

HEC-RAS 1D Sediment Transport

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1 1D Sediment Transport User's Manual

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 - [Entering and Editing Quasi-Unsteady Flow Data \(see page 15\)](#)
- [Entering and Editing Sediment Data \(see page 54\)](#)
 - [Initial Conditions and Transport Parameters \(see page 56\)](#)
 - [Sediment Boundary Conditions \(see page 77\)](#)
 - [Sediment Properties Options \(see page 104\)](#)
- [Geometric Considerations for a Sediment Transport Model \(see page 156\)](#)
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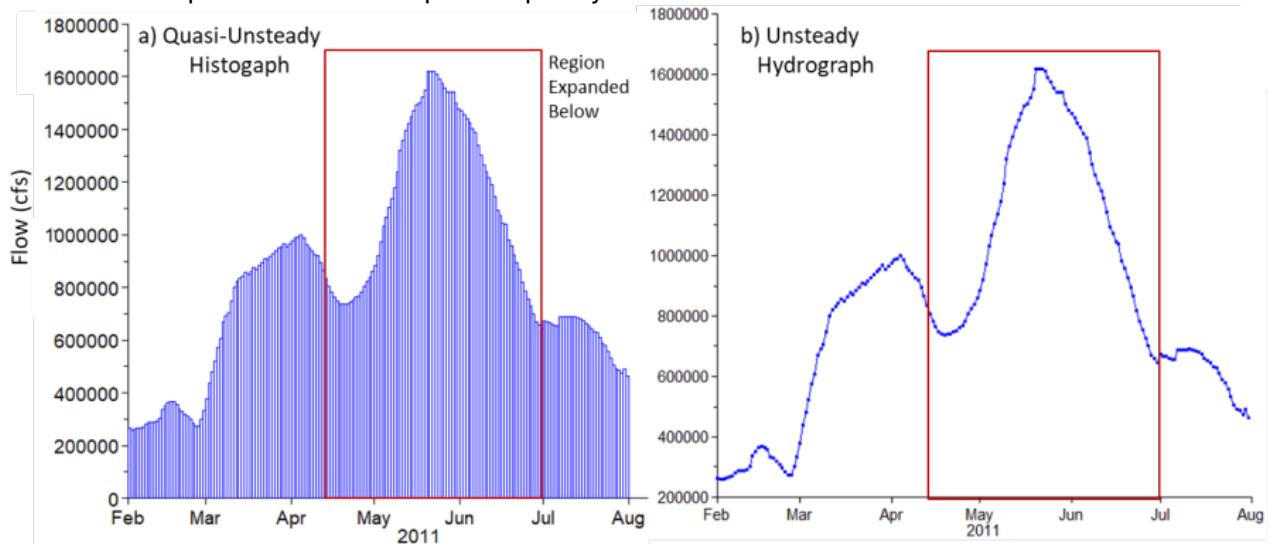
- Visualizing HDF5 Results with R, Python, and Matlab (see page 284)
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- Acknowledgement (see page 296)

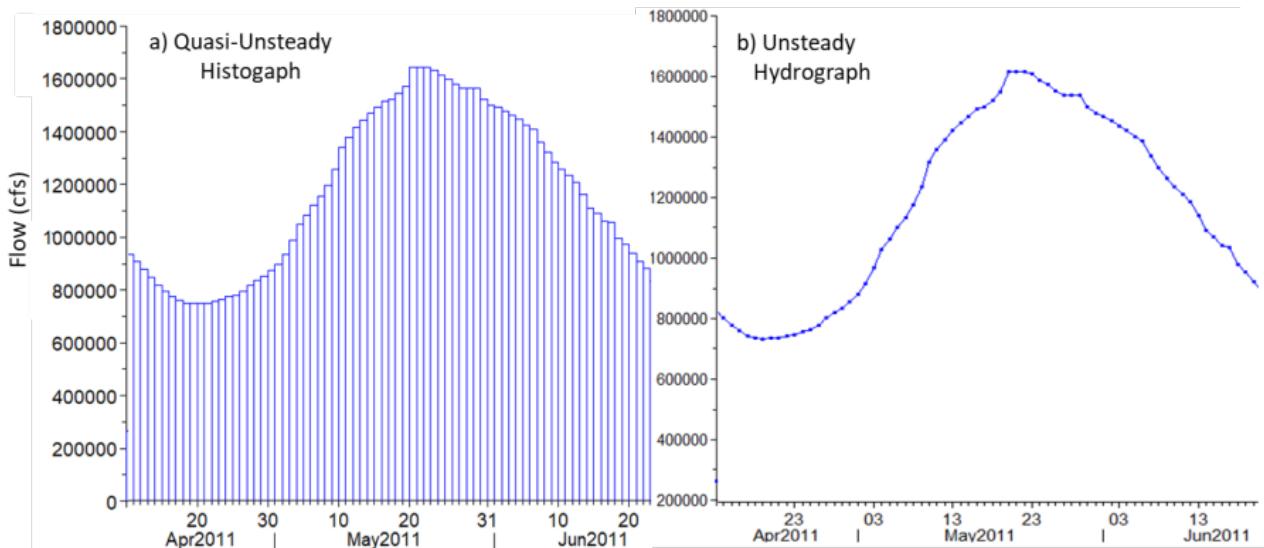
1.1 Flow Data and Event Conditions

The current version of HEC-RAS includes two hydrodynamic approaches to Sediment Transport Analysis:

- Quasi-Unsteady Flow and
- Unsteady Flow.

HEC-RAS allows users to run Quasi-unsteady flow simulations without sediment transport (e.g. for riparian vegetation analysis) but sediment transport models are the most common application of the quasi-unsteady flow method. The quasi-unsteady hydrodynamic model simulates the flow series with a sequence of steady flow computations (the (a) Quasi Unsteady Histogram plots on the left, below). Hydrodynamic parameters for the sediment model are computed with the HEC-RAS steady flow engine, then applied over specified time windows to compute sediment transport temporally.



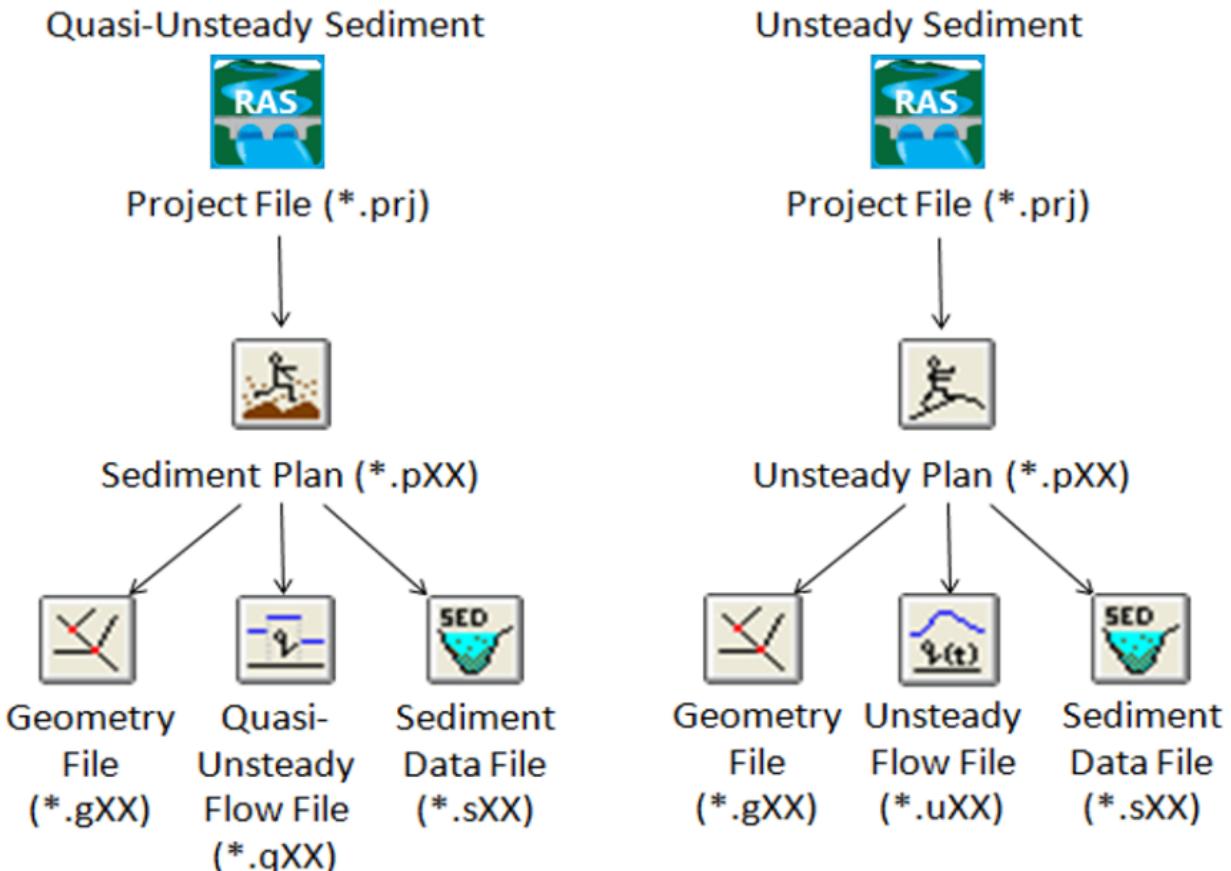


Unsteady sediment transport capabilities are new in HEC-RAS version 5.0 (The (b) Unsteady Hydrograph plots on the right above). HEC-RAS can run unsteady flow simulations without sediment. Setting up unsteady flow files and troubleshooting unsteady flow models are covered in detail in Chapter 8 (Performing and Unsteady Flow Analysis). Constructing an accurate, calibrated, stable unsteady hydraulic model is the first step in unsteady sediment modeling.

Selecting the appropriate hydrodynamic model for an HEC-RAS sediment transport analysis involves classic trade-offs between precision and effort (Gibson 2013). Quasi-unsteady modeling tends to be easier, but because it does not conserve flow, it can introduce unacceptable errors, particularly in systems with significant storage.

Unsteady flow modeling requires careful and skillful practice because the solution can be unstable with a fixed bed. Moving unsteady model cross sections can make model stability problems worse, because bed change can introduce instabilities. Making an unsteady flow model robust is not trivial. However, unsteady flow conserves mass and accounts explicitly for volume change, making it particularly applicable for reservoir modeling (Gibson and Boyd, 2014), models with lateral structure flows, reverse flows, or engineering problems where hydrograph timing is critical.

The table below summarizes the costs and benefits of the two approaches and the tree diagram above it outlines the file structure of both approaches.



File structure for quasi-unsteady and unsteady sediment transport models.

Table 1 1: Decision Criteria for Selecting Unsteady or Quasi-Unsteady Sediment Simulations.

| Quasi-Unsteady | Unsteady |
|---|---|
| Solves the steady flow backwater equations for a series of flows with associated times (a histogram). | Solves the Saint-Venant equation implicitly. |
| Does not conserve flow or account for storage. | Conserves flow and accounts for reservoir storage. |
| More stable. | Less stable. Bed change can exacerbate the unsteady model instabilities, common to the Saint-Venant solution. |

| | |
|---|--|
| Individual time steps take longer, but the variable time step feature usually translates into shorter model runs. | The unsteady flow engine is faster than steady flow, so each unsteady computation is faster. But the unsteady hydraulics usually require a smaller time step for stability, which makes run times longer.* |
| Limited to steady flow options. | Complex flow boundary conditions available including groundwater interflow, rules, lateral structures, internal boundary gate controls, pumps and others. |

*Version 5.0 and later include variable time steps in unsteady simulations and 6.0 decoupled the flow and sediment time steps, giving users some flexibility with these time steps. But unsteady flow runs are still, generally, more computationally expensive.

1.1.1 Entering and Editing Quasi-Unsteady Flow Data

The 1D sediment model in HEC-RAS can use unsteady  or quasi-unsteady  hydraulics. The main HEC-RAS user manual includes a section on [entering and editing unsteady hydraulic data](#)¹.

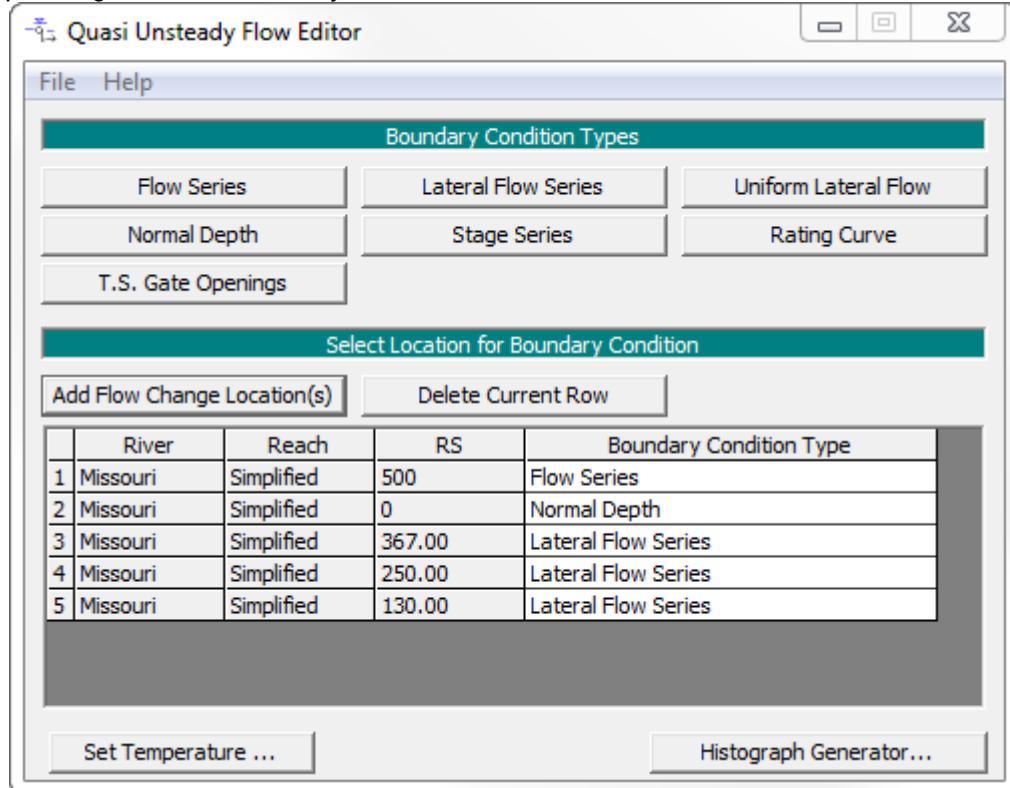
However, quasi-unsteady hydraulics apply almost exclusively to sediment transport modeling. Therefore, they are included here.

The quasi-unsteady approach approximates a flow hydrograph by a series of steady flow profiles associated with corresponding flow durations (see the quasi-unsteady section of the Technical Reference Manual).

This analysis requires different information than steady or unsteady flow: a separate quasi-unsteady flow dialog is available by selecting **Quasi-Unsteady Flow** under the **Edit** menu of the main HEC-RAS dialog or by

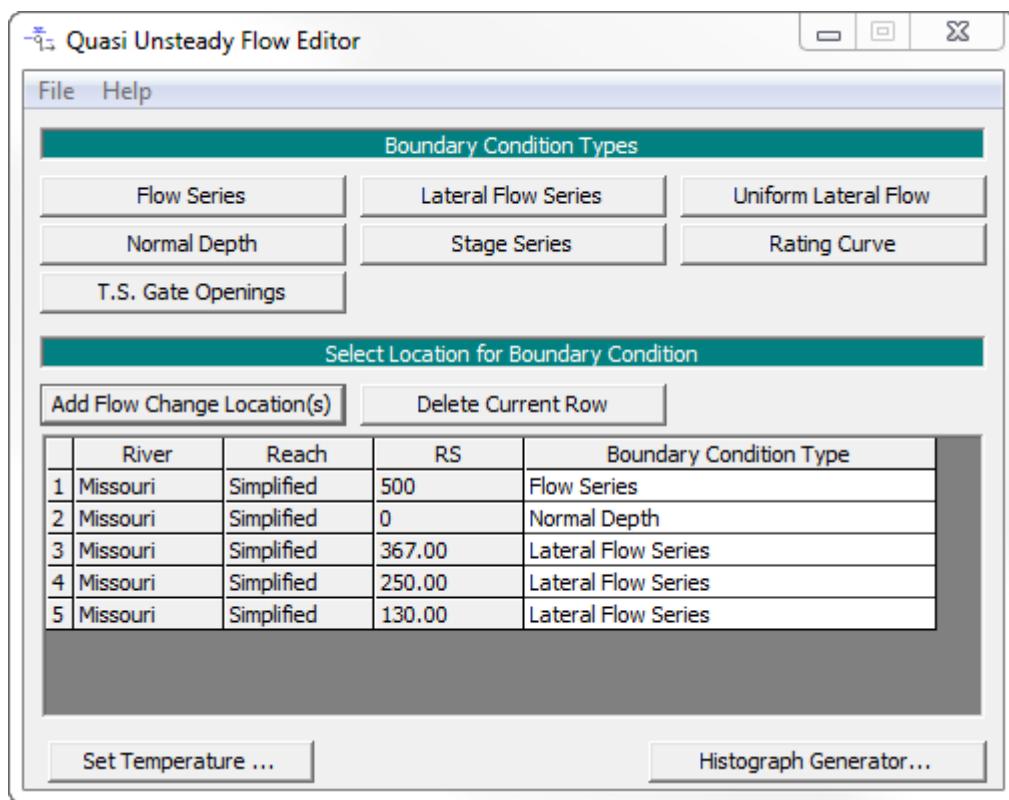
¹ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/performing-a-1d-unsteady-flow-analysis/entering-and-editing-unsteady-flow-data>

pressing the Quasi-Unsteady Flow shortcut button.



1.1.1.1 Boundary Conditions

HEC-RAS includes several quasi-unsteady boundary conditions, but only one upstream quasi-unsteady boundary type. Each upstream boundary (the upstream cross section of an open-ended upstream reach) requires a Flow Series boundary. Quasi-unsteady flow models must be dendritic, which means they will have one and only one downstream boundary. HEC-RAS includes three options for setting quasi-unsteady downstream boundary conditions: Stage Time Series, Rating Curve, or Normal Depth. Optional internal boundaries include Lateral Flow Series, Uniform Lateral Flow Series, and Time Series Gate Operations.



1 Quasi-Unsteady Flow Dialogue

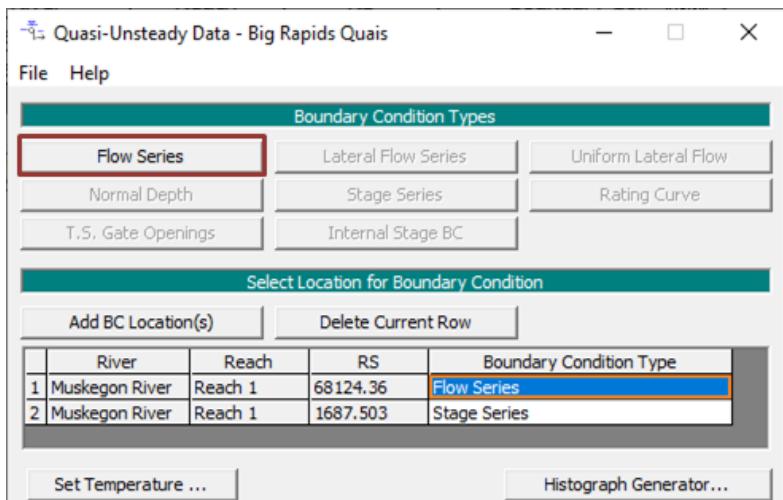
1.1.1.1 Upstream Boundary Conditions

HEC-RAS requires external (upstream and downstream) boundary conditions to run sediment analyses. The **Quasi-Unsteady Flow** editor automatically includes entries for external boundary cross sections, requiring boundary conditions.

The quasi-unsteady flow model has multiple boundary condition options for downstream and internal boundary conditions, but only one Upstream Boundary Option: the **Flow Series**.

Select and define a **Flow Series** for each upstream boundary.

Click the blank **Boundary Condition Type** field associated with the upstream node and then press the **Flow Series** button to open the **Flow Series** editor.



1.1.1.1.1.1 Flow Series

Define upstream boundary flow in the **Flow Series** editor, depicted in the figure below. The **Quasi-Unsteady Flow** series editor shares the look and feel of the **Unsteady Flow** series editor with a few important differences. The time reference conventions are the same as unsteady flow (DDMMYY YYYY). Most sediment models tie the flow series to a **Fixed Start Time** reference. This feature ties historical records or synthetic future records to a fixed start date, allowing simulation windows that include all or any part of the record. For example, in the figure below the historical record starts at 01May1955 2400 but the simulation starts on 15Oct1957 2400. The shaded dates indicate that those flows are outside the simulation window (defined in the plan editor described [here \(see page 163\)](#)).

Flow Series for White White 44233

Read from DSS before simulation

File:
Path:

Enter Table

Select/Enter the Data's Starting Time Reference

Use Simulation Time: Date: 01Jan1984 Time: 2400
 Fixed Start Time: Date: 01Jan1984 Time: 2400

| Hydrograph Data | | | | | |
|-----------------|--------------------|--------------|---------------|-----------------------|------------|
| No. Ordinates | Interpolate Values | Del Row | Ins Row | | |
| | Simulation Time | Elapsed Time | Flow Duration | Computation Increment | Flow (cfs) |
| | | (hours) | (hours) | (hours) | |
| 1 | 02Jan1984 0000 | 24 | 24 | 24 | 935 |
| 2 | 03Jan1984 0000 | 48 | 24 | 24 | 1520 |
| 3 | 04Jan1984 0000 | 72 | 24 | 6 | 5450 |
| 4 | 05Jan1984 0000 | 96 | 24 | 1 | 8220 |
| 5 | 06Jan1984 0000 | 120 | 24 | 1 | 6350 |
| 6 | 07Jan1984 0000 | 144 | 24 | 6 | 4260 |
| 7 | 08Jan1984 0000 | 168 | 24 | 24 | 3810 |
| 8 | 09Jan1984 0000 | 192 | 24 | 24 | 2840 |
| 9 | 10Jan1984 0000 | 216 | 24 | 24 | 2380 |
| 10 | 11Jan1984 0000 | 240 | 24 | 24 | 1810 |
| 11 | 12Jan1984 0000 | 264 | 24 | 24 | 1910 |
| 12 | 13Jan1984 0000 | 288 | 24 | 24 | 2330 |
| 13 | 14Jan1984 0000 | 312 | 24 | 24 | 2290 |
| 14 | 15Jan1984 0000 | 336 | 24 | 24 | 1700 |
| 15 | 16Jan1984 0000 | 360 | 24 | 24 | 1450 |
| 16 | 17Jan1984 0000 | 384 | 24 | 24 | 1200 |
| 17 | 18Jan1984 0000 | 408 | 24 | 24 | 1000 |

Compute computation increments based on flow

| | Qlow | Qhigh | CI |
|---|------|-------|----|
| 1 | 0 | 4000 | 24 |
| 2 | 4000 | 6000 | 6 |
| 3 | 6000 | 20000 | 1 |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |

2 Flow series editor

One of the unique (and sometimes confusing) details of the quasi-unsteady editor is that each time step and flow has two time steps associated with it: a **Flow Duration** and a **Computational Increment**. The Flow Duration has the resolution of the flow data (e.g. daily flows have 24 hour durations) while the Computational

Increment is the actual computational time step, at which HEC-RAS recomputes the hydraulic backwater and simulates transport.

Flow Duration:

The flow duration is a constant flow input increment. It does not control the model time step. For example, if flow data are from a daily USGS flow gage, flow durations would be 24 hours, regardless of the computational time step applied to the sediment model. The Computational Increment (e.g. hydraulic and sediment transport time step) can be smaller than the Flow Duration, but not larger. Therefore, the Flow Duration is also the maximum time step.

Modeling Note: Develop Longer Flow Durations for Low Flow Periods With the Histogram Generator

Modelers often want to use very large (multi-day) time steps during low flow, low transport seasons. In these cases, users can combine multiple flow durations into one, and run the long duration with an average flow and a single computational increment. (e.g. run a week of baseflow with insignificant transport as a single flow duration of 168 hours with a 168 hour computation increment). However, averaging flow does not average sediment. Running a sediment model with average flow introduces sediment errors, usually overpredicting the sediment load. If loads are during the averaged flow periods are significant, the [Histogram Generator](#) (see page 44), will compute load-scaled time series with sediment-averaged flows that conserve sediment mass.

Specify Flow Durations in the first column of the flow editor (in hours). Values can be copied from Excel and pasted into the Flow Series Editor with the *Ctrl+C* and *Ctrl+V* commands, but all of the destination cells must be selected. (Note: all destination cells can be selected by clicking on the heading. Users can also populate the table (particularly if all the durations are the same) by dragging a value (hover over the bottom right corner of the cell to get cross hairs to drag values) or populating the first and last value and pressing the **Interpolate Values** button.

Quasi-unsteady flow can handle irregular (varying) time steps, allowing coarse time steps

Flow durations for different boundary conditions do not need to match. If boundary conditions have different time steps (flow durations or computational increments) HEC-RAS will compute and use the smallest time step common to all.

The **Flow Series** editor defaults to 100 rows. Almost all sediment studies require more flow records. Press the **No. Ordinates** (number of ordinates) button to customize the Flow Series length up to about 40,000 flows.

If the model requires more than 40,000 flows, either combine low flows into longer durations (possibly using the [Histogram Generator](#) (see page 44) tool) or consider running the model in two phases, hotstarting the geometry and bed gradation (see [Hotstart](#) (see page 207) section below).

Computational Increment:

The Computational Increment subdivides the Flow Duration. The quasi-unsteady model computes new steady flow profiles at each computational increment, applying the hydraulic parameters over this time step.

This approach assumes bed geometry does not change enough between computational increments to alter hydrodynamics appreciably.

Sediment transport is highly non-linear. Most transport and bed change is concentrated in relatively brief periods of high flow, and flood events are often highly dynamic. Large quasi-unsteady time steps (e.g. 24 hours or more) are often sufficient for low flow periods with little bed change. However, moderate to high flows can change channel geometry quickly, undermining the assumption that the hydrodynamics are the same throughout a large time step. Therefore, moderate to high flows require smaller computational increments.

Model stability is very sensitive to computational increment. If the simulation window reports "Model fills with sediment" when the model fails, the computational increment associated with that flow duration is probably too large. If channel geometry is updated too infrequently (i.e. if the computational increment is too large), too much material could be eroded or deposited in a time step, causing the model to over correct in the next time step, generating oscillations and model instabilities.

For example, the first two flow records in the figure 'Flow Series Editor' shown above, (02 and 03 January) are daily flow records with 24 hour computational increments. Therefore, HEC-RAS will only compute hydraulic parameters once over these days. However, the third- and fourth-time steps (ending 04Jan and 05Jan) have daily flow durations but are subdivided into multiple steps. HEC-RAS will update the hydraulics four times during the third flow record (every 6 hours, based on the 6 hour computational increment) and will update hydraulics 24 times (every hour, for the fourth and fifth flows), at the beginning of each 1-hour computation increment.

Modeling Note: Computational Increments Drive Run Times and Model Stability

While smaller computation increments will increase run time, re-computing geometry and hydraulics too infrequently (e.g. computation increments that are too large) is the most common source of model instability.

1.1.1.1.1.2 Automate Computational Increments (Optional)

It is often useful to apply a consistent flow-computational increment (CI) relationship to the entire flow series, particularly when trying to optimize the increment for a long flow series. HEC-RAS will automatically populate computational increments with user specified flow ranges. Click the Compute Computation Increment Based on Flow check box (below). This will open an editor to associate consecutive, non-overlapping flow ranges with computational increments. The feature also grays out the computational increment column, because it populates automatically. The computational increments persist and become editable if the user turns the Compute computation increments based on flow off (i.e. uncheck the check box), but the tool will overwrite any existing computational increments if it is turned on.

Flow Series for Arghandab Dahlia Dam US 19889.30

Select/Enter the Data's Starting Time Reference

 Use Simulation Time:

Date: 15Oct1957 Time: 2400

 Fixed Start Time:

Date: 01May1955 Time: 2400

Hydrograph Data

| | Simulation Time | Elapsed (hours) | Flow Duration (hours) | Computation Increment (hours) | Flow (m ³ /s) |
|-----|--------------------|--------------------|-----------------------------|-------------------------------------|-----------------------------|
| 897 | 14Oct1957 0000 | 21528 | 24 | 12 | 90.3 |
| 898 | 15Oct1957 0000 | 21552 | 24 | 12 | 95.2 |
| 899 | 16Oct1957 0000 | 21576 | 24 | 6 | 109 |
| 900 | 17Oct1957 0000 | 21600 | 24 | 6 | 114 |
| 901 | 18Oct1957 0000 | 21624 | 24 | 6 | 129 |
| 902 | 19Oct1957 0000 | 21648 | 24 | 6 | 143 |
| 903 | 20Oct1957 0000 | 21672 | 24 | 6 | 159 |
| 904 | 21Oct1957 0000 | 21696 | 24 | 6 | 164 |
| 905 | 22Oct1957 0000 | 21720 | 24 | 6 | 159 |
| 906 | 23Oct1957 0000 | 21744 | 24 | 6 | 155 |
| 907 | 24Oct1957 0000 | 21768 | 24 | 6 | 155 |
| 908 | 25Oct1957 0000 | 21792 | 24 | 6 | 152 |
| 909 | 26Oct1957 0000 | 21816 | 24 | 6 | 150 |
| 910 | 27Oct1957 0000 | 21840 | 24 | 6 | 153 |
| 911 | 28Oct1957 0000 | 21864 | 24 | 6 | 193 |
| 912 | 29Oct1957 0000 | 21888 | 24 | 3 | 382 |
| 913 | 30Oct1957 0000 | 21912 | 24 | 3 | 314 |
| 914 | 31Oct1957 0000 | 21936 | 24 | 3 | 256 |

 Compute computation increments based on flow

| | Qlow | Qhigh | CI |
|---|------|-------|----|
| 1 | 0 | 50 | 24 |
| 2 | 50 | 100 | 12 |
| 3 | 100 | 200 | 6 |
| 4 | 200 | 400 | 3 |
| 5 | 400 | 1200 | 1 |
| 6 | | | |
| 7 | | | |

Modeling Note

If your flow time series includes flows lower than the smallest flow or higher than the largest flow in your automated computational increment, HEC-RAS will automatically use the Computational increment associated with the lowest or highest range respectively. (Note: this is new in version 6.0. Previous versions returned an error)

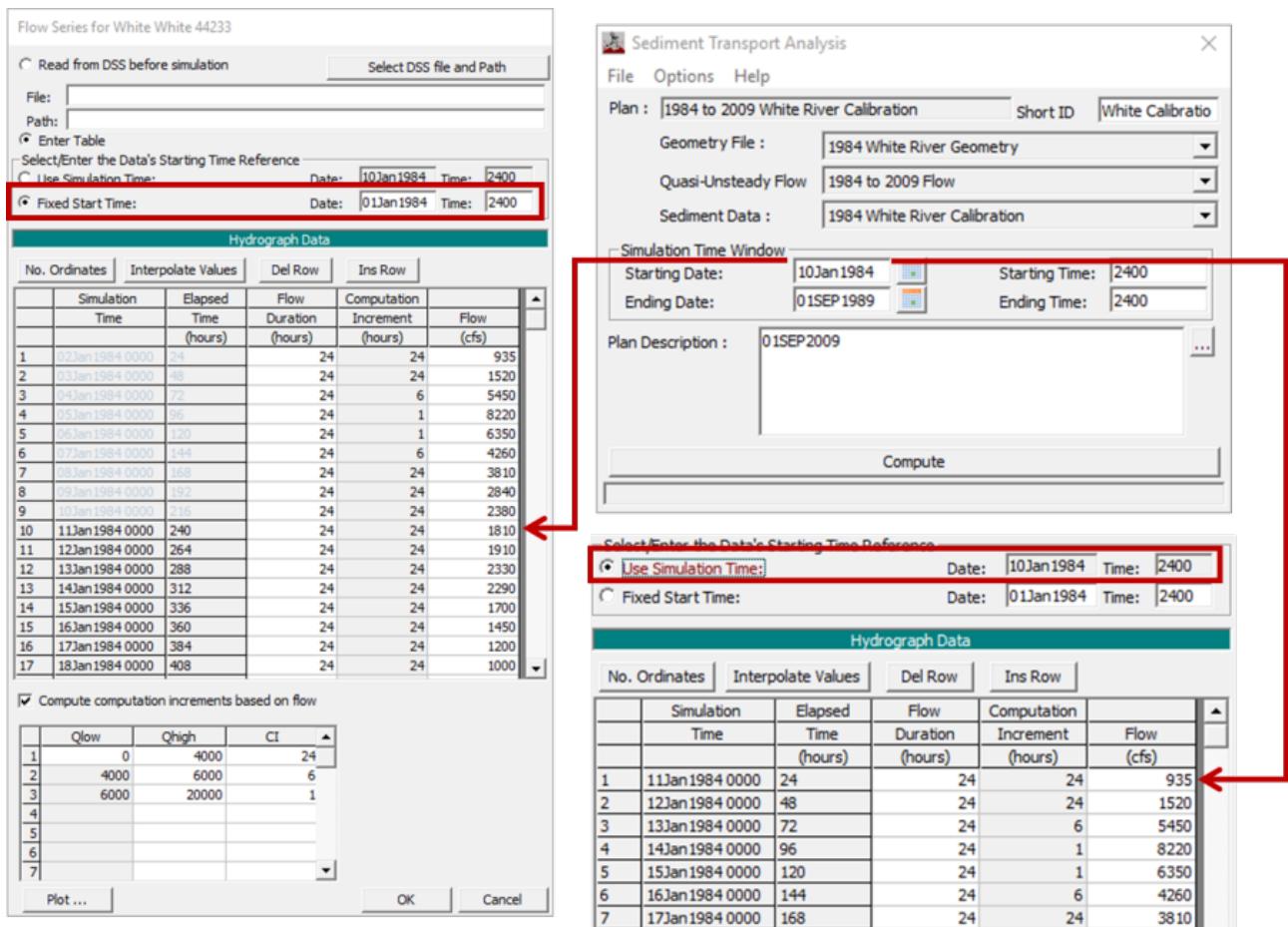
1.1.1.1.3 Fixed or Simulation Start Time?

Most HEC-RAS time series editors ask users to **Select/Enter the Data's Starting Time Reference**. This is one of the places in HEC-RAS where the default is usually not the best practice. **Use Simulation Time** is the default. In this method, the time series is always relative in time. The first record will always adopt the starting time in the **Simulation** time window. So in the figure below, the simulation starts on 10Jan1984, so the default time reference (bottom right of the figure) automatically assigns that time stamp to the first flow (the Simulation Time in quasi-unsteady marks the end of the time step, so it shows 11Jan).

However, apart from experimental studies with set start times or synthetic hydrographs, flow data are almost always temporally fixed. The example on the left in the figure above shows a **Fixed Start Time** that begins on 01Jan. Now the simulation that starts on 10Jan starts on the 10th daily record. The **Fixed Start Time** has two main advantages:

1. First, using fixed start times allows users to simply enter their complete data time series for different boundary conditions without trimming them all to the same start time.
2. Second, Fixed Start Times give modelers a lot of flexibility in the simulations. By fixing time series, modelers can shift the simulation time window to simulate a wet-dry decade, a three-day flood, a full period of record that is longer than the project window, multiple calibration periods, or other sensitivity/calibration/credibility tests without editing the flow file.

Therefore, the **Fixed Start Time** is the appropriate data format for most sediment models, whether the data are historical or synthetic future.



3 Examples of how the Fixed and Simulation Start Times work in the quasi-unsteady editor..

Warning: Select the radio button when setting a fixed start time

A common error in HEC-RAS modeling involves setting a fixed start time but forgetting to select it with the radio button. This can be a problem in models with many boundary conditions. After adding all the flow boundary conditions, go in to each one and make sure the **Fixed Start Time** is not only specified, but also selected.

| | |
|---|----------------------------|
| Select/Enter the Data's Starting Time Reference | |
| <input checked="" type="radio"/> Use Simulation Time: | Date: 10Jan1984 Time: 2400 |
| <input type="radio"/> Fixed Start Time: | Date: 01Jan1984 Time: 2400 |

↑
But Not Selected ↑ Specified

4 A common error in the flow boundary condition involves specifying a fixed start time but failing to select it.

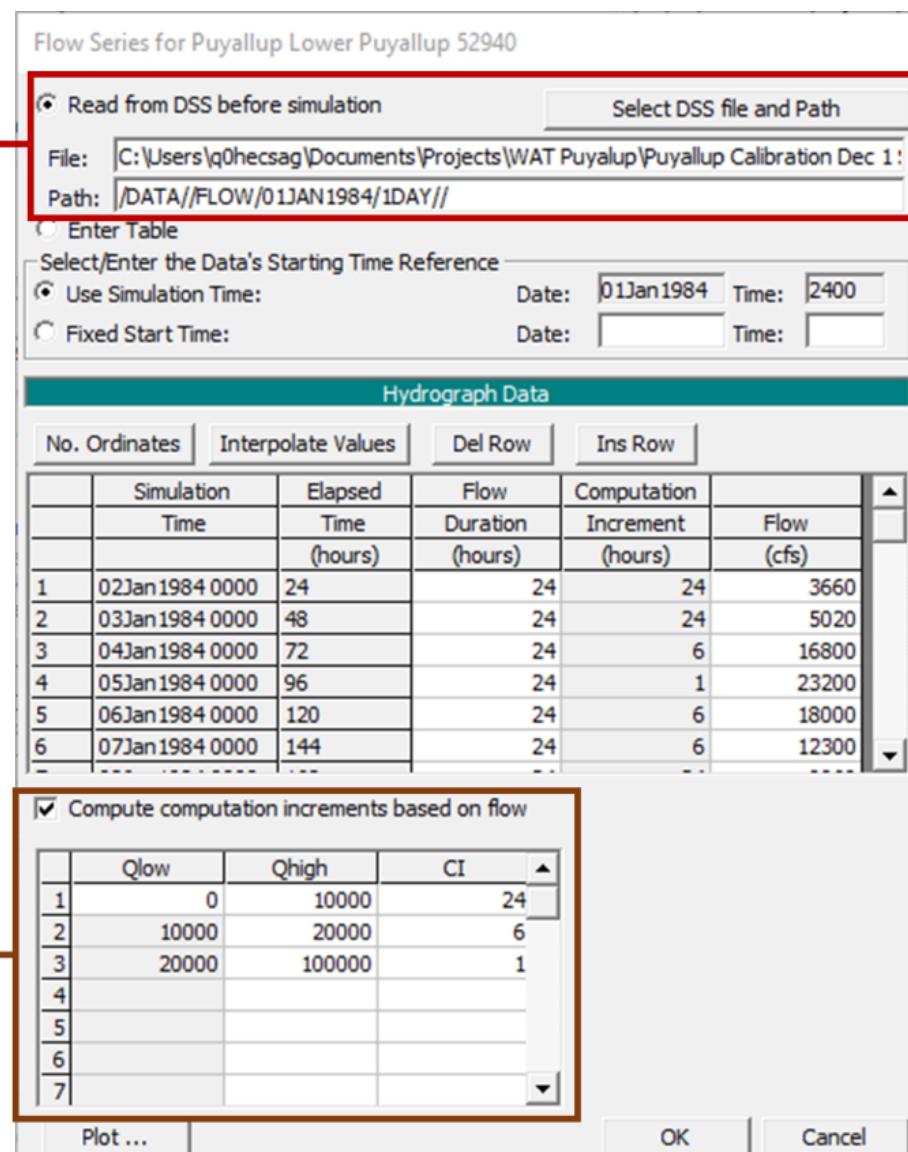
1.1.1.1.4 Using DSS Flow Data for a Quasi-Unsteady Simulation

Previous versions (before 6.0) of HEC-RAS could not use DSS files to define quasi-unsteady flow boundaries. Current versions can define quasi-unsteady flows with a regular time-step DSS flow record. Defining flows with a DSS record helps coordinate the sediment transport model with other HEC software, flow data bases, and allows HEC's stochastic engine (HEC-WAT) to sample hydrologic realizations and automate stochastic simulations that evaluate the role of hydrologic uncertainty on quasi-unsteady sediment transport.

However, irregular time steps are important in long term sediment transport models. Daily flow time steps are often too coarse for floods, requiring modelers to subdivide daily flows into smaller computational increments for high flows. Therefore, the **Compute Computation Increments Based on Flow** feature works with regular time-step DSS flows, assigning irregular computational increments to each flow, based on its magnitude. This gives users control over an irregular computational time step even if they import a regular time step DSS record.

Users can also use the [histography generator \(see page 0\)](#) to convert a regular time-step DSS file into an irregular time step quasi-unsteady flow file based on equal sediment mass flux.

Get Quasi-
Unsteady
Flow Data
From DSS
File

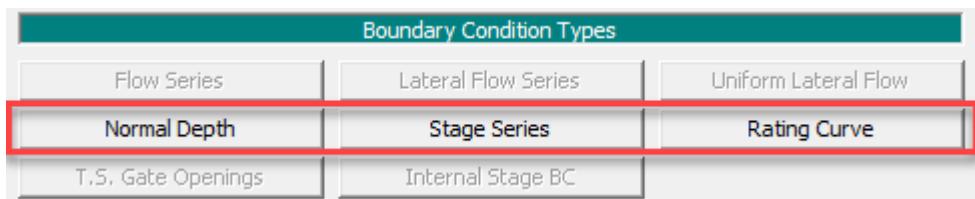


Subdivide DSS Flows into Computational Increments Using the Flow-Dependent CI Tool

5 Define a DSS flow file at a quasi-unsteady boundary condition and define flow-dependent computational increments to subdivide regular time steps.

1.1.1.2 Downstream Boundary Conditions

The downstream cross section is a mandatory hydraulic model boundary location, so the Quasi-Unsteady flow editor automatically populates a row for the downstream cross section. HEC-RAS has three quasi-unsteady, downstream boundary conditions.



6 The three valid downstream boundary conditions for Quasi-Unsteady flow.

1.1.1.1.2.1 Stage Time Series

Quasi-unsteady flow has three downstream boundary conditions, all specifying downstream stages for each steady flow backwater computation. If stage data are available or projected for the simulation period, the **Stage Time Series** can set the downstream boundary (below).

This editor follows the standard irregular time series format of a duration associated with a stage. No computation increment is required for a **Stage Time Series**.

Stage Series for Arghandab Dahlia Dam US 233.1825

Select/Enter the Data's Starting Time Reference

Use Simulation Time: Date: 24Feb1952 Time: 2400
 Fixed Start Time: Date: 24Feb1952 Time: 2400

| Hydrograph Data | | | | |
|-----------------|--------------------|---------|----------|--------|
| No. Ordinates | Interpolate Values | Del Row | Ins Row | |
| | Simulation | Elapsed | Stage | |
| | Time | Time | Duration | Stage |
| | | (hours) | (hours) | (m) |
| 1 | 25Feb1952 0000 | 24 | 24 | 1092.2 |
| 2 | 26Feb1952 0000 | 48 | 24 | 1097.1 |
| 3 | 27Feb1952 0000 | 72 | 24 | 1099.5 |
| 4 | 28Feb1952 0000 | 96 | 24 | 1101.3 |
| 5 | 29Feb1952 0000 | 120 | 24 | 1102 |
| 6 | 01Mar1952 0000 | 144 | 24 | 1102.7 |
| 7 | 02Mar1952 0000 | 168 | 24 | 1103.2 |
| 8 | 03Mar1952 0000 | 192 | 24 | 1103.7 |
| 9 | 04Mar1952 0000 | 216 | 24 | 1104.2 |
| 10 | 05Mar1952 0000 | 240 | 24 | 1104.7 |
| 11 | 06Mar1952 0000 | 264 | 24 | 1105.6 |
| 12 | 07Mar1952 0000 | 288 | 24 | 1106.6 |
| 13 | 08Mar1952 0000 | 312 | 24 | 1107.5 |

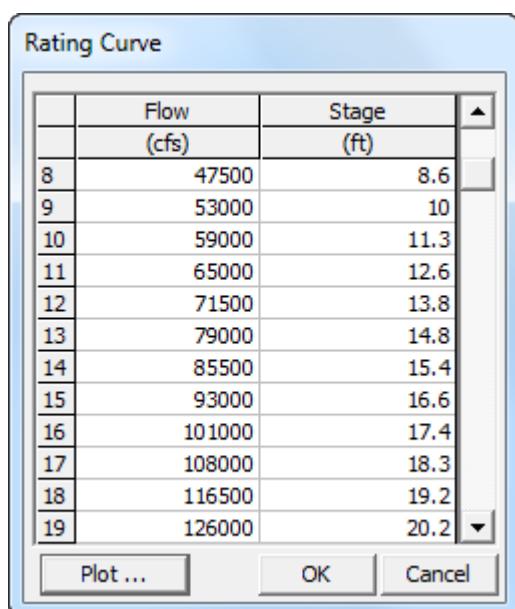
Plot ... OK Cancel

7 Specifying stage with a stage time series.

The stage time series is usually the best option for historical analysis. When using this feature for to predict future time series, however, be careful to set it at a reach in morphological quasi-equilibrium (e.g. a reach that is not actively aggrading or degrading on the decadal time scale).

1.1.1.1.2.2 Rating Curve

In the absence of time series data, a rating curve can define a downstream relationship between stage and flow, computing downstream boundary stages in response to the simulation flow series. The **Rating Curve** button launches a dialogue where users can enter a flow-stage rating curve for the downstream cross section (below). Be careful to place flow and stage in the correct columns (they are inverted from other editors). HEC-RAS will interpolate a boundary stage from the rating curve for each time step based on the flow. Like the stage time series, applying a rating curve boundary condition to predictive analyses assumes the downstream boundary condition is essentially in morphological quasi-equilibrium (i.e. not expecting long term deposition or erosion trends).



8 Rating curve editor for downstream boundary condition.

1.1.1.1.2.3 Normal Depth

The final downstream boundary option is Normal depth. The **Normal Depth** button launches a simple window requesting a single parameter: the Friction Slope. The friction slope (S_f in Manning's equation) is the slope of the energy grade line and can be estimated *a prior* by measuring the slope of the bed (press the *Alt* key in the HEC-RAS Water Surface Profile output view to get a tool that will measure the slope). With the friction slope, the flow, the n-value and the cross-section shape specified, HEC-RAS can back-calculate stage from Manning's Equation.

Modeling Note: Downstream Boundary Condition – Depth vs. Stage

Normal Depth is a popular boundary condition in steady and unsteady flow because it requires so little data. However, it also introduces more uncertainty than the stage series or the rating curve options. It is also popular in quasi-unsteady sediment analysis, for the same reasons.

However **Normal Depth** can introduce troubling numerical feedback in the sediment model in addition to hydraulic uncertainties and should be used with caution.

Setting a downstream *depth* rather than *stage*, makes the water surface elevation independent of the computed channel elevation. There is no feedback between bed change and water surface elevation. For stage boundary conditions, if the bed aggrades, shear will increase, and the rate of aggradation will drop until the cross-section approaches equilibrium. Erosion will introduce the opposite feedback, settling similarly on an equilibrium geometry. Therefore, stage boundary conditions should be specified in quasi-equilibrium reaches.

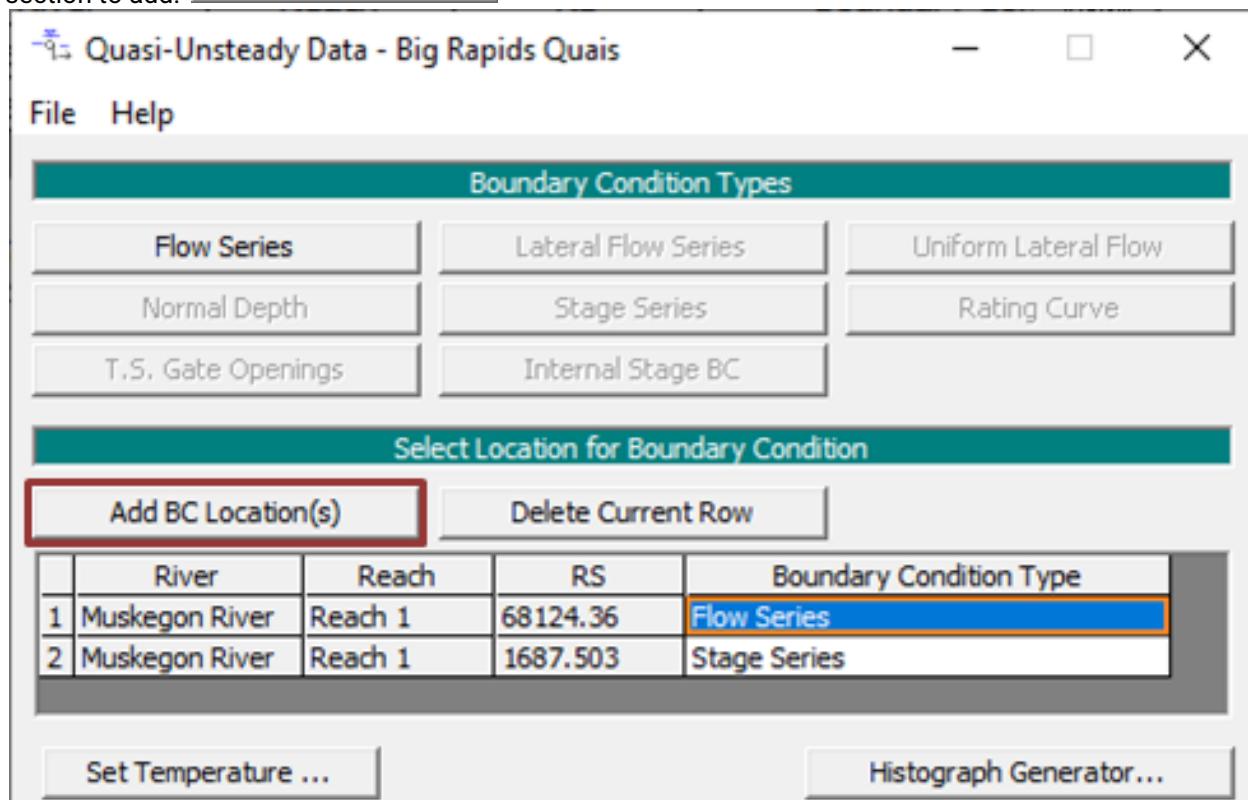
A depth boundary condition will continue to aggrade or degrade without water surface feedbacks. The next time step will simply compute a new depth on the new cross section shape. This can introduce numerical artifacts, where normal depth boundary conditions aggrade or degrade unrealistically over the simulation. Therefore, while convenient, normal depth is often a poorly posed boundary condition for sediment transport models, unless the downstream cross section is in equilibrium. The user can force equilibrium by setting the downstream boundary condition as a **Pass Through Node**, however, this sometimes just pushes the numerical problem one cross section upstream.

1.1.1.3 Adding Tributary Flow as Lateral Flow Series

Users can also define boundary conditions at internal cross sections. Internal cross sections are mostly optional (except for Gate Openings; if an inline structure has gates HEC-RAS will add it to the boundary condition editor for gate opening information).

To add an internal boundary condition press the Add BC Location(s) button (below) and specify the cross section to add.

Add BC Location(s)



Sorry, the widget is not supported in this export.
But you can reach it using the following URL:

https://www.youtube.com/watch?v=z1GA0c_yuJ4

1.1.1.1.3.1 Lateral Flow Series

A lateral flow series can also be associated with any internal cross section in a project. This feature usually accounts for flows from un-modeled tributaries. The user must add an internal cross section to the **Quasi-Unsteady Flow** dialog before assigning it a quasi-unsteady boundary condition.

Add a flow change location with the **Add Flow Change Location(s)** button on the **Quasi Unsteady Flow** dialog. This will open the **Select River Station Locations** dialog (used elsewhere in the program e.g. Figure 1 51). Select one or more river stations by double clicking them or selecting them and pressing the arrow button. Pressing OK will create a boundary condition location for each selected station in the **Quasi-Unsteady Flow Editor**. The Lateral Flow Series editor is identical to the flow series editor in **Upstream Boundary Conditions** (see page 17).

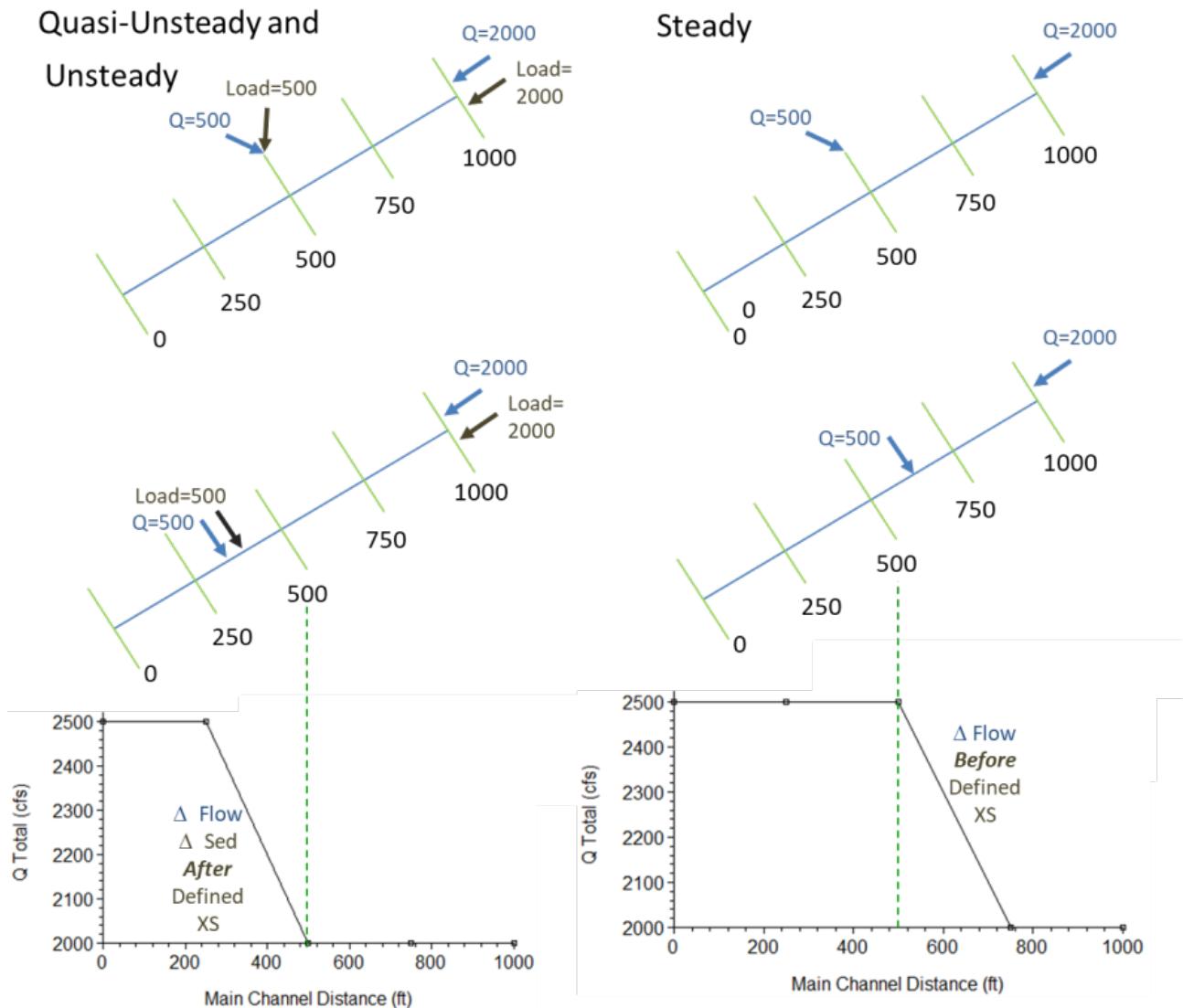
1.1.1.1.3.2 Location of Lateral Flows and Sediment Loads

Steady and Unsteady flow bring "lateral flows" (a lateral boundary condition in unsteady and a flow change location) upstream and downstream of the specified cross section respectively (below). Steady flow changes show up at the specified cross section (conceptually entering the model upstream) and unsteady lateral flow boundaries show up at the cross section downstream of the defined cross section (conceptually entering the model downstream of the control volume).

Quasi unsteady follows the unsteady flow convention Quasi-unsteady only follows the unsteady convention in more recent versions of HEC-RAS. In earlier versions, quasi-unsteady followed the steady flow convention, entering the model upstream of the specified cross sections. (despite being a series of steady flows). A Quasi-unsteady flow model will bring flow into the model downstream of the specified cross section. If a sediment rating curve is assigned to one of these lateral flow series boundary conditions, it will come in at the same location as the flow, downstream of the specified cross section (below).

Modeling Note: Locating a Tributary

Because both quasi- and unsteady flow models bring tributary flows into the model downstream of the specified cross section, define the tributary flow and load at the cross section upstream of the point where it enters the system. Conceptually, the Tributary enters the model at the transition between the two control volumes. Therefore, a model that lays out the cross sections so a tributary (modeled as a lateral flow series) enters between the cross sections will work well.



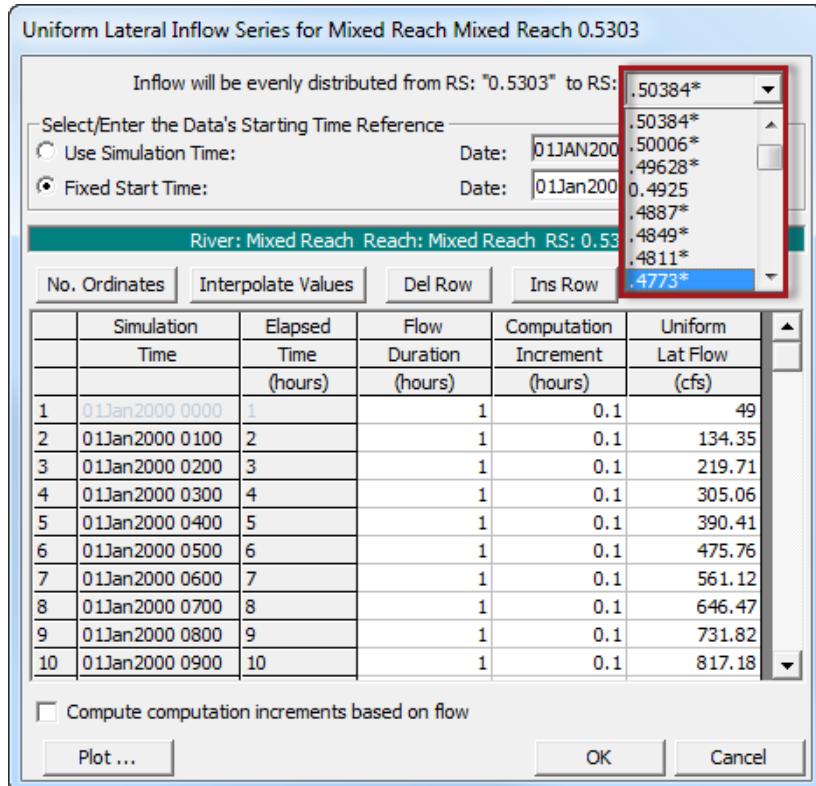
9 Schematic of flow change location associated with a lateral flow (and associated sediment) for the three flow models. This example increases flow from 2000 to 2500 at XS 500. The DQ shows up downstream of the cross section (at the next one) in quasi- and unsteady, and upstream of the XS (at the specified XS) for steady.

1.1.1.1.3.3 Uniform Lateral Flow

HEC-RAS can also distribute a lateral flow series over several cross sections. This feature often distributes overland watershed runoff, computed from a hydrologic model, along the hydraulic reach instead of concentrating it at one point.

Defining a uniform lateral flow follows the same steps as the lateral flow series (above). Add a lateral boundary location with the **Add Flow Change Location(s)** button at the cross section upstream of those HEC-RAS will distribute the flow over. Select the **Uniform Lateral Flow** button. The **Uniform Lateral Flow** button opens the editor shown below. This dialog is similar to the other flow series dialogs (Figure 1 4) with one addition, a drop down list of downstream cross sections at the top.

HEC-RAS will distribute the flow by reach weighted averages, apportioning more flow to cross sections with longer downstream channel reach lengths. Uniform lateral flows cannot be specified across stream junctions, bridges, inline or lateral structures.



10 Uniform lateral flow series dialog.

1.1.1.1.4 Internal Boundary Conditions (Gates and Internal Stage)

1.1.1.1.4.1 Gate Time Series

Inline structures with gates can be included in a quasi-unsteady sediment model. However, gate and reservoir operations are ill posed in a quasi-unsteady model. Since the quasi-unsteady approach uses a series of steady flows, it will compute a reservoir elevation based on the head required to reach steady state equilibrium, to 'push' the reach flow through the gates. This can lead to dramatic fluctuations in reservoir stage from time step to time step and does not conserve mass.

To replicate historic reservoir stages with gates in quasi-unsteady flow, a modeler could use the orifice equation to back calculate the orifice opening that will produce the historic head for the historic flow. But recent versions of HEC-RAS include an Internal Stage Boundary Condition

Unsteady sediment transport and in HEC-RAS version 5.0 should make quasi-unsteady gate operation mostly obsolete (with the exception of flushing studies, see section below on Interaction Between Internal Stage and BC Gates), which is why the quasi-unsteady gates have only one boundary condition while there are four different ways to operate gates in an unsteady flow simulation.

However, if an inline structure has gates, HEC-RAS requires gate openings (even if the model does not use them – see the section on Interaction Between Internal Stage BC and Gates (see page 0)) and the quasi-unsteady editor will generate a mandatory internal boundary condition for the structure (see the figure below). If the user does include gated inline structures in a quasi-unsteady model, however, the **T.S. Gate Openings** boundary condition in the Quasi-Unsteady Flow editor will control them. The **T.S. Gate Openings** boundary condition is required. Therefore, if the project includes an inline with gates the structure will show up in the **Quasi-Unsteady Flow Editor**.

| Boundary Condition Types | | | | | |
|---------------------------|---------------------|----------------------|--|--|--|
| Flow Series | Lateral Flow Series | Uniform Lateral Flow | | | |
| Normal Depth | Stage Series | Rating Curve | | | |
| T.S. Gate Openings | Internal Stage BC | | | | |

| Select Location for Boundary Condition | | | | | |
|--|--------|--------------------|----------|-------------------------|--|
| Add BC Location(s) | | Delete Current Row | | | |
| 1 | River | Reach | RS | Boundary Condition Type | |
| 1 | Mekong | S5 | 542104.9 | Flow Series | |
| 2 | Mekong | S5 | 285000 | | |
| 3 | Mekong | S5 | 261119.7 | Normal Depth | |

11 Inline Structure with gates requires a boundary condition and populates in the quasi unsteady flow editor automatically.

If the model includes multiple gate groups, the boundary condition will require gate openings to cover the entire simulation time for *each* gate group. A drop-down menu in the upper right-hand corner allows users to specify gates for each gate group in a structure.

Modeling Note: Specify Openings for ALL Gate Groups

A common error involves only specifying gates for the gate group that is active when the editor opens, and not realizing there are others that need gates.

Warning: Quasi-Unsteady Flow Does Not Route Through Reservoirs or Gates

Instead it simply computes the backwater stage for each time step based on the flow through the gates, leading to unrealistic reservoir stage fluctuations. Quasi-unsteady gate operations are **NOT RECOMMENDED** for most applications. Consider running reservoir models in unsteady flow or use one of the quasi-unsteady reservoir approaches described in the reservoir modeling video series like the [Internal Stage Boundary Condition \(see page 0\)](#) (next heading).

Gate Time Series for Nittany River Weir Reach 41.75

| Hydrograph Data | | | | |
|-----------------|--------------------|--------------|----------|--------------|
| No. Ordinates | Interpolate Values | Del Row | Ins Row | |
| | Simulation Time | Elapsed Time | Duration | Gate Opening |
| | | (hours) | (hours) | (ft) |
| 1 | 08Apr1999 0000 | 1 | 1 | 5 |
| 2 | 08Apr1999 0100 | 2 | 1 | 5.17 |
| 3 | 08Apr1999 0200 | 3 | 1 | 5.33 |
| 4 | 08Apr1999 0300 | 4 | 1 | 5.5 |
| 5 | 08Apr1999 0400 | 5 | 1 | 5.67 |
| 6 | 08Apr1999 0500 | 6 | 1 | 5.83 |
| 7 | 08Apr1999 0600 | 7 | 1 | 6 |
| 8 | 08Apr1999 0700 | 8 | 1 | 6.17 |
| 9 | 08Apr1999 0800 | 9 | 1 | 6.33 |
| 10 | 08Apr1999 0900 | 10 | 1 | 6.5 |
| 11 | 08Apr1999 1000 | 11 | 1 | 6.67 |
| 12 | 08Apr1999 1100 | 12 | 1 | 6.83 |
| 13 | 08Apr1999 1200 | 13 | | |

Gate Closure Elevation

12 Time series gate editor

1.1.1.1.4.2 Internal Stage BC

Recent versions of HEC-RAS include an internal stage time series boundary condition

Internal Stage BC

that can control stage within the model. The most common use for this is to control reservoir stages. By defining a stage series at the cross section just upstream of the inline structure representing a dam, modelers can control reservoir stages directly throughout the duration of the model. This allows modelers to use the Quasi-Unsteady mode to simulate reservoir operation without routing the flows (if they know the reservoir stage for the entire simulation).

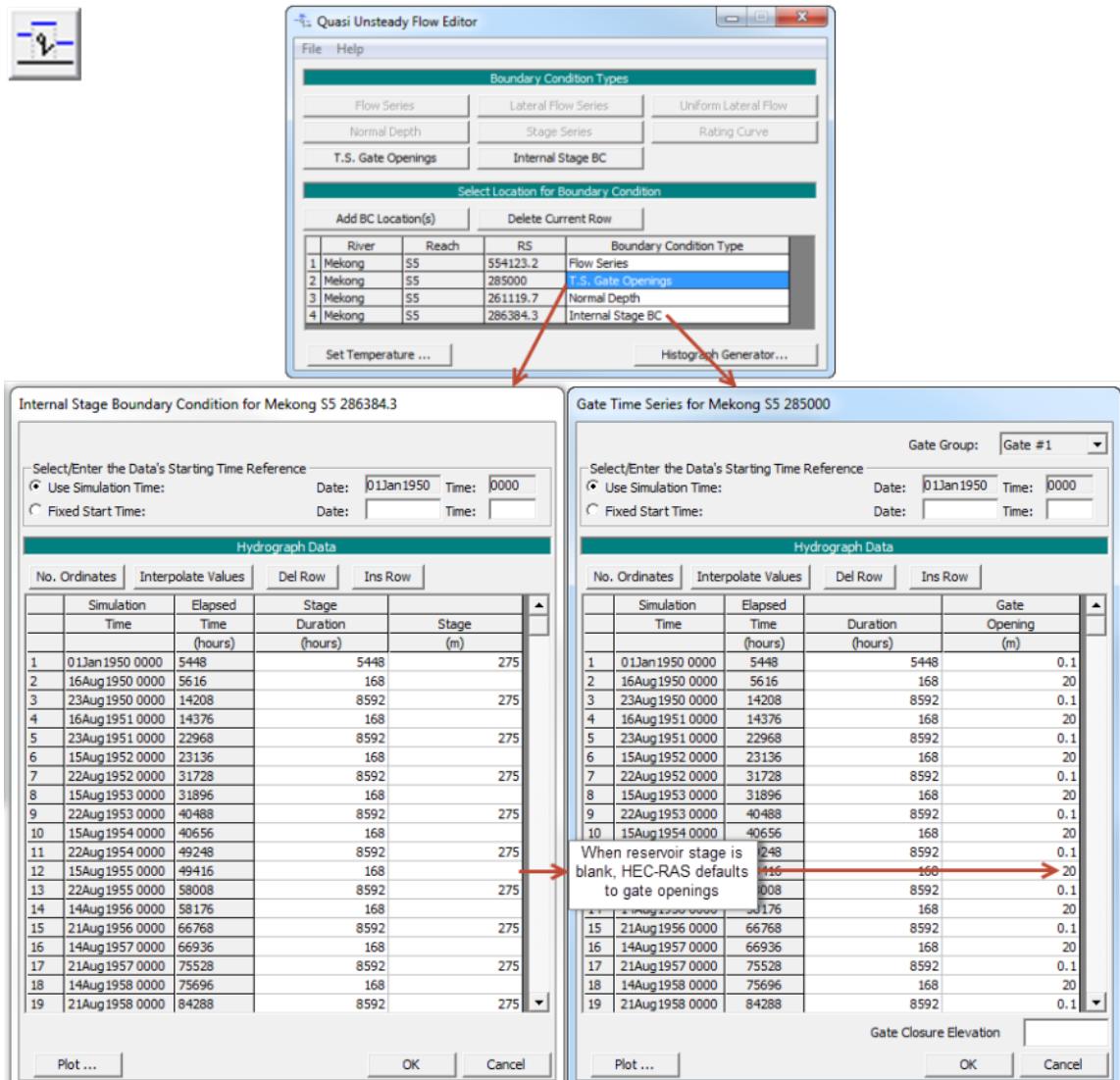
| Boundary Condition Types | | | |
|--------------------------|--------------------------|----------------------|--|
| Flow Series | Lateral Flow Series | Uniform Lateral Flow | |
| Normal Depth | Stage Series | Rating Curve | |
| T.S. Gate Openings | Internal Stage BC | | |

| Select Location for Boundary Condition | | | | |
|--|--------|---------------------------|----------|-------------------------|
| Add BC Location(s) | | Delete Current Row | | |
| | River | Reach | RS | Boundary Condition Type |
| 1 | Mekong | S5 | 542104.9 | Flow Series |
| 2 | Mekong | S5 | 285000 | T.S. Gate Openings |
| 3 | Mekong | S5 | 261119.7 | Normal Depth |
| 4 | Mekong | S5 | 286384.3 | |

The model will still require Gate Openings if the inline structure has gates. However, the quasi-unsteady model does not use the gates to compute flow through the structure (it is a backwater calculation, so the flow is specified), only the reservoir stage. Therefore, if the user specifies the stage upstream of the dam, HEC-RAS does not end up using these Gate Openings and the modeler can fill them with place-holder values.

Modeling Note – Transition Between Stage and Gate Control

Sometimes it can be useful to switch between stage control and gate control in a reservoir model. The most common application of this is for a periodic reservoir flush. The figure below shows a simplified, quasi-unsteady approach to simulating an annual flush over an extended period of record, simulation. The Internal Stage Boundary Condition holds the reservoir stage for most of the year (8567 hours is 51 weeks). But then, for 1 week per year (168 hours) the stage field is blank. When HEC-RAS encounters a blank stage in the Internal Stage Series, it reverts to the backwater computation. In this example, the blank internal stages correspond to fully opening the gates (20m). This does not gradually drain the reservoir. A modeler would have to gradually decrease the internal stages to simulate a gradual drawdown. But it does switch the reservoir between a specified pool and a run-of-river flush.



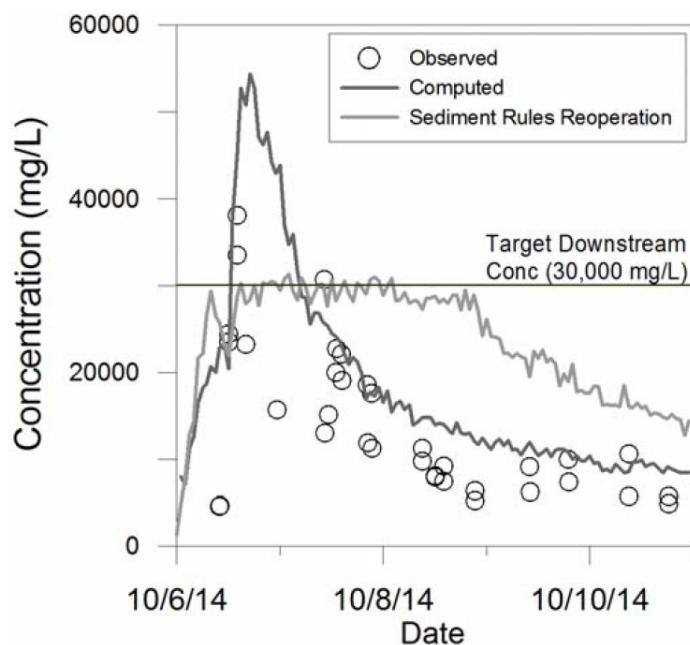
13 A weekly reservoir flush simulated in HEC-RAS quasi-unsteady mode by leaving the fixed stage blank during the annual, 1-week, flush and opening the gates to run-of-river flow.

1.1.1.1.4.3 Modeling Reservoirs with Unsteady Sediment

Reservoir modeling is the most common application of Unsteady Sediment Transport. In addition to routing and conserving flow, unsteady flow has a range of tools that make reservoir modeling easier and more powerful. In particular, the Operational Rules feature in the unsteady flow editor is an exceptionally powerful tool to model reservoir sediment management. The operational rules include concentration and bed elevation triggers, so users can write simple, but powerful, rules to operate their reservoir based on sediment output. For example, Gibson and Boyd (2016) used the very simple concentration rules in to re-operate a reservoir flushing event to maintain a proposed TMDL (result in the right pane in the Figure below).

'DS_Conc' = Cross Sections:Sediment Concentration(Niobrara River,Reach 1,179818.5
 'SimTime' = Time:Hour of Simulation(Beginning of time step)

```
!
! Check Downstream Concentration
If (DS_Conc' > 30000) Then
  ! If Concentration Exceeds "TMDL" Slowly Close Gate
  Gate.Opening(Sluice Gate) = 0
  Gate.Opening(TainterGates) = 0
Else
  !
  ! If the Concentration is less than the threshold
  ! continue with the standard flushing operations
  If ('SimTime' > 14) Then
    Gate.Opening(Sluice Gate) = 18
    Gate.Opening(TainterGates) = 6
  Elseif ('SimTime' > 7) Then
    Gate.Opening(TainterGates) = 0.15 * 'SimTime' + 0.2
  End If
End If
```



14 HEC-RAS operational rules (top) that controlled simulated reservoir operations (bottom) to maintain a maximum downstream concentration of 30,000 mg/L.

There are several published examples (with sample code) of simulating reservoir management alternatives with operational rules in HEC-RAS sediment simulations, including:

Gibson, S. and Boyd, P. (2016) "Designing Reservoir Sediment Management Alternatives with Automated Concentration Constraints in a 1D Sediment Model²," River Sedimentation: Proceedings of the 13th International Symposium on River Sedimentation, ed edited by S. Wieprecht, et al.

Gibson, S. and Crain, J. (2019) Modeling Sediment Concentrations during a Drawdown Reservoir Flush: Simulating the Fall Creek Operations with HEC-RAS³, RSM Tech Note ERDC/TN RSM-19-7. Vicksburg, MS: U.S. Army Engineer Research and Development Center. <http://dx.doi.org/10.21079/11681/33884>

Gibson, S. and Boyd, P. (2014) "Modeling Long Term Alternatives for Sustainable Sediment Management Using Operational Sediment Transport Rules⁴," Reservoir Sedimentation – Scheiss et al. (eds), 229-236.

1.1.1.2 Temperature Data

1.1.1.2.1 Quasi-Unsteady Temperature

Fall velocity and some sediment transport equations are sensitive to water viscosity, which is a function of water temperature. Therefore, sediment transport analyses require temperature data. Finer systems (systems with finer sediment) are more sensitive to temperature. Currently, users can only specify one temperature per time step for the entire model.

To specify a temperature time series, press the **Set Temperature** button on the bottom of the **Quasi-Unsteady Flow** editor (see figure in [Boundary Conditions \(see page 16\)](#)). This will open the temperature series editor depicted in the figure below, an irregular time series editor very similar to the other quasi-unsteady time series editors.

² https://www.researchgate.net/publication/325603707_Designing_Reservoir_Sediment_Management_Alternatives_with_Automated_Concentration_Constraints_in_a_1D_Sediment_Model

³ <https://erdc-library.erdc.dren.mil/jspui/handle/11681/33884>

⁴ https://www.researchgate.net/publication/325603707_Designing_Reservoir_Sediment_Management_Alternatives_with_Automated_Concentration_Constraints_in_a_1D_Sediment_Model

Temperature Series

Select/Enter the Data's Starting Time Reference

Use Simulation Time: Date: 01Oct1982 Time: 0100
 Use Fixed Start Time: Date: Time:

| Temperature Data | | | | |
|------------------|----------------|----------------------------|----------|---------|
| No. | Ordinates | Interpolate Missing Values | Del Row | Ins Row |
| | Simulation | Elapsed | | |
| | Time | Time | Duration | Temp |
| | | (hours) | (hours) | (F) |
| 1 | 01Oct1982 0100 | 24 | 24 | 55 |
| 2 | 02Oct1982 0100 | 48 | 24 | 54.91 |
| 3 | 03Oct1982 0100 | 72 | 24 | 54.83 |
| 4 | 04Oct1982 0100 | 96 | 24 | 54.74 |
| 5 | 05Oct1982 0100 | 120 | 24 | 54.65 |
| 6 | 06Oct1982 0100 | 144 | 24 | 54.57 |
| 7 | 07Oct1982 0100 | 168 | 24 | 54.48 |
| 8 | 08Oct1982 0100 | 192 | 24 | 54.39 |
| 9 | 09Oct1982 0100 | 216 | 24 | 54.3 |
| 10 | 10Oct1982 0100 | 240 | 24 | 54.22 |
| 11 | 11Oct1982 0100 | 264 | 24 | 54.13 |
| 12 | 12Oct1982 0100 | 288 | 24 | 54.04 |
| 13 | 13Oct1982 0100 | 312 | 24 | 53.96 |
| 14 | 14Oct1982 0100 | 336 | 24 | 53.87 |
| 15 | 15Oct1982 0100 | 360 | 24 | 53.78 |
| 16 | 16Oct1982 0100 | 384 | 24 | 53.7 |

OK Cancel

Modeling Note: Developing Long-Term Temperature Records

Temperature data are seldom sufficient to generate a daily time series for multi-decadal, historical models. And modelers must make some temperature assumption to simulate the future. There are a few options to define multi-decadal historical or future temperature data in the absence of a long-term temperature record (Options 1 and 3 are most common):

1. Constant Temperature: Any of the irregular time step editors in the quasi-unsteady flow boundary conditions can define a constant condition by specifying large durations (e.g. 240,000 hrs or 10,000 days/>25 years in the figure below). In coarse systems (rivers with significant gravel and/or cobble), that are less sensitive to temperature, detailed temperature data may be unnecessary. Perform sensitivity analysis to evaluate this assumption.

Temperature Series

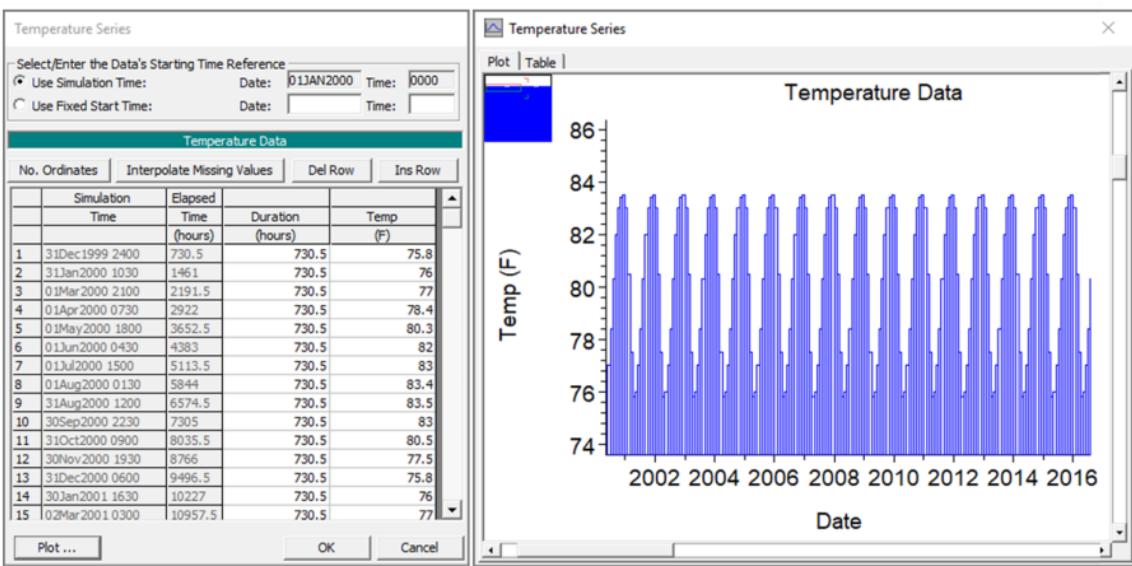
Select/Enter the Data's Starting Time Reference

Use Simulation Time: Date: 01Aug1975 Time: 0000
 Use Fixed Start Time: Date: _____ Time: _____

| Temperature Data | | | | |
|------------------|----------------|----------------------------|----------|---------|
| No. | Ordinates | Interpolate Missing Values | Del Row | Ins Row |
| | Simulation | Elapsed | | |
| | Time | Time | Duration | Temp |
| | | (hours) | (hours) | (C) |
| 1 | 31Jul1975 2400 | 240000 | 240000 | 15 |
| 2 | 16Dec2002 2400 | 480000 | 240000 | 15 |
| 3 | 03May2030 2400 | 720000 | 240000 | 15 |
| 4 | 18Sep2057 2400 | 960000 | 240000 | 15 |
| 5 | 03Feb2085 2400 | 1200000 | 240000 | 15 |
| 6 | 22Jun2112 2400 | 1440000 | 240000 | 15 |
| 7 | 08Nov2139 2400 | 1680000 | 240000 | 15 |

Plot ... **OK** **Cancel**

2. **Interpolating Annual Highs and Lows:** If results are sensitive to temperature, HEC-RAS can generate a simple time series with a little more user effort. Estimate max and min water temperatures and input them at approximate dates each year, leaving the intermediate dates blank. Then press the **Interpolate Missing Values** button (below). For example a user could create a weekly time series (Durations=7*24 hrs = 168 hrs) that interpolates between an early July high and early December low by defining the high temperature in all of the rows aligned with the first week of July, the low temperature with all the rows associated with the first week of December, and pressing the **Interpolate Missing Values** button.
Interpolate Missing Values
3. **Monthly Average Temperatures:** Often a gage has some opportunistic temperature readings. You cannot use them as a times series or even interpolate a time series from them. The gage has enough water temperature data to compute monthly averages. Give each monthly average temperature a **730.48 hour** (30.4368 day) durations will create an approximate average monthly temperature time series that you can repeat for multiple years (demonstrated in figure below) and it will remain relatively consistent over long simulations (including leap years).

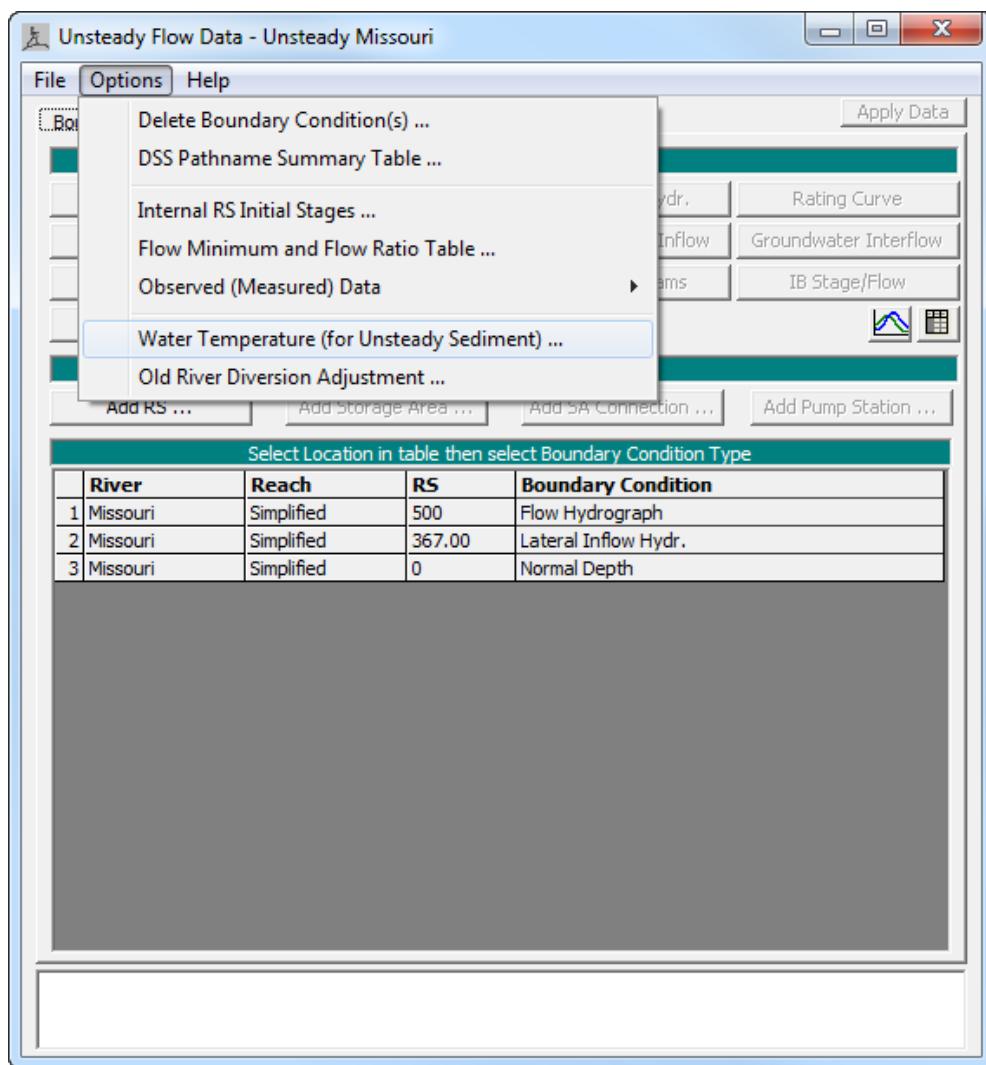


15 Repeated sequence of monthly average temperature data developed from opportunistic temperature measurements that only account for a small portion of the historical record. The 730.5 hour duration averages to one month over long time periods.

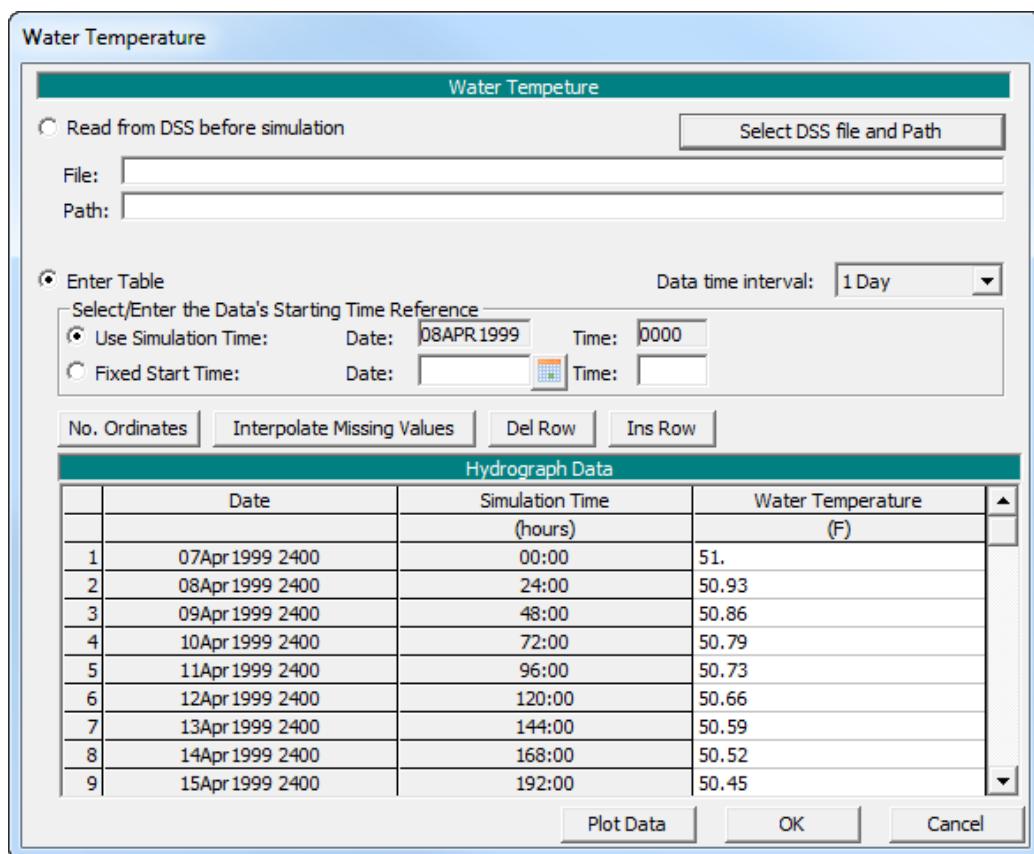
1.1.1.2.2 Unsteady Temperature

Temperature is the only data the unsteady flow editor requires 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 (top) to get an unsteady temperature time series editor, similar to the unsteady flow and stage editors (bottom). In the absence of temperature data in the unsteady flow file, HEC-RAS will assume 55° F. The unsteady temperature editor will allow users to specify actual monthly temperatures by setting the **Data time interval** to **1 Month**:

Data time interval: **1 Month** ▾



16 Specifying water temperature for unsteady sediment models.



17 Unsteady Temperature Editor.

1.1.1.3 The Histogram Generator

1.1.1.3.1 Averaging Low Transport Time Steps

The computational increment can subdivide Flow Durations (e.g. daily average flows) into smaller time steps to evaluate bed change feedbacks on hydraulics more frequently. However, modelers sometimes want to "go the other way" with their time steps, and combine multiple flow durations into a single computation increment (e.g. combine seven daily, low-transport, summer flows into a weekly time step).

Combining low-flow/low-transport time steps to reduce run times is a relatively standard practice (though it was more standard 10-20 years ago when computational power was more limiting). But modelers should consider the implications of transport non-linearity when averaging flows for a sediment transport model.

Consider two unit less flows (100 and 200) a simple sediment rating curve, where:

$$Load = 0.01Flow^2$$

Averaging the flows, and then using the average flow to compute transport will yield a different result than computing the loads and then averaging the loads. However, the latter is likely more correct.

Average Flows First

| | | |
|--------------|--------------|------------------------|
| Flow 1 | 100 | |
| Flow 2 | 200 | Load from Average Flow |
| Average Flow | 150 → | 225 |

Compute Loads First

| | | Loads | |
|--------|--------------|--------------|-------------------------------|
| Flow 1 | 100 → | 100 | |
| Flow 2 | 200 → | 400 | Flow that Yields Average Load |
| | Average Load | 250 → | 158 |

These errors might be small (though, over a 50 year simulation, they can add up, particularly if the averaging is aggressive), but it is more important to conserve sediment mass in a quasi-unsteady sediment model than water volume. Therefore, when averaging flows for a sediment model, the best practice includes computing loads for those flows, averaging the loads, and then backing out a flow that produces the average load.

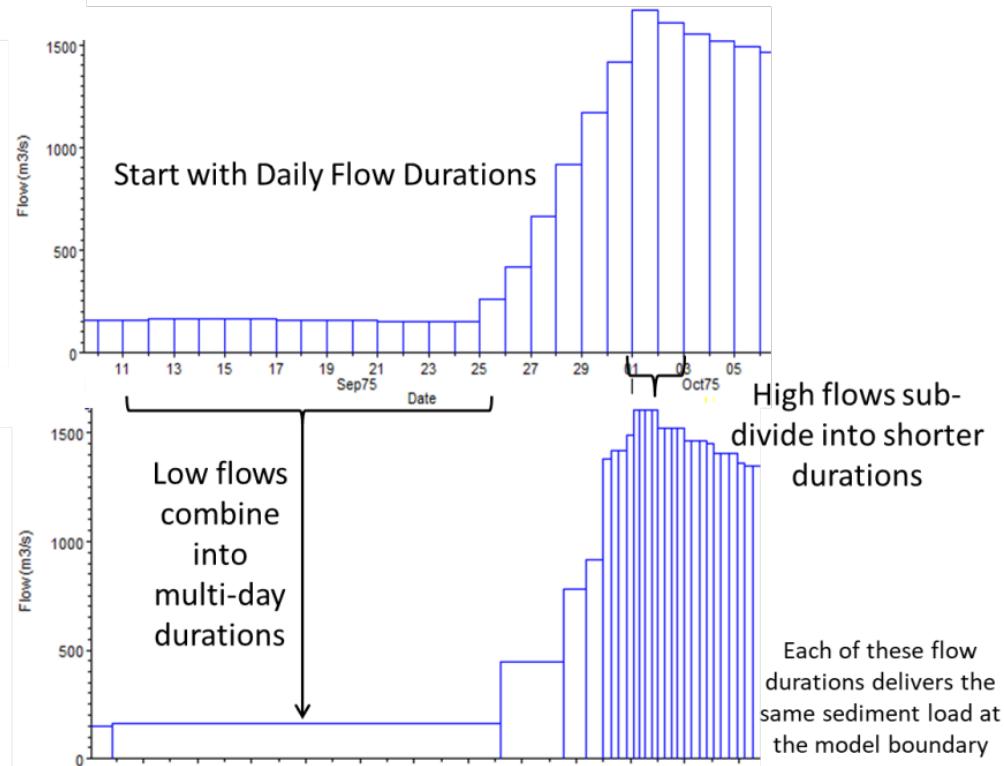
This process also can be more important when the flow data is sub-daily. For example, one year of 15-minute data will nearly fill the available rows ($4*24*365=35,040$) in the quasi-unsteady editor and make run times unacceptable. It used to be impossible to run multiple years of 15-minute flow data in quasi-unsteady flow because the data simply would not fit in the editor. Now users can attach and run as many years of 15 minute data as they have by specifying it as a DSS boundary condition. However, run times will still make this impractical for most models. Therefore, it is critical to combine low (and moderate) flows for high resolution flow time series.

If this sounds like a lot of work, the Histogram Generator may be able to help.

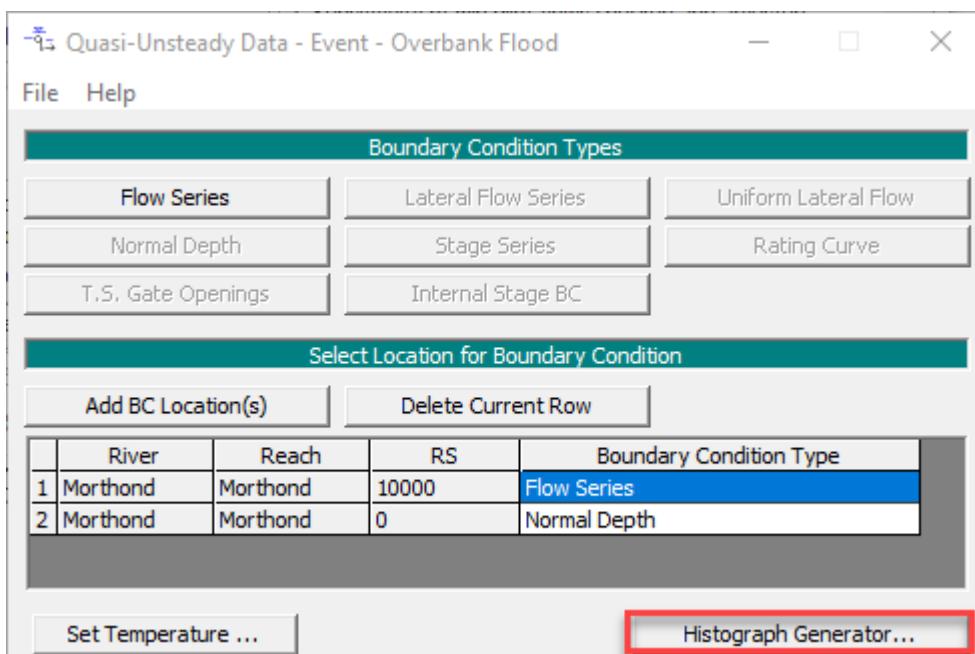
1.1.1.3.2 The Histogram Generator Tool

Because sediment transport is non-linear, and high transport periods can punctuate long periods of low transport that may be morphologically insignificant, sediment modelers often want to optimize their time step. Particularly when computers were slower, modelers wanted to group low flow time periods into long computation increments to save run time. This practice is less common now that computers are faster, but period of record simulations can still have significant run times. Therefore, the histogram generator provides a tool to determine the time step based on the sediment flux. It scales the flow durations to bring in an equal, user specified, load over each flow period, which could be a few seconds at the peak of the flood of record, or a few weeks during a drought (below). These irregular, equivalent load, flow durations can then be sub-

divided by the computational increment for model stability.

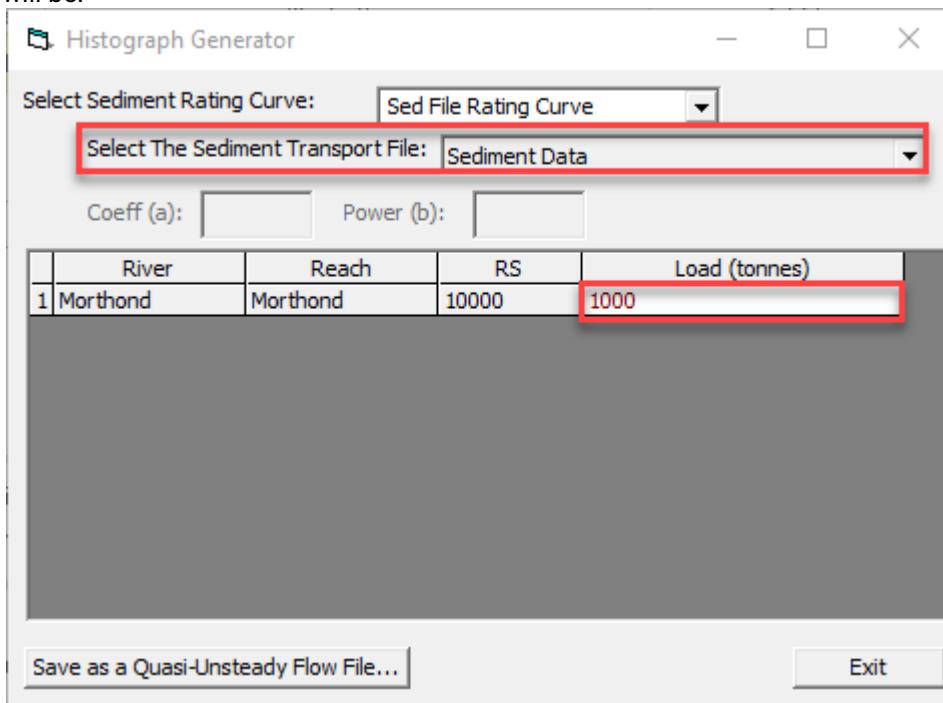


The Histogram Generator creates a new quasi-unsteady flow file with an irregular flow duration. If the histogram tool combines flows, it computes the flow that generates the average sediment flux (instead of the average flow). To launch the tool, select the **Histogram Generator** button on the Quasi-Unsteady Editor, from the base quasi-unsteady flow file. To launch this tool, press the **Histogram Generator** button on the **Quasi-Unsteady** flow editor (below).



HEC-RAS requires two user inputs to create an equal-load increment flow file: a constant load and a flow-load rating curve.

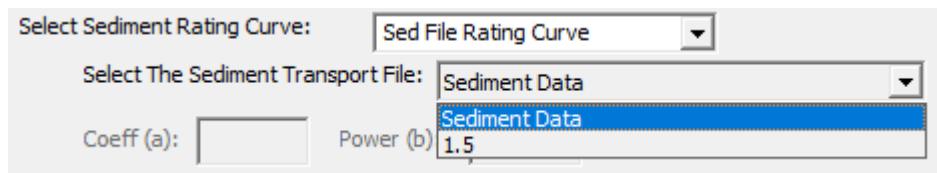
First, the tool requires a user-specified load (below). Define the load that will determine the duration of each time step. The Histogram generator will use the flow-load relationship to determine how long each time step will be.



Second, the tool requires a relationship between flow and load. There are three options to define a sediment rating curve:

1.1.1.3.2.1 Sediment File Rating Curve:

If you have created a sediment transport file with a rating curve boundary condition, the Histogram generator can use that file directly. Select **Sed File Rating Curve** and then use the dropdown box labeled **Select The Sediment Transport File** (figure under **Power Function:**) to pick the sediment file with the appropriate rating curve boundary condition.



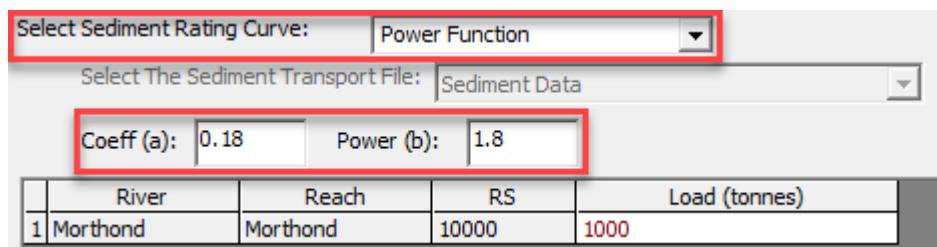
18 Select a sediment file with a Rating Curve boundary condition. The Histogram generator will use that relationship.

1.1.1.3.2.2 Power Function:

If the sediment relationship can be defined by a single power function, HEC-RAS can compute load data for the flow series from a simple power function, defined by two coefficients, where:

$$\text{Flow} = aQ^b$$

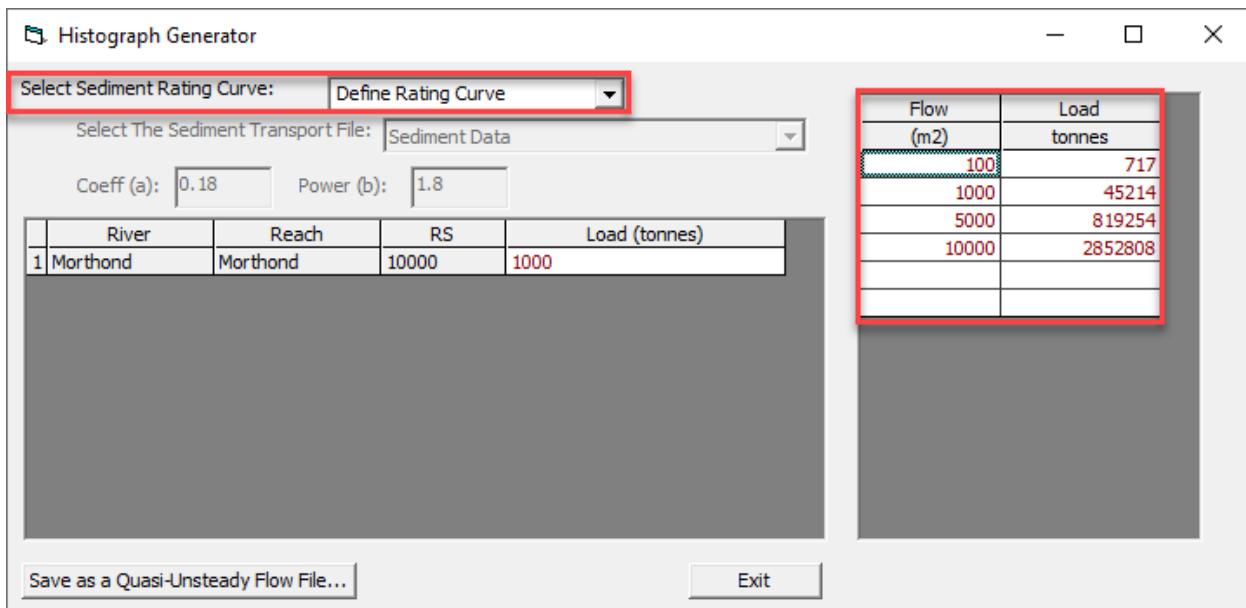
Select "Power Function" and define the two coefficients in the fields depicted in the figure below:



19 Define the coefficients of a flow-load power function with the two coefficients.

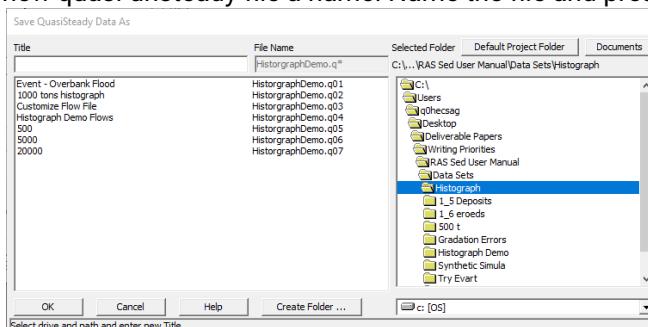
1.1.1.3.2.3 User Defined Rating Curve:

Finally, users can enter a flow-load rating curve directly into the histogram tool by selecting **Define Rating Curve** (below). This can be particularly useful for "bent" or "inflected" rating curves that cannot be described by a single power function.



1.1.1.3.3 Creating a New Equal-Load Time Step Quasi-Unsteady Flow File

Once the load increment and the flow-load relationship are specified, press **Save as a Quasi–Unsteady Flow File**. [Save as a Quasi–Unsteady Flow File...](#) This will launch a Save-As dialogue prompting the user to give the new quasi-unsteady file a name. Name the file and press OK.



This simply adds the computed histogram to the project as a new quasi-unsteady file. Open the quasi-unsteady file in the quasi-unsteady editor. This file will only have an upstream flow boundary condition. Open

that flow boundary condition and press **Plot** to review the histogram.

| | Simulation Time | Elapsed Time (hours) | Flow Duration (hours) | Computation Increment (hours) | Flow (m³/s) |
|----|-----------------|----------------------|-----------------------|-------------------------------|-------------|
| 1 | 01Jul1975 0000 | 385.0918 | 385.0918 | 385.0918 | 150.5225 |
| 2 | 17Jul1975 0105 | 611.4158 | 226.324 | 226.324 | 202.2247 |
| 3 | 26Jul1975 1124 | 778.5887 | 167.1729 | 167.1729 | 239.2881 |
| 4 | 02Aug1975 1035 | 983.701 | 205.1123 | 205.1123 | 213.5878 |
| 5 | 10Aug1975 2342 | 1296.373 | 312.6718 | 312.6718 | 168.9906 |
| 6 | 24Aug1975 0022 | 1700.037 | 403.6641 | 403.6641 | 146.6351 |
| 7 | 09Sep1975 2002 | 2045.405 | 345.3685 | 345.3685 | 159.9069 |
| 8 | 24Sep1975 0524 | 2100.623 | 55.21718 | 55.21718 | 442.7691 |
| 9 | 26Sep1975 1237 | 2120.475 | 19.85243 | 19.85243 | 781.5795 |
| 10 | 27Sep1975 0828 | 2135.365 | 14.88993 | 14.88993 | 917 |
| 11 | 27Sep1975 2321 | 2142.513 | 7.147673 | 7.147673 | 1378.598 |
| 12 | 28Sep1975 0630 | 2149.315 | 6.80279 | 6.80279 | 1417 |
| 13 | 28Sep1975 1318 | 2156.118 | 6.80279 | 6.80279 | 1417 |
| 14 | 28Sep1975 2007 | 2162.324 | 6.205565 | 6.205565 | 1491.213 |
| 15 | 29Sep1975 0219 | 2167.736 | 5.411921 | 5.411921 | 1609 |
| 16 | 29Sep1975 0744 | 2173.147 | 5.411921 | 5.411921 | 1609 |
| 17 | 29Sep1975 1308 | 2178.559 | 5.411921 | 5.411921 | 1609 |
| 18 | 29Sep1975 1833 | 2183.971 | 5.411921 | 5.411921 | 1609 |

Low flows
combined into
multiple day
durations

High flows
sub-divided
into sub-day
durations

Each of these rows brings in an equal load and computes the flow that brings in the correct load (rather than averaging flows)

1.1.1.3.4 Preserving Low Flow Computational Increments

The tool only computes equal-load **Flow Durations** so it sets the **Computational Increments** equal to the durations. Users can edit the computational increments to sub-divide the high flows further. However, this is tedious to do manually. The option to Compute Computational Increments Based on Flow can be a helpful tool to automate that.

But if users want to subdivide high flow durations but keep the computational increments equal to the flow duration for lower flows, they need to use this tool in a particular way. The tool was designed to *NOT* overwrite computational increments in flow ranges left blank for this particular purpose. So in the example in the figure below, flow records between 0 and 800 cms keep the Computational Increment from the histogram analysis (= the Flow Duration, so HEC-RAS runs it in one sediment time step) and those >800 cms get the user specified sub-divisions. Includes an example of a 15-minute flow series converted into an equal-load increment quasi-unsteady flow file (from Gibson and Helminiack, 2020).

Records retained original Cls for flow ranges left blank

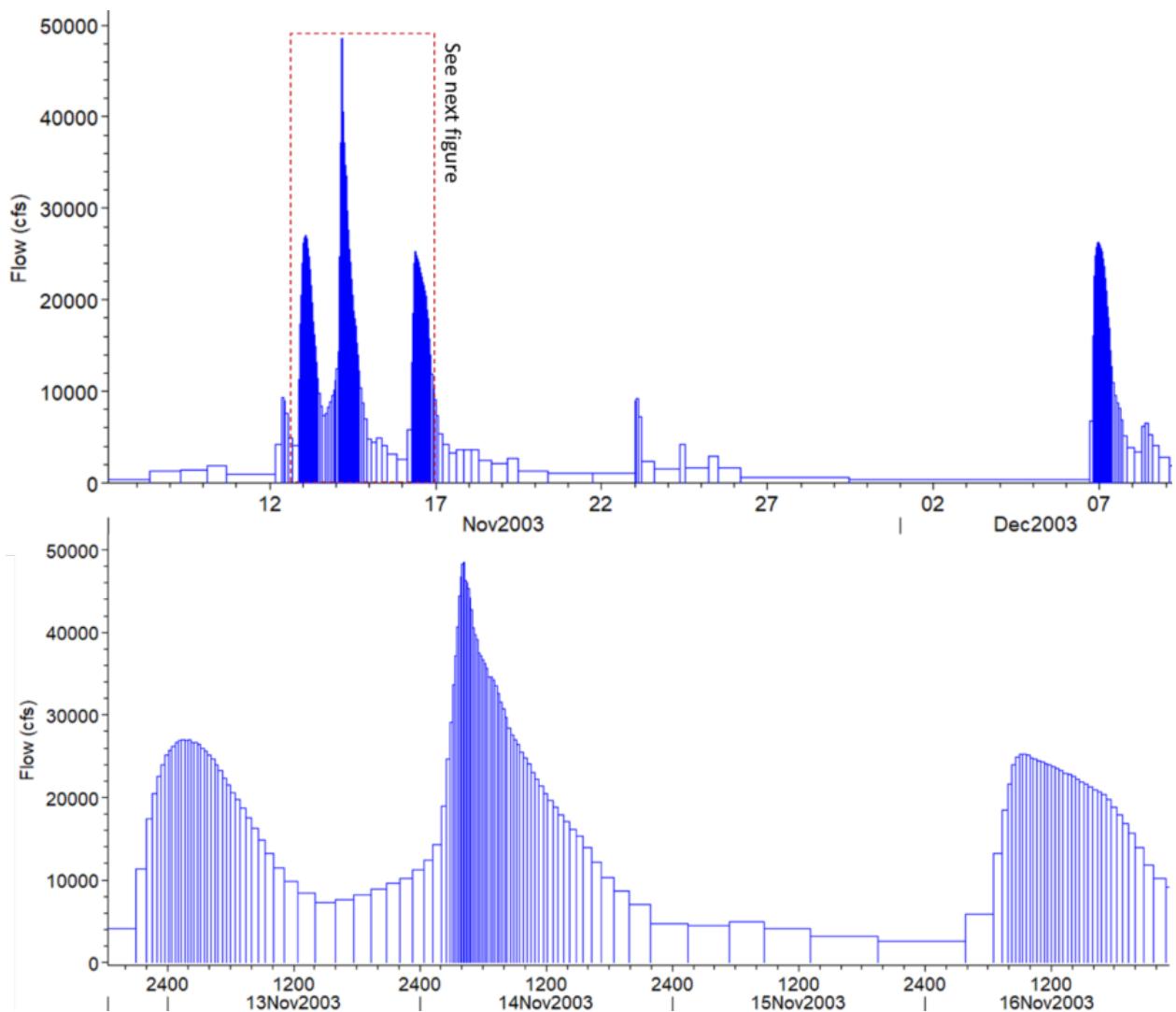
| | Simulation | Elapsed | Flow | Computation | |
|----|---------------------------------|---------------------|---|--------------------------------------|--|
| | Time | Time | Duration | Increment | Flow |
| | | (hours) | (hours) | (hours) | (m ³ /s) |
| 4 | 02Aug1975 1035 | 983.701 | 205.1123 | 205.1123 | 213.5878 |
| 5 | 10Aug1975 2342 | 1296.373 | 312.6718 | 312.6718 | 168.9906 |
| 6 | 24Aug1975 0022 | 1700.037 | 403.6641 | 403.6641 | 146.6351 |
| 7 | 09S 24S 26S 27S 27S 28S 28S 28S | 1075.0000 1245.4000 | 345.3685 55.21718 19.85243 14.88993 7.147673 6.80279 6.80279 6.205565 | 345.3685 55.21718 19.85243 3 3 3 3 3 | 159.9069 442.7691 781.5795 917 1378.598 1417 1417 1491.213 |
| 8 | | | | | |
| 9 | | | | | |
| 10 | | | | | |
| 11 | | | | | |
| 12 | | | | | |
| 13 | | | | | |
| 14 | | | | | |
| 15 | 29Sep1975 0219 | 2167.736 | 5.411921 | 1 | 1609 |
| 16 | 29Sep1975 0744 | 2173.147 | 5.411921 | 1 | 1609 |
| 17 | 29Sep1975 1308 | 2178.559 | 5.411921 | 1 | 1609 |
| 18 | 29Sep1975 1833 | 2183.971 | 5.411921 | 1 | 1609 |

Compute computation increments based on flow

| | Olow | Ohigh | CI |
|---|------|-------|-----|
| 1 | 0 | 800 | |
| 2 | 800 | 1500 | 3 |
| 3 | 1500 | 2000 | 1 |
| 4 | 2000 | 5000 | 0.5 |
| 5 | 5000 | | |

Records overwrite Cls for flow ranges with user data

20 Histogram result from the previous figure with the high flow Computational Increments sub-divided and the low flows retained (by leaving the field blank).



21 Irregular time series developed from 15-minute flow data with the histogram generator. Each flow duration introduces 1,000 tons at the model boundary (Gibson and Helminiack, 2020).

Modeling Note

This tool is available but not widely used for daily data. For most studies, the computational expense of running daily flows during low-transport months is acceptable. But it becomes very useful if the flow data comes in 15-minute increments.

Modeling Note: Testing the Histogram

It is important to test the histogram against the base flow file to make sure it reproduces the results.

Modeling Note: Multiple Upstream Boundary Conditions

The histogram generator works best for models with just one upstream, sediment boundary condition. Dendritic models will populate multiple load fields to specify and the tool will try to find a common denominator, but stripping the analysis to a single boundary flow and load relationship will usually yield better results.

Modeling Note: 15 Minute Tidal Data

The other data that sometimes come in 15-minute increments are tide data. Again, the 40,000 maximum rows in the stage editor will not hold much more than 1 year of 15-minute data. So tidal stages must be averaged. Depending on the model objectives, some simulations can use a single representative stage, and others use a 6-hour representative stages (not necessarily averages) around the maximum and minimum cycle. However, downstream stages have non-linear effects as well, that are more difficult to tease out. It is a good practice to run a year of the sediment transport simulation with the 15-minute stage data and the proposed simplification to make sure the simplification reproduces the full time series.

Wish List

Wish List – Currently, the histogram generator is built around the "equal mass per time step" principle. However, it would be useful to have simpler, more flexible, averaging tools available that create flow series based on load conservation principles, but are not constrained to the constant load approach. We would like to add a simpler feature that retains the flow duration and computational increments selected above a specified flow and simply combines low flows (under a certain threshold – or combines different flow ranges into different). We'd also like to add a DSS record to the downstream stage series editor and average it at the dynamic scale of the flow computational increment.

Wish List

Wish List – Plotting feature that plots the result before it writes to a new Quasi-Unsteady file. At this point users have to create a new quasi-file and open it to evaluate the load increment and results. A Plot feature would run the analysis and plot the result without creating the file, which would be quicker and cleaner.

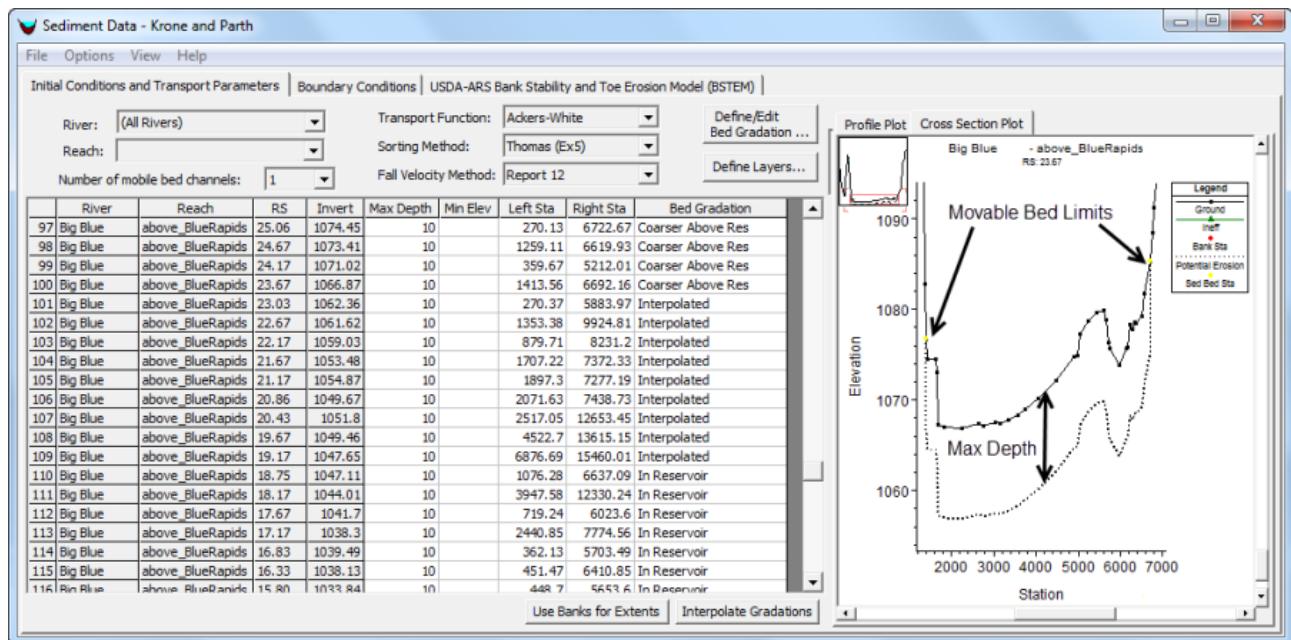
1.2 Entering and Editing Sediment Data

Hydraulic models in HEC-RAS require three files: a flow file (steady or unsteady), a geometry file, and a plan file to tie them together. Sediment analyses (steady or unsteady) require a fourth file: a sediment data file (see Flow Data and Event Conditions). Specify sediment data after the geometry file is complete. Some mandatory sediment parameters are specified by cross section. If the geometry changes (e.g. cross sections change, new cross sections are added, cross sections are interpolated a new resolutions or in new locations) sediment data will 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 Steady Flow Analysis option (or the Unsteady Flow Analysis option if the sediment model will be unsteady), calibrating the n-values for various flows, identifying ineffective flow areas, and evaluating cross section spacing. Identify hydraulics model problems before adding the bed change complexity. Only add sediment data after crafting a careful, robust, hydraulic model.

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 the figure below. The sediment data editor has three tabs: **Initial Conditions and Transport Parameters**, **Sediment Boundary Conditions**, and the **USDA-ARS Bank Stability and Toe Erosion Model (BSTEM)**. The first two tabs are mandatory. The third (BSTEM) is only for bank process computations and is not required for a sediment transport model.



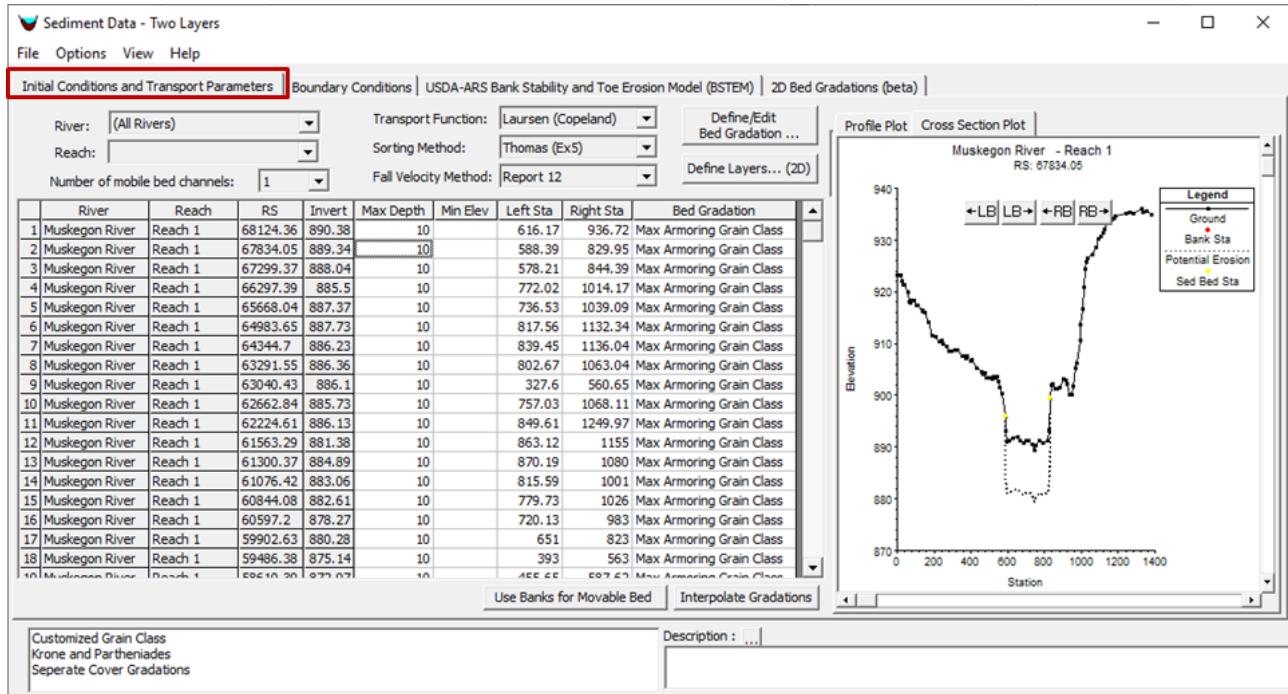
22 The Sediment Data Editor.

- [Initial Conditions and Transport Parameters](#) (see page 56)
 - [Transport Function](#) (see page 57)

- [Sorting Method \(see page 59\)](#)
- [Fall Velocity Methods \(see page 62\)](#)
- [Maximum Depth or Minimum Elevation \(see page 62\)](#)
- [Movable Bed Limits \(see page 64\)](#)
 - [Multiple Movable Bed Limits \(see page 67\)](#)
- [Bed Gradation \(see page 69\)](#)
- [Sediment Parameters for Bridges \(see page 76\)](#)
- [Sediment Boundary Conditions \(see page 77\)](#)
 - [Add Sediment Boundary Location \(see page 78\)](#)
 - [Rating Curve \(see page 79\)](#)
 - [Creating a Sediment Rating Curve \(Best Practices\) \(see page 83\)](#)
 - [Diversion Load \(see page 88\)](#)
 - [USGS Load and Gradation Data \(see page 90\)](#)
 - [Defining a Sediment Time Series \(Manual & DSS\) \(see page 91\)](#)
 - [Equilibrium Load \(see page 98\)](#)
 - [Clear Water Boundary Condition \(see page 99\)](#)
 - [Junctions and Flow Splits \(see page 99\)](#)
- [Sediment Properties Options \(see page 104\)](#)
 - [Define Grain Classes and Sediment Properties* \(see page 109\)](#)
 - [Cohesive Options \(see page 114\)](#)
 - [Bed Change Options \(see page 118\)](#)
 - [Alternate Deposition Methods \(see page 124\)](#)
 - [Alternate Erosion Method \(CEM\) \(see page 130\)](#)
 - [Local \(Reach\) Bed Change Methods \(see page 133\)](#)
 - [Additional Bed Change Modeling Notes \(see page 133\)](#)
 - [XS Specific Bed Change Options \(see page 135\)](#)
 - [Transport Method \(see page 136\)](#)
 - [Transport Function and Calibration \(see page 136\)](#)
 - [2D Options \(see page 140\)](#)
 - [BSTEM Options \(see page 140\)](#)
 - [Lateral Structure \(see page 141\)](#)
 - [Bed Mixing Options \(see page 143\)](#)
 - [Subsidence \(see page 147\)](#)
 - [Set Pass Through Nodes \(see page 149\)](#)
 - [Observed Data \(see page 152\)](#)

1.2.1 Initial Conditions 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. For each cross section, users must specify the sediment control volume and the bed gradation.



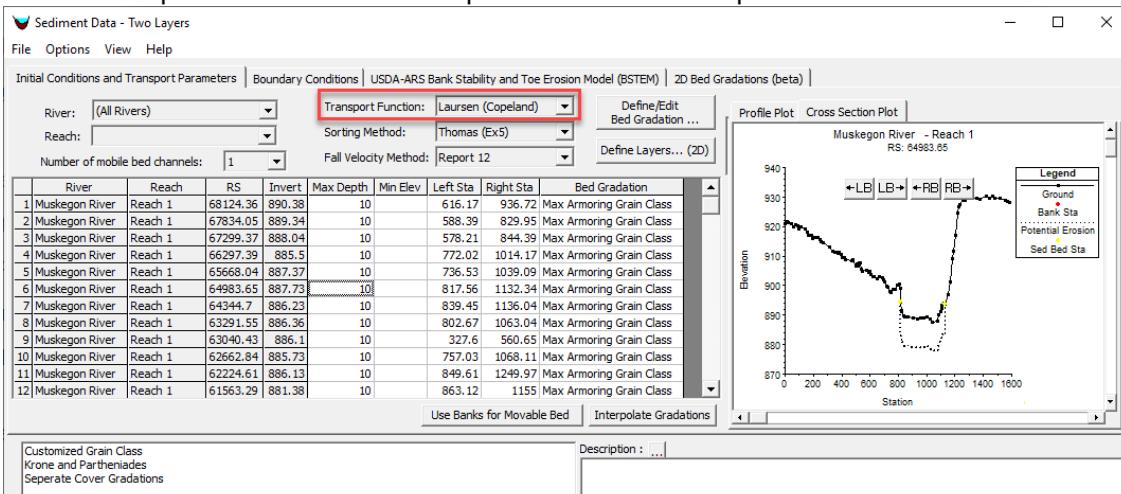
| Transport Function (see page 57) | Transport Function: Laursen (Copeland) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|--|----------|-----------|-----------|----------|-----------|----------|----|--------|--------|------|---------|---------|----|--------|--------|------|---------|---------|----|--------|--------|------|-------|----|----|--------|--------|------|---------|----|
| Sorting Method (see page 59) | Sorting Method: Thomas (Ex5) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fall Velocity Method (see page 62) | Fall Velocity Method: Report 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Max Depth or Min Elevation (see page 62) | <table border="1"> <tbody> <tr> <td>River</td> <td>Reach</td> <td>RS</td> <td>Invert</td> <td>Max Depth</td> <td>Min Elev</td> </tr> <tr><td>17</td><td>Euclid</td><td>Euclid</td><td>4175</td><td>571.566</td><td>571.566</td></tr> <tr><td>18</td><td>Euclid</td><td>Euclid</td><td>4125</td><td>571.519</td><td>571.519</td></tr> <tr><td>19</td><td>Euclid</td><td>Euclid</td><td>4100</td><td>571.5</td><td>10</td></tr> <tr><td>20</td><td>Euclid</td><td>Euclid</td><td>4075</td><td>571.481</td><td>10</td></tr> </tbody> </table> | River | Reach | RS | Invert | Max Depth | Min Elev | 17 | Euclid | Euclid | 4175 | 571.566 | 571.566 | 18 | Euclid | Euclid | 4125 | 571.519 | 571.519 | 19 | Euclid | Euclid | 4100 | 571.5 | 10 | 20 | Euclid | Euclid | 4075 | 571.481 | 10 |
| River | Reach | RS | Invert | Max Depth | Min Elev | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | Euclid | Euclid | 4175 | 571.566 | 571.566 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | Euclid | Euclid | 4125 | 571.519 | 571.519 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | Euclid | Euclid | 4100 | 571.5 | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | Euclid | Euclid | 4075 | 571.481 | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Left and Right Movable Bed Limits (see page 64) | <table border="1"> <thead> <tr> <th>Left Sta</th> <th>Right Sta</th> </tr> </thead> <tbody> <tr><td>616.17</td><td>936.72</td></tr> <tr><td>588.39</td><td>829.95</td></tr> </tbody> </table> | Left Sta | Right Sta | 616.17 | 936.72 | 588.39 | 829.95 | | | | | | | | | | | | | | | | | | | | | | | | |
| Left Sta | Right Sta | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 616.17 | 936.72 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 588.39 | 829.95 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | | | |
|--|--|---------------|--------------------------|--------------------------|
| <p>Bed Gradation (see page 69)</p> | <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">Bed Gradation</td></tr> <tr> <td style="padding: 2px;">Max Armoring Grain Class</td></tr> <tr> <td style="padding: 2px;">Max Armoring Grain Class</td></tr> </table> | Bed Gradation | Max Armoring Grain Class | Max Armoring Grain Class |
| Bed Gradation | | | | |
| Max Armoring Grain Class | | | | |
| Max Armoring Grain Class | | | | |
| <p>Multiple Movable Bed Limits</p> | <p>Number of mobile bed channels: <input style="width: 20px; height: 20px; border: 1px solid black;" type="button" value="2"/></p> | | | |

- [Transport Function \(see page 57\)](#)
- [Sorting Method \(see page 59\)](#)
- [Fall Velocity Methods \(see page 62\)](#)
- [Maximum Depth or Minimum Elevation \(see page 62\)](#)
- [Movable Bed Limits \(see page 64\)](#)
- [Bed Gradation \(see page 69\)](#)
- [Sediment Parameters for Bridges \(see page 76\)](#)

1.2.1.1 Transport Function

Select a transport function from the drop-down box near the top of the editor.



The current version of HEC-RAS includes eight transport one-dimensional functions:

- [Ackers and White \(see page 302\)](#)
- [England and Hansen \(see page 303\)](#)
- [Copeland's form of Laursen \(see page 303\)](#)
- [Meyer-Peter and Müller \(MPM\) \(see page 306\)](#)
- [Toffaleti \(see page 307\)](#)
- [MPM-Toffaleti \(see page 309\)](#)
- [Yang \(sand and gravel eqns.\) \(see page 310\)](#)
- [Wilcock and Crowe \(see page 311\)](#)

The other three transport functions (Soulsby-van Rijn, van Rijn, and Wu) are only available for 2D transport in the current version of HEC-RAS.

See the [transport function section \(see page 301\)](#) of the Technical Reference Manual for detailed descriptions of each of these functions.

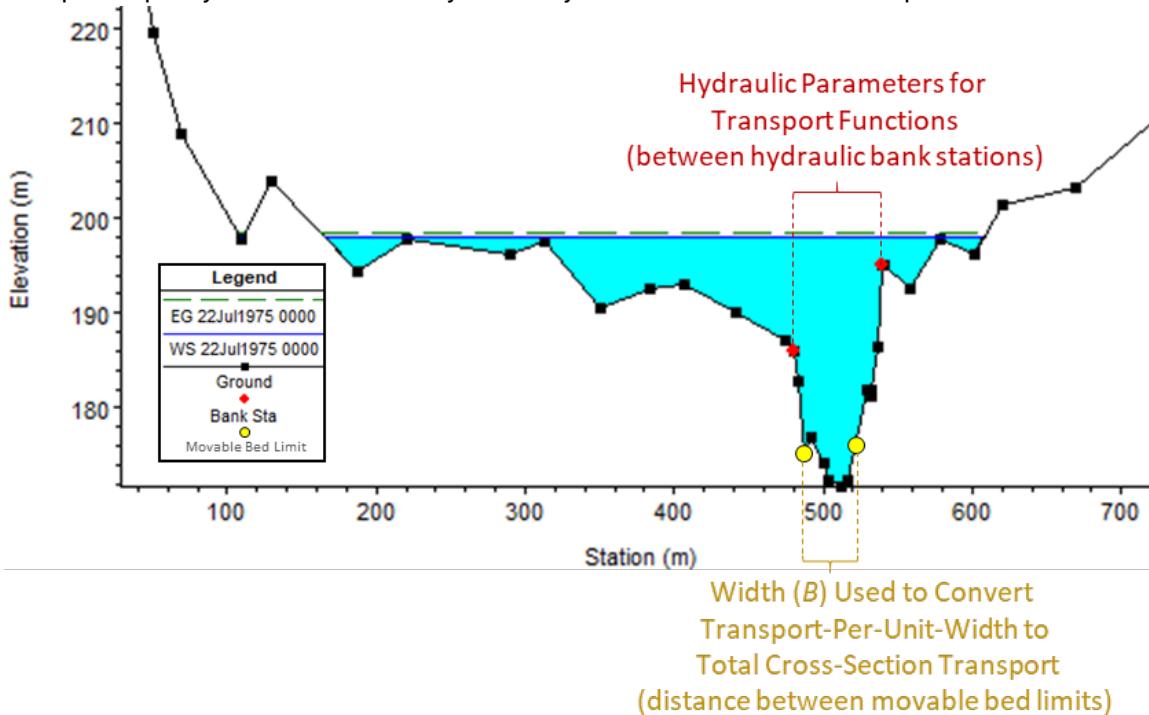
Modeling Note: Transport Function Sensitivity

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 river bed change.

Modeling Note: Transport Based on Channel Hydraulics

The transport functions compute a transport capacity for each cross section based on they hydrodynamic results (e.g. shear stress, shear velocity, friction slope, velocity, fall velocity, etc...) of the **channel**. By default, the 1D hydraulic simulations in HEC-RAS uses "bank stations" to divide each cross section laterally in into a "channel" zone and two "overbank" zones (LOB, ROB). The transport functions only use the channel hydraulics. (not the cross section average hydraulics and not the hydraulics between the movable bed limits, which are the most common misunderstandings).

However, because HEC-RAS uses channel hydraulics for transport, does not mean overbank hydraulics are not important. Flow that spills out to the overbanks is "lost" to transport. So users must choose good overbank n values and apply ineffective flow areas skillfully, to make sure that transport capacity transitions relatively smoothly from bank-full flow to floodplain inundation.



1.2.1.2 Sorting Method

Transport functions compute transport potential without accounting for sediment 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. "Armoring" is the most common impact of bed sorting, where a coarse cover layer forms above a subsurface layer that is more representative of the river's bed material load (see example below).



23 Gravel/Cobble cover layer on a river bar on the Rio de la Plata. The cover layer has been removed in the center (brown) section, to reveal a much finer subsurface layer just below. (photo by Andrew Branard)

Select a bed mixing and armoring algorithm from the drop-down box titled **Sorting Method** below the transport function.

Initial Conditions and Transport Parameters | Boundary Conditions | USDA-ARS Bank Stability and Toe Erosion Model (BSTEM) | 2D Bed Gr

| | | | | | | | | |
|--------------------------------|--------------|-----------------------|--|-------------------------------|----------|----------|-----------|--------------------------|
| River: | (All Rivers) | Transport Function: | Laursen (Copeland) | Define/Edit Bed Gradation ... | | | | |
| Reach: | | Sorting Method: | Thomas (Ex5) | Define Layers... (2D) | | | | |
| Number of mobile bed channels: | 1 | Fall Velocity Method: | Thomas (Ex5) Active Layer Copeland (Ex7) | | | | | |
| River | Reach | RS | Invert | Max Depth | Min Elev | Left Std | Right Std | Bed Gradation |
| 1 Muskegon River | Reach 1 | 68124.36 | 890.38 | 10 | | 616.17 | 936.72 | Max Armoring Grain Class |
| 2 Muskegon River | Reach 1 | 67834.05 | 889.34 | 10 | | 588.39 | 829.95 | Max Armoring Grain Class |
| 3 Muskegon River | Reach 1 | 67299.37 | 888.04 | 10 | | 578.21 | 844.39 | Max Armoring Grain Class |
| 4 Muskegon River | Reach 1 | 66707.39 | 885.5 | 10 | | 772.07 | 1014.17 | Max Armoring Grain Class |

Three methods are currently available:

- [Thomas \(Ex5\) \(see page 322\)](#) – This method uses a three-layer bed model that forms an independent coarse armor layer which limits erosion of deeper layers. HEC-RAS 4.1 and earlier called this method Exner 5 and was the default method in HEC-6.
- [Copeland \(Ex7\) \(see page 329\)](#) – Copeland (1993) developed an alternate version of the Thomas mixing algorithm (Exner 7). This method was designed for sand bed rivers because it forms armor layers more slowly and computes more erosion.

- [Active Layer \(see page 330\)](#) – The two armoring methods above have been successfully applied on many river systems. However, they are complex and can suffer from 'black box' effects, producing results that users have trouble interpreting. Both armoring methods also have numerical thresholds that generate gradational non-linearities introducing noise in the gradational results. Therefore, HEC-RAS also includes a simple two-layer active layer method. The active layer thickness is set equal to the d_{90} by default (an assumption is only appropriate for gravel beds) but is editable since version 5.0 ([{*}Sediment Options](#)[{*}Bed Mixing Options](#)[{*}](#)).

See the [Sorting and Armoring Section \(see page 320\)](#) in the Technical Reference Manual for detailed descriptions of the three sorting methods.

Users can specify separate gradations for the active or cover layers, either manually or with a model hotstart (using Bed Mixing Options or Gradational Hotstarts).

Modeling Note: Mixing Method Sensitivity

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

Modeling Note: Hiding

HEC-RAS assumes grain class independence. HEC-RAS 5.1 and earlier did not include any hiding functions except for those embedded in the Wilcock and Crowe transport function. Version 6.0 and later include additional hiding functions that can be used with other transport functions.

Use Active Layer with Wilcock Crowe

The Wilcock and Crowe sediment transport function is a surface based method, which accounts for armoring implicitly. Therefore, selecting both Wilcock and Crowe and the Thomas/Copland armoring methods would double-count armoring effects. Select the Active Layer mixing method with the default active layer thickness when using Wilcock and Crowe.

Modeling Note: Thomas Method Erodes Less

The Thomas method tends to form a more effective armor layer which tends to reduce or slow erosion compared to the other two.

1.2.1.3 Fall Velocity Methods

Several methods are available for computing fall velocity and the user should select the most appropriate algorithm. The options include:

- Ruby
- Toffaleti
- Van Rijn
- Dietrich
- Report 12 (Default method in HEC-6)

1.2.1.4 Maximum Depth or Minimum Elevation

The **Initial Conditions and Transport Parameters** tab includes a list of model cross sections where users specify initial sediment conditions for each cross section. The editor will filter sections with the **River:** and **Reach:** drop down lists to focus the display on a particular study river or reach, however the sediment model will not run unless the user specifies the control volume (two movable bed limits and either a depth or elevation) and bed gradation for each cross section.

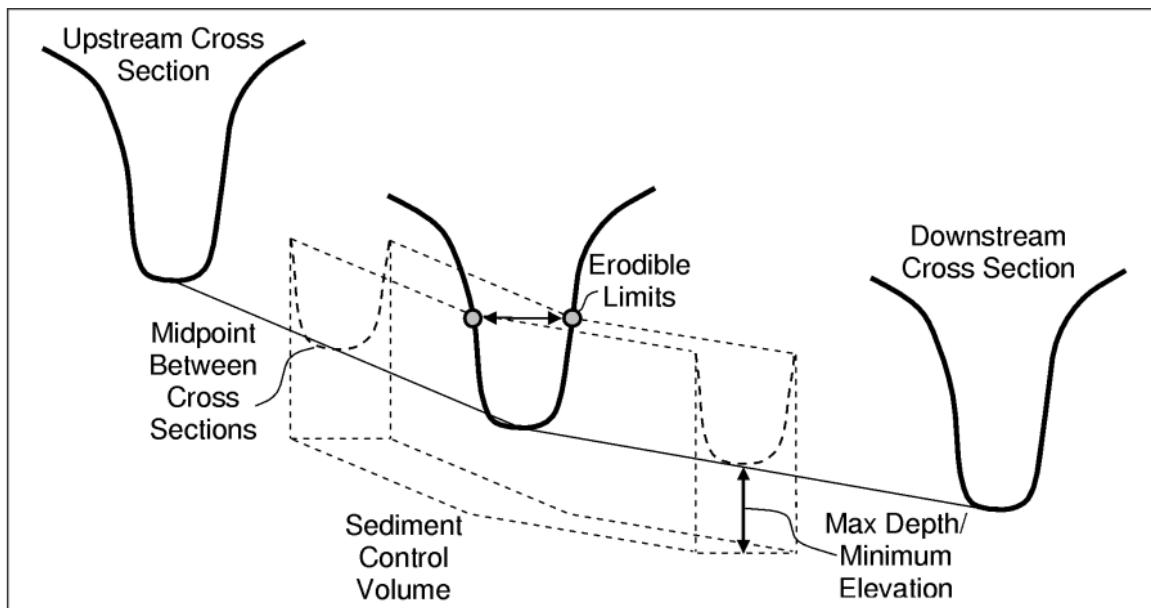
Modeling Note: Geometry Changes and Sediment Files

Sediment files depend on the geometry and hydrodynamic files for their data structure. Each cross section requires data and the boundary condition locations inherit from the flow boundary conditions. Like other files in HEC-RAS, users can mix and match sediment files in a plan. However, if users make major changes to geometry files (e.g. adding or deleting cross sections, interpolating, or moving the boundary conditions) it will change the sediment file structure. Two models with different cross section layouts or boundary condition locations cannot share a sediment file. If you make significant changes to the cross sections in your model and – particularly – if you change the boundary condition locations, the Sediment Editor will try to adjust. But it is often easier to just create a new sediment file which will start with a clean data structure that matches the active geometry and hydraulic boundary conditions than to try to edit an old sediment file that is tied to different cross sections and boundary conditions.

HEC-RAS sediment control volumes are 'centered' around each cross section as depicted in the figure below. Control volumes extend from the midpoint between the cross section and the next one upstream to the same midpoint downstream. The user must specify the width and vertical thickness of the control volume, however. The dotted line in the **Cross Section** Plot traces the vertical and lateral control volume extents. The control volume contains the available erodible sediment, which can be thought of as a 'sediment reservoir' (see [Entering and Editing Sediment Data \(see page 54\)](#)).

Specify the sediment control volume's vertical dimension in either **Max Depth** or **Min Elev** column. (Note: The editor will only allow one of these per cross section, deleting the first if the user specifies both.) The **Max Depth** (see [Entering and Editing Sediment Data \(see page 54\)](#)) approach is more common. With **Max Depth** the user sets the bottom of the control volume to a distance below the original invert of the channel.

The second option, **Min Elev**, sets a 'hard' elevation below which the model cannot erode. This option often simulates known bedrock control, grade control structure, a flume bottom, or a concrete channel lining. The model allows erosion as long as the *thalweg* is higher than this elevation, but will not scour below it.



24 Schematic of sediment control volume associated with each cross section.

| | River | Reach | RS | Invert | Max Depth | Min Elev | |
|---|----------|----------|-------|----------|-----------|----------|-------------------------------------|
| 1 | Morthond | Morthond | 10000 | 171.7 | | 10 | Approximate Sediment Thickness |
| 2 | Morthond | Morthond | 9500 | 171.4361 | | 10 | |
| 3 | Morthond | Morthond | 9000 | 172.1256 | | 170.2 | Known Bed Rock Or Hard Channel Elev |
| 4 | Morthond | Morthond | 8500 | 172.1088 | | 168.8 | |
| 5 | Morthond | Morthond | 8000 | 171.6018 | | 166.5 | |
| 6 | Morthond | Morthond | 7500 | 170.8866 | 10 | | Approximate Sediment Thickness |
| 7 | Morthond | Morthond | 7000 | 171.2124 | 10 | | |
| 8 | Morthond | Morthond | 6500 | 170.4816 | 10 | | |
| 9 | Morthond | Morthond | 6000 | 170.4605 | 10 | | |

25 Example uses of Max Depth and Min Elev.

Modeling Note: When to use Min Elev

Good data on non-erodible depth is rare. Therefore, most models use the Max Depth option, and increase the max depth if credible simulation results erode all the way through it. Min Elev is used in two primary cases: known bed rock or hard pan elevations from blow-count or geophysical data and 2) concrete channels, where the Min Elev is the same as the invert (which would be equivalent to a Max Depth = 0) or buried beneath deposition but built at a known slope and elevation.

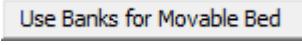
1.2.1.5 Movable Bed Limits

Finally, each sediment control volume requires width. Specify lateral '**Movable Bed Limits**,' in the **Sta Left** and **Sta Right** columns, which constrain erosion and deposition to the cross-section nodes between them (see other options in the Bed Change Options section below). **Movable Bed Limits** are *inclusive*. If the movable bed limits have the same station as a station-elevation point, that point will move. They are the last nodes to move, not the first points that can't move (this worked differently in very early versions of HEC-RAS sediment).

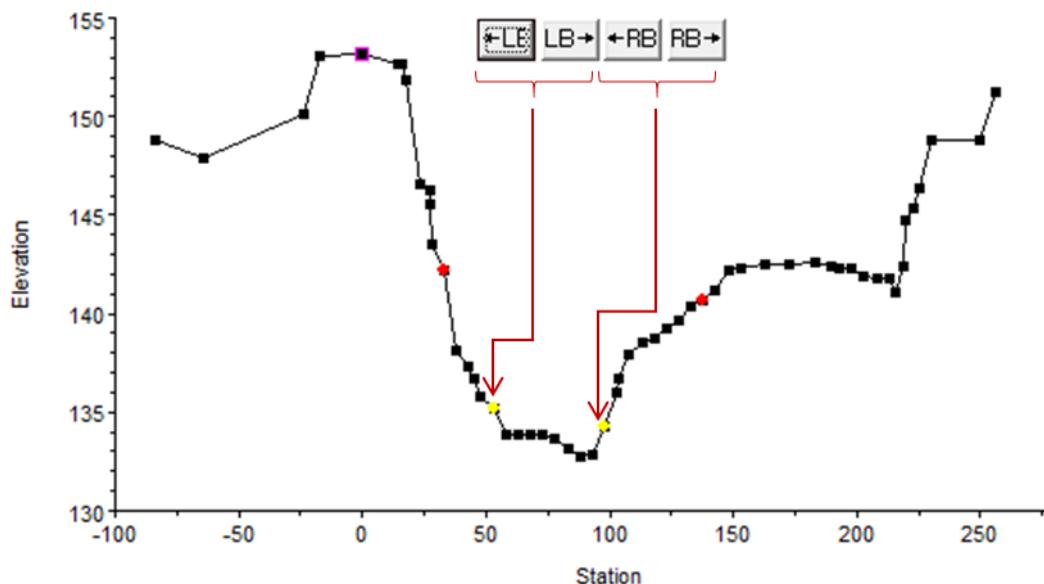
HEC-RAS will only deposit or erode wet cross section points between these lateral limits by default. Select lateral limits carefully. The wetted top width between the **Movable Bed Limits** is also the width used to scale some transport functions that compute transport per-unit-width. So if inundated, the movable bed limits selected can also influence transport capacity.

Movable bed limits should be selected carefully and do not always, or even often correspond to channel banks. However, for the cases in which they do, the **Use Banks for Extents** button sets all erodible bed limits to the main channel bank stations as an initial estimate.

1.2.1.5.1 Movable Bed Limit Tools

HEC-RAS includes two tools to help modelers define movable bed limits quickly. The first is the **Use Banks for Movable Bed** button  at the bottom of the Sediment Data editor. This button automatically sets all of the movable bed limits to the bank stations from the geometry file. Bank stations are not necessarily the best choice for movable bed limits. It is usually appropriate to adjust movable bed limits based on bank stations. But this button helps populate the data quickly for exploratory runs and to initialize these cross-section parameters before adjusting them at each cross sections.

Modelers should review movable bed limits at each cross section and make intentional decisions about where they should be located. Current versions of HEC-RAS make this more convenient, including buttons from the Graphical Cross Section Editor to adjust these nodes. The  and  buttons move the left movable bed limit and the  and  buttons adjust the right movable bed limit (each by one cross section node per button-push).



Using these two tools together, setting all the movable bed limits to the bank stations and then using the buttons to adjust them at each cross section is often the most efficient and reliable way to choose these parameters.

Modeling Note: Movable Bed Limit Sensitivity

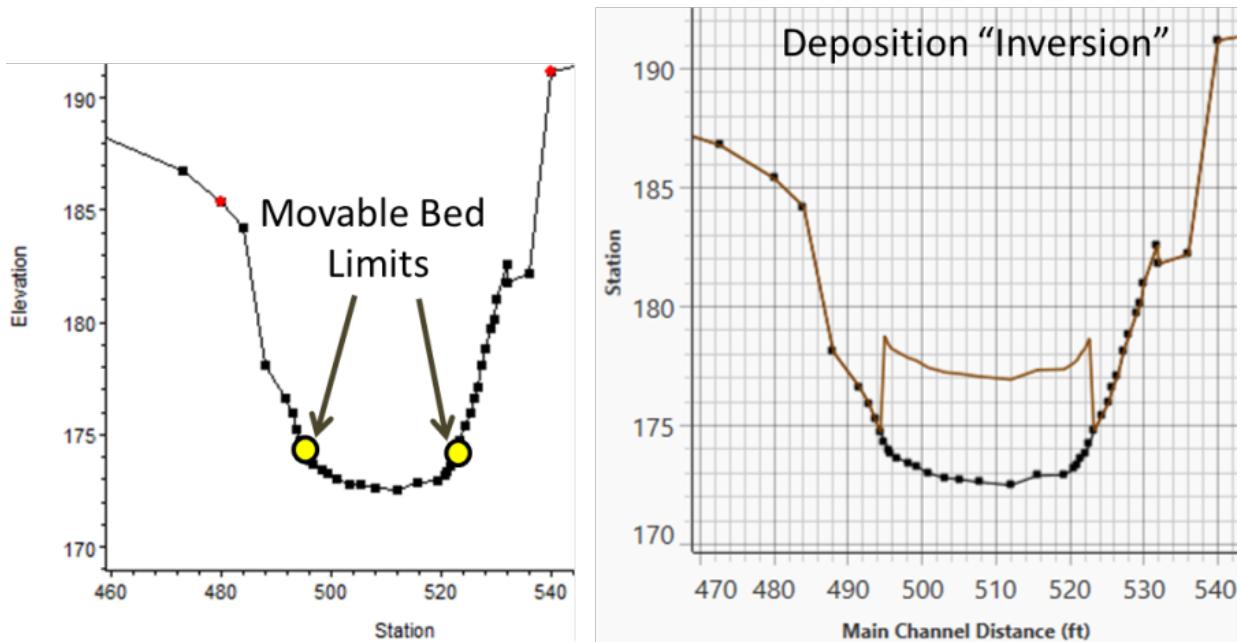
Select movable bed limits carefully. Model results can be sensitive to this parameter. They affect deposition rate, converting mass change to bed change. However, they can also affect transport. Several of the transport functions compute transport *per unit width*. The unit transport is applied to the "movable" portion of the cross section (i.e. $G_s=f(W)$, where G_s is transport and W is the distance between movable bed limits). Therefore, moving the movable bed limits out can have a complicated effect on transport, slowing the invert change by distributing mass change over a larger area, but also increasing transport capacity by increasing the width that HEC-RAS applies the unit transport rate to.

Modeling Note: Identifying the Movable Bed

Just because HEC-RAS offers a convenient tool to set the movable bed limits to the channel banks, does not mean that that is always the best place for them. Movable bed limits are often more appropriate at the toe of the banks. Carefully consider the morphology of the system you are modeling and decide which portion of the cross section is actually vertically active (figure below-left).

Modeling Note: Avoiding Cross Section "Inversion"

Selecting movable bed limits close to the bank toe (figure below-left) can lead to unrealistic cross section shapes in depositional conditions. In the figure below, the movable nodes inside the movable bed limits deposit enough that they end up significantly higher than the immediately adjacent nodes. This cross-section inversion is common when the MBL is inside of a similar station-elevation point and the model only deposits between the movable bed limits.

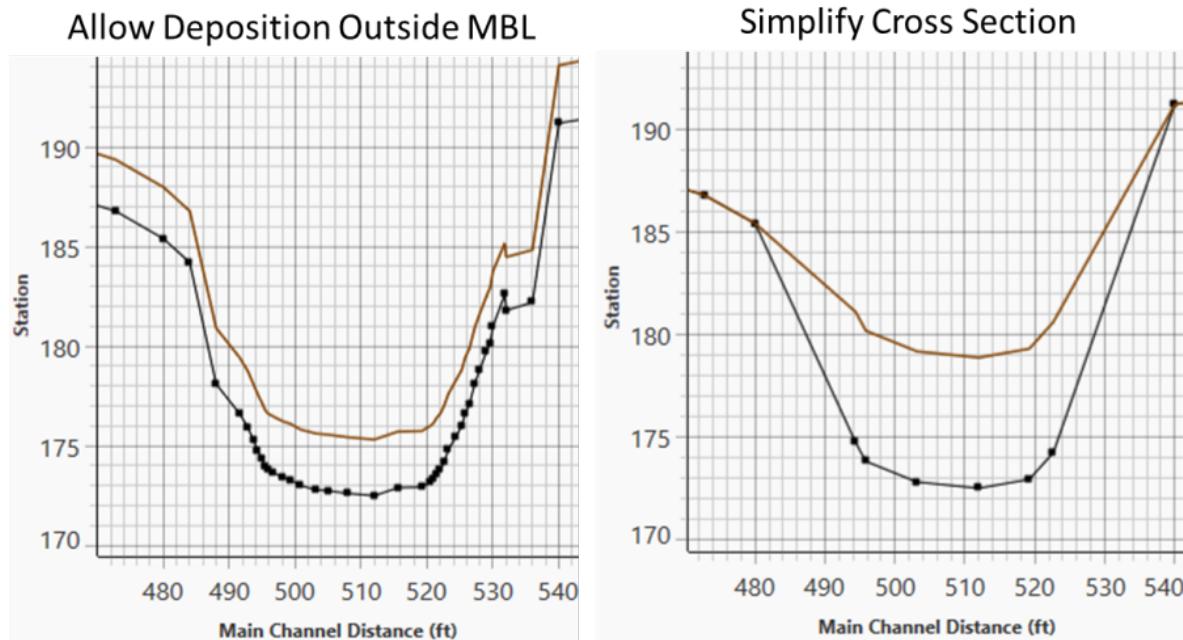


When placing the movable bed limits at the bank toe, deposition can cause “inverted” cross section shapes, where the depositing nodes rise above those that do not move.

This condition has a few reasonable fixes:

- First, the modeler could turn on the option to allow deposition outside of the movable bed limits (figure below-left).
- The modeler could experiment with moving the movable bed limits out to include all of the movable nodes.
- Or the modeler could simplify the cross section to get rid of the intermediate nodes between the movable bed limits and the banks (figure below-right). [Filtering cross sections \(see page 157\)](#) to <100 station elevation nodes (and often <60) is usually good modeling practice for 1D sediment models.

When placing the movable bed limits at the bank toe, deposition can cause “inverted” cross section shapes, where the depositing nodes rise above those that do not move.

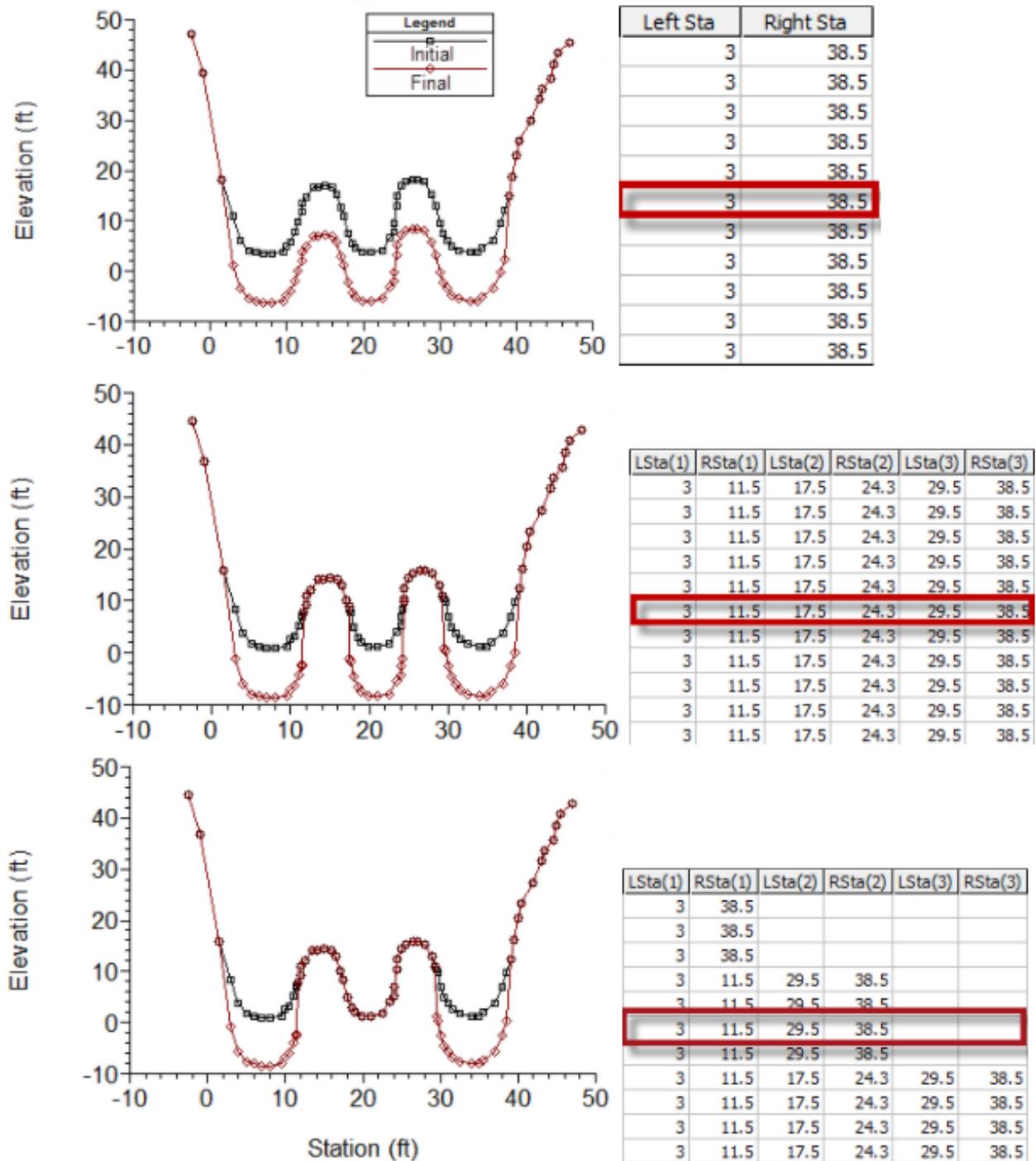


These approaches all embed assumptions that may or may not be acceptable for the analysis and objective. Of course, the first question the modeler would want to ask in this situation is: "is this result credible"? Is the modeled period of record likely to deposit 5m of sediment or is this a symptom of a larger mode problem (e.g. overloaded boundary condition or upstream erosion)?

1.2.1.5.2 Multiple Movable Bed Limits

HEC-RAS computes bed change with the "veneer method" by default, raising or lowering all of the wetted nodes within the movable bed limits an equal distance to translate mass change into cross section change. This is often a reasonable 1D assumption but sometimes produces unrealistic cross section change. HEC-RAS includes several features allowing users to diverge from the veneer assumption when advantageous, mostly in the **Bed Change Options** editor (under the **Options** menu, see section below). However, one of these features is on the **Initial Conditions and Transport Parameters** tab of the **Sediment Data** editor.

The **Multiple Movable Bed Limits** feature allows user to select several 'active channels' that can erode, leaving 'islands' of 'non-movable' cross section, between them. These 'islands' outside or between the movable bed limits will not erode and will only deposit if the option to deposit outside movable bed limits is selected.



For example, consider the cross section in the top two figures. If capacity exceeds supply, this cross section will erode all of the wetted nodes equally (middle two figures). However if the raised portions of the cross section are stabilized, vegetated islands, that do not scour appreciably even during flood flows, the veneer assumption will not match field observations. The cross section change in bottom two figures will simulate these processes better.

To define multiple mobile channels, select the **Number of Mobile Bed Channels** drop down box in the upper left of the **Initial Conditions and Transport Parameters** tab of the **Sediment Data** editor. Selecting more than

one mobile bed channel expands the input table to include more movable bed station pairs, left and right movable bed limits for each discrete channel (figure above). HEC-RAS only requires one set of movable bed limits per cross section, even multiple bed limits are selected. Users can also vary the number of ineffective flow limits between cross sections, ignoring any left undefined after the first pair.

Modeling Note: Multiple Movable Bed Limit Applications

Users have applied this feature to two primary morphological conditions: modeling flow splits and modeling reservoir deltas. First, modeling flow splits or islands with sediment in HEC-RAS can be challenging. So anastomosing or braided channels assumed laterally fixed on simulation time scales can be modeled with multiple movable channels. The limitations of this approach should be taken seriously. HEC-RAS is a 1D model, it does not confine flow or sediment continuity to the sub channels from cross section to cross section, and it still assumes that all the wetted nodes within the movable bed limits change uniformly, even in separate channels. The multiple movable bed limits method also performed well in reservoir models. Reservoir deltas often form multiple channels that scour during floods, separated by stable vegetated islands. This method captured those processes well. (Gibson and Boyd, 2015)

1.2.1.6 Bed Gradation

Each cross section requires initial bed gradation data. Instead of requiring users to input gradations for each cross section individually, HEC-RAS uses a template concept similar to that in the Channel Modification Editor. Users define sediment gradations in a database and then associate them with the appropriate cross sections.

HEC-RAS first requires the creation of bed material gradation templates. Then the bed gradation templates can be associated with the appropriate range of cross sections using pick and drag functionalities.

HEC recommends defining sediment gradations using the AGU classification system, which is why the editors use this system by default. The regular spacing of the AGU grain size classes (log base 2 scale) generally works better with numerical computations. Users will have to request gradations in this format, because it is not the default format for most laboratories.

Warning - Request Data Based on the AGU Scale NOT ASTM

If you send a bed or flux sediment sample to the laboratory for gradation analysis they are likely to use the ASTM (Or US Standard) sieve scale. The ASTM scale does not correspond to the gradations in HEC-RAS and are not spaced well for the sediment transport equations and algorithms. The study team should scope the gradation analyses based on the AGU scale used in HEC-RAS. When specifying a gradation analysis, the cohesionless sediment should be processed with sieve sizes 230 (0.063mm), 120 (0.125mm), 60 (0.25mm) 35 (0.5mm), 18 (1mm), 10 (2mm), 5 (4mm). Hydrometer or laser diffraction results for the fine fraction should also be reported on the HEC-RAS/AGU scale (e.g. 0.004, 0.008, 0.016, 0.032 mm).

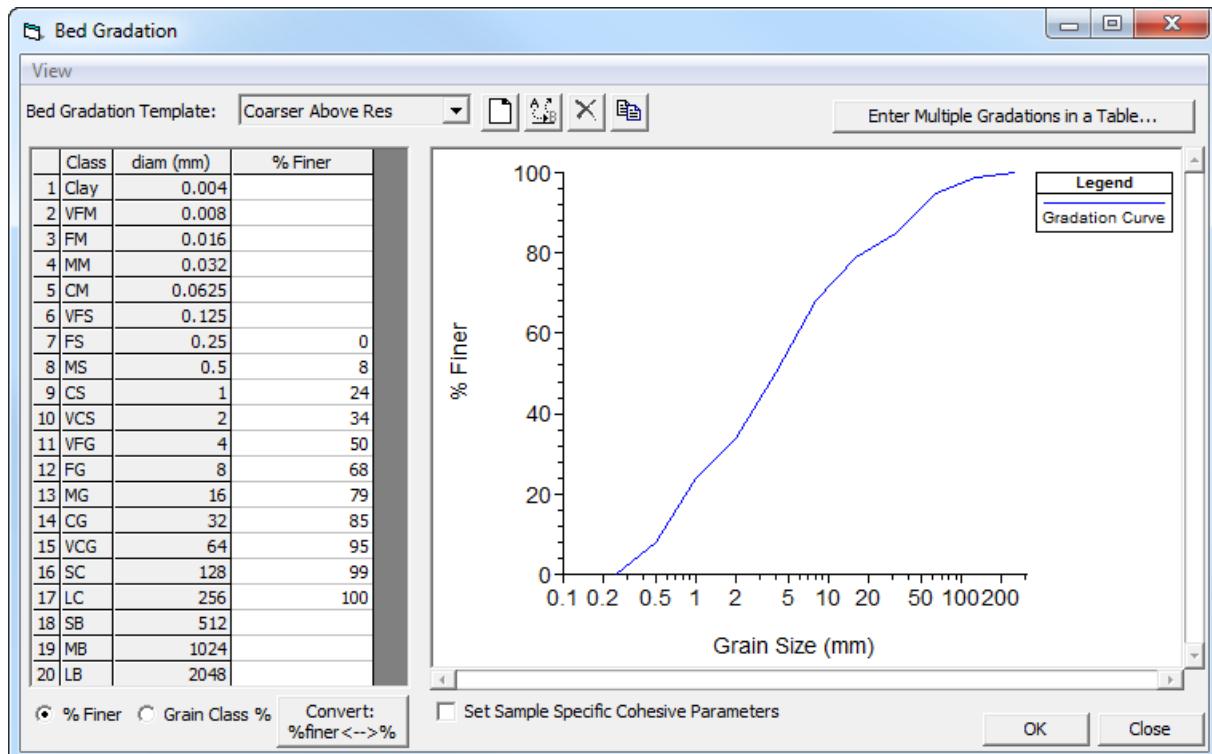
1.2.1.6.1 Bed Gradation Templates:

To assign bed gradations to the cross section, first create bed gradation templates. In many applications, these templates will correspond to individual bed samples taken in the project reach. Templates are created and edited by pressing the **Define/Edit Bed Gradation** button, which will launch the dialog depicted in the figure below.

First, create a new bed gradation template by selecting the **New Bed Gradation Sample** button:  Then enter a name for the sample. (Alternatively, data for several different samples can be entered at once; see the section, **Multiple Bed Gradation Table**, below.)

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:

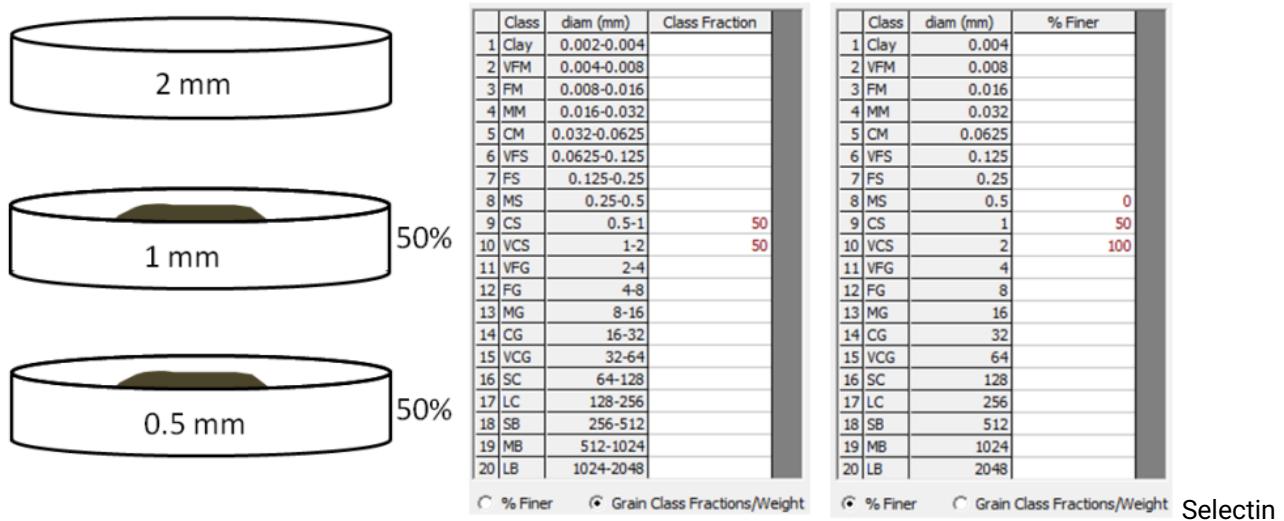
- **% Finer:** % Finer defines the sample using as a cumulative bed gradation curve with percent finer defined by the upper bound of each grain class. The diameter listed for each grain class is the upper bound of that grain class and values should be entered as percent. (e.g. since this is specified 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.



26 Gradation template editor.

Modeling Note: Percent Finer Diameter

Specifying gradations using the % Finer method in HEC-RAS can be confusing. However, geotechnical and soil sample convention defines soil gradations with cumulative, "% finer" notation. The % finer convention is based on the traditional method of using sieves to determine the soil gradation. Thinking of "% finer" as "% passing" might be helpful since % finer is traditionally the percent of the sample passing a given sieve size. In HEC-RAS, % finer is defined by the upper bound (Max) of the grain class. Consider the example in the figure below, a simplified 3 sieve system with 100% passing the 2 mm sieve, 50% passing the 1 mm sieve, and 0 % passing the 0.5 mm sieve. The gradation information can be entered this way in HEC-RAS. However, for many it is more intuitive to think of the gradation as the amount retained on each sieve. Therefore HEC-RAS also allows users to specify gradations using the Grain Class Fraction method. In the example, 50% of the sample is retained on the 1 mm sieve and 50% of the sample is retained on the 0.5 mm sieve. In the Grain Class Fraction method, this would translate to 50 in the VCS (0.5-1 mm) and VFG (1-2 mm) grain class..



Selecting a Template:

After users define the sediment 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 (table (a) in the figure below). A single bed sample is frequently associated with multiple cross sections. 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 (table (b)).

| Sta Right | Bed Gradation |
|-----------|---------------|
| (a) 74 | |
| 74 | Sample 1 |
| 74 | Sample 2 |
| 74 | Sample 3 |
| 74 | |
| 74 | |
| 74 | |
| 103.8 | |
| 103.8 | |

| Sta Right | Bed Gradation |
|-----------|---------------|
| (b) 74 | Sample 1 |
| 74 | |
| 74 | |
| 74 | |
| 74 | |
| 74 | |
| 103.8 | |
| 103.8 | |

| Sta Right | Bed Gradation |
|-----------|---------------|
| (c) 74 | Sample 1 |
| 74 | Sample 1 |
| 74 | Sample 1 |
| 74 | Sample 1 |
| 74 | Sample 1 |
| 74 | |
| 74 | Sample 1 |
| 103.8 | Sample 2 |
| 103.8 | Sample 3 |

1.2.1.6.2 Interpolation:

In cases where channel geology justifies assumptions of gradual bed gradation transitions between samples the option to interpolate between specified gradational templates is available. To interpolate, select the appropriate bed gradation templates for the known cross sections, leaving the other rows of the **Bed Gradation** field blank (table b in the figure below). Then press the **Interpolate Gradations** button on the **Sediment Data editor**. (see page 54)

HEC-RAS will interpolate a bed gradation at any station that occurs between two defined gradations within a reach and write "Interpolated" in the **Bed Gradation** field for those nodes. If a cross section occurs between one defined gradation and either the upstream or downstream end of the reach, the closest gradation template will be copied to the node as depicted in the first two fields of the figure below.

| Bed Gradation |
|---------------|
| |
| |
| Sample 1 |
| |
| |
| Sample 2 (a) |

| Bed Gradation |
|---------------|
| Copy Sample 1 |
| Copy Sample 1 |
| Sample 1 |
| Interpolated |
| Interpolated |
| Sample 2 (b) |

27 Gradation interpolation process.

Modeling Note – Copy/Paste to the Bed Gradation Column

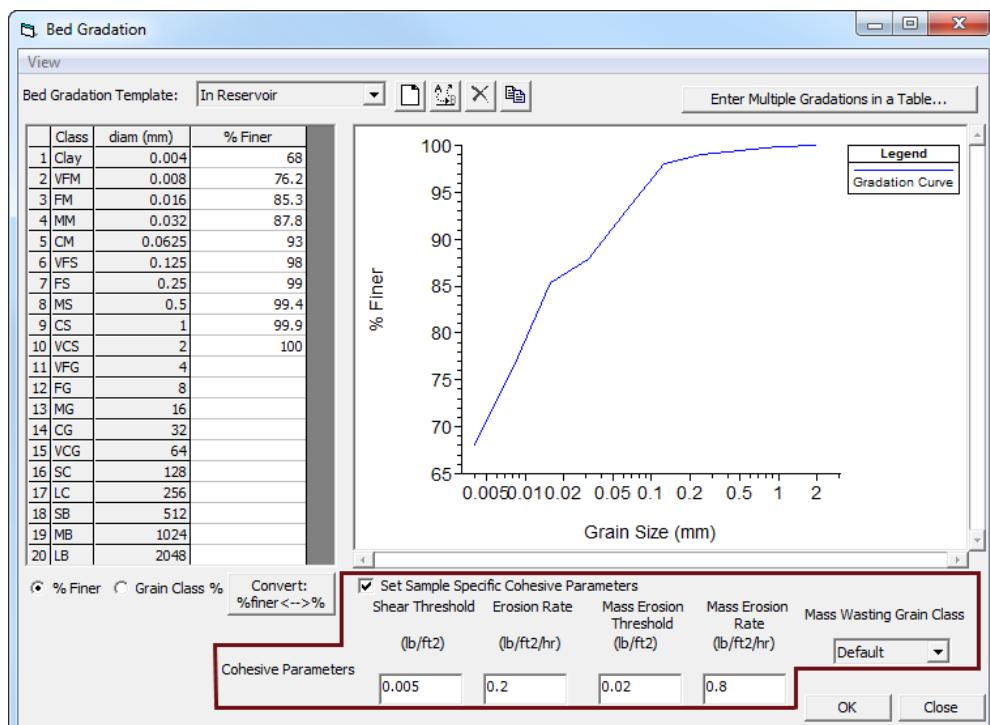
While the Bed Gradation column is populated with a drop-down box of the sample database, it stores the data as text. Therefore, the text in these columns can be copied and pasted. This can be useful for large models where selecting each gradation individually would be tedious. But the modeler must be careful when pasting test gradations that each one corresponds precisely to a sample title in the database.

1.2.1.6.3 Sample Specific Cohesive Parameters (Optional):

Previous versions of HEC-RAS used global cohesive parameters, assigning a single set of shear thresholds and erodibility coefficients (see **Cohesive Parameters** (see page 114) section) to all cross sections. Version 5.0 retains this capability, but also allows spatially varied cohesive parameters.

Specify spatially varied cohesive parameters by assigning cohesive parameters to bed gradation samples. In some cases different samples might have the same gradation but distinct cohesive parameters. Then assign the samples with the appropriate cohesive parameters to the appropriate cross section or layers. Users do not have to assign **Sample Specific Cohesive Parameters** for all **Bed Gradation Samples** if they do it for one or several. Any samples without local parameters defined will default to global parameters.

Check the **Set Sample Specific Cohesive Parameter** box to define cohesive parameters for a sample. Any cross section or bed layer associated with that gradation will adopt the local cohesive parameters.



28 Defining sample specific cohesive parameters

1.2.1.6.4 Multiple Bed Gradation Table

Large models can include many bed gradations, (e.g. Shelley and Gibson, 2015). Inputting dozens of samples one at a time can be tedious. Therefore, HEC-RAS includes a tabular input to upload large bed gradation databases. By conforming to a simple input format, multiple gradations can be copied from a spreadsheet directly into an HEC-RAS editor and HEC-RAS will create **Bed Gradation Templates** for each record as if they were added manually (see figure entitled, "Samples from previous figure added to the bed gradation data" below).

To input multiple gradations, press the **Enter Multiple Gradations in a Table...** button on the upper right of the **Bed Gradation** editor (above). This button launches the table shown in below (top).

Order data in adjacent columns with rows corresponding to the following:

Header Row (Name): Unique Sample Name

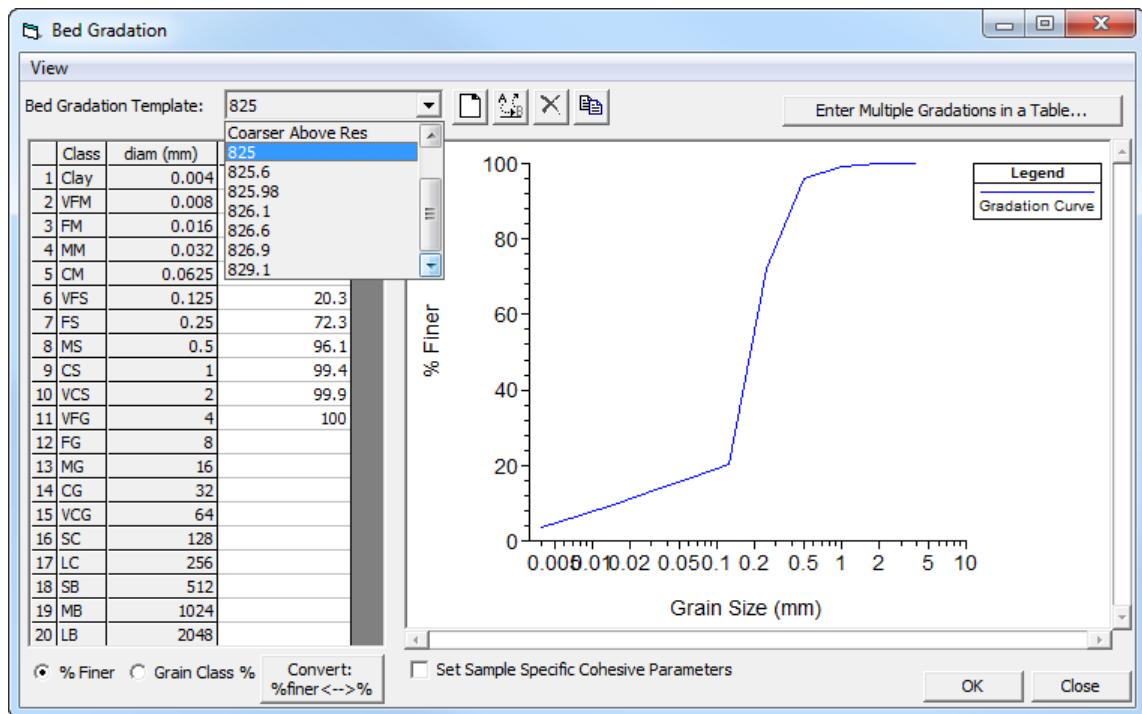
Rows 1-20: The cumulative percentage of each grain class. Note: this editor only supports the % finer input format from the figure, "Gradation template editor" at the top of this page and the figure above.

Row 21 (Cohesive Param): Sample Specific Cohesive Parameters Flag. This corresponds to the **Set Sample Specific Cohesive Parameters** check box in the figure "Gradation template editor" and the figure above. "0" or blank will deselect this feature while "1" will turn it on. Note: Users can specify sample specific cohesive parameters but de-select the method. HEC-RAS will store the parameters as 'dormant.' They will be stored in the model and available but will not be used unless the box is subsequently checked.

Rows 22-25 (Optional): Sample Specific Cohesive Parameters. tc is the critical shear stress for particle erosion, M is the erosion rate, tc (MW) is the critical shear above which the cohesive model transitions to the "mass wasting" erosion rate and M (MW) is the erosion rate for shear stresses above tc (MW).

| Load Specification | | | | | | | |
|----------------------------|----------------------|--------|-------|--------|-------|-------|-------|
| Number of flow-load points | | 7 sets | | | | | |
| | Name | 825 | 825.6 | 825.98 | 826.1 | 826.6 | 826.9 |
| 1 | Clay (0.002-0.004) | 3.4 | 0 | 0.002 | 0.01 | 0.002 | 0.01 |
| 2 | VFM (0.004-0.008) | 6.8 | 0.01 | 0.003 | 0.01 | 0.004 | 0.01 |
| 3 | FM (0.008-0.016) | 10.1 | 0.01 | 0.005 | 0.02 | 0.005 | 0.02 |
| 4 | MM (0.016-0.032) | 13.5 | 0.02 | 0.006 | 0.02 | 0.007 | 0.02 |
| 5 | CM (0.032-0.0625) | 16.9 | 0.02 | 0.008 | 0.03 | 0.009 | 0.03 |
| 6 | VFS (0.0625-0.125) | 20.3 | 0.03 | 0.009 | 0.03 | 0.011 | 0.03 |
| 7 | FS (0.125-0.25) | 72.3 | 1.61 | 0.034 | 0.44 | 1.1 | 0.4 |
| 8 | MS (0.25-0.5) | 96.1 | 44.6 | 1.3 | 28.7 | 50.2 | 4.79 |
| 9 | CS (0.5-1) | 99.4 | 89.4 | 38.4 | 72.5 | 86 | 20.9 |
| 10 | VCS (1-2) | 99.9 | 100 | 77.7 | 95 | 97.6 | 44.1 |
| 11 | VFG (2-4) | 100 | | 93 | 99.4 | 99.6 | 57.1 |
| 12 | FG (4-8) | | | 97.1 | 99.9 | 99.9 | 69.2 |
| 13 | MG (8-16) | | | 98.5 | 100 | 100 | 86 |
| 14 | CG (16-32) | | | 99.7 | | | 97.7 |
| 15 | VCG (32-64) | | | 100 | | | 100 |
| 16 | SC (64-128) | | | | | | 100 |
| 17 | LC (128-256) | | | | | | |
| 18 | SB (256-512) | | | | | | |
| 19 | MB (512-1024) | | | | | | |
| 20 | LB (1024-2048) | | | | | | |
| 21 | Cohesive Param (0/1) | | | | | | |
| 22 | tc | | | | | | |
| 23 | M | | | | | | |
| 24 | tc (MW) | | | | | | |
| 25 | M (MW) | | | | | | |

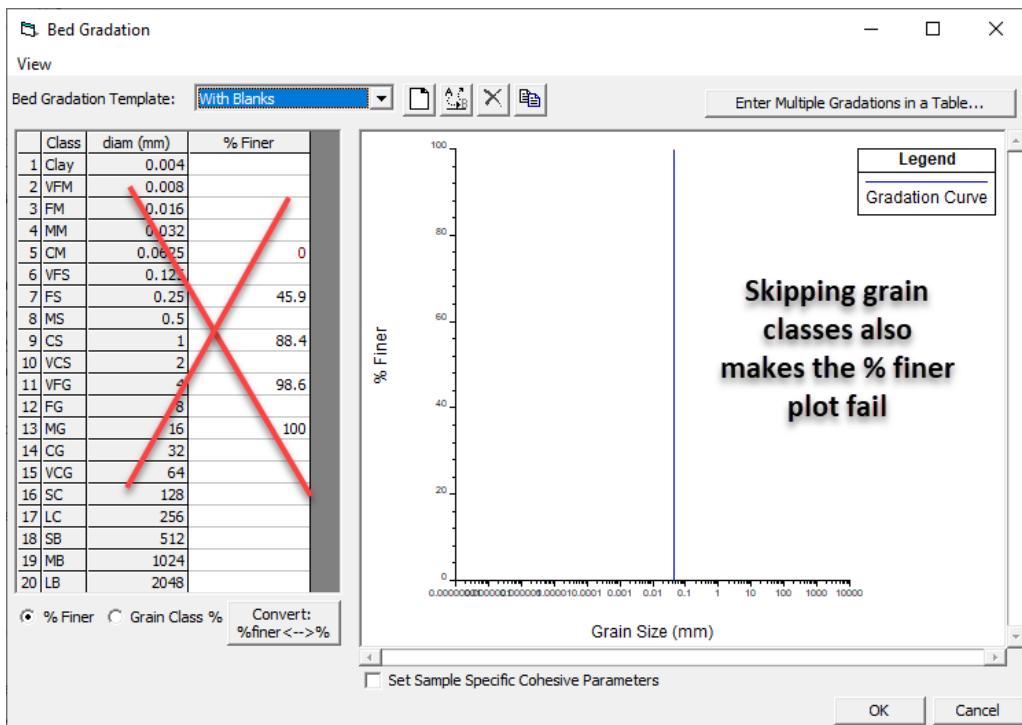
29 Gradation table for loading multiple bed gradations into the sediment sample data base.



30 Samples from previous figure added to the bed gradation data.

Modeling Note: Interpolate Bed Gradations:

Often sieve data do not align with the grain classes in HEC-RAS. In those cases, users can either change their grain classes to line up with their sieve data or interpolate the sieve data to populate the standard grain classes. Skipping grain classes is not recommended. Skipping grain classes in the bed gradations will generate numerical artifacts unless the grain class is excluded from the model entirely (all bed gradations and boundary conditions). Including all grain classes also generates smoother results.



31 Avoid skipping grain classes in the bed gradations.

1.2.1.7 Sediment Parameters for Bridges

The **Sediment Data** editor will populate rows for all HEC-RAS nodes (e.g. cross sections, bridges, culverts, lateral structures, inline structures, etc...) but only requires sediment data for cross sections. Bridges and other non-cross section nodes are grayed out to indicate they do not require sediment data.

Unlike other non-cross section nodes, however, bridges include cross sections that can deposit or erode. Bridges in HEC-RAS replicate the upstream and downstream cross sections on the upper and lower face of the structure and the sediment model will adjust these cross section nodes (link). HEC-RAS will also project the initial sediment conditions associated with the upstream and downstream cross sections with the respective internal cross section.

Modeling Note: Local Scour and Bridge Sediment Limitations

The bridge approaches in HEC-RAS can pose be challenging to apply in a sediment transport model. See the section on [bridges and sediment modeling](#) (see page 76) for more on this topic.

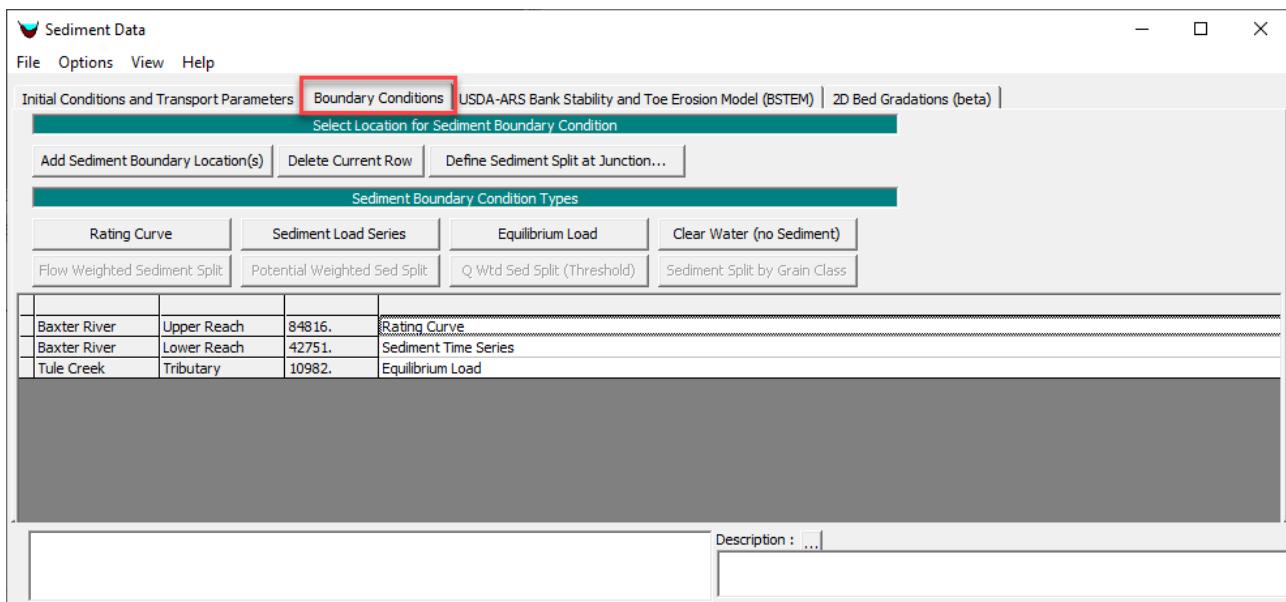
Modeling Note: Local Scour and Bridge Sediment Limitations

Federal Highway Guidance for Bridge Scour analysis includes three major components: regional bed level change, contraction scour, and local scour (i.e. pier and abutment effects). The movable bed sediment transport capabilities in HEC-RAS **ONLY** account for one of those three

processes: regional bed change. To compute contraction and local scour use the **Bridge Scour** tool in the **Hydraulic Design** editor.

1.2.2 Sediment Boundary Conditions

The second tab on the **Sediment Data Editor** defines sediment boundary conditions (see figure below). Like the unsteady and quasi-unsteady flow boundary conditions, HEC-RAS requires sediment data at each upstream model boundary and can include optional, local, lateral sediment loads where necessary. The editor automatically lists external model boundaries and users can add local sediment loads at internal cross sections by pressing the **Add Sediment Boundary Location(s)** button.



32 Boundary Conditions Tab of the Sediment Data Editor

Click on the link or button to go to the section on each sediment boundary condition option:

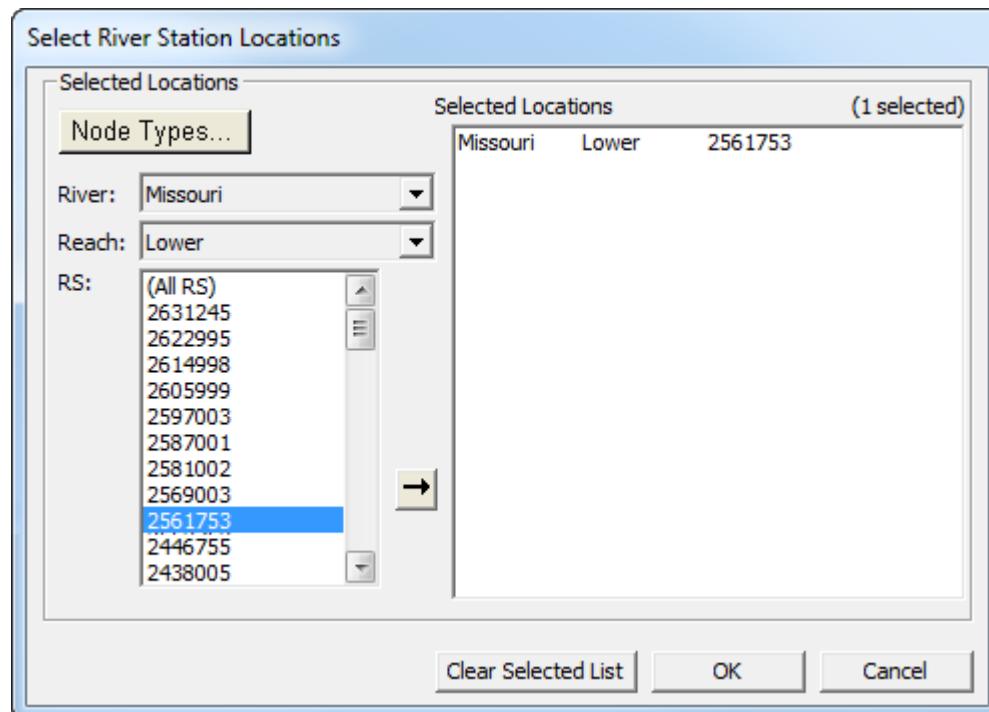
| | |
|--|---|
| Add a Sediment Boundary Location (see page 78) | Add Sediment Boundary Location(s) (see page 78) |
| Rating Curve Boundary Condition (see page 79) | Rating Curve (see page 79) |
| Sediment Load Time Series (see page 91) | Sediment Load Series (see page 91) |

| | |
|---|--|
| Equilibrium Load Boundary Condition (see page 98) | Equilibrium Load (see page 98) |
| Clear Water Boundary Condition (see page 99) | Clear Water (no Sediment) (see page 99) |
| Sediment Split Methods (see page 99) (Junctions) | Define Sediment Split at Junction... (see page 99) |

1.2.2.1 Add Sediment Boundary Location

Although HEC-RAS will automatically list external boundaries, the user must specify internal locations where sediment boundary conditions are required. To add an internal boundary, press the **Add Sediment Boundary Location(s)** button, which will launch the river station selector depicted in the figure below. Select one or more of these river stations by double clicking on the list or selecting locations while holding down the control or shift button then pressing the arrow key. Remove cross sections from the selected locations list by double clicking on them or pressing the **Clear Selected List** button.

Chose sediment boundary conditions by selecting the row associated with the cross section. HEC-RAS will populate the sediment boundaries allowed at the selected node.



33 Editor for selecting a lateral flow load boundary location.

1.2.2.2 Rating Curve

A rating curve computes sediment boundary loads based on boundary flows. Select sediment **Rating Curves** at any cross section with a boundary flow series: upstream, lateral, or lateral uniform. The sediment **Rating Curve** boundary condition is always available for upstream boundaries. If the user selects an internal cross section in the **Sediment Data** editor **Boundary Condition** tab, the **Rating Curve** button will only activate if a selected internal cross section has an associated flow boundary condition. If a **Rating Curve** is associated with a **Uniform Lateral Flow Series**, HEC-RAS distributes sediment loads in the same proportion it distributes flow. This option will open the **Rating Curve** editor depicted in the figure below.

Rating Curve for Arghandab Dahlia Dam US 19889.30

| Number of flow-load points | | 2 sets | |
|----------------------------|--|--------|---------|
| Flow (m ³ /s) | | 1 | 1000 |
| Total Load (tonnes/day) | | 5 | 2400000 |
| 1 Clay (0.002-0.004) | | 0.2 | 0.15 |
| 2 VFM (0.004-0.008) | | 0.3 | 0.35 |
| 3 FM (0.008-0.016) | | 0.2 | 0.25 |
| 4 MM (0.016-0.032) | | 0.2 | 0.07 |
| 5 CM (0.032-0.0625) | | 0.1 | 0.07 |
| 6 VFS (0.0625-0.125) | | | 0.06 |
| 7 FS (0.125-0.25) | | | 0.05 |
| 8 MS (0.25-0.5) | | | |
| 9 CS (0.5-1) | | | |
| 10 VCS (1-2) | | | |
| 11 VFG (2-4) | | | |
| 12 FG (4-8) | | | |
| 13 MG (8-16) | | | |
| 14 CG (16-32) | | | |
| 15 VCG (32-64) | | | |
| 16 SC (64-128) | | | |

Define Diversion Load Load Concentration Conc<-->Load Plot ... OK Cancel

34 Load specification editor.

1.2.2.2.1 Flow-Load Data:

To correlate sediment loads with boundary discharge, the Rating Curve includes paired Flow-Load data. The number of columns, one for each Flow-Load pair, is set using the **Number of flow-load points** drop down box at the top of the dialog. Blank columns are not allowed. Select a range of flows that completely encompasses the flows expected during the simulation. If flows occur that exceed the upper bound of the rating curve, HEC-RAS will not extrapolate, but will use the largest sediment load specified in the table. HEC-RAS will interpolate loads below the smallest entered flow, assuming a zero-sediment load at zero flow. The **Plot...** button plots flow versus total load in log space.

New HEC-RAS Tool Downloads Data and Helps Develop Rating Curves

The latest version of HEC-RAS includes a [Rating Curve Analysis Tool](#)⁵, that helps modelers download and analyze sediment load and gradation data to fill out this editor.

1.2.2.2.2 Flow-Concentration Data:

The rating curve editor uses load (mass/time) data by default. But users can also specify a sediment rating curve in Concentration units (mass/volume) (see figure below). Like particle size, Concentration is always in SI units in HEC-RAS (mg/L). To define a rating curve with Concentration data, click the Concentration Radio button on the bottom of the editor.

Load Concentration

This radio button only defines the entered data as Concentration, it does not convert it. But the Conc↔Load Button allows users to move back and forth between concentration and Load.

Conc<-->Load

Rating Curve for Arghandab Dahlia Dam US 19889.30

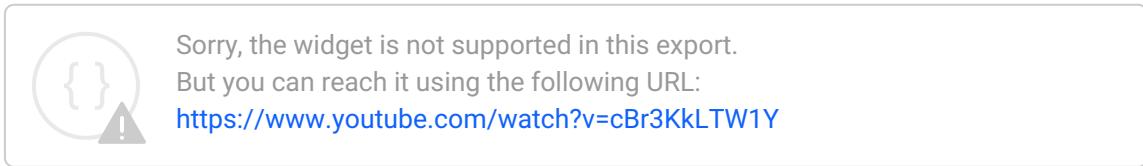
| Number of flow-load points | | |
|----------------------------|--------------------------|----------|
| 2 sets | | |
| 1 | Flow (m ³ /s) | 1000 |
| 2 | Conc (mg/L) | 27777.78 |
| 3 | Clay (0.002-0.004) | 0.15 |
| 4 | VFM (0.004-0.008) | 0.35 |
| 5 | FM (0.008-0.016) | 0.25 |
| 6 | MM (0.016-0.032) | 0.07 |
| 7 | CM (0.032-0.0625) | 0.07 |
| 8 | VFS (0.0625-0.125) | 0.06 |
| 9 | FS (0.125-0.25) | 0.05 |
| 10 | MS (0.25-0.5) | |
| 11 | CS (0.5-1) | |
| 12 | VCS (1-2) | |
| 13 | VFG (2-4) | |
| 14 | FG (4-8) | |
| 15 | MG (8-16) | |
| 16 | CG (16-32) | |
| 17 | VCG (32-64) | |
| 18 | SC (64-128) | |

Define Diversion Load Load Concentration

Modeling Note: Estimating a Flow-Load Curve from Noisy Data

⁵ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/sediment-rating-curve-analysis-tool>

Flow load data, if available, are usually noisy, spanning one or two orders of magnitude. Seasonal effects, non-stationarity, hysteresis, sample error and random processes make flow an imperfect predictor of load. Therefore, defining a single flow-load rating curve requires approximating the 'data cloud' with a single curve of flow-load points. Several considerations should guide flow-load estimation. Best practices in developing a sediment rating curve are discussed [here \(see page 83\)](#), and several of them are described in the second half of this video:



1.2.2.2.3 Load-Gradation Data:

Each column of the sediment rating curve has a flow and an associated total load entered as mass per time (e.g. tons/day). Users must also specify the *gradation* of each of these sediment loads (below). (Note: These are **incremental percentages or fractions not cumulative curves**. (See figure titled, "Enter incremental (not cumulative or % finer) gradations in the rating curve editor.") Do not use %Finer conventions here.) Percentages (or decimal fractions) can be entered for each grain class for each load. If the total of the percentages (decimal fractions) does not equal 100 (or 1.0), HEC-RAS will normalize the total during computations (so that a given flow will produce the entered total load based on the ratios of the grain sizes).

Rating Curve for Arghandab Dahlia Dam US 19889.30

| Number of flow-load points | | 2 sets | <input type="button" value="▼"/> |
|----------------------------|--------------------------|--------|----------------------------------|
| | Flow (m ³ /s) | 1 | 1000 |
| | Total Load (tonnes/day) | 5 | 2400000 |
| 1 | Clay (0.002-0.004) | 0.2 | 0.15 |
| 2 | VFM (0.004-0.008) | 0.3 | 0.35 |
| 3 | FM (0.008-0.016) | 0.2 | 0.25 |
| 4 | MM (0.016-0.032) | 0.2 | 0.07 |
| 5 | CM (0.032-0.0625) | 0.1 | 0.07 |
| 6 | VFS (0.0625-0.125) | | 0.06 |
| 7 | FS (0.125-0.25) | | 0.05 |
| 8 | MS (0.25-0.5) | | |
| 9 | CS (0.5-1) | | |
| 10 | VCS (1-2) | | |
| 11 | VFG (2-4) | | |
| 12 | FG (4-8) | | |
| 13 | MG (8-16) | | |
| 14 | CG (16-32) | | |
| 15 | VCG (32-64) | | |
| 16 | SC (64-128) | | |

Define Diversion Load Load Concentration Conc<-->Load Plot ... OK Cancel

35 Gradational subdivisions for each sediment load in the flow-load boundary condition.

Warning: Do Not Enter Cumulative Gradations in this Editor

This editor does not take cumulative % finer data. This causes confusion, because the [bed gradation editor \(see page 69\)](#) can take data either in % finer or %/fraction per grain class. Do not enter % finer data in the rating curve editor. These should be incremental fractions (e.g. 0.3) or incremental % (30) in each grain classes (below).

| | Flow (m ³ /s) | 100 | 100 | 100 | 100 | 100 |
|----|--------------------------|-----|-----|-----|-----|-----|
| | Total Load (tonnes/day) | 500 | 500 | 500 | 500 | 500 |
| 1 | Clay (0.002-0.004) | 0.2 | 20 | 477 | 0.2 | 20 |
| 2 | VFM (0.004-0.008) | 0.3 | 30 | 716 | 0.5 | 50 |
| 3 | FM (0.008-0.016) | 0.2 | 20 | 477 | 0.7 | 70 |
| 4 | MM (0.016-0.032) | 0.2 | 20 | 477 | 0.9 | 90 |
| 5 | CM (0.032-0.0625) | 0.1 | 10 | 239 | 1 | 100 |
| 6 | VFS (0.0625-0.125) | | | | | |
| 7 | FS (0.125-0.25) | | | | | |
| 8 | MS (0.25-0.5) | | | | | |
| 9 | CS (0.5-1) | | | | | |
| 10 | VCS (1-2) | | | | | |

Fraction Per Grain Class
OK

Percent Per Grain Class
OK

Mass Per Grain Class
OK*

% Finer Fraction
Not OK

% Finer Fraction
Not OK

*If these numbers do not add up to 1 or 100 HEC-RAS will sum them, and compute the fraction of the whole.

Therefore HEC-RAS converts this:

| | Flow (m ³ /s) | 100 |
|---|--------------------------|-----|
| | Total Load (tonnes/day) | 500 |
| 1 | Clay (0.002-0.004) | 0.2 |
| 2 | VFM (0.004-0.008) | 0.2 |
| 3 | FM (0.008-0.016) | 0.2 |
| 4 | MM (0.016-0.032) | |
| 5 | CM (0.032-0.0625) | |
| 6 | VFS (0.0625-0.125) | |
| 7 | FS (0.125-0.25) | |
| 8 | MS (0.25-0.5) | |

| | Flow (m ³ /s) | 100 |
|---|--------------------------|---------|
| | Total Load (tonnes/day) | 500 |
| 1 | Clay (0.002-0.004) | 33.3333 |
| 2 | VFM (0.004-0.008) | 33.3333 |
| 3 | FM (0.008-0.016) | 33.3333 |
| 4 | MM (0.016-0.032) | |
| 5 | CM (0.032-0.0625) | |
| 6 | VFS (0.0625-0.125) | |
| 7 | FS (0.125-0.25) | |
| 8 | MS (0.25-0.5) | |

This video (starting at 8:34) describes two common errors we see in this editor.



Sorry, the widget is not supported in this export.

But you can reach it using the following URL:

http://youtube.com/watch?v=rA_8IFWVMEw

Modeling Note: Estimating a Flow-Gradation

HEC-RAS requires precise gradational subdivisions of each boundary load in order to compute grain-class specific transport. However, these data rarely exist, and when they do they are usually either unhelpfully biased towards low flows that do little morphological work or are so noisy that

it is difficult to infer a trend. Sediment load can also coarsen or fine with flow, making it difficult to estimate how to vary these data.

Gibson and Cui (2017)⁶ "Flow Dependence of Suspended Sediment Gradations," *Water Resources Research*, 53(11), 9546-9563, doi.org/10.1002/2016WR020135 ([proof](#)⁷) examined the flow-gradation relationships from 78 US gages and provide some guidance on estimating this parameter. But estimating this parameter is part of the 'art' of sediment transport modeling, combining data, system process understanding, scientific intuition, and engineering judgment. Because load gradation is among the least certain and most sensitive data, it often emerges as a target calibration parameter (Gibson and Pridal, 2015).

1.2.2.2.4 Creating a Sediment Rating Curve (Best Practices)

HEC-RAS Includes a New Tool to Support These Analyses

Since version 6.2, HEC-RAS includes a [Sediment Rating Curve Analysis Tool](#)⁸⁹, that downloads or imports sediment data (automatically from a USGS gage) and walks users through the analyses described on this page and video.

Flow load data, if available, are usually noisy, spanning one or two orders of magnitude. Seasonal effects, non-stationarity, hysteresis, sample error and random processes make flow an imperfect predictor of load. Therefore, defining a single flow-load rating curve requires approximating the 'data cloud' with a single curve of flow-load points. Several considerations should guide flow-load estimation. Best practices in developing a sediment rating curve are discussed below, and several of them are described in the second half of this video:



Sorry, the widget is not supported in this export.
But you can reach it using the following URL:
<http://youtube.com/watch?v=cBr3KkLTW1Y>

Gray and Simoes¹⁰ also wrote an excellent chapter in the ASCE Sediment Engineering Manual of Practice (110) on sediment load and rating curve data that provides good context for developing a rating curve boundary condition.

1. Consider Unmeasured Load:

Most sediment load measurements exclude bed load and near-bed, high concentration suspended load. If the river has substantial bed load, particularly at high flows, augment the flow-load curve to reflect these.

6 <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016WR020135>

7 https://www.researchgate.net/publication/319857228_Flow_Dependence_of_Suspended_Sediment_Gradations

8 <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/sediment-rating-curve-analysis-tool>

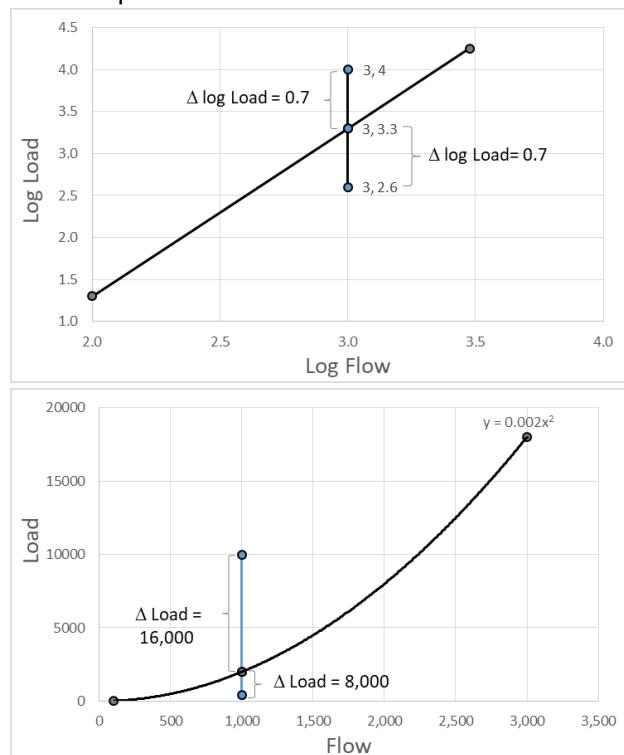
9 <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/sediment-rating-curve-analysis-tool>

10 https://water.usgs.gov/osw/techniques/Gray_Simoes.pdf

2. Use Predictor-Correctors to Un-bias Flow-Load Rating Curves:

The most common way to fit a noisy data cloud, with a general, linear trend in log-log space, is a transformed regression. When Excel or R fit a power function to flow-load data, they log transform the data and then fit a straight line to the log-transformed data with a least-root-mean-squared (LMRE) regression.

However, when the regression is untransformed, the positive residuals are always larger than the negative residuals. The figure below shows equal log transformed residuals, that balance in a transformed, LRME, regression (left). But after the reverse transform, the positive residual is almost twice the negative residual. This asymmetry of the transformed residuals biases power fits low. A standard power fit of flow-load data in Excel will underestimate load substantially (often by 5-60%).



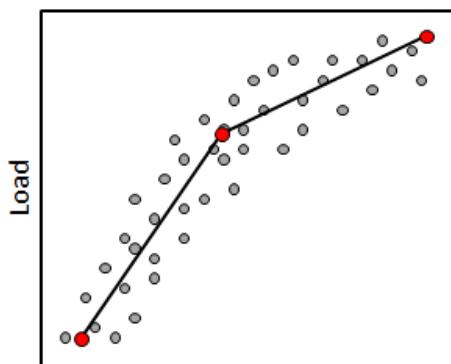
Modelers should unbias their rating curve when fitting a power function to flow-load data. USACE modelers (Copeland and Lombard, 2009) have used Ferguson (1986) correct the transform bias in a flow-load power function. More recently, the USBR, USGS, and USACE modelers tend to use the Duan (1983) 'smearing factor.*' HEC is working on a Rating Curve calculator to help with this analysis (and others described in this section). At the least, be prepared to increase the loads by 10-60% during model calibration when using an un-corrected, power fit to represent measured flow-load data.
(*Note: Another option is to regress concentration - which is not monotonic - with a polynomial).

3. Select as Few Flow Load Points as Possible:

A flow-load curve should span the entire range of flows, including a minimum of two points. The rating curve must include a low flow and a high flow that bound observed or expected flows and their accompanying loads. A common error involves developing a flow-load rating curve that only extends to the maximum flow with a concentration sample, and not the maximum flow in the model.

Keep boundary conditions as simple as possible, but no simpler. There are two reasons to add intermediate flow-load points:

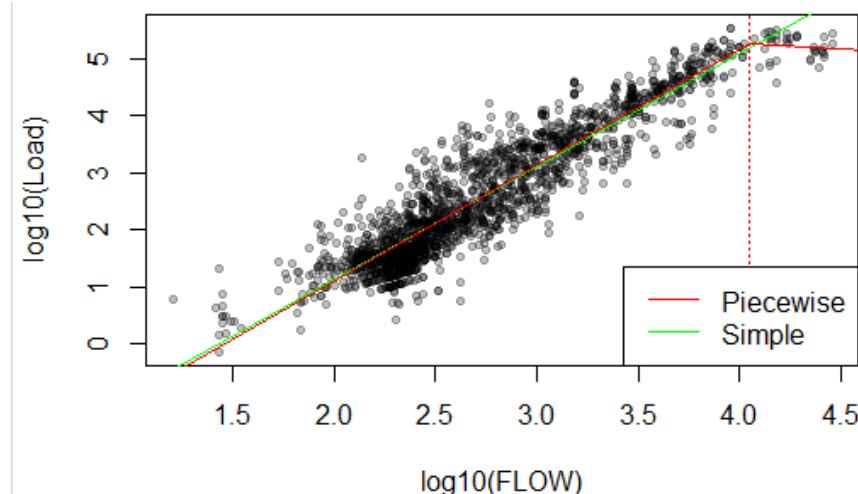
- Rating Curve Slope Change: HEC-RAS uses log interpolation to associate loads with flows between specified flow-load pairs. Sometimes sediment load curves have inflection points, though. Supply limitation may flatten the upper portion of the curve or the curve might steepen in the higher flows. Add intermediate points to capture these inflection points.



(below).

Flow

HEC has developed an algorithm to find the inflection point in a rating curve and fit a continuous piecewise-linear regression to a "bent" rating curve. This will be available in the **Rating Curve Analysis** tool in future versions of HEC-RAS.



- Gradation Change: Users must enter gradational breakdowns for each point on the flow-load curve (see [Flow-Gradation section¹¹](#)). However, gradational changes also require flow-load records. Define intermediate flow-load points at any flow that requires unique gradation data, even if it approximates the load that the rating curve would select automatically.

4. Calibration:

Sediment models must be calibrated to provide reliable predictive results. Calibration parameters, those adjusted to replicate historical bed change, should be those that are most uncertain and most

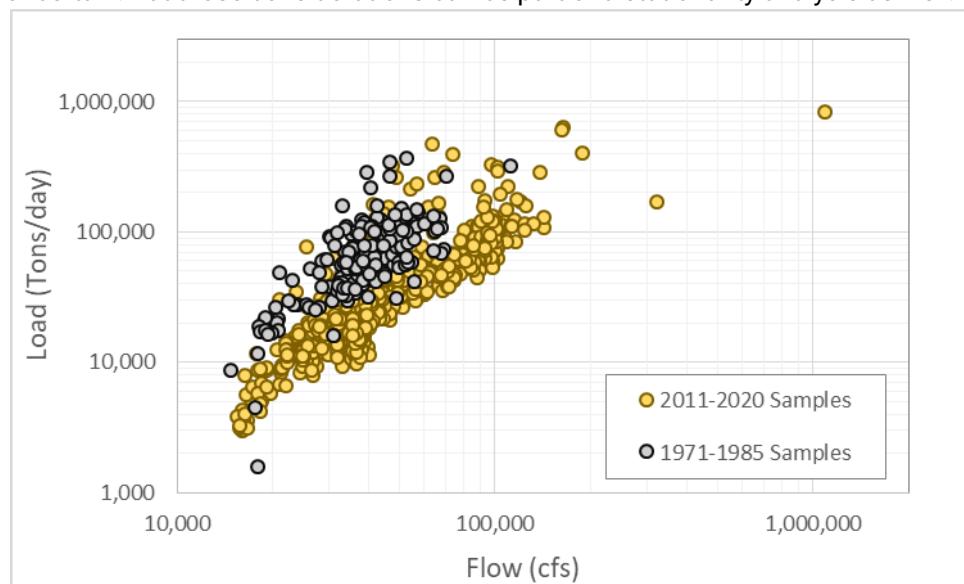
¹¹ <https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/entering-and-editing-sediment-data/sediment-boundary-conditions/rating-curve#RatingCurve-Load-GradationData>:

sensitive. Sediment models are often highly sensitive to the load boundary condition, which is uncertain even if good data are available. Therefore, estimated flow-load curves should be provisional, refined during the calibration process.

5. Stationarity Analysis

Sediment load changes over time. Agricultural impacts, land use changes, fires, mass wasting events, dam removals, and eruptions while dams, pavement, and improved agricultural practices can decrease sediment loads (Walling and Fang (2003). Walling D.E. and Fang D. (2003) "Recent trends in the suspended sediment loads of the world's rivers." Global and Planetary Change 39:111–126.

Because sediment load data are often scarce, modelers want to make use of all the data available. But it is important to test the load stationarity (does it change over time). Plot and analyze the data in time blocks, particularly before and after known system changes like a dam or gravel mining policies. If there is a big shift in the rating curve over time, consider using the most recent data to develop the future conditions rating curve. The effects of climate change on future sediment loads is regional and uncertain. But those considerations can be part of a stationarity analysis as well.



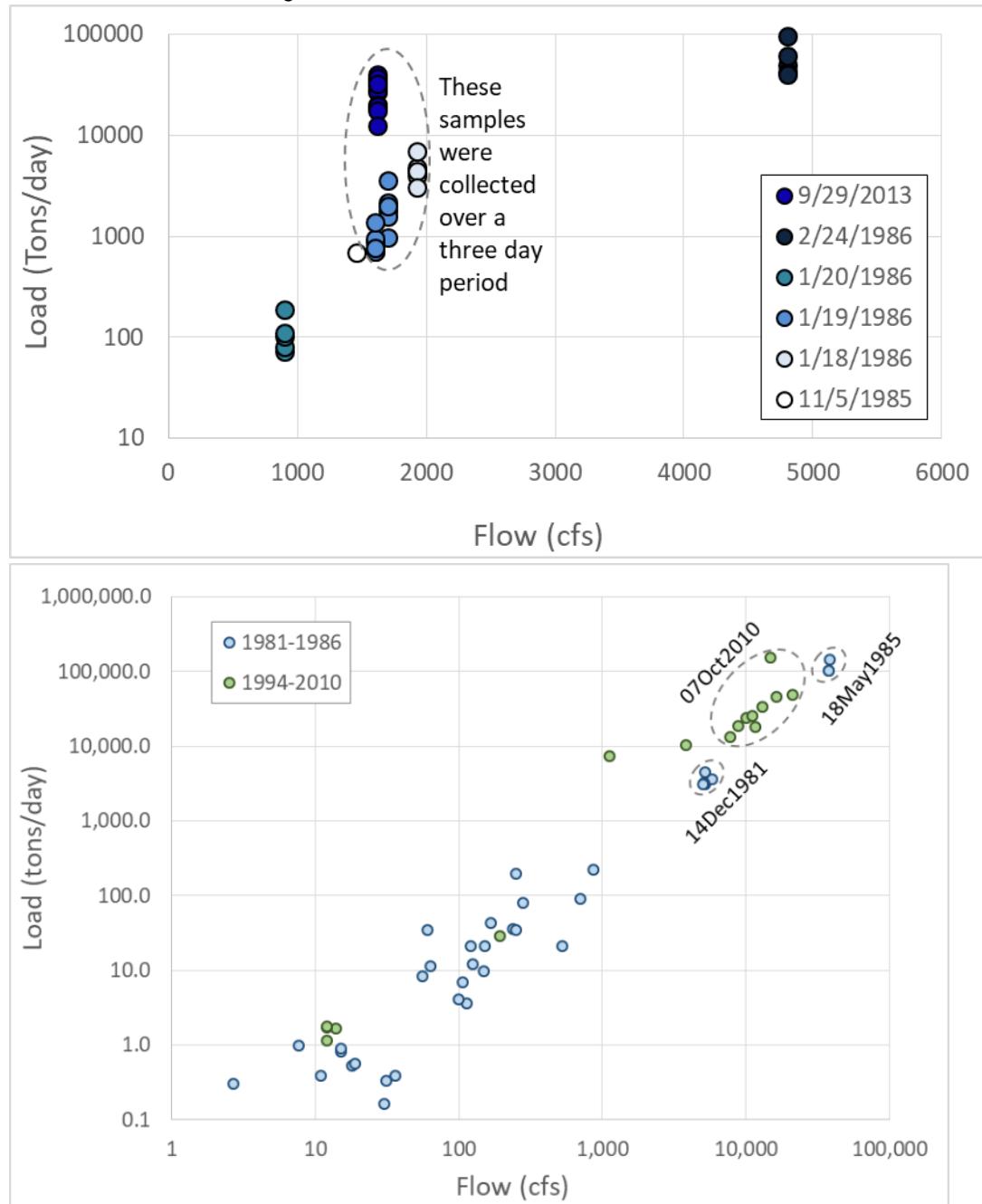
6. Serial Correlation

Regression analyses – including the transformed, LMSE regression used to fit a power function and unbiasing corrections – assume observation independence. However, most sediment load data are opportunistic. It is common to find several of the load measurements in the flow-load measurements at a gage are collected on the same day.

When developing a flow-load curve, the analyst must decide if these same-day samples are replicates or independent enough to add value. Including replicates, over-weights those observations in the regression and biases the sample (i.e. serial correlation or autocorrelation).

But if the rate-of-rise of the hydrograph is sufficient, these samples can be independent enough to

include several or all of them, particularly when they represent and under-sampled portion of the curve (e.g. high, 07Oct2010 flows in Figure 1 58 and Figure 1 59) . Figure 1 58 and Figure 1 59 include two examples of flow-load data with same-day sample clusters. However, each sampling day in Figure 1 58 covers a constrained flow range, making these more like replicates. The 07Oct2010 samples in Figure 1 59, however, cover a wide range of flows.



Modelers should – at least - make this decision, whether to include temporally clustered data as independent observations or average them as replicates. But the best practice includes a statistical test to determine the independence of these data. The USGS software package SAID¹² (The

12 <https://water.usgs.gov/osw/SALT/SAID/index.html>

Surrogate Analysis and Index Developer Tool) includes serial correlation analyses and quantitative methods to distinguish observations from replicates.

7. Statistical Power of Low Flow Samples:

Most sediment samples are collected at low flows when sampling conditions are safe. However, these loads are not very important morphologically. So many rating curve regressions over-weight the influence of the least significant samples. Use common sense to evaluate the rating curve, recognizing that the 50% recurrence-interval flow (and larger events) will do most of the morphological work in the system. If a quantitative fit of the available data does not reflect the flow-load relationship of the most morphologically significant flows and loads, an estimated hand fit (and using load as a calibration parameter) might be more appropriate.

1.2.2.2.5 Diversion Load

Sediment **Rating Curves** require positive flows and loads. Sometimes lateral flow boundary conditions simulate bidirectional flow, modeling inflows with positive values and abstractions with negative flows. Large weirs in large rivers have been modeled this way in legacy models (e.g. HEC-6T). HEC-RAS computes weir flow and sediment diversion with Lateral Structures. However, sometimes users want more control over diversion assumptions, defining them explicitly with diversion coefficients. This feature should be restricted to lateral flow series.

The **Rating Curve** option includes a diversion feature that gives users control over diversion mass and gradation. If the lateral flows are positive (into the cross section) HEC-RAS will use the rating curve, but if flows are negative (out of the cross section) the **Diversion Rating Curve** will control the sediment diverted by grain class.

To define a sediment diversion relationship, specify a sediment rating curve at a cross section with a lateral flow boundary condition and select the **Define Diversion Load** checkbox. This option expands the editor to include a second rating curve that ties grain class specific diversion data to negative flows (see figure below).

The diversion rating curve will have the same number of flow-load points as the standard rating curve. The user must populate the first row of the diversion data with negative flows that span the range of negative flows expected in the lateral flow series.

Columns: The diversion rating curve columns are coupled to the flow-load curve. The **Number of Flow-Load Points** drop down box controls both. Both must have the same number of columns.

Flow: Like the rating curve, the diversion curve is tied to flows in the lateral flow series associated with the cross section. However, the diversion curve flows are negative, decreasing (larger negative numbers) from left to right.

Total Load (Optional): By default, the diversion option removes sediment proportional to the diverted flow (e.g. if the lateral flow series removes 10% of the flow, HEC-RAS removes 10% of the sediment). Users can override this default, however, directing the program to remove defined masses for particular flows.

Grain Class Coefficients (the next 20 rows): After HEC-RAS computes the total sediment mass of diverted it subdivides the diverted mass by grain class. The initial gradation of the diverted sediment adopts the gradation of the transported sediment (mass into the control volume). However, diversions do not divert all sediment equally. Finer grain classes, more evenly distributed in the water column, are more likely to divert in proportion to the flow. Coarser materials, concentrated near the bed will divert less sediment than flow and the coarsest grain classes often do not divert at all.

Load Specification for Sacramento Sac to Nimbus 84.5

| Number of flow-load points | | 5 sets | | | | | |
|----------------------------|-----------------------|--------|-------|-------|-------|-------|--|
| | Flow (cfs) | 1 | 100 | 1000 | 10000 | 50000 | |
| | Total Load (tons/day) | 0.272 | 27.25 | 272.5 | 2725 | 13635 | |
| 1 | Clay (0.002-0.004) | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | |
| 2 | VFM (0.004-0.008) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| 3 | FM (0.008-0.016) | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | |
| 4 | MM (0.016-0.032) | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | |
| 5 | CM (0.032-0.0625) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | |
| 6 | VFS (0.0625-0.125) | | | | | | |
| 7 | FS (0.125-0.25) | | | | | | |
| 8 | MS (0.25-0.5) | | | | | | |
| 9 | CS (0.5-1) | | | | | | |
| 10 | VCS (1-2) | | | | | | |
| 11 | VFG (2-4) | | | | | | |
| 12 | FG (4-8) | | | | | | |
| 13 | MG (8-16) | | | | | | |
| 14 | CG (16-32) | | | | | | |
| 15 | VCG (32-64) | | | | | | |
| 16 | SC (64-128) | | | | | | |

Define Diversion Load Plot ...

HEC-RAS uses this rating curve if the lateral flows are positive

| | Flow (cfs) | -90000 | -19200 | -15300 | -11500 | -1 |
|----|-------------------------|--------|--------|--------|--------|-------|
| | Div Load(opt)(tons/day) | | | | | |
| 1 | Clay | 1 | 1 | 1 | 1 | 1 |
| 2 | VFM | 1 | 1 | 1 | 1 | 1 |
| 3 | FM | 1 | 1 | 1 | 1 | 1 |
| 4 | MM | 1 | 1 | 1 | 1 | 1 |
| 5 | CM | 1 | 1 | 1 | 1 | 1 |
| 6 | VFS | 0.88 | 0.88 | 0.82 | 0.69 | 0.62 |
| 7 | FS | 0.47 | 0.47 | 0.37 | 0.2 | 0.14 |
| 8 | MS | 0.09 | 0.09 | 0.05 | 0.01 | 0.003 |
| 9 | CS | 0.002 | 0.002 | 0.0013 | 0.0002 | |
| 10 | VCS | | | | | |
| 11 | VFG | | | | | |
| 12 | FG | | | | | |
| 13 | MG | | | | | |
| 14 | CG | | | | | |
| 15 | VCG | | | | | |
| 16 | SC | | | | | |

HEC-RAS uses this rating curve if the lateral flows are negative

OK Cancel

36 Lateral Flow-Load Rating Curve with Sediment Diversion.

The grain class coefficients apply a screen for each grain class diversion, reducing mass diversion by grain class for these effects. Assign a coefficient of "1" to divert the total computed grain class mass. Coefficients less than one reduce the diverted mass (e.g. 0.35 will only divert 35% of the grain class). Blank or "0" coefficients divert no mass in those grain classes.

Modeling Note: Diversion Relationship Application

The load diversion rating curve either requires copious data with good vertical concentration resolution or analytical estimates (e.g. with a Rouse computation). In general, especially with unsteady sediment transport available in versions since version 5.0, lateral structures can model sediment diversions more directly. Modeling a sediment diversion with a [lateral structure](#) (see page 141) will almost certainly be easier, and - unless the project has excellent gradation data of the gradation sediment or high confidence in analytical distributions – may perform comparably.

1.2.2.2.6 USGS Load and Gradation Data

The [Rating Curve Analysis Tool](#)¹³in the latest versions of HEC-RAS is designed to streamline the process of downloading and analyzing sediment load, concentration, and gradation data. Please let HEC know if encounter issues with data access or if there are analyses you would like to perform with this tool.

But the legacy information about how to manually download USGS sediment data are collected here.

Modeling Note: Flow-Load gage data

HEC-RAS has a tool since version 6.2 that automatically imports sediment load and gradation data from the USGS website.

<https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/sediment-rating-curve-analysis-tool>

Making the following information obsolete. But this is how we used to get data.

In the United States, the US Geological survey publishes sediment load samples at gages that have them online. If the system you are modeling has a gage, go to the "Water Quality" data portal:

<https://nwis.waterdata.usgs.gov/usa/nwis/qwdata>

to see if the gage has sediment data. The easiest way to search is by Gage #, but you can also search by other criteria (e.g. gage name, river, location). You can download the file with all of the data

You can also limit the search to records that only have sediment loads or concentrations. The USGS data codes for these measurements are:

00060 - Discharge, cubic feet per second

00061 - Discharge, instantaneous, cubic feet per second Load measurements are usually associated with instantaneous measurements, but sometimes associated with the period-averaged flows, so it is often useful to download both even though this usually generates a file with more data to simplify. Sometimes sediment concentrations or loads are not reported with flows, but for larger rivers, the daily flows associated with the sample are available outside the water quality database.

¹³ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/sediment-rating-curve-analysis-tool>

80154 - Suspended sediment concentration, milligrams per liter

80155 - Suspended sediment discharge, tons per day

Other sediment parameter codes are available [here](#)¹⁴.

- Samples and parameters to include:
 - Samples that include only above parameter selection criteria (Count: 0)
 - Samples that include above selection criteria and all associated parameters
 - Samples that include above selection criteria plus one or more of these parameter codes separated by a comma (Limit: 200 codes).

```
80154,80155,00060,000
61
```

<--Find [parameter codes](#)

- Samples that include above selection criteria plus one or more of these parameters in a file

Enter the full pathname of a file containing parameter codes. (Limit: 200 codes)

No file chosen

- Table of data

- Tab-separated data

* Save compressed files with a .gz file extension.

Alternately, the USGS has excellent tools available to retrieve these data with R. See the [USGS R library tools and tutorials](#)¹⁵.

Modeling Note: Flow-Gradation gage data

In the United States, the US Geological survey publishes sediment load gradation samples at gages that have them online. These are not common, and where they exist they are not numerous. If the system you are modeling has a gage, go to the "Water Quality" data portal: <https://nwis.waterdata.usgs.gov/usa/nwis/qwdata>

and download all of the water quality data. There are [many ways](#)¹⁶ to report sediment gradation data. The most common records (particularly for historical sieve and hydrometer data) are 70326-70347.

1.2.2.3 Defining a Sediment Time Series (Manual & DSS)

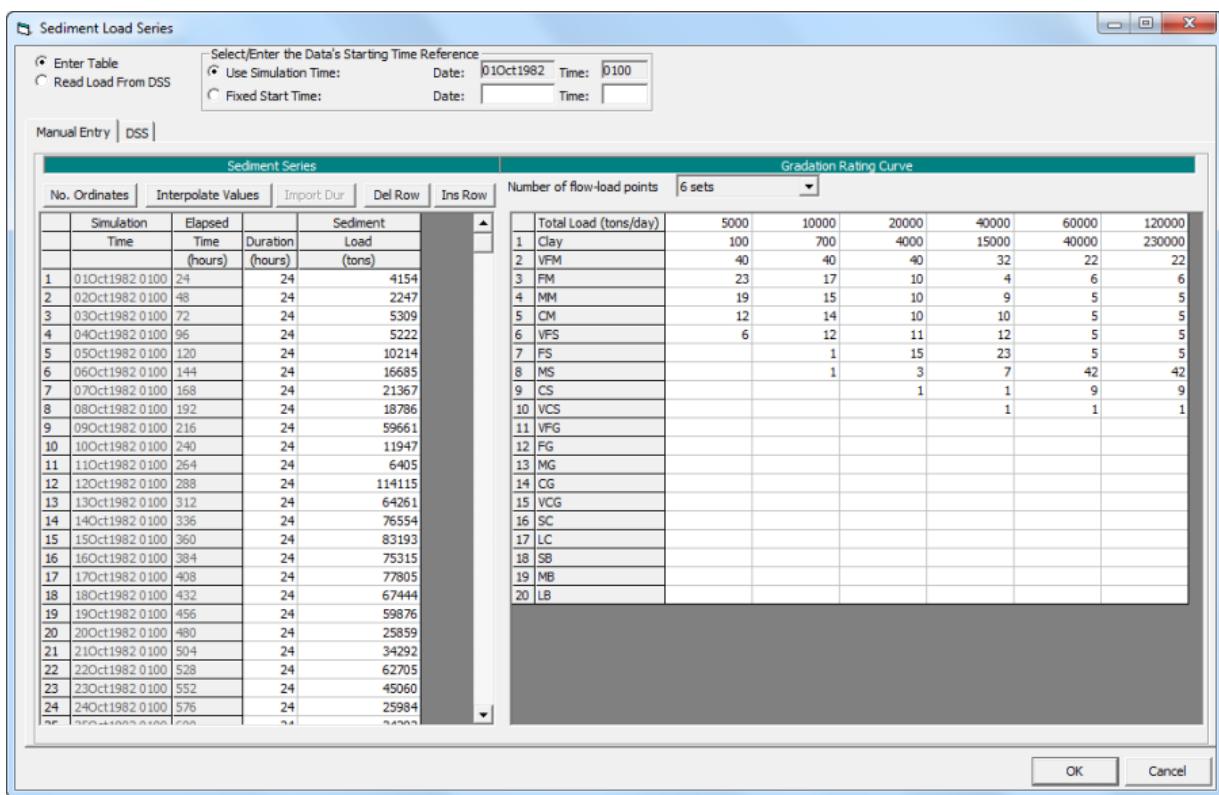
1.2.2.3.1 Sediment Time Series: Manual Data Entry

If sediment load cannot be coupled to flow, include it as a Sediment Load Series (below). Since the sediment series boundary does not depend on a flow boundary, it introduces sediment to any cross section whether it has a flow series or not (except for the downstream boundary). For example, if the sediment load rate is 1,000 tons per day, the load would be 1,000 tons for a 24-hour duration but 250 for a 6 hour duration.

¹⁴ https://help.waterdata.usgs.gov/parameter_cd?group_cd=SED

¹⁵ <https://owi.usgs.gov/R/>

¹⁶ https://nwis.waterdata.usgs.gov/nwis/pmcodes?radio_pm_search=param_group&pm_group=Sediment&pm_search=&casrn_search=&srsname_search=&format=html_table&show=parameter_group_nm&show=parameter_nm&show=casrn&show=srsname&show=parameter_units



37 Point load sediment time series editor.

HEC-RAS requires all sediment data by grain class. Therefore, the sediment load series also needs gradation data. Enter a rating curve that defines grain size distributions for load rates. Like the flow-load rating curve, these are individual fractions or percentages (HEC-RAS will normalize them assigning each grain class the respective percentage of the sum) not a cumulative gradation curve. These gradations are tied to sediment transport *rates* in mass per day, so they only match up with the sediment loads if the durations are 24 hours. For example, if an entry on the sediment time series was 250 tons over a 6 hour duration, it would select/interpolate a gradation for 1,000 tons/day.

Coupling gradation to the load can constrain this boundary condition, making it unhelpful for some applications. The **DSS** tab provides more flexibility, defining more general sediment loads the **Manual Entry** sediment time series.

Modeling Note: Negative Sediment Time Series

The sediment time series editor supports negative sediment loads. Negative sediment time series can be a simplified approach to model floodplain deposition or dredging (though, the [dredging](#) (see page 180) features are recommended). Mixing positive and negative sediment loads in one time series can be problematic, however. HEC-RAS uses a log-interpolation to compute the gradation from the rating curve. Log interpolations do not work across zero. To model intermittent positive and negative loads at a location, apply two separate load series at adjacent cross sections.

1.2.2.3.2 Sediment Load Series: From DSS - Sediment Load Time Series by Grain Class

The HEC-DSS Sediment Load Series editor is the most general sediment boundary condition option, allowing users to specify independent sediment time series for each grain class.

HEC-DSS¹⁷ is a database that all HEC models read from and write to. It is a powerful tool to store hydrologic time series and pass data between HEC tools (e.g. parsing flows and sediment loads from HEC-HMS to HEC-RAS). This boundary condition requires an HEC-DSS file, populated with sediment time series records for each modeled grain class, and requires the HEC-DSS model to follow a several conventions to make it compatible with the sediment model.

1.2.2.3.2.1 Setting Up an HEC-DSS Sediment Time Series File:

Unless another HEC software generates the sediment DSS file automatically, users must create HEC-DSS sediment time file before using the DSS sediment Boundary. In HEC-DSSVue (or the DSS editor in HEC-RAS) create a single HEC-DSS file, with a separate DSS record, with a unique DSS path name following the conventions in the figure below (top).

HEC-DSS identifies, stores, and retrieves time series with six-part path names (A-F). A, B, D, and E are common to all DSS time series. A and B identify the series location, and D and E set the start time and time step. The C and F pathname parts are sediment specific. Set the C part to "Sediment". HEC-RAS requires this convention to recognize the time series as sediment data. The last pathname part (F) is a user note. Name the grain class in this field to make it easier to identify when linking it to HEC-RAS. Finally, the HEC-RAS sediment model assumes sediment time series are Period-Cumulative (**PER-CUM**), indicating that the sediment mass represents the total associated with the time step rather than an instantaneous rate. This is different from the manual sediment time series.

Users can create HEC-DSS time series from non-stationary data, non-HEC sediment delivery model output (e.g. GESHA, SWAT, etc..), or synthetic/stochastic loads. These data can be imported or pasted to HEC-DSS directly from Excel if it is in the correct Excel format. Split the date and time into separate columns, with the loads in another column, and then set the Excel Number type for the date and time columns to "Custom", defining "**ddmmmyyyy**" for the date and "**00:00**" for the time (bottom).

¹⁷ <http://www.hec.usace.army.mil/software/hec-dssvue/>

The screenshot shows the HEC-DSS software interface for editing a sediment load series. The dialog box has the following fields:

- River/Project:** A: MISSOURI
- Location:** B: ST JOSEPH
- Parameter = Sediment:** C: SEDIMENT
- Start Time:** D: 01JAN1994
- Time Step:** E: 1DAY
- Grain Class ID:** F: 10_VCS
- Pathname:** /MISSOURI/ST JOSEPH/SEDIMENT/01JAN1994/1DAY/10_VCS/
- Start Date:** 31 July 1994
- Start Time:** 24:00
- Units:** tons
- Type:** PER-CUM

The data table below shows sediment time series data:

| Ordinate | Date | Time | ST JOSEPH SEDIMENT 10_VCS |
|----------|-----------|-------|---------------------------------|
| 1 | 31 Jul 94 | 24:00 | 3.56 |
| 2 | 01 Aug 94 | 24:00 | 3.52 |
| 3 | 02 Aug 94 | 24:00 | 3.53 |
| 4 | 03 Aug 94 | 24:00 | 3.73 |
| 5 | 04 Aug 94 | 24:00 | 3.64 |
| 6 | 05 Aug 94 | 24:00 | 3.70 |
| 7 | 06 Aug 94 | 24:00 | 3.62 |
| 8 | 07 Aug 94 | 24:00 | 3.38 |
| 9 | 08 Aug 94 | 24:00 | 3.56 |
| 10 | 09 Aug 94 | 24:00 | 3.72 |
| 11 | 10 Aug 94 | 24:00 | 3.55 |
| 12 | 11 Aug 94 | 24:00 | 3.29 |
| 13 | 12 Aug 94 | 24:00 | 3.30 |
| 14 | 13 Aug 94 | 24:00 | 3.35 |

Buttons at the bottom include Plot, Graphically Edit, Save, and Cancel.

Annotations explain the following:

- Sediment load series in HEC-RAS are specified by grain class. Identifying the grain class will make it easier to link the DSS file to RAS.
- Pathname can be defined directly but is generally concatenated automatically from the six individually defined components above.
- Sediment time series data are defined in total mass.
- PER-CUM (Period Cumulative) is the “Data Type” used for sediment load series. This identifies the values as total mass per time interval.*
- Copy and paste time series** of loads into this column.
- Pathname parts A, B, and F are flexible. Pathname parts C, D, and E are model parameters that have to be specified precisely.

38 Adding a grain class specific sediment load time series in HEC-DSS.

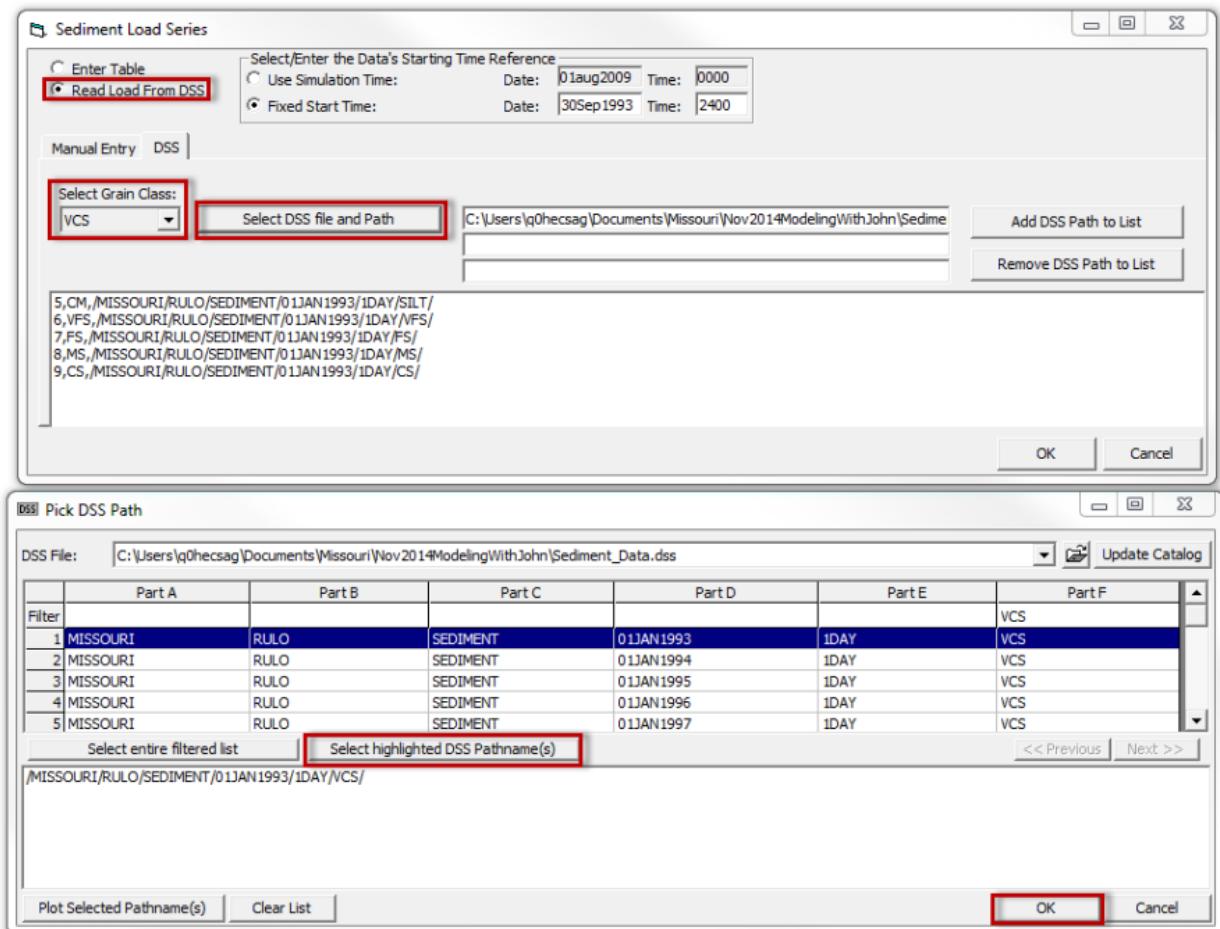
| | Date | Time | Mass-VFS (tons) |
|---|---------------|-------------|-----------------|
| 1 | 7/1/1975 0:00 | 12:00:00 AM | 0 |
| 2 | 7/1/1975 0:00 | 12:14:24 AM | 0.362687 |
| 3 | 7/1/1975 0:00 | 12:28:48 AM | 0.700165 |
| 4 | 7/1/1975 0:00 | 12:43:12 AM | 1.010883 |
| 5 | 7/1/1975 0:00 | 12:57:36 AM | 1.295731 |
| 6 | 7/1/1975 0:00 | 1:12:00 AM | 1.555773 |

39 Formatting Excel data to import into HEC-DSS.

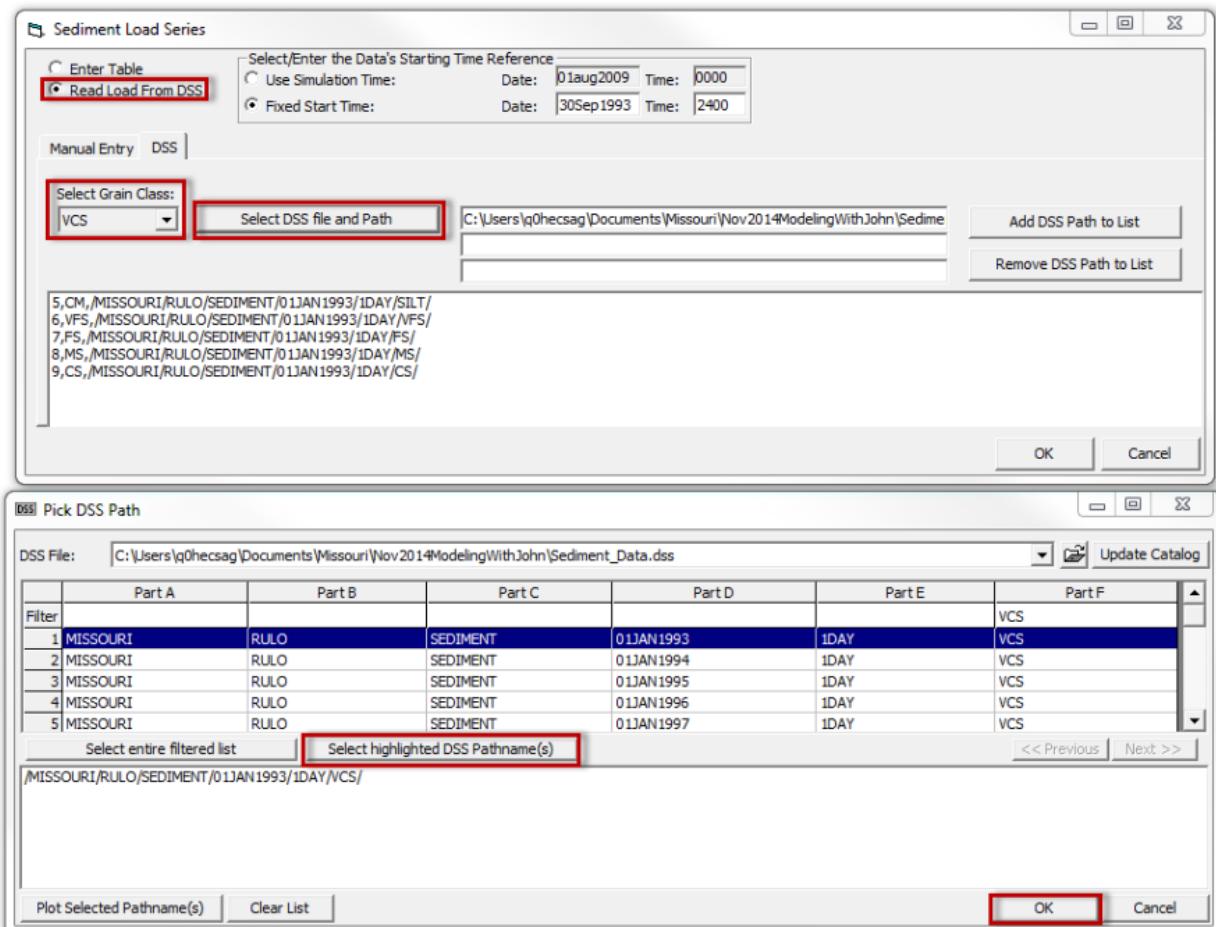
1.2.2.3.2.2 Specifying HEC-DSS Sediment Time Series in HEC-RAS:

After populating the HEC-DSS file with sediment mass records for each pertinent grain class, open the **Sediment Load Series Editor** and select **DSS** tab. A Sediment Load Series can contain both **Manual Entry** and **DSS boundary conditions**. Make HEC-RAS use the DSS data by selecting the **Read Load From DSS** option in the upper left of the dialogue (top figure below).

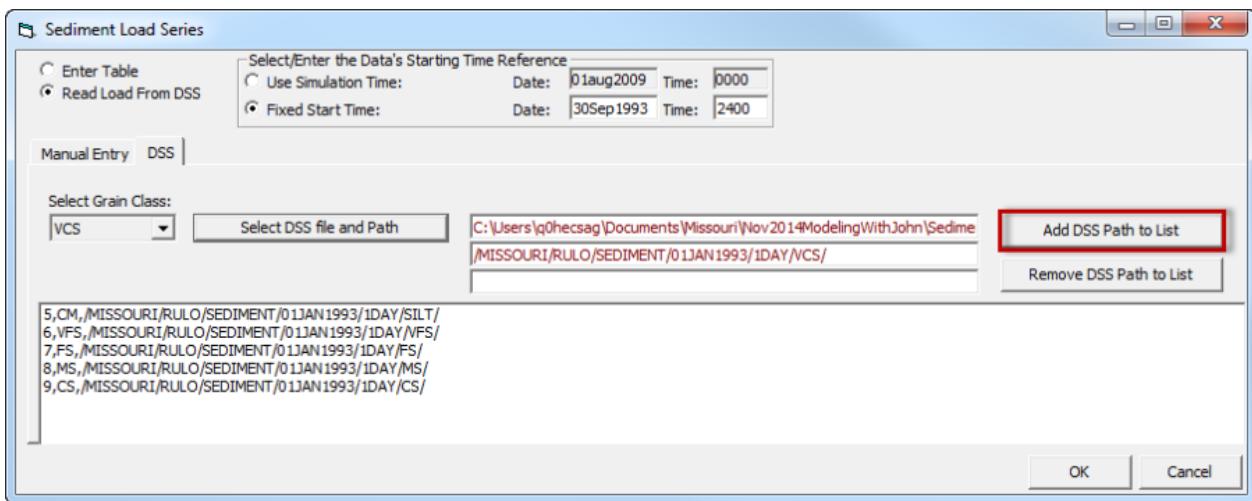
Specify load series by grain class. First **Select Grain Class** with the drop down box. Then Select press the **Select DSS file and Path** button to launch the **Pick DSS Path** editor and select the DSS file and path associated with the grain class (Figure 1 66). Select one DSS path, using the filters to isolate the correct path in a large file. If multiple paths appear, identical in everything but date, select the first one (middle). Click **OK** to write this file and pat to the time series editor. Finalize the connection between the grain class and the DSS record by pressing **Add DSS Path to List** (bottom). This will add a line to the list box below that indicates the Grain Class Index, Grain Class Name, DSS Path. To delete a record, double click on the record in the list.



40 Select a grain class from the drop down menu and press the Select DSS file and path to associate a load series with that grain class. Select the Read DSS radio button to get sediment data from DSS.



41 Use the DSS editor to select a DSS Path.



42 Once a DSS path is selected, add the grain class-DSS Path association to the list with the Add button. To remove an association double click on the list.

Modeling Note: DSS Path Workflow

To avoid selecting a new DSS file and path each time, users can select a new grain class and edit the path name manually (if, for example, the only difference is the F pathname part, which reflects the grain class).

Modeling Note: Sediment Time Series/DSS Applications

Lateral flow series are appropriate whenever flow and load are uncoupled. It is appropriate for sediment added without flows (e.g. gravel augmentation) or tributary loads driven by reservoir releases or dam removals rather than flows. They are also used to model non-stationary relationships where the flow-load relationship or the gradation changes over a long simulation (e.g. Shelley and Gibson, 2015). The DSS sediment series can also import sediment data computed by the HEC-HMS sediment model automatically (Gibson et al. 2010) or can be created from time series from other sediment delivery models. Negative sediment series can also remove sediment from a system (e.g. to simulate interception technology).

1.2.2.4 Equilibrium Load

The **Equilibrium Load** boundary condition is only available for upstream boundaries. This method computes the boundary sediment load from the bed gradation and the transport capacity. HEC-RAS computes the equilibrium sediment transport capacity – for each time step and grain class – at the upstream cross section and introduces these capacities as load time series into the next cross section. Since load is set to capacity at this boundary, equilibrium load cross sections are essentially pass through nodes. They will not aggrade or degrade.

Warning: Use Equilibrium Load with Caution

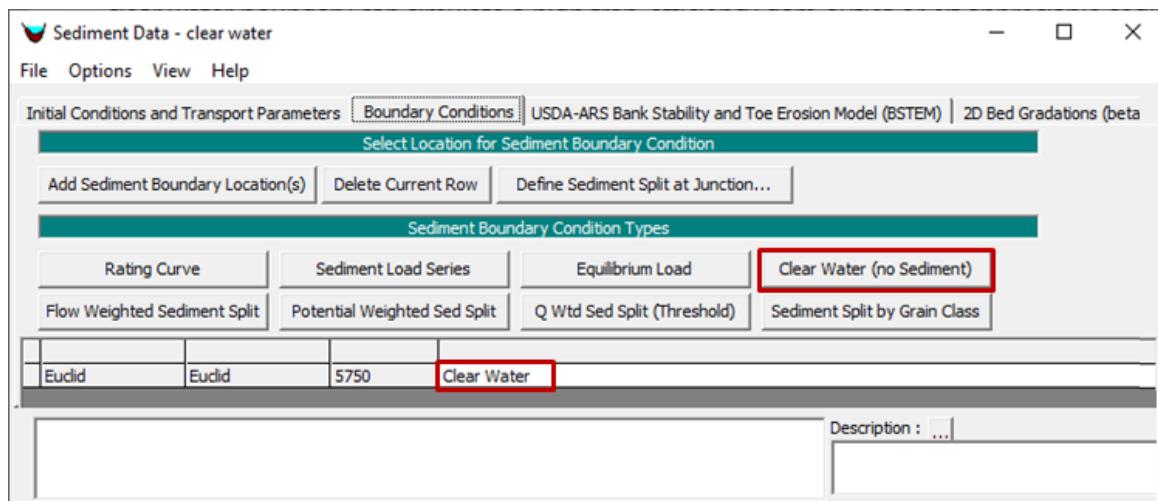
Like the Normal Depth downstream flow condition, the equilibrium load sediment boundary condition is popular because it is easy. It avoids difficult and data intensive preprocessing involved in developing a sediment rating curve or a sediment time series. However, the equilibrium load sediment boundary is often insufficient. Most sediment models are commissioned because the modeled reach is either depositing or eroding, departing from equilibrium by definition. Additionally, the equilibrium boundary condition is extremely sensitive to the bed gradation at the upstream cross section and the selected transport function, which can easily distort it by orders of magnitude. Even without data, users are often better off specifying a speculative rating curve and then calibrating it to observed bed change. When the

equilibrium load boundary condition is used, assign it to a cross section well upstream of the area of interest, in a reach known to be in dynamic equilibrium.

1.2.2.5 Clear Water Boundary Condition

HEC-RAS 6.0 and later include a "Clear Water" boundary condition. The clear water boundary condition is just a simple way to define a no-sediment boundary. The model will bring flow in at this cross section but no sediment.

A clear water boundary can simulate a high trap-efficiency dam outlet or other flow boundaries without appreciable sediment.



Clear Water Scour

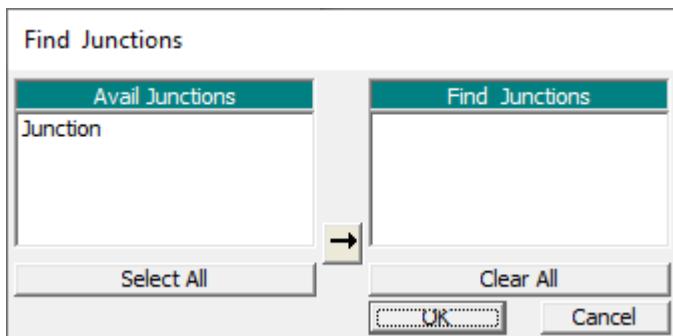
This condition usually causes scour, unless the reach has a fixed bed, is pass-through, or heavily armored.

1.2.2.6 Junctions and Flow Splits

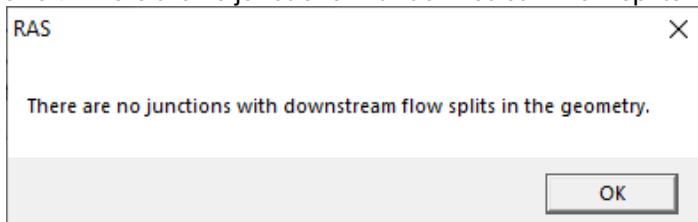
HEC-RAS 6.0 does not require user input to model sediment at junctions. Dendritic junctions, those with two upstream reaches and one downstream reach, simply combine sediment. Flow splits, junctions with one upstream reach and multiple downstream reaches, split the sediment of each grain class proportional to the flow split.

In order to select a different flow-split assumption at a junction, you will have to add the junction as a

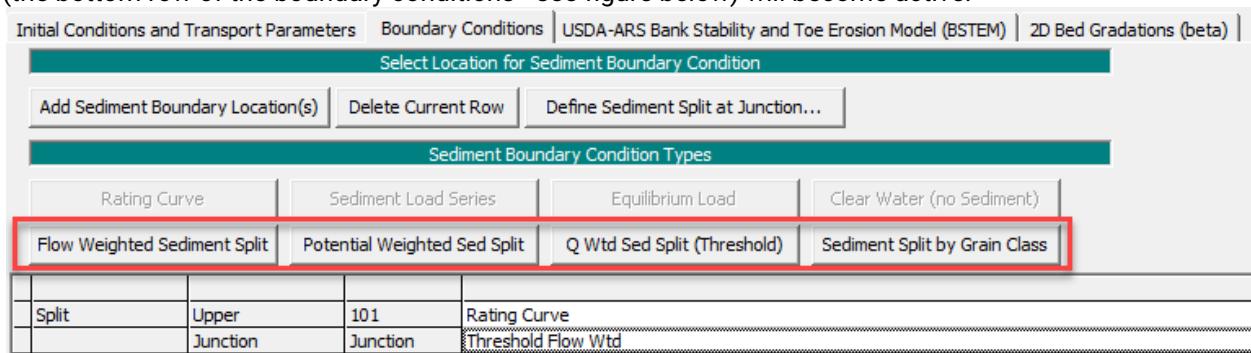
boundary condition. Press the **Define Sediment Split at Junction...** button. If the model has junctions that "split" (e.g. transition from one upstream reach to two-or-more downstream reaches), HEC-RAS will launch an editor with the junctions that it can add.



If the system is dendritic, (i.e. all reaches combine in the downstream direction so all junctions have only one downstream river/reach) HEC-RAS will not allow a junction split boundary condition. Pressing the **Define Sediment Split at Junctions** button for dendritic models (or single reach models) will return the following error: "There are no junctions with downstream flow splits in this geometry".



After adding a flow-split junction, click on the white field next to the junction name. The flow split options (the bottom row of the boundary conditions - see figure below) will become active.



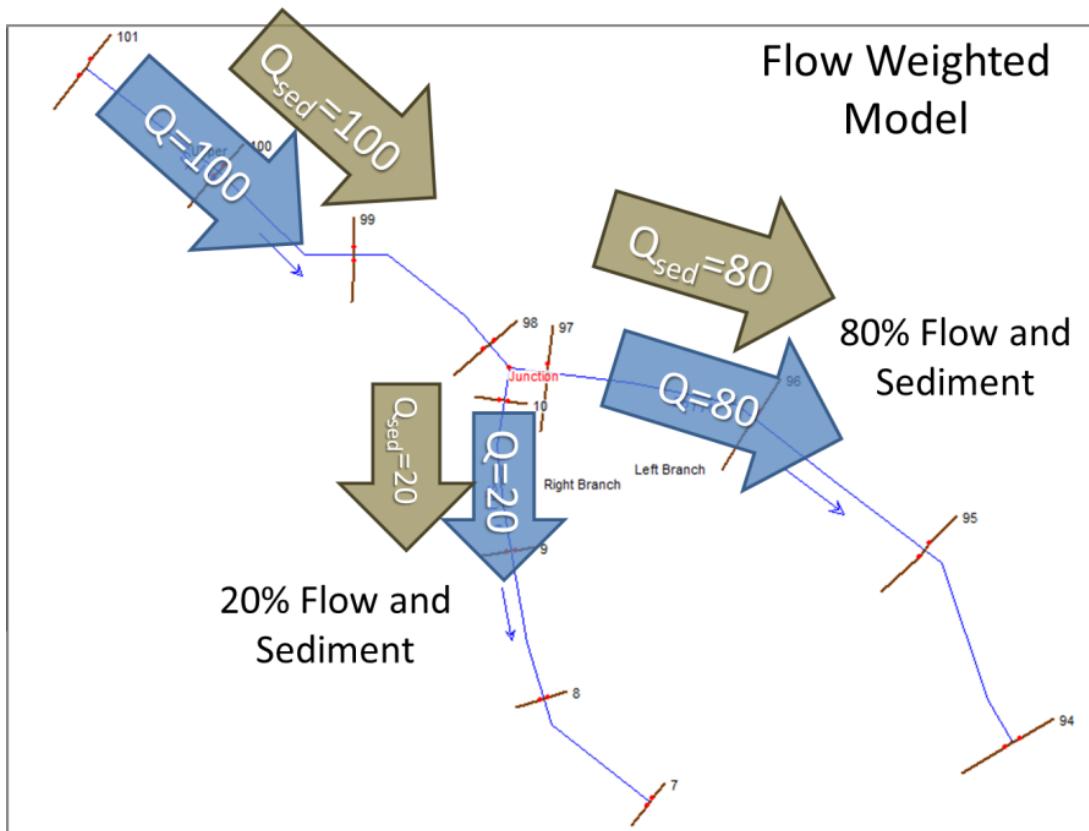
Modeling Note: Side Channel Filling

Because sediment transport is non-linear (e.g. doubling the flow generally more than doubles the transport) flow splits tend to deposit. In particular, the lower flow channel tends to deposit quickly as the flow weighted sediment partition puts more sediment in the low flow channel relative to the transport than the higher flow channel. These theoretical considerations do translate to the field, as side channels tend to deposit. However, multi-dimensional effects and perched channels tend to keep prototype channels open longer than one-dimensional split flow models. If one channel downstream of a flow split fills unreasonably, consider modeling the flow split without the junction, using single cross sections to capture both channels. Multiple movable bed limits may also be helpful.

Perched distributaries can pose another challenge to modeling flow splits. When the two downstream channels have different thalweg elevations, so most of the bed load follows one of the channels, a flow weighted split may not be appropriate for a perched distributary. Users sometimes model systems like this with lateral weirs (with grain class filters) instead of junctions. However, the current version of HEC-RAS includes grain class-specific flow split methods for junctions as well.

1.2.2.6.1 Flow Weighted Sediment Split Flow Weighted Sediment Split

This is the default calculation at a sediment split. Sediment flux in each reach is proportional to the flow. For example, if 80% of the flow goes into one reach and 20% into another, the sediment flux will have the same 80%/20% split for each grain class. If users do not add the junction to the sediment boundary condition editor, HEC-RAS will automatically split sediment this way. This feature is in the interface to help users toggle between methods and select the default without deleting the junction.

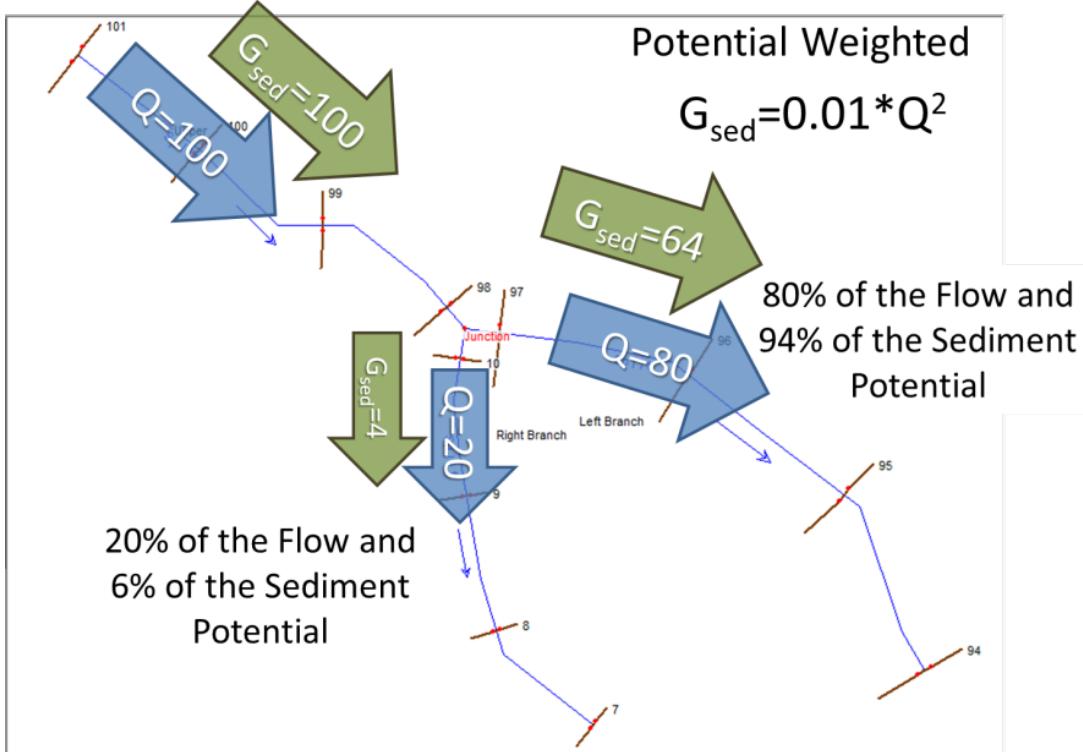


1.2.2.6.2 Potential Weighted Sediment Split Potential Weighted Sed Split

Because sediment transport is non-linear, a distributary with more flow will transport disproportionately more sediment. Therefore, a flow-weighted split tends to overestimate sediment diverted to the lower-flow distributary, which can cause the lower flow reach to deposit quickly.

The potential weighted sediment split addresses this issue, computing the sediment split based on the computed transport potential instead of the flow. Figure 1 71 reproduces the example in Figure 1 70 with a simple transport potential (G_s) equation ($G_s=0.01Q^2$) to illustrate the potential weighted approach.

Because of the non-linearity (i.e. power function) of the sediment transport potential equation, the 80%/20% flow split does not produce the same capacity split. The larger tributary has 94% of the capacity ($G_s=0.001(80)^2=64\sim94\%$) while the smaller tributary only has 6% of the capacity ($G_s=0.001(20)^2=4\sim6\%$).



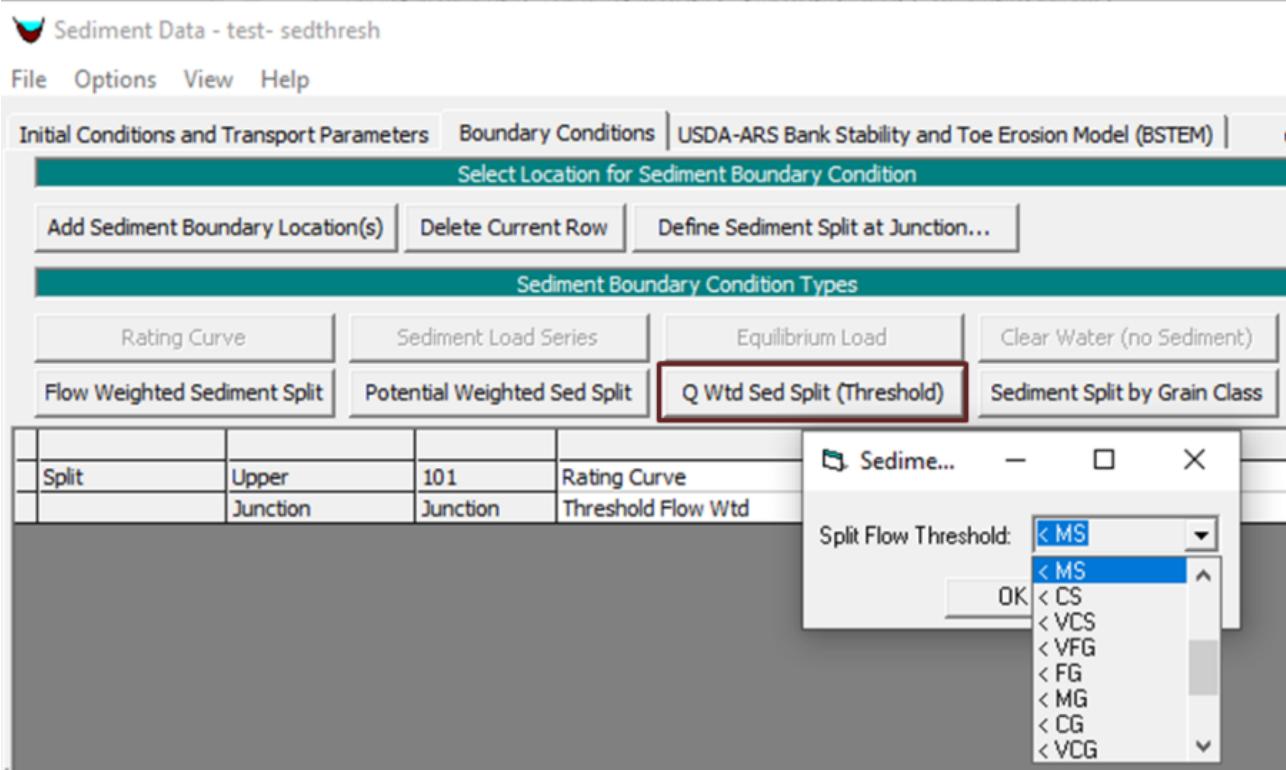
The potential weighted split divides sediment based on the percentage of the potential in all downstream reaches, instead of the flow. Another feature of the non-linear transport equations also emerges from this example. The sum of the potential in the two downstream reaches is less than the potential in the upstream reach ($64+4<100$). This is a function of the non-linear transport equations and is one of the reasons most sediment models will deposit downstream of a flow split. The combined flow has more transport potential. But splitting the flow based on potential rather than flow can slow this process and make the model more realistic.

1.2.2.6.3 Flow Weighted Split with a Grain Class Threshold

[Q Wtd Sed Split \(Threshold\)](#)

This feature works like the grain class threshold option associated with [lateral structures](#) (see page 141). This feature applies a flow weighted split for all grain classes less than a user specified threshold and sends 100% of the sediment greater than that threshold down the main reach (the reach with the same "River" name). This feature is designed to send suspended or wash load into a perched distributary while keeping bed load in the main channel.

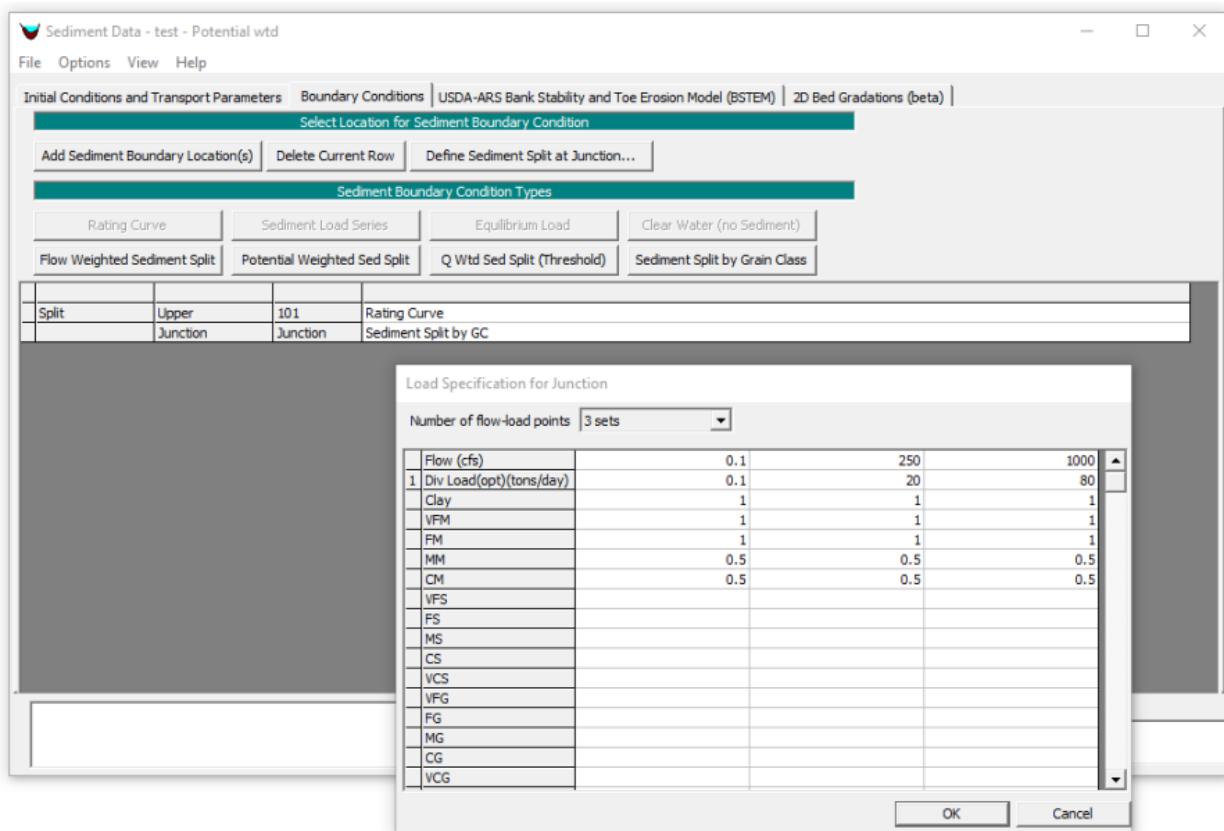
HEC-RAS uses the "River" designation to determine the main and secondary channels. HEC-RAS will check the River names downstream of the junction. The reach that has the same river name downstream of the junction is considered the main channel. The threshold keeps sediment smaller than (or equal to) the defined grain class in the main channel and only allows finer grain classes in the side channel.



43 Flow weighted sediment split with a sediment split threshold. HEC-RAS will only send sediment finer than the user specified threshold to the secondary reach.

1.2.2.6.4 Sediment Splits by Grain Class Sediment Split by Grain Class

This feature works like the [diversion \(see page 88\)](#) rating curve boundary condition. This method monitors the flow leaving the flow split. The user can choose a diverted sediment mass associated with each flow to specify the flow-load split directly. But the load split is optional. Leaving the **Div Load** row blank triggers a standard flow weighted split, and then adjusts each grain class individually from the base flow-weighted assumptions.

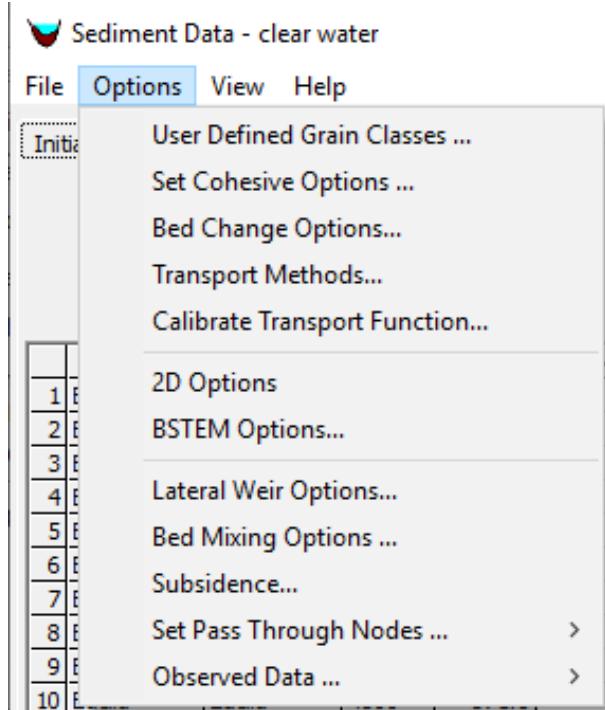


The Sediment Split by Grain Class tool then adjusts the sediment load for each grain class, from the initial value computed from the user specified or flow-weighted load. Specify a multiplier between zero and one to reduce the diverted sediment for each grain class.

For example, defining a factor of 0.5 for Very Fine Sand will half the diverted very fine sand and will send the other half in the main downstream channel. So in the example in the figure, 20 tons per day (combined for all grain classes) would be diverted to the distributary when the distributary flow is 250 cfs *if* the ratio for all grain classes was 1. Clay, very fine silt (MM), and fine silt (FM) will be diverted in their entirety. However, only half the computed medium silt (MM) and coarse silt (CM) fractions will divert, and nothing coarser than coarse silt will be diverted (because the fields are blank, entering zero in these fields would have the same result).

1.2.3 Sediment Properties Options

There are several default values used by HEC-RAS that can be changed by the user. To change the defaults, select the various options available from the **Options** menu on the Sediment Data editor. Only make changes to the default settings if it is appropriate for the specific application. A list of the options available follows.



Click on the link or button below to navigate to one of the options.

| Define Grain Classes and Sediment Properties | | | | | | | | | | |
|--|-------|--------|--------|-------|------|------|----|------|------|--|
| Sediment Diameters (mm) | | | | | | | | | | |
| Class | Label | Min | Max | Mean | SG | n | UW | Coh? | De | |
| 1 | Clay | 0.002 | 0.004 | 0.003 | 2.65 | 0.82 | 30 | 1 | 1 | |
| 2 | VFM | 0.004 | 0.008 | 0.006 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 3 | FM | 0.008 | 0.016 | 0.011 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 4 | MM | 0.016 | 0.032 | 0.023 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 5 | CM | 0.032 | 0.0625 | 0.045 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 6 | VFS | 0.0625 | 0.125 | 0.088 | 2.65 | 0.3 | 93 | 0 | 0.4 | |
| 7 | FS | 0.125 | 0.25 | 0.177 | 2.65 | 0.3 | 93 | 0 | 0.4 | |
| 8 | MS | 0.25 | 0.5 | 0.354 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 9 | CS | 0.5 | 1 | 0.707 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 10 | VCS | 1 | 2 | 1.41 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 11 | VFG | 2 | 4 | 2.83 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 12 | FG | 4 | 8 | 5.66 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 13 | MG | 8 | 16 | 11.3 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 14 | CG | 16 | 32 | 22.6 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 15 | VCG | 32 | 64 | 45.3 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 16 | SC | 64 | 128 | 90.5 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 17 | LC | 128 | 256 | 181 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 18 | SB | 256 | 512 | 362 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 19 | MB | 512 | 1024 | 724 | 2.65 | 0.3 | 93 | 0 | 0.09 | |
| 20 | LB | 1024 | 2048 | 1448 | 2.65 | 0.3 | 93 | 0 | 0.09 | |

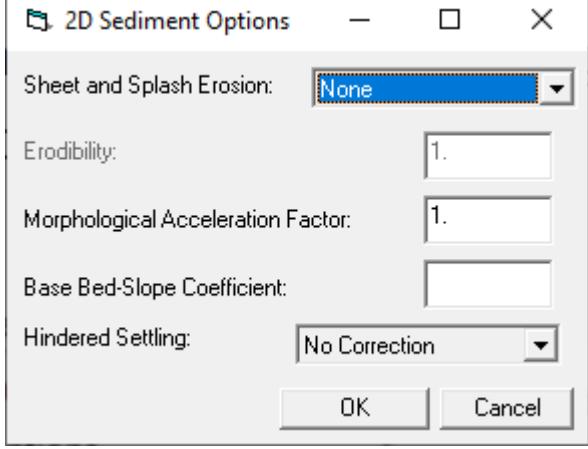
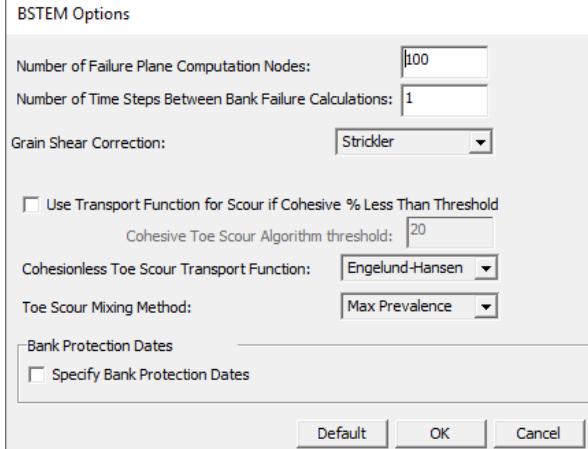
Currently Customized

Density Method: Unit Weight (All Classes) Defaults
 Enforce Adjacent-Non-Overlapping Grain Classes and Geometric Mean OK Cancel

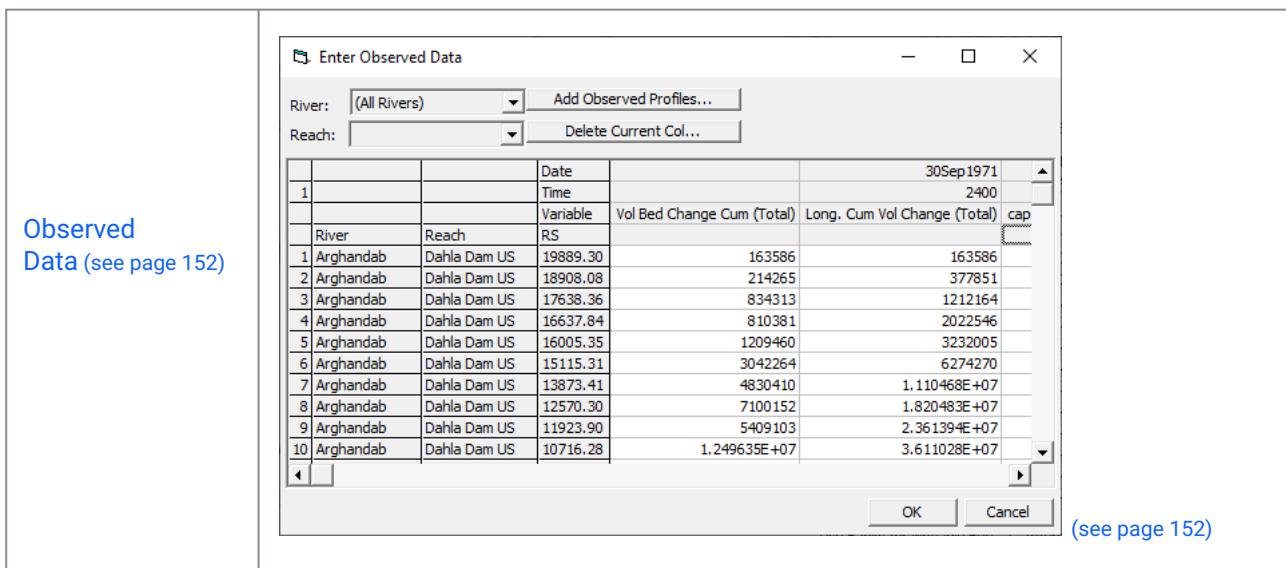
(see page 109)

Sediment Grain Classes and Properties (see page 109)

| | | | | | | | |
|---|---|---|--|---|--|---|---|
| <p>Cohesive Options (see page 114)</p> | <p>Erodibility Parameter Type: M</p> <table border="0"> <tr> <td style="text-align: center;">Particle Erosion</td><td style="text-align: center;">Mass Wasting Erosion</td></tr> <tr> <td>Threshold (τ_c) <input type="text" value="0.2"/> (lb/ft²)</td><td>Threshold (τ_{mw}) <input type="text" value="1.6"/> (lb/ft²)</td></tr> <tr> <td>Slope of the Erosion Rate Curve (M) <input type="text" value="0.6"/> (lb/ft²/hr)</td><td>(M_{mw}) <input type="text" value="15."/></td></tr> </table> <p><input type="checkbox"/> Use Effective Depth (De) for Cohesive Settling Flocculation (2D Only) >></p> <p style="text-align: right;">(see page 114)</p> | Particle Erosion | Mass Wasting Erosion | Threshold (τ_c) <input type="text" value="0.2"/> (lb/ft ²) | Threshold (τ_{mw}) <input type="text" value="1.6"/> (lb/ft ²) | Slope of the Erosion Rate Curve (M) <input type="text" value="0.6"/> (lb/ft ² /hr) | (M _{mw}) <input type="text" value="15."/> |
| Particle Erosion | Mass Wasting Erosion | | | | | | |
| Threshold (τ_c) <input type="text" value="0.2"/> (lb/ft ²) | Threshold (τ_{mw}) <input type="text" value="1.6"/> (lb/ft ²) | | | | | | |
| Slope of the Erosion Rate Curve (M) <input type="text" value="0.6"/> (lb/ft ² /hr) | (M _{mw}) <input type="text" value="15."/> | | | | | | |
| <p>Bed Change Options (see page 118)</p> | <table border="0"> <tr> <td style="text-align: center;">Channel</td> <td style="text-align: center;">Overbank</td> </tr> <tr> <td>Deposition <input type="button" value="Veneer"/></td> <td>Deposition <input type="button" value="Veneer"/></td> </tr> <tr> <td>Erosion <input type="button" value="Veneer"/></td> <td>Erosion <input type="button" value="None"/></td> </tr> </table> <p style="text-align: right;">(see page 118)</p> | Channel | Overbank | Deposition <input type="button" value="Veneer"/> | Deposition <input type="button" value="Veneer"/> | Erosion <input type="button" value="Veneer"/> | Erosion <input type="button" value="None"/> |
| Channel | Overbank | | | | | | |
| Deposition <input type="button" value="Veneer"/> | Deposition <input type="button" value="Veneer"/> | | | | | | |
| Erosion <input type="button" value="Veneer"/> | Erosion <input type="button" value="None"/> | | | | | | |
| <p>Transport Methods (Mostly 2D) (see page 136)</p> | <p>1D Methods:</p> <table border="0"> <tr> <td>Routing Method (1D):</td> <td><input type="button" value="Continuity"/></td> </tr> <tr> <td>Sediment Junction Split Method:</td> <td><input type="button" value="Flow Weighted"/></td> </tr> <tr> <td>Pool Pass Through Method:</td> <td><input type="button" value="Upstream Capacity"/></td> </tr> </table> <p style="text-align: right;">(see page 136)</p> | Routing Method (1D): | <input type="button" value="Continuity"/> | Sediment Junction Split Method: | <input type="button" value="Flow Weighted"/> | Pool Pass Through Method: | <input type="button" value="Upstream Capacity"/> |
| Routing Method (1D): | <input type="button" value="Continuity"/> | | | | | | |
| Sediment Junction Split Method: | <input type="button" value="Flow Weighted"/> | | | | | | |
| Pool Pass Through Method: | <input type="button" value="Upstream Capacity"/> | | | | | | |
| <p>Transport Function Calibration (see page 136)</p> | <p>Transport and Mobility Scaling Factors</p> <table border="0"> <tr> <td>Transport Function Scaling Factor: <input type="text" value="1"/></td> <td>Increasing This Factor Increases Transport</td> </tr> <tr> <td>Critical Mobility Scaling Factor: <input type="text" value="1.2"/></td> <td>Increasing This Factor Decreases Transport</td> </tr> </table> <p style="text-align: right;">(see page 136)</p> | Transport Function Scaling Factor: <input type="text" value="1"/> | Increasing This Factor Increases Transport | Critical Mobility Scaling Factor: <input type="text" value="1.2"/> | Increasing This Factor Decreases Transport | | |
| Transport Function Scaling Factor: <input type="text" value="1"/> | Increasing This Factor Increases Transport | | | | | | |
| Critical Mobility Scaling Factor: <input type="text" value="1.2"/> | Increasing This Factor Decreases Transport | | | | | | |

| | | |
|---|---|---------------------------------------|
| <p>2D Options (see page 140)</p> |  | <p>(see page 140)</p> |
| <p>BSTEM Options (see page 140)</p> |  | |
| <p>Lateral Structure Options (see page 141)</p> | | <p>(see page 141)</p> |

| Bed Mixing Options (see page 143) | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------------------------|--|----------|--------------|----|--------------|-------------|------------|----------|--------|-------------|------------|----------|--------|-------------|------------|--------|--------|-------------|------------|--------|--------|-------------|------------|--------|--------|
| Subsidence (see page 147) | <p>Subsidence Rates</p> <p>River: (All Rivers) ▾</p> <p>Reach: ▾</p> <table border="1"><thead><tr><th>River</th><th>Reach</th><th>RS</th><th>Rate (ft/yr)</th></tr></thead><tbody><tr><td>Mississippi</td><td>Mainstem 1</td><td>515539.1</td><td>0.0296</td></tr><tr><td>Mississippi</td><td>Mainstem 1</td><td>510771.7</td><td>0.0296</td></tr><tr><td>Mississippi</td><td>Mainstem 1</td><td>504954</td><td>0.0299</td></tr><tr><td>Mississippi</td><td>Mainstem 1</td><td>499537</td><td>0.0305</td></tr><tr><td>Mississippi</td><td>Mainstem 1</td><td>494769</td><td>0.0303</td></tr></tbody></table> <p>OK Cancel</p> | River | Reach | RS | Rate (ft/yr) | Mississippi | Mainstem 1 | 515539.1 | 0.0296 | Mississippi | Mainstem 1 | 510771.7 | 0.0296 | Mississippi | Mainstem 1 | 504954 | 0.0299 | Mississippi | Mainstem 1 | 499537 | 0.0305 | Mississippi | Mainstem 1 | 494769 | 0.0303 |
| River | Reach | RS | Rate (ft/yr) | | | | | | | | | | | | | | | | | | | | | | |
| Mississippi | Mainstem 1 | 515539.1 | 0.0296 | | | | | | | | | | | | | | | | | | | | | | |
| Mississippi | Mainstem 1 | 510771.7 | 0.0296 | | | | | | | | | | | | | | | | | | | | | | |
| Mississippi | Mainstem 1 | 504954 | 0.0299 | | | | | | | | | | | | | | | | | | | | | | |
| Mississippi | Mainstem 1 | 499537 | 0.0305 | | | | | | | | | | | | | | | | | | | | | | |
| Mississippi | Mainstem 1 | 494769 | 0.0303 | | | | | | | | | | | | | | | | | | | | | | |
| Pass Through Nodes (see page 149) | <p>Set Pass Through Nodes ... ></p> <p>Standard Pool</p> | | | | | | | | | | | | | | | | | | | | | | | | |



1.2.3.1 Define Grain Classes and Sediment Properties*

1.2.3.1.1 Default and User Defined Grain Classes:

HEC-RAS defaults to twenty grain classes that follow the ψ scale (Parkers and Andrews, 1985) for which the grain class boundaries are defined by $D=2^{\psi}$, where ψ includes the integers between -8 and 11. The default grain classes are detailed in the table below.

The user can define a customized set of grain classes in order to focus more detail in a particular size range or model specific grain sizes. Selecting the **User Defined Grain Classes** item on the **Options** menu allows the user to override default HEC-RAS grain classes. This menu option will open the dialog depicted in the figure below. The **User Defined Grain Classes** dialog defaults to the grain classes outlined in the table below, and will write a text line at the bottom of the dialog with a "Currently Default" message if this is the case (below).

HEC-RAS must have twenty grain classes, but it will only compute grain classes that exist in the model. HEC-RAS will ignore any grain classes that do not exist in the bed or the boundary conditions. Including fewer grain classes will speed up run times – particularly in the 2D sediment model.

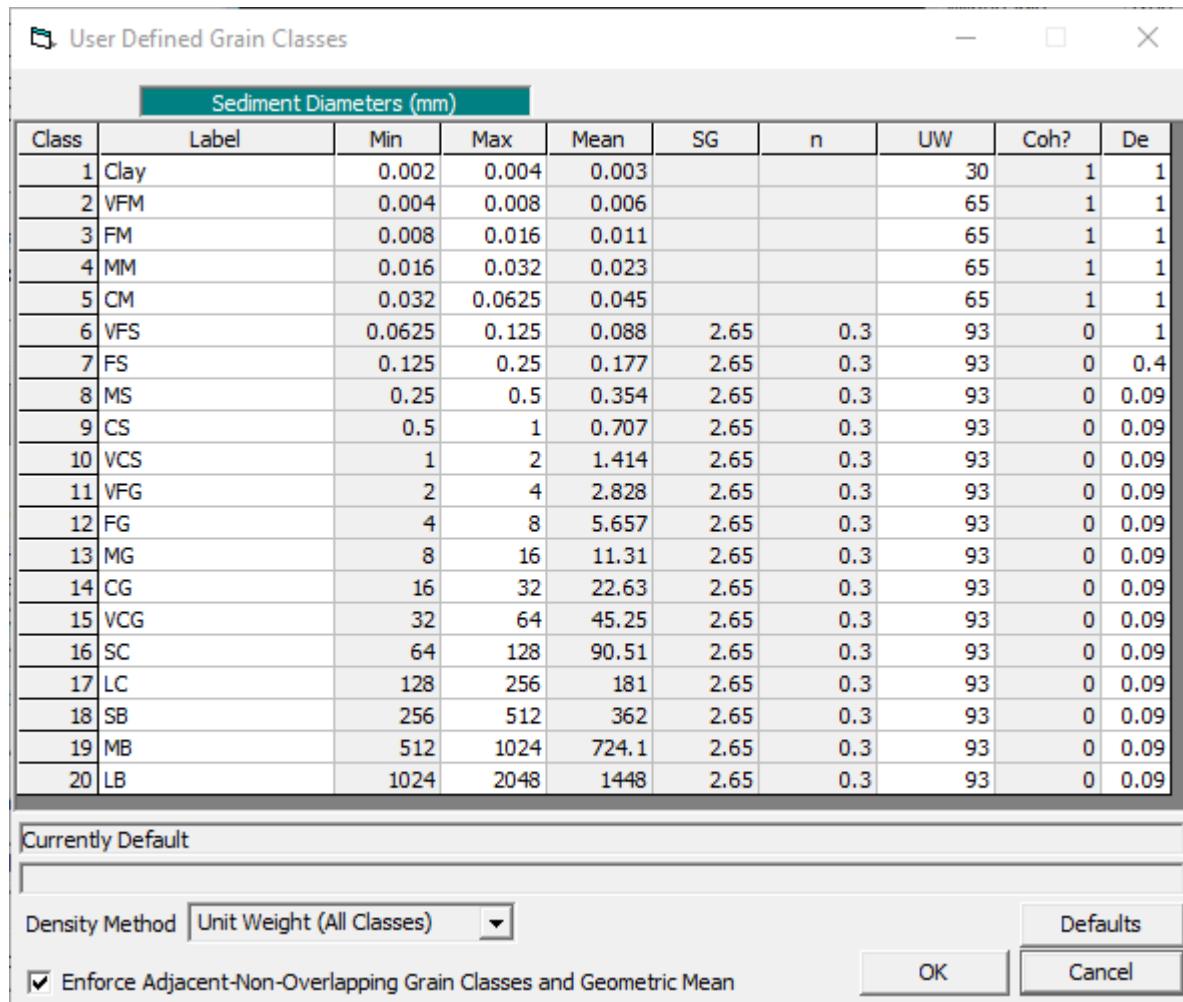
Earlier versions of HEC-RAS required grain classes that are adjacent, increasing, and non-overlapping. Defining adjacent, increasing, non-overlapping grain classes is still usually best practice. Therefore, by default the lower bound of each grain class (except the first one) copies to the upper bound of the previous class. Users edit the grain classes in this mode by changing the upper bounds (labeled max in the figure below). The editor computes geometric means (which are the actual, representative grain size HEC-RAS uses in the computation) in the **Mean**. If the user changes the grain classes, the dialog will show the "Currently Customized" message in the panel below the buttons. Reset to the default parameters by pressing the **Defaults** button.

Default grain classes in HEC-RAS (mm).

18 http://hydrolab.illinois.edu/people/parkerg/_private/Man54/Man54Chap3WholeText.pdf

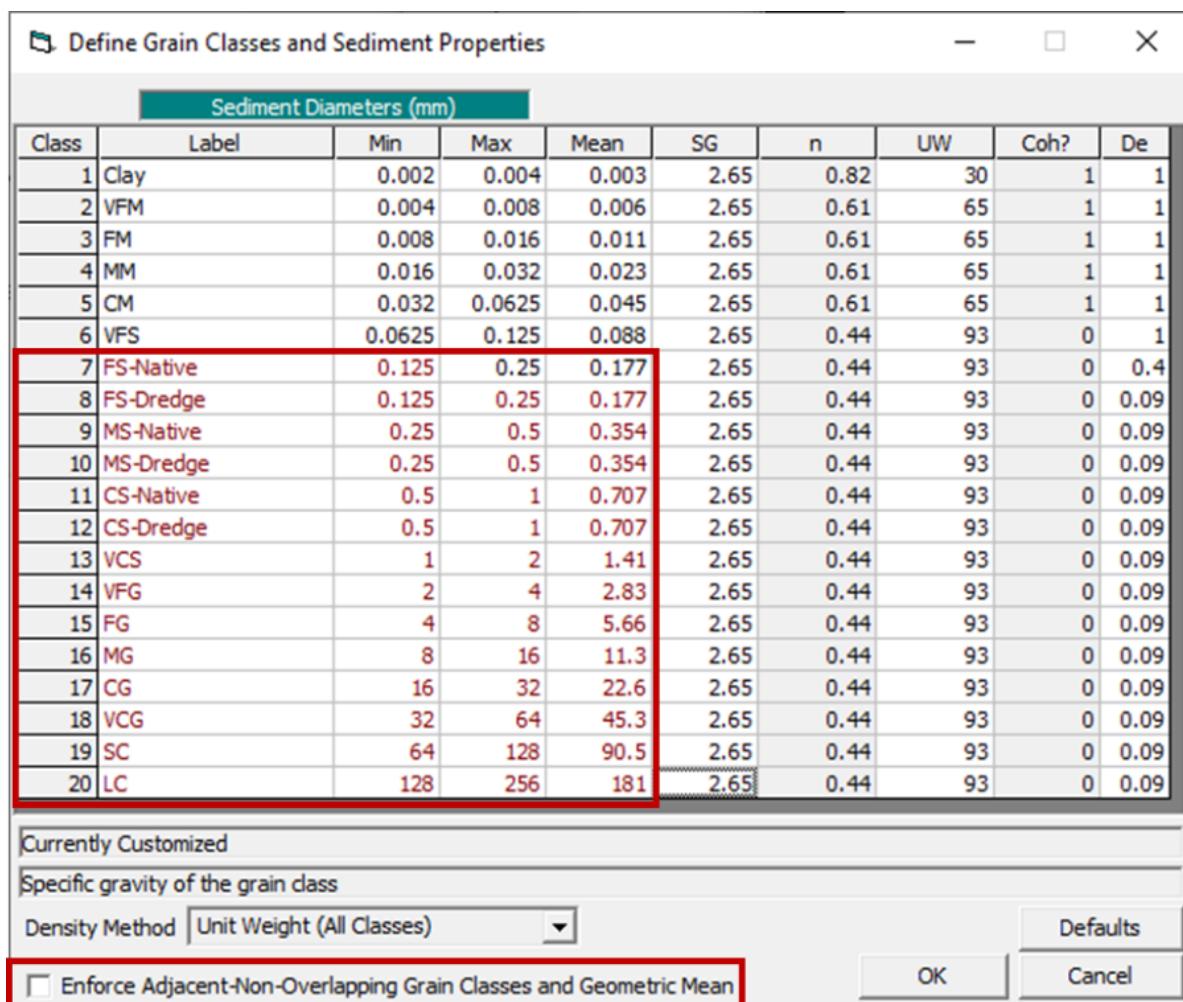
| Grain Classes | | Lower Bound | Upper Bound | Mean Diameter | Geometric Mean |
|--------------------|------|-------------|-------------|---------------|----------------|
| Clay | Clay | 0.002 | 0.004 | 0.003 | 0.00283 |
| Very Fine Silt | VFM | 0.004 | 0.008 | 0.006 | 0.00566 |
| Fine Silt | FM | 0.008 | 0.016 | 0.011 | 0.0113 |
| Medium Silt | MM | 0.016 | 0.032 | 0.023 | 0.0226 |
| Coarse Silt | CM | 0.032 | 0.0625 | 0.045 | 0.0447 |
| Very Fine Sand | VFS | 0.0625 | 0.125 | 0.088 | 0.0884 |
| Fine Sand | FS | 0.125 | 0.25 | 0.177 | 0.177 |
| Medium Sand | MS | 0.25 | 0.5 | 0.354 | 0.354 |
| Coarse Sand | CS | 0.5 | 1 | 0.707 | 0.707 |
| Very Course Sand | VCS | 1 | 2 | 1.41 | 1.41 |
| Very Fine Gravel | VFG | 2 | 4 | 2.83 | 2.83 |
| Fine Gravel | FG | 4 | 8 | 5.66 | 5.66 |
| Medium Gravel | MG | 8 | 16 | 11.3 | 11.3 |
| Coarse Gravel | CG | 16 | 32 | 22.6 | 22.6 |
| Very Coarse Gravel | VCG | 32 | 64 | 45.3 | 45.3 |
| Small Cobbles | SC | 64 | 128 | 90.5 | 90.5 |
| Large Cobbles | LC | 128 | 256 | 181 | 181 |
| Small Boulders | SB | 256 | 512 | 362 | 362 |

| | | | | | |
|-----------------|----|------|------|------|------|
| Medium Boulders | MB | 512 | 1024 | 724 | 724 |
| Large Boulders | LB | 1024 | 2048 | 1448 | 1450 |



44 User defined grain classes dialog, default on the left and example customized grain classes, with clay and fine sand subdivided, on the right.

Current versions of HEC-RAS make the grain classes more flexible. Uncheck the **Enforce Adjacent-Non-Overlapping Grain Classes and Geometric Mean** box. This removes the interface control that enforces these constraints and allows users to edit the first four columns of this editor without limitation. In most cases, the adjacent, increasing, non-overlapping constraint is appropriate, and violating it can cause problems in the mixing algorithms (see Warning below). HEC-RAS also stops computing the geometric mean of the grain class if this feature is disengaged, so users will have to compute and enter their own representative grain class for edited grain classes. But this feature does allow users to generate duplicate grain classes of the same size class if they want to keep track of one of them.



45 User defined grain classes with duplicate grain classes. Representative grain classes must be set to the new geometric mean manually. HEC-RAS does not compute these in when the enforce adjacent-non-overlapping mode is off.

Warning: Impact of Grain Class Order on Sorting Algorithms

The Thomas and Copeland sorting and mixing algorithms compute armoring based on the prevalence of coarser grain classes. These algorithms compute how much of each grain class the flow field has access to based on how much of the cover layer is composed of coarser particles. It identifies "coarser particles" as those particles in larger grain classes. Therefore, duplicate particles (or finer particles) in coarser (higher **Class** number) grain classes will artificially limit erosion in these algorithms. The representative grain size should never decrease as the grain class number increases.

Warning: Limit the First Five Grain Classes to Fine Sediment Sizes

While grain classes are flexible the first five grain classes are considered 'cohesive' regardless of their size. The cohesive algorithms and parameters selected in the **Cohesive Options** will be applied to these grain classes. The **Unit Weight and Densities** in the **Sediment Properties Editor** tie unit weight to these grain classes. Additionally, mixing and armoring algorithms in both the main sediment model and BSTEM compute a "% cohesive" and take different approaches based on the percentage of the bed material in the first five grain classes. Therefore, when defining new grain classes, reserve the first five for materials that behave like cohesives and constrain cohesive materials (e.g. that will deposit and scour according to Krone and Partheniades methods) to these first five grain classes. (Note: Future versions will use the **Coh?** Column to control this behavior, but current and past versions assume these grain classes – and only these grain classes – are cohesive).

| Sediment Diameters (mm) | | | | | | | | | | |
|-------------------------|-------|--------|--------|-------|------|------|----|------|------|--|
| Class | Label | Min | Max | Mean | SG | n | UW | Coh? | De | |
| 1 | Clay | 0.002 | 0.004 | 0.003 | 2.65 | 0.82 | 30 | 1 | 1 | |
| 2 | VFM | 0.004 | 0.008 | 0.006 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 3 | FM | 0.008 | 0.016 | 0.011 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 4 | MM | 0.016 | 0.032 | 0.023 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 5 | CM | 0.032 | 0.0625 | 0.045 | 2.65 | 0.61 | 65 | 1 | 1 | |
| 6 | VFS | 0.0625 | 0.125 | 0.088 | 2.65 | 0.44 | 93 | 0 | 1 | |
| 7 | FS | 0.125 | 0.25 | 0.177 | 2.65 | 0.44 | 93 | 0 | 0.4 | |
| 8 | MS | 0.25 | 0.5 | 0.354 | 2.65 | 0.44 | 93 | 0 | 0.09 | |

First five grain classes are always “cohesive” (e.g. they use the cohesive algorithms regardless of user specified grain size)

1.2.3.1.2 Specific Gravity, Porosity, and Unit Weight

Specific Gravity: The default specific gravity for all sediment particles is 2.65. While generally appropriate, this assumption is not universally valid. Users can change this value, but the current version of HEC-RAS only applies one specific gravity to all grain classes throughout the model. The grain class-specific specific gravity option is included for 2D sediment transport which has variable density algorithms.

Unit Weight/Density: Sediment unit weights or densities are used to convert deposited or eroded masses into volumes that translate into bed elevation changes. This is one of the only parameters that is different for SI and US customary units. US customary is defined in terms of unit weights (lb/ft^3) while SI is defined in terms of density (kg/m^3). HEC-RAS converts between density and unit weight internally. Clay (grain class 1), silt (grain classes 2-5) and sand/gravel (grain classes 6-20) each have distinct, default grain classes.

Modeling Note: Cohesive unit weight/density

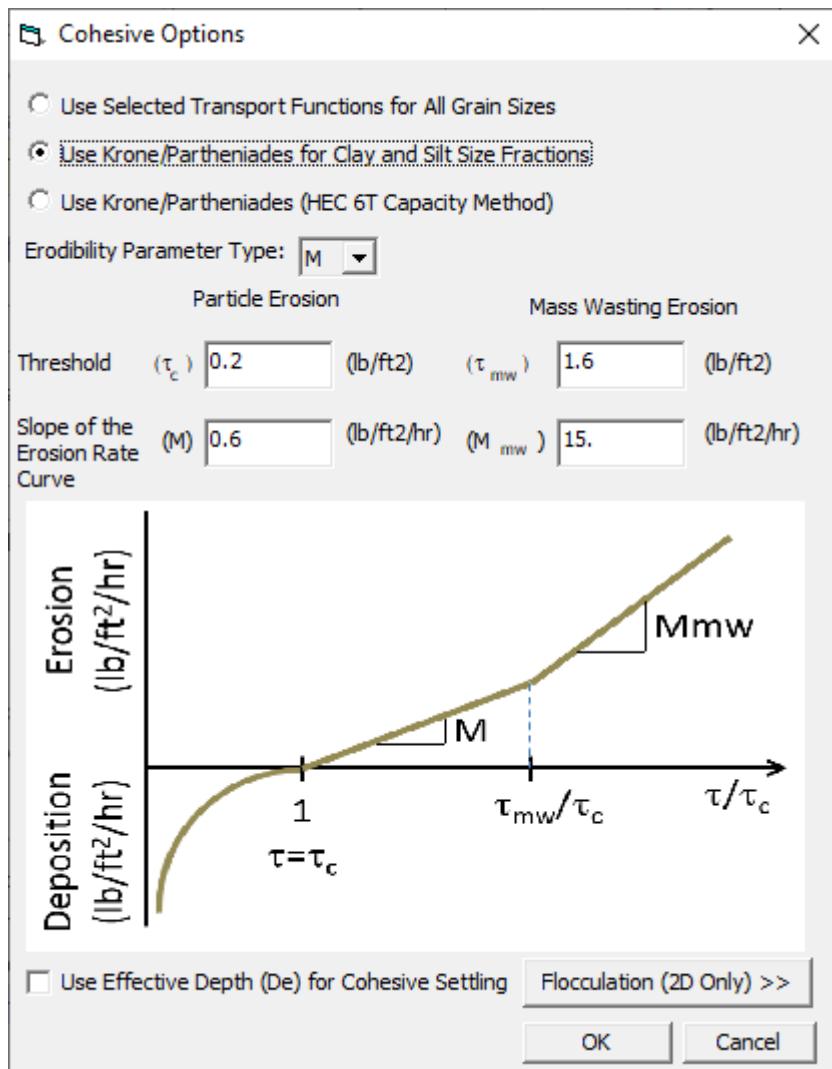
Cohesive unit weight can vary substantially between systems and even within the same reservoir (e.g. deeper consolidated clays are often consolidated and much denser than surficial deposits). HEC-RAS adopted defaults from HEC 6 but are on the low end of the range, representing 'fluffy,' reservoir deposits. When calibrating a depositional cohesive model to volume change computed from repeated cross sections, cohesive density will be a very sensitive parameter. If you are over-predicting cohesive deposition, consider the applicability of this parameter.

*This editor combines two different menus in version 5.0.7 and earlier. Because recent versions of HEC-RAS allow users to define sediment properties like density and unit weight by grain class, these properties are included in this editor.

1.2.3.2 Cohesive Options

Cohesive methods and parameters can be specified by selecting **Set Cohesive Options** under the Options Menu. The method selected will be applied to the first five grain classes (GC 1-5) which are silts and clays in the default grain classes (but will apply to the first five grain classes regardless of size if the user edits them).

HEC-RAS can either compute fine particle transport with the standard transport capacity approach - using the selected transport function to extrapolate transport potential for the silt and clay grain classes outside of the developed range of these equations, or with the Krone and Partheniades equations.



HEC-RAS includes two versions of the Krone and Partheniades equations, the HEC-RAS method from previous versions and the HEC 6T method. See the Technical Reference Manual for formulations of [Krone](#) (see page 114) and [Partheniades](#) (see page 344) as well as a description of the [difference between HEC-RAS and HEC 6T](#)¹⁹ methods. Both use the thresholds and slopes, computing erosion rates in the same way. However, once erosion rates are computed, the methods apply them to the multi-grain class bed materials differently. The methods have several differences, but mostly the HEC-RAS method distributes the erosion rate over all grain classes while the HEC 6T applies it to each (after reducing it based on inflowing load). The HEC 6T method generally computes more erosion.

Note: 2D Cohesive Distinctives

¹⁹ <https://www.hec.usace.army.mil/confluence/display/RAS1DTechRef/Computational+Differences+Between+HEC-RAS+and+HEC-2>

While 1D and 2D sediment use the same interface, they have distinct approaches and equations. See the appropriate sections of the technical reference manuals ([1D here²⁰](#) and [2D here²¹](#)) for the distinctives of the approaches.

1.2.3.2.1 Method

HEC-RAS includes three methods for modeling cohesive transport. Modelers should be aware that ***The Default Method is Not Recommended***. Cohesive transport should be parameterized using the Krone and Partheniades approaches, especially if the system erodes cohesive materials.

Modeling Note: Parameterizing Cohesive Transport

Cohesive transport parameters can be difficult or expensive to collect, but are also highly variable (spanning at least five orders of magnitude) and site specific. They should either be measured with a SedFlume (Briaud, 2008; USACE, 2012) or similar apparatus or jet tests in the field or should be the primary calibration parameter. SEDFLUME analyses are available at the US Army Corps of Engineers Engineering Research and Development Center (ERDC-CHL, formerly WES) or at a handful of universities. ERDC-CHL can also conduct jet tests as well as the USDA-Agricultural Research Station and several universities, districts and contractors. See the [Cohesive Parameter Estimation](#) (see page 349) section of the Technical Reference Manual for more information on this and some example data.

Modeling Note: Bed-Material Load Modeling Option

If the fine sediment in the model is wash load, and is not interacting with the bed, it may be appropriate to ignore it, and remove it from the model. Removing wash load avoids the uncertainty and numerical artifacts of transporting fine sediment with transport functions developed for cohesionless sediment and avoids speculating about uncertain cohesive parameters. Alternately, setting the erosion threshold low enough that wash load remains in suspension is another approach to keeping wash load in your model, without detailed cohesive sediment data. However, if the objective of the model includes cohesive erosion, these parameters must be measured and/or calibrated.

²⁰ <https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-technical-reference-manual/cohesive-transport>

²¹ <https://www.hec.usace.army.mil/confluence/rasdocs/d2sd/ras2dsedtr/numerical-methods/cohesive-parameters>

1.2.3.2.2 Erodibility Parameter Type:

There are two forms of the excess shear equation: the dimensional equation (K_d) and dimensionless equation (M). The erodibility parameters in these equations are not equivalent and have different units. They are related to each other by the critical shear stress:

$$M = K_d \tau_c$$

See the [M-Kd Section of the Technical reference manual \(see page 348\)](#) for more discussion of these two equations. But the critical consideration is that users must make sure they understand which form their data are in. Selecting the appropriate Erodibility Parameter Type:

Erodibility Parameter Type: 

Will change the units in the interface and align your data with the correct form of the equation.

Modeling Note: Linear Erosion Model

HEC-RAS requires all four parameters, even if your erodibility data suggests a linear model (e.g. only one Erodibility slope). To simulate a linear shear-erosion rate relationship, make the two erosion rates the same and/or set the mass wasting threshold stress much higher than the shear stresses in the simulation.

Modeling Note: Reservoir Cohesive Deposition

Despite the volume default effects described in the previous note, HEC-RAS under predicts cohesive deposition – particularly in reservoirs - more often. There are several reasons for this.

1. The Continuity (Exner) equation is just a mass balance model and does not track longitudinal transport physically, like the Advection-Diffusion approach. If the control volume depth is large relative to the distance between cross sections (e.g. the sediment Courant condition is <<1), the Exner equation will not compute enough residence time to compute appropriate deposition with fall velocity-based approaches. Always use the **Limit to Water Velocity** method, (Sediment Data->Options->Transport Methods: 1D Routing Method) when simulating reservoirs or other low Velocity depositional zones:

1D Routing Method:

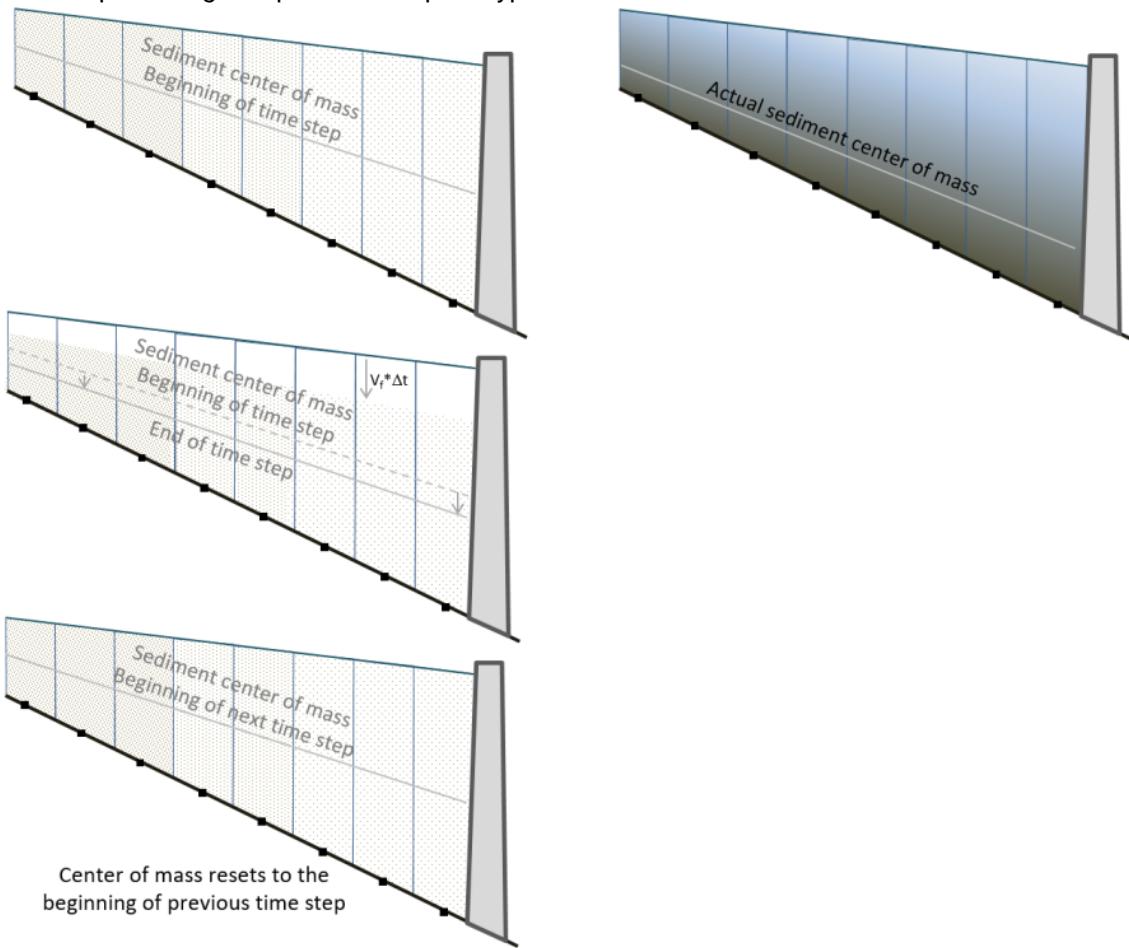
 Limit to Water Velocity

2. HEC-RAS fully mixes sediment vertically at the beginning of every time step, forcing the sediment to settle out of the whole water column. In a reservoir with high residence time, the center of mass of the cohesives may drop below the center of mass of the water over time (and space). HEC-RAS 6.0 gives users some opportunity to influence the vertical mixing of each cohesive grain class vertically, by extending the effective depth to the cohesive

deposition equation Use Effective Depth (De) for Cohesive Setting Flo⁺, but it is still a limitation of the model.

3. Aggregates and flocculation – Cohesive sediment often transports in aggregates or flocs – which are clusters of combined cohesive particles. These behave like larger particles, with higher fall velocities, and deposit more quickly (giving reservoirs higher trap efficiencies for aggregate cohesives or estuaries higher trap efficiencies for flocs)

Therefore, it is often appropriate to "coarse" the fines in the boundary load gradation to offset these biases and calculate more cohesive deposition during the calibration process if HEC-RAS is under predicting compared to the prototype.

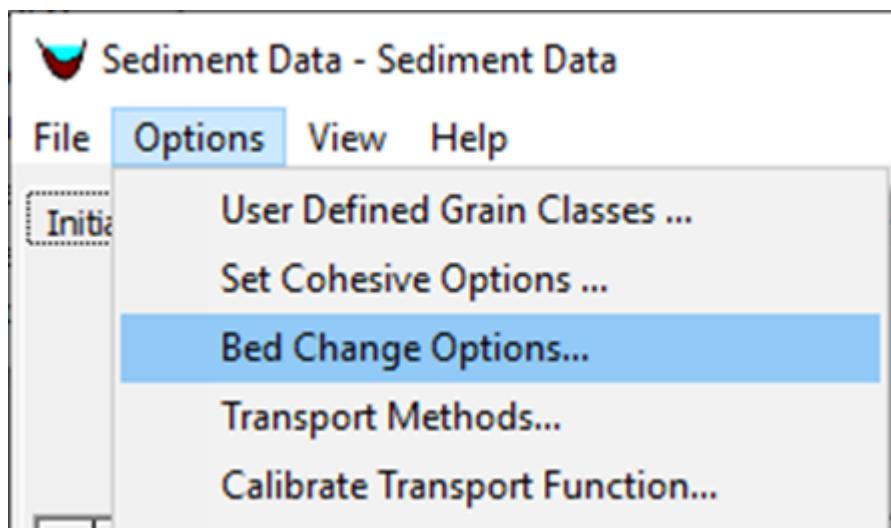


1.2.3.3 Bed Change Options

To select **Bed Change Options** select the **Options->Bed Change Options** menu in the **Sediment Data** editor.

The 1D bed change methods are relatively simple. They are easy to understand. However, selecting the right bed change approach can be one of the most sensitive and difficult parts of 1D sediment modeling. The 1D bed change algorithms often attempt to simplify laterally heterogeneous processes into cross-section averaged behavior. These assumptions can lead to numerical artifacts and unintended consequence.

Modelers must select their bed change model carefully and experiment with their sensitivity, to select the one that introduces the least error.



1.2.3.3.1 Selecting a Modular, Global Bed Change Method

The default approach to bed change in 1D sediment transport is always the “veneer method.” The veneer method adjusts each wet, movable node the same vertical distance to deposit or erode the computed mass at each cross section.^[1] (see page 0) But the new editor gives users more flexibility to mix-and-match appropriate bed change methods in the channel and floodplains.

The **Global Bed Change Editor** allows user to select a bed change method in a 2X2 matrix, making selections by process (erosion or deposition) and location (channel and overbank).

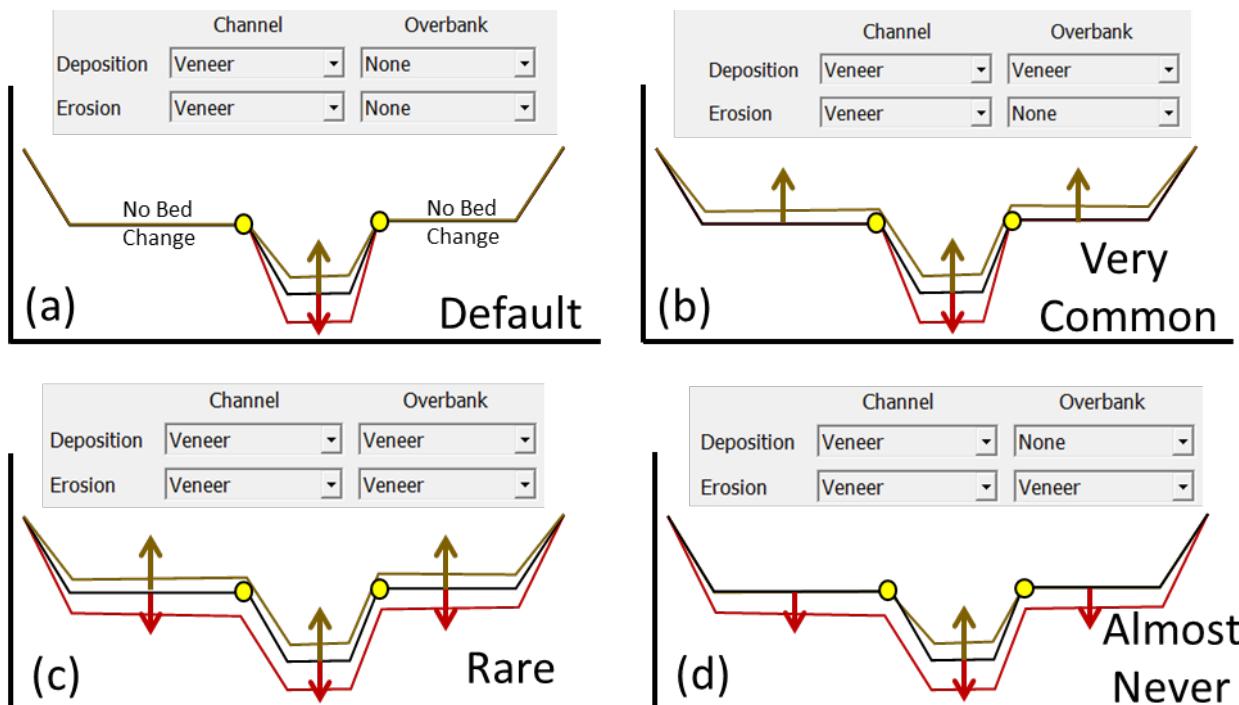
| | River | Reach | RS | Deposition Channel | Erosion Channel | Deposition Over Bank | Erosion Over Bank | Decay |
|---|----------|----------|-------|-----------------------|--------------------|-------------------------|----------------------|-------|
| 1 | Morthond | Morthond | 10000 | | | | | Coeff |
| 2 | Morthond | Morthond | 9500 | | | | | |
| 3 | Morthond | Morthond | 9000 | | | | | |

Global Bed Change Options (with default values)

"Channel" and "Overbank" Based on Movable Bed Limits

"Channel" and "Overbank" in these methods are determined by **Movable Bed Limits** NOT Bank Stations. In most places in HEC-RAS, the bank stations mark the transition between the channel and the overbank of floodplain. That is also true in the sediment model, where transport capacity is based on the results from the *hydraulic* channel (the portion of the model between the hydraulic bank stations). But in the bed change options, the channel and the overbanks transition at the [Movable Bed Limits](#)²².

HEC-RAS requires erosion and deposition in the channel. But users can select erosion and/or deposition in the overbank. This gives users four possible permutations of channel-overbank processes. These four options are illustrated in the figure below (in order of how often they are used). The first two are the most common and should be used for most applications.



a. Deposition and Erosion in the Channel and No Bed Change in the Overbanks. This is the default approach. The name of the "movable bed limits" suggests this approach. The channel can move within the movable bed limits but not outside of them. However, if the prototype deposits significant sediment outside of the channel, this method can overpredict channel deposition. It can even lead to the [Unrealistic Vertical Adjustment](#) (see page 0) or "Channel Filled with Sediment" Errors, that can crash the sediment model. It can also lead to a perched channel or an inverted channel (as depicted in the figure below). Therefore, option (b) in the figure above (and described below) is very common.

b. Channel Deposition and Erosion, Deposition in Overbank but no Erosion in the Overbank: If the modeled

²² <https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/entering-and-editing-sediment-data/initial-conditions-and-transport-parameters/movable-bed-limits>

system deposits in the floodplain, it can be useful for the model to deposit in the floodplain. Floodplain flows can carry (usually fine) sediment and deposit, but rarely scour across the cross section. So the most common alternative **Bed Change Method** is option (b) in the figure above, allowing deposition in the overbank, but not erosion. This approach may, actually, be the appropriate method in more models than the default.

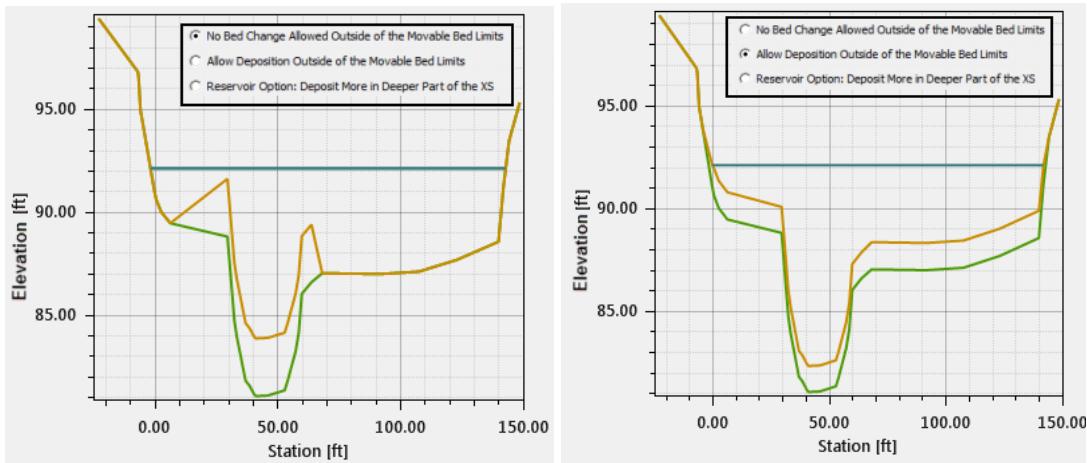


Figure 1-69: Deposition with the default method (Method 1), which confines deposition to movable bed limits (Left) and the method (Method 2) that allows deposition outside the movable bed limits (right).

The Veneer method tends to over-predict floodplain deposition

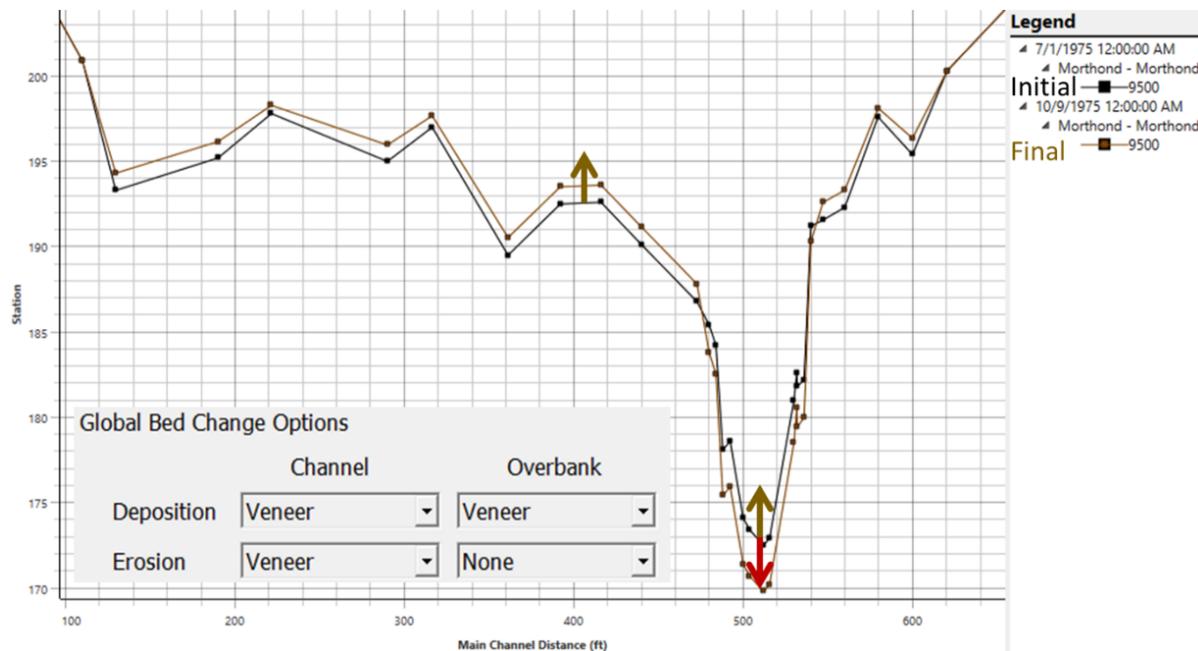
While method (1) over predicts channel deposition and under predicts floodplain deposition. Method 2 tends to over-predict overbank deposition (which can lead to artificial channel erosion). There are a couple reasons that the overbank deposition algorithms over predict floodplain deposition. First, method (b) does not account for floodplain scour mechanism. Second, if the time step is too large, the algorithms do not account for the loss of floodplain conveyance quickly enough (see next Modeling Note).
But, by far the most important reason that the 1D model overpredicts overbank deposition is the 1D gradation assumption. HEC-RAS extends the active layer gradation to the entire mobile, wet, portion of the bed the material it erodes or deposits in the channel has the same gradation as the floodplain. Therefore, the 1D assumptions tend to deposit coarser sediment in the numerical flood plain than the prototype. Version 6.2 includes a new [Rouse-Diffusion method](#)²³ to try to avoid the under/over prediction issues of these two methods.

c. Deposition and Erosion in All Locations: The current version of HEC-RAS also allows erosion in the overbanks (By selecting Veneer in the Overbank/Erosion quadrant). This would be similar – in some ways – to setting the movable bed limits to the edge of the cross section. Floodplain erosion – where it happens – is usually localized or channelized. The veneer method is rarely an appropriate modeling approach. So this method should be used with caution, and should be carefully justified with field observations in the model documentation.

²³ <https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-technical-reference-manual/bed-change/diffusion-rouse-method>

d. Deposition and Erosion in the Channel, Only Erosion in the Overbank: This modular approach to bed change allows users to select floodplain erosion and exclude floodplain deposition. This is not a standard morphological process and is almost never appropriate.

The figure below includes results from the most common channel erosion/deposition and overbank deposition method.



However, HEC-RAS calculates transport based on the *channel* hydraulic properties, and sometimes the single process bed change can generate unrealistic deposition. Floodplain deposits also tend to be finer than channel sediment in rivers, but HEC-RAS is a 1D model that only tracks a single bed gradation. Minor deposition on very large floodplains during large floods can introduce an artificial sediment sink causing illicit scour in the channel.

Depth Dependent Deposition Method (reservoirs): Some depositional systems, particularly prograding reservoir deltas, depart from the veneer assumption, depositing more in the deeper parts of the channel. **The Reservoir Option: Deposit More in the Deeper Parts of the XS** method adjusts bed change proportional to water depth.

The Veneer Method is the primary approach to cross section change in 1D models. But several of these global drop down menus include other options. HEC-RAS includes alternate erosion and deposition methods that can depart from the veneer assumptions and use different algorithms to change the cross section node elevation, when appropriate.

These include:

1.2.3.3.2 Alternate Erosion Methods

| | Channel | Overbank |
|------------|---------|----------|
| Deposition | Veneer | Veneer |
| Erosion | Veneer | None |

Veneer
Simplified CEM

None
Veneer

1.2.3.3.3 Alternate Deposition Methods

Global Bed Change Options

| | Channel | Overbank |
|------------|---------|----------|
| Deposition | Veneer | Veneer |
| Erosion | Veneer | None |

(S Specific Bed Change Options (will r
iver: (All Rivers) Reach: []

Reservoir
Veneer
Reservoir
Distance Decay
Diffusion

1.2.3.3.4 Selecting Local Bed Change Methods

1.2.3.3.5 Area-Volume Conversion Method

- * Backwards compatible - uses Simpson for bed sorting, rectangle for bed change
- * Average end area - uses HEC-6 method for bed sorting and bed change
- * Simpson - uses Simpson for bed sorting and bed change
- * Single -V - uses rectangle for bed sorting and bed change

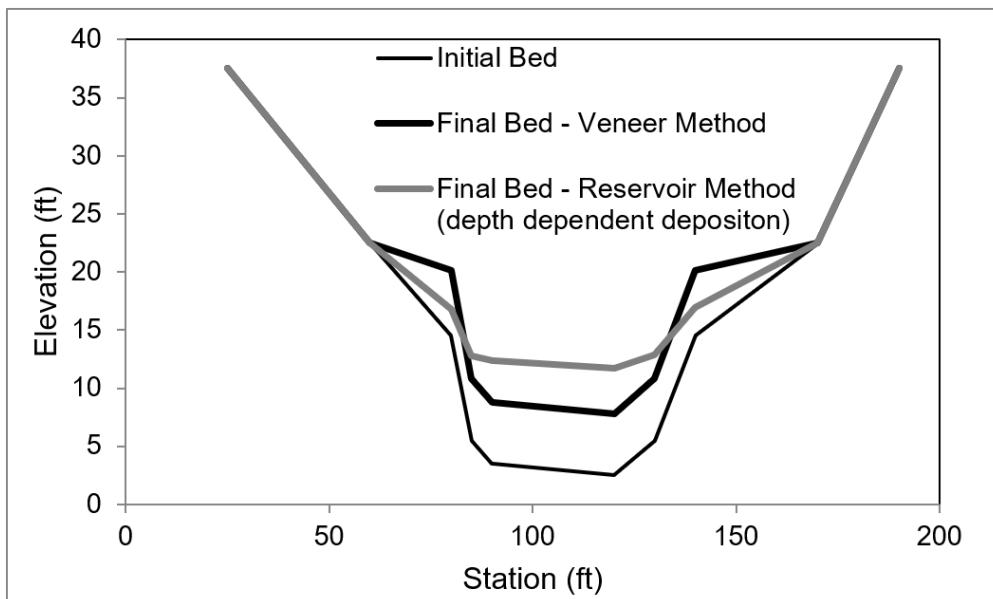
See the section of the technical reference manual on [Volume-Area conversions](#) (see page 118) for technical detail on these methods.

[1] (see page 0) The veneer method is sometimes - colloquially - called the “peanut butter method” because it is like trying to spread a uniform layer of sediment across all of the movable cross-section points.

1.2.3.3.6 Alternate Deposition Methods

1.2.3.3.6.1 Reservoir Method (Depth Dependent Deposition)

Some depositional systems, particularly prograding reservoir deltas, depart from the veneer assumption, depositing more in the deeper parts of the channel. The **Reservoir Option** Deposits More in the Deeper Parts of the XS method adjusts bed change proportional to water depth. The Reservoir deposition method is available in the channel and overbank, but it is designed to fill the channel in backwater situations.



Differential Deposition will Generate Flat Cross-Sections in non-Monotonic Bed Change Regimes

Depth dependent deposition may seem like an attractive alternative to the veneer method in non-reservoir, riverine settings. However, it is often unstable in systems that alternately deposit and erode. Depth dependent deposition cross sections converge on flat channels and can presently lose the channel shape during deposition events. This method performs best in settings of monotonic channel deposition.

Differential deposition vs Veneer in a Reservoir

Differential deposition based on depth is a function of length of reservoir, longitudinal location, and gradation of inflowing material (i.e. fall velocity). In the upstream portion of the reservoir, where coarser materials fill the valley, the channel will fill. The depth dependent method is

appropriate here. However, fine materials that settle out in the reservoir pool, tend to blanket the flooded valley with a fine uniform veneer, often maintaining the pre-reservoir cross section shape through decades of deposition.

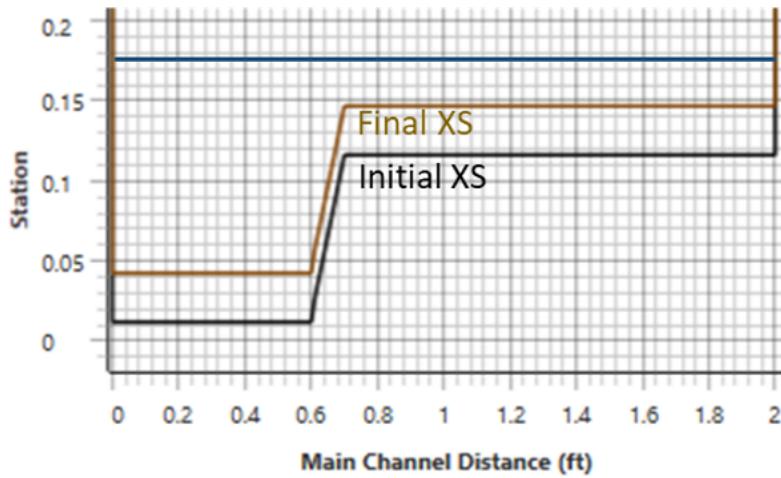
1.2.3.3.6.2 Distance Decay Floodplain Deposition Method

When sediment deposits in floodplains, it is not always evenly distributed. More sediment tends to settle out closer to the channel than in the father reaches of the floodplain. Walling and He (1998) and others have demonstrated that distance-decay models can estimate this distance-dependence of floodplain deposits. Therefore, HEC has included a distance-decay floodplain deposition model in HEC-RAS.

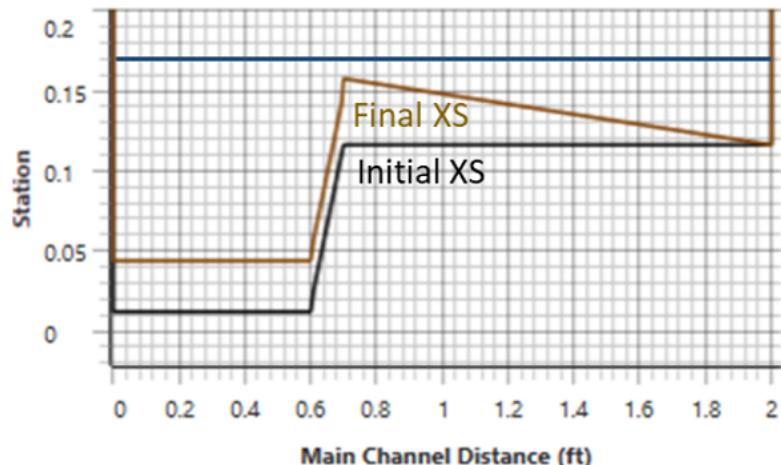
HEC is working on more sophisticated versions of these distance-decay models, but the current version of HEC-RAS has a simple, linear decay model. The linear decay model deposits the full “veneer” deposition thickness at the movable bed limits and reduces the bed change proportionally along the distance between the movable bed limit and the water surface extent. The figure below includes results from a simplified model of a floodplain deposition flume ([Branß et al., 2018²⁴](#)).^[1] (see page 0)

²⁴ https://www.e3s-conferences.org/articles/e3sconf/pdf/2018/15/e3sconf_riverflow2018_02018.pdf

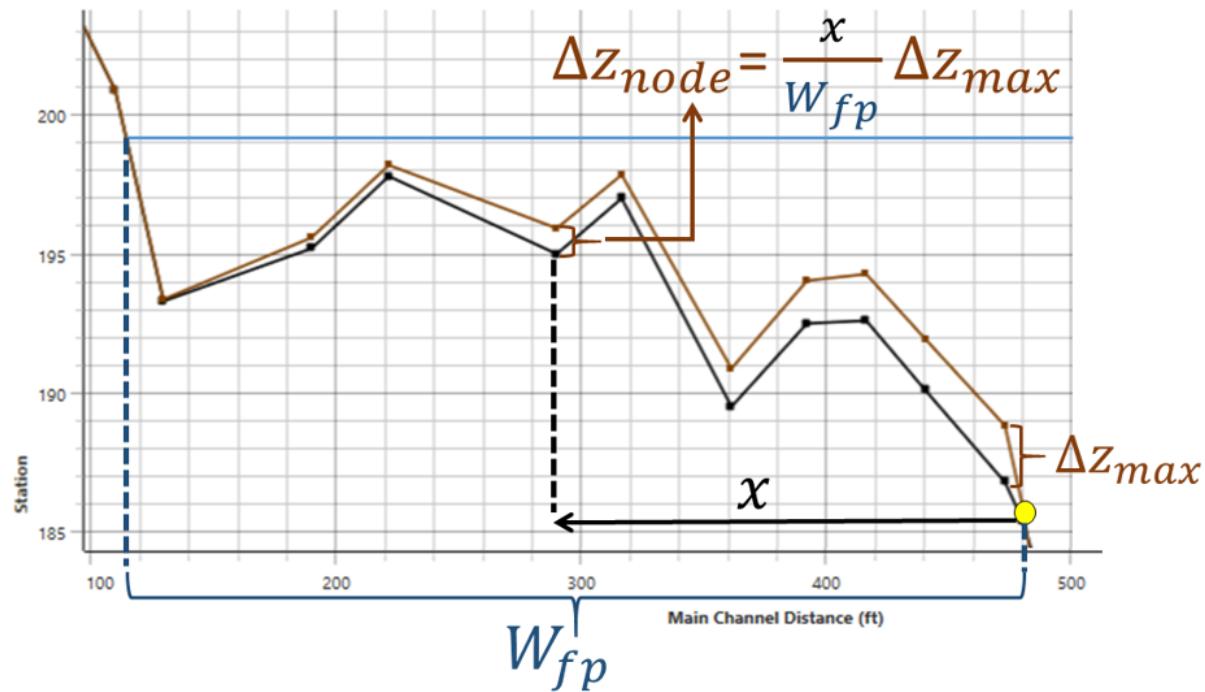
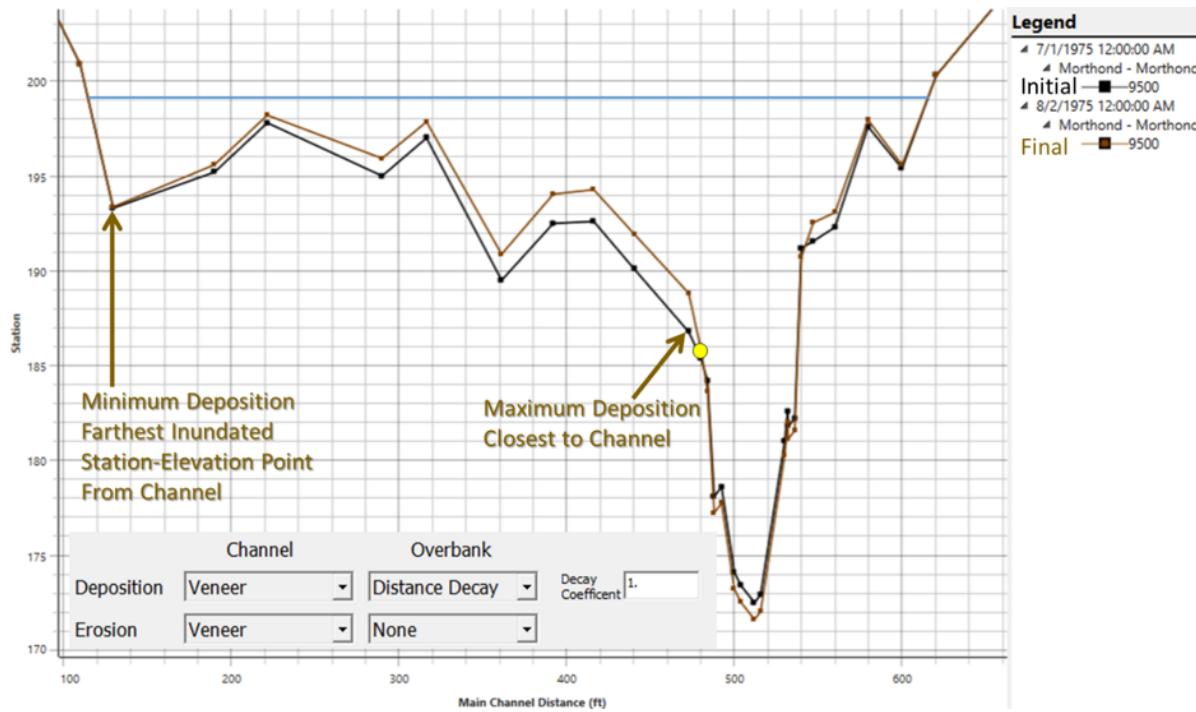
Veneer (Classic Method)



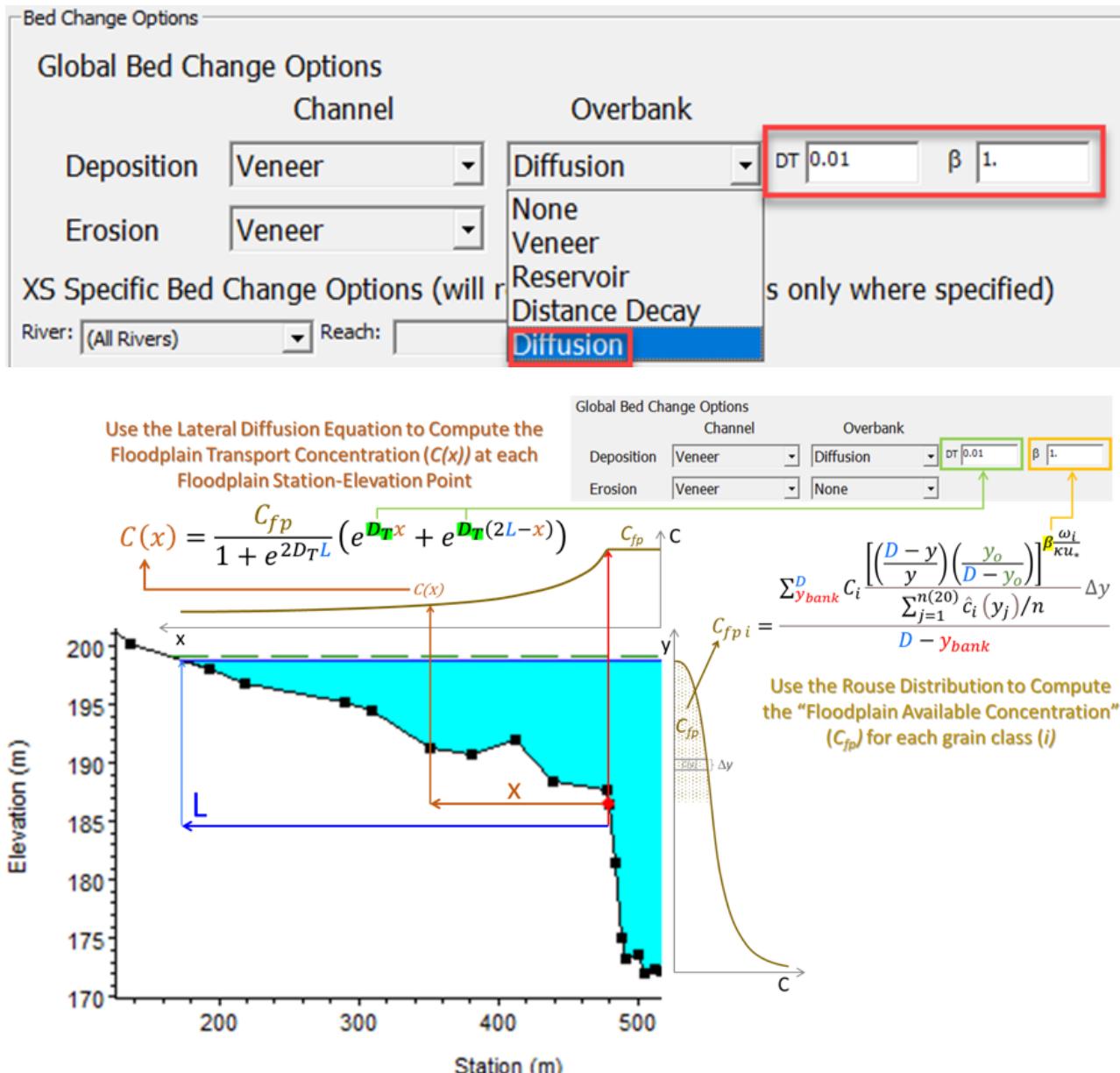
Distance Decay (New Method)



The two figures below include an example of a more complicated cross section with depth-decay floodplain deposition and the calculation of bed change at a particular node).



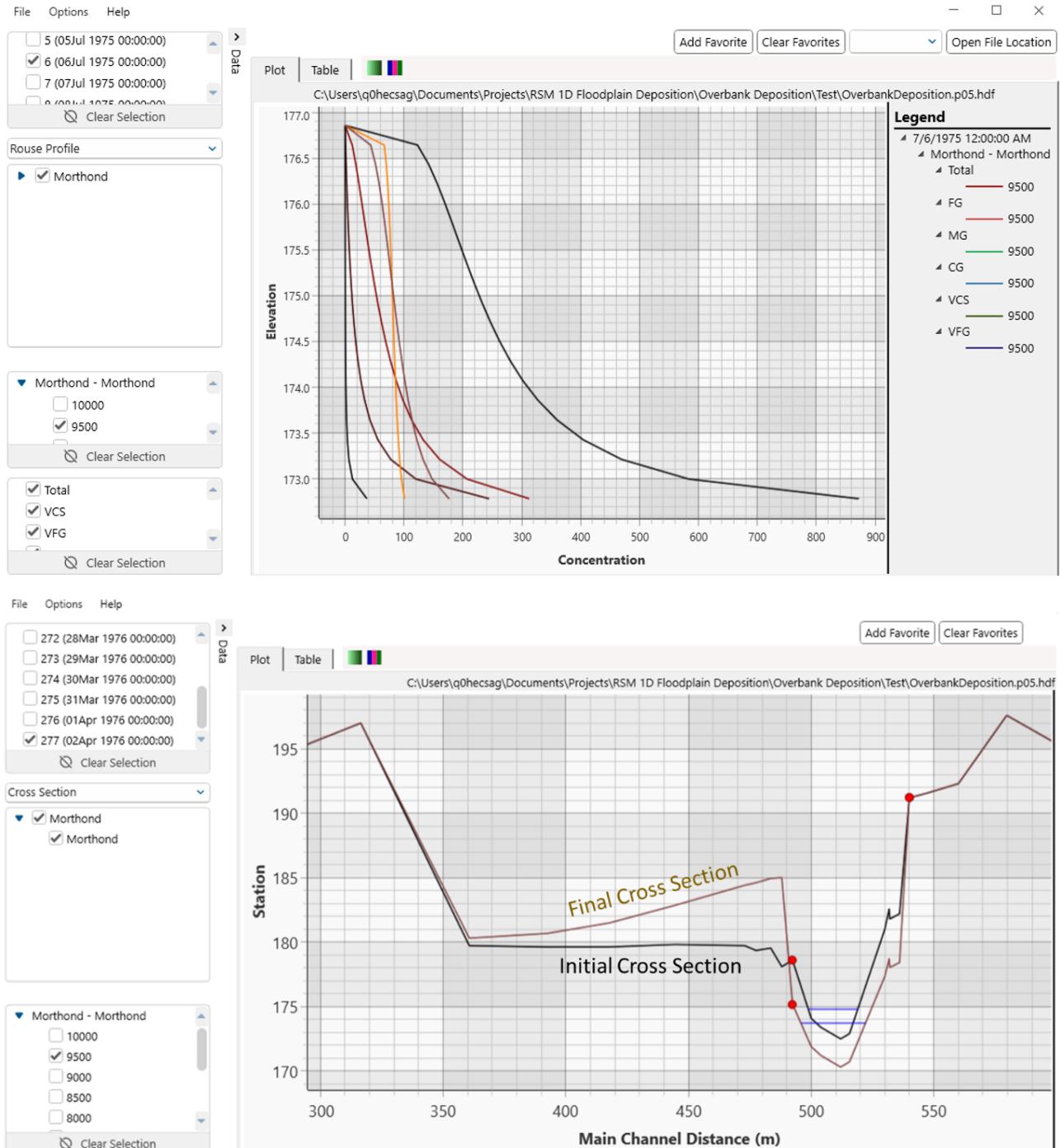
1.2.3.3.6.3 Rouse-Diffusion Method



Selecting Rouse-Diffusion Coefficients

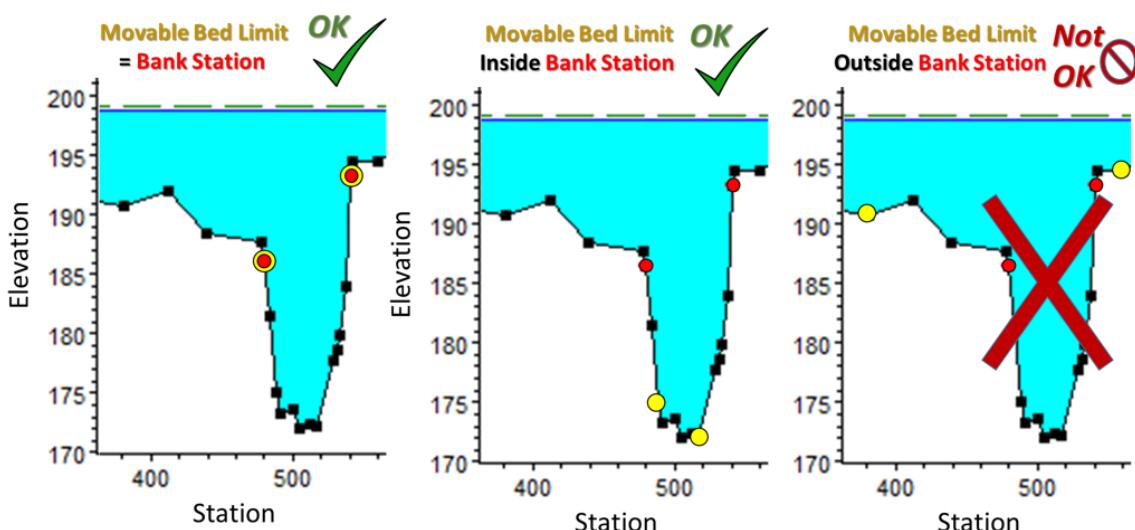
Beta: Floodplain deposition is inversely related to beta. Lower Beta values make more sediment available for overbank deposition. Beta<1 puts more sediment in the overbank than the Rouse number predicts.

DT: Lower values of DT spreads sediment over the floodplain more evenly. DT=0 spreads sediment evenly across the floodplain. DT=1 concentrates sediment very close to the channel, mostly forming natural levees.



Place Movable Bed Limits At or Inside Bank Stations For This Method

This method tracks floodplain and channel bed-change separately. But it uses the bank stations to determine the floodplain deposition and movable bed limits to identify the channel nodes. Therefore, the movable bed limits should be at or inside the bank stations for this method. If the movable bed limits are outside the bank stations HEC-RAS will apply both methods to the nodes between them which will cause problems.



[1] (see page 0) Also Branß, T., Dittrich, A., Gonzalez, N., (2018) “Reproducing natural levee formation in an experimental flume,” The International Conference On Fluvial Hydraulics (River Flow 2016).

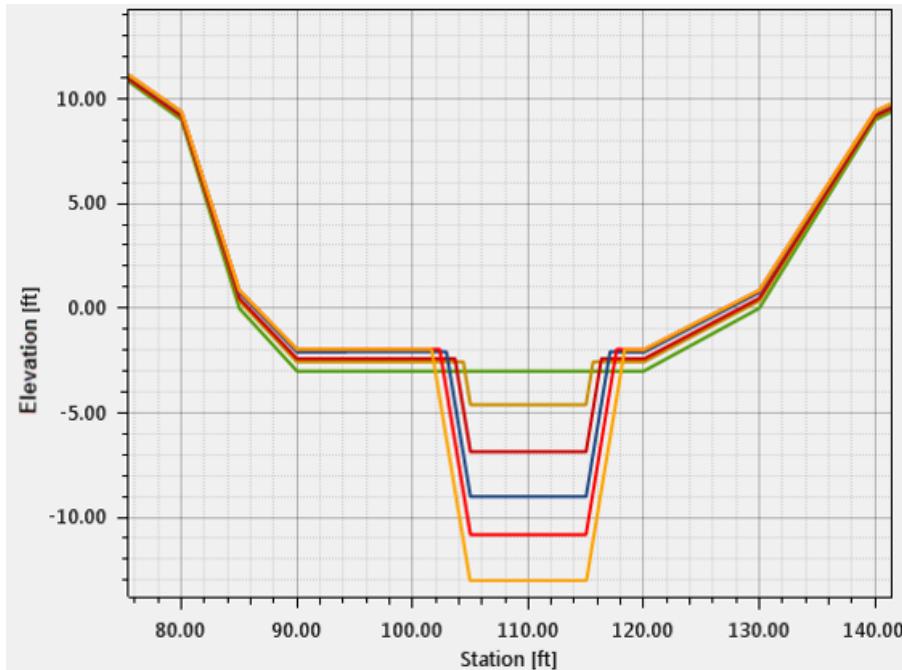
1.2.3.3.7 Alternate Erosion Method (CEM)

1.2.3.3.7.1 Simplified Channel Evolution Model (CEM)

The veneer method is the default method for channel erosion and is available (though rarely appropriate) for floodplain erosion. HEC-RAS includes one additional channel erosion method: the **Simplified CEM** method. The Simplified Channel Evolution Model is also designed for reservoir applications, in particular dam removals and reservoir flushing models.

The veneer method can under predict erosion in reservoir deposits. When a river scours reservoir deposits, following either a dam removal (Echevarria, 2012) or a reservoir flushing drawdown, it does not remove sediment uniformly from the flat reservoir deposits. Rivers tend to form one or more distinct channel through reservoir deposits during drawdowns or dam removals. The shear and hydraulic radius of a developing channel will erode more sediment than removing an even veneer from the top of a reservoir deposit. But these channels will also reach an equilibrium slope faster than a veneer approach and leave sediment embankments behind. The Simplified CEM model approximates these processes by eroding sediment in a defined, expanding, channel rather than a uniform veneer.

HEC-RAS translates parameters from the **Erosion Bed Change Option** into a simplified channel evolution model, eroding sediment in the shape of a trapezoidal channel with the specified parameters (after Cui et al., 2005 and Cantelli et al., 2004).



HEC will only apply this method to cross sections with **Max Width** and **Side Slope** data. The program will erode all other cross sections with the veneer method. Therefore, in a dam removal or reservoir flushing model, users can specify these variables for the cross sections with reservoir deposits to cut through and leave the rest to respond with the veneer method.

| Global Bed Change Options | | | | |
|---------------------------|---|---------------------------------------|----------------------------|---------------------------------|
| | Channel | Overbank | | |
| Deposition | <input type="button" value="Veneer"/> | <input type="button" value="Veneer"/> | | |
| Erosion | <input type="button" value="Simplified CEM"/> | <input type="button" value="None"/> | Width <input type="text"/> | Side Slope <input type="text"/> |

Max Width: The Simplified Channel Evolution Model assumes that the channel will expand until it reaches a maximum width (after Morris et al., 2008). Once it scours to the **Max Width** it incises, maintaining that trapezoidal bottom width, until it reaches the bottom of the sediment volume (**Max Depth** or **Min Elevation** from the **Initial Conditions and Transport Parameters Tab**). If the river still has capacity to erode when the channel reaches the bottom of the sediment control volume, the trapezoidal channel will expand laterally, maintaining the bottom elevation and side slopes, but increasing the bottom width.

Selecting a maximum bottom width is difficult and uncertain. Quantitative tools can help estimate this variable. Dimensionless analysis (Parker, 2008), regime theory, and other empirical geomorphic equations can guide bottom width estimates. Adkinson (1996) fit a regression to the bottom widths of channels scoured during several reservoir flushing events, and the equation is included in HEC-RAS (press the **Width Calculator...** button). However, all of these relationships have a lot of scatter. Selecting a bottom width requires good, regional, soil specific, geomorphic intuition. Even the best estimates are still uncertain and are candidates for calibration parameters or sensitivity analysis (Echevarria, 2012).

Side Slope: The side slopes define the shape of the trapezoidal channel. While empirical equations can guide **Max Width** estimation, there is little guidance for **Side Slope** selection. Angle of repose is a good place to start, but sensitivity analysis should also quantify the impact of this uncertain parameter.

Center Station (opt) - XS Specific Only: HEC-RAS centers the trapezoidal channel between the movable bed limits. Because channels often form randomly in reservoir sediment and, often, a single channel is a numerical surrogate for multiple developing channels, this assumption is often good enough, given the other uncertainties. However, reservoirs that are flushed regularly, often form channels in the general location. If it is advantageous to capture that lateral channel position either computationally or, simply visually, specify the channel center station here.

XS Specific Bed Change Options (will replace Global Options only where specified)

River: (All Rivers) Reach: []

| | River | Reach | RS | Deposition Channel | Erosion Channel | Deposition Over Bank | Erosion Over Bank | Decay Coeff | Max Width | Side Slope | Center Sta (opt) | Left Dep Sta (opt) | Right Dep Sta (opt) |
|---|----------|----------|-------|--------------------|-----------------|----------------------|-------------------|-------------|-----------|------------|------------------|--------------------|---------------------|
| 1 | Morthond | Morthond | 10000 | | | | | | | | | | |
| 2 | Morthond | Morthond | 9500 | | | | | | | | | | |
| 3 | Morthond | Morthond | 9000 | | | | | | | | | | |
| 4 | Morthond | Morthond | 8500 | | | | | | | | | | |
| 5 | Morthond | Morthond | 8000 | | | | | | | | | | |



Eroding Valley Walls

The Simplified Channel Evolution Model removes sediment from the cross section at the specified side slope without considering physical limits of channel morphology. For example, if the side slope extends through a bedrock cliff or reinforced valley walls, the algorithm will still clip the cross section at the specified slope, 'eroding' the bluff or bank. Monitor the method carefully to assure physically reasonable results.

Eroding to Bedrock

The Channel Evolution Model will often erode to the bottom of the sediment control volume, particularly if the reservoir was built on a previously bed-rock channel, or if the model is designed to return the channel to the historic grade (e.g. if there is a coarse, historic, cobble layer buried underneath the reservoir silt deposits, and the modelers decide to limit scour to that historic control). Previous versions of the **Simplified CEM** model would oscillate once HEC-RAS scoured to the bottom of the sediment control volume, because there was no bed sediment available to compute capacity. Recent versions of HEC-RAS partition capacity based on the initial bed gradation if the cross section erodes to the **Max Depth** or **Min Elev** (by either the CEM or the Veneer Method). HEC-RAS will also throw a runtime error, if the model scours to the bottom of the control volume:

**One or more cross section(s) eroded to the bottom
of the sediment control volume.
At the following location(s) and first time(s).**

This is often a sign that the model is eroding too aggressively (because the bed is too fine or the transport function too powerful) or that the alluvial control volume was too small. But in cases where the model is expected to erode to a known vertical control, this error is expected and acceptable.

1.2.3.3.8 Local (Reach) Bed Change Methods

The most recent version of HEC-RAS also includes an option to override the Global Bed Change Options by specifying a different method at a cross section or – more appropriately – a group of cross sections.

Bed Change Methods Should Apply to Morphologically Similar Reaches, not to Individual Cross Sections

Just because HEC-RAS allows users to define different bed change methods for each cross section, does not mean they should. This method should not change from cross section-to-cross section. If you do choose to override the default method, it should be for a particular reason over a coherent morphological setting, usually comprising a set of consecutive cross sections.

| | River | Reach | RS | Deposition Channel | Erosion Channel | Deposition Over Bank | Erosion Over Bank | Decay Coeff | Max Width | Side Slope | Center Sta (opt) |
|---|----------|----------|-------|-----------------------|--------------------|-------------------------|----------------------|----------------|--------------|---------------|---------------------|
| 1 | Morthond | Morthond | 10000 | Veneer | | None | | | | | |
| 2 | Morthond | Morthond | 9500 | Reservoir | Simplified CEM | Reservoir | Veneer | | 20 | 2 | 510 |
| 3 | Morthond | Morthond | 9000 | Veneer | Veneer | None | None | | | | |
| 4 | Morthond | Morthond | 8500 | Veneer | Simplified CEM | Distance Decay | | | 20 | 2 | 510 |
| 5 | Morthond | Morthond | 8000 | Reservoir | Veneer | Veneer | | | | | |
| 6 | Morthond | Morthond | 7500 | | Simplified CEM | Distance Decay | | | 20 | 2 | 510 |

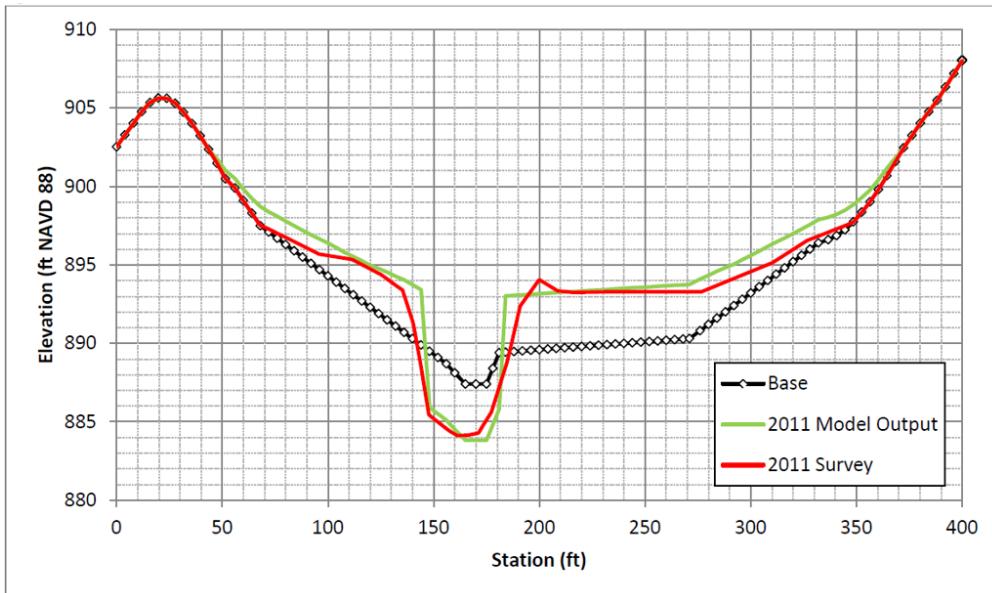
Examples of appropriate application of these local bed change methods would be:

- Choosing the **Reservoir** method for channel deposition along the topset slope of a reservoir delta while the **Veneer** method is the default elsewhere.
- Using the **Simplified CEM** method to compute erosion for a dam removal through the reservoir deposits, but default to the **Veneer** method for erosion downstream of the dam.

1.2.3.3.9 Additional Bed Change Modeling Notes

Floodplain Deposition-Channel Erosion

Even though the 1D model assumes cross-sectional average bed change, the veneer method sometimes computes different bed change trends in different parts of the cross section. The most common example of this is depicted in the overbank deposition example above. If the flow-load relationship makes high flows depositional and low flows erosional, HEC-RAS can compute channel erosion and overbank deposition. [Gibson and Nelson \(2010\)](#)^{25[1]} (see page 0) explain how this works. This phenomenon can be a numerical artifact. But it is also an observed process in some systems. This figure (USACE, 2012) includes an example where both the 1D model and the prototype deposited in the floodplain and eroded in the channel.



[1] (see page 0) Gibson, S. and Nelson, A. (2016) Modeling differential lateral bed change with a simple veneer method in a one-dimensional sediment transport model, River Flow 2016, International Conference on Fluvial Hydraulics.

Optional Overbank Deposition Method in version 5.0.7 is mandatory in 6.0 and later

Versions of HEC-RAS late in the 5.0.x series added a new way to compute overbank deposition, that calculated deposition during each mixing time step, rather than once for the entire computation increment. This method improved results with no known liabilities. Therefore, HEC not only made this method default in version 6.0 but made it mandatory. This may change model results but will improve model performance.

²⁵ https://www.researchgate.net/publication/311507008_Modeling_differential_lateral_bed_change_with_a_simple_veneer_method_in_a_one-dimensional_sediment_transport_model

Deposition

- No Bed Change Allowed Outside of the Movable Bed Limits
- Allow Deposition Outside of the Movable Bed Limits
 - Update between mixing time steps.
- Reservoir Option: Deposit More in Deeper Part of the XS

1.2.3.3.10 XS Specific Bed Change Options

The **XS Specific Bed Change Options** override the global bed change options for any cross section that has them. In the figure below, most cross sections use the veneer method in the channel (erosion and deposition) and the overbank (deposition only) but overrides the channel deposition with the reservoir method, to apply that method in the delta of the reservoir.

Bed Change Options

Bed Change Options

| | Channel | Overbank |
|------------|---------|----------|
| Deposition | Veneer | Veneer |
| Erosion | Veneer | None |

XS Specific Bed Change Options (will replace Global Options only where specified)

River: (All Rivers) Reach:

| | River | Reach | RS | Deposition | Erosion | Deposition | Erosion | Decay | Max | Side | Center | Left Dep | Right Dep |
|----|-----------|--------------|----------|------------|---------|------------|-----------|-------|-------|-------|-----------|-----------|-----------|
| | | | | Channel | Channel | Over Bank | Over Bank | Coeff | Width | Slope | Sta (opt) | Sta (opt) | Sta (opt) |
| 1 | Arghandab | Dahla Dam US | 19889.30 | Reservoir | | | | | | | | | |
| 2 | Arghandab | Dahla Dam US | 18908.08 | Reservoir | | | | | | | | | |
| 3 | Arghandab | Dahla Dam US | 17638.36 | Reservoir | | | | | | | | | |
| 4 | Arghandab | Dahla Dam US | 16637.84 | Reservoir | | | | | | | | | |
| 5 | Arghandab | Dahla Dam US | 16005.35 | | | | | | | | | | |
| 6 | Arghandab | Dahla Dam US | 15115.31 | | | | | | | | | | |
| 7 | Arghandab | Dahla Dam US | 13873.41 | | | | | | | | | | |
| 8 | Arghandab | Dahla Dam US | 12570.30 | | | | | | | | | | |
| 9 | Arghandab | Dahla Dam US | 11923.90 | | | | | | | | | | |
| 10 | Arghandab | Dahla Dam US | 10716.28 | | | | | | | | | | |
| 11 | Arghandab | Dahla Dam US | 9808.335 | | | | | | | | | | |
| 12 | Arghandab | Dahla Dam US | 8330.597 | | | | | | | | | | |
| 13 | Arghandab | Dahla Dam US | 5317.656 | | | | | | | | | | |
| 14 | Arghandab | Dahla Dam US | 4276.377 | | | | | | | | | | |
| 15 | Arghandab | Dahla Dam US | 2731.771 | | | | | | | | | | |
| 16 | Arghandab | Dahla Dam US | 1846.269 | | | | | | | | | | |
| 17 | Arghandab | Dahla Dam US | 233.1825 | | | | | | | | | | |

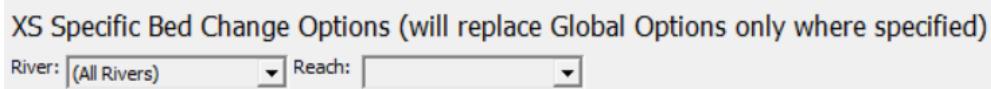
Widen channel after it incises to the bottom of the sediment control volume.

Area Method: Backward Compatible

OK Cancel

River Reach Bug Workaround

Bug: The XS Specific Bed Change Options do not update the grid.

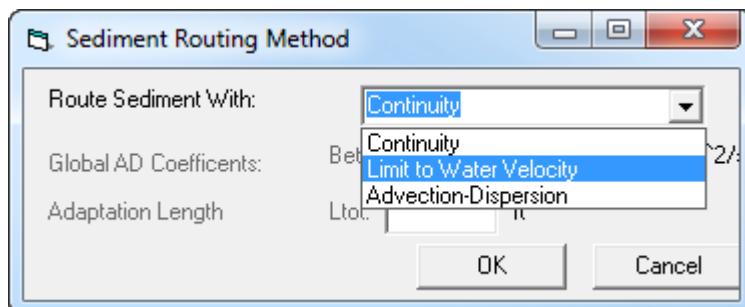


But this data table reflects the main sediment editor. If you close this editor, and then use the River and Reach drop down menus to select the reach you want to edit, that reach will show up in this editor.

1.2.3.4 Transport Method

HEC-RAS routes sediment with the Exner equation, modeling sediment mass with the continuity equation. This approach includes no physical limitation on sediment velocity and, depending on cross section spacing and time step, often moves sediment faster than the water velocity.

HEC-RAS includes an option that limits sediment velocity to the water velocity, only releasing sediment from each control volume that the water passing through that control volume can carry. To activate this option, select **Sediment Routing Method** from the **Options** menu and pick **Limit to Water Velocity** from the drop down list.



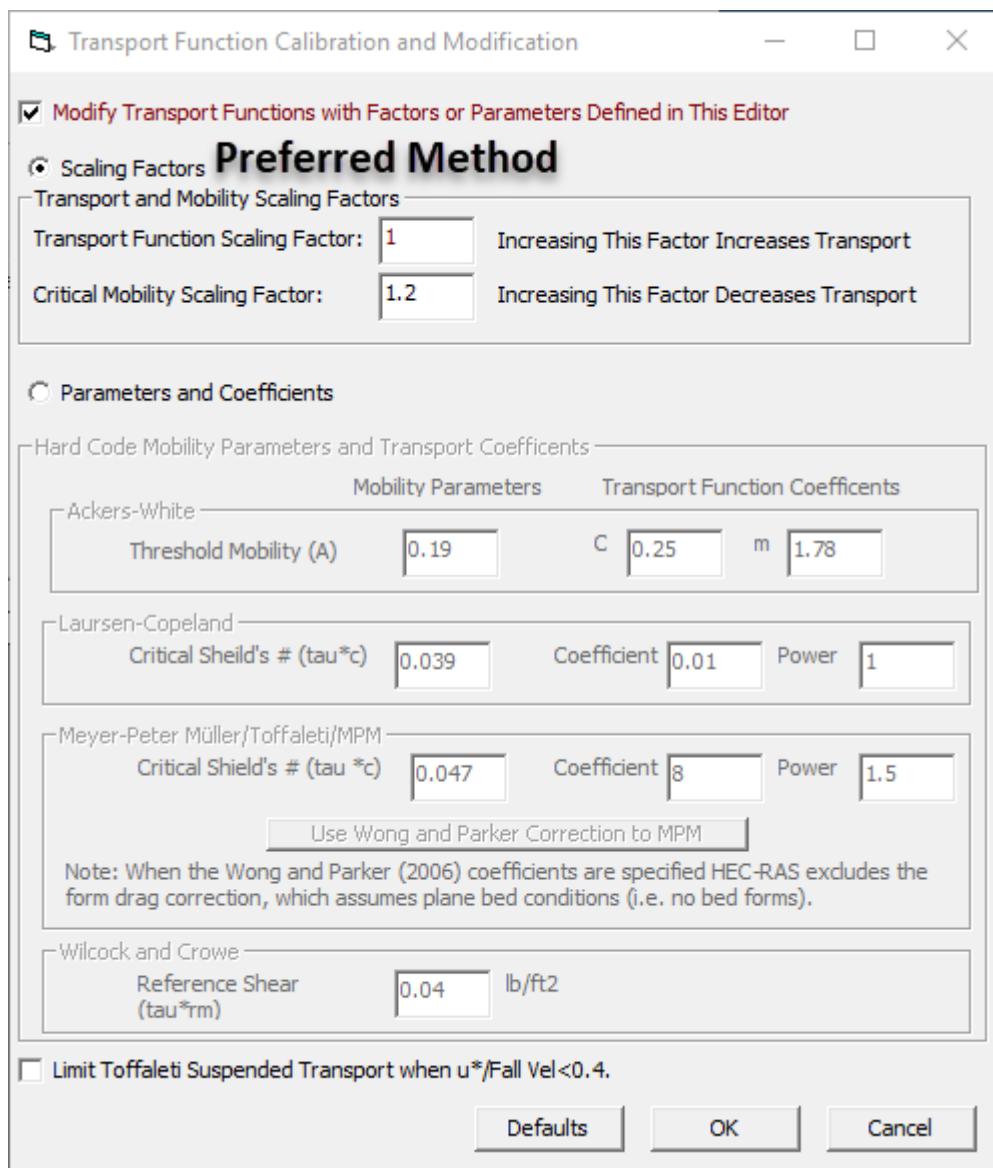
Wish List: 1D Advection-Diffusion

We would like to improve on this simplification, offering the Advection-Diffusion equation to route sediment according to more physical processes and user specified coefficients.

1.2.3.5 Transport Function and Calibration

The sediment transport functions are, to varying degrees, combinations of theoretical and empirical science. Even the most theoretically detailed equations were fit to data using empirical coefficients. These coefficients represent the central tendencies of the data considered but will not likely reflect the transport of a specific site precisely, even if an appropriate transport function is selected. Therefore, HEC-RAS provides opportunities to "Calibrate" the transport function. This should be the last stop in calibration, after the user

has selected the most appropriate (theoretically and based on initial performance) transport function, carefully checked all data and parameters, and considered calibrating by adjusting data within the observed range. To use calibration parameters first click the box labeled **Modify Transport Functions with Factors or Parameters Defined in This Editor**. If the box is not checked, variables can be edited and changed but they will not be used for transport calculations.



46 Transport Function Calibration and Modification Editor.

1.2.3.5.1 Scaling Factors:

Scaling Factors are (new in 5.1) are the preferred method for calibrating transport equations. Most transport functions are built around an excess shear or stream power function, where the shear or stream power is compared to a critical mobility factor (τ_c^* , SV_c) raised to some power. So a simplified version of the MPM equation is often written:

$$q_b^* = 8(\tau^* - \tau_c^*)^{3/2}$$

where q_b^* is a dimensionless measure of transport (the Einstein number), τ^* is the dimensionless shear stress (the Shields number) and τ_c^* is the critical dimensionless shear.

The **Scaling Factor** calibration method provides users two opportunities to scale results. So, the simplified MPM function could be re-written with the two scaling factors:

$$q_b^* = \alpha \times 8(\tau^* - \epsilon \times \tau_c^*)^{3/2}$$

where α is the **Transport Function Scaling Factor** and ϵ is the **Critical Mobility Scaling Factor**.

The transport function scaling factor is a simple linear multiplier on the capacity equation (e.g. 1.1 increases capacity 10% and 0.9 decreases capacity by 10%). The **Critical Mobility Factor** is a little more complicated, but also easier to justify physically. The **Critical Mobility Scaling Factor affects the competence** (the minimum flow at which water can move a grain class) as well as the **capacity**. It is inversely related to flow (a factor of 1.1 will make the sediment less mobile and will decrease transport). Additionally, because it is usually inside of the power, the effects are non-linear. Finally, not all transport functions use an excess shear/power/mobility form, so some (Engelund Hansen and Toffaleti) do not have a Critical Mobility Scaling Factor.

However, [Buffington and Montgomery \(1997\)](#) - among others - point out that the original critical shear data from Shields research had significant scatter and studies that have back-calculated critical Shields' parameters have found a wide range of values. So some modelers find mobility to be an appropriate, and more physically defensible parameter to adjust.

1.2.3.5.1.1

Table: List of the critical mobility factor adjusted with the scaling factor in each transport function (where applicable).

| | Transport Scaling Factor | Critical Mobility Scaling Factor |
|--------------------|--------------------------|----------------------------------|
| Ackers-White | X | A |
| Engelund-Hansen | X | |
| Laursen (Copeland) | X | τ_c^* |
| Meyer-Peter Muller | X | τ_c^* |
| Toffaleti | X | |
| MPM-Toffaleti | X | τ_c^* in MPM |

| | | |
|---------------|---|-----------------------------|
| Yang | X | SV _c |
| Wilcock-Crowe | X | τ _m [*] |

Warning: Be Careful Calibrating the Transport Function

These variables should only be adjusted within reasonable ranges in response to a hypothesis based on observed physical processes. Only change the critical shields parameter within a reasonable range, with physical justification. Changing coefficients no longer honors the form of the transport function.

1.2.3.5.2 Define Transport Function Parameters and Coefficients:

The second calibration option exposes parameters in four of the HEC-RAS transport functions. **This feature is not recommended.** The scaling factors are preferred, and the second method is mainly maintained for backward compatibility.

Each of the four transport functions has a variable that quantifies the force or energy required to mobilize the particle. In Laursen-Copeland and MPM it is the critical shear stress, τ_c^* (also known as the Shields number), in Ackers-White it is the Threshold Mobility (A) and in Wilcock it is the reference Shear Stress τ_{rm}^* . When calibrating a sediment transport function using this feature, these mobility factors should be the main parameters adjusted, since they can be related to physical phenomena. For example, imbricated or vegetated particles will be harder to move than the critical Shields parameter would suggest, so a physical case could be made for a higher τ_c^* , which would decrease transport. Conversely, the presence of substantial fine particles could make it easier for the flow field to entrain coarser particles, resulting in a lower τ_c^* .

Consider, again, the simplified form of MPM:

$$q_b^* = 8(\tau^* - \tau_c^*)^{3/2}, \quad \tau_c^* = 0.047$$

where q_b^* is a dimensionless measure of transport (the Einstein number), τ^* is the dimensionless shear stress (the Shields number) and τ_c^* is the critical dimensionless shear. 8 and 3/2 are coefficients fit to the simple excess shear relationship in the original formulation. Exposing the critical shear stress, the coefficient and the power of the MPM relationship turns it into a generic excess shear formula that can be used to customize a site-specific excess shear, power function. In fact, Wong and Parker (2006) recently reanalyzed the data set initially used to develop the MPM equation and found that the relationship

$$q_b^* = 4.93(\tau^* - \tau_c^*)^{1.6}, \quad \tau_c^* = 0.047$$

fit the original MPM data better than the MPM equation. Pressing the **Use Wong and Parker Correction to MPM** button, will automatically set the coefficient and power to the corrected values.

The transport function calibration menu offers the opportunity to use the Wong and Parker correction to the MPM equation, based on their 2006 paper. This reduces the MPM coefficient from 8 to 4.93, maintains the critical Shield's number of 0.047, and increases the power (MPM exponent) from 1.5 to 1.6. Wong and Parker's function was developed based only on reanalysis of data sets used by MPM *without* bed forms. Wong and Parker (2006) argued that the form drag correction embedded in many versions of MPM (including the one used in HEC-RAS) is not justified for lower-regime plane-bed conditions, and that MPM

over-predicts bed load transport without it. Therefore, if the Wong Parker coefficients ($a=4.93$, $\tau_c^*=0.047$, $b=1.6$) are used with MPM, whether entered manually or selected with the interface button, HEC-RAS will set the form drag correction to 1, which implies plane-bed conditions (i.e. no bed forms).

Warning: Be Careful Overwriting Dynamic Parameters

Several of the parameters exposed in this editor are actually functions that can have different values in different hydrodynamic and sediment settings. You may notice that selecting this method but leaving the parameters default may change the result because the default does not reflect the model conditions. This is why the scaling factors calibration method should be preferred (the direct parameterization may disappear in future versions). For example, the critical mobility scaling factor can adjust the reference shear in Wilcock and Crowe - as recommended - (Wilcock, personal communication) without over-writing the sand dependency built into the reference shear that is the main feature of the transport function.

1.2.3.5.3 Toffaleti Limiter

Yaw et al²⁶, (2019) Yaw, M., Pizzi, D., AuBuchon, J., Gronewold, R., Gibson, S. (2019) Middle Rio Grande and Tributaries Numerical Sediment Routing Study, Cochiti Dam to Elephant Butte Reservoir, Proceedings, SedHyd Interagency Sediment Conference. demonstrated that the Toffaleti equation (and the combined Toffaleti-MPM equation) include a discontinuity in high energy conditions for high energy conditions. This can lead to unrealistic transport under certain conditions. The issue emerges when the suspended zone equations try to compute transport for materials that are not suspended.

The [Toffaleti Limiter](#)²⁷ (which is included in the [Transport Function Calibration editor](#) (see page 136)) uses a shear velocity-to-fall velocity ratio ($u^*/w \leq 0.4$) to determine if the grain class is likely to be suspended by the hydraulics. The feature limits suspended transport to grain classes under that threshold and only includes the larger particles in the bed load (near bed) portion of the equation.

[Limit Toffaleti Suspended Transport when \$u^*/Fall\ Vel < 0.4\$.](#)

1.2.3.6 2D Options

These options are described in the 2D sediment manuals.

1.2.3.7 BSTEM Options

These options are only applicable to models with bank failure and toe erosion, using the USDA-ARS Bank Stability and Toe Erosion Model (BSTEM). BSTEM has a separate manual and these options are described in that [manual](#) (see page 223).

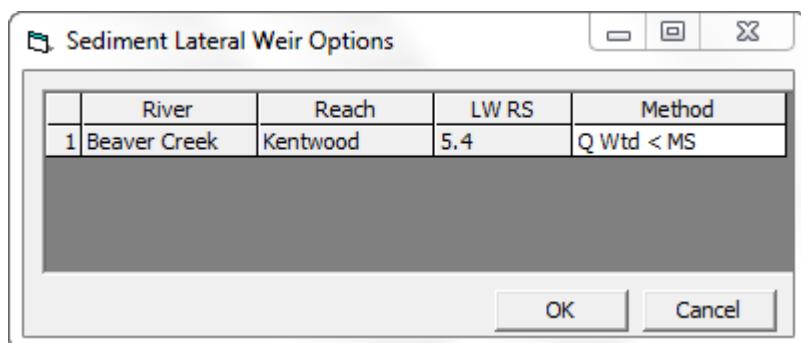
²⁶ https://www.sedhyd.org/2019/openconf/modules/request.php?module=oc_program&action=view.php&id=130&file=1/130.pdf
²⁷ /confluence/display/Transport+Function+and+Calibration#_Toffaleti_Limiter

1.2.3.8 Lateral Structure

HEC-RAS can simulate sediment transport with Lateral Structures in both quasi-unsteady and unsteady modes. Like flow splits, Lateral structures use the default assumption that sediment is diverted in proportion to the diverted flow (i.e. if 10% of flow leaves over a Lateral Structure, 10% of the transporting sediment will also divert, with the same gradation as the transporting sediment).

However, diverted sediment is usually substantially finer than sediment transporting in the main channel, especially if the diversion structure is perched higher than the bed load transport zone, or even the vertical center of mass of grain classes with low Rouse numbers. The **Lateral Weir Options** provide a "screen option" that prevents coarse grain classes from diverting.

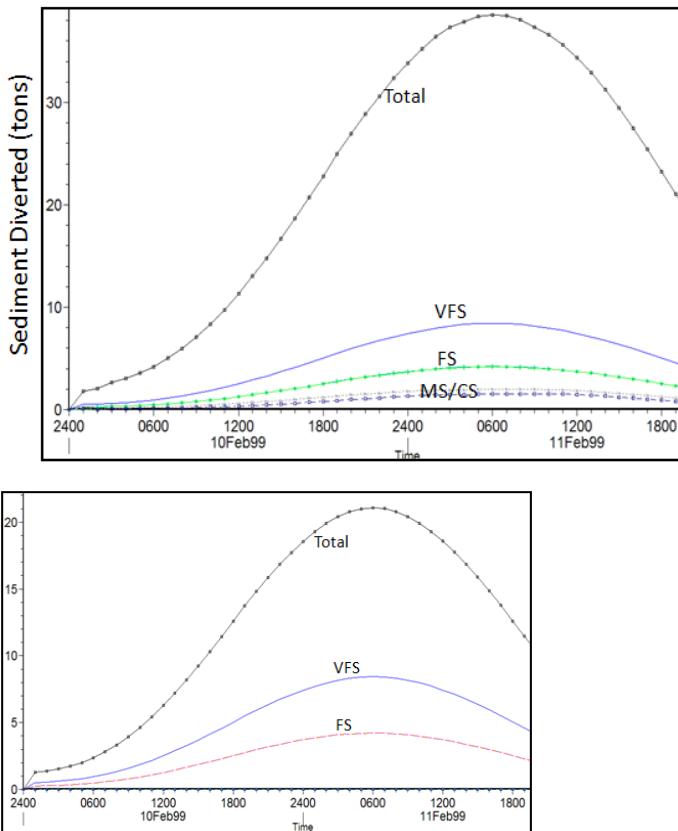
Select the **Lateral Weir Options** to set Lateral Structure **Diversion Thresholds**. The editor will list all the Lateral Structures in the project and the **Flow Weighted** method will populate for each by default. HEC-RAS will compute the percentage of flow diverted, and then will divert that percentage of sediment, but will exclude the grain class selected and all coarser. For example, in the figure below, only the grain classes *finer* than medium sand will be diverted (producing the plot on the right). Because screened grain classes are excluded after the original sediment diversion computation, the diverted sediment mass will be *less than* proportional to flow (which is why the total sediment diverted drops as the filter is applied in the graphs below).



47 Setting a Diversion Threshold in the Lateral Weir Editor.

See the SedRuleLat.prj files in the example data sets for an example Lateral Structure application. This data set also illustrates how to leverage native Lateral Structure features for sediment studies, using operational rules to monitor sediment variables and operate gates in response to them.

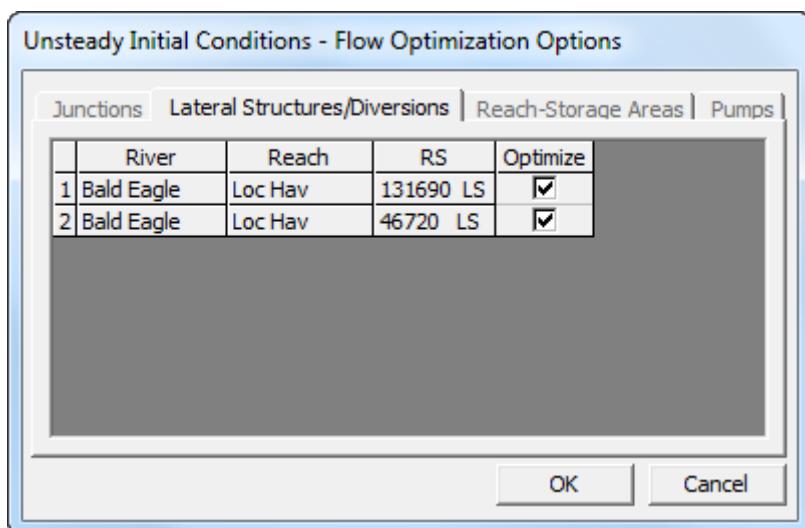
HEC-RAS storage areas and 2D areas are not connected to the 1D sediment transport model. If sediment from a 1D model is routed to a storage area with a Lateral Structure, it disappears from the model.



48 Sediment time series diverted over a Lateral Structure with (left) default assumption and (right) the diversion filter applied in the previous figure.

Modeling Note: Quasi-Unsteady Lateral Structures:

A note of caution on Lateral Structures and quasi-unsteady flow: flow over lateral structures is principally an unsteady phenomenon. As flow is diverted by a lateral weir, water levels drop, which leads to less flow over the weir. In unsteady flow, these feedbacks are accounted for implicitly. This is not the case with steady flow. An iterative approach can be employed in HEC-RAS to account for the feedbacks between flow diversion and the water level and converge on a solution. This option is not the default and has to be selected by going to the *OptionsFlow Optimization* menu in the **Sediment Transport Analysis** editor and selecting the **Lateral Structures/Diversions** tab.



49 Lateral structure optimization option.

Quasi-unsteady hydrodynamics are a series of steady flow analyses, so Lateral Structure flows are not accounted for implicitly. In order to account for feedbacks between diverted flows and water levels in quasi-unsteady flow optimize flow. However, this will increase run times dramatically, because the iteration required every time step by the optimization routines is computationally expensive. The alternatives are to move to an unsteady sediment transport model or compute a time series of flow diversion externally (e.g. with an unsteady flow run), add them as negative flows in the quasi-unsteady editor, and use the rating curve method (method 4 above) to compute sediment loads in the diversion.

Modeling Note: Lateral Structure Output

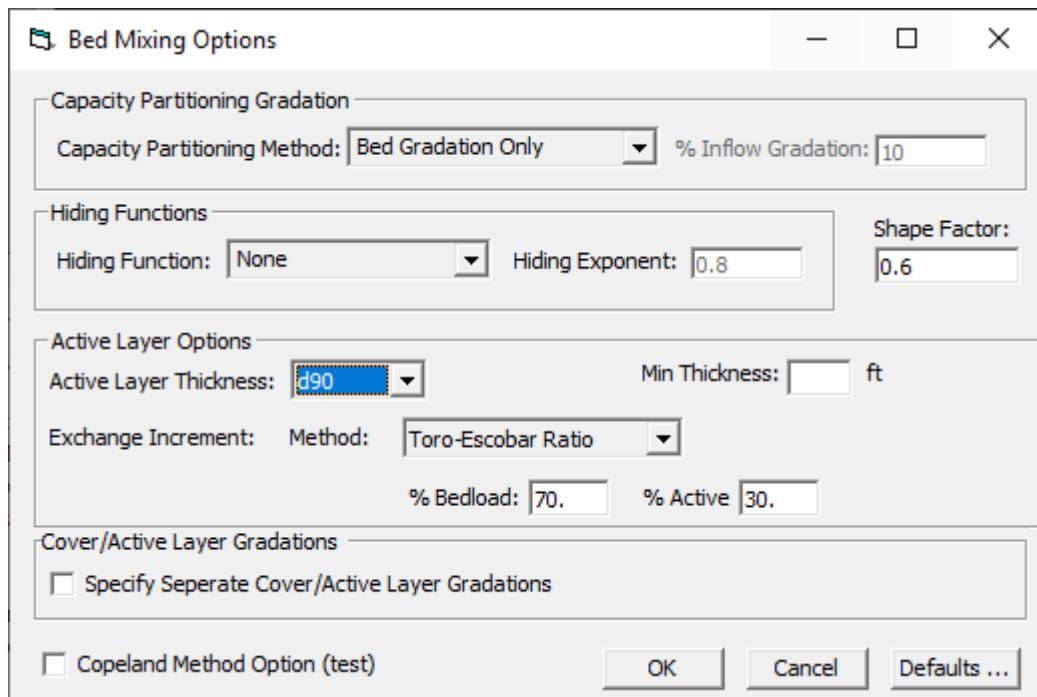
HEC-RAS does not provide sediment output by lateral structure. Instead, each cross section has a **Lateral Diversion** output variable, which sediment diverted from that cross-section's control volume by Lateral Structures or user specified diversions in the Rating Curve Boundary condition. Therefore, since lateral structures can span several cross sections, the total diverted sediment must be summed over all contributing cross sections.

1.2.3.9 Bed Mixing Options

Bed mixing options are associated with the fractionation of the transport capacity partitioning, hiding, and the [bed mixing \(sorting and armoring\)](#) (see page 320) algorithms, including the Active Layer, Thomas, and Copeland Methods. Sediment transport models can be very sensitive to the bed mixing algorithm.

1.2.3.9.1 Capacity Partitioning

HEC-RAS follows the fundamental assumption most multiple-grain class sediment transport models employ, partitioning transport capacity by the relative grain class fraction in the bed. The Technical Reference Manual includes more detail on this capacity partitioning approach (Einstein, 1960)



50 Options for Bed Mixing

1.2.3.9.2 Shape Factor

The shape factor is the ratio of b-axis to the a-axis of a particle, the length of the intermediate axis, perpendicular to the longest axis divided by the length of the longest axis. A spherical particle has a shape factor of 1 while a particle with a long axis that is two twice as long as the smallest axis has a shape factor of 0.5. HEC-RAS only uses the shape factor in the **Report 12** fall velocity method.

1.2.3.9.3 Active Layer Options

The three-layer mixing methods (e.g. Thomas and Copeland) regulate their layer thickness parameters automatically, based on their equilibrium depth and cover layer algorithms. The two-layer **Active Layer** method is a simpler alternative. It does not have the sophisticated cover layer dynamics of the three-layer methods, but it is more intuitive.

Therefore, HEC-RAS exposes key parameters of the active layer method, allowing the users to adjust them for their system. [Ruark et al.²⁸](#) (2011)* demonstrated that simple, active-layer sediment models can be very sensitive to the Active Layer Thickness.

²⁸ <https://ascelibrary.org/doi/full/10.1061/%28ASCE%29HY.1943-7900.0000343>

The default Active Layer thickness is set to one-d₉₀ of the active layer material. So HEC-RAS computes the 90th percentile particle size in the active layer mixture for each time step, and makes the active layer that thickness. The algorithm will either pull sediment up from the inactive layer or push extra sediment down into the inactive layer to achieve that thickness.

While the active layer is a conceptual simplification (Parker) that is [not, entirely, self-defining](#)^{29,**} experimental and laboratory observations suggest that **gravel beds** transport in a layer that is approximately equivalent to the thickness of one-to-three diameters of the largest particles in the mixture (e.g. d₈₄, d₉₀, d₁₀₀). However, the active layer thickness for a **sand bed** usually scales to the bedform amplitude so a sand bed active layer is usually one-to-two orders of magnitude larger than the d₉₀.

HEC-RAS allows users to define the active layer thickness in multiples of the d₉₀. This is usually between 1 and 5 for gravel beds, and over 10 for sand beds.

To adjust the active layer thickness (from the default of 1d₉₀) select the *OptionsBed Mixing Options* menu from the Sediment Editor and click on the dropdown box next to **Active Layer Thickness**, selecting **Xd90**. This will make a **Multiplier** box visible. Define the active layer thickness in multiples of the d₉₀.



Defining the active layer thickness in terms of a d₉₀ is very common for rivers with gravel and cobble armor layers. However, it is vulnerable to numerical artifacts if the load suddenly fines. A fine pulse (e.g. from a dam removal or reservoir flush) can suddenly make the active layer much finer, dropping the active layer thickness to a few millimeters or – in extreme cases – fractions of a millimeter.

The **Min Thickness** option makes the active layer more resilient to gradational disequilibrium. If the default **d90** or the user-specified **Xd90** are larger than the minimum active layer thickness (half a foot in the figure), HEC-RAS will compute the active layer thickness dynamically, based on that parameter. However, if the dynamic active layer falls below this **Min Thickness** HEC-RAS will default to this minimum thickness.

Modeling Note: Select an Active Layer thickness that will not run out of sediment

Users should size their active layer to avoid running out of sediment during any time step. If HEC-RAS scours all of the sediment from the active layer in a [bed mixing time step \(see page 143\)](#) (SPI) it will not replenish the layer. This will artificially limit scour and make the model artificially resistant to scour. Users can increase the number of Bed Mixing Time steps per computational increment or increase the size of the active layer to avoid active layer exhaustion. HEC-RAS versions 6.0 and later generates [runtime errors \(see page 143\)](#) if the active layer runs out of sediment. See the section on [selecting the active layer \(see page 143\)](#) thickness in the Technical Reference Manual.

Modeling Note: Xd90 is much larger for sand bed rivers

²⁹ <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016WR019675%4010.1002/%28ISSN%291944-9208.COMHES1>

The default Active Layer method is parameterized for bimodal beds with significant gravel or cobble components. The active layer concept is different for sand bed rivers. In order to avoid active layer exhaustion – and to adhere to the theoretical definition of the active layer – sand bed rivers require many multiples of the d_{90} . The Copeland method was designed for sand bed rivers and is often appropriate. However, when modelers apply the Active Layer method to sand bed rivers, **Xd90s** of 30, 100 or more are often appropriate, and defining a **Min Thickness** is a best practice to avoid active layer exhaustion.

Modeling Note: Active Layer Parameters will not affect Thomas or Copeland methods

The Thomas and Copeland methods do have "active layer" components. However, they conceptualize the active layer differently and compute it automatically. Therefore, adjusting these parameters will only affect the simulation if the **Active Layer Sorting Method** is selected.

1.2.3.9.4 Cover/Active Layer Gradations

Rivers with significant gravel or cobble components often form coarse cover or armor layers. But the default sediment editor only assigns one gradation per cross section. In settings with coarse cover layers and finer sub-surface layers, this single gradation will either underestimate the gradation of the cover layer or overestimate the gradation of the subsurface layer.

This feature allows users to define a separate cover layer gradation for armored cross sections. Defining a bed gradation in this editor will initialize the cover layer in the Thomas or Copeland Sorting Methods and the active layer in the Active Layer Mixing method with the gradation defined in this editor. The bed gradation defined in the main sediment editor will initialize the sub-surface layer. Any cross section left blank in this editor will initialize the cross section with a single gradation defined in the main manual.

To define separate active or cover layer gradations click on the **Specify Separate Cover/Active Layer Gradations** check box. This will expand the editor to show a list of cross sections in the model. Click on the **Bed Gradation** box to select the cover or active layer gradation for the cross section from a drop down of all the gradations specified.

This drop-down list of gradations will include all of the bed gradations specified in the **Bed Gradation editor**³⁰. Create a **Bed Gradation Template** for each gradation you would like to select in either the main sediment editor or this cover gradation editor.

This method also requires an initial **Layer Thickness** to initialize these layers. The cover or active layers with the specified gradations will have an initial layer thickness defined in the **Layer Thickness** field. Running a warm-up period or using a **hotstart**³¹ are alternate ways of developing coarse cover layer gradations without eroding the bed.

³⁰ <https://www.hec.usace.army.mil/confluence/display/RAS2DSed/Bed+Gradations>

³¹ <https://www.hec.usace.army.mil/confluence/display/RAS2DSed/Sediment+Hotstart>

| Cover/Active Layer Gradations (1D Only) | | | | |
|--|----------------|-----------------------|----------|--------------------|
| <input checked="" type="checkbox"/> Specify Separate Cover/Active Layer Gradations | | | | |
| River: | (All Rivers) | Layer Thickness (ft): | 1.5 | |
| Reach: | | | | |
| | River | Reach | RS | Bed Gradation |
| 2 | Muskegon River | Reach 1 | 67834.05 | Max Armoring G |
| 3 | Muskegon River | Reach 1 | 67299.37 | Max Armoring Grain |
| 4 | Muskegon River | Reach 1 | 66297.39 | Max Armoring Grain |
| 5 | Muskegon River | Reach 1 | 65668.04 | Max Armoring Grain |
| 6 | Muskegon River | Reach 1 | 64983.65 | Max Armoring Grain |
| 7 | Muskegon River | Reach 1 | 64344.7 | Max Armoring Grain |
| 8 | Muskegon River | Reach 1 | 63291.55 | Max Armoring Grain |
| 9 | Muskegon River | Reach 1 | 63040.43 | Max Armoring Grain |
| 10 | Muskegon River | Reach 1 | 62662.84 | Very Coarse |
| 11 | Muskegon River | Reach 1 | 62224.61 | Very Coarse |

| RS | Bed Gradation |
|----------|----------------------------------|
| 43494.34 | Very Coarse |
| 42754.92 | Coarse |
| 41418.61 | Very Coarse |
| 40114.02 | Only Cobble Boulder |
| 38859.25 | Mega Boulders |
| 37595.53 | Max Armoring Grain good armor |
| 36611.74 | |
| 35300.58 | |
| 33681.7 | |
| 32161.16 | |
| 30007.26 | |
| 28403.04 | |
| 26855.63 | |
| 25377.07 | |
| 23496.62 | |
| 21598.97 | |
| 20637.43 | |
| 19160.91 | |
| 18370.29 | |

If this cover field is left blank, HEC-RAS will use a homogeneous bed gradation from the main sediment editor for the entire cross section.

| Cover/Active Layer Gradations (1D Only) | | | | |
|--|----------------|-----------------------|----------|---------------|
| <input checked="" type="checkbox"/> Specify Separate Cover/Active Layer Gradations | | | | |
| River: | (All Rivers) | Layer Thickness (ft): | 1.5 | |
| Reach: | | | | |
| | River | Reach | RS | Bed Gradation |
| 29 | Muskegon River | Reach 1 | 50715.04 | good armor |
| 30 | Muskegon River | Reach 1 | 48555.73 | good armor |
| 31 | Muskegon River | Reach 1 | 47783.64 | good armor |
| 32 | Muskegon River | Reach 1 | 46967.16 | good armor |
| 33 | Muskegon River | Reach 1 | 46171.99 | good armor |
| 34 | Muskegon River | Reach 1 | 45331.7 | good armor |
| 35 | Muskegon River | Reach 1 | 43947.92 | good armor |
| 36 | Muskegon River | Reach 1 | 43494.34 | good armor |
| 37 | Muskegon River | Reach 1 | 42754.92 | |
| 38 | Muskegon River | Reach 1 | 41418.61 | |
| 39 | Muskegon River | Reach 1 | 40114.02 | |
| 40 | Muskegon River | Reach 1 | 38859.25 | |
| 41 | Muskegon River | Reach 1 | 37595.53 | |
| 42 | Muskegon River | Reach 1 | 36611.74 | |
| 43 | Muskegon River | Reach 1 | 35300.58 | |
| 44 | Muskegon River | Reach 1 | 33681.7 | |
| 45 | Muskegon River | Reach 1 | 32161.16 | |
| 46 | Muskegon River | Reach 1 | 30007.26 | |
| 47 | Muskegon River | Reach 1 | 28403.04 | |
| 48 | Muskegon River | Reach 1 | 26855.63 | |

Use gradation from the main editor for the subsurface and use this gradation for the cover layer

Use gradation from the main editor for the subsurface and the cover layer

*Ruark, M.D., Niemann, J.D., Greimann, B.P. and Arabi, M. (2011) Method for Assessing Impacts of Parameter Uncertainty in Sediment Transport Modeling Applications, ASCE Journal of Hydraulic Engineering, 137(6).

**Church, M. and Haschenburger, J.K. (2016) What is the "active layer"? Review of Geophysics.

1.2.3.10 Subsidence

In some locations, regional subsidence drops the land elevation relative to sea level. Regional subsidence can complicate mobile bed calculations for systems where the river datum is changing relative to the tail water. Therefore, HEC-RAS includes a **Subsidence** feature. Users can define constant subsidence rates for

each cross section. HEC-RAS will lower all the cross-section nodes (inside and outside of the movable bed limits) at this rate over the duration of the simulation.

Subsidence Rates

| River | Reach | RS | Rate (ft/yr) |
|-------------|------------|----------|--------------|
| Mississippi | Mainstem 1 | 515539.1 | 0.0296 |
| Mississippi | Mainstem 1 | 510771.7 | 0.0296 |
| Mississippi | Mainstem 1 | 504954 | 0.0299 |
| Mississippi | Mainstem 1 | 499537 | 0.0305 |
| Mississippi | Mainstem 1 | 494769 | 0.0303 |
| Mississippi | Mainstem 1 | 489377.5 | 0.0301 |
| Mississippi | Mainstem 1 | 483936.1 | 0.0306 |
| Mississippi | Mainstem 1 | 478530.5 | 0.0308 |
| Mississippi | Mainstem 1 | 472714.8 | 0.0307 |
| Mississippi | Mainstem 1 | 466026.6 | 0.0311 |
| Mississippi | Mainstem 1 | 460800.4 | 0.0309 |
| Mississippi | Mainstem 1 | 455221.3 | 0.0312 |
| Mississippi | Mainstem 1 | 449712.8 | 0.0312 |
| Mississippi | Mainstem 1 | 443689.8 | 0.0312 |
| Mississippi | Mainstem 1 | 437683.8 | 0.0312 |
| Mississippi | Mainstem 1 | 432232.3 | 0.0312 |
| Mississippi | Mainstem 1 | 427812.5 | 0.0312 |
| Mississippi | Mainstem 1 | 422404.7 | 0.0311 |
| Mississippi | Mainstem 1 | 416460 | 0.0308 |
| Mississippi | Mainstem 1 | 410587.4 | 0.0308 |
| Mississippi | Mainstem 1 | 405036.4 | 0.0308 |
| Mississippi | Mainstem 1 | 400252.5 | 0.0308 |

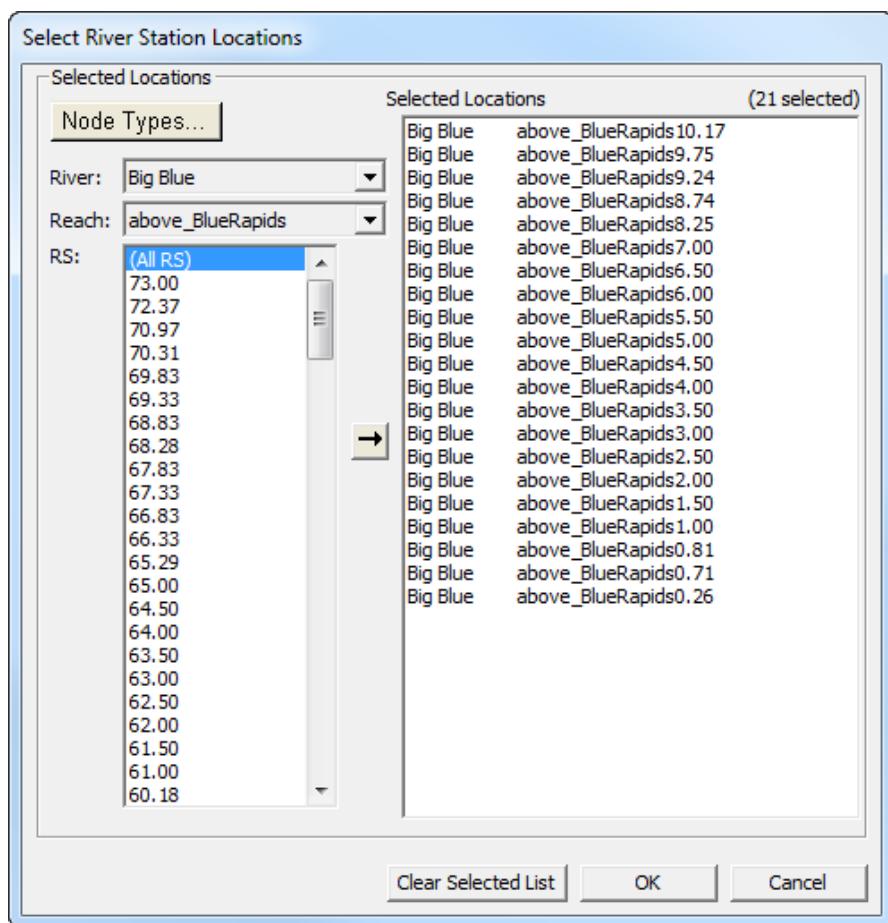
Modeling Note: Using Subsidence with Fixed Bed Models

HEC-RAS only includes subsidence in the sediment model. But users sometime want to apply subsidence for fixed-bed hydraulic models. Modelers can apply subsidence to a hydraulic model by creating a "dummy" sediment file with simple, synthetic, sediment data, and then set all the cross sections to Pass Through Nodes (see next section). This will signal that HEC-RAS should adjust cross sections due to subsidence but not erosion or deposition.

1.2.3.11 Set Pass Through Nodes

1.2.3.11.1 Classic Pass Through Nodes

Pass through nodes remain fixed throughout the sediment simulation. Sediment that enters the cross-section control volume associated with that cross section leaves that control volume. Capacity for the node is set equal to supply. The cross section will not deposit or erode. This feature was designed for channel bends where multi-dimensional channel dynamics keep sediment from depositing but the one-dimensional transport approach computes deposition. To use this option the user simply selects the river station locations in which they would like all sediment to pass through (i.e. no deposition or erosion).



51 Selecting pass through nodes.

Modeling Note: Using Pass Through Nodes to Troubleshoot Models

Pass through nodes can stabilize an unsteady sediment model, focusing bed change on the region of interest, running the rest of the model as flow only. They can also help add complexity incrementally, getting a stable hydraulic model first, then bringing sediment cross sections

(upstream to downstream) online incrementally. Additionally, pass through nodes only limit vertical bed change. They do not prevent BSTEM bank failure or toe scour. Therefore, users sometimes use them to isolate bank processes from bed processes.

1.2.3.11.2 Pool Pass Through Nodes

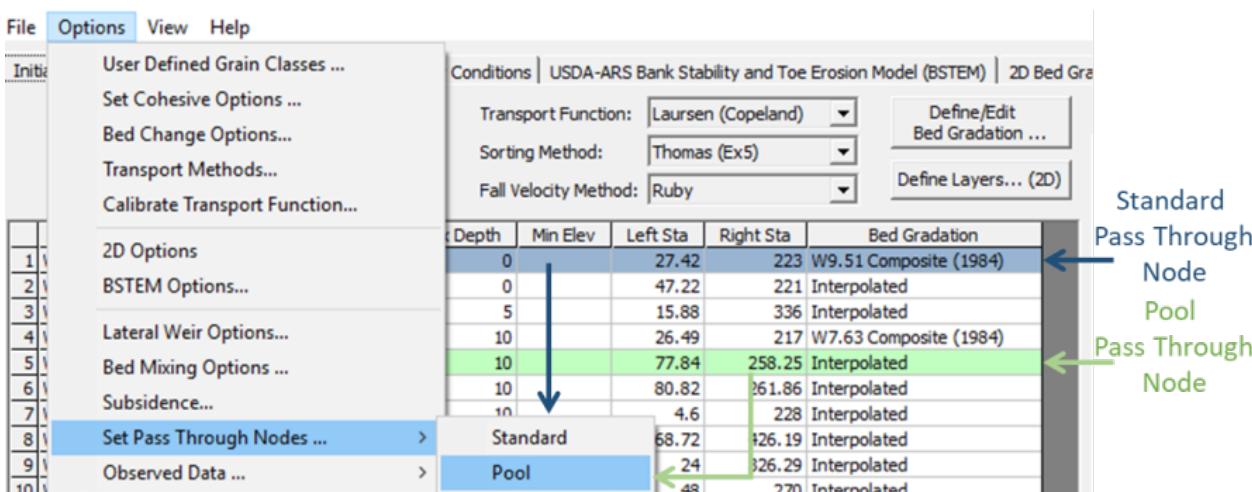
Pools are one of the primary applications of pass through nodes. Pools are fundamentally three-dimensional features. One-dimensional morphodynamic models do not simulate helical currents and mobility inversions that maintain pools.* Because 1D models do not simulate these multidimensional pool maintenance processes, cross-section averaged models convert the larger cross-section area of pool cross sections to low velocity transport nodes. Therefore, 1D models tend to deposit in pools. These deposits become artificial, numerical, sediment sinks, removing sediment load from the model, and inducing erosion in other cross sections.

Pass-through nodes are one way to mitigate artificial pool deposition in HEC-RAS. Making pools pass-through nodes keeps them "open." Pass through nodes do not erode or deposit. Turning bed change off can seem like an aggressive solution to a numerical artifact, but in most cases, forcing a pool to no-change leads to a more realistic local- and reach-scale model than depositing with the standard morphodynamic equations.

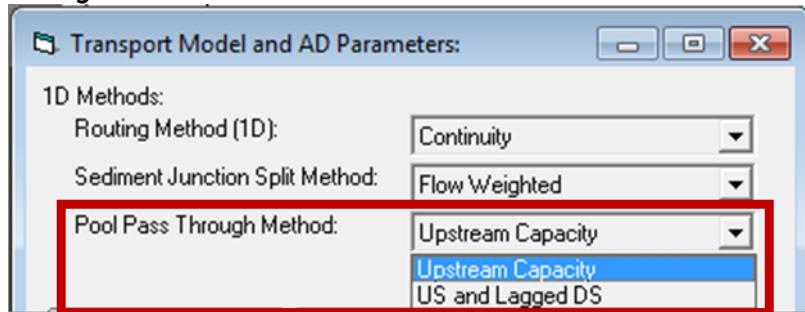
However, if the base-level change of the reach is changing over time, making pools pass-through will fix their elevation, while the rest of the reach rises or falls together. HEC developed the **Pool Pass Through Node** option as an intermediate tool, that allows the pools to adjust with the neighboring cross sections, without over-depositing based on the 1D assumptions.

The **Pool Pass Through Node** applies the transport capacity of the bounding cross section(s) to the specified node. If the modeler selects multiple, consecutive, **Pool Pass Through Nodes**, HEC-RAS will assign the transport capacity of the non-pass through cross section(s) next to the pool pass through cluster. Assigning pool nodes the transport capacity from a "representative" bounding cross section, will allow the pool nodes to erode or deposit at a similar rate as the upstream run or crossing reach, without artificially depositing in a pool that the river keeps open.

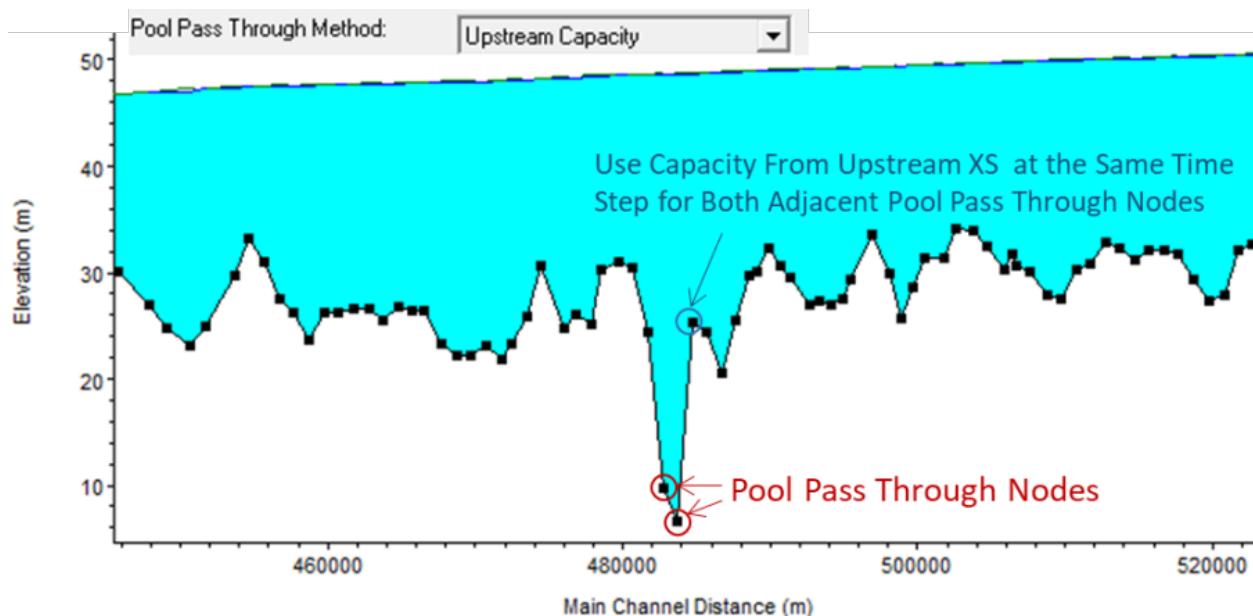
Define **Pool Pass Through Node(s)** by selecting the **Options** Menu, and then selecting Set *Pass Through NodesPool{*}. This will launch a cross section selection dialogue. Select designated Pool Pass Through Cross Sections. The HEC-RAS Sediment Data interface will highlight standard and pool pass through nodes in blue and green respectively to help modelers keep track.



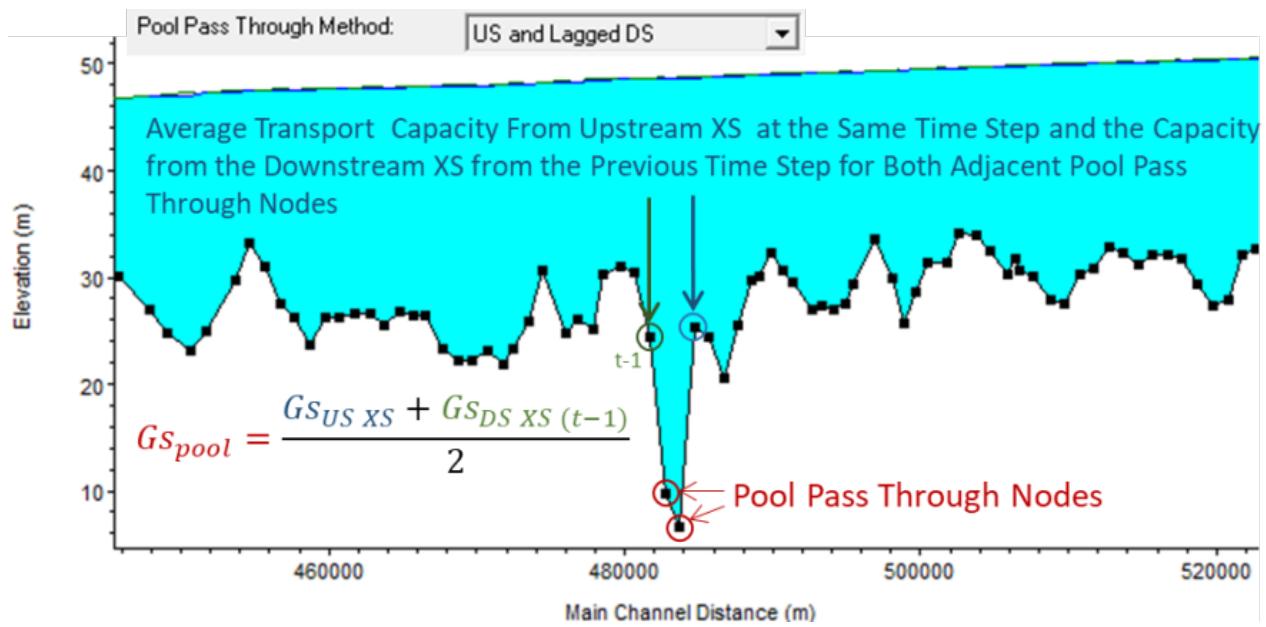
Because HEC-RAS computes sediment transport from upstream-to-downstream and transport capacity is dynamic based on bed gradation, the **Pool Pass Through Node** option cannot average the upstream and downstream transport capacities during the same time step. So the **1D Methods** under the *OptionsTransport Methods* menu offers two different approaches to compute the capacity of **Pool Pass Through Nodes**.



Method 1: Upstream Capacity – The **Pool Pass Through Node(s)** adopt the transport capacity of the next upstream cross section that is not a pass through node (from the same time step). See the schematic of this approach below.**



Method 2: US and Lagged DS – HEC-RAS averages the transport capacity of the upstream cross section (from the same times step) and the capacity of the downstream cross section at the previous time step. The **Pool Pass Through Node(s)** adopt the averaged of the synchronous upstream capacity and the lagged downstream capacity.



*Incidentally, 2D models do not simulate some of these processes either. Three-dimensional modelers in the USACE have found that even 3D models tend to under-represent these process. At this point, most numerical models require some form of empiricism or simplification to simulate transport through pools.

**This is one of the large bluff-associated pools (#3 in Figures 5 and 8) on the Madeira river documented in Gibson et al (2019) "Two pool-to-pool spacing periods on large sand-bed rivers: Mega-pools on the Madeira and Mississippi³²," Geomorphology, 328, 196-210.

1.2.3.12 Observed Data

The observed sediment data changed substantially in HEC-RAS version 6.0. Previous versions only included one generic observed profile. Current versions allow multiple profiles which can persist throughout the simulation or be associated with particular dates and can be associated with standard HEC-RAS, sediment output variables (to plot with computed results of the same kind) or novel observations that will show up in the sediment results under their own heading.



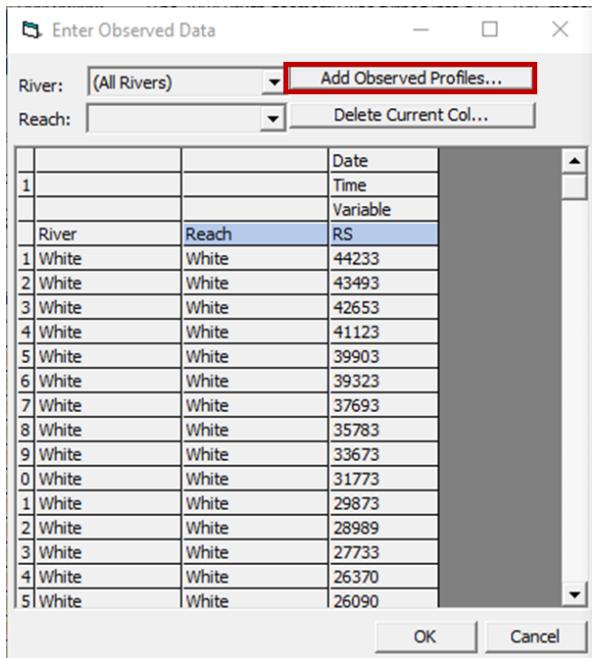
Sorry, the widget is not supported in this export.
But you can reach it using the following URL:

<http://youtube.com/watch?v=7muyCdZLjt4>

³² <https://www.sciencedirect.com/science/article/pii/S0169555X18305208?via%3Dihub>

1.2.3.12.1 Observed Profile Data

Select **Observed Profile** data by selecting *OptionsObserved DataProfile. This will launch the dialogue below. Press the ***Add Observed Profiles** button to add observed data. To designate observed data as one of the standard HEC-RAS sediment output variable types (so it shows up just below the computed results with an _obs tag) select one of the variables from the list by double clicking or pressing the arrow. The date and time are optional. Leaving the date and time blank, will generate a persistent observed profile, which will write the observed data to every time step at the specified cross section. Adding a date and time will only write the observed data at the closest output time step to the date and time entered.



If Date/Time is blank – the result will write to all profiles

Select Sediment Output Variables

Date: Time: (Leave blank to plot for all time steps)

Create New Variable Name:

| Sediment Variables Available: | Selected Variables |
|-------------------------------|------------------------------|
| Invert Change | |
| Invert Elevation | |
| Long. Cum Vol Change (Total) | Long. Cum Vol Change (Total) |
| Long. Cum Vol Change (by GC) | |
| Long. Cum Mass Change (Total) | |
| Long. Cum Mass Change (by GC) | |
| Vol Bed Change (Total) | |
| Vol Bed Change (by GC) | |
| Mass Bed Change (Total) | |
| Mass Bed Change (by GC) | |
| Vol Bed Change Cum (Total) | |
| Vol Bed Change Cum (by GC) | |
| Mass Bed Change Cum (Total) | |
| Mass Bed Change Cum (by GC) | |
| Water Surface | |
| Flow | |
| Shear Stress | |
| Slope | |
| Velocity | |
| Vol In (Total) | |
| Vol In (by GC) | |
| Mass In (Total) | |
| Mass In (by GC) | |
| Mass In Cum (Total) | |
| Mass In Cum (by GC) | |
| Vol In Cum (Total) | |
| Vol In Cum (by GC) | |
| Vol Out (Total) | |
| Vol Out (by GC) | |
| Mass Out (Total) | |
| Mass Out (by GC) | |

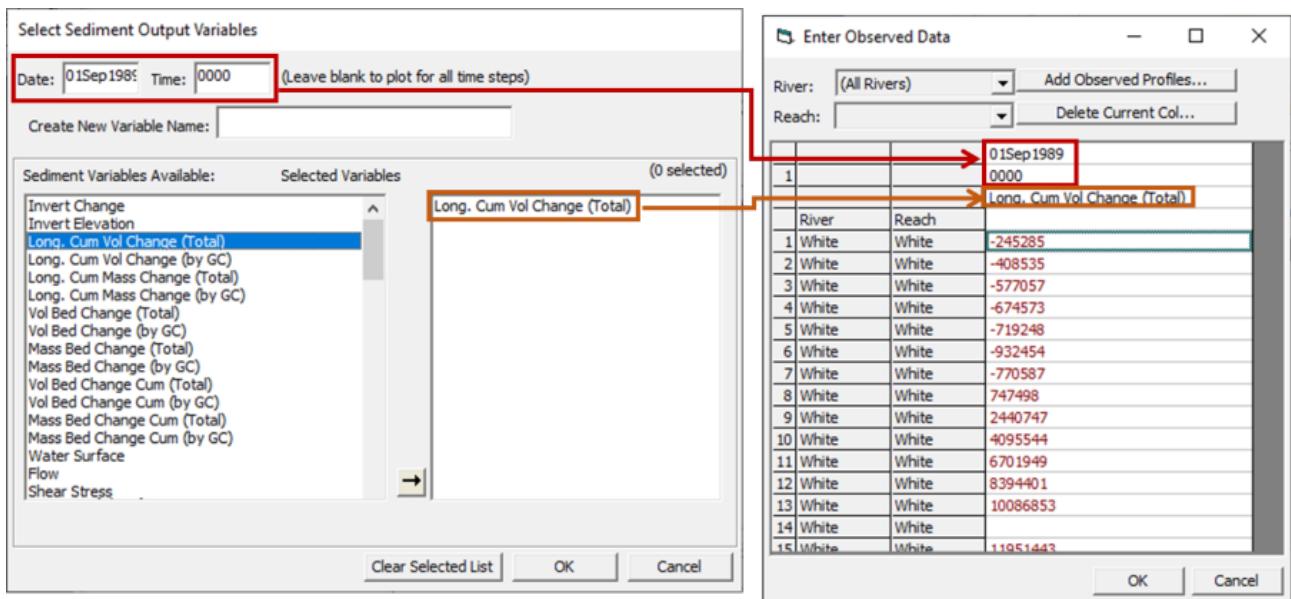
Enter Observed Data

River: Add Observed Profiles...

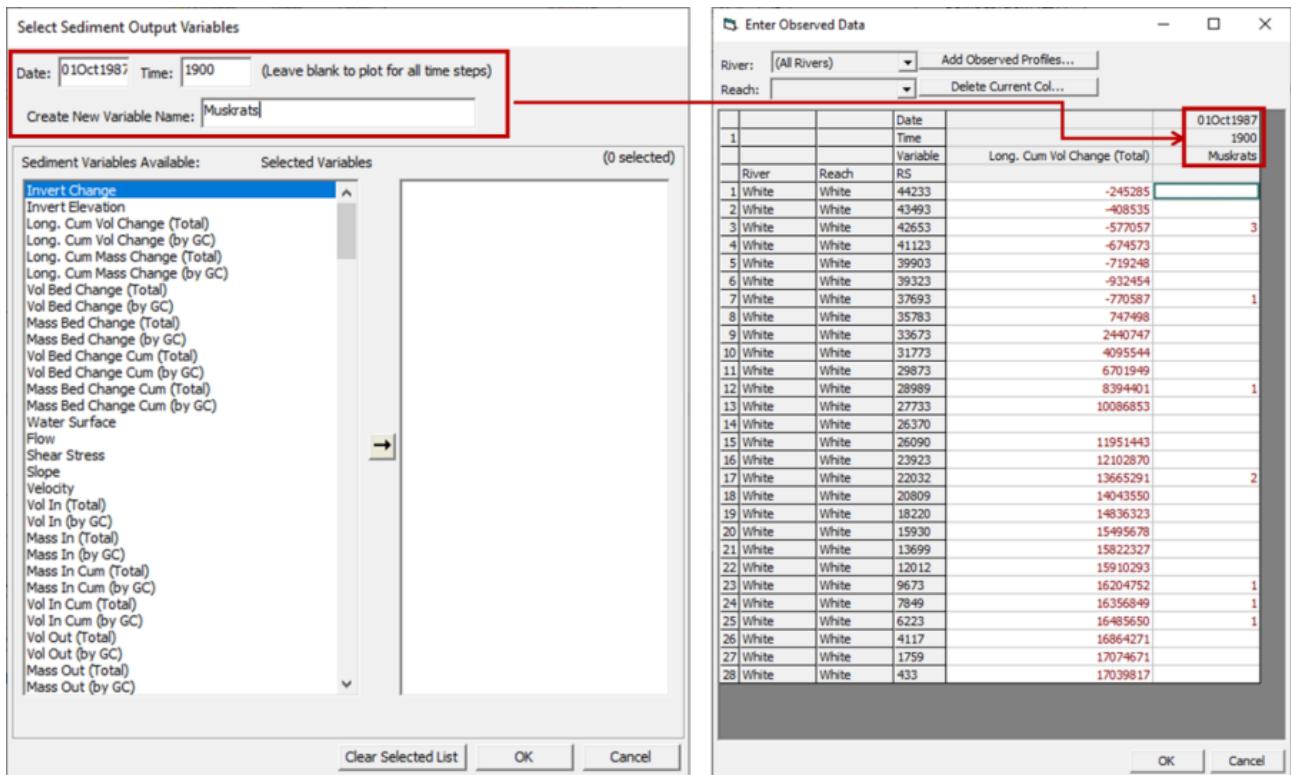
Reach: Delete Current Col...

| | | Date | Time | Variable |
|---|-------|-------|------|------------------------------|
| 1 | White | 44233 | | Long. Cum Vol Change (Total) |
| 2 | White | 43493 | | |
| 3 | White | 42653 | | |
| 4 | White | 41123 | | |
| 5 | White | 39903 | | |
| 6 | White | 39323 | | |
| 7 | White | 37693 | | |
| 8 | White | 35783 | | |
| 9 | White | 33673 | | |
| 0 | White | 31773 | | |
| 1 | White | 29873 | | |
| 2 | White | 28989 | | |
| 3 | White | 27733 | | |
| 4 | White | 26370 | | |
| 5 | White | 26090 | | |

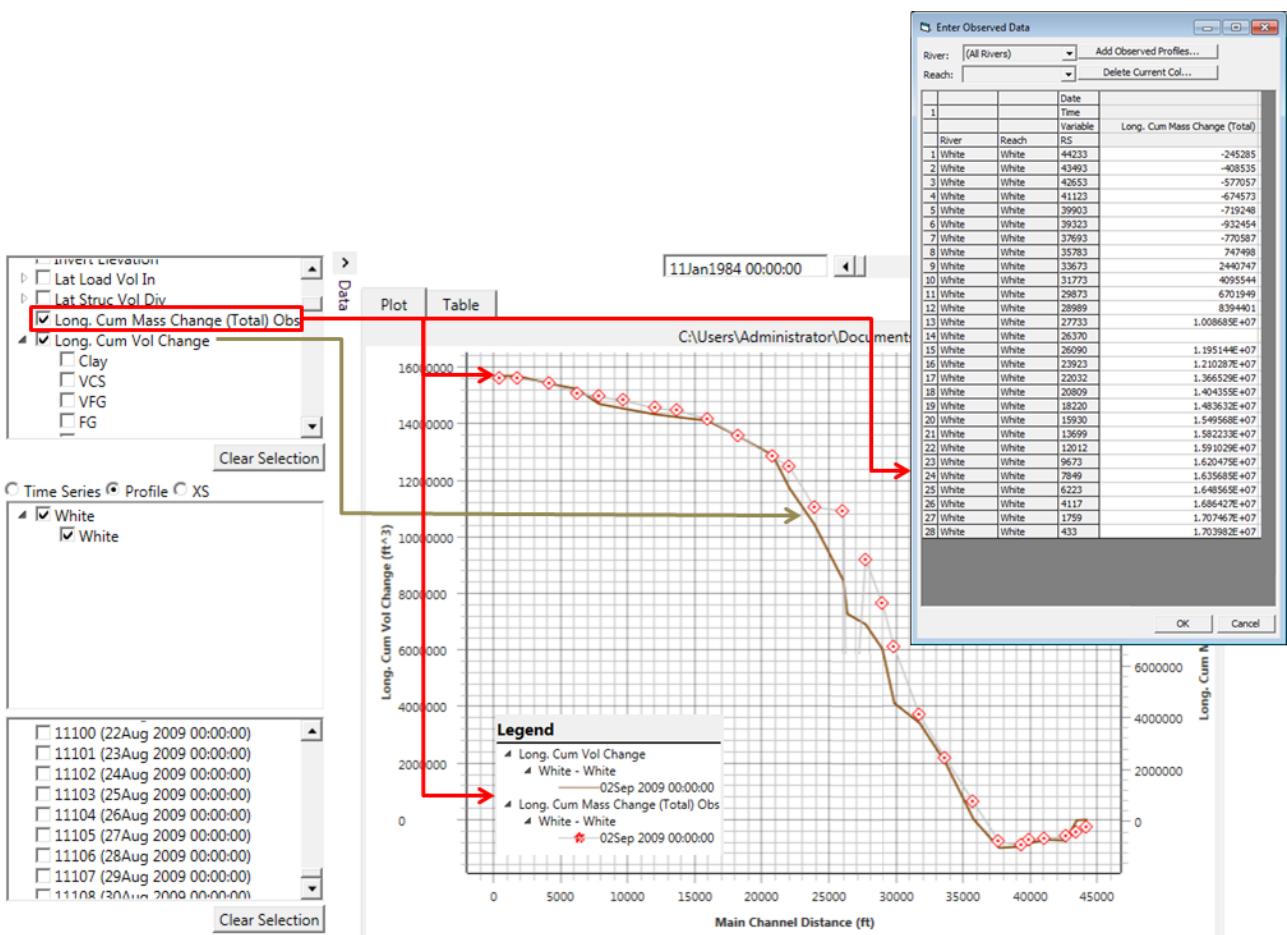
Finally, modelers can define a profile (either persistent throughout time or at a particular date) with a customized label. This can be useful if modelers want to coordinate some other system process with flow or sediment results. Type in the new variable name in the **Create New Variable** Name text box instead of selecting a sediment variable, add a date if appropriate, and press **OK**. The figure below adds observations from a hypothetical muskrat survey that will then write to the sediment results file and can be viewed with the other data.



52 Define a date and time for profiles for them to show up with the simulated results closest to the date and time.



The following is an example of a Longitudinal Volume Change Calibration, including the observed input data and the compared result:



1.3 Geometric Considerations for a Sediment Transport Model

One of the advantages of using HEC-RAS for a sediment transport simulation is that many systems have existing, fixed bed, HEC-RAS hydraulic models. Because the sediment transport model uses the same geometry file, building the sediment file from an existing sediment model includes some efficiencies. However, sediment models require special attention to certain aspects of the 1D hydraulics. There are some cases where the sediment model will be more sensitive to 1D hydraulic assumptions than a standard hydraulic analysis, and other cases where users might want to set up a 1D sediment model a little differently than they would if it was just a fixed-bed hydraulic model.

This section covers some of the issues sediment users should consider as they set up their [hydraulic model](#), before they even open the sediment data editor.

- [Historic Geometry for a Calibration \(see page 157\)](#)
- [Filter the Cross Section Points \(see page 157\)](#)
- [Modeling Bridges in a Sediment Simulation \(see page 158\)](#)
- [Sediment Implications of Other Geometric Tools in HEC-RAS \(see page 161\)](#)
 - [Blocked Obstructions \(see page 161\)](#)

1.3.1 Historic Geometry for a Calibration

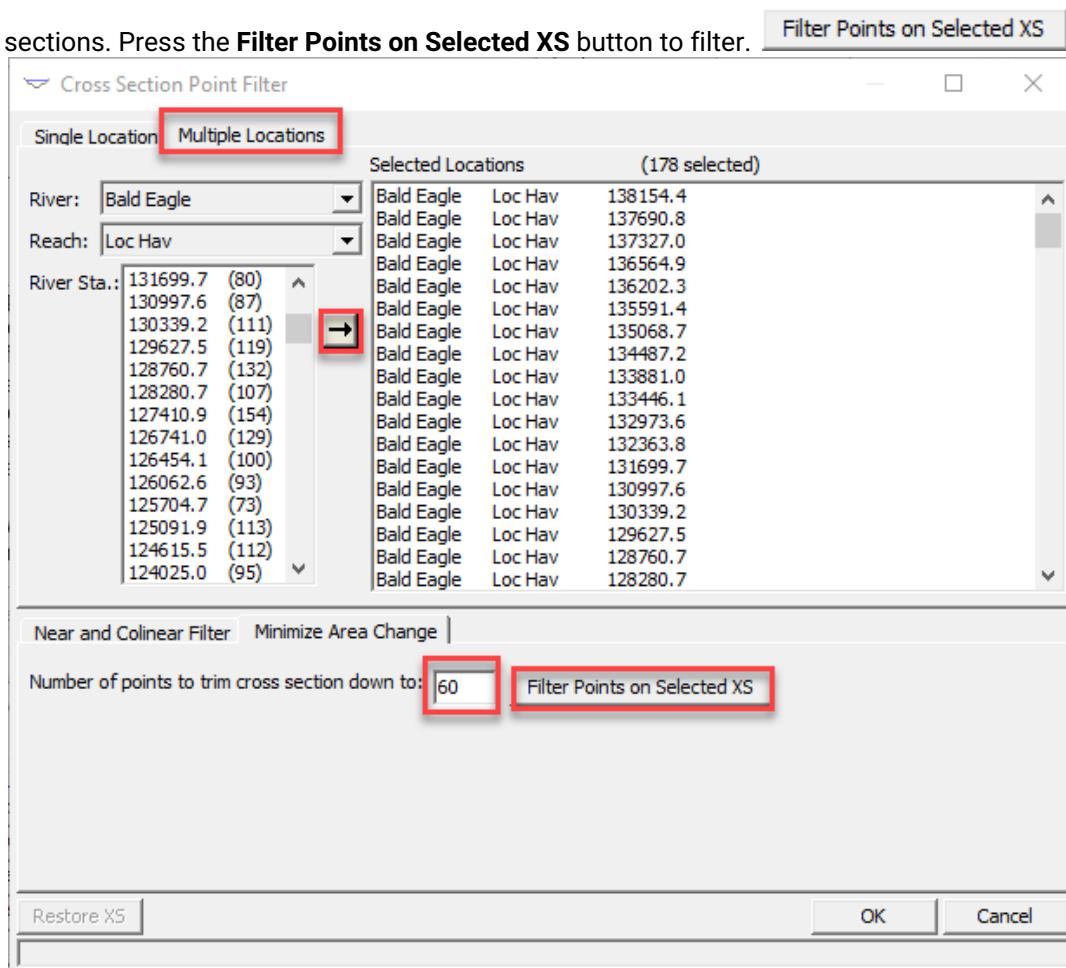
Most fixed bed, hydraulic studies in HEC-RAS start with the best, most recent, cross section information available. Sediment studies, however, often start with historic cross sections, and calibrate by running the period of record between these historic cross sections and a contemporary bathymetry. After the model is calibrated, then future projections often start with the best, most recent bathymetry available. But a good set of historic cross sections is one of the most valuable assets a sediment transport study can have.

1.3.2 Filter the Cross Section Points

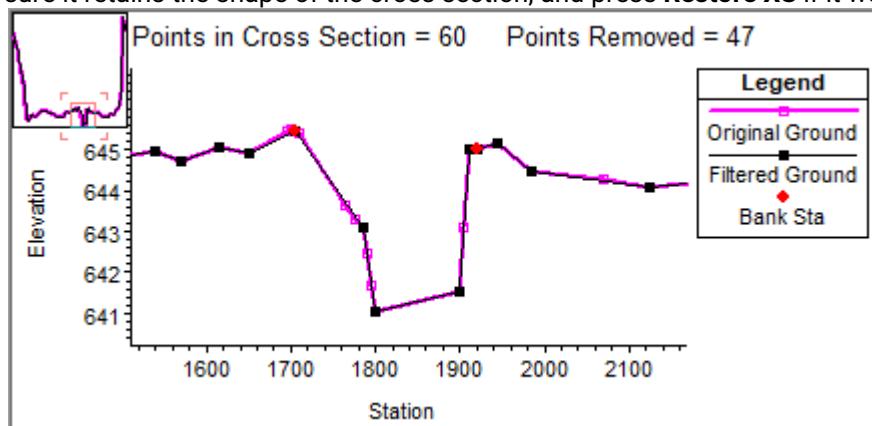
HEC-RAS limits cross sections to 500 station-elevation points. But 500 points is almost always far more than required to adequately represent the shape of the cross section. In hydraulic modeling, too many station-elevation points can affect run time (which is exacerbated in sediment which runs the steady flow computations every time step) but is mostly innocuous. Dense station-elevation points can cause several issues in a 1D sediment transport model including [bed inversion](#) (see page 64) and node stranding.

Almost any cross section can be reasonably represented with 100 station-elevation curves and sediment models often perform best when cross sections are limited to 60 station-elevation points or less. To optimize the shape representation with the fewest station elevation points use the point filter in HEC-RAS. In the geometry file, select **Tools--> Cross Section Point Filter**. See the main HEC-RAS user manual to learn about the different options and how to evaluate the quality of the filter methods, but the simplest method to reduce the cross section point density is to select the **Multiple Location** and **Minimize Area Change** tables (below), and define the maximum station-elevation points. Then press the **Select All** button to select all cross

sections. Press the **Filter Points on Selected XS** button to filter.



After you filter the cross sections, you can return to the **Single Location** tab and evaluate the filter, making sure it retains the shape of the cross section, and press **Restore XS** if it went poorly.



1.3.3 Modeling Bridges in a Sediment Simulation

The HEC-RAS bridge modeling approaches (particularly Pressure-Weir) can cause instabilities in HEC-RAS sediment models. Bridge cross sections tend to be much closer together than standard cross section

spacing. Additionally, the upstream and downstream bridge face cross sections replicate themselves just inside the bridge, which usually generates four tightly spaced cross sections, much closer together than the cross section spacing throughout the rest of the model. This cross section spacing can cause model instabilities and erratic scour patterns around structures. There are three main options for dealing with problematic bridges in HEC-RAS.

1.3.3.1 Option 1: Delete the Bridge:

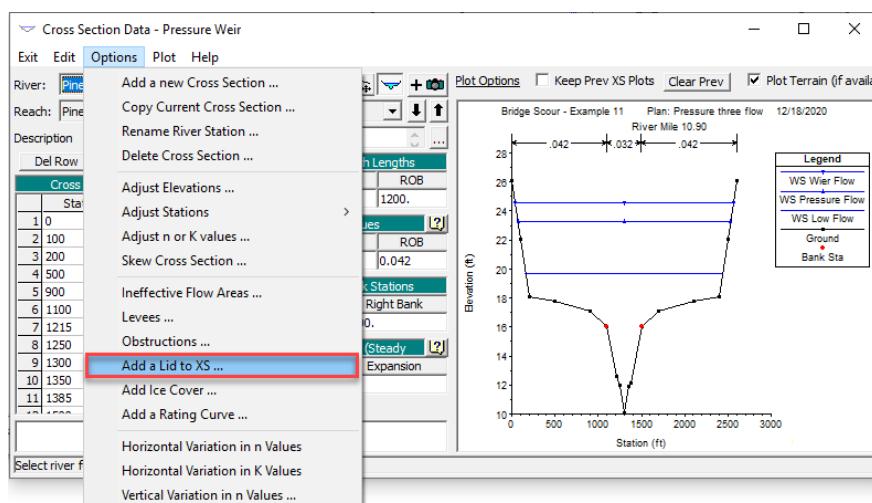
If the bridge does not affect upstream hydraulics significantly, consider the impact of deleting it. It is common to remove high chord bridges from sediment models. If the bridge does induce upstream backwater effects that affect transport, there are two other common modeling approaches.

1.3.3.2 Option 2: Bound the Bridge with Pass Through Nodes:

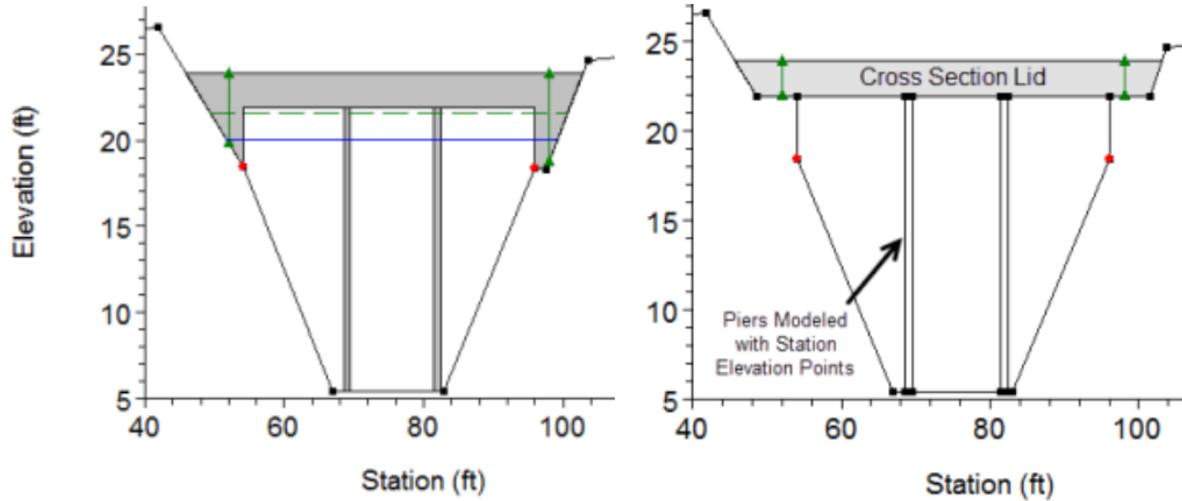
Setting the upstream and downstream cross sections to [Pass-Through Nodes](#) (see page 149) will also make the bridge "pass through". Making the bridge a pass through element, converts the bridge into a fixed-bed feature. The model will use the standard HEC-RAS hydraulics to compute backwater effects and bridge influences on hydraulics, without scouring (or depositing) in the bridge itself. This approach leverages the bridge hydraulics capabilities that are useful in a reach-scale model (e.g. backwater effects, not contraction scour) without computing localized sediment effects at the structure, which the 1D, mobile bed model cannot resolve. The pass through bridge approach does make one major assumption. It does not allow reach-wide base level change. If the whole reach incises 1m, the pass through bridge will not, and will create a numerical check dam.

1.3.3.3 Option 3: Model the Bridge as a Lidded Cross Section:

If bridges cause instabilities in the sediment model but cannot be removed without affecting the hydraulics, consider modeling the bridge with a **Lidded Cross Section** (see discussion of Lidded Cross Sections in the main HEC-RAS manual). Define the bridge as a cross section, including piers as elevated station-elevation points (see figure below). Then, in the cross section editor, select *Options → Add Lid to XS...* to model the bridge deck as a lid.

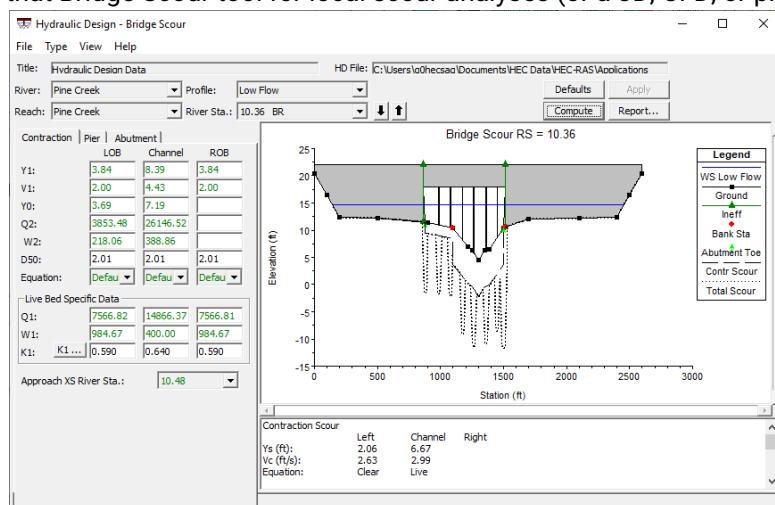


Lidded cross sections do not provide full bridge hydraulics computations. HEC-RAS will not compute pressure flow or momentum loss at lidded cross section. But lidded cross sections (with piers represented in station elevation data) will account for bridge area and wetted perimeter, solving the energy equation.



Warning: Do Not Use the Sediment Model to Simulate Bridge Scour

The 1D, mobile-bed, sediment transport features in HEC-RAS are reach-scale capabilities. It is not appropriate to use this model to calculate bridge scour, especially pier or abutment scour. Bridge scour is a fundamentally multi-dimensional process that is outside the scope of many of the assumptions of the 1D transport model. The empirical, Department of Transportation, HEC-18 bridge scour capabilities are available in the Hydraulic Design editor of HEC-RAS. Use that Bridge Scour tool for local scour analyses (or a 3D, CFD, or physical model).



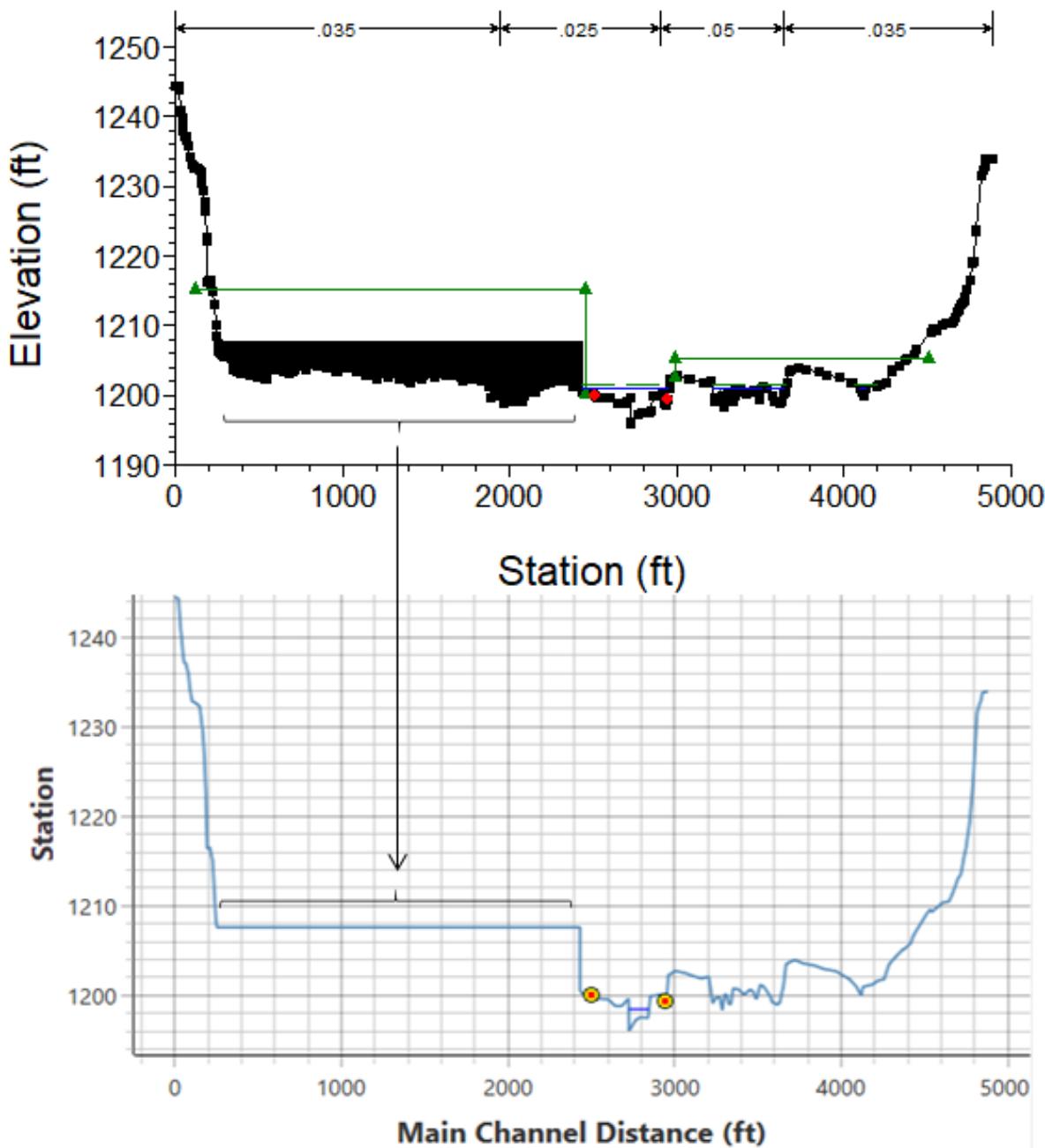
1.3.4 Sediment Implications of Other Geometric Tools in HEC-RAS

HEC-RAS has a wide range of geometric tools. Most of these geometric tools and features in the 1D geometric editor have been adapted to work with sediment. However, they may not always interact with sediment in the way a user expects. This section describes the sediment assumptions associated with several of the 1D geometric features not described elsewhere in the model.

1.3.4.1 Blocked Obstructions

HEC-RAS does not compute sediment transport with blocked obstructions, but does support models that include these features.

A 1D HEC-RAS sediment model will convert all blocked obstructions into station-elevation points, stamping them into the cross section before the first time step. Therefore, the blocked obstruction can erode or deposit with the rest of the cross section (if it is in conveyance zone that erodes and/or deposits).



1.4 Simulating Sediment Transport

- [Creating a Plan](#) (see page 163)
- [Sediment Computation Options and Tolerances](#) (see page 165)
 - [Sediment Computational Options](#) (see page 167)
 - [Sediment Transport Energy Slope](#) (see page 168)
 - [Bed Roughness Predictors](#) (see page 175)

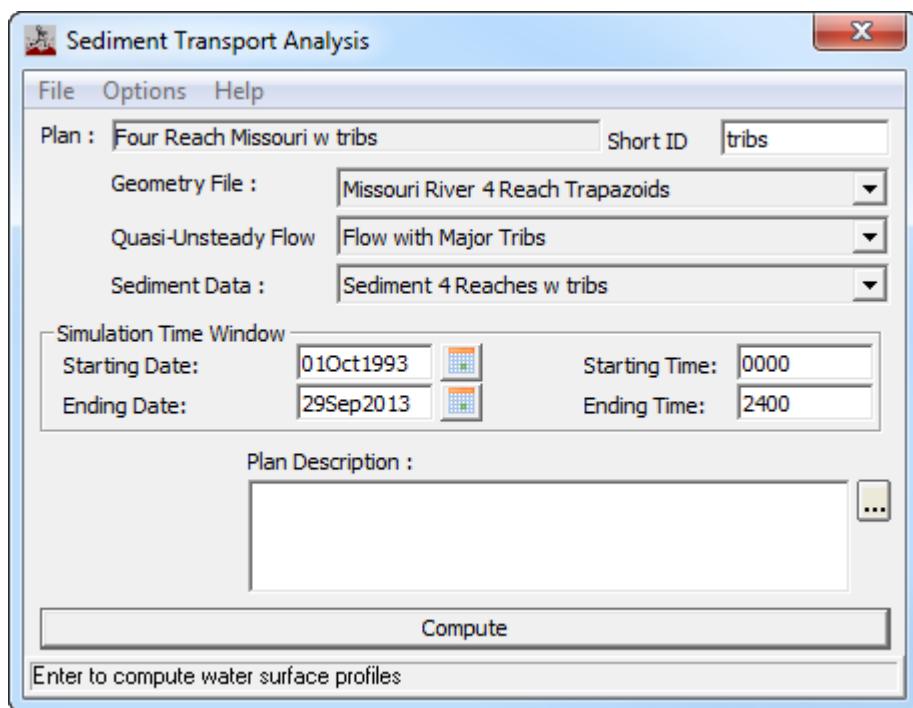
- [Sediment Computation Run Time Multiplier](#) (see page 177)
- [Cross Section Weighting Factors \(Default Recommended\)](#) (see page 178)
- [2D Computational Options](#) (see page 180)
- [Dredging](#) (see page 180)
 - [Elevation Methods](#) (see page 181)
 - [Mass Methods](#) (see page 183)
 - [Dredge End Date](#) (see page 184)
 - [Set Range of Values](#) (see page 184)
 - [Re-Introduce part of Dredged Load](#) (see page 184)
 - [Dredge Output](#) (see page 185)
- [Sediment Output Options and Tolerances](#) (see page 185)
 - [Output Level](#) (see page 186)
 - [Output in Mass or Volume?](#) (see page 199)
 - [Set Output Increment](#) (see page 200)
 - [Set Cross Section Bed Change Output](#) (see page 201)
 - [Select Customized Output](#) (see page 202)
 - [HDF5 output](#) (see page 204)
 - [Sediment Hotstart From Output File \(Versions 6.0+\)](#) (see page 207)
 - [Gradation Hotstart \(5.x Legacy Version\)](#) (see page 209)
 - [Write Classic Output \(WSE Profile etc. – O file\)](#) (see page 211)
 - [Write Legacy Binary Output](#) (see page 212)
 - [DSS Output](#) (see page 212)
- [Create Geometry Files from Sediment Results](#) (see page 214)
- [Specific Gage Post-Processor](#) (see page 216)

1.4.1 Creating a Plan

For sediment transport computations, the user is required to create a Plan file. A sediment plan includes a geometry file (.gxx), a sediment file (.zxx), a flow file (quasi-unsteady: .qxx), and some plan level options data. To create and simulate a quasi-unsteady sediment model, open **Sediment Analysis** under the **Run**

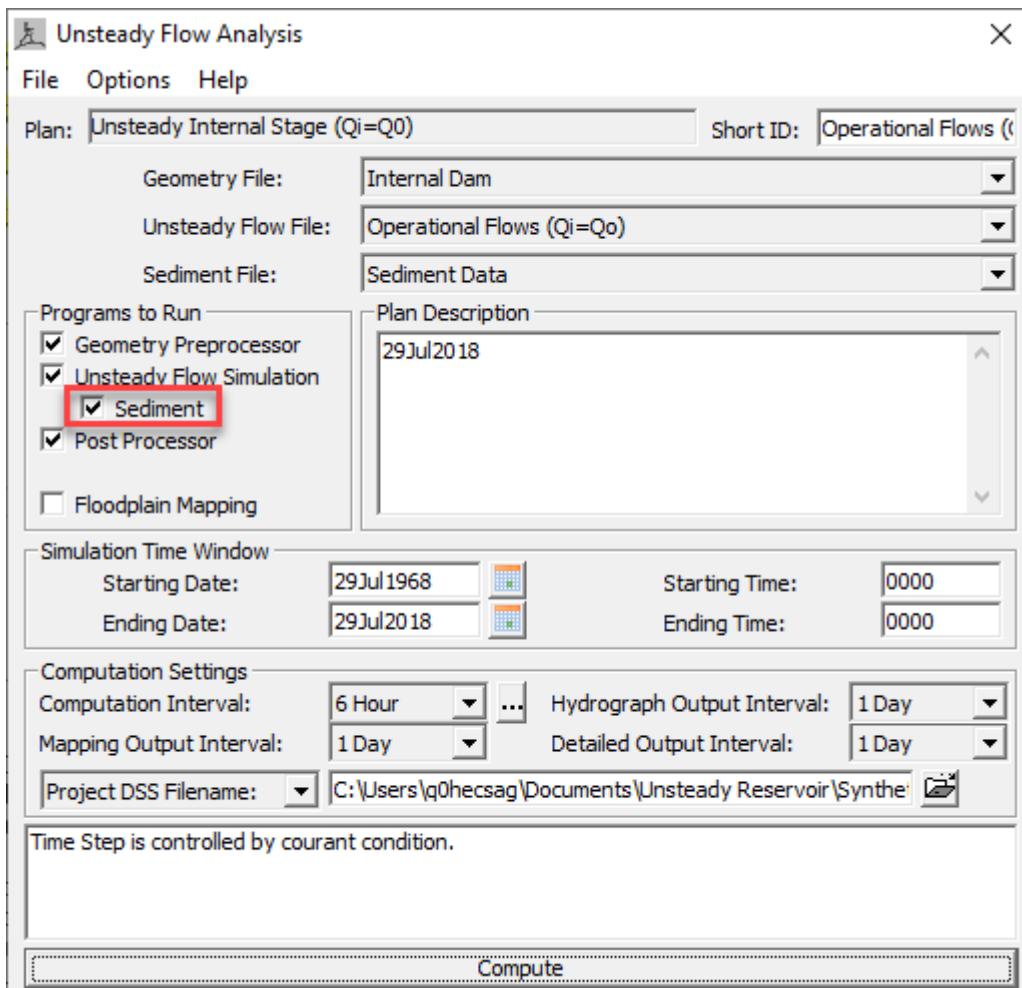
menu on the main HEC-RAS dialog or press the **Sediment Analysis** button:  When this option is selected, the Sediment Transport Analysis window will appear as shown in the figure below.

As with Unsteady Flow, a time window must also be specified for the sediment analysis. This requires start and end dates (in DDMMYYYY format) as well as start and end times (2400 clock) in the **Simulation Time Window** (below).



53 Sediment analysis window.

To create and simulate an unsteady sediment plan, open the **Unsteady Flow Analysis** editor by selecting it from the **Run** menu or pressing the **Unsteady Analysis** button .

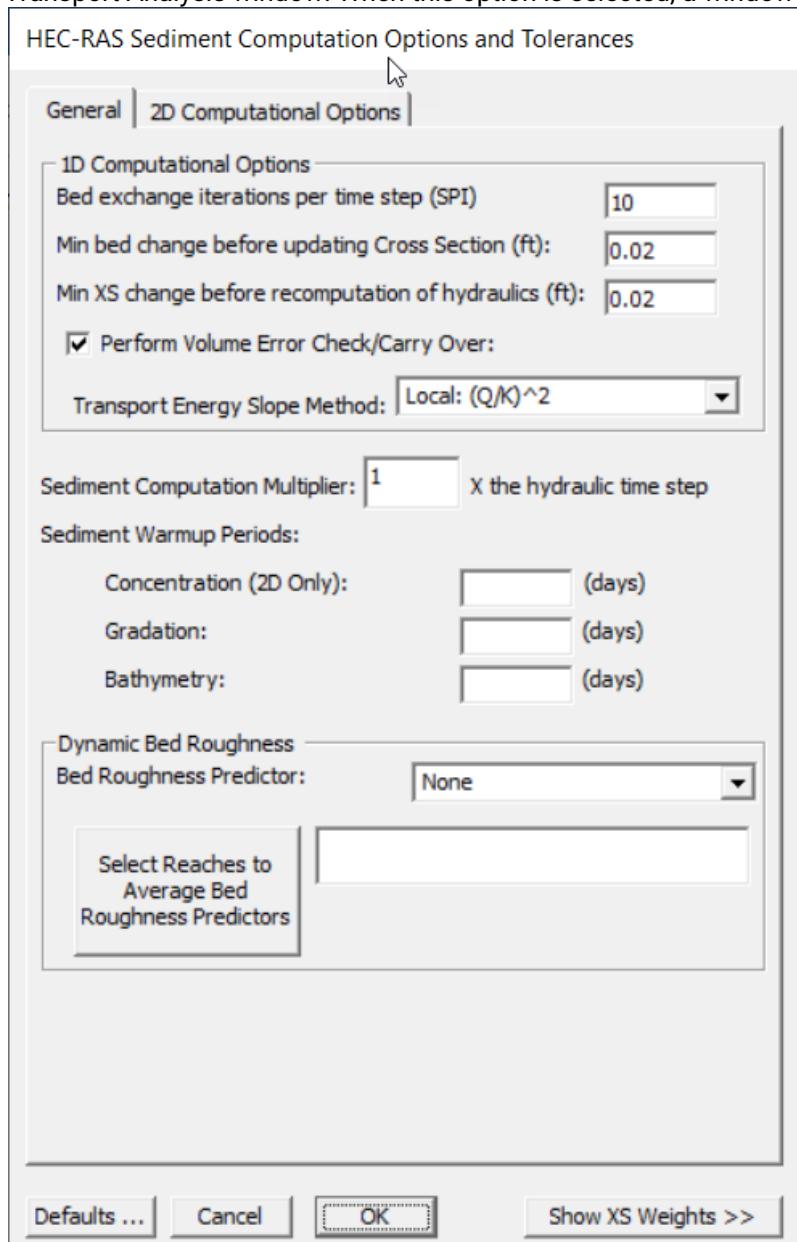


54 Unsteady flow analysis.

1.4.2 Sediment Computation Options and Tolerances

HEC-RAS includes several settings and model coefficients under the **Options** menu of the Sediment Analysis dialog. Many of these **Options** are identical to those in the Steady Flow Analysis dialog and are documented in The Steady Flow manual. However, there are four **Options** specific to **Sediment Transport Analyses**. Sediment specific options include the **Sediment Computation Options and Tolerances**, **Transport Energy Slope**, and **Sediment Output Options** menu items available from the **Options** menu of the Sediment

Transport Analysis window. When this option is selected, a window will appear as shown in the figure below.



1.4.2.1 Sediment Computational Options

Computational Options

| | |
|--|-----------------------------------|
| Bed exchange iterations per time step (SPI): | <input type="text" value="10"/> |
| Min bed change before updating Cross Section (ft): | <input type="text" value="0.02"/> |
| Min XS change before recomputation of hydraulics (ft): | <input type="text" value="0.02"/> |
| <input checked="" type="checkbox"/> Perform Volume Error Check/Carry Over: | |

1.4.2.1.1 Bed Mixing Time Steps (SPI)

The mixing and armoring algorithms update several times per computational interval. HEC-RAS subdivides the computational increments into mixing time steps or **Bed Exchange Iterations**. Set the **Bed Exchange Iterations** (SPI factor in HEC-6) to control the mixing updates per computation increment. For example, if **Bed Exchange Increments** variable is 10 (default) HEC-RAS will update the mass and gradation of the bed layers every 10% of the computation increment, updating bed layer gradations and exchange increments ten time between backwater and bed change computations. Sorting and armoring iterations are important to track supply limitation in order to keep the model from over predicting erosion. However, they also affect run times. The recommended range for this parameter is 1 to 50. Start with a high **Bed Exchange Iteration Per Time Step** value and drop it as much as possible without changing the results. (see [Sediment Computational Options and Tolerances \(see page 165\)](#))

1.4.2.1.2 Minimum Bed Change Before Updating Hydraulics

Similarly, hydraulic parameters are not automatically computed after each computational increment unless one of the cross sections has undergone appreciable change. This conserves computational resources since the frequency with which hydraulic computations are performed drives run times. This parameter is, by default, set equal to the **Minimum Bed Change Before Updating Cross Section** parameter so that every time the cross sections change, the hydraulics are recomputed but can be edited separately.

1.4.2.1.3 Minimum Bed Change Before Updating Cross Sections

HEC-RAS does not update the cross sections every computational increment. Instead it tracks erosion or deposition at a cross section until a minimum bed change is achieved. When this threshold is exceeded at one of the cross sections the bathymetry is re-computed. The default is 0.02 feet which will generally be exceeded in streams with relatively active beds. This tolerance can be increased to lower run times or decreased to make the model more sensitive to bed change.

Modeling Note: Min Bed Change and Stability

The hydraulic and bed change thresholds are legacy features. They do not often improve run times dramatically and can introduce instabilities, particularly in simplified channels. Test the sensitivity of these parameters. If they do not improve run times, consider setting them to 0.

1.4.2.1.4 Volume Change Method

HEC-RAS computes deposition or erosion in mass. Then it converts mass to a uniform vertical bed change, applied to all wetted nodes in the movable bed limits. This computation requires iteration to converge on a precise solution, which is computationally expensive. Instead, HEC-RAS converts the computed bed change into mass change (by computing the area change between the original and updated cross sections), compares it to the computed mass change, and carries remainders over into the next time step. HEC-RAS selects this option by default. It is recommended unless results are being compared with HEC-6 which does not use this option.

Modeling Note: Volume Check and BSTEM

HEC-RAS will not apply the volume check for cross sections selected for USDA-ARS Bank Stability and Toe Erosion (BSTEM) modeling (even if it is checked), because volume change in that module is incompatible with this feature.

1.4.2.2 Sediment Transport Energy Slope

Most sediment transport equations are very sensitive to Slope. These models tend to use the friction slope, which is the slope of the energy grade line. But there are different ways to compute that slope that can generate divergent results under some conditions. You can select the appropriate transport energy slope method under the Sediment Computational Options (Note: this moved to the Computational Options in version 6.3)

HEC-RAS Sediment Computation Options and Tolerances

General | 2D Computational Options |

1D Computational Options

Bed exchange iterations per time step (SPI):

Min bed change before updating Cross Section (ft):

Min XS change before recomputation of hydraulics (ft):

Perform Volume Error Check/Carry Over:

Transport Energy Slope Method:

Sediment Computation Multiplier:

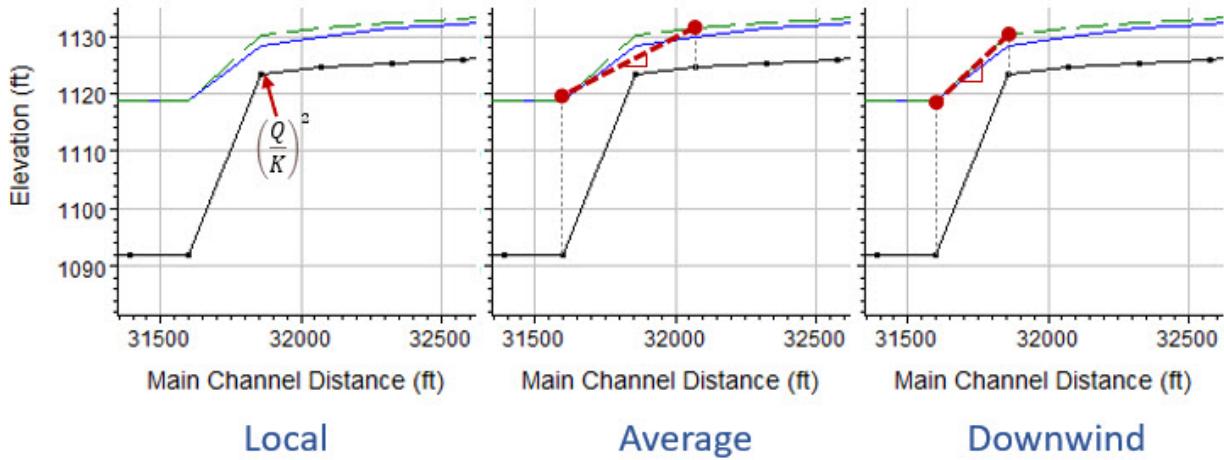
Sediment Warmup Periods:

Concentration (2D Only): (days)

Gradation: (days)

Bathymetry: (days)

This slope does not affect the hydraulic calculations. HEC-RAS only uses it in the sediment transport equations. The model includes three approaches, illustrated in the following figure and described below.

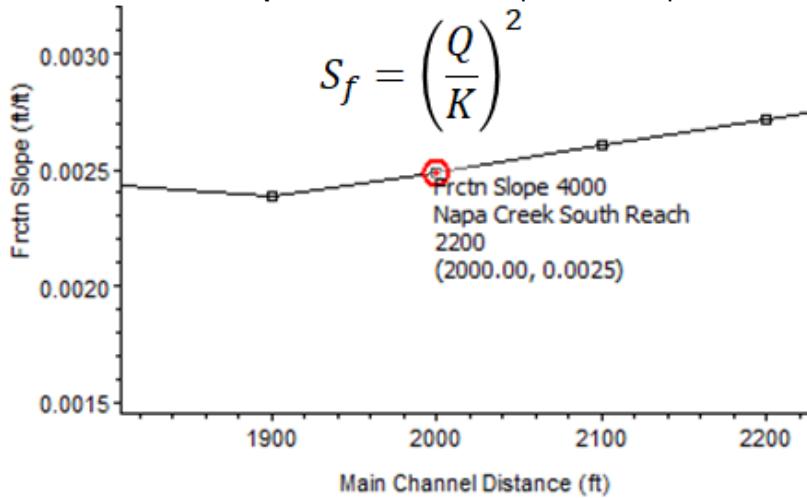


1.4.2.2.1 Local Energy Slope Method (Default)

By default HEC-RAS computes this slope locally at the cross section by back calculating the friction slope from Manning's equation (**Local Energy Slope**), which in US Customary units, is:

$$S_f = \left(\frac{Flow}{Conveyance} \right)^2 = \left(\frac{Flow}{\frac{1.486 A R^{\frac{2}{3}}}{n}} \right)^2$$

This is the **Friction Slope** that HEC-RAS computes and reports in the Hydraulic Results:



However, other models use the slope of the Energy Grade Line across multiple cross sections. This can improve results if the model includes a sharp slope change. These are the Average energy slope methods.

1.4.2.2.2 Average Energy Slope - Cell Centered

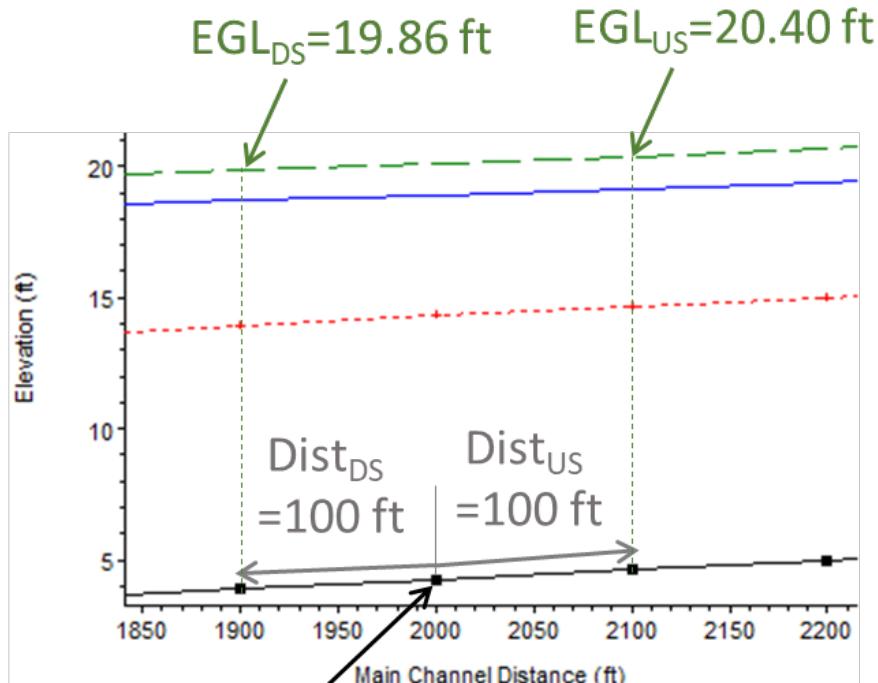
The Cell Centered Average Energy Slope (**Average Energy Slope (Cell Centered)**) computes a gradient between the Energy Grade Lines (EGLs - Green Line in Default RAS results) upstream and downstream of the computational cross section:

$$S_f = \frac{EGL_{US\ XS} - EGL_{DS\ XS}}{DS\ Dist_{US\ XS} + DS\ Dist_{XS}}$$

Where:

$EGL_{US\ XS}$ is the Energy Grade Elevation at the cross section upstream of the computational node,
 $EGL_{DS\ XS}$ is the Energy Grade Elevation at the cross section downstream of the computational node,
 $DS\ Dist_{US\ XS}$ is the downstream channel distance associated with the cross section upstream of the computational node (distance between the upstream cross section and the computational cross section) and
 $DS\ Dist_{XS}$ is the downstream channel distance associated with the computational node (distance between the computational cross section and the next cross section downstream).

Average Energy Slope Method Cell Centered



$$S_f = \frac{EGL_{US} - EGL_{DS}}{Dist_{US} + Dist_{DS}} = \frac{20.40 \text{ ft} - 19.86 \text{ ft}}{100 \text{ ft} + 100 \text{ ft}} = 0.0027$$

1.4.2.2.3 Average Energy Slope - Downwind

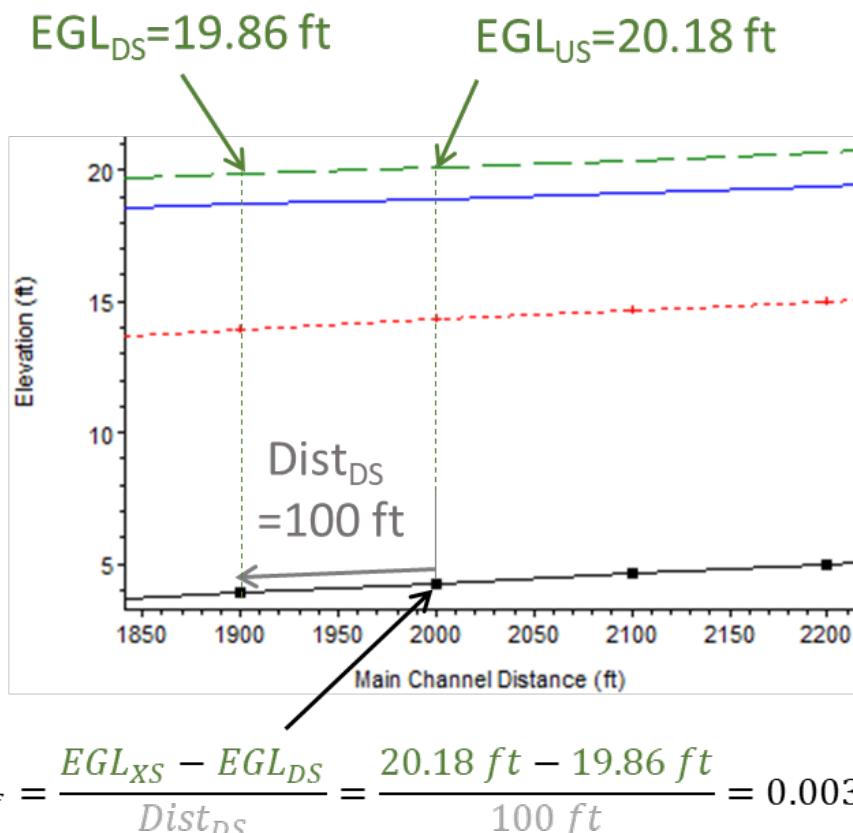
Sometimes the Cell Centered Average Energy Slope (**Average Energy Slope (Cell Centered)**) causes numerical instabilities (leap-frog errors). Therefore, versions 6.2 and later include an alternate form that computes the slope of the energy grade line between the computational cross section and the next cross section downstream (**Average Energy Slope (Downwind)**)

$$S_f = \frac{EGL_{XS} - EGL_{DS\ XS}}{DS\ Dist_{XS}}$$

Where:

EGL_{XS} is the Energy Grade Elevation at the computational cross section,
 $EGL_{DS\ XS}$ is the Energy Grade Elevation at the cross section downstream of the computational node, and
 $DS\ Dist_{XS}$ is the downstream channel distance associated with the computational node (distance between the computational cross section and the next cross section downstream).

Average Energy Slope Method Downwind



Users choose the alternate methods most often when modeling headcuts³³ or dam removals.

New Location in Version 6.3+

This feature moved to make it more prominent in version 6.3. In previous versions it had its own menu under the Sediment Analysis Options. It moved to the Computational Options with other modeler decisions.

2D Sediment Workshop Videos³⁴

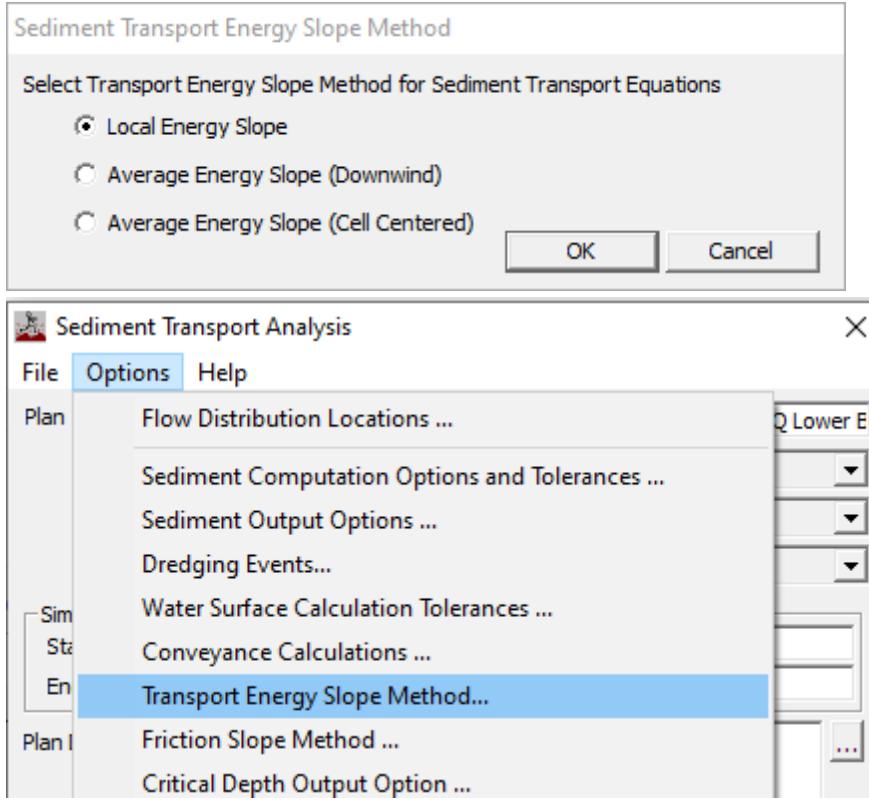
HEC hosted a 2D sediment workshop for several district and USACE laboratory modelers using these new tools. Edited videos of most of these talks³⁵ are included on the [HEC training page](#)³⁶.

³³ <https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/simulating-sediment-transport/sediment-transport-energy-slope/modeling-headcuts-with-hec-ras-1d-sediment>

³⁴ <https://www.hec.usace.army.mil/confluence/rasdocs/rastraining/latest/hec-ras-classes/2d-sediment-transport-2021>

³⁵ <https://www.hec.usace.army.mil/confluence/rasdocs/rastraining/latest/hec-ras-classes/2d-sediment-transport-2021>

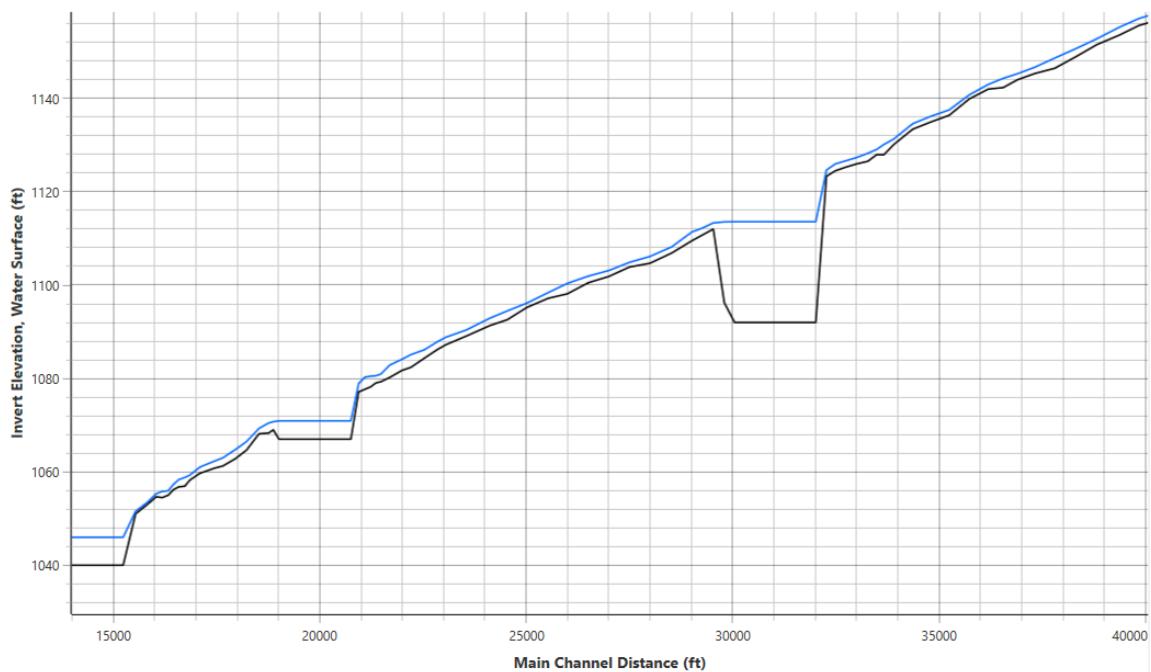
³⁶ <https://www.hec.usace.army.mil/confluence/rasdocs/rastraining/latest>



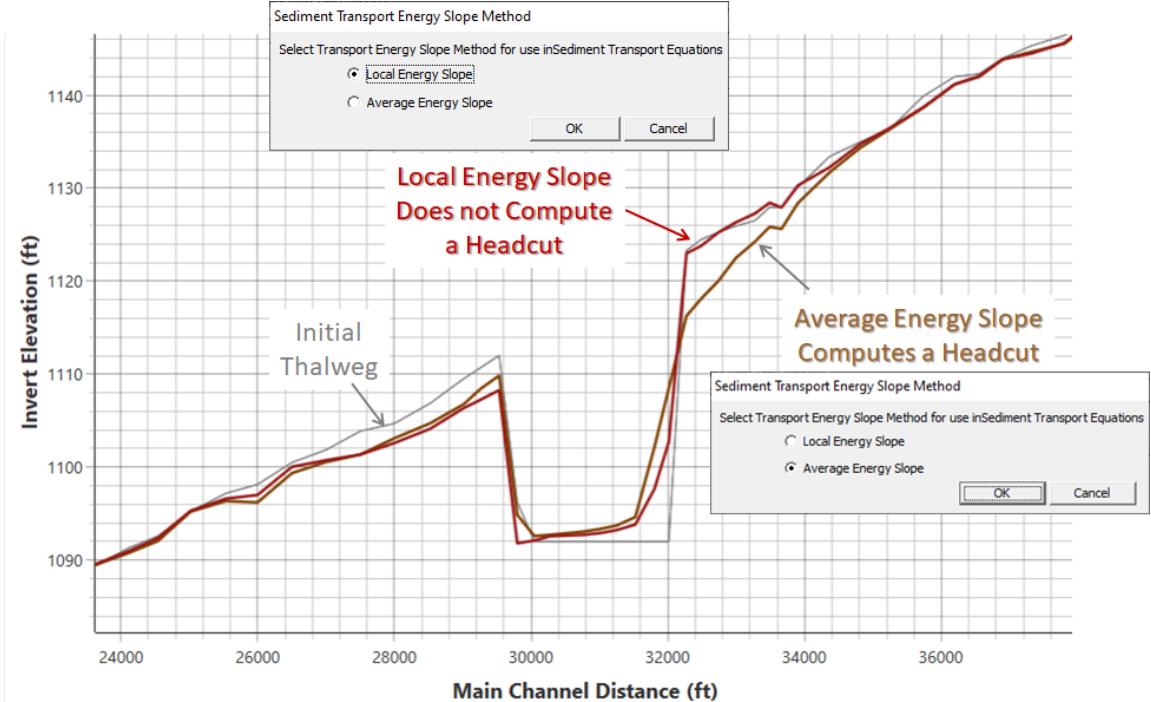
1.4.2.2.4 Modeling Headcuts with HEC-RAS 1D Sediment

Modeling Note - Use Average Energy Slope for Headcuts or Models with Sharp Vertical Drops

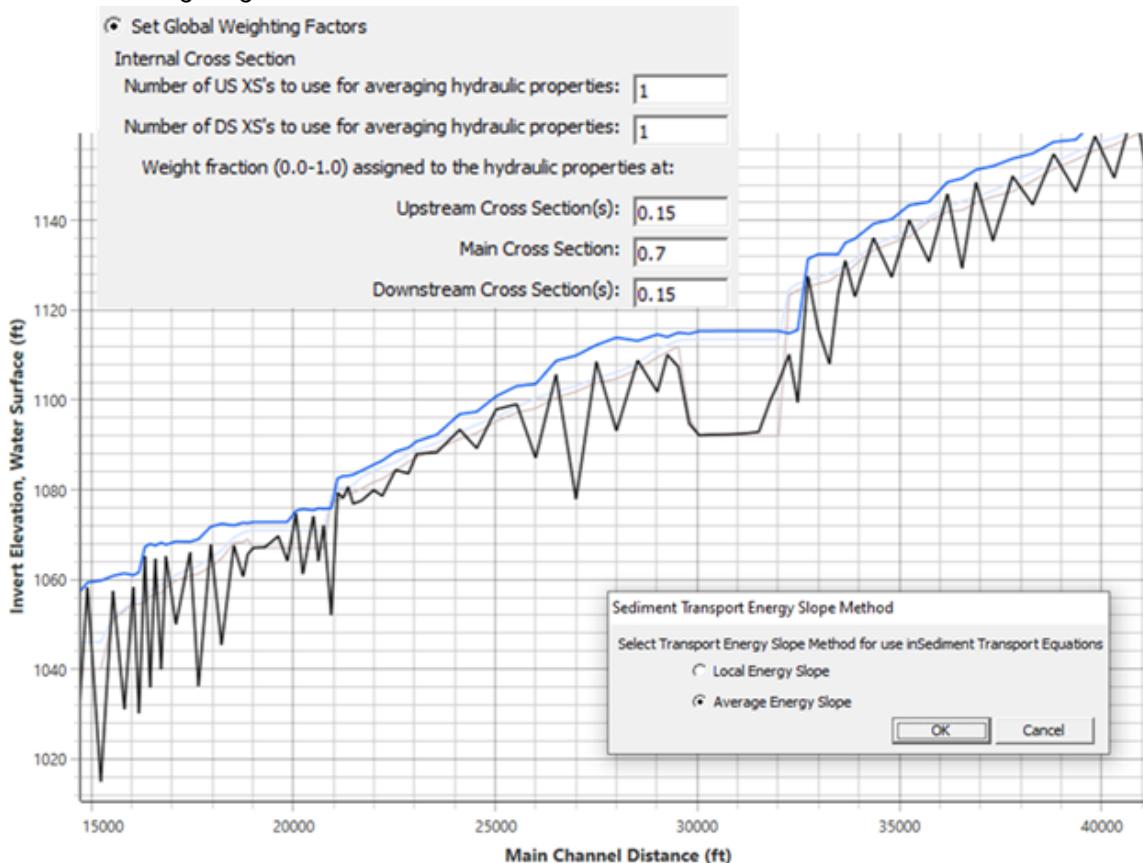
The main reason to switch to the **Average Energy Slope** is to model a headcut or some other thalweg discontinuity. The model below was designed to simulate a headcut caused by a large event through a gravel mining pit in an ephemeral river.



Because the **Local Energy Slope** method only uses the conveyance at each cross section to back-calculate the energy slope, the transport equation does not "see" the sharp change in the friction slope downstream. But the **Average Energy Slope** method computes the actual slope in the energy grade line over the discontinuity, and passes the transport function a much steeper friction slope.



However, the average energy slope does not mix well with [hydraulic weighting factors](#)³⁷ in models with sharp thalweg discontinuities (e.g. headcuts or drop structures). HEC-RAS has moved away from these hydraulic weighting factors for most models because they can cause instabilities and the "leap frog" or "saw tooth" error. But because the **Average Energy Slope** method also uses upstream and downstream hydraulics to compute the transport friction slope, which can exacerbate weighting instabilities.

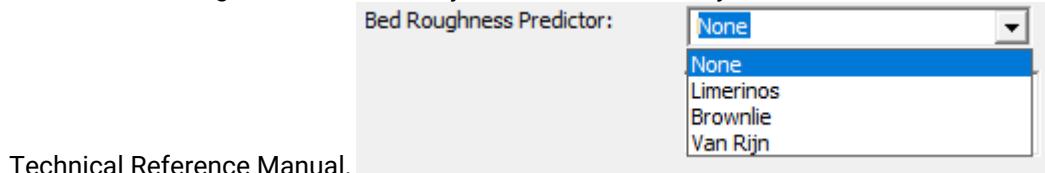


1.4.2.3 Bed Roughness Predictors

HEC-RAS includes multiple methods to vary channel roughness spatially or temporally. HEC-RAS can vary manning n value as a function of flow, stage, lateral station, or season. Calibrating one-dimensional hydraulic models often requires process dependent roughness parameters. Use these features to calibrate a steady or unsteady flow hydraulic model *before* adding sediment data.

³⁷<https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/simulating-sediment-transport/sediment-computation-options-and-tolerances/cross-section-weighting-factors-default-recommended>

However, bed roughness can also vary based on sediment dynamics. These are discussed in detail in the



Technical Reference Manual.

1.4.2.3.1 Limerinos:

The Limerinos method 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.

1.4.2.3.2 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.

1.4.2.3.3 Van Rijn:

Van Rijn (1984) 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.

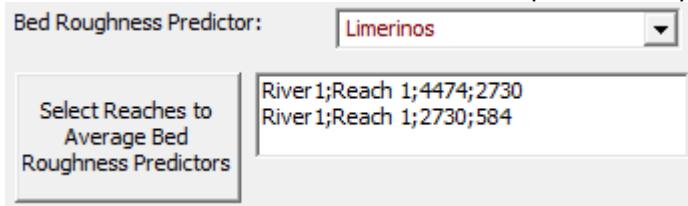
Modeling Note: Check Roughness Predictors

1D modelers have had mixed success with automated n-value equations. It can be valuable to calculate a dynamic n-value based on evolving hydrodynamic and sediment conditions, but n-value is a very sensitive parameter in sediment models, and is should be calibrated during the hydraulic modeling. Check the n-values computed by these equations against those selected during the hydraulic calibration. Or run a sediment model without bed-change (by making all the nodes pass-through) to see the range of computed n-values for the hydraulic simulation alone. If the equations are not computing n-values that calibrate the hydraulic model, they are not appropriate for a sediment model.

1.4.2.3.4 Reach Averaging Bed Roughness Predictors

Bed roughness predictors can be noisy. Calculating separate roughness parameters for each cross section based on dynamic hydraulic and sediment parameters can make roughness vary erratically both in space

and time, sometimes switching regimes from cross section to cross section or time step to time step. The



reach average tool smooths these effects.

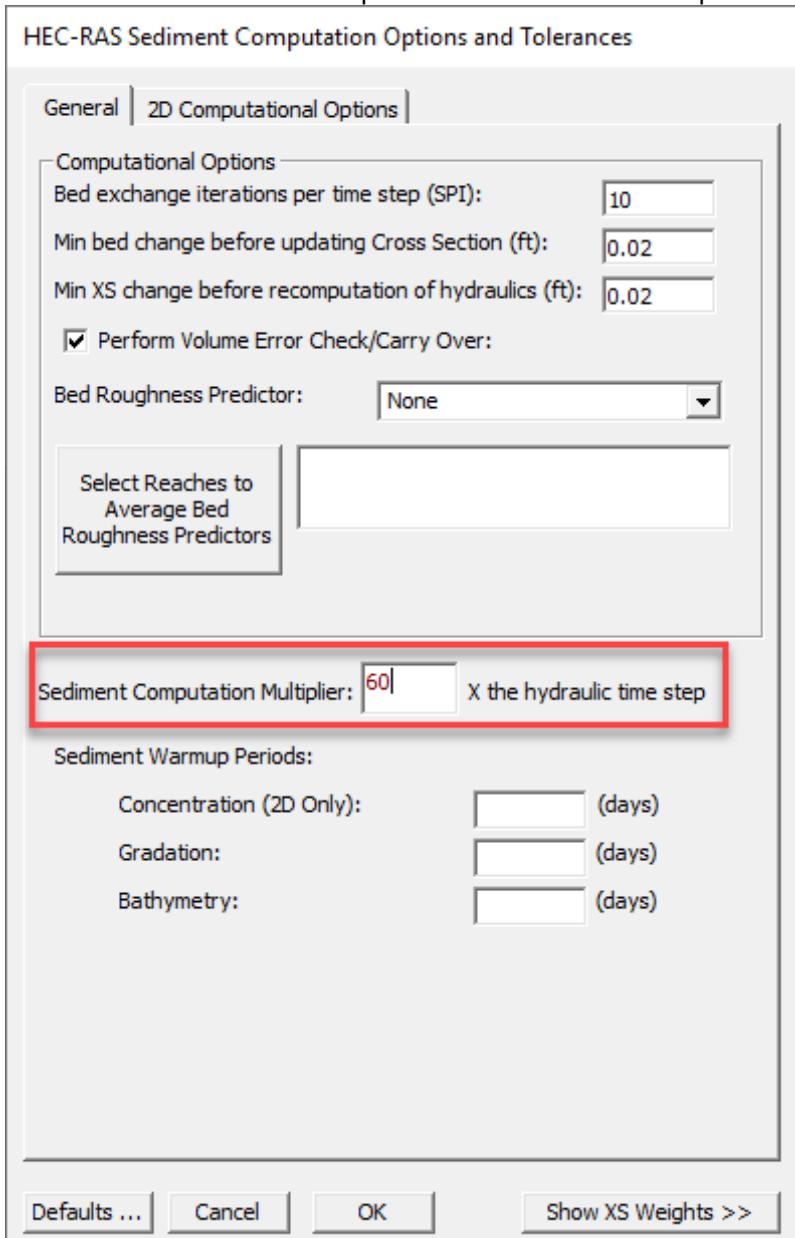
Group sequential cross sections with similar morphological setting (e.g. flow, slope, gradation) into a 'bed roughness averaging reach' by pushing the button: **Select Reach to Average Bed Roughness Predictors**. HEC-RAS will average the hydraulic and sediment parameters for the cross sections included in each reach and use the average values to compute a single bed roughness for all included cross sections. This tends to smooth the results in space and time. Any cross section not included in a reach will compute bed roughness locally, based on its own parameters.

To delete a bed roughness averaging reach, double click on the record in the list.

1.4.2.4 Sediment Computation Run Time Multiplier

The **Sediment Computation Time Multiplier** allows users to decouple the time step for unsteady hydraulics and sediment transport. For stability, the unsteady hydraulic computations in HEC-RAS often require smaller

time steps than the sediment model requires. But the sediment computations are a significant portion of the



run time.

This method allows users to run sediment computations at some multiple of the hydraulic time step. For example, if the hydraulic model is stable at 6 seconds, and this multiplier is set to 10, HEC-RAS would compute sediment transport with a 1 minute computation increment.

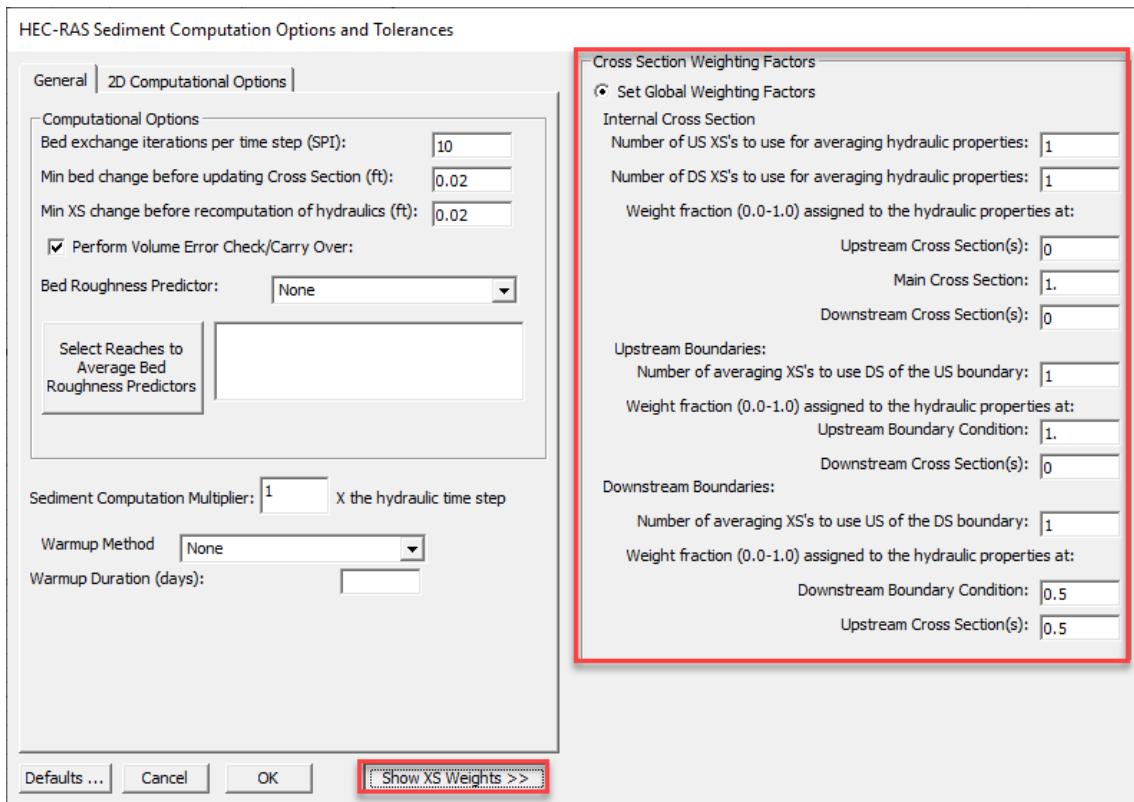
Modelers can use this feature in conjunction with the Unsteady Hydraulics **Advanced Time Step Control** to optimize the stability-run time trade off.

1.4.2.5 Cross Section Weighting Factors (Default Recommended)

Cross sections are a bathymetric sample of the river form over a particular reach. Depending on their location, they can approximate the channel form and transport capacity well, or poorly. A 1D model assumes the cross section is representative of the control volume. Small divergences between the measured cross

section and the reach-average behavior do not usually trouble hydraulic simulations (unless cross section selection is egregious, like missing a control point or non-orthogonal placement). But small hydrodynamic differences between cross sections can cause local deposition and erosion in an equilibrium sediment transport model.

Transport capacity fluctuates from cross section to cross section due to random changes in transport capacity. Sediment scoured from one cross section is often deposited in the next cross section. This numerical artifact often generates oscillations, alternating erosion-deposition patterns, particularly early in a simulation.



55 Cross Section Weights Editor (Press the Show XS Weights to show this).

HEC 6 introduced cross section weighting factors to smooth out these effects. Cross section weighting factors average the hydrodynamic parameters of several cross sections to compute transport capacity. Earlier versions of HEC-RAS adopted this feature as well as the 0.25-0.5-0.25 weighting default. This default gave half the weight to the computational cross section, and quarter weight to the upstream and downstream cross sections. The upstream and downstream weights could also be spread over multiple cross sections.

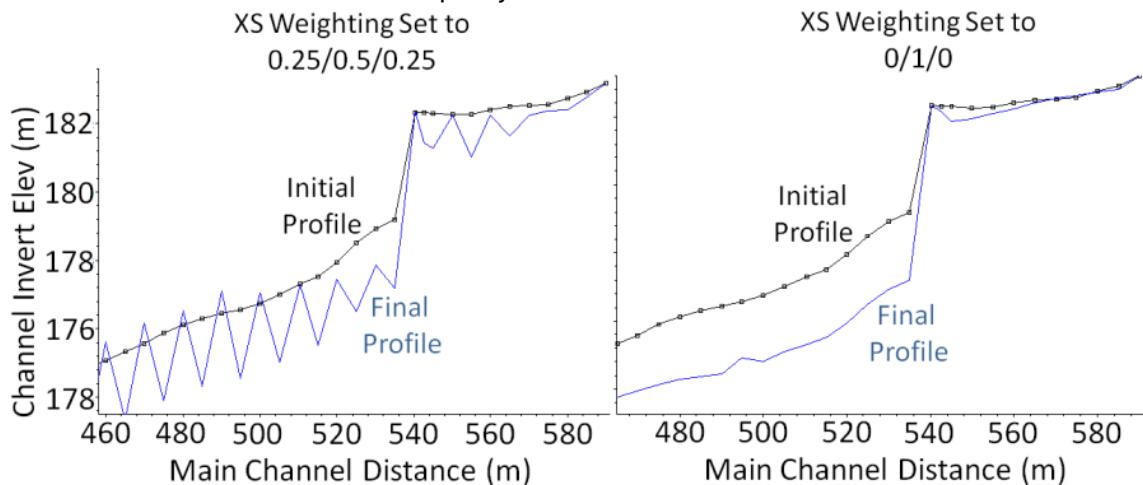
However, these weighting factors can also cause model instabilities (see Modeling Note). The defaults for this method changed in version 5.0, and more recent versions de-emphasized this feature even more, by

requiring users to press a button to view this feature.

HEC-RAS retains hydraulic weighting for backward compatibility and user flexibility, but it is not recommended for most models, particularly simplified cross sections (e.g. trapezoid or rectangular channels). Current versions of HEC-RAS include "Warm Up" and hotstart options to deal with early simulation cross section adjustments.

Modeling Note: Saw Tooth Instability and Weighting Factors

A "Saw Tooth" instability often indicates errors propagated by cross section weighting factors. Weighting factors are particularly problematic with rectangular, trapezoidal, or other simple cross sections. Try setting weighting factors to 0-1-0, which will only use hydrodynamics from the current cross section for sediment capacity calculation.



1.4.2.6 2D Computational Options

See the HEC-RAS 2D sediment manual for discussion of these options.

1.4.3 Dredging

Dredging removes sediment from the river beds mechanically. These processes can introduce system feedback (e.g. inducing deposition) and often must be modeled explicitly, because transport and continuity equations cannot account for anthropogenic processes. Therefore, HEC-RAS includes dredging capabilities, with multiple methods to incorporate dredging into sediment simulations. Go to **Options** menu of the **Sediment Analysis Editor** to find the [Dredging Events Editor](#) (see page 181). HEC-RAS 5.0 includes several new dredging features.

Create a **Dredging Event** by pressing the **New Dredging Event** button: 

A dredging event removes sediment from a cross section or cross sections at the **Dredging Start Time** or between the **Dredging Start Time** and **Dredging End Time**. Simulate complex dredging configurations or recurring dredging schedules over an extended simulation by defining multiple **Dredging Events**.

Select a **Method** for each **Dredging Event**. There are seven dredging methods, including two basic types: Elevation (the first three) and Mass (the last four).

This video describes the basic, elevation dredging features.



Sorry, the widget is not supported in this export.
But you can reach it using the following URL:
<http://youtube.com/watch?v=Qgjm73NdAZE>

1.4.3.1 Elevation Methods

The elevation methods are generally for navigational dredging, where dredges remove sediment from the bed to a new bed elevation specified *a priori*. (See the Dredging Model in the Sample Data Sets). These methods superimpose a rectangular template on the cross section and remove all the material within.

Three **Elevation Methods**, which define the **Elevation and Lateral Extent** of dredging. The **Elevation Methods** remove whatever sediment found in a spatial template. The **Dredging Editor** also includes four Mass Methods, methods that remove a prescribed mass from the cross section. The different methods take different approaches to translate the mass removal into cross section change.

Dredging Events

| | RS | Invert (ft) | Left Sta (ft) | Right Sta (ft) | Mass (tons) |
|----|--------|----------------|------------------|-------------------|----------------|
| 8 | 453.44 | 783.39 | 250.78 | 856.43 | 3822.9 |
| 9 | 452.80 | 779.61 | 292.11 | 812.58 | 6393.9 |
| 10 | 452.31 | 781.76 | 504.51 | 1064.28 | 447.1 |
| 11 | 451.88 | 779.39 | 1308.96 | 1888.95 | 234.7 |
| 12 | 451.41 | 775.64 | 1786.76 | 2541.74 | 15.6 |
| 13 | 451.09 | 776.85 | 2060.9 | 2550.83 | 333.1 |
| 14 | 450.52 | 778.45 | 1632.04 | 2207.52 | 390.1 |
| 15 | 449.99 | 776.77 | 1198.36 | 1703.07 | 2459.2 |
| 16 | 449.44 | 777.01 | 450.1 | 1060.12 | 793.6 |
| 17 | 448.89 | 772.85 | 582.92 | 1132.76 | 912.1 |
| 18 | 448.49 | 774.37 | 489 | 1068.54 | 1676.7 |
| 19 | 448.21 | 769.98 | 487.14 | 1186.95 | 1017.2 |
| 20 | 447.91 | 776.63 | 3184.96 | 3694.62 | 1810.9 |
| 21 | 447.78 | 775.68 | 1230.71 | 1765.75 | 2537.4 |
| 22 | 447.51 | 775.29 | 1679.66 | 2249.8 | 6192.7 |
| 23 | 447.16 | 773.09 | 1633.17 | 2283.06 | 699.7 |
| 24 | 446.83 | 771.46 | 2593.97 | 3204.18 | 859.6 |
| 25 | 446.33 | 775.36 | 3770.21 | 4295.17 | 939 |
| 26 | 445.88 | 774.36 | 4252.17 | 4871.83 | 234.7 |
| 27 | 445.33 | 773.18 | 10815.6 | 11419.44 | 648.3 |
| 28 | 444.86 | 774.88 | | | |
| 29 | 444.36 | 770.9 | | | |
| 30 | 443.86 | 775.17 | | | |

Set Range of Values

Upstream RS: 458.18
Downstream RS: 293.421

Project at a slope | Interpolate |

Sediment Elevation:

- Same elevations to all sections
- Project Sediment elevation from upper RS at slope: []
- Project Sediment elevation from lower RS at slope: []

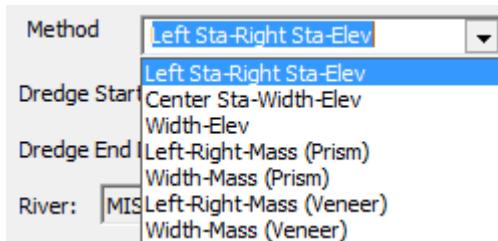
Apply Dredging Elevations to Selected Range

Dredge Template Side Slopes
Right: [] :1 Left: [] :1

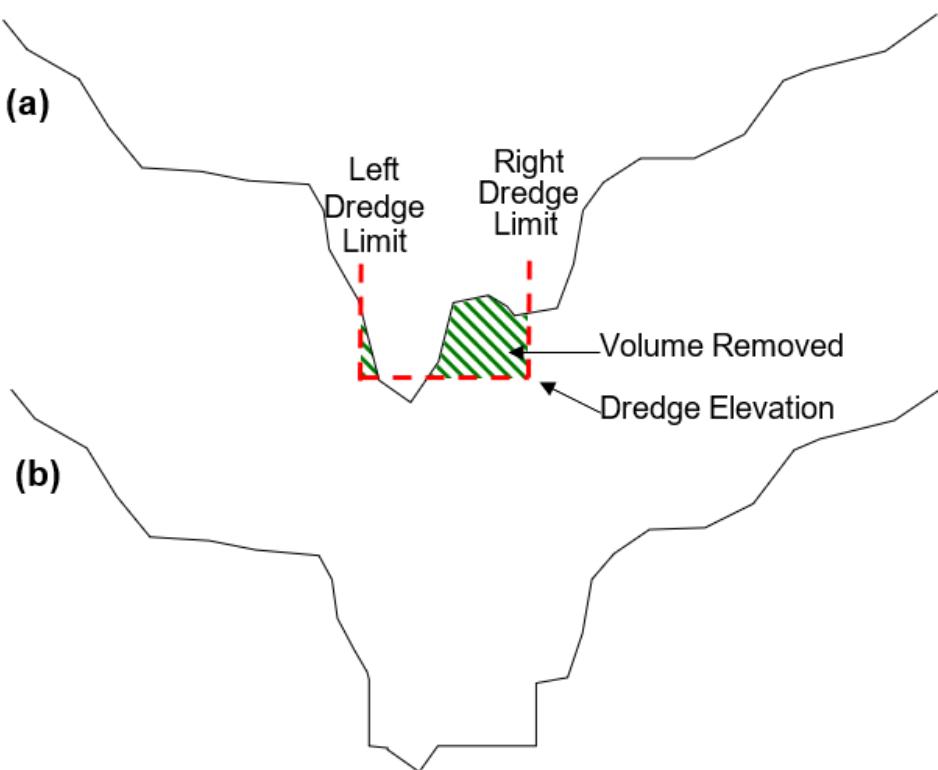
Automatic Dredge Trigger
 Re-Introduce Part of Dredge Load

OK Cancel

56 Dredging events editor.



57 Dredging Methods.



58 The top image (a) illustrates a schematic of a dredging template and an example cross section. All of the material inside the volume is removed at the dredge event time. The resulting cross section is depicted in (b) the bottom image.

The three elevation methods all remove sediment to the specified elevation but offer options for defining the horizontal dredging extents.

Left Sta–Right Sta–Elev: Input three parameters for each dredged cross section, including the left and right stations that bound the dredge template and the bottom elevation.

Center Station–Width–Elev: Sometimes dredging schedules are not defined in absolute cross section stations but width around a center station. In this method, define the center station of the dredge prism and the width.

Width–Elev: Computing the precise right and left dredge extent stations or the centerline can be time consuming and iterative in complex models with many alternatives. The Width-Elev method can expedite preliminary alternative analysis, requiring only the width and elevation of the dredge prism. HEC-RAS will then center it between the bank stations.

1.4.3.2 Mass Methods

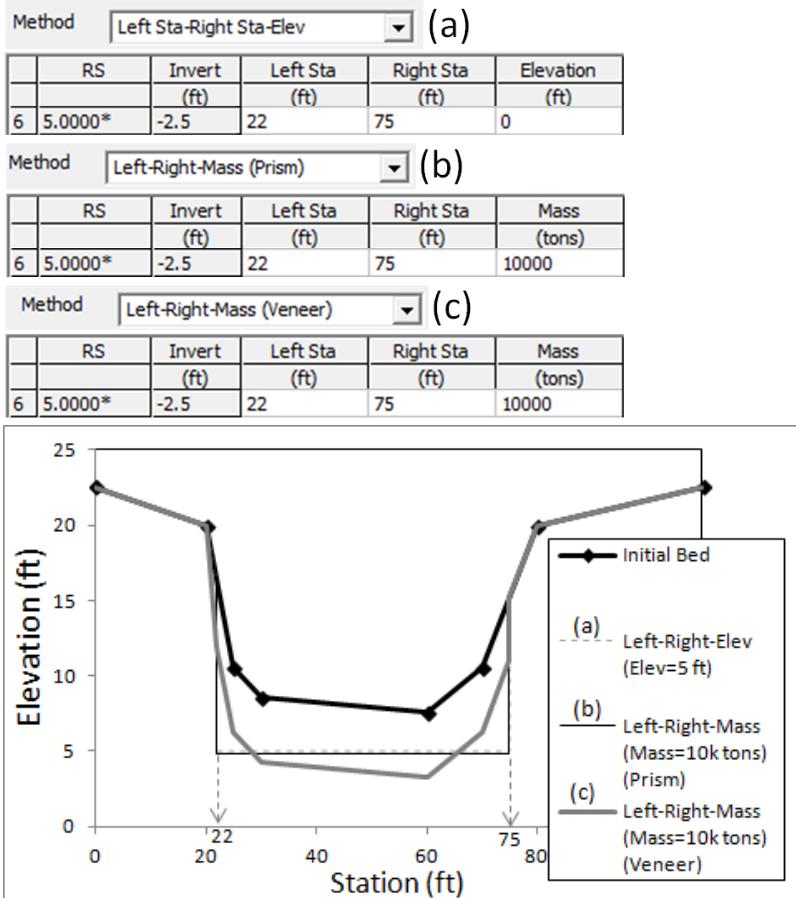
Sometimes dredge mass is known and the geometry of the dredge cut is not known. This is often the case for in-channel aggregate mining where historical records and permits specify mass. The mass methods remove user specified sediment mass from the cross section. The four mass options offer flexibility to translate mass removal into cross section change.

Left–Right–Mass (Prism): This feature is analogous to the **Left Sta–Right Sta–Elev** method. Input the left and right stations that bound the dredge template in precisely the same way. However, instead of specifying an elevation, specify the mass removed from that cross section, and given the dredging extents, HEC-RAS will calculate elevation, removing material from a rectangular dredging template (Prism) that removes the specified mass.

Width–Mass (Prism): This feature is analogous to the **Width–Elev** feature. It centers the rectangular dredge cut between the channel banks, computing the bottom elevation that removes the mass from the specified width.

Left–Right–Mass (Veneer): This method is similar to **Left–Right–Mass (Prism)**, except that dredged mass is no longer removed as a prism, but by the rules of the veneer method HEC-RAS uses to deposit and erode cross sections by other processes. HEC-RAS drops cross section nodes uniformly between the dredged limits (**Right** and **Left**) until cross section change reflects the dredged mass.

Width–Mass (Veneer): This method is identical to **Left–Right–Mass (Veneer)**, except that instead of dropping bank stations uniformly between user specified left and right dredge limits, nodes are dropped if they fall within the specified width between the movable bed limits.



1.4.3.3 Dredge End Date

Previous versions of HEC-RAS followed HEC 6, removing dredged mass instantaneously, in the time step closest to the **Dredge Event Start Date/Time**. Users could specify staged dredging with multiple dredging events, but this was tedious and still discontinuous. Instantaneous dredging is still the default method. All of the dredge methods only require one date. However, HEC-RAS 5.0 includes the option to distribute dredging over a time window, but pairing a **Dredge Start Date** with a **Dredge End Date**. This distributes the prescribed dredging over a time window.

The Dredge End Date was added to use with the four *Mass* dredge methods. Dividing a specified dredged mass over several time steps, removing proportional mass from each one is straight forward. Dredging end dates are a little more complicated in association with the *Elevation* methods, because it has to update the scour rate to account for cross section aggradation or degradation over the dredge window, to arrive at the specified elevation at the end of the dredge window.

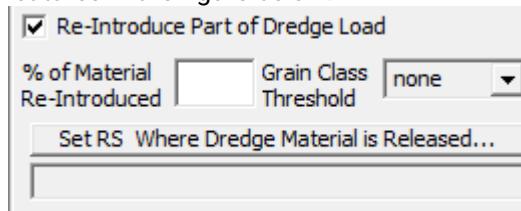
1.4.3.4 Set Range of Values

Dredging elevations are often constant over reaches or zones, making them easy to specify. However, HEC-RAS includes tools to project non-uniform dredge elevations at a slope upstream or downstream. The Set Values tools were adopted from the Channel Modification editor ([link](#)) to project dredge cut elevations.

1.4.3.5 Re-Introduce part of Dredged Load

Most dredge methods do not remove 100% of sediment but re-entrain sediment that was not actively transporting in the navigation channel. Users can model the fate and transport of these materials with the Reintroduction Dredge feature.

Click on the **Re-Introduce Part of Dredge Load** feature in the [Dredging Editor](#) (see page 79), which will reveal the features in the figure below.



1.4.3.5.1 % or Material to Re-Introduce:

HEC-RAS will monitor dredged mass and will re-introduce this, user specified percentage, back into the model as Mass In (mass flowing into the control volume, as if it were coming in from a lateral boundary or upstream cross section). It will re-introduce mass proportional to the gradation of the mass removed (usually the gradation of the active layer).

1.4.3.5.2 Grain Class Threshold:

Of course, not all grain classes are likely to be lost during the dredge process. Fines are far more likely to re-entrain and transport downstream while gravel losses are usually too small to care about and immediately re-deposit. The **Grain Class Threshold** is a filter. Only grain classes finer than this threshed is re-entrained.

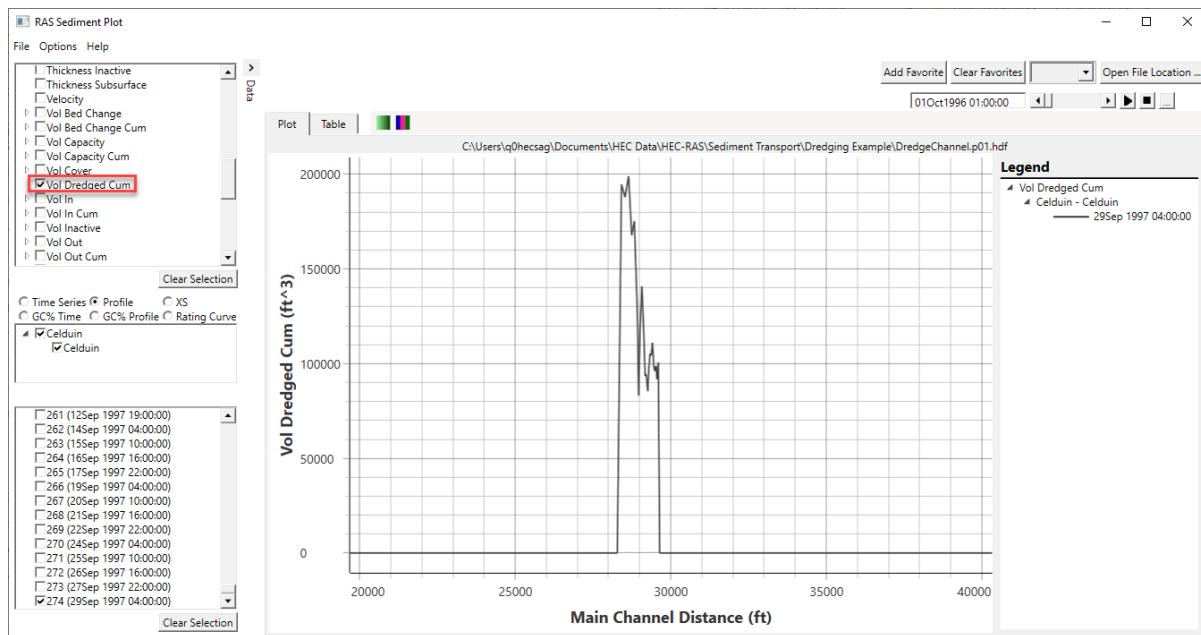
1.4.3.5.3 Set RS Where Dredge Material is Released:

Dredged materials are not always re-entrained where they are extracted. Push the **Set RS** button to inject dredge losses somewhere else in the model. All the dredged sediment can be transferred to another cross section if dredged materials are piped or barged downstream (e.g. % Re-Introduced = 100) using this feature.

1.4.3.6 Dredge Output

HEC-RAS tracks the dredged mass as an output variable and can be reported in mass or volume. The Dredged Mass is reported as a cumulative variable, which reports the total mass or volume removed from the cross section since the beginning of the simulation. Users can visualize this as a time series at a specific cross section, along the reach at a particular time, or the impact on cross section shape.

The mass dredged in a given time step, or the cumulative mass dredged in the model can be displayed in profile and time series shown below.



1.4.4 Sediment Output Options and Tolerances

- [Output Level](#) (see page 186)
- [Output in Mass or Volume?](#) (see page 199)
- [Set Output Increment](#) (see page 200)
- [Set Cross Section Bed Change Output](#) (see page 201)
- [Select Customized Output](#) (see page 202)
- [HDF5 output](#) (see page 204)
- [Sediment Hotstart From Output File \(Versions 6.0+\)](#) (see page 207)
- [Gradation Hotstart \(5.x Legacy Version\)](#) (see page 209)
- [Write Classic Output \(WSE Profile etc. – O file\)](#) (see page 211)
- [Write Legacy Binary Output](#) (see page 212)

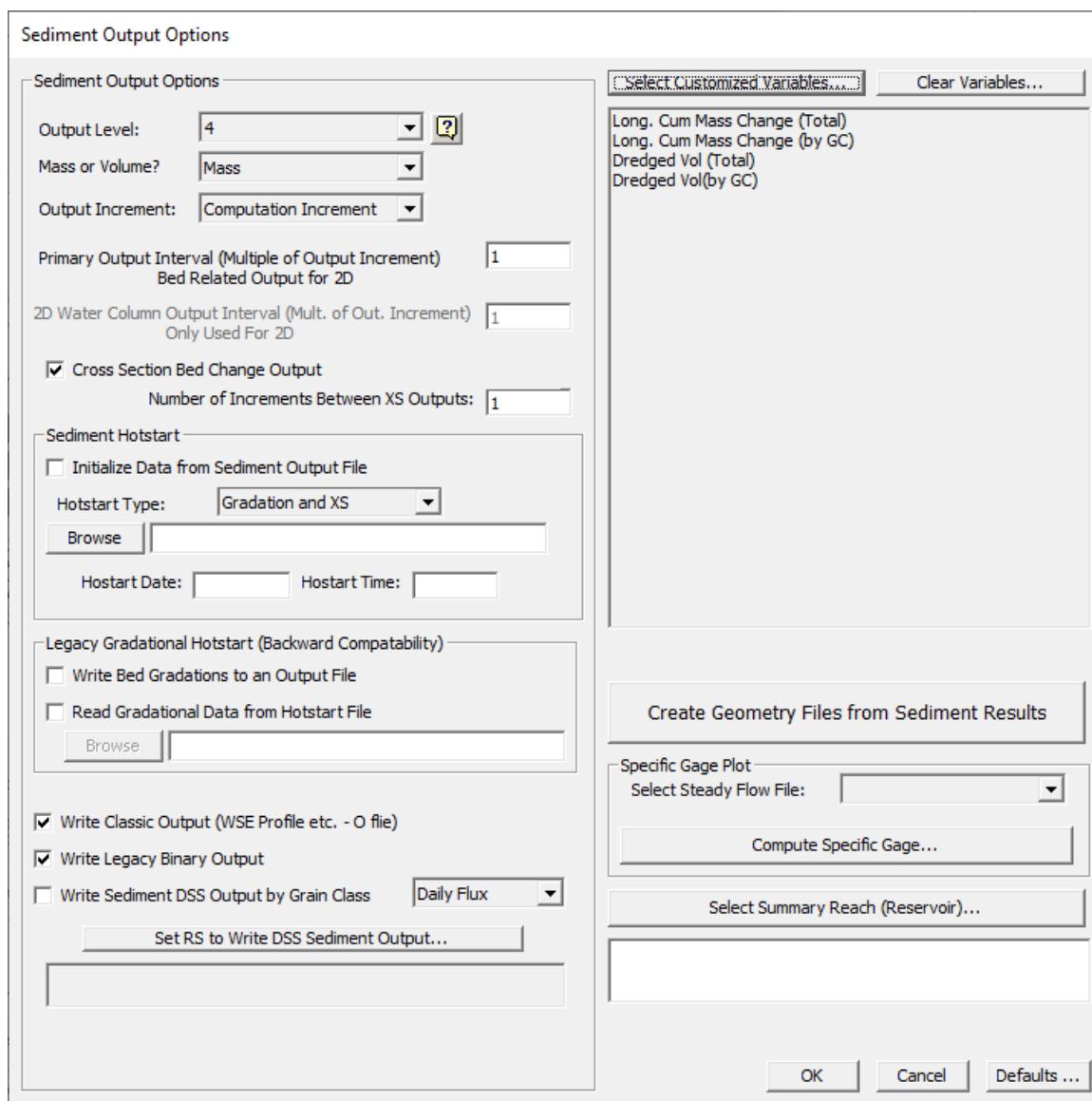
- DSS Output (see page 212)

1.4.4.1 Output Level

The sediment model in HEC-RAS can generate over a hundred result variables. Many of those variables also have sub-results as they are sub-divided by grain class or reported in either mass and volume. Output files can get very large, and the variable list can be unwieldy, when the calibration phase of a model study often evaluates the same three-to-five plots each run.

Therefore, HEC-RAS includes several tools to control the number of variables reported. The user can control the number of output variables, as well as the frequency at which HEC-RAS will generate them in the

Sediment Output Options. The Output Level controls the variables output. Select and **Output Level** from one (four variables) to six (all variables) at the top of the **Sediment Output Options** window (below). The default output level is 4, which reports 14 variables at each time step. It is often advantageous to increase the level to six, to see all variables. However, sediment output files can get very large, because they output most variables by grain class, increasing file size by about an order of magnitude. Multi-Gigabyte sediment output files are common, but more output does not increase run time appreciably. Select the output level that optimizes the tradeoff between file size management and information required. The variables associated with each level are included in the following section, including and detailed description of many of the variables.



59 Sediment output options editor.

Modeling Note: Be Careful with Instantaneous Results

Any variable that does not have a Cum label is instantaneous. This is unproblematic for instantaneous variables like shear stress or concentration. However, if users do not choose to output every computation increment, mass flux and change variables will not balance and may miss peaks.

1.4.4.1.1**Table: Variables associated with each level of output.****1.4.4.1.1.1 Level 1**

| Level | Variables |
|---------|--|
| Level 1 | <p>Invert Elevation (ft) (m) – The elevation of the channel invert of each cross section – the lowest elevation between the channel banks.</p> <p>Invert Change (ft) (m) – The total change in the invert (the lowest elevation station-elevation point between the bank stations) since the beginning of the simulation.</p> <p>Water Surface (ft) (m) – The water surface elevation at that at the cross section during the time step.</p> <p>Mass (or Volume) Bed Change Cum*: All (tons or ft³) (tonnes or m³) – Cumulative mass or volume added (+) or removed (-) from the control volume since the beginning of the simulation. Only Total in Level 1. For Grain Class specific results, increase to level 4.</p> <p>Long. Cum Mass (or Volume) Change (tons or ft³) (tonnes or m³) – The cumulative mass or volume change (see above) since the beginning of the simulation, summed from the upstream cross section in that reach. (e.g. the sum of the mass change for all of the cross sections between the selected XS and the upstream reach limit). The total value at the downstream XS of the reach is equal to the total mass change of the entire reach. This is a powerful model evaluation tool metric modelers become familiar with it. Only Total in Level 1. For Grain Class specific results, increase to level 4.</p> |

*Cum = Cumulative – results are summed since the beginning of the run

Modeling Note: Incremental Results Only Reflect Computation Increment

The Mass or Volume parameters track sediment mass movement through each control volume. Users can view discrete mass variables for each specified computation increment, as snapshots in time, or as cumulative masses, accumulated over time (CUM). All mass variables can also be viewed as volumes. Incremental mass or volume results, that is output at intervals coarser than the computation increment (by default results are reported every 10 computation increments) can cause confusion. Because these mass results only reflect the single computation increment output, they will not sum to the cumulative result.

1.4.4.1.1.2 Level 2

| | |
|---------|--|
| Level 2 | <p>All Variables from Level 1. Level 2 includes additional hydraulic parameters used in the sediment model (which may be different than the HEC-RAS hydraulic output).</p> <p>Flow (cfs) (m^3/s) – The flow at the cross section at the time step.</p> <p>Velocity (ft/s) (m/s) – Average channel/** velocity – the flow between the channel banks divided by the area of eht channel.</p> <p>Shear Stress (lb/ft^2) (Pa or N/m^2) – Channel average shear stress. The is the computational shear stress from the sediment computations:</p> $\tau = \gamma_w \cdot EfD \cdot S_f$ <p>where,</p> <p>γ_w is the unit weight of water</p> <p>EfD is the Effective Depth <i>in the channel</i> (between the channel banks see level 3 for the EfD equation) and</p> <p>S_f is the friction slope (which can be local or averaged from the bounding cross sections – see Section on Sediment Energy Slope (see page 168)).†</p> |
|---------|--|

**Because the sediment model uses channel hydraulics in the transport equations, the hydraulic output usually reflect channel hydraulics (i.e. only the hydraulics between the channel banks, excluding overbank flows). The channel shear and velocity are usually substantially higher than the cross section averages
 †The computed sediment shear stress can differ from the shear stress displayed in the general, HEC-RAS hydraulic output. The HEC-RAS hydraulics do not compute shear stress, so the shear stress visualizations outside the sediment editors are computed on the fly from other hydraulic parameters. The hydraulic shear visualization is computed from

$$\tau = \gamma_w \times R \times S_f = \gamma_w \times \frac{\text{Area}}{P_w} \times \left(\frac{\text{Flow}}{K} \right)$$

Where P_w is the wetted perimeter and K is conveyance. Note, the hydraulic display also computes the channel, overbanks, and full cross section, while the computational sediment shear is for the channel only.

1.4.4.1.1.3 Level 3

| |
|--|
| <p>Level 3</p> <p>Level 3 includes gradation data, some additional hydraulic parameters, and a sediment flux term.</p> <p>d_{50} Cover/Subsurface/ Inactive Layers (mm) – the median grain size of the specified mixing layer at that cross section. (Note: Layer names can change base on the mixing method – see Table 1 5)</p> <div style="border: 1px solid #00AEEF; padding: 10px; margin-top: 10px;"> <p>Note:</p> <p>All particle sizes are always in mm in input and output even if the model is in US customary units.</p> </div> <p>d_{10} Cover/Subsurface/ Inactive Layers (mm)</p> <p>d_{90} Cover/Subsurface/ Inactive Layers (mm)</p> <p>Effective Depth (ft) – A weighted average depth that often reflects the total cross section shape and change more than the invert change. This is also used in the shear stress equation.</p> $\text{Effective Depth} = \frac{\sum_{i=1}^n D_i \cdot A_i \cdot D_i^{2/3}}{\sum_{i=1}^n A_i \cdot D_i^{2/3}}$ <p>where:</p> <p>D_i is the average water depth in each cross section element (the trapezoid subsection "i" associated with each station elevation point),</p> <p>A_i is the area of that element, and n is the number of subsections.</p> <p>Effective Width (f–) - Effective width is the comparable channel width that preserves cross section area given the Effective Depth - (Units: ft or m)</p> $\text{Effective Width} = \frac{\sum_{i=1}^n A_i \cdot D_i^{2/3}}{\sum_{i=1}^n A_i \cdot D_i^{2/3}}$ <p>Manning's n Channel ($s/\text{ft}^{1/3}$ or $s/\text{m}^{1/3}$) - This is the Manning's n value in the channel (between the channel banks). If the channel has laterally varied n values, it is the composite channel n. It can be dynamic in time if the water surface weights the composite n-values differently, if there is a flow, or seasonal n value dependency, or if a dynamic, sediment bed roughness predictor is selected. Unlike the Chezy equation the manning coefficient is <u>not</u> dimensionless.</p> <p>Froude Number Channel - The Froude number in the channel (between the channel banks). HEC-RAS computes the Froude Number as:</p> |
|--|

$$FR = \sqrt{\frac{Q_{ch}^2 \cdot W_{ch}}{g \cdot A_{ch}^3}}$$

where:

Q_{ch} is the flow in the channel,

W_{ch} is the top width of the channel,

g is the acceleration of gravity and

A_{ch} is the area of the channel, where the channel is the portion of the cross section between the channel banks.

Mass (Vol) In Cum (tons or ft³) (tonnes or m³) – The total sediment flux into the control volume since the beginning of the simulation (Cum is "cumulative" in time. Mass In Cum at the upstream cross section should reflect the model boundary and the runtime sediment budget report. Only Total in Level 3. For Grain Class specific results, increase to level 4.

Mass (Vol) Dredge Cum (tons or ft³) (tonnes or m³) – The total mass or volume dredged from that cross section since the beginning of the simulation. Note: This variable will only populate if the model has a dredging event. This output has also changed from version 5, which only reported instantaneous results. See and example in the [Dredging section \(see page 185\)](#).

Table: Bed Layer Mass/Volume and Gradation Index Variables by bed mixing algorithm.

| Thomas (Ex5) and Copeland (Ex 7) | Active Layer |
|--|---|
| Cover (Mass/Vol) (GC) | Active (Mass/Vol) (GC) |
| Subsurface (Mass/Vol) (GC) | Inactive (Mass/Vol) (GC) |
| Inactive (Mass/Vol) (GC) | |
| Cover Thickness | Active Thickness |
| Subsurface Thickness | Inactive Thickness |
| Inactive Thickness | |
| d ₁₀ ,d ₁₆ , d ₅₀ , d ₈₄ , d ₉₀ Cover | d ₁₀ ,d ₁₆ , d ₅₀ , d ₈₄ , d ₉₀ Active |

| | |
|---|---|
| d ₁₀ ,d ₁₆ , d ₅₀ , d ₈₄ , d ₉₀ Subsurface | d ₁₀ ,d ₁₆ , d ₅₀ , d ₈₄ , d ₉₀ Inactive |
| d ₁₀ ,d ₁₆ , d ₅₀ , d ₈₄ , d ₉₀ Inactive | |

1.4.4.1.1.4 Level 4

| | |
|--|---|
| <p>Level 4 (Mass or Vol by Grain Class)</p> | <p>Includes variables from levels 1-3. This is the default level, so it includes the most used variables.</p> <p>Starting in level 4, the Mass and Volume results include total and each active grain class.+ This includes new Mass and Volume variables in this level as well as mass and volume variables (e.g. Mass Bed Change, Vol in CUM) inherited from previous levels.</p> <p>Sediment Concentration (mg/L) – HEC-RAS reports concentration of the flux out of the control volume. Therefore, Concentration is:</p> $C \frac{\text{Mass out}/\text{Time Step (days)}}{\text{Flow}}$ <p>Slope (no units, ft/ft or m/m) – This is the Energy Slope used in the shear stress equation, which is either computed locally at the cross section ($Q/\text{Conveyance}$)^{0.5} or the slope between the EGLs at the bounding cross sections. See the section on Sediment Transport Energy Slope (see page 168).</p> <p>Lateral Load Mass (Volume) In (tons or ft³) (tonnes or m³) – This variable records the sediment entering the model through lateral boundary conditions at each cross section and time step. It is only the lateral loads for the computation increment, not a cumulative value. Total and by grain class.</p> <p>Lateral Structure Mass (or Vol) Div (ton or ft³) (tonnes or m³) – This tracks the sediment that is removed from each control volume (or added) by sediment associated with flow over a lateral structure (see page 186). Total and by grain class.</p> <p>Mean Eff Channel Invert (ft) (–) - This is a measure of representative bed change. The Effective Channel Invert is the maximum <i>channel</i> elevation (the elevation associated with the higher channel bank station) minus the Effective Depth (see description in level 3).</p> <p>Mean Eff Channel Invert Change (ft) – This is the net change in the Mean Effective Invert since the beginning of the simulation. It is similar to the Invert Change variable, reporting bed elevation change (an intuitive measure of morphologic change) but is a more robust reflection of total cross section change than Invert Change, which can generate idiosyncratic results depending on how one node responds to the simulation.</p> <p>Invert Elevation Max (ft) (m)[◊] – The maximum channel invert (lowest elevation point between the channel banks) since the beginning of the simulation. The final profile indicates the maximum deposition at each cross section during the simulation.</p> |
|--|---|

Invert Elevation Min (ft) (m)[◊] – The minimum channel invert (lowest elevation point between the channel banks) since the beginning of the simulation. The final profile indicates the maximum erosion at each cross section during the simulation.

Mass (or Volume) Bed Change Cum: Max (tons or ft³) – The maximum (positive) deposition in mass or volume since the beginning of the simulation. This result is monotonic. It only increases with time.

Mass (or Volume) Bed Change Cum: Min (tons or ft³) - The maximum negative mass or volume change since the beginning of the simulation. This result is monotonic. It only decreases (larger negative value) with time.

Toffaleti Sub Zone Capacities:

Toff Zone Capacity U (tons/day) (tonnes/day) – The fraction of the Toffaleti transport capacity computed in the "Upper Zone" – the top 60% (above 1/2.5 Depth from the bottom) of the water column. Only written if the Toffaleti function is selected. Modelers sometimes compare the upper three zones of Toffaleti Capacity to suspended load measurements (which exclude bed load).

Toff Zone Capacity M – The fraction of the Toffaleti transport capacity computed in the "Middle Zone" – approximately 31% of the water column in the zone between 1/2.5 Depth and 1/11.24 Depth (from the bottom of the channel). Only written if the Toffaleti function is selected.

Toff Zone Capacity L – The Toffaleti transport capacity computed in the "Lower Zone" – approximately the bottom 8-9% of the water column, excluding the bed zone. Only written if the Toffaleti function is selected.

Toff Zone Capacity B – The "Bed Zone" portion of the Toffaleti transport capacity. This is the MPM capacity if the Toffaleti-MPM function is selected.

See example in the [Toffaleti Transport Function Section](#) (see page 307)

+To manage file size and simplify visualization, HEC-RAS only includes grain classes that exist in the model. So a model that only uses grain classes 6-9 will only include four grain-class specific results. However HEC-RAS also outputs intermediate grain classes that do not exist in the model. So if a model only includes two grain classes, 6 and 9, it will output four grain classes, because it will also output zero mass/volume for grain classes 7 and 8.

1.4.4.1.1.5 Level 5

| |
|--|
| <p>Level 5</p> <p>Level 5 is intended to be a "mixing" level, which includes the more detailed results to help understand/troubleshoot the bed mixing algorithms. It also includes all of the terms required to balance the sediment budget for each control volume (or sub-reach). Level 5 also includes some preliminary (station movement and total mass) of BSTEM results (including all of the grain-class specific results) if the model includes any BSTEM cross sections. For BSTEM variable descriptions see the Output section (see page 186) of the BSTEM manual and Table 41.</p> <p>Includes all the variables from Levels 1-4</p> <p>Mass Bed Change[▲]: (tons or ft³) (tonnes or m³) – The sediment eroded or deposited from the control volume in that computational increment (the Cumulative version of this variable is included in Level 1. Total and by grain class).</p> <p>Mass Out[▲]: (tons or ft³) (tonnes or m³) – Sediment flux leaving the control volume in that computation increment. The cumulative version of this result is included in Level 3. Total and by grain class.</p> <p>Mass In[▲] and Mass In Cum: (tons or ft³) (tonnes or m³) – Sediment flux into the control volume, in the specific time series and for all time since the beginning of the simulation respectively. Total and by grain class. The mass balance for each control volume (for the simple Continuity (see page 186) approach) should be :</p> $\text{Mass Bed Change} = \text{Mass In} - \text{Mass Out}$ <p>Mass (Vol) Capacity and Mass (Vol) Capacity Cum (tons/day or ft³/day) (tonnes/day or m³/day) – this is the sum of the transport capacity (see page 186) computed for each grain class. This is before limiters (see page 186) like fall velocity or armoring are applied, so, usually:</p> $\text{Mass Bed Change} \neq \text{Mass In} - \text{Mass Capacity}$ <p>However, it provides a sense of how transport varies with the hydrodynamics and bed evolution. The Cumulative version of this parameter sums the total capacity for all time steps since the beginning of the simulation. Level 5 only includes the totals. HEC-RAS reports these by grain class in level 6.</p> <p>Temperature (°F) (°C) – Water temperature. Current versions of the model only allow one temperature per time step, so this can vary in time but not space.</p> <p>Thickness Cover (Active)[●] (ft) (m) – The vertical thickness of surficial layer of the bed mixing (sorting and armoring) algorithm. This is the Active Layer or the Cover Layer (in the Thomas or Copeland mixing methods).</p> <p>Thickness Subsurface (ft) (m) – The vertical thickness of an intermediate layer between the cover and inactive layer in the Thomas and Copeland mixing algorithms. The Active Layer method does not have a comparable layer.</p> <p>Thickens Inactive (ft) (m) – The vertical thickness of the deepest layer of the bed mixing (sorting and armoring) algorithm. All three methods use the same terminology for this.</p> |
|--|

Mass Cover (Active) (Volume): (tons or ft³) (tonnes or m³) – The sediment mass or volume (total and by grain class) in the surface mixing layer (Active or Cover Layer) of the control volume. The other layers are included in Level 6.

Fall Velocity – (ft/s) (m/s) Reports the fall velocity computed for each grain class. Also reports a "total" fall velocity which is a weighted average:

$$\text{Fall Velocity}_{\text{Total}} = \sum_{i=1}^n \text{Fall Velocity}_i \cdot \text{fraction}_i$$

Where i is each grain class, and n is the number of grain classes in the model. This weighted fall velocity is just a summary heuristic, however. It has no physical analogue and is not used anywhere in the computations. The individual fall velocities can be useful, and vary with temperature. Because HEC-RAS currently only allows one temperature per time step, these values will be constant in space and vary in time.

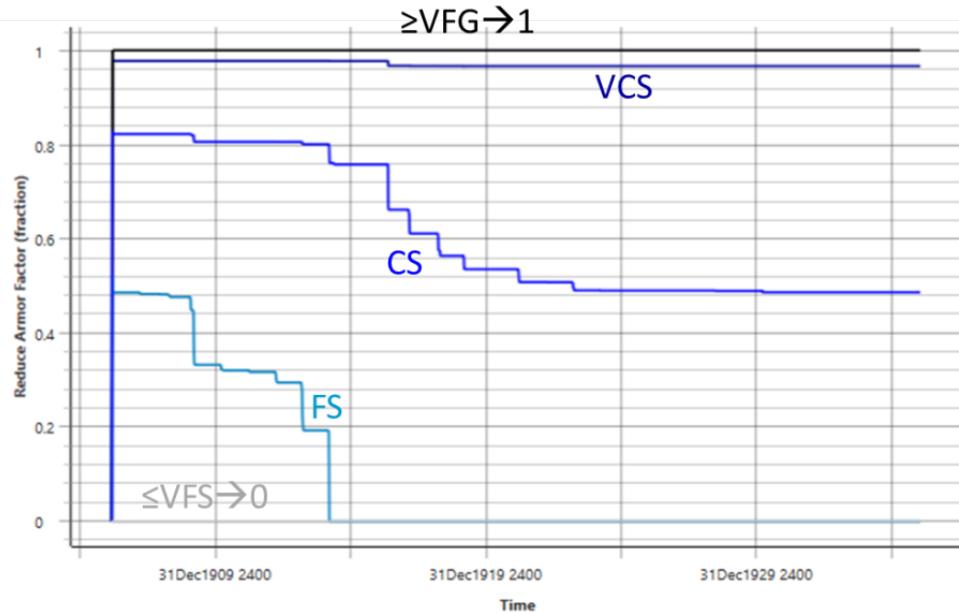
- ▲ Be careful comparing the computational increment mass and volume results. They only report the result for the reported computation increment. If the [Output Increment](#) (see page 200) is set to more than 1 (default is 10) this result will skip the flux or bed change between the reported computational increment and the sum of the time series will not add up to the total flux or bed change.
- The names of these layers can change depending on the bed mixing algorithm. See Table 1 5 for descriptions of the output layer names associated with each mixing algorithm.

1.4.4.1.1.6 Level 6

| | |
|---------|--|
| Level 6 | <p>Level 6 includes some more detailed results and a wider suite of BSTEM results (including all of the grain-class specific results) if the model includes any BSTEM cross sections. For BSTEM variable descriptions see the Output section (see page 186) of the BSTEM manual and Table 41.</p> <p>Includes all variables from Levels 1-5.</p> <p>Mass (or Volume) Capacity (for every grain class) (tons/day or ft³/day) – This is the transport capacity computed by the transport function for each grain class (which is the transport HEC-RAS actually uses in its grain-class independent rout</p> <p>Long. Cum Mass (or Volume) Movable Limits (tons or ft³) - This is the same as the Longitudinal Cumulative Mass or Volume change in Level 1, except it excludes any bed change outside the movable bed limits. The Longitudinal Cumulative Mass (Volume) change sums the mass or volume change from the beginning of the simulation and from upstream-to-downstream, so that the downstream cross section at the last time step of the Longitudinal Cumulative Mass Curve (LCMC) is a summary of the total aggradation or degradation in that reach for the simulation. Comparing the full LCMC (or LCVC) to this one, that only reports the result in the movable bed limits, is a helpful way to differentiate between overbank and channel processes (e.g. determine what percentage of deposition is floodplain deposition or identify overbank deposition offsetting channel erosion). (Total and by grain class)</p> <p>Mass Subsurface (Volume): (tons or ft³) (tonnes or m³) – The sediment mass or volume (total and by grain class) in an intermediate mixing layer between the cover (which is in Level 5) and inactive layers in the Thomas and Copeland mixing methods. The Active Layer method does not have this layer.</p> <p>Mass Inactive (Volume): (tons or ft³) (tonnes or m³) – The sediment mass or volume (total and by grain class) in the deepest mixing layer of the control volume. The deepest mixing layer has the same name for all mixing algorithms.</p> <p>Hydraulic Radius – The area of the channel (the part of the cross section between the movable bed limits) divided by the wetted perimeter of the channel.</p> <p>Movable Elv L and Movable Elv R: (ft) (m) – These are the elevations of the movable bed limits. Tracking the MBL movement relative to the channel can be useful, but these are mainly used to track toe migration in BSTEM models.</p> <p>Movable Sta L and Movable Sta R: (ft) (m) – These are the stations (lateral stations of the station-elevation points) of the movable bed limits. These will remain constant unless the cross section has BSTEM parameters. Only the BSTEM algorithms move cross section station-elevation points laterally.</p> <p>Reduce Armor Factor (decimal between 0 and 1) – The Armor Reduction Factor determines how effective the cover layer is in the Thomas and Copeland mixing algorithms. It is the "Armoring Ratio"³⁸ in Figure 217 and Figure 220. HEC-RAS multiplies the capacity deficit of each grain class by this ratio (computed from the "equivalent particle diameters" of coarser particles in the cover layer). An armor ratio of 1 is no armoring, 0 is complete armoring (for that grain class) and</p> |
|---------|--|

³⁸ https://www.hec.usace.army.mil/confluence/display/_Armoring_Ratio

anything in between is partial armoring. For example, in the figure below, all the grain gravel and cobble grain classes remain unarmored throughout the simulation ($RAF=1$). Very Fine Sand and finer grain classes are all completely armored after the first time step ($RAF=1$). Three sand size classes gradually armor over time, with fine sand fully armoring (goes to zero) during the simulation and Coarse Sand eventually reducing erosion by ~50% because of armoring effects ($RAF=0.5$).



Shear Velocity (ft/s) (m/s) – Shear velocity (u_*) is an expression of the shear stress with velocity units:

$$u_* = \sqrt{\frac{\tau}{\rho}}$$

where τ is the bed shear stress and ρ is the density of the fluid.

The shear velocity is a popular way to express shear and shows up in many of the equations and algorithms included in HEC-RAS because the ratio of fall velocity to shear velocity becomes a dimensionless parameters that has a range of meaningful transport applications.

d_{16} Cover/Subsurface/ Inactive Layers (mm) – The 16th percentile particles size of the specified mixing layer. Some practitioners prefer the d_{16} to d_{10} because it is two standard deviations below the mean.

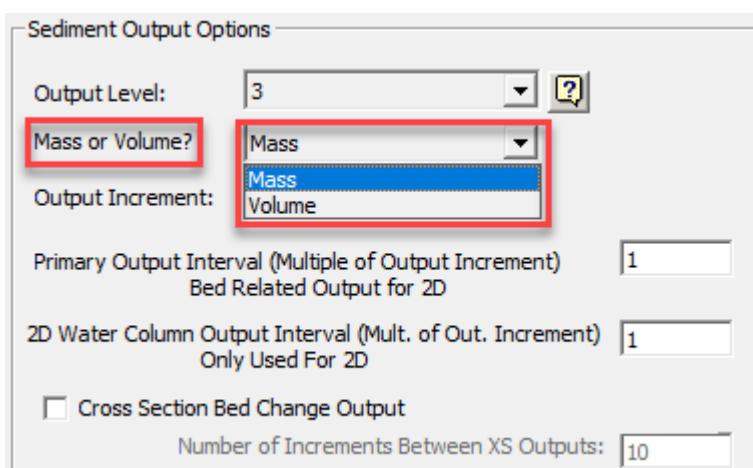
d_{84} Cover/Subsurface/ Inactive Layers (mm) The 84th percentile particles size of the specified mixing layer. Some practitioners prefer the d_{84} to d_{90} because it is two standard deviations above the mean.

1.4.4.1.2 Only Customized

In general, if users **Select Customized Output** (see page 202) variables, HEC-RAS will add the selected variables to the results associated with the selected **Output Level**. However, this option turns off all automatic results, reporting only the results the user individually selects.

1.4.4.2 Output in Mass or Volume?

Converting between mass and volume in HEC-RAS is a relatively simple matter of multiplying or dividing by the unit weight of the material, though the multiplier is different for clay, silt, and cohesionless grain classes. Some users prefer to view the magnitude of erosion, deposition, transport or other variables either in mass or volume units. Volume is the default reporting unit but it can be switched to mass using this option. In recent versions, users can get both by selecting whichever choice is not selected in this drop-down in the **Customized Variables** tool.



Modeling Note: Calibrating to Volume

Repeated cross sections are the most common and –often - the most reliable calibration data. Repeated cross sections can be converted to volume change by multiplying the area change by the control volume reach length, or can be summed from upstream to downstream to compare Longitudinal Cumulative Volume Change Curves (See later) HEC-RAS produces. Therefore, while mass change can be more intuitive, volume change is often easier to compare to common calibration data.

Modeling Note: What if I want Mass AND Volume?

The default sediment results will only report the mass/volume results (e.g. Mass/Volume Bed Change) in the form selected in this option. However, users can add the other one with the [Customized Output](#) (see page 202) option. So if you select Volume but also want Mass bed change, simply select it and HEC-RAS will write both.

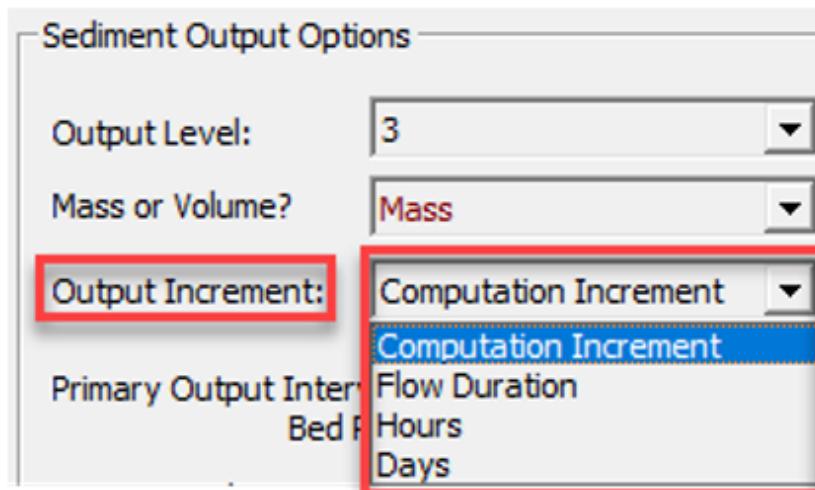
1.4.4.3 Set Output Increment

1.4.4.3.1 Controlling the Quasi-Unsteady Sediment Output Increment

Outputting data periodically can also reduce file size, without eliminating output variables. Control output frequency with the **Number of Increments Between Outputs** parameter (see page 186). First select the basic output 'unit' with the **Output Increment**, then specify the number of increments between outputs:

1.4.4.3.2 Output Increment:

HEC-RAS has four options increments to choose from. Two increments are the two time steps used in the quasi-unsteady flow editor (the **Flow Duration** and **Computational Increment**) and the other two are regular time increments (**Hours** and **Days**). The **Computation Increment** defined in the [Quasi-Unsteady Flow Editor](#) (see page 298) is the default output increment. This option also generates output at the end of each flow duration, whether it is a multiple of the **Computation Increment** or not. Users can also request output every **Flow Duration** or some multiple of them.



Both the **Computation Increment** and the **Flow Duration Output Increment** can distort animated profile results in time (if they are not constant). Larger or rapidly changing flows are often modeled with smaller Computation Increment, which will generate more output profiles during these morphologically active times. Temporal distortion can be valuable or problematic when visualizing results. Consider pros and cons.

The other two options, hours and days, set the output increment to a constant absolute time. This avoids the temporal distortion in the time series plots and animations but can result in skipping over interesting changes and overemphasize boring, low change, periods.

After selecting the **Output Increment**, define the number of **Output Increments** between results using the **Number of Increments Between Profile/Time Series Outputs**. HEC-RAS will write output for every selected variable at this multiple of the base increment. For example, in first figure in [Output Level](#) (see page 186) (the default values) HEC-RAS writes results every ten computation increments.

Modeling Note: Discrete Output for the Increment NOT the Elapsed Time

HEC-RAS reports incremental output like Mass Out, Mass In, or Mass Bed Change (the mass entering, leaving, and depositing/eroding in the control volume in a time step) for the last computational increment. Therefore, if the output increment is longer than the computational increment, HEC-RAS will not sum data between the output increment. Instead a series of 'snapshots' in time are reported. The cumulative variables are usually more helpful for tracking mass through a simulation. To compute increments, select the cumulative outputs and subtract or output every computational increment.

Modeling Note: Setting Output Increment in Unsteady Sediment Transport

The legacy ("Old") sediment output does not work well with unsteady sediment transport. View unsteady sediment output with the new HDF5 viewer ([View->Sediment Output](#)) and control the output increment with the **Mapping Output Interval**. Sometimes HEC-RAS will provide unsteady sediment results with the legacy viewer if the output increment is set to 1.

1.4.4.4 Set Cross Section Bed Change Output

HEC-RAS can plot and animate cross section changes computed as part of a sediment run. Cross section data is usually much more memory intensive since the vertical position of each node on each cross section is stored. Therefore, cross section output is turned off by default and must be selected by checking the **Cross Section Bed Change Output** check box. When users select cross section output the multiple that controls cross section output is multiples of the profile output. For example, in the figure in [Output Level](#) (see page 186), output is generated every 10th profile output or every 100th computation increment. To set the cross section output to write for every profile set the **Number of Profiles Outputs Between XS Outputs** to 1.

As a default HEC-RAS reports variables after every tenth computational increment and at the end of each flow duration. Choosing a less frequent output interval yields a minor improvement in run times.

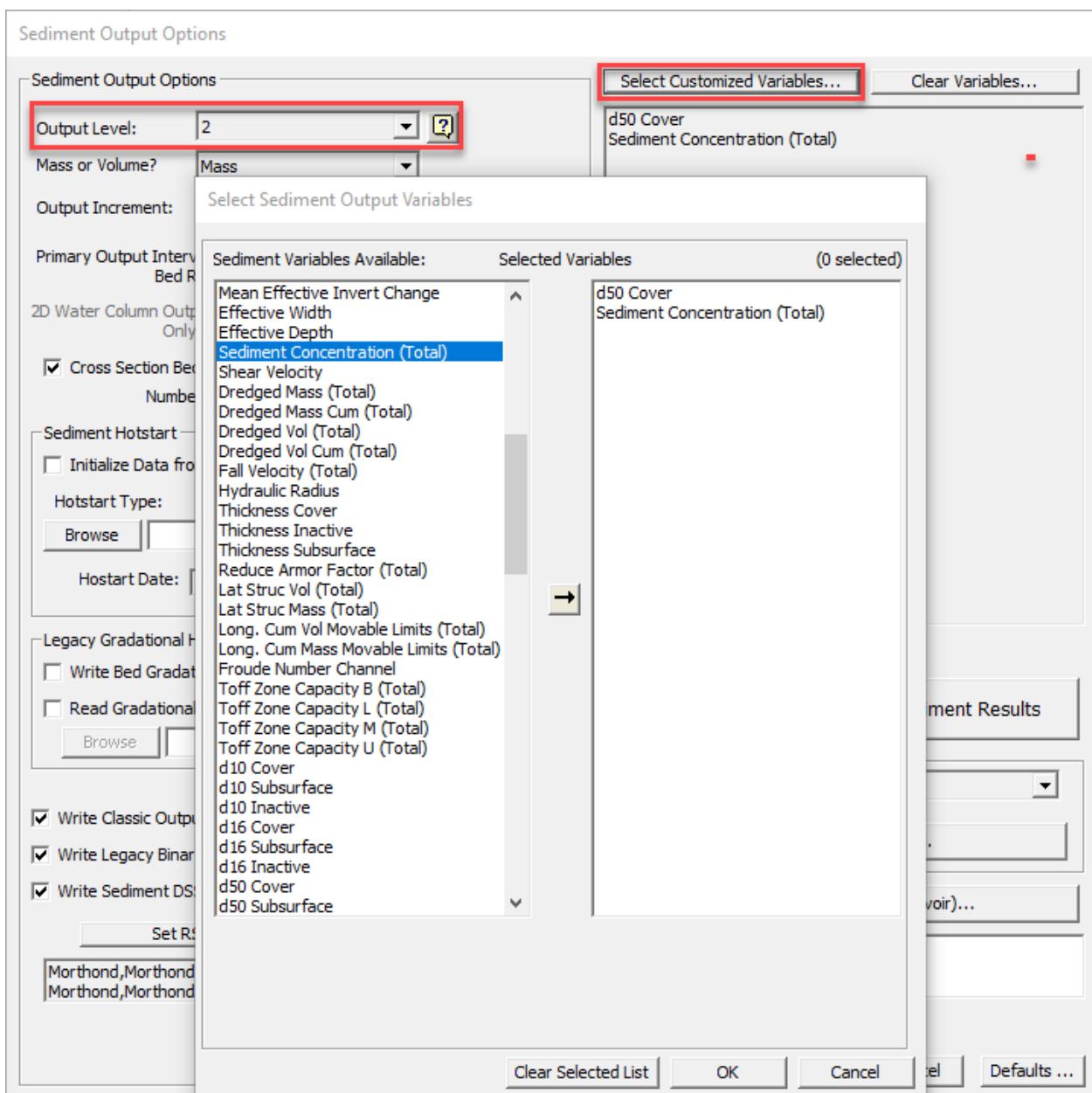
Modeling Note – Large Output Files:

Choosing a high Output Level (e.g. 6) and a low time increment between outputs (e.g. 1) can produce extremely large sediment output files. The classical viewers have a 2GB limit. If output files grow larger than that limit, they will not open, and large files under that limit can be very sluggish. The new HDF5 sediment output viewer can open much larger files, working well with multi-GB files. However, small time steps and large variable requests can produce very large (e.g. a 20 year unsteady sediment model run at a 5 min time step can produce a 30GB output file) which can impact performance.

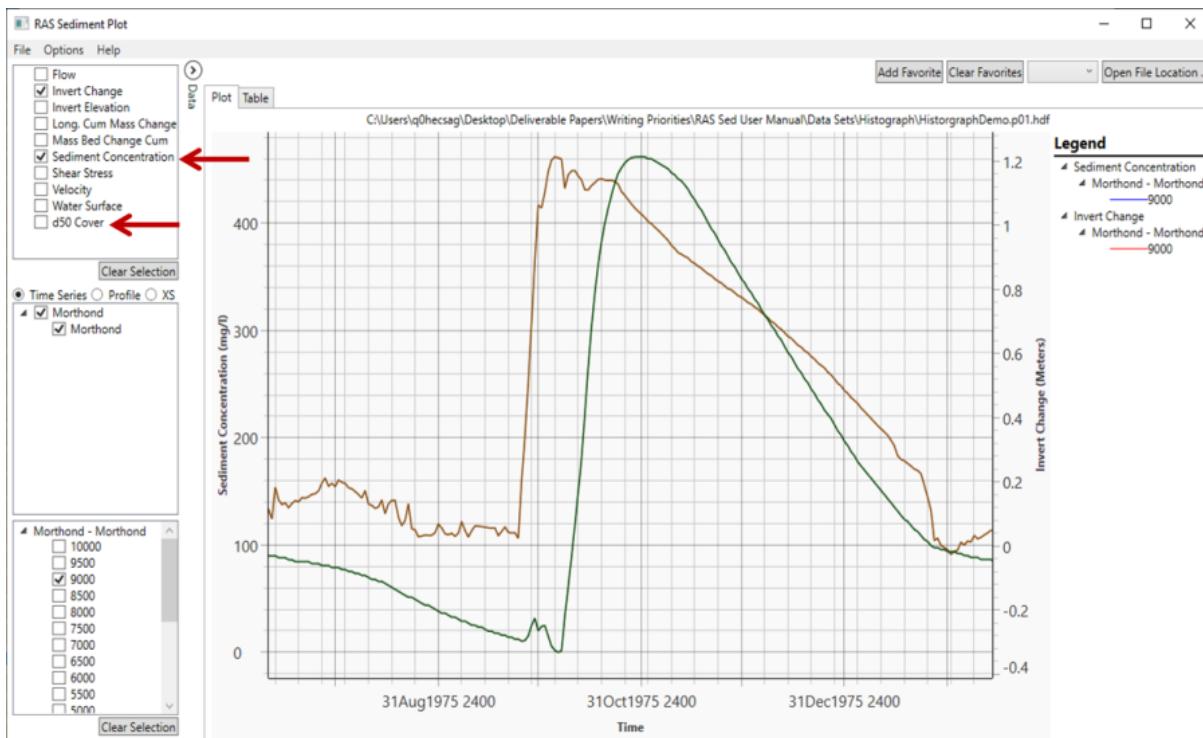
1.4.4.5 Select Customized Output

HEC-RAS sediment simulations generate a lot of data. The **Output Level** forces users to chose between minimizing the results, or getting a lot of data they did not want to get the results they do want. The current version of HEC-RAS has added **Customized Output** to address that issue.

The Customized Output will add the user selected variables to the results from the Output Level, so users can choose a very basic output level (e.g. 2 or 3), and just add the results they are interested in. Or they can choose **Only Customized** under the output level and HEC-RAS will only write the user selected variables. To customize the output level, press the **Select Customized Variables...** button.



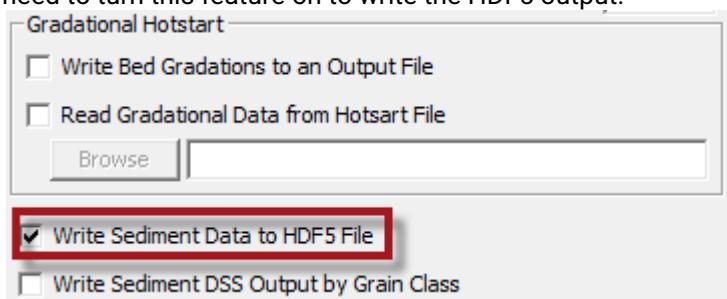
HEC-RAS adds these variables to the result file and they show up as options in the sediment result plotter as shown below:



To delete customized variables, double click on them in the list and to delete all of them press the **Clear Variable** button.

1.4.4.6 HDF5 output

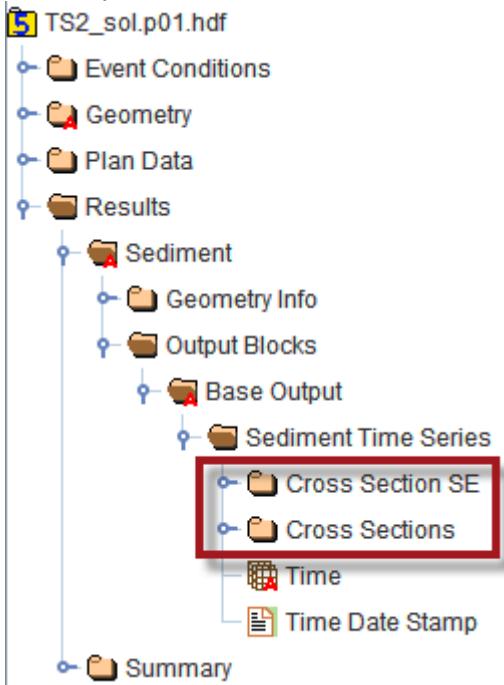
Recent versions of HEC-RAS write results to HDF5, a binary data standard that users can access with free, public domain, viewers, and which is much easier to use and faster to access than the customized binary output used for previous sediment output. HDF5 files can be large, so HEC-RAS provides the option to write them or not. But they should be written for most sediment modeling applications. If they get too large, change the output increment. The current release version of HEC-RAS writes HDF5 files by default. The **Sediment Output** viewer access these data and will not work unless this feature is selected. If you open an HEC-RAS sediment model develop in a previous version and the Sediment Output does not work, you may need to turn this feature on to write the HDF5 output.



Modeling Note – Data Mining the HDF5 file:

One of the advantages of moving to HDF5 output is that user can access the data directly with free, open source, editors (like [HDFView³⁹](#)) or can write code against these files to generate customized plots and isolate interesting results. See more about accessing these data externally in the section

HEC-RAS generates two HDF5 files, storing the geometry data in one named (plan name).gxx.hdf and the results in a file named (plan name).pxx.hdf (where xx is the geometry or plan number). Sediment results are written to the *.pxx.hdf file in the Results → Sediment → Output Blocks → Base Output → Sediment Time Series folder (top). HEC-RAS writes time series for each cross section (or profiles for each time step) to the **Cross Sections** folder (middle-top) and updated cross sections for each requested time step to **Cross section SE**. Metadata, the profile names (time) and the cross section id's (space) that correspond to the rows and columns are stored in the **Time** entry under the **Sediment Time Series** (top) and the **River Reach Station** entry under **Cross Section SE** respectively. Cross section data are stored in **Cross Section SE** at each output cross section with two entries, a "value" entry with all the station-elevation for all cross sections at that time step stored sequentially and an "info" entry which stores the metadata to parse this string, reporting the first and last point in each cross section, named in the **River Reach Station** entry.



³⁹ <https://www.hdfgroup.org/downloads/hdfview/>

File/URL C:\Documents and Settings\HEC User\My Documents\LargeTepTS\TS2_sol.p01.hdf

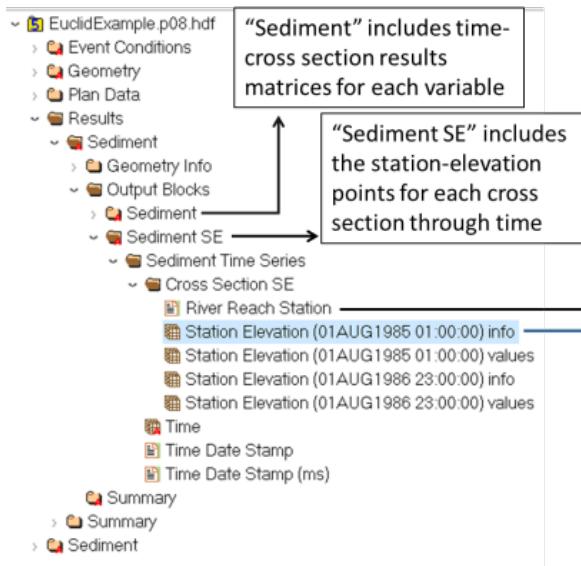
Sediment Time Series

- Cross Section SE
- Cross Sections
- All
- Dredged
- Dredged Cum
- Effective Depth
- Effective Width
- Flow
- Froude Number Channel
- Invert Change
- Invert Elevation
- Lat Struc Mass Div
- Lat Struc Mass Div 10
- Lat Struc Mass Div 11
- Lat Struc Mass Div 12
- Lat Struc Mass Div 13
- Lat Struc Mass Div 14
- Lat Struc Mass Div 7
- Lat Struc Mass Div 8
- Lat Struc Mass Div 9
- Long. Cum Mass Change
- Long. Cum Mass Change 10
- Long. Cum Mass Change 11
- Long. Cum Mass Change 12
- Long. Cum Mass Change 13
- Long. Cum Mass Change 14

TableView - Long. Cum Mass Change - /Results/Sediment/Output Blocks/Base ...

Profile Cross Sections (space)

| | 0 | 1 | 2 | 3 | 4 | 5 |
|----|-----|------------|-----------|------------|-----------|-----------|
| 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.0 | 0.18073036 | 0.5328563 | 0.32827684 | 0.3606387 | 1.3741459 |
| 2 | 0.0 | 0.31451693 | 0.967488 | 0.6457152 | 0.7079736 | 2.5057863 |
| 3 | 0.0 | 0.41639262 | 1.3251157 | 0.9461199 | 0.9648669 | 3.255602 |
| 4 | 0.0 | 0.49635547 | 1.6224989 | 1.2255709 | 1.2215039 | 3.922055 |
| 5 | 0.0 | 0.56090844 | 1.872335 | 1.4874839 | 1.4744865 | 4.4080677 |
| 6 | 0.0 | 0.6141842 | 2.0839581 | 1.7300342 | 1.7206318 | 4.866742 |
| 7 | 0.0 | 0.66010725 | 2.2668612 | 1.9509037 | 1.9625927 | 5.3062916 |
| 8 | 0.0 | 0.7001221 | 2.4258657 | 2.146833 | 2.1917582 | 5.725644 |
| 9 | 0.0 | 0.659834 | 2.3657408 | 2.1906273 | 2.2865813 | 5.902163 |
| 10 | 0.0 | 0.6301672 | 2.3201396 | 2.1996493 | 2.3606236 | 6.081173 |
| 11 | 0.0 | 0.60867757 | 2.2868223 | 2.1885066 | 2.4120998 | 6.2576447 |
| 12 | 0.0 | 0.5939655 | 2.2647755 | 2.1679008 | 2.4449983 | 6.429212 |
| 13 | 0.0 | 0.5846166 | 2.2524283 | 2.1466637 | 2.4630132 | 6.592748 |
| 14 | 0.0 | 0.5792682 | 2.247847 | 2.1267288 | 2.4689722 | 6.7452397 |
| 15 | 0.0 | 0.57689756 | 2.2496533 | 2.1081963 | 2.4656093 | 6.885687 |
| 16 | 0.0 | 0.57746243 | 2.259677 | 2.0946796 | 2.460122 | 7.0200253 |
| 17 | 0.0 | 0.58016866 | 2.2754219 | 2.0839667 | 2.4506435 | 7.14447 |
| 18 | 0.0 | 0.5859495 | 2.2979245 | 2.0790815 | 2.4442313 | 7.2660565 |
| 19 | 0.0 | 0.5927819 | 2.323663 | 2.0762844 | 2.4371235 | 7.3795466 |
| 20 | 0.0 | 0.6022416 | 2.3559988 | 2.081264 | 2.4376385 | 7.3894477 |
| 21 | 0.0 | 0.61205703 | 2.3905323 | 2.0886123 | 2.4390054 | 7.411506 |
| 22 | 0.0 | 0.62287986 | 2.4283905 | 2.1004984 | 2.4447849 | 7.4498286 |
| 23 | 0.0 | 0.63515973 | 2.4704216 | 2.1184916 | 2.4574945 | 7.5053816 |
| 24 | 0.0 | 0.64751405 | 2.5137806 | 2.1389148 | 2.4725792 | 7.570217 |
| 25 | 0.0 | 0.6597493 | 2.557802 | 2.1610138 | 2.4894493 | 7.6424856 |
| 26 | 0.0 | 0.6722384 | 2.6029966 | 2.1855462 | 2.5093763 | 7.7229457 |
| 27 | 0.0 | 0.6845423 | 2.6483326 | 2.2110565 | 2.4664083 | 7.6266174 |
| 28 | 0.0 | 0.6974502 | 2.695272 | 2.2395654 | 2.4392245 | 7.556504 |



"Sediment" includes time-cross section results matrices for each variable

"Sediment SE" includes the station-elevation points for each cross section through time

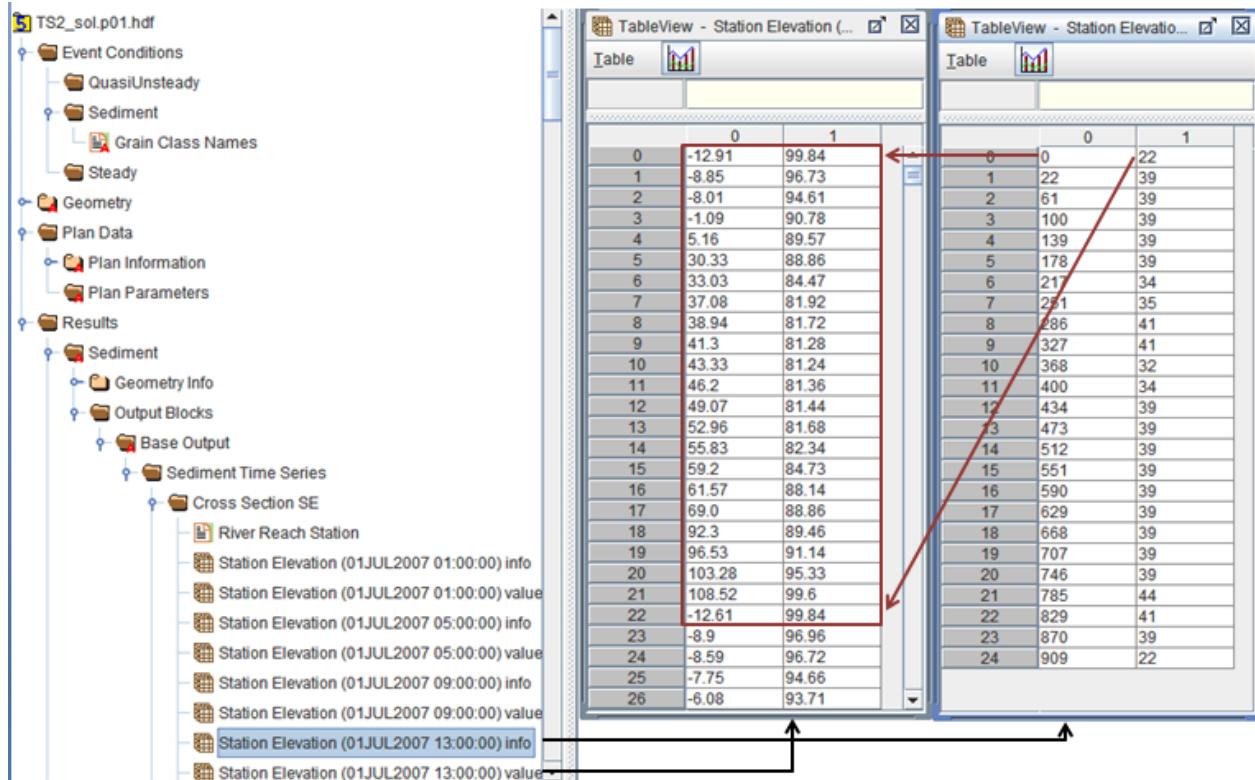
Info tells you the first station elevation point associated with each XS and how many points the XS has, which can be cross-referenced with the "values"

River Reach Station identifies each XS

| | | | |
|----|--------|--------|------|
| 0 | Euclid | Euclid | 5750 |
| 1 | Euclid | Euclid | 5700 |
| 2 | Euclid | Euclid | 5600 |
| 3 | Euclid | Euclid | 5500 |
| 4 | Euclid | Euclid | 5400 |
| 5 | Euclid | Euclid | 5100 |
| 6 | Euclid | Euclid | 4900 |
| 7 | Euclid | Euclid | 4700 |
| 8 | Euclid | Euclid | 4600 |
| 9 | Euclid | Euclid | 4500 |
| 10 | Euclid | Euclid | 4350 |
| 11 | Euclid | Euclid | 4325 |

info

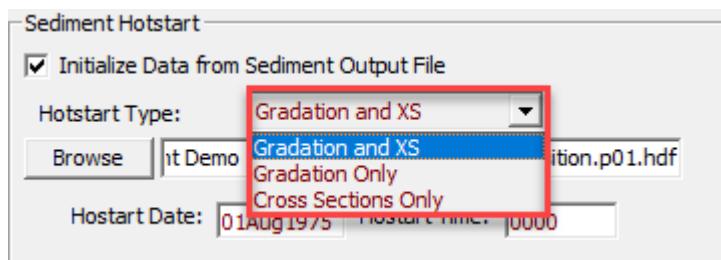
| | | | | | |
|----|-----|---|----|--------|---------|
| 0 | 0 | 8 | 0 | 1000.0 | 589.4 |
| 1 | 8 | 7 | 1 | 1010.0 | 588.1 |
| 2 | 15 | 8 | 2 | 1029.0 | 588.4 |
| 3 | 23 | 7 | 3 | 1041.0 | 583.58 |
| 4 | 30 | 7 | 4 | 1070.0 | 582.575 |
| 5 | 37 | 7 | 5 | 1101.0 | 583.58 |
| 6 | 44 | 7 | 6 | 1112.0 | 589.8 |
| 7 | 51 | 7 | 7 | 1125.0 | 590.0 |
| 8 | 58 | 7 | 8 | 0.0 | 587.0 |
| 9 | 65 | 7 | 9 | 30.0 | 587.0 |
| 10 | 72 | 7 | 10 | 46.0 | 582.85 |
| 11 | 79 | 7 | 11 | 71.0 | 581.85 |
| 12 | 96 | 0 | 12 | 96.0 | 582.85 |
| 13 | 112 | 0 | 13 | 112.0 | 587.0 |
| 14 | 130 | 0 | 14 | 130.0 | 587.0 |
| 15 | 0 | 0 | 15 | 0.0 | 587.0 |
| 16 | 30 | 0 | 16 | 30.0 | 587.0 |



1.4.4.7 Sediment Hotstart From Output File (Versions 6.0+)

The new (HEC-RAS 6.0 and later) Sediment Hostart feature will initialize the model with the cross sections and bed gradations from any output time period in a sediment transport output file (gradation hotstart requires **Volume** results at **Output Level 6**).

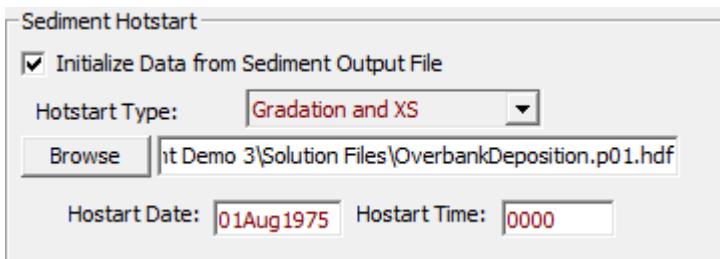
To read initial bed gradations or cross sections from a 1D sediment output file check the **Initialize Data From Sediment Output File**.



Then, from the **Hotstart Type** dropdown menu, select which data to initialize. The options include:

- **Cross Sections Only:** This option will read the updated Cross Sections (XS) from a sediment simulation output file. This will initialize the new model with the updated station-elevation points of the specified time step of the selected simulation. The hotstart will not read bed gradations from the file, but will use those specified in the Sediment data editor.
- **Gradation Only:** This option will read bed gradations from the specified output file. It will initialize the new model with the mass of each grain class (not just the percentage) in each bed mixing layer at the output time step. Make sure the model and the output file used the same bed mixing algorithm.

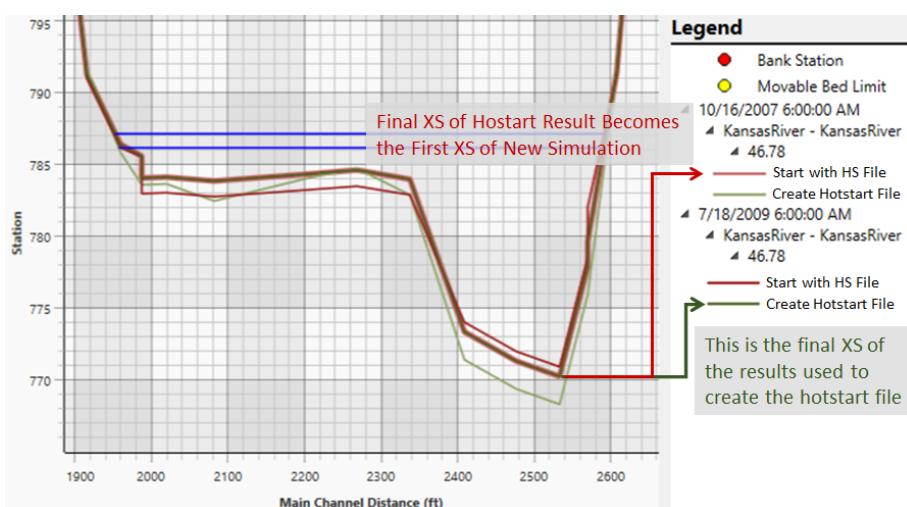
- **Gradation and XS:** This option reads in the station elevation data from the



60 To hotstart with an output file, select the appropriate .pxx.hdf output file and specify the date and time of gradations and/or cross sections to read in.

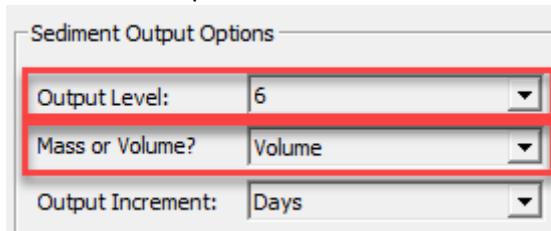
Press the **Browse** button to find the sediment output file to use as a hotstart. Sediment output files have the suffix pxx.hdf (where xx is a number between 01 and 99). The number of the pxx.hdf file corresponds to the plan number in of the simulation (e.g. the figure above is the result from plan 1 (.p01)).

Specify a date and time. HEC-RAS will select the output (gradation and/or cross sections) closest to that time from the output file. It will then initialize the new model with those data.



Output File Must Have Supporting Bed Mass/Volume Variables

If you want to use model results for a gradational hotstart, you must run it at [Output 6](#) and Set the Mass/Volume option to [Volume](#).



HEC-RAS will generate an error if the user requests a gradational hotstart from an output file that does not have all of the required bed layer results by grain class:

Hotstart file missing Mass (or Vol) Inactive data set
Try recreating the hotstart file with additional output
Please recheck your files

The gradational hotstart cannot use results files created with output level 1-3 (unless the user adds the layer masses by grain class). Run the model at output level 4 to generate a results file complete enough for a gradational hotsart.

The New Model Must Have the Same Cross Sections as the Output File

All hotstart features require that the model used to develop the hotstart file has the same cross sections and other nodes (bridges, inline/lateral structures, etc...) as the simulation file uses. HEC-RAS has some logic to try to reconcile hotstart files with extra or missing cross sections (relative to the starting geometry). But users should just be careful that the geometry used to generate the hotstart file has the same cross sections (and other features) as the geometry file in the plan that uses it.

Gradational Hotstarts Require the Same Bed Mixing Algorithm

Bed gradation output are algorithm specific. The Active Layer method cannot hotstart from Copeland or Thomas. Make sure the model and the output file you hotstart with have the same bed mixing algorithm.

1.4.4.8 Gradation Hotstart (5.x Legacy Version)

Note

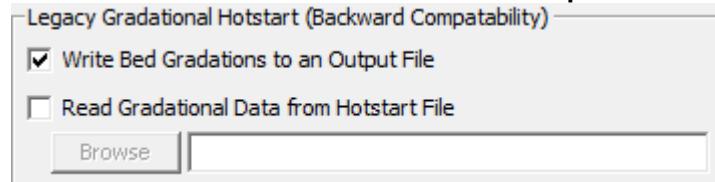
This feature is superseded by the [Sediment Hotstart from and Output File \(see page 207\)](#). It has been retained for backward compatibility, but new models should use the new feature, which is much more powerful, flexible, and intuitive.

Sediment bed gradations are often vertically discontinuous (e.g. a thin, coarse armor layer often covers finer, well graded/poorly sorted sub surface material). HEC-RAS accounts for cover layers computationally with the bed sorting and armoring algorithm, but it can be useful to start simulations with different gradations in the cover/active layer and the subsurface/inactive layer.

Users can manually define and select separate cover layers using the *Options→Mixing Options* menu or users can import layer-specific bed gradations from a previous HEC-RAS sediment run with the [Gradation](#)

[Hotstart tool](#) (see page 186).

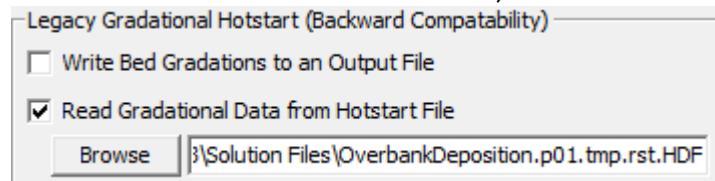
The **Gradation Hotstart** has two steps. First, an HEC-RAS sediment model must write out sediment gradation data. Select the **Write Bed Gradations to an Output File** check box under **Gradational Hotstart** (below).



This will write an HDF5 file (*.tmp.rst.HDF extension) with the bed gradation for each mixing layer of each cross section (below). HEC-RAS writes the fraction associated with each grain class in rows 0-19 and the total layer mass in row 20, and will read these in automatically as initial conditions if prompted.

| | Cover Layer | Inactive Layer |
|----|--------------|----------------|
| 0 | 0.0 | 0 |
| 1 | 0.0 | 1 |
| 2 | 0.0 | 2 |
| 3 | 0.0 | 3 |
| 4 | 0.0 | 4 |
| 5 | 0.0 | 5 |
| 6 | 0.1553889... | 6 |
| 7 | 0.0597968... | 7 |
| 8 | 0.1610565... | 8 |
| 9 | 0.1809985... | 9 |
| 10 | 0.2953516... | 10 |
| 11 | 0.0884444... | 11 |
| 12 | 0.0294814... | 12 |
| 13 | 0.0294814... | 13 |
| 14 | 0.0 | 14 |
| 15 | 0.0 | 15 |
| 16 | 0.0 | 16 |
| 17 | 0.0 | 17 |
| 18 | 0.0 | 18 |
| 19 | 0.0 | 19 |
| 20 | 0.0282651... | 4.91667 |

To use a **Gradational Hotstart** file as initial bed gradations, check the **Read Gradational Data from Hotstart File** check box in **Gradational Hotstart** box, then **Browse** to the HDF5 hotstart file (below).



HEC-RAS always requires user specified gradations in the sediment editor, but HEC-RAS will use hotstart gradations instead of gradations specified in the sediment editor when users select the hotstart feature. However if the geometry includes cross sections that do not exist in the hotstart file, the program will default to the gradations specified in the sediment editor.

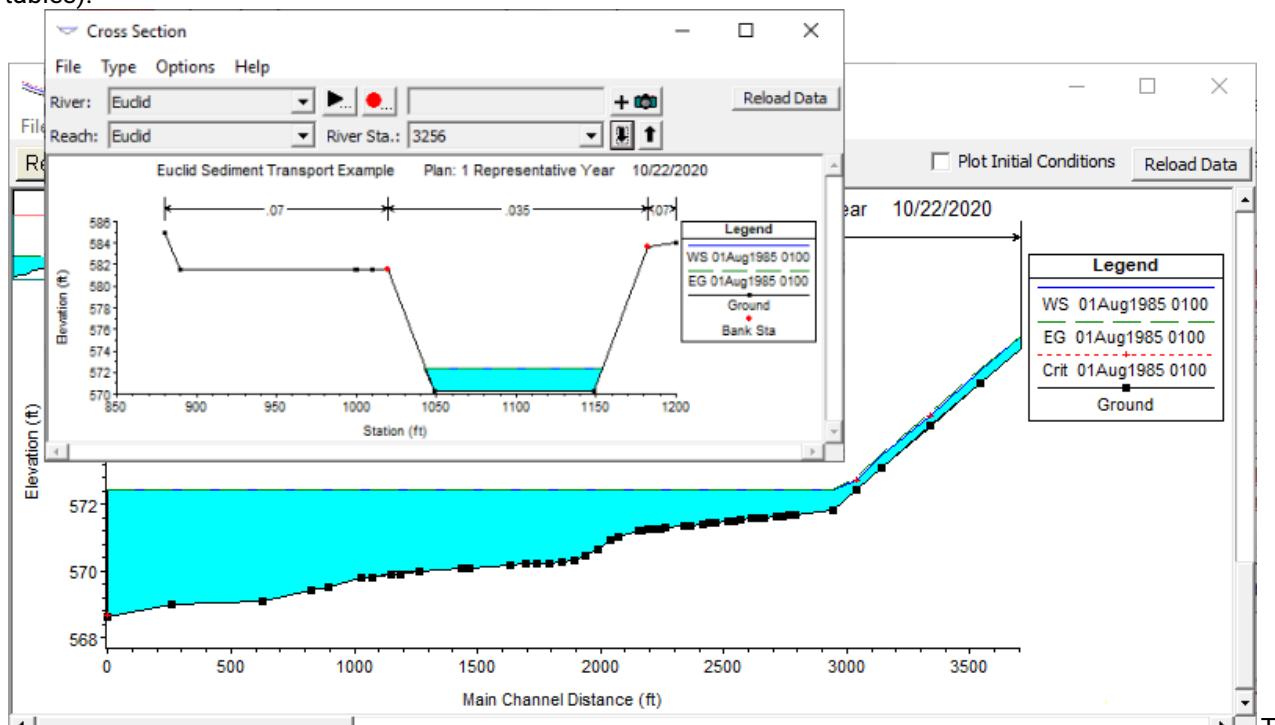
Modeling Note - Graduation Warm Up Simulation

The feature can be used to perform a 'warm up' run to develop starting bed gradations for the actual simulation. TD13 (HEC, 1992) and Thomas and Chang (2008) recommend running a 'robustness test' to evaluate the numerical stability of 1D sediment models. Robustness runs involve running a constant representative flow (often the 'channel forming discharge') through model until the solution converges on a final stable geometry. By requesting a graduation hotstart file a robustness test and selecting them as the Hostart gradations of the actual simulation, the robustness test can double as a 'bed graduation warm up' and will reduce the numerical fluctuations early in the simulation as the mixing algorithms converge on stable gradations.

1.4.4.9 Write Classic Output (WSE Profile etc. – O file)

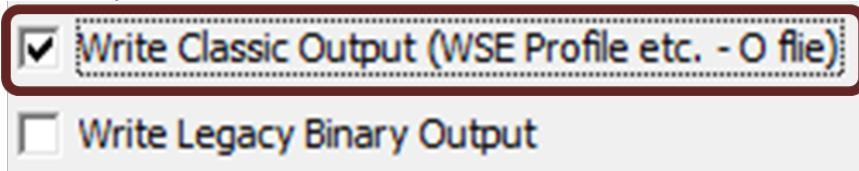
Recent versions of the sediment model write results to HDF5 and read those results with the sediment plotter. Sediment output files can get very large, and the HEC-RAS sediment transport model writes two additional files that can get very large (and affect run time) that may not be useful to users. HEC-RAS provides switches to turn these output files off.

The O file is the standard steady flow output file. Both the quasi-unsteady and unsteady sediment models write hydraulic results to the O file so users can view the standard hydraulic output with the standard hydraulic results tools (e.g. the profile plot, the cross section plot, the generalized output plot, the results tables).



The 1D sediment model in HEC-RAS is a decadal scale model and is usually most effective when applied to multi-decadal calibrations and projections. So hydraulic output files can get large. If the O. file grows **larger**

than 2GB, it will not plot and it has trouble writing to disk over 4GB. The sediment HDF5 file does not have these limitations (which is part of the reason HEC-RAS migrated to this file format). Therefore, HEC-RAS can plot the sediment results (and hydraulic output associated with the sediment results) if the file gets large. Modelers can use the [Output Increment \(see page 200\)](#) to request less output. But this feature also allows users to turn the steady flow output off, saving disk space and run time, and get all of their results from the sediment plotter.



1.4.4.10 Write Legacy Binary Output

The sediment plotter in HEC-RAS 6.0 and later reads the HDF results which can read large files (though very large files will degrade performance – so output increment management can still be helpful). But these recent versions of HEC-RAS still include [legacy sediment results \(see page 212\)](#) viewers for users who have built a work-flow comfort level with them.

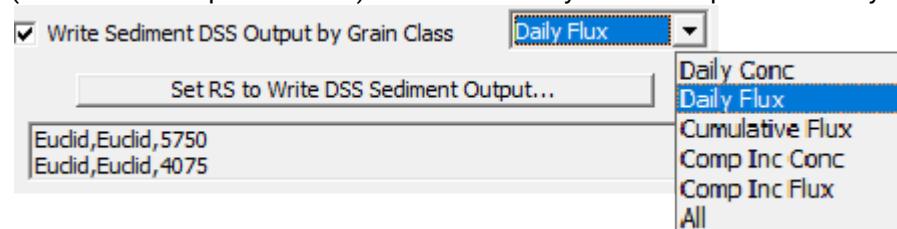


One of these legacy viewers read a binary output file which can get large, and like the O file (see previous section) will not plot if it grows larger than 2GB. There is no reason to write this file if you are not using the original sediment result viewers. (The new sediment plotter has all of the functionality of the previous viewers and many new features, so HEC recommends transitioning to this tool.) Unless you are using these legacy viewers, this file is only taking up disk space and run time. This interface option allows users to choose whether to write it.

New projects, created in version 6.0 or later do not write these files by default. So users have to check this box to use the legacy sediment output. But models created in earlier versions will write these files by default. By deselecting this feature, HEC-RAS will stop writing these files that are generally unnecessary.

1.4.4.11 DSS Output

Quasi-unsteady sediment analysis does not generate DSS data by default. Users can request limited DSS time series at any cross section(s). HEC-RAS will write out a DSS file named (project name).PXX.sed.dss (where XX is the plan number). This feature only works for quasi-unsteady analyses.



Users can choose one or more cross sections to write DSS output. To add additional cross sections press the **Set RS to Write DSS Sediment Output...** button. To delete or clear a node from the DSS list double click on list. Double clicking removes nodes.

Users can also select five different DSS results (or all five) These DSS output options were expanded in version 6.0. Earlier versions had much more limited DSS output.. Different result options generate different

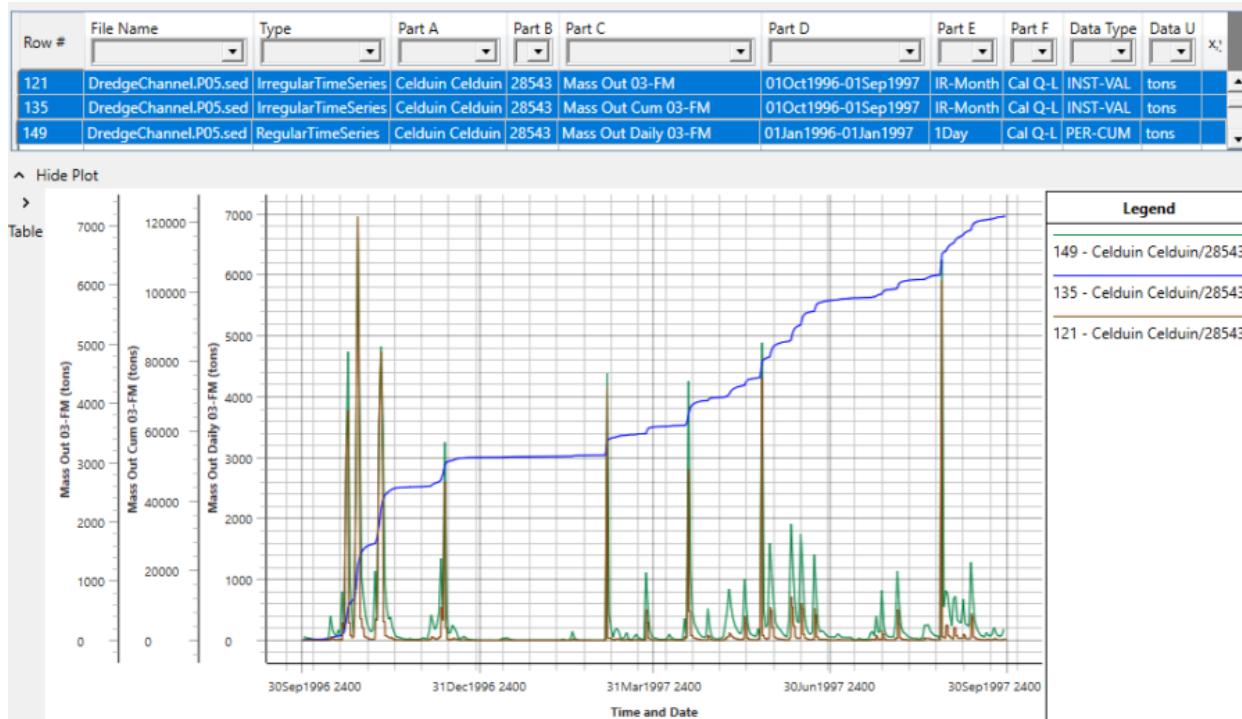
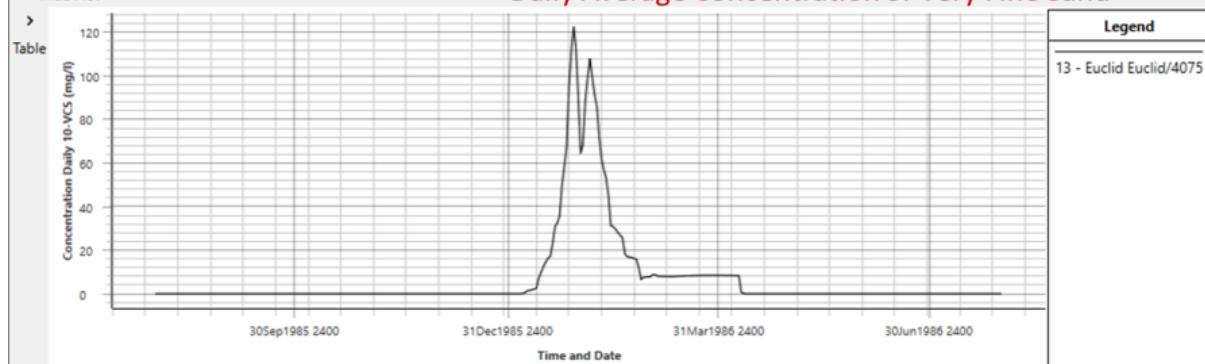
DSS formats, and some of them trigger HEC-RAS to write multiple Results. All DSS results are written by grain size.

HEC-RAS can write Concentration as an instantaneous value at for each computational increment (INST-VAL, IR-Month) or average the Concentration over each day, which it writes as a regular daily time series (PER-AVE, 1 Day). The mass flux leaving the cross-section control volume has three options instantaneous flux for each Computational Increment (INST-VAL, IR-Month), daily period cumulative data (PER-AVE, 1Day) that accumulates mass over time, and an instantaneous cumulative mass flux (INST-VAL, IR-Month).

Instantaneous, Irregular Concentration of Very Fine Sand

| | | | | | | | | | | |
|----|-----------------------|---------------------|---------------|------|----------------------------|---------------------|----------|--------|----------|------|
| 4 | EuclidExample.P08.sed | IrregularTimeSeries | Euclid Euclid | 4075 | Concentration 10-VCS | 01Aug1985-01Aug1986 | IR-Month | 1 Year | INST-VAL | mg/l |
| 5 | EuclidExample.P08.sed | IrregularTimeSeries | Euclid Euclid | 4075 | Concentration 11-VFG | 01Aug1985-01Aug1986 | IR-Month | 1 Year | INST-VAL | mg/l |
| 6 | EuclidExample.P08.sed | IrregularTimeSeries | Euclid Euclid | 4075 | Concentration 12-FG | 01Aug1985-01Aug1986 | IR-Month | 1 Year | INST-VAL | mg/l |
| 7 | EuclidExample.P08.sed | IrregularTimeSeries | Euclid Euclid | 4075 | Concentration 13-MG | 01Aug1985-01Aug1986 | IR-Month | 1 Year | INST-VAL | mg/l |
| 8 | EuclidExample.P08.sed | IrregularTimeSeries | Euclid Euclid | 4075 | Concentration 14-CG | 01Aug1985-01Aug1986 | IR-Month | 1 Year | INST-VAL | mg/l |
| 9 | EuclidExample.P08.sed | IrregularTimeSeries | Euclid Euclid | 4075 | Concentration 15-VCG | 01Aug1985-01Aug1986 | IR-Month | 1 Year | INST-VAL | mg/l |
| 10 | EuclidExample.P08.sed | RegularTimeSeries | Euclid Euclid | 4075 | Concentration Daily 07-FS | 01Jan1985-01Jan1986 | 1Day | 1 Year | PER-AVE | mg/l |
| 11 | EuclidExample.P08.sed | RegularTimeSeries | Euclid Euclid | 4075 | Concentration Daily 08-MS | 01Jan1985-01Jan1986 | 1Day | 1 Year | PER-AVE | mg/l |
| 12 | EuclidExample.P08.sed | RegularTimeSeries | Euclid Euclid | 4075 | Concentration Daily 09-CS | 01Jan1985-01Jan1986 | 1Day | 1 Year | PER-AVE | mg/l |
| 13 | EuclidExample.P08.sed | RegularTimeSeries | Euclid Euclid | 4075 | Concentration Daily 10-VCS | 01Jan1985-01Jan1986 | 1Day | 1 Year | PER-AVE | mg/l |

Daily Average Concentration of Very Fine Sand



The time series written to DSS are equivalent to the MASS Out Cum variable in HEC-RAS, computing the

cumulative total sediment mass leaving the control volume over time by grain class. Cumulative mass time series are stored by grain class (part C indicates that they are sediment data, the grain class number and the grain class name) and stored as irregular monthly (IR-Month) data.

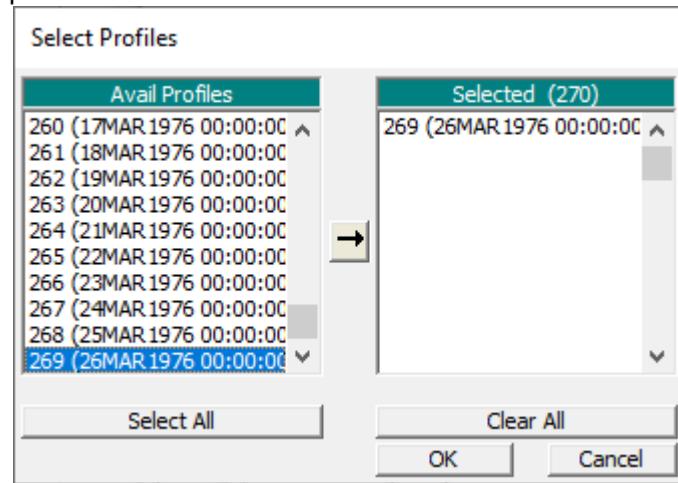
1.4.5 Create Geometry Files from Sediment Results

It is very common for users to convert the results from a sediment simulation into a new HEC-RAS geometry file. The most common motivation for this is re-evaluating risk assessment (e.g. run HEC-FDA, the 1% flood or a 2% riparian flow) for future conditions, after a period of record sediment simulation. However, this feature can also be useful for "robustness" tests or model warm-up.

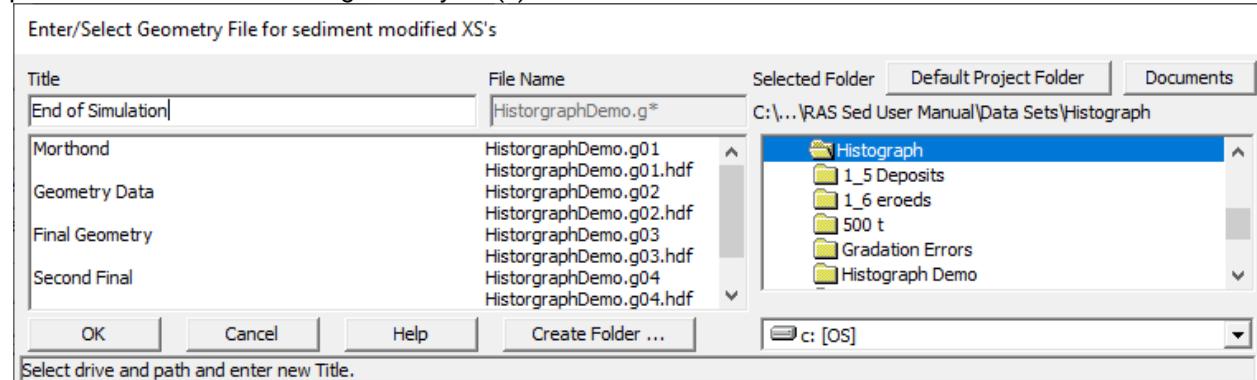
To create a geometry file from the updated cross sections from a sediment transport simulation press the **Create Geometry Files from Sediment Results** button on the **Sediment Output Options** menu.

Create Geometry Files from Sediment Results

A dialogue will appear (below) with all the result profiles from the sediment simulation. Select one or more of these to convert the cross-section station-elevation points from that (those) time(s) in the simulation into geometry files. For example, to create a geometry file from the final simulation result, scroll to the bottom profile and select it.

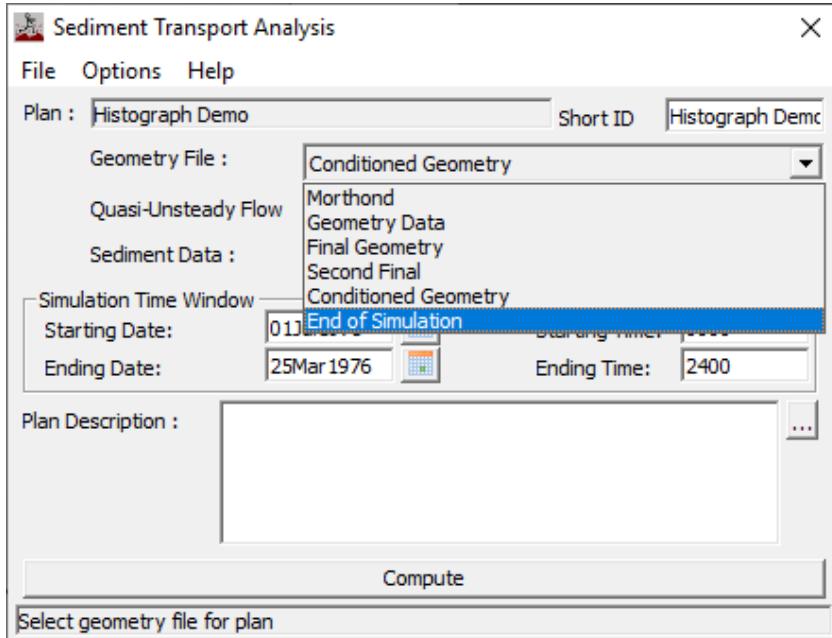


A naming dialogue will appear for each of the profiles selected. Name the geometry file(s)



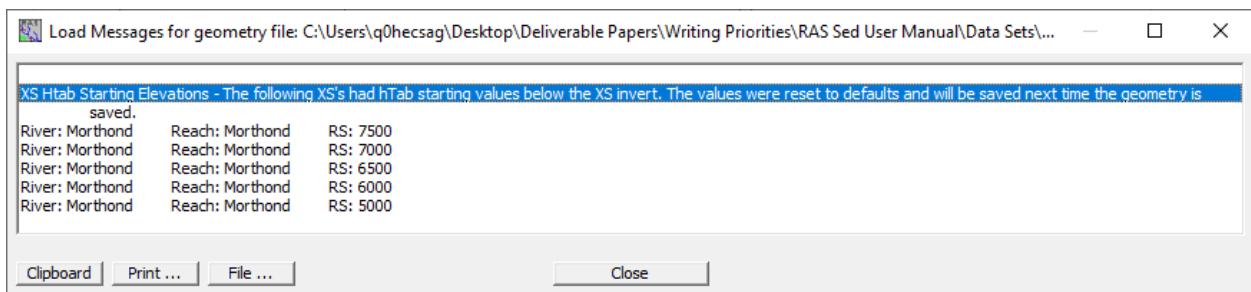
The new geometry file will inherit all of the parameters, variables, settings and features of the geometry file used for the sediment simulation (e.g. n-values, ineffective flow areas, structures, etc...) and will only update the station-elevation points (and, in cases where BSTEM is not used, only the elevations of those points).

HEC-RAS will add the new geometry file to the project, and it becomes available for new steady, unsteady or sediment simulations.



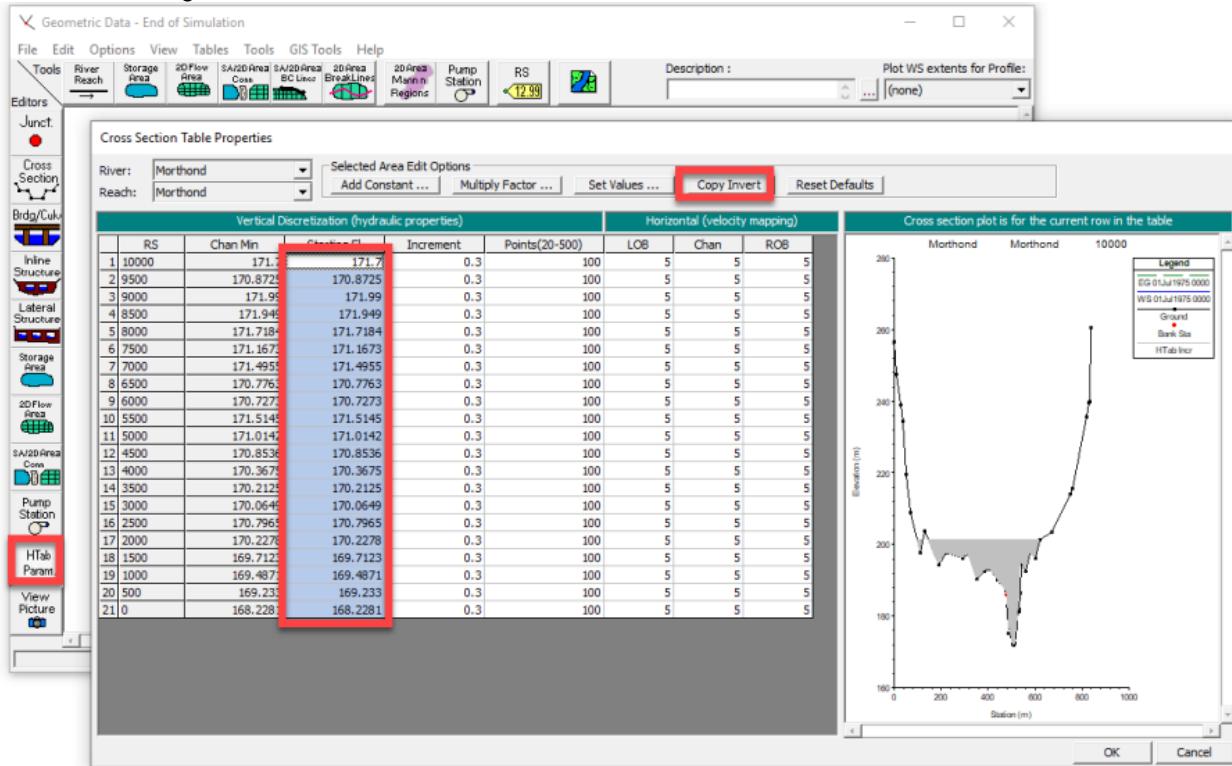
Modeling Note – XS Htab Starting Elevation Error:

When using a geometry file created from a sediment simulation in a new hydraulic or sediment simulation, the new simulation will often throw an Htab error (below). The HTab (Hydraulic Table) editor sets the increments for the pre-processed hydraulic computations and is supposed to start at or near the thalweg. The new geometry file inherits these from the geometry file used during the sediment simulation, but the thalwegs of many of the cross sections have probably changed.



This issue has a simple fix. Open the geometry file and press the HTab button on the left, vertical, button bar (you may need to expand the geometry editor vertically to see it). This will open the **Cross Section Table** Properties editor (below). Select the header of the **Starting El** column to select all of the initial elevations. Then press the **Copy Invert** button. This will reset the base elevation of all the HTab tables and will clear up

the error message.

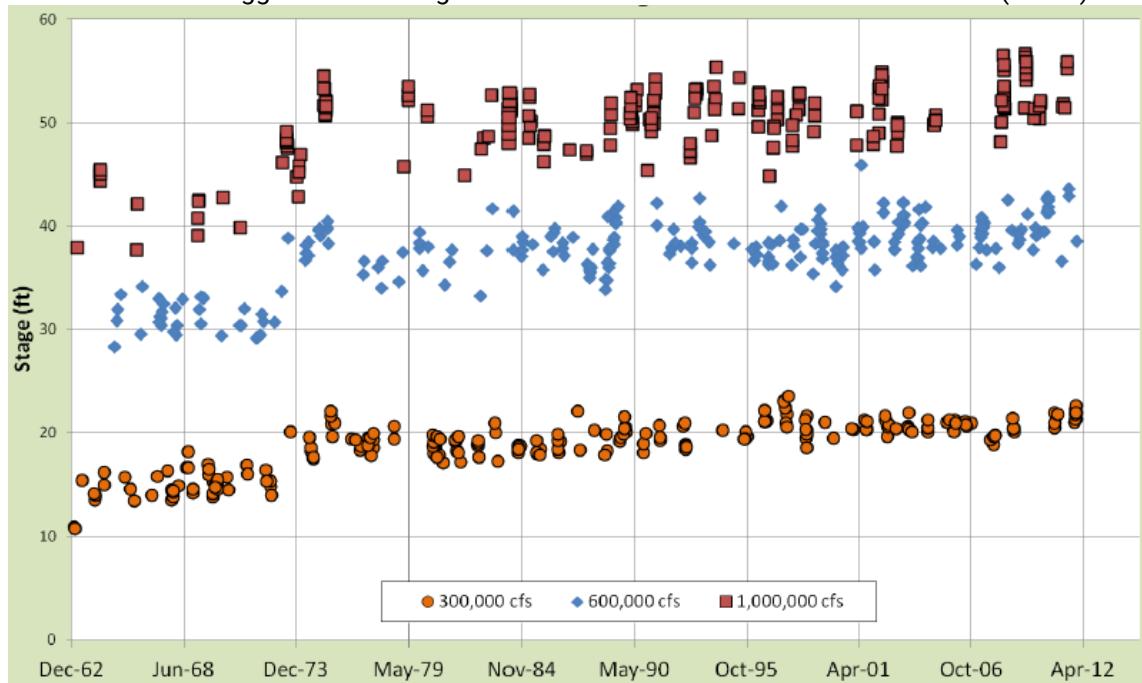


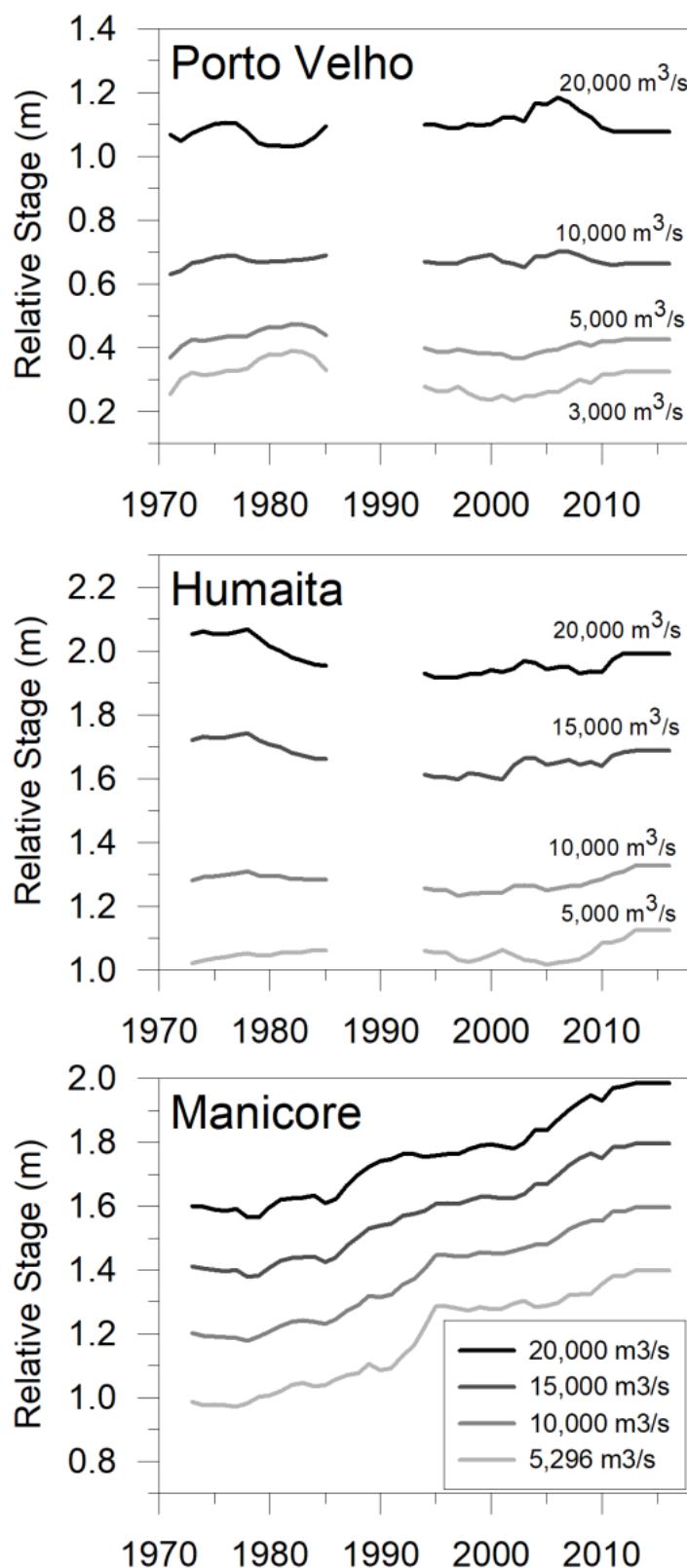
1.4.6 Specific Gage Post-Processor

Note: The Specific Gage Tool was redesigned in version HEC-RAS 6.0 and will be different than previous versions. Previous versions ran this process as part of a sediment simulation. The new version is a post-processor that creates new geometry files from the HDF5 output files.

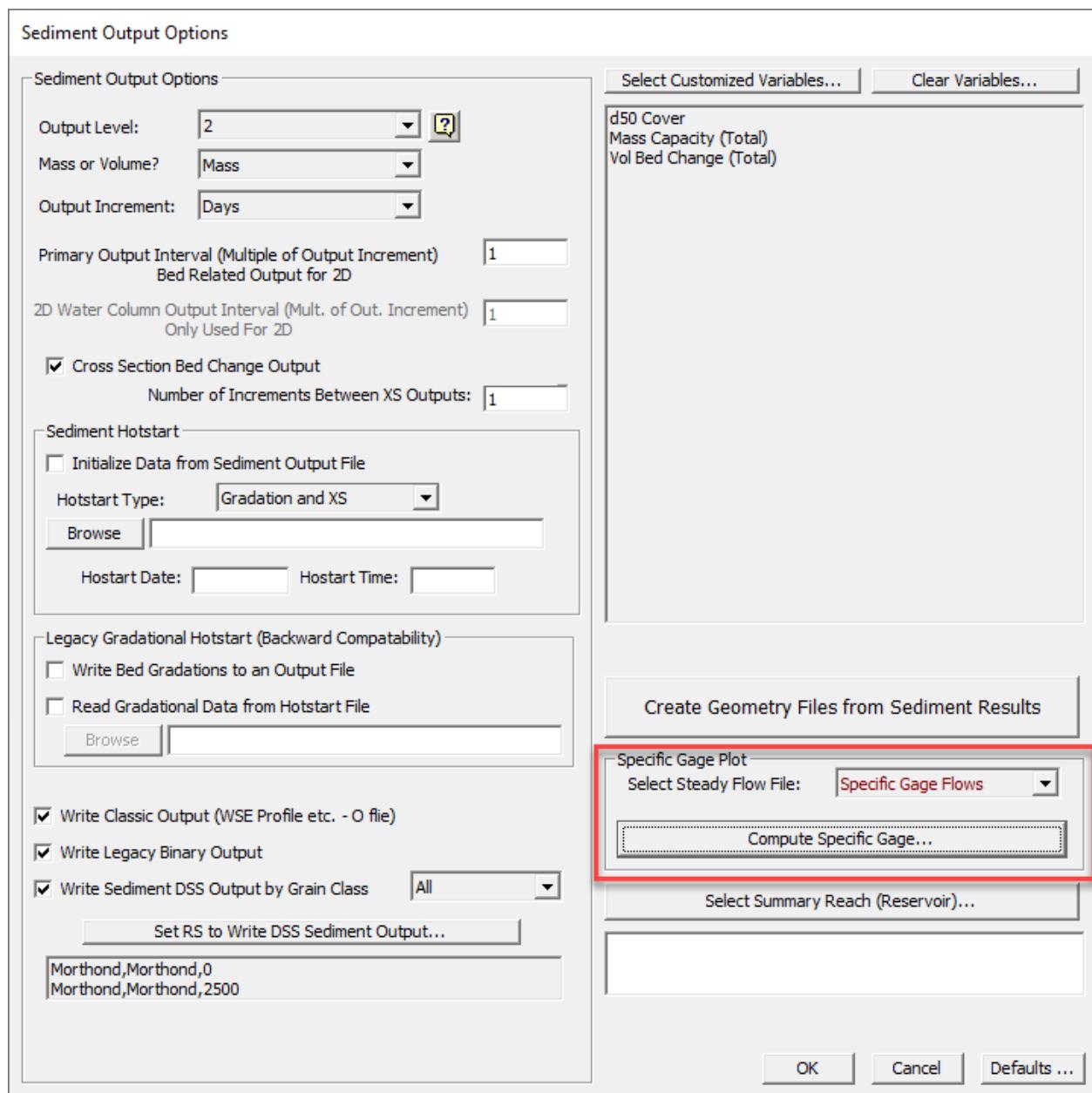
A specific gage analyses can be a useful way to measure and calibrate long term aggradation and degradation in settings with abundant historical water surface elevation data but little bed elevation information. Specific gage analyses tracks the water surface elevations associated with defined flows, to

evaluate historical aggradation or degradation without direct bed elevation evidence (below).





With the Specific Gage capability in HEC-RAS users can compare movable bed simulations to historic specific gage data. The current version of HEC-RAS includes a Specific Gage post-processor which converts mobile bed simulation results into geometry files and then runs repeated steady flow analyses to produce the data required to generate Specific Gage plots. To perform a Specific Gage Analysis elect *Options→Sediment Output Options and Tolerances* in the **Sediment Analysis Window** (below).

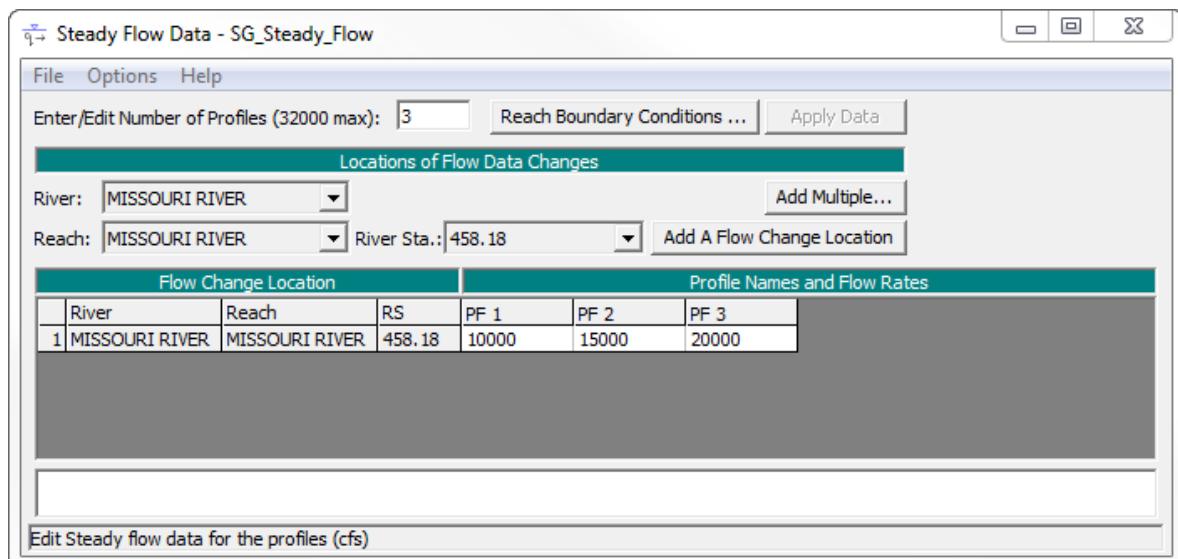


61 Specific Gage Post Processor

The Specific Gage Post processor performs a steady flow analysis with consistent, pre-defined flows, and geometries mined from the HEC-RAS sediment output. At each date and time specified in the **Specific Gage Plot** editor HEC-RAS will:

- Create a new geometry file from the sediment output (updated cross sections) at the output time step closest to that specified in the Specific Gage Plot editor.
- Create a new Steady Flow plan for each selected date by pairing the new geometry with the Steady Flow file selected in the dropdown box.
- Copy the flow file and save the new geometry and plan files in a new project in a new sub-folder.
- Run each steady flow plan.
- Create a table with the water surface elevation at each cross section from each intermediate sediment output geometry for each flow specified in the steady flow editor.

The Specific Gage feature is a Steady Flow post-processor that inherits evolving cross-section data over time, from the sediment output files. It creates a series of dated, steady flow, plans and runs the steady flow engine to compute water surface elevation time series at each cross section. The Specific Gage feature requires a **Steady Flow** file. Therefore, create a **Steady Flow** file and run it with the initial sediment geometry to test it.

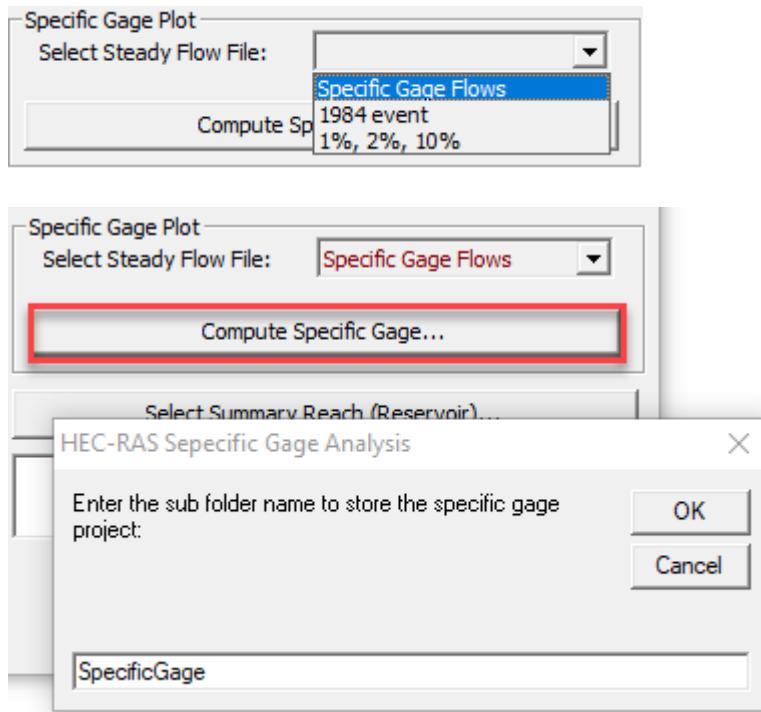


62 Steady flow file built to support the specific gage analysis, selected in the drop down box in the previous figure. The Specific Gage Analysis will perform a steady flow analysis with each of these flows and geometries created from sediment output at each date specified in the previous figure.

The steady flow file should include the flows targeted for water surface elevation trend analysis and must be a complete steady flow file with all of the data required to perform a steady flow analysis with the geometry file used in the sediment transport analysis (e.g. downstream boundary conditions, reservoir elevations, gate settings, etc...).

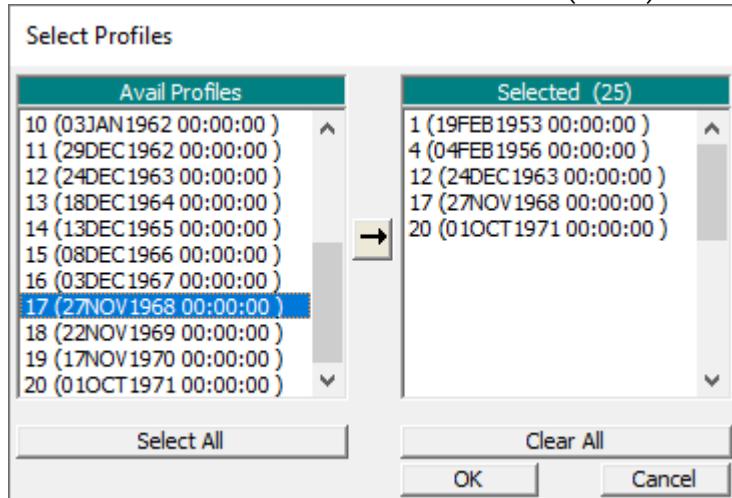
After creating a steady flow file and testing it with a Steady Flow simulation, open the **Sediment Output Options and Tolerances** editor from the **Options** menu of the **Sediment Analysis** dialog (from the original Sediment Analysis project and plan). Select the steady flow file created for the Specific Gage analysis in drop down box as depicted in the figure below. Then press the **Compute Specific Gage** button (below).

HEC-RAS will prompt for an "Analysis Name." The analysis will generate several steady flow files and output, so it creates a sub folder in the project directory with this name. Define the name of the analysis in this dialogue (below) and make sure the name is unique, and not the name of any existing folders.



63 Name the Specific Gage Analysis (which will become the name of the Steady Flow sub-folder).

HEC-RAS will then launch a dialogue with all of the sediment output profiles, named by their simulation dates. Select (double click or press the button) the times that the Specific Gage analysis should evaluate water surface elevations for the constant flows (below).



Then press **OK** to launch the post processor. This will prompt the user for a file name, will generate a new project file in a sub folder (using the name provided), create a geometry file from the sediment output of the active plan at each specified date/time, pair each with the flow file by creating steady flow plans for each, run each steady flow plan. After the analysis the steady flow project, plans, and output exist in the sub folder and can be reviewed or analyzed independently. However, the Specific Gage feature also consolidates the water surface profiles for each flow in the steady flow file for each date in the Specific Gage editor in a table (below) that can be easily translated into Specific Gage plots.

| Specific Gage | | | | | | | | | | | | | | | |
|-------------------------------------|----------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------|-----|-----|--|
| Three Flows at First Requested Time | | | | | | | | | | | | | | | |
| | | | 01Nov1993_0000 | 01Nov1993_0000 | 01Nov1993_0000 | 01Dec1993_0000 | 01Dec1993_0000 | 01Dec1993_0000 | 01Feb1994_0000 | 01Feb1994_0000 | 01Feb1994_0000 | PF1 | PF2 | PF3 | |
| 1 | Missouri | Simplified | 495.07* | 837.4952 | 848.4603 | 834.6731 | 837.4952 | 848.4603 | 834.6731 | 838.0884 | 848.9392 | 835.3204 | | | |
| 2 | Missouri | Simplified | 490.15* | 833.0726 | 844.0357 | 830.2565 | 833.0726 | 844.0357 | 830.2565 | 833.3746 | 844.319 | 830.561 | | | |
| 3 | Missouri | Simplified | 485.22* | 828.6459 | 839.6089 | 825.8288 | 828.6459 | 839.6089 | 825.8288 | 828.92 | 839.8761 | 826.0973 | | | |
| 4 | Missouri | Simplified | 480.30* | 824.2103 | 835.1786 | 821.3929 | 824.2103 | 835.1786 | 821.3929 | 824.4967 | 835.4462 | 821.679 | | | |
| 5 | Missouri | Simplified | 475.37* | 819.7855 | 830.7542 | 816.9642 | 819.7855 | 830.7542 | 816.9642 | 820.049 | 831.0058 | 817.2293 | | | |
| 6 | Missouri | Simplified | 470.44* | 815.3608 | 826.3288 | 812.5427 | 815.3608 | 826.3288 | 812.5427 | 815.6133 | 826.571 | 812.7975 | | | |
| 7 | Missouri | Simplified | 465.52* | 810.9347 | 821.9037 | 808.1137 | 810.9347 | 821.9037 | 808.1137 | 811.1807 | 822.1371 | 808.3608 | | | |
| 8 | Missouri | Simplified | 460.59* | 806.5106 | 817.4786 | 803.6923 | 806.5106 | 817.4786 | 803.6923 | 806.7425 | 817.7014 | 803.9274 | | | |
| 9 | Missouri | Simplified | 455.67* | 802.0847 | 813.0525 | 799.2646 | 802.0847 | 813.0525 | 799.2646 | 802.311 | 813.2681 | 799.4899 | | | |
| 10 | Missouri | Simplified | 450.74* | 797.6582 | 808.6248 | 794.8407 | 797.6582 | 808.6248 | 794.8407 | 797.8782 | 808.8359 | 795.0627 | | | |
| 11 | Missouri | Simplified | 445.81* | 793.2286 | 804.1975 | 790.4092 | 793.2286 | 804.1975 | 790.4092 | 793.4388 | 804.3989 | 790.6279 | | | |
| 12 | Missouri | Simplified | 440.89* | 788.8036 | 799.7729 | 785.9846 | 788.8036 | 799.7729 | 785.9846 | 789.0072 | 799.9664 | 786.1919 | | | |
| 13 | Missouri | Simplified | 435.96* | 784.3788 | 795.3483 | 781.5581 | 784.3788 | 795.3483 | 781.5581 | 784.5707 | 795.533 | 781.7506 | | | |
| 14 | Missouri | Simplified | 431.04* | 779.9548 | 790.9236 | 777.1361 | 779.9548 | 790.9236 | 777.1361 | 780.1409 | 791.1037 | 777.3248 | | | |
| 15 | Missouri | Simplified | 426.11* | 775.5295 | 786.4979 | 772.7097 | 775.5295 | 786.4979 | 772.7097 | 775.7111 | 786.6747 | 772.8901 | | | |
| 16 | Missouri | Simplified | 421.19* | 771.1032 | 782.071 | 768.2853 | 771.1032 | 782.071 | 768.2853 | 771.2831 | 782.2445 | 768.4677 | | | |
| 17 | Missouri | Simplified | 416.26* | 766.675 | 777.6451 | 763.8554 | 766.675 | 777.6451 | 763.8554 | 766.8498 | 777.8138 | 764.0298 | | | |

Clipboard | Print ... | File ... | Close

64 Specific Gage summary output including stages for three flows at three dates.

| Specific Gage | | | | | | | | | | | | | | | | |
|---------------|----------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------|----------|-----|-----|--|
| | | | 01Oct1994_0000 | 01Oct1995_0000 | 01Oct1996_0000 | 01Oct1997_0000 | 01Oct1998_0000 | 01Oct1999_0000 | 01Oct2000_0000 | 01Oct2001_0000 | 01Oct2002_0000 | 01Oct2003 | PF1 | PF2 | PF3 | |
| 78 | Missouri | Simplified | 129.00 | 520.919 | 521.2371 | 521.3805 | 521.6473 | 521.8589 | 522.0834 | 522.1553 | 522.2974 | 522.1979 | 522.2268 | | | |
| 79 | Missouri | Simplified | 124.04* | 516.2335 | 516.6115 | 516.7928 | 517.0782 | 517.2424 | 517.5346 | 517.5801 | 517.7468 | 517.7549 | 517.7545 | | | |
| 80 | Missouri | Simplified | 119.08* | 511.6375 | 511.9109 | 512.1819 | 512.452 | 512.6892 | 512.975 | 513.0438 | 513.1551 | 513.2494 | 513.301 | | | |
| 81 | Missouri | Simplified | 114.12* | 507.1217 | 507.2805 | 507.5514 | 507.8943 | 508.1066 | 508.429 | 508.4649 | 508.6244 | 508.6709 | 508.7437 | | | |
| 82 | Missouri | Simplified | 109.15* | 502.6869 | 502.7625 | 502.9347 | 503.3242 | 503.5598 | 503.86 | 503.9336 | 504.0643 | 504.1238 | 504.1739 | | | |
| 83 | Missouri | Simplified | 104.19* | 498.2323 | 498.3192 | 498.4326 | 498.7189 | 499.007 | 499.3329 | 499.3835 | 499.5271 | 499.5907 | 499.6194 | | | |
| 84 | Missouri | Simplified | 99.23* | 493.7862 | 493.8632 | 493.9739 | 494.1877 | 494.4086 | 494.7838 | 494.8491 | 495.0164 | 495.0401 | 495.0981 | | | |
| 85 | Missouri | Simplified | 94.27* | 489.3253 | 489.4111 | 489.5364 | 489.7441 | 489.9051 | 490.1981 | 490.3058 | 490.4773 | 490.5358 | 490.5644 | | | |
| 86 | Missouri | Simplified | 89.31* | 484.8561 | 484.9583 | 485.0704 | 485.2973 | 485.4509 | 485.6866 | 485.7464 | 485.9147 | 485.9962 | 486.0381 | | | |
| 87 | Missouri | Simplified | 84.35* | 480.4339 | 480.4999 | 480.6342 | 480.8404 | 481.0114 | 481.2404 | 481.2881 | 481.3714 | 481.436 | 481.5092 | | | |
| 88 | Missouri | Simplified | 79.38* | 475.9586 | 476.0463 | 476.1696 | 476.3934 | 476.541 | 476.7968 | 476.8262 | 476.9263 | 476.9344 | 476.9775 | | | |
| 89 | Missouri | Simplified | 74.42* | 471.4996 | 471.5824 | 471.7211 | 471.9263 | 472.1024 | 472.3299 | 472.3791 | 472.4789 | 472.4929 | 472.5361 | | | |

Clipboard | Print ... | File ... | Close

65 Specific Gage summary output including stages for one flow at the beginning of each water year.

| Modeling Note: Other Uses for the Specific Gage Feature | | | | | | | | | | | | | | |
|---|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
| Modeling Note: I press OK and nothing happens | | | | | | | | | | | | | | |
| Make sure a sediment plan with simulation results is open and is the active plan. | | | | | | | | | | | | | | |

Wish List: Alternate (easier) specific gage analysis tool

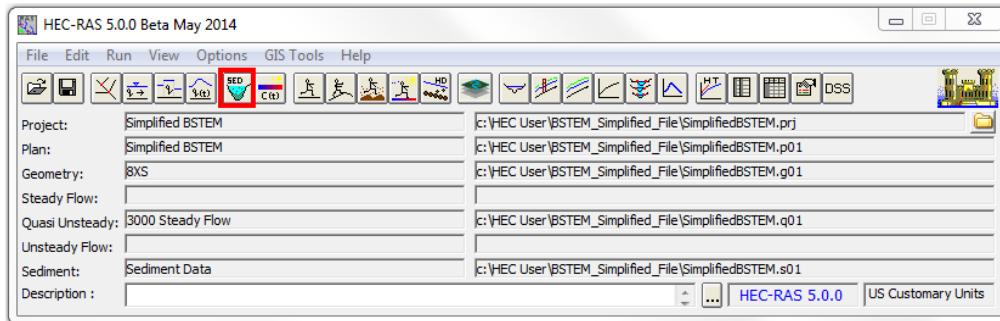
Another way to analyze specific gage results would involve plotting computed stages within user-specified flow ranges (potentially, with observed data) in the Sediment Plotter.

1.5 BSTEM - User's Manual

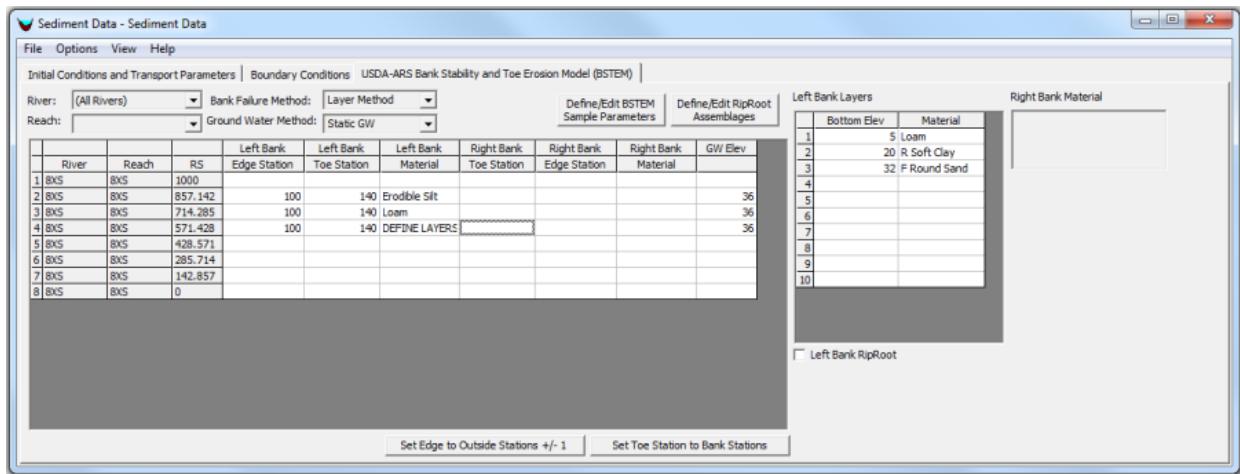
Getting Started

BSTEM toe erosion and bank failure analysis will be performed as part of a sediment transport analysis on any cross section bank that has all the necessary parameters. Computing bank failure at every bank will increase run times. Therefore, it may be advantageous to only specify BSTEM parameters for banks that have a probability of failure.

To enter BSTEM data in HEC-RAS, from the HEC-RAS main Window, from the Toolbar, click Sediment Boundary Conditions (below). Bank failure analysis is currently only computed as part of a sediment transport analysis. The Sediment Data Editor will open (bottom). From the Sediment Data Editor the user will enter standard sediment transport data on the first two tabs (bottom). To enter BSTEM information, click the USDA-ARS Bank Stability & Toe Erosions MODEL (BSTEM) tab (bottom).



66 HEC-RAS Window.



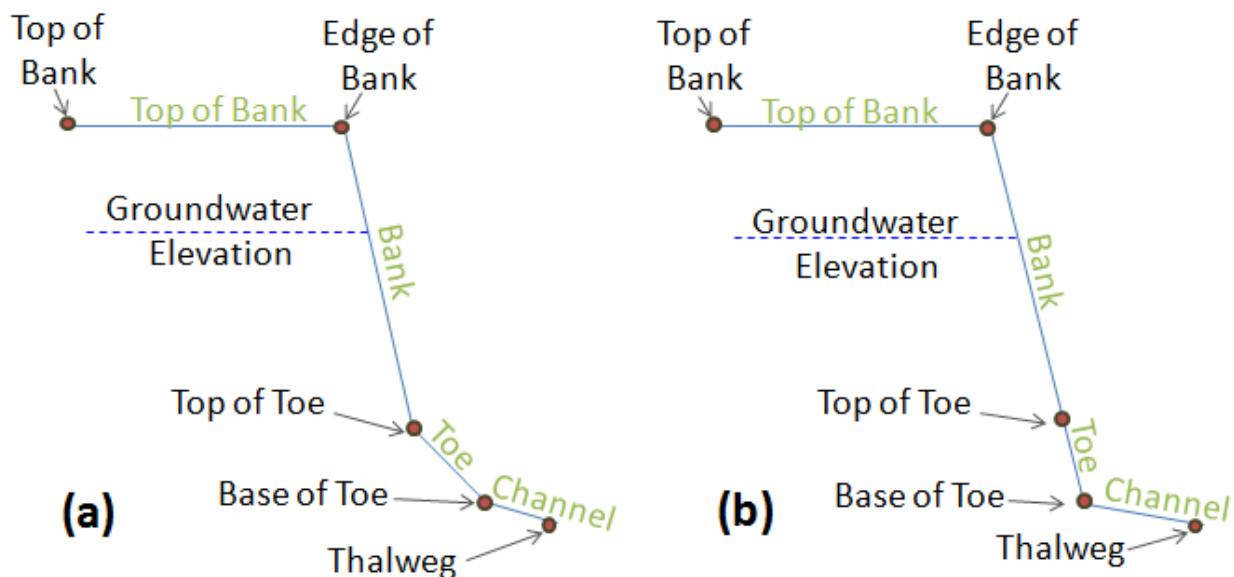
67 HEC-RAS Sediment Data Editor - USDA-ARS BSTEM Tab.

- Defining Cross Section Configuration (see page 225)
 - Left Bank Edge Station_ (see page 227)
 - Right Bank Edge Station_ (see page 227)
 - Left Bank Toe Station_ (see page 227)
 - Right Bank Toe Station_ (see page 227)
 - GW Elev_ (see page 228)
- Defining Cross Section Materials (see page 228)
 - Left or Right Bank Material_ (see page 228)
 - 1. Selecting Pre-Defined Default Parameters (see page 228)
 - 2. Select a Single Set of User Defined Material Parameters for a Bank (see page 230)
 - 3. Define Separate Parameters for Multiple Layers for Each Cross Sections (see page 235)
- USDA-ARS BSTEM Options (see page 237)
 - Number of Failure Plane Computation Nodes (see page 238)
 - Number of Time Steps Between Failure Computations (see page 238)
 - Grain Shear Correction (see page 238)
 - Minimum Percent Cohesive to Use Toe Scour Algorithms (see page 238)
- Transport Function (BSTEM) (see page 239)
- Toe Scour Mixing Method (see page 239)
- Output (see page 240)
- Model Validation (see page 247)
- BSTME Modeling Guidelines, Tips, and Troubleshooting (see page 248)
 - Stepwise Modeling Process (see page 249)
 - Selecting a Toe (see page 249)
 - Monotonic Bank Geometry (see page 250)
 - Floodplain Geometry (see page 250)

- Too Much Scour (see page 251)
- Common Runtime Error Messages (see page 252)
- Unusual Cross Section Shape (see page 253)
- Groundwater Table (see page 254)
- Scour Outside of a Bend (see page 254)
- References (see page 255)
- Scour Units (see page 256)
- SI Table (see page 258)
- Acknowledgements (see page 258)

1.5.1 Defining Cross Section Configuration

Setting up HEC-RAS cross sections (for the left or right bank) in such a way that it is also compatible with BSTEM is an extremely important step in getting physically appropriate failures from the BSTEM computations. The conceptual BSTEM half cross section (below) is composed of four segments (green labels in the figure below) with unique slopes:

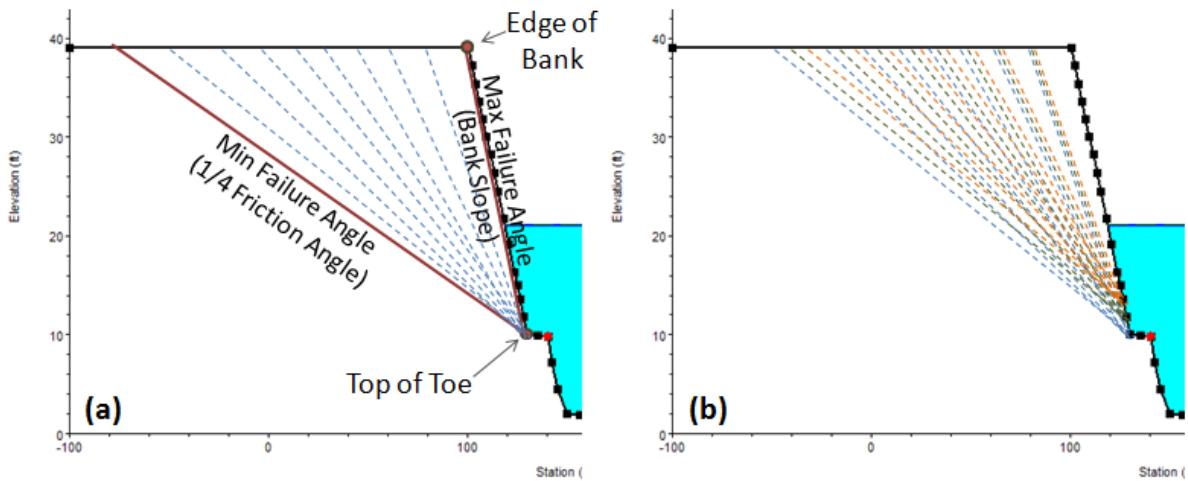


68 Definition of station points for BSTEM half cross sections

1. The **Top of Bank** which is the relatively flat portion of the cross section above the bank.
2. The **Bank** which is the steepest part of the cross section.
3. The **Toe** which is a mild slope between the bank and the channel, presumably composed of blocks of material that have fallen and accumulated at the base of the bank and are protecting the toe or some sort of rip rap or toe protection.
4. The **Channel** which is the region between the toe and the thalweg.

HEC-RAS divides a cross section at the thalweg and uses the station-elevation points to the left of the thalweg for the left BSTEM half-cross section and those to the right of the thalweg for the right BSTEM geometry. There are at least four important current considerations for setting up an HEC-RAS cross section to get good performance from the BSTEM routines.

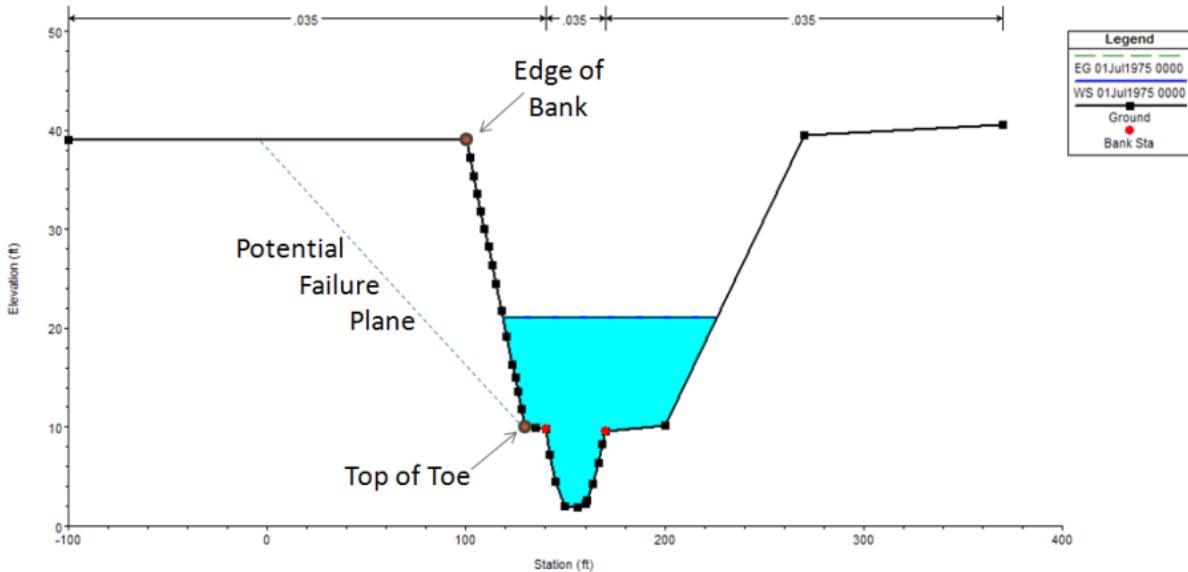
1. The **Top of Bank** point should be far enough to the left or right (depending on which bank is being modeled) of the **Edge of Bank** to accommodate the full range of possible failure slopes (below).
2. HEC-RAS 5.0 with BSTEM works best if the **Top of Bank** is not the farthest node to the left or right and if there are no station-elevation points between the **Top of Bank** and the **Edge of Bank**.
3. There should be a number of relatively evenly spaced points between the **Edge of Bank** and the **Top of Toe**. BSTEM starts its failure plane search method at each station.



4. Elevation point between the **Edge of Bank** and the **Top of Toe** (below). The spacing of nodes between these points will affect the precision of the failure plane computations.
5. HEC-RAS will automatically select the lowest station-elevation point in the cross section to be the **Thalweg**.

Each bank of each cross section being analyzed requires two user defined points, an **Edge of Bank Station** and a **Top of Toe Station**. Note that these points are defined by their station across the cross section, not their elevation. These points are depicted in [Unusual Cross Section Shape](#) (see page 253) and are entered on

the HEC-RAS Sediment Data Editor below and are defined in the following.



1.5.1.1 Left Bank Edge Station_

This should be the inflection point between the bank and the top of the bank. All failure planes considered will intersect the top of bank between the edge of bank and the first cross section station-elevation point.

1.5.1.2 Right Bank Edge Station_

Analogous to the Left Bank Edge station, this should be the inflection point between the bank and the top of the bank on the left side of the cross section. All failure planes considered will intersect the top of bank between the edge of bank and the last cross section station-elevation point

1.5.1.3 Left Bank Toe Station_

BSTEM divides the bank into two sections, the Bank and the Toe (see figures in [Defining Cross Section Configuration \(see page 225\)](#)) sections. Conceptually, the toe is material composed of blocks of failed material or engineered toe protection. Therefore, failure planes are only computed through the bank surface above the **Top of Toe**. The **Top of Toe** often corresponds to a break in slope or material type but it does not have to. In future versions of BSTEM, users will be able to select a separate material type for the toe but in the first alpha version of BSTEM, the software adopts the material type of the bank or layer associated with the toe. This parameter can be automatically set to the HEC-RAS left bank station for every cross section that has **Left Bank Material** defined. From the [HEC-RAS Sediment Data Editor \(see page 223\)](#) (bottom figure in link), click **Set Toe Station to Bank Stations** and click the **Set Toe Stations to Movable Bed Stations** (movable bed limits). Setting movable bed limits and toe stations at the same node is recommended.

1.5.1.4 Right Bank Toe Station_

The **Right Bank Toe** is analogous to the **Left Bank Toe** section and can be set to the right bank station for every bank that has **Right Bank Material** defined. From the [HEC-RAS Sediment Data Editor \(see page 223\)](#)

(bottom figure of link), click **Set Toe Station to Bank Stations** and click the **Set Toe Stations to Movable Bed Stations** (movable bed limits). Setting movable bed limits and toe stations at the same node is recommended.

1.5.1.5 GW Elev_

In order to compute bank failure on either side of any cross section a **Groundwater Elevation** must be specified. Results will be very sensitive to this parameter. BSTEM does not yet have a physical limit to negative pore water pressure so a very low groundwater table could generate nearly infinite bank stability.

If the static groundwater option is selected, BSTEM will use this groundwater elevation for the entire cross section simulation. If the dynamic groundwater option is selected, the user specified groundwater elevation will become the initial elevation, and groundwater will rise and fall in response to the hydraulic conductivity. The overbank is modeled as a "reservoir" with a volume determined by the distance between cross sections and the user specified "Reservoir Width" parameter in the BSTEM material parameters, which the model moves between the groundwater reservoir and the channel at the rate of the user specified saturated hydraulic conductivity.

1.5.2 Defining Cross Section Materials

To define cross section materials for BSTEM, the user will enter information from the [HEC-RAS Sediment Data Editor](#) (see page 223) (bottom figure of link) from the BSTEM tab:

- [Left or Right Bank Material_](#) (see page 228)
 - [1. Selecting Pre-Defined Default Parameters](#) (see page 228)
 - [2. Select a Single Set of User Defined Material Parameters for a Bank](#) (see page 230)
 - [3. Define Separate Parameters for Multiple Layers for Each Cross Sections](#) (see page 235)

1.5.2.1 Left or Right Bank Material_

HEC-RAS requires at least one set of material properties to be specified for each bank it performs bank failure analysis on. Three levels of detail are available for specifying this parameter including:

1. [Selecting Pre-Defined Default Parameters](#) (see page 228)
2. [Select a Single Set of User Defined Material Parameters for a Bank](#) (see page 230)
3. [Define Layers of Unique Material at a Bank](#) (see page 235)

The material specification approach is bank-specific, so different approaches can be used for different banks within the same model.

1.5.2.1.1 1. Selecting Pre-Defined Default Parameters

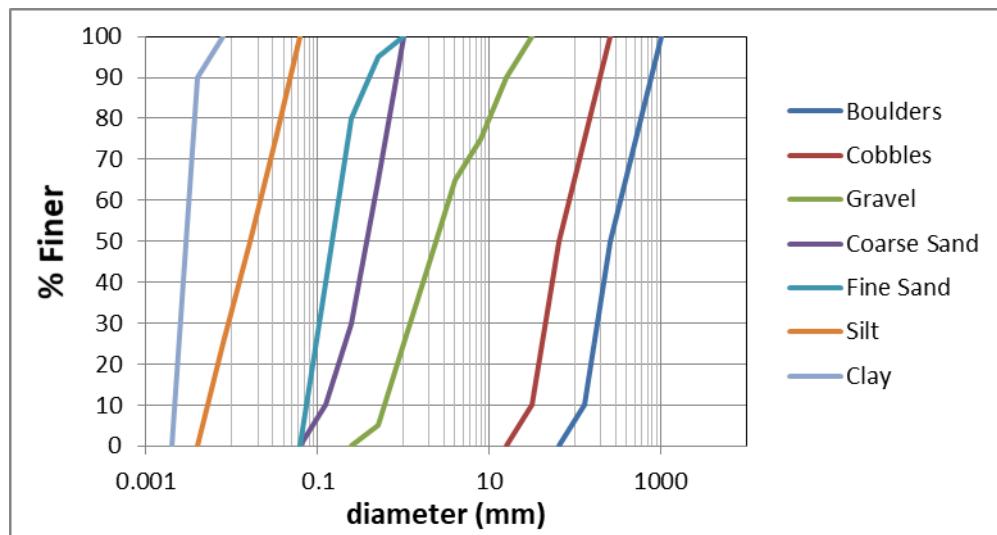
The standalone version of BSTEM includes sixteen default material types that are also included in HEC-RAS. These default material types are each populated with characteristic soil properties distilled from a database of field data collected by the USDA-ARS. The unit weight, friction angle (ϕ'), cohesion, Φ^b , critical shear stress (τ_c), and erodibility are listed in Table 2 below (SI parameters are included at the end of the document). See the description of these parameters in the next section (Soil Strength Parameters).

Table 2. Default materials and material parameters

| Default Material Type | Saturated Unit Weight (lbf/ft ³) | Friction Angle (°) | Cohesion (lb/ft ²) | ° | Critical Shear (lb/ft ²) | Erodibility (ft ³ /lbf-s) |
|-----------------------|--|-------------------------------------|--------------------------------|------------------|--------------------------------------|--------------------------------------|
| Boulders | 127.3 | 42.0 | 0 | 15 | 10.4 | 2.85E-05 |
| Cobbles | 127.3 | 42.0 | 0 | 15 | 2.59 | 5.73E-05 |
| Gravel | 127.3 | 36.0 | 0 | 15 | 0.23 | 1.92E-04 |
| Coarse Angular Sand | 117.8 | 32.3 | 8.354 | 15 | 0.0106 | 8.95E-04 |
| Course Round Sand | 117.8 | 28.3 | 8.354 | 15 | 0.0106 | 8.95E-04 |
| Fine Angular Sand | 117.8 | 32.3 | 8.354 | 15 | 0.00267 | 8.95E-04 |
| Fine Round Sand | 117.8 | 28.3 | 8.354 | 15 | 0.00267 | 8.95E-04 |
| Erodible Silt | 114.6 | 26.6 | 89.81 | 15 | 0.00209 | 2.01E-03 |
| Moderate Silt | 114.6 | 26.6 | 89.81 | 15 | 0.1044 | 2.86E-04 |
| Resistant Silt | 114.6 | 26.6 | 89.81 | 15 | 1.0443 | 8.91E-05 |
| Erodible Soft Clay | 112.7 | 26.4 | 171.26 | 15 | 0.00209 | 2.01E-03 |
| Moderate Soft Clay | 112.7 | 26.4 | 171.26 | 15 | 0.1044 | 2.86E-04 |
| Resistant Soft Clay | 112.7 | 26.4 | 171.26 | 15 | 1.0443 | 2.01E-03 |
| Erodible Stiff Clay | 112.7 | 21.1 | 263.16 | 15 | 14.6 | 2.01E-03 |
| Moderate Stiff Clay | 112.7 | 21.1 | 263.16 | 15 | 0.1044 | 2.86E-04 |
| Resistant Stiff Clay | 112.7 | 21.1 | 263.16 | 15 | 1.0443 | 2.01E-03 |

It is worth noting, however, that these parameters are extremely site specific, and the default parameters are central tendencies of very noisy data sets, particularly for cohesive material types. Therefore, default parameters will often generate substantial errors.

Coupling these bank failure algorithms with the mass balance computations in the mobile bed capabilities in HEC-RAS introduced one additional parameter requirement. Any mass that "fails" into the channel requires a gradation so HEC-RAS can partition it into grain classes for transport. Therefore, idealized gradations were selected for each material type based on their description. These gradations are depicted in the figure below.

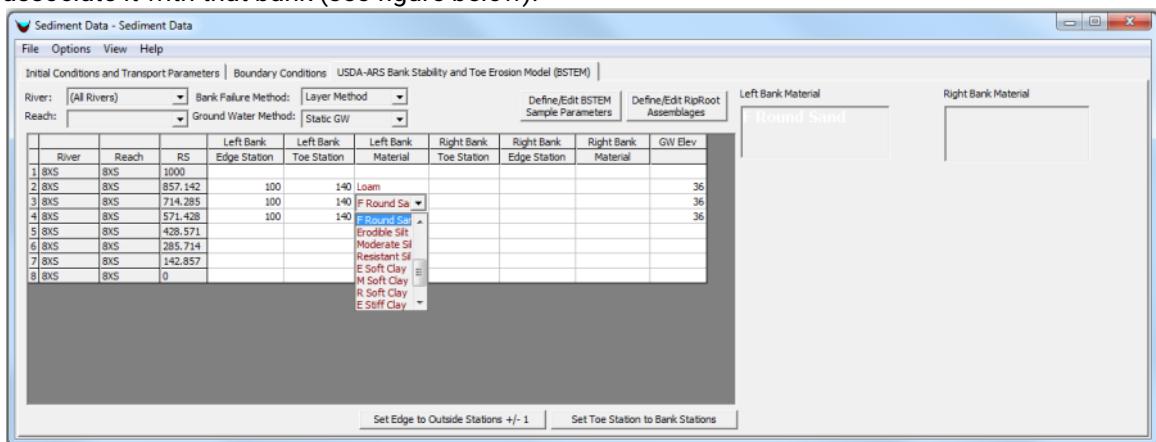


69 Idealized gradations selected for the default material types.

Modeling Note/Warning

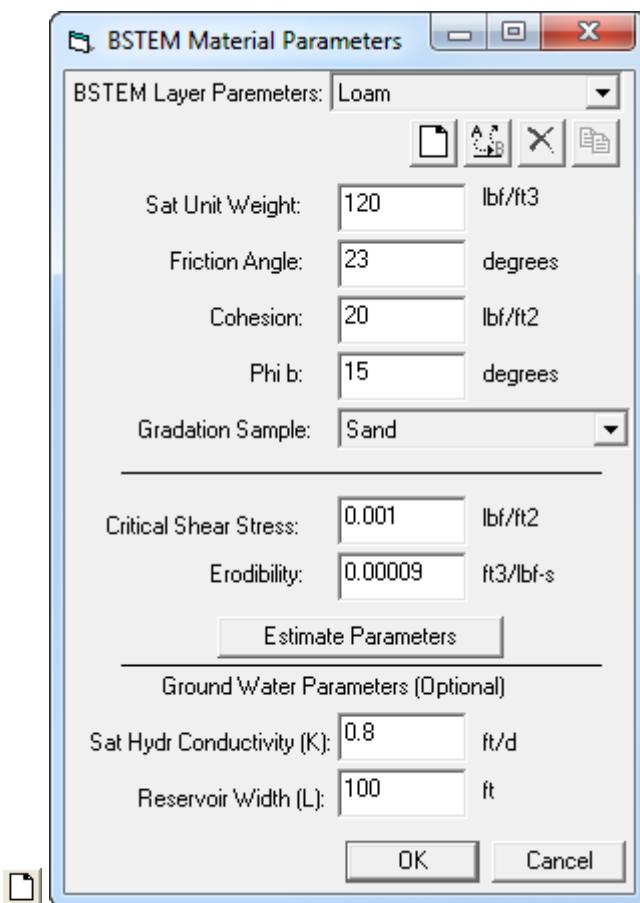
Models constructed without direct erodibility measurements or calibration data are speculative. Additionally, using default sand materials or coarser will invoke the cohesionless scour methods, which are based on transport functions and tend to over-predict scour. Interpret default material results carefully.

In order to select one of the default material types, from the table on the **Sediment Data Editor, BSTEM Tab** (see bottom figure [here \(see page 223\)](#)), from the columns labeled **Left Bank Material** or **Right Bank Material** click at the cross section of interest. A list of default material types that are available will appear as in the figure below. Ignore the option "**DEFINE LAYERS**", from the list and select the desired material type and it will associate it with that bank (see figure below).



1.5.2.1.2 2. Select a Single Set of User Defined Material Parameters for a Bank

Because of the inherent variability of these parameters, site specific measurements are recommended. If data is available, customized material types can be associated with a bank. This is analogous to the process for defining sediment gradations in the **Initial Conditions and Transport Parameters Tab** of the **Sediment Data Editor**, where gradation records are defined and then associated with the appropriate cross section.



Before selecting customized materials a user must define the materials by clicking **Define/Edit BSTEM Sample Parameters**. The **BSTEM Material Parameters Editor** will open (above). To create a new BSTEM material, click **New Record** and specify the name. HEC-RAS will reject any names that are identical to existing or default material names. Five mandatory intrinsic soil strength parameters (used to compute the failure plane and factor of safety), two mandatory erodibility parameters (used to compute toe scour) and one optional parameter can then be entered.

1.5.2.1.2.1 Soil Strength Parameters

The first five parameters are intrinsic soil strength parameters and are associated with the computation of a critical failure plane and the FS associated with that failure plane. These five parameters emerge from classical geotechnical measurements that most soils labs would be able to handle. HEC-RAS uses four user defined parameters with hydrodynamic and geometric data to compute a factor of safety for a range of possible failure planes by computing the ratio of the resisting forces to the driving forces: cohesion (c'), saturated unit weight (W), the angle of internal friction (Φ'), and the angle representing the relationship between shear matrix suction and apparent cohesion (Φ^b). These four user defined parameters are entered in the **BSTEM Material Parameters Editor** (above) and are described below.

1.5.2.1.2.2 Unit Weight:

This is the *saturated unit weight*⁷ (combined weight of the solids and water of the soil when saturated). Note that this is different than the unit weight used elsewhere in HEC-RAS sediment transport computations. The

unit weight used elsewhere in HEC-RAS sediment transport computations is the mass of the solids per unit volume.

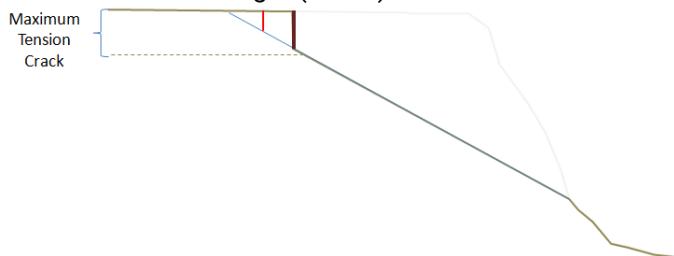
Friction Angle (Φ):

The friction angle is a classic geotechnical parameter that is a measurement of the soil strength that quantifies the friction shear resistance of soil. The "angle" of the "friction angle" is derived from the Mohr-Coulomb failure criterion and is the angle of inclination in the classical Mohr diagram. The angle of inclination is a theoretical angle⁸ used to compute soil strength and should not be confused with physically intuitive angles like the angle of repose. This also is not the minimum angle of the failure plane. In cases where groundwater elevation is higher than the water surface elevation the bank can lose frictional strength and be left only with cohesion, allowing for a shallower failure plane angle. The friction angle can be determined by collecting "undisturbed" cores for tri-axial testing in a soils laboratory or it can be measured *in situ* with a borehole shear test. The Iowa Borehole Shear device (Thorne, 1981) is a hand held instrument that is commonly used to collect this parameter from hand augured eight centimeter boreholes for BSTEM studies.

Cohesion:

Cohesion is the attractive force of particles in a soil mixture, usually as a result of electrochemical or biological bonding forces. These forces increase the strength of a soil matrix. Cohesion is generally a minor consideration in granular soils but can account for a substantial amount of soil strength in cohesive materials. Cohesion is computed from the same data as the friction angle and, therefore, must be measured either by tri-axial laboratory tests or *in situ* borehole shear measurements.

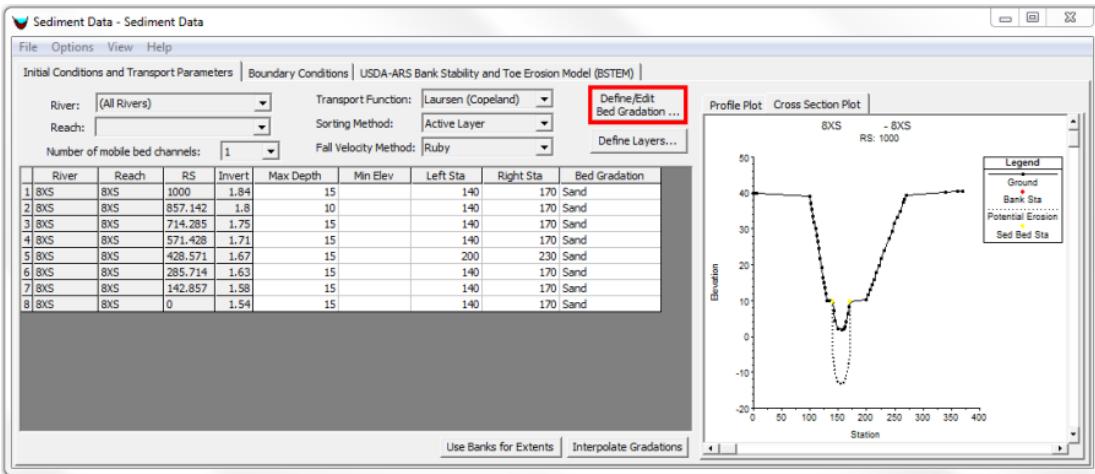
Phi b (Φ^b): As soil drains, capillary tension induce negative pore water pressure or matrix suction. Suction resists bank failure and increases the shear strength of the soil matrix. In the bank failure algorithms, suction is quantified as an "apparent" cohesion" or the equivalent increase in cohesion required to generate the same increase in shear strength (below).



Φ^b is a function of soil moisture and maximizes at the friction angle (Φ') at saturation. For most materials Φ^b is generally between ten to thirty degrees depending on soil type. Φ^b is very difficult to go out and fundamentally measure Φ^b . Φ^b has been measured a handful of times in research settings. Most applications start between ten and fifteen degrees but Φ^b goes to a maximum of the friction angle when the material is saturated (Fredlund, 1986). Because of the estimated nature of this parameter it can be used as a calibration factor.

Gradation Sample:

HEC-RAS requires a fifth bank material parameter that is required but not used until after the failure calculation. In order to partition any failed material into grain classes for transport by the sediment transport model, the bank material has to have a bed gradation associated with it. Bed gradations are defined by clicking **Define/Edit Bed Gradation** from the **Initial Conditions and Transport Parameters** Tab of the **HEC-RAS Sediment Data Editor** (below).



Any gradations defined here become automatically available in the **Gradation Sample** list on the **BSTEM Material Parameter Editor** (*BSTEM Material Parameters Editor*).

1.5.2.1.2.3 Erodibility Parameters

The second set of parameters on the **BSTEM Material Parameters Editor** (top) are the erodibility parameters. These parameters are specialized for bank failure analysis. Erodibility parameters are measurements of the erodibility of the soils in response to hydrodynamic forcing. Standard soil testing laboratories are not likely to have the capabilities to collect these parameters. However, the USACE Coastal and Hydraulic Lab (ERDC-CHL), other federal agencies, and several universities can quantify these parameters. Bank jet tests (Hanson, 1990) and SEDFLUME laboratory tests (Braud et al., 2001, Smith et al., 2010) are the best ways to estimate these parameters.

Critical Shear Stress: Critical shear stress is when the bank begins to scour.

Erodibility: The rate of sediment removal in response to a unit shear stress.

In the absence of these parameters Simon et al., 2000 summarized their database of cohesionless measurements to find a relationship between critical shear stress and erodibility:

$$E = 1.42\tau_c^{-0.824}$$

This relationship is based on the regression depicted in the figure below which includes a great deal of scatter in log space. This underscores the variable and site specific nature of these parameters, therefore local measurement of these parameters is highly recommended. Also note that this relationship does not account for cohesion and, therefore, should not be used for cohesive soils.

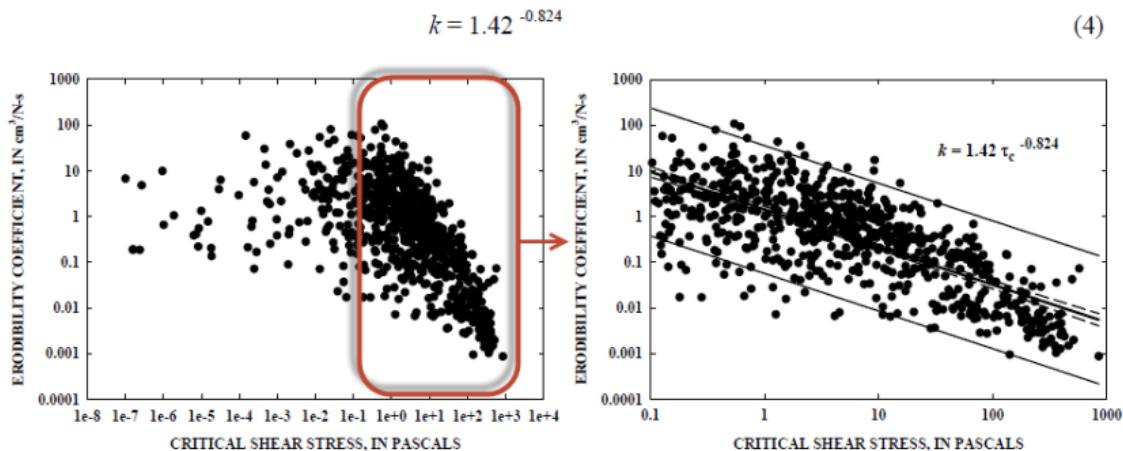


Figure 4 Data spread between τ_c and k based on 822 tests using the original (Hanson, 1990) jet-test device (left), and resulting regression relation for condition where $\tau_c \geq 0.10$ Pa (702 tests) (right). Dashed lines represent 95% confidence limits and the outer, solid lines represent 95% prediction limits.

70 Relationship between erodibility and critical shear stress from Simon et al. (2000).

1.5.2.1.2.4 Groundwater Parameters (Optional)

Groundwater parameters are optional and are only used if the dynamic groundwater option is selected in the BSTEM section of HEC-RAS. There are two parameters that determine the rate that water can drain from or infiltrate into a bank. In turn, this determines the lag between the rising or falling of groundwater elevation with respect to the water surface elevation.

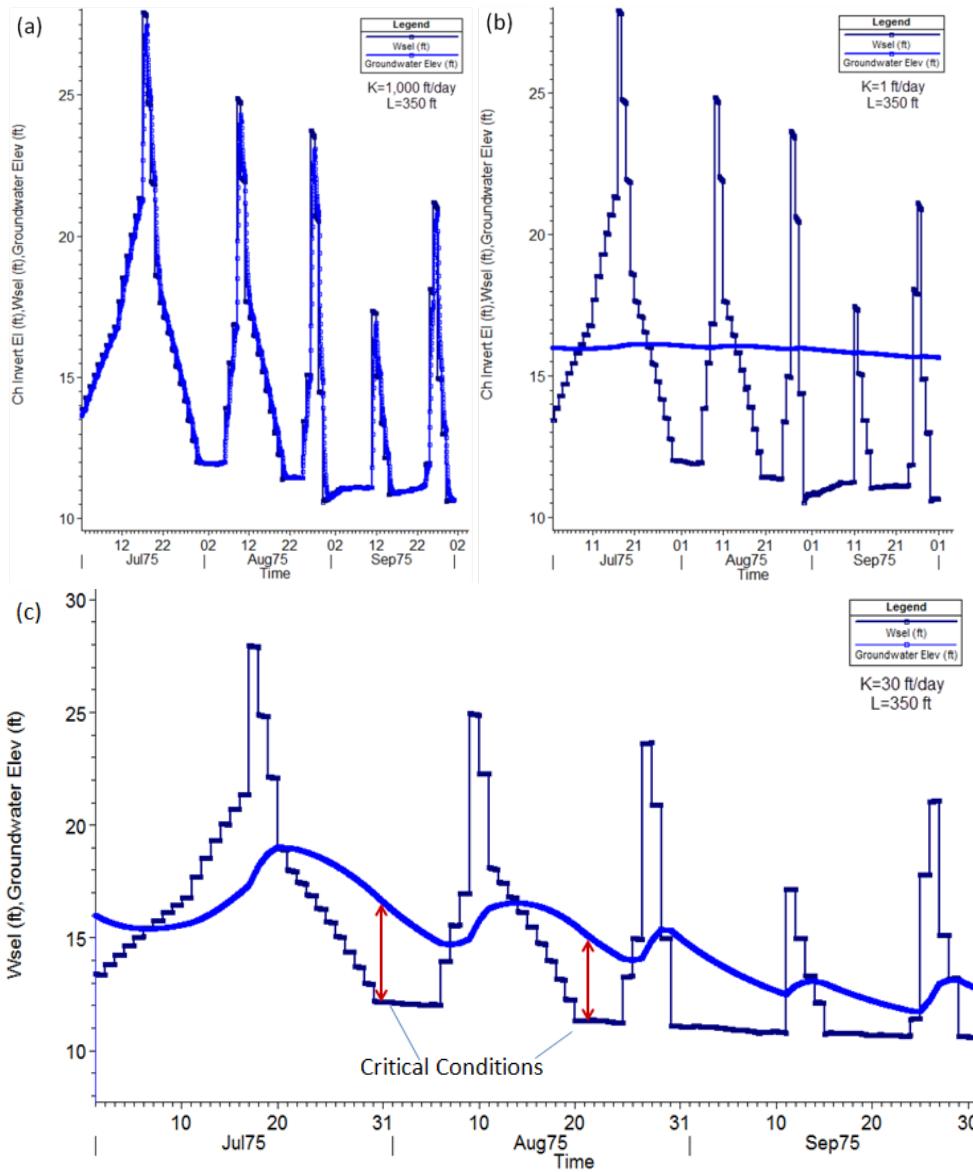
Hydraulic Conductivity:

Is the standard Darcy "K" parameter used in groundwater modeling. The hydraulic conductivity is a linear parameter that determines velocity of groundwater proportional to a gradient. Hydraulic conductivity can be measured with field or laboratory tests but is also often documented in regional literature or estimated by expert intuition (analogous 'o Manning's n).

Reservoir Length:

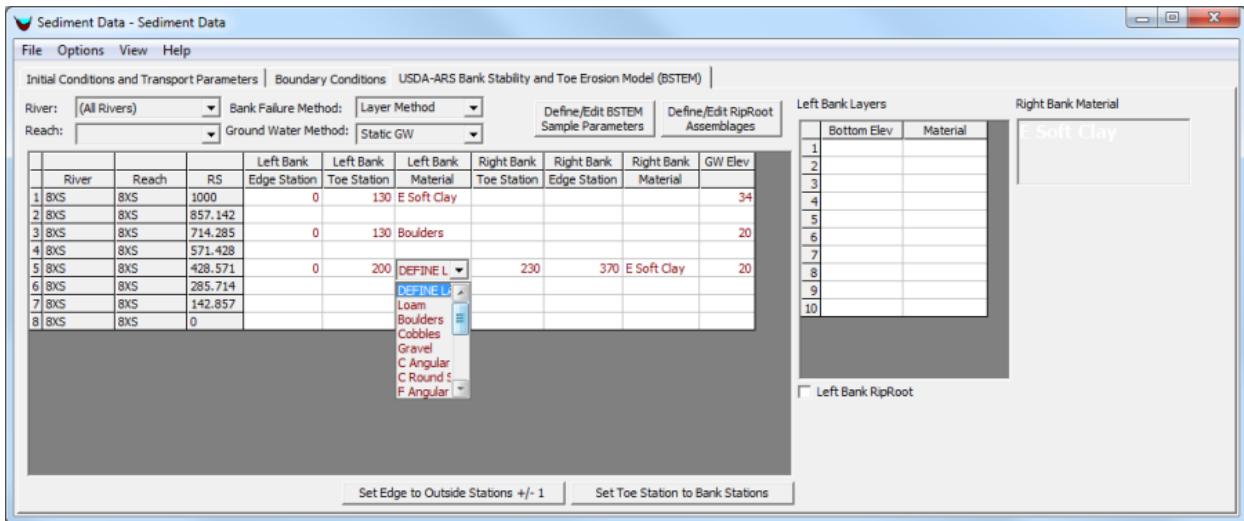
Groundwater dynamics follows a simple reservoir routing model that assumes the banks store water. Water can be added to or drained from the rate of the saturated hydraulic conductivity. The "length" of this reservoir is the bank thickness (perpendicular to the river) that contributes water to the river on pertinent time scales.

If the soils are very permeable or the reservoir is small (high K or low L) the groundwater elevation will track the channel water surface elevation (figure a below). If the soils are impermeable or the reservoir is very large, the groundwater will not respond much to flow depth in the channel (figure b below). However, intermediate hydraulic conductivities will introduce a lag between channel water surfaces and groundwater elevation (figure c below). Because groundwater elevations higher than the confining water surface elevation are the critical condition, groundwater lag can induce failures on the falling limb of the hydrograph, both in the field and in the model.



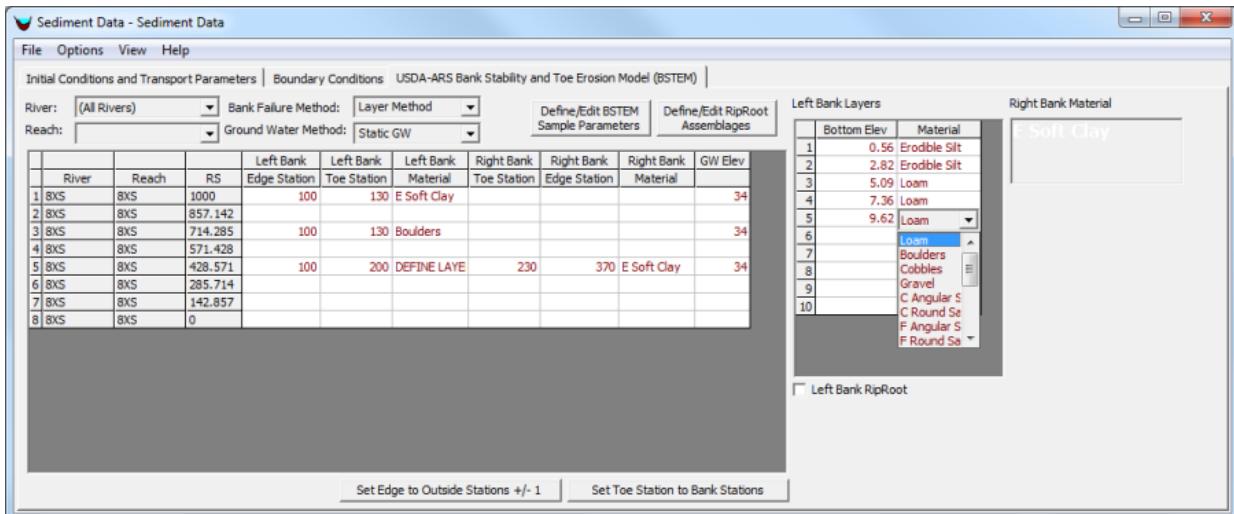
1.5.2.1.3 3. Define Separate Parameters for Multiple Layers for Each Cross Sections

Finally, it is often advantageous to define several bank material layers. Some banks have distinct stratigraphy, stacking soil layers. Sometimes vegetation is modeled by introducing a surface layer with the same friction angle as the parent material but with a higher cohesion. To specify layers, select **Define Layers**, from the **Left/Right Bank Material** lists available in the **HEC-RAS Sediment Data Editor** (below). If the **Define Layers** option is selected, a new table will appear on the right side of the editor (below).



71 Selecting the layer mode for a bank failure.

The bank material layer table requires two parameters: a bottom elevation and a material. Each layer exists between its own bottom elevation and the bottom elevation of the higher layer. The top layer will extend from the highest point on the half-cross section to the highest specified **Bottom Elevation**. (Note - in the current version bottom elevations MUST be entered from low to high).

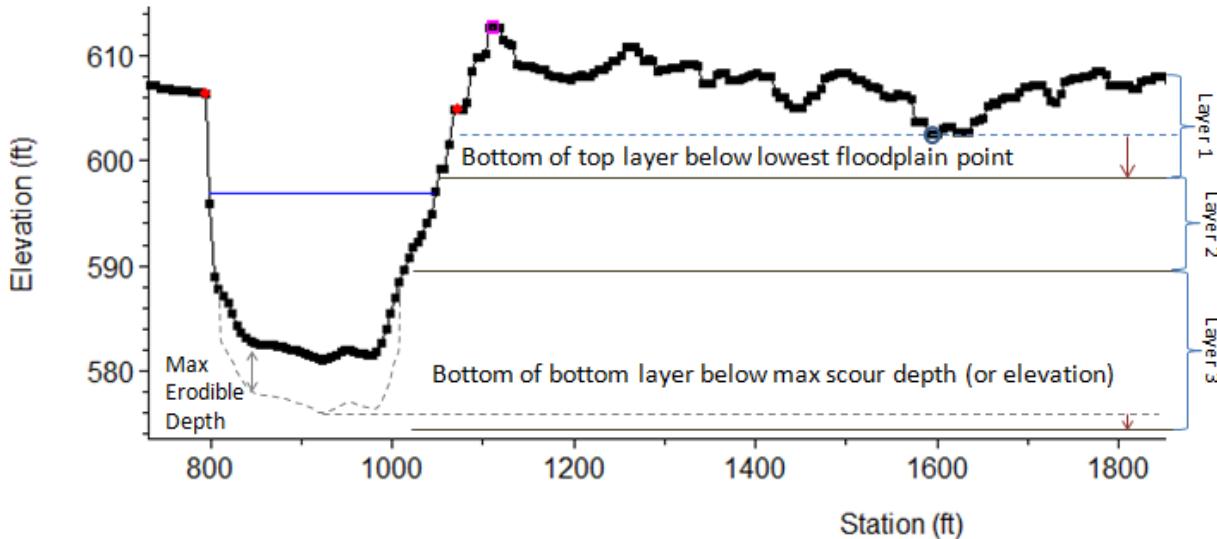


72 Defining layers and layer material types.

Then, just like the **Bank Material Type** option in the main BSTEM editor, a list of bank materials can be accessed by clicking on the **Material** column (above). Each layer has to have its own material specified, but the materials do not have to be unique and can be any combination of default or user specified material types. Add layers until the last **Bottom Elevation** extends below the conceivable bottom of the model (i.e., the elevation the model is likely to scour to). The bottom of the deepest layer has to at least extend to the thalweg elevation for the model to run.

Guidelines for Selecting Layer Elevations: Setting layer elevations according to a couple conventions can make an HEC-RAS/BSTEM model more stable. First, set the bottom of the top layer below the lowest point of the overbank, so the layer only intersects the cross section at one point, between the toe and the top of bank

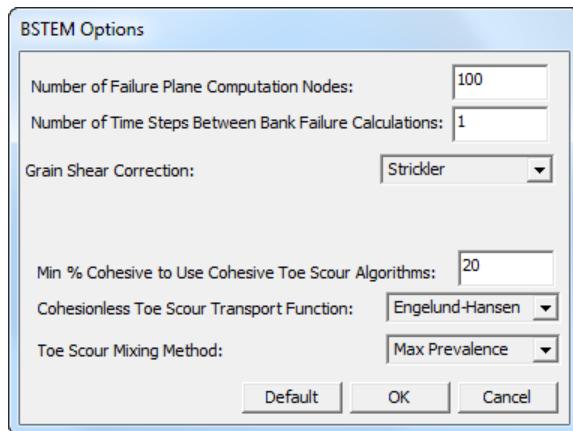
(below). Second, set the bottom of the bottom layer below the deepest possible thalweg elevation (e.g., thalweg-max erodible depth) so the model never scours below the defined layers (below).



73 Guidelines for setting layer elevations.

1.5.3 USDA-ARS BSTEM Options

The HEC-RAS/BSTEM model integration included several arbitrary parameter thresholds and two processes with multiple methods. These parameters and methods influence results and run times. The **BSTEM Options Editor** (below) exposes them so users can adjust or select them.



74 BSTEM Options Editors.

- [Number of Failure Plane Computation Nodes](#) (see page 238)
- [Number of Time Steps Between Failure Computations](#) (see page 238)
- [Grain Shear Correction](#) (see page 238)
- [Minimum Percent Cohesive to Use Toe Scour Algorithms](#) (see page 238)

1.5.3.1 Number of Failure Plane Computation Nodes

The bank failure algorithm computes a critical failure plane at every one percent of the elevation between the toe and edge stations, computing critical failure planes at 100 evenly spaced vertical bank intersection points (see [Steps in a Bank Failure Analysis \(see page 369\)](#), first figure). This is computationally expensive and often much more detail than necessary and the parameter is editable in HEC-RAS. Users can specify the number of vertical computation bank failure points. HEC-RAS will evenly distribute the computation points vertically, between the bank toe and edge elevations.

1.5.3.2 Number of Time Steps Between Failure Computations

Bank failure algorithms are computationally expensive. These algorithms can increase sediment model run times by an order of magnitude. Users can reduce run times by defining BSTEM parameters only at the half-cross sections where bank processes are expected. Bank failure conditions (i.e., FS less than one) are not usually instantaneous. If FS drops below one, the failure condition generally lasts for several time steps. Skipping bank failure computations will introduce error, but given the uncertainties of the model, the error may be acceptable trade off for run time.

1.5.3.3 Grain Shear Correction

Only part of the shear stress water exerts on soils translates into transport. Shear partitioning theory for bed transport is more mature, parsing shear into form and grain shear (and sometimes into other components). This theory is not as applicable to banks. However, the isolated measurements, either by jet tests in the field or SEDFLUME in the lab, tend to isolate grain shear effects. Therefore, the toe scour mechanisms apply a **Strickler** grain shear correction by default. From the [BSTEM Options Editor \(see page 237\)](#)(see figure in link), from the **Grain Shear Correction** list, select **None**, this will turn the correction off. Turning the grain shear correction off will increase the shear stress on the bank and will increase scour.

1.5.3.4 Minimum Percent Cohesive to Use Toe Scour Algorithms

BSTEM has two approaches to toe scour. The cohesive algorithms use the excess shear equation to compute scour rates based on measured erodibility data. The cohesionless algorithms apply transport functions to compute scour. The cohesionless methods are generally less accurate, but it is difficult to estimate cohesionless erodibility either in the lab or in the field.

HEC-RAS/BSTEM decides between these methods for each soil layer by computing the percentage of the bank soil that is cohesive (i.e., in the first five HEC-RAS grain classes, less than .063 millimeters is the default grain class definition). HEC-RAS computes this percentage from the gradation defined in the [BSTEM Material Parameter Editor \(see page 228\)](#)(see second figure in the link) from the soil type list, or the narrow gradations of the default soil types. By default, if **20 percent** or more of the soil is cohesive, (clay or silt), BSTEM uses the cohesive methods. However, if less than **20 percent** of the soil is finer than the cohesive threshold, BSTEM will apply the cohesionless transport equations.

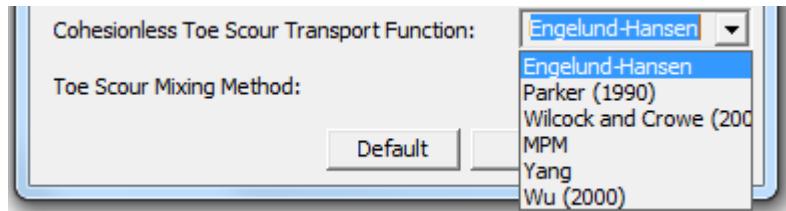
The twenty percent threshold is not entirely arbitrary. Around twenty percent cohesive content, the fine particles fill the soil voids enough for their cohesive properties to dominate the erodibility of the larger particles. However, in reality, the transition from cohesive matrix support to cohesionless framework support is a gradient not a step function. Therefore, the parameter is exposed as a user option in the BSTEM Options in the Sediment Data Editor.

If the transport functions return unreasonable scour rates, as often happens, users can model cohesionless materials with the cohesive erodibility approach. To force the cohesive, excess shear, erodibility method, set the **Min % Cohesive** to **0** in the BSTEM Options in the Sediment Data Editor.

1.5.4 Transport Function (BSTEM)

As described in the previous section, if a soil layer has less than 20 percent (or a user specified percentage) cohesive material, BSTEM will apply a transport function to compute toe scour (below). The USDA-ARS BSTEM model uses an NSED transport function library to compute transport. This library includes six transport functions, including:

- Engelund-Hansen
- Parker (1990)
- Wilcock and Crowe (2000)
- Meyer-Peter Muler
- Wu (2000)



Select and apply transport functions with

extreme caution recognizing the intent and range of applicability of each. Transport functions are notoriously uncertain, computing transports that commonly differ by at least one order of magnitude. Engelund and Hansen (1967) and Yang (1996) work best for sand. Meyer-Peter and Müller (MPM) (1948) will probably perform best for coarse materials. Parker (1990) and Wilcock and Crowe (2003) are both **surface based** methods, intended for heterogeneous soil mixtures with sand and gravel components. These two methods account for mixing, hiding and armoring implicitly, which tends to moderate transport and sometimes makes the methods more appropriate for toe scour in heterogeneous materials.

Also, it should be noted that most of these transport functions were derived for one-dimensional alluvial transport at the cross section scale. BSTEM applies these transport functions to bank scour at the node scale. This makes transport functions, already uncertain in their intended setting, loose process analogies in toe scour. The transport functions often over predict scour substantially and results should be interpreted carefully.

1.5.5 Toe Scour Mixing Method

The HEC-RAS sediment transport follows Einstein(1950), HEC-6, and most sediment transport models by apportioning transport across available grain classes in proportion to the gradation of the bed.

$$T_c = \sum_{j=1}^n \beta_j T_j$$

Where: T_c is Total transport capacity, n is the number of grain size classes, β_j is the percentage of the active layer composed of material in grain size class " j ", and T_j is the Transport potential computed for the material in grain class " j ". Partitioning capacity based on the gradation of the active layer is a classic assumption based Einstein's (1950), who proposed sediment discharge of a size class is proportional to the fractional abundance of that size class in the bed

This approach generally works when couple with an "active layer" bed model that tracks the gradation of a surface layer separately. Without an active layer, transport functions compute huge masses for small particles, removing these materials from deep within the bed, much deeper than physically possible.

The toe scour method does not have an active layer. Therefore, transport methods have unrestricted access to all the fine materials in the bank. Apart from the standard uncertainty of the transport functions, this is the primary reason that the cohesionless method overpredicts transport, it can numerically wick fine materials deep in the bank, while the coarser materials remain.

The HEC-RAS/BSTEM development team experimented with three mixing methods to mitigate this numerical artifact:

Cumulative: Applies the same assumption as the bed, apportioning capacity by the prevalence in the bank layer. However, since the bank layer has no active layer and does not update, this provides an unlimited supply of finer material and usually over-predicts scour.

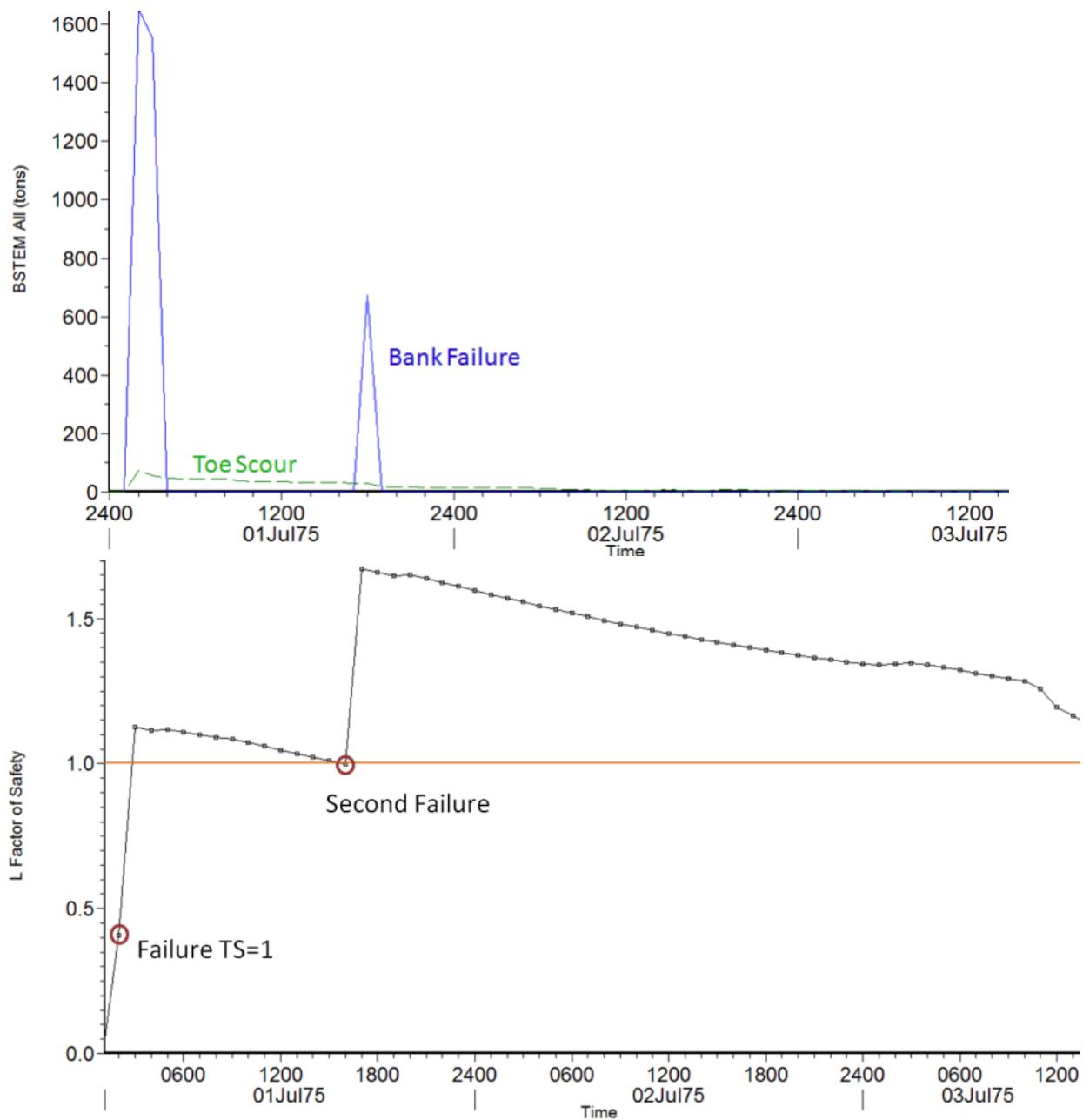
Maximum Prevalence (default): This method apportions capacity according to the relative proportion of the bank gradation. However, it only erodes the most prevalent grain class. This assumes that the dominant grain class moderates scour. This method is more appropriate if trace fines and low percentage fine sands cause the other methods to over-predict scour and was designed for framework supported materials.

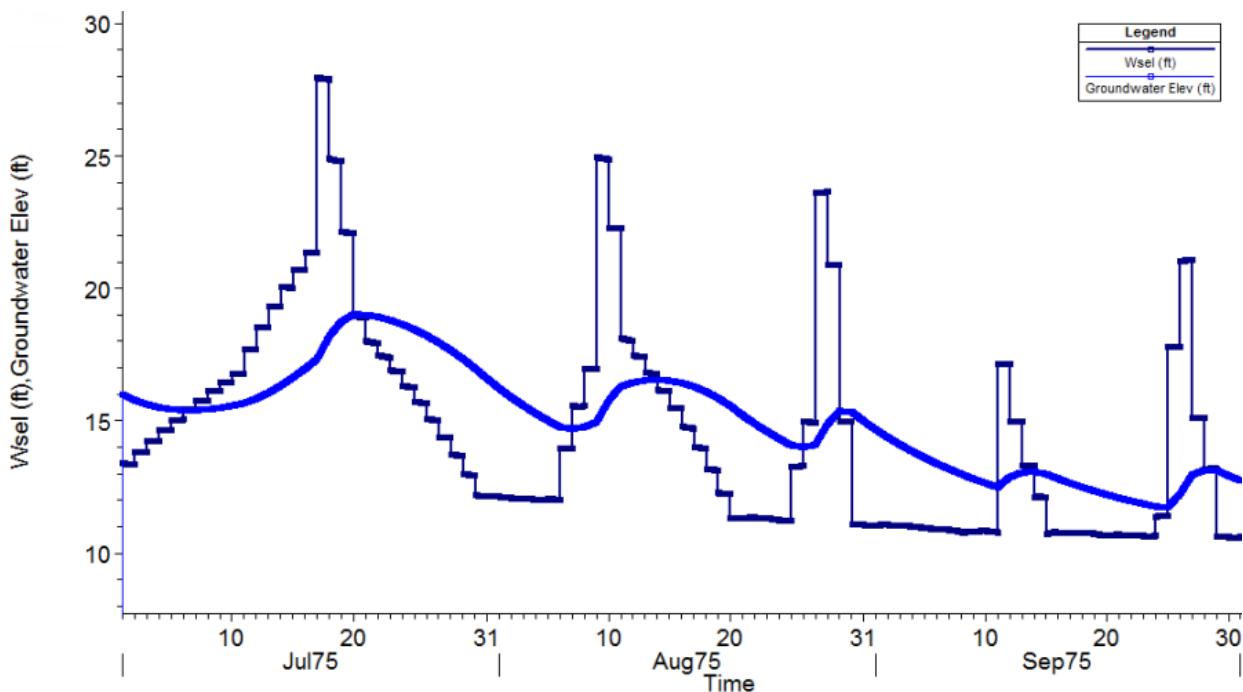
Maximum Capacity: This method was designed for matrix supported materials. It assumes that the prevalent fine material, the one with the largest product of transport potential and prevalence, controls the scour distance. So the scour distance associated with the largest capacity grain class is applied, assuming that the other particles are larger clasts that will fall into the channel when released from the scoured fine matrix.

1.5.6 Output

HEC-RAS does not compute USDA-ARS BSTEM results by default. To request BSTEM output, from the **Sediment Transport Analysis** dialog box, from the **Options** menu, click **Sediment Output Options**. The **Sediment Output Options** dialog box will open, **from the Output Level** list select **6**. Once that setup is done, from the [HEC-RAS main window \(see page 223\)](#)(figure in link), from the **View** menu, click **Sediment Output**. The **Sediment Plot** dialog box will open. In general, the new sediment output (which reads HDF5 output), is more complete and user friendly. However, the legacy sediment output viewers from HEC-RAS Versions 4.0 were retained because they have a few capabilities (e.g. plotting multiple variables and creating new geometry files) that the new viewers lack.

HEC-RAS computes several commonly used BSTEM results. The total mass eroded from a cross section in a computation increment (for both banks and both processes) is reported under **BSTEM All**. The total mass eroded from the banks can also be reported by grain class (e.g. BSTEM (7)) or by bank and process (top). Finally **Factor of Safety** (middle) for each bank and **Groundwater Elevation** (bottom) are available. All of these variables can be viewed as profiles (all the cross sections in a reach at a selected time step) or as time series, (all values over time at a selected cross section). The BSTEM output variables are defined in the table below.





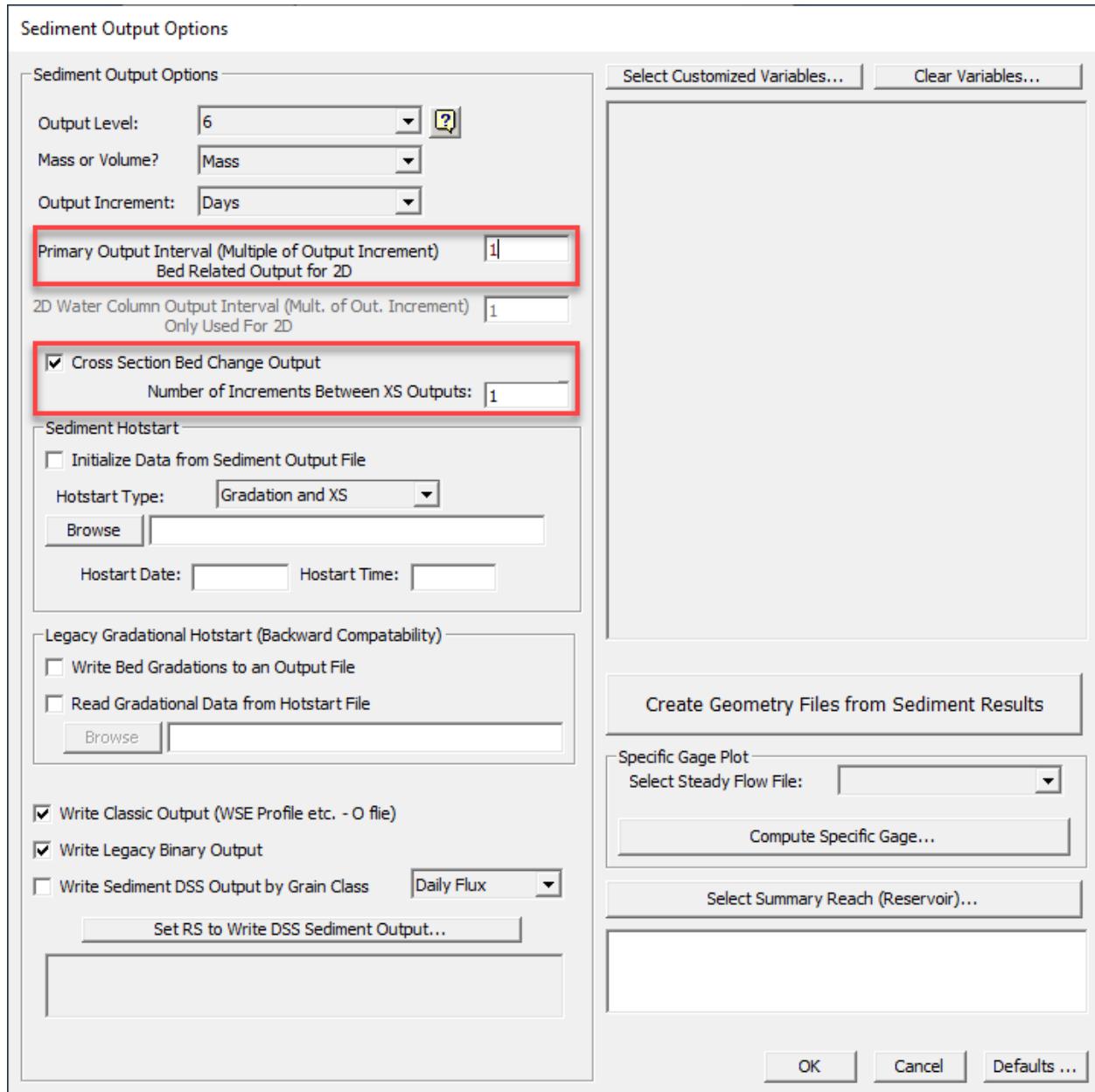
HEC-RAS modifies cross sections when the sediment model computes bed change or when BSTEM computes bank migration. Viewing cross section changes is often the most valuable output to understand and troubleshoot an HEC-RAS/BSTEM model. Cross section output files can be very large. HEC-RAS only outputs starting and final cross sections by default. The user can request more frequent cross section output from the **Sediment Output Options** dialog box (below, top). From the **Sediment Transport Analysis** dialog box, from the **Options** menu, click **Sediment Output Options**. The **Sediment Output Options** dialog box will open (below, top). From this dialog box users can request cross section data and specify the increment, the middle figure below provides an example. The **Sediment Output Viewer** from version 5.0 also plots the water surface elevation and the BSTEM toe associated with the cross section (below, bottom).

1.5.6.1

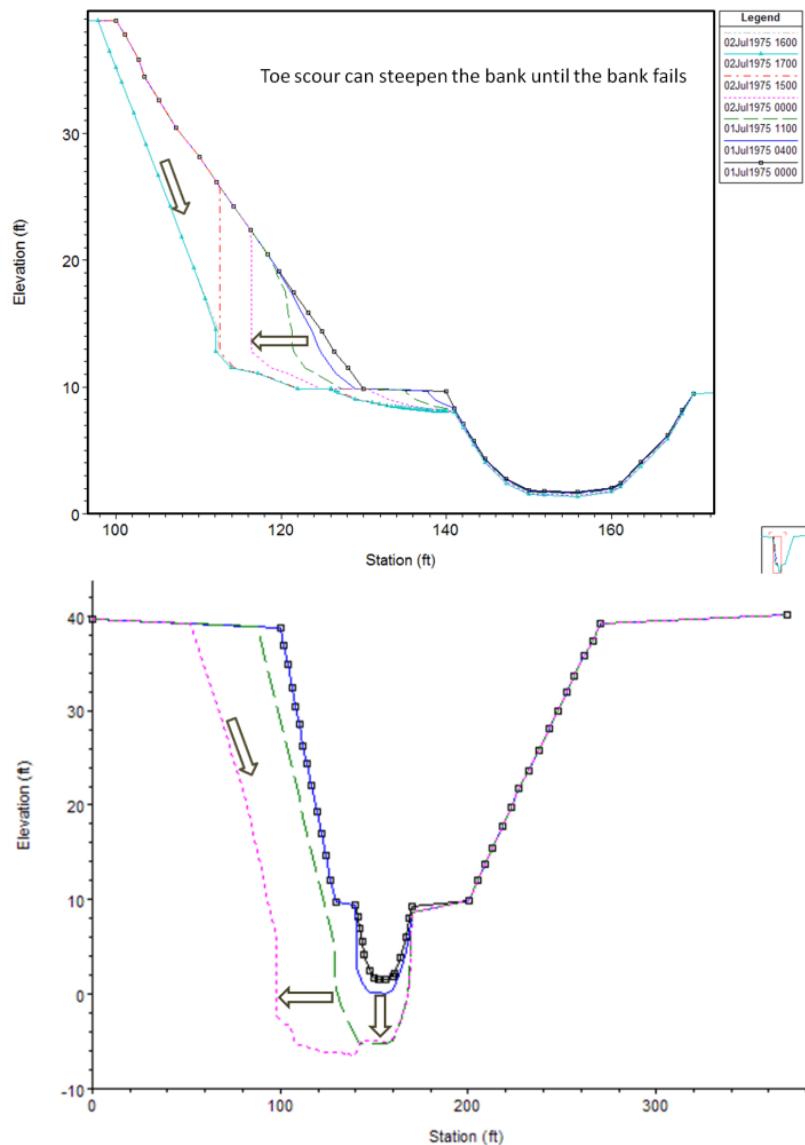
Table: BSTEM Output Variable Names and Descriptions in HEC-RAS

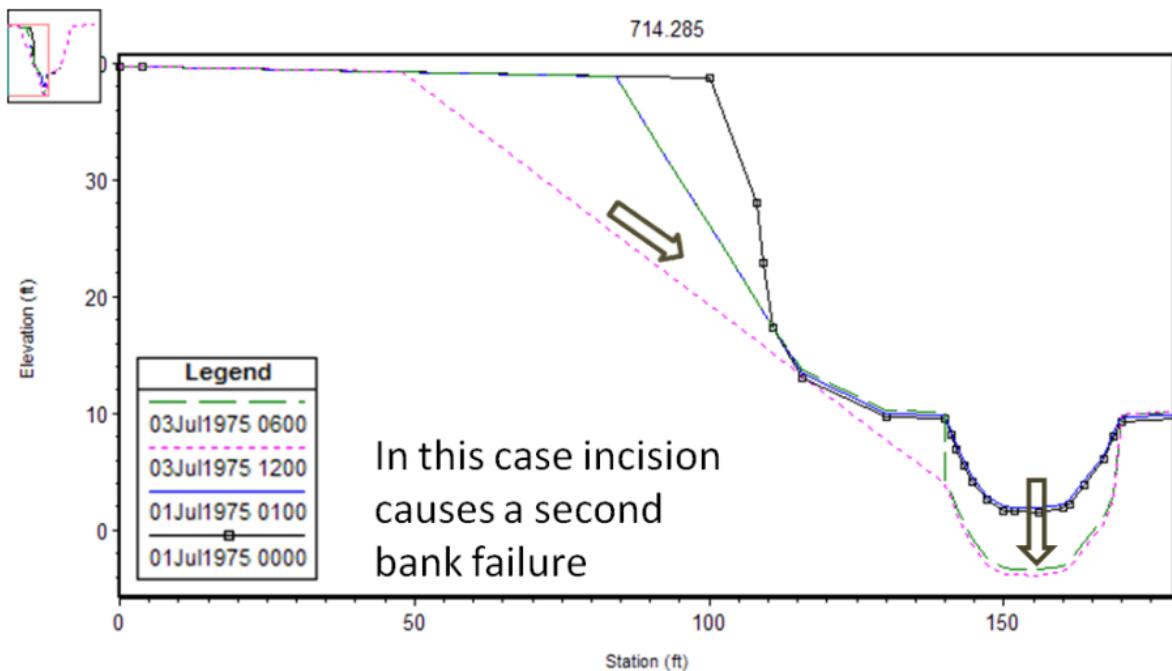
| Variable | Descriptions |
|--|---|
| BSTEM Mass (Vol) (tons or ft ³) | Total sediment mass (or volume) –obilized - from both cross-section banks - by toe scour and bank failure for each cross section for each computation increment. (Total and by Grain Class) |
| BSTEM CumMass (Vol) (tons or ft ³) | Cumulative mass (or volume) mobilized from the cross section for both banks and both BSTEM processes since the beginning of the simulation. (Total and by Grain Class) |

| | |
|---|--|
| BSTEM Long CumMass (Vol) (tons or ft ³) | The cumulative mass mobilized from the toe and banks since the beginning of the simulation, summed from upstream to downstream. (i.e. The value at the downstream cross section is the total eroded from the banks for the whole reach). |
| L/R BSTEM Mass Failure (tons or ft ³) L/R BSTEM Mass Failure Cum | Mass removed from the left or right bank by bank failure processes for each computation increment. This variable is available for the selected computation increment and the total since the beginning of the simulation (Cum). |
| L/R BSTEM Toe Mass (tons or ft ³) L/R BSTEM Toe Mass Cum | Mass removed from the left bank by toe scour for each computation increment. This variable is available for the selected computation increment and the total since the beginning of the simulation (Cum). |
| L/R Factor of Safety (Decimal Fraction) | Minimum factor of safety computed in the left or right bank for each computation increment. |
| BSTEM L/R Toe Station (ft or m) | The lateral station (i.e. the station-elevation point) of the toe. This tracks the lateral migration of the toe. |
| BSTEM L/R Toe Elevation (ft or m) | The elevation of the station-elevation point identified as the toe. |
| BSTEM L/R Top Station (ft or m) | The lateral station (i.e. the station-elevation point) of the point identified as the "top of bank". This tracks the lateral migration of a second point on the bank (besides the toe). |
| BSTEM L/R Top Elevation (ft or m) | The elevation of the station-elevation point identified as the "top of bank". |
| Movable Elv L/R: (ft) | The elevation of the movable bed limit. This is not a BSTEM specific variable, but can be helpful if the MBL is the BSTEM toe. |
| Movable Sta L/R: | Tracks the lateral position of the movable bed limit. If the BSTEM toe is the same as the MBL, this result will quantify toe scour distance. |
| Groundwater Elev (feet) | Ground water elevation computed in BSTEM, either static, user specified, or computed with the groundwater lag method. |

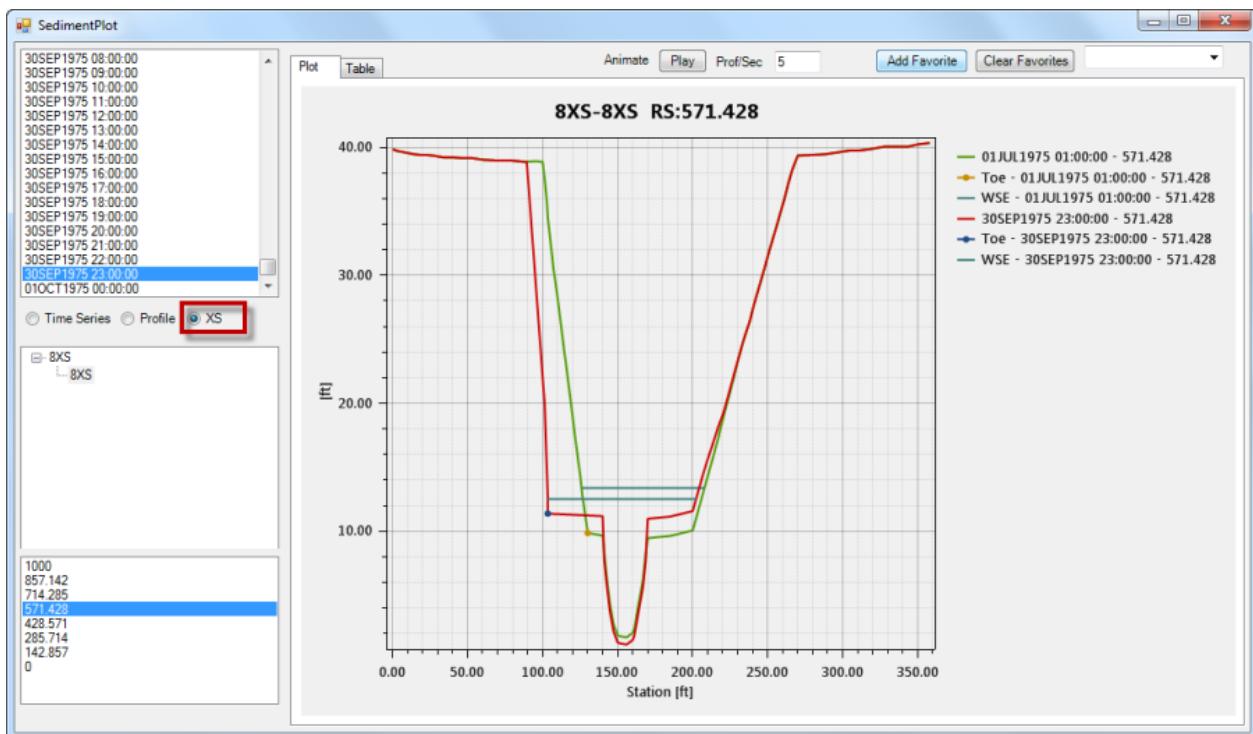


75 Requesting and specifying the frequency of sediment cross section output in the Sediment Output Options dialog box.





76 Example HEC-RAS cross section outputs including toe scour, incision and bank failure at various stages in the simulations.

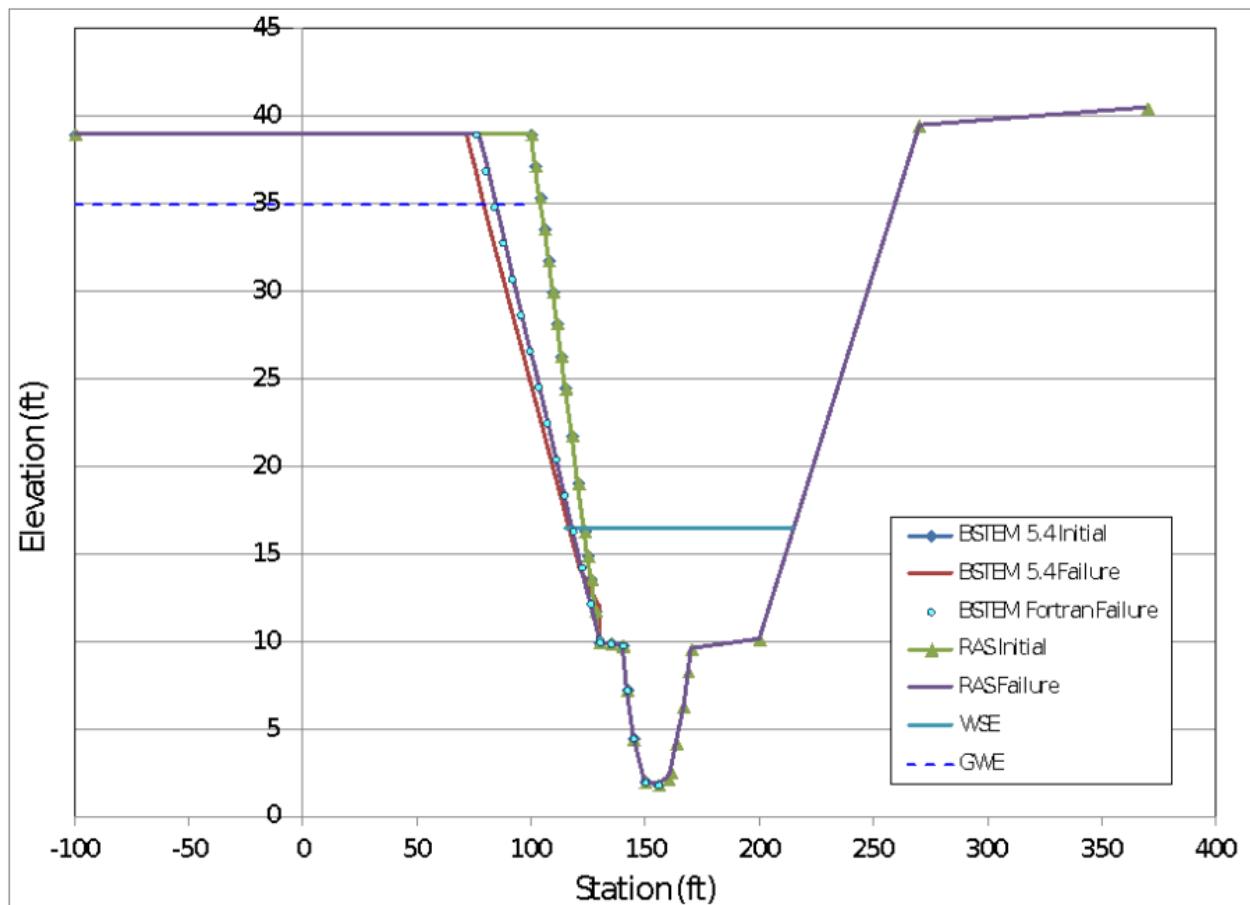


77 Bank migration cross section output with the new Sediment Output viewer.

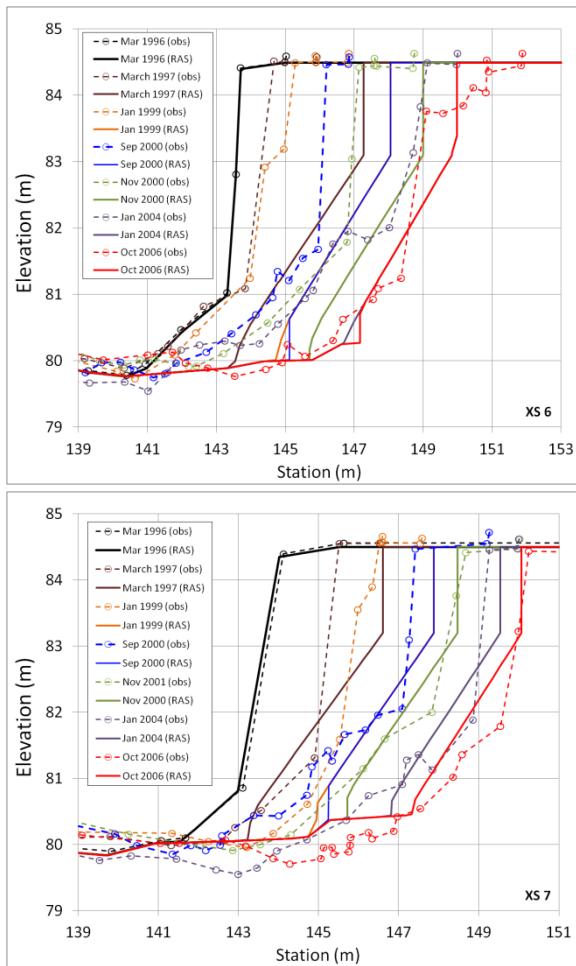
1.5.7 Model Validation

Finally, model testing was conducted to demonstrate the reliability of the HEC-RAS/BSTEM algorithms. Several test scenarios were constructed and modeled with HEC-RAS, the standalone version of BSTEM 5.4 and the standalone FORTRAN version of BSTEM used in the integration (which was subjected to rigorous independent validation against BSTEM 5.4 (Simon et al., 2010)). The before and after cross sections for a bank failure event are displayed in the figure below. The FORTRAN version of the algorithms in HEC-RAS replicates BSTEM 5.4 very closely. Small divergence can be explained by a couple algorithm differences between the FORTRAN version and BSTEM 5.4.

Gibson et al. (2015) also applied the model to Goodwin Creek, following the work of Langendoen and Simon (2008). Goodwin creek is a highly instrumented reach with substantial bank migration, carefully measured over a decade with dozens of repeated cross sections, making it an ideal site for evaluating a bank process model. Gibson et al. (2015) used the parameters from of Langendoen and Simon (2008), to test the model against a known calibration. The integrated HEC-RAS/USDA-ARS BSTEM model performed well compared to prototype data (bottom figure) and the CONCEPTS runs in Langendoen and Simon (2008).



78 Output from a validation test of the HEC-RAS implementation of the bank failure capabilities and the standalone models.



79 Select Goodwin Creek repeated right bank surveys at the two central cross sections with HEC-RAS/BSTEM cross section migration from Gibson et al. (2015).

1.5.8 BSTME Modeling Guidelines, Tips, and Troubleshooting

The HEC-RAS/BSTEM development team has compiled several modeling tips and guidelines that can make coupled bed-bank modeling more stable and less frustrating. Consider the following approaches and tips before setting up a model or to help troubleshoot models that are crashing or behaving poorly.

- [Stepwise Modeling Process \(see page 249\)](#)
- [Selecting a Toe \(see page 249\)](#)
- [Monotonic Bank Geometry \(see page 250\)](#)
- [Floodplain Geometry \(see page 250\)](#)
- [Too Much Scour \(see page 251\)](#)
- [Common Runtime Error Messages \(see page 252\)](#)
- [Unusual Cross Section Shape \(see page 253\)](#)
- [Groundwater Table \(see page 254\)](#)

- [Scour Outside of a Bend \(see page 254\)](#)

1.5.8.1 Stepwise Modeling Process

Sediment transport modeling with HEC-RAS was already complex and highly parameterized before bank failure. Bank failure makes it more complex. Complex models that account for more processes explicitly make careful, strategic, sequential modeling practice more important.

Model processes from simple to complex. Add complexity one step at a time. A stepwise modeling process, that adds complexity incrementally, carefully calibrating and evaluating results of each modeling step, will produce more accurate models and sane modelers.

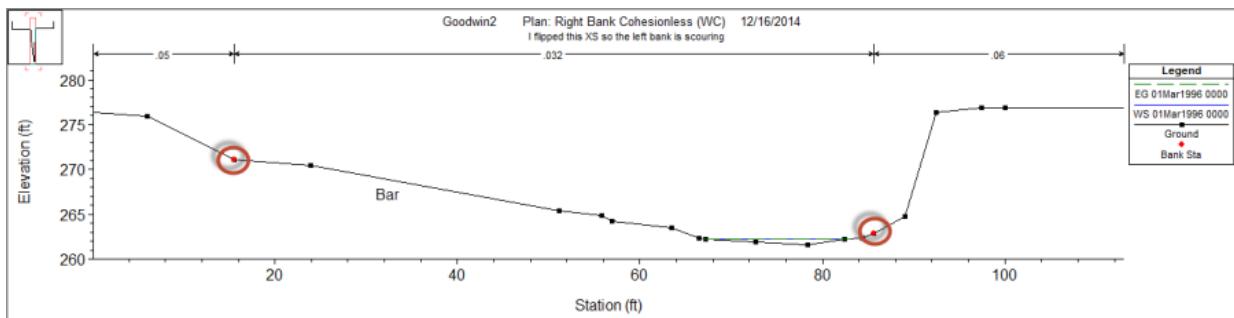
Create an HEC-RAS/BSTEM model in the following incremental steps, carefully completing, evaluating, and calibrating each step before adding the complexity of the next step.

1. **Calibrate Hydraulics:** Create the geometry and calibrate model hydraulics in the steady flow module over the range of expected flows.
2. **Model/Calibrate Sediment Transport:** Isolate the sediment transport mechanics by carefully modeling bed sediment without bank processes first. Build a robust (Thomas and Chang, 2012) calibrated model, or at least, evaluate results to understand the sensitive parameters.
3. **Model/Calibrate Bank Erosion and Bank Failure:** By setting the cross sections as **Pass Through Nodes** (under the **Options** menu in the **Sediment Data Editor**), users can isolate bank processes and refine bank methods and parameters without the complexity bed process feedbacks.
4. **Integrate Bank Erosion and Failure plus Mobile Bed Sediment Transport Model:** After the hydraulics are calibrated and the bed and bank sediment models have been refined independently, then combine all the components, and calibrate the coupled model to bed and bank change.

1.5.8.2 Selecting a Toe

The USDA-ARS BSTEM model is very sensitive to the toe node selected. Tips for selecting the toe include:

1. Make the **BSTEM Toe Station** the same as the **Movable Bed Limit (Left Station and Right Station in Initial Conditions and Transport Parameters** in the **Sediment Data Editor**). While there is a tool to set the **Toe Stations** to the **Movable Bed Limits**, it is often better to go the other way, selecting a toe and then setting the **Movable Bed Limit** station equal to the **Toe Station**.
2. HEC-RAS distorts cross sections vertically in the cross section display. This makes them easier to visualize, but can make it difficult to select a toe. When selecting toe stations, change the aspect ratio of the cross section plotter and zoom in along the horizontal axis to get a 1:1 H:V ratio from the plot (below). This adjustment will make it easier to pick an actual toe from an undistorted cross section plot.

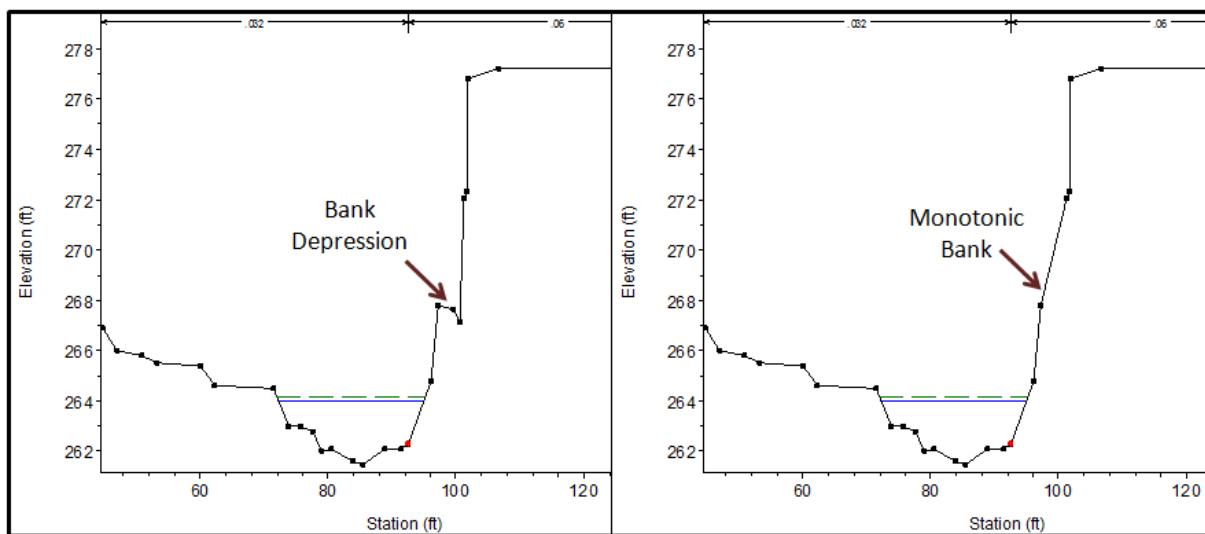


80 Cross section viewer adjusted to approximately a 1:1 aspect ratio to help select the toe station.

1.5.8.3 Monotonic Bank Geometry

HEC-RAS allows complex cross sections. USDA-ARS BSTEM idealized cross sections in a couple of important ways. HEC added logic to adapt BSTEM to complex cross sections but some cross sections shapes still tend to be unstable. In particular, avoid "bank depressions" (see figure below) if possible. Cross section node elevations should increase from the toe to the edge of the bank.

The model can become unstable when a soil layer boundary crosses the cross section more than once. Therefore, if the cross section includes an important bank depression, make sure that the soil layer does not pass through it.



81 Avoid bank depressions (left) where possible, particularly with soil layers. Monotonic

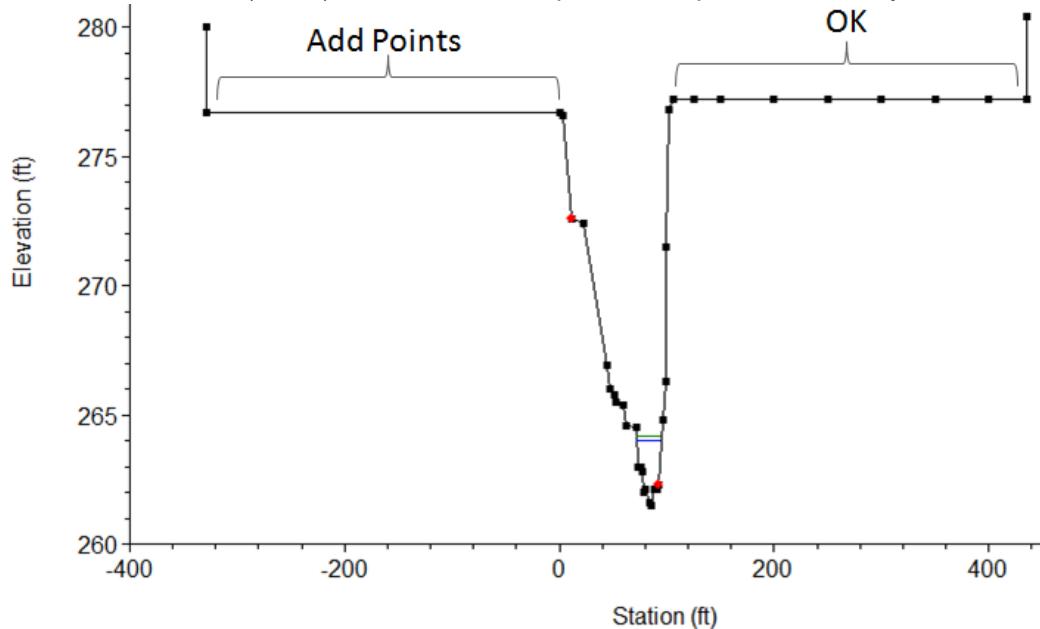
1.5.8.4 Floodplain Geometry

The portion of the cross section outside the **Edge of Bank Station** must conform to three conventions to provide optimal results:

1. The floodplain must be wide enough to include the maximum failure plane angle. For long term simulations this includes the maximum failure plane from the maximum scour location. As a rule of

thumb, include a floodplain wide enough to encompass at least a ten degree angle from the toe station.

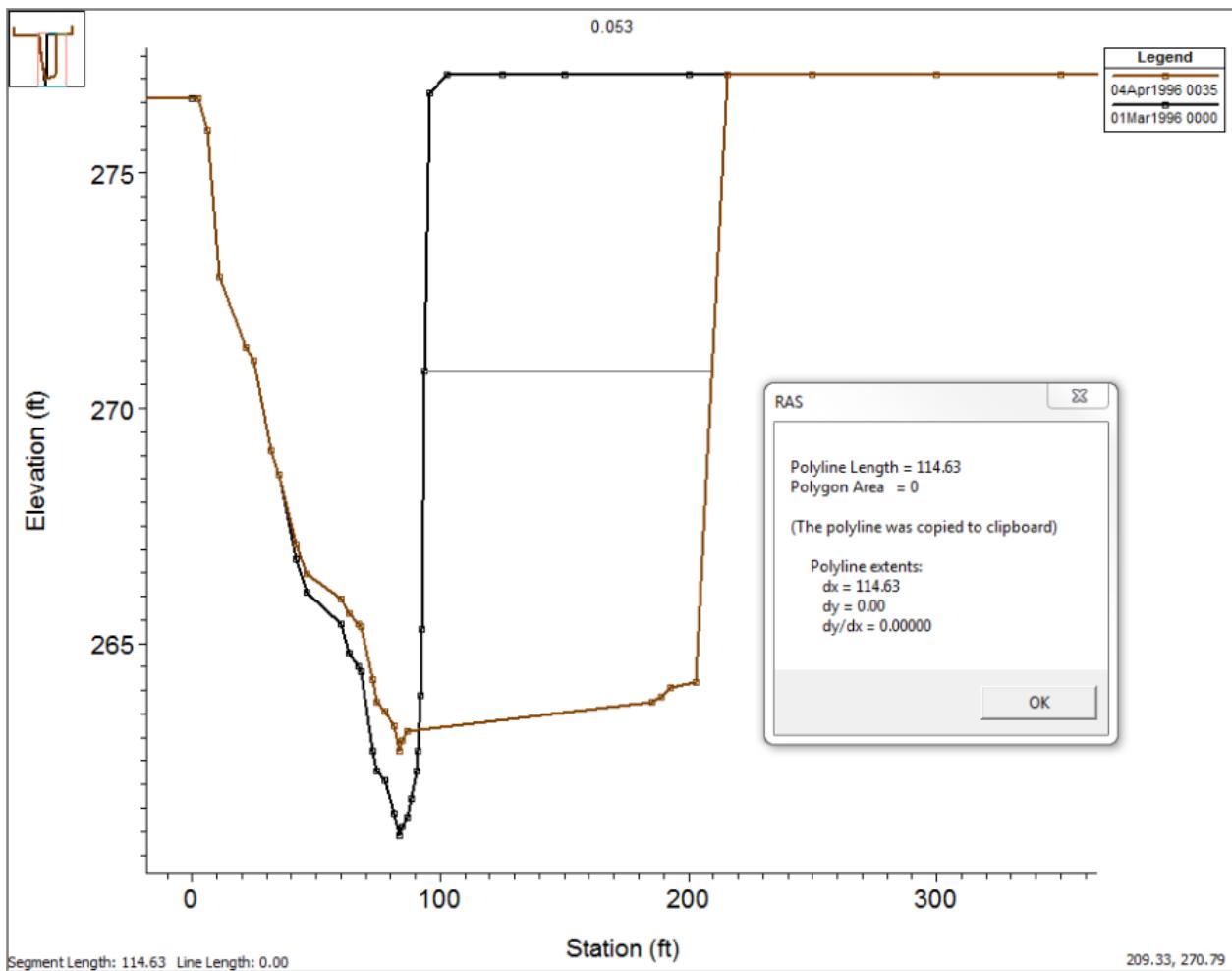
2. The floodplain needs intermediate station-elevation points between the edge of the bank and the end of the cross section (below) for BSTEM to compute failure planes effectively.



3. If the floodplain is irregular (like in the figure in [Too Much Scour \(see page 251\)](#)) it should not intersect with a layer. If the cross section includes multiple soil layers, the top layer should include all of the cross section nodes outside of the bank edge station.
4. HEC-RAS should be able to handle wet depressions and ineffective flow areas outside the bank edge, but the more floodplain complexity in a cross section the more likely that the bracket and Brent method (Teukolsky et al., 2007) will converge on a false maximum or that the cross section update will encounter a problem. So avoid incidental cross section complexity, particularly in the overbank.

1.5.8.5 Too Much Scour

Most HEC-RAS/BSTEM model failures come from having too much toe scour. Since soil erodibility data can vary by orders of magnitude, even in the same site, selecting high cohesive erodibility will compute excessive scour. Cohesionless methods (below), that compute toe scour with transport equations almost always over predict scour, sometimes dramatically



82 In this model, the cohesionless transport methods computed more than 100 feet of bank scour in just over a month, which is order of magnitude faster than the actual bank recession rate.

1.5.8.6 Common Runtime Error Messages

The **unrealistic vertical adjustment** error shown in the figure below is the most common sediment error in general and HEC-RAS/BSTEM in particular. This error indicates that HEC-RAS computed very large bed changes at the indicated cross section in the final time step before the program stopped.

ERROR during Sediment Simulation

Unrealistic vertical adjustment at
8XS 571.428

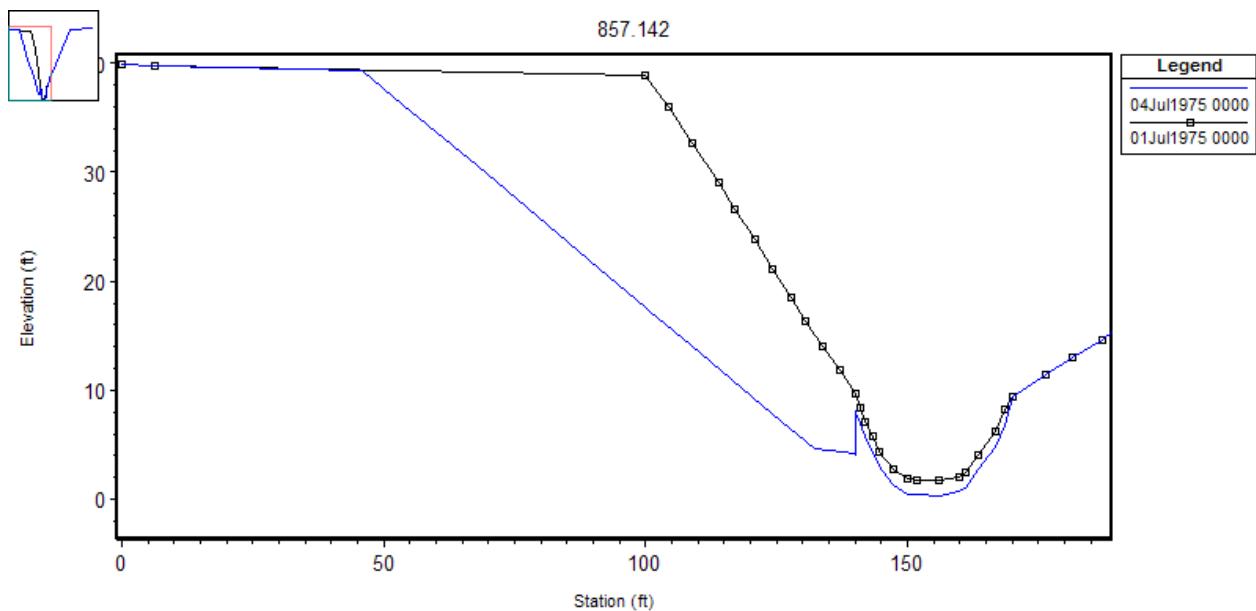
Often this error can be resolved by reducing the computation increment. However, sometimes more systemic model or data problems make the error persist at very small computational increments. The most common causes include:

1. Excessive toe scour: The most common cause of model failure is excessive toe scour (see [previous section \(see page 251\)](#)). Lower the erodibility substantially or turn off the cohesionless transport methods (go to the BSTEM Options editor under the Options menu in the Sediment Data editor) to stabilize the model.

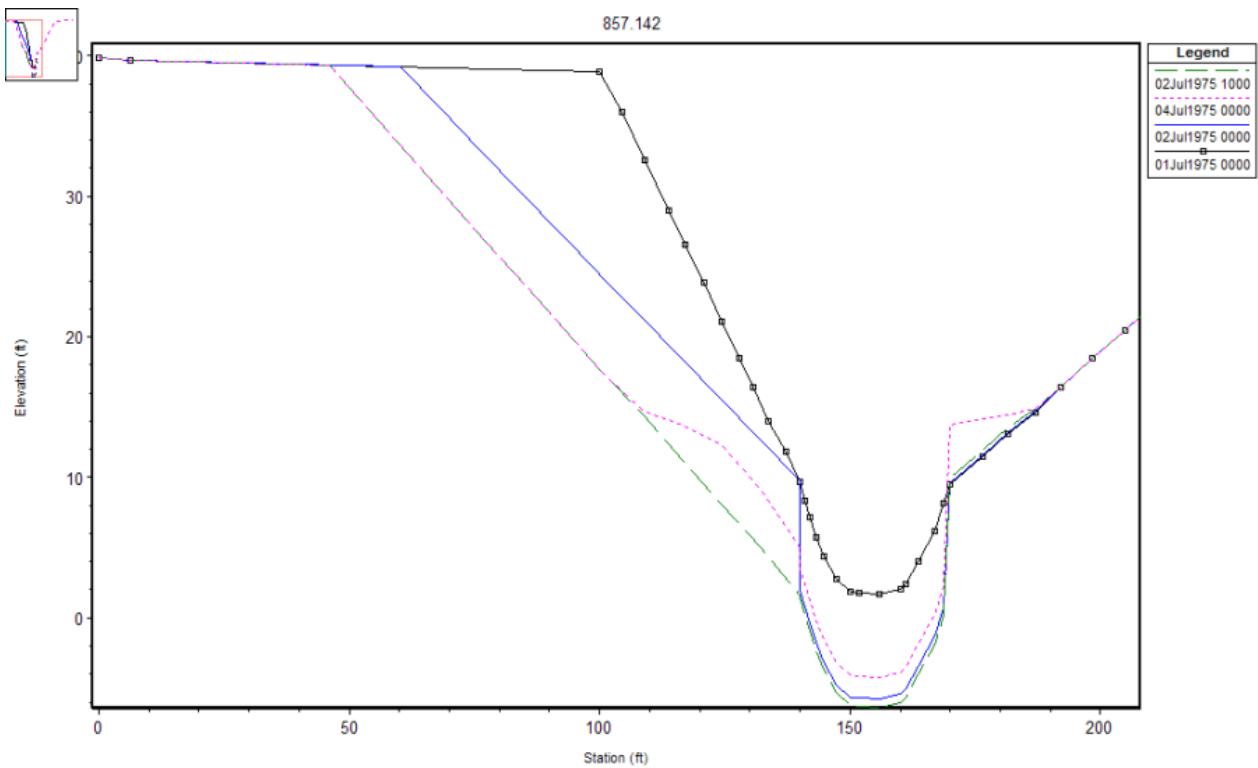
2. Bed material does not match transport function: If the bed material is too fine for the transport function, or if the transport function over predicts transport in the reach, the mis-match can lead to large, rapid bed changes, destabilizing the model. A common error involves assigning fine bank material gradations to the bed.
3. Equilibrium Load: If the equilibrium load boundary condition is used with bed gradations that include no-trivial silt or clay, this boundary condition can compute enormous fine grained sediment loads at the boundary. Small decreases in transport downstream can cause large bed changes. User defined rating curves are almost always better sediment boundary condition options, even if they are speculative.

1.5.8.7 Unusual Cross Section Shape

Sometimes active cross sections can produce strange shapes, like the example shown in the figure below (top). First, make sure the toe station and the movable bed limits are set to the same station. Second, the ARS-USDA BSTEM features often work best if HEC-RAS allows deposition outside the movable bed limits. In the **Sediment Data Editor**, go to the **Options** menu and select **Bed Change Options**. Then, under **Deposition** select the **Allow Deposition Outside of the Movable Bed Limits** option. This will constrain erosion to the movable bed limits (which will migrate with the toe if they have the same starting station) but will deposit any wetted node in the cross section. The model in the top figure was re-run in bottom figure with this option selected and produced more realistic results.



83 Strange cross section shape caused by deposition inside the movable bed limits, but not outside.



84 The same simulation as Figure 55, but allowing for deposition in the overbanks.

1.5.8.8 Groundwater Table

Results can be very sensitive to groundwater. Two particular groundwater errors that can create model problems:

1. Never specify a starting or static groundwater table that is higher than the bank edge.
2. Groundwater elevations far below the channel water surface elevation will prevent the bank from failing. The USDA-ARS BSTEM applies a hydrostatic assumption, computing suction according to a hydrostatic gradient from the groundwater elevation. Therefore, in ephemeral streams or situations where the groundwater table is unknown, estimate the groundwater elevation or put it at an average surface water elevation banks should fail.

1.5.8.9 Scour Outside of a Bend

In natural systems, banks are usually most active on the outside of a bend or meander. HEC-RAS is a one-dimensional model and does not simulate the multi-dimensional forces that cause this preferential erosion. Banks migrate more on the outside of bends because multi-dimensional effects produce higher shears there. Because HEC-RAS uses an excess shear equation to compute scour, users can simulate preferential bank scour by decreasing the critical shear at bend cross sections. This will approximate the physical process, increasing the $(\tau - \tau_c)$ shear difference by decreasing the critical shear instead of increasing the shear.

1.5.9 References

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1.5.10 Scour Units

The cohesive model used in the bed model is different than that used in the bank model. The bed model removes sediment by mass. Mass is removed per area, per time in response to a force (e.g. N/m²-hr/Pa which translates to the slope of the relationship between mass removed per area per time and the force, which is 1/time). In the bank model a volume is removed in response to a force, so the units are Volume/force-time (e.g. M³/Pa-hr).

This difference is because bulk mass is removed from the bed and applied uniformly over the bed. The bank model shifts each node laterally, independently. Therefore, a "volume" is translated into a lateral shift, per node.

The following table provides conversion factors to move between SI and US customary units.

1.5.10.1 Table: Conversion Factors.

| From | Multiply by | To |
|---------------------|-------------|------|
| m ³ /N/s | 0.42 | 1/hr |

| | | |
|------------------------|----------|------------------------|
| Pa | 0.0208 | psf |
| m ³ /N-s | 6365.9 | ft ³ /lbf-s |
| | | |
| 1/hr | 2.39 | m ³ /N/s |
| psf | 47.9 | Pa |
| ft ³ /lbf-s | 0.000157 | m ³ /N-s |

1.5.11 SI Table

1.5.11.1

Table: Default materials and material parameters.

| Case Material | Wt (kN/m ³) | frAng | C (kPa) | <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> | Tc(Pa) | E (cm ³ /Ns) |
|-----------------------|--|--------------------|----------------|---|---------------------|-----------------------------------|
| Default Material Type | Saturated Unit Weight (kN/m ³) | Friction Angle (°) | Cohesion (kPa) | <input type="checkbox"/> <input type="checkbox"/> | Critical Shear (Pa) | Erodibility (m ³ /N-s) |
| Boulders | 20.0 | 42.0 | 0 | 15 | 498 | 4.48E-09 |
| Cobbles | 20.0 | 42.0 | 0 | 15 | 124 | 9.00E-09 |
| Gravel | 20.0 | 36.0 | 0 | 15 | 11 | 3.02E-08 |
| Coarse Angular Sand | 18.5 | 32.3 | 0.4 | 15 | 0.506 | 1.41E-07 |
| Course Round Sand | 18.5 | 28.3 | 0.4 | 15 | 0.506 | 1.41E-07 |
| Fine Angular Sand | 18.5 | 32.3 | 0.4 | 15 | 0.128 | 1.41E-07 |
| Fine Round Sand | 18.5 | 28.3 | 0.4 | 15 | 0.128 | 1.41E-07 |
| Erodible Silt | 18.0 | 26.6 | 4.3 | 15 | 0.1 | 3.16E-07 |
| Moderate Silt | 18.0 | 26.6 | 4.3 | 15 | 5 | 4.50E-08 |
| Resistant Silt | 18.0 | 26.6 | 4.3 | 15 | 50 | 1.40E-08 |
| Erodible Soft Clay | 17.7 | 26.4 | 8.2 | 15 | 0.1 | 3.16E-07 |
| Moderate Soft Clay | 17.7 | 26.4 | 8.2 | 15 | 5 | 4.50E-08 |
| Resistant Soft Clay | 17.7 | 26.4 | 8.2 | 15 | 50 | 3.16E-07 |
| Erodible Stiff Clay | 17.7 | 21.1 | 12.6 | 15 | 699.1 | 3.16E-07 |
| Moderate Stiff Clay | 17.7 | 21.1 | 12.6 | 15 | 5 | 4.50E-08 |
| Resistant Stiff Clay | 17.7 | 21.1 | 12.6 | 15 | 50 | 3.16E-07 |

1.5.12 Acknowledgements

The integration of the USDA-ARS Bank Failure and Toe Erosion Methods (BSTEM) in HEC-RAS has been a significant effort with multiple funding partners including:

- The Regional Sediment Management Program (USACE)
- The Missouri River Recovery Project (USACE)
- The Australian Rivers Institute
- The Flood and Coastal R&D Program (USACE)

HEC has also collaborated with and received code and/or technical guidance from:

- Andrew Simon PhD and Natasha Bankhead PhD (Cardno Entrix)
- Eddy Langendoen PhD and the USDA-ARS
- The US Bureau of Reclamation

The integration of HEC-RAS and BSTEM has been a substantial undertaking including multiple contributors in the USACE, the private sector, other Federal agencies, and even international interests. Andrew Simon (PhD - Cardno ENTRIX, formerly of USDA-ARS) partnered with HEC to initiate, envision and facilitate the integration. Eddy Langendoen (PhD - USDA-ARS) has provided essential technical support and advice throughout the process. The integration utilized code developed by Rob Thomas (PhD - University of Hull, formerly of University of Tennessee) and Yong Lai (PhD - USBR), funded by the Bureau of Reclamation and the Taiwanese Water Resources Agency, with input from Yavuz Ozeren (PhD - University of Mississippi). John

Shelly (PhD - NWK) and Paul Boyd (PhD - NWO) provided District guidance and feedback on the development. Stanford Gibson (PhD - HEC) and Steve Piper (RMA) worked on the integrated HEC-RAS code. Funding for the development, troubleshooting, and documentation of the integrated HEC-RAS/BSTEM product has come from multiple sources including two Corps's R&D Programs (Regional Sediment Management and Flood & Coastal Storm Damage Reduction), the Australia Rivers Institute, and the Missouri River Recovery Program.

1.6 Viewing Results

The sediment output has evolved over the years, keeping up with new output formats and visualization technology in HEC-RAS. This has led to an idiosyncratic output legacy, where each of the last three major releases have featured a new sediment visualization tool.

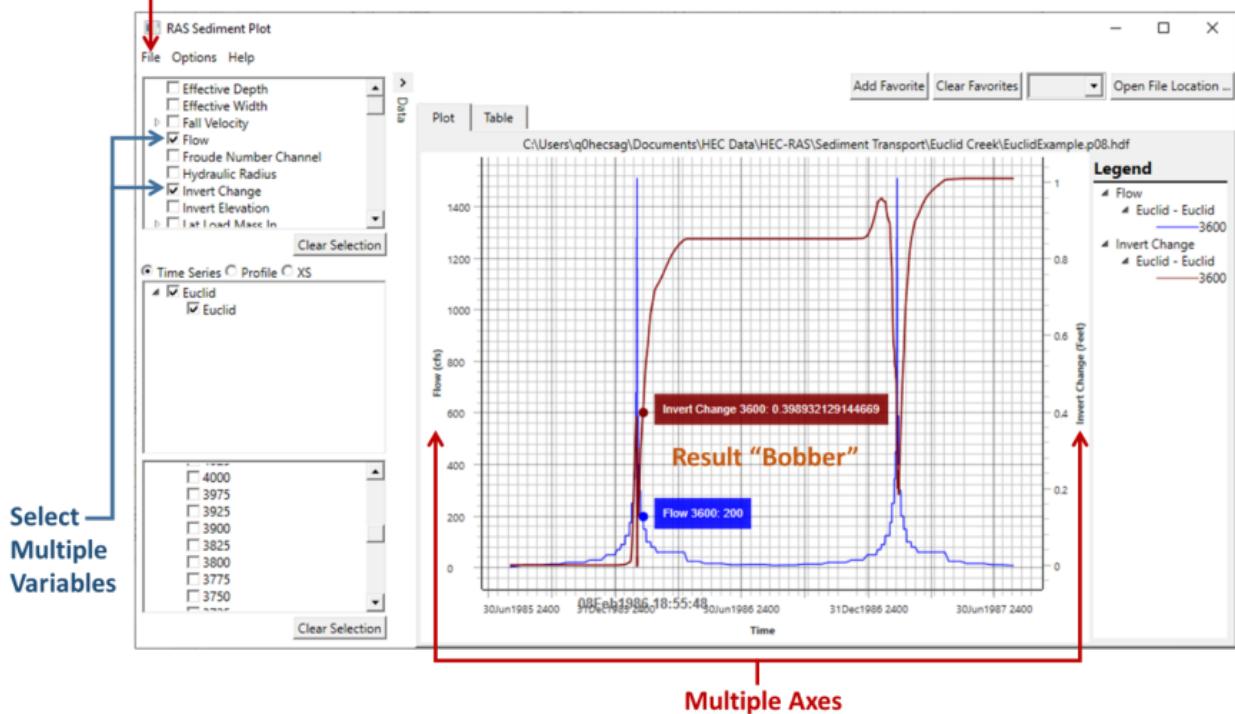
HEC-RAS writes detailed sediment and hydraulic output during sediment simulation and can display these results in three sets of plots and tables in spatial, temporal, or cross section formats. For most purposes, the new Sediment Results Viewer will be superior to the legacy plotters.

- [Sediment Results Viewer \(see page 259\)](#)
 - [Legacy Output \(see page 269\)](#)
 - [Output Variables \(see page 271\)](#)
 - [Visualizing HDF5 Results with R, Python, and Matlab \(see page 284\)](#)

1.6.1 Sediment Results Viewer

1.6.1.1 New Features in the New Sediment Results Viewer

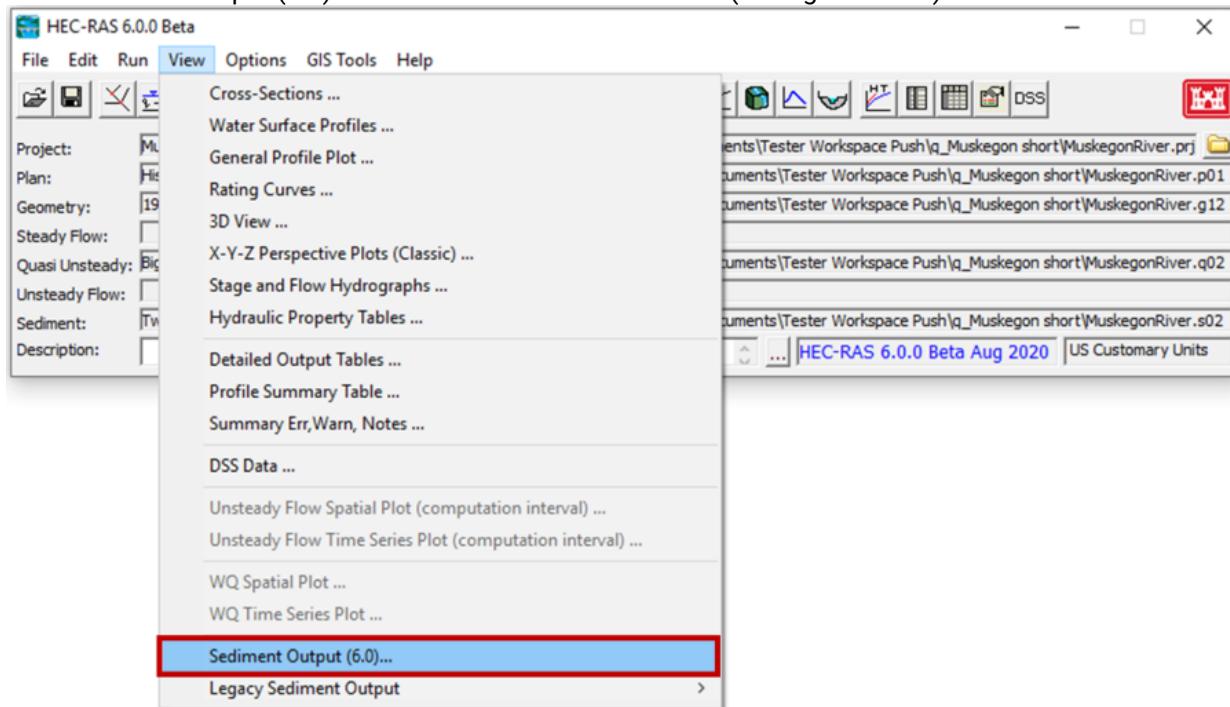
The sediment results viewer (new in HEC-RAS version 6.0) combines the advantages of the previous viewers and includes several new features. This new viewer allows users to view results from multiple sediment plans at the same time and view simultaneous time series results on separate axes – if they plot meaningfully on different scales.

View Multiple Plans

The new sediment results viewer has the same three modes that previous viewers had.

- Time Series
- Profile
- Cross section

There is no button on the main HEC-RAS editor to view sediment results. To access Sediment Results Select *ViewSediment Output (6.0)...* from the main HEC-RAS menu (see figure below).

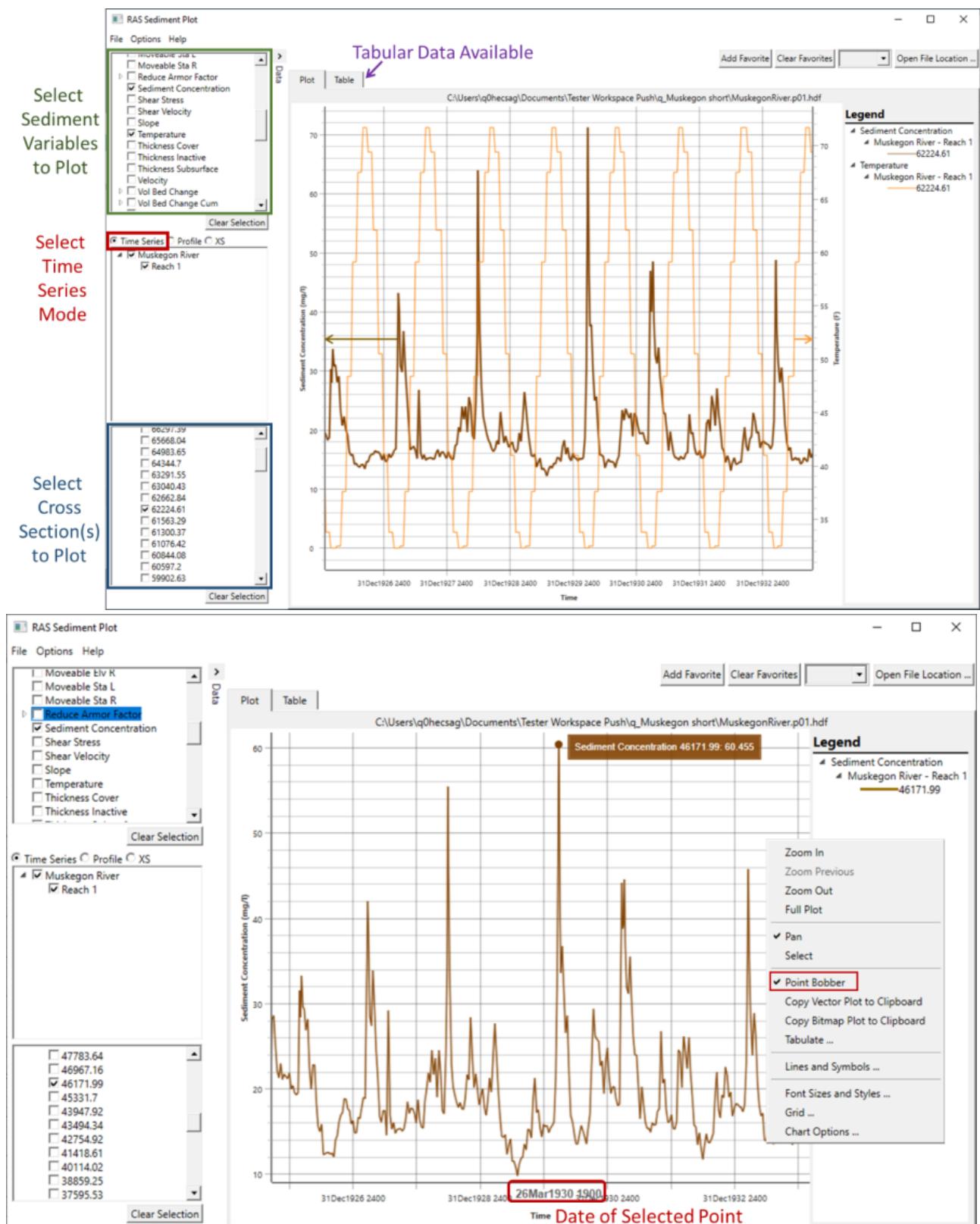


 Sorry, the widget is not supported in this export.
But you can reach it using the following URL:
<http://youtube.com/watch?v=n9gwCx2J3fg>

1.6.1.2 Time Series

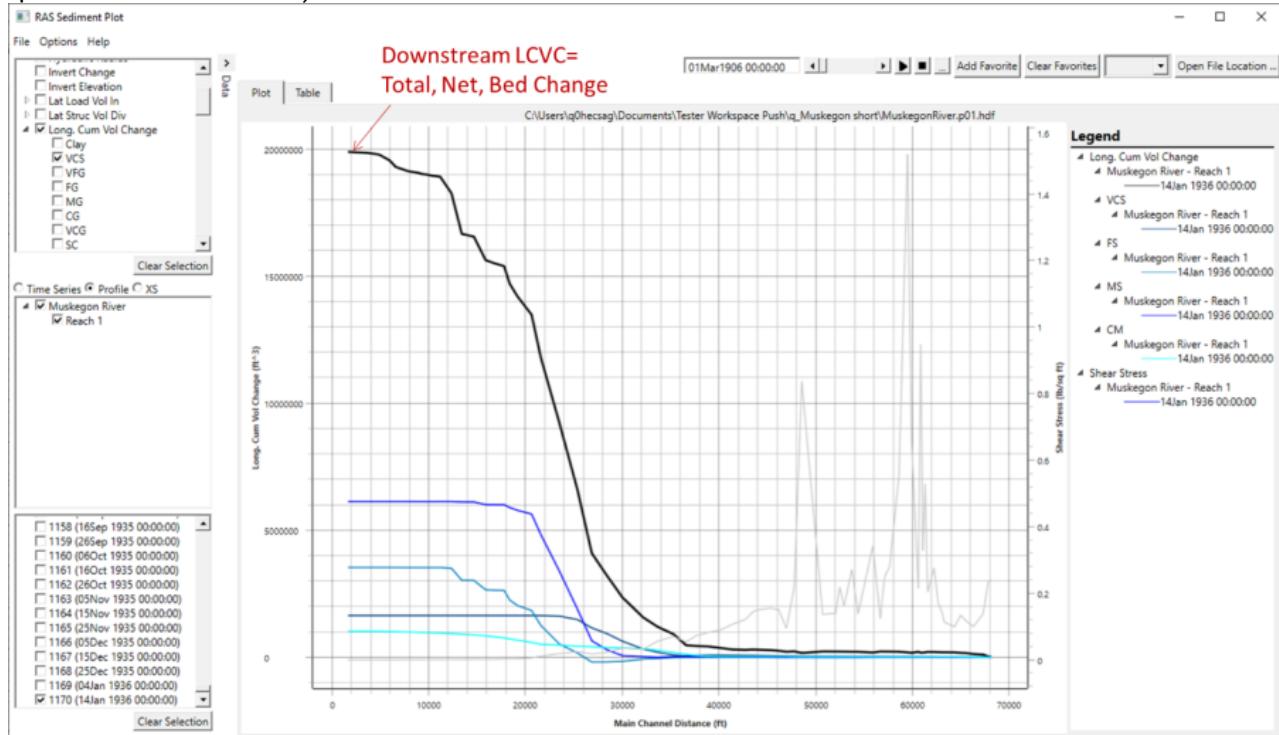
Time series results can be extremely valuable to analyze after a sediment transport simulation. To view sediment time series select the **Time Series** mode on the left bar of the Sediment Results Viewer. Then select one or more variables to plot in the upper left box and one or more cross sections to view them in the lower left box. The first figure below plots regular month-averaged temperature the model used and several years of concentration results for a single cross section. These results plot on separate axes (concentration left, temperature right) because they report in different magnitudes. The color scheme and line weights were edited (right click on plot and select **Lines and Symbols** to edit lines or add points). To get tabular data click on the **Table** tab.

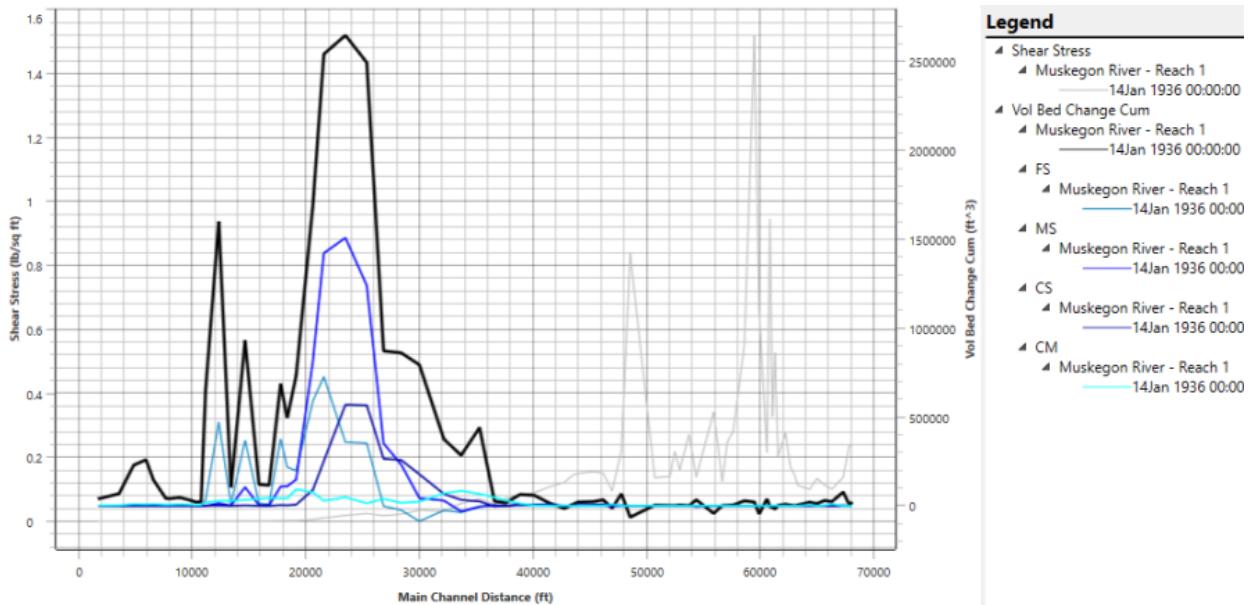
The second plot below demonstrates how to query the value and date of individual points from a time series plot. Right click on the plot and turn on the **Point Bobber**. Once the **Point Bobber** is on, you can hover over a location on the time series (like the peak concentration in the figure below) and the plotter will return the value and provide the date and time of the value along the time axis.



1.6.1.3 Profile

Profiles can be useful for several analyses, but they are used most often to evaluate bed change and bed gradation evolution. The figure below plots Longitudinal Cumulative Volume Change for a reservoir model (positive slope is deposition the downstream value is the total net bed change for the simulation) with several of the most important grain classes and shear stress (light grey). The results show the river deposits in the low shear backwater, and the grain classes deposit in different locations. The second plot shows the same results, but with the cumulative volume change (total for the simulation but not summed from upstream to downstream).



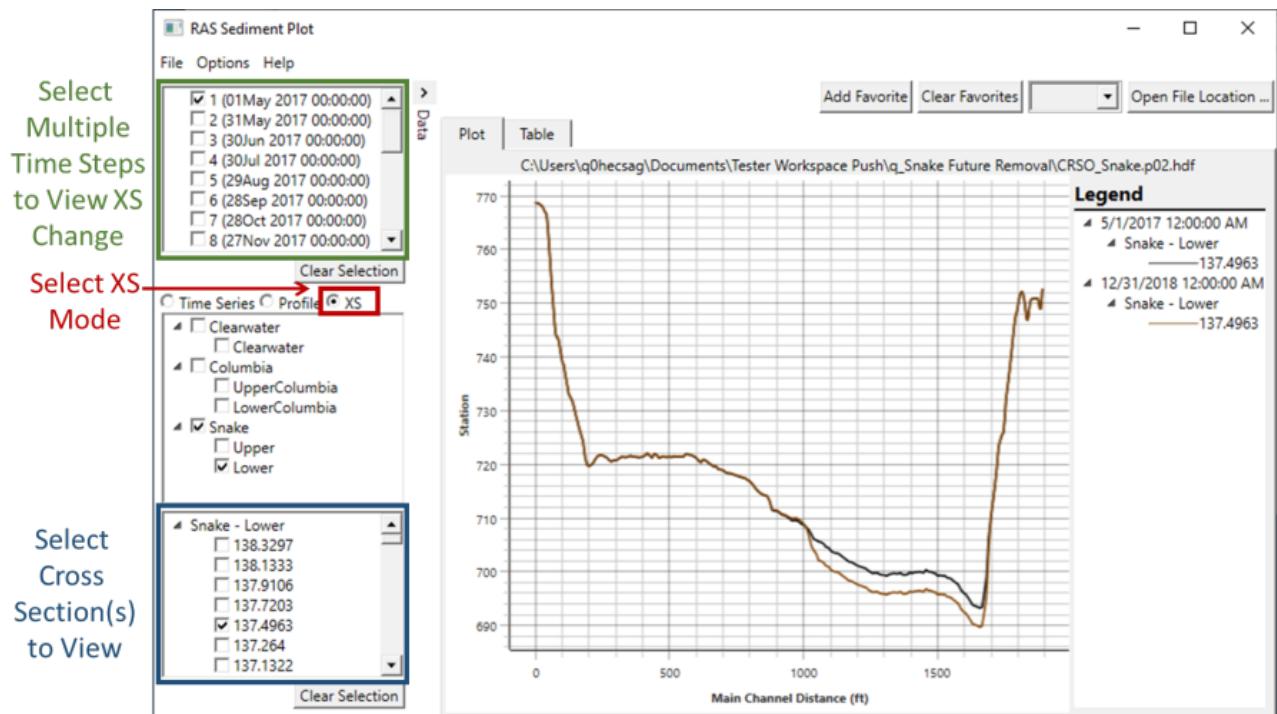


Modeling Note: Expect a Time Lag the First Time the Plotter Accesses Profile Data

The HEC-RAS data model makes retrieving time series data much faster than retrieving profile data. Therefore, profile data can lag more than time series data in the sediment viewer. This should only happen the first time you request a particular profile variable. HEC-RAS will generate a sub-folder with a transposed results file, that the plotter can access more efficiently if the modeler requests the profile data again.

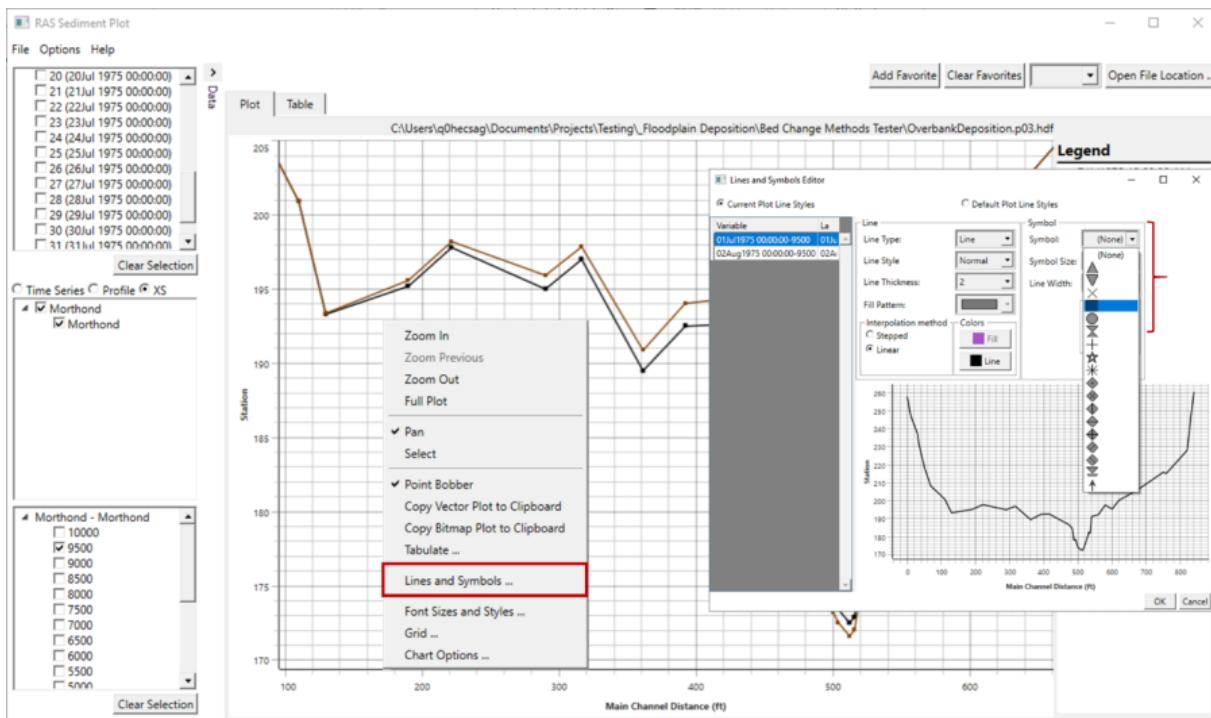
1.6.1.4 Cross Sections

Cross section change is one of the central features of a mobile boundary sediment transport model. Reviewing cross section change is also one of the easiest way to identify numerical artifacts and unintended consequences of modeling choices, making models more realistic and robust. To view cross section change select XS button in the left pane of the Sediment Plotter. The upper pane will populate the time stamps that HEC-RAS generated cross section output and the lower left pane lists the cross sections available to view. Plot the cross sections at multiple time steps to help visualize cross section change. It is important to view at least the final cross section shapes to make sure that erosion and deposition were simulated in physically believable patterns.



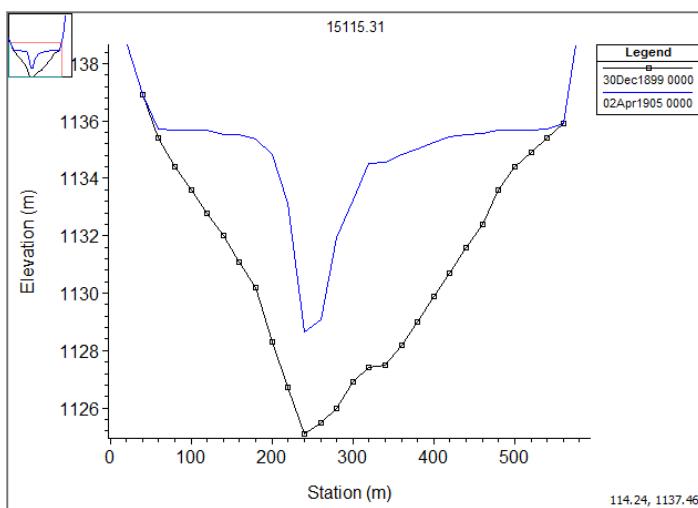
Modeling Note: Station Elevation Points

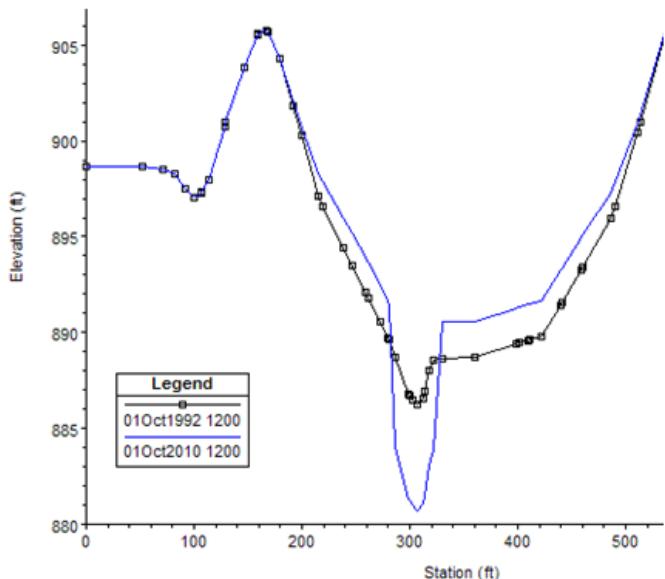
The sediment results viewer only includes lines (no points) by default. Points take require more resources to render, slowing the plotter down substantially. But station-elevation points are often helpful when viewing cross section results. To turn points on, right click on the results, and select **Lines and Symbols** (see figure below).



Modeling Note: Invert Change Limitation

This can return good results and is appropriate for scour chains but can also lead to data distortions and does not optimize the value of repeated cross sections or bathymetry data. Computing mass or volume change from repeated cross sections or bathymetry and comparing to **Mass/Vol Bed Change CUM or Longitudinal Mass/Vol Change** is better modeling practice. (Units: ft or m).





85 Common bed change results where invert change does not capture actual morphological change.

1.6.1.5



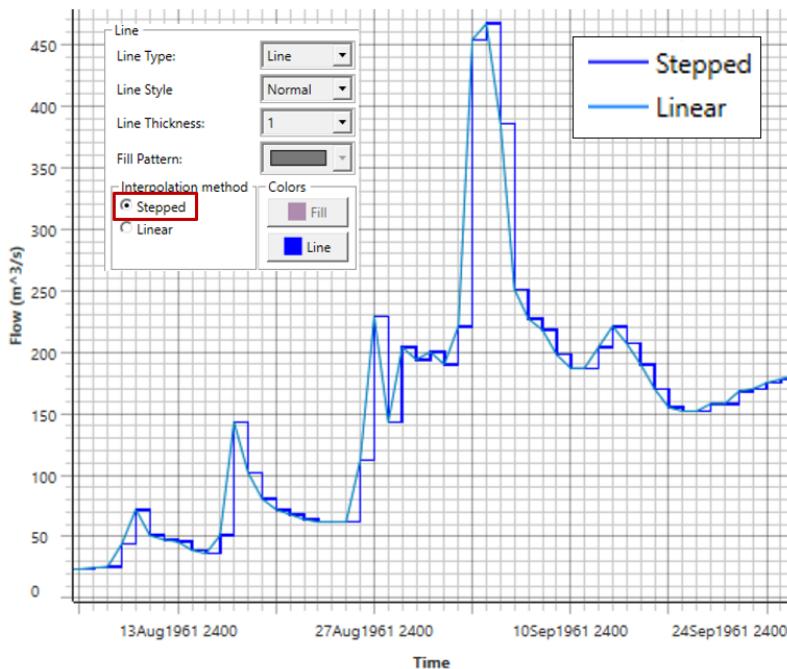
Sorry, the widget is not supported in this export.
But you can reach it using the following URL:

<http://youtube.com/watch?v=C9d4e-XCWIs>

1.6.1.6 Using Stepped Interpolation to View Quasi-Unsteady Results

The sediment results viewer has two interpolation approaches. The default **Linear** approach draws a straight line between the plotted value at the beginning of the time steps. **Stepped** "interpolation," does not interpolate. The **Stepped** feature holds the result value constant over the entire time step that it represents.

Most hydrologic and hydraulic time series in HEC-RAS interpolate. However, Quasi-Unsteady flow is a series of steady flows. So the **Stepped** result can sometimes reflect or report quasi-unsteady results in helpful ways.



Wish List

Plot Water Surface and Movable Bed Limits with Cross Section Results

Wish List

We would like to provide several additional sediment results

- Standard Rating Curves
- User Defined Result Rating Curves (variable 1 vs variable 2, variable 3)
- Sediment gradation curves (particle size vs % finer)
- Gradation over space and time (temporal or longitudinal area plot of grain class %)
- Heat map in time-cross section space (where result magnitude is represented by the color intensity in a time-space plot)
- Specific gage output (plot the water surface elevations associated with defined flow ranges over time)

Wish List

Integrate sediment results into standard HEC-RAS viewers (Rating Curve, generalized profile, hydrograph, etc...)

1.6.1.7 Legacy Output

Moving to the new sediment plotter is highly recommended. However, because some users are comfortable and familiar with the old viewers, and because they may have workflows that depend on them, HEC has made them available in the recent release.

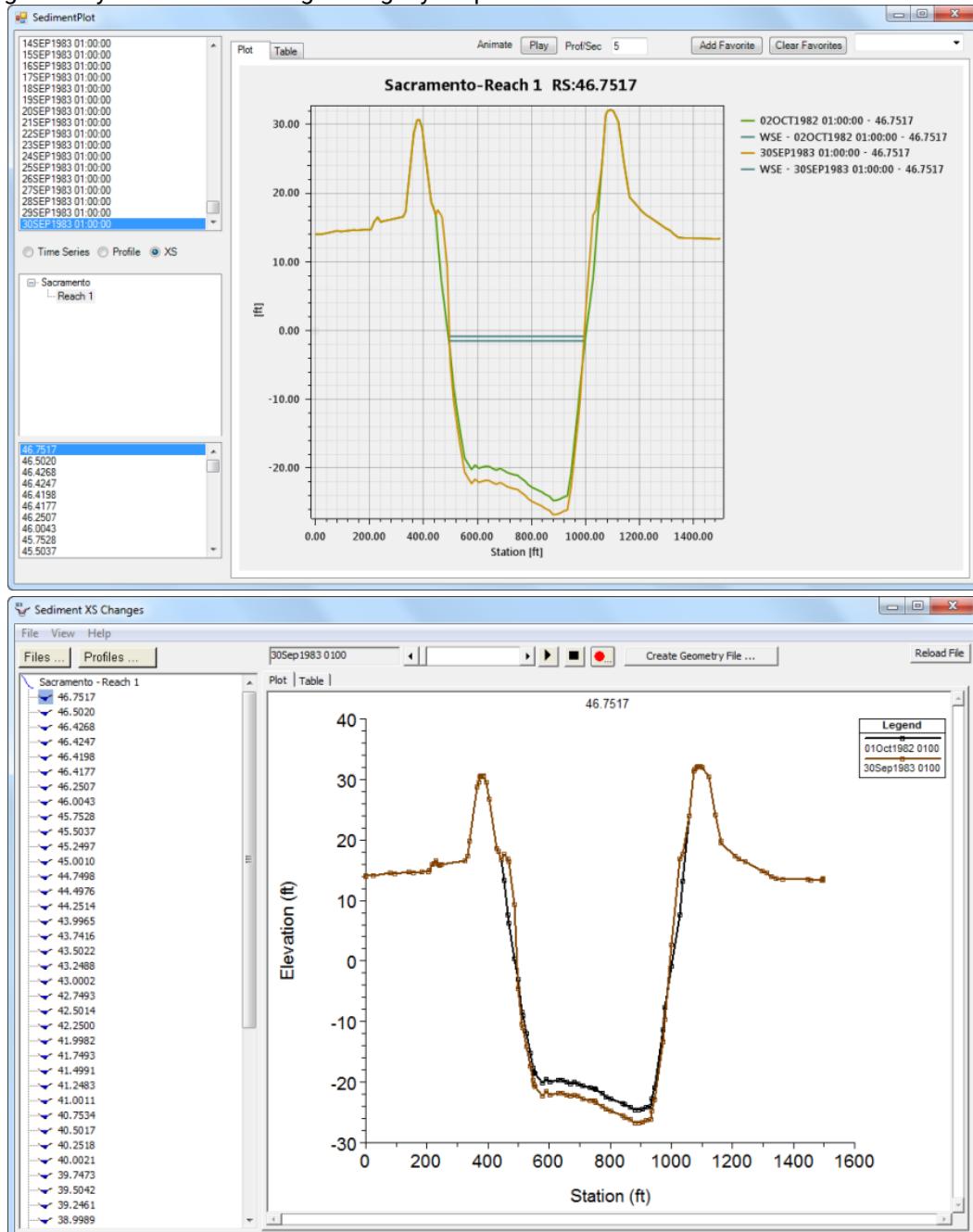
1.6.1.7.1 Table: Comparative Advantages and Disadvantages of the two legacy Sediment Plots

| 5.0 Legacy Output | 4.x Legacy Output |
|--|---|
| Reads from HDF5, so it can read very large output files (tested on files >64GB) quickly. Reads all unsteady sediment output at any interval. | Will not open files greater than 2GB or unsteady sediment files with more than 1 computation increment per profile. Large files that do open, are sluggish. There are simply some files that the old output cannot read, making the new output the only option. |
| Recording animation requires external software (e.g. Snagit). | Built in video recording. |
| Default line color and weight. | More control over line color and weight. |
| Only plots one reach and variable at a time. | Plots multiple variables and reaches on the same plot. |
| Better cross section and profile selection tools. | Users can only create new geometry files from the old sediment cross section editor. |
| Plots water surface elevation and BSTEM nodes (Toe and Movable Bed Limits) with Cross Sections | |
| Available at the end of a simulation. No intermediate output if the simulation crashes. | Output available as the simulation run. Allows troubleshooting if the model crashes. |

Stores favorites.

The main utility of the legacy output is that users can open the the 4.x output during a run and review results before the simulation completes.

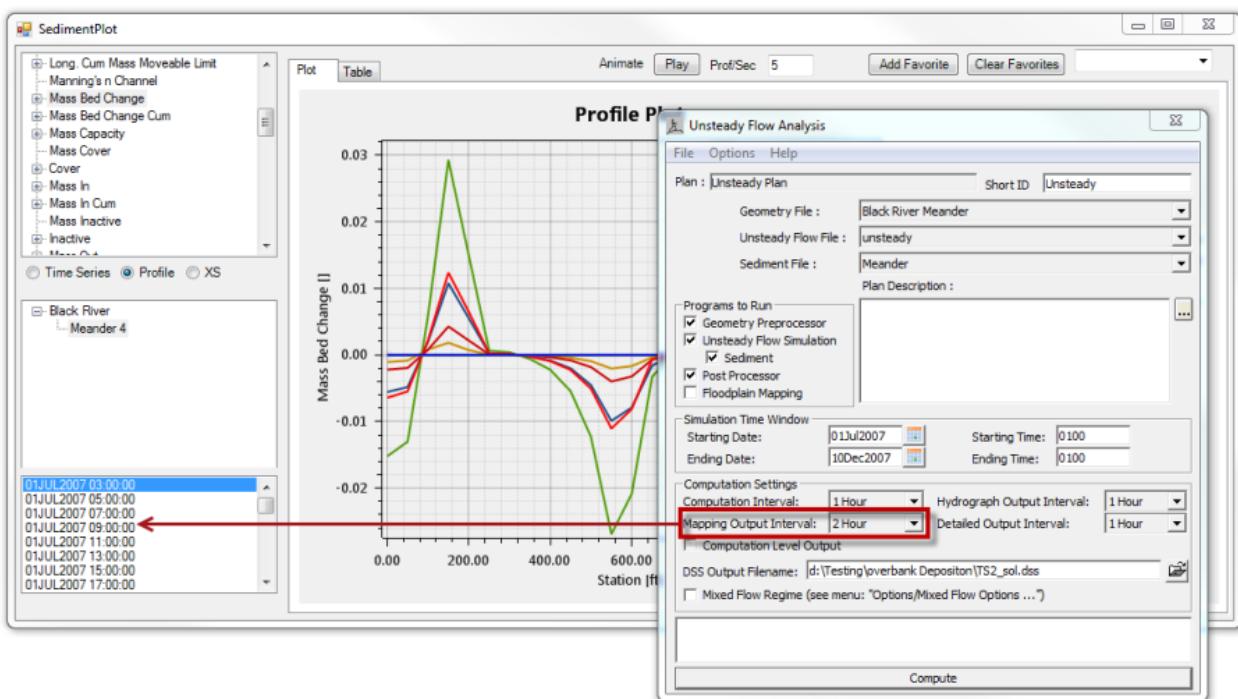
The 4.x cross section viewer also has a feature that used to be the only way to generate new geometry files from updated cross sections. However, current versions of HEC-RAS has a tool available in the Sediment Output Options menu to [Create Geometry Files From Sediment Results](#) (see page 214) so users can create new geometry files without using the legacy output viewers.



1.6.1.7.2 Unsteady Sediment Output

The new HDF5 *unsteady* sediment output is controlled by the but the **Mapping Output Interval** in the **Unsteady Flow Analysis** window (below), not the [Sediment Output Options](#) (see page 186) editor. The legacy ("old") time series and profiles generally do not work for unsteady sediment runs. However, setting the output interval to 1 (**Error! Reference source not found.**) will often get HEC-RAS to write these data files for unsteady transport.

The **Computational Level Output** is generally very useful for trouble shooting unsteady sediment simulations. However, HEC-RAS can only write Unsteady Computation Output or the legacy sediment data. HEC-RAS will not write the legacy sediment output if the **Computational Level Output** is selected. View sediment output with the new HDF5 viewer.



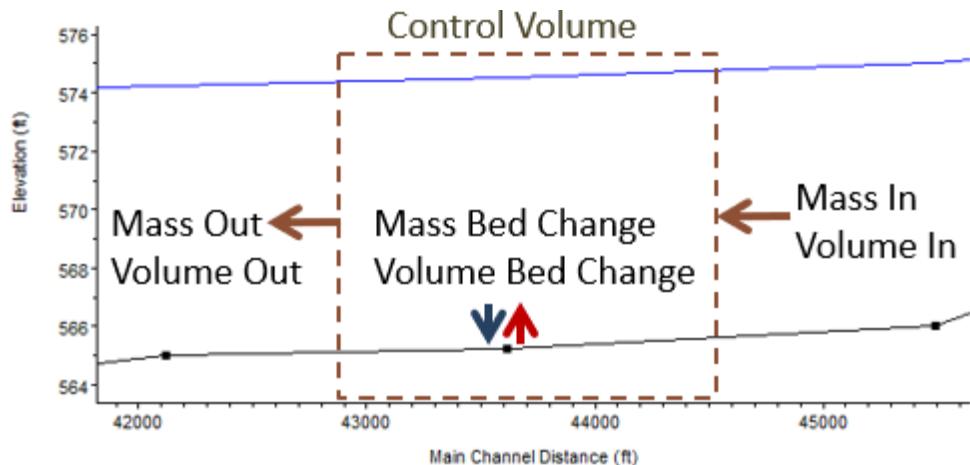
1.6.1.7.3 Favorites Plot

Sediment modeling work flow often involves accessing the exact same plot or table after each simulation. Selecting the same variables, cross sections and time step form the long lists of available options each time can be time consuming. To improve this work flow, the new HDF5 **Sediment Output** viewer includes a favorite option. Select the commonly accessed plot and then press the **Add to Favorites** button. Name the plot. HEC-RAS will add this name to the Favorites drop down box, and will automatically reconstruct the plot (and table) when it is selected.

1.6.2 Output Variables

The description of the variables in each output level in the [Output Level Section](#) (see page 271) describes each output variable, categorized by available level. The Output Variables are listed here in alphabetical order with more description, example visualizations, and modeling notes.

Two types of output, control volume terms (Mass In, Out, and Bed Change) and the results associated with each layer in the different bed mixing options are depicted in the Figures below.



| Active Layer Method | Thomas and Copeland Methods |
|---|--|
| Mass Active Volume Active Thickness Active $d_{10}, d_{16}, d_{50}, d_{84}, d_{90}$ Active | Mass Cover Volume Cover Thickness Cover $d_{10}, d_{16}, d_{50}, d_{84}, d_{90}$ Cover Reduce Armor Factor |
| Mass Inactive Volume Inactive Thickness Inactive $d_{10}, d_{16}, d_{50}, d_{84}, d_{90}$ Inactive | Mass Subsurface Volume Subsurface Thickness Subsurface $d_{10}, d_{16}, d_{50}, d_{84}, d_{90}$ Subsurface |

1.6.2.1 Sediment Transport Output Variables

| Variable Name | Units (U S/ SI) | Description |
|----------------------|-----------------|---|
| Active Thickness | ft/m | Thickness of the active layer at the start of each computational time step. Used in the simple active layer bed sorting and armoring routine. |
| Armor Reduction: All | fraction | Fraction that the total sediment transport capacity is reduce to, based on the concepts of a cover layer computation. |

| Variable Name | Units (U S/ SI) | Description |
|---|---|--|
| Armor Reduction: Class 1-20 | fraction | Fraction for each individual grain size, that the transport capacity is reduced to, based on the concepts of a cover layer computation. |
| Ch Froude Num | - | Main channel Froude number at the end of the current computational time step. |
| Ch Invert El | ft/m | Minimum elevation of the main channel at each output time step. |
| Ch Manning n | s/ft ^{1/3} s/m ^{1/3} | Main channel Manning's n value. |
| Cover Thickness | ft/m | Thickness of the cover layer at the end of each computational time step. Used in the Exner 5 bed sorting and armoring routine. |
| d ₁₆ Cover/Subsurface /Inactive | ft | The 16 th percentile particles size of the specified mixing layer. Some practitioners prefer the d ₁₆ to d ₁₀ because it is two standard deviations below the mean. |
| d ₈₄ Cover/Subsurface /Inactive Layers | - | The 84 th percentile particles size of the specified mixing layer. Some practitioners prefer the d ₈₄ to d ₉₀ because it is two standard deviations above the mean. |
| d ₅₀ Active | mm | d ₅₀ of the active layer of the simple active layer bed sorting and armoring routine. |
| d ₅₀ Cover | mm | d ₅₀ of the cover layer at the end of the computational increment. Used in the Exner 5 bed sorting and armoring routine. |
| d ₅₀ Inactive | mm | d ₅₀ of the inactive layer at the end of each computational time step. Used in the Exner 5 and simple active layer bed sorting and armoring routine. |

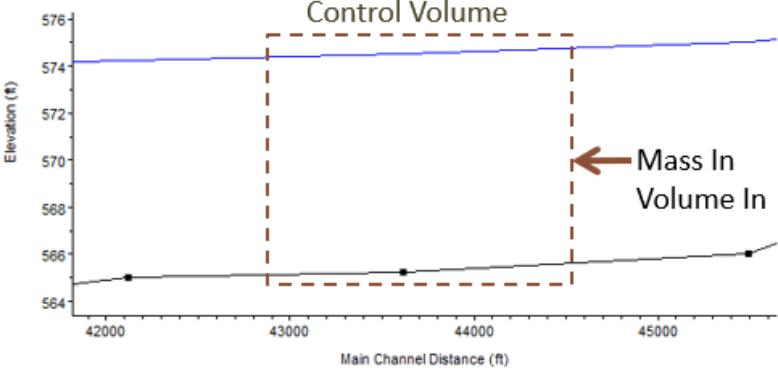
| Variable Name | Units (U S/ SI) | Description |
|----------------|-------------------------------------|---|
| d50 Subsurface | m m | d50 of the surface layer material at the end of the computational time step. Used in the Exner 5 bed sorting and armoring routine. |
| d90 Active | m m | d90 of the active layer of the simple active layer bed sorting and armoring routine. |
| d90 Cover | m m | d90 of the cover layer at the end of the computational increment. Used in the Exner 5 bed sorting and armoring routine. |
| d90 Inactive | m m | d90 of the inactive layer at the end of each computational time step. Used in the Exner 5 and simple active layer bed sorting and armoring routine. |
| d90 Subsurface | m m | d90 of the surface layer material at the end of the computational time step. Used in the Exner 5 bed sorting and armoring routine. |
| Dredge Vol Cum | ft ³ / m ³ | Total volume of sediment removed from each cross section by the dredging routines. |
| Eff Depth | ft/ m | Effective depth of the water in the mobile portion of the cross section, at the end of the computational time step. |
| Eff Width | ft/ m | Effective width of the water in the mobile portion of the cross section, at the end of the computational time step. |
| EG Slope | ft/ ft m/ m | Slope of the energy grade line at each output time step. This can be a point value at the cross section or an average value between cross sections. |
| Fall Velocity | ft/ s / m/ s | Reports the fall velocity computed for each grain class. Also reports a "total" fall velocity which is a weighted average |

| Variable Name | Units (U S/ SI) | Description |
|-------------------------|--|---|
| Flow | ft ³ /s / m ³ /s | Total flow at the cross section for each output time step. |
| Hydraulic Radius | – | The area of the channel (the part of the cross section between the movable bed limits) divided by the wetted perimeter of the channel. |
| Invert Change | ft/m | The total change in the invert (the lowest elevation station-elevation point between the bank stations) since the beginning of the simulation. |
| Invert Elevation | ft/m | The elevation of the channel invert of each cross section – the lowest elevation between the channel banks. |
| Invert Elevation Max | ft/m | The maximum channel invert (lowest elevation point between the channel banks) since the beginning of the simulation. |
| Invert Elevation Min | ft/m | The minimum channel invert (lowest elevation point between the channel banks) since the beginning of the simulation. |
| Lateral Load Mass | ton s/ ton ne s | This variable records the sediment entering the model through |
| Lateral Load Vol | ft ³ /m ³ | lateral boundary conditions at each cross section and time step. It is only the lateral loads for the computation increment, not a cumulative value. Total and by grain class. |
| Lateral Structural Mass | ton s/ ton ne s | This tracks the sediment mass that is removed from each control volume (or added) by sediment associated with flow over a lateral structure (see page 271). Total and by grain class. |

| Variable Name | Units (U S/ SI) | Description |
|-------------------------------|----------------------------------|--|
| Lateral Structural Vol | ft ³ / m ³ | This tracks the sediment volume that is removed from each control volume (or added) by sediment associated with flow over a lateral structure (see page 271). Total and by grain class. |
| Long. Cum Mass change | ton s/ ton ne s | Total change in bed mass (or Volume), cumulative in space and time. Spatial accumulation is from the current cross section to the upstream end of the river reach in which this cross section resides. |
| Long. Cum Mass Movable Limits | ton s/ ton ne s | Sums the mass or volume change from the beginning of the simulation and from upstream-to-downstream, so that the downstream cross section at the last time step of the Longitudinal Cumulative Mass Curve (LCMC) is a summary of the total aggradation or degradation in that reach for the simulation. Comparing the full LCMC (or LCVC) to this one, that only reports the result in the movable bed limits, is a helpful way to differentiate between overbank and channel processes (e.g. determine what percentage of deposition is floodplain deposition or identify overbank deposition offsetting channel erosion). (Total and by grain class) |
| Mass Bed Change | | |
| Mass Bed Change | ton s/ ton ne s | Incremental total mass change in the bed for the current computational time step. |

| Variable Name | Units (U S/ SI) | Description |
|---------------------------------|------------------------|--|
| Mass Bed Change: Class 1–20 | ton s/ tonnes | Incremental mass change in the bed for the current time step. |
| Mass Bed Change Cum | ton s/ tonnes | Cumulative mass of the change in the bed elevation over time. |
| Mass Bed Change Cum: class 1-20 | ton s/ tonnes | Cumulative mass of the change in bed elevation over time, per grain size fraction (Bins 1 – 20). This only displays the size fraction bins that are being used. |
| Mass Bed Change Cum: Max | ton s/ tonnes | The maximum (positive) deposition in mass or volume since the beginning of the simulation. This result is monotonic. It only increases with time. |
| Mass Bed Change Cum: Min | (tons) | The maximum negative mass or volume change since the beginning of the simulation. This result is monotonic. It only decreases (larger negative value) with time. |
| Mass Capacity | ton s/ day tonnes/ day | Transport capacity in total mass at the current computational time step. |

| Variable Name | Units (U S/ SI) | Description |
|---------------------------|---------------------------|--|
| Mass Capacity: Class 1-20 | ton s/ day tonnes/ day | Transport capacity in mass, by grain size fraction, at the current computational time step. |
| Mass Cover | ton s/ tonnes | Total tons of material in the cover layer at the end of each computational time step. Used in the Exner 5 bed sorting and armoring routine. |
| Mass Cover: Class 1-20 | ton s/ tonnes | Tons of material in the cover later at the end of each computational time step, by individual grain size fraction. Used in the Exner 5 bed sorting and armoring routine. |
| Mass Dredge Cum | ton s/ tonnes | The total mass or volume dredged from that cross section since the beginning of the simulation. |
| Mass Inactive | ton s/ tonnes | Total tons of material in the inactive layer at the end of each computational time increment. |
| Mass Inactive: Class 1-20 | ton s/ tonnes | Tons of material in the inactive layer at the end of each computational increment, by individual grain size fraction. |

| Variable Name | Units (U S/ SI) | Description |
|-------------------------|-----------------|--|
| Mass In | | |
| | |  |
| Mass In | ton s/ ton ne s | Total sediment mass, for all grain size classes, coming into the sediment control volume, per individual computational time step. |
| Mass In: Class 1-20 | ton s/ ton ne s | Sediment mass entering the sediment control volume per grain size fraction, per computational time step by individual grain size fraction. |
| Mass In Cum | ton s/ ton ne s | Cumulative total sediment mass entering the sediment control volume for a specific cross section since the beginning of the simulation. |
| Mass In Cum: Class 1-20 | ton s/ ton ne s | Cumulative sediment mass entering the sediment control volume per grain size fraction, at a cross section since the beginning of the simulation. |

| Variable Name | Units (U S/ SI) | Description |
|--------------------------|-----------------|---|
| Mass Out | | |
| | | |
| Mass Out | ton s/ ton ne s | Total sediment mass, for all grain size classes, going out of the sediment control volume, per individual computational time step. |
| Mass Out: Class 1-20 | ton s/ ton ne s | Sediment mass leaving the sediment control volume per grain size fraction, per computational time step. |
| Mass Out Cum | ton s/ ton ne s | Cumulative total sediment mass leaving the sediment control volume for a specific cross section since the beginning of the simulation. |
| Mass Out Cum: Class 1-20 | ton s/ ton ne s | Cumulative sediment mass leaving the sediment control volume per grain size fraction, at a cross section since the beginning of the simulation. |

| Variable Name | Units (U S/ SI) | Description |
|-----------------------------|-----------------|---|
| Mass Subsurface | ton s/ ton ne s | Total tons of material in the surface layer at the end of each computational time step. |
| Mass Subsurface: Class 1-20 | ton s/ ton ne s | Tons of material in the surface layer at the end of each computational time step, by individual grain size fraction. |
| Mean Eff Ch Invert | ft/ m | Average channel invert elevation computed by subtracting the effective depth of the main channel from the water surface elevation. |
| Mean Eff Ch Invert Change | ft/ m | Change in the average channel invert elevation, which is computed by subtracting the effective depth of the main channel from the water surface elevation. |
| Movable Elv L and R | ft/ m | These are the elevations of the movable bed limits. Tracking the MBL movement relative to the channel can be useful, but these are mainly used to track toe migration in BSTEM models. |
| Movable Sta L and R | ft/ m | These are the stations (lateral stations of the station-elevation points) of the movable bed limits. These will remain constant unless the cross section has BSTEM parameters. Only the BSTEM algorithms move cross section station-elevation points laterally. |
| Reduce Armor Factor | -- | The Armor Reduction Factor determines how effective the cover layer is in the Thomas and Copeland mixing algorithms. It is the "Armoring Ratio" ⁴⁰ in Figure 217 and Figure 220. HEC-RAS multiplies the capacity deficit of each grain class by this ratio (computed from the "equivalent particle diameters" of coarser particles in the cover layer). An armor ratio of 1 is no armoring, 0 is complete armoring (for that grain class) and anything in between is partial armoring. |

40 https://www.hec.usace.army.mil/confluence/display/_Armoring_Ratio

| Variable Name | Units (U S/ SI) | Description |
|------------------------|-------------------------|---|
| Sediment Concentration | (m g/l) | Total sediment concentration in mg/liter leaving of the sediment control volume at the end of the computational time step. This parameter is computed from the Mass Out and Flow results. Converting to concentration removes time from the result and allows comparison to sample durations that do not match the time step. |
| Sediment Discharge | ton s/day tonnes/day | Total sediment discharge in tons/day leaving of the sediment control volume for a specific cross section, per individual computational time step. This is the Mass Out variable normalized to a daily flux. |
| Shear Stress | lb/sq ft Pa | Average shear stress of the movable portion of the bed at each time step. |
| Shear Velocity u* | ft/s m/s | Shear velocity. Used in Shields diagram and several sediment transport potential equations. |
| Slope | - | This is the Energy Slope used in the shear stress equation, which is either computed locally at the cross section $(Q/\text{Conveyance})^{0.5}$ or the slope between the EGLs at the bounding cross sections. |
| Subsurface Thickness | ft/m | Thickness of the surface layer at the end of each computational time step. Used in the Exner 5 and simple active layer bed sorting and armoring routine. |
| Temperature | °F/°C | Water temperature. Current versions of the model only allow one temperature per time step, so this can vary in time but not space. |
| Thickens Inactive | ft/m | The vertical thickness of the deepest layer of the bed mixing (sorting and armoring) algorithm. All three methods use the same terminology for this. |

| Variable Name | Units (U S/ SI) | Description |
|----------------------|------------------------|--|
| Thickness Cover | ft/m | The vertical thickness of surficial layer of the bed mixing (sorting and armoring) algorithm. This is the Active Layer or the Cover Layer (in the Thomas or Copeland mixing methods). |
| Thickness Subsurface | ft/m | The vertical thickness of an intermediate layer between the cover and inactive layer in the Thomas and Copeland mixing algorithms. The Active Layer method does not have a comparable layer. |
| Toff Zone Capacity B | ton s/ day tonnes/ day | The "Bed Zone" portion of the Toffaleti transport capacity. This is the MPM capacity if the Toffaleti-MPM function is selected. |
| Toff Zone Capacity L | ton s/ day tonnes/ day | The Toffaleti transport capacity computed in the "Lower Zone" – approximately the bottom 8-9% of the water column, excluding the bed zone. Only written if the Toffaleti function is selected. |
| Toff Zone Capacity M | ton s/ day tonnes/ day | The fraction of the Toffaleti transport capacity computed in the "Middle Zone" – approximately 31% of the water column in the zone between 1/2.5 Depth and 1/11.24 Depth (from the bottom of the channel). Only written if the Toffaleti function is selected. |

| Variable Name | Units (U S/ SI) | Description |
|-----------------------|--------------------------|--|
| Toffa Zone Capacity U | ton s/ day ton ne s/ day | The fraction of the Toffaleti transport capacity computed in the "Upper Zone" – the top 60% (above 1/2.5 Depth from the bottom) of the water column. Only written if the Toffaleti function is selected. Modelers sometimes compare the upper three zones of Toffaleti Capacity to suspended load measurements (which exclude bed load). |
| Velocity | ft/ s m/ s | Average water velocity between the movable bed limits for each time steps. |
| Water Surface | ft/ m | The water surface elevation at that at the cross section during the time step. |

1.6.3 Visualizing HDF5 Results with R, Python, and Matlab

1.6.3.1 Reading HEC-RAS HDF5 Results with R

Multiple packages read HDF5 data into R. The sample code below uses the Bioconductor package, available at: www.bioconductor.org⁴¹.

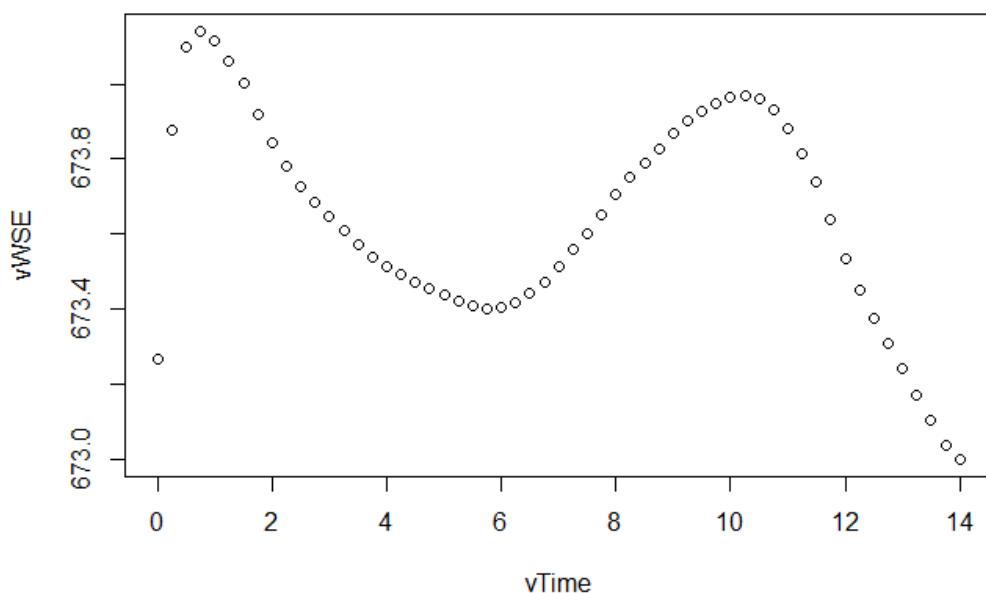
1.6.3.1.1 Reading Results Matrix

The easiest way to deal with HEC-RAS results in R involves reading a time-space result matrix directly into an R dataframe and then interacting with the dataframe. The simplest data call involves defining a path to the HDF output file and an HDF path to the result.

For example, the following arguments import all of the water surface elevations, for all cells into a dataframe:

⁴¹ <http://www.bioconductor.org>

```
FilePath<-“C:\\\\Users\\\\q0hecsag\\\\Documents\\\\Projects\n2D Sediment\nTestFile.p02.hdf”\n dfWSE<-h5read(FilePath,”/Results/Unsteady/Output/Output Blocks/Base Output/Unsteady Time Series/2D\nFlow Areas/Chippewa/Water Surface”)\n To plot stage hydrograph at a specific cell (e.g. to compare with observed data):\n vTime<-h5read(DynamicPath,”/Results/Unsteady/Output/Output Blocks/Base Output/Unsteady Time Series/\nTime”)\n vWSE<-dfWSE[Cell,]\n plot (vTime,vWSE)
```



(Note: vTime is just the relative time from the beginning of the simulation. The next section describes how to format HEC-RAS formatted date-time data)

1.6.3.1.2 Formatting HEC-RAS Date-Time Data in R

The HDF5 Data in HEC-RAS include two time results that match the rows of the result matrix.

Cells →

| | 0 | 1 | 2 | 3 | 4 |
|----|---------|---------|-----------|-----------|---------|
| 0 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 1 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 2 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 3 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 4 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 5 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 6 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 7 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 8 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 9 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 10 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |
| 11 | 701.125 | 701.125 | 700.66895 | 700.66895 | 700.875 |

| | | |
|----|------------|-----------------------|
| 0 | 0.0 | 0 02APR2019 00:00:00 |
| 1 | 0.24999... | 1 02APR2019 06:00:00 |
| 2 | 0.50000... | 2 02APR2019 12:00:00 |
| 3 | 0.75000... | 3 02APR2019 18:00:00 |
| 4 | 0.99999... | 4 03APR2019 00:00:00 |
| 5 | 1.24999... | 5 03APR2019 06:00:00 |
| 6 | 1.49999... | 6 03APR2019 12:00:00 |
| 7 | 1.74999... | 7 03APR2019 18:00:00 |
| 8 | 1.99999... | 8 04APR2019 00:00:00 |
| 9 | 2.24999... | 9 04APR2019 06:00:00 |
| 10 | 2.49999... | 10 04APR2019 12:00:00 |
| 11 | 2.74999... | 11 04APR2019 18:00:00 |

Time is the relative, elapsed, time since the beginning of the simulation. This is a simple approach. R can interpret **Time** as a numerical vector and can plot any column (Cell or XS) of any of the results against it without further formatting.

However, plotting against absolute time is often better, particularly when comparing to observed data with their own time reference. R will import the **Time Date Stamp** as a *string* vector. You must define the date format to convert this to a date⁴².

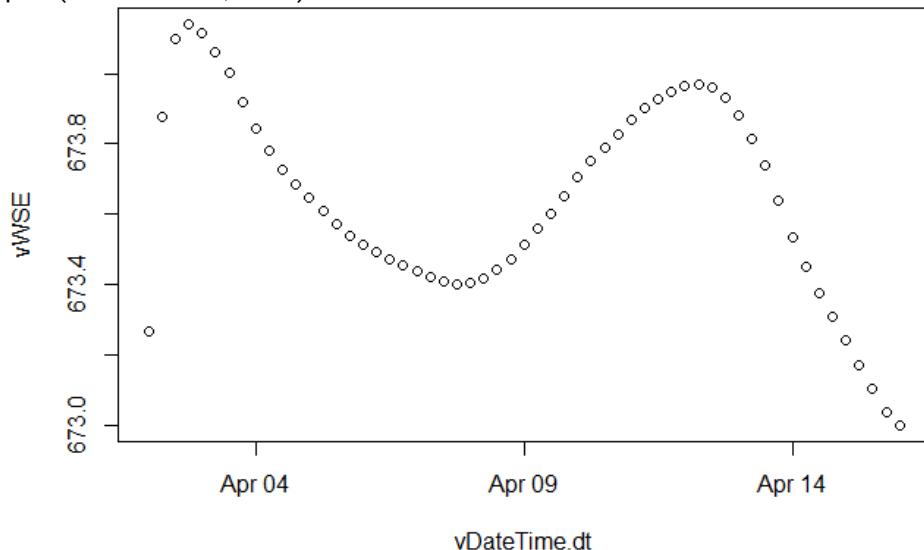
One way to convert the HEC-RAS date format is:

```
vDateTime.dt<-strptime(vDateTime(),"%d%b%Y %H:%M:%S")
```

where vDateTime() is the **Time Date Stamp** vector extracted from the HDF file.

42 <https://stat.ethz.ch/R-manual/R-devel/library/base/html/strptime.html>

Then you can plot against these absolute dates, for example:
 plot (vDateTime.dt,vWSE)

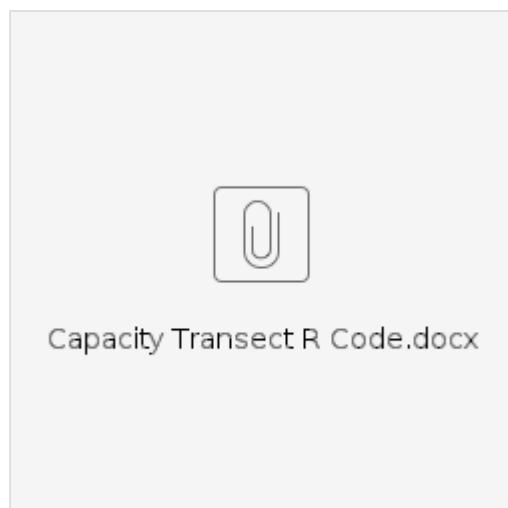


1.6.3.2 Reading HEC-RAS HDF5 Results with Python

Dysarz (2018)⁴³ Dysarz, T. (2018) Application of Python Scripting Techniques for Control and Automation of HEC-RAS Simulations, *Water*, 10(10):1382, doi: 10.3390/w10101382. includes sample code that accessed sediment HDF5 data from Python.

1.6.3.3 Example Code

Examples of third-party scripts that users developed to interact with HEC-RAS results are included below.



⁴³ <https://www.mdpi.com/2073-4441/10/10/1382>

1.7 Trouble Shooting

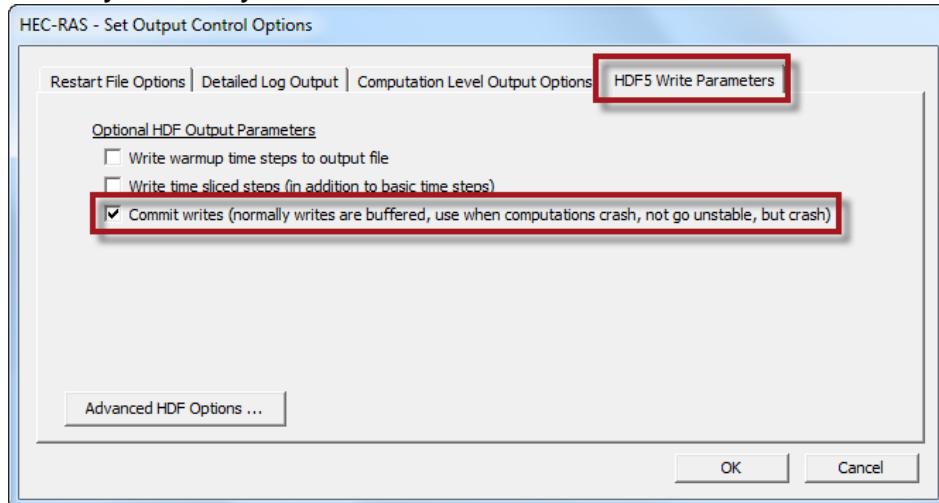
- [Get Unsteady HDF5 Output if Model Crashes \(see page 289\)](#)
- [Common Sediment Transport Error Messages \(see page 289\)](#)

1.7.1 Get Unsteady HDF5 Output if Model Crashes

One of the liabilities of the new HDF5 output is that HEC-RAS does not release these until the end of the simulation. Users cannot view these files until the run is complete. Additionally, if the model crashes, it will not generate a final output file to help troubleshoot the simulation.

Users can request HEC-RAS to write intermediate results, so results will be available if the model crashes. This will create stable HDF5 output file when HEC-RAS crashes, but it involves saving and closing the file each time step, so this feature will increase run times substantially and is off by default.

To request intermediate HDF5 writes to access output after a crash, go to *OptionsOutput Options* in the **Unsteady Flow Analysis** editor. Select the **HDF5 Write Parameters** and check the **Commit Writes** box.

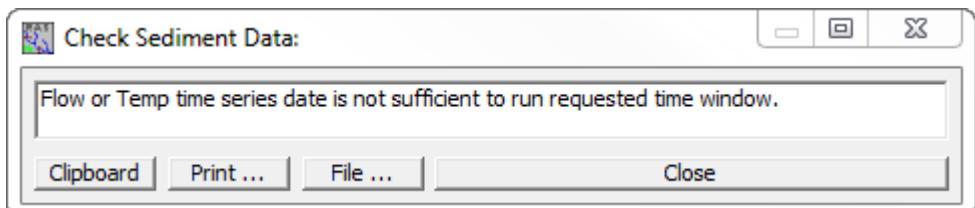


1.7.2 Common Sediment Transport Error Messages

There are several common error messages users encounter when modeling sediment in HEC-RAS. These fall in two basic categories: Pre-Run errors (those that HEC-RAS throws before it starts computations, usually alerting users to incomplete data) and Runtime Errors (those written in the computational window during a run).

1.7.2.1 Flow or Temp Time Series Date is Not Sufficient to Run Requested Time Window

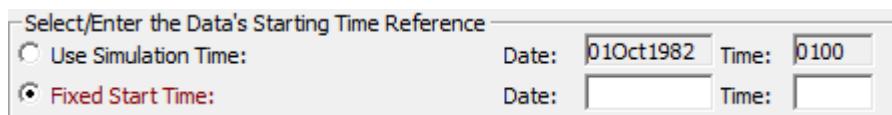
The most common pre-run error message alerts users that there is not enough flow or temperature data to run the simulation (below).



This message indicates that one of the flow, temperature, or sediment time series in the quasi-unsteady or sediment data do not span the computational interval. Check to make sure that all the time series start at or before the simulation start time and end at or after the simulation end time.

However, other data errors, which can be harder to find can generate this error. Here are three common culprits:

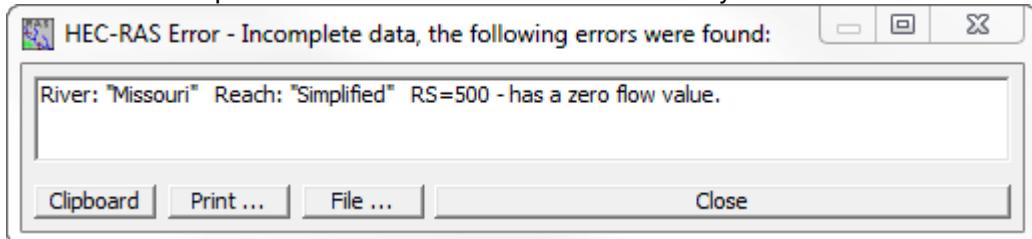
1. **No Temperature Data:** Temperature data⁴⁴are mandatory, but requires pressing a button on the quasi-unsteady flow editor. Blank temperature data will return this error.
2. **Blank or mistaken Fixed Start Time:** If the fixed start time is either missing or mis-formatted (see below) HEC-RAS does not know when the boundary condition begins.



3. **Missing Computation Increments.** A quasi-unsteady time series can span the entire simulation time window, but if one or more flows lack computation increments HEC-RAS will return this error. If the **Automated Computation Increment** tool does not span the range of flows, it will leave Computation Increments blank and return this error.

1.7.2.2 Incomplete data: "Zero flow value"

Another common pre-Run error indicates that a flow boundary condition has a zero flow value (below).



HEC-RAS cannot specify a zero flow external boundary condition. However, more often, this error is the result of:

1. **Mis-formatted Date:** If the Fixed Start Time or the simulation time window is defined with a date that does not conform to the HEC-RAS DDMMYYYY convention the date will not register correctly. An

⁴⁴<https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/flow-data-and-event-conditions/entering-and-editing-quasi-unsteady-flow-data/temperature-data>

example of this common error is:

Simulation Time Window

| | | | | |
|----------------|------------|------------------------------------|----------------|------|
| Starting Date: | 01Jan2000 | <input type="button" value="..."/> | Starting Time: | 0000 |
| Ending Date: | 01July2015 | <input type="button" value="..."/> | Ending Time: | 0000 |

2. Non-English Settings, Months, or Special Characters: The months also have to be in English. The following table includes the only MMM abbreviations RAS accepts

| | | | | | |
|-----|-----|-----|-----|-----|-----|
| JAN | FEB | MAR | APR | MAY | JUN |
| JUL | AUG | SEP | OCT | NOV | DEC |

An example of a common error is:

Simulation Time Window

| | | | | |
|----------------|-----------|------------------------------------|----------------|------|
| Starting Date: | 01Jan2000 | <input type="button" value="..."/> | Starting Time: | 0000 |
| Ending Date: | 01Dec2015 | <input type="button" value="..."/> | Ending Time: | 0000 |

Additionally, in order to accept dates, the Microsoft language settings on your computer must be set to English (US).

3. End Date earlier than the Start Date: Another common error includes specifying an end date later than the start date (e.g. setting up a water year run but failing to change the second date):

Simulation Time Window

| | | | | |
|----------------|-----------|------------------------------------|----------------|------|
| Starting Date: | 01Oct2000 | <input type="button" value="..."/> | Starting Time: | 0000 |
| Ending Date: | 31Sep2000 | <input type="button" value="..."/> | Ending Time: | 0000 |

1.7.2.3 Unrealistic Vertical Adjustment

The **Unrealistic Vertical Adjustment** error is the most common sediment runtime error. This error indicates that the cross section eroded or deposited too much sediment in a time step, potentially destabilizing the simulation.

ERROR during Sediment Simulation

Unrealistic vertical adjustment at
8XS 571.428

This error occurs most often at the upstream cross section. If the transport function, load, bed gradation, and load gradation are not in quasi-equilibrium at the beginning of the simulation, the upstream cross section will often deposit until it is full.

If the model deposits unrealistically at the upstream cross section, one-or-more of three factors are likely:

1. **Load is too large. (Sediment boundary condition)**
2. **Capacity is too small. (Transport Function)**
3. **Load is too coarse. (Boundary condition gradation)** - Sometimes modelers will use their bed gradation for their boundary-condition load gradations. But transporting gradations are almost

always substantially finer than the bed gradation. Therefore these models often deposit unrealistically at the upstream cross section even if the total load is appropriate.

Other less-common causes include:

1. **Large Computational Increment**: Large computation increments (or moderate computation increments during large flows) are the most common source of sediment model instability and, therefore, this error. Users can often resolve this error by reducing the computation increment.
2. **Model Should Deposit Outside the Movable Bed Limits**: If the modeled system deposits significant sediment in the floodplain, an HEC-RAS model that forces all bed change in the channel (by confining the movable bed limits to the channel and selecting the default bed change method that only modifies the cross section within the channel) can force too much deposition in the channel, causing unrealistic bed change. In systems (or reaches) with significant floodplain deposition, change the **Bed Change Options** to [allow deposition outside the movable bed limits](#) (see page 289) (or extend the movable bed limits).
3. **Bed Material is Too Fine**: If the bed material is too fine for the transport function, or if the transport function over predicts transport in the reach, the mismatch can lead to large, rapid bed changes, destabilizing the mode
4. **Equilibrium Load**: If the upstream gradation associated with an equilibrium load boundary condition includes substantial silt or clay, the equilibrium load condition can compute enormous fine grained sediment loads at the boundary. Small decreases in transport downstream can cause large bed changes. User defined rating curves are almost always better sediment boundary condition options, even if they are speculative.

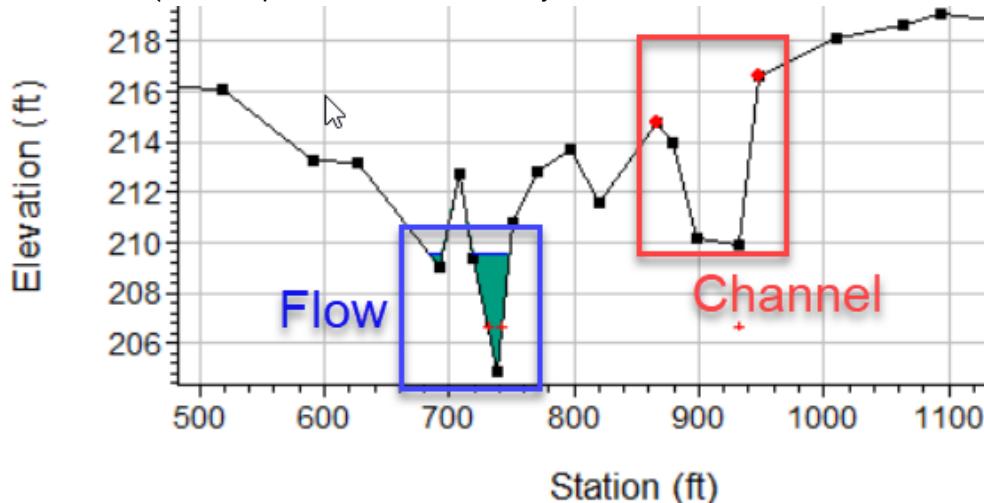
1.7.2.4 No flow in channel at river/station (channel may have overfilled with sediment)

No flow in channel at river/station
Beaver Creek Kentwood 5.99
(channel may have overfilled with sediment).

This message is pretty self explanatory. If the channel fills with sediment - pushing all flow to the overbanks - the model will stop. If your channel is filling with sediment, this requires the same approaches as Unrealistic Vertical Adjustment (see the troubleshooting approaches above). There are a few additional issues that can cause this error that you might explore:

1. If your overbank/floodplain cross section has a depression that is lower than the channel thalweg it can empty the channel at low flows if there is enough low-elevation conveyance in the overbank. Either include this area in the channel if it conveys flow or make it ineffective up to the elevation of

the channel. (these depressions should usually be ineffective in a sediment model anyway).



2. Bank stations are too narrow or low. Move banks stations up/out.
3. Switch to [allow deposition outside the channel](#)⁴⁵. If the model only deposits in the channel (the default) the channel can fill with sediment that should be depositing in the floodplain. Allowing floodplain deposition can clear this up.
4. If you are using unsteady flow hydraulics, this can indicate hydraulic model instability. If the unsteady hydraulics go unstable the channel will often go dry which the sediment model interprets as "overfilled with sediment." This is an unsteady hydraulic stability issue and requires unsteady troubleshooting.

1.7.2.5 Sediment Rating Curve Extrapolation

Users sometimes enter flow-load rating curves that do not cover the entire range of flows. Users often develop a flow-load curves for their measured data - collected over a more narrow range of flows than the simulated flow range, so the model that includes a much wider variety of flows.

HEC-RAS will produce two errors if it encounters flows lower or higher than the maximum and minimum rating curve flows:

If HEC-RAS encounters flows below the lowest flow-load rating curve point it will generate the error:
The sediment boundary condition(s) include(s) a flow that is lower than the maximum flow in the sediment rating curve. HEC-RAS extrapolated between the lowest load and zero.

This error is blue because it is not critical. Because it is reasonable to assume that 0 flow is associated with 0 load, HEC-RAS will extrapolate below the lowest flow in the rating curve by interpolating between that point and 0, 0 (cfs-T/d, cms-T/d, cfs-mg/L, or cms-mg/L).

If the flow series includes flows higher than the highest flow-load point, HEC-RAS will report:
The sediment boundary condition(s) include(s) a flow that is higher than the maximum flow in the sediment rating curve. HEC-RAS used the highest load in the rating curve.

This error is red, because HEC-RAS will not extrapolate beyond the highest flow point on a sediment rating curve. Results will be very sensitive to loads associated with high flows and it is important for the user to make this site-specific decision explicitly. Therefore, HEC-RAS will only use the highest specified load for all

⁴⁵[1D Sediment Transport User's Manual – 293](https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/entering-and-editing-sediment-data/sediment-properties-options/bed-change-options#BedChangeOptions>Selecting a Modular Global Bed Change Method</p>
</div>
<div data-bbox=)

flows that are larger than the highest flow point in the flow-load curve, and will produce this error message in the runtime window to ask the user to increase the max flow in the flow-load curve.

1.7.2.6 Active Layer Exhaustion

If the model erodes all the sediment in the active layer during a [bed mixing time step](#) (see page 289), it can artificially limit erosion. For small active layers or large time steps, eroding the entire active layer during some or most of the high transport time steps can artificially reduce erosion significantly. Therefore, HEC-RAS generates an error if the active layer is completely eroded and indicates which cross sections empty at which times.

Sediment Output Summary:

The active layer completely eroded at one or more cross section(s)

Consider making the layer thicker or using a smaller time step.

At the following location(s) and first time(s).

River Morthond Reach Morthond

From river stations 10000 to 8000 at 25SEP1975 00:00:00 22JUL1975 00:00:00

River Morthond Reach Morthond

From river stations 7000 to 6500 at 21JUL1975 00:00:00 25JUL1975 00:00:00

Morthond Morthond 5500 28JUL1975 06:00:00

River Morthond Reach Morthond

From river stations 4500 to 0 at 01OCT1975 00:00:00 01JUL1975 00:00:00

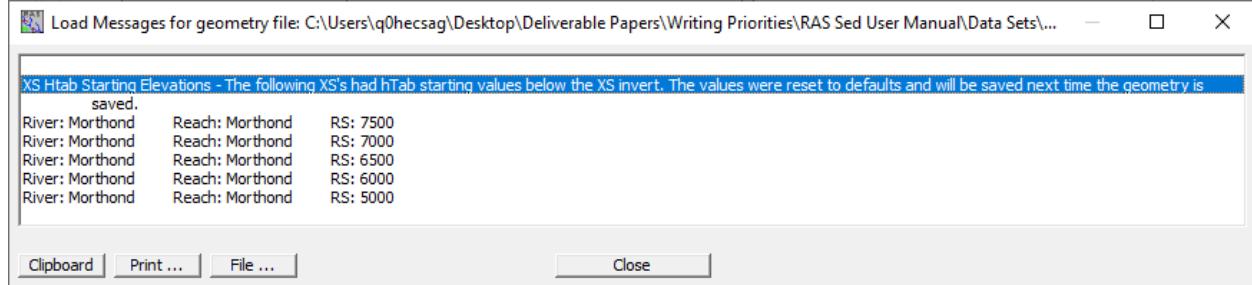
Increasing the active layer thickness, using the **Minimum Active Layer Thickness** feature, or increasing the number of [bed mixing time steps](#)⁴⁶ for each computation increment are common fixes for this error, particularly for fine sediment beds.

1.7.2.7 XS Htab Starting Elevations – The Following XS's had HTab starting values below the XS invert.

This error is often the result of using a geometry file created from a sediment result and there is a simple fix. Re-set the starting elevations in the HTAB editor to the invert. This work flow is described [here](#) (see page 214)

⁴⁶[https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/simulating-sediment-transport/sediment-computation-options-and-tolerances/sediment-computational-options#SedimentComputationalOptions-BedMixingTimeSteps\(SPI\)](https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/1d-sediment-transport-user-s-manual/simulating-sediment-transport/sediment-computation-options-and-tolerances/sediment-computational-options#SedimentComputationalOptions-BedMixingTimeSteps(SPI))

(Workflow to fix the HTab starting elevation error.).



1.7.2.8 Program Exception - Access Violation

There are several versions of this error. There can be many reasons for this. But regardless of the cause (including user-error), this should be considered a bug. Even if this is cause by user-error, we would like RAS to fail more gracefully and provide more useful feedback on what went wrong. Any indecipherable error like this with a list of indecipherable, red, routine codes should be considered a bug. Send a [bug report to the HEC-RAS inbox](#)⁴⁷. HEC will need the files to identify the problem/bug. Follow [these instructions](#)⁴⁸ to transfer the files.

```
Performing Unsteady Sediment Flow Simulation HEC-RAS 6.4.1 June 2023
forrtl: severe (157): Program Exception - access violation
Image          PC          Routine      Line      Source
RasUnsteadySedime 00007FF7163F678C Unknown           Unknown Unknown
RasUnsteadySedime 00007FF715915A19 READ_UN_S2D_BC     102 Read_UN_S2D_BC.f90
RasUnsteadySedime 00007FF71591CF93 READ_UN_S2D         150 Read_UN_S2D.f90
RasUnsteadySedime 00007FF7156A7F22 SNETREAL2          197 Snetreal2.for
RasUnsteadySedime 00007FF715953719 UNETREAL          75 Unetreal.for
RasUnsteadySedime 00007FF7155BA9F4 UNET_START        144 Unet_start.for
RasUnsteadySedime 00007FF7159537D7 MAIN__            70 Unet.for
RasUnsteadySedime 00007FF716B1AB1E Unknown           Unknown Unknown
RasUnsteadySedime 00007FF71C127A79 Unknown           Unknown Unknown
RasUnsteadySedime 00007FF71C12799E Unknown           Unknown Unknown
RasUnsteadySedime 00007FF71C12785E Unknown           Unknown Unknown
RasUnsteadySedime 00007FF71C127AEE Unknown           Unknown Unknown
KERNEL32.DLL      00007FFA46197614 Unknown           Unknown Unknown
ntdll.dll        00007FFA46A62681 Unknown           Unknown Unknown

Error with program: RasUnsteadySediment.exe Process Count = 6 Exit Code = 157
```

Computations Summary

Search Keywords: forrtl: severe(157): Program Exception - access violation, Error with program: RasUnsteadySediment.exe Process Count = 6 Exit Code = 157

In the current version, we have seen the following issues cause this error:

- Attaching sediment data to an internal boundary condition

⁴⁷ https://www.hec.usace.army.mil/software/hec-ras/bug_report.aspx

⁴⁸ <https://youtu.be/gW-95DZ9toQ>

1.8 New 1D Sediment Features in HEC-RAS

This document provides an overview of the new 1D sediment features in HEC-RAS.



1.9 Acknowledgement

The 1D sediment transport approach and algorithms in HEC-RAS were based on the approach originally developed in HEC 6 and HEC 6T by Tony Thomas.

Tony Thomas was the Corps of Engineer's original, numerical, sediment modeler, developing the first mobile-bed transport model at the Little Rock District before moving to HEC to develop HEC 6, which was the industry-standard, numerical, sediment-transport model for decades.

After developing HEC 6 at HEC, Mr. Thomas continued to develop 1D and 2D sediment models at the Waterways Experiment Station (now ERDC) and then worked for many years developing and applying HEC 6T in the private sector, advancing the technology he developed while with the Corps.

In the early stages of HEC-RAS sediment development (circa 2000) Tony came to HEC as a visiting scholar, and spent several months helping the RAS sediment team understand the HEC 6 code, providing insight into HEC 6T innovations, and helping us develop and test initial alpha version of the 1D, mobile-bed model in HEC-RAS.

In the last 20 years HEC has added some new approaches and technology to 1D Sediment in RAS, but the framework and approach remain deeply in the HEC6 tradition.

Much of the technology in the 1D, HEC-RAS sediment model comes from HEC6 and reflects Tony Thomas' algorithm development and mentorship.

2 1D Sediment Transport Technical Reference Manual

Sediment transport modeling is notoriously difficult. Sediment data are uncertain and transport theory is empirical and highly sensitive to a broad array of physical variables and model parameters which are difficult to measure and estimate. However, with good data, a skilled modeler can use a calibrated sediment model to predict regional, long term trends that can inform planning decisions and evaluate project alternatives. HEC-RAS includes mobile boundary, sediment transport modeling capabilities which route sediment and adjust channel cross sections in response to sediment dynamics. This chapter describes the theory and assumptions used for this analysis.

- [Hydrodynamics in a Sediment Model](#) (see page 298)
- [Quasi-Unsteady Flow](#) (see page 298)
- [Sediment Continuity](#) (see page 299)
- [Computing Transport Capacity](#) (see page 300)
 - [Grain Classes](#) (see page 301)
 - [Sediment Transport Potential](#) (see page 301)
 - [Classic Bed Partitioning](#) (see page 314)
- [Capacity Sensitivity to Bank Stations and Movable Bed Limits](#) (see page 315)
- [Continuity Limiters](#) (see page 315)
 - [Temporal Deposition Limiter](#) (see page 316)
 - [Temporal Erosion Limiter](#) (see page 319)
 - [Sorting and Armoring](#) (see page 320)
- [Bed Change](#) (see page 332)
 - [Volume Change and Area Change Conversions](#) (see page 332)
 - [Veneer Method](#) (see page 335)
 - [Diffusion-Rouse Method](#) (see page 336)
- [Cohesive Transport](#) (see page 344)
 - [Krone and Partheniades Methods](#) (see page 344)
 - [Standard Transport Equations](#) (see page 349)
- [Bed Roughness Predictors0](#) (see page 350)
 - [Limerinos_](#) (see page 350)
 - [Brownlie_](#) (see page 350)
 - [van Rijn_](#) (see page 351)
- [BSTEM – Technical Reference Manual](#) (see page 353)
 - [Overview](#) (see page 354)
 - [Bank Failure](#) (see page 355)
 - [Selecting a Method](#) (see page 368)
 - [Steps in a Bank Failure Analysis](#) (see page 369)
 - [Toe Erosion \(Fluvial or Hydraulic Erosion\)](#) (see page 374)
- [Appendix A_Sample Transport Calculations](#) (see page 378)

- [Ackers White Sample Calculation \(see page 379\)](#)
- [Engelund Hansen Sample Calculation \(see page 383\)](#)
- [Laursen-Copeland Sample Calculation \(see page 386\)](#)
- [Meyer-Peter Muller Sample Calculation \(see page 390\)](#)
- [Toffaleti Sample Calculation \(see page 395\)](#)
- [Yang Sample Calculation \(see page 402\)](#)

2.1 Hydrodynamics in a Sediment Model

Sediment transport models require hydraulic parameters. Therefore, HEC-RAS computes hydraulics each time step before it routes sediment or updates cross sections. HEC-RAS 5.0 couples sediment transport computations with either quasi-unsteady hydraulics or unsteady hydraulics. The User's Manual offers pros and cons of both approaches. Unsteady flow is not unique to sediment studies. HEC-RAS can simulate unsteady flow without sediment data and Chapter 2 documents the unsteady equations in detail.

Quasi-unsteady hydraulics, on the other hand, are only used for sediment studies. Therefore, the quasi-unsteady approach is described below.

2.2 Quasi-Unsteady Flow

The quasi-unsteady flow model simplifies hydrodynamics, representing a continuous hydrograph with a series of discrete steady flow profiles. HEC-RAS keeps flow constant for each flow record, computing transport over flow record duration. The steady flow profiles are more stable than the matrix solution of the unsteady Saint-Venant equations, but approximating a hydrograph with a series of steady flows does not conserve flow or explicitly account for volume.

The quasi-unsteady flow model divides time into three time step. HEC-RAS divides each discrete steady flow profile (**Flow Duration**), over which HEC-RAS holds flow constant, into **Computational Increments**, which are the hydraulic and sediment transport time step. HEC-RAS updates the hydraulics and cross sections every **Computational Increment**, but further subdivides this time step into **Bed Mixing Time Steps**, updated bed gradation accounting for each bed layer several times each **Computational Increment**.

2.2.1 Duration

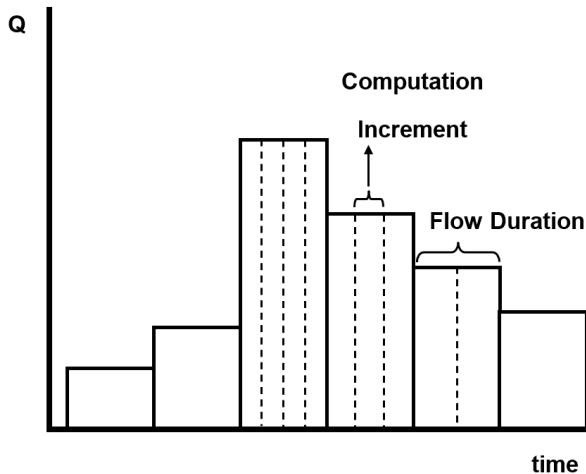
The Duration is the coarsest time step. HEC-RAS assumes that flow, stage, temperature, or sediment are constant over the Duration (below). For example, enter daily flow data (e.g. from a USGS day) with twenty-four hour Flow Durations.

2.2.2 Computational Increment

The **Computational Increment** is the primary quasi-unsteady hydraulic and sediment time step. The **Computation Increment** usually subdivides the **Duration** (below), though it can be equal (but not larger) to the duration. While flow remains constant over the entire flow duration, HEC-RAS updates the bed geometry and hydrodynamics after each computational increment. If cross sections change, particularly if they change rapidly, sediment sensitive hydraulic parameters can change even if the flow does not.

Model stability can be sensitive to the **Computation Increment**, because HEC-RAS assumes that hydraulics and bed geometry are constant. If the bed changes rapidly, large computation increments decouple the feedbacks between sediment and hydraulic processes, leading to unreasonable deposition or erosion, which can cause the model to crash. If HEC-RAS computes erratic bed change, experiment with **Computation Increment** sensitivity.

QtimeFlow Duration Computation Increment



86 A Quasi-Unsteady Flow Series with time step.

2.2.3 Bed Mixing Time Step

Finally, HEC-RAS also subdivides Computational Increments into the bed mixing time step (sometimes called the SPI parameter). Bed gradation can evolve very quickly, so HEC-RAS updates the bed gradation accounting (running the bed sorting and armoring routines) several times during each computation increment.

HEC-RAS holds hydraulic parameters and cross section elevation constant over all mixing time step in a computation increment throughout the **Computation Increment**. However, the model updates the composition of the bed mixing layers (e.g. the active, cover and/or inactive layers) at the **Mixing Time Step**, revising the grain class accounting in these layers several times between hydraulic and sediment capacity computations. The vertical gradational profile changes response to the deposition or erosion even though the bed does not change until the end of the **Computation Increment**. Tighter accounting of bed gradation affects transport. HEC-RAS computes transport capacity base on the active layer gradation, so while the hydraulics (and transport potential, see below) remain constant throughout the **Computation Increment**, transport capacity can change between **Bed Mixing Time Steps**.

2.3 Sediment Continuity

The HEC-RAS sediment routing routines solve the sediment continuity equation also known as the Exner equation:

$$(1 - \lambda_p) B \frac{\delta n}{\delta t} = - \frac{\delta Q_s}{\delta x}$$

where:

B = channel width

η = channel elevation

λ_p = active layer porosity

t = time

x = distance

Q_s = transported sediment load

Like most continuity equations, the Exner equation simply states that the difference between sediment entering and leaving a control volume must be stored or removed from storage. The unique feature of the Exner equation is that sediment storage is stored in the bed in a multi-phase mixture with water, requiring porosity to translate mass change into volume change. The Exner equation translates the difference between inflowing and outflowing loads into bed change, eroding or depositing sediment.

HEC-RAS solves the sediment continuity equation by computing a sediment transport capacity for control volume (Q_{s-out}) associated with each cross section, comparing it to the sediment supply (Q_{s-in}) entering the control volume from the upstream control volume or local sources (e.g. lateral sediment loads). If capacity is greater than supply, HEC-RAS satisfies the deficit by eroding bed sediments. If supply exceeds capacity, HEC-RAS deposits the sediment surplus.

2.4 Computing Transport Capacity

The right-hand side of the continuity equation, the sediment gradient across the control volume, compares the sediment inflow with the sediment outflow. Sediment inflow is simply the sediment entering the control volume from the upstream control volume(s) and any local sources (lateral sediment inflows). Computing the sediment leaving the control volume is more difficult, a measure of the sediment mass the water can move, which is a complex function of the hydrodynamics and sediment properties. **Sediment transport capacity** is a measure of the control volume competence to pass sediment, computing the maximum sediment it can transport by grain class.

- [Grain Classes \(see page 301\)](#)
- [Sediment Transport Potential \(see page 301\)](#)
 - [Ackers and White \(see page 302\)](#)
 - [Engelund-Hansen \(see page 303\)](#)
 - [Laursen-Copeland \(see page 303\)](#)
 - [Meyer-Peter Müller \(see page 306\)](#)
 - [Toffaleti \(see page 307\)](#)
 - [Toffaleti-MPM \(see page 309\)](#)
 - [Toffaleti Limiter \(see page 309\)](#)
 - [Yang \(see page 310\)](#)
 - [Wilcock and Crowe \(see page 311\)](#)
- [Classic Bed Partitioning \(see page 314\)](#)

2.4.1 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.

2.4.2 Sediment Transport Potential

Sediment **transport potential** is the transportable mass of a *particular* grain class in response to cross channel hydraulic parameters. HEC-RAS computes **transport potential** for each grain class with one of the sediment transport equations available in the program.

The sediment transport equations are empirical equations or algorithms that translate hydrodynamics into transport. However, most of these equations were developed for a single representative grain size.

To apply these equations to sediment mixtures, with multiple discrete grain classes, HEC-RAS computes **transport potential**, allying the transport function independently to each grain class present in the system, as if it were the only grain class in the system. Later **transport potential** is prorated by the prevalence of the grain class, to compute the **transport capacity** (see discussion below), which is the transport used in the Exner equation. But first HEC-RAS applies the transport function to each available grain class *independently*, computing a **transport potential** for each.

HEC-RAS includes eight 1D sediment transport potential functions. The three 2D (Wu, van Rijn, and Soulsby-van Rijn) functions are not available in 1D yet. Since sediment transport is sensitive to so many variables, transport potentials computed by the different equations can vary by orders of magnitude, depending on how the material and hydrodynamics compare to the parameters over which the transport function was developed. As much as possible, select a transport function developed for similar gradations and hydraulic parameters as the project reach. Appendix E in this document include the actual equations and algorithms. This section includes brief, qualitative notes on the use, applicability, and sensitivity of each equation.

Most sediment transport functions are based either on shear stress or stream power. They usually use an excess-shear or excess-power form, which compare the actual shear or power to a threshold. HEC-RAS does not compute any transport for that grain class if it is below the threshold (i.e. the grain class is not "competent"). The stream power equations use two different versions of stream power, the product of velocity and slope (VS) and the product of velocity and shear stress (tV). The six shear stress or stream power equations are:

2.4.2.1 Table: Transport functions based on excess shear stress and stream power.

| Excess Shear Stress | Stream Power |
|---------------------|-----------------------|
| Meyer-Peter Muller | Ackers-White (tV) |

| | |
|-------------------|--------------------------|
| Laursen-Copeland | Englund-Hansen (tV)* |
| Wilcock and Crowe | Yang (VS) |

*Englund-Hansen is not an excess form of the stream power equation, but just a function of stream power.

- Ackers and White (see page 302)
- Engelund-Hansen (see page 303)
- Laursen-Copeland (see page 303)
- Meyer-Peter Müller (see page 306)
- Toffaleti (see page 307)
- Toffaleti-MPM (see page 309)
- Toffaleti Limiter (see page 309)
- Yang (see page 310)
- Wilcock and Crowe (see page 311)

2.4.2.2 Ackers and White

Ackers and White (1973) is a total load function, developed from flume data for relatively uniform gradations ranging from sand to fine gravels. Ackers and White derived the equation dimensional analysis and did not include a grain shear partition. They fit coefficients to the equation based on experiments that included a range of bed configurations including ripples, dunes, and plane bed conditions.

This function does not have an intuitive shear stress, excess shear stress, or excess stream power formulation that drives most of the other equations. But it is built on a very similar excess "mobility" power function. The sediment flux is a function of a "Transport Parameter":

| | |
|---|--|
| Sediment Flux $X = \frac{G_{gr} s d}{D \left(\frac{u_*}{V} \right)^n}$ | Transport Parameter G_{gr} Where: s = sediment specific gravity d = median particle size D = effective depth u_* = Shear Velocity (τ) ^{1/2} V = Average Channel Velocity n = transition exponent (based on sediment size) |
|---|--|

Which is just a simple, dimensionless, power function, of excess "Mobility" with empirical coefficients and an empirical mobility threshold:

| | |
|--|---|
| Transport Potential $G_{gr} = C \left[\frac{F_{gr}}{A} - A \right]^m$ | Sediment Mobility Threshold Mobility F_{gr} A m C Empirical Power Coefficients e.g. for $d > 2\text{mm}$ $A = 0.17$ $m = 1.78$ $C = 0.25$ |
|--|---|

HEC-RAS exposes the threshold mobility (A) and the coefficients (C and m) so users can calibrate them. However, these are not fixed parameters. They are dynamic, changing with sediment properties and flow. Molders who chose to calibrate Ackers-White should use [scaling factors⁴⁹](#) instead.

Mobility in this transport approach is a function of the Bagnold version of stream power (tV) where t is represented by u^*):

Sediment

Mobility

$$F_{gr} = \frac{u_*^n V^{1-n}}{\sqrt{g(s-1)d}(\sqrt{32 \log(ad/D)})^{1-n}}$$

2.4.2.3 Engelund-Hansen

Engelund-Hansen (1967) is a total load transport equation, developed from flume data, using relatively uniform sand sizes between 0.19 mm and 0.93 mm. Engelund Hansen is the simplest transport equation, an explicit function of stream power ($V^2\tau^{3/2}$) and the d_{50} of the material. It is not an "excess" stream power equation, so it does not control for competence and often can, therefore, compute low transports for large grain classes. Engelund-Hansen should usually be restricted to sand systems.

The equation is:

$$g_s = V^2 \left(\frac{\tau_b}{(\gamma_s - \gamma) d_{50}} \right)^{\frac{3}{2}} \sqrt{\frac{d_{50}}{g \left(\frac{\gamma_s}{\gamma} - 1 \right)}} = V^2 (\tau^*)^{\frac{3}{2}} \sqrt{\frac{d_{50}}{g \left(\frac{\gamma_s}{\gamma} - 1 \right)}}$$

Where:

g_s = Sediment transport by unit width

γ = Unit weight of water

γ_s = Unit weight of sediment

V = Average channel velocity

τ_b = Bed shear stress

τ^* = Dimensionless Shields Number ($\tau_b/\gamma_s \cdot d_{50}$)

d_{50} = Median particle size

2.4.2.4 Laursen-Copeland



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But you can reach it using the following URL:

<http://youtube.com/watch?v=fweoPEHjgzU>

Laursen (1968) developed a total-load, excess-shear transport function with the form:

$$C = 0.01\gamma \left(\frac{d}{D} \right)^{\frac{7}{6}} \left(\frac{\tau'}{\tau_c} - 1 \right) f \left(\frac{u_s}{\omega} \right)$$

⁴⁹ https://www.hec.usace.army.mil/confluence/display/_Scaling_Factors

This equation makes Concentration (C) a function three dimensionless parameters, the ratio of the representative particle size (d) to the water depth (D), the rouse number (ratio of the shear velocity (u^*) to the fall velocity (w) - and the dimensionless form of excess shear stress. Instead of making shear stress dimensionless with the Shields number, this equation makes the excess shear relationship dimensionless (similar to the dimensionless excess shear in the Partheniades equation):

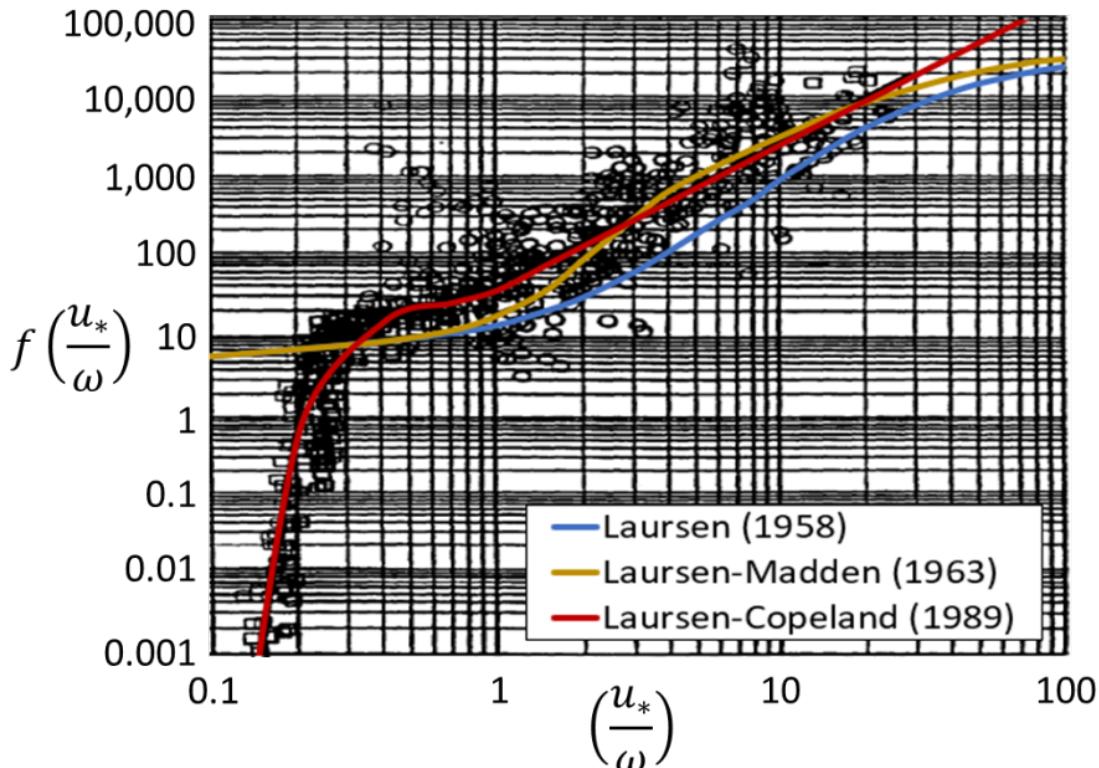
$$\left(\frac{\tau'}{\tau_c} - 1 \right) \text{ or } \left(\frac{\tau' - \tau_c}{\tau_c} \right)$$

Where τ' is the grain shear stress and τ_c is the critical shear stress. Laursen and Madden modified the transport function in 1963, to data from the Arkansas River. They updated the graphical function of the Rouse number based on additional data from the Arkansas River.

In the late 1980s, Ron Copeland Copeland, R. (1993) Numerical Modeling of Hydraulic Sorting and Armoring in Alluvial Rivers, Dissertation, University of Iowa, 284p (Appendix B). updated the equation again, including three significant developments. The Laursen-Copeland version of this function:

1. Expanded the empirical Rouse function $f(u^*/\omega)$ to include additional data over a wide range of grain classes.
2. Replaced the total shear stress with a grain shear stress based on a hydraulic grain roughness.
3. Computed a dynamic, critical shear stress based on a variable Shields parameter.

Copeland's most significant update was the new empirical (fu^*/ω) function. The Laursen transport approach builds the empiricism into this function which Laursen and Madden fit to a handful of available measurements in the 1960s. Copeland fit this empirical kernel to flume results from seven gravel studies and two sand studies, and transport from six large sand or sand and gravel rivers (below). This expanded the applicable range of the transport function in both directions, including gravel and coarse silt, giving it the largest applicable range of the equations in HEC-RAS.



Second, Copeland exchanged total bed shear stress for grain shear stress by replacing depth (D) in Laursen's shear (τ') equation with the hydraulic radius due to grain roughness (R'), such that:

$$\tau' = \frac{\rho V^2}{58} \left(\frac{d}{D} \right)^{\frac{1}{3}} \text{ becomes } \tau' = \frac{\rho V^2}{58} \left(\frac{d}{R'} \right)^{\frac{1}{3}}$$

where R' comes from the Limerinos equation (Burkham and Dawdy, 1976):

$$\frac{V}{u_s} = \frac{V}{\sqrt{g R' S}} = 3.28 + 5.75 \log \left(\frac{R'}{d_{84}} \right)$$

The hydraulic radius appears in both sides of this equation, so the transport function iterates to solve for R' .

Finally, the Laursen equation computes the dimensional critical shear stress from a stipulated dimensionless Critical Shields number (0.03). Copeland implemented Paintal's (1971) conclusion that the Shields parameter adjusts in response to the applied Shields stress. Therefore, the Laursen-Copeland equation adjusts the critical Shields parameter based on the dimensionless shear stress, such that:

$$\tau_c^* = \begin{cases} 0.039 & x > 0.05 \\ 0.647\tau^* + 0.0064 & 0.05 > \tau^* > 0.02 \\ 0.02 & \tau^* < 0.02 \end{cases}$$

The wide range of materials used to develop the Copleand version of Laursen's equation gives it the widest range of potential applicability of the transport functions included in HEC-RAS. It is the only transport function developed over the coarse silt range and unpublished work at Colorado State (Watson, personal communication) demonstrated that this equation outperformed other transport functions in the very fine sand and very coarse silt range.

2.4.2.5 Meyer-Peter Müller

The Meyer-Peter and Müller (MPM) equation (1948) was one of the earliest equations developed and is still one of the most widely used. It is a simple excess shear relationship. Parker (2006)⁵⁰⁴ casts MPM in its simplest, dimensionless, volumetric form as.

$$q_b^* = 8(\tau^* - \tau_c^*)^{3/2}, \quad \tau_c^* = 0.047$$

Where q_b^* and τ^* are dimensionless transport and mobility parameters respectively, where:

$$\tau^* = \frac{\tau}{(\gamma_s - \gamma) d_m} \text{ and } q_b^* = \frac{q_b}{\sqrt{R g d_m} d_m}$$

MPM is strictly a bedload equation developed from flume experiments of sand and gravel under plane bed conditions. The MPM experiments mostly examined uniform gravel, making the transport function MPM most applicable in gravel systems. MPM tends to under predict transport of finer materials.

HEC-RAS uses the version of MPM from Vanoni (1975), ASCE Manual 54, the version used in HEC 6.

$$\left(\frac{k_r}{k'_r}\right)^{\frac{3}{2}} \gamma R S = 0.047 (\gamma_s - \gamma) d_m + \left(\frac{\gamma}{g}\right)^{\frac{1}{3}} \left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{\frac{2}{3}} g_s^{\frac{2}{3}}$$

where:

g_s = Unit sediment transport rate in weight/time/unit width

k_r = A roughness coefficient

k'_r = A roughness coefficient based on the grains

γ = Unit weight of water

γ_s = Unit weight of sediment

g = Acceleration of gravity

d_m = Median particle diameter

R = Hydraulic radius

S = Energy gradient

Solving for transport, this equation starts to take the familiar dimensionless, form:

$$g_s \propto 8 \left(\left(\frac{k_r}{k'_r}\right)^{\frac{3}{2}} \tau^* - 0.047 \right)^{\frac{3}{2}}$$

with an additional term in the excess shear equation. The full derivation of Parker's simple dimensionless, volumetric form from the Vanoni version used in HEC-RAS is included in the transport appendix (see page 393). This version includes a form drag correction, $(k_r/k'_r)^{1.5}$, based on the roughness element ratio computed from the Darcy –Weisbach bed friction factor. This form drag partitions bed shear stress, isolating grain shear. By imbedding the form shear correction, this version of the equation computes transport based on the bed shear component acting only on the particles.

The form drag correction should be unnecessary in plane-bed conditions, so some versions of MPM exclude it. Wong and Parker (2006) demonstrate that using MPM without the form drag correction over-predicts bed load transport.

Therefore, HEC-RAS offers the Wong Parker correction to MPM based on their 2006 paper. The Wong Parker correction changes MPM in two ways. First, it sets the form drag correction to unity ($k_r/k'_r=1$), effectively

50 http://hydrolab.illinois.edu/people/parkerg/powerpoint_lectures.htm

removing it from the equation. Second, it sets the MPM coefficients to those Wong and Parker (2006) computed using the *plane-bed* data sets from the original MPM analysis recasting:

$$q_b^* = 8(\tau^* - \tau_c^*)^{3/2}, \quad \tau_c^* = 0.047$$

As

$$q_b^* = 3.97(\tau^* - \tau_c^*)^{3/2}, \quad \tau_c^* = 0.0495$$

Where: q_b^* is the Einstein bedload number (correlated with bedload), τ^* is the Shield's stress which is compared to, τ_c^* which is the 'critical' Shields stress.

The effects of these changes can push transport higher or lower than MPM based on the magnitude of the form drag correction. Removing the form drag correction can increase transport (if it was computing a partition) and changing the coefficients decreases transport.

Wong and Parker (2006) based their work on the *plane-bed* data sets MPM analyzed, those without appreciable bed forms. Therefore, their correction is directly applicable only to lower-regime plane-bed conditions.

Modeling Note:

Dr. Gary Parker's ebook⁵¹ is an excellent place to start for anyone new to sediment transport theory.

⁴Parker (2006) 1D Sediment Transport Morphodynamics with applications to River and Turbidity Currents, e-book.

2.4.2.6 Toffaleti

Toffaleti (1968) is a total load function developed primarily for sand sized particles, which followed the basic principles of the Einstein approach, replacing some of the empirical assumptions. Toffaleti is usually applied to 'large rivers', since most of the data used to develop it were from large, suspended load systems. The function is not driven by excess shear velocity or bed shear. Instead, it describes the relationship between sediment, hydraulics, and water temperature with a set of regressions.

Toffaleti divides the water column down into four vertical zones and computes the concentration of each zone with a simple approximation of a Rouse concentration profile. The four zones are based on theoretical inflection points and transitions in the vertical velocity profile. The function then computes transport in each of the zones (see figure below) based on a "reference unit sediment discharge" (M_i):

$$M_i = \frac{G_{ss} (1 + n_v - 0.756z_i)}{\left(\frac{R}{11.24}\right)^{1+n_v-0.756z_i} - (2d_{si})^{1+n_v-0.756z_i}}$$

Where g_{ssLi} is the "nucleus load"

⁵¹ http://hydrolab.illinois.edu/people/parkerg/morphodynamics_e-book.htm

$$g_{ssLi} = \frac{0.600p_i}{\left(\frac{T_A k_4}{V^2}\right)^{\frac{5}{3}} \left(\frac{d_{si}}{0.00058}\right)^{\frac{5}{3}}}$$

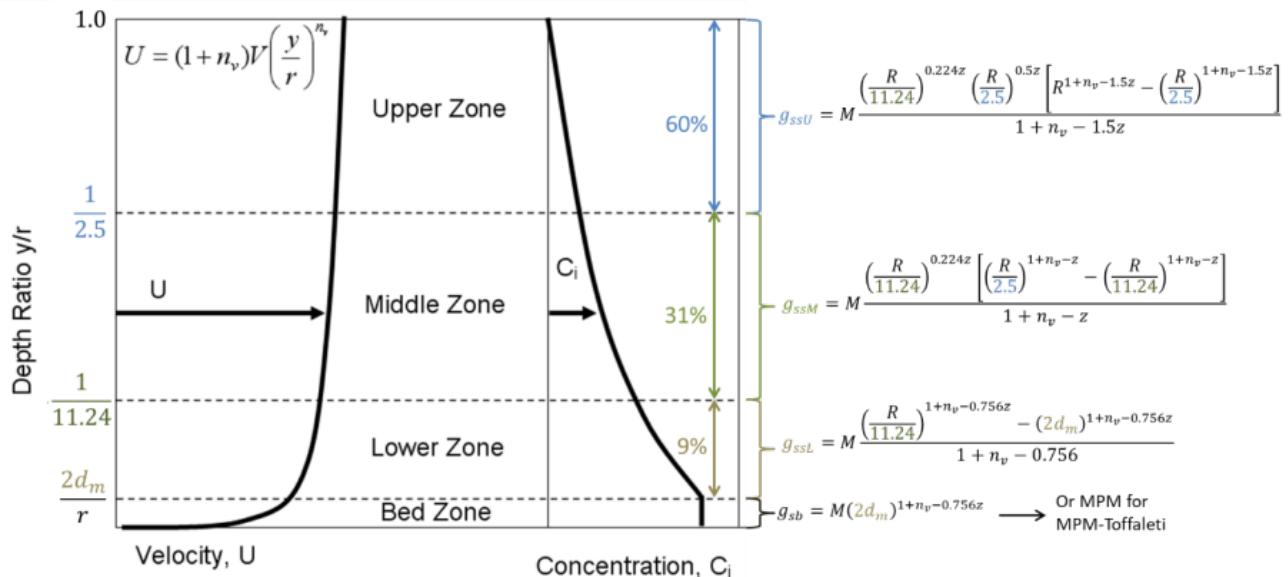
and the two exponents are:

$$z_i = \frac{\omega V}{(260.67 - 0.667T)rS}$$

$$n_v = 0.1198 + 0.000048T$$

In these equations, T is temperature, V is the 1D, depth averaged water velocity, r is the full, average water depth, S is the river slope, d_{si} and w_i are the particle size and fall velocity of the particular grain class (i) and p_i is the fraction of that grain class. Because of the dimensionality of this equation, all units are US customary, and HEC-RAS converts SI units before and after calculating Toffaleti transport.

$$g_s = g_{ssU} + g_{ssM} + g_{ssl} + g_{sb}$$

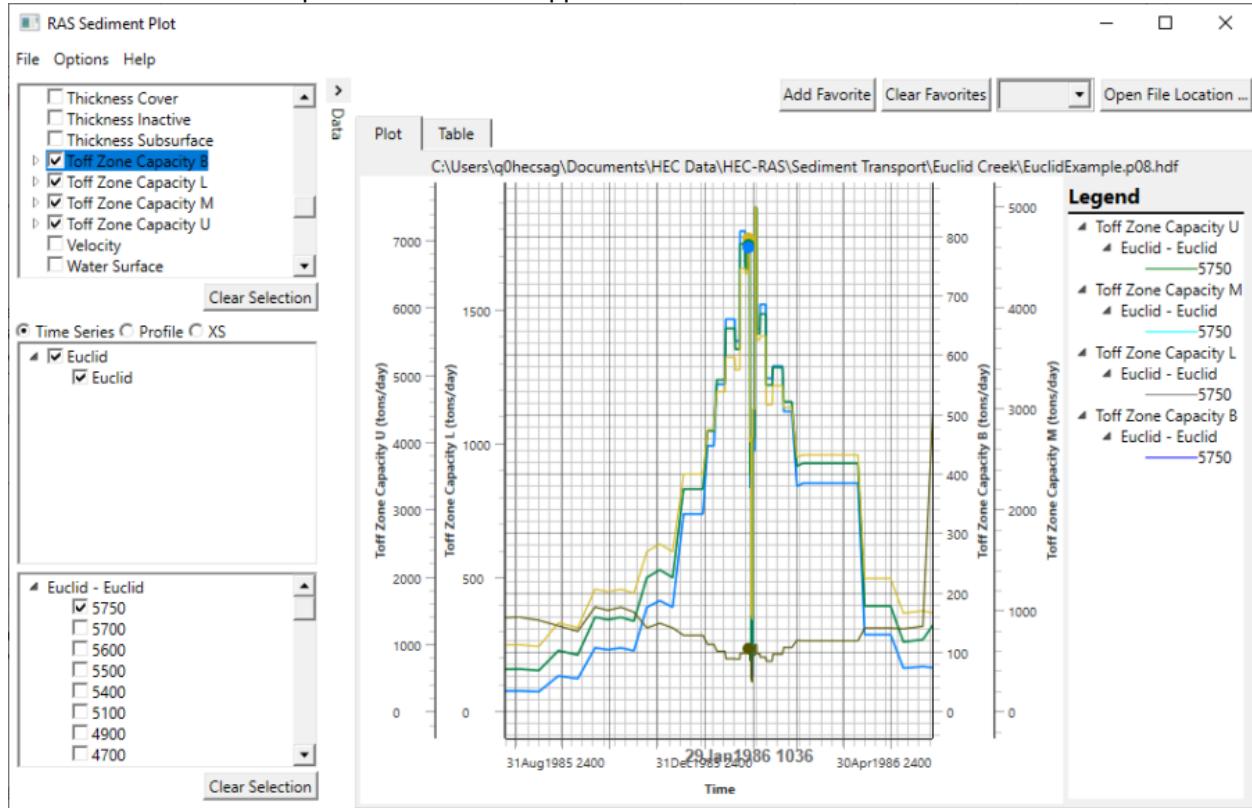


Modeling Note: Toffaleti temperature sensitivity

Temperature appears in both the z and n_v exponents, which can make Toffaleti more sensitive to temperature than excess shear equations.

The USACE has applied the function successfully to large systems like the Mississippi, Arkansas, Sacramento, and the Atchafalaya Rivers. However, it performs particularly poorly for gravel size particles. Additionally, the Toffaleti equation uses two different grain sizes, a d_{50} and a d_{65} , to quantify transport dependence on the gradational deviation from the mean. This made more sense when the equation was used to compute the transport of the bulk gradational material. When HEC-RAS applies it to the individual grain classes, it will use the d_{50} and d_{65} for the given grain class, stretching the original intent of the d_{65} parameter.

HEC-RAS can output transport for each zone separately, approximating the vertical concentration profile. Sometimes modelers will use this feature to calibrate to suspended load measurements, comparing the measurement to the computed flux from the upper three zones.



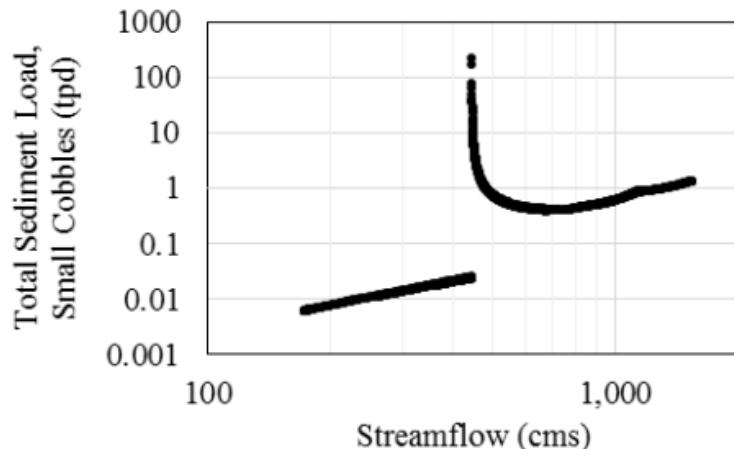
2.4.2.7 Toffaleti-MPM

The Toffaleti equation was developed for large, sand bed river, and does not perform well for coarse particles (Williams and Julian, 1989). Williams, D. T., and Julian, P. Y. (1989). "Applicability index for sand transport equations." Journal of Hydr. Eng., 115(11), 1578– 1581. But some large domain models include large sand-bed rivers as well as coarser tributaries. Because HEC-RAS requires user to select one transport function, these models have to use the same equation for both. HEC 6 addressed systems where Toffaleti was appropriate for down-gradient rivers that have coarse bed-load up-gradient, but integrating the Toffaleti and the Meyer-Peter Muller equations. This combined function replaces the bed component of Toffaleti with the MPM bed load equation which is more appropriate for coarse material.

2.4.2.8 Toffaleti Limiter

The Toffaleti transport function was not developed for these large particles or high gradient systems and has a numerical artifact that can arise under these conditions. Yaw et al. (2019)⁵² demonstrated a load discontinuity, under certain shallow, large particle settings. This discontinuity is native to the Toffaleti equation so it can show up in the original formula or its hybrid with MPM which was designed to extend the approach to larger particle sizes.

⁵² https://www.sedhyd.org/2019/openconf/modules/request.php?module=oc_program&action=view.php&id=130&file=1/130.pdf



As long as the hydraulic radius is roughly an order of magnitude larger than twice the particle size the form of the Toffaleti equation works. But as $2d_{si}$ approaches Rh11.24 the denominator of the reference unit sediment discharge (see *Mi* equation in Toffaleti Section) goes to zero (generating infinite transport) and then negative as grain size continues to increase relative to shallow depths.

But particles that invert the Toffaleti transport denominator are unlikely to be suspended. These particles will almost always be limited to bed load. So HEC-RAS added a "Toffaleti limiter" that uses Julian's (2002) Rouse number, suspension test, that a grain class is likely to be suspended if the fall velocity (w) is less than 40% of the shear velocity (u) ($u/w > 0.4$). Therefore, HEC-RAS checks the Rouse number (u_*/w) of each grain class in each time step and sets the transport capacity to zero for all transport ones where Rouse number is less than or equal to 0.4,

2.4.2.9 Yang

Yang (1973, 1984) is a total load transport equation which bases transport on Stream Power, the product of velocity and shear stress. The function was developed and tested over a variety of flume and field data. The equation includes two separate relations for sand and gravel transport. Yang tends to be very sensitive to stream velocity, and it is more sensitive to fall velocity than most.

Yang is fundamentally a power law equation where Concentration (C_t) is a function of excess stream power ($VS - VS_{cr}$):

$$C_t = a(VS - VS_{cr})^b$$

The log-transformed version of that equation is:

$$\log C_t = b + \log a(VS - VS_{cr})$$

Stream Power Critical Stream Power

The actual form of the Yang (1973) sand (particle size, $d < 2\text{mm}$) equation is:

$$\log C_t = 5.435 - 0.286 \log \frac{\omega d_m}{V} - 0.457 \log \frac{u_*}{\omega} + b$$

a $\left(1.799 - 0.409 \frac{\omega d_m}{V} - 0.314 \log \frac{u_*}{\omega} \right) \log \left(\frac{VS}{\omega} - \frac{V_{cr} S}{\omega} \right)$

Where the power and coefficient are functions that include dimensionless parameters (e.g. the classic ratio

of shear velocity and fall velocity that is often used to determine if a grain class can be suspended.

The variables are:

C_t = Total sediment concentration

ω = Particle fall velocity

d_m = Median particle diameter

ν = Kinematic viscosity

u^* = Shear velocity

V = Average channel velocity

S = Energy gradient

This transport function switches to Yang's (1984) gravel equation for grain classes larger than 2 mm.

$$\log C_t = 6.681 - 0.633 \log \frac{\omega d_m}{\nu} - 0.282 \log \frac{u_s}{\omega} + \left(2.784 - 0.305 \frac{\omega d_m}{\nu} - 0.282 \log \frac{u_s}{\omega} \right) \log \left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega} \right)$$

The transition between the sand and gravel equations is not always smooth. If results have counter intuitive results around the sand-gravel boundary, investigate the computed potential across that transition.

2.4.2.10 Wilcock and Crowe

Wilcock and Crowe (2003) is a bedload equation designed for well-graded (poorly-sorted) rivers containing both sand and gravel. It is a "surface" transport method based on the theory that transport depends on the material in direct contact with the flow and it is the bed surface that modulates bed mobility. It was developed based on the surface gradations of flumes and rivers and sediments with bulk sand contents between 6-34%. The beds were often armored with much lower sand content on the surface than in the subsurface. Therefore, users should choose active layer algorithms and gradations should reflect the bed surface properties. **Always use this function with the Active Layer bed mixing method** and consider defining separate, initial active layer gradations to reflect the cover layer.

The Wilcock and Crowe equation is based on the ratio of the shields number (τ^*) to a "reference shields" number (τ_{ri}^*), making it a sort of excess shear stress. The reference shields parameter is comparable to the critical Shields parameter in MPM or Laursen-Copeland, but recognizes that rivers transport trace sediment volumes at very low shear stresses. Therefore, instead of defining a "critical" shear stress, below which no particles move, this function uses a reference shear stress where transport is trivial. The factor 0.002 in the transport equation below corresponds to the reference transport rate.

They define transport Wi^* as two functions of the dimensionless shear ratio τ^*/τ_{ri}^* :

$$Wi^* = \begin{cases} 0.002 \left(\frac{\tau^*}{\tau_{ri}^*} \right)^{7.5} & \text{if } \frac{\tau^*}{\tau_{ri}^*} < 1.35 \\ 14 \left(1 - \frac{0.894}{\sqrt{\frac{\tau^*}{\tau_{ri}^*}}} \right)^{4.5} & \text{if } \frac{\tau^*}{\tau_{ri}^*} \geq 1.35 \end{cases}$$

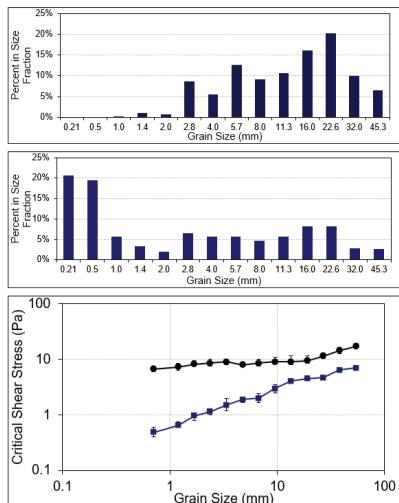
The Wilcock and Crowe approach is distinct from the other transport functions because include a hiding equation that accounts for grain class inter-dependence. When a single grain size is used to represent the sediment mixture, the transport equation assumes the same reference shear stress will mobilize all the sizes. This is accurate for very well mixed sediments but becomes less accurate as a sediment grain size distribution develops. In the figures shown below, the grain size distribution of the bed sediment shown in brown (graph A below) is well mixed (or poorly sorted) and the grain size distribution of the bed sediment shown in brown (graph B below) is poorly mixed (well sorted). Both are representative of natural gravel and sand river systems. The influence of mixture on grain inter-dependence causes the sizes in the brown mixture to mobilize at a similar critical shear stress for all but the largest grains. In graph C below, the critical

shear stress curve is near flat until the largest size fractions. In contrast, the green sediment, which is poorly mixed / well sorted, has a much larger range of critical shear stresses at which the different grain size fractions mobilize. Transport of the brown sediment could be reasonably approximated using the d_{50} grain size and a single critical shear stress value. Transport rates for the green sediment require grain size specific calculations. The Wilcock and Crowe model accounts for this inter-dependence and sensitivity of critical shear stress on grain size mixture through a hiding factor that explicitly incorporates grain size.

The last two decades of graded sediment transport research suggests that gravel and cobbles affect sand transport and visa versa. Wilcock and Crowe quantify grain class dependence with hiding and sand dependent gravel transport equations:

Hiding: Wilcock and Crowe computes the inter-dependence of grain sizes and the influence on mobility and transport with a hiding function. The hiding function relates the transport potential of bed surface to the distribution of finer and larger sizes.

Where there is a small amount of sand on the surface, sand nestles between larger gravel clasts, which reduces the bed shear it experiences. In this way coarse clasts reduce the transport of fine particles to occurring only when a large grain is mobilized. In contrast, gravel transport increases with sand content. As sand content of the bed surface increases, it 'lubricates' the bed, depositing between surface gravels and reducing the framework integrity. Once mobilized, the gravels are transported more easily over the sandier bed surface.



Wilcock and Crowe adjusts the reference shear (τ_{ri}^*) for the specific grain size class using the base reference shear (τ_{rm}^*) for the median grain class, the ratio of the grain class particle size (d_i) on the surface to the median mixture surface grain size (d_{sm}), and the hiding factor, b :

$$\tau_{ri}^* = \tau_{rm}^* \left(\frac{d_i}{d_{sm}} \right)^b \text{ and } b = \frac{0.67}{1 + \exp \left(1.5 - \frac{d_i}{d_{sm}} \right)}$$

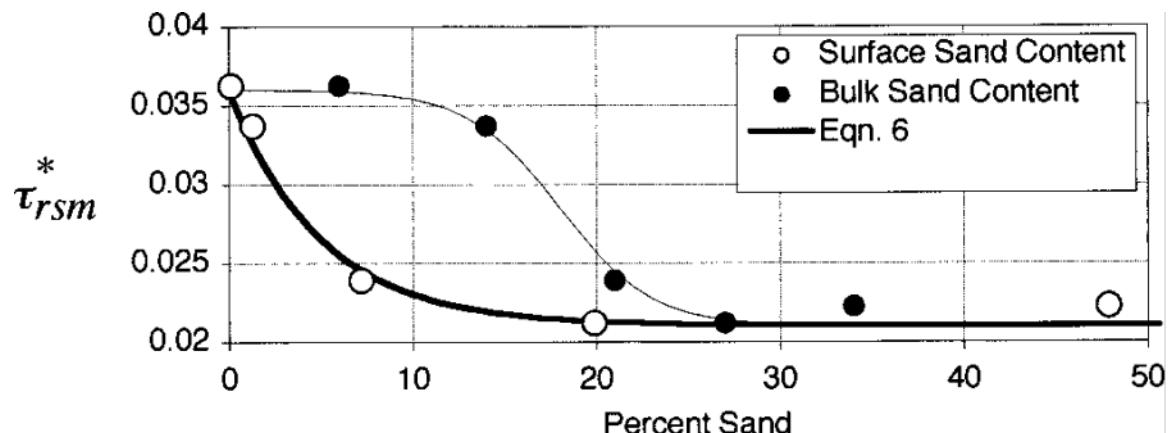
Modeling Note:

Modeling Note: HEC-RAS version 6.0 included [hiding features](#) (see page 311) independent of the transport functions. Because Wilcock and Crowe includes a hiding algorism, modelers should not use it with the generic hiding features in the Bed Mixing Options. Adding a hiding feature to this transport function would double-count the process.

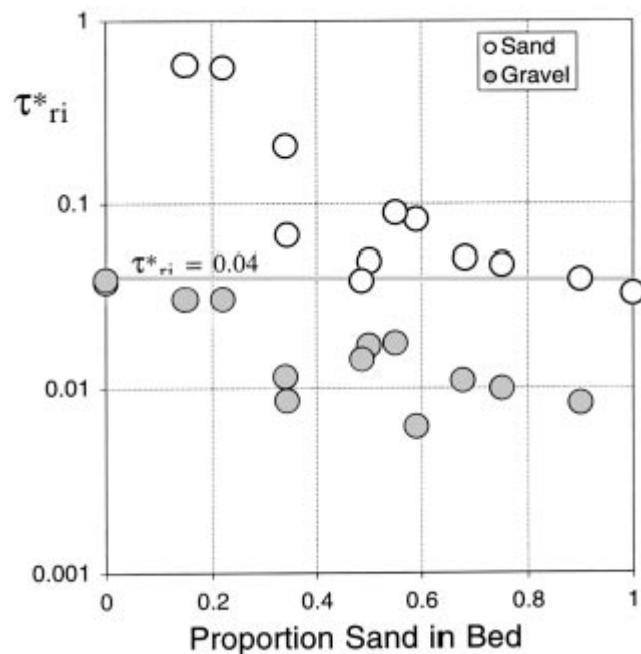
Wilcock and Crowe also include this effect in the base reference shear stress (τ_{rm}^*). The reference shear is a function of the sand content (FS) of the bed surface (in percent):

$$\tau_{rm}^* = 0.021 + 0.015e^{-20FS}$$

The equation for base reference shear stress is derived using the surface sand content, as shown in the figure below. The reduction in reference shear stress occurs for both sand content on the bed surface and in the subsurface. However, the equations in the Wilcock and Crowe model are fit to the surface sand.



The figure below illustrates the influence of the sand content on the bed surface over the reference shear stress for the sand and gravel fractions. As the sand content increases and sand becomes able to transport independent of gravel movement, the reference shear stress for sand decreases from a maximum of 0.8 to a minimum of 0.04. At the same time the reference shear stress for the gravel fraction decreases from 0.04 to 0.01 as the increase in sand on the bed surface makes it easier to transport.



As the sand content increases: the reference shear decreases, increasing the excess bed shear, and total transport. This equation is very sensitive to this sand content parameter, making field data collection of a separate gravel count and surface sand content estimate very important.

Modeling Note - Calibrating Wilcock and Crowe:

To calibrate (see page 311) Wilcock & Crowe (2003), adjust the mobility scaling factor⁵³, which will be allied to t_{rm} . Adjusting t_{rm} corrects error in the drag partition or other site-specific mobility factors while preserving both the hiding function and the transport function. Choosing to specify t_{rm}^* directly, overwrites the mobility parameter and loses the sand dependence from the t_{rm}^* equation above

Modeling Note - Sensitivity to Surface Grain Size Distribution Bias:

Surface gradations are usually measured with Wolman pebble counts or photoseiving. Numerous studies have shown that manual particle count surveys tend to be biased against the largest and smallest size fractions, particularly random walk methods in the water. See Bunte and Abt (2001) [Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams](#)⁵⁴, for a discussion of common surface gradation sample biases and best practices. The gravel count should be truncated at 8 mm at the finer end and 128 mm at the coarser end. When truncating, sampled grains are grouped together as 'finer than' or 'greater than' and a visual estimate is made of the percent bed surface cover by the fractions. A grid-based sampling system reduces the error associated with random walks and selection by touch. Particles as small as 4 mm may be counted when using a grid. Pebble counts also bias the percent of sand on the bed. Therefore, the sand component should be estimated by eye. "Photoseiving" also includes biases. Overlapping or buried particles tends to underrepresent the coarser grain classes by as much as 20%. Surface based transport methods are sensitive to these gradations and will be affected by biased measurements.

This modeling note is based on recommendations from transport function developer Dr. Joanna Curran (Crowe).

Transport Capacity

Once HEC-RAS computes **transport potential**, applying the transport equation to each grain class, (i.e. as if the system was composed of 100% of that grain class) the model must translate that into the actual grain class transport, as a function of the composition of the sediment mixture. The **transport capacity** prorates the **transport potential**, reducing the transport of each grain class based on its prevalence in the bed.

2.4.3 Classic Bed Partitioning

The **transport capacity** for each grain class is the **transport potential** multiplied by the percentage of that grain class in the bed. Therefore, the total transport capacity is:

53 https://www.hec.usace.army.mil/confluence/display/_Scaling_Factors

54 <https://www.fs.fed.us/rm/pubs/rmr074.pdf>

$$T_c = \sum_{j=1}^n \beta_j T_j$$

Where: T_c is Total transport capacity, n is the number of grain size classes, β_j is the percentage of the active layer composed of material in grain size class "j", and T_j is the Transport potential computed for the material in grain class "j". Partitioning capacity based on the gradation of the active layer is a classic assumption based Einstein's (1950), who proposed sediment discharge of a size class is proportional to the fractional abundance of that size class in the bed (Vanoni, 1975).

Modeling Note – Partition Gradations for Empty Sediment Control Volumes

As long as the sediment control volume has bed sediment, it can partition the transport potential into capacity. However, if the active layer thickness = 0, either because it is a concrete channel with no starting sediment thickness (Initial Max Depth = 0) or because it scoured through the entire erodible depth, the bed partitioning assumption will run into trouble. If the active layer has no sediment, the fraction of each grain class is zero ($j=0$ in the previous equation). Therefore, regardless of the computed potential, this approach will compute no transport capacity over a fixed bed. If the model computes no transport capacity, it will deposit all of the sediment in one time step, and erode in the next, causing oscillating errors and decreasing transport in half, because it only transports every other time step.

To offset this numerical artifact, recent versions of HEC-RAS uses the initial bed gradation to partition potential into capacity if the control volume has no bed sediment. This is also why HEC-RAS requires bed gradations for concrete channels. It uses the gradation to compute capacity.

2.5 Capacity Sensitivity to Bank Stations and Movable Bed Limits

The first consideration when selecting movable bed limits should be which portion of the cross section the river will deposit or erode. The movable bed limits delineate which cross-section, station-elevation points can move vertically.

However, placing the movable bed limits can also affect the total sediment transport capacity. Most transport equations compute transport capacity per unit width. HEC-RAS converts this transport-per-unit-width to total transport by multiplying the unit rate by the distance between the movable bed limits. Therefore, though there are complicating feedbacks between cross section shape, channel bank placement, and movable bed limits, movable bed limits that are farther apart, often generate more transport capacity.

2.6 Continuity Limiters

The continuity equation compares the transport capacity to the supply (i.e. inflowing sediment load) for each grain class for each time step. If the capacity exceeds the supply HEC-RAS computes a sediment deficit. If the supply exceeds capacity the model computes a sediment surplus. In general, the model converts surplus into deposition and deficit into erosion. However, HEC-RAS applies some physical constraints to the

continuity equation, checking if computed deficit or surplus can actually erode or deposit. HEC-RAS models these constraints with three basic limiters: a temporal deposition limiter, a temporal erosion limiter, and the sorting and armoring algorithms that provide an additional constraint on erosion.

- [Temporal Deposition Limiter \(see page 316\)](#)
 - [Fall Velocity \(see page 316\)](#)
 - [Effective Transporting Depth \(see page 317\)](#)
- [Temporal Erosion Limiter \(see page 319\)](#)
- [Sorting and Armoring \(see page 320\)](#)
 - [Thomas Mixing Method \(Exner 5\) \(see page 322\)](#)
 - [Copeland Mixing Method \(Exner 7\) \(see page 329\)](#)
 - [Active Layer Mixing Method \(see page 330\)](#)

2.6.1 Temporal Deposition Limiter

The temporal constraint on deposition is the limiter based on the simplest and most robust theory. Fall velocity controls how fast particles can drop out of the water column and deposit. By comparing the vertical distance a particle has to travel to reach the bed surface and the vertical distance a particle can travel in a time step (fall velocity * time), HEC-RAS computes the percentage of a sediment surplus can actually deposit in a given control volume in a given time step. The model computes a **deposition efficiency coefficient** for each grain class (i) :

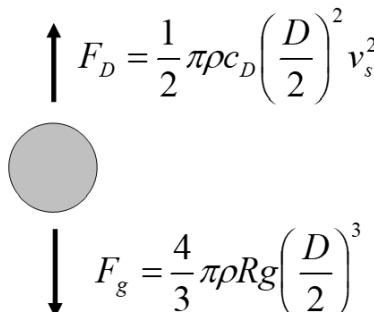
$$C_d = \frac{V_s(i) \times \Delta t}{D_e(i)}$$

Where: C_d is the deposition efficiency coefficient, $V_s(i)$ is the fall velocity for the grain class, t is the time step, and D_e is the effective depth of the water column over which the grain class is transported.

The coefficient is a fraction, which will reduce deposition if the product of the fall velocity and the time step is less than the effective depth. If the time and fall velocity are sufficient for the grain class to fall the entire effective depth (i.e. the numerator is greater than the denominator), all of the surplus sediment deposits. This ratio requires two parameters (in addition to the time step, which HEC-RAS provides automatically): fall velocity and the effective transport depth.

2.6.1.1 Fall Velocity

Most fall velocity derivations start with balancing the gravitational force and the drag force on a particle falling through the water column. The free body diagram is included in the figure below.



$$\uparrow F_D = \frac{1}{2} \pi \rho c_D \left(\frac{D}{2} \right)^2 v_s^2$$

$$\downarrow F_g = \frac{4}{3} \pi \rho R g \left(\frac{D}{2} \right)^3$$

However, the resulting equation is circular because fall velocity is function of the drag coefficient C_D , which is a function of the Reynolds number, which is itself a function of fall velocity. This self-referential quality of the force balance requires either an approximation of the drag coefficient/Reynolds number or an iterative solution. The fall velocity options in HEC-RAS are detailed in Chapter 12, pages 12-30 to 12-32, but a few brief comments on how each of these methods attempts to solve this equation (fall velocity dependence on fall velocity) are given below.

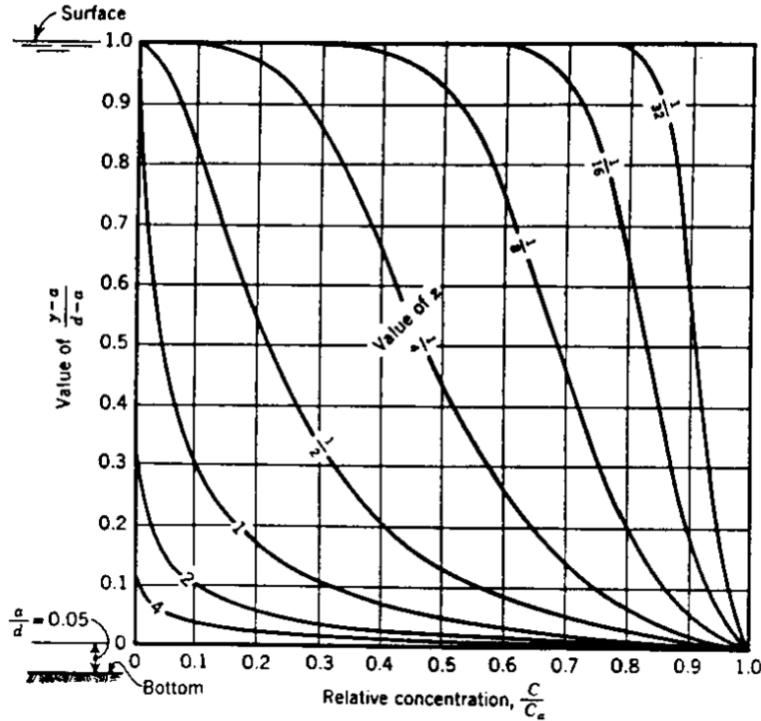
Rubey assumes a Reynolds number to derive a simple, analytical function for fall velocity. Toffaleti developed empirical, fall velocity curves that, based on experimental data, which HEC-RAS reads and interpolates directly. Van Rijn uses Rubey as an initial guess and then computed a new fall velocity from experimental curves based on the Reynolds number computed from the initial guess. Finally, Report 12 is an iterative solution that uses the same curves as Van Rijn but uses the computed fall velocity to compute a new Reynolds number and continues to iterate until the assumed fall velocity matches the computed within an acceptable tolerance.

Fall velocity is also dependent upon particle shape. The aspect ratio of a particle can cause both the driving and resisting forces in Figure 2.9 to diverge from their simple spherical derivation. All of the equations assume a shape factor or build one into their experimental curve. Only Report 12 is flexible enough to compute fall velocity as a function of shape factor. Therefore, HEC-RAS exposes shape factor as a user input variable but only uses it if the Report 12 method is selected.

2.6.1.2 Effective Transporting Depth

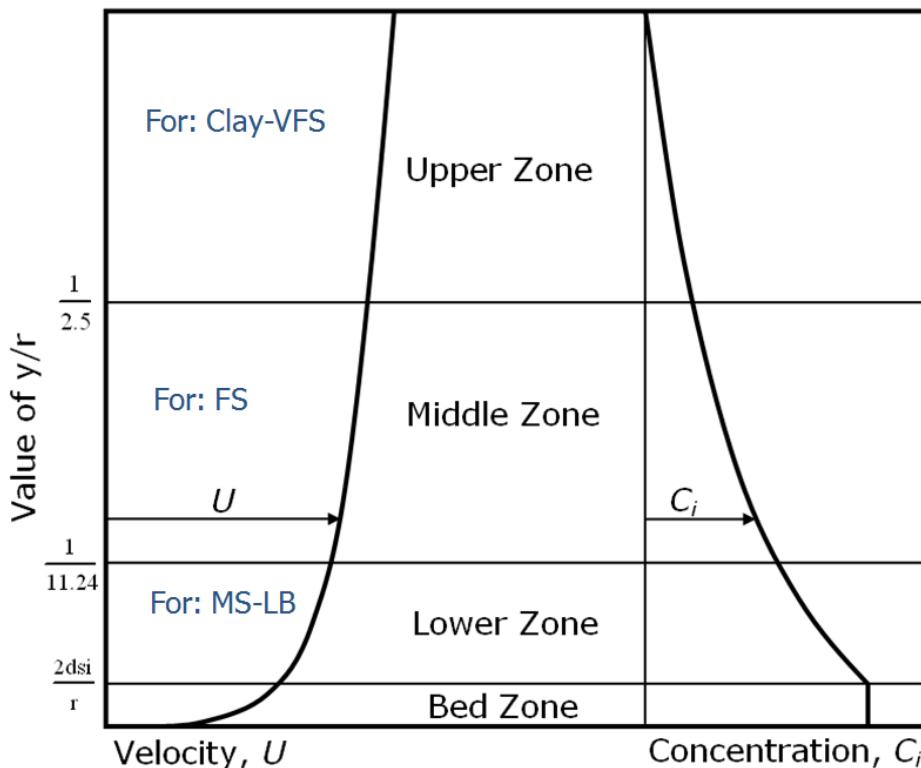
The deposition limiter works by comparing how far a particle can fall in a time step versus the distance available for it to travel. The fall velocity computes how far the particle can fall in a time step, but the temporal limiter equation also requires an average vertical distance that the grain class can fall. That distance depends on the concentration profile of the grain class in the flow field (i.e. sediment is not uniformly distributed in the water column).

Rouse (1963) developed the classic concentration profile theory (below). The Rouse number z is higher for larger particles and lower for higher shear velocities. Smaller particles and higher shears distribute suspended particles over more of the water column. Grain classes with higher Rouse numbers have to fall farther to deposit.



Toffaleti (1968) subdivided the

water column into four zones, computing transport separately for each zone (below). HEC-RAS uses these zones as a (coarse) integration of vertical concentration profiles. HEC-RAS adopts these four zones as the effective transporting depth for different grain sizes, assuming that the grain class is evenly mixed and in equilibrium in the zone. The model distributes grain classes smaller than fine sand throughout the entire water column (Effective Depth = 1). The model distributes fine sand over the middle, lower, and bed zone which compose the lower 40% of the water column. All coarser particles (\geq Medium Sand) transport relatively close to the bed, in the lower zone and bed zone, the deepest 9% of the water column.



This approach has limitations. It distributes sediment evenly throughout the zone at the beginning of each time step. This assumption simplifies the concentration gradients depicted in Rouse Concentration Profiles above. Additionally, assuming the effective depth (based on the transporting depth) is only a function of grain size ignores the Rouse dependence on shear velocity. Finally, the algorithm mixes the transporting zone fully at the beginning of each time step, retaining no memory of how far material settled in the previous time step. Despite the limitations, however, the temporal deposition limiter improves the continuity approach, limiting the deposition with physical process.

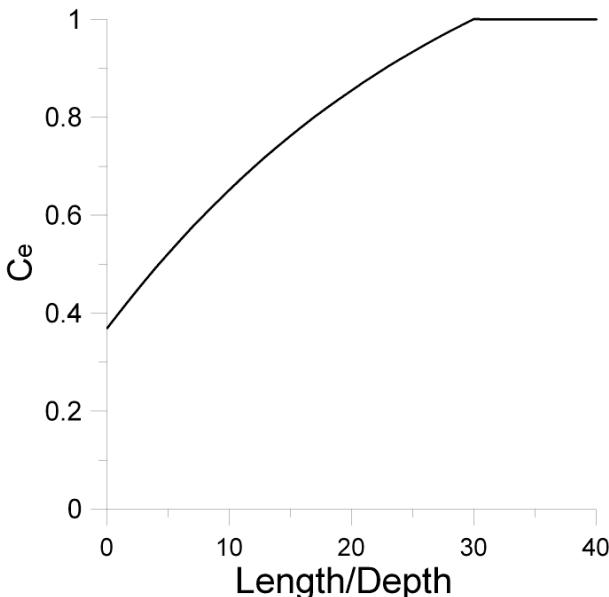
2.6.2 Temporal Erosion Limiter

Like deposition, erosion is also a temporal process. Physical processes delay erosion, potentially limiting the continuity surplus to a smaller erosion mass. Therefore, erosion also requires a temporal limiter. Unfortunately, the physical processes that delay erosion are more diverse, site specific, and difficult to quantify than those that limit deposition. The equations used are more empirical and generally less accurate.

HEC-RAS adopted its erosion limitation equation from HEC 6. It is similar to 'Characteristic Flow Length' principles, but predates them. The governing assumption, based on undocumented flume experiments, is that an unarmored reach requires thirty times the water depth for erosion to fulfill the capacity. This assumption is reflected in the equation for the entrainment coefficient:

$$C_e = 1.368 - e^{-\left(\frac{L}{30 \times D}\right)}$$

Where: C_e is the entrainment coefficient, D is flow depth, and L is length of control volume. This equation produces the relationship between the entrainment coefficient and length/depth ratios in the figure below. HEC-RAS multiplies the sediment deficit by this entrainment coefficient to calculate erosion.



If the length exceeds the flow depth by thirty times or more, the entrainment coefficient goes to one and HEC-RAS erodes the full deficit. In the lower limit, as the length approaches the depth, the second term of the C_e equation goes to 1 leaving a minimum entrainment coefficient of 0.368. Therefore, the program will always allow at least 36.8% of the deficit to erode.

2.6.3 Sorting and Armoring

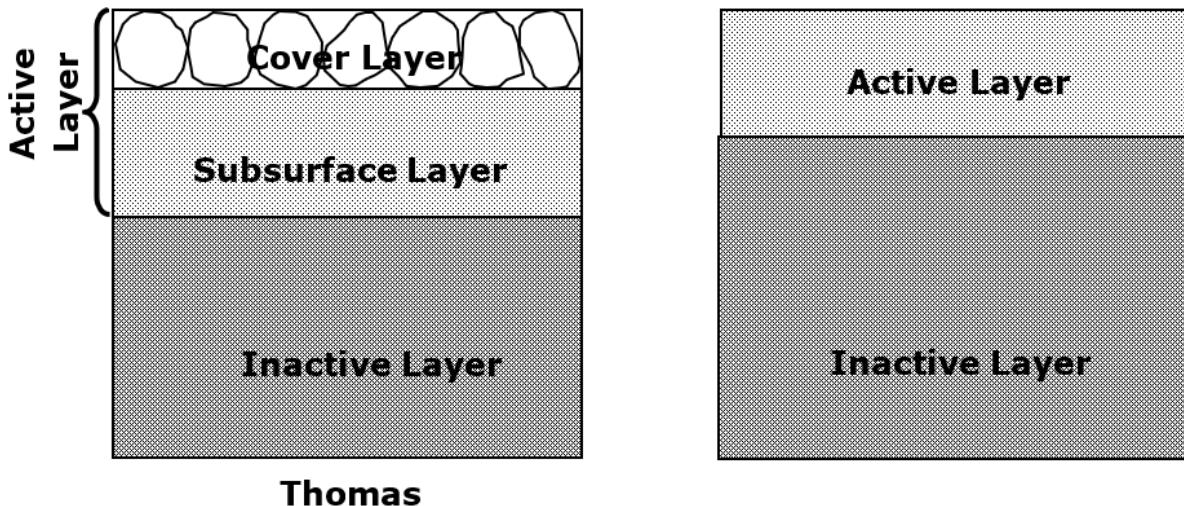
Erosion can also be supply limited. In many well graded rivers, a coarse armor layers forms on top of a subsurface layer, composed of the representative reach gradation. Rivers form these coarse armor layers by static or dynamic armoring (Parker, 2008). Static armoring comes from differential transport of finer materials, where finer particles transport, leaving the coarse particles behind until the immobile coarse particles armor the bed, precluding future erosion. Static armoring processes often dominate downstream of dams, where attenuated flow regimes are competent to move finer particles but not coarser particles. Dynamic armoring can also form armor layers in systems where large flows are competent to move all grain classes. Dynamic armoring forms coarse cover layers while all grain classes are mobile because equilibrium transport of graded material requires over representing coarse particles at the surface, compensating for their lower transportability by increasing their availability (Parker, 2008).



In either case, armor layers decrease total transport because the surface particles available for transport tend to be coarser and more difficult to move. This is also a physical limiter on the transport capacity.

HEC-RAS includes three algorithms to simulate bed sorting and armoring. All three algorithms divide the bed into an active layer and an inactive layer. The active layer is a surface layer that represents actively

transporting material (or material that could be transported). The active layer gradation evolves independently and material is moved between it and the parent material in the inactive layer below it. HEC-RAS computes transport capacity based on the gradation of the active layer, not the entire bed.



87 Schematic of two mixing layers in HEC-RAS sorting and armoring methods.

- [Thomas Mixing Method \(Exner 5\)](#) (see page 322)
- [Copeland Mixing Method \(Exner 7\)](#) (see page 329)
- [Active Layer Mixing Method](#) (see page 330)

2.6.3.1 Thomas Mixing Method (Exner 5)

The **Thomas** method (formerly Exner 5) is the default sorting and armoring method in HEC-RAS. This is a [three-layer bed mixing algorithm](#) (see page 320), which was designed to account for the influences of static armoring. Tony Thomas developed this method (Thomas, 1982), which was the default method in HEC-6. It subdivides the active layer into a cover layer and a subsurface layer, allowing a thin cover layer to coarsen and regulate erosion, while maintaining the more broadly graded active layer. HEC-RAS computes transport capacity computation based on the gradation of the entire active layer, which includes the combined cover and subsurface layers. Sediment deposits into and erode from the cover layer. Thomas developed this mixing algorithm based on the photograph in Figure 13-8 and the data in Harrison (1950).

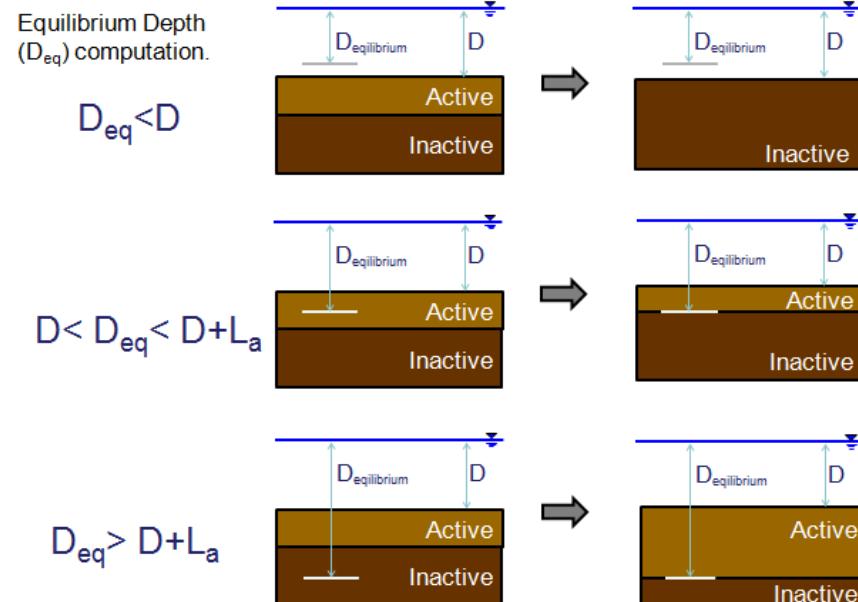
If finer grain classes erode faster than coarser glasses (relative to their abundance) the cover layer coarsens, regulating the sediment that transport capacity can remove from the active layer. HEC-RAS can erode a grain class long as it is available in the cover layer. But once the model strips a grain class from the cover layer it will try to satisfy the grain class transport capacity with subsurface layer sediment. The cover layer can reduce or preclude erosion from the subsurface layer, leaving capacity unfulfilled.



The Copeland (1992) method followed the basic approach and architecture of the Thomas method made a few critical changes. The discussion that follows generally applies to both methods, then the algorithm elements particular to Copeland are discussed in the next section.

2.6.3.1.1 Active Layer and Equilibrium Depth:

The Thomas method computes the Active Layer (cover layer + subsurface layer) at the beginning of each time step by computing the **Equilibrium Depth** (D_{eq}). Equilibrium Depth is the smallest water depth at which surface sediment does not move, where hydraulic forces are too small to move bed particles. Alternately, it is the maximum potential scour depth. Then it adjusts the active layer to the equilibrium depth (Figure 215).



Equilibrium Depth (D_{eq}) is based on a relationship between hydraulic energy, bed roughness and sediment

transport intensity. The Thomas method combines Manning's equation for flow velocity, Strickler's equation for grain roughness, and Einstein's Transport Intensity equation to compute equilibrium depth:

Manning's Equation

$$V = \frac{1.49}{n} R^{\frac{2}{3}} S_f^{\frac{1}{2}}$$

Strickler's Roughness Equation

$$n = \frac{d^{\frac{1}{6}}}{29.3}$$

Einstein's Transport Intensity Equation

$$\Psi = \frac{\rho_s - \rho_w}{\rho_w} \times \frac{d}{D \times S_f}$$

Where:

V = Velocity

R = Hydraulic Radius

S_f = Friction Slope

n = Manning's n value

d = representative particle size

ρ_s = grain density

ρ_w = water density

D = Depth

The Einstein Equation assumes particle erosion when the transportability ≥ 30 . Submerged particle density ($\rho_s - \rho_w$) is 1.65. Substitution reduces the Einstein's Transport Intensity equation to:

$$S_f = \frac{d}{18.18D}$$

HEC-RAS solves these three equations for unit water discharge by replacing the sub-sectional hydraulic radius in the Manning equation with the panel depth, D, and the n-value with Strickler's equation such that:

$$q = \frac{1.49}{\left(\frac{d^{\frac{1}{6}}}{29.3}\right)} \times D^{\frac{5}{3}} \times \left(\frac{d}{18.18D}\right)^{\frac{1}{2}}$$

or

$$q = 10.21 \times D^{\frac{7}{6}} \times d_i^{\frac{1}{3}}$$

Where:

q = water discharge in cfs per ft of width

d_i = the particle diameter

D = is the depth that does not transport the grain class, or the equilibrium depth D_{eq}.

Solving for D_{eq} yields:

$$D_{eq} = \left(\frac{q}{10.21 \times d_i^{\frac{1}{3}}} \right)^{\frac{6}{7}}$$

Where: D_{eq} = Equilibrium depth for particle size, i

The Thomas method solves the equilibrium depth equation for each grain class, and sets the active layer thickness to the largest, which is the maximum possible scour.

2.6.3.1.2 Splitting the Active Layer: Cover and Subsurface Layers

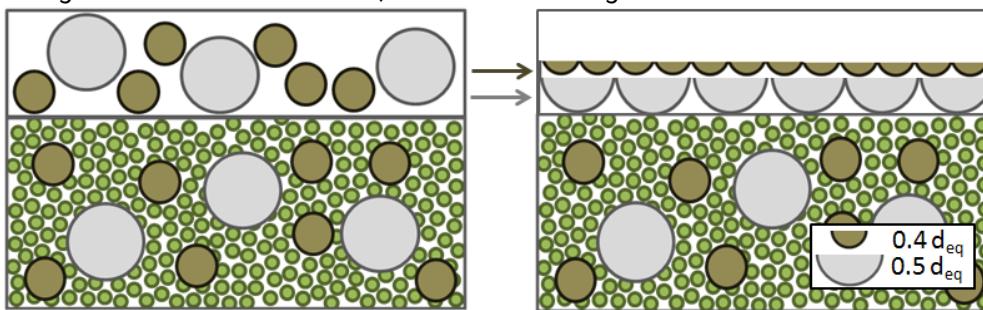
Thomas' main innovation was dividing the active layer into two sub layers: a **cover layer** and a **subsurface layer**. The algorithm computes transport capacity based on the entire active layer, but the cover layer coarsens independently and regulates erosion from the rest of the active layer (the subsurface layer).

At the beginning of the bed mixing stage, HEC-RAS computes a new active layer thickness – based on the equilibrium depth. HEC-RAS carries the cover layer over from the previous time step but re-creates the subsurface layer each time based on the new active layer thickness computed by equilibrium depth.

2.6.3.1.3 Equivalent Particle Diameter:

The Thomas function (and the Copeland method after it) computes cover layer armoring based on an **equivalent particle diameter** principle. This **equivalent particle diameter** can be difficult to conceptualize, but is central to understanding the algorithm.

The **equivalent particle diameter (d_{eq})** converts the mass of each grain class into an equivalent thickness, expressed as a fraction or multiple of the grain class diameter. For example, if the large (grey) grain class in the figure below were spread evenly over the control volume, it would form a layer approximately half the particle diameter thick (half an equivalent particle diameter or $0.5d_{eq}$). Likewise, if the medium (brown) grain class in the cover layer (below) would form a layer approximately 40% of its diameter thick if spread evenly over the entire control volume ($d_{eq}=0.4$). The **equivalent particle diameter** converts the cover layer mass of each grain class into a thickness, normalized to the grain class diameter.

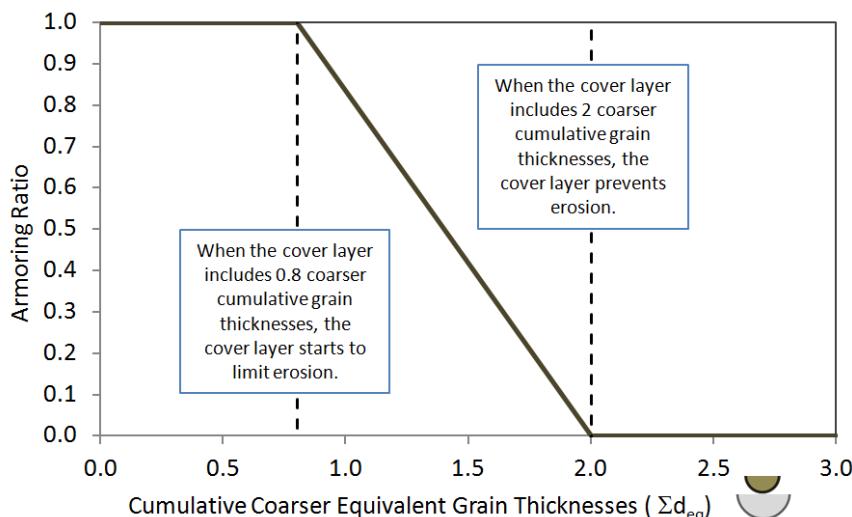


2.6.3.1.4 Armoring Ratio:

The Thomas and Copeland methods both use the equivalent particle diameter to compute an **Armor Ratio**. The Armor Ratio is a coefficient between 0 and 1, which reduces the sediment deficit HEC-RAS will erode from the sub-surface layer, if the cover layer includes enough coarser material.

The Thomas algorithm has five basic steps:

1. Compute Sediment Deficit by Grain Class: First HEC-RAS computes transport capacity for each grain class and compares it to supply. If capacity exceeds supply, it tries to erode the deficit from the bed.
2. Sum the Equivalent Particle Diameters of all coarser grain classes in the cover layer: Before HEC-RAS removes any sediment from the sub-surface layer, it computes the equivalent particle diameter of every *coarser* grain class in the cover layer, and then sums them.
3. Remove the Grain Class Mass from the Cover Layer: If the cover layer contains the enough of the grain class, HEC-RAS removes the entire deficit from the cover layer. If the cover layer does not have enough of the grain class to satisfy the deficit, HEC-RAS removes all of the grain class from the cover layer, and then tries to remove the balance from the sub-surface layer. For example, in the simplified substrate in the figure above, if HEC-RAS tried to remove the smallest grain class (green), it would sum the equivalent diameter of the two coarser grain classes. HEC-RAS uses the sum of the equivalent grain diameters for cover layer grain classes, coarser than the eroding grain class ($\Sigma d_{eq}=0.9$ in the figure above) to compute armor layer regulation (i.e. reduce the amount of deficit the model can erode from the sub-surface layer).
4. Compute an Armoring Ratio: The Thomas method computes an armor ratio from the cumulative coarser equivalent diameter according to the relationship in the figure below. This relationship interpolates between a low bound, where the cover layer has no effect on erosion and an upper bound where the armor layer totally prevents erosion from the subsurface layer.



Low Bound: If there is less than one total cumulative equivalent diameter of coarser material in the cover layer ($\Sigma d_{eq} < 1$), then the cover layer can't be continuous. For $\Sigma d_{eq} < 0.8$, 20% of the subsurface layer is exposed. At this thickness, the method assumes the cover layer has too many gaps to regulate the subsurface layer. The Thomas method does not reduce erosion for this case.

High Bound: On the other extreme, if the sum of the equivalent grain diameters of coarser grain classes is greater than 2 ($\Sigma d_{eq} > 2$) the cover layer will not allow any erosion of that grain class from the sub surface layer. This end point comes from broad empirical evidence that flow cannot 'suction' fine sediment through more than two grain diameters of immobile armored layer.

The Thomas method interpolates linearly between these end points:

No Armoring (Armor Ratio = 1 → erosion =deficit) for $\Sigma d_{eq} < 0.8$ and

No Erosion (Armor Ratio = 0 → erosion =0) for $\Sigma d_{eq} > 2$.

5. Erode the grain class from the sub-surface layer, reducing the deficit by the Armor Ratio: HEC-RAS multiplies the sediment deficit for each grain class by the armor ratio such reducing erosion for each grain class (i) according to the expression: $\text{Erosion}(i) = \text{Armor Ratio}(i) * \text{Sediment Deficit}$ For the example in Figure 216, where $\Sigma d_{eq}=0.9$, the Thomas method returns an armor ratio of 0.91, and HEC-RAS would remove 91% of the deficit of the fines grain class from the subsurface layer.(i)

2.6.3.1.5 Cover Layer Reset: Destruction or Burial

The cover layer evolves during the simulation, coarsening or fining in response to capacity and upstream load. However, there are two situations which cause the cover layer to 'reset,' which introduce bed gradation non-linearity. Understanding these processes will help interpret bed gradation results.

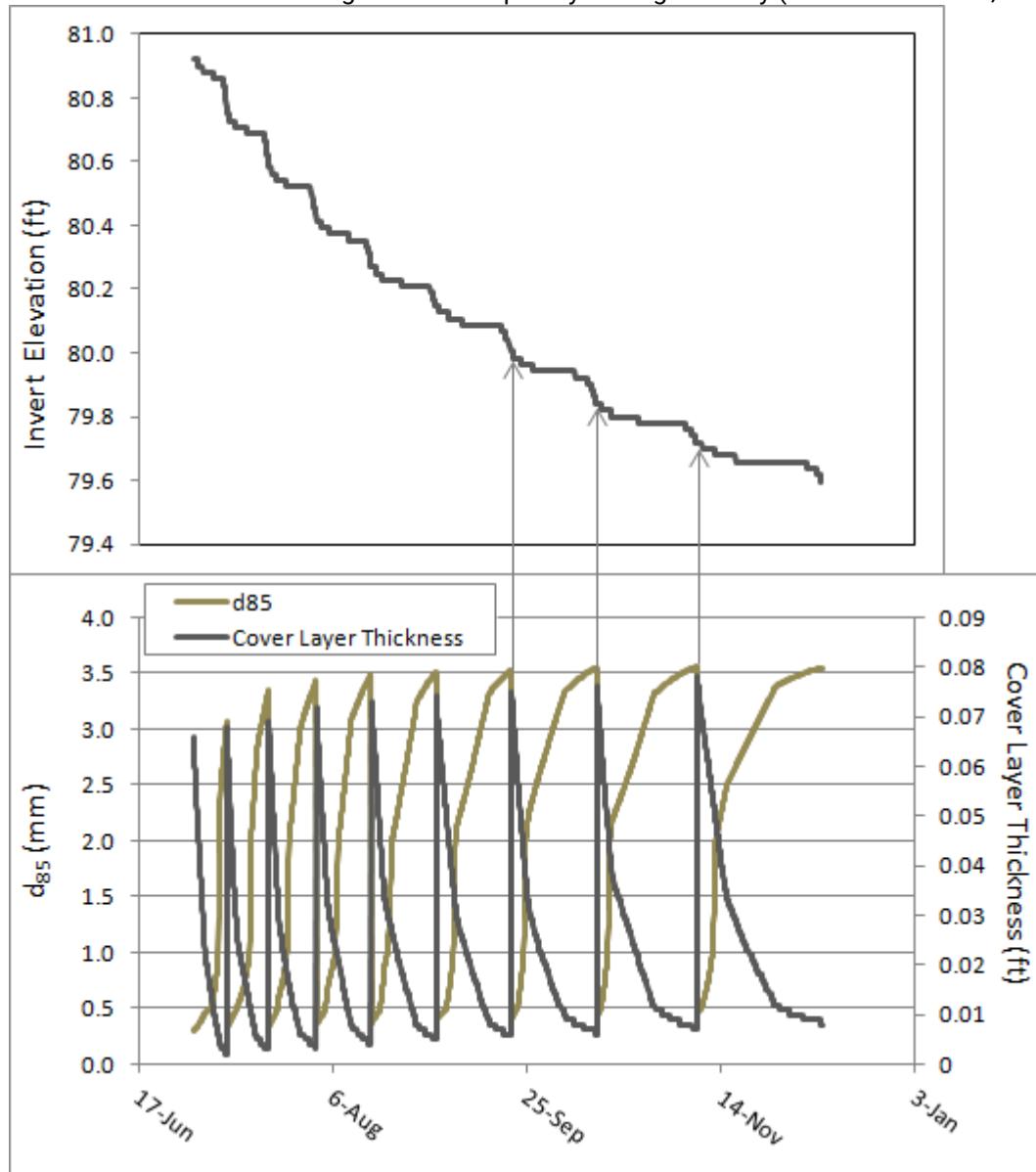
2.6.3.1.5.1 Cover Layer Destruction:

The cover layer can erode until it is too thin to regulate the bed. At that point, the Thomas method resets the layer, mixing it with the rest of the active layer, and cutting a new, thicker cover layer from the mixed active layer bed material.

At the beginning of each computation time step, HEC-RAS computes the **stratification weight** of the cover layer. The **stratification weight** is simply the combined **equivalent particle diameter** of *all* grain classes in the cover layer. If the stratification weight, the total cumulative equivalent particle diameter is less than 0.5, HEC-RAS destroys the cover layer. Thomas based the 0.5 threshold on Harrison's (1950) experiments, which demonstrated that equilibrium sediment transport dropped when 40% of the bed surface was covered in his flume experiments.

Cover layer destruction can generate gradation results that are difficult to interpret, like those in the figure below. This model eroded monotonically, and the capacity was high enough that the cover layer periodically slowed erosion but never stopped it. Therefore, as the bed eroded, the cover layer periodically coarsened, but as it coarsened it also thinned. When the cover layer thinned to less than 0.5 d_{eqs} , it reset, instantly fining as it adopted the gradation of the parent material. So, while the cover layer algorithm can form a static armor layer and keep the model from over-predicting erosion in graded sediment systems, cover layer dynamics

also make it difficult to track gradation temporally or longitudinally (Gibson and Pridal, 2015).



2.6.3.1.5.2 Cover Layer Burial:

HEC-RAS also resets the cover layer if deposition buries it. If the cover layer grows to 2 ft thick, the Thomas method assumes that the cover layer no longer exists as a distinct stratigraphic layer, and mixes the bed, resetting the cover layer with sediment from the mixed substrate. This feature is helpful in rapidly changing environments that alternate between deposition and armoring erosion, but can also introduce non-linear shifts in the gradation output.

The HEC-6 User's Manual includes more discussion on this mixing method, calling it Method 2 (p. 25)

2.6.3.2 Copeland Mixing Method (Exner 7)

The Thomas method was developed for coarse, well graded systems. It was initially developed for the Snake River, then generalized for other systems. But it tended to over predict armoring, and, therefore, under predict erosion on finer systems (USACE, 1993, Thomas, 2010). Copeland (1992) adjusted the method, to make it more applicable to sand beds. The Copeland method follows the Thomas method in concept and approach. It subdivides the active layer into cover and subsurface layers, allowing the gradation of the former to regulate erosion from the later. The Copeland method adds a "bed source" layer, but is still, practically, a three layer method, like the Thomas method. It computes an **armor ratio** based on the **equivalent particle diameters** of coarser grain classes. But the Copeland method changes some of the equations and assumptions, and generally allows more scour, making it popular for large, sand bed rivers.

There are three main differences between the Copeland and Thomas methods:

1. The Copeland method doesn't compute active layer thickness with the **equilibrium depth** concept. Instead it starts at the maximum or 2 d₉₀ or 15% of the water depth.



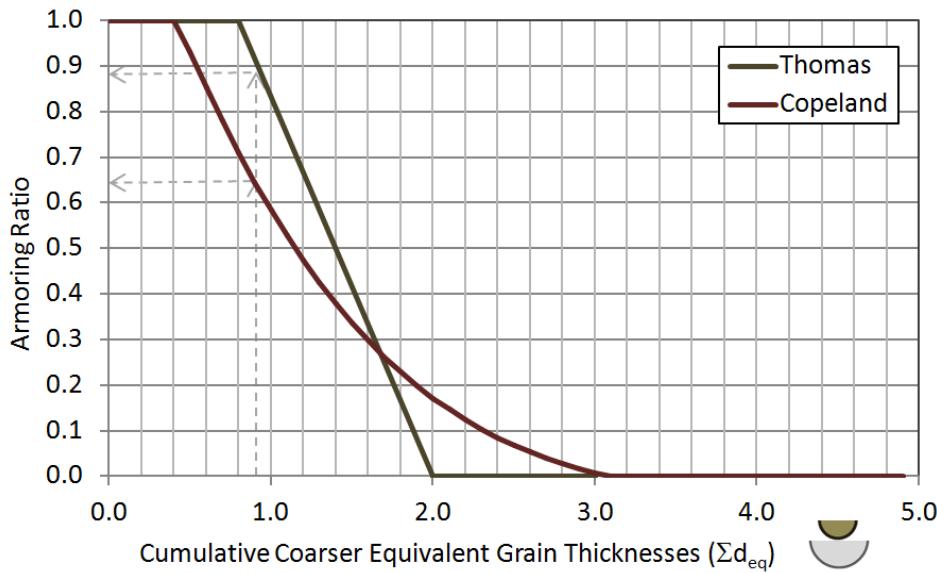
88 Schematic of the Copeland (1992) method

2. The Copleand method replaces the linear interpolation between $0.8 < \sum d_{eq} < 2$ (from the figure titled, "Armor ratio relationship used in the Thomas method" on [previous page \(see page 322\)](#)) with a polynomial:

$$AR = -0.026 * (\sum d_{eq})^3 + 0.28 * (\sum d_{eq})^2 - 1.07 * (\sum d_{eq}) + 1.40$$

This relationship has the same basic trend as the Thomas relationship but (Figure 2 20) starts armoring at a smaller $\sum d_{eq}$ ($0.4 < \sum d_{eq}$, following the Harrison observation) but not fully preventing subsurface erosion until $\sum d_{eq}$ is much higher ($\sum d_{eq} > 4$).

3. The cover layer is limited to a maximum thickness of $3d_{90}$. However, burial does not reset the cover layer.



The main differences between the Thomas and Copeland methods are summarized in the table below:

2.6.3.2.1 Table: Differences Between the Thomas and Copeland Armoring Methods.

| Thomas (Ex 5) | Copeland (Ex 7) |
|--|---|
| Active Layer (L_a) thickness based on Equilibrium Depth (D_{eq}) | Active Layer (L_a) thickness based on 15% of Water Depth or $3d_{90}$. |
| Linear Armor Ratio | Polynomial Armor Ratio. |
| Armors more rapidly, ↓ erosion | Armors more gradually, ↑ erosion |

2.6.3.3 Active Layer Mixing Method

The Thomas and Copeland methods are sophisticated, multi-layer approaches to bed mixing and armoring. They are also complicated, doing a lot of math behind the scenes, providing results that can be difficult to interpret. Because HEC-RAS computes transport capacity for each grain class independently, these methods limit erosion while computing transport that reflects the subsurface gradation, which is generally observed in rivers.

However, a simplified two-layer active layer method (figure in [Sorting and Armoring \(see page 320\)](#)) is also included in HEC-RAS. A simple active layer approach has obvious disadvantages including less vertical resolution and no explicit armoring factor. Use it with caution. However, it is a more intuitive and transparent method, it can form a coarse or fine active layer, and, with an appropriate exchange increment, it may be preferable in some cases for modeling mobile armor systems (Gibson and Piper, 2007).

Hirano (1971) is often credited with introducing the "active layer" approach for sediment transport modeling,

though HEC was doing similar work at the same time. This approach divides the substrate into an active (mixing or surface) layer, available for transport, and an inactive layer that has no influence on the computations for a given time step.

2.6.3.3.1 Selecting an Active Layer Thickness

2.6.3.3.2 Active Layer Exchange Increments

As the bed aggrades and degrades the sediment passes the active layer resets to a specified thickness (e.g. the d_{90}), and the layers pass material between them. If the bed erodes, the inactive layer sends sediment, an "**exchange increment**" to the active layer, to restore it. If the bed deposits, the active layer resizes and sends an **exchange increment** to the inactive layer.

The gradational composition of the erosion exchange increment is straight forward. The material the inactive layer sends to the active layer has the gradation of the inactive layer, and is mixed with the active layer sediment.

The depositional case is more complicated because the deposited material has a different gradation than the active layer. Three basic options have been proposed.

1. Mixed active Layer/Deposition Gradation: Adds the deposited material to the active layer, mix them, and send an exchange increment with the fully mixed gradation to the inactive layer. This method assumes the depositing material and the active layer are mixing fully at tight temporal scales.
2. Ambient Active Layer Gradation: Remove the exchange increment from the active layer and send it to the inactive layer first, then add the deposited material to the active layer and mix them. This method assumes static stratigraphy, that the deepest material, which would have the active layer gradation, would become inactive.
3. Deposited Material Gradation: Early work on dynamic armoring recognized that actively transporting channels maintain an armor layer even in depositional environments. But the previous two methods would cause depositing beds to fine, burying the cover layer (Parker et al. 1991a,b). So this method sends the deposited material directly to the inactive layer. This maintains a coarse cover layer, but does not allow any gradational evolution in the active layer.

Toro-Escobar et al (1996) tested these hypotheses and found that the was not composed entirely of the active layer or bed load gradations, but it also wasn't proportional (e.g. fully mixed). They found that method 3 was closer to their observations than method 2, but was not sufficient. So they proposed a depositional exchange increment during deposition was composed of 30% active layer material and 70% deposited material. This maintains a coarse cover layer better than methods 1 and 2 above, but also allows gradational evolution.

HEC-RAS follows this approach, passing depositional exchange increments to the inactive layer that are 30% active layer material and 70% depositional material. For example, if HEC-RAS deposited 10 tons of material in a time step (assuming the active layer remained the same thickness) it would transfer 3 tons from the active layer to the inactive layer and add 7 tons of the deposited material directly to the inactive layer. It would then mix the remaining 3 tons of the deposited material into the active layer.

Surface Based Transport Equations and the Active Layer Method: The Thomas and Copeland methods subdivide the active layer to address competing principles in sediment transport:

1. Transporting sediment generally has the same gradation as the subsurface layer, so transport capacity must be computed based on subsurface gradations.

2. The cover layer regulates erosion.

These bed mixing and armoring algorithms allow HEC-RAS to attribute the transport potential of classic transport functions based on subsurface gradations, computing transport capacity based on these gradations, without over predicting erosion.

In the years since these algorithms were developed, a different conceptual approach to graded bed transport has emerged: surface-based transport functions. Parker (2008) suggested that basing transport functions on surface gradations automatically account for dynamic armoring processes.

Wilcock and Crowe (2003), which is included in HEC-RAS, is a **surface-based** equation in this tradition. It accounts for inter-particle interactions like hiding and sand-dependent gravel transport explicitly, but builds the armor layer regulation into the equation implicitly, by basing transport on armor layer gradations. Therefore, when using the Wilcock and Crowe (2003) equation in HEC-RAS, always use the active layer Mixing algorithm. Using Thomas or Copeland with a surface-based transport equation double counts armoring and miss-matches conceptual frameworks.

2.7 Bed Change

HEC-RAS computes sediment mass balance. Therefore, final erosion or deposition computations are masses. It is relatively straight forward to convert mass to volume (multiply by the unit weight or use porosity and density). However, converting volume change in a control volume to area change is not trivial. And then, applying the area change to the cross section to get a new cross section shape that makes physical sense requires additional assumptions and algorithms.

2.7.1 Volume Change and Area Change Conversions

- [Single Control Volume Method \(Single CV\)](#) (see page 333)
- [Simpson's Rule](#) (see page 334)
- [End Area Method](#) (see page 334)
- [Combining Area-Volume Methods](#) (see page 334)

2.7.2 Veneer Method

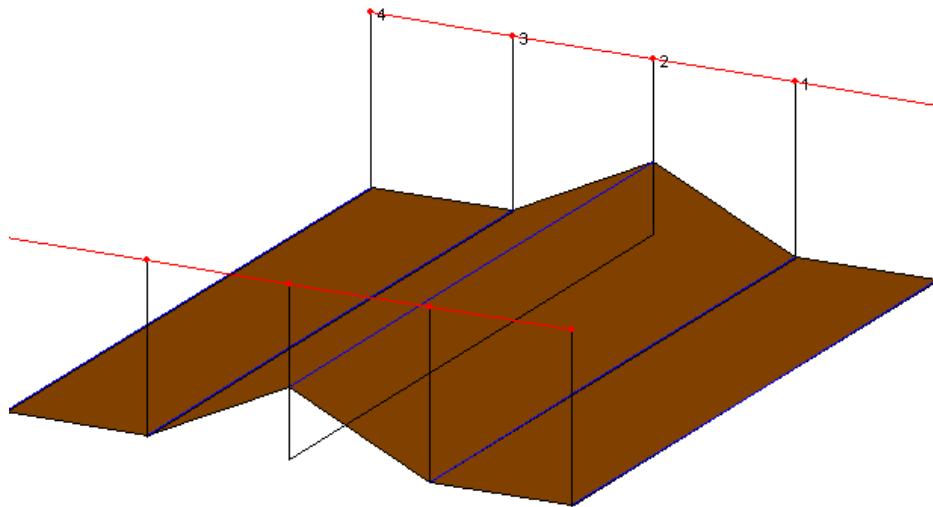
2.7.3 Diffusion-Rouse Method

2.7.4 Volume Change and Area Change Conversions

The simplest way to convert volume change to cross section change is to consider each cross section and its control volume independently (this is called the Single CV method in HEC-RAS). However, when distributing the volume longitudinally, it is advantageous to spread the volume out over the control volume in a way that transitions between the cross sections.

The other bed changes methods in HEC-RAS follow HEC6, assuming that the volume change is not equally distributed over the control volume. In order to compute a smooth transition between cross sections, HEC-RAS assumes the mass is distributed in a "wedge", tapering out between the maximum volume change at the central cross section, to zero at the upstream and downstream cross sections (below). This assumption

allows HEC-RAS to use a couple common numerical approximations to compute volume from irregular areas and, in this case, the inverse.



"Wedge" used to distribute erosion or deposition volume longitudinally over the control volume.

Note - Legacy Method Can Cause Strange Behavior

We added new volume to area change methods in HEC-RAS version 6.0 because the default method, inherited from HEC 6, used different methods to compute volume/area change for the active layer and the cross section nodes. This meant that the area and volume change did not always "match" and in extreme cases, HEC-RAS could compute a positive volume change (deposition) in the control volume but lower the cross section nodes (erosion) - or the opposite. We have left this method in the model for backward compatibility and it should remain default if the model was created in a previous version. But the other methods use the same algorithm for the active layer and the cross section change, and are recommended.

- [Single Control Volume Method \(Single CV\)](#) (see page 333)
- [Simpson's Rule](#) (see page 334)
- [End Area Method](#) (see page 334)
- [Combining Area-Volume Methods](#) (see page 334)

2.7.4.1 Single Control Volume Method (Single CV)

The Single Control Volume Method (Single CV) is the simplest method to convert volume change to cross section area change. It simply ignores the upstream and downstream cross sections. So the area change is simply the volume change divided by the length of the control volume (the half the downstream distance of the upstream and current evaluated cross sections) and the wetted, mobile, cross section width. The uniform, veneer, elevation change (z) in this method is:

$$\Delta z = \frac{\Delta Volume}{W_2 \times (\frac{L_{32}}{2} + \frac{L_{21}}{2})}$$

Where:

W_2 = the wet, mobile, width of the cross section or the top width of the water within the movable bed limits,

L_{32} = the downstream distance associated with the upstream cross section (XS_1), and

L_{21} = the downstream distance associated with the cross section evaluated (XS_2).

2.7.4.2 Simpson's Rule

Simpson's rule(s) approximate of a function by fitting a polynomial through representative points. They are particularly useful for approximating the volume between three irregular shapes, when no other information is available on the transition between them. Because the length-volume relationship along a river is an irregular, but continuous function with periodic observations (cross sections), hydrographers often use Simpson's rule to compute the volume associated with a three-cross sections sequence. The simple insight of Simpson's result is that a parabolic fit weights the central observation (e.g. XS_2) in a simple ratio to the bounding observations (the upstream and downstream cross sections). The version of Simpson's rule used in HEC-RAS (following HEC6) is sometimes calls Simpson's Second rule or the 3/8ths. It is actually designed to find the volume from four equally spaced observations, but is modified to account This approach was adopted from HEC6 and was developed by W. Tony Thomas for three irregular spaced cross sections. The veneer elevation change (applied to the wetted, movable width W) is:

$$\Delta z = \frac{\Delta Volume}{(\frac{1}{8}(W_3 \times L_{32}) + \frac{3}{8}(W_2 \times L_{32}) + \frac{3}{8}(W_2 \times L_{21}) + \frac{1}{8}(W_1 \times L_{21}))}$$

2.7.4.3 End Area Method

The end area method uses the wedge concept, distributing the volume longitudinally along the cross section, tapering upstream and downstream to zero Δz (elevation change) points at the bounding cross sections. But unlike Simpson's rule, the end-area method just assumes linear transitions. So:

$$\Delta z = \frac{\Delta Volume}{(\frac{(W_3+W_2)}{2} \frac{L_{32}}{2} + \frac{(W_2+W_1)}{2} \frac{L_{21}}{2})}$$

The model converts mass to volume and spreads the volume change upstream and downstream from the cross section in a "wedge", to determine the area change at the cross section. An exaggerated bed change is shown at river station 2, in the figure in [Volume Change and Area Change Conversions \(see page 332\)](#). HEC-RAS then converts the area change into cross section change.

Once HEC-RAS computes sediment surplus or deficit and applies the limiters, it computes a final mass to erode or deposit from the control volume. HEC-RAS adds or removes mass by adjusting the cross-section station/elevation points.

2.7.4.4 Combining Area-Volume Methods

HEC-RAS computes volume from cross section area change or vice versa in two places. It uses these methods to compute the cross-section change, and also bed material accounting. Earlier versions of HEC-RAS followed HEC 6, using Simpson's rule for the cross section change and a rectangular, single cross section, control volume (Single CV) for bed mixing. This sometimes generated volume errors and numerical

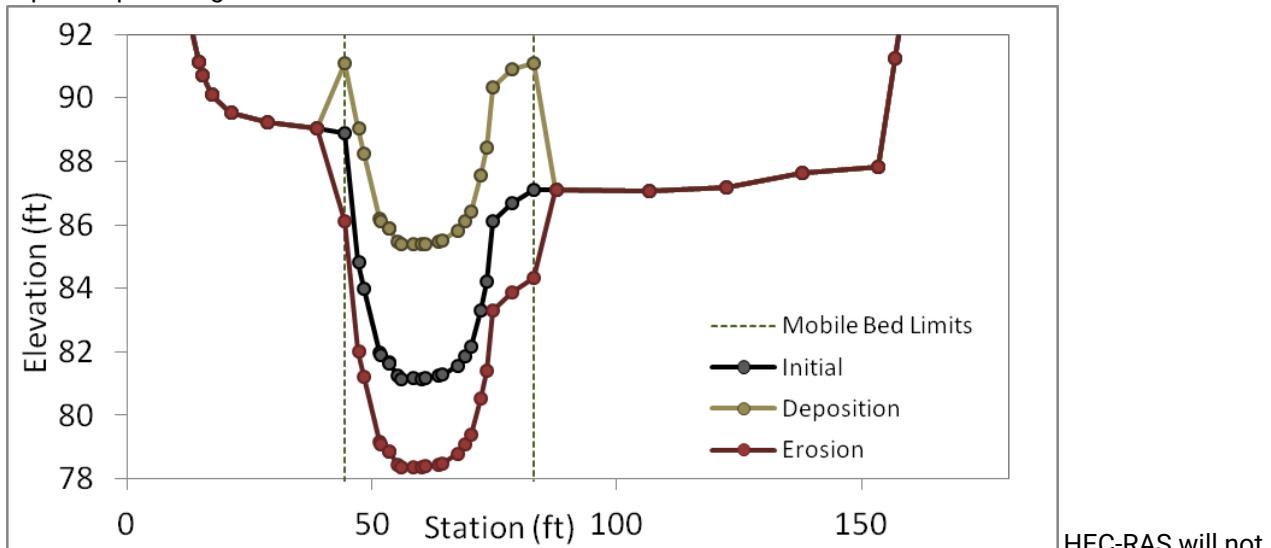
artifacts, which could include cross section deposition ($\uparrow A$) while the Exner routines computed negative mass.

Recent versions of HEC-RAS are backward compatible, maintaining the legacy computational approach. But new models use Simpsons' rule by default. Additionally, users can select to apply any of the three approaches to both bed change and mixing, or select the legacy method ("Backward Compatible" – not recommended)

2.7.5 Veneer Method

2.7.5.1 Veneer Method

By default, HEC-RAS uses the "veneer method" to change cross sections. The veneer method changes all the wetted nodes within the movable bed limits the same vertical distance. Currently the only method available for translating erosion or deposition into changes in the cross-section shape is to deposit or erode each wetted, movable cross section station/elevation point equally. Following these guidelines, an example of a cross section update for erosional or depositional cases is included in the figure below. The points that move are both within the erodible bed limits and beneath the water surface elevation. For the erosion case, a duplicate point is generated if the mobile bed limit is wet.

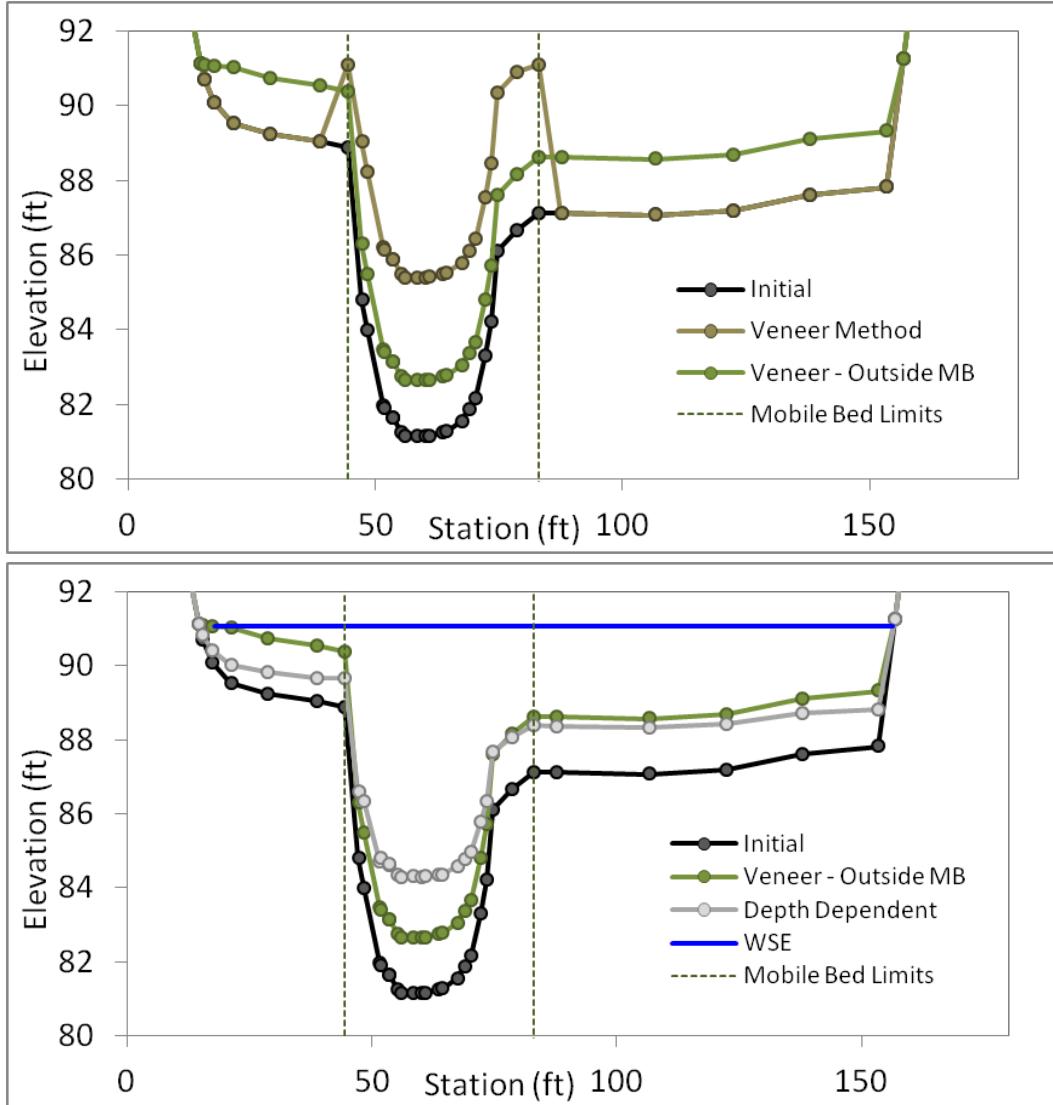


HEC-RAS will not erode any node included in an ineffective flow area regardless of the bed change method or where the erodible bed limits are placed. Water velocity in an ineffective flow area is, by definition, zero. Therefore, scour cannot occur at the cross section points in an ineffective flow area. However, HEC-RAS will allow deposition in ineffective flow areas.

There are a couple of exceptions to these basic rules however. First, an alternate method which allows overbank deposition is available. This option handles erosion in precisely the same way as the default method, confining erosion to the movable bed limits. For the depositional case, however, HEC-RAS distributes bed change equally between all of the wetted points regardless of whether they are between the erodible bed limits or not (below, top). The principle behind this method is that eroding velocities or shears are limited to the channel, but deposition can occur in the floodplain where slowly moving water allows material to settle out.

Finally, HEC-RAS includes a depositional method that preferentially deposits in deeper parts of the cross section (bottom). This method can be useful in reservoirs, particularly in the prograding delta, where sand fills the channel. However, use it with care. Shear is often highest where the water is deepest, so depth

dependent deposition requires low energy-high supply conditions.



2.7.6 Diffusion-Rouse Method

The Rouse-Diffusion method uses three analytical equations to compute 1D floodplain deposition.

1. First, it uses the Rouse equation to compute how much of each grain class is available for floodplain deposition.
2. Then it uses a diffusion equation to compute how much of that available sediment can diffuse out to each floodplain node.
3. Finally, it does a mass balance and fall velocity analysis to determine how much of the floodplain concentration can deposit at each node.

This method offers three main advantages over the veneer method.

1. First, it limits floodplain deposition to suspended load. Grain classes that are entirely (or mostly) bed load will not deposit in the floodplain.
2. Second, it computes non-uniform lateral floodplain deposits. The algorithm deposits more sediment closer to the channel, forming natural levees and thinner deposits farther from the bank.
3. Third, it decouples floodplain deposition and channel deposition. By removing floodplain sediment from the Exner equation and then applying the Exner equation only to bed-material load in the channel, it avoids some of the numerical artifacts that arise from applying the Exner equation to the channel and floodplain simultaneously.

However, this method also has one major liability:

This Method Does Not Account For Floodplain Advection

This method does not account for floodplain deposition by advection. Because this algorithm is in the 1D model, the model has no mechanism to consider 1D advection. But advection is often an order of magnitude more important for floodplain deposition (Pizzuto, personal communication). Therefore, using a diffusion model to simulate 1D floodplain deposition under-predicts the process and becomes a heuristic for a larger suite of processes. This will be a better approximation in some systems than others. If the diffusion assumption breaks down in your model, consider moving to a 2D sediment transport model.

2.7.6.1 Step 1: Computing Floodplain Available Concentrations

First, HEC-RAS uses the Rouse (1937) distribution to compute a vertical concentration distribution for each grain class.

This analytical distribution compares the shear velocity (u^*) to the fall velocity (w) in a dimensionless parameter called the Rouse Number:

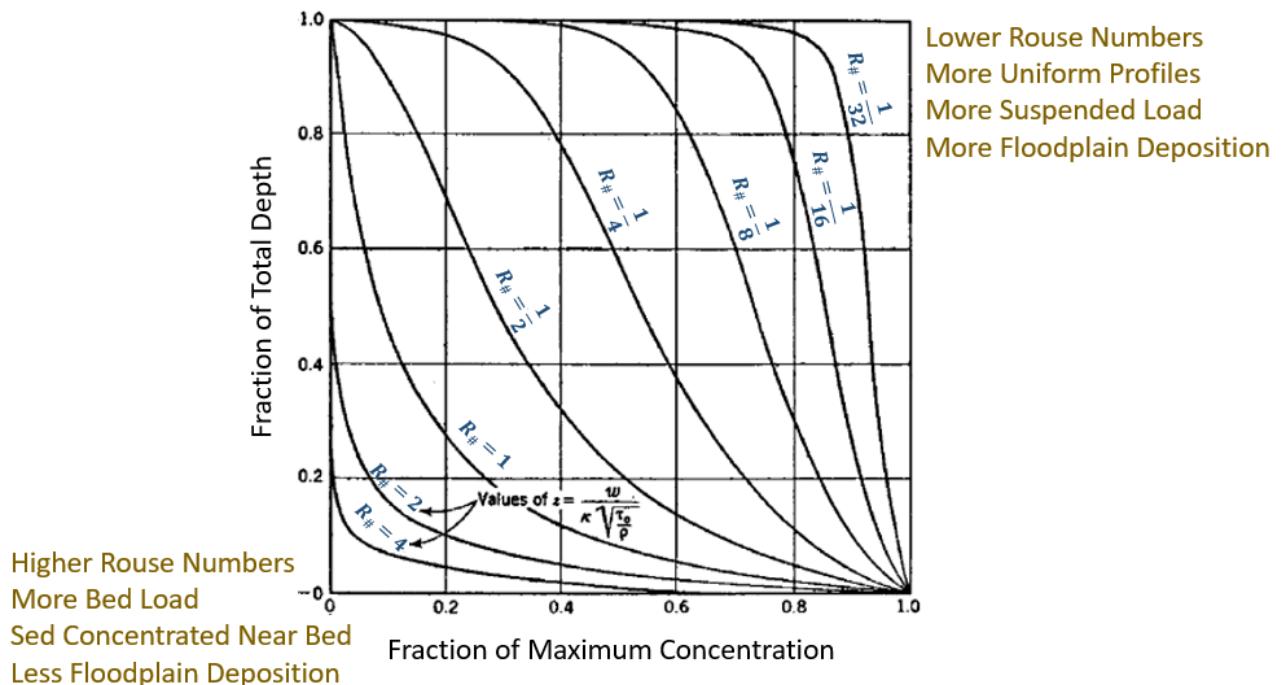
$$R_{\#} = \frac{\omega_s}{\kappa u_*} = \frac{\omega_s}{\kappa \sqrt{\tau/\rho}}$$

where K is the dimensionless von Karman coefficient (~ 0.4) and u^* is the square root of the ratio between shear stress and fluid density.

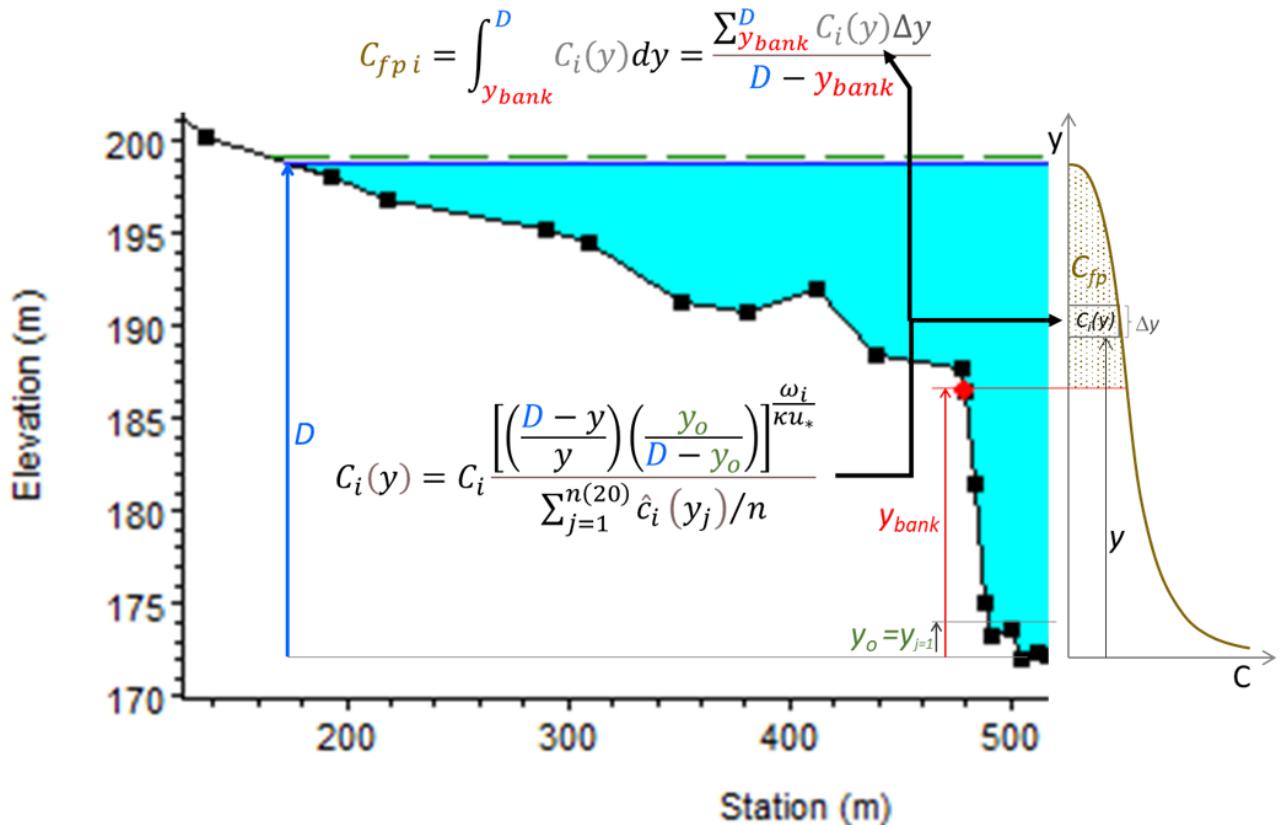
The smaller the rouse number is, the more uniform the vertical concentration profile is (i.e. concentrations near the surface are closer to concentrations near the bed). The larger the Rouse Number is the more transport is concentrated near the bed. Rule of thumb approaches sometimes suggest that Rouse Numbers > 2.5 mean that the grain class is primarily bedload, Rouse Numbers < 0.8 indicate wash load, and the zone between those include some combination of bed and suspended load. But the actual distributions are more continuous. In the analytical distribution, the rouse number becomes the power of a relationship between the computed depth (y), the total depth (D), and the "reference depth" (y_0)- a distance above the bed where a reference concentration (C_0) is measured or known.

$$c_i(y) = c_o \left[\left(\frac{D - y}{y} \right) \left(\frac{y_o}{D - y_o} \right) \right]^{\frac{\omega_i}{\kappa u_*}}$$

This generates the classic, unit, concentration profiles in the following diagram (each labeled with the associated Rouse number), plotted as a vertical fraction of the total depth and a horizontal fraction of the maximum concentration.



HEC-RAS already computes a concentration for each grain class in each control volume with the transport functions, so it does not use the reference concentration approach. It uses the Rouse distribution to distribute those computed concentrations and determine the fraction of sediment that is transporting above the bank stations. Therefore, it computes a unit Rouse profile with the approach illustrated in the figure below.



89 HEC-RAS uses the Rouse equation to distribute the mass flux vertically, and then integrates the available mass for each grain class above the bank station, finding the concentration of each grain class available to move into the floodplain and deposit here.

Then the algorithm scales the unit Rouse distribution so the mass represented in the Rouse profile equals the mass computed by the transport function (C_i).

$$C_i(y) = C_i \frac{\hat{c}_i(y)}{\sum_{j=1}^{n(20)} \hat{c}_i(y_j) / n}$$

Then the model integrates the concentration in the portion of the water column between the bank elevation and the water surface elevation (for each grain class). That concentration is the "floodplain available" concentration (C_{fp}). Floodplain deposition for each grain class is limited to the sediment between the bank elevation and the water surface elevation. Therefore, the Rouse component of this algorithm will mostly exclude coarse material (with high fall velocities and large Rouse numbers that transport as bedload) from floodplain deposition.

ASCE Retrospective on The Career of Dr. Hunter Rouse

Dr. Hunter Rouse, the source of the Rouse distribution is one of the important figures in sediment transport. ASCE did a [retrospective on his career](#)⁵⁵ that is worth reading:
 Ettema, R. "Hunter Rouse - His Work in Retrospect," *ASCE Journal of Hydraulic Engineering*, 132(12), [https://doi.org/10.1061/\(ASCE\)0733-9429\(2006\)132:12\(1248\)](https://doi.org/10.1061/(ASCE)0733-9429(2006)132:12(1248))

2.7.6.2 Step 2: Distribute Floodplain Available Sediment Across Floodplain

After HEC-RAS computes the floodplain-available concentration for each grain class, the algorithm uses an analytical diffusion equation to distribute that concentration laterally, across the wet nodes of the floodplain. HEC-RAS uses an equation developed by [Yotsukura and Cobb](#)⁵⁶ (1972) and applied to sediment in [Pizzuto \(1987\)](#)⁵⁷:

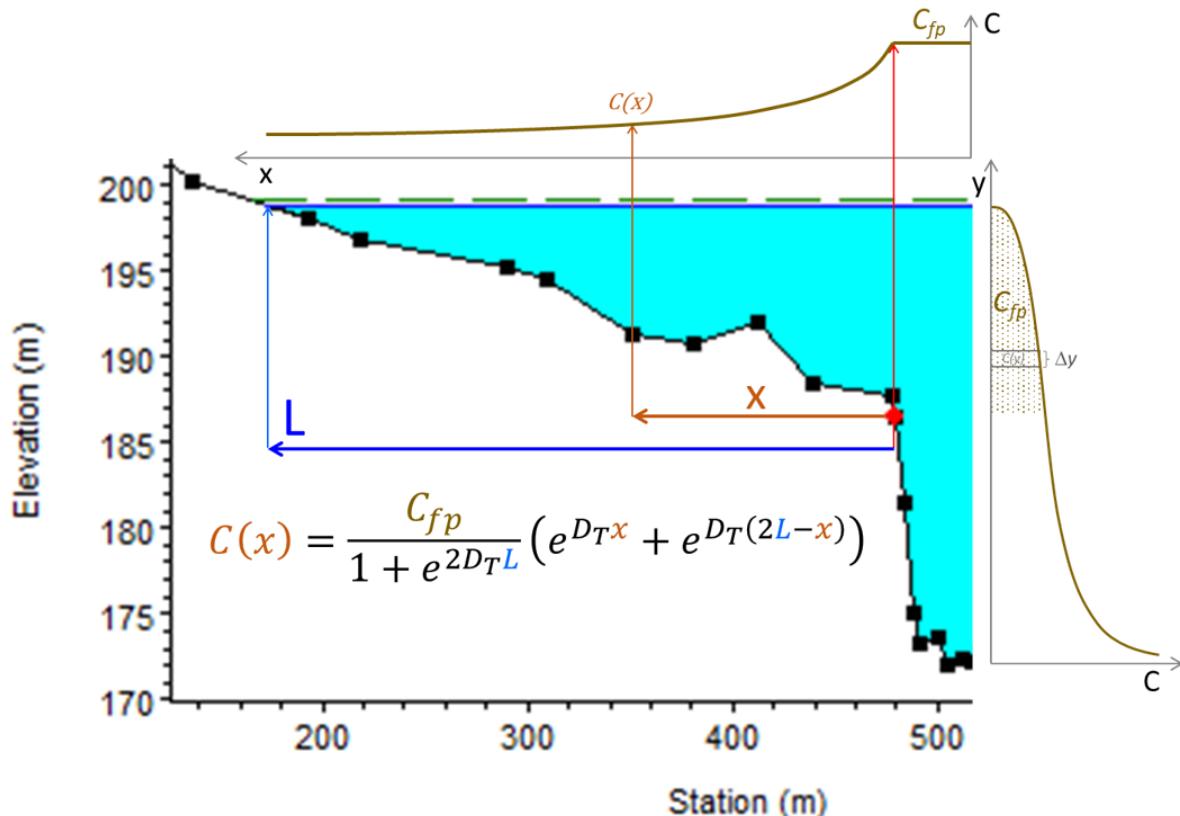
$$C(x_i) = \frac{C_{fp}}{1 + e^{2DTL}} (e^{DTx_i} + e^{DT(2L-x_i)})$$

where the variables and parameters are defined in the following figure. $C(x_i)$ is the concentration at each station-elevation point (i), L is the wet "length" (lateral width) of the floodplain, x is the horizontal distance between each floodplain station-elevation point (i) and the channel bank, C_{fp} is the floodplain available concentration computed from the Rouse algorithm (Step 1) and DT is the diffusion coefficient. This analytical distribution computes a concentration "decay" process, as less sediment transports farther from the channel. DT is the diffusion parameter exposed to the user. Increasing DT makes more sediment available at the farther floodplain nodes.

⁵⁵ <https://ascelibrary.org/doi/10.1061/%28ASCE%290733-9429%282006%29132%3A12%281248%29>

⁵⁶ <https://pubs.er.usgs.gov/publication/pp582C>

⁵⁷ <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-3091.1987.tb00779.x>

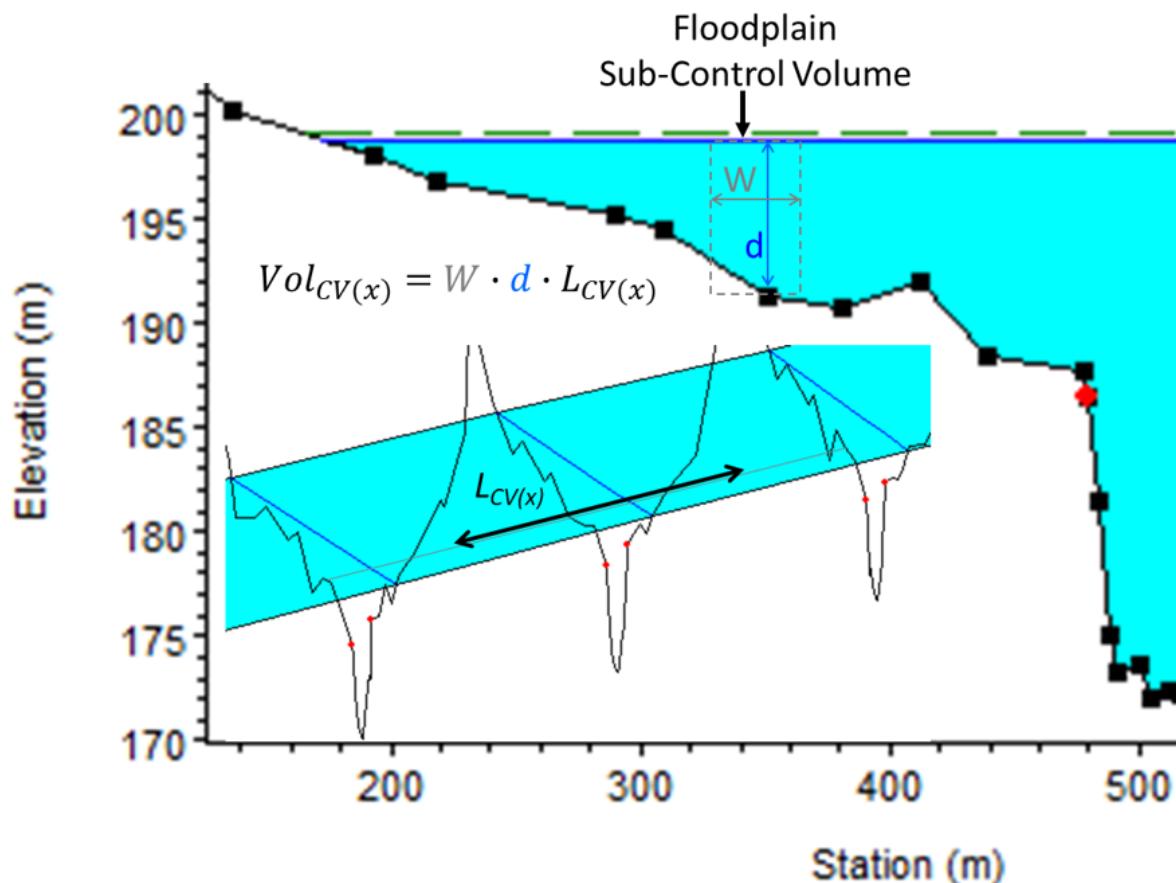


Select Bank Stations and Movable Bed Limits Carefully

The Rouse component of this algorithm is sensitive to the elevation of the hydraulic bank station (not the movable bed limit) and the diffusion component is sensitive to the station of the bank station. It is always important to select bank stations carefully in 1D sediment models. But selecting bank stations that reflect the actual transition from channel flow-to-floodplain flow is especially important in this method. Additionally, if you use the Rouse-Diffusion floodplain method, set the movable bed limits at or inside of the bank stations. The algorithm will use the floodplain method outside the bank stations and the Exner equation inside the movable bed limits. If the movable bed limits are outside the bank stations, those nodes will be subject to both processes which will double-count and may lead to strange numerical artifacts and cross section shapes.

2.7.6.3 Step 3: Compute Deposition at Each Station-Elevation Point

Next, HEC-RAS must convert the concentration at each station-elevation point into a depositional mass, to determine how much to raise the node elevation. The algorithm builds a control volume around each wet, floodplain, station-elevation point (see following figure).



It is good modeling practice to select a time step that achieves a “Sediment Courant Condition” close to 1; the sediment travels through a control volume in one time step. However, because different grain classes have different transport velocities at different flows, most models do not have universal, sediment, Courant number. During each sediment time step, the water volume that passes through a control volume can be much greater or much smaller than the control volume itself. To estimate the mass of sediment that has an opportunity to deposit at each cross-section node in a time step, the model must compute the water flux that passed over it.

First HEC-RAS computes the scaled water flux through the local control volume, which is the water flux through the whole cross section, scaled by the static volume ratio of the local control volume to the water volume in the whole-XS control volume.

$$Vol_{flux(x)} = Vol_{Flux-XS} \frac{Vol_{CV(x)}}{Vol_{CV-XS}}$$

Then HEC-RAS computes a sediment flux passing over the station-elevation point in a time step by combining the local water flux and the concentration at that location from Step 2:

$$Mass(x) = C_i(x) \cdot Vol_{flux(x)}$$

Once HEC-RAS computes the mass available at each floodplain station-elevation point in a time step, it is a simple matter of comparing the residence time to the fall velocity of each grain class to compute deposition.

$$\Delta Mass(x) = Mass(x) \frac{\omega_i \cdot Vol_{CV-XS} \Delta t / Vol_{Flux-XS}}{d}$$

Then, the mass change (deposition) can be divided by the local, control-volume area ($W*LCV$ in the previous figure) to compute elevation change for the floodplain node.

For more information on how to use this method, see the appropriate section of the User Manual

User Manual

2.7.6.4 References

Pizzuto, J.E. (1987) "Sediment diffusion during overbank flows⁵⁸." *Sedimentology*, 34, 301-317.

Rouse, H. (1937) "Modern conceptions of the mechanics of fluid turbulence⁵⁹." *Transactions of the American Society of Civil Engineers*, 102, 463–541.

Yotsukura, N. and Cobb, E.D. (1972) "Transverse diffusion of solutes in natural streams⁶⁰." USGS Professional Paper 582, 18p, DOI: 10.3133/pp582C.

This Draft RSM Tech Note (Gibson et al., 2022 - In Review) also describes these methods.



Floodplain Deposition Documentation).pdf

⁵⁸ <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-3091.1987.tb00779.x>

⁵⁹ <https://ascelibrary.org/doi/10.1061/TACEAT.0004872>

⁶⁰ <https://pubs.er.usgs.gov/publication/pp582C>

2.8 Cohesive Transport

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, 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.

HEC-RAS considers the smallest five grain classes 'fine sediment.' HEC-RAS applies the **cohesive method** selected to these grain classes. In the default grain classes, these five grain classes are the clay and silt classes, and are all finer than 0.0625 mm. If the user edits these, the cohesive methods will still apply to the first five grain classes, regardless of their size. However, if more than 20% of the active layer is cohesive, then the model considers the sediment 'matrix supported,' assuming cohesive sediment is abundant enough to fill the voids and regulate the erosion rate of all particles.

HEC-RAS includes three cohesive methods: applying the standard transport equations, or two different implementations of the Krone and Partheniades approach.

2.8.1 Krone and Partheniades Methods

If the model objectives and systems morphology make cohesive erosion and deposition important, however, the standard transport equations are not sufficient. The Krone and Partheniades equations are simpler than the cohesionless transport functions, building much of the predictive power into several, site specific parameters.

Earlier versions of HEC-RAS included a version of the Krone and Partheniades cohesive approach. This approach differed from the algorithm implemented in HEC 6 and, subsequently HEC 6T. Both are defensible, taking alternate approaches applying the Partheniades scour relationship to a mixed bed. Therefore, the original HEC-RAS algorithm was retained but the HEC 6T algorithm was added as an option. Both methods apply the Krone and Partheniades equations to compute deposition and erosion rates in the same way.

HEC-RAS uses either the Krone equation to compute deposition or the Partheniades equations to compute erosion and selects between them based on the bed shear stress. Two user defined shear thresholds define three cohesive transport conditions: Deposition, Particle Erosion, and Mass Erosion.

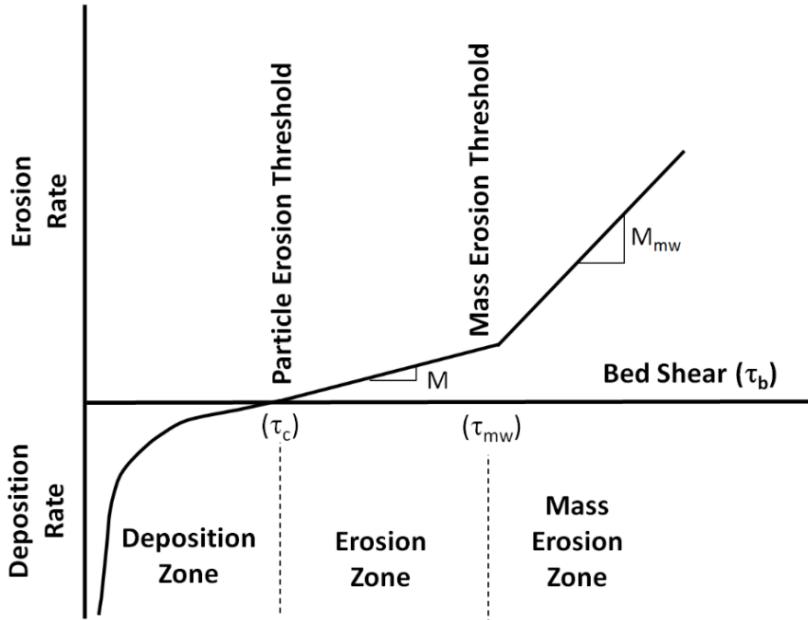
The user defined thresholds are:

τ_c : Critical shear threshold for particle erosion

τ_m : Critical shear threshold for mass erosion

where $\tau_c \leq \tau_m$. HEC-RAS computes a bed shear stress (τ_b) for each cross section and compares it to these two thresholds, determining the appropriate cohesive process, and applying the appropriate equation (Figure

13-9).



Previous models often included a fourth zone, an equilibrium zone, which neither eroded nor deposited. This approach subdivided τ_c into deposition τ_d and erosion τ_e shears. In the intermediate zone between these ($\tau_d < \tau_b < \tau_e$) binding forces exceeded the erosion forces, but turbulence was sufficient to keep transported particles in suspension. This approach computed no bed change if bed shears fell in this equilibrium zone. More recent work has caused this concept to fall out of favor (Sanford and Halka, 1993). Therefore, HEC-RAS uses a single critical shear threshold (τ_c), above which particles erode and below which they deposit.

2.8.1.1 Deposition

HEC-RAS deposits cohesive sediment based on Krone (1962). Krone's observed that suspended sediment decreased logarithmically, in his experiments, for concentrations less than 300 mg/l, quantifying the deposition rate with the equation:

$$\left(\frac{dC}{dt}\right)_d = -\left(1 - \frac{\tau_b}{\tau_c}\right) \frac{V_s C}{y}$$

where:

C = sediment concentration

t = time

τ_b = bed shear stress

τ_c = critical shear stress for deposition

V_s = fall velocity

y = water depth (Effective Depth in HEC-6)

This equation yields an exponential deposition relationship, where the deposition rate increases non-linearly as bed shear drops farther below the critical shear:

$$\int \frac{dC}{C} = \int -\left(1 - \frac{\tau_b}{\tau_c}\right) \frac{V_s}{y} dt \rightarrow C = C_o e^{-\left(1 - \frac{\tau_b}{\tau_c}\right) \frac{V_s t}{y}}$$

Because of the logarithmic assumption the Krone equation only requires one empirical coefficient, the critical shear (τ_c).

If the calculated bed shear (τ_b) is less than the critical erosion shear (τ_c) HEC-RAS will deposit transporting cohesive sediment based on this equation. The equation is not applicable for shear stresses greater than the depositional threshold.

As Krone (1962) recognized, the cohesive deposition rate is also dependent on the flocculation rate, which is a function of the sediment concentration and the water chemistry. Many sophisticated coupled flocculation-deposition models account for these processes. However, HEC-RAS does not attempt to compute flocculation. Therefore, the grain size distribution should reflect the distribution of flocculants rather than discrete grains, even though standard particle sized distribution methods tend to report the latter.

2.8.1.2 Erosion

Erosion is more difficult to compute than deposition. The cohesive erosion equations are far more empirical. HEC-RAS computes cohesive erosion based on Partheniades (1962). Partheniades (1962) argued that the force resisting erosion is mainly electrostatic in nature, since the average electrochemical force exerted on a clay particle is a million times greater than the average weight of the particle. Therefore, cohesive erosion is not based on particle size, but an empirical 'erodibility' that accounts for the other binding processes.

Partheniades (1962) modeled cohesive erosion rates as a pair of linear functions of bed shear. When bed shear exceeds critical shear, particle erosion begins as the shear stress removes individual 'particles' or flocs are removed. This particle erosion rate increases, approximately, a linear function of shear.

However, if bed shear gets high enough, it begins to remove clods from the bed, introducing a non-linear inflection point (τ_{mw} in the figure in [Deposition \(see page 345\)](#)) in the erosion rate. This has historically been called 'mass wasting' or 'mass erosion.' The terminology is ambiguous, but HEC-RAS retained it for continuity. Erosion rate above the mass erosion threshold is also linear, but increases as a function of shear at a different (usually higher) slope (see figure below).

Particle Erosion ($\tau_c < \tau < \tau_{mw}$)

According to the Partheniades equation (1965):

$$\left(\frac{dm}{dt} \right)_e = M \left(\frac{\tau_b}{\tau_c} - 1 \right)$$

where: m = mass of material in the water column

t = time

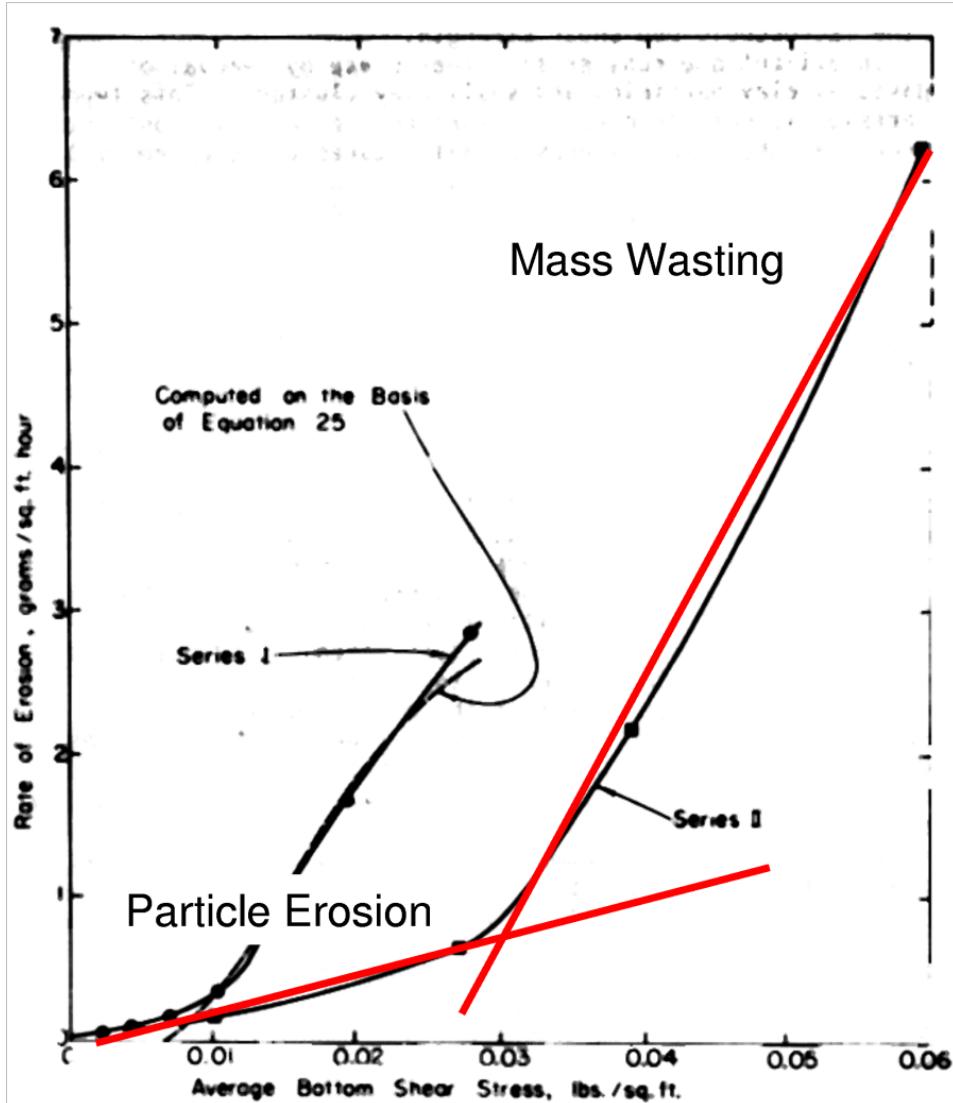
τ_b = bed shear stress

τ_c = critical shear stress for erosion

M = empirical erosion rate for particle scour

Therefore:

$$\int dm = \int M \left(\frac{\tau_b}{\tau_c} - 1 \right) dt \rightarrow m = M \left(\frac{\tau_b}{\tau_c} - 1 \right) t + m_o$$



This equation essentially interpolates cohesive erosion between the lower and upper end of the particle erosion zone, based on an empirical, linear, user specified coefficient, the **Erodibility Coefficient (M)**.
Mass Erosion ($\tau_m < \tau$)

The Partheniades approach is a piece-wise linear erodibility model. Beyond the mass erosion threshold, the cohesive algorithm extrapolates erosion rates from the maximum computed particle erosion rate, with a similar linear extrapolation, based on a new **Mass Erosion Erodibility Coefficient M_{MW}** .

Therefore, the full piecewise-linear model, in three zones is:

$$\text{Erodibility} = \begin{cases} 0 & , \quad \tau_c < \tau \\ M \left(\frac{\tau_{MW} - \tau_c}{\tau_c} \right) & , \quad \tau_c < \tau \leq \tau_{MW} \\ M \left(\frac{\tau_{MW} - \tau_c}{\tau_c} \right) + M_{MW} \left(\frac{\tau - \tau_{MW}}{\tau_c} \right), & \tau_{MW} < \tau \end{cases}$$

Where τ_c is the critical shear where erosion begins, τ_{MW} is the critical shear where the higher shear erosion rate ("mass wasting") starts, M is the base erodibility rate (between τ_c and τ_{MW}) and M_{MW} is the "mass wasting" erodibility rate, which is associated with shears greater than τ_{MW} .

Erodibility has units of Mass/Area/Time, so this approach computes the mass eroded from each cross section in each time step with:

$$Mass = \begin{cases} 0 & , \quad \tau_c < \tau \\ M \left(\frac{\tau_{MW} - \tau_c}{\tau_c} \right) * A * \Delta t & , \quad \tau_c < \tau \leq \tau_{MW} \\ M \left(\frac{\tau_{MW} - \tau_c}{\tau_c} \right) * A * \Delta t + M_{MW} \left(\frac{\tau - \tau_{MW}}{\tau_c} \right) * A * \Delta t, & \tau_{MW} < \tau \end{cases}$$

$$Mass = M \left(\frac{\tau_{MW} - \tau_c}{\tau_c} \right) * Area + M_{MW} \left(\frac{\tau - \tau_{MW}}{\tau_c} \right) * Area$$

Modeling Note:

Some changes were made to this approach and conversion factors between versions 5.0.7 and 6.0.

2.8.1.3 Kd vs M

There are two main versions of the excess shear, erodibility equation. The one used in the Parthenaides (1965) (the "dimensionless" form) equation normalizes the excess shear by the critical shear, making the shear term dimensionless. This approach has the intuitive advantage of giving the erodibility coefficient (M) the same units (Mass/Area/Time) as the Erosion rate:

$$Erodibility = M \frac{(\tau - \tau_c)}{\tau_c}$$

However there is an alternate version of the excess shear equation (the "dimensional" form, where erodibility is directly proportional to the simple excess shear).

$$Erodibility = K_d (\tau - \tau_c)$$

The ratio of erodibility to excess shear (K_d) is also called the "erodibility coefficient", but is not the same value. This expression is more intuitive (erodibility is directly proportional to excess shear), but makes the units of the coefficient less intuitive.

Different disciplines and practitioners tend to favor the different forms of this equation. Make sure you know whether the "Erodibility Coefficient" provided is K_d or M . HEC-RAS includes the option to input either, but setting these equations equal to each other demonstrates a pretty simple conversion between the two coefficients, M is simply the product of K_d and τ_c :

$$M \frac{(\tau - \tau_c)}{\tau_c} = K_d (\tau - \tau_c)$$

$$M = K_d \tau_c$$

The 1D sediment calculations in HEC-RAS use the dimensionless (M) form of the excess shear equation, so if users enter K_d , HEC-RAS converts it to M. HEC-RAS converts K_d to M as it writes the data file, so if you open the HDF file the K_d parameters in the interface will not match those written.

2.8.1.4 Estimating Cohesive Thresholds and Rates

2.8.1.4.1 The Importance of Site Specific Measurements

Applying the Partheniades method successfully requires estimating the shear thresholds and the erosion rates well. These parameters are site specific and can differ by five orders of magnitude between sites. Even within the same reach, τ_c , τ_{mw} , M, and M_{mw} can vary significantly between samples or at different depths. Therefore, the parameters can be determined experimentally (e.g. with a SEDFLUME apparatus) or are calibration parameters, adjusted to replicate measured bed change. These parameters cannot be estimated *a priori*. Briaud et al. (2001) summarize the situation well:

"Today, no widely accepted correlation could be found (between cohesive erodibility and bulk soil parameters) after extensive literature reviews. If a correlation is likely to exist on one hand, and if it has not been found after forty years of effort on the other hand, the correlation must be complex...Considering all the problems associated with correlations, a direct measurement with the (erodibility testing) is favored." Briaud et al. (2001) *Journal of Geotechnical and Geoenvironmental Engineering*

Others concur:

"With the vast number of factors involved in the determination of the erodibility of cohesive soils, it becomes necessary to test cohesive soils for critical shear stress for erosion and deposition rather than using soil properties for predicting threshold values or using methods similar to those for coarse sediments." Huang et al. (2006) *Erosion and Sedimentation Manual*

"Unfortunately, the erodibility of cohesive sediment cannot be predicted on the basis of environmental parameters. As a consequence, researchers have developed various test apparatus to empirically measure sediment erodibility." Ravens (2007) *ASCE Journal of Hydraulic Engineering*

The cohesive literature is full of pronouncements that these parameters must either be measured or calibrated including: Roberts et al. (1998), McNeil et al (1996), Jepsen et al., (1997), Hanson (1996), Julian and Torres (2006), Hansen and Simon (2001), Kappen et al. (2007), Sanford and Maa (2001). Therefore, HEC-RAS does not include default parameters.

In the absence of robust calibration data, the Partheniades method requires experimental data for reliable results. The SEDFLUME is the most common apparatus used to measure the cohesive parameters, usually computing parameters from Shelby tube samples. This device pushes a core of the cohesive bed material through the bottom of the flume. The Corp's sediment lab in ERDC, and several universities, can perform these experiments. ERDC's has a portable SEDFLUME that can deploy to a project site, avoiding sample disturbance during transport.

2.8.2 Standard Transport Equations

The default option for silt and clay simply applies the selected transport function for the fine material as well. The transport equation will extrapolate well outside its derived range and usually compute enormous (often

unreasonable) transport potentials. These transport potentials should not be considered remotely representative. They can be useful, however, to model fine sediment as wash load. With huge transport potentials, even a tiny amount of silt and clay in the active layer will produce essentially unlimited sediment transport capacity. This method can route fine wash load through the system, treating fine material as throughput load.

2.9 Bed Roughness Predictors

Hydraulic computations are sensitive to bed roughness. Bed roughness is a dynamic property and changes in response to sediment dynamics. If a fine pulse covers a coarse substrate, bed roughness will drop. As flow increases on sand rivers, bed form amplitude increases, increasing bed roughness, until the river passes into a plane bed regime which results in substantial drops in n-values.

Mobile bed sediment models simulate changes in bed gradation, which the model can use to compute roughness, computing feedbacks between sediment transport and bed roughness. HEC-RAS includes three **bed roughness predictors**, equations and algorism that compute manning's-n from hydraulics and sediment properties, including: Limerinos, Brownlie, and Van Rijn. The **bed roughnes predictors**, compute new manning's n values each time step, as the bed gradation and cross section evolve, which the program uses to compute hydraulics in the next computational increment.

- [Limerinos_ \(see page 350\)](#)
- [Brownlie_ \(see page 350\)](#)
- [van Rijn_ \(see page 351\)](#)

2.9.1 Limerinos_

The Limerinos equation computes bed roughness based on grain roughness. It is primarily applicable to channels without active bed forms, where grain roughness is the primary source of bed roughness. It is the simplest equation, computing bed roughness as a function of the hydraulic radil(R) of the channel and the d_{84} particle size (the partial size diameter two standard deviations above the mean):

$$n = \frac{0.0926R^{1/6}}{1.16 + 2.0\log\left(\frac{R}{d_{84}}\right)}$$

2.9.2 Brownlie_

The Brownlie (1983) computes bed roughness in sand beds where form roughness (bed roughness from bed forms) is much more important than grain roughness. The Brownlie method computes bed roughness base on the median particle size (d_{50}), the hydraulic radil(R), the bed slope (S), and the geometric standard deviation of the mixture (σ). Because the Brownlie method is based on bed form mechanics it can shift between upper and lower regime relationships, causing non-linear changes in n-value:

Upper Regime:

$$n = \left[1.6940 \left(\frac{R}{d_{50}} \right)^{0.1374} S^{0.1112} \sigma^{0.1605} \right] 0.034(d_{50})^{0.167}$$

Lower Regime:

$$n = \left[1.0213 \left(\frac{R}{d_{50}} \right)^{0.0662} S^{0.0395} \sigma^{0.1282} \right] 0.034(d_{50})^{0.167}$$

Where R is the channel hydraulic radius in ft, d_{50} is the median particle size in ft, σ is the geometric standard deviation of sediment mixture: $\sigma = 0.5(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}})$

Brownlie defined S as the bed slope, HEC-RAS approximates this variable with the energy slope computed at the cross section.

To determine which equation to apply, HEC-RAS uses the Brownlie criteria to identify the regime.

If $S > 0.006$, HEC-RAS always assumes the system is in the upper regime. Otherwise, Brownlie computes an empirical parameter F_g'

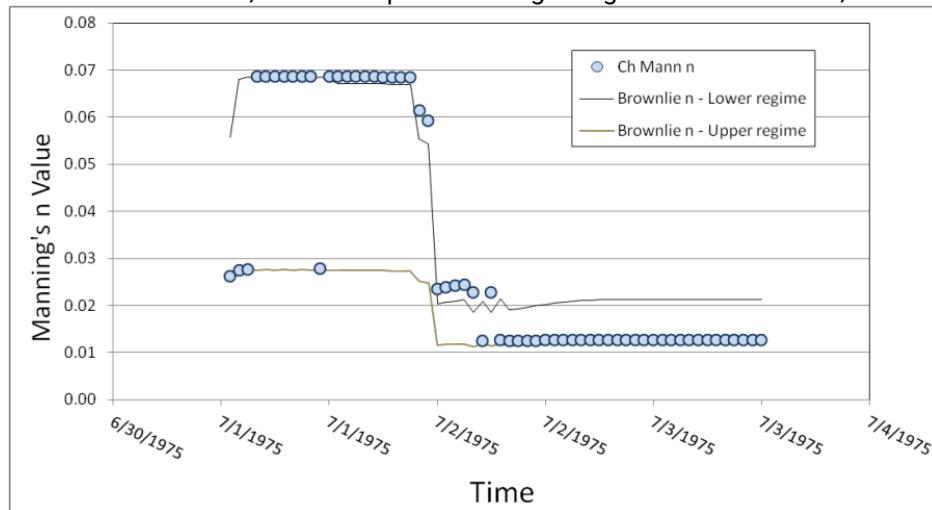
$$F_g' = \frac{1.74}{S^{1/3}}$$

which can be compared to the grain Froude number F_g :

$$F_g = \frac{V}{\sqrt{(S_s - 1)g d_{50}}}$$

(where V is the flow velocity, g is the gravitational constant and S_s is specific gravity of sediment particles).

HEC-RAS selects the lower regime flow if $F_g \leq F_g'$ and upper regime if $F_g \geq F_g'$. An example application of Brownlie in HEC-RAS, for a sand pulse arriving at a gravel cross section, is included in the figure below.



2.9.3 van Rijn_

van Rijn (1984) is a more recent method based on the flume and field data, and it has a good predictive ability in the dune and plane bed regimes. Van Rijn computes bed forms dimensions and the equivalent bed roughness. It estimates a Chezy-coefficient, which HEC-RAS converts into a Manning n, from bed roughness from flow, sediment transport parameters. The van Rijn method computes four key dimensionless parameters to estimate bed-form roughness.

1. Particle Parameter

$$d_* = d_{50} \left[\frac{(s - 1)g}{v^2} \right]^{1/3}$$

Where d_{50} is the median particle size (ft), s is the specific gravity ratio ($s = \frac{\rho_s}{\rho}$), where ρ_s is the sediment density, and ρ is the fluid density, g is the gravitational acceleration and v is kinematic velocity.

2. Transport Stage Parameter:

$$T = \frac{(u'_*)^2 - (u_{*,cr})^2}{(u_{*,cr})^2}$$

Which u^* is grain bed-shear velocity:

$$u'_* = \frac{g^{0.5}}{C'} \bar{u}$$

where u is mean flow velocity, C' is the Chezy-coefficient.

$$C' = 18 \log \left(\frac{12R}{3d_{90}} \right)$$

where R is the hydraulic radius of the bed, $u_{*,cr}$ is the critical Shields parameter

$$u_{*,cr} = \sqrt{\frac{\tau_{cr}}{\rho}}$$

where τ_{cr} is the critical shear stress, and it is expressed as $\tau_{cr} = \tau_c^* \rho R g d_{50}$, and the dimensionless critical shear is computed with the equation

$$\tau_c^* = 0.5 \left[0.22 Re_p^{-0.6} + 0.06 \times 10^{(-7.7 Re_p^{-0.6})} \right]$$

where

$$R = \frac{\rho_s - \rho}{\rho}, \text{ and } Re_p = \frac{\sqrt{g R D}}{v}, \text{ and } \rho \text{ is the fluid density.}$$

3. Bed-form dimensional parameters: The Bed-form parameter computes the bed form dimensions which the algorithm uses in the roughness computation:

$$\frac{\Delta}{h} = 0.11 \left[\frac{d_{50}}{h} \right] [1 - e^{-0.5T}] [25 - T]$$

$$\frac{\Delta}{\lambda} = 0.015 \left[\frac{d_{50}}{h} \right] [1 - e^{-0.5T}] [25 - T]$$

and it computes a ratio of the bed form height to the wavelength:

$$\psi = \frac{\Delta}{\lambda}$$

Where Δ is bed-form height, λ is bed-form length and is expressed as $\lambda=7.3$ h, and $_h$ represents flow depth. If $T \leq 0$ and $T \geq 25$, bed would be considered almost plane, and C' calculated in step 2 will be used as Chezy-coefficient in step 4 for further calculation. ψ is bed-form steepness.

- Equivalent roughness of bed forms: Finally, the algorithm uses the bed form height and height-to-wavelength ratio to compute a bed roughness.

$$k_s = 3d_{90} + 1.1\Delta [1 - e^{-25\psi}]$$

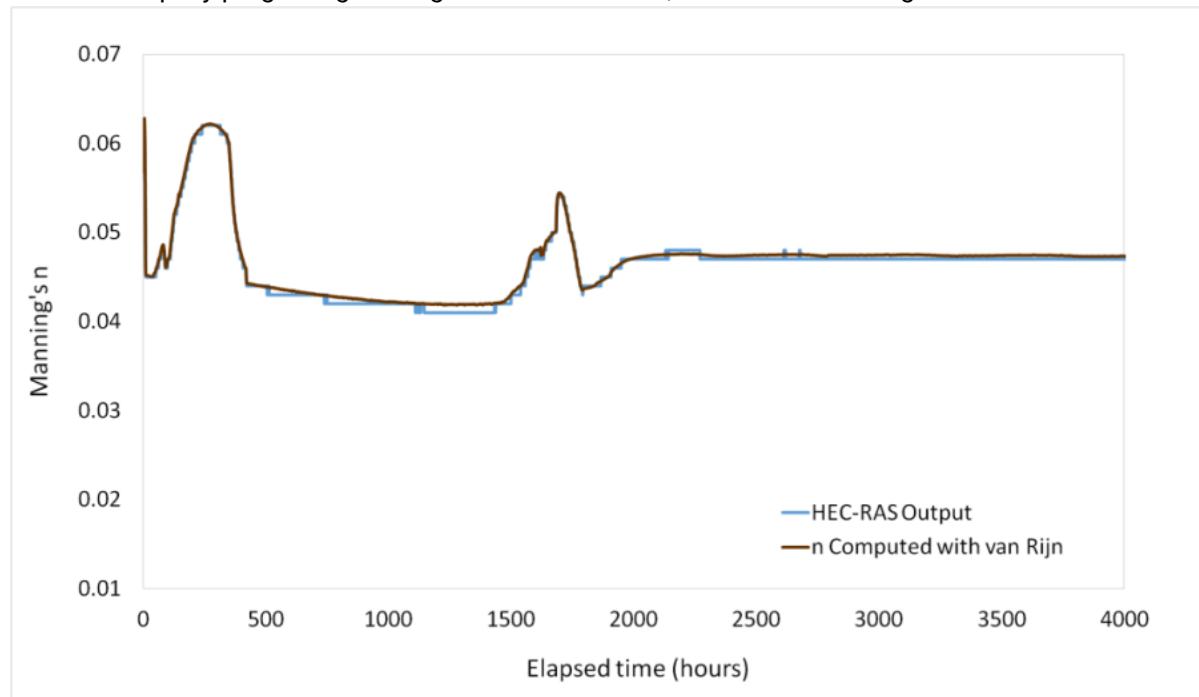
Van Rijn computes a Chezy-coefficient from the bed roughness:

$$C = 18 \log \left(\frac{12R}{k_s} \right)$$

HEC-RAS converts the Chezy coefficient to a Manning's n (in English units) with the equation:

$$n = 1.49 \frac{R^{1/6}}{C}$$

An example roughness time series, using van Rijn (in HEC-RAS unsteady sediment transport) for a sand delta rapidly prograding into a gravel cross section, is included in the figure below.



90 Bed roughness times series computed with HEC-RAS using the van Rijn predictor, compared to external computations.

2.10 BSTEM – Technical Reference Manual

The HEC-RAS (Hydrologic Engineering Center's (HEC) River Analysis System) software has included mobile bed capabilities since Version 4.0. These capabilities compute vertical bed changes in response to dynamic sediment mass balance and bed processes. However, many riverine sediment problems involve lateral bank erosion that does not fit in the current computational paradigm. There are many published methodologies

that compute bank failure. The methodologies span a spectrum from basic angle of repose methods that require very few parameters but simplify bank processes considerably, to full blown geotechnical bank stability models that require a full suite of geotechnical parameters yet lack a framework for hydraulic toe feedbacks. The Bank Stability and Toe Erosion Model (BSTEM) developed by the National Sediment Laboratory, United States Department of Agriculture (USDA), Agricultural Research Station (ARS) is a physically based model that accounts for the dominant stream bank processes but requires an intermediate level of complexity and parameterization. This method was selected for implementation in HEC-RAS.

BSTEM (Simon, 2000; Langendoen, 2008; Simon, 2010) couples iterative, planer bank failure analysis based on a fundamental force balance, with a toe scour model that allows feedback between the hydraulic dynamics on the bank toe which could exacerbate failure risk (in the case of toe scour) or decrease failure risk (in the case of toe protection). The goal of coupling HEC-RAS with BSTEM is to build a model that simulates feedbacks between bed and bank processes. For example, if HEC-RAS computes a decrease in the regional base level or local channel scour it will decrease bank stability and increase the risk of a failure. Similarly, when a bank does fail, the bank material will be added to the sediment mass balance of the mobile bed model which will simulate the river's capacity to "metabolize" and transport these point sources.

- [Overview \(see page 354\)](#)
- [Bank Failure \(see page 355\)](#)
 - [Layer Method \(see page 355\)](#)
 - [Soil Forces \(see page 357\)](#)
 - [Hydraulic Forces \(see page 358\)](#)
 - [Method of Slices \(see page 361\)](#)
 - [Tension Cracks \(see page 365\)](#)
 - [Cantilever Failures \(see page 367\)](#)
- [Selecting a Method \(see page 368\)](#)
- [Steps in a Bank Failure Analysis \(see page 369\)](#)
- [Toe Erosion \(Fluvial or Hydraulic Erosion\) \(see page 374\)](#)
 - [Determining the Zone of Scour \(see page 374\)](#)
 - [Determining \$\tau_{node}\$ \(see page 374\)](#)
 - [Scour \(see page 377\)](#)

2.10.1 Overview

As the name suggests, there are two major, interacting components to BSTEM (Bank Stability and Toe Erosion Model):

1. **Bank Failure:** A geotechnical bank failure model that computes failure planes through the bank to determine if the gravitational driving forces exceed the frictional resisting forces (and the interactions of pore water pressure).
- Toe Scour:** An erosion model that computes the progression of bank undercutting by hydraulic forces. As the toe scours, the bank becomes less stable, so toe scour can initiate bank failure.

These two processes also interact with a third process native to the classic sediment methodology in HEC-RAS computations:

2. **Vertical Erosion or Deposition:** The vertical adjustment of the cross section can also decrease the stability of the bank and interact with toe scour computations. Conversely, a large bank failure could add enough sediment mass to the system to deposit downstream and increase the stability of downstream banks.

Modeling the interactions and feedbacks between these three processes were the main motivation for including the USDA-ARS BSTEM algorithms into HEC-RAS. The science, methods and math of vertical erosion and deposition are covered in the HEC-RAS User's Manual (HEC, 2010) and the HEC-RAS Technical Reference Manual (HEC, 2010a).

2.10.2 Bank Failure

The bank failure methods employ classical, planar, analyses to compare gravitational driving forces of the soil, soil water and overburden, and frictional resisting forces (including the influences of pore water pressure) to determine the most likely failure plane through the bank and to compute whether that failure plane is stable. If the weakest failure plane is unstable, the bank fails and the sediment from the failed bank is added to the sediment transport model.

The bank stability model goes through a series of iterative computations to select potential failure planes, evaluate the factor of safety, and converge on the failure plane most likely to fail by following the steps below:

1. Find the critical Factor of Safety (FS_{cr}), the failure plane with the lowest Factor of Safety (FS) for nodes at several vertical locations up the bank.
2. Select the bounding Failure Planes (minimum and maximum angles) and compute a FS for each
3. Select a most probable critical failure plane ($FS_i \sim FS_{cr}$)
4. Compute the FS_i
5. Use that information to select a more likely critical failure plane (using the "bracket and Brent" optimization algorithm from Teukolsky et al., 2007) (set FS_{i+1} to updated estimate of FS_{cr})
6. Decide when the FS is close enough to FS_{cr} to stop
7. If FS_{cr} is less than one, fail the bank, update the cross section, and send the bank sediments to the routing model

The failure plane selection and optimization algorithms are covered below. Since computing a FS for each failure plane (Step 3) is the physical algorithm at the core of this process, the description below starts with the basic physics and then moves to the optimization scheme.

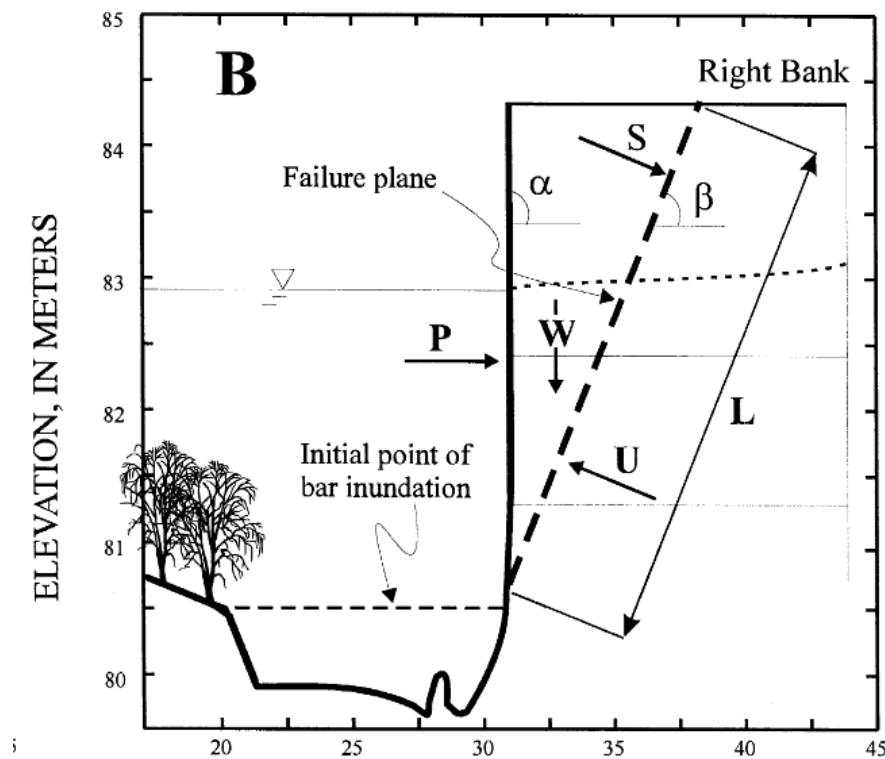
There are two basic computational approaches to computing the FS of a failure plane through the bank:

- [Layer Method \(see page 355\)](#)
- [Method of Slices \(see page 361\)](#)

2.10.2.1 Layer Method

The Layer Method is based on Simon (2000) and it is the default method (below) in USDA-ARS BSTEM Version 5.4. This method was developed specifically for bank failure applications and is derived superficially

to compute failure planes through vertically heterogeneous bank sediments. The layered configuration makes it easier to formulate a stability equation for bank sediments divided into discrete horizontal layers (which is the basic configuration of BSTEM stratigraphy). The Layer Method also eliminates one cycle of iteration required in the Method of Slices which reduces runtimes in long simulations.



STATIONING FROM LEFT BANK, IN METERS

Force diagram for the "Layer

Method" from Simon (2000).

The Layer Method solves a non-iterative equation (Equation 1, Layer Method Force Balance) for the FS that compares driving forces to resisting forces:

$$FS = \frac{\sum_{i=1}^I (c'_i L_i + S_i \tan \phi_i^b + [W_i \cos \beta - U_i + P_i \cos(\alpha - \beta)] \tan \phi'_i)}{\sum_{i=1}^I (W_i \sin \beta - P_i \sin(\alpha - \beta))} \quad (1)$$

where:

 i = layer L = length of the failure plane S = matrix suction force U = hydrostatic uplift P = hydrostatic confining force of the water in the channel' Φ' = friction angle ϕ^b = relationship between matrix suction and apparent cohesion' c' = effective cohesion b = angle of the failure plane

However, Equation 1 combines the driving forces in the numerator and resisting forces in the denominator, because both the numerator and denominator have negative components. Equation 2 displays the components of the Layer Method Force Balance equation, with the driving forces indicated in red and resisting forces in green.

$$F_s = \frac{\sum_{i=1}^I [c_i L_i + S_i \tan \phi_i^b + (W_i \cos \beta - U_i + P_i \cos(\alpha - \beta)) \tan \phi_i]}{\sum_{i=1}^I (W_i \sin \beta - P_i \sin(\alpha - \beta))}$$

Weight of soil Hydrostatic Normal force
 ↑ frictional ↓ frictional of water ↑
 resistance resistance frictional
 Cohesion Suction
 Gravitational force along the Hydrostatic confining force.
 inclination of the failure plane.

The forces in Equation 2 can be categorized into soil forces (weight of soil block, cohesion) and hydraulic forces (hydrostatic confining forces, pore water pressure). Equation 3 displays the hydraulic and soil forces of the Layer Method Force Balance equation:

$$F_s = \frac{\sum_{i=1}^I [c_i L_i + S_i \tan \phi_i^b + (W_i \cos \beta - U_i + P_i \cos(\alpha - \beta)) \tan \phi_i]}{\sum_{i=1}^I (W_i \sin \beta - P_i \sin(\alpha - \beta))}$$

Soil Water Soil Water Water
 Soil Water Water

2.10.2.1.1 Soil Forces

$$F_s = \frac{\sum_{i=1}^I [c_i L_i + S_i \tan \phi_i^b + (W_i \cos \beta - U_i + P_i \cos(\alpha - \beta)) \tan \phi_i]}{\sum_{i=1}^I (W_i \sin \beta - P_i \sin(\alpha - \beta))}$$

Soil Water Soil Water Water
 Soil Water Water

2.10.2.1.1.1 Weight of the Soil in the Failure Block

The weight of the soil in the failure block is an instrumental parameter in both the driving and resisting forces. The gravitational force on the mass of the bank "inside" of the failure plane is the primary driver of bank failure. However, the component of this weight normal to the failure plane also increases the frictional resistance to failure.

$W_i \sin\beta$ = The component of the weight down the failure plane, driving the soil into the water.

$W_i \cos\beta \tan\phi'_i$ = The frictional resistance of the soil along the failure plane, where:

$W_i \cos\beta$ = component of the weight normal to the failure plain

ϕ'_i = friction angle (which can be measured in the laboratory with triaxial testing or *in situ* with borehole shear equipment).

2.10.2.1.1.2 Cohesion

Cohesion is the inter-particle attraction in a soil matrix. For very fine soils (generally less than 0.0625 mm), particularly those composed of clay minerals, the electrochemical forces between particles can be stronger than the frictional forces. These electrochemical binding forces resist failure in cohesive soils such that:

$c'_i L_i$ = The effective cohesion per unit length (c'_i) acting along the length of the failure plane in a soil layer L_i . (Note: cohesion is actually a shear strength that acts over an area, but L_i becomes an area when it is projected along the streamwise or longitudinal direction).

2.10.2.1.2 Hydraulic Forces

$$F_s = \frac{\sum_{i=1}^I [c'_i L_i + S_i \tan \phi_i^b + [W_i \cos \beta - U_i + P_i \cos(\alpha - \beta)] \tan \phi'_i]}{\sum_{i=1}^I [W_i \sin \beta - P_i \sin(\alpha - \beta)]}$$

Soil Water Soil Water Water

For hydraulic forces there are two terms that consider the weight of the water and two terms that consider the pore water pressure.

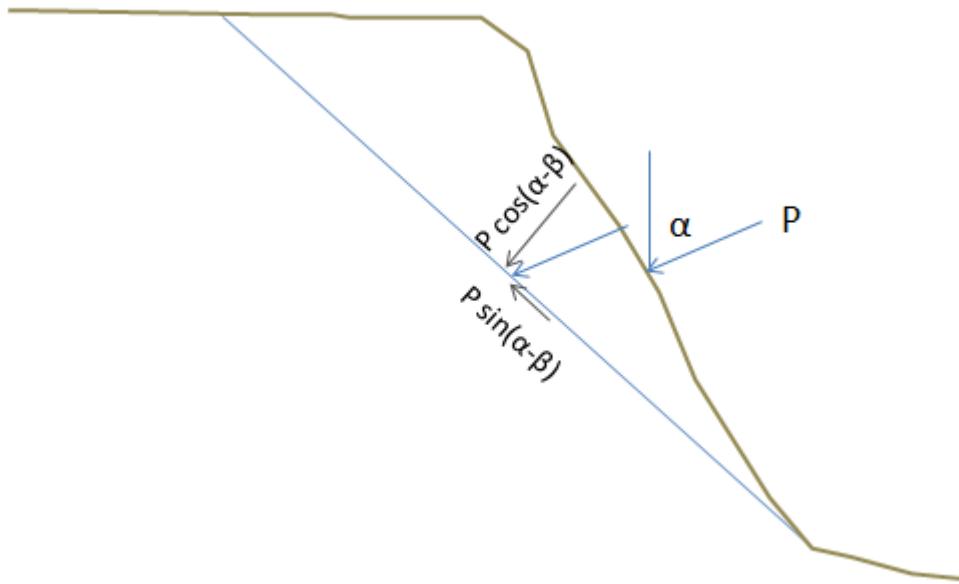
2.10.2.1.2.1 Hydrostatic Confining Force

The terms that consider the force of the water in the channel:

$P_i \cos(\alpha - \beta) \tan \phi'_i$ = The normal component of the hydrostatic confining force of the water in the channel. This is a resisting force because it adds to the normal force acting on the failure plane and, therefore, increases the frictional strength.

$P_i \cos(\alpha - \beta)$ = The component of the hydrostatic confining force acting along the failure plane against the direction of failure. The weight of the soil (the primary driving force) is reduced by this component, where:

α = is the angle between vertical and the vector the hydrostatic force (below) exerted by the channel water (orthogonal to the weighted average of the inundated bank slope) are both resisting forces



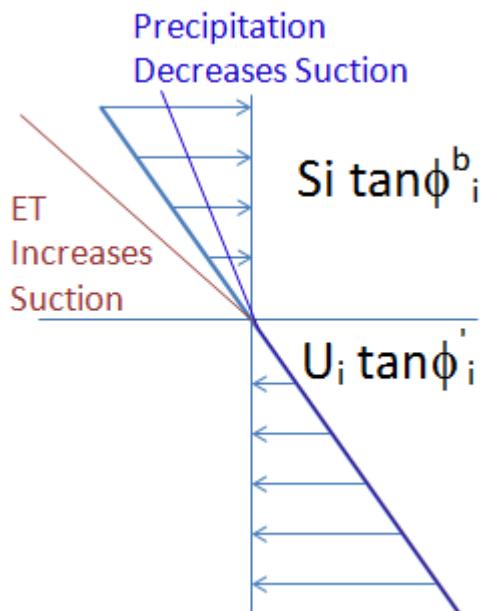
Pore Water Pressure

The pore water pressure is divided into two components in the numerator:

$-U_i \tan\Phi'_i$ = Hydrostatic uplift force (buoyancy is a driving force while suction is a resisting force). Water exerts a vertical force on submerged sand grains, reducing the normal force along the failure plane and, therefore, the frictional resistance to failure. U_i is simply the hydrostatic force, which increases linearly with depth below the groundwater table (below). In the saturated zone ' $b = \varphi'$ so the hydrostatic force is multiplied by $\tan \varphi'$ and can be included in the frictional term of the numerator.

$S_i \tan\Phi^b_i$ = The suction forces increase the soil strength due to the development of negative pore water pressure in the unsaturated zone of the soil which pulls the soil grains together. In the unsaturated zone, as water drains, evaporates, transpires, and is not replaced with atmospheric air, negative pressures (suction) develop.

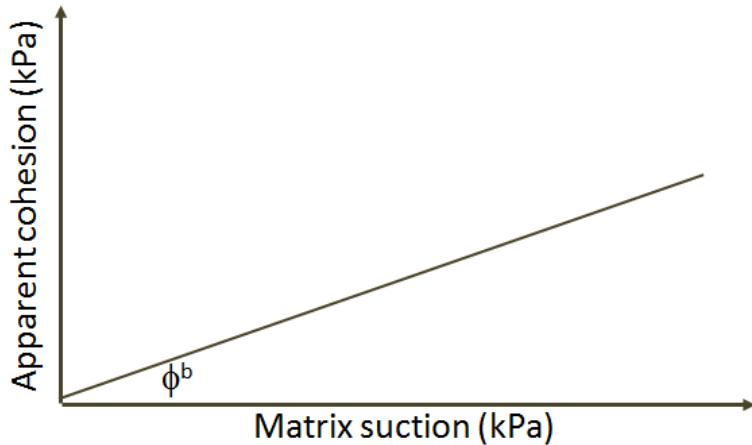
In general, suction S_i is estimated as a continuation of the hydrostatic force into the unsaturated zone. Suction increases with vertical distance above the water table at the same rate that the hydrostatic force increases with vertical distance below the water table. Positive and negative pore water pressures are assumed symmetrical around the water table. This is an idealized assumption, however, that only accounts for gravity draining. Precipitation and infiltration will add water to the unsaturated zone and decrease suction effects and evapo-transpiration will increase negative pore water pressures. If these processes are important, unsaturated pore water pressures will have to be measured (e.g., with a tensiometer).



Translating negative pore water pressures or suction effects into a force in the free body diagram is the most empirical step of computing the factor of safety. Every other parameter can be measured directly or computed. However suction effects are accounted for with an empirical assumption analogous to the friction slope parameter. The suction is translated into "apparent cohesion", (the equivalent amount of cohesion required to produce the same resisting force as the soil suction). Apparent cohesion (shown below) is easily included in the force balance, but is not a physical parameter that can be measured and is very difficult to compute. The angle ϕ^b is simply the linear relationship between the matrix suction measured or computed and the corresponding equivalent cohesion force it represents. This angle can be computed but is heavily labor and data intensive to measure so it is often selected based on user judgment. For most materials ϕ^b is generally between ten to thirty degrees depending on soil type. Most applications use a base ϕ^b between ten and fifteen, but it goes to a maximum of the friction angle when the material is saturated (Fredlund, 1986). Since it is one of the least certain parameters it is often considered a calibration parameter.

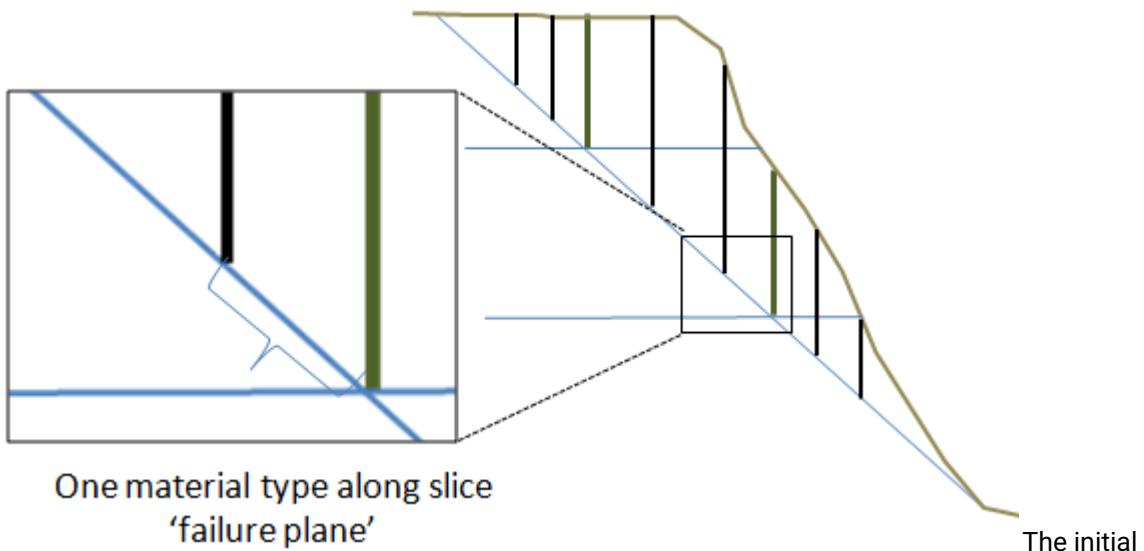
If the water surface in the channel is close to the groundwater elevation the confining forces of the water in the channel offset most of the driving force of the interstitial water. However, if the water in the channel is substantially lower than the soil water elevation (e.g., in the case of a rapid channel drawdown in poorly drained soils, leaving a perched groundwater table), the confining forces of the water will be removed while the driving forces (the weight of the water and the buoyant reduction in soil friction) remain. This is why the **critical failure condition** is often a case of substantial differential between ground water and surface water

elevations.

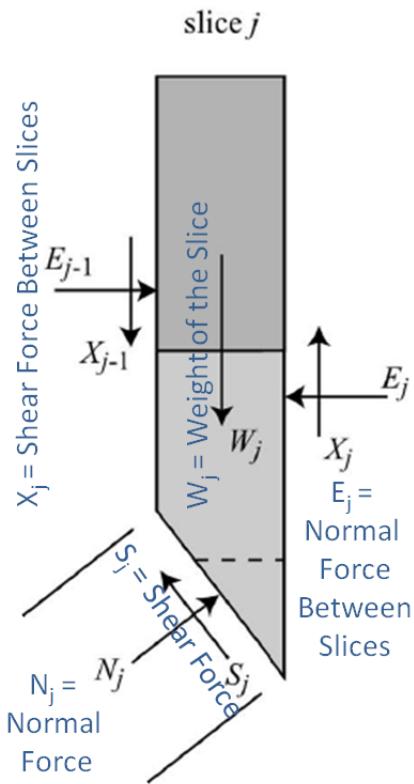


2.10.2.2 Method of Slices

The Method of Slices methodology included in HEC-RAS follows the more classical geotechnical approach to planar failure. The formulation of the method of slices for bank failure analysis comes from Langendoen (2008). Before the analysis the algorithm divides each user specified material layer into three vertical slices of equivalent width (below). This ensures that the force and momentum balance computed for each segment of the failure plan will not include more than one material type.



formulation of the method of slices (Bishop, 1955) considered forces acting at the base of each slice (along the failure plane) and included force (below) and momentum balances that were both vertical and normal to the slip surface. The Morgenstern and Price method (1965) added inter-slice forces in their analysis of earthen dams. The algorithms in USDA-ARS BSTEM for HEC-RAS include both inter-slice forces. The forces that act on each slice include: the weight of the slice W_j , the normal force acting on the base of the slice N_j , the shear force induced at the base of the slice S_j , inter slice normal forces E_j , and the vertical shear forces between slices X_j .



E_j and X_j = The inter-slice normal (E_j) and shear (X_j) forces are unique to the method of slices and deserve attention before the algorithm is described. Calculating inter-slice normal forces (E_j) from a horizontal force balance on the slice is relatively straight forward (Equation 4, Inter-slice Shear Forces). However, there is not an elegant theoretical approach to computing inter-slice shear forces. Stress-strain soil data demonstrate that there is a reasonably reliable empirical relationship of the ratio of inter-slice normal (E_j) and shear (X_j) such that:

$$X_j = \lambda E_j f(x) = 0.4 E_j \sin(\pi x/L_x)$$

(4)

where:

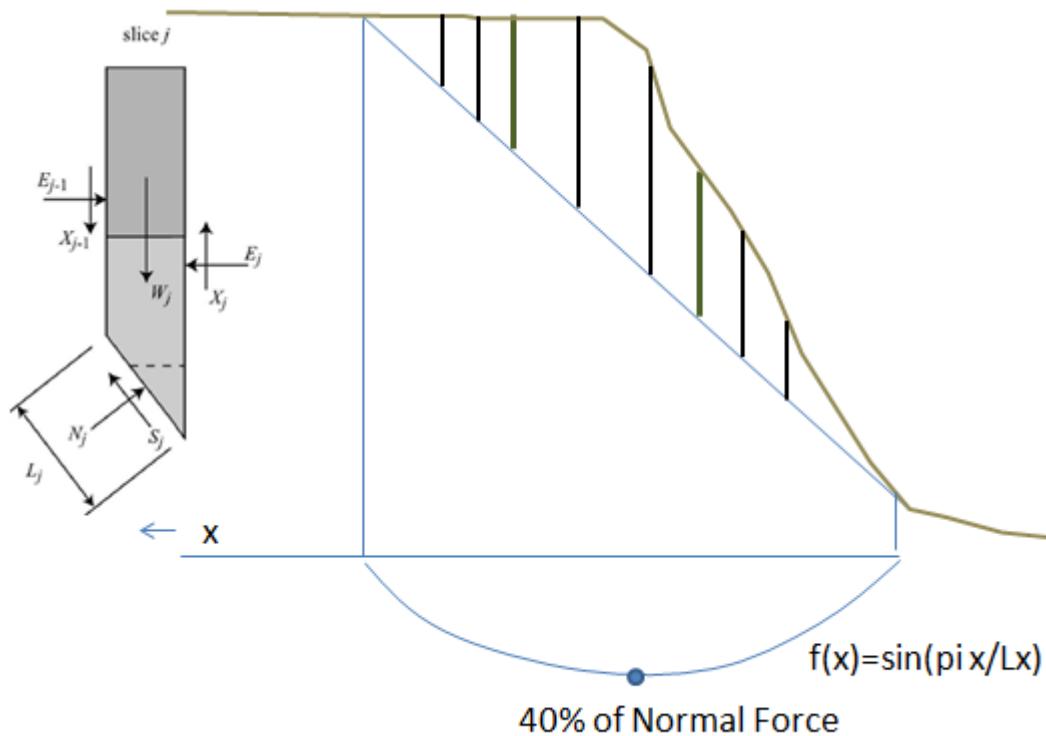
λ =the maximum ratio (forty percent),

$f(x)$ =a non-linear function between zero (0) and one (1) that apportions the ratio spatially,

x =the lateral distance into the bank

L =lateral width of the failure plane

In other words, at its maximum (in the center of the failure block) the shear force is forty percent of the normal force (below), and the shear-to-normal ratio decreases for slices farther from the center and closer to the margins.



FS can be computed by summing (for all slices, j) the forces acting along the failure plane. The equation for computing FS along the failure slope is a familiar mix (from the Layer Method) of driving (red labels) and resisting (green labels), soil (brown circles) and hydraulic (blue circles) forces in the following equation (Force Balance).

$$FS = \frac{\sec \beta \sum_{j=1}^J (L_j c'_j + N_j \tan \phi'_j - U_j \tan \phi_j^b)}{\tan \beta \sum_{j=1}^J (W_j - F_w)}$$

Hydrostatic
 ↓ frictional
 resistance

Frictional
 cohesion resistance

Weight of
 soil

Hydrostatic
 confining force
 force

where:

- FS = factor of safety
- U = hydrostatic uplift
- P = hydrostatic confining force of the water in the channel

Φ' = friction angle

Φ^b = relationship between matrix suction and apparent cohesion

c' = effective cohesion

W = weight of the soil

F_w = hydrostatic confining force

This is the Bishop (1955) approach that accounts only for the forces native to the individual slice. However, the normal force at the base of the slice is not a function of the forces intrinsic to the slice itself. It is modified by the inter-slice normal forces on either side (E_j and E_{j-1}) and the inter-slice shear (X_j and X_{j-1}) on either side of the slice. An iterative solution including two additional equations is required to compute these effects.

The inter-slice forces are calculated from the horizontal force balance (Equation 6, Horizontal Force Balance) for the slice:

$$E_j - E_{j-1} = [W_j - (X_j - X_{j-1})] \tan\beta \left(c_j L_j + N_j \tan\phi'_j - U_j \tan\phi_j^b \right) \frac{\sec\beta}{FS} \quad (6)$$

(6)

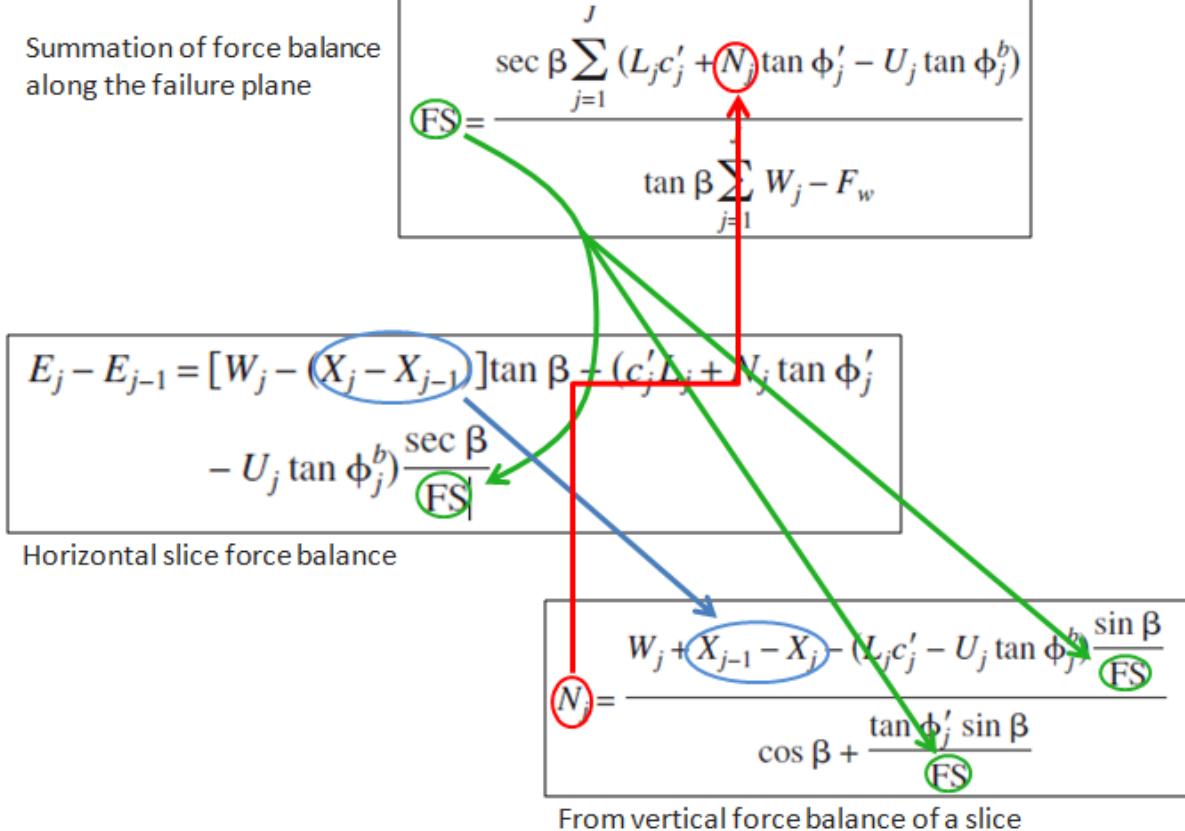
Equation 6 has FS imbedded and uses the FS computed in Equation 5. With FS being computed in Equation 5, and the shear forces between neighboring slices (X_j and X_{j-1}) coming from Equation 6, a Normal force at the base of the slice that is modified for inter-slice effects, can be computed from the vertical force balance (Equation 7) of the slice:

$$N_j = \frac{W_j + X_{j-1} - X_j - (L_j c'_j - U_j \tan\phi_j^b) \frac{\sin\beta}{FS}}{\cos\beta + \frac{\tan\phi'_j \sin\beta}{FS}} \quad (7)$$

(7)

The new normal force at the base of the slice is then substituted back into Equation 5 to compute a new FS, which is used to update the inter-slice forces in Equation 6 and to update the Normal force in Equation 7. The Method of Slices iterates on these three equations (below) until the change in FS between iterations drops below 0.5 percent.

There are some considerations in the code to decrease the computational expense of iteration. The code checks the denominators of the equations for FS and N_j to determine if iteration is necessary.



91 Iterative scheme to compute FS for the method of slices including the dependency of the normal force at the base of the slice on the inter-slice forces.

2.10.2.2.1 Tension Cracks

Tension cracks are a special case of the Method of Slices computation. Because of the vertical nature of tension cracks, they can only be computed by the Method of Slices. The USDA-ARS standalone version of BSTEM uses the Layer Method by default but switches to the Method of Slices if the tension crack parameter is defined and a tension crack is identified.

If the inter-slice normal forces are negative E less than zero the slice is in "tension". Soil generally performs very poorly under tension. Tension slices tend to be on the "upslope" portion of the failure block because there is more material "sliding away" pulling on the slice. Therefore, the code starts at the (channel side) and works inland, checking each slice interface for E less than zero.

When a slice in tension is found, the software compares the height of the slice interface to the user specified (or internally calculated) "maximum tension crack "depth". If the slice interface is greater than maximum tension crack, then no tension crack is computed at that location and the next inland interface is analyzed. Therefore the tension crack happens at the slice interface closest to the channel that fulfills the two following criteria:

1. E less than 0 (i.e. the slice interface is "in tension")
2. The height of the interface between the slices is less than the maximum tension crack (below)

The vertical thickness of tension cracks is soil specific and can be determined by visual field inspection of the vertical cut at the upper portion of existing bank failures. It can also be computed with the equation for the depth at which active pressure goes to zero (Equation 8) (Lambe and Whitman, 1969):

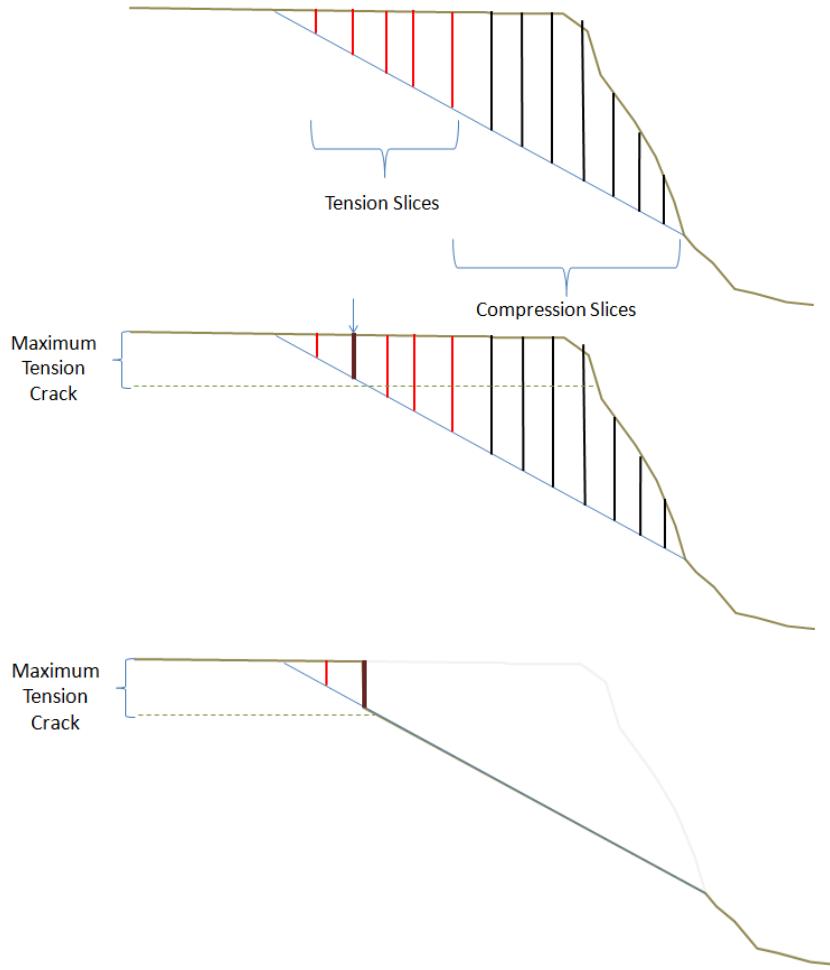
$$Z_c = \frac{2c'}{\gamma} \tan(45^\circ + \phi'/2)$$

(8)

HEC-RAS currently uses this equation by default for the method of slices. The standalone version of BSTEM can override this value with a user specified maximum tension crack, but this is not available in HEC-RAS at this time.

If a tension crack is identified, the slices inland from the tension crack are excluded from the stability analysis. Because the failure plane along these inland slices is higher, the inland slices will tend to have higher suction forces and lower buoyant forces. Therefore, a tension crack that excludes these inland slices will reduce the FS and make the bank more likely to fail.

If FS is less than zero and a tension crack is computed, the failure block on the river side of the tension crack is removed from the bank and added as sediment load to the sediment model, while the inland slices remain fixed to the bank, resulting in a vertical wall.

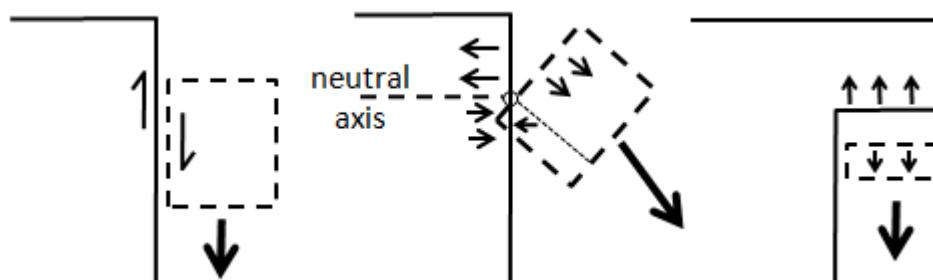


92 Tension crack computation criteria

2.10.2.2.2 Cantilever Failures

Cantilever failures, mass wasting of overhanging soil blocks, are also a special case of the Method of Slices. Thorn and Tovey (1981) established three types of cantilever failures (below) that include three distinct processes:

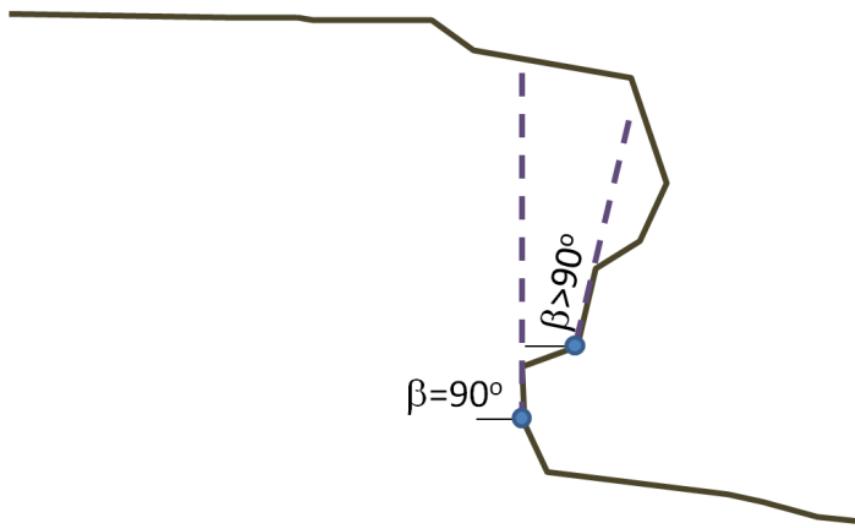
1. The soil block shears off along the vertical or obtuse failure plane.
2. The soil block rotates off the bank due to the tension (e.g., inter-slice normal forces go to zero and cohesion is not sufficient to keep the overhanging block in place).
3. The lower layer of the block falls off.



93 A taxonomy of cantilever failure mechanisms (after Thorn and Tovoy, 1981).

There is no special cantilever case algorithm in HEC-RAS. The methods available in HEC-RAS can only apply the Method of Slices to overhanging bank configurations, and therefore can only simulate the first (sliding) mechanism of cantilever failure. Ninety degrees is the maximum failure angle that HEC-RAS will consider.

To identify cantilever failure HEC-RAS checks to see if the maximum β (the maximum failure plane angle that is entirely included in the bank soil) at any evaluation point is greater than or equal to ninety degrees (below). This indicates an overhanging bank and that Method of Slices was used for the evaluation at that point even if the Layer Method is selected.



2.10.3 Selecting a Method

The Layer Method and the Method of Slices generally produce very similar results. Differences between the two methods are summarized in the table below. The standalone version of the USDA-ARS BSTEM model uses the Layer Method unless it has to compute tension cracks or cantilever failure, which cause it to switch to the Method of Slices. The choice mainly involves a trade-off between a theoretical consideration (the normal force distribution) and a practical consideration (run time).

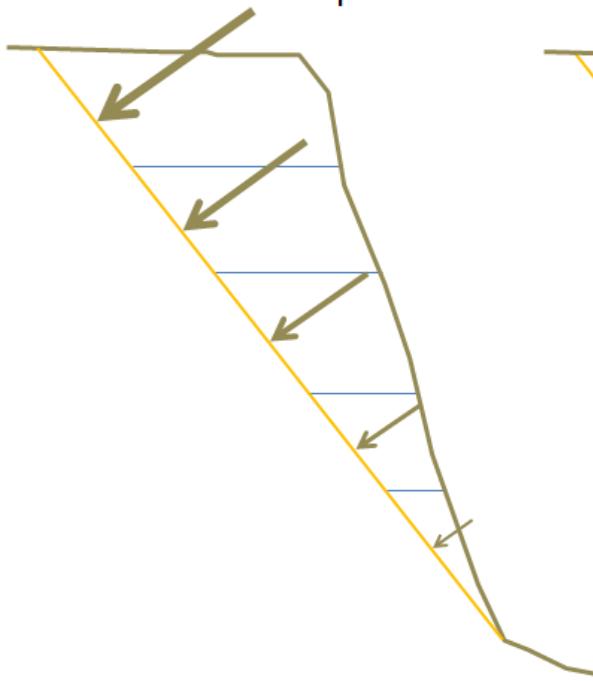
Method of Slices computes a somewhat more realistic distribution of normal stresses along the failure plane (below). The Layer Method computes larger normal stress for larger layers, which tend to be along the top of the failure plane while the Method of Slices computes larger normal stresses for larger slices which tend to exert their forces at the base of the failure plane (which is a more realistic assumption). Therefore, without tension cracks, the Method of Slices will generally compute a slightly higher FS for the same data set. However, because the Method of Slices allows tension cracks, which tend to remove more resisting forces than driving forces, the Method of Slices often returns a lower FS, and more failures.

2.10.3.1 *Table: Method selection criteria*

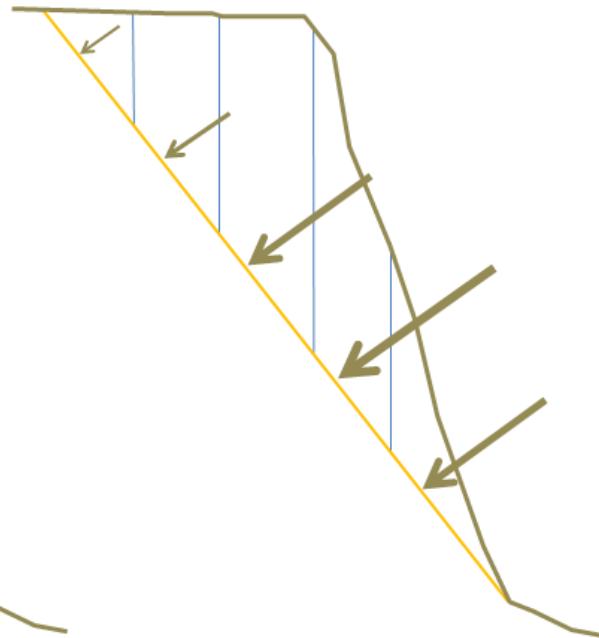
| Layer Method | Method of Slices |
|--|--|
| Customized for bank failure applications. | Closer to the comparable geotechnical analyses. |
| Higher normal stresses along the failure plane generally computed for the higher layers. | Higher normal stresses along the failure plane generally computed for the deeper layers. |
| Non-Iterative. More computationally efficient. | Apportions normal stresses according to more physically based assumptions. |
| Switches to method of slices if tension cracks or overhanging banks form. | Computes tension crack and cantilever failures. |

However, because the Method of Slices is iterative and the Layer Method is not, the Layer Method is more computationally efficient and can decrease run times. Since there are already two iterative computations in BSTEM outside of the FS computation (e.g., analysis for several nodes up the bank face and the selection of the critical failure plane for each node) bank failure analysis can be computationally expensive for big projects or long runs. The Layer Method may reduce those run times.

Layer Method: Larger normal forces at the top.



Method of Slices: Larger normal forces at the toe.

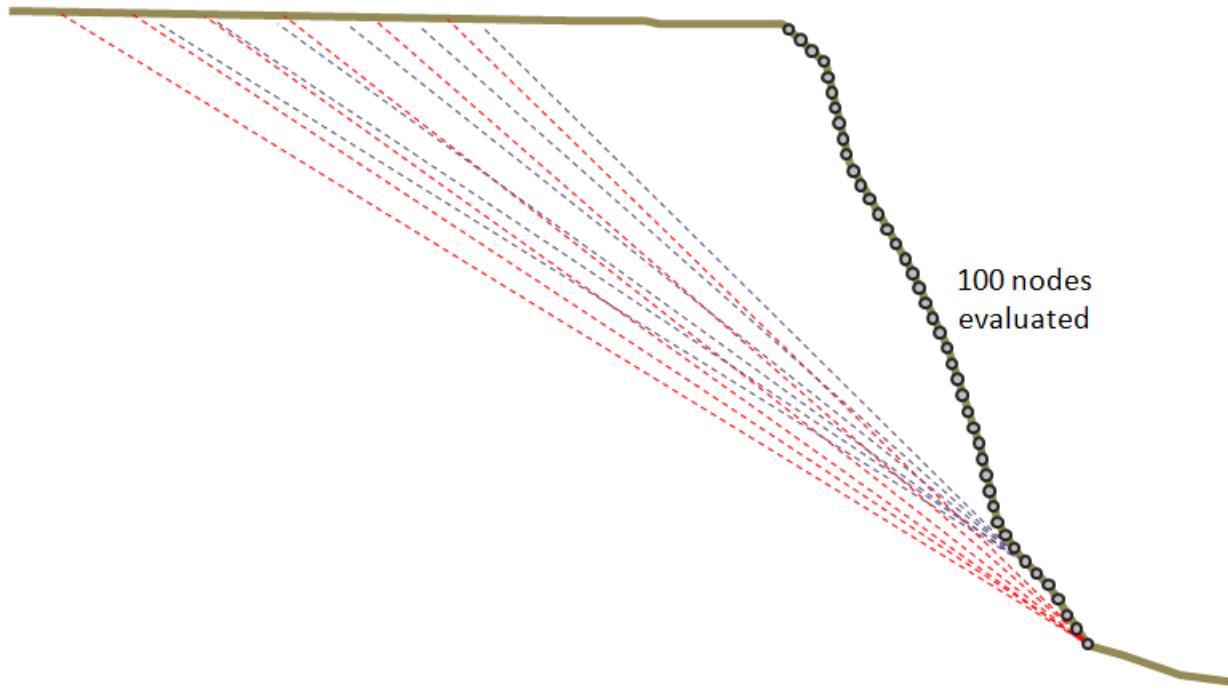


94 Theoretical difference in normal stress computed by Layer Method and Method of Slices.

2.10.4 Steps in a Bank Failure Analysis

The physics described the sections above, computes the FS for a single failure plane. However to determine if the bank will fail and where it will fail several failure planes 1) with different starting elevations on the face of the bank and 2) with different angles have to be evaluated (below). Therefore, regardless of what method was used to compute the physical FS, the following is a six step iterative evaluation for each bank and time step analyzed:

1. Evaluate nodes at several vertical locations up the bank. Then for each node:
2. Select the bounding failure planes (minimum and maximum angles) and an initial guess for FS_{cr}
3. Compute the FS_i
4. Use that information to select a more likely critical failure plane (using the "bracket and Brent" optimization algorithm from Teukolsky et al. (2007)) (setting FS_{i+1} to a new estimate of FS_{cr})
5. Decide when FS is close enough to FS_{cr} to stop, otherwise repeat Step 3
6. Select the FS_{cr} for all nodes and if FS_{cr} is less than one, fail the bank, update the cross section, and send the bank sediments to the routing model



The following describes the above steps in more depth.

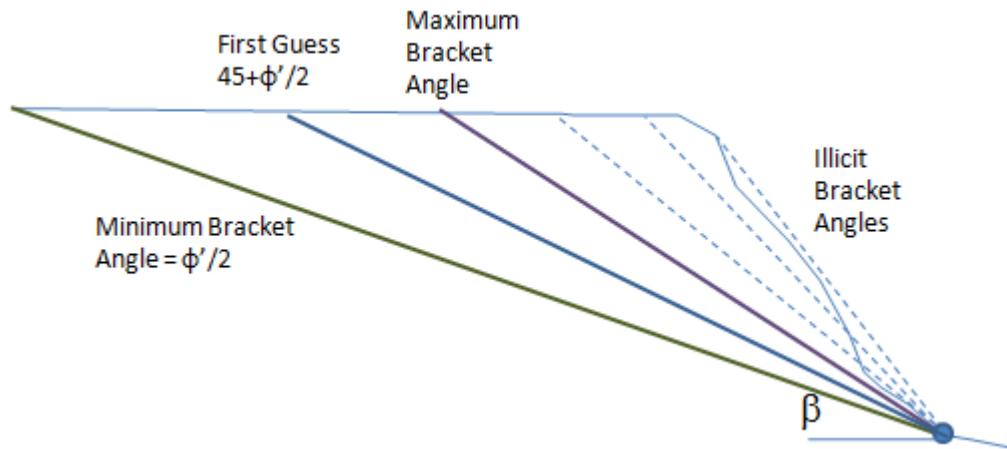
- 1. Evaluate nodes at several vertical locations up the bank**

The software will find a critical failure plane that starts at several vertical locations along the face of the bank. HEC-RAS evaluates 100 points which are evenly spaced vertically between the user specified toe and top of bank (one percent evaluation intervals) by default. Fewer evaluation points can be specified under BSTEM to improve run time. However, bank points that are evenly spaced will not be evenly spaced along an irregular bank.

For each elevation, the bank failure algorithms will find a critical FS failure plane. Instead of running many angles for each node at very small increments, a minimization algorithm with quadratic convergence (bracket and Brent) is used to find the failure plane with the minimum FS at each node with as few failure planes as possible. This process includes the next Steps.

- 2. Select the bounding failure planes (minim and maximum angles) and compute a FS for each**

The first step of finding the critical FS of a given bank node is to bound the possible angles (the "bracket" in bracket and Brent). The minimum angle is set to half of the friction angle, which is a reasonable angle below which most bank configurations would be expected to remain stable. The maximum angle is the largest angle that is entirely in the soil matrix (below).

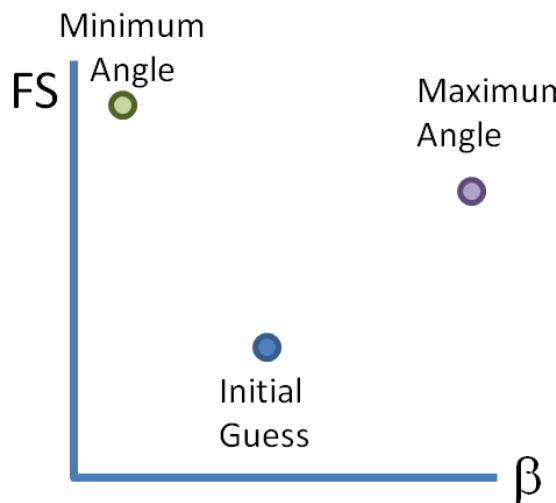


Then the bank failure method makes an initial guess for the critical failure plane to start the parabolic search, which is 45degrees plus half the friction angle.

However, sometimes it is not as simple as the classical configuration in the figure above. A number of unique configurations posed by natural channel banks can cause the default maximum angle to be less than half the friction angle or can generate an initial guess ' $45^\circ + \Phi'/2$ ' to fall outside of the bracket among other complications. Therefore, there are special cases to deal with unique configurations.

With the maximum and minimum angles set and a first estimate established, the bank failure algorithm is prepared to start the iterative search to determine a critical failure plane angle.

In the initial iteration, an FS is computed for the maximum, minimum, and initial estimate failure plane angles by the methods described above (below). In each successive iteration, an FS is computed for the new failure plane angle selected by the parabolic search.



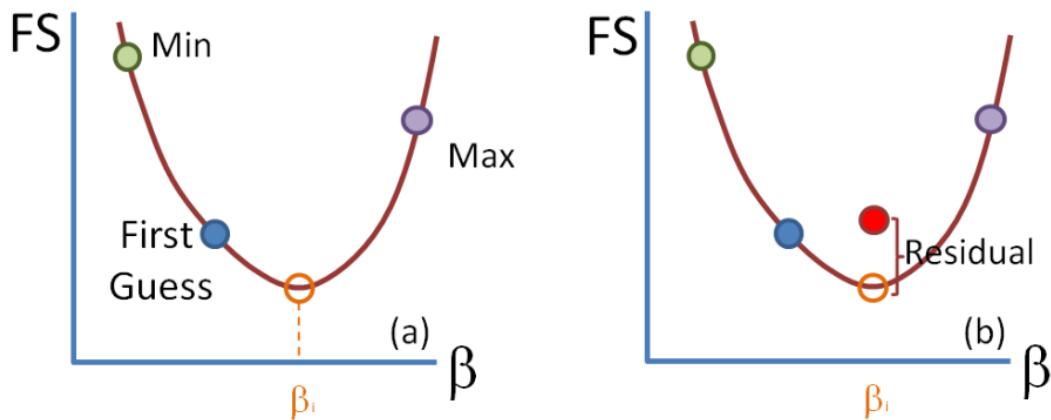
FS is computed for the maximum, minimum and best guess angles with the physics described above, and then the three angle-FS pairs are passed to the bracket and Brent (Teukolsky et al. 2007) routine, which fits a parabola to the FSs associated with the three angles and then iterates to find the minimum. With each iteration, the bracket shrinks (the maximum and minimum possible angles converge) and the algorithm completes when the bracket drops below 0.5 deg.

3. Compute FS_i

The algorithm computes an FS for the β_i selected by the methods described in detail above.

4. Use that information to select a more likely critical failure plane

Next HEC-RAS uses a parabolic optimization algorithm (bracket and Brent) to find an angle (β) that is likely to have a lower FS. The software fits a second order quadratic equation through the three factors of β - FS points and identifies the angle (β_i in figure (a) below) associated with the parabolic minimum.

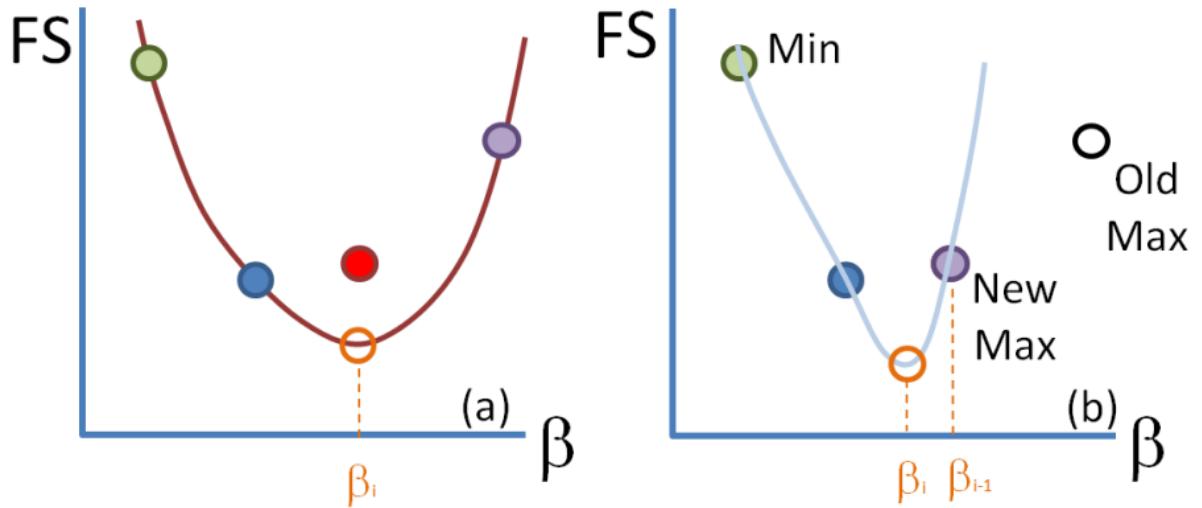


5. Decide when the FS is close enough to FS_{cr} to stop, otherwise Iterate

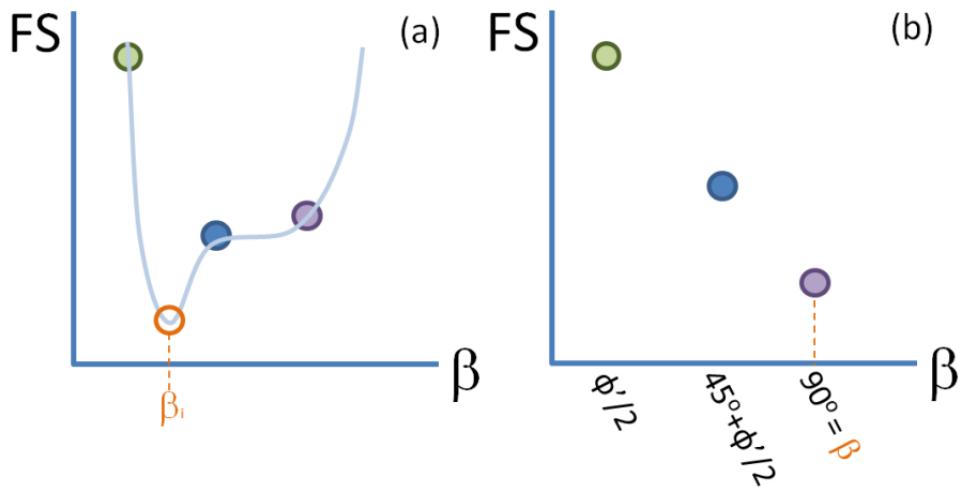
The actual relationship between β_i and FS does not necessarily fit a second order quadratic equation. Therefore, the FS computed for the angle selected (β_i) will not precisely match that predicted by the function. Therefore, the bank failure algorithm evaluates the difference between the computed FS and the predicted FS ("residual" in figure b above). If the difference is less than half a percent (i.e., residual less than 0.5 percent) then the parabolic function is considered a good approximation of the β -FS relationship and the β_i is adopted as the critical failure plane for this bank node.

However, if the residual is greater than 0.5 percent, the algorithm will iterate and return to Step 3, by trying to identify the most likely critical failure plane angle given the new information. The new β_i - FS_i point becomes the new maximum or minimum (depending on which side the last β_i is on) and a new, narrower, second order quadratic is fit to the new three points (below). A new β_{i+1} is selected at the minimum of the function. The FS is calculated (Step 4) and the residual evaluated (Step 5). As this algorithm iterates the range between the maximum and the minimum shrinks as the function converges (usually within a few iterations) to a solution.

However, sometimes β - FS functions that depart substantially from the parabolic model can return false, local minimums. For example, the theoretical function in "Monotonic β -FS function associated with a cantilever curve" (a) passes through the same points as (b) below but would not be predicted by the "narrowing parabolic" method. Therefore, the iteration optimization includes occasional searches to find other β regions with low FSs.



Additionally, sometimes the relationship between β and FS is monotonic (graph b below). This occurs in the case of cantilever failures where the highest factor of safety is often associated with the maximum angle. If the maximum angle has the lowest factor of safety in Step 2, this is automatically accepted as the critical failure plane and the model does not iterate.



6. Select the FS_{cr} for all nodes and if FS_{cr} is less than one, fail the bank, update the cross section, and send the bank sediments to the routing model

Finally, after the critical failure plane is iteratively computed for each of the vertical evaluation points on the bank, the failure plane with the lowest overall failure plane is selected. If the FS is greater than one, the bank is stable. However, if the FS is less than one, then the bank fails and the bank material inside of the failure plane is removed from the bank and added to the control volume of the sediment routing model associated with the cross section. The material inside of the failure plane is removed, the cross section is updated, and the material is introduced into the sediment routing model as a lateral load.

2.10.5 Toe Erosion (Fluvial or Hydraulic Erosion)

The combination of vertical bed change in the classical HEC-RAS mobile bed computations and the bank failure algorithms can model the interaction of model incision and bank failure. As a channel incises the potential failure plane through the new exposed toe, the bank steepens and the FS drops. Therefore, incision can induce bank failure (or conversely deposition can stabilize banks). However, there is a third that neither the HEC-RAS sediment model nor the bank failure model covered above capture, which is important in modeling bank erosion and loads - toe scour.

Toe scour is a fluvial, hydraulic process driven by the flow (versus bank failure which is primarily a gravity driven geotechnical process). The classical mobile bed algorithms in HEC-RAS only compute vertical movement of the bed, but hydraulic forces can undermine the toe of a bank, which can reduce the length of the failure plane (and the frictional resistance) and decrease the factor of safety of the critical failure plane faster than incision.

- [Determining the Zone of Scour \(see page 374\)](#)
- [Determining \$\tau_{node}\$ \(see page 374\)](#)
- [Scour \(see page 377\)](#)

2.10.5.1 Determining the Zone of Scour

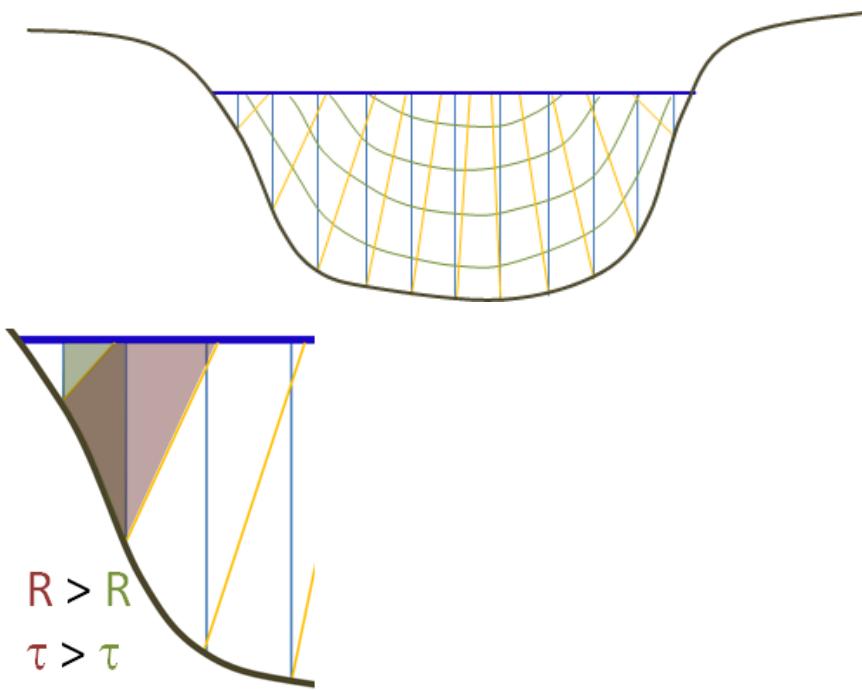
The movable bed limits in the HEC-RAS sediment transport module define the transition between incision and scour. Inside of the movable bed limits, the channel is modified by the movable bed model (incision and deposition translated into vertical node movement). Outside of the movable bed limits, scour equations are used⁵. The model is very sensitive to the selection of these limits.

The scour equations in the USDA-ARS BSTEM that are implemented in HEC-RAS compute lateral bed change of the wetted nodes outside the movable bed limits for cohesive or cohesionless soils based on a radial shear distribution.

2.10.5.2 Determining τ_{node}

Unlike channel deposition or erosion, toe scour does not affect all nodes equally. This is important for its interaction with the bank failure model because the failure plane will likely pass through the vertical location of maximum scour. However, to compute differential lateral scour, the software must compute a local shear stress for each node.

There are several ways to post process one-dimensional hydraulics to compute local shear stress. The most common is to subdivide the cross section into vertical "prisms" (blue lines in the figure below) and compute a local shear stress based on the hydraulic radius of each one. However, the assumption of zero inter-prism friction only holds along the planes normal to the isolines (contours of constant velocity). Vertical divisions violate this assumption because they are not perpendicular to the isolines.



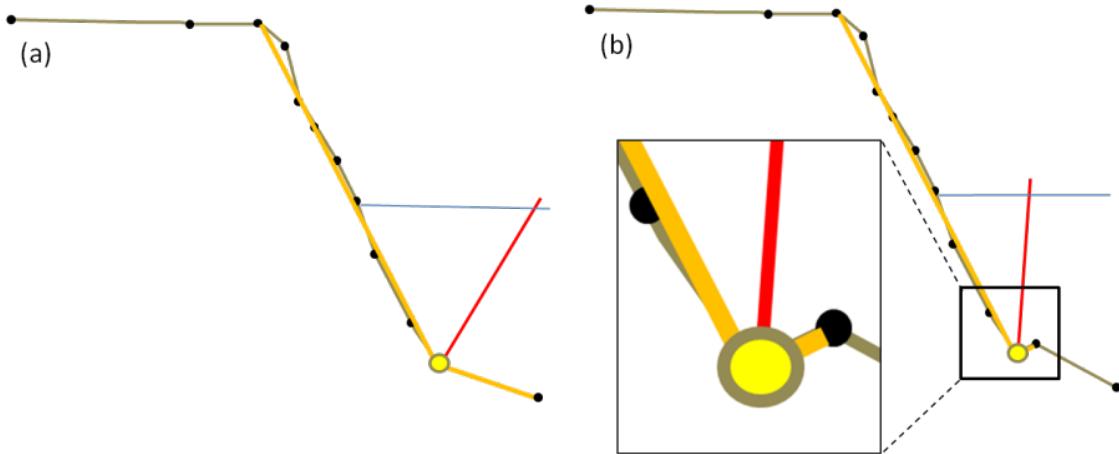
95 Subdividing the cross section into vertical conveyance prisms (blue) versus zones (yellow) perpendicular to the isovels (green).

Alternately, the one-dimensional cross section can be divided into "radial prisms", non-vertical zones by partitions perpendicular to the isovels (yellow lines in the figure above). These approaches will compute different hydraulic radii (a sensitive variable for computing the shear stress) especially in the zone closest to the bank where the toe scour computations are applied. The radial prisms tend to have higher hydraulic radii, and therefore, higher shear stress than the vertical prism associated with the same bank segment and represent a more realistic shear stress distribution (above). Therefore, the bank erosion algorithms use a radial distribution, dividing the flow field, hydraulic radius, and shear stress with radial prisms.

If bed and bank roughness are approximately the same, then we can assume that the line that bisects the toe is normal to the isovels (Kean and Smith, 2001). Therefore, the first step in developing the radial shear distribution is finding the angle bisecting the toe (graph a below). Bank and channel segments are computed by connecting the scour toe (the movable bed limit) to the edge of bank and the next interior channel point respectively (below). This segment determines the zone of the one-dimensional cross section dedicated to toe scour.

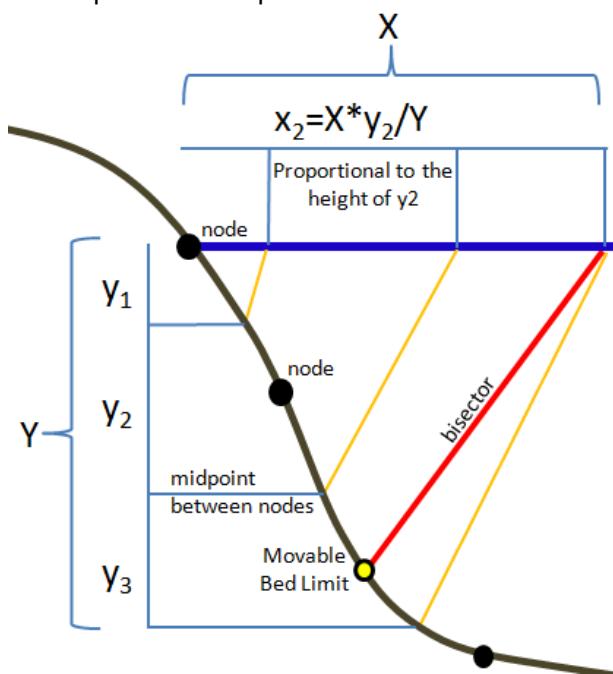
Modeling Note:

This computation makes the scour computations sensitive not only to the selection of the mobile bed limits but also to the elevation of the interior node. Random bed fluctuations can cause this node to diverge from the basic lateral channel slope (Figure 20b) which could result in an artificially truncated or enlarged.



96 Finding the bisecting angle at the toe which will determine the portion of the water column that is contributing to toe scour.

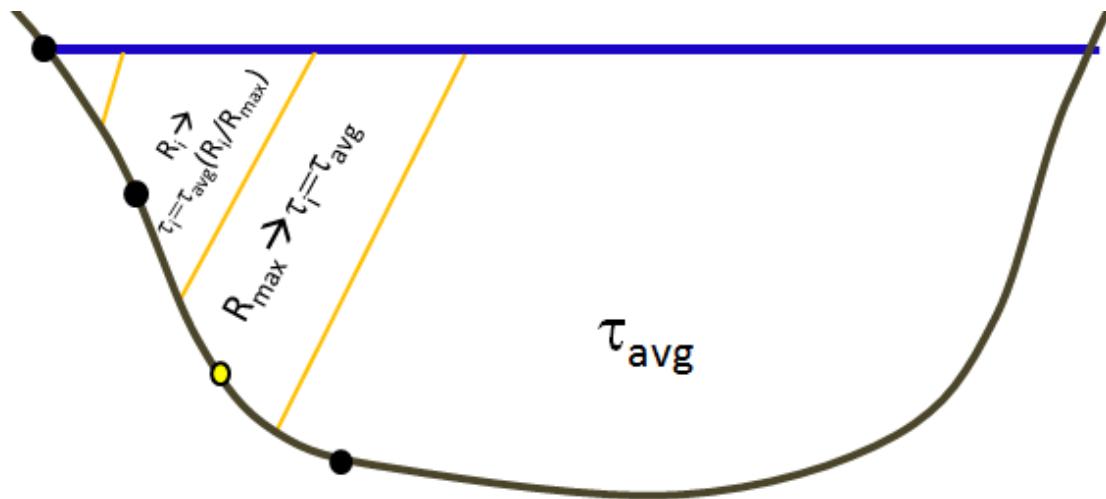
Next a "radial prism" is associated with each node (cross section station-elevation points in the toe scour zone). The water surface intersection point connects the midpoint between wetted bank nodes. The water surface intersection point is a relative proportion of the water depth of the midpoint between nodes and the total depth to the midpoint of the movable bed limit and the next interior node (below).



Once the radial flow prism is computed for each wetted bank node (below), the hydraulic radius of the prism is computed from the area and wetted perimeter (water-water boundaries are ignored). Then the shear stress for each radial prism is computed from the average one-dimensional shear stress as a ratio of:

$$\tau_i = \tau_{avg} (R_i / R_{max})$$

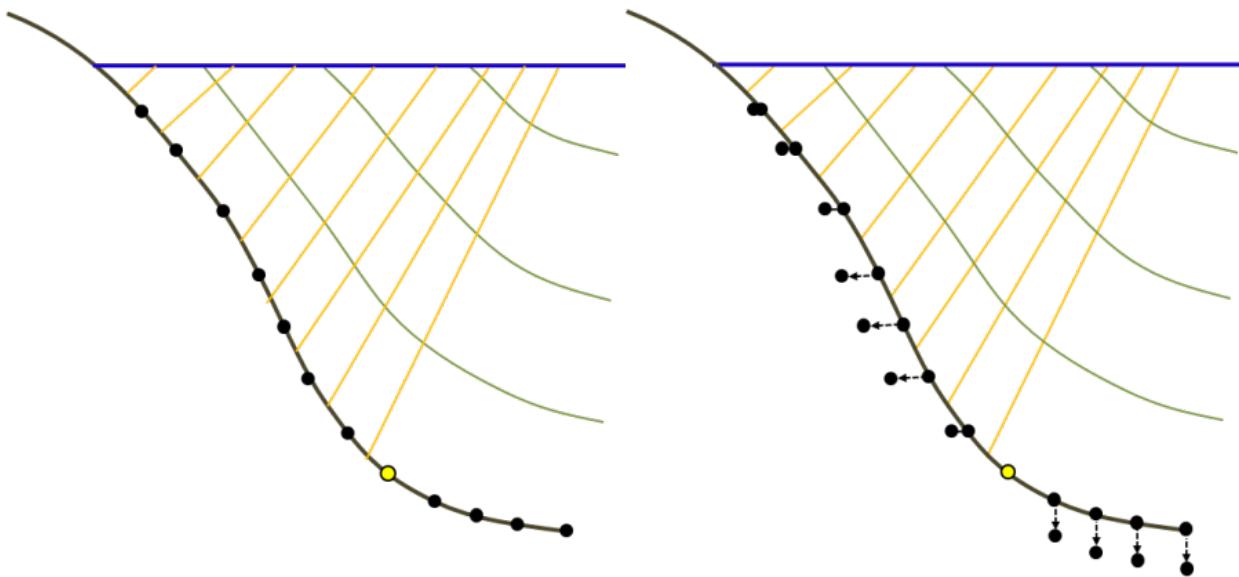
where R_{max} which is typically R_{toe} is the largest hydraulic radius among the radial flow prism.



97 Apportioning the local shear by a ratio of the hydraulic radius of the radial prisms.

2.10.5.3 Scour

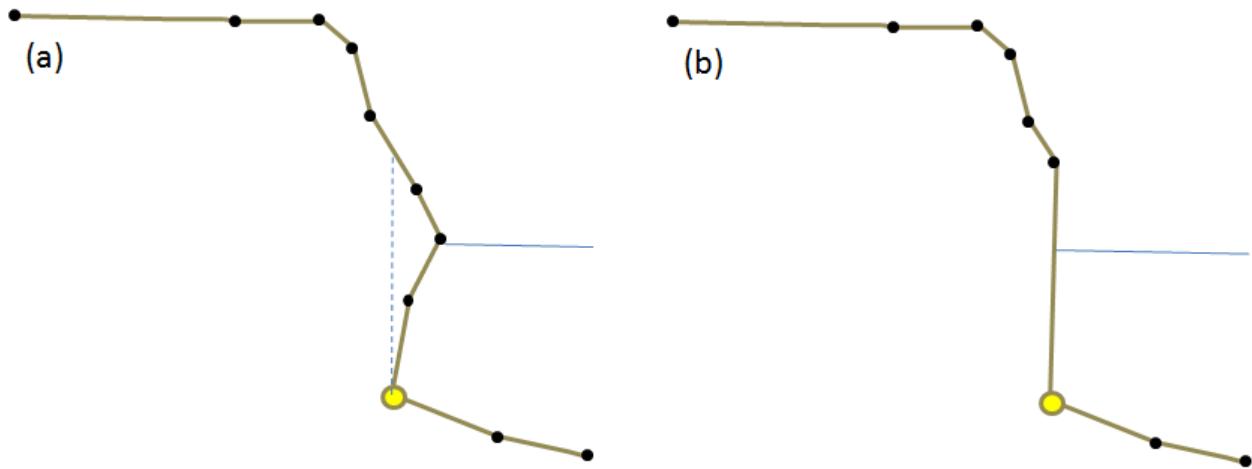
If the clay content of the layer is greater than twenty percent, the software uses an excess shear cohesive equation, scoring material based on the erodibility and shear. For clay content less than twenty percent, scour is computed using a transport function. Different nodes (below) can invoke different transport equations depending on the associated layer material. Then the nodes in the toe scour region of the model are adjusted laterally.



98 Nodes between the movable bed limits are adjusted vertically (and uniformly) and the wetted nodes outside the movable bed limits are adjusted laterally (and independently).

This radial shear distribution commonly computes maximum shear stress at the toe. Therefore, the toe will often scour more than the other nodes, yielding an overhanging bank like the one in graph a below. HEC-RAS requires increasing station values, so it cannot retain or represent overhanging banks in the current version. Therefore, HEC-RAS assumes that overhanging banks fail vertically, as depicted in the figure below. Because

overhanging banks eventually fail, this should not introduce substantial error in long term models.



2.11 Appendix A_ Sample Transport Calculations

The following sample calculations were the basis for the algorithm used in the HEC-RAS sediment functions. These example calculations use a single grain size. They were adapted in the HEC-RAS code for multiple grain sizes.

- Ackers White Sample Calculation (see page 379)
- Engelund Hansen Sample Calculation (see page 383)
- Laursen-Copeland Sample Calculation (see page 386)
- Meyer-Peter Muller Sample Calculation (see page 390)
 - Derivation of the Dimensionless form of MPM from the Vanoni Form (see page 393)
- Toffaletti Sample Calculation (see page 395)
- Yang Sample Calculation (see page 402)

2.11.1 Ackers White Sample Calculation

By Ackers-White (ASCE Journal of Hydraulics, 1973)

Ackers-White Sediment Transport Function

by Ackers-White (ASCE Jour. Of Hyd, Nov 1973)

Input Parameters

| | | | |
|---------------------------------------|--------------------|---------------------------------------|---------------------------|
| Temperature, F | T = 55 | Average Velocity, ft/s | V = 2 |
| Kinetic viscosity, ft ² /s | $\nu = 0.00001315$ | Discharge, ft ³ /s | Q = 5000 |
| Depth, ft | D = 10 | Unit Weight water, lb/ft ³ | $\gamma_w = 62.385$ |
| Slope | S = 0.001 | Overall d ₅₀ , ft | d ₅₀ = 0.00232 |
| Median Particle Diamter, ft | | $d_{50} = 0.00232$ | |
| Specific Gravity of Sediment, | | s = 2.65 | |

Constants

Acceleration of gravity, ft/s² g = 32.2

Solution

*note: Ackers-White required the use of d₃₅ as the representative grain size for computations in their original paper. In the HEC-RAS approach, the median grain size will be used as per the 1993 update. The overall d₅₀ is used for the hiding factor computations.

Hiding Factor from Profitt and Sutherland has been added for this procedure, but will be included as an option in HEC-RAS.

Computations are updated as per Acker's correction in Institution of Civil Engineers Water Maritime and Energy, Dec 1993.

Dimensionless grain diameter,

$$d_{gr} = d_{si} \left[\frac{g \cdot (s-1)}{\nu^2} \right]^{\frac{1}{3}}$$

$$d_{gr} = 15.655$$

Shear velocity u

$$u_{star} = \sqrt{g \cdot D \cdot S}$$

$$u_{star} = 0.567$$

Sediment size-related transition exponent n,

$$n = \begin{cases} 1 & \text{if } d_{gr} \leq 1 \\ (1 - 0.056 \cdot \log(d_{gr})) & \text{if } 1 < d_{gr} \leq 60 \\ 0 & \text{if } d_{gr} > 60 \end{cases}$$

$$n = 0.331$$

Initial motion parameter A,

$$A = \begin{cases} \frac{0.23}{\sqrt{d_{gr}}} + 0.14 & \text{if } d_{gr} \leq 60 \\ 0.17 & \text{otherwise} \end{cases}$$

$$A = 0.198$$

Sediment mobility number F_{gr},

$$\alpha = 10 \quad (\text{assumed value used in HEC6 and SAM})$$

$$\alpha = 10$$

$$F_{gr} = \frac{u_{star}^{-n}}{\sqrt{g \cdot d_{si} \cdot (s-1)}} \cdot \left(\frac{V}{\sqrt{32} \cdot \log\left(\alpha \cdot \frac{D}{d_{si}}\right)} \right)^{1-n}$$

$$F_{gr} = 0.422$$

Hiding Factor HF,

Shield's Mobility Parameter \square

$$\theta = \frac{u_{star}^2}{g \cdot (s-1) d_{50}}$$

$$\theta = 2.612$$

$$dRatio = \begin{cases} 1.1 & \text{if } \theta \leq 0.04 \\ (2.3 - 30 \cdot \theta) & \text{if } 0.04 < \theta \leq 0.045 \\ (1.4 - 10 \cdot \theta) & \text{if } 0.045 < \theta \leq 0.095 \\ 0.45 & \text{otherwise} \end{cases}$$

$dRatio = 0.45$

$$dAdjust = d_{50} \cdot dRatio$$

$dAdjust = 1.044 \times 10^{-3}$

$$HFRatio = \frac{d_{si}}{dAdjust}$$

$HFRatio = 2.222$

$$HF = \begin{cases} 1.30 & \text{if } HFRatio \geq 3.7 \\ (0.53 \cdot \log(HFRatio) + 1) & \text{if } 0.075 \leq HFRatio < 3.7 \\ 0.40 & \text{otherwise} \end{cases}$$

$HF = 1.184$

Adjust Sediment Mobility Number for Hiding Factor

$$F_{gr} = HF \cdot F_{gr}$$

$F_{gr} = 0.5$

Check for too fine sediment based on F_{gr} and A,

$$Check = \frac{F_{gr}}{A}$$

$Check = 2.522$

Sediment transport function exponent m,

$$m = \begin{cases} \left(\frac{6.83}{d_{gr}} + 1.67 \right) & \text{if } d_{gr} \leq 60 \\ 1.78 & \text{otherwise} \end{cases}$$

$m = 2.106$

Check for too fine sediment based on m,

$$Check = \begin{cases} 0 & \text{if } m > 6 \\ Check & \text{otherwise} \end{cases}$$

$Check = 2.522$

Sediment transport function coefficient C,

$$C = \begin{cases} 10^{2.79 \cdot \log(d_{gr}) - 0.98(\log(d_{gr}))^2 - 3.46} & \text{if } d_{gr} \leq 60 \\ 0.025 & \text{otherwise} \end{cases} \quad C = 0.0298$$

Transport parameter G_{gr} ,

$$G_{gr} = C \cdot \left(\frac{F_{gr}}{A} - 1 \right)^m \quad G_{gr} = 0.072$$

Sediment flux X , in parts per million by fluid weight,

$$X = \frac{G_{gr} s d_{si}}{D \left(\frac{u_{star}}{V} \right)^n} \quad X = 6.741 \times 10^{-5}$$

Sediment Discharge, lb/s

$$G = \gamma_w Q X \quad G = 21.027$$

Sediment Discharge, tons/day

$$G_s = \frac{86400}{2000} \cdot G \quad G_s = 908$$

Check to make sure particle diameter and mobility functions are not too low,

$$G_s = \begin{cases} G_s & \text{if Check} > 1 \\ 0 & \text{otherwise} \end{cases} \quad G_s = 908$$

2.11.2 Engelund Hansen Sample Calculation

From Vanoni (1975) and Raudkivi (1976)

Engelund Hansen Sediment Transport Function

by Vanoni (1975), and Raudkivi (1976)

Input Parameters

| | | | |
|---|--------------------|---------------------------------------|---------------------|
| Temperature, F | T = 55 | Average Velocity, ft/s | V = 5.46 |
| Kinematic viscosity, ft ² /s | | $\nu = 0.00001315$ | |
| Depth, ft | D = 22.9 | Unit Weight water, lb/ft ³ | $\gamma_w = 62.385$ |
| Slope | S = 0.0001 | | |
| Median Particle Diamter, ft | $d_{si} = 0.00232$ | Channel Width, ft | B = 40 |
| Specific Gravity of Sediment, | | s = 2.65 | |

Constants

Acceleration of gravity, ft/s² g = 32.2

Solution

Bed level shear stress τ_b

$$\tau_b = \gamma_w \cdot D \cdot S \quad \tau_b = 0.143$$

Fall diameter d_f ,

$$d_f = \begin{cases} \left(-69.07 \cdot d_{si}^2 + 1.0755 \cdot d_{si} + 0.000007 \right) & \text{if } d_{si} \leq 0.00591 \\ \left(0.1086 \cdot d_{si}^{0.6462} \right) & \text{otherwise} \end{cases} \quad d_f = 2.13 \times 10^{-3}$$

Sediment discharge lb/s,

$$g_s = 0.05 \cdot \gamma_w \cdot s \cdot V^2 \cdot \sqrt{\frac{d_f}{g \cdot (s-1)}} \cdot \left[\frac{\tau_o}{(\gamma_w \cdot s - \gamma_w) \cdot d_f} \right]^{\frac{3}{2}} \cdot B \quad g_s = 32.82$$

Sediment discharge ton/day,

$$G_s = g_s \cdot \frac{86400}{2000} \quad G_s = 1418$$

2.11.3 Laursen-Copeland Sample Calculation

From Copeland (SAM Code, 1996)

Input Parameters

| | | | |
|---|--------------------|---------------------------------------|---------------------|
| Temperature, F | T = 55 | Average Velocity, ft/s | V = 5.46 |
| Kinematic viscosity, ft ² /s | $\nu = 0.00001315$ | Discharge, ft ³ /s | Q = 5000 |
| Depth, ft | D = 22.90 | Unit Weight water, lb/ft ³ | $\gamma_w = 62.385$ |
| Slope | S = 0.0001 | 84% Particle diameter, ft | $d_{84} = 0.00294$ |

Median Particle Diameter, ft $d_{si} = 0.00232$

Specific Gravity of Sediment $s = 2.65$

Constants

Acceleration of gravity, ft/s² $g = 32.2$

Solution

*Note: the difference between the final result presented here and the result in SAM is due to

the method for determining fall velocity. Rubey is used here, whereas SAM computes a

value based on a drag coefficient determined from Reynolds number. Calculation routine taken from SAM.

Because the grain distribution is reduced to standard grade sizes representing each present

grade class, the d_{84} will equal the standard grade size, d_{si} , in this procedure.

$$d_{84} = d_{si}$$

Grain-related hydraulic radius R

$$R' = \frac{0.0472 \cdot V^{\frac{3}{2}} \cdot (3.5 \cdot d_{84})^{\frac{1}{4}}}{(g \cdot s)^{\frac{3}{4}}} \quad R' = 14.189$$

$$R' = 15.248$$

$$\begin{aligned}
 & u_*' = \sqrt{g \cdot R' \cdot S} & u_*' = 0.222 \\
 & FNRP = \left(\frac{V}{u_*'} \right) - 3.28 - 5.75 \cdot \log \left(\frac{R'}{d_{84}} \right) \\
 & FNRP = 5.195 \times 10^{-4} \\
 & DFNRP = \frac{V + 5 \cdot u_*'}{2.0 \cdot u_*' \cdot R'} & DFNRP = 0.972 \\
 & RPRI2 = R' + \frac{FNRP}{DFNRP} & RPRI2 = 15.249 \\
 & \Delta R = |RPRI2 - R'| & \Delta R = 5.345 \times 10^{-4} \\
 & R' = \begin{cases} R' & \text{if } \Delta R \leq 0.001 \\ RPRI2 & \text{otherwise} \end{cases}
 \end{aligned}$$

$$R' = 15.248$$

Grain-related bed shear stress τ'_b ,

$$\tau'_b = R' \gamma_w \cdot S \quad \tau'_b = 0.095$$

$$\tau_b = D \cdot \gamma_w \cdot S \quad \tau_b = 0.143$$

$$\tau'_b = \begin{cases} \tau'_b & \text{if } \tau'_b < \tau_b \\ \tau_b & \text{otherwise} \end{cases} \quad \tau'_b = 0.095$$

$$u_*' = \sqrt{\frac{\tau_b' \cdot g}{\gamma_w}}$$

$$u_*' = 0.222$$

$$RRP = \left(\frac{d_{si}}{R} \right)^{1.16667}$$

$$RRP = 2.187 \times 10^{-5}$$

Dimensionless bed shear stress τ_b^* ,

$$\tau_b^* = \frac{\tau_b'}{\gamma_w \cdot (s-1) \cdot d_{si}}$$

$$\tau_b^* = 0.398$$

Shield's parameter for coarse grains θ^* ,

$$\theta^* = 0.647 \cdot \tau_b^* + 0.0064$$

$$\theta^* = \begin{cases} 0.02 & \text{if } \theta^* < 0.02 \\ \theta^* & \text{otherwise} \end{cases}$$

$$\theta^* = 0.264$$

Critical shear stress, τ_{cr}

$$\tau_{cr} = \begin{cases} [\theta^* \cdot \gamma_w \cdot (s-1) \cdot d_{si}] & \text{if } \tau_b^* \leq 0.05 \\ [0.039 \cdot \gamma_w \cdot (s-1) \cdot d_{si}] & \text{otherwise} \end{cases}$$

$$\tau_{cr} = 9.315 \times 10^{-3}$$

Shear stress mobility parameter TFP,

$$TFP = \frac{\tau_b'}{\tau_{cr}} - 1$$

$$TFP = 9.214$$

Fall velocity ω ,

Use Rubey's equation, Vanoni p. 169

$$F_1 = \sqrt{\frac{2}{3} + \frac{36 \cdot v^2}{g \cdot d_{si}^3 \cdot (s-1)}} - \sqrt{\frac{36 \cdot v^2}{g \cdot d_{si}^3 \cdot (s-1)}} \quad F_1 = 0.725$$

$$\omega = F_1 \cdot \sqrt{(s-1) \cdot g \cdot d_{si}} \quad \omega = 0.255$$

Particle velocity ratio SF,

$$SF = \frac{u_*}{\omega} \quad SF = 0.870$$

Particle velocity ratio parameter Ψ ,

$$\Psi = \begin{cases} \left[7.04 \cdot 10^{15} \cdot (SF)^{22.99} \right] & \text{if } SF \leq 0.225 \\ (40.0 \cdot SF) & \text{if } 0.225 < SF \leq 1.0 \\ (40 \cdot SF^{1.843}) & \text{if } SF > 1.0 \end{cases} \quad \Psi = 34.804$$

Sediment transport G_s , tons/day

$$G_s = 0.432 \cdot \gamma_w \cdot Q \cdot RRP \cdot TFP \cdot \Psi \quad G_s = 945$$

2.11.4 Meyer-Peter Muller Sample Calculation

From Vanoni (1975) and Schlichting's Boundary Layer Theory (1968)

Input Parameters

| | | | |
|---|--------------------|---------------------------------------|---------------------|
| Temperature, F | T = 55 | Average Velocity, ft/s | V = 5.46 |
| Kinematic viscosity, ft ² /s | $\nu = 0.00001315$ | Discharge, ft ³ /s | Q = 5000 |
| Depth, ft | D = 22.9 | Unit Weight water, lb/ft ³ | $\gamma_w = 62.385$ |
| Slope | S = 0.0001 | Overall d ₅₀ , ft | $d_{90} = 0.00306$ |
| Median Particle Diamter, ft | $d_{50} = 0.00232$ | Channel Width, ft | B = 40 |
| Specific Gravity of Sediment, | | s = 2.65 | |

Constants

Acceleration of gravity, ft/s² g = 32.2

Solution

Shear velocity u,

$$u_* = \sqrt{g \cdot D \cdot S} \quad u_* = 0.272$$

Shear Reynold's number, R_s,

$$R_s = \frac{u_* \cdot d_{90}}{\nu} \quad R_s = 63.189$$

Schlichting's B coefficient, Bcoeff

$$BCoeff = \begin{cases} (5.5 + 2.5 \cdot \ln(R_s)) & \text{if } R_s \leq 5 \\ 0.297918 + 24.8666 \cdot \log(R_s) - 22.9885 \cdot (\log(R_s))^2 \dots \\ + 8.5199 \cdot (\log(R_s))^3 - 1.10752 \cdot (\log(R_s))^4 \\ 8.5 & \text{otherwise} \end{cases} \quad \text{if } 5 < R_s \leq 70$$

Friction factor due to sand grains f' ,

$$f' = \left(\frac{2.82843}{BCoeff - 3.75 + 2.5 \cdot \ln\left(2 \cdot \frac{D}{d_{90}}\right)} \right)^2 \quad f' = 9.565 \times 10^{-3}$$

Nikaradse roughness ratio RKR,

$$RKR = \sqrt{\frac{f'}{8}} \cdot \frac{V}{\sqrt{g \cdot D \cdot S}} \quad RKR = 0.695$$

Sediment discharge lb/s,

$$g_s = \left[\frac{(RKR)^{\frac{3}{2}} \cdot \gamma_w \cdot D \cdot S - 0.047 \cdot (\gamma_w \cdot s - \gamma_w) \cdot d_{si}}{0.25 \cdot \left(\frac{\gamma_w}{g}\right)^{\frac{1}{3}} \cdot \left(\frac{\gamma_w \cdot s - \gamma_w}{\gamma_w \cdot s}\right)^{\frac{2}{3}}} \right]^{\frac{3}{2}} \cdot B \quad g_s = 7.073$$

Sediment discharge ton/day,

$$G_s = g_s \cdot \frac{86400}{2000} \quad G_s = 306$$

2.11.4.1 Derivation of the Dimensionless form of MPM from the Vanoni Form

Converting the HEC-RAS version of MPM (from Vanoni, 1975) to the dimensionless Form

$$\left(\frac{k_r}{k'_r}\right)\gamma RS = 0.047(\gamma_s - \gamma)d_m + 0.25\left(\frac{\gamma}{g}\right)^{\frac{1}{3}}\left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{\frac{2}{3}}g_s^{\frac{2}{3}}$$

Get transport (gs) on the left side of the equation and the shear terms on the right.

$$0.25\left(\frac{\gamma}{g}\right)^{\frac{1}{3}}\left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{\frac{2}{3}}g_s^{\frac{2}{3}} = \left(\frac{k_r}{k'_r} \text{ right}\right)\gamma RS - 0.047(\gamma_s - \gamma)d_m$$

Divide by 0.25 and by $\gamma_s - \gamma d_m$ to convert shear to the dimensionless shields number and isolate the critical shear (0.047):

$$\frac{\left(\frac{\gamma}{g}\right)^{\frac{1}{3}}\left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{\frac{2}{3}}g_s^{\frac{2}{3}}}{(\gamma_s - \gamma)d_m} = 4\left(\left(\frac{k_r}{k'_r}\right)^{\frac{3}{2}}\tau^* - 0.047\right)$$

Because the Shields number is:

$$\tau^* = \frac{\gamma RS}{(\gamma_s - \gamma)d_m}$$

The right side of this equation is already looking familiar.

Next raise everything to the 3/2 power to prepare to isolate transport (gs):

$$\frac{\left(\frac{\gamma}{g}\right)^{\frac{1}{2}}\left(\frac{\gamma_s - \gamma}{\gamma_s}g_s\right)^{\frac{3}{2}}}{((\gamma_s - \gamma)d_m)^{\frac{3}{2}}} = 8\left(\left(\frac{k_r}{k'_r}\right)^{\frac{3}{2}}\tau^* - 0.04732\right)^{\frac{3}{2}}$$

The Right side of the equation is in the final form, so simplify the left side of the equation into the dimensionless transport parameter (q^*):

$$q^* = \frac{g_s/\gamma_s}{\sqrt{Rg}d_m^{\frac{3}{2}}}$$

Where R is the difference between the specific gravity of the solids and liquid usually (S-1), (2.65-1) or 1.65 and g is the acceleration of gravity.

Simplify the expression until the dimensionless transport parameter emerges on the left side of the equation.

$$\frac{\gamma^{\frac{1}{2}} \gamma(R) g_s}{g} \gamma_s ((\gamma_s - \gamma) d_m^{\frac{3}{2}}) = 8 \left(\left(\frac{k_r}{k'_r} \right)^{\frac{3}{2}} \tau^* - 0.047 \right)^{\frac{3}{2}}$$

$$\frac{(\gamma)^{\frac{1}{2}} \gamma(R) g_s}{(g)^{\frac{1}{2}} \gamma_s^{\frac{3}{2}} R^{\frac{3}{2}} d_m} = 8 \left(\left(\frac{k_r}{k'_r} \right)^{\frac{3}{2}} \tau^* - 0.047 \right)^{\frac{3}{2}}$$

$$\frac{(\gamma)^{\frac{1}{2}} \gamma}{\gamma_s^{\frac{3}{2}}} \frac{g_s}{g^{\frac{1}{2}} R^{\frac{1}{2}} d_m^{\frac{3}{2}}} = 8 \left(\left(\frac{k_r}{k'_r} \right)^{\frac{3}{2}} \tau^* - 0.047 \right)^{\frac{3}{2}}$$

At this point, most of the left side of the equation collapses to the dimensionless transport parameter

$$\frac{g_s}{(R)^{\frac{1}{2}} (g)^{\frac{1}{2}} (d_m)^{\frac{3}{2}}} = q^*$$

Leaving only the unit weight of the soil:

$$\frac{1}{\gamma_s} q^* = 8 \left(\left(\frac{k_r}{k'_r} \right)^{\frac{3}{2}} \tau^* - 0.04732 \right)^{\frac{3}{2}}$$

But the original MPM equation computes the unit transport by *weight* while the dimensionless transport parameter calculates unit *volume* transport, so the unit weight of the solids converts the volume flux to a mass flux. But to leave it in the volume flux format, we can drop this conversion, yielding:

$$q^* = 8 \left(\left(\frac{k_r^{\frac{3}{2}}}{k'_r} \right) \tau^* - 0.047 \right)^{\frac{3}{2}}$$

2.11.5 Toffaleti Sample Calculation

From Vanoni (1975) for a single grain size

Input Parameters

Slope, $S = 0.0001$ Temperature, F $T = 55$

Hydraulic Radius, ft $R = 10.68$ viscosity, ft^2/s $\nu = 0.00001315$

Width, ft $B = 40$ Median Particle Size, ft $d_{50} = 0.00232$

Velocity, ft/s $V = 5.46$ 65% finer Particle
Size, ft $d_{65} = 0.00257$

Fraction of Total Sediment $p_i = 1$

Unit Weight of Water, lb/ ft^3 $\gamma_w = 62.385$

Constants

Acceleration of gravity, ft/s^2 $g = 32.2$

Solution

Nikaradse Roughness Value, using d_{65} , as per Einstein, 1950, p.

$$k_s = d_{65} \quad k_s = 2.57 \times 10^{-3}$$

Grain-related shear velocity as per Einstein, 1950, p. 10

```

    graph TD
      A[Guess  $u'_{*ny} = 0.199$ ] --> B[" $r' = \frac{u'_{*ny}^2}{g \cdot S}$ "]
      B --> C[" $u'_{*} = \frac{V}{5.75 \cdot \log\left(12.27 \cdot \frac{r'}{k_s}\right)}$ "]
      C --> D["Assume hydraulically rough grain first."]
  
```

Assume hydraulically rough grain first.

$$r' = \frac{u'_{*ny}^2}{g \cdot S}$$

$$r' = 12.298$$

$$u'_{*} = \frac{V}{5.75 \cdot \log\left(12.27 \cdot \frac{r'}{k_s}\right)}$$

Check $u'_* = 0.199$

Check for hydraulically rough or smooth grains...

Guess $u'_{*ny} = 0.169$

$$r' = \frac{u'_{*ny}^2}{g \cdot S} \quad r' = 8.87$$

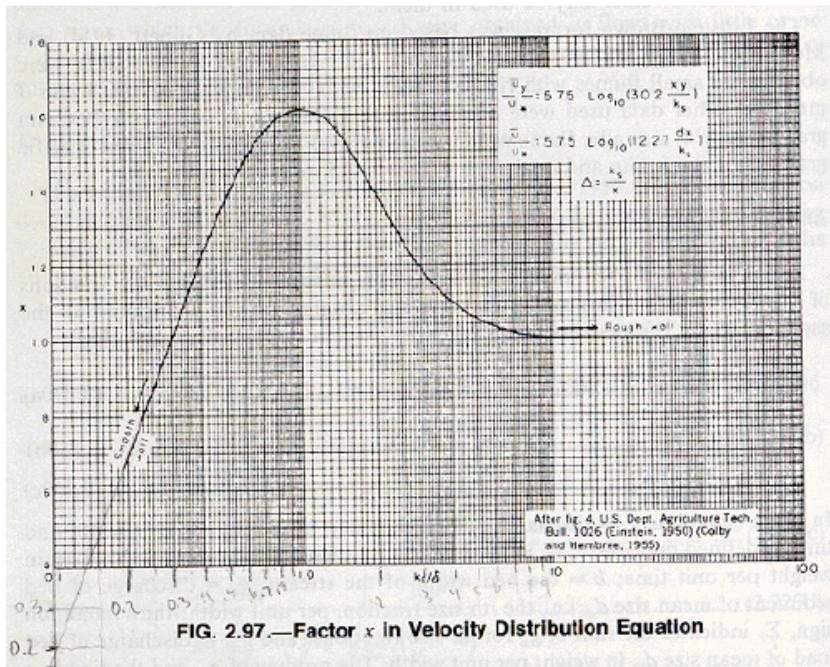
$$\delta' = \frac{11.6 \cdot v}{u'_{*ny}} \quad \delta' = 9.026 \times 10^{-4}$$

$$\text{Check} = \frac{k_s}{\delta'} \quad \text{Check} = 2.847 \quad \frac{k_s}{\delta'} = 2.847$$

$$u'_* = \begin{cases} \frac{V}{5.75 \cdot \log\left(3.67 \cdot \frac{r' \cdot u'_{*ny}}{v}\right)} & \text{if Check} < 5 \quad \text{Smooth} \\ u'_* & \text{otherwise} \end{cases} \quad \text{Rough}$$

Check $u'_* = 0.169$

Check for Transitional regime



$$\Phi = \frac{k_s}{\delta'} \quad \Phi = 2.847$$

$$x = 1.14$$

$$\Phi = 3.416$$

from figure 2.97, Vanoni, page 196

$$u'_* = \begin{cases} \frac{V}{5.75 \cdot \log\left(12.27 \cdot \frac{r \cdot x}{k_s}\right)} & \text{if } 0.1 < \Phi < 10 \\ u'_* & \text{otherwise} \end{cases}$$

$$\delta' = \frac{11.6 \cdot v}{u'_*} \quad \Phi = \frac{k_s}{\delta'} \quad \Phi = 3.416$$

$$u'_* = 0.203$$

****Note: Einstein's method for determining u^* was compared with Toffaleti's graphical approach.

Results showed that the two methods are in acceptable agreement, with differences on the order

of less than 3%. Einstein's approach was selected for its established reputation and its relative

simplicity.

Toffaleti coefficients, A and k_4 ,

$$A_{\text{factor}} = \frac{(10^5 \cdot v)^{\frac{1}{3}}}{10 \cdot u'^*} \quad A_{\text{factor}} = 0.54$$

$$A = \begin{cases} (9.5987 \cdot A_{\text{factor}})^{-1.5445} & \text{if } A_{\text{factor}} \leq 0.5 \\ (39.079 \cdot A_{\text{factor}})^{0.481} & \text{if } 0.5 < A_{\text{factor}} \leq 0.66 \\ (221.85 \cdot A_{\text{factor}})^{4.660} & \text{if } 0.66 < A_{\text{factor}} \leq 0.72 \\ 48 & \text{if } 0.72 < A_{\text{factor}} \leq 1.3 \\ (22.594 \cdot A_{\text{factor}})^{2.872} & \text{if } A_{\text{factor}} > 1.3 \end{cases} \quad A = 29.065$$

$$k_{4\text{Factor}} = \frac{(10^5 \cdot v)^{\frac{1}{3}}}{10 \cdot u'^*} \cdot 10^5 \cdot S \cdot d_{65} \quad K_{4\text{Factor}} = 0.014$$

$$k_4 = \begin{cases} (1.0) & \text{if } k_{4\text{Factor}} \leq 0.25 \\ (5.315 \cdot k_{4\text{Factor}})^{1.205} & \text{if } 0.25 < k_{4\text{Factor}} \leq 0.35 \\ (0.510 \cdot k_{4\text{Factor}})^{-1.028} & \text{if } k_{4\text{Factor}} > 0.35 \end{cases} \quad k_4 = 1$$

$$Ak_4 = A \cdot k_4$$

Check for too low values for the product Ak_4 ,

$$Ak_4 = \begin{cases} 16 & \text{if } Ak_4 < 16 \\ Ak_4 & \text{if } Ak_4 \geq 16 \end{cases} \quad Ak_4 = 29.065$$

More Coefficients,

More Coefficients,

$$T_T = 1.10 \cdot (0.051 + 0.00009 \cdot T) \quad T_T = 0.062$$

$$n_V = 0.1198 + 0.00048 \cdot T \quad n_V = 0.146$$

$$c_z = 260.67 - 0.667 \cdot T \quad c_z = 223.985$$

Fall Velocity for Medium Sand from Toffaleti Tables at 55 degrees F,

$$w_i = 0.340$$

$$z_i = \frac{w_i \cdot V}{c_z \cdot R \cdot S} \quad z_i = 7.76$$

$$z_i = \begin{cases} (1.5 \cdot n_V) & \text{if } z_i < n_V \\ z_i & \text{otherwise} \end{cases} \quad z_i = 7.76$$

Empirical Relationship for g_{ssLi} ,

$$g_{ssLi} = \frac{0.600 \cdot p_i}{\left(\frac{T_T \cdot A k_4}{V^2} \right)^{\frac{5}{3}} \cdot \left(\frac{d_{si}}{0.00058} \right)^{\frac{5}{3}}} \quad g_{ssLi} = 6.473$$

$$M_i = \frac{g_{ssLi}}{\left[\frac{\left(\frac{R}{11.24} \right)^{1+n_V-0.756 \cdot z_i} - (2 \cdot d_{si})^{1+n_V-0.756 \cdot z_i}}{1+n_V-0.756 \cdot z_i} \right]} \quad M_i = 2.948 \times 10^{-10}$$

Concentration,

$$C_{Li} = \frac{M_i}{43.2 \cdot p_i \cdot (1+n_V) \cdot V \cdot R^{0.756 \cdot z_i - n_V}} \quad C_{Li} = 1.425 \times 10^{-18}$$

Check for unrealistically high concentration and adjust M_i if necessary,

$$C_{2d} = C_{Li} \cdot \left(\frac{2 \cdot d_{si}}{R} \right)^{-0.756 \cdot z_i} \quad C_{2d} = 75.536$$

$$C_{Li} = \begin{cases} C_{Li} & \text{if } C_{2d} < 100 \\ \frac{100}{\left(\frac{2 \cdot d_{si}}{R}\right)^{-0.756 \cdot z_i}} & \text{if } C_{2d} \geq 100 \end{cases} \quad C_{Li} = 1.425 \times 10^{-18}$$

$$M_i = C_{Li} \cdot [43.2 \cdot p_i \cdot (1 + n_V) \cdot V \cdot R^{0.756 \cdot z_i - n_V}] \quad M_i = 2.948 \times 10^{-10}$$

Bed Load Transport,

$$g_{sbi} = M_i \cdot (2 \cdot d_{si})^{(1+n_V-0.756 \cdot z_i)} \quad g_{sbi} = 30.555$$

Lower Layer Transport,

$$g_{ssLi} = M_i \cdot \left[\frac{\left(\frac{R}{11.24}\right)^{(1+n_V-0.756 \cdot z_i)} - (2 \cdot d_{si})^{(1+n_V-0.756 \cdot z_i)}}{1 + n_V - 0.756 \cdot z_i} \right] \quad g_{ssLi} = 6.473$$

Middle Layer Transport,

$$g_{ssMi} = M_i \cdot \frac{\left(\frac{R}{11.24}\right)^{0.244 \cdot z_i} \cdot \left[\left(\frac{R}{2.5}\right)^{1+n_V-z_i} - \left(\frac{R}{11.24}\right)^{1+n_V-z_i}\right]}{1 + n_V - z_i} \quad g_{ssMi} = 5.674 \times 10^{-1}$$

Upper Layer Transport,

$$g_{ssUi} = M_i \cdot \frac{\left(\frac{R}{11.24}\right)^{0.244 \cdot z_i} \cdot \left(\frac{R}{2.5}\right)^{0.5 \cdot z_i} \cdot \left[R^{(1+n_V-1.5 \cdot z_i)} - \left(\frac{R}{2.5}\right)^{1+n_V-1.5 \cdot z_i}\right]}{1 + n_V - 1.5 \cdot z_i} \quad g_{ssUi} = 1.72 \times 10^{-15}$$

Total Transport per Unit Width,

$$g_{si} = g_{sbi} + g_{ssLi} + g_{ssMi} + g_{ssUi} \quad g_{si} = 37.027$$

Total Transport,

$$G = g_{si} \cdot B \quad G = 1481 \text{ tons/day}$$

2.11.6 Yang Sample Calculation

From Yang – ASCE Journal of Hydraulics (1975 and 1984)

Input Parameters

Temperature, F $T = 55$ Average Velocity, ft/s $V = 5.46$

Kinematic viscosity, ft^2/s $\nu = 0.00001315$ Discharge, ft^3/s $Q = 5000$

Hydraulic Radius, ft $R = 10.68$ Unit Weight water, lb/ft^3 $\gamma_w = 62.385$

Slope, $S = 0.0001$

Median Particle Diameter, ft $d_{si} = 0.00232$

Specific Gravity of Sediment $s = 2.65$

Constants

Acceleration of gravity, ft/s^2 $g = 32.2$

Solution

Shear Velocity, ft/s,

$$u_* = \sqrt{g \cdot R \cdot S} \quad u_* = 0.185$$

Particle Fall Velocity, ft/s,

Use Rubey's equation, Vanoni p. 169

$$F_1 = \sqrt{\frac{2}{3} + \frac{36 \cdot \nu^2}{g \cdot d_{si}^3 \cdot (s-1)}} - \sqrt{\frac{36 \cdot \nu^2}{g \cdot d_{si}^3 \cdot (s-1)}}$$

$$F_1 = 0.725$$

$$\omega = F_1 \cdot \sqrt{(s-1) \cdot g \cdot d_{si}} \quad \omega = 0.255$$

Shear Reynolds Number,

$$R_s = \frac{u_* \cdot d_{si}}{\nu} \quad R_s = 32.717$$

Critical Velocity, ft/s,

$$V_{cr} = \begin{cases} \omega \cdot \left(\frac{2.5}{\log\left(\frac{u_* \cdot d_{si}}{\nu}\right) - 0.06} + 0.66 \right) & \text{if } 0 < R_s < 70 \\ (\omega \cdot 2.05) & \text{if } R_s \geq 70 \end{cases} \quad V_{cr} = 0.606$$

Log of Concentration,

$$\log C_t = \begin{cases} \left[5.435 - 0.286 \cdot \log\left(\frac{\omega \cdot d_{si}}{\nu}\right) - 0.457 \cdot \log\left(\frac{u_*}{\omega}\right) \dots \right. \\ \left. + \left(1.799 - 0.409 \cdot \log\left(\frac{\omega \cdot d_{si}}{\nu}\right) - 0.314 \cdot \log\left(\frac{u_*}{\omega}\right) \right) \cdot \log\left(\frac{V \cdot S}{\omega} - \frac{V_{cr} \cdot S}{\omega}\right) \right] & \text{if } d_{si} < 0.00656 \quad \text{Sand} \\ \left[6.681 - 0.633 \cdot \log\left(\frac{\omega \cdot d_{si}}{\nu}\right) - 4.816 \cdot \log\left(\frac{u_*}{\omega}\right) \dots \right. \\ \left. + \left(2.784 - 0.305 \cdot \log\left(\frac{\omega \cdot d_{si}}{\nu}\right) - 0.282 \cdot \log\left(\frac{u_*}{\omega}\right) \right) \cdot \log\left(\frac{V \cdot S}{\omega} - \frac{V_{cr} \cdot S}{\omega}\right) \right] & \text{if } d_{si} \geq 0.00656 \quad \text{Gravel} \end{cases}$$

$$\log C_t = 1.853$$

Concentration, ppm

$$C_t = 10^{\log C_t} \quad C_t = 71.284$$

Sediment Discharge, lb/s

$$G = \frac{\gamma_w \cdot Q \cdot C_t}{1000000} \quad G = 22.235$$

Sediment Discharge, tons/day

$$G_s = \frac{86400}{2000} \cdot G \quad G_s = 961$$

3 Hydraulic Design Functions

The Hydraulic Design tools currently include the following six hydraulic and sediment transport calculators. They are distributed between the main HEC-RAS user's manual and the sediment manual. Click the link or icon below to go to the appropriate section.

| Icon | Analysis | Description |
|-----------------------------------|--|--|
| | Bridge Scour⁶¹ | Applies the US Federal Highway Administration's bridge scour equations and algorithms from HEC-18 to a steady flow hydraulics profile |
| | Riprap⁶² | Computes a stable rock size for bank protection using the USACE guidance in EM 1110-2-1601 and applies a suite of general and bend scour equations to help design toe protection. |
| | Uniform Flow⁶³ | A normal depth calculator, that allows users to apply manning's equation to compute a hydraulic geometry without a full HEC-RAS model. |
| | Stable Channel Design⁶⁴ | A suite of tools (including tractive force, Lane, and Copeland methods) that compute the hydraulic geometry that is in transport equilibrium with the flow and sediment in a channel, or visa versa. |
| $\frac{\partial G_s}{\partial t}$ | Sediment Transport Capacity⁶⁵ | Simplified calculator that computes sediment transport capacity for a steady flow profile - with a suite of sediment transport equations - ignoring supply, flux, or feedback that make a sediment transport model both more useful, and more difficult. |

⁶¹ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.1/hydraulic-design-hd-calculators/computing-scour-at-bridges>

⁶² <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.1/hydraulic-design-hd-calculators/riprap-and-scour-calculator>

⁶³ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.1/hydraulic-design-hd-calculators/uniform-flow-computations>

⁶⁴ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.1/hydraulic-design-hd-calculators/stable-channel-design-functions>

⁶⁵ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.1/hydraulic-design-hd-calculators/sediment-transport-capacity>

| Icon | Analysis | Description |
|---|---|---|
|  | SIAM ⁶⁶ | The Sediment Impact Analysis Methods is a sediment budget tool that uses steady flow results from HEC-RAS, transport functions, and user specifications of watershed and point-source loads to screen sediment impacts alternatives on a watershed scale. |
|  | Sediment Rating Curve Analysis Tool ⁶⁷ | Imports sediment load, concentration, and load-gradation data and leads analysts through common statistical and conceptual analyses to help them fit an appropriate rating curve through the data cloud. |

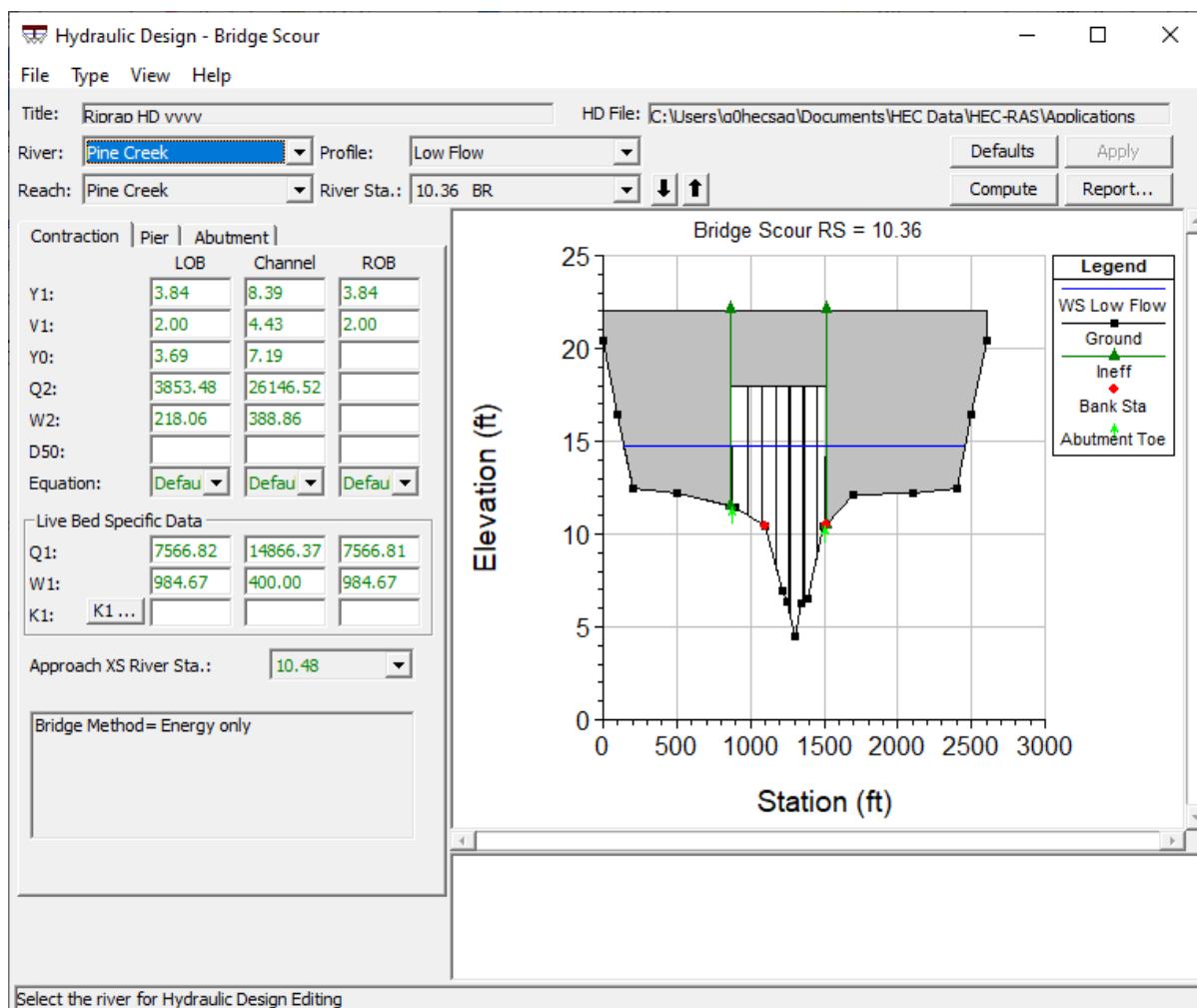
3.1 Bridge Scour

The Bridge Scour User Documentation is in the HEC-RAS User Guide: [Click Here](#)⁶⁸

⁶⁶ <https://www.hec.usace.army.mil/confluence/rasdocs/rassed1d/hydraulic-design-functions/sediment-impact-analysis-methods-siam>

⁶⁷ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/latest/hydraulic-design-hd-calculators/sediment-rating-curve-analysis-tool>

⁶⁸ <http://4RaPCB@xvQT2z1Wfe7JNdqZiuQcHR>

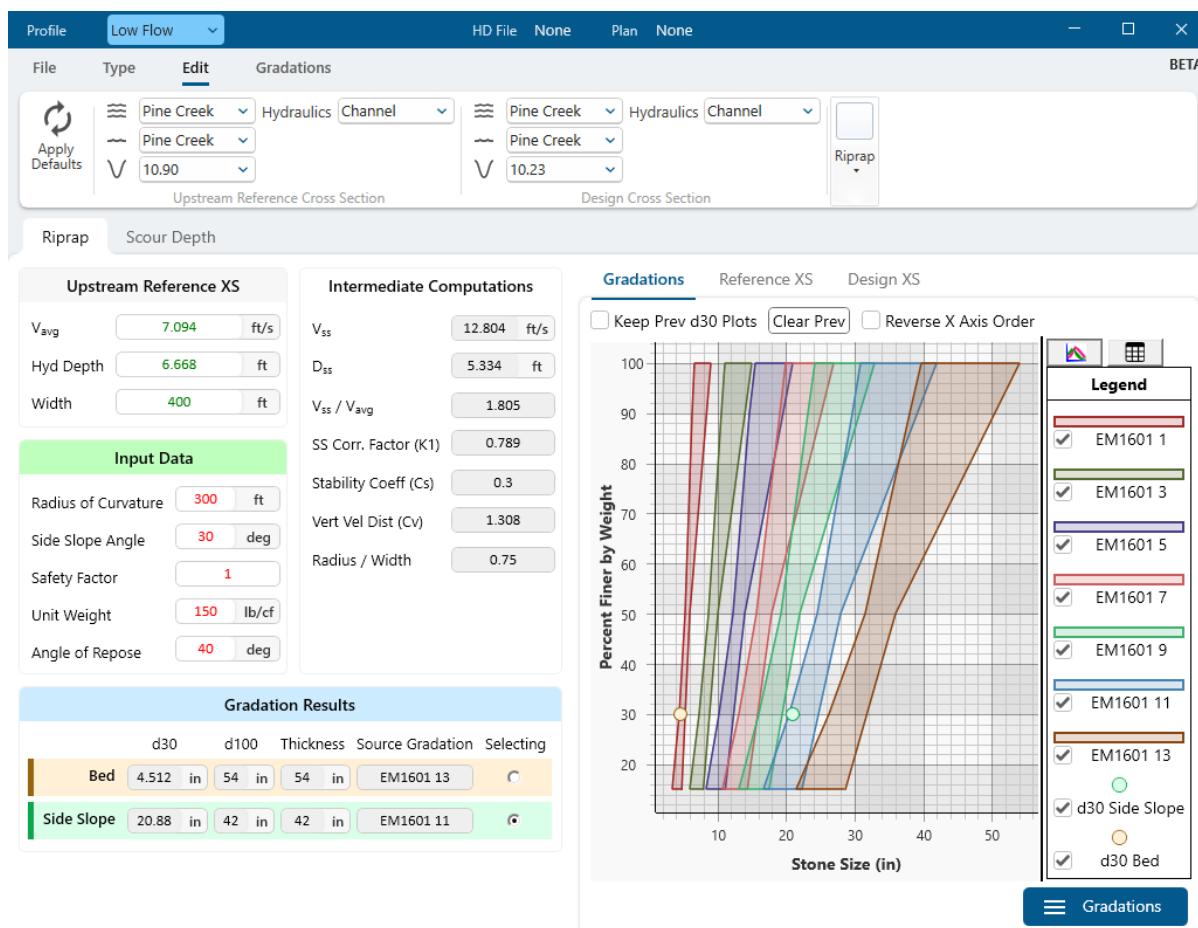


3.2 Riprap and Scour Calculator

The Riprap and Scour Calculator user guide materials are in the main HEC-RAS user page.

You can access them [here](#)⁶⁹.

⁶⁹ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/latest/hydraulic-design-hd-calculators/riprap-and-scour-calculator>

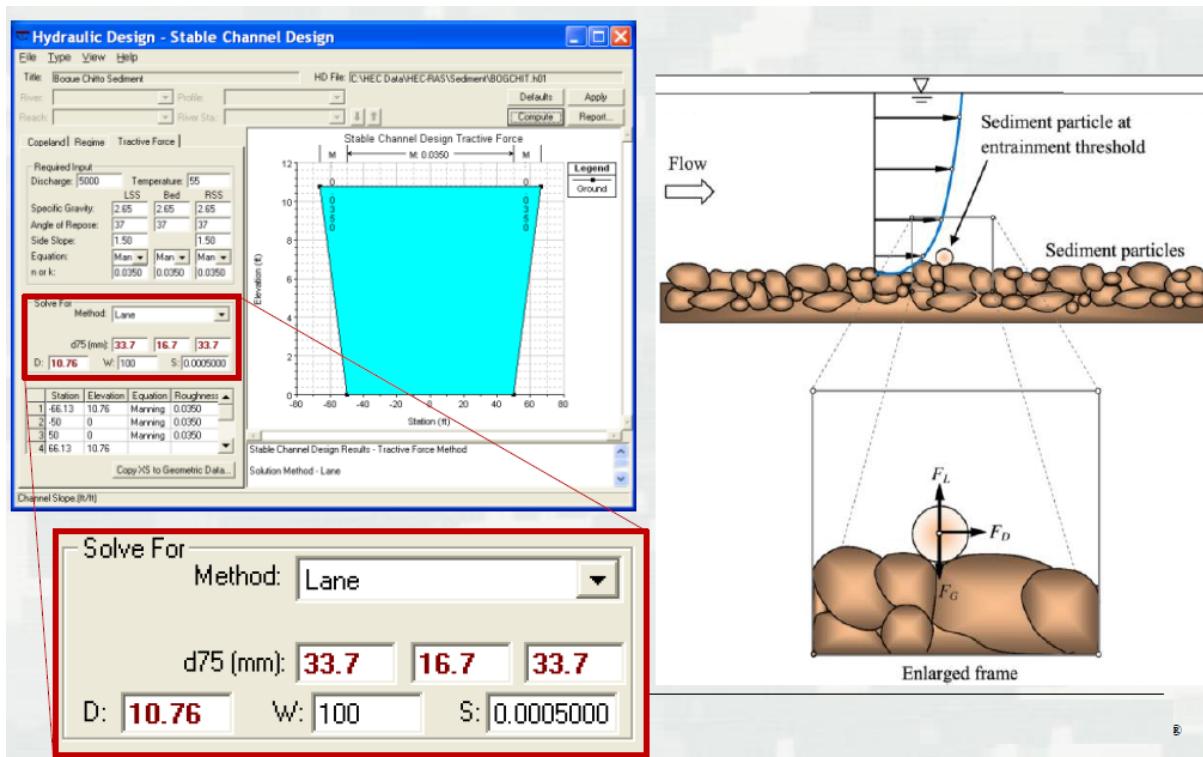


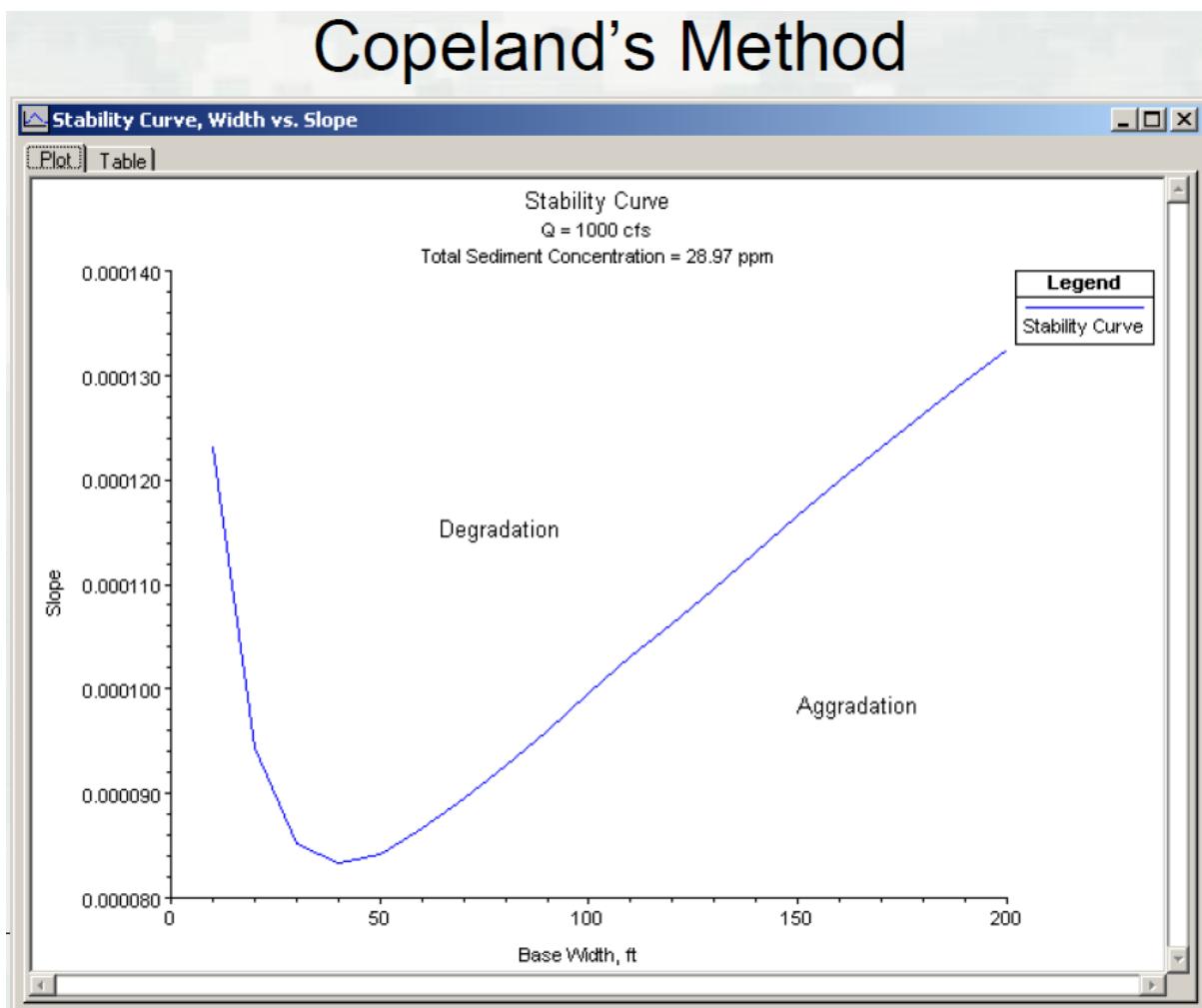
3.3 Stable Channel Design Tools

The Stable Channel Design User Guide is in on main HEC-RAS Page.

You can access it: [here](https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/stable-channel-design-functions)⁷⁰.

⁷⁰ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/stable-channel-design-functions>





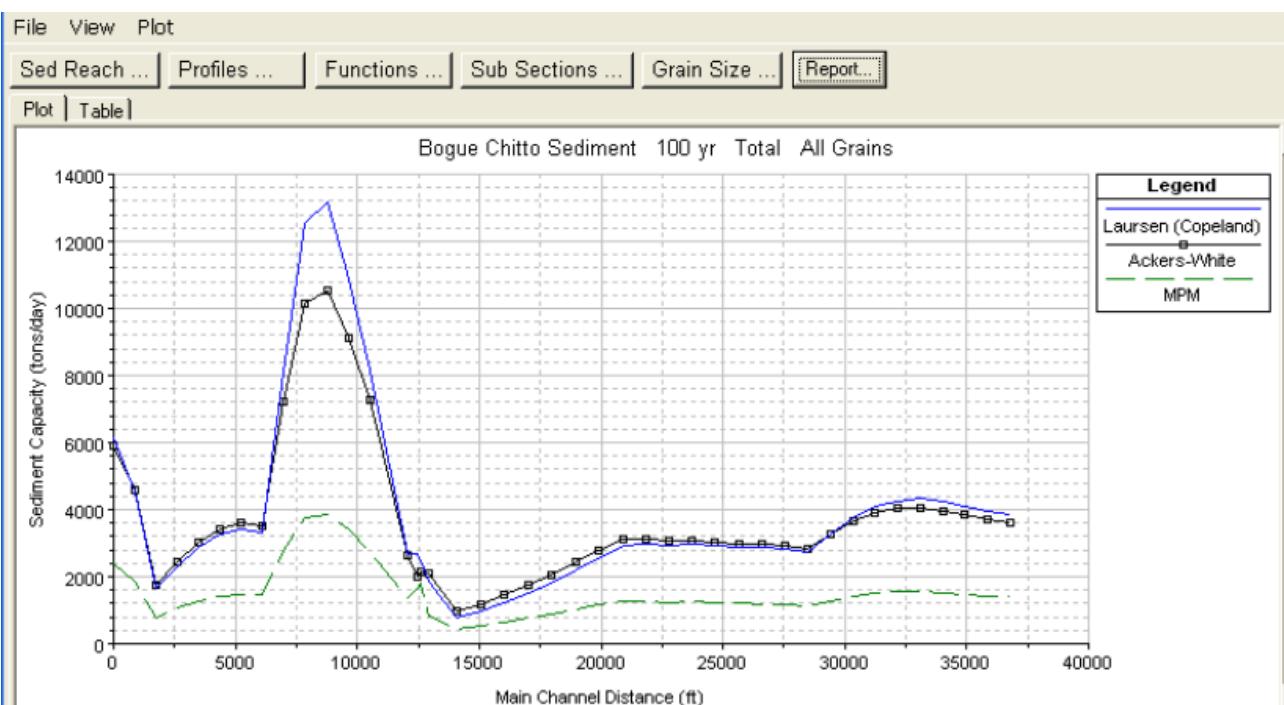
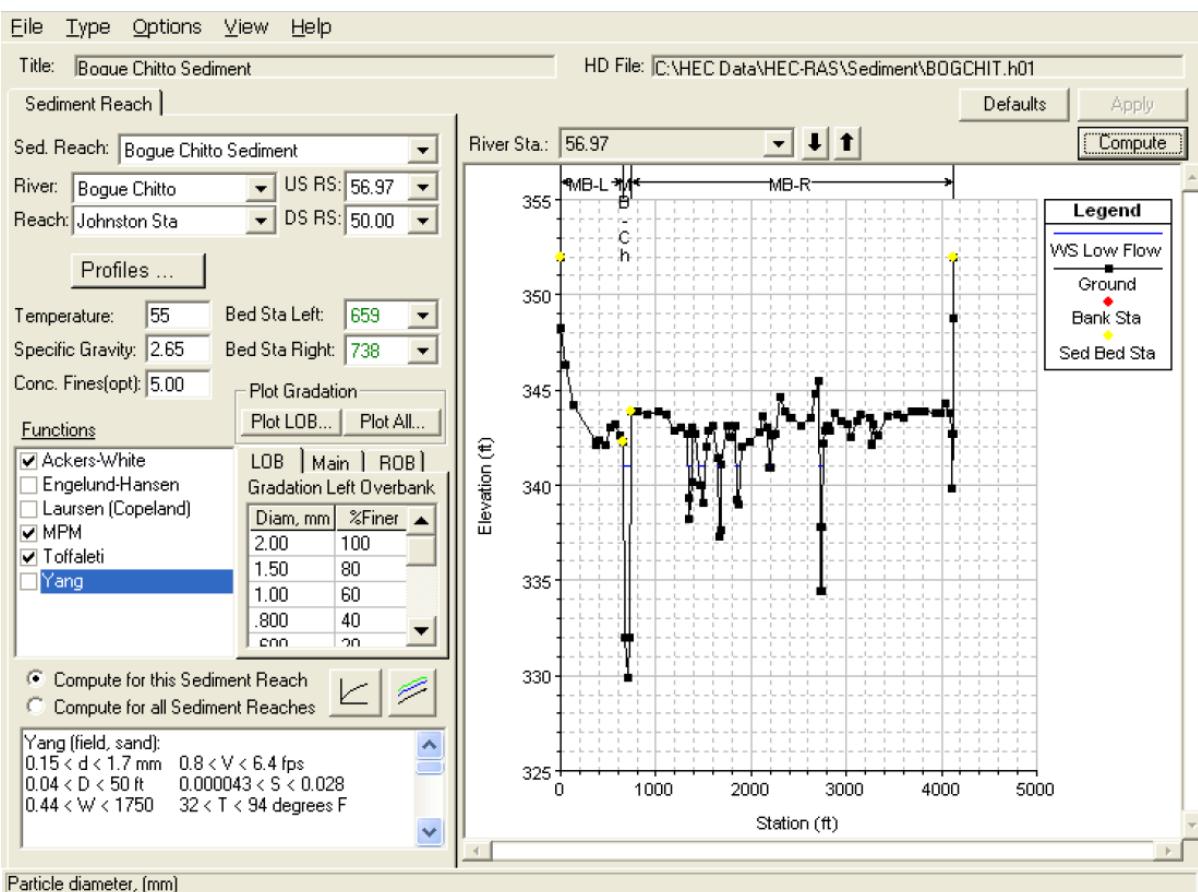
3.4 Sediment Transport Capacity Calculator

The Sediment Transport Capacity HD function computes capacity at each cross section with several transport functions.

The User Guide for this feature is in the main HEC-RAS page.

You can access the user guide: [here](#)⁷¹.

⁷¹ <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/latest/hydraulic-design-hd-calculators/sediment-transport-capacity>



3.5 Sediment Impact Analysis Methods (SIAM)

SIAM is a sediment budget tool that compares annualized sediment reach transport capacities to supplies and indicates reaches of overall sediment surplus or deficit. SIAM is a screening level tool to compute rough, relative responses to a range of alternatives, in order to identify the most promising alternatives (which should then be modeled in more detail). The algorithms in SIAM evaluate sediment impact caused by local changes on the system from a sediment continuity perspective. The results map potential imbalances and instabilities in a channel network and provide the first step in designing or refining remediation.

Users can begin with existing geometry and flow data and develop a set of sediment reaches with unique sediment and hydraulic characteristics. The SIAM program will then perform sediment transport capacity computations to determine potential imbalances and instabilities in a channel network. SIAM does not predict intermediate or final morphological patterns and does not update cross sections, but rather indicates trends of locations in the system for potential sediment surpluses or deficits. The results can be used to design or refine remediation efforts in the system.

3.5.1 Getting Started

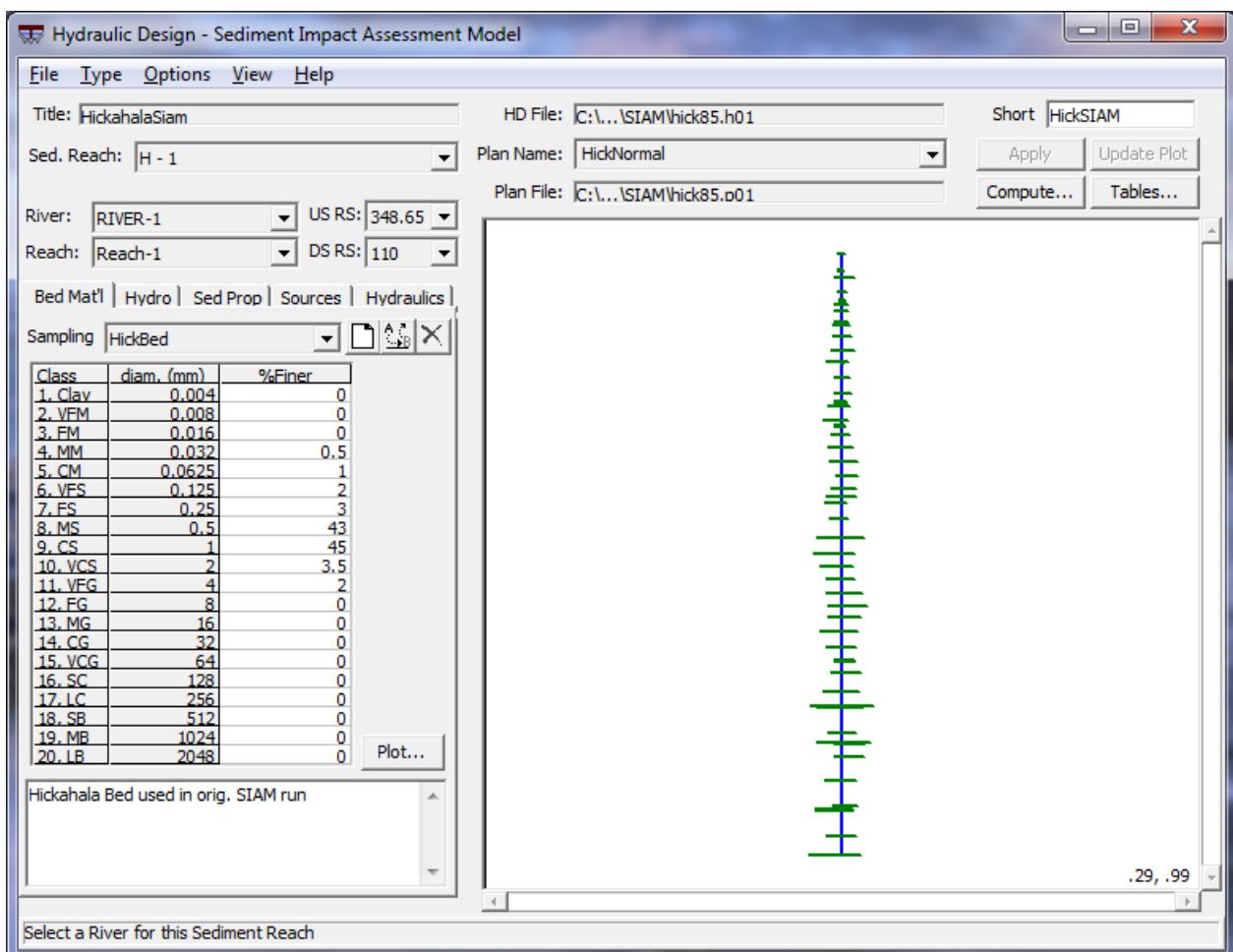
SIAM is located in the Hydraulic Design Functions module and can be accessed by selecting **Hydraulic Design Functions** under the **Run** menu or by pressing the HD button. SIAM is not the default Hydraulic Design tool, so it must be selected from the **Type** menu from the Hydraulic Design editor. The SIAM window in the



HD editor is depicted in the figure below.

3.5.2 Defining a Sediment Reach

The HEC-RAS hydraulic model must initially be subdivided into sediment reaches. A sediment reach is a grouping of cross sections with relatively consistent hydraulic and sediment properties. Hydraulic parameters are averaged over the cross sections comprising a sediment reach and a single set of sediment data is entered for it. When the user first opens SIAM, they will be prompted to provide a name for the first sediment reach. Additional sediment reaches can be created by selecting **New Sediment Reach** under the sediment menu. Sediment reaches must be defined such that all cross sections are included within one and only one sediment reach. The four drop down selectors: **River**, **Reach**, **US RS**, and **DS RS** are designed to designate the upstream and downstream cross sections that form the limits of the sediment reach. (below) Sediment reaches cannot cross junctions and, therefore, must exist entirely within the same hydraulic reach. For example, if an HEC-RAS model contains three hydraulic reaches, it must have three or more sediment reaches. Hydraulic reaches should be subdivided into sediment reaches if they have significantly distinct hydraulic properties, hydrology or sediment data.



99 SIAM editor in the hydraulic design window with the bed material tab active.

Once the sediment reaches are defined, they must be populated with data. There are five data tabs:

Bed Mat'l – Bed material gradation data

Hydro – Annualized flow distribution

Sed Prop – A variety of sediment properties required to run the model

Sources – Accounting of local and annual sediment sources to the reach

Hydraulics – Reach weighted averaged hydraulic parameters for the sediment reach (automatically populated by HEC-RAS)

Each of these data tabs must be completed before the model will run.

3.5.3 Entering Data

- [Bed Material \(see page 414\)](#)
- [Hydrology \(see page 414\)](#)
- [Sediment Properties \(see page 416\)](#)
- [Sediment Sources \(see page 419\)](#)
- [Hydraulics \(see page 421\)](#)

3.5.3.1 Bed Material

Each sediment reach requires bed material information. However, any number of bed material sampling records can be defined in the **Bed Mat'l** records tab. A given bed material sample can be used exclusively for one sediment reach or can be shared by more than one sediment reach. The record shown in the sampling drop-down box when data is saved will be the record assigned to the sediment reach active at that time. When a new sediment reach is selected, the contents of the tabs records are automatically saved to the previously active sediment reach. The SIAM window with the bed material tab activated is shown in the SIAM Editor figure in [Defining Sediment Reach](#) (see page 412). When a new SIAM project is started, after the user enters a name for the new sediment reach, a prompt will be given to name a new bed sampling record. Once this is done, the new bed sampling record will appear in the Sampling drop-down box, as will all other created bed material records.

Once a bed sample template is created the gradation can be specified in the grid. Twenty grain classes are available. The name and geometric mean grain size for each class are displayed. Gradation is entered as the percent of the total sediment gradation, which is finer than the listed particle diameter, by weight (e.g a number between 0 and 100). Any grade classes that are not assigned a percent finer value will be treated as if they do not exist in the bed material.

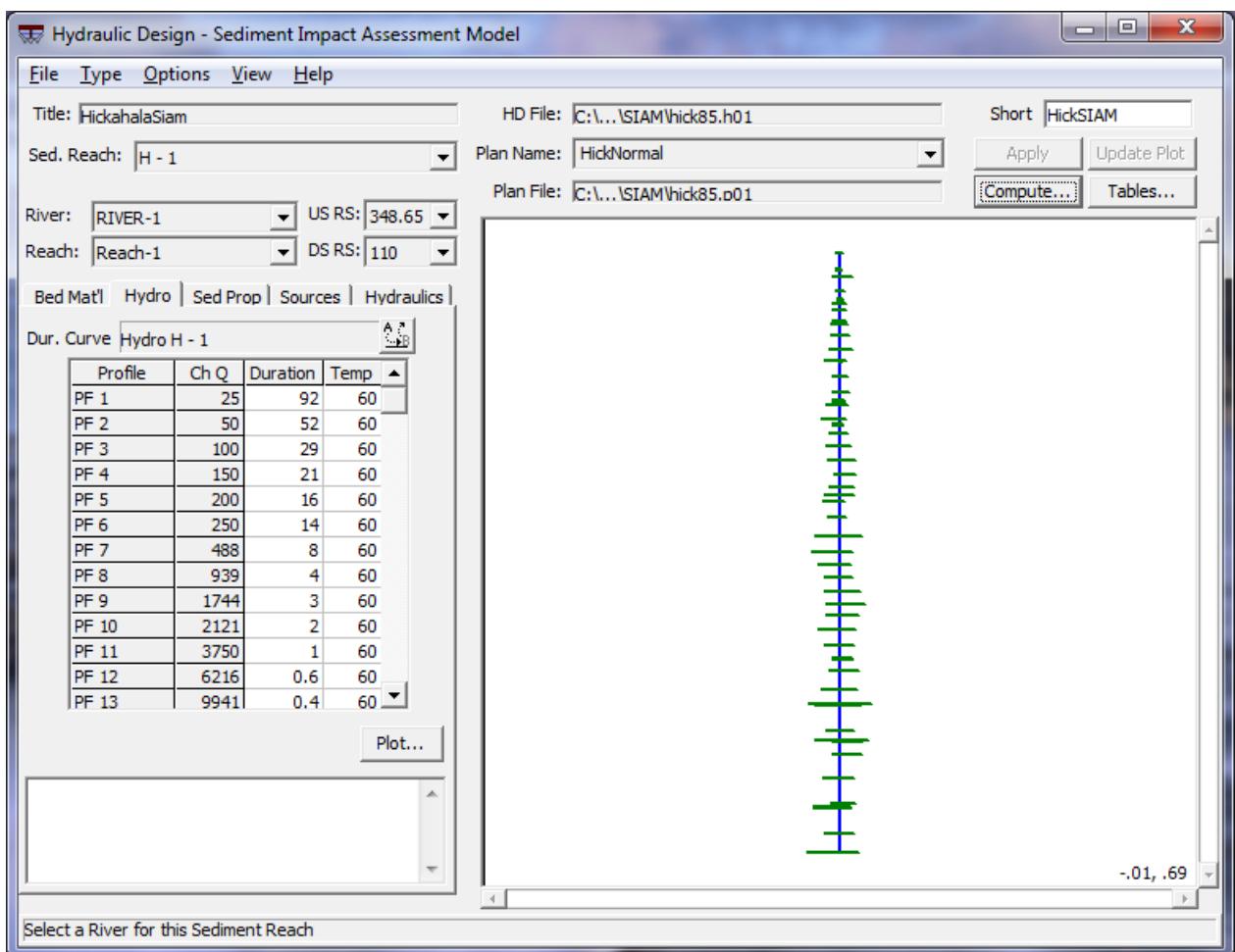
A text box is located at the bottom of the tab for the user to add notes that identify or otherwise describe the currently active bed material record.

Buttons available on the bed material tab are:

-  Create a new Bed Material Sampling record.
-  Rename the current Bed Material Sampling record.
-  Delete the current Bed Material Sampling record.
-  Plot... Plot the current Bed Material Gradation curve.

3.5.3.2 Hydrology

Before a SIAM model can be developed a standard, steady flow HEC-RAS model must be created and run. The SIAM **Hydro** tab is automatically populated with Hydrology records when a new sediment reach is defined. By default, the new hydrology record will be named "Hydro – (Sediment Reach Name)". Although this record must remain with the sediment reach it was created with, the user can change its name. The Hydro tab is shown in the figure below.



The **Profile** column is automatically populated with the profile associated with the current plan file. The **Ch Q** column is also automatically populated with a sediment reach length-weighted channel discharge. These values update if the bounding cross sections of the sediment reach change.

SIAM predicts annual trends and is based on an annualized flow duration curve. Therefore, the populated profiles must be distributed over 365 days. The user enters duration increments in the **Duration** column, for each profile, in units of days per year. These durations should sum to 365. SIAM will utilize all of the days input for its annualized flow and will not normalize to a year.

Water temperature is also required for each profile. This allows the user to vary the temperature seasonally. Buttons available on the Hydro tab are:

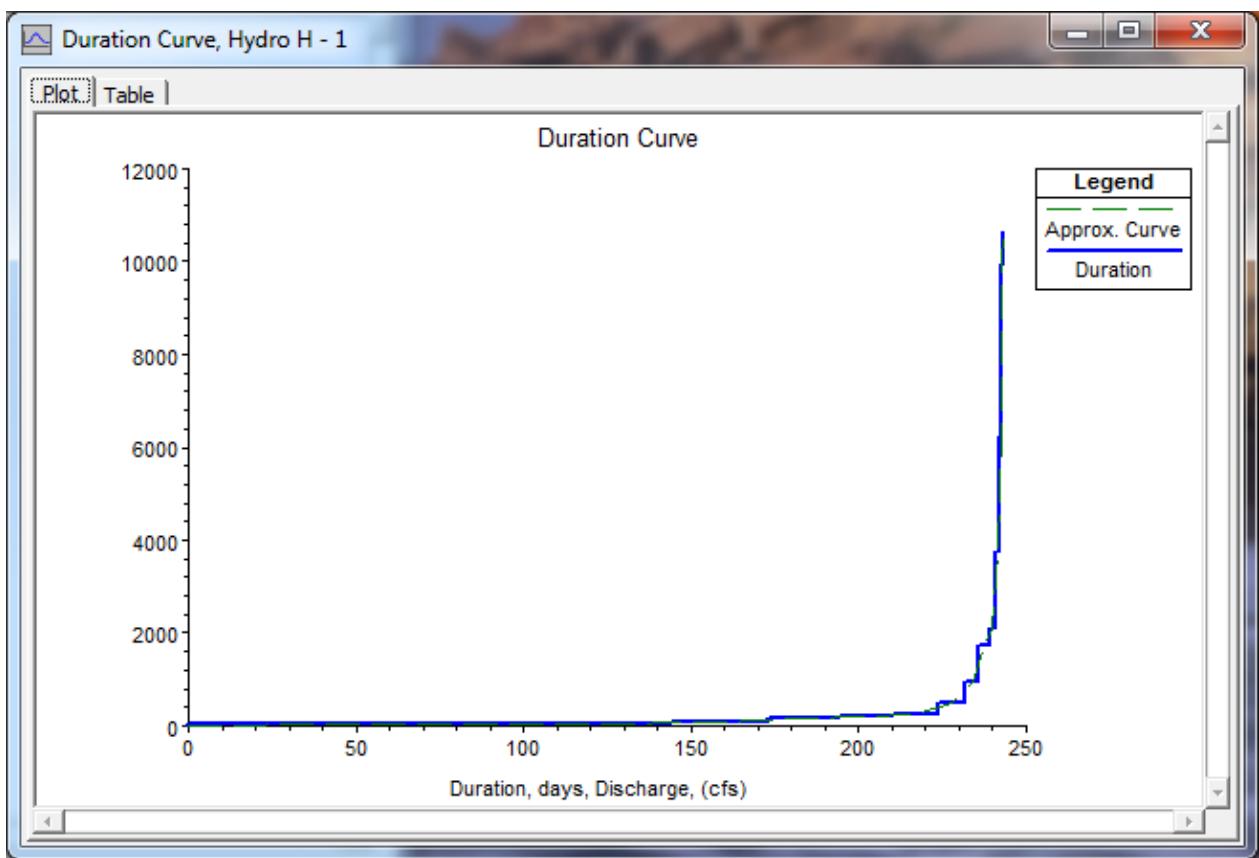
- Rename the Current Hydrology record:



- Plot the current Duration curve:



An example plot of a full hydrologic record is shown in the figure below.



100 Plot of annualized duration curve.

3.5.3.3 Sediment Properties

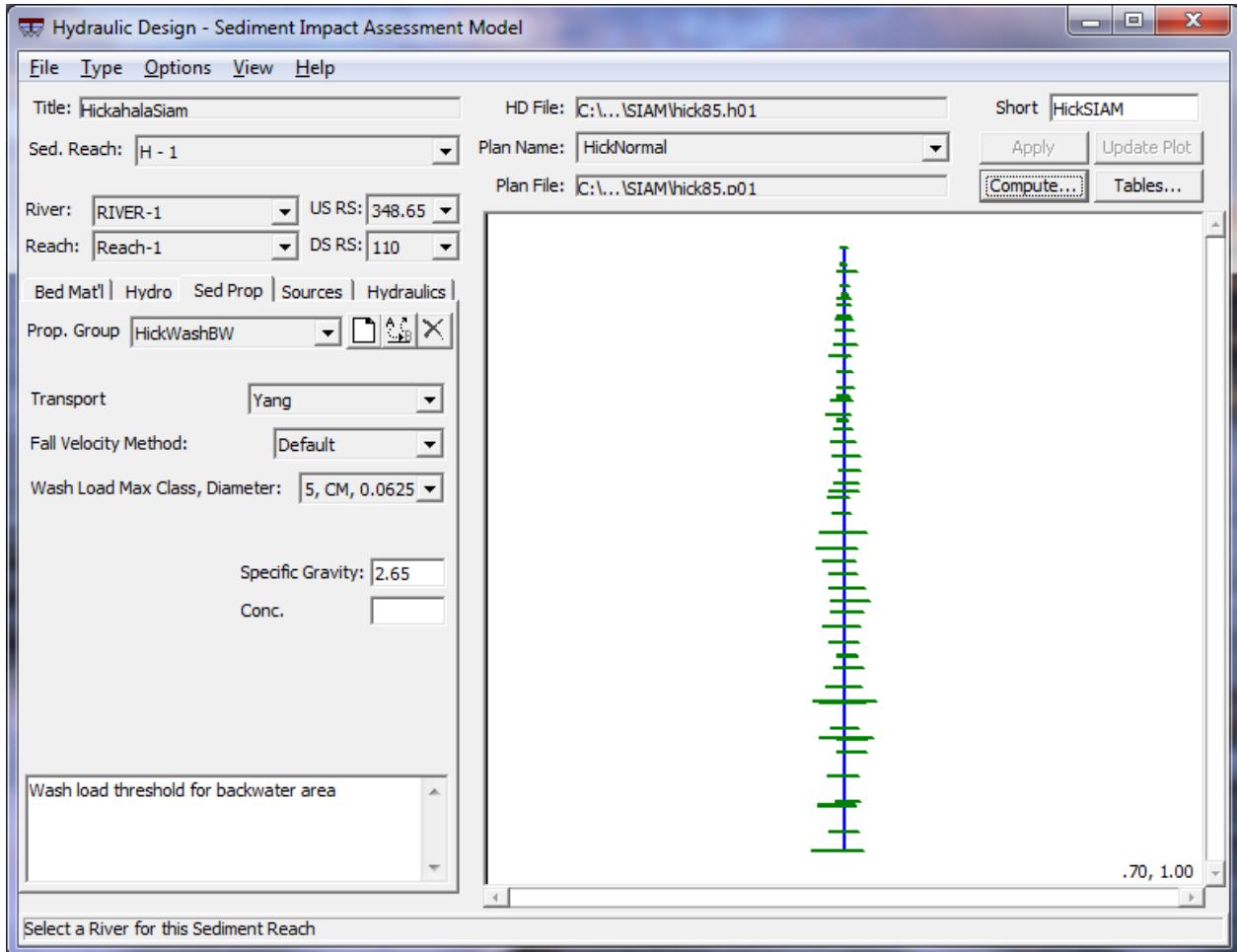
Sediment Property records are similar to the Bed Gradation templates in that a given Sediment Property record can be used exclusively for one sediment reach or can be shared by more than one sediment reach. These properties are defined in the **Sed Prop** tab. The record shown in the **Prop. Group** drop-down box at the time data is saved, will be the record assigned to the currently active sediment reach. The SIAM window with the **Sed Prop** tab activated is shown in figures on the following page, [Transport Function1](#) (see page 416).

- [Transport Function1](#) (see page 416)
- [Fall Velocity Method](#) (see page 418)
- [Wash Load Max Class, Diameter](#) (see page 418)
- [Specific Gravity](#) (see page 419)
- [Conc. of Fines \(opt\)](#) (see page 419)

3.5.3.3.1 Transport Function1

SIAM uses one of six transport functions to compute the annualized transport capacity. The appropriate equation is selected from the drop down box labeled **Transport Function**. Results are very sensitive to the transport function selection so care should be taken when selecting this option. For more description of these functions see Chapter 17 as well as the technical reference manual.

Separate transport functions can also be applied for different grain classes by selecting **Multiple Transport Functions by Grain Size** from the **Options** menu item. When this is selected, the transport function dropdown box becomes a command button with the caption **Multiple Transport Eqs**. Clicking this button to accessed the multiple transport functions grid, as shown in the bottom figure.



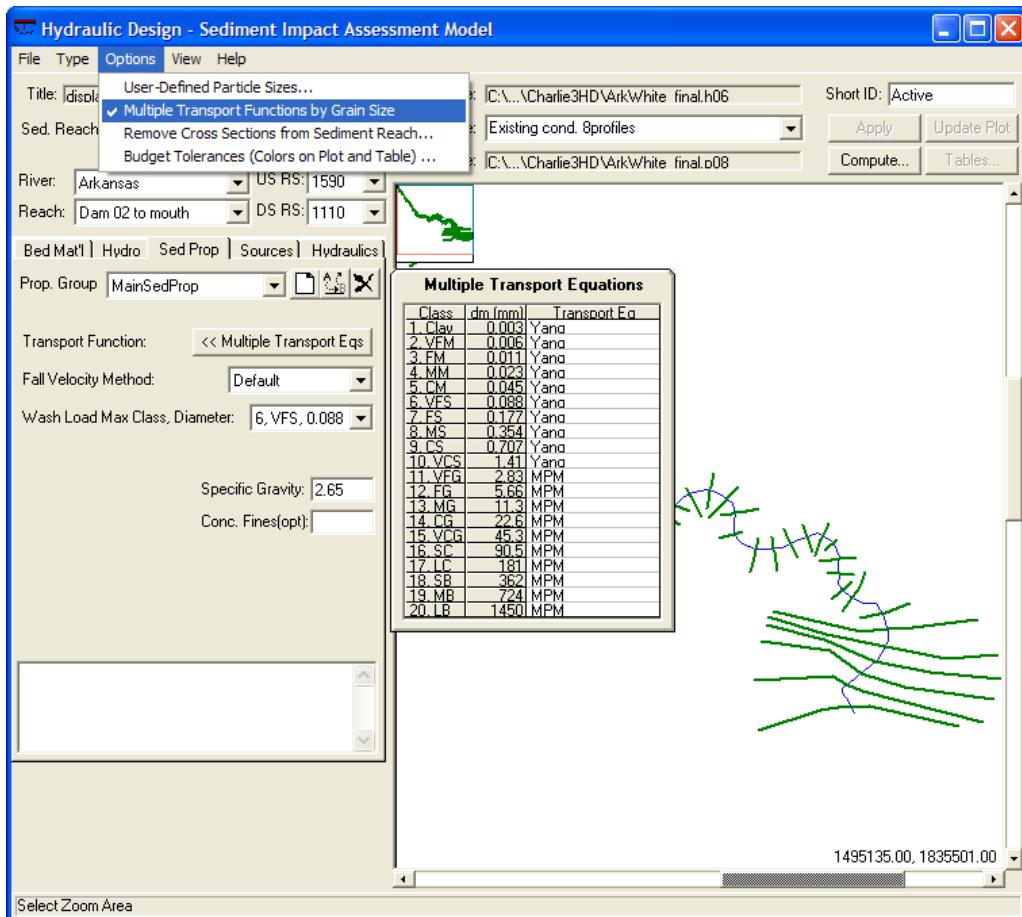
101 Sediment property tab.

This grid lists the 20 grain classes and their respective geometric mean particle diameter size. By clicking on a cell in the **Transport Eq.** Column, the user can access a drop down box which allows selection of a grain class specific transport equation. Once selected, all cells below the currently active cell populate with the same transport equation.

Note:

The grain class specific transport equation feature should be used with caution. When two different transport functions are used to compute transport potential for adjacent grain classes a discontinuity is often introduced. This could result in such difficulties as a larger computed potential for the larger grain class or an unreasonable drop in transport potential from one grain class to another. If this option is selected, pay careful attention to the results for material around

the size of the transport transition(s). A similar caution should also be observed when attributing different transport equations to different reaches. This will cause spatial rather than gradational discontinuities and should be approached with similar caution.



102 Grain class specific grain class function feature.

3.5.3.3.2 Fall Velocity Method

The **Fall Velocity Method** drop down box allows the user to select the method of fall velocity computation. If **Default** is selected, the method associated with the respective transport function in the literature is used. Otherwise, the selected fall velocity method will be used. The three fall velocity methods available are: Toffaleti, Van Rijn, and Rubey.

3.5.3.3.3 Wash Load Max Class, Diameter

Wash load is the material in the system, but not present in appreciable quantities in the bed. SIAM does not apply the standard transport equations to compute a mass balance for wash load materials. Instead, it automatically passes them through the sediment reach. If the wash load threshold drops from one sediment

reach to the next adjacent downstream reach, the material in the grain class(es) that is no longer wash load is added to the bedload and subjected to the standard mass balance approach.

A wash load threshold must be set for each sediment reach. The drop down box labeled **Wash Load Max Class** lists 10 grade classes (clays through sands for the standard grain classes) and their upper bound particle size in mm.

3.5.3.3.4 Specific Gravity

The specific gravity of sediment is also required. It can be entered in the field labeled **Specific Gravity**. The default is 2.65.

3.5.3.3.5 Conc. of Fines (opt)

The concentration of fine sediments is an optional value used to adjust the transport rate for high concentration scenarios. The adjustment is based on Colby's (Colby, 1964) findings regarding the effects of fine sediment and temperature on kinematic viscosity, and consequently particle fall velocity. Values are given in parts sediment per one million parts water, by weight.

3.5.3.4 Sediment Sources

In order to compare capacity to supply, sediment supply data must be entered. In SIAM sediment annual source information is entered for each sediment reach. This information is specified on the **Sources** tab. (below) Each **Sediment Reach** requires a **Source Group**, a collection of sediment source records. A given Sediment Source Group record can be used exclusively for one sediment reach or can be shared by more than one sediment reach.

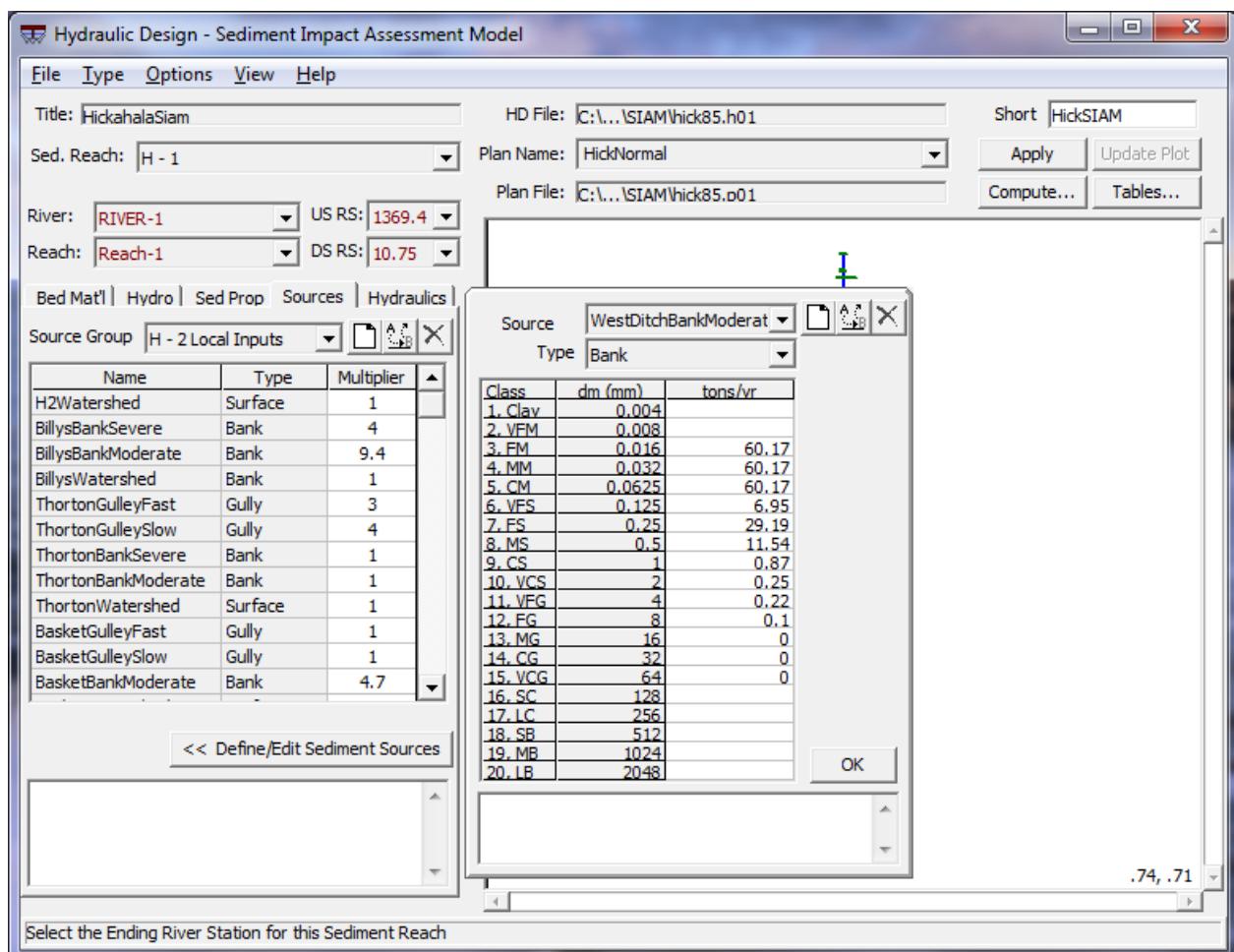
Before sediment supply information can be selected for a **Source Group** source templates must be created. Sediment source records can be created or edited by selecting the **Define/Edit Sediment Sources** button:



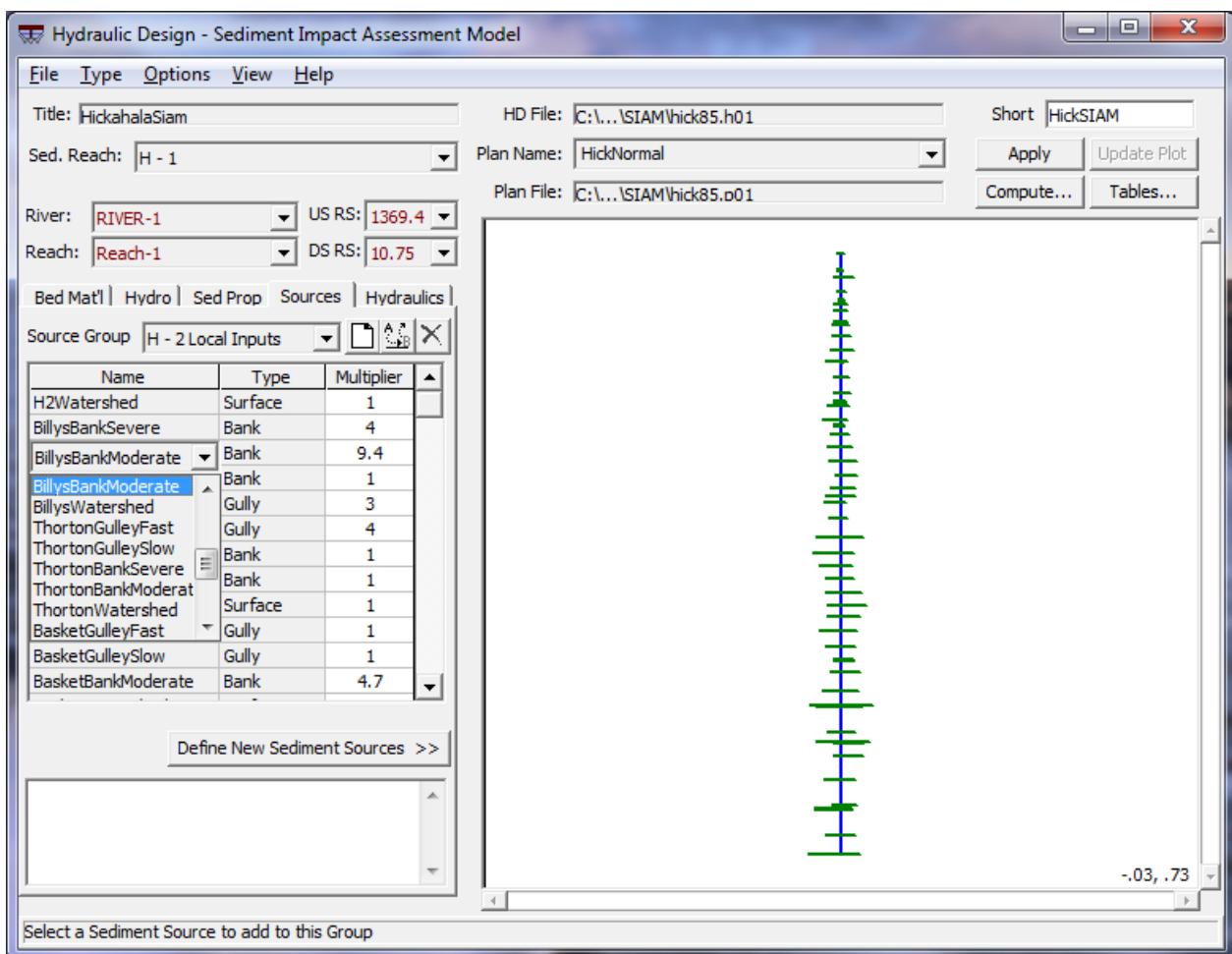
An inset window will appear for source definition. Press the "new record" button and name the source template. In addition to naming the source, a source **Type** also must be selected. A source can be labeled: gully, bank, surface erosion or other. This is only a grouping descriptor and has no impact on the computations.

Once the sediment load template is generated the annual load must be specified by grain size. The second column of the table displays the upper grain size diameter limit of each grain class. Annual loads in tons/year are entered in the third column (below).

When the sediment sources are specified, close the source editor by pressing the **OK** button or the **<< Define/Edit Sediment Sources** button, then select the appropriate source templates for each source group. A source record can be selected by clicking on the **Name** column of the **Sources** table. A drop down menu will appear populated with the source templates previously created. When a source record is selected the **Type** column will automatically populate. The **Multiplier** column defines the relative magnitude of the load. If the load record represents the load coming into the reach precisely then enter a multiplier of 1 and the numbers entered will be used.



103 Define new sediment sources on the sources tab.

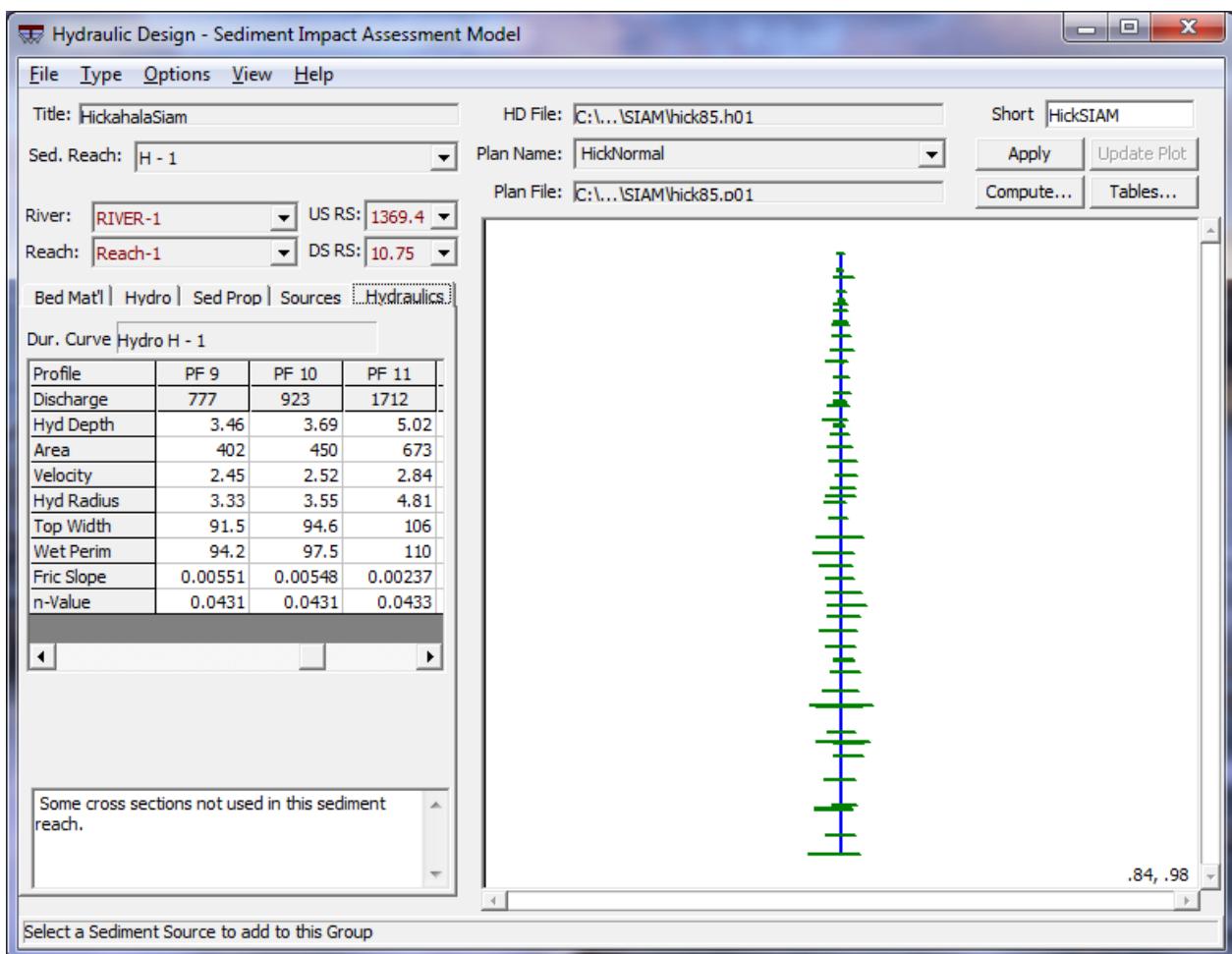


104 Source selection.

However, if the load was entered per linear bank foot or per watershed acre (see note at the bottom of the load template in the figure above) then the material entering the reach will be the source record multiplied by the multiplier entered. For example, in the figure above (bottom) the coarse bank material is entered in annual load generated by each linear foot of bank. This load is then multiplied by the length of exposed banks in the sediment reach. Additionally, a negative multiplier can also be entered, which will remove material from the sediment reach.

3.5.3.5 Hydraulics

The final tab is the **Hydraulics** tab. HEC-RAS computes this information and populates the table on this tab automatically. For each **Hydro** record, HEC-RAS computes a single set of hydraulic parameters for each sediment reach from the associated backwater profile, based on a reach weighted average of the included cross sections. The parameters in the grid are all sediment reach length-weighted values taken from the *channel* (not the full cross section) and are automatically updated if the bounding cross sections of the sediment reach are changed (below). Values cannot be changed directly on the grid by the user.



105 Average hydraulic properties populated by HEC-RAS.

3.5.4 Options

Several user capabilities are available in the **Options** menu. These options provide analysis flexibility in several aspects of the computations.

3.5.4.1 User Defined Particle Sizes

The grain size bins used by default in HEC-RAS are based on a standard log base 2 scale based on the American Geophysical Union (AGU). This option allows the user to redefine the particle size class ranges to either simplify the analysis or provide more detail in a certain grain size range. The user can enter in the upper and lower bound of the first grade class and the upper bound of the rest of the grade classes in the figure below. Lower bounds automatically adjust to eliminate gaps. The grain class labels can also be edited. Edited grain class names and sizes will appear in the corresponding dialogs. If the Defaults button is

selected, all of the grid entries will return the AGU default values.

| Class | label | ddown | dup | dm |
|-------|-------|--------|--------|-------|
| 1 | Clay | 0.002 | 0.004 | 0.003 |
| 2 | VFM | 0.004 | 0.008 | 0.006 |
| 3 | FM | 0.008 | 0.016 | 0.011 |
| 4 | MM | 0.016 | 0.032 | 0.023 |
| 5 | CM | 0.032 | 0.0625 | 0.045 |
| 6 | VFS | 0.0625 | 0.125 | 0.088 |
| 7 | FS | 0.125 | 0.25 | 0.177 |
| 8 | MS | 0.25 | 0.5 | 0.354 |
| 9 | CS | 0.5 | 1 | 0.707 |
| 10 | VCS | 1 | 2 | 1.41 |
| 11 | VFG | 2 | 4 | 2.83 |
| 12 | FG | 4 | 8 | 5.66 |
| 13 | MG | 8 | 16 | 11.3 |
| 14 | CG | 16 | 32 | 22.6 |
| 15 | VCG | 32 | 64 | 45.3 |
| 16 | SC | 64 | 128 | 90.5 |
| 17 | LC | 128 | 256 | 181 |
| 18 | SB | 256 | 512 | 362 |
| 19 | MB | 512 | 1024 | 724 |
| 20 | LB | 1024 | 2048 | 1450 |

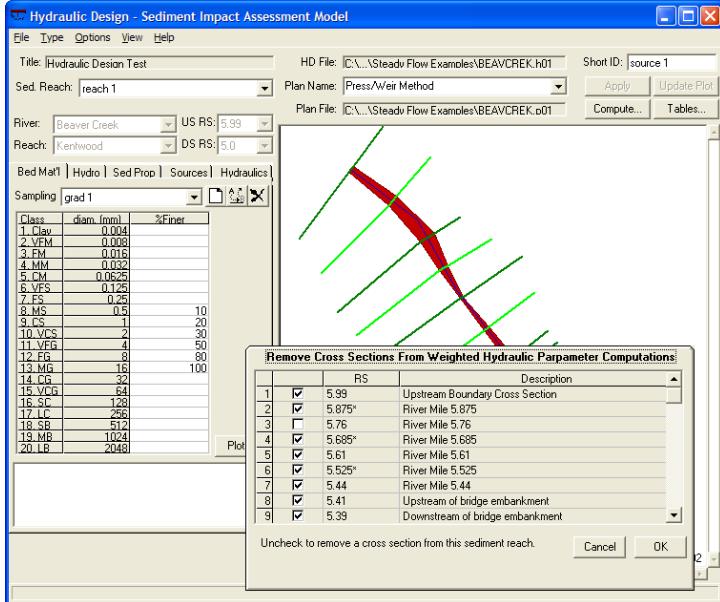
3.5.4.2 Multiple Transport Functions

The multiple transport functions option allows the user to specify distinct transport functions for different grain classes. A more detailed description of this feature is included on page 5.

3.5.4.3 Remove Cross Section from Sediment Reach

It may occasionally be desirable to omit one or more cross sections within a defined sediment reach from the hydraulic parameters averaging and sediment transport computation. If the hydrodynamics at a cross section are spurious and non-typical they may be omitted by de-selecting them in the editor depicted in the

figure below.



3.5.4.4 Set Budget Tolerances

When SIAM displays output, results are color coded in three categories: sediment deficit, surplus or equilibrium. Since the supply will never precisely equal the capacity, equilibrium is a range of acceptable deficit or surplus. This acceptable zone is strongly site and project specific and therefore must be entered by the user. The budget tolerance editor (below) allows the user to set a range of acceptable fluctuation (in tons/year) that will be displayed as equilibrium for each reach.

HEC-RAS

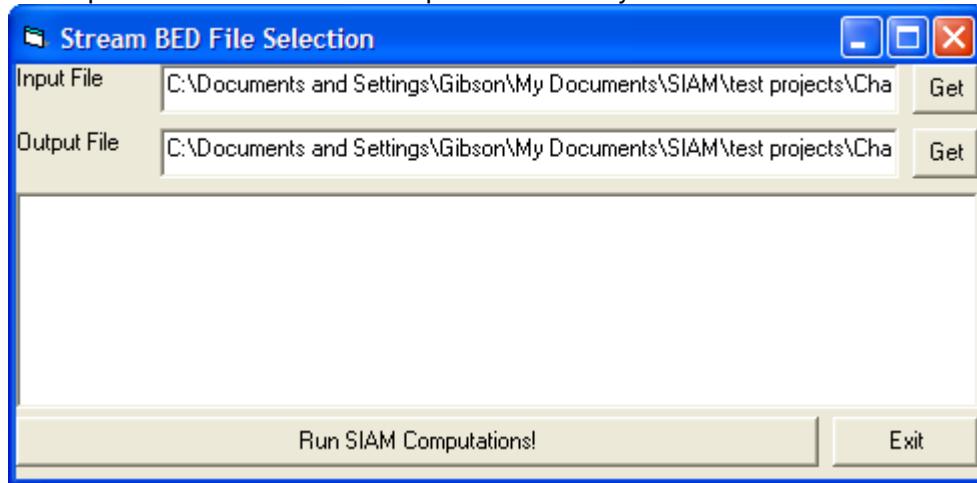
Edit the Budget Tolerances

| | Sediment Reach | Tolerance |
|---|----------------|-----------|
| 1 | BasketCreek | 2000 |
| 2 | SenatobiaCreek | 2000 |
| 3 | Hickahala1 | 4000 |
| 4 | Hickahala2 | 3000 |
| 5 | Hickahala3 | 2000 |
| 6 | Hickahala4 | 2000 |
| 7 | Hickahala5 | 2000 |

OK Cancel

3.5.5 Command Buttons

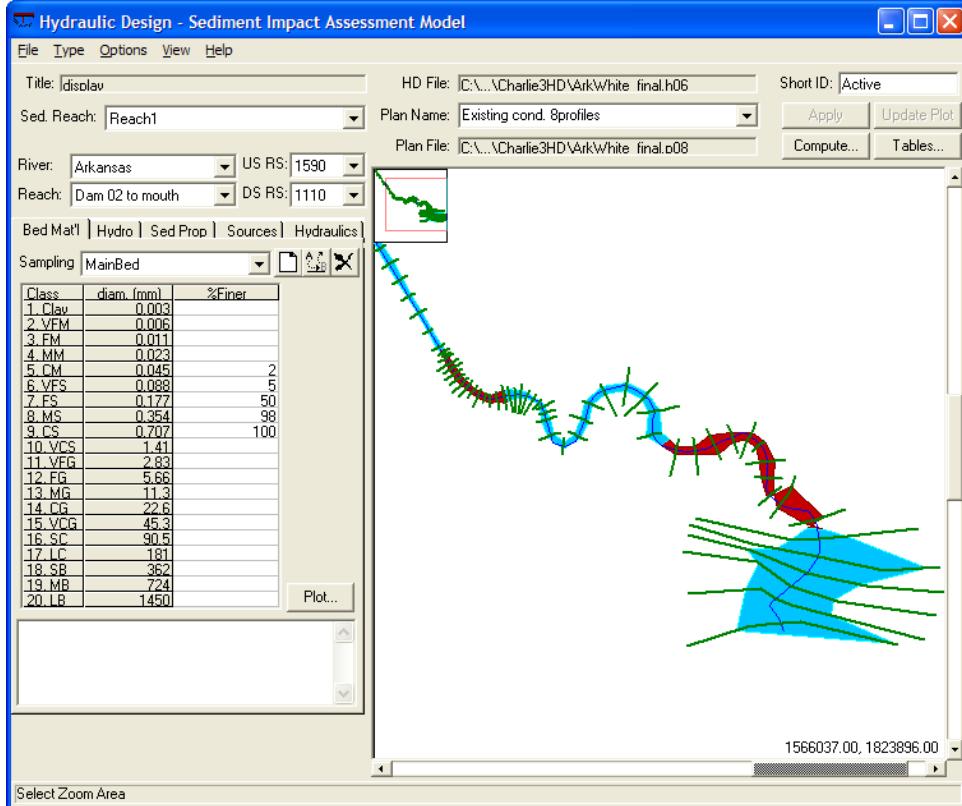
Four command buttons can be found in the upper right corner of the dialog. The **Apply** button will store the entries on the current window into memory. The **Compute** button launches a computational window depicted in the figure below. To execute the SIAM computations press the **Run SIAM Computations** button. Computation times are generally short. Very complex models will run in several seconds. Finally, the **Tables** button provides access to SIAM output after an analysis is conducted.



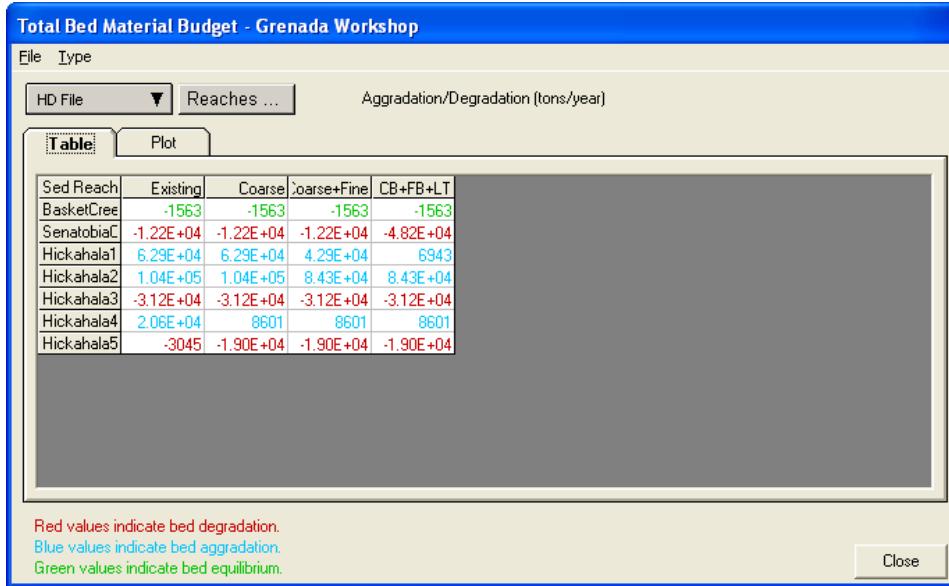
3.5.6 Model Output

Once SIAM has completed computations it will update the inset schematic display to reflect the results. Sediment reaches for which a deficit is calculated are colored red while surplus reaches are colored blue and those that fall within the equilibrium tolerance will be green. (below) The quantitative local balance for each

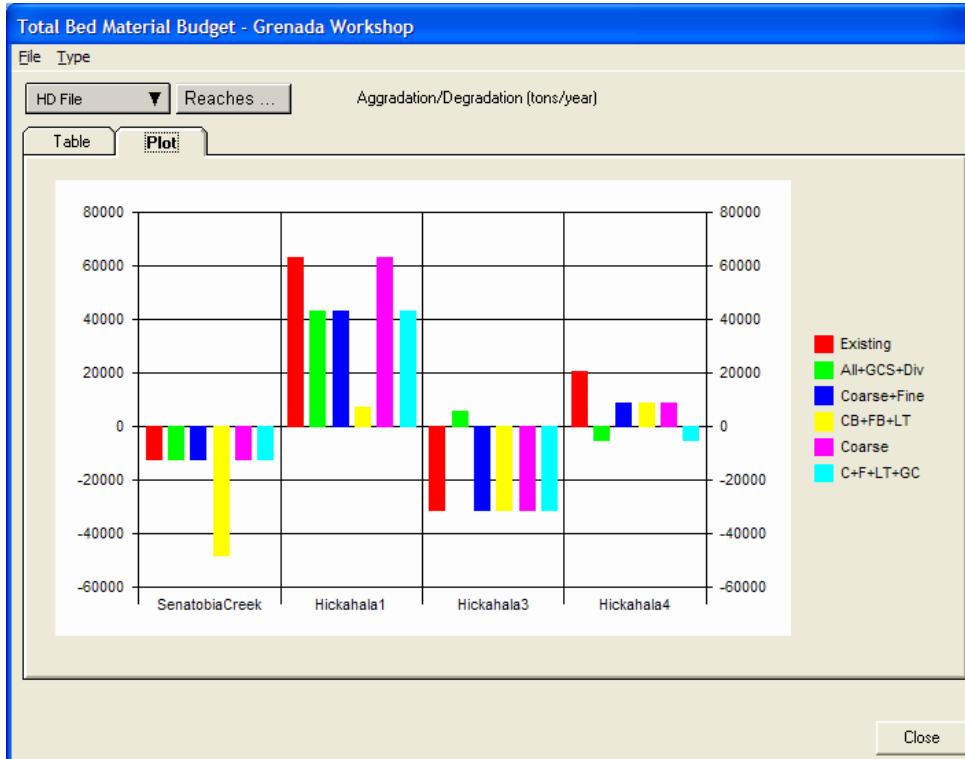
sediment reach can be queried by clicking on the colored region.



Plots and tables are available by pushing the **Table** button above the display. The standard output is **Local Balance** which reports the annualized sediment surplus or deficit for each sediment reach. Output can be viewed in the figures below, either in tabular (top) or graphical format (bottom). All plots are bar graphs. In either tabular or graphical form multiple HD files and reaches can be selected or deselected too look at different scenarios or simplify the plot. Lists of the available reaches and HD files are available by pressing the **HD File** and **Reaches** buttons.



106 Tabular local balance output.



107 Graphical local balance Output.

The following output options are available from the **Type** menu:

Local Balance: the annualized surplus or deficit for a given reach

Sediment Transport Potential: the transport potential computed for each grain size as if it comprised 100% of the bed material. These numbers are prorated by their relative abundance in the bed to compute transport capacity.

Supply and Balance: a summary plot that reports local supplies and the capacity which are compared to compute the local balance (also reported). It also breaks the supply into bed supply and wash supply components.

Then there are several tables and plots where output is reported by grain size. Reaches can be activated or deactivated for these output options but because of the additional dimension multiple HD files cannot be viewed simultaneously. The grain size specific outputs are:

Local Supply: sums the total annual sources applied to each sediment reach by grain size.

Annual Capacity: reports the computed, cumulative, annual capacity for each reach and breaks it down into the capacity contribution of each grain class.

Wash Material and Bed Material: summarize the total wash and bed material supplies for each reach and the relative contributions of each grain class.

Local Balance: reports the same local balance output as depicted in **Error! Reference source not found.** except it also depicts the local balance for each grain class (**Error! Reference source not found.**). It is of note in this figure that different grain classes can report deficits and surpluses in the same reach.

Normalized Local Balance: Since longer reaches will generally have exaggerated local balances when compared to shorter reaches, the normalized local balance divides the result from each sediment reach by the reach's channel distance. Therefore, local balance is reported per linear channel foot, making it easier to compare reaches of different lengths.

| Local Sediment Balance By Grain Size- Grenada Workshop | | | | | | | | | | | |
|--|-----------|---------------------------|--------|-------|-------|----------|----------|-------|-------|-------|---------|
| File Type | | Local Balance (tons/year) | | | | | | | | | |
| HD File | | Reaches ... | | | | | | | | | |
| Table | | Plot | | | | | | | | | |
| Sediment Reach | Total | 1, Clay | 2, VFM | 3, FM | 4, MM | 5, CM | 6, VFS | 7, FS | 8, MS | 9, CS | 10, VCS |
| BasketCreek | -1436 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -136 | -102 | -1183 |
| SenatobiaCreek | 7191 | 0 | 0 | 0 | 0 | 0 | 2.53E+04 | -8355 | -7188 | -2289 | -301 |
| Hickahala1 | 3.94E+04 | 0 | 0 | 0 | 0 | 3.60E+04 | 1111 | 1004 | 955 | 333 | 46.5 |
| Hickahala2 | 8573 | 0 | 0 | 0 | 0 | 0 | 9557 | -452 | -339 | -152 | -41.1 |
| Hickahala3 | 2.29E+04 | 0 | 0 | 0 | 0 | 0 | 0 | 9293 | 9056 | 4153 | 412 |
| Hickahala4 | 1.16E+04 | 0 | 0 | 0 | 0 | 0 | 0 | -1495 | 7523 | 3646 | 1906 |
| Hickahala5 | -1.63E+04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -9872 | -5591 | -840 |

Red values indicate bed degradation.
Blue values indicate bed aggradation.
Green values indicate bed equilibrium.

Close

108 Local balance by grain size.

3.5.7 Notes on Program Applicability and Limitations

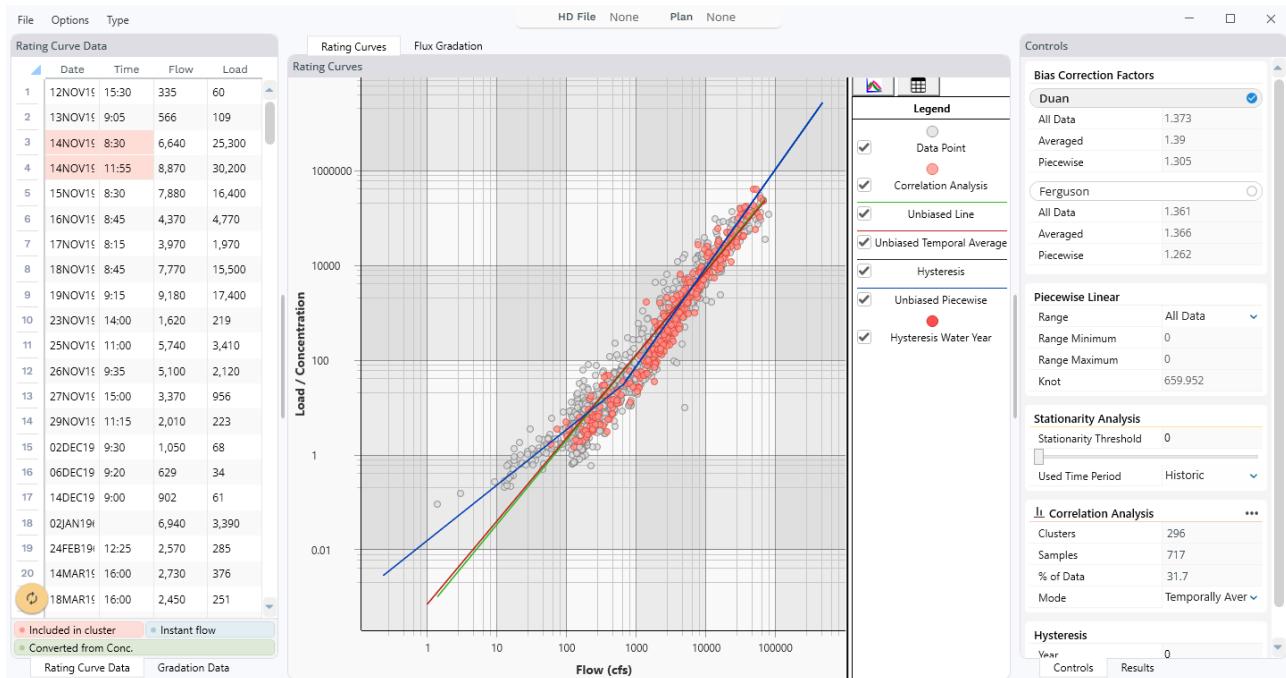
SIAM *is not* a sediment routing model. A mobile bed model will update hydraulics in response to sediment deficits and surpluses generally resulting in mitigated rates of erosion or deficit over time, as the channel adjusts its morphology. SIAM does not update the bed and, therefore, does not account for changing capacities in response to erosion or deposition.

Therefore, SIAM should be used as a screening tool for sediment budget assessment. The numbers reported should be treated cautiously and interpreted as general trends of surplus and deficit *not* volumes of eroded or deposited material. One of the advantages of SIAM is the ease with which sensitivity, management or design alternatives can be evaluated. SIAM should be used to assess the impact of a wide range of alternatives in order to select the best few for more detailed modeling and analysis.

3.6 Sediment Rating Curve Analysis Tool

The Sediment Rating Curve Analysis Tool User Guide is on the Main HEC-RAS page.

You can access it: [here](#)⁷².



⁷² <https://www.hec.usace.army.mil/confluence/rasdocs/rasum/latest/hydraulic-design-hd-calculators/sediment-rating-curve-analysis-tool>

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