcell

The **Constant** erosion method is the simplest and most computationally efficient. For every cell, a single erosion potential is computed using wet-area averaged hydraulics, and bed properties. The bed properties include erosion coefficients, roughness, and grain size distribution, etc. The **Depth-Weighted** erosion method also computes a single erosion potential for every cell but applies a depth-weighting to compute the subgrid erosion potentials. Therefore, the **Depth-Weighted** method uses averaged bed and hydraulics to compute a cell erosion potential, but which is then weighted using the water depths to compute the subgrid erosion potentials. Again, subgrid erosion rates always take into account the subgrid grain fractions (material availability). The **Depth-Weighted** method is only slightly more computationally expensive than the **Constant** method. The **Variable Bed** erosion method does not perform depth-weighting but computes subgrid erosion potentials utilizing the subgrid bed properties. The **Variable Bed** method utilizes average hydraulic variables for the wetted area of the cell. The **Full Subgrid** erosion method does not perform depth-weighting but computes subgrid erosion potentials utilizing the subgrid bed properties and hydraulics. The method requires estimating subgrid hydraulic variables such as current velocities, shear stresses, shear velocities, depths, etc. depending on the transport potential formula utilized. The **Full Subgrid** method is the most computationally expensive of all the methods and will generally lead to the largest variations in subgrid erosion compared to the other methods. All of the erosion methods assume that a constant adaptation coefficient within the cell.

HEC-RAS 2D sediment has three subgrid deposition methods (see table below). All the deposition methods assume that the sediment concentration and adaptation coefficient are constant within a cell. The first is the **Veneer** method. The **Veneer** method applies a spatially constant deposition rate over the wet portion of the cell. The **Veneer** method is the simplest and most computationally efficient of the methods. The **Veneer** deposition method is analogous to the **Veneer** method utilized in HEC-RAS 1D sediment transport. The **Depth-Weighted** deposition method is similar to the **Reservoir** method in HEC-RAS 1D sediment transport. The **Capacity-Weighted** deposition method is similar to the **Capacity-Weighted** erosion method.

Table 2. Summary of subcell deposition approaches.

Method	Depth-Weighting	Capacity-Weighting
Veneer (Constant)	None	None
Depth-Weighted	Yes	None
Capacity-Weighted	None	Yes

4.2.2 Advection Scheme

HEC-RAS 2D sediment transport has the option to choose between four advection schemes:

1. Upwind
2. Exponential
3. Minmod
4. Harmonic

The selected advection schemes are designed to off the use a wide range of options. The **Upwind** and **Exponential** schemes are first-order difference schemes (Patankar 1980). The schemes are linear and therefore have the benefit of not requiring additional outer loop iterations. In addition, difference schemes are relatively simple, and provide smooth bounded solutions. The **Exponential** scheme is based on the analytical solution of the steady 1D advection-diffusion equation (without sources and sinks) and is less diffusive than the **Upwind** scheme. However, when the horizontal mixing is turned off, the **Exponential** scheme reduces to the **Upwind** scheme.
The **Minmod** and **Harmonic** schemes are high-resolution Total Variance Diminishing (TVD) schemes (Harten 1983). High-resolution TVD schemes allow for second order or higher accuracy in smooth and first-order accuracy in sharply varying regions without producing spurious oscillations (bounded solutions). The TVD schemes are implemented here using a flux-limiter formulation and a deferred correction approach which requires outer loop iterations to converge. The **Minmod** scheme has good convergence characteristics but is the most diffusive of the two TVD schemes. The **Harmonic** scheme is less diffusive, produces good convergence characteristics in implicit schemes, and is equivalent to the Hybrid Linear/Parabolic Approximation (HLPA) scheme of Zhu (1992).

4.2.3 Matrix Solvers

HEC-RAS 2D Sediment Transport solves an implicit Advection-Diffusion (transport) equation for the fractional total-load concentrations. The discretization produces a linear system of equations which may be represented by a sparse-matrix problem. The sparse matrix solver is an important component of the computational options because a large portion of the computational time can be spent solving the sparse matrices for each grain class transport equation. HEC-RAS has three options for the matrix solver:

1. PARDISO
2. FGMRES-SOR
3. FGMRES-ILU0

The **PARDISO** solver is a high-performance, robust, memory efficient and easy to use solver for solving large sparse symmetric and non-symmetric linear systems of equations on shared memory and distributed-memory architectures. Here the Intel Math Kernel Libraries (MKL) **PARDISO** solver is utilized. The solver utilizes a combination of parallel left- and right-looking supernode pivoting techniques to improve its factorization process (Schenk et al. 2004; Schenk et al. 2011).
Iterative solvers require an initial guess to the solution. Iterative solvers generally require less memory for because unlike with direct solvers, the structure of the matrix does not change during the iteration process. In addition, iterative solvers utilize matrix-vector multiplications which can be efficiently parallelized. The main drawback of iterative solvers is that the rate of convergence depends greatly on the condition number of the coefficient matrix. For poorly conditioned matrices, the iterative solver may not converge at all. Therefore, the efficiency of iterative solvers greatly depends on the size and condition number of the

coefficient matrix.
Iterative solvers may be classified into stationary and projection methods. In stationary methods the solution for each iteration is expressed as finding a stationary point for the iteration. The number of operations for iteration step for stationary methods is always the same. Stationary methods work well for small problems but generally converge slowly for large problems. Projection methods extract an approximate solution from a subspace. Generally, projection methods have better convergence properties than stationary methods but because each iteration is generally more computationally demanding than stationary methods, they tend to be more efficient for medium to large systems of equations. The main disadvantage of iterative solvers is their lack of robustness.
HEC-RAS 2D sediment has the option of two iterative solvers: **FGMRES-SOR** and **FGMRES-ILU0**. The first part FGMRES refers to the matrix solver while second parts SOR and ILU0 refer to the preconditioner utilized. FGMRES (Flexible Generalized Minimal RESidual) is a projection method which is applicable to coefficient matrices which are non-symmetric indefinite (Saad, 1993). The "flexible" variant of the Generalized Minimal RESidual method (GMRES) allows for the preconditioner to vary from iteration to iteration. The flexible variant requires more memory than the standard version, but the extra memory is worth the cost since any iterative method can be used as a preconditioner. For example, the SOR could be used as a preconditioner with different relaxation parameter values each time it is applied. The FGMRES (and GMRES) method becomes impractical for large number of iterations because memory and computational requirements increase linearly as the number iterations increases. To remediate this the algorithm is restarted after iterations with the last solution used as an initial guess to the new iterative solution. This procedure is repeated until convergence is achieved. The FGMRES solver with restart is often referred to as FGMRES(m) where m is the restart parameter. However, here the shorter name FGMRES is used for simplicity. If m is too small, the solver may converge too slowly are even fail completely. A value of m that is larger than necessary involves excessive work and memory storage. Typical restart values are between 5 and 20. Here m is set to 10 which works well for the most practical applications.
The Successive-Over-Relaxation (SOR) is a stationary iteration method based on the Gauss-Seidel (GS) method. When $\omega = 1$, the SOR method reduces to the Gauss-Seidel method. In addition, for $\omega < 1$, the method technically applies under-relaxation and not over-relaxation. However, for simplicity and convenience the method is referred to as SOR for all values of ω. Kahan (1958) showed that the SOR method is unstable for relaxation values outside of $0 < \omega < 2$. The optimal value of the relaxation factor is problem specific. The SOR method is guaranteed to converge if either (1) if $0 < \omega < 2$, and (2) the matrix is symmetric positive-definite, or strictly or irreducibly diagonally dominant. However, the method sometimes converges even if the second condition is not satisfied. For simplicity, the relaxation parameter is set to 1.3 here and cannot be adjusted by the user. The value of 1.3 has been found to work reasonably well for a wide range of problems. A simple parallel version of the SOR is utilized here which is referred to as the Asynchronous SOR (ASOR) which uses new values of unknowns in each iteration/updates as soon as they are computed in the same iteration (see Chazan and Miranker 1969; Leone and Mangasarian 1988). The ASOR is part of a class of iterative solvers known as chaotic relaxation methods. Since the order of relaxation is unconstrained, synchronization is avoided at all stages of the solution. However, the convergence behavior can be slightly different for different number of threads. The ASOR solver has been parallelized with OpenMP.
The SOR preconditioner is based on the SOR solver except that no convergence checking is done during the iteration process (DeLong 1997). This is done for simplicity and to avoid additional computations associated with the determining the convergence status. The SOR preconditioner is utilized for non-symmetric matrices. The SOR preconditioner matrix is given by
The ILU0 (Incomplete Lower Upper with Zero Infilling) is part of a large class of preconditioners which utilize incomplete factorizations of the coefficient matrix. The effectiveness of the preconditioner depends on how well the sparse matrix by factored into lower and upper sparse matrices. ILU0 is one of the most common types of incomplete factorizations. In this factorization, all non-zero values of the exact factorization which are located in zero value positions are discarded. The advantage of the ILU0 preconditioner is that it preserves the structure of the original matrix. Another advantage of ILU0 versus other similar factorizations is that it does not require specifying additional tolerances and settings.

4.2.4 Outer Loop Convergence Options

The outer loop refers to the loop in which the transport equations are coupled to the bed change and sorting equations whereas the inner loop is the iterative solver loop. The outer loop is also necessary for updating the deferred corrections from the high-resolution advection schemes. If a direct sparse matrix solver is utilized, there is no inner loop. The maximum number of outer loop iterations may be set by user (see figure below). The maximum number of outer loop iterations is a compromise between computational efficiency and accuracy. If the sediment model is iterating every time step and going to the maximum number of iterations, this is an indication, the either the time step is too big or the convergence tolerances have been set too small. Outer loop convergence is monitored by change in the sediment concentrations and active layer bed fractions between outer loop iterations. The convergence of the fractional total-load sediment concentrations is assessed by means of two tolerances. The first is the maximum value of the absolute differences (errors) in concentrations between outer loop iterations. The second is the root-mean-square of the differences (errors) between outer loop iterations. For the first iteration, the error is approximated by comparing the current concentrations with the previous time step values. The convergence of the active bed grain fractions is assessed by means of a maximum absolute error tolerance. This approach works well for both constant density and variable density simulations.

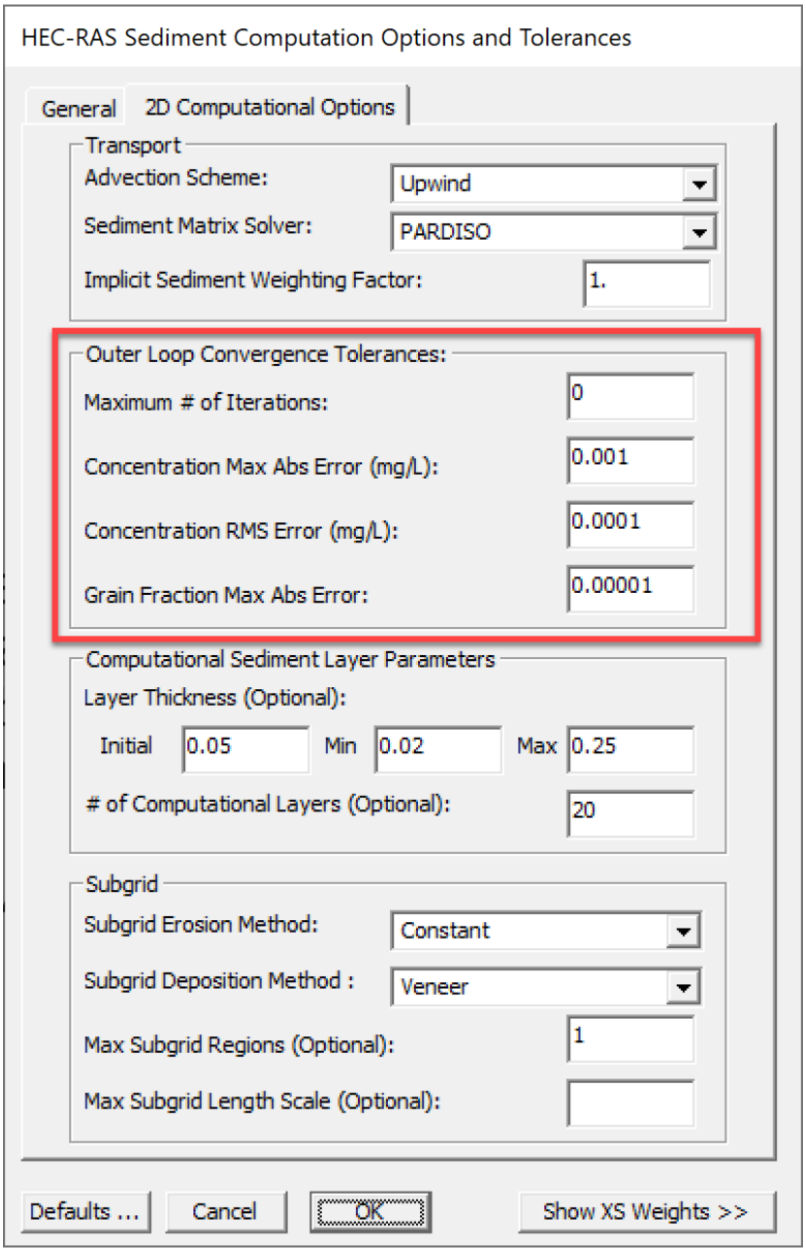


Figure 2. Outer loop Convergence Parameters.

Whenever, the sediment concentrations or active layer grain fractions do not converge or reach the maximum number of iterations, a message is printed to the log file. In addition, the convergence status is written to the HDF5 file at the Mapping Output Interval. This log information can be used to optimize the convergence parameters and computational time step.
When simulating **Non-erodible Surfaces**, the active layer grain fractions can vary significantly in a time step and even within a time step (outer-loop iterations). Therefore, it is expected that when simulating **Non-erodible Surfaces** with multiple-grain classes, at least one or two iterations will be needed for the active layer fractions to converge. In fact, even when simulating a single grain class, iterations are still required because for the sediment concentrations to convergence above **Non-erodible Surfaces** because the erosion rates are limited before solving concentrations using an expression which includes an estimate of the deposition rates from the previous iteration.

4.2.5 Computational Sediment Layer Parameters

There are two types of layers in HEC-RAS. The first type is the bed layers which are used to specify the bed gradations and the second is the computational bed layers which are used in the solution of the bed sorting and layering. Specifying initial sediment bed layers is optional. If the user does not specify initial bed layers, a vertically uniform bed composition is assumed, and computational bed layers are created based on the user-specified initial bed layer thickness (see figure below).

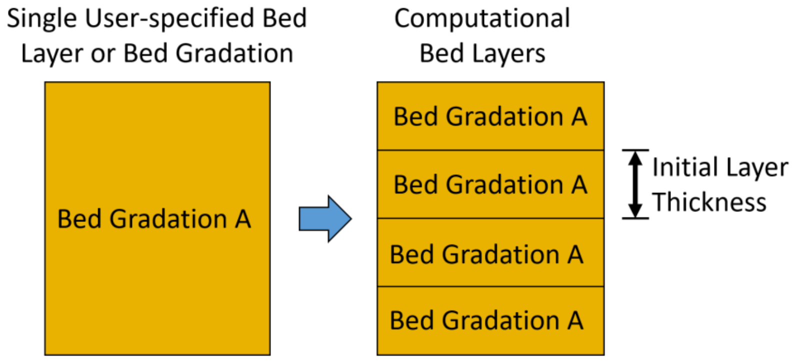


Figure 3. Calculation of computational bed layer thickness from a single user-specified initial bed layer or bed gradation.

If the user specifies initial bed layers, these are subdivided (discretized) such that the initial bed layer thickness is equal to or less than then the user-specified initial bed layer thickness (see figure below).

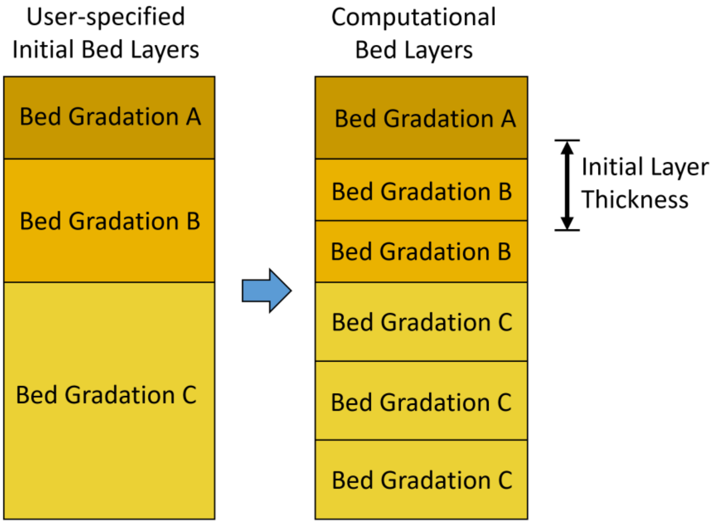


Figure 4. Calculation of computational bed layer thickness and composition from user-specified initial bed layers.

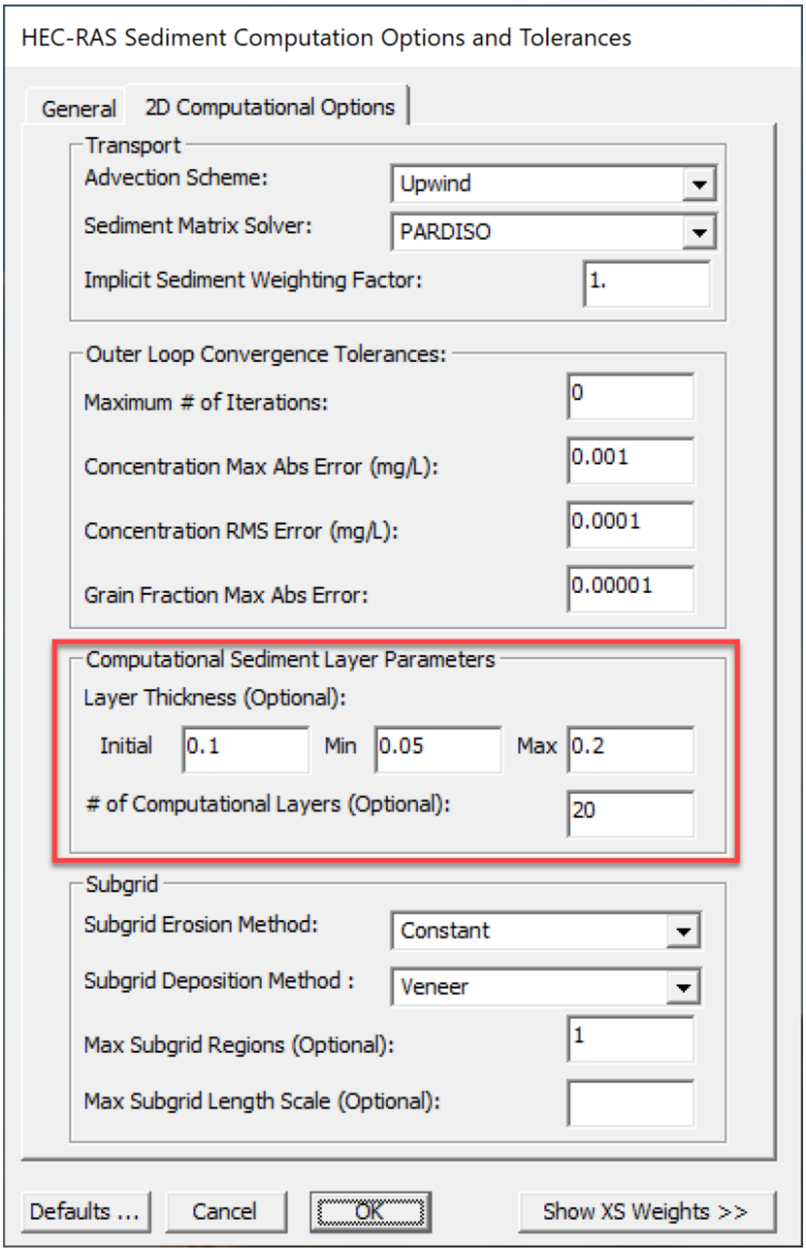


Figure 5. Computational Sediment Layer Parameters section in the HEC-RAS Sediment Computation Options and Tolerances editor.

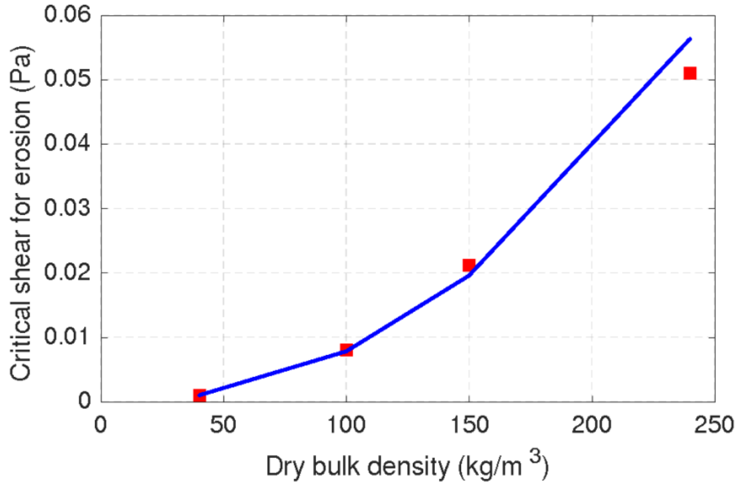


Figure 6. Example of a power-law parameterization of the critical shear for erosion as a function of the dry bulk density.

5 Sediment Output Options

The sediment output options are entered in the apply named **Sediment Output Options** editor which can be accessed from the **Option | Sediment Output Options…** menu in the **Unsteady Flow Analysis** editor (see figure below).

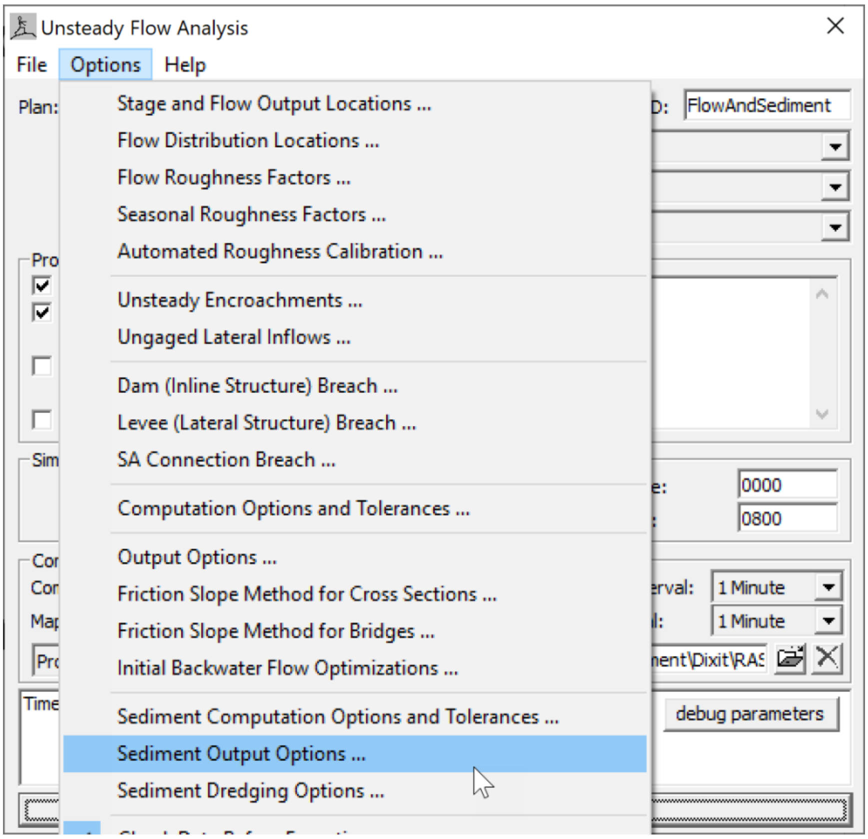


Figure 1. Opening the Sediment Output Options editor from the Unsteady Flow Analysis editor.

The **Sediment Output Options** editor allows the user to specify which variables to output and at what frequency.

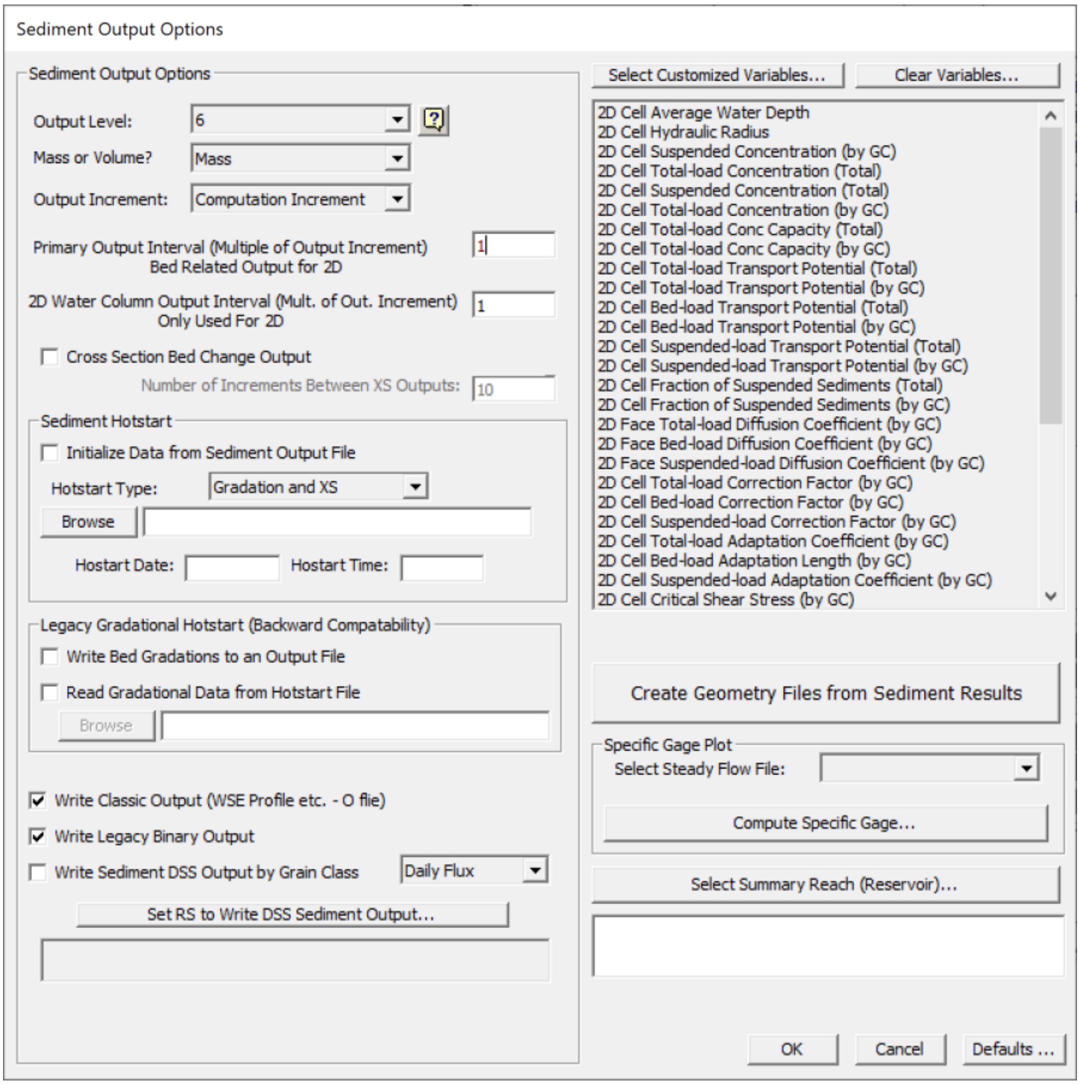


Figure 2. Sediment Output Options editor.

5.1 Output Level

The **Output Level** allows the user to control how much logging information is written to the **Computation Log File** as well as select a predefined list of output variables. The **Output Level** is set within the **Sediment Output Options** editor which is accessed by clicking on the **Options | Sediment Output Options** menu within the **Unsteady Flow Analysis** editor (see figure below).

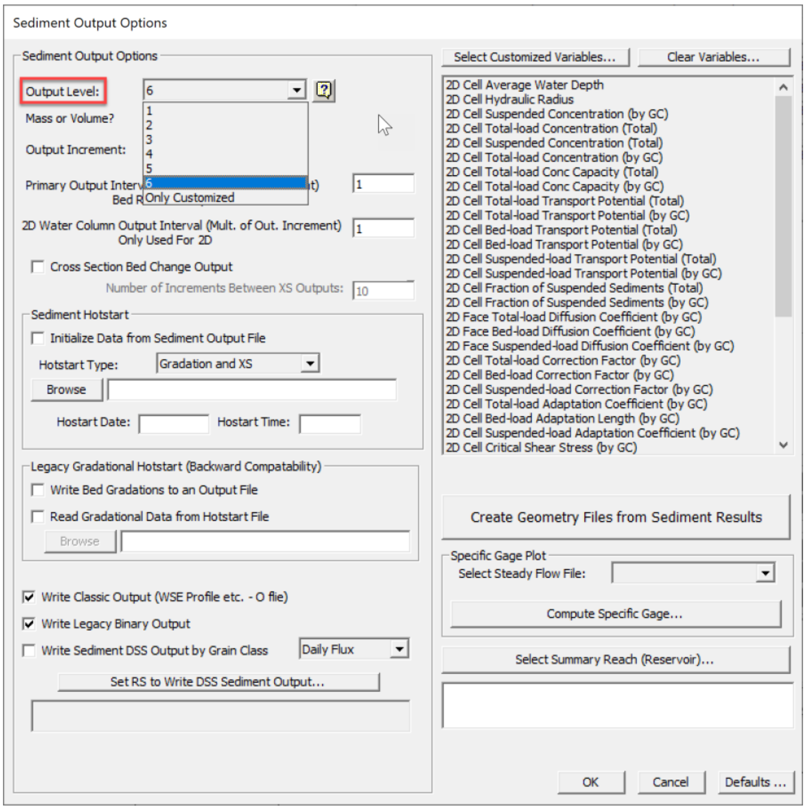


Figure 1. Opening the User Defined Grain Classes editor from the Sediment Data editor.

Table 1. Output sediment variables as function of the Output Level.

Output Level	**Sediment Output Variable**	**Units**
≥1	Cell average bed change	ft or m
≥1	Cell total total-load concentration	mg/L
≥2	Cell average bed elevation	ft or m
≥2	Cell total total-load concentration capacity (i.e. equilibrium total-load concentration).	mg/L
≥3	Cell fractional total-load concentrations (for each grain class)	mg/L
≥4	Cell fractional total-load concentration capacities (i.e. fractional equilibrium total-load concentrations)	mg/L

≥5	Cell total fraction of suspended sediments (not by grain class)	-
≥5	Cell total total-load transport potential	lb/ft/s or kg/m/s
≥6	Cell fractional fraction of suspended sediments (for each grain class)	-
≥6	Cell total bed shear stress	lb/ft^2 or Pa
≥6	Cell grain bed shear stress	lb/ft^2 or Pa
≥6	Cell critical shear stress for each grain class	lb/ft^2 or Pa
≥6	Cell fall velocity for each grain class	ft/s or m/s
≥6	Cell 16^{th} percentile diameter (d_{16})	mm
≥6	Cell 50^{th} percentile diameter (d_{50})	mm
≥6	Cell 90^{th} percentile diameter (d_{90})	mm

5.2 Output Interval Multiples

Sediment transport output is classified into two groups referred to as **Output Blocks**: (1) **Sediment Transport** and (2) **Sediment Bed**. The main reason for this classification is to be able to easily control the output interval of variables which vary at similar time scales. Generally, "transport variables" which are usually within the water column (e.g. concentrations, transport rates, etc.) vary at time scales similar to the hydraulics, while sediment variables on the bed (e.g. bed elevations and gradations) vary at longer time scales. Allowing the user to specify different output intervals for these two output groups helps reduce the size of the HDF5 Output File by allowing the user to specify a larger output interval for variables which change slowly, compared to the hydraulics. The variables which correspond to the **Sediment Bed** are the bed roughness's, bed elevations, bed changes, bed change rate, bed slopes, bed layer fractions, bed layer thicknesses, bed layer percentile diameters, bed layer dry densities. All other variables correspond to the **Sediment Transport** group. The precise Output Block for each output variable is noted in the captions of Tables 26 through 214.

5.3 Customized Sediment Output Variables

There is a large number of variables that the user can select to output. The optional output variables are selected within the **Sediment Output Options** editor which is accessed from the **Options | Sediment Output Options…** menu from the **Unsteady Flow Analysis** editor. The following Tables list all of the optional output variables related to 2D sediment transport and their units.

Table 1. Output hydraulic variables. These variables correspond to the Sediment Transport Output Block.

Output Variable	**Units**
Shear Stress	Pa or lb/ft^2
Shear Velocity	m/s or ft/s
Velocity	m/s or ft/s
2D Cell Hydraulic Depth	m or ft
2D Cell Hydraulic Radius	m or ft
2D Subcell Velocity	m/s or ft/s
2D Subface Hydraulic Radius	m or ft

Table 2. Output sediment concentrations. These variables correspond to the Sediment Transport Output Block.

Output Variable	**Units**
2D Cell Total-load Concentration (Total)	mg/L
2D Cell Total-load Concentration (by GC)	mg/L
2D Cell Suspended Concentration (Total)	mg/L
2D Cell Suspended Concentration (by GC)	mg/L

2D Cell Bed-load Concentration (Total)	mg/L
2D Cell Bed-load Concentration (by GC)	mg/L
2D Cell Total-load Concentration Capacity (Total)	mg/L
2D Cell Total-load Concentration Capacity (by GC)	mg/L
2D Cell Suspended Concentration Capacity (Total)	mg/L
2D Cell Suspended Concentration Capacity (by GC)	mg/L

Table 3. Output sediment transport potentials. These variables correspond to the Sediment Transport Output Block.

Output Variable	**Units**
2D Cell Total-load Transport Potential (Total)	kg/m/s or lb/ft/s
2D Cell Total-load Transport Potential (by GC)	kg/m/s or lb/ft/s
2D Cell Bed-load Transport Potential (Total)	kg/m/s or lb/ft/s
2D Cell Bed-load Transport Potential (by GC)	kg/m/s or lb/ft/s
2D Cell Suspended-load Transport Potential (Total)	kg/m/s or lb/ft/s
2D Cell Suspended-load Transport Potential (by GC)	kg/m/s or lb/ft/s

Table 4. Output sediment transport variables. These variables correspond to the Sediment Transport Output Block.

Output Variable	**Units**

2D Cell Fraction of Suspended Sediments (Total)	-
2D Cell Fraction of Suspended Sediments (by GC)	-
2D Face Total-load Diffusion Coefficient (by GC)	m^2/s or ft^2/s
2D Face Bed-load Diffusion Coefficient (by GC)	m^2/s or ft^2/s
2D Face Suspended-load Diffusion Coefficient (by GC)	m^2/s or ft^2/s
2D Cell Total-load Correction Factor (by GC)	-
2D Cell Bed-load Correction Factor (by GC)	-
2D Cell Suspended-load Correction Factor (by GC)	-
2D Cell Total-load Adaptation Length (by GC)	m or ft
2D Cell Total-load Adaptation Coefficient (by GC)	-
2D Cell Bed-load Adaptation Length (by GC)	m or ft
2D Cell Suspended-load Adaptation Coefficient (by GC)	-
2D Cell Erosion Rates (by GC)	$kg/m^2/s$ or $lb/ft^2/s$
2D Cell Deposition Rates (by GC)	$kg/m^2/s$ or $lb/ft^2/s$
2D Cell Deposition Dry Density	kg/m^3 or lb/ft^3

Table 5. Output incipient motion variables. These variables correspond to the Sediment Transport Output Block.

Output Variable	**Units**

2D Cell Critical Shear Stress (by GC)	Pa or lb/ft^2
2D Cell Critical Velocity (by GC)	m/s or ft/s
2D Cell Hiding and Exposure Correction Factor (by GC)	-

Table 6. Output sediment settling variables. These variables correspond to the Sediment Transport Output Block.

Output Variable	**Units**
2D Cell Settling Velocity (Total)	m/s or ft/s
2D Cell Settling Velocity (by GC)	m/s or ft/s

It is noted that the units of density in the **US Customary Unit System** are represented as lb/ft^3. Here lb represent pounds mass and are obtained by multiplying $slugs/ft^3$ by a standard gravity of 31.174 ft/s^2.

Table 7. Output sediment active layer variables. These variables correspond to the Sediment Bed group (Output Block).

Output Variable	**Units**
2D Cell Active Layer d10	mm
2D Cell Active Layer d16	mm
2D Cell Active Layer d35	mm
2D Cell Active Layer d50	mm
2D Cell Active Layer d65	mm
2D Cell Active Layer d84	mm

2D Cell Active Layer d90	mm
2D Cell Active Layer Dry Density	kg/m^3 or lb/ft^3
2D Cell Active Layer Fractions	by mass
2D Cell Active Layer Porosity	-
2D Cell Active Layer Thickness	m or ft
2D Subcell Active Layer d10	mm
2D Subcell Active Layer d16	mm
2D Subcell Active Layer d35	mm
2D Subcell Active Layer d50	mm
2D Subcell Active Layer d65	mm
2D Subcell Active Layer d90	mm
2D Subcell Active Layer Dry Density	kg/m^3 or lb/ft^3
2D Subcell Active Layer Porosity	-
2D Subcell Active Layer Fractions	by mass
2D Subcell Active Layer Thickness	m or ft

Table 8. Output Sediment bed Composition and layering variables. These variables correspond to the Sediment Bed Output Block.

Output Variable	**Units**
2D Layer Fractions	-

2D Layer Thickness	m or ft
2D Layer Dry Density	kg/m^3 or lb/ft^3

Table 9. Output bed roughness variables. These variables correspond to the Sediment Bed Output Block.

Output Variable	**Units**
2D Cell Manning Total	s/m$^{1/3}$
2D Cell Manning Grain	s/m$^{1/3}$
2D Cell Manning Bedform	s/m$^{1/3}$
2D Cell Manning Transport	s/m$^{1/3}$

Table 10. Output bathymetry variables. These variables correspond to the Sediment Bed Output Block.

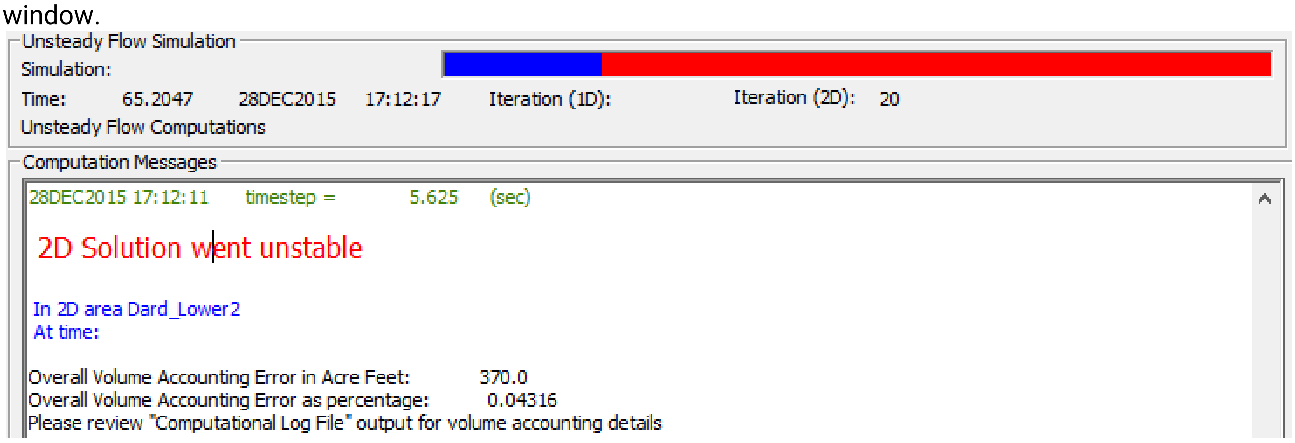
Output Variable	**Units**
2D Cell Bed Change	m or ft
2D Cell Bed Change (by GC)	m or ft
2D Cell Bed Change Mass	ton
2D Cell Bed Change Mass (by GC)	on
2D Cell Bed Change Rate	m/s or ft/s
2D Cell Bed Change Volume	m^{3}3 or ft^3
2D Cell Bed Change Volume(by GC)	m^3 or ft^3
2D Cell Bed Elevation	m or ft

2D Face Bed Elevation	m or ft
2D Face Bed Change	m or ft
2D Face Bed Change Rate	m/s or ft/s
2D Subcell Bed Elevation	m or ft
2D Subcell Bed Change	m or ft
2D Subface Bed Elevation	m or ft
2D Subface Bed Change	m or ft

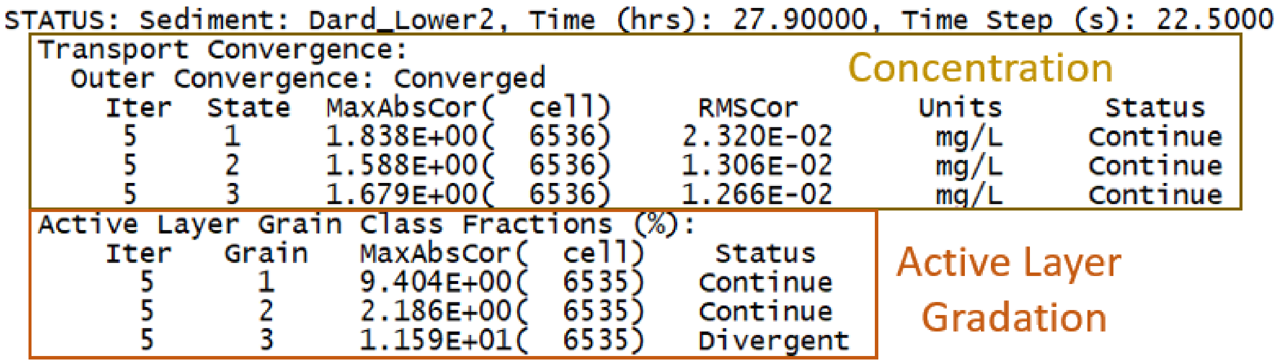
5.4 Computational Level Output (Troubleshooting)

5.4.1 Computational Log File

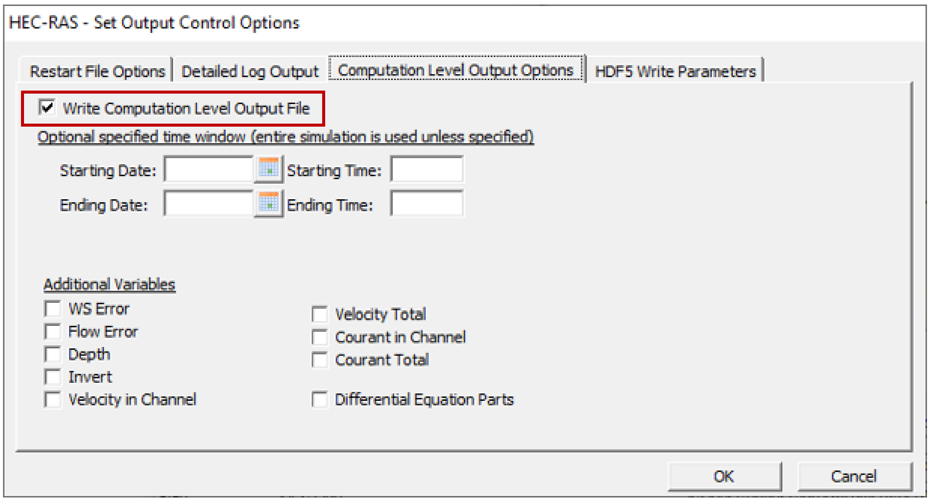
Sometimes a 2D sediment model will crash without iteration or other useful information in the runtime window.



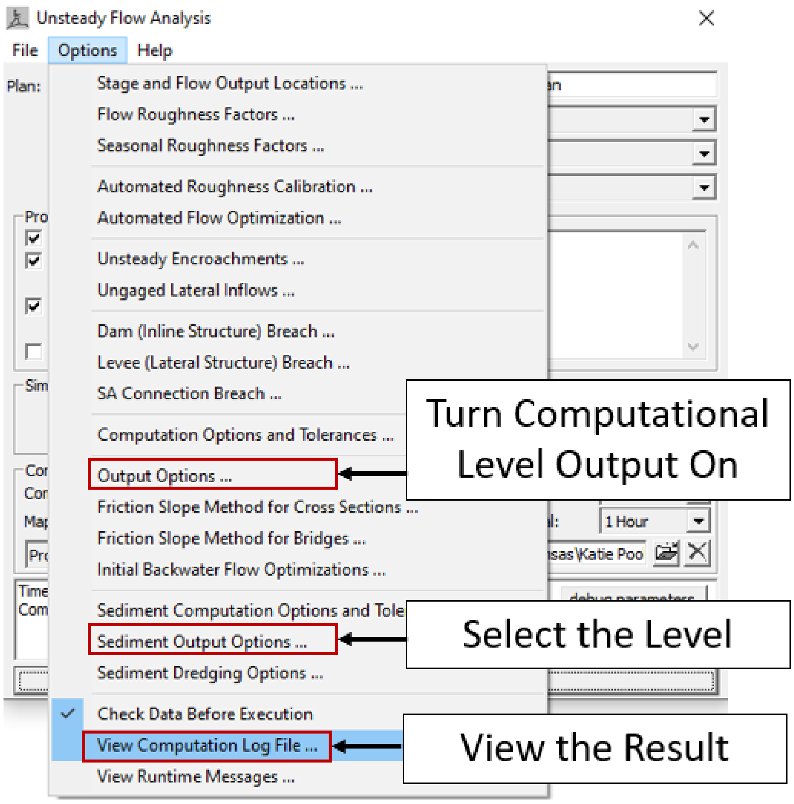
The runtime window only provides information on they hydraulic iterations. It does not include information on sediment iterations. But you can access sediment convergence and critical cell information to help troubleshoot a model like this. The image below includes an example of a single time-step result from a default computational log file (with three grain classes). By default (sediment output "Level 3"), the computational log file includes information on the final convergence criteria for concentration and active layer gradation, for each grain class, at the end of each time step.



The file will only reflect the input parameters unless you request computational level output. To turn on the computational level output select **Options** → **Output Options** from the Plan editor and choose the **Computation Level Output Options** tab.



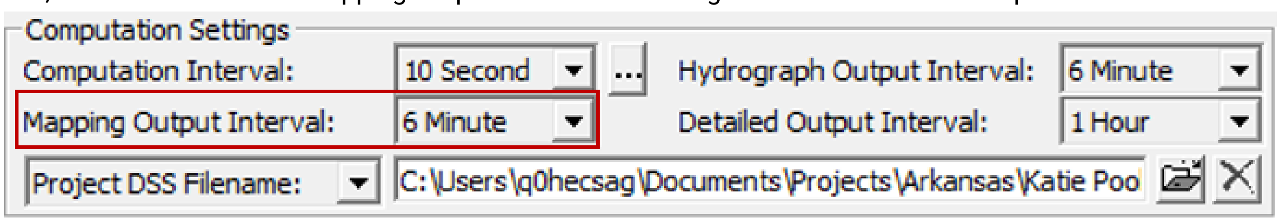
To access the Computational log file, select **Options** → **View Computational Log File** from the Plan editor.



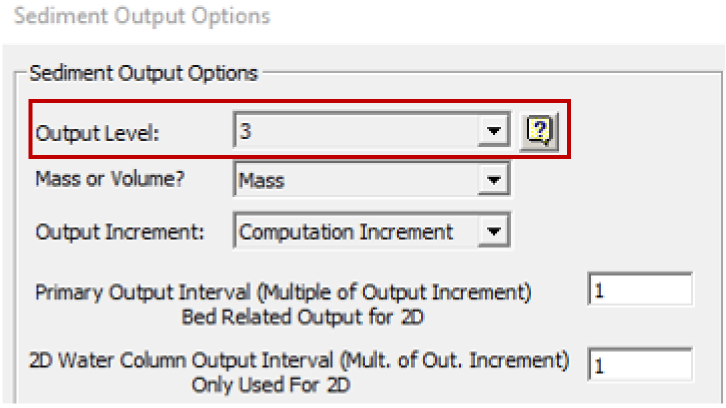
5.4.1.1 Controlling the Computational Log File

Users can control two aspects of the computational log file that affect the amount of data it includes: the time step and the "Output Level." This is a simple text file and it can get very large, so you can use these controls to optimize the tradeoff between useful information and file size.

First, this file writes to the Mapping Output Interval. You will get results at this time step.

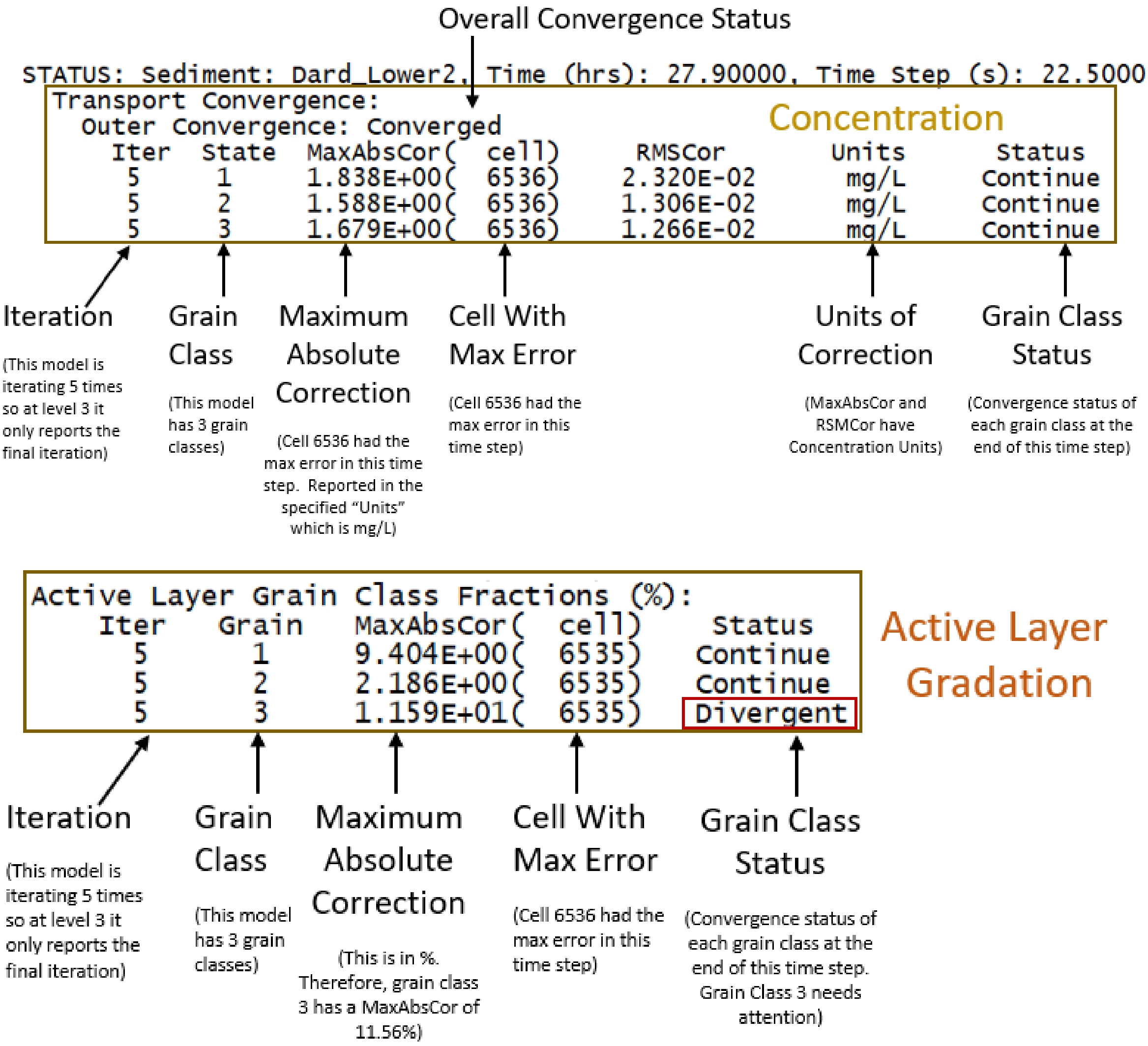


Second, the "Sediment Output Level" controls the amount of data included in this file. You can se the Output Leve by navigating to **Options→ Sediment Output Options** in the Plan editor. The default output level ("3") includes the final convergence results for concentration and active bed fractions for each grain class, the end of each Mapping Output Interval. It also lists the convergence status and the cell with the larges error during that time step.



Higher levels include information on the sub-iterations of each Mapping Output Interval.

5.4.1.2 Interpreting the Computational Log File



At output level 3 the Computational Log file generates the output pictured above for concentration and active layer gradation at the end of each Mapping Output time step. For higher output levels, HEC-RAS will write this same information at the end of each iteration within the time step (e.g. the result above has five iterations so it would generate five of these results per time step). The log file reports results by grain class and provides the Maximum Absolute Correction and the Root Mean Squared Correction. (Note: In sediment "correction" is the same as "error" in hydraulics. It is just the difference between the solution at the beginning and end of the iteration). The Max Absolute is spatial, it reports the cell with the biggest difference between the beginning and end of the iteration. The MaxAbsCor is in mg/L for concentration and % for gradation. This file also reports the cell with the largest error (like the runtime window does The RSMCor is a more general diagnostic. It reports a root mean squared value of the differences between results at the beginning and end of the simulation for all cells so you can tell how the model is converging on average.

Finally, each grain class gets one of four designations to indicate its convergence status at the end of the time step (Output Level 3) or the iteration (Output Levels >3). These are described below.

Status	Definition
Converged	The solution at the end of the iteration is within the convergence tolerance of the result of the previous iteration. However, if the other grain classes have not converged, it will continue to iterate because the grain classes are coupled.
Continue	This grain class did not reach the criteria by the end of the iteration but did not diverge. The model will carry over the best result to the next time step.
Iterating	The grain class has it hasn't converged yet but it hasn't reached max iterations yet. (Will only show up in intermediate iterations, not the final - so this should never show up for "Level 3 or lower").
Divergent	The grain class not only did not converge but the difference increased until it reached some large divergence criteria (e.g. 100X the initial solution). This grain class is unstable for this time step.

5.5 Sediment Hotstart

5.5.1 Overview

The **Hotstart** feature allows the sediment model to be initialized based on the model output from a previous simulation. The feature also allows the user to choose what type of information to utilize from the previous model simulation and what to ignore. There are three types of Sediment Hotstarts:

1. Bed Gradations and Bed Elevations
2. Bed Gradations Only
3. Bed Elevations Only

Sediment concentrations are hotstart only if the hydraulics is also initialized with a Prior Solution no matter what **Sediment Hotstart Type** is selected.

5.5.2 Specifying the HotStart File

The **Hotstart** file is specified as part of the plan data in the **Sediment Output Options** of the **Unsteady Flow Analysis** editor.

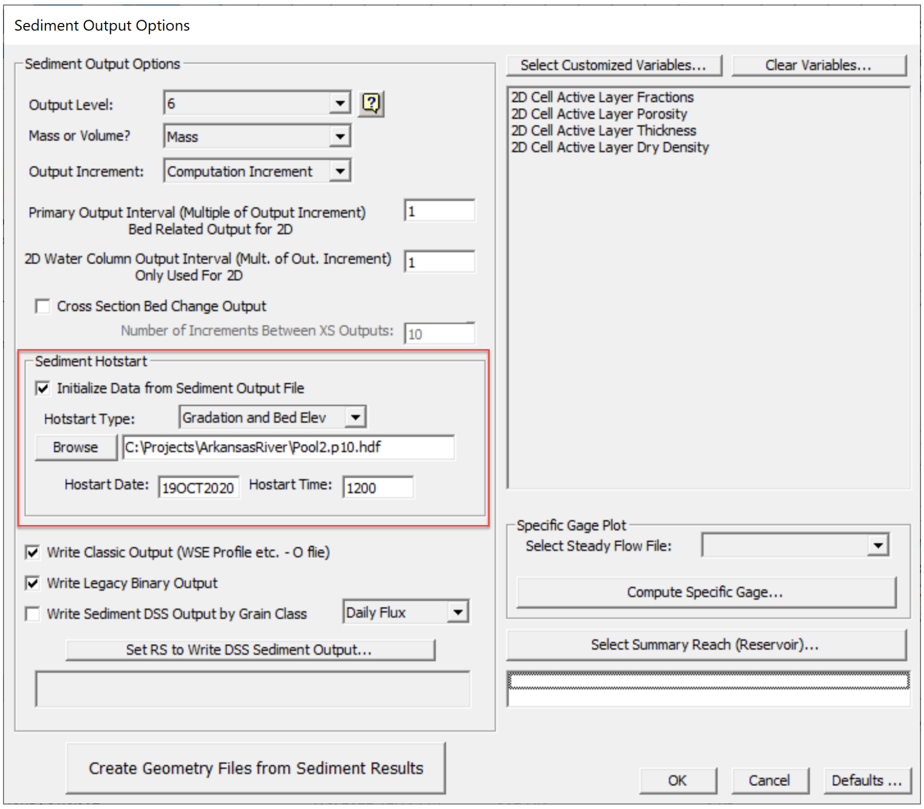


Figure 1. Sediment Hotstart section within the Sediment Output Options editor.

5.5.3 Hotstart Variables

5.5.3.1 Bed Gradations

When hotstarting bed gradations, the following datasets are always to read in:

1. Layer Fractions or if it does not exist the Cell Active Layer Grain Fractions
2. Layer Thickness
3. Layer Dry Density

Note that if the Layer Fractions dataset does NOT exist in the **Hotstart** file, then the program will try to read the Cell Active Layer Grain Fractions dataset. If the program cannot find any of the datasets, then the specific variable is not hortstart.

None of the variables are above are output by default and therefore need to be turned on when creating the Hotstart file.

5.5.3.2 Bed Elevations

When hotstarting bed elevations, the following datasets are read in:

1. Subcell Initial Hydraulic Bed Elevations
2. Subcell Hydraulic Bed Change
3. Subcell Initial Bed Elevation
4. Subcell Bed Change
5. Subface Initial Bed Elevation
6. Subface Bed Change

5.5.3.3 Sediment Concentrations

When hotstarting sediment concentrations, the following datasets are read in

1. Cell Total-load Concentrations

Even though the option to read in the sediment concentrations is tied to whether the hydraulics is also hotstart, the sediment concentrations are read in from the sediment HotStart file at the sediment Hotstart date and time.

5.6 Sediment Restart

5.6.1 Overview

The **Restart** feature writes the state of the model at a user-specified time or intervals and can be used to initialize a subsequent simulation. The **Restart File** contains all of the necessary information for hydraulics, infiltration, precipitation, and sediment transport to initialize a simulation state. The main limitation of the **Restart File** is that the Geometry, number of active grain classes, number of bed computational bed layers, and subgrid resolution must the same in both the simulations writing and reading the **Restart File**. Reading and writing **Restart Files** is supported in HEC-RAS Versions 6.2 and later.

5.6.2 Writing a Restart File

The options to output the **Restart File** (also referred to as the **Initial Condition** file) are set within the **Output Options** editor which can be accessed from the **Unsteady Flow Analysis | Options** menu (see figure below).

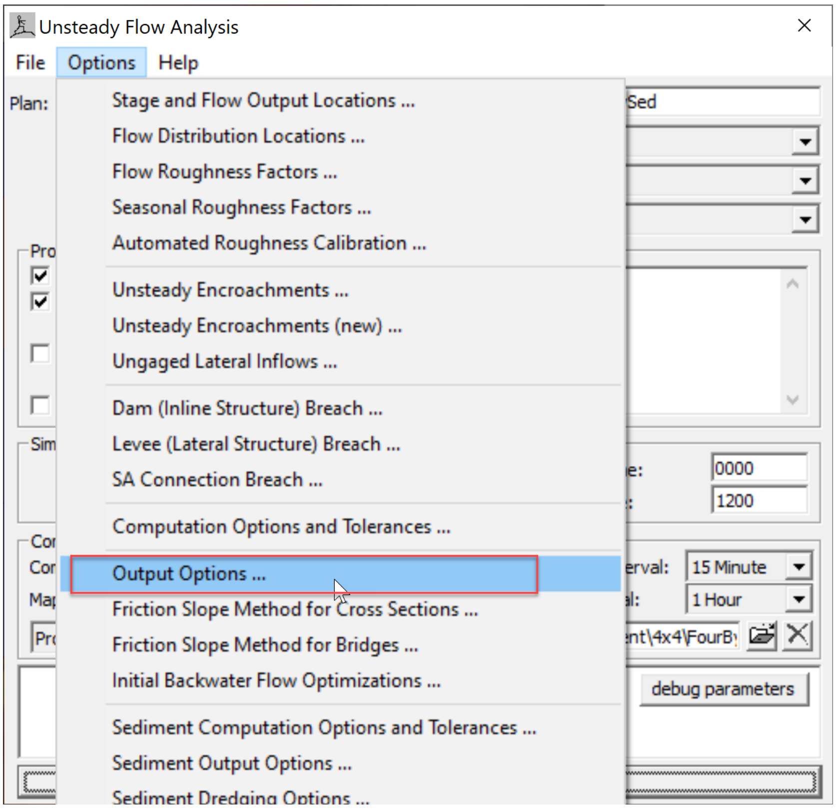


Figure 1. Opening the **Output Options** editor from the HEC-RAS **Unsteady Flow Analysis** editor.

The **Restart (Initial Conditions) File** options are set within the first tab of the Output Options editor (see figure below).

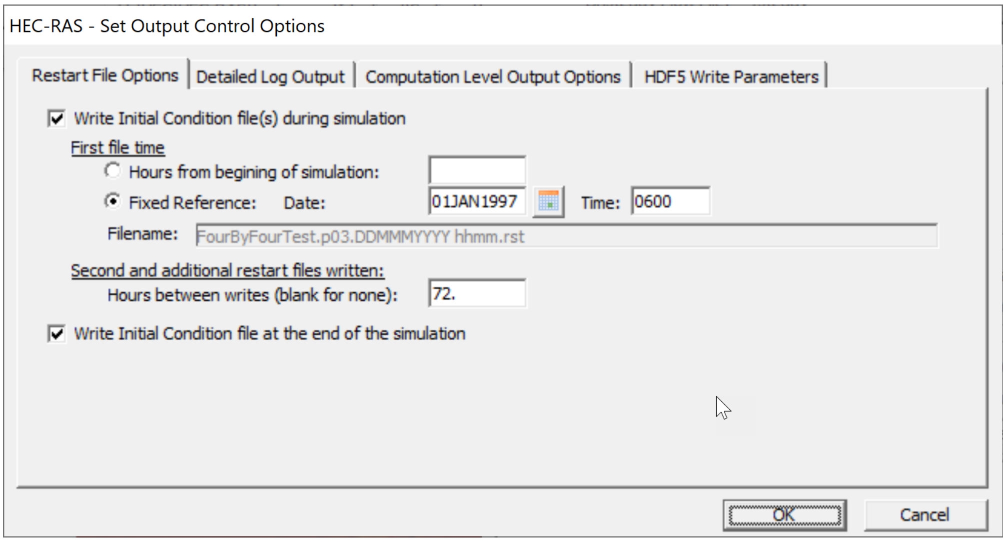


Figure 2. **Restart File Options** tab of the **HEC-RAS - Set Output Control Option**s editor.

A single or first **Restart File** may be output at a specific from the beginning of the simulation or a fixed reference time. A second and additional restart file may be specified at a user-specified time interval. Finally, the option is also provided to write a Restart File at the end of the simulation. In the example above, the first

Restart File is specified on January 1, 1997 06:00 AM, subsequent Restart Files are written every 72 hours, and a final one is written at the end of the simulation.

5.6.3 Specifying the Restart File

In order to initialize a simulation with a **Restart File**, the file name and path are specified within the **Initial Conditions** tab of the **Unsteady Flow Data** editor as shown in the figure below.

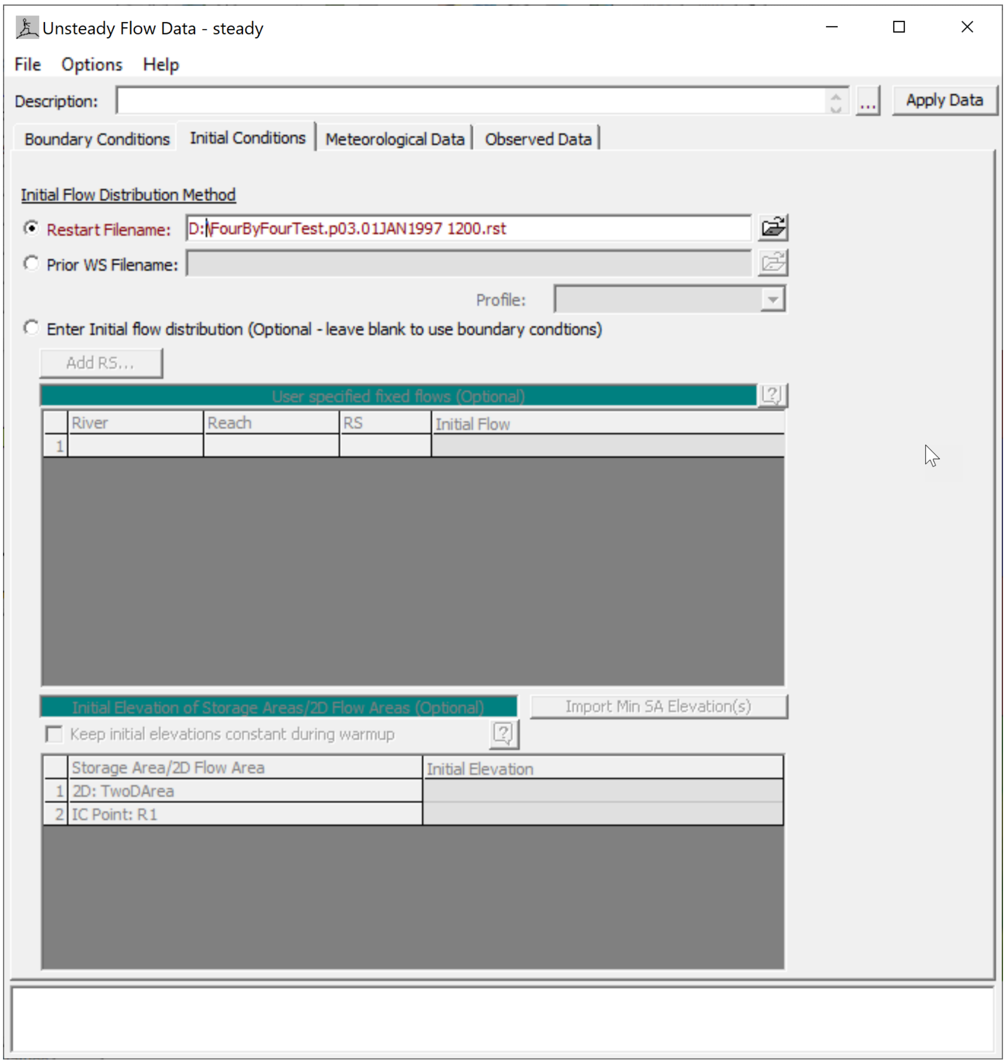


Figure 3. Specification of the **Restart File** within the **Initial Conditions** tab of the **Unsteady Flow Data** editor.

6 Viewing Results

6.1 Viewing Sediment Results in RASMapper

HEC-RAS and RASMapper do not write sediment results by default. The default results include Depth, Velocity, and Water Surface Elevation (WSE). Users must add sediment results to the **Results** tab like they would add any other hydraulic parameters. Expand the **Results** node in the RASMapper tree. Each simulated plan has a node under **Results**. Right click on the plan and select **Create a New RAS Map Layer** to add variables.

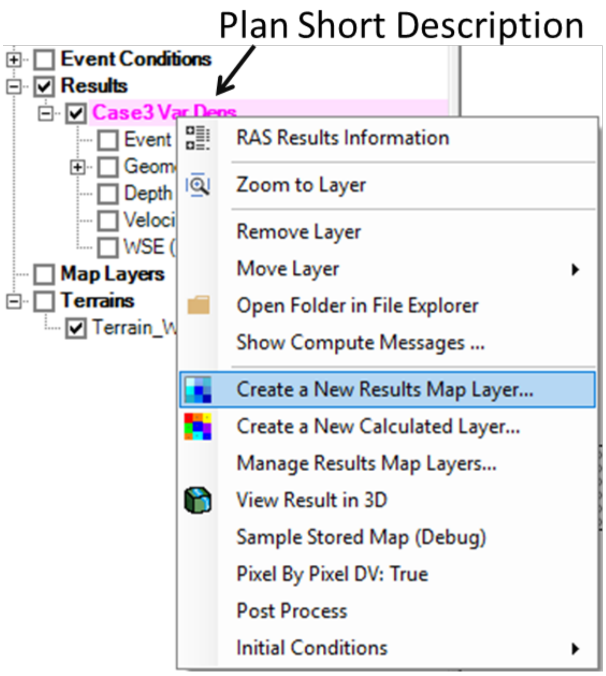


Figure 1. Right click on the Plan Description under Results and Select Create a New Results Map Layer to add Sediment results (or non-default hydraulic results).

The **Results Map Parameters** editor has two main **Map Types**: Hydraulics and Sediment. Expand the **Sediment** tree in the left pane of the editor to see the available sediment parameters. The figure below includes the default sediment results avialble. Select additional 2D sediment results by selecting **Customized Variables** in the **Sediment Output Options** menu.

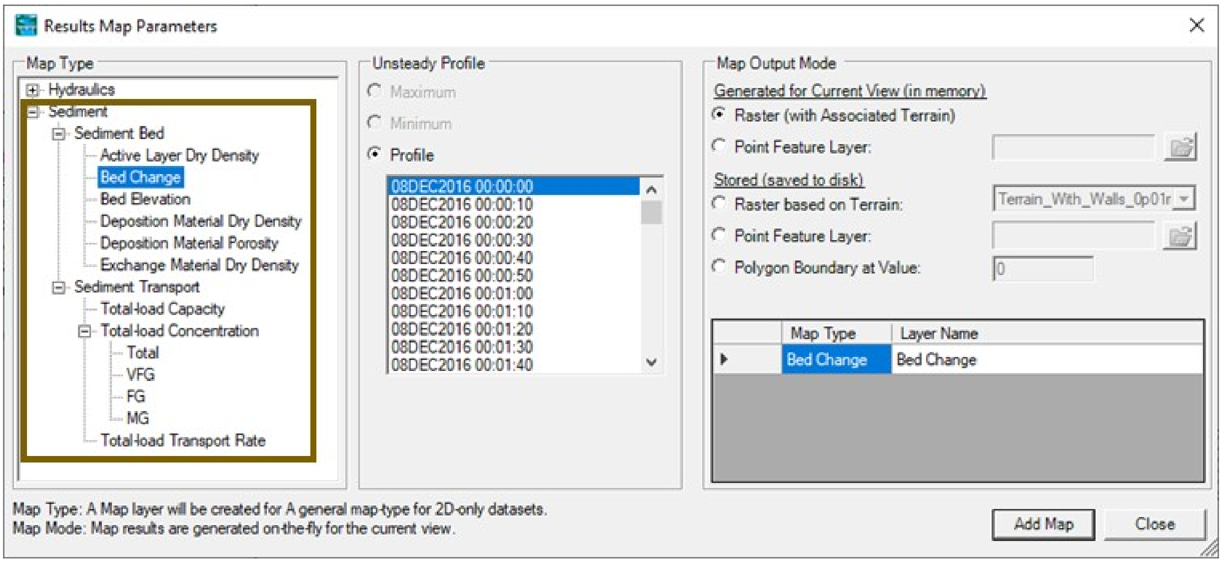
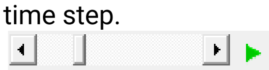


Figure 2. Two types of sediment results (Bed and Transport) in the Results Map Parameter editor.

2D sediment maps fall into two main catagories: **Sediment Bed Maps** and **Sediment Transport** Maps. Sediment Bed maps include results like bed change, bed elevation, bed gradation, and other bed properties. Sediment Transport includes results like concentration, capacity, and other results dynamic, water column or flux results. Any results that HEC-RAS also computes by grain class will also include an expandable tree of results (like Total-load Concentration in the example above). Select the variable node (e.g. Total-load Concentraiton in the example above) to add the Total and all the grain classes to RASMapper. Or, click on one of the sub nodes (e.g. Total, VFG, MG) to add only the total or only one grain class at at time. In the example bleow the user added **Bed Change** and all of the **Total-load Concentration** results but is only diplaying the Fine Gravel Concentration (FG).
Simply clicking the checkbox to turn sediment results on often does not display any results because sediment reuluts are often not initialized in the first time step.

Use the animation bar to view results through time. 

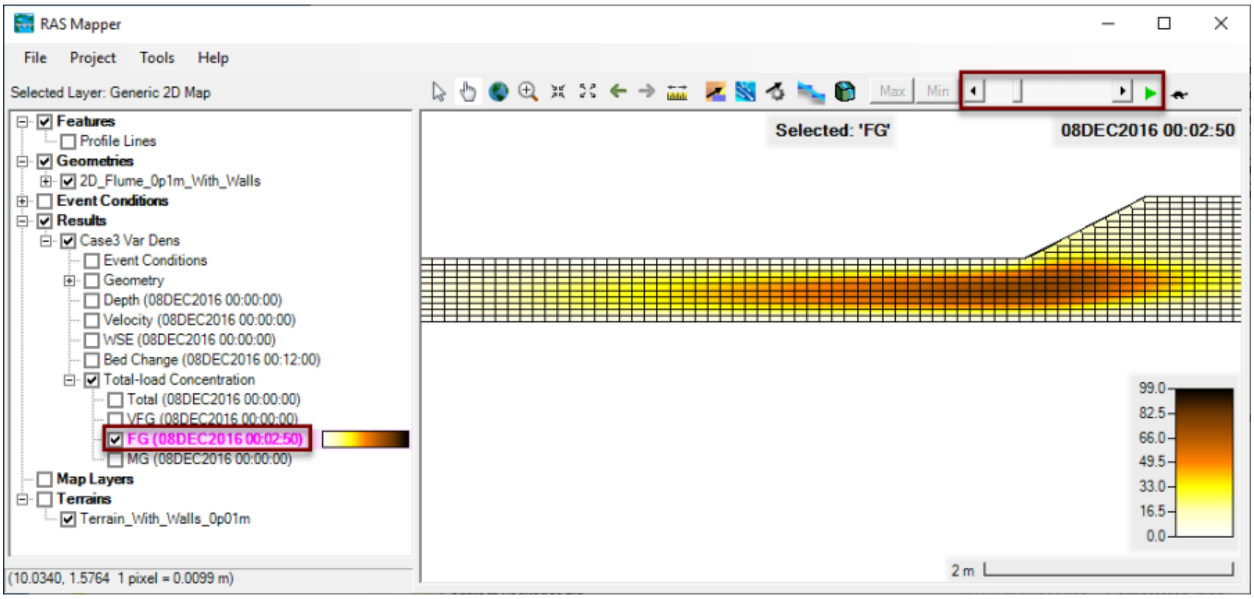
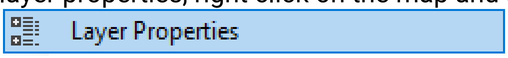


Figure 3. Example use of the animation bar to view sediment concentrations in time.

HEC-RAS 6.0 cannot plot cell face results yet.
Modeling Note – Subgrid Visualization - Because the 2D model updates the bed on the subgrid scale but RAS Mapper does not display subgrid results yet, RAS Mapper will map average results over the wet, dry, or total cell. "Wet" cell results will average the bed properties and bed change properties from the sub-grid portions of the cell below the computed water surface elevation and "dry" results plot the sub-grid results for the cell above the computed water surface. Sediment bed results that are not specified as wet or dry average results over the whole cell.
After adding the map or maps, **Close** the Parameter Selection editor. The selected map(s) should appear under the plan heading in the **Results** node (see Figure below). It is almost always useful to edit the default color ramp to visualize sediment results, and there are some standard practices for some variables. To edit layer properties, right click on the map and select **Layer Properties** (see figure below)**.**



This will launch the **Layer Properties** editor (see figure below). To edit the color ramp press the **Edit** button under **Surface**.

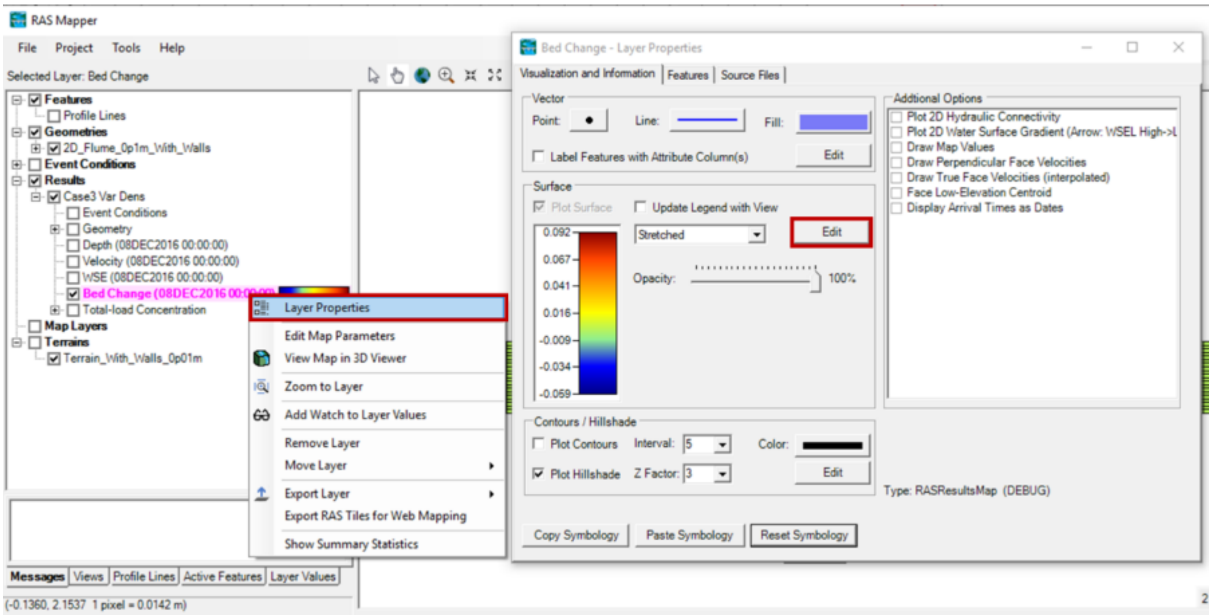


Figure 4. To edit the color ramp and display properties of the sediment maps, right click on the map and select **Layer Properties**. Then Click **Edit** under the **Surface** menu.

RAS Mapper includes a standard **Bed Change** color ramp designed to display this common sediment result map (see figure below). However, this display works best if it is symmetrical, where white is "no/minor change" and aggradation and degradation get their own colors. To make bed change symmetrical, turn of the **Use Dataset Min/Max** to make the **Min** and **Max** editable, and then set them both equal to whichever value is larger, making sure to keep the **Min** negative (e.g. if the **Max** in the example below is 0.091 and the **Min** is -0.073, set the **Min** to -0.091 to make the bed change display symmetrical).

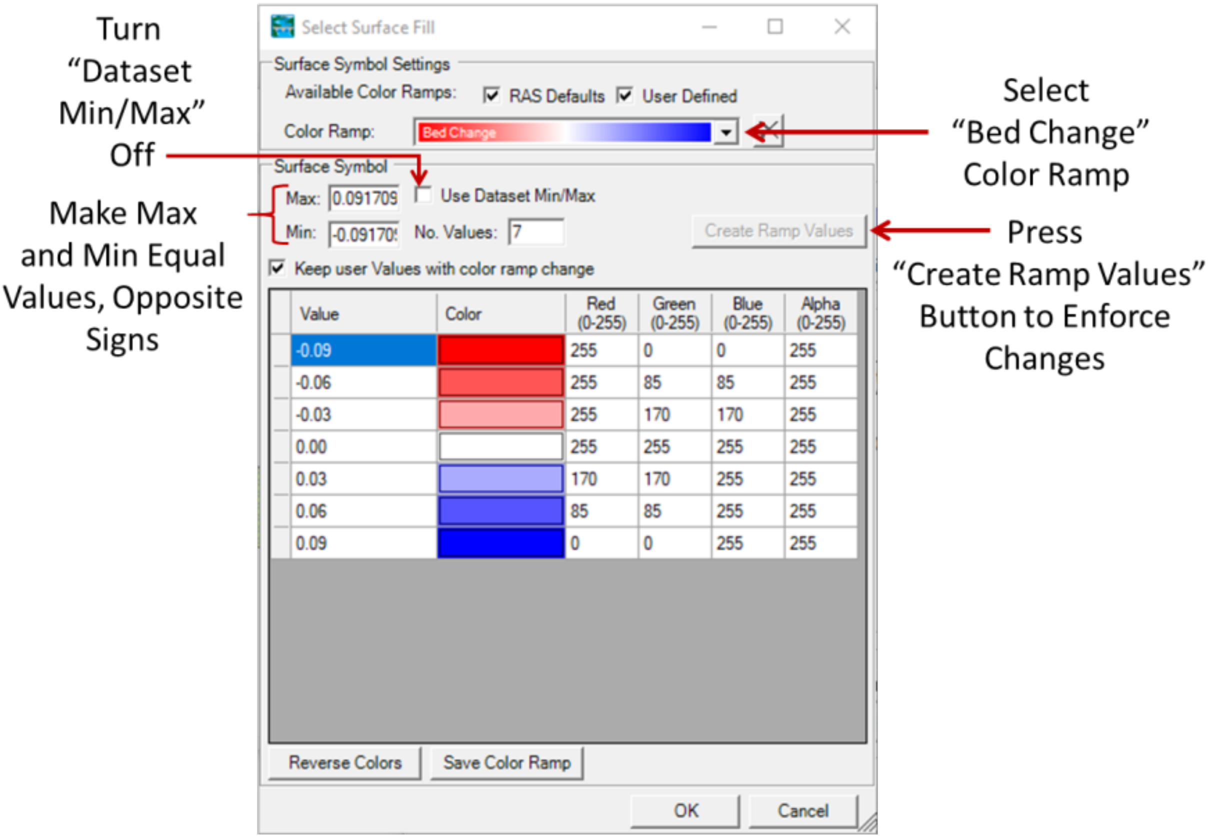


Figure 5. Setting the **Max** and **Min** to equal values (whichever abolute value is larger) with opposite signs, centers the **Bed Change** plot, making all depsoitin and erosion the same colors and the range of no change white.

RAS Mapper has two default sediment color maps: Bed Change and Concentration.

Modelers will develop preferred color ramps and visualization approaches. RAS Mapper allows users to add customized color ramps and visualization parameters to the color ramp editor (see figure below). Edit the color ramp to optimize the visualization, then press **Save Color Ramp**. Give the customized color ramp a name, and it will show up at the bottom of the color ramp list for any result in this project.

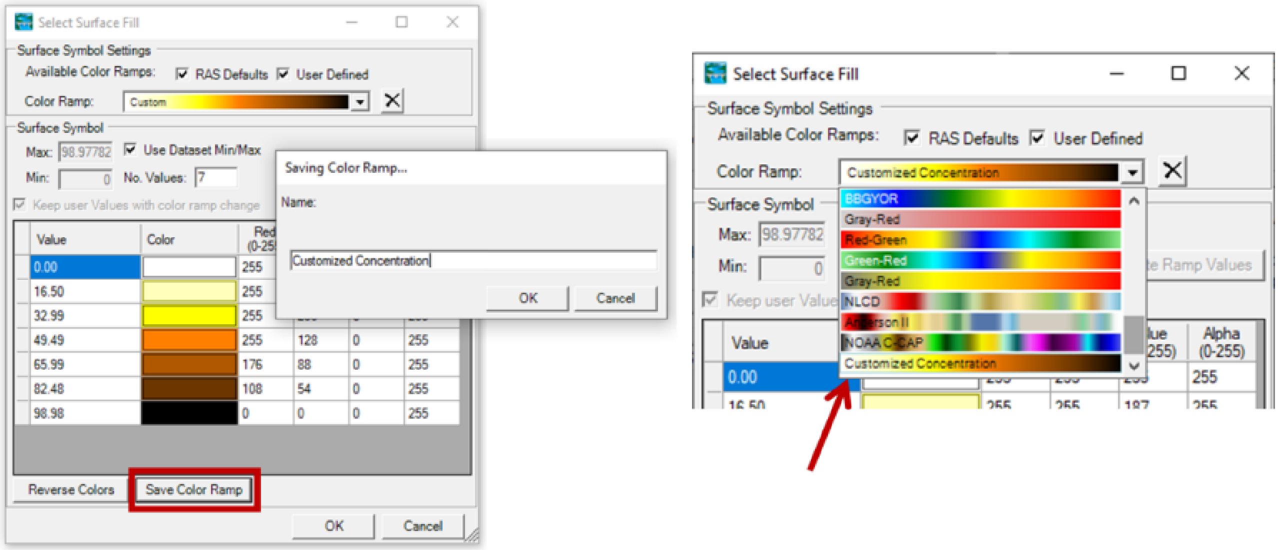
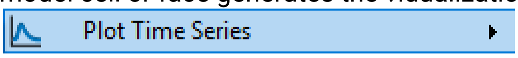


Figure 6. Save customized sediment color ramps that persist throughout the project with the **Save Color Ramp** button.

6.1.1 Plotting 2D Sediment Time Series

Right click on a cell or cell face to visualize sediment time series within the model domain. Right clicking on a model cell or face generates the vidualization menu depeicted in the figure below. Select **Plot Time Series** 

. The **Plot Time Series** option expands into a sub-menu with that includes all of the Results maps (default and added) included in the active plan(s). Only the Results Maps selected (checked) in RASMapper are avialble, however. In the example below, WSE, Velocity, Depth, and Courant are not selected (checked) in RASMapper, so they are greyed out. But bot Bed Change and Total-Load Concentration are checked, so they are availbe. The example below slected **Cell Bed Change**, requesting the depicted time series at this cell.
If sediment results have multiple grain classes, (e.g. Total-load Concentration below) these variables have additional sub-menus where users can choose if they want to plot the Total result or the result from individual grain classes. Again, only the sub-class results selected in the main RASMapper pane will be available.

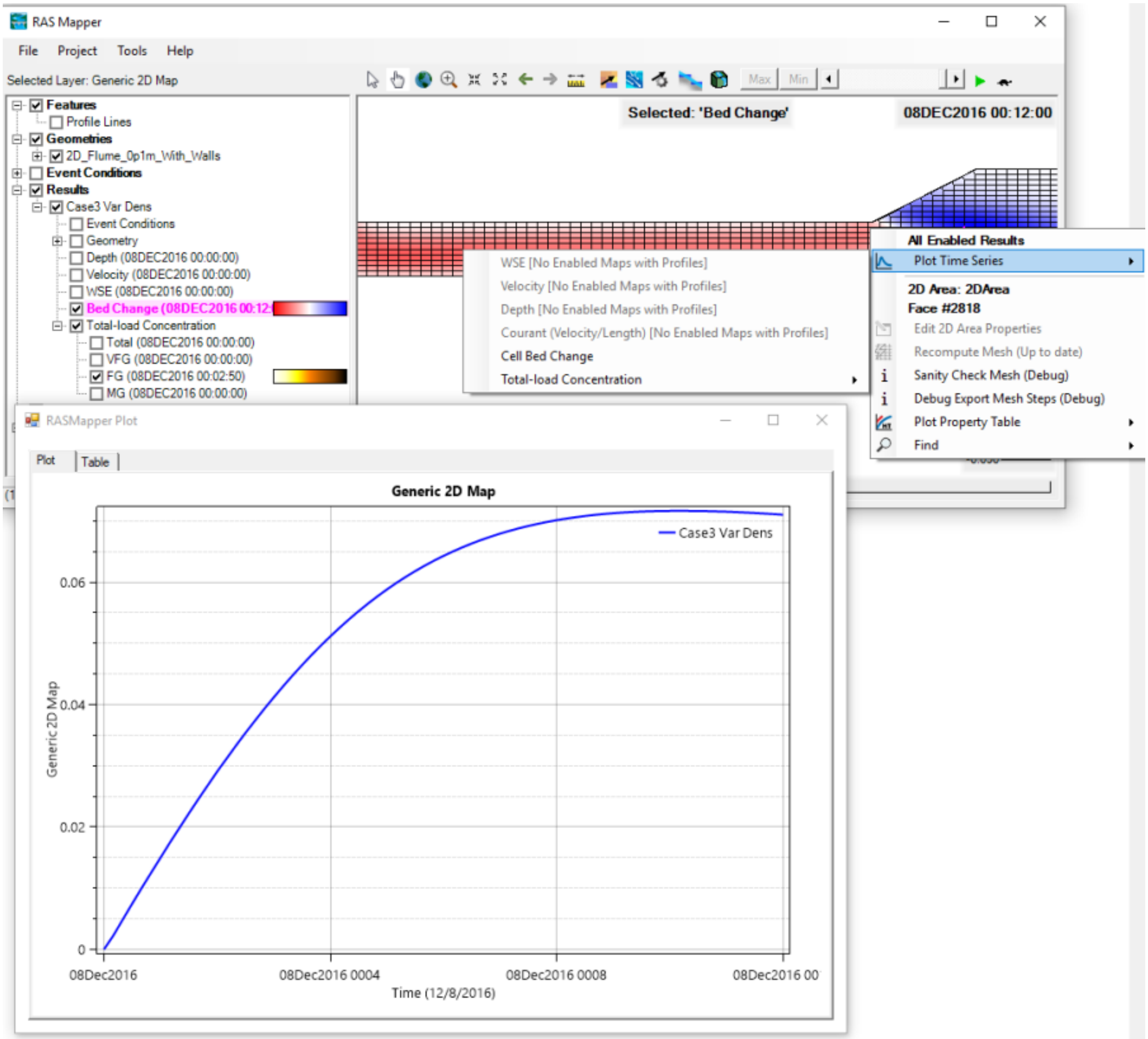


Figure 2 51. View a time series of a sediment (or hydraulic) result by selecting (chekcing) it in the RASMapper result tree and then right clicking on the cell. Select **Plot Time Series** and then the result map to launch the time series for that cell or cell face.

6.1.2 Plotting 2D Sediment Profile Lines

RAS Mapper can also display results for multiple cells along a transect. HEC-RAS calls transects of 2D results **Profile Lines**. To create a results transect Right Click on **Features** menu and select **Create a New Layer** | **Polyline Layer**. Name the Profile Line and press OK (see figure below).

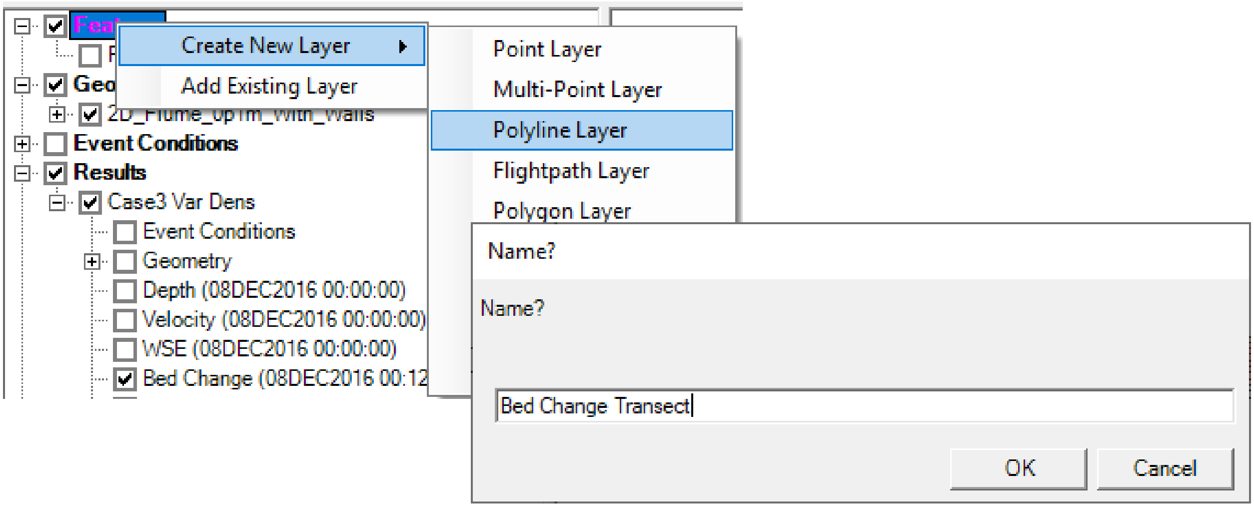
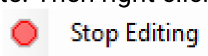


Figure 1. Right Click on the **Feature** menu to create a Polyline Layer.

This adds the transect to **Features** and activates the drawing tool. Draw the polyline that you would like to visualize results along. Double click when it is complete. Then right click on the new Feature (Bed Change Transect in the figure below) and select **Stop Editing**. 

Click **Yes** when asked to save.

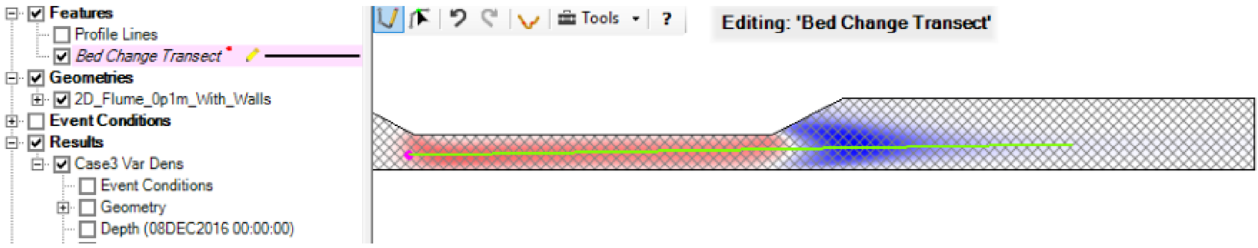


Figure 2. Draw the polyline layer along the 2D sediment results transect.

Now, right clicking on this feature, generates a menu similar to the menu RAS Mapper provides when right clicking a cell or cell face. Users can select a profile plot and animate it with time. A profile will plot a longitudinal transect of the selected result for the displayed time step. As with all of the time series and profile plots in RAS Mapper, press the **Table** tab to retrieve the numerical results behind this plot.

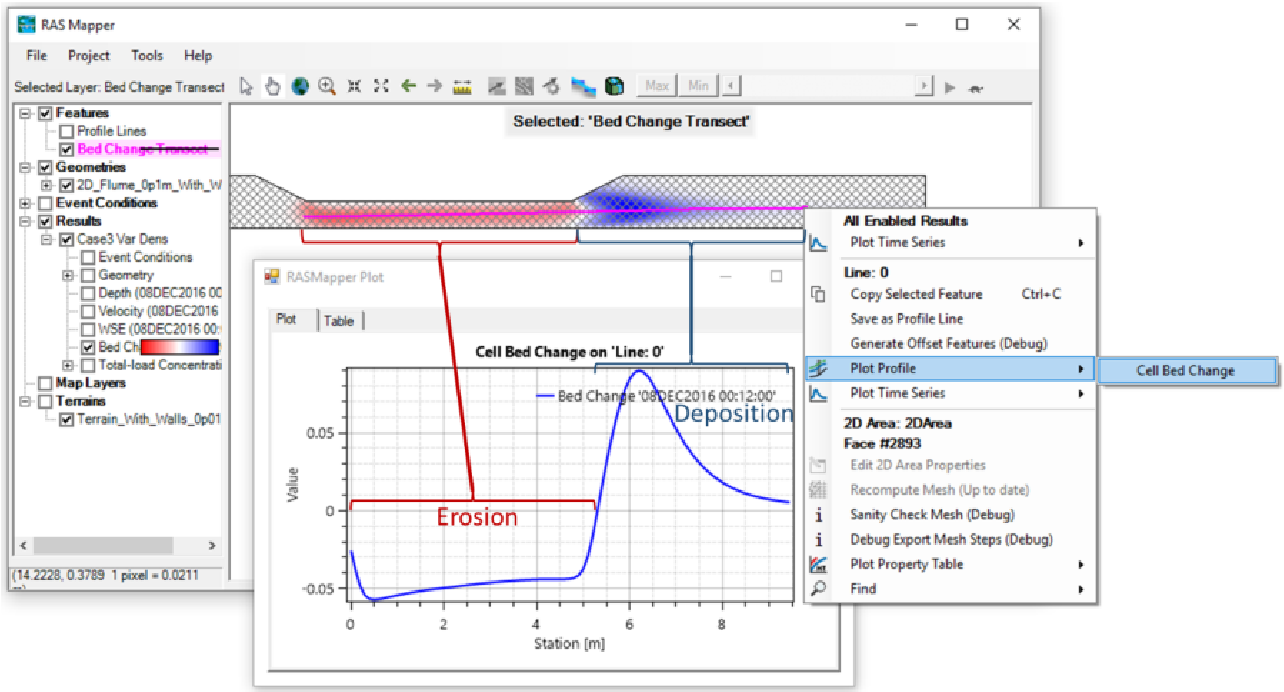


Figure 3. Plot a bed change transect with a polyline profile plot.

6.2 HDF5 Output and the Log File

Users sometimes want to create visualizations or interact with data in ways that are not available in RASMapper yet. In these canses, they can access the HEC-RAS, HDF5 output files or log files either directly, or with scripting tools like MATLAB, R, or PYTHON.

- Exploring the HDF5 File (see page 117)
- Log Output (see page 118)

6.2.1 Exploring the HDF5 File

The HEC-RAS **HDF5 Output File** may be explored by reading the file with a computer language (e.g. MATLAB or Python) or by opening it with an external HDF5 utility such as HDFView (https://www.hdfgroup.org/downloads/hdfview/) or Panoply (https://www.giss.nasa.gov/tools/panoply/). The HEC-RAS output is grouped in the HDF5 file into **Output Blocks**. There are several output blocks including **Base Output**, **Computation Block**, **DSS Hydrograph Output**, **DSS Profile Output**, among others. HEC-RAS 2D sediment output is separated into two Output Blocks: **Sediment Transport** and **Sediment Bed**. The path of the **Output Blocks** within the HDF5 file is /Results/Unsteady/Output/Output Blocks/. The name of each output dataset follows a specific convention as <Location> <Variable Name> for variables which are not specific to each grain class and <Location> <Variable Name> – <Grain Class Name> for variables which are output for each grain class. For all the output variables, the rows indicate the output times and the columns indicate the variation location (i.e. cell, face, subcell, or subface).

Sample code written against the HEC-RAS HDF5 results can be found here[3].

6.2.2 Log Output

Monitoring the convergence status of a model is important but often difficult due the complexity of the sediment transport models. The sediment log output may be grouped similar to the HDF5 spatial output as:

1. **Sediment Transport** (sediment concentrations)
2. **Sediment Bed** (grain class fractions and dry densities in the active layer)

In addition, the logging output is written out to two different places: (1) the **Computation Log File** (**.bco**), and (2) the **HDF5 Output File** (.p.hdf).
The amount of information which is written to the **Computation Log File** depends on the sediment **Output Level** (see Section 2.4 Sediment Output Options) and the convergence status. The log output in the **Computation Log File** is output only when a convergence tolerance is exceeded for **Output Levels** less than 5. If the output level is 5 or 6, a log record is written at a constant computation time step interval. For an **Output Level** of 5, the log record only contains convergence information for the last outer-loop iteration. For an **Output Level** of 6 the log record contains convergence information for all iterations.

6.2.2.1 HDF5 Log Output

The log output in the **HDF5 Output File** is written to the same location as the **Sediment Transport** and the **Sediment Bed** output blocks and is therefore written at the corresponding output intervals. The output interval for the **Sediment Transport** and the **Sediment Bed** output blocks can be controlled by the user by specifying a multiple of the **Mapping Output Interval** (see Section 2.4 Sediment Output Options for details). The log output is written as floating point datasets instead of compound datasets or other forms for computational speeds.

6.2.2.1.1 Sediment Transport

The log output for **Sediment Transport** is written in the **HDF5 Output File** under

Dataset Name: Log Sediment Transport
Dataset Path: /Results/Unsteady/Output/Output Blocks/Sediment Transport/Unsteady Time Series/2D Flows Areas/<2D Flow Area Name>/

where <2D Flow Area Name> is the name of each 2D flow area.

Table 1. Sediment Transport Log Output. Note: HDF5 columns begin at 0.

Column	Log Output Variable	Units
0	Overall convergence status flag	-

[3] https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/viewing-results/visualizing-hdf5-results-with-r-python-and-matlab

1	Transport convergence status flag	-
2	Number of outer-loop iterations	-
3	Maximum total total-load concentration	mg/L
4	Cell location of maximum total total-load concentration	-
5	Maximum fractional total-load concentration	mg/L
6	Cell location of maximum fractional total-load concentration	-
7	Grain class corresponding to maximum fractional total-load concentration	-
8	Concentration maximum absolute correction for all grain classes	mg/L
9	Cell location of maximum absolute concentration correction for all grain classes	-
10	Grain class corresponding to maximum absolute concentration correction for all grain classes	-
11	Percent of active grid	%
12	Minimum total inner loop iterations (only for iterative matrix solvers)	-
13	Grain class corresponding to minimum inner loop iterations (only for iterative matrix solvers)	-
14	Maximum total inner loop iterations (only for iterative matrix solvers)	-
15	Grain class corresponding to maximum inner loop iterations (only for iterative matrix solvers)	-
16	Maximum root-mean-squared residual of inner-loop iterations (only for iterative matrix solvers)	-

17	Grain class corresponding to maximum root-mean-squared residual of inner-loop iterations (only for iterative matrix solvers)	-

Currently when the model diverges, it stops the simulation. In future versions, diverged time steps will be repeated with subcycles in order to try to obtain a converged solution. Usually divergence indicates a NaN (not a number for bed change, bed fractions, or sediment concentrations). However, it could also mean an internal divergence tolerance was exceeded. Future versions of the model will include more information on how the model diverged. A description of the convergence flags are described in the table below.

The convergence status flags indicate different model states (see Table 1). A status is computed each outer iteration for the sediment transport and bed calculations. The overall convergence status takes into account transport and bed sorting.

Table 2. Convergence Status Flags.

Status Flag	**Status Name**	**Description**
-1	Diverged	The solution has diverged. Divergence is determined with a variety of tolerances and checks for many variables.
1	Iterating	Either the convergence tolerances or minimum number of iterations have not been satisfied.
0	Converged	Both the convergence tolerances and minimum number of iterations have been satisfied.
2	Continue	Either the convergence has stalled, or the maximum number of iterations has been reached. The solution will continue to the next time step.

6.2.2.1.2 Sediment Bed

The logging output for the **Sediment Bed** is written in the **HDF5 Output File** under

Dataset Name: Log Sediment Bed
Dataset Path: /Results/Unsteady/Output/Output Blocks/Sediment Bed/Unsteady Time Series/2D Flows Areas/<2D Flow Area Name>/

where again <2D Flow Area Name> is the name of each 2D flow area.

Table 3. Sediment Bed Log Output. Note: HDF5 begin start at 0.

Column	Log Output Variable	Units
0	Overall status flag	-
1	Sediment bed status flag	-
2	Number of outer-loop iterations	-
3	Maximum absolute value of active layer fraction correction (difference between outer-loop iteration values)	%
4	Cell location of maximum absolute value of active layer fraction correction	-
5	Subarea corresponding to maximum absolute value of active layer fraction correction	-
6	Grain class corresponding to maximum absolute value of active layer fraction correction	-
7	Number of avalanching iterations	-
8	Number of avalanches at last iteration	-
9	Maximum bed change due to avalanching	ft or m
10	Cell location of maximum bed change to due avalanching	-

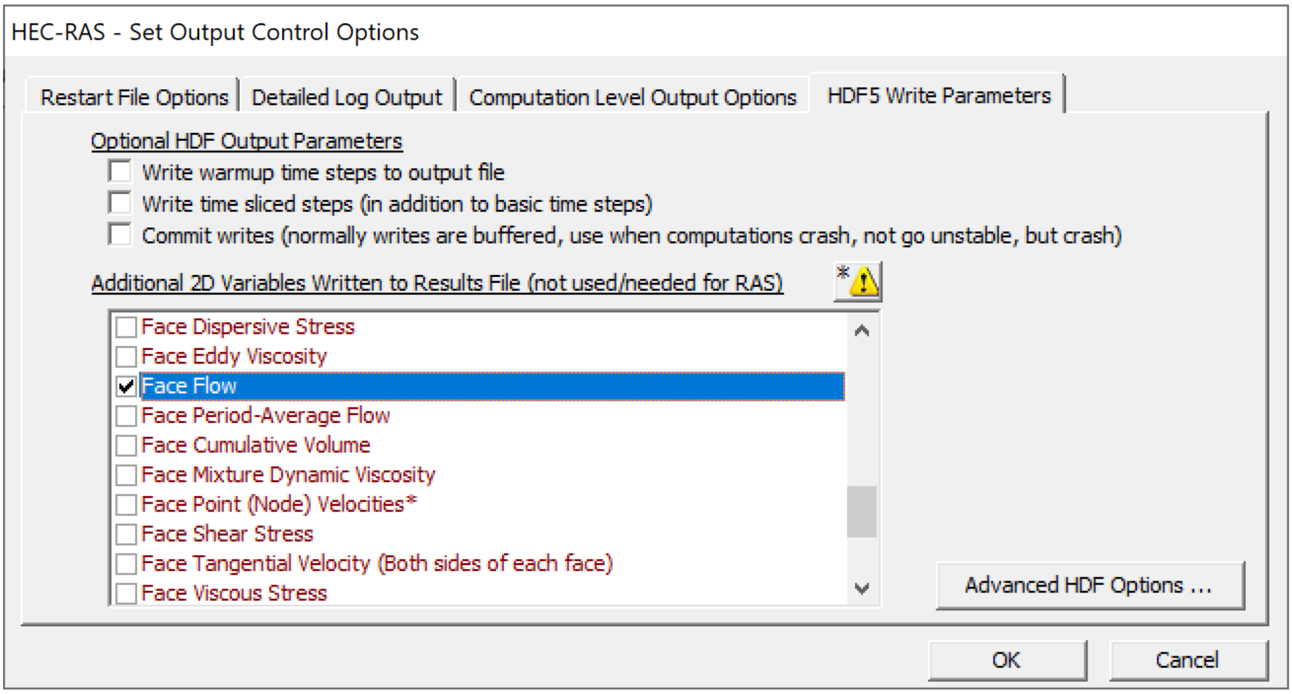
7 Known Issues

7.1 Depth Map in RAS Mapper

When plotting the **Depth** layer for 2D areas in RAS Mapper, this layer does not take into account bed change in mobile bed simulations. Therefore, in cases where the bed change is significant, the water depths will be significantly incorrect results. There is currently no workaround for this issue.

7.2 Profile Line Flow Hydrographs

Flow hydrographs may be computed across profiles in RAS Mapper. The user output **Face Flows**, the computed flows from the engine are utilized. However, if the **Face Flows** are not output, the flows at faces are computed as the face velocities multiplied by the initial face areas. Since the face areas change during mobile bed simulations, the face flows are not correct for mobile bed simulations. The work around for this issue is for the user to output **Face Flows**. The **Face Flows** output dataset is turned on in the **Unsteady Flow Analysis** editor, by selecting **Options | Output Options** and then navigating to the **HDF5 Write Parameters** tab shown in the figure below.



7.3 Profile Line Terrain Elevations

When plotting a profile plot of terrain elevations either by themselves or with other variables such as the water surface elevation, the terrain elevations represent the initial bed elevations and do not account for the bed change during mobile bed simulations.

8 Summary of 2D Sediment Parameters and Options

The 2D sediment model in HEC-RAS has many features and capabilities. These make the model flexible and robust and offer users a lot of calibration and pre-calibration options. But this feature richness can also be overwhelming. It can be difficult to know where to start, which features are important (and which don't matter), what parameters to change, and what an appropriate range for those parameters are. The editors for these parameters and methods are also distributed in different menus across different editors in HEC-RAS, so they can be difficult to think through systematically.

This page compiles some of the early experience with this model to provide some guidance and priority on which methods and parameters are most important, morphological settings that make certain methods more or less important, how these choices tend to affect model results, and common ranges of parameter when appropriate.

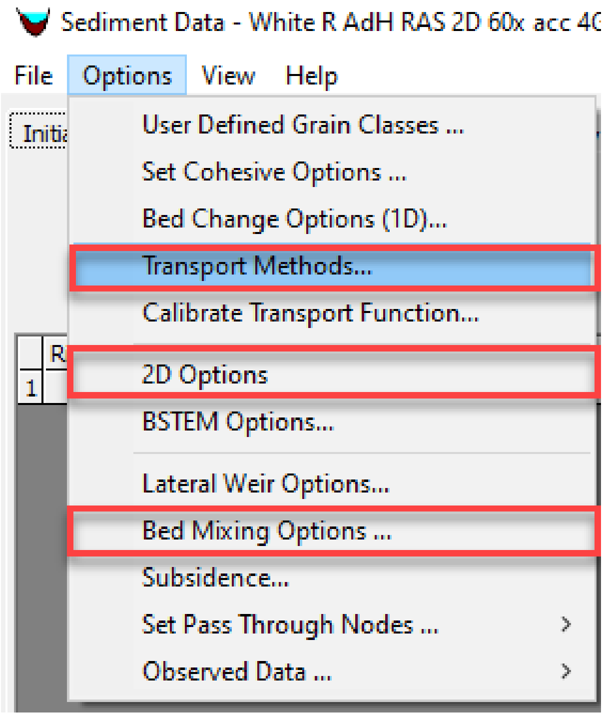
The methods and parameters are listed in the order that HEC tends to engage or adjust them, with the most common/important listed first and the parameters we tend to leave as is listed last. The first column of the chart is linked to the user documentation on the parameter.

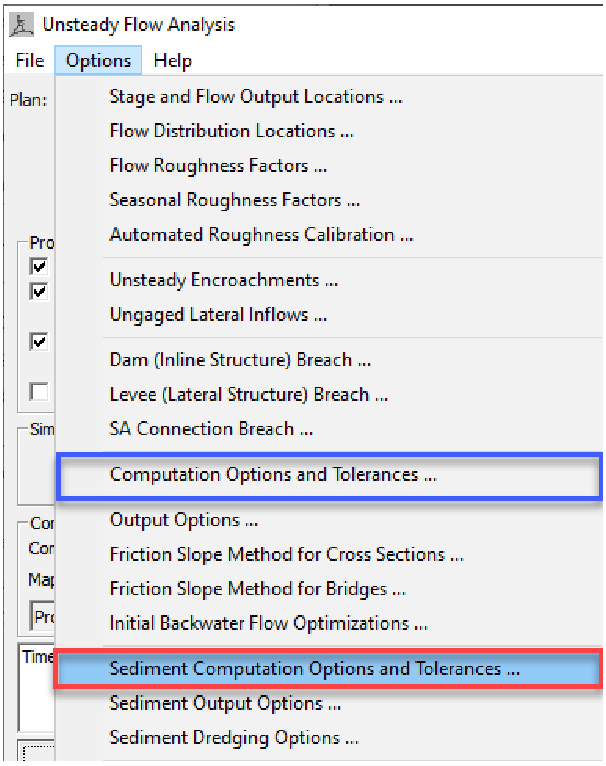
Note: This Guidance is in Progress

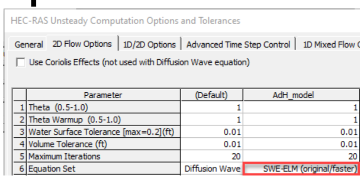
The 2D sediment has been available long enough that HEC is getting feedback on these parameters (and developing enough models). But HEC is still learning about the sensitivity of these methods in parameters in the full range of morphological settings. This page will be a living document which we will update as we learn.

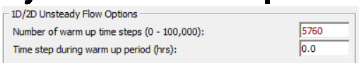
These methods and parameters can be found in five main places.
First, many of them are in three **Options** menus in the **Sediment Data Editor**: the **Transport Methods**, **2D Options**, and **Bed Mixing Options**. Other methods and parameters are in **Options** menu in the the **Unsteady Analysis** editor. This editor launches the **Sediment Computational Optons and Tolerances** as well as the

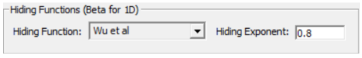
standard, hydraulic, **Computation Options and Tolerances.**



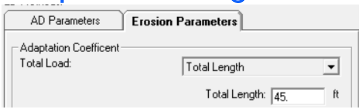
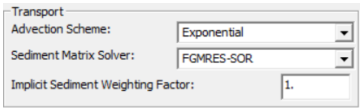
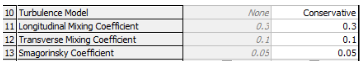


Method	Description	Effect	Recommendation	Location/Menu
Tier 0: Hydraulic Prerequisites for Most Models				
Shallow Water Flow Equations 	Uses the full form of the shallow water flow equations (instead of the diffusion wave simplification).	2D Sediment requires the shallow water flow equations.	**Mandatory!** Sediment results with diffusion wave hydraulics will be useless. The **SWE-ELM (original/ faster)** method is usually appropriate.	Unsteady Flow Analysis → Computational Options and Tolerances→ 2D Flow Options→ 6 Equation Set

Hydraulic Warmup 	2D models start dry. This fills them with water and reaches an equilibrium depth before the model adds sediment.	Models that compute sediment transport as they fill the mesh with water usually scour and encounter instability and begin with poor initial conditions.	Warm up the model hydraulics - either with the Warmup or Initial Conditions - until the mesh is completely wet and water surfaces are in equilibrium.	Unsteady Flow Analysis → Computational Options and Tolerances→ 2D Flow Options→ Number of Warmup Time Steps (Note: You can leave the warmup time step=0.0, this means RAS will use the simulation time step.)

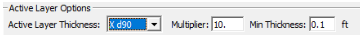
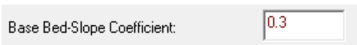
Tier 1: Methods and Parameters Recommended for Most Models				
Hiding and Exposure[4] 	Hiding and exposure account for the interaction between different sized particles. Fine particles "hide" in the "shadow" of larger particles and coarser particles sit on top of smaller particles "exposing them to" more of the flow forces.	Decreases transport of finer grain classes and increases transport of coarser grain classes. Because of the non-linearity of transport, this will reduce total transport and make your model more stable. The coefficients vary between 0-1 and higher coefficients increase these effects.	Most 2D models with Wu or van Rijn transport functions perform better with hiding. Turn this on. There are a lot of methods. Start with Wu and the default coefficient.	Sediment Data → Options→ Bed Mixing Options

4 https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/latest/sediment-data/bed-mixing-options#id-.BedMixingOptionsv6.1-HidingFunctions

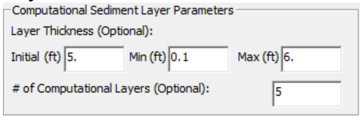
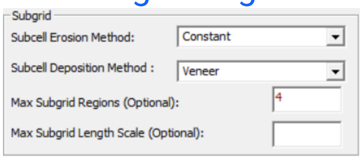
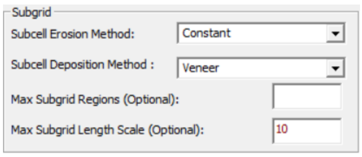
Adaptation Length[5]  	Controls the rate of erosion and deposition. Rivers do not erode or deposit instantly. This parameter accounts for temporal lags in deposition and erosion.	Larger adaptation lengths will slow both erosion and deposition, smoothing the result. Shorter lengths increase erosion and deposition.	Start with a total adaptation length on the order of 1-2X the average cell size.	Sediment Data → Options→ Transport Methods→ Erosion Parameters Tab
Sediment Matrix Solver[6]  	Numerical method applied to solve the sediment transport equations.	The default (Paradiso) is the most accurate but adds runtime. FGMRES-SOR runs faster.	The faster solver (FGMRES-SOR) is usually sufficiently accurate. You could do most of your runs with the faster solver and then switch to PARADISO for fine tuning the final model.	Unsteady Flow Analysis (Plan)→ Options→ Sediment Computation Options and Tol→ 2D Computational Options
Turbulence  	Computes momentum transfer between cells.	Increases lateral transfer of sediment between cells (e.g. moves sediment into the floodplain or backwater)	Select the Conservative Method and leave the default parameters.	Sediment Data → Options→ 2D Computational Options→ Turbulence Model

5 https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/latest/sediment-data/transport-methods#id-.TransportMethodsv6.3-ErosionParameters

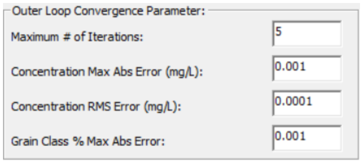
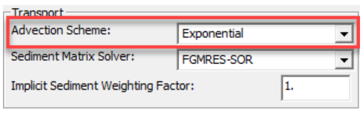
6 https://www.hec.usace.army.mil/confluence/rasdocs/ras1dtechref/latest/theoretical-basis-for-one-dimensional-and-two-dimensional-hydrodynamic-calculations/2d-unsteady-flow-hydrodynamics/numerical-methods/matrix-solvers

Active Layer d90 Multiplier and Min Thickness 	Sets the active layer thickness (default of 1d90 is too small for sand)	Increasing the Xd90 or adding a minimum thickness can make the model more stable. It can also increase erosion.	Default is fine for gravel, but you **MUST update this** for sand beds. If you set a minimum thickness of 1 ft or .3 m for sand beds it will dominate. But even a min thickness of 0.1 ft can help stabilize the model.	Sediment Data → Options→ Bed Mixing Options
Tier 2: Methods That Are Helpful for Many Models				
Sediment Computation Multiplier[7] 	Water travels faster than sediment and the hydraulic computations often require	Increasing this multiplier will decrease run time but can affect results and stability.	Keep this <10 in most cases. Test the model sensitivity to this multiplier. If results are not sensitive to it, increase it to improve run time. You can also use this for exploratory runs and then set it to 1 for detailed simulations.	Unsteady Flow Analysis (Plan) → Computational Options and Tolerances→ General
Base Bed Slope Coefficient 	Accounts for down-slope movement of sediment (transport by gravity instead of flow).	Increasing this parameter tends to smooth bed elevations and improve stability. Influences larger grain sizes more.	Range of ~ 0.1 - 0.5 This factor will be more important for lower transport rates.	

7 https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/simulating-sediment-transport/sediment-computation-options-and-tolerances/sediment-computation-run-time-multiplier

Layer Thickness 	Determines the initial thickness of the bed layers and the minimum and maximum thickness they can reach before they are combined or split.	HEC-RAS uses a small initial thickness for the first layer by default	3-5 ft (1-2 m) is often a good Initial Thickness	Unsteady Flow Analysis (Plan)→ Options→ Sediment Computation Options and Tol→ 2D Computational Options→ Computational Layer Thickness
Tier 3: Methods We Change As Needed in Specific Situations				
Max Subgrid Regions[8] 	HEC-RAS will compute bed and gradation change for sub-regions within each cell.	The model will resolve detailed bathymetric effects better and generate smoother results.	Subgrid analysis adds runtime but can capture detailed hydraulic and sediment results with larger cell sizes. This is worth experimenting with after the model is stable.	Unsteady Flow Analysis (Plan)→ Options→ Sediment Computation Options and Tol→ 2D Computational Options→ Subgrid
Max Subgrid Length Scale 				Plan → Options→ Sediment Computation Options and Tol→ 2D Computational Options→ Subgrid

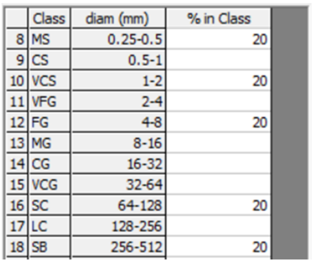
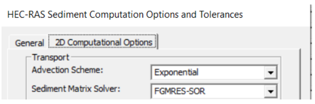
8 https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/latest/sediment-computation-options-and-tolerances/2d-computational-options

Hindered Settling 	Hindered settling accounts for the effect of particle interference	Fall velocity is lower for hyperconcentrated flows and debris flows, decreasing deposition and increasing transport.	Only use this for volumetric concentrations >~10% (e.g. ~100,000 mg/L). Generally you would only turn this on if you are using the Non-Newtonian transport features.	
Tier 4: Methods We Rarely of Never Change				
Outer Loop Convergence Parameters[9] 	This is the acceptable error before the model moves on to the next time step.	Flume and laboratory scale models may want to decrease these.	Do not change these without a very good reason. Relaxing these are not a good way to make your model faster or more stable.	Sediment Data → Options→ 2D Computational Options
Transport Advection Scheme[10] 		Second order schemes are more accurate and increase runtime.	Leave as default: Exponential. The accuracy improvement from the second order schemes do not generally add enough value to sediment models to justify the runtime.	

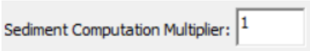
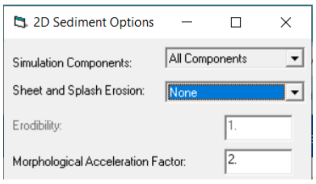
9 https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/latest/sediment-computation-options-and-tolerances/2d-computational-options#id-.2DComputationalOptionsv6.3-OuterLoopConvergenceOptions
10 https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/latest/sediment-computation-options-and-tolerances/2d-computational-options#id-.2DComputationalOptionsv6.3-AdvectionScheme

9 Improving Model Runtime

Two-Dimensional Sediment Transport models can take a long time to run.

<table>
<tr><th>Method</th><th>Description/Recommendation</th><th>Comments</th></tr>
<tr><td>Optimize Hydraulic Runtime</td><td>Align cells with flow[11].
Consider a channel cell size that is 1/5th to 1/7th the channel width and larger cells in the floodplains.
Try to keep cell sizes relatively uniform (very small cells will drive stable time step)
Apply hydraulic best practices to make the model hydraulically stable before you add sediment.
Choose a stable time step
-consider the automated time step selection tool[12]</td><td>A large time step that iterates can take longer to run than a short time step that is stable.
-Find and work on iterating cells[13]
-Avoid thin slivers of flow through cells when possible</td></tr>
<tr><td>Limit the Number of Grain Classes

<table>
<tr><th></th><th>Class</th><th>diam (mm)</th><th>% in Class</th></tr>
<tr><td>8</td><td>MS</td><td>0.25-0.5</td><td>20</td></tr>
<tr><td>9</td><td>CS</td><td>0.5-1</td><td></td></tr>
<tr><td>10</td><td>VCS</td><td>1-2</td><td>20</td></tr>
<tr><td>11</td><td>VFG</td><td>2-4</td><td></td></tr>
<tr><td>12</td><td>FG</td><td>4-8</td><td>20</td></tr>
<tr><td>13</td><td>MG</td><td>8-16</td><td></td></tr>
<tr><td>14</td><td>CG</td><td>16-32</td><td></td></tr>
<tr><td>15</td><td>VCG</td><td>32-64</td><td></td></tr>
<tr><td>16</td><td>SC</td><td>64-128</td><td>20</td></tr>
<tr><td>17</td><td>LC</td><td>128-256</td><td></td></tr>
<tr><td>18</td><td>SB</td><td>256-512</td><td>20</td></tr>
</table></td><td>Try to limit the model to 3-5 grain classes, at least in early, exploratory simulations.
Be careful to use the same, targeted, grain classes in the bed and boundary gradations.</td><td>Runtime increases approximately linearly with grain classes
A model with 5 grain classes will take ~5X as long as the same model with 1 grain class
2D models tend to use fewer grain classes than 1D sediment models. In fact, this kind of gap-graded approach is discouraged in 1D sediment modeling.
Note: Skipping grain classes is NOT recommended in 1D models[14] but best practice in 2D</td></tr>
<tr><td>Sediment Matrix Solver

</td><td>Set Sediment Matrix Solver to FGMRES-SOR, at least for early exploratory runs</td><td>HEC-RAS uses the Paradiso solver by default.
Paridiso is more robust, but it takes longer to run than FGMRES-SOR.
FGMRES-SOR runs faster without much loss of accuracy.</td></tr>
</table>

11 https://youtu.be/oTfFdSmXbYQ
12 https://youtu.be/kcBrOML3iS0
13 https://youtu.be/tKB0gNTUd_A
14 https://youtu.be/rA_8IFWVMEw

Method	Description/Recommendation	Comments
Sediment Time Step Multiplier 	Water surface elevations respond to river changes faster than bed elevations or gradations. HEC-RAS time steps are generally selected for hydraulic stability. Larger time steps might be stable for sediment. This feature directs RAS to compute several hydraulic time steps between each sediment computation. Factors of 2, 4, or 5 are common.	Because sediment computations tend to be more expensive than hydraulic computations, doubling this factor can almost halve the run time. However, if the bed does change quickly, this factor delays the sediment feedbacks, and can decrease stability.
Morphological Acceleration[15] 	The Morphological Acceleration feature scales bed change during a sediment transport simulation. It increases the morphological response, allowing modelers to run a shorter time series. (e.g. A 30 day event could be compressed to a 10 day event with morphological acceleration set to 3). Morphological Acceleration Factors <25 are recommended.	Morphological acceleration introduces more approximation to sediment model results. This feature can also make the model less stable. The flow time step does not update automatically. Users must change the time step of their boundary conditions to compensate. For example, if you have a 24 hour flow time step and use a morphological acceleration factor of 4, change your flow time step to 6 hrs. More guidance is available here[16].

15 https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/latest/sediment-data/2d-options#id-.2DOptionsv6.3-MorphologicAccelerationFactor
16 https://www.hec.usace.army.mil/confluence/rasdocs/h2sd/ras2dsed/latest/sediment-data/2d-options#id-.2DOptionsv6.3-MorphologicAccelerationFactor