

# User Guide

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## RIVER HYDRAULICS & SEDIMENT TRANSPORT



**One Water Solutions Institute**

Colorado State University

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## EXECUTIVE MESSAGE

Catena Analytics offers powerful platforms for building accessible and scalable analytical tools and simulation models that can be accessed via desktop or mobile devices. Our team has spent the last decade developing the Environmental Resource Assessment and Management System (eRAMS), an open source technology that provides cloud-based geospatially-enabled software solutions as online services and a platform for collaboration, development, and deployment of online tools. Our services are used to assist with strategic and tactical decision making for sustainable management of land, water and energy resources. Thank you for choosing Catena Analytics and the eRAMS platform to meet your data, modeling, analysis and geospatial needs.

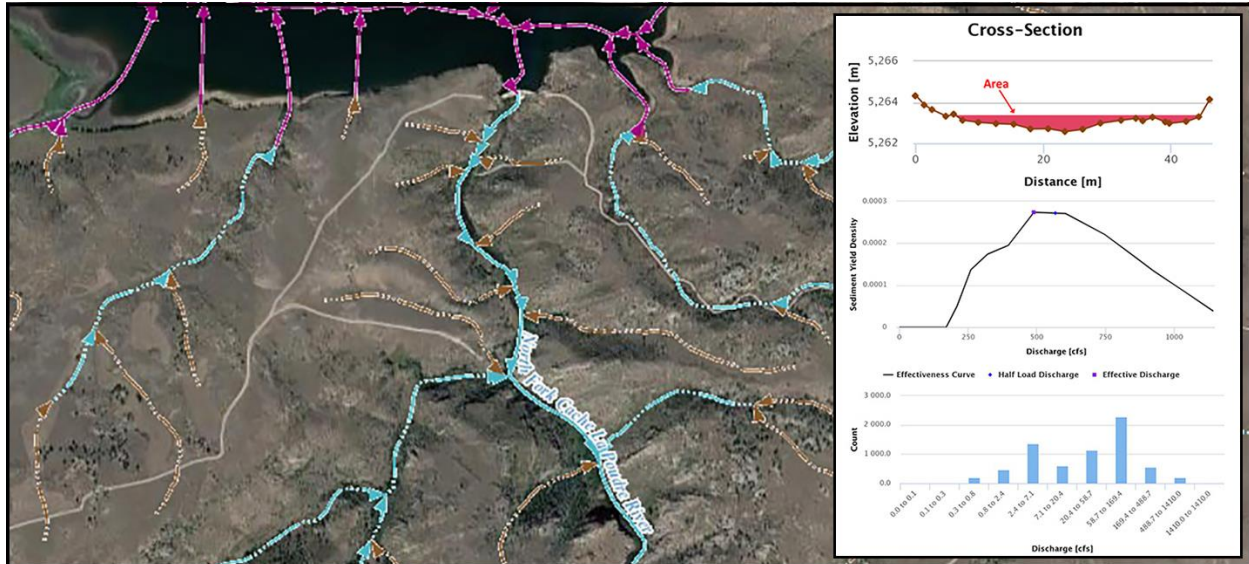
### WHO SHOULD USE THIS GUIDE

This guide is a tutorial to get you started using eRAMS and the [River Hydraulics & Sediment Transport](#) (RHST) tool. The guide provides instructions for commonly performed tasks and uses of the tool. This tool is intended for use by urban planners and water managers, academic groups, regulatory officials, consultants as well as state, local and federal agencies planning for the future of water resources.

### NEED HELP?

After reviewing the guide if you need additional assistance we are here to help! This guide is designed to provide instruction on commonly performed operations and answers to many frequently asked questions. If you find any aspect of the tool challenging or missing information from this guide, please engage an eRAMS expert to guide you through any hurdles. Contact us at: [eramsinfo@gmail.com](mailto:eramsinfo@gmail.com)

# INTRODUCTION



## PURPOSE

This tool allows users to examine hydraulic properties of river transect cross-sections and calculate sediment transport.

## DESCRIPTION

The [River Hydraulics & Sediment Transport](#) (RHST) analysis tool extracts and analyzes a stream cross-section's hydraulic properties and sediment transport conditions. Using a 10-meter DEM, RHST extracts a valley-scale cross-section which can be downloaded and used in further analyses and/or enhanced with user-supplied channel-scale survey data. The extracted cross-section's hydraulic properties can be summarized for a single flow event or combined with data from a stream monitoring site. When combined with a stream discharge record RHST creates rating curves for depth, area, hydraulic radius, and sediment transport in addition to a sediment effectiveness curve which can be used to determine the 'effective discharge' (peak of the curve). The cross-section can also be modified to analyze different channel rehabilitation configurations and simulate the resulting effect on hydraulic and sediment conditions.

## SOFTWARE AVAILABILITY

### Domain

[www.erams.com/hydraulics](http://www.erams.com/hydraulics)

### Documentation URL

<https://erams.com/catena/tools/river-basin-planning/hydraulics/>

## AUTHORIZED USE PERMISSION

The information contained in the [River Hydraulics & Sediment Transport](#) (RHST) tool (the "Service") is for general information purposes only. Colorado State University's One Water Solutions Institute ("CSU-OWSI") assumes no responsibility for errors or omissions in the contents of the Service. In the Service ([www.erams.com/hydraulics](http://www.erams.com/hydraulics)) you agree to hold neither the creators of the software platform nor CSU-OWSI liable for any action resulting from use or misuse of the Service. In no event shall CSU-OWSI be liable for any special, direct, indirect, consequential, or incidental damages or any damages whatsoever, whether in an action of contract, negligence or other sort, arising out of or in connection with the use of the Service or the contents of the Service. CSU-OWSI reserves the right to make additions, deletions, or modification to the contents of the Service at any time without prior notice.

# GETTING STARTED

## QUICK START

Click on the links below and follow this simple workflow to get started using the RHST analysis tool:

1. [Create a Cross-Section](#)
2. [Identify Hydraulic Properties](#)
3. [Calculate Sediment Transport](#)
4. [Calculate Sediment Yield](#)
5. [Examine Results](#)

## SYSTEM REQUIREMENTS

A modern web-browser is required to connect and run RHST. Browser options include: Google Chrome v.69, Mozilla Firefox v.62, Safari v.11.1, and Microsoft Edge v.17.

# USING THE TOOL

## ACCESS THE TOOL

### Public Access

The RHST tool can be accessed without registering an eRAMS account. In the public-facing version the data and analysis will only be available for the duration of the browser session. Once the browser is closed the project will no longer be available (i.e. users cannot save their work or share their project).

If a user prefers to save their project, share it with collaborators or revisit their analysis, an account is required. Follow the instructions below to create your free account and save your projects or visit our website to get started: <https://erams.com/account/>

### Create an eRAMS Account

1. From the [eRAMS Registration page](#), select "Register Now" from the top menu and enter a username, password, your first and last name, and your email address. Click "Create Account".
  - eRAMS will display a popup box alerting you that an email confirmation has been sent to the provided email address
2. Open the email account provided in the registration form from either a new browser window or from your local email application.
  - Search for an email from eRAMS with the subject line "eRAMS Email Check"
3. Open this email and click on the provided link to confirm your email address.
  - **Note:** *If you do not see the confirmation email appear in your email inbox immediately, check your spam or junk email folder to ensure that the confirmation message wasn't automatically discarded. You may also need to wait a few moments to ensure the email is delivered successfully.*
4. Once you click on the provided email link, you should be redirected to eRAMS, where you'll be automatically logged in

## Registered User Access (recommended)

1. Login to your eRAMS account here: <https://erams.com/account/>
2. Select the "Projects" tab from the left panel
  - **Hint:** You must be logged into your eRAMS account
3. Select "Create Project" from the top toolbar
4. Enter a Project Name
  - Alternatively, select a project from the list to access previous projects
5. Select "River Hydraulics and Sediment Transport" from the Project Type drop down
  - Optional: Select layers from previously saved project under the "Include Layers from Project" drop down
6. Click "OK"
7. Locate the name of the project you have created in the project list, click the link
  - The link will redirect you to the interface where you can conduct analysis and save your work to your account

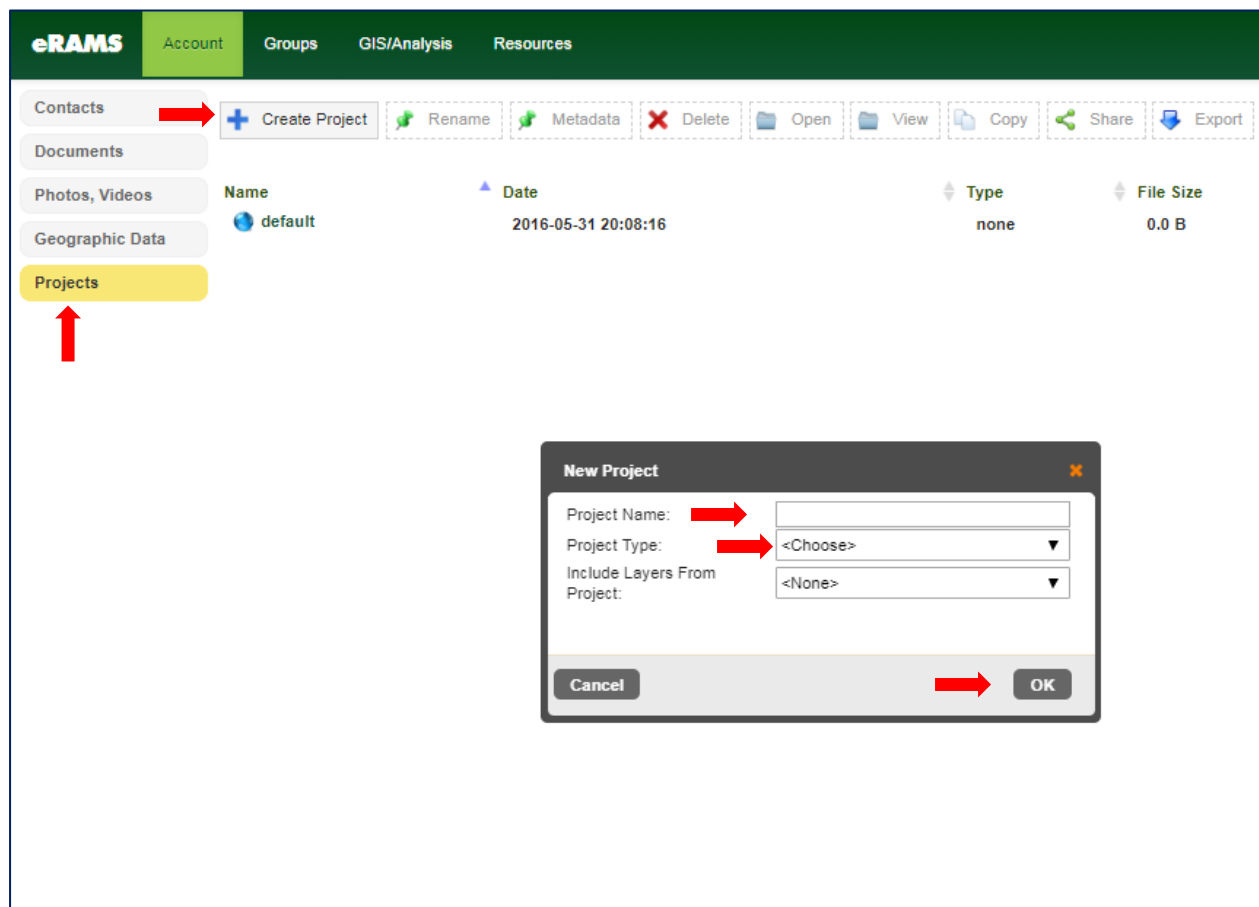


Figure 1: Registered user process for creating a project in eRAMS



## STEP 1 – CREATE A CROSS-SECTION

### Modify Base Layer (optional)

If you prefer to modify the base layer in the RHST interface, click the "Map" tab on the left dashboard and:

1. Select the "Base Layers" drop-down
2. Select the desired base layer
  - Options include: None, Google, Bing or USGS National Map

### Define River Transect

With the RHST interface open, click the "River Hydraulic Analysis" tab on the left dashboard. Create or select your area of interest by performing one of the following operations:

#### *USGS National Elevation Dataset (NED)*

The RHST tool includes options to use the [National Elevation Dataset](#) (NED). Each cross-section point that is calculated accesses this dataset through the [NED Point Query Service](#) which calculates the elevation of a point based on its latitude and longitude. The 10-meter USGS NED Digital Elevation Map (DEM) can then be used to create and extract a cross-section by performing the operations described below (Fig. 2). Users can also combine the 10-meter NED DEM with user supplied raster of elevation data as described in the subsequent section.

To extract a cross-section from the NED

1. Select "Create on Map" to extract a cross-section from a DEM:
2. Zoom to the stream/river channel of interest
3. Click "Create"
4. Single-click a start point on the map
5. Single-click an end point on the map, this defines a transect within the channel
6. Name the selection

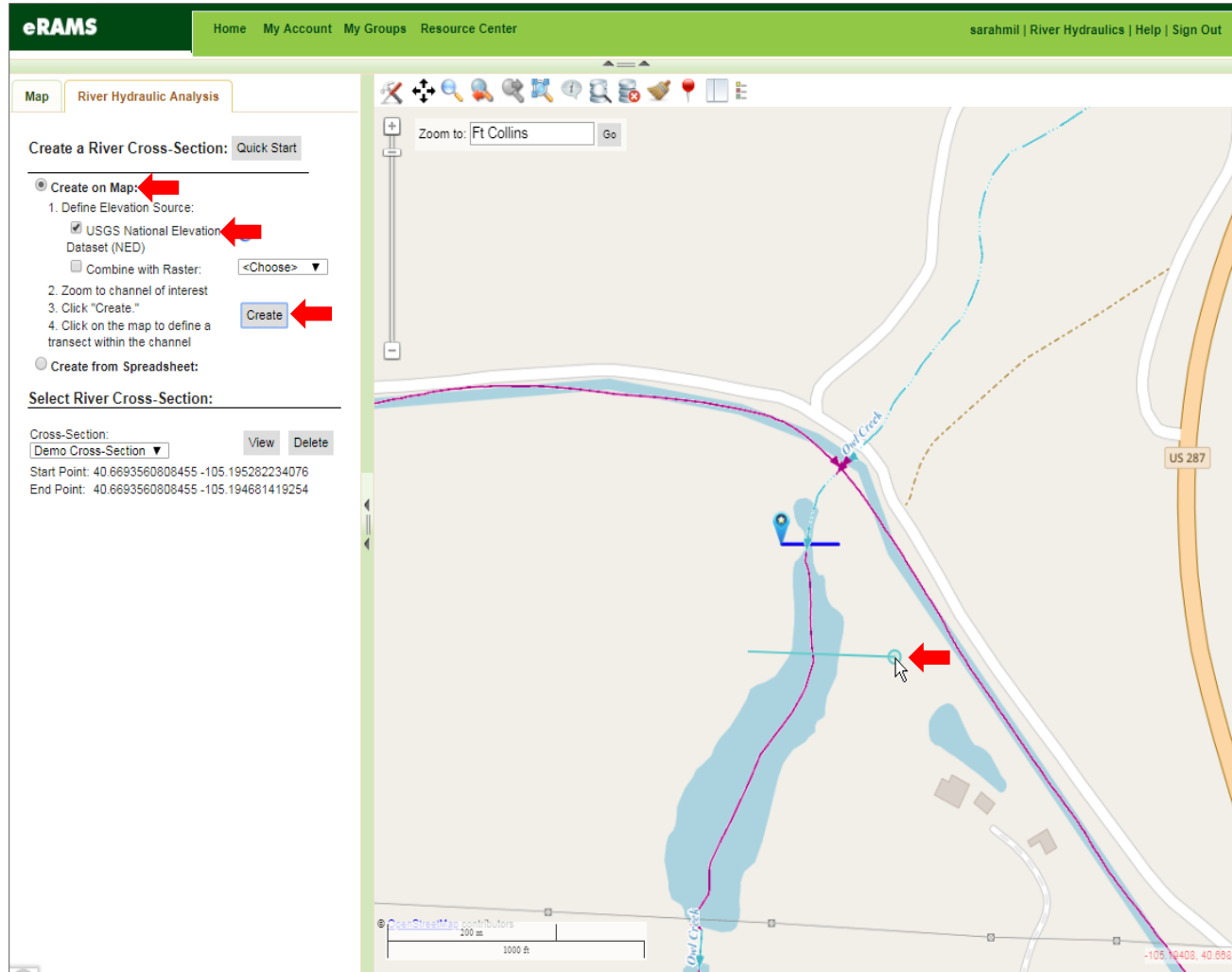


Figure 2: Create cross-section from 30-meter NED-DEM

### Upload File

In addition to using the 10-meter NED-DEM users can also upload a raster of elevation data, datasets (e.g. spreadsheet with survey points of a cross-section points), and geospatial layers as described below. There are three ways you can add your own information under the “Map” tab:

1. Geospatial Layers – Public facing access for uploading files
2. Project Layers – Registered user access, these files correspond to the current project and will be available to any members of the project (i.e. used within a project). Check out the [eRAMS Grouping capabilities](#) for more information about sharing projects.
3. User Layers – Registered user access, these files are associated with your user account and can be accessed from any project (i.e. used across projects)

**Note:** All files associated with a shapefile can be zipped into a ZIP archive (\*.zip) then uploaded, or multiple files can be uploaded at the same time outside of a ZIP archive. Depending on the size of your file(s), it may take a few minutes to process.

Once you have uploaded the dataset(s), perform the following operations:

1. Click "Create on Map"
2. Select "Combine with Raster"
3. Select file from the "Choose" dropdown

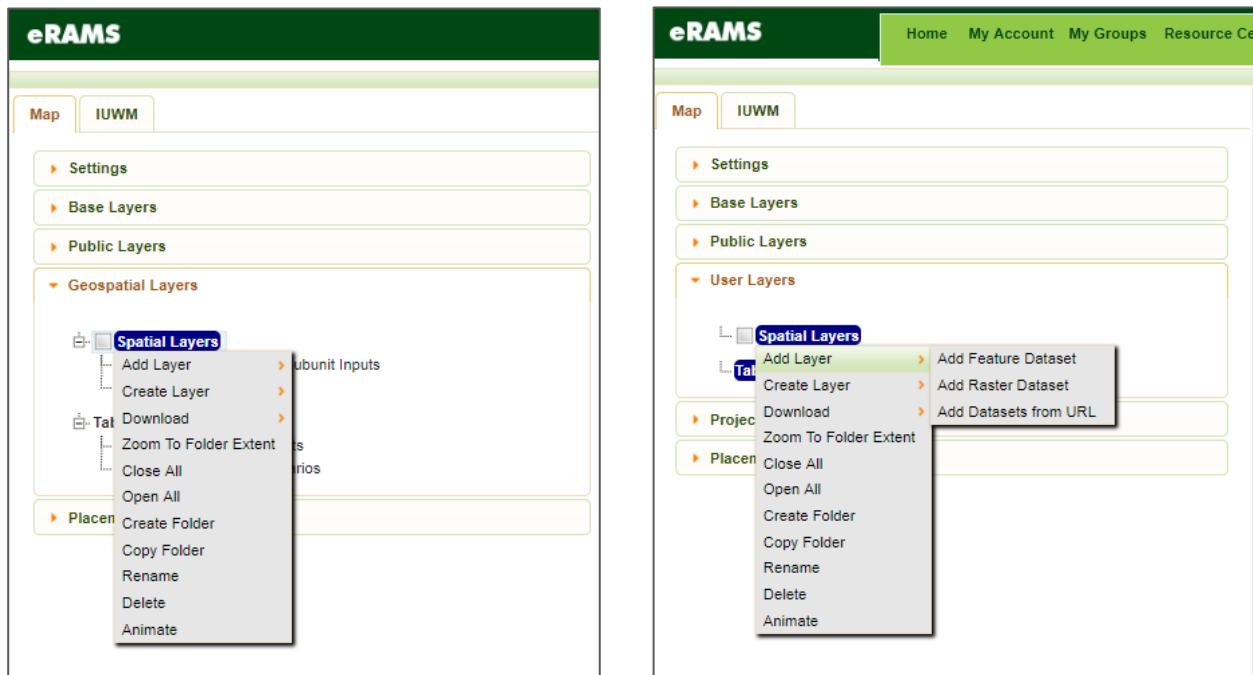


Figure 3: Adding Layers - public access pictured left, registered user access pictured right

### Create from Spreadsheet

A user can alternatively create a cross-section by uploading comma separated value (CSV) file with coordinates as described below (Fig. 4). The specified latitude and longitude for the end point does not need to line up exactly with the last point in the spreadsheet, the tool will adjust the length of the cross-section's line on the map as needed.

**Note:** You can also use the "From Map" buttons to extract the latitude and longitude of a point selected from the map rather than typing in your cross-section's latitude and longitude.

### File Format Instructions

The uploaded file must be a two-column, comma separated value (CSV) file, formatted as follows:

- The first row must contain a label for the columns like "x, y".
- The remaining rows must contain pairs of x-y points of a cross-section with the first row containing x = 0 (column 1) and its associated elevation (column 2).
- The units of x and y should be meters.

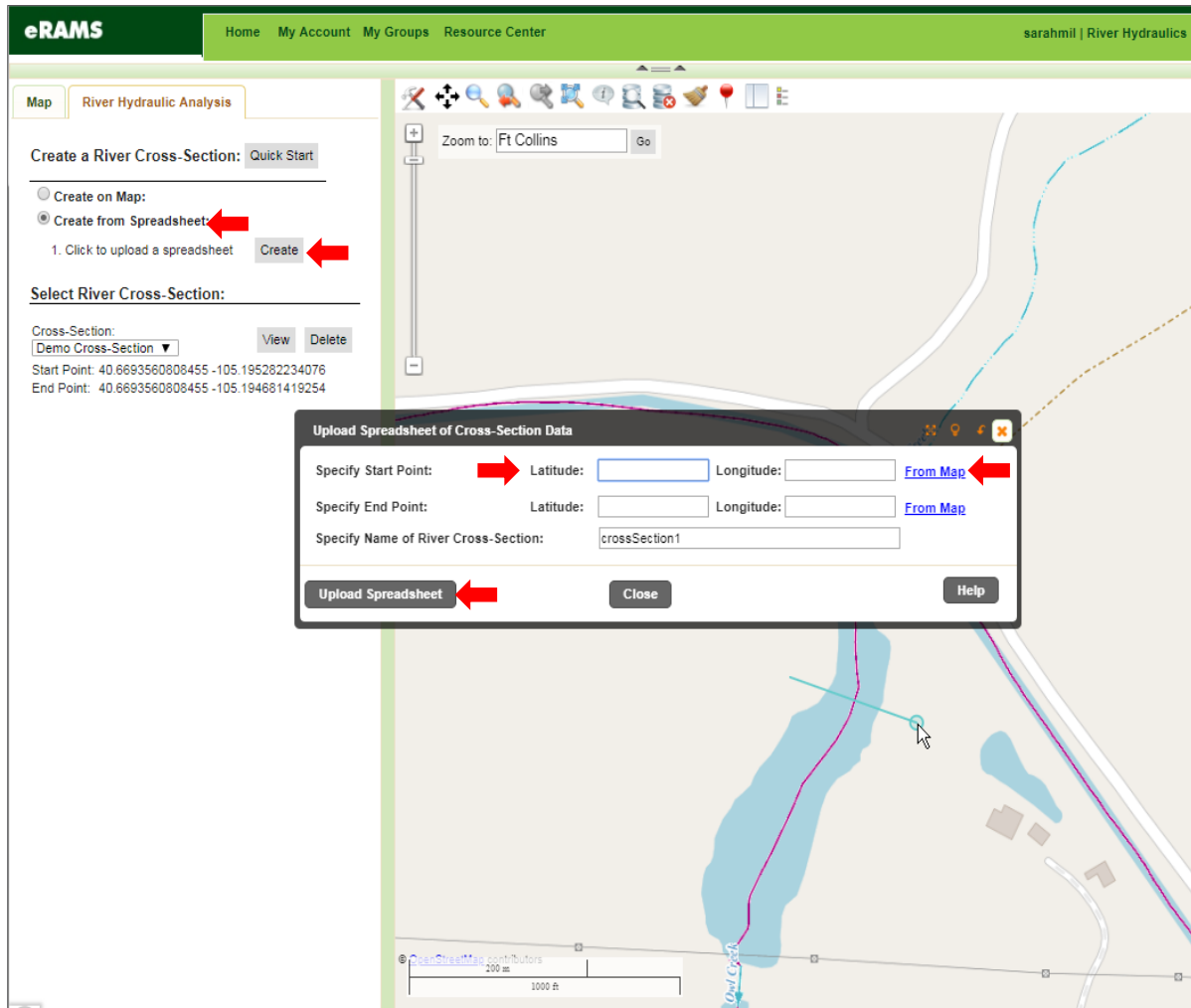



Figure 4: Create a cross-section from spreadsheet

## Modify Cross-Section

Once you have created a cross-section(s) the following operations can be used to select, use and/or edit a cross-section:

1. Select desired cross-section from drop-down list under the "Select River Cross-Section" dashboard (Fig. 5):
  - Once a cross-section is selected, the  icon represents the x=0 location for the selected cross-section

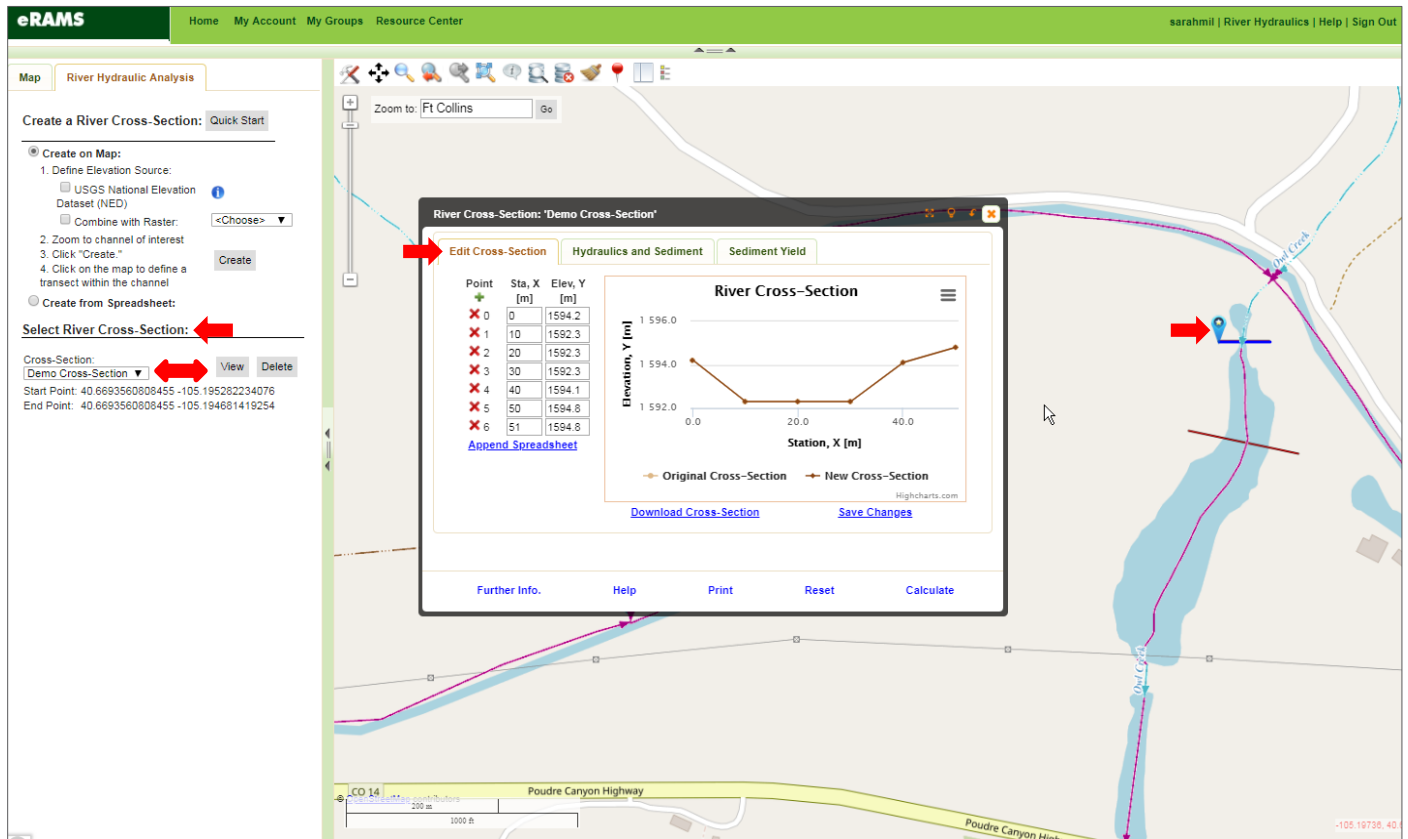




Figure 5: Select and/or modify cross-section

2. Click "View" to launch the edit/view interface for the selected cross-section
  - The  icon allows a new point, station (x) and elevation (y) to be added to the cross-section.
  - The  icon allows the current point, station (x) and elevation (y), to be removed from the cross-section.
  - Each point's station (x) and elevation (y) is editable, once you have made a change and hit enter or click off of the box you edited and the graph will update to view the changes (light brown) compared to the unmodified cross-section (dark brown).
    - These changes are not final until you click "Save Changes"

- "Append Spreadsheet" will allow you to upload a spreadsheet with the below properties and add it to the existing cross-section as more points. See below for file format instructions.
  - "Download Cross-Section" downloads a csv file with the start and end latitudes and longitudes as well as all the cross-section locations (x) and elevations (y).
  - "Save Changes" will permanently save the modified version of the cross-section.
  - "Reset" will restore the cross-section to its original un-edited version. This will only affect un-saved changes (i.e. remove the light brown line). Saved changes cannot be reset.
3. Click "Delete" to permanently delete the selected cross-section

## STEP 2 – IDENTIFY RIVER HYDRAULIC PROPERTIES

Users can calculate hydraulic properties in two easy steps. Descriptions, calculations and model assumptions follow in the subsequent sections.

1. Specify Depth of Flow
2. Click "Calculate"

### Specify Depth of Flow

Once a cross-section has been created, the user has the ability to calculate its hydraulic properties, namely area, wetted-perimeter, top-width, hydraulic-radius, hydraulic-depth. However, in order to calculate these properties a flow depth is required. Users can specify a depth of flow to characterize the sections hydraulic properties using one of the following methods:

#### *User-Defined Flow Depth*

If you know the depth of flow you are interested in, select this choice.

#### *Critical Depth*

If you know flow conditions cause a critical depth of flow to occur, specify the discharge in the channel to calculate and use the critical depth at this cross-section.

#### *Normal Depth (Manning's Equation)*

If you know flow conditions cause a normal depth of flow to occur here; specify the following and a normal depth will be calculated using [Manning's Equation](#) (1891) based on the provided channel roughness:

- Discharge in the channel
- Channel bed slope
- [Manning's Hydraulic Roughness Coefficient \(n\)](#)

## Assumptions and Calculations

### *Manning's Hydraulic Roughness Coefficient*

One variable required by Manning's Equation for calculation of a 'normal' depth is a hydraulic roughness coefficient,  $n$ . This coefficient takes into account roughness from submerged channel bed forms, vegetation, and more. 'Normal' depth of flow in a channel is very sensitive to the value of  $n$  and changes with depth as various roughness-factors (vegetation, boulders, etc.) become submerged or revealed. While there is great variability in the roughness parameter,  $n$ , some simplified guidance is provided below based on a number of different studies.

Bed Characteristics	Reference Manning's Roughness Coefficient, $n$
<b>Sand</b>	
Plane Bed	0.011 - 0.020
Ripple Bed	0.018 - 0.035
Dune Bed	0.020 - 0.035
Standing Waves	0.014 - 0.025
Antidunes	0.015 - 0.035
Gravel and Cobbles	0.020 - 0.030
Boulder	<i>Roughness varies greatly. Usually roughness increases with decreasing flow depth. <math>n</math> can reach 0.1</i>
<b>Vegetation</b>	
<i>Roughness varies greatly with changes of density, height, flexibility of vegetation, and the relative ratio between flow depth and vegetative elements</i>	
Bermuda, Kentucky, Buffalow Grasses	<i>Flow depth more than 5 times vegetation height: <math>n</math> between 0.01 and 0.2</i>
Extremely Dense Vegetation:	<i>Vegetation height above flow depth: <math>n</math> can exceed 1</i>
<b>Natural Sandy Streams</b>	
Clean and Straight	0.025 - 0.04
Winding and Some Weeds	0.03 - 0.05
Mountain Streams with Boulders	0.04 - 0.1
<b>Floodplains</b>	
Short Grass	0.02 - 0.04
High Grass	0.03 - 0.05
Dense Willow, Brush, etc.:	0.05 - 0.20

Table 1: Variation of Manning's Roughness Coefficient,  $n$ , with Channel Bed Type (adapted from Shen et al., 2003, Table 12.2.1)

### Manning's Equation

$$Q = \frac{\phi}{n} AR^{2/3} S^{1/2}$$

Where:

$Q$  = Discharge in the channel

$\phi$  = Unit conversion parameter,

= 1 if equation is in SI units (meters and seconds)

= 1.4859 if equation is in U.S. Customary Units (feet and seconds)

$n$  = Manning's Hydraulic Roughness Coefficient

$A$  = Area of flow

$R$  = Hydraulic Radius of flow

$S$  = Slope of the Hydraulic Grade Line (if channel bed slope is used,  
the resultant depth from a given discharge is a "normal" depth)

### Area

To calculate channel properties the model assumes: if the depth of water is higher than the left and/or right edge point(s) of the cross-section, a vertical edge wall is assumed at that edge. For this reason it is recommended to make sure each cross-section not only includes points in the river but well out onto the floodplain as well. Each of these properties is shown below (Fig. 6) to better understand what they represent.



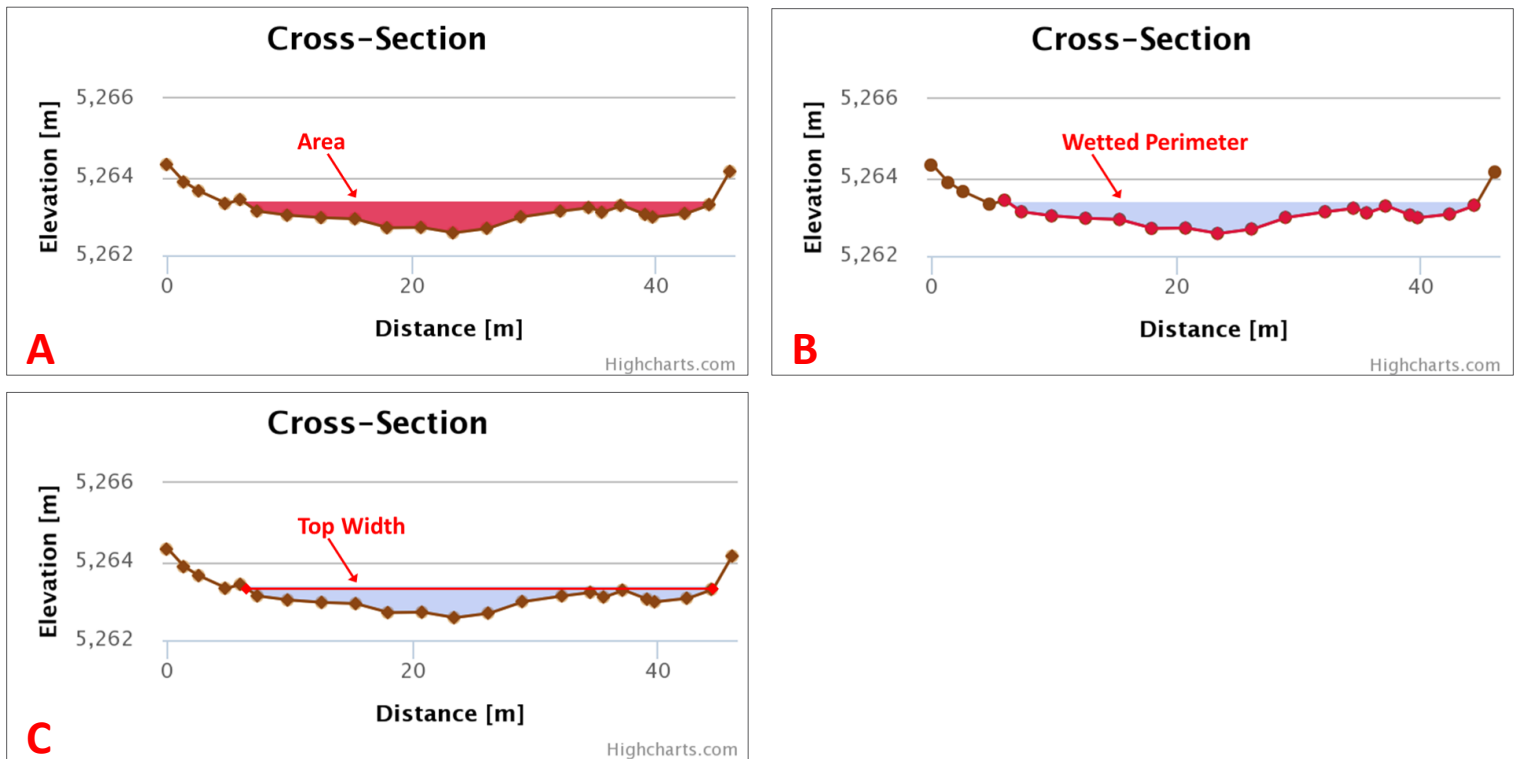


Figure 6: RHST area calculation properties pictured clockwise area (A), wetted perimeter (B), and top width (C).

### Radius and Depth

Hydraulic radius and depth are calculated as follows:

#### Hydraulic Radius:

$$\text{Hydraulic Radius} = \frac{\text{Area}}{\text{Wetted Perimeter}}$$

#### Hydraulic Depth:

$$\text{Hydraulic Depth} = \frac{\text{Area}}{\text{Top Width}}$$

**Disclaimer:** These materials are not intended for final designs, but instead are intended to inform preliminary thinking on hydraulics and guide future analyses. Catena Analytics and One Water Solutions Institute developers are not liable for use of this model (including but not limited to information extracted and results).

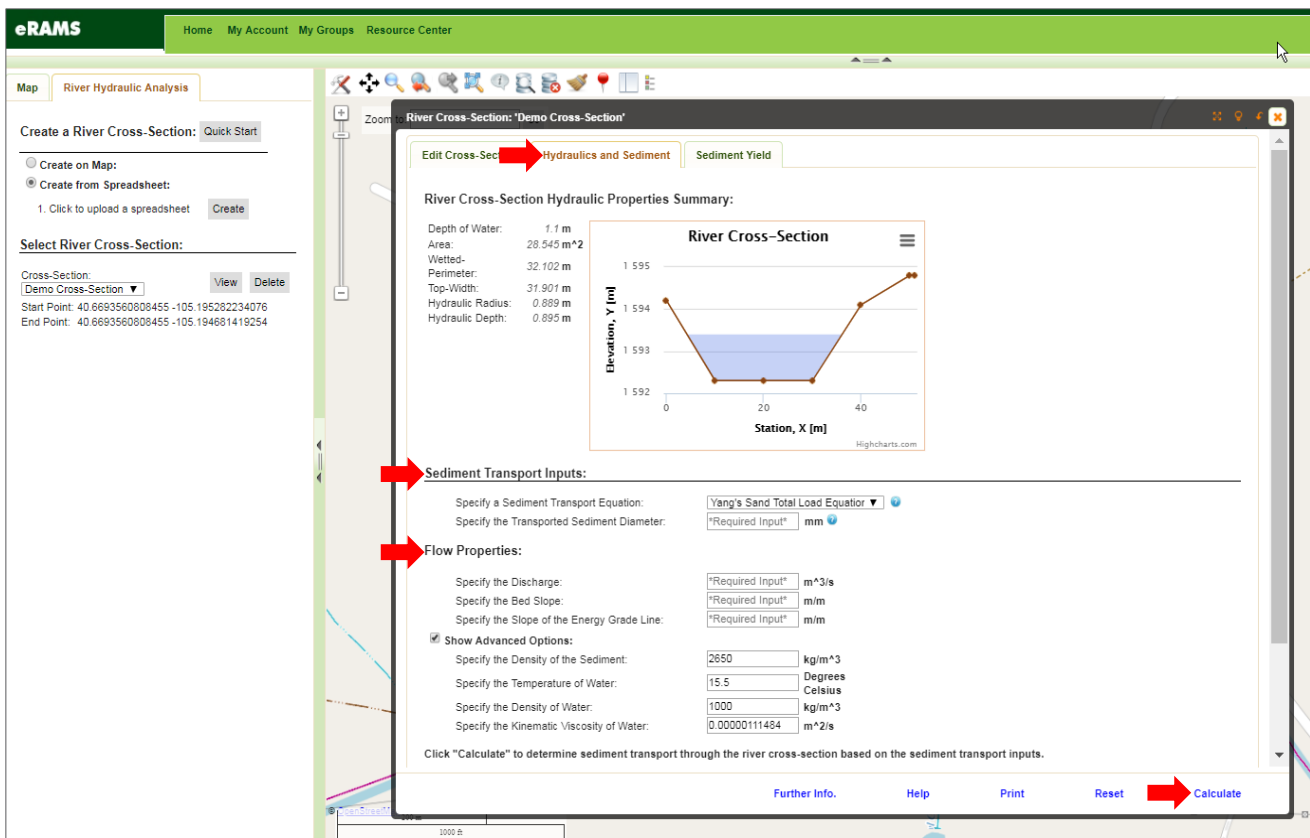
## STEP 3 – CALCULATE SEDIMENT TRANSPORT

Once you have [created a cross-section](#) and [calculated hydraulic properties](#), you can then examine sediment transport.

### Select a Sediment Transport Equation

First select desired sediment transport equation (described in detail below) and specify the required inputs. Click "Calculate" to complete the sediment transport analysis. Descriptions, calculations and model assumptions follow in the subsequent sections.

**Note:** advanced options are available to specify the density of the sediment, water temperature and density as well as the Kinematic Viscosity of the water.



**eRAMS** Home My Account My Groups Resource Center

**Map** River Hydraulic Analysis

Create a River Cross-Section: Quick Start

☐ Create on Map:

☒ Create from Spreadsheet:

1. Click to upload a spreadsheet **Create**

Select River Cross-Section:

Cross-Section: Demo Cross-Section **View** **Delete**

Start Point: 40.6693560808455 -105.195282234076

End Point: 40.6693560808455 -105.194681419254

**River Cross-Section: 'Demo Cross-Section'**

Edit Cross-Section **Hydraulics and Sediment** Sediment Yield

River Cross-Section Hydraulic Properties Summary:

Depth of Water: 1.1 m

Area: 28.545 m<sup>2</sup>

Wetted-Perimeter: 32.102 m

Top-Width: 31.901 m

Hydraulic Radius: 0.889 m

Hydraulic Depth: 0.895 m

**River Cross-Section**

Elevation, Y [m]

Station, X [m]

**Sediment Transport Inputs:**

Specify a Sediment Transport Equation: Yang's Sand Total Load Equation

Specify the Transported Sediment Diameter: \*Required Input\* mm

**Flow Properties:**

Specify the Discharge: \*Required Input\* m<sup>3</sup>/s

Specify the Bed Slope: \*Required Input\* m/m

Specify the Slope of the Energy Grade Line: \*Required Input\* m/m

☒ Show Advanced Options:

Specify the Density of the Sediment: 2650 kg/m<sup>3</sup>

Specify the Temperature of Water: 15.5 Degrees Celsius

Specify the Density of Water: 1000 kg/m<sup>3</sup>

Specify the Kinematic Viscosity of Water: 0.00000111484 m<sup>2</sup>/s

Click "Calculate" to determine sediment transport through the river cross-section based on the sediment transport inputs.

**Calculate**

Figure 7: Sediment transport inputs

### Total Load Equations

Total load equations are typically used on fine grain sand-bed rivers because they calculate the total sediment transported in the water column. The total load equations for fine grain and sand bed rivers are:

- [Yang's Sand Total Load Equation \(1996\)](#)

- [Brownlie's Total Load Equation \(1981\)](#)
- [Power-Function Rating Curve](#) (derived from a separate analysis)

Yang's Sand Total Load Equation (1996)

One choice for sediment transport is Yang's (1996) sand total load sediment transport equation. The sediment transport equation and parameter descriptions are shown below.

**Note:** when using Yang 1996 the model assumes the fall velocity of the sediment particle is calculated using [Rubey's Formula \(1933\)](#), shown below:

$$\log C_{ppm} = 5.435 - 0.286 \log \left( \frac{\omega d_s}{\nu} \right) - 0.457 \log \left( \frac{u_*}{\omega} \right) + \left( 1.799 - 0.409 \log \left( \frac{\omega d_s}{\nu} \right) - 0.314 \log \left( \frac{u_*}{\omega} \right) \right) * \log \left( \frac{VS}{\omega} - \frac{V_c S}{\omega} \right)$$

Where:

$C_{ppm}$  = concentration of total sediment load being transported in parts – per – million

$\omega$  = fall velocity of a gravel, sand, or silt particle [ft/s]

$d_s$  = diameter of sediment being transported [ft]

$\nu$  = kinematic viscosity of water [ft<sup>2</sup>/s]

$u_*$  = shear velocity [ft/s]

$V$  = velocity of flow in the channel [ft/s]

$S$  = slope of the channel bed [ft/ft]

And dimensionless critical velocity,  $V_c/\omega$ , at incipient motion can be expressed as:

$$\frac{V_c}{\omega} = \frac{2.5}{\log \left( \frac{u_* d}{\nu} \right) - 0.06} + 0.66 \quad \text{for } 1.2 < \frac{u_* d}{\nu} < 70$$

$$\frac{V_c}{\omega} = 2.05 \quad \text{for } \frac{u_* d}{\nu} \geq 70$$

Rubey's Formula for Fall Velocity (1933)

$$\omega = F \left( d_s g \left( \frac{\gamma_s - \gamma}{\gamma} \right) \right)^{0.5}$$

Where:

$\gamma$  = specific weight of water [lbs/ft<sup>3</sup>]

$\gamma_s$  = specific weight of sediment [lbs/ft<sup>3</sup>]

$g$  = gravitational constant [ft/s<sup>2</sup>]

And the parameter F is expressed as:

$F = 0.79$  for  $d_s > 1\text{mm}$  and  $10^\circ\text{C} < \text{water temp.} < 25^\circ\text{C}$

$$F = \left( \frac{2}{3} + \frac{36\nu^2}{gd_s^3(\gamma_s/\gamma - 1)} \right)^{0.5} - \left( \frac{36\nu^2}{gd_s^3(\gamma_s/\gamma - 1)} \right)^{0.5} \quad \text{otherwise}$$

$\nu$  = kinematic viscosity of water [ft<sup>2</sup>/s]

Brownlie's Total Load Equation (1981)

Another choice for a total sediment load calculation is Brownlie's 1981 equation for sediment transport as shown below.

$$C_{ppm} = 9022 \left( \frac{V - V_c}{\sqrt{(G-1)gd_s}} \right)^{1.978} S_f^{0.6601} \left( \frac{R}{D_{50}} \right)^{-0.3301}$$

Where:

$C_{ppm}$  = concentration of total sediment load being transported in parts – per – million

$V$  = velocity of flow in the channel [ft/s]

$d_s$  = diameter of sediment being transported [ft]

$g$  = gravitational constant [ft/s<sup>2</sup>]

$G$  = specific gravity of sediment  $\cong 2.65$

$R$  = the hydraulic radius of the cross – section [ft]

$D_{50}$  = diameter of sediment being transported [ft]

$$\frac{V_c}{\sqrt{(G-1)gd_s}} = 4.596 \tau_{*c}^{0.529} S_f^{-0.1405} \sigma_g^{-0.1606}$$

$S_f$  = slope of the friction grade line [ft/ft]

$$\sigma_g = \sqrt{\frac{D_{84}}{D_{16}}} = \text{a grain size distribution parameter}$$

$D_{84}$  = diameter of 84th percentile sediment in the grain size of sediment [ft]

$D_{16}$  = diameter of 16th percentile sediment in the grain size of sediment [ft]

And Brownlie's (1981) fitted function to the Shields curve can be expressed as:

$$\tau_{*c} = 0.22 Y + 0.06 * 10^{-7.7 Y}$$

$$Y = \left( \frac{\sqrt{(G-1)gD_{50}^3}}{v} \right)^{-0.6}$$

### Bed-Load Equations

Bed-Load equations are typically used on coarse grain rivers like gravel-bed and cobble rivers. The equations in this interface which are bed-load equations for gravel and cobble bed rivers are:

- [Martin and Church's Revisitation of Bagnold's Bed Load Equation \(2000\)](#)
- [Wilcock and Kenworthy's Two-Phase Bed Load Equation \(2002\)](#)
- [Power-Function Rating Curve \(derived from a separate analysis\)](#)

Martin and Church's Revisitation of Bagnold's Bed Load Equation (2000)

A further choice of sediment transport is the bed load equation originally developed by Bagnold (1980) as revisited and modified by Martin and Church (2000) as shown below:

$$q_{bm} = \frac{\text{width}}{\sqrt{(\rho_s - \rho)g}^{0.25}} \left( \frac{d_s^{0.25}}{h} \right) (\omega - \omega_o)^{1.5}$$

Where:

$q_{bm}$  = mass of bedload transport per time for the channel [kg/s]

$\rho_s$  = density of sediment [kg/m<sup>3</sup>]

$\rho$  = density of water [kg/m<sup>3</sup>]

$g$  = gravitational constant [m/s<sup>2</sup>]

$d_s$  = diameter of sediment being transported [m]

$h$  = depth of flow in channel [m]

$\omega = \frac{\rho S Q}{\text{width}}$  = specific stream power in mass per time per unit channel width

$S$  = slope of the channel bed [m/m]

$Q$  = discharge in the channel [m<sup>3</sup>/s]

$\omega_o = (\tau_{*c}(G - 1)d_s)^{1.5} \rho \sqrt{g} \left( 5.75 * \log \left( \frac{12h}{d_s} \right) \right)$  = critical specific stream power

$G$  = specific gravity of sediment  $\cong 2.65$

$\tau_{*c}$  = critical dimensionless shear stress

(equation calibrated with 0.04, so this value is used)

Wilcock and Kenworthy's Two-Phase Bed Load Equation (2002)

A further choice of sediment transport is the two-part (sand and gravel) bed load equation developed by Wilcock and Kenworthy (2002) for mixtures of sand and gravel as shown below:

$$q_{bm} = q_{bm_{gravel}} + q_{bm_{sand}}$$

$$q_{bm_i} = width * \rho * \sqrt{(G-1)gd_i^3} * \frac{0.002F_i}{\tau_{*ri}^{7.5}} * \tau_*^9 \quad \text{if } \phi_i < 1.27$$

$$q_{bm_i} = width * \rho * \sqrt{(G-1)gd_i^3} * 115F_i * \left(1 - 0.923 \left(\frac{\tau_{*ri}}{\tau_*}\right)^{0.25}\right)^{4.5} \tau_*^{1.5} \quad \text{if } \phi_i \geq 1.27$$

Where:

$i$  = sand or gravel

$G_i$  = specific gravity of sediment (gravel or sand)  $\cong 2.65$

$d_i$  = diameter of sediment being transported (gravel or sand)[m]

$g$  = gravitational constant [m/s<sup>2</sup>]

$F_i$  = fraction of sediment content (sand or gravel, ranges from 0 to 1)

$\phi_i = \frac{\tau_*}{\tau_{*ri}} = \text{ratio of shear stress to reference shear stress (sand or gravel)}$

$\tau_* = \frac{RS}{(G_i - 1)d_i} = \text{shear stress (sand or gravel)}$

$R$  = the hydraulic radius of the cross – section [m]

$S$  = slope of the channel bed [m/m]

$\tau_{*ri} = \tau_{*ri1} + (\tau_{*ri0} - \tau_{*ri1})e^{-14F_{sand}} = \text{reference shear stress (sand or gravel)}$

$\tau_{*rgravel0} = 0.035 = \text{incipient motion parameter for gravel}$

$\tau_{*rgravel1} = 0.011 = \text{incipient motion parameter for gravel}$

$\tau_{*rsand0} = \tau_{*rgravel0} \left(\frac{d_{gravel}}{d_{sand}}\right) = \text{incipient motion parameter for sand}$

$\tau_{*rsand1} = 0.065 = \text{incipient motion parameter for sand}$

### Power-Function Rating Curve

A cross-section independent choice of sediment transport is a power-function sediment rating curve. This is typically accomplished through a regression on existing gauge data for a stream gauging site to determine the coefficient and exponent of the relationship shown below:

$$Q_s = c * Q^\beta$$

Where:

$Q$  = Discharge in the channel

$Q_s$  = Sediment Transport (in units provided by the user)

$c$  = Power function coefficient

$\beta$  = Power function exponent

### Specify Transported Sediment Size

While there is great variability in the sediment sizes in river channels, some simplified guidance is provided below:

<b>Sediment Name</b>	<b>Size [mm]</b>
Boulder:	> 256
Cobble:	64 - 256
Pebble:	4 - 64
Granule:	2 - 4
Very Coarse Sand:	1 - 2
Coarse Sand:	0.5 - 1
Medium Sand:	0.25 - 0.5
Fine Sand:	0.125 - 0.25
Very Fine Sand:	0.0625 - 0.125
Silt:	0.004 - 0.0625
Clay:	< 0.04

Table 2: Sediment grade and sizes (adapted from Wentworth, 1922)



## STEP 4 - CALCULATE SEDIMENT YIELD

The following operations should be followed to calculate sediment yield. Once required inputs have been completed, click "Calculate" to complete the analysis and generate interactive reports.

1. [Select flow duration curve source](#)
2. [Provide sediment transport inputs](#)
3. [Specify flow properties](#)

### Flow Duration Curve

Users can select a flow duration curve source from gauge station data or use a regional flow duration curve. Alternatively, users can upload their own data to generate the flow duration curve.

#### *Gauge Station or Regional Data*

Click either the "Select a Flow Gauging Station" link (Fig. 8) or "Use Regional Flow Duration Curve" to search for local stream gauging stations and use the flow record to create a flow duration curve of exceedance values for each flow.

1. Search for and select a station
2. Enter dates or select "preview data"
3. Download results or return for use in your sediment yield analysis

#### *Upload File*

To work with this analysis tool the uploaded file must be a two-column, comma separated value (CSV) file, specifically:

- The first row must contain a label for the columns "flow duration curve, flow (cfs)".
- The remaining rows must contain pairs of flow exceedances (column 1) and their associated flows (column 2).
- The units of exceedance are on a percent scale from 0 (the largest flow) to 100 (the lowest flow) and flows should be in cubic feet per second (cfs).

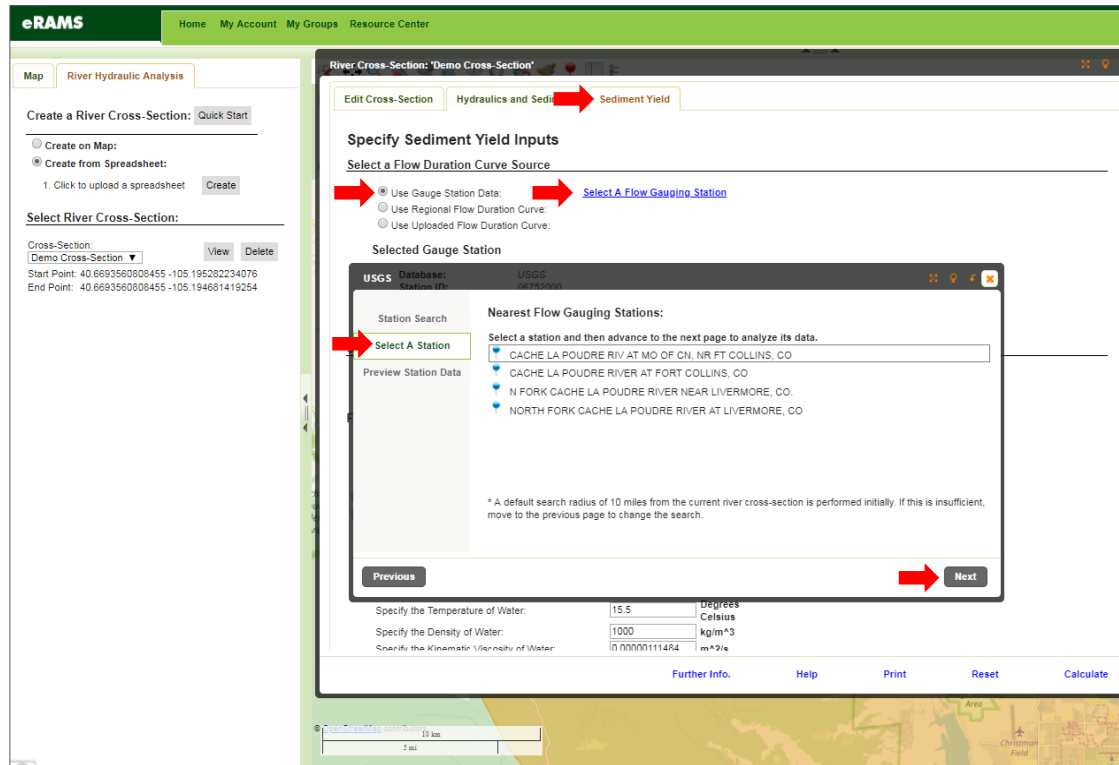


Figure 8: Select gauge station

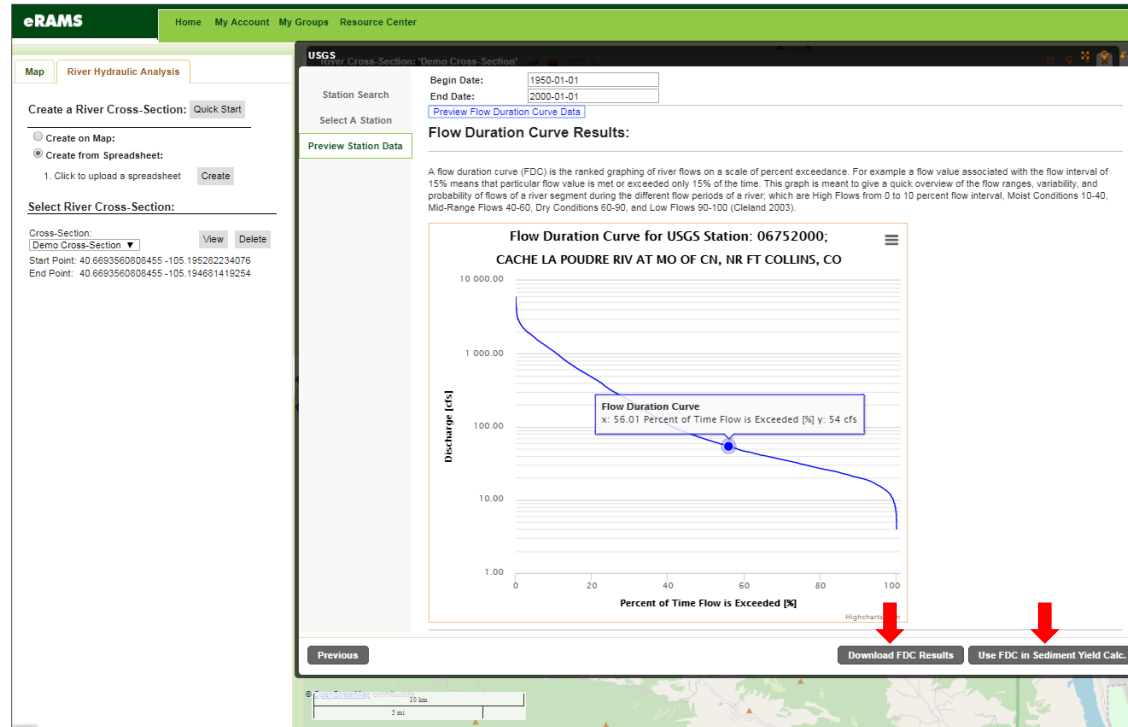


Figure 9: Flow duration curve results with options to download or use in sediment yield calculation

## Sediment Transport Inputs

Users will select a [sediment transport equation](#) and [transported sediment diameter](#) as described in described in [Step 3](#).

## Flow Properties

Users must specify [hydraulic roughness](#), bed slope, bottom width and slope of the energy grade line, depending on which sediment transport equation is selected. Advanced options are available to specify the number of interpolation points on the flow duration curve, the density of the sediment and the temperature, density and Kinematic viscosity of the water as well as the number and type of histogram bins.

## STEP 5 – EXAMINE RESULTS

Each analysis produces a printable interactive report that allows users to download the raw data or an image of the histogram by clicking the “hamburger” menu (three gray lines) in the upper right corner of the graph and selecting the desired file type (pdg, jpeg, pdf, svg, csv, xls).

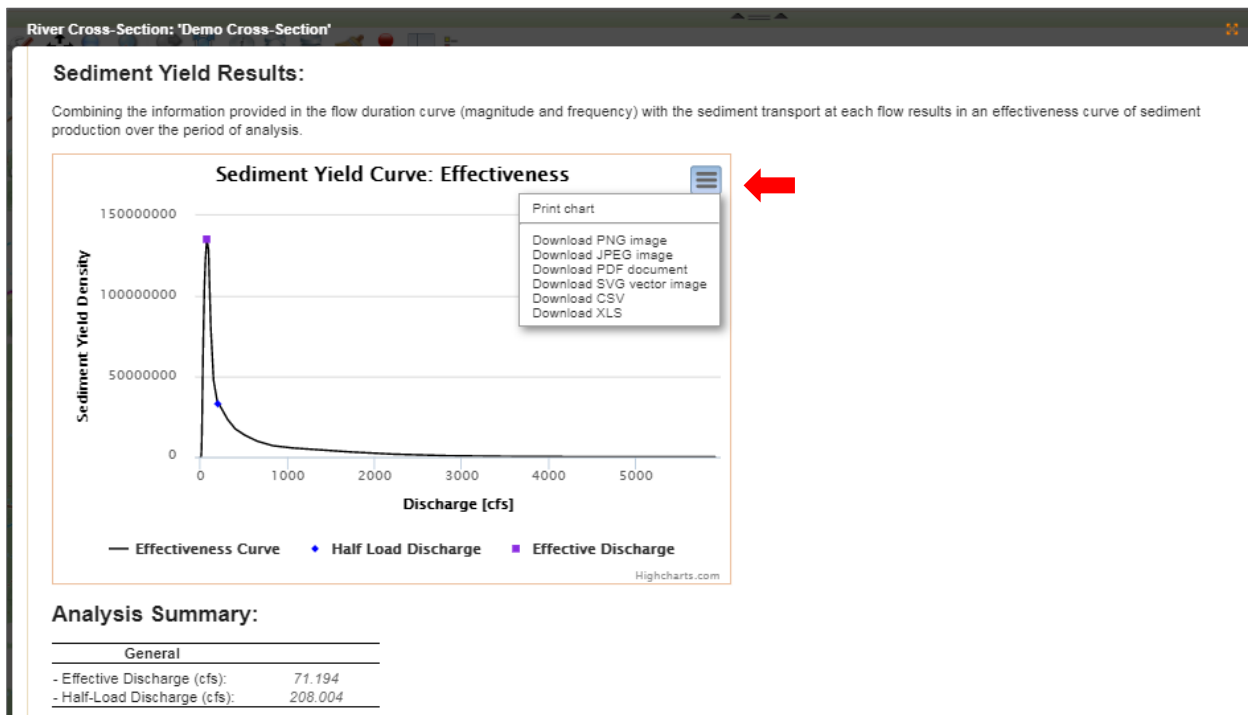


Figure 10: Download analysis results

## Hydraulic Properties & Sediment Transport

The selected river cross-section hydraulic properties are summarized in a printable and/downloadable report as shown below (Fig. 11).

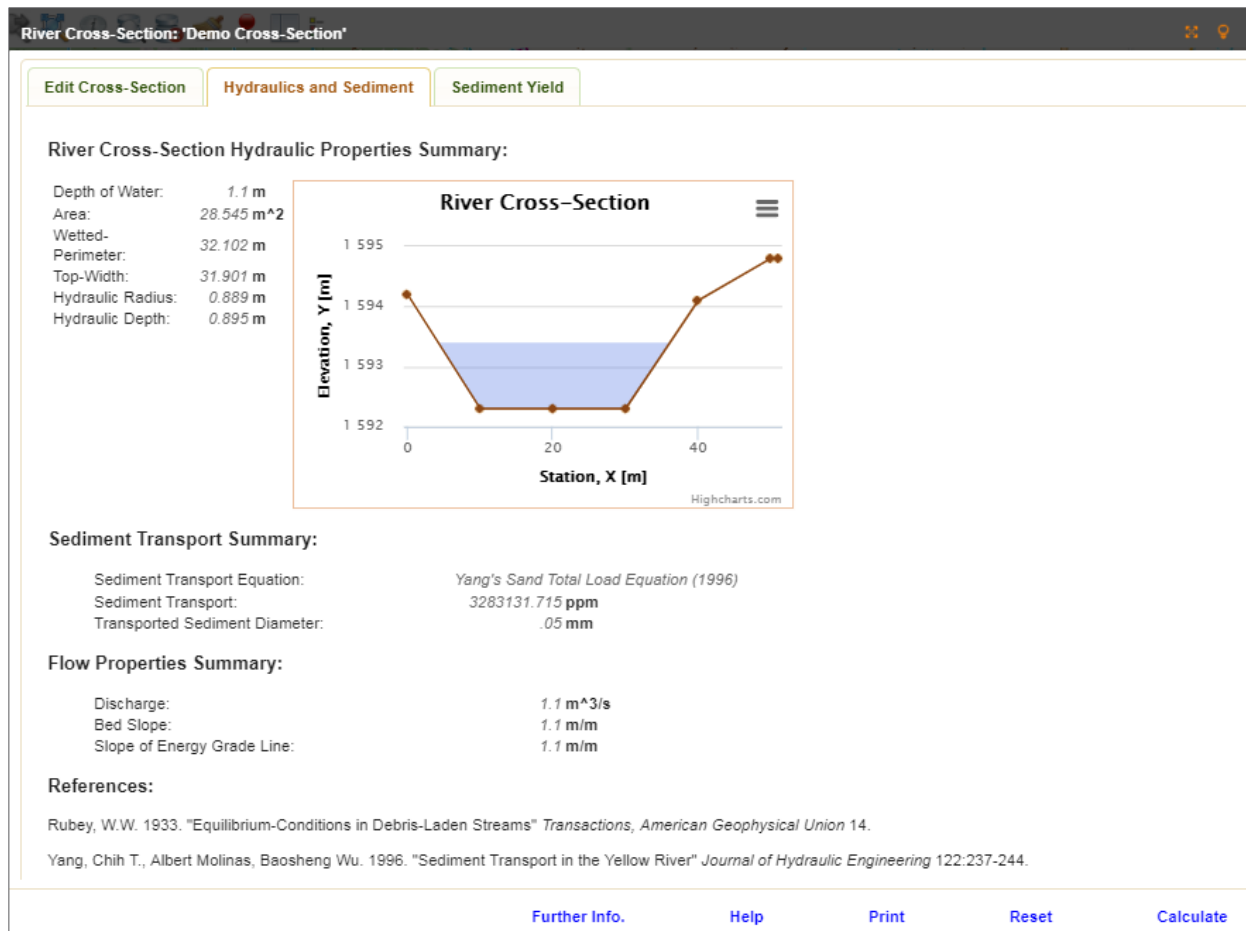


Figure 11: Hydraulic properties summary report

## Sediment Yield Results

The sediment yield analysis produces several interactive summary graphics and tables as described below.

### Sediment Yield Curve

Combining the information provided in the flow duration curve (magnitude and frequency) with the sediment transport at each flow results in an effectiveness curve of sediment production over the specified period.

### Analysis Summary

The effective discharge and half-load discharged are calculated as described below and displayed in the "Cumulative Sediment Yield" graph.

### Effective Discharge

The concept of an 'effective discharge' of a river was introduced by Wolman and Miller (1960) as the stream discharge that transports the most sediment over time. This is based on the argument that over long periods of time, small frequent flows will carry a greater amount of sediment than infrequent large flows. The effectiveness of a river's discharge is determined by multiplying the frequency of flows, probability density function (pdf), with the amount of sediment transported during each flow. The peak of this curve is called the 'effective discharge' although this must be interpreted carefully if the curve is not well defined or has more than one prominent peak.

### Half-Load Discharge

Due to variation in the interpretations and method of calculation of an 'effective discharge', there have been proposals to use new discharge indices to represent sediment transport for stream flows. One such index is the 'half-load discharge' (Klonsky and Vogel; 2011) which is defined as the discharge above and below which half of the total sediment load is transported. Generally, the half-load discharge corresponds to a larger discharge than the effective discharge.

### Flow, Cross-Section Hydraulics, and Sediment Transport

Both the calculation of an effective discharge and a half-load discharge require an estimate of sediment transport at each flow as well as hydraulic properties like cross-sectional area and hydraulic radius. Rather than calculate this for each flow on record, a number of points (default 50, but can be changed under advanced options) are interpolated from the flow record. This interpolation may be linear or log interpolated between the maximum and minimum flows based on the user selection under advanced options.

Then for each interpolated flow, a normal depth is assumed based on the cross-section and hydraulic roughness and other necessary hydraulic properties for the specified sediment transport relationship are calculated. A histogram of these bin-ned flows (based on the limits of the interpolated points) is also provided as output.

### Flow Histogram

All data is summarized in the flow histogram.

### Rating Curves

For each flow provided in the flow duration curve, the normal-depth hydraulic properties of the flow are calculated for the river cross-section. A summary of the resulting rating curves for the river cross-section's hydraulic properties and sediment transport are provided in the following categories:

- Normal depth
- Cross-sectional area
- Hydraulic radius
- Sediment transport

### Rating Curves:

For each flow provided in the flow duration curve, the normal-depth hydraulic properties of the flow are calculated for the river cross-section. A summary of the resulting rating curves for the river cross-section's hydraulic properties and sediment transport are provided below.

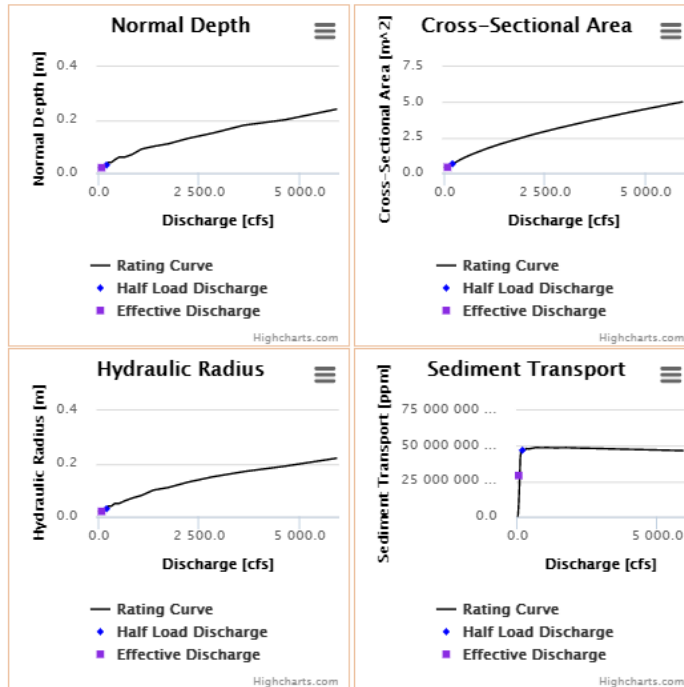


Figure 12: Rating curve summary graphics

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