RiverNET
Community Water QUANTITY Monitoring Protocols

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YERC 2019 field techs Kyle Roberts and Mikaela Howie collecting subsectional depth and velocity measurements on Mill Creek, Upper Yellowstone River Watershed.

INTRODUCTION

These protocols describe the water quality monitoring methods developed by the Yellowstone Ecological Research Center (YERC) for the *RiverNET* Community Science Program. Among

RiverNET's initial goals were to develop a suite of user-friendly, low-cost, fast-turnaround tools and techniques to empower local communities to have an active role in monitoring water quality and quantity. In addition to fostering local participation, the program aims to increase the spatial and temporal resolution of water quality and quantity data at the watershed scale in order to (a) establish current baselines and annual/seasonal trends across important main stem and tributary sites, and (b) identify deviations from those trends that could indicate a water quality impairment event, prompting a focused investigation with additional sampling, community organization, and other responses. As soon as it has passed quality assurance/quality control review, all *RiverNET* data is made publicly available on an online download and visualization platform at www.yellowstoneresearch.org/rivernet, so that local communities can use and act on them in a timely manner.

RiverNET began in 2010 as a collaborative project between YERC and the University of Montana as part of a National Science Foundation-funded EPSCoR proposal, with products including concepts used in the dissertation work of Dr. Brian Hand and the 2018 article he published in Frontiers in Ecology and the Environment, *A social-ecological perspective for riverscape management in the Columbia River Basin*. In 2017, those concepts were applied to the Upper Yellowstone Watershed during YERC's *Envision Yellowstone* conference, a strategic planning meeting of thought-leaders from the private technology sector aimed at identifying the most pressing conservation issues in the Greater Yellowstone Ecosystem as well as solutions using the best available science and technology. The following two summers (2018 and 2019), YERC piloted *RiverNET* in the Upper Yellowstone Watershed in collaboration with local partners including the Park County Environmental Council, Montana Trout Unlimited, Upper Yellowstone Watershed Group, and Angler's West Fly Fishing Outfitters, with support and participation from numerous other local residents, K-12 students, fishing guides, landowners, and businesses.

Upon completion of the pilot program and in fulfillment of *RiverNET*'s long-term goals, it now seeks to ensure that (a) all protocols and procedures involved in project design, sample collection, analysis, data management, and data interpretation, can be managed by local community organizations with minimal scientific training, and (b) the program is capable of being scaled and transferred to other watersheds beyond the Upper Yellowstone, so that other communities and watersheds can benefit from the work as well as join *RiverNET*'s online data access and visualization network.

RiverNET's water *quantity* monitoring objectives complement its water *quality* monitoring objectives by measuring the discharge of tributaries where water quality is monitored. They also complement overall program goals by (a) increasing the spatial and temporal resolution of in-stream monitoring sensors by expanding on the USGS stream gauge network, (b) fostering local participation with Bluetooth-enabled sensors that volunteers can retrieve data from and landowners/local businesses can sponsor, and (c) displaying the data online. With these low-cost, user-friendly sensors and publicly available online visualization platform, we hope *RiverNET*' will become the "Weather Underground® for Rivers".

How to use these protocols:

All content here was originally sourced from manufacturer instruction and from established field procedure manuals cited in **Section X** (References). YERC staff amalgamated these sources to provide a single source for all procedures with simplified step-by-step instructions within the capacity of small-scale local organizations with minimal staff and financial resources, and to include YERC's standard safety protocols. It is applied to the *RiverNET* program in the Upper Yellowstone Watershed, but can serve as a template for any other watershed or community water monitoring program, using the Yellowstone-specific site locations, parameters, and procedures as example placeholders.

To establish new sites in a different watershed, recreate the table described in **Section II.C** (Site Selection/Site Establishment) and displayed in **Appendix B** (*RiverNET* Site Location Database). Most other content should be transferable as is with minimal changes.

This content can be used in whole or in part by any other community water monitoring program. However, **for other programs to be included in the *RiverNET* network, they must follow these protocols exactly, or with modifications approved by YERC program managers**. To be included in *RiverNET*, contact YERC or your participating community watershed organizer responsible for local outreach and coordination, prepare and send the metadata in your Site Location Database, and we will coordinate with you on Data Entry so that your data is included on the *RiverNET* online platform. **We welcome and encourage participation from other organizations in other watersheds**, and will provide technical assistance to get you started.

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I. EQUIPMENT

A. Stream Gauge Site Establishment

- Staff gauge (***n* = 1/site**)
- Steel T-post (***n* = 1/site**)
- Staff gauge mounting hardware:
  - #8 roundhead bolts/nuts (***n* = 2/site**)
  - Marine epoxy

- Rebar stakes (***n*** **= 2/site**)
- Post pounder
- Hand sledge hammer
- Drill
- Fully charged drill batteries (***n*** **= 2**)
- 8mm carbide drill bits (***n*** **= 4**)
- Slip Joint Pliers (***n*** **= 2**)
- Fully charged phone with GPS
- Camera
- Data sheets, clipboard, pens
- Waders, wader boots, wader belt
- PPE (safety goggles, ear plugs, personal floatation device, bear spray, work gloves)

B. **Rating Curve Data Collection**

- Flowmeter
- Depth measuring rod (depth stick)
- 50m transect tape
- Extra batteries for flowmeter
- Ziplock bag full of uncooked rice
- Fully charged phone with GPS
- Camera
- Data sheets, clipboard, pens
- Waders, wader boots, wader belt
- PPE (safety goggles, ear plugs, personal floatation device, bear spray)

C. **Sensor Installation/Operation/Maintenance**

- Onset MX2001 sensor (***n*** **= 1/site**):
  - Data logger
  - Pressure transducer sensor head
  - Cable
  - AA batteries (***n*** **= 2**)
- PVC stilling well (2” diameter, 6’ length; ***n*** **= 1/site**)
- Stilling well cap:
  - Yellow hinged cap
  - Black plastic data logger mount
  - Bolt
- Steel T-posts (***n*** **= 3/site**)
- Post pounder
- Hand sledge hammer
- Drill
- Fully charged drill batteries (***n*** **= 2**)
- 8mm carbide drill bits (***n*** **= 4**)
- 4” hose clamps (***n*** **= 3/site**)
- 6” hose clamps (***n*** **= 3/site**)
- Rubber-coated wire

- Plastic zip ties
- Depth measuring rod
- Data sheets, clipboard, pens
- Waders, wader boots, wader belt
- PPE (safety goggles, ear plugs, personal floatation device, bear spray)
- Fully charged smartphone **with HoboMobile app**

II. SITE SELECTION

A. Watershed Scale

- River (main stem) sites should be chosen for:
  - Consistent spatial distribution relative to other sites on the river (i.e., USGS stream gauges)
  - Adequate distance from tributaries, diversions, and other instream structures that could influence measurements
- Tributary sites, generally located near the mouth of the tributary, should be chosen considering:
  - Consistent spatial distribution across watershed
  - Ecological importance of tributary (e.g., high volume, spawning habitat, thermal refugia)
  - Social impacts or concerns (e.g., offtake for irrigation or urban water supplies, point source contamination)
    - Such tributaries should have stream gauge sites above and below the suspected influence to quantify its impact
  - Representation of the watershed's variable environmental factors (e.g., topography, geomorphology, vegetative cover, land use)

B. Local Scale

- All stream gauge sites (river and tributary) should be:
  - **Safely and legally accessible**
  - Fully within the body of water listed in the site description
  - Not influenced by nearby bodies of water (i.e., > 10m above the stream's mouth, and away from water entering the stream from a tributary)
  - Located **behind a permanent structure** (e.g., bridge pier, boulder) that will protect them from floating debris during spring runoff
- Ideally, they will also be:
  - In a stretch where the stream is **confined** to a single, unbraided channel
  - In a stretch with a **straight flow line** and a **consistent grade** (no sudden drop offs, bends, or backwaters) for 100 yards on either side of the site
  - In a channel with **stable geomorphology** (permanent banks, large heavy substrate with minimal scouring)
  - In the **deepest** part of the channel or a location that is underwater all year
  - Near the main current (**thalweg**)
  - Not influenced by dynamic vegetation or log jams

- **Not on or near known spawning redds** (characterized by fine substrate in subtle eddies -- watch for congregating adult fish in the late spring/late fall and fry in the summer
- In a location that will be **minimally visibly obtrusive** to homeowners or river users
- Whenever possible, immediately downstream of a **concrete control structure** (e.g., weir, culvert, bridge piers)
  - ➢ See Rantz et al. 1982, Chapter 2, for additional guidelines
  - ➢ Not all sites will have all of the above attributes, so
    - A....1. thoroughly scout the area for multiple potential sites,
    - A....2. examine banks/vegetation/high water marks/etc. to think how each site might look at different stream stages, and
    - A....3. use your best judgement to pick the best available site

C. **<u>Stream Gauge Site Establishment</u>**

Once a suitable site is selected:

A.1. Record **metadata** to enter into the [*RiverNET* Site Location Database]:

- A.1.A. **Site ID**: Alphanumeric identifier with (a) first 3 letters of site name, and (b) unique number (e.g., "Yel1")
- A.1.B. **Site Name**: Full name. Make sure that descriptive adjectives such as "upper" and "lower" follow the full name and are separated by columns (e.g., "Mill Creek, upper"), unless they are part of the proper name (e.g., "Upper Deer Creek"). All main stem sites should include the name of the river and a specific location separated by a hyphen (e.g., "Yellowstone River - Gardiner Airport")
- A.1.C. **Latitude**: Decimal Degrees
- A.1.D. **Longitude**: Decimal Degrees
- A.1.E. **Watershed**: Descriptive name of the watershed
- A.1.F. **Tributary?**: Binary (1 = yes, 0 = no) indicating whether river (main stem) or tributary site
- A.1.G. **Water Quality?**: Binary indicating whether water quality samples are collected
- A.1.H. **Water Quantity?**: Binary indicating whether water quantity data are collected
- A.1.I. **Observation Types**: Used for categorizing datastreams
- A.1.J. **Group**: Descriptive name of sites sharing locational attributes
- A.1.K. **Order**: Arrangement of sites within a group
- A.1.L. **Rating Curve; Min Stage; Max Stage**: If applicable, the current rating curve formula calculated for each site and the range of stages for which it is applicable (stage where rating curve produces a discharge of 0 for the minimum, and highest stage recorded in rating table for the maximum)

A.1.M. **Stage:Depth Correction**: Distance, in feet, between 0-level on staff gauge and the stream bed

A.1.N. **Max Channel Width (m)**: Distance, in meters, between the high water marks (monumented with rebar stakes) on either side of the staff gauge in water *quantity* monitoring sites

A.1.O. **Device Serial #s**: Manufacturer serial numbers from any instream monitoring devices

A.1.P. **Device YERC ID #s**: In-house ID numbers from any instream monitoring devices

A.1.Q. **Device Maintenance Logs**: Maintenance logs from any instream monitoring devices

A.1.R. **Notes**: Any important notes pertaining to the site

A.2. Include additional information to help **locate** the site, including:

- Narrative descriptions of the site as well as parking and access info
- Photos of the site from multiple angles
- Clear, hand-drawn map of the site that includes:
  - Parking spot and approach route
  - Important landmarks
  - Exact sample collection site
  - Compass rose
- Anything else that would help future crews locate the site

A.3. **Install** the staff gauge in a protected, continuously submerged, accessible, and minimally visible location, **with the base of the staff gauge (0.00' level) resting on the streambed.** There are two ways to install a staff gauge:

A.1.a. **Pound in a steel T-post** with the flanges perpendicular to the flow line until the flanges are completely buried, drill holes through the T-post that align with the holes on the staff gauge, and attach with bolts and nuts, **OR:**

A.1.b. **Drill holes into a boulder** that align with the holes on the staff gauge, fill the holes with epoxy, and press the bolts through the staff gauge and into the epoxy-filled holes

A.4. **Install** the rebar stakes at the edge of the high water marks on either side of the staff gauge so that these **three points line up perpendicular to the flow line**: these will be used to align the transect tape while recording discharge data.

A.5. On the *RiverNET* Site Location Database, **record** the distance between the stakes in **Column N** (Max Channel Width (m)), and in **Column R** (Notes) record which bank the "initial point" is indicating where future subsection transects should begin

A.6. Open the *RiverNET* Rating Curve Database, open the Site Summary Data tab, create a new row for the new site, and copy the relevant metadata there as well

III. RATING CURVE DATA COLLECTION

A. Overview

In order to convert the stage (i.e., depth) measured by a sensor into discharge (i.e., stream flow), each site must have a "rating curve", which is a formula describing the relationship between stage and discharge. Discharge itself is a relationship between the stream's cross-sectional area and its velocity (Turnipseed and Sauer 2010). We calculate rating curves using 8-10 paired stage:discharge observations recorded across a season's range of flow conditions, from winter base flows just after ice-off to high water during spring run-off. Because rating curves are dependent on channel morphology (e.g., bank erosion that widens the channel will make the same volume of water show a lower stage; sediment deposition that raises the streambed would make the same volume of water show a higher stage), channel morphology must be monitored and validation discharge data must be collected throughout the year that the rating curve was calculated. In subsequent years, validation and/or additional paired stage:discharge observations must be collected in the early season to either refine/recalibrate the existing rating curve, or calculate a new one if conditions have changed so much that the former rating curve is no longer reliable.

When collecting the paired stage:discharge data:

1. Determine which method to record discharge you will use, either:
   - **Subsection Method (Low-Water),** or
   - **Modified Float-Area Method (High-Water),**

   depending on the ability to safely wade across the channel (see **Sections III.B** and **III.C** for details)
2. Record the following on the *RiverNET* Rating Curve Field Datasheet:
   A. **Site Name & Site Location:** Each site is given a unique name and the location of the sensor and transect are recorded using **Latitude** and **Longitude** (recorded in decimal degrees)
   B. **Date and Collection Time:** The date of collection is recorded using the format MM/DD/YYYY as well as the start/end time (24:00) of data collection
   C. **Sample #:** The Sample # is correlated with the date of collection with the first collection date being assigned "A" and each subsequent collection assigned the next consecutive alphabetical letter
   D. **Observer/Recorder/Visitors:** First and Last Initials are used to distinguish field technicians. The observer is the technician assessing the measurements while the recorder is the technician recording the measurements onto the data sheet while in the field. Any visitors at the site during data collection are also recorded
   E. **H_2O Temperature:** Water temperature is measured and using the Flowmeter and recorded to the nearest 1/100th of a degree (F)
   F. **Average Cloud Cover:** Record an estimate of the average cloud cover using the following key:
      P = precipitating
      PC = partly cloudy (25-75%)
      MC = mostly cloudy (>= 75%)
      S = sunny (<25% clouds)
   G. **Stream Stage:** Simply record the depth observed on the staff gauge (in feet, to the 1/100th of a foot)
   H. **Depth at Gauge:** The water depth at the location of the stream gauge is

recorded during each site visit using the depth stick. This offers a reference water depth level over the season and is recorded to the nearest 1/10th of a foot

I. **Sample Protocol: Low H_20 protocol** versus **High H_20 protocol** can be simply checked off according to whether the stream is wadeable and a complete transect is being sampled (Low H_20 protocol) or if the high water conditions exist making it unsafe to wade the stream and only representative depths and velocities are recorded (High H_20 protocol). The same data sheet can be used for both **High H_20 protocol** and **Low H_20 protocol** events. During **High H_20 protocol** events, simply check the appropriate box for protocol type, record all site data, and use the top row to record a representative depth and velocity. The notes section should be used to describe where in the channel the representative depth and velocities were measured

J. **Subsection Data:** Once the site information is completed in the top portion of the data sheet, the following rows should be used to record data for each measured **point** along the transect. Each point correlates with a 1ft wide subsection of the stream and should include the distance to the "initial point" of orientation (see *Site Selection* above), a depth measurement (ft), 1-2 velocity measurements (ft/s) depending on depth, and any notes for the subsection

K. **Additional Notes:** section at the bottom of the datasheet should be used for any general site observations including stream channel obstructions or changes, major weather events, or other observations that may have an impact on data collection

L. **Data Entry:** There is a section at the top of the data sheet to record the initials and of the technician who enters the data electronically as well as the date on which the data is entered

M. **Data Quality Control:** There is a section at the top of the data sheet to record the initials of the technician who performs quality control of the data electronically as well as the date on which quality control takes place.

N. **Site Name & Site Location:** Each site is given a unique name and the location of the sensor and transect are recorded using **Latitude** and **Longitude** (recorded in decimal degrees)

O. **Date and Collection Time:** The date of collection is recorded using the format MM/DD/YYYY as well as the start/end time (24:00) of data collection

P. **Sample #:** The Sample # is correlated with the date of collection with the first collection date being assigned "A" and each subsequent collection assigned the next consecutive alphabetical letter

Q. **Observer/Recorder/Visitors:** First and Last Initials are used to distinguish field technicians. The observer is the technician assessing the measurements while the recorder is the technician recording the measurements onto the data sheet while in the field. Any visitors at the site during data collection are also recorded

R. **H_2O Temperature:** Water temperature is measured and using the

Flowmeter and recorded to the nearest $1/100^{th}$ of a degree (F)

S. **Average Cloud Cover:** Record an estimate of the average cloud cover using the following key:
   - **P** = precipitating
   - **PC** = partly cloudy (25-75%)
   - **MC** = mostly cloudy (>= 75%)
   - **S** = sunny (<25% clouds)

T. **Stream Stage:** Simply record the depth observed on the staff gauge (in feet, to the $1/100^{th}$ of a foot)

U. **Depth at Gauge:** The water depth at the location of the stream gauge is recorded during each site visit using the depth stick. This offers a reference water depth level over the season and is recorded to the nearest $1/10^{th}$ of a foot

V. **Sample Protocol: Low $H_2$0 protocol** versus **High $H_2$0 protocol** can be simply checked off according to whether the stream is wadeable and a complete transect is being sampled (Low $H_2$0 protocol) or if the high water conditions exist making it unsafe to wade the stream and only representative depths and velocities are recorded (High $H_2$0 protocol). The same data sheet can be used for both **High $H_2$0 protocol** and **Low $H_2$0 protocol** events. During **High $H_2$0 protocol** events, simply check the appropriate box for protocol type, record all site data, and use the top row to record a representative depth and velocity. The notes section should be used to describe where in the channel the representative depth and velocities were measured

W. **Subsection Data:** Once the site information is completed in the top portion of the data sheet, the following rows should be used to record data for each measured **point** along the transect. Each point correlates with a 1ft wide subsection of the stream and should include the distance to the "initial point" of orientation (see *Site Selection* above), a depth measurement (ft), 1-2 velocity measurements (ft/s) depending on depth, and any notes for the subsection

X. **Additional Notes:** section at the bottom of the datasheet should be used for any general site observations including stream channel obstructions or changes, major weather events, any observations of conditions that may have an impact on data collection, or any other observations relevant to watershed ecology, the overall study/program, general ecology, or anything else of interest

Y. **Data Entry:** There is a section at the top of the data sheet to record the initials and of the technician who enters the data electronically as well as the date on which the data is entered

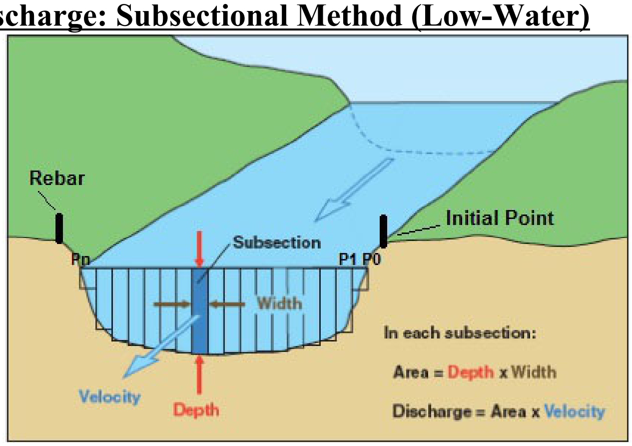
Z. **Data Quality Control:** There is a section at the top of the data sheet to record the initials of the technician who performs quality control of the data electronically as well as the date on which quality control takes place

- General considerations for rating curve data collection:
  - DO NOT wade into deep, swift water -- **if you are starting to feel unsafe,**

you have already gone too far**

- Before entering any water, take some time to **observe** the stream for snags and other **floating hazards** -- DO NOT enter any water when there is **any** risk of floating hazards
- If you determine water conditions to be unsafe/unwadable, you can always:
    a. Employ the High-Water Protocols, or, if necessary
    b. Choose to not collect data -- **NO DATA IS WORTH PUTTING LIVES AT RISK!** If you do not complete assigned data collection objectives for any reason, **please notify your supervisor right away**
- Take care of the field datasheets in the wet environment, using waterproof paper (e.g., Rite in the Rain) when necessary
- Use a dark pen (**NOT pencil**) and **write legibly** on the datasheet
- Next to crew safety, take care of the safety of the **electronic flow meter**:
    - ➢ Don't drop the reader in the water, and if you do, remove the batteries, keep the battery door open, and put the unit in the bag of uncooked rice IMMEDIATELY
    - ➢ Be careful of the propeller blades, avoid allowing them to strike rocks on the stream bed, and keep an extra blade on hand
    - ➢ When transporting the flow meter, load it carefully in the vehicle so neither the reader, propeller, or any other part will get damaged by any other equipment or people loading in or out of the vehicle

B. Discharge: Subsectional Method (Low-Water)



USGS Water Science School

When the **ENTIRE** channel is safely wadable:

B.1. **Run** the transect tape between the two rebar posts, making sure it is both **taut** and **perpendicular** to the flow line. You will use the transect tape to define your data collection points (subsections), spaced **every foot** for channels (Michaud and Wierenga 2005)

B.2. **Measure** the stream width from high water mark to stream edge to stream edge using the transect tape and record to the 1/10th of a foot on the datasheet

B.3. Starting on one end of the channel, **establish** the first observation point (Point 0) at the edge of the water at the "initial point" of orientation established during transect setup and gauge installation. R**ecord** the distance between **Point 0** and the nearest rebar stake (the **"initial point"**). Using the Flowmeter, measure and record the depth in feet to the nearest 1/100th of a foot and 1-2 velocity measurements as detailed below (Turnipseed and Sauer 2010):

- If the depth is < 2', **record** one velocity measurement at a depth of 0.6 * total depth, and **enter** this SAME observation in BOTH velocity fields ("Velocity1", "Velocity2")
- If the depth is > 2', **record** one velocity measurement at a depth of 0.2 * total depth, **enter** it under "Velocity1", **record** another velocity measurement at a depth of 0.8 * total depth, and **enter** it under "Velocity2".
    - * See table below for approximate velocity measurement depths.
- When measuring velocity, make sure that the observer is standing ~1-3' DOWNSTREAM of the transect tape, and ~1.5' TO THE SIDE of the flow line so as not to influence the velocity measurement.

Total Depth	Velocity 1	Velocity 2
0.5	0.3	NA
1	0.6	NA
1.5	0.9	NA
2	1.2	NA
2.5	0.5	2
3	0.6	2.4
3.5	0.7	2.8
4	0.8	3.2
4.5	0.9	3.6
5	1	4

B.4. **Move** to the next observation point (Point 1; 1 foot away from Point 0 for channels), and **record** the distance from the initial point, the depth (in feet, to the nearest 1/100th of a foot), **Repeat** Step 3, **recording** observation points (Point *n*), distances from the initial point, depths, and velocity measurements up to the last possible observation point at the stream edge on the opposite bank

B.5. **Record** any additional observations in the "Notes" column for each subsection (e.g., observed changes/disturbances since the previous data collection period, relative water clarity, staff gauge condition, aquatic vegetative growth, spawning trout observed, problems/obstacles that hampered data collection, etc.)

B.6. **Repeat** Steps 1-6 for subsequent data collection events (approximately 10 in total) distributed between low- and high-flow stream conditions, filling out a separate datasheet for each data collection interval. For consistency, it is best to have the same technician acting as "observer" as well as that the same technician acts as "recorder" for each interval

B.7. **Enter** the data in the digital database as soon as possible following data collection along with a symbol indicating which method was used ("L" for Low Water), and

file the hardcopy datasheet in the "Rating Curve Data 2019" file folder

B.8. **Calculate** the area of each subsection by simply multiplying the depth(ft) measurement recorded at each subsection by the subsectional width (1ft for all subsections)

B.9. **Determine** the discharge for each subsection by multiplying the calculated area(ft^2) for a subsection by the velocity(ft/s) measurement recorded for the same subsection. When 2 velocity measurements are taken for a subsection, the calculated average is used to determine subsectional discharge.

B.10. **Sum** all subsectional discharges together to determine the **Total Discharge** for the transect for each data collection event

C. **<u>Discharge: Modified Float-Area Method (High-Water)</u>**

When any part of the channel is not wadable, there is any risk of floating hazard, or entry into the water is unsafe for any other reason:

1. **Reference** the width and subsectional data from the last data collected under the Subsection Method (Low Water) to establish (a) whether there are new wetted subsections on either side of the channel, and (b) the previous cross-sectional area.
2. **Calculate** the **new cross-sectional area** [A] of the channel by **(a)** calculating the areas of the new subsections following the standard method (depth * subsection width), **(b)** calculating the ***difference*** between the current stage height and the previous stage height **(c)** multiplying that difference by the previous channel width, and then adding that product to the previous cross-sectional area, and **(d)** summing all these areas together.
3. For velocity, use the Flowmeter to record a **representative velocity** measurement [V] from a safely accessible section of the current that is representative of the average of the channel current. Measurements will be taken as close to the surface as possible, allowing for full submersion of the propellor blades.
4. Based on the average water depth (the new cross-sectional area from Step 2 above divided by the number of subsections) **select** the appropriate roughness coefficient [c] from this table:

Coefficients for Converting Float Velocity to Mean Channel	
Avg. Depth (ft)	Coeff.
1	0.66
2	0.68
3	0.7
4	0.72
5	0.74
12	0.78
Source: USBR Water Measurement Manual (1997)	

5. **Calculate** the discharge [Q] by multiplying the new cross-sectional area, the representative velocity, and the roughness coefficient (Q=A*V*c). Record this discharge value, along with a symbol indicating which method was used ("H" for High Water), the calculated average depth, and the roughness coefficient used in the appropriate columns on the database

IV. RATING CURVE DATA MANAGEMENT & ANALYSIS

A. Data Entry

A.1. Open the RiverNET Rating Curve Database

A.2. Open the tab for the site where data was collected, or create a new one if this is the first time entering data for a new site

A.3. Copy data from the field data sheet into the relevant fields on the database, with one row for each subsection, entering **NA** in any cell with no data available

A.4. Assign an alphabetic sample ID (in sequence starting at A) for the data collected that day in **Column N** (Samples), and copy that ID across all rows for that day

A.5. Select the *last* cells entered for the previous data collection event in **Columns U,V,** and **W** (Avg. Velocity, Subsection Area, and Subsection Discharge), and drag them down through *all* the rows you just entered to copy and apply their automatic formulas to the new data

A.6. Select the *first* cells entered for the previous data collection event in **Columns X** and **Y** (Total Discharge, Cross Section Area), copy them, and paste them in the *first* row of data you just entered to copy and apply their automatic summation formulas. Copy the *values* (NOT the formulas) in the remaining rows

A.7. Upon completion, the data enterer will put their initials in **Column AC** (Data Enterer)

A.8. Immediately after entering the data, a separate tech must review the entered data, compare them to the field data sheets, make any corrections (and note them in the Notes section), and adjust any formula results (as needed). Once the new data has completed Quality Control, that tech will enter their initials in **Column AD** (Data

QC).

A.9. Open the **Stage-Discharge Data** tab, and copy the Site Name/ID, Date, Sample ID, Protocol Type, **Stage**, **Total Discharge**, and Notes from the newly entered data -- these are one set of the paired stage:discharge data that, at the end of the season after 3-10 sets of stage:discharge data are collected, will be used to calculate the site's rating curve

B. Quality Assurance/Quality Control

Considering the high volume of data to be collected and entered throughout this process, there is a high likelihood of mistakes. In addition to the data entry review in **Step 8** above, ensure that all data on the Stage-Discharge Data tab is both (a) accurate relative to the data entered in the individual site location tabs, and (b) reasonable considering expected stage and discharge values relative to other sites and previous data from that site. In addition:

- Keep all sources of data on hand for a thorough review
- Have multiple techs independently review entries and results
- Keep hard copies of datasheets on file in the office, and backup digital copies (including photos of the field data sheets) on multiple mediums, at least one of which must be offsite (i.e., cloud storage)
- Record thorough notes on any questions/issues/concerns
- Take your time when entering and reviewing data: if you start to feel bored, tired, or distracted, take a break
- **Accurate data entry, and a thorough review for QA/QC, are essential for this and all other YERC projects!**

C. Rating Curve Analysis [SUBJECT TO REVISION]

After ~8 stage:discharge observations representing the full scale of stage levels have been collected for the season (some observations, though collected on widely space dates, may be redundant with previous observations, so keep an eye on the weather and stage at nearby USGS stream gauges when planning field work:

1. Save the Stage-Discharge Tab in the RiverNET Rating Curve Database as a comma-separated value file (.csv) named "**RatingCurve_FINAL.csv**" into a file on your *desktop* named "**RatingCurve**"
2. Download and install up-to-date versions of RStudio and R from the Internet (unless you already have them installed)
3. Open RStudio, copy/paste the R code from **Appendix E** into the upper left quadrant of the RStudio interface, and adjust the code with the site names under "### subset by site" as needed, using existing code as a template
4. Save the R file as "**RatingCurve_R**" in the RatingCurve folder
5. Select the entire body of code (by either quadruple clicking one of the lines, or by clicking the front of the first line and dragging your cursor through the last line while holding Shift)
6. Run the code (by either pressing Ctrl+Enter on a PC, or by clicking the Run button with the green arrow icon above and center-right of the RStudio code dialogue window (upper left quadrant)

7. Scroll through the RStudio console window (lower left quadrant) to reach the "##### Simple Linear Regression #####" section, find the summary report for each site, and under the "Coefficients:" heading, copy down the Estimates for the Intercept (EI) and the Stage (ES); continue scrolling through the report, and copy down the Adjusted R-squared value (RS)
8. Write out the formula for each site as **y = EI + ES*x** with y being discharge and x being stage. **THIS IS THE SITE'S RATING CURVE FORMULA**
9. Copy the formula into **Column L** of the *RiverNET* Site Location Database for that site's row
10. Returning to the R Code, scroll down to the "##### Plots #####" section, adjust the formulas and R2 (aka R-Squared) values written in the *main="*... command for that site's plot and/or use an existing group of code to start a new plot for a new site
11. Select and run the entire body of code again (see Steps 5-6), drag the edges of the RStudio plot window (lower right quadrant) to expand it to fill your whole screen, then export the plot by:
    a. Clicking "Export" on top of the plot window, and selecting "Save as image…"
    b. Clicking the "Directory" button in the resulting popup box, and browsing to/selecting the RatingCurve folder, then clicking "Open"
    c. Changing the file name to correspond with the plot title
    d. Clicking "Save"
12. Use the arrows to move to the next plot, and repeat steps 11a-11d
13. Review the plots to ensure that the plotted line closely follows the individual data points, examine any data points that are far off the line for errors and consider removing them if justified (i.e., there is an obvious error). If the plotted line does not fit the points well or the R-squared value is less than 0.5, consider using a more complex model than Simple Linear Regression

V. SENSOR INSTALLATION/OPERATION MAINTENANCE

A. Sensor Installation

At the **exact same location** where the staff gauge was installed:

1. Pound in 3 T-posts in a triangular configuration, with the flanges completely buried in the streambed and each post ~4-6 inches away from the next
2. Drill ~24 holes in the PVC stilling well, with 4 vertical rows of 6 holes
3. Insert the yellow well cap in the top of the PVC stilling well, and place the bottom on the streambed within the triangle of T-posts
4. Use the hose clamps and/or wire to tighten the T-posts around the PVC stilling well, ensuring that all are well anchored

5. Open the well cap, remove the black plastic data logger mount, carefully remove the bolt (don't drop it in the water), and use the bolt to attach the circular top of the Onset MX2001 data logger (with the AA batteries already installed back at the truck
6. Run out about 3 feet of cable from the sensor head to the data logger, coil up the rest, and zip tie the coil to the data logger
7. Hang the sensor head down into the stilling well, making sure that it is several inches up from the streambed -- adjust the cable length as necessary
8. Reinsert the black data logger mounting cap (with the data logger attached) into the stilling well, and close the cap
9. Open the HoboMobile app on your smartphone (make sure Bluetooth is enabled), wait for the app to detect the sensor, and click on the sensor when it does
10. Open the Configure menu (with the wrench/screwdriver icon) and set:
    a. Units (temperature = degrees fahrenheit, depth = feet)
    b. Time Interval (1 hour)
    c. Reference Depth (current staff gauge reading)
    d. Site name
11. Save the settings, and start logging
12. **Record the Reference Depth in the Notes section of the RiverNET Site Location Database.** This must be recorded/updated any time the reference depth is changed (i.e., during calibration or if the staff gauge was moved or adjusted for any reason)
13. Update the Hobo MX2001 Water Sensor Log with the sensor's serial numbers, location information, reference depth, etc.

B. **Sensor Operation**

1. *Download* and install the HoboMobile app, and *enable* the Bluetooth and WiFi functions on your phone
2. *Configure* the HoboMobile app:
    2.a. Click the "Settings" icon from the lower menu on the opening screen
    2.b. Click "HOBOlink"
    2.c. Flip the switches next to "Upload Data" and "Wi-Fi only" (the switches will show blue when activated), then click on "Account" and enter "rivernet" for both the Username and Password– this enables auto data uploads
3. *Connect* to any sensor within 100 feet range by:
    3.a. Giving the app a minute to scan for devices, then clicking on the sensor that pops up
    3.b. After connecting, click the "Readout" icon, then "Data Files" on the lower menu
    3.c. A plot will pop up showing the hourly depth (blue) and the temperature (black) readings since the sensor was installed. Click on the plot, then click the download icon in the upper right

3.d. In the next page, select “CSV comma separated values”, and then click your phone’s email icon, and email it to rivernet@yellowstoneresearch.org – this is a redundant, fail-safe measure so that we can get the data if the HOBOlink function fails. You could repeat this step and email it to yourself or a friend, if interested, otherwise the data file and plot will remain on your phone for future reference

4. *When you get home* (i.e., within WiFi range), turn on HoboMobile and click on Data Files: there will be a cloud icon at the upper right corner of each plot, indicating whether the automatic data upload is complete (green check), pending (gray clock), or failed (red exclamation). If the upload fails, please let us know when you email the data.

C. **Sensor Maintenance**

Periodically check on the sensor *throughout the season* and:

- Remove any debris that is piling up against the T-posts and stilling well
- Check that the reported depth corresponds with the staff gauge, and readjust the reference depth if necessary
- Pull out the sensor and clean the sensor head
- Remove the sensor if it or the stilling well/anchors are compromised in any way
- Record notes and photos of any significant changes to the sensor site or surrounding area that have occurred throughout the season (e.g., log jams, fallen trees, new channels).

At the end of the season (i.e., late October, before the sensor is frozen in place):

- Remove the whole sensor from the stilling well
- Thoroughly clean it
- Remove the batteries
- Store it with the other sensors
- Update the Hobo MX2001 Water Sensor Log

VI. SAFETY

With all YERC projects, **crew safety** is prioritized above project objectives.

- Be careful working around rivers with cold, swift currents
- Be mindful of the weather, and don’t be on the water if thunderstorms are approaching
- Be careful driving to and from collection sites, especially when merging on or off of Highway U.S. 89, which has a speed limit of 70 mph.
- Be careful working on slippery river rocks: a 102-year-old rancher on the nearby Boulder River used to always warn fishermen that “those rocks are a lot harder than you are.”
- Avoid excessive sun exposure, which could result in severe sunburns, heat exhaustion, or heat stroke.
- Be aware of rattlesnakes: don’t put your hands or feet anyplace you can’t see.

- Wear Personal Protective Equipment (goggles, ear protection, gloves) when installing T-posts so as to protect your eyes and ears from metal shards and loud sharp noise
- Wear a Personal Flotation Device when wading in the water, and carry bear spray at all times
- You have both the **right** and the **responsibility** to shut down any operation that you feel is unsafe or that you are otherwise uncomfortable with. Contact the project manager with any concerns immediately.
- **Review additional field safety information in Section IX of the RiverNET Community Water QUALITY Monitoring Protocols**

Also, please be courteous and respectful of other river users, interacting with them and answering questions as best you can.

VII. REFERENCES

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Turnipseed DP, Sauer VB. 2010. Discharge measurements at gaging stations. United States Geological Survey Techniques and Methods book 3, chapter A8. Available at: https://pubs.usgs.gov/tm/tm3-a8/ (February 2019).

VIII. GLOSSARY

Cross-sectional Area: the two-dimensional area of the entire stream channel from along the transect line. It is delineated by stream edge to stream edge and water surface to stream bed across the transect. The cross-sectional area is comprised of multiple subsectional areas described below (see subsectional area).

Data Quality Control: refers to comparing hard copy datasheets and notes to the electronic database and correcting and data entry mistakes using the hard copy data sheets as the reference.

Depth: Distance between streambed and water surface, used here for subsection data

Depth Measuring Rod: synonymous with depth stick used to take water depth measurements. The rod is a 5' long PVC pipe delineated with 1/10th of a foot, ½ foot, and foot increments using differentiating colors.

Discharge: volume of water flowing past a given point, measured in cubic feet per second, used here for subsection data

Flow: synonymous with discharge

Flowmeter: consists of a display unit, probe and propeller and records H_20 temperature and water flow velocity. Measurements can be set to display average, maximum, and/or minimum.

Google Drive: a cloud storage service from Google that lets users store and synchronize digital content across computers, laptops and mobile devices, including Android-powered tablet and smartphone devices.

High Water Mark: the point on a stream bank reached at maximum water capacity for the channel.

Initial Point of Orientation: Start of transect where subsectional data is collected.

Max Channel Width: the width of the stream channel at maximum capacity, or high water to high water mark on each bank.

Rating Curve: A formula describing the depth:discharge relationship at a given point on a given stream, used to convert depth observations from stream gauge equipment to discharge estimates.

Representative Velocity: A single velocity measurement taken in a section of stream that is safely accessible and representative of the average velocity of the stream, used during high water.

Staff Gauge: Metal measuring device with 1/100th foot graduations, used to monument stream gauge site and record stage.

Stage: Water level as measured on the staff gauge (a relative measure, different from actual depth).

Stream Gauge: Location and equipment where water quantity information is collected.

Stream Width: Distance across wetted area of channel during a given data collection event.

Subsection: Unit of the channel with a set width for which area and velocity are measured, summed for total channel area and discharge.

Subsectional Area: Width by depth of a given subsection.

Total Discharge: Discharge um of subsectional discharge.

T-post: Steel fencing post used to anchor staff gauges.

Winter Base Flow Conditions: Annual low water depth recorded at staff gauge during installation in early spring.

IX. APPENDIX

A. **2019 Final Report to Montana Fish, Wildlife and Parks and Sweet Grass Conservation District for rating curve work in the Upper Yellowstone Watershed** (example image- click for ling; also available online at www.yellowstoneresearch.org/rivernet)

YELLOWSTONE ECOLOGICAL RESEARCH CENTER

YELLOWSTONE ECOLOGICAL RESEARCH CENTER

Final Report
Headwaters Project – FWP Contract # FWP19-0148

Completed by Yellowstone Ecological Research Center (on behalf of Sweet Grass Conservation District)
Patrick Cross -- research director, project manager
Mikaela Howie -- assistant lab manager
Spencer Link -- lead field technician
Robert Crabtree -- executive director, chief scientist

July 30, 2019

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B. ***RiverNET* Site Location Database** (example image-click for link)

Site ID	Site Name	Lat	Long	Watershed	Tributary?	Water Quality?	Water Quantity?	Observation Types	Group	Order	Rating Curve; Min Stage; Max Stage	age:Depth Correction (fe	Devices Serial #s	Device YERC ID #s	:e Maintenance	Notes
Gar1	Gardiner River	45.02905	-110.70039	Upper Yellowstone Watershed	1	1	0	WaterQuality	Yankee Jim Tributaries	1	NA	NA	NA	NA	NA	NA
Yel1	Yellowstone River - Gardiner Airport	45.0445	-110.73794	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	1	NA	NA	NA	NA	NA	NA
Lan1	Landslide Creek	45.04554	-110.74589	Upper Yellowstone Watershed	1	1	0	WaterQuality	Yankee Jim Tributaries	2	NA	NA	NA	NA	NA	NA
Yel2	Yellowstone River - Corwin Springs Fishing Access	45.10781	-110.79016	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	2	NA	NA	NA	NA	NA	NA
Mul1	Mulherin Creek	45.12792	-110.80634	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	Yankee Jim Tributaries	3	-141.78+171.32x; 0.83; 1.3	0	20668424	MX2001-9	https://docs.goo	NA
Ced1	Cedar Creek	45.14327	-110.81286	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	Yankee Jim Tributaries	4	-13.34+79.45x; 0.17; 0.7	0	NA	NA	NA	NA
Joe1	Joe Brown Creek	45.16534	-110.83945	Upper Yellowstone Watershed	1	1	0	WaterQuality	Yankee Jim Tributaries	5	NA	NA	NA	NA	NA	NA
Sph1	Sphinx Creek	45.17118	-110.87528	Upper Yellowstone Watershed	1	1	0	WaterQuality	Yankee Jim Tributaries	6	NA	NA	NA	NA	NA	NA
Tom1	Tom Miner Creek	45.198197	-110.9086	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	West Bank Tributaries	1	28.16+134.05x; -0.21; 0.5	0.25	20668460	MX2001-10	https://docs.goo	NA
Yel3	Yellowstone River - Tom Miner Bridge	45.2045	-110.902	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	3	NA	NA	NA	NA	NA	NA
Big1	Lower Big Creek	45.29916	-110.8315	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	West Bank Tributaries	4	41.8+209.81x; -0.19; 0.81	1.208	20449344	MX2001-1	https://docs.goo	NA
Big2	Upper Big Creek	45.30552	-110.86668	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	West Bank Tributaries	3	36.19+159.28x; -0.22; 0.44	2.042	20449345	MX2001-2	https://docs.goo	NA
Dry1	Dry Creek Pre-Diversion	45.31766	-110.82704	Upper Yellowstone Watershed	1	1	0	WaterQuality	West Bank Tributaries	5	NA	NA	NA	NA	NA	NA
Yel4	Yellowstone River - Reedfly Farm	45.32877	-110.77301	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	4	NA	NA	NA	NA	NA	NA
Emi1	Emigrant Gulch	45.32059	-110.70985	Upper Yellowstone Watershed	1	1	0	WaterQuality	East Bank Tributaries	2	NA	NA	NA	NA	NA	NA
Fri1	Fridley Creek, South Fork	45.34184	-110.75401	Upper Yellowstone Watershed	1	1	0	WaterQuality	West Bank Tributaries	6	-12.77+93.76x; NA; NA	NA	NA	NA	NA	NA
Yel5	Yellowstone River - Grey Owl Fishing Access	45.398	-110.704	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	5	NA	NA	NA	NA	NA	NA
BigT	Big Timber Creek	45.85436	-109.93336	Upper Yellowstone Watershed	1	0	0	WaterQuantity	Sweet Grass Tributaries	1	83.95+148.34x; NA; N	NA	NA	NA	NA	NA
Eig1	Eight Mile Creek	45.40911	-110.69962	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	West Bank Tributaries	7	37.02+92.49x; -0.4; 0.42	0.771	20593597	MX2001-6	https://docs.goo	NA
LowD	Lower Deer Creek	45.78173	-109.79162	Upper Yellowstone Watershed	1	0	0	WaterQuantity	Sweet Grass Tributaries	4	33.48+140.41x; NA; NA	NA	NA	NA	NA	NA
Mil1	Mill Creek, lower	45.413	-110.649	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	East Bank Tributaries	4	29.33+224.63x; 0.14; 1.4	-0.18	20593593	MX2001-3	https://docs.goo	NA
Yel6	Yellowstone River - Dan Bailey Fishing Access	45.421	-110.637	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	7	NA	NA	NA	NA	NA	NA
Yel7	Yellowstone River - Mallards Rest Fishing Access	45.483	-110.62	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	8	NA	NA	NA	NA	NA	NA
Pin1	Pine Creek, lower	45.50474	-110.56789	Upper Yellowstone Watershed	1	1	0	WaterQuality	East Bank Tributaries	6	-8.15+186.19x; NA; NA	NA	NA	NA	NA	NA
Otter	Otter Creek	45.85708	-109.90333	Upper Yellowstone Watershed	1	0	0	WaterQuantity	Sweet Grass Tributaries	2	61.65+52.58x; NA; NA	NA	NA	NA	NA	NA
Rock	Rock Creek	45.21087	-110.9039	Upper Yellowstone Watershed	1	0	1	WaterQuantity	West Bank Tributaries	2	32.37+127.3x; 0.26; 1.0	0.625	20593595	MX2001-5	https://docs.goo	NA
SixM	Six Mile Creek	45.32144	-110.77164	Upper Yellowstone Watershed	1	0	1	WaterQuantity	East Bank Tributaries	1	49.28+111.32x; 0.45; 1.9	0.854	20593596	MX2001-7	https://docs.goo	NA
UpperD	Upper Deer Creek	45.7934	-109.83289	Upper Yellowstone Watershed	1	0	0	WaterQuantity	Sweet Grass Tributaries	3	103.52+33.6x; NA; NA	NA	NA	NA	NA	NA
Mil2	Mill Creek, upper	45.29237	-110.55551	Upper Yellowstone Watershed	1	1	1	WaterQuality:Water Quantity	East Bank Tributaries	3	49.43+325.4x; 0.16; 0.9	0.542	20593594	MX2001-4	https://docs.goo	NA
Pin2	Pine Creek, upper	45.49973	-110.5217	Upper Yellowstone Watershed	1	1	0	WaterQuality	East Bank Tributaries	5	5.89+128.03x; NA; NA	NA	NA	NA	NA	NA
Yel8	Yellowstone River - Pine Creek Fishing Access	45.512	-110.583	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	9	NA	NA	NA	NA	NA	NA
Yel9	Yellowstone River - Carters Bridge Fishing Access	45.597	-110.566	Upper Yellowstone Watershed	0	1	0	WaterQuality	Yellowstone River	10	NA	NA	NA	NA	NA	NA
Yel10	Yellowstone River - Mill Creek Road Bridge	45.41982	-110.64234	Upper Yellowstone Watershed	0	0	1	WaterQuantity	Yellowstone River	6	NA	NA	180900068066	NA	https://docs.goo	NA

C. *RiverNET* Rating Curve Field Datasheet

Entered by __________ on _____________ QC BY ________________ on _________

Site Name:			Lat:	Lon g:
Date:	Sample #:	Start Time (24:00):	End Time (24:00):	Observer:
Stream Width (ft):	**Stream Stage (ft):**	Depth at Gauge (ft):	Cloud Cover Code:	Recorder:
Low H_2O Protocol) ________ **High H_2O Protocol** ________			H_2O temp (ºF):	Visitors:

Point #	Distance (ft)	Total Depth (ft)	Velocity A (ft/s)	Velocity B (ft/s)	Notes

ADDITIONAL NOTES:

Page ______ of ______

D. ***RiverNET*** **Rating Curve Database** (example image- click for link) docs.google.com/spreadsheets/d/1gpkMJ1_eK1wKdMoDNeI9hYGwvzYB70Lo3eipBQrMmfs/edit#gid=772170039

RiverNET Rating Curve Database

File Edit View Insert Format Data Tools Add-ons Help Last edit was made on September 29 by Mikaela Howie

Share

	Site Name:	Site ID	Date (mm/dd/yy)	Start Time (00:00)	End Time (00:00)	Observer	Recorder	Cloud Cover	Stream Width (ft)	H_2O Temp (°F)	Total 7-day Precip (in)	H_2O depth at gauge (ft)	Stage (ft)	Sample	High, Low H_2O or Low H_2O Average	Su
2	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
3	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
4	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
5	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
6	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
7	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
8	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
9	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
10	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
11	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
12	Cedar Creek	Ced1_Qty	4/12/2019	12:53	13:07	KJR	MGH	PC	10	NA		0.5	0.2	A	L	
13	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
14	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
15	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
16	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
17	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
18	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
19	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
20	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
21	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
22	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
23	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
24	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
25	Cedar Creek	Ced1_Qty	4/26/2019	10:20	10:31	MGH	MS	MC	11.3	NA		0.5	0.35	B	L	
26	Cedar Creek	Ced1_Qty	5/6/2019	12:05	12:15	MGH	SL	PC	10.9	41.1		0.5	0.3	C	L	
27	Cedar Creek	Ced1_Qty	5/6/2019	12:05	12:15	MGH	SL	PC	10.9	41.1		0.5	0.3	C	L	
28	Cedar Creek	Ced1_Qty	5/6/2019	12:05	12:15	MGH	SL	PC	10.9	41.1		0.5	0.3	C	L	
29	Cedar Creek	Ced1_Qty	5/6/2019	12:05	12:15	MGH	SL	PC	10.9	41.1		0.5	0.3	C	L	
30	Cedar Creek	Ced1_Qty	5/6/2019	12:05	12:15	MGH	SL	PC	10.9	41.1		0.5	0.3	C	L	
31	Cedar Creek	Ced1_Qty	5/6/2019	12:05	12:15	MGH	SL	PC	10.9	41.1		0.5	0.3	C	L	
32	Cedar Creek	Ced1_Qty	5/6/2019	12:05	12:15	MGH	SL	PC	10.9	41.1		0.5	0.3	C	L	

Site Summary Data · Stage-Discharge Data · SUMMARY STATS · HW Protocol Data · HW Data Total Discharge · Cedar Creek · Mulherin Creek · Explore

D. *RiverNET* Rating Curve Analysis R Code

```
##### RATING CURVES #####

##### setup #####
### load data
setwd("C:/Users/USER/Desktop/RatingCurve")
RatingCurve<-read.csv("RatingCurve_FINAL.csv", header=T)
# this .CSV can be replicated by amalgamating the rating tables included in the Final Report for FWP19-
0148
### subset by site
BTC<-RatingCurve[RatingCurve$Site=="Big Timber Creek",]
CC<-RatingCurve[RatingCurve$Site=="Cedar Creek",]
EMC<-RatingCurve[RatingCurve$Site=="Eight Mile Creek",]
FC<-RatingCurve[RatingCurve$Site=="Fridley Creek",]
LBC<-RatingCurve[RatingCurve$Site=="Lower Big Creek",]
LDC<-RatingCurve[RatingCurve$Site=="Lower Deer Creek",]
LMC<-RatingCurve[RatingCurve$Site=="Lower Mill Creek",]
LPC<-RatingCurve[RatingCurve$Site=="Lower Pine Creek",]
MC<-RatingCurve[RatingCurve$Site=="Mulherin Creek",]
OC<-RatingCurve[RatingCurve$Site=="Otter Creek",]
RC<-RatingCurve[RatingCurve$Site=="Rock Creek",]
SMC<-RatingCurve[RatingCurve$Site=="Six Mile Creek",]
TMC<-RatingCurve[RatingCurve$Site=="Tom Miner Creek",]
UBC<-RatingCurve[RatingCurve$Site=="Upper Big Creek",]
UDC<-RatingCurve[RatingCurve$Site=="Upper Deer Creek",]
UMC<-RatingCurve[RatingCurve$Site=="Upper Mill Creek",]
UPC<-RatingCurve[RatingCurve$Site=="Upper Pine Creek",]

##### simple linear regression #####
BTClm<-lm(Discharge~Stage, BTC)
summary(BTClm)
# BTC wide scatter/poor fit - staff gauge was damaged and nearby stream bank stabilization work
happened during data collection
CClm<-lm(Discharge~Stage, CC)
summary(CClm)
EMClm<-lm(Discharge~Stage, EMC)
summary(EMClm)
FClm<-lm(Discharge~Stage, FC)
summary(FClm)
LBClm<-lm(Discharge~Stage, LBC)
summary(LBClm)
LDClm<-lm(Discharge~Stage, LDC)
summary(LDClm)
LMClm<-lm(Discharge~Stage, LMC)
summary(LMClm)
```

```
LPClm<-lm(Discharge~Stage, LPC)
summary(LPClm)
MClm<-lm(Discharge~Stage, MC)
summary(MClm)
OClm<-lm(Discharge~Stage, OC)
summary(OClm)
RClm<-lm(Discharge~Stage, RC)
summary(RClm)
SMClm<-lm(Discharge~Stage, SMC)
summary(SMClm)
TMClm<-lm(Discharge~Stage, TMC)
summary(TMClm)
UBClm<-lm(Discharge~Stage, UBC)
summary(UBClm)
UDClm<-lm(Discharge~Stage, UDC)
summary(UDClm)
UMClm<-lm(Discharge~Stage, UMC)
summary(UMClm)
UPClm<-lm(Discharge~Stage, UPC)
summary(UPClm)

##### plots #####
plot(BTC$Stage, BTC$Discharge, main="Big Timber Creek
y = 183.95 + 148.34x ; r2 = 0.28", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(BTClm)
plot(CC$Stage, CC$Discharge, main="Cedar Creek
y = -13.34 + 79.45x ; r2 = 0.86", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(CClm)
plot(EMC$Stage, EMC$Discharge, main="Eight Mile Creek
y = 37.02 + 92.49x ; r2 = 0.81", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(EMClm)
plot(FC$Stage, FC$Discharge, main="Fridley Creek
y = -12.77 + 93.76x ; r2 = 0.80", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(FClm)
plot(LBC$Stage, LBC$Discharge, main="Lower Big Creek
y = 41.8 + 209.81x ; r2 = 0.90", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(LBClm)
plot(LDC$Stage, LDC$Discharge, main="Lower Deer Creek
y = 33.48 + 140.41x ; r2 = 0.95", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(LDClm)
plot(LMC$Stage, LMC$Discharge, main="Lower Mill Creek
y = -29.33 + 224.63x ; r2 = 0.91", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(LMClm)
plot(LPC$Stage, LPC$Discharge, main="Lower Pine Creek
y = -8.15 + 186.19x ; r2 = 0.75", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(LPClm)
```

```
plot(MC$Stage, MC$Discharge, main="Mulherin Creek
y = -141.78 + 171.32x ; r2 = 0.78", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(MClm)
plot(OC$Stage, OC$Discharge, main="Otter Creek
y = 61.65 + 52.58x ; r2 = 0.87", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(OClm)
plot(RC$Stage, RC$Discharge, main="Rock Creek
y = -32.37 + 127.30x ; r2 = 0.67", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(RClm)
plot(SMC$Stage, SMC$Discharge, main="Six Mile Creek
y = -49.28 + 111.32x ; r2 = 0.93", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(SMClm)
plot(TMC$Stage, TMC$Discharge, main="Tom Miner Creek
y = 28.16 + 134.05x ; r2 = 0.67", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(TMClm)
plot(UBC$Stage, UBC$Discharge, main="Upper Big Creek
y = 36.19 + 159.28x ; r2 = 0.85", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(UBClm)
plot(UDC$Stage, UDC$Discharge, main="Upper Deer Creek
y = 103.52 + 33.60x ; r2 = 0.64", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(UDClm)
plot(UMC$Stage, UMC$Discharge, main="Upper Mill Creek
y = -49.43 + 325.40x ; r2 = 0.90", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(UMClm)
plot(UPC$Stage, UPC$Discharge, main="Upper Pine Creek
y = 5.89 + 128.03x ; r2 = 0.97", xlab="Stage (ft)", ylab="Discharge (CFS)")
abline(UPClm)
```