Stream Assessment for Natural Channel Design

The how, why, and lessons learned…

Natural Channel Design

- "emulates natural river systems"
- "integrates fluvial processes over temporal and spatial scales of self-formed and self-maintained natural rivers"
- "reestablish the physical, chemical and biological functions of the river system by creating the conditions that emulate the natural stable form by integrating the geomorphic, hydrologic, and ecological processes responsible for self-regulation"
- "involves procedures for three different reaches throughout the methodology: the existing reach, the reference reach, and the proposed design reach"

Rosgen's Natural Channel Design Approach

- Phase I – Define Restoration Goals
- Phase II – Develop Local and Regional Relations
- Phase III – Conduct Watershed, River and Biological Assessments
- Phase IV – Consider Passive Recommendations
- Phase V – Develop Conceptual Plan
- Phase VI – Develop and Evaluate Preliminary NCD
- Phase VII – Design Stabilization and Enhancement Structures
- Phase VIII – Finalize NCD
- Phase IX – Implement NCD
- Phase X – Conduct Monitoring and Maintenance

Rosgen's Phase I - Objectives

- Define objectives so can later determine success
- Common Objectives:
  - Fish passage
  - Instream habitat
  - Water quality
  - Bank stabilization
  - Protect infrastructure

Schuylkill River, PA

Schuylkill Tributary, PA

Rosgen's Phase I - Objectives

- Need to include aesthetics – keep it natural looking

Rosgen's Phase II – Local & Regional Relations

- Regional curves or USGS gage to calibrate bankfull
  - wmc.ar.nrcs.usda.gov/technical/HHSWR/Geomorphic/index.html

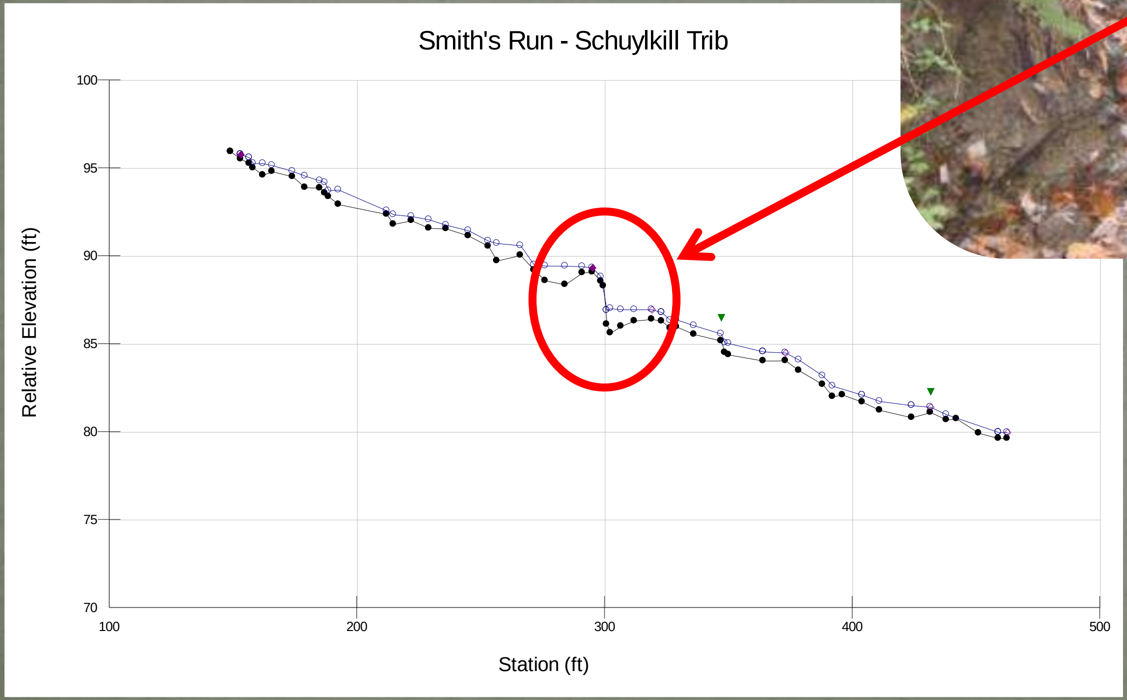
East Branch Perkiomen Creek, PA

Rosgen's Phase II – Local & Regional Relations

- Regional curves or USGS gage to calibrate bankfull
  - wmc.ar.nrcs.usda.gov/technical/HHSWR/Geomorphic/index.html
- Geomorphic Characterization
  - ★ Longitudinal Profile Survey
  - ★ Cross-Section Surveys
  - ★ Pebble Counts
  - ★ Bar Sample or Pavement/Sub-Pavement Sample
  - Stream Geometry
  - Calculate Bankfull Discharge and Velocity
- Sediment Relations

- Looks at **project reach AND reference reach**!

Phase II – Geomorphic Characterization Longitudinal Profile



Smith's Run, PA

Phase II – Geomorphic Characterization Longitudinal Profile

- Why?
  - Reach Slope
    - Sinuosity
    - Stream classification
    - Velocity and discharge calculations
  - Facet Slope
  - Facet Spacing
  - Facet Depth

Valley Slope (S_{val})	0.006	ft/ft	Average Water Surface Slope (S)	0.0028	ft/ft	Sinuosity (S_{val} / S)	2.15
Stream Length (SL)	1740	ft	Valley Length (VL)	805	ft	Sinuosity (SL / VL)	2.16

Low Bank Height (LBH)	start	3.21	ft	Max Depth (d_{max})	start	3.21	ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start	1
	end	3.2	ft		end	3.2	ft		end	1

Facet Slopes	Mean	Min	Max		Dimensionless Facet Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})	0.006	0.002	0.012	ft/ft	Riffle Slope to Average Water Surface Slope (S_{rif} / S)	2.000	0.571	4.204
Run Slope (S_{run})	0.013	0.003	0.020	ft/ft	Run Slope to Average Water Surface Slope (S_{run} / S)	4.661	1.114	6.971
Pool Slope (S_p)	0.002	0.000	0.007	ft/ft	Pool Slope to Average Water Surface Slope (S_p / S)	0.879	0.075	2.332
Glide Slope (S_g)	0.003	0.000	0.005	ft/ft	Glide Slope to Average Water Surface Slope (S_g / S)	1.039	0.168	1.789
Step Slope (S_s)	0.000	0.000	0.000	ft/ft	Step Slope to Average Water Surface Slope (S_s / S)	0.000	0.000	0.000

Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{maxrif})	2.11	1.65	2.64	ft	Max Riffle Depth to Mean Riffle Depth (d_{maxrif} / d_{bkf})	1.43	1.115	1.78
Max Run Depth (d_{maxrun})	2.84	2.28	3.65	ft	Max Run Depth to Mean Riffle Depth (d_{maxrun} / d_{bkf})	1.92	1.541	2.47
Max Pool Depth (d_{maxp})	4	2.88	5.21	ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	2.7	1.946	3.52
Max Glide Depth (d_{maxg})	1.96	1.61	2.39	ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})	1.32	1.088	1.61
Max Step Depth (d_{maxs})	0	0	0	ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})	0	0	0

Phase II – Geomorphic Characterization Longitudinal Profile

- How?
  - Harrelson et al., 1994, Stream Channel Reference Sites: An Illustrated Guide to Field Technique
    - www.stream.fs.fed.us/publications/PDFs/RM245E.PDF
  - Doll et al., 2003, Stream Restoration: A Natural Channel Design Handbook
    - www.bae.ncsu.edu/programs/extension/wqg/sri/stream_rest_guidebook/guidebook.html

Phase II – Geomorphic Characterization Longitudinal Profile

- Tips
  - Walk the whole site first – get your bearings

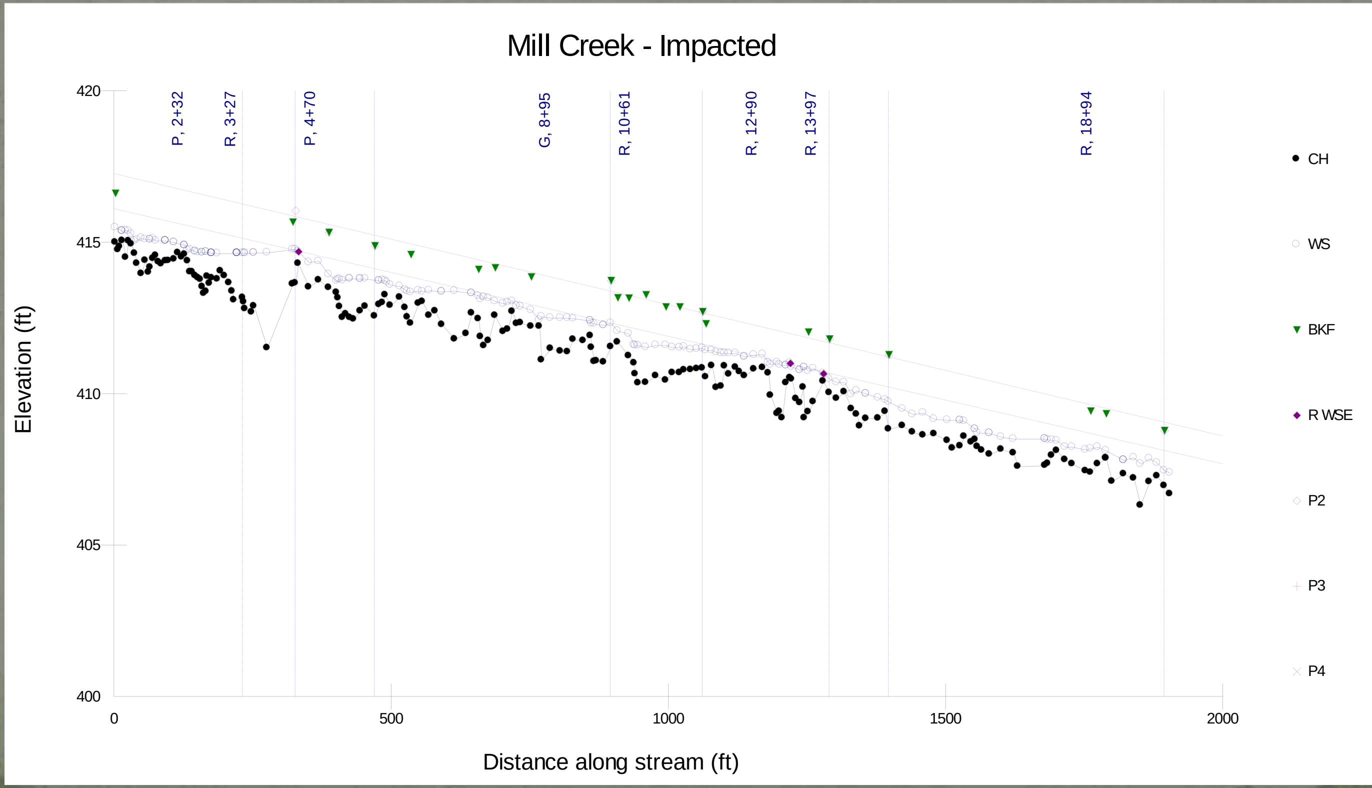
Tinicum Creek, PA

Phase II – Geomorphic Characterization Longitudinal Profile

- Tips
  - Walk the whole site first – get your bearings
  - Easier to read with 0+00 at upstream end
  - Note how the tape was run
    - Top of bank vs. center of bankfull channel
  - Start and end at the same feature
  - Note XS stations and take elevations
  - Get good water surface elevations
  - Note facets in the field, confirm from plot in the office
  - Note compound pools and compound bends in the field
  - Close out your survey
  - **Good field maps and notes hugely helpful!**

Phase II – Geomorphic Characterization Longitudinal Profile

- Tips
  - BKF slope and WS slope should be the same
  - Know how to calculate facet measurements



Phase II – Geomorphic Characterization Cross-Sections

Tinicum Creek, PA

Swamp Creek, PA

Phase II – Geomorphic Characterization Cross-Sections

- WHY?
  - Bankfull dimensions (width, depth, area)
  - Entrenchment ratio ($ER=W_{fpa}/W_{bkf}$)
  - Classify stream type
  - Correlate regional curve

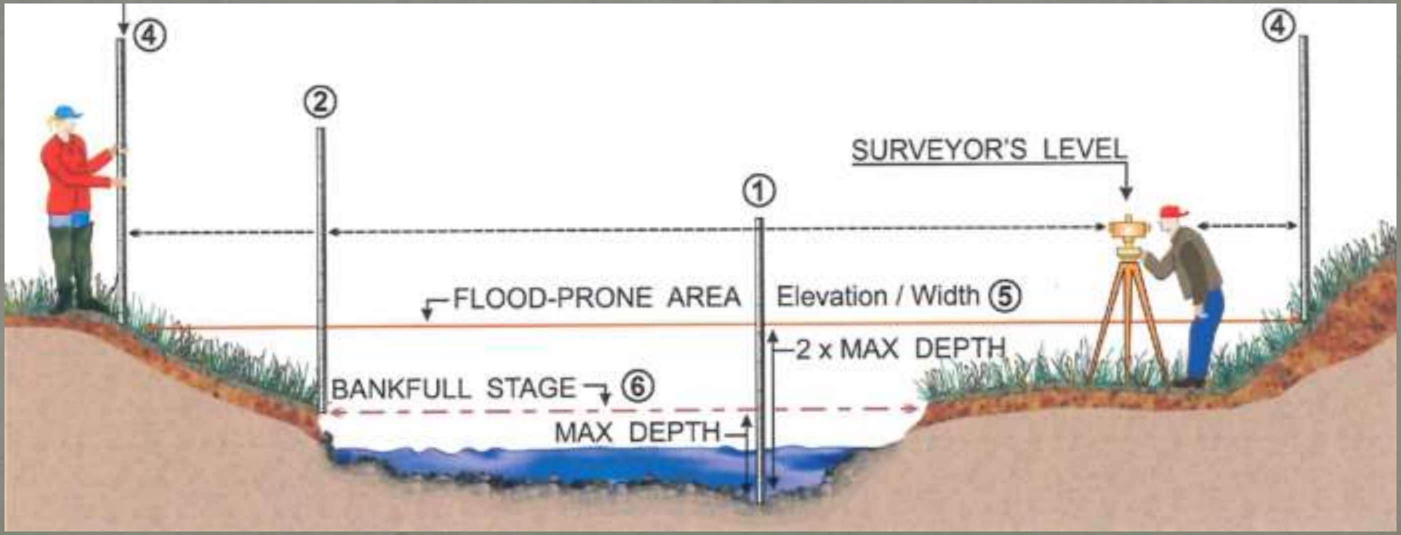


Image from: "River Stability: Field Guide; Dave Rosgen, 2008.

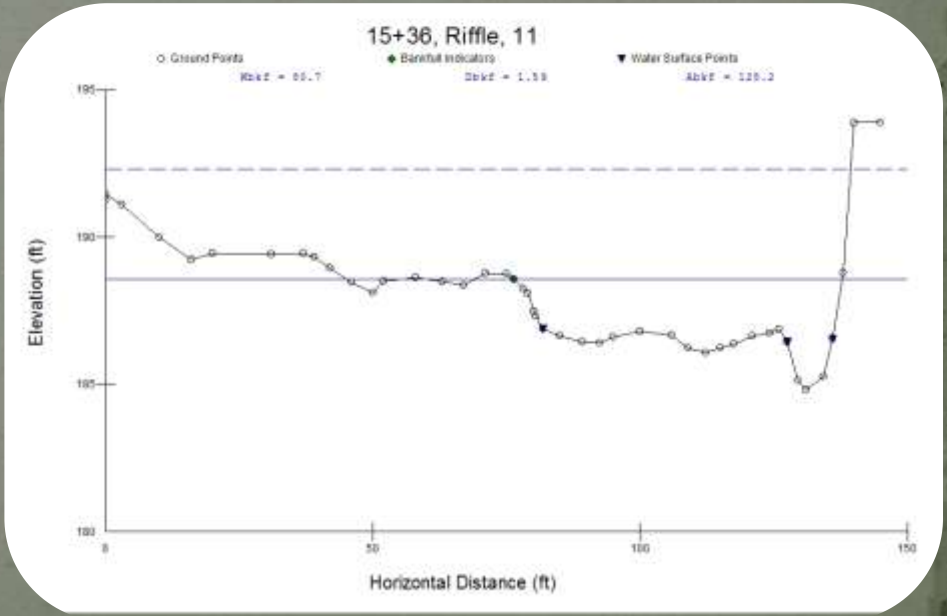
Phase II – Geomorphic Characterization Cross-Sections

- WHY?
  - Calculate wetted perimeter ($Wp=2d+W$)
  - Calculate hydraulic radius ($R=A/Wp$)
    - Calculate relative roughness ($=R/D84$)
    - Calculate and then velocity ($u=(1.4895*R^{2/3}*S^{1/2})/n$)
  - Calculate discharge ($Q=A_{bkf} * u$)

Mill Creek, PA

Phase II – Geomorphic Characterization Cross-Sections

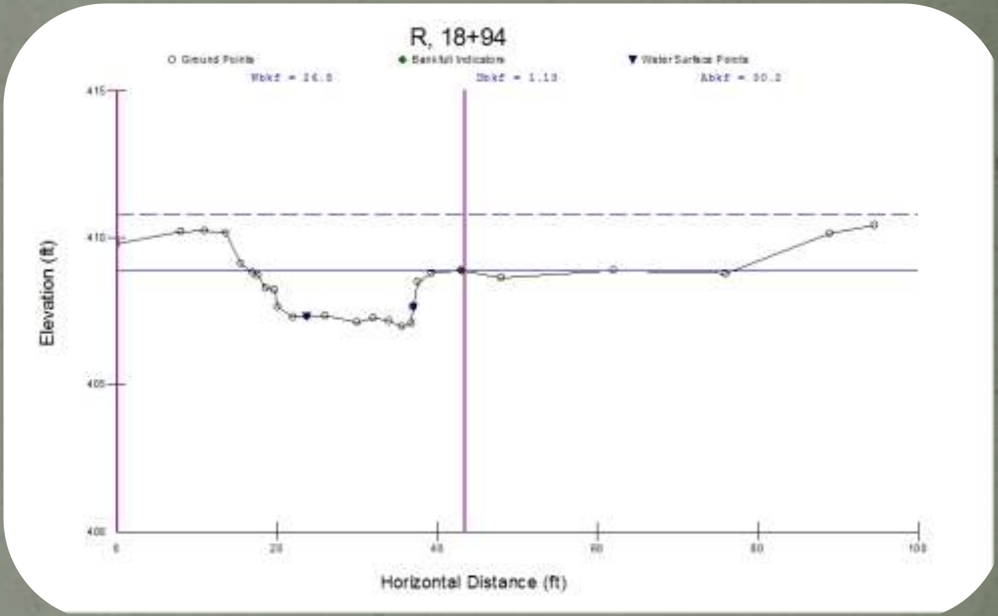
- Tips
  - Benchmark both endpoints… you will be back
    - Photograph location and measure to local landmarks
  - Always put 0+00 on the left bank
  - Take photos looking downstream and across XS



Tinicum Creek, PA

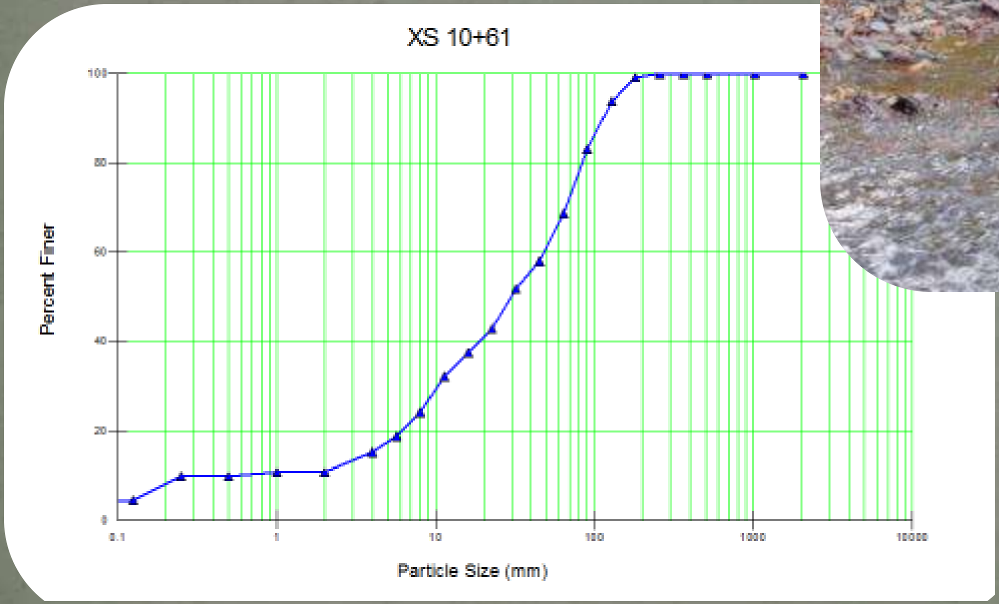
Phase II – Geomorphic Characterization Cross-Sections

- Tips
  - Get bankfull right
    - As a rule we usually underestimate
  - Flag bankfull calls for long pro
  - Collect enough data
  - Run the cross-section far enough to determine entrenchment ratio
  - Do more than 1 riffle XS



Mill Creek, PA

Phase II – Geomorphic Characterization
Pebble Counts



Mill Creek, PA

Phase II – Geomorphic Characterization Pebble Counts

- Why Reach-wide?
  - Classify stream type

- Why Active Riffle?
  - Determine D84
  - Calculate relative roughness (=R/D84)
  - Calculate velocity and discharge
  - Sediment competence

Phase II – Geomorphic Characterization Pebble Counts

- Tips
  - Intermediate axis
  - Two people or a gravelometer make life easier
  - For boulders, logs, sand bed, or bed rock streams use protrusion height

Swamp Creek, PA

Phase II – Geomorphic Characterization Pebble Counts

- Tips
  - Do reach counts proportionally to pools and riffles
  - Take active riffle counts at surveyed riffle
  - Do not take more than 5% of particles from the bank

Swamp Creek, PA

Phase II – Geomorphic Characterization
Bar Samples

Phase II – Geomorphic Characterization Bar Samples

- WHY?
  - D50 and Dmax
  - Calculate dimensionless shear stress
  - Calculate sediment competence
  - Calculate bankfull depth and slope needed to entrain largest particle
- How?
  - Doll et al., 2003, Stream Restoration: A Natural Channel Design Handbook
    - www.bae.ncsu.edu/programs/extension/wqg/sri/stream_rest_guidebook/guidebook.html

Phase II – Geomorphic Characterization
Bar Samples

- Tips
  - Bar samples much easier
  - Field truth your D_{max} as you walk the reach
  - Change in stream type = another bar sample
  - Record station and photograph location
  - If possible sieve in the field at the end of the day
  - Do >1 if you can per reach

Swamp Creek, PA

Phase II – Geomorphic Characterization Bar Samples

- Tips
  - Don't forget the two largest particles you sat aside
  - In fine materials excavate 4-6 inches (not twice the intermediate axis of largest surface particle)
  - If hit a layer of larger rocks in the subpavement – STOP
  - Be ready to SHAKE!

Swamp Creek, PA

Rosgen's Phase III – Watershed, River & Biological Assessments

- Stream Stability Indices
- Predict Streambank Erosion – BANCS Model
- Predict Sediment Supply and Transport Capacity
- Validate River Stability Prediction
  - Streambank Erosion
    - Bank pins
    - Bank profiles
  - Sediment Competence
    - Scour chains
    - Measure bedload and suspended
  - Repeat Cross-section and Profile Surveys

Phase III – Stream Stability Indices

- Vegetation
- Flow Regime
- Stream order and size
- Meander Pattern
- Depositional Patterns
- Channel Blockages
- Channel Incision
- W/D Ratio State
- Degree of Confinement
- ★ Modified Pfankuch Channel Stability Rating

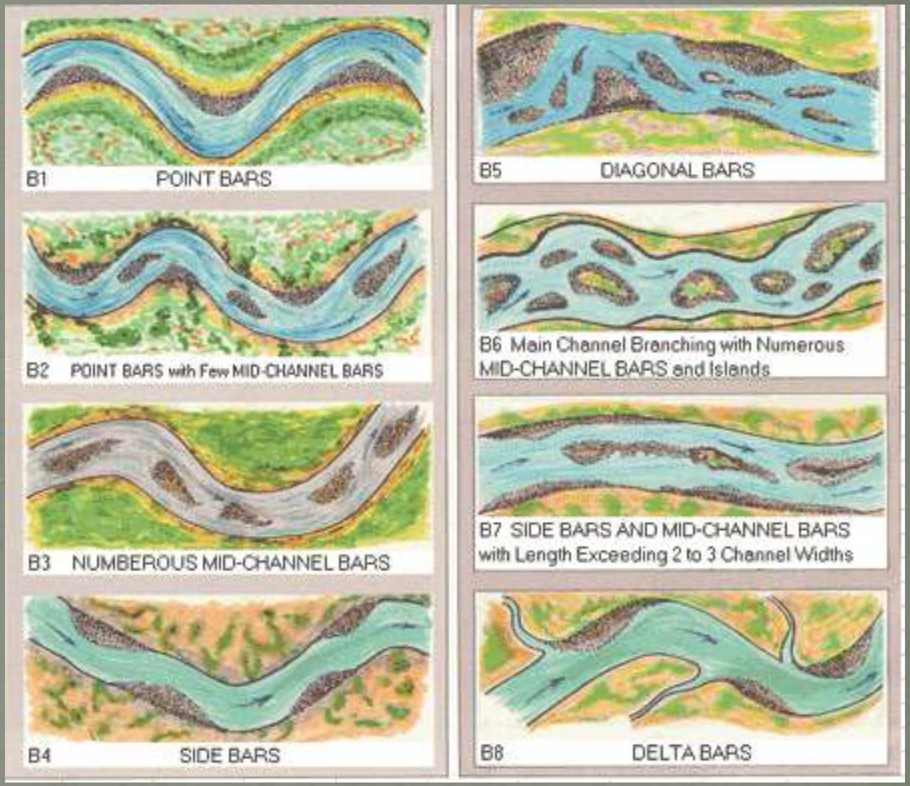


Image from: "River Stability: Field Guide; Dave Rosgen, 2008.

Phase III – Modified Pfankuch

- Upper Banks
  - Landform slope
  - Mass erosion
  - Debris Jam potential
  - Vegetative bank protection
- Lower Banks
  - Channel capacity
  - Bank rock content
  - Obstructions to

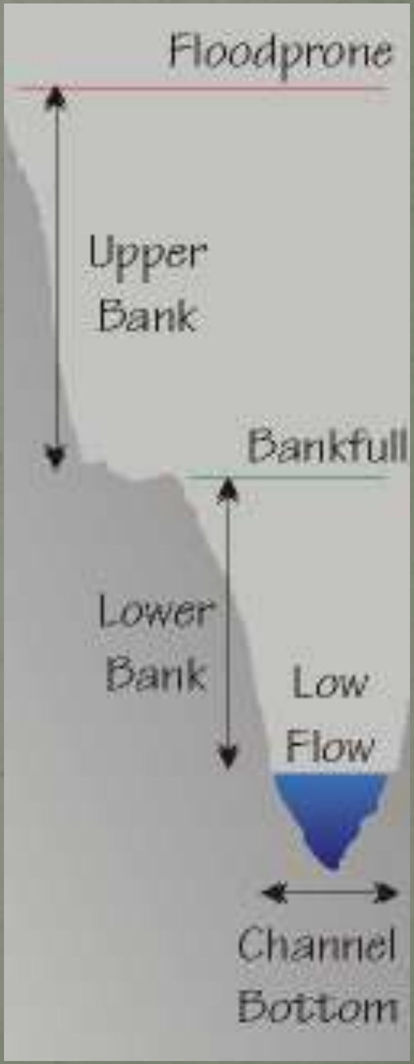


Image from: RiverMorph software

Phase III – Modified Pfankuch

- Bottom
  - Rock angularity
  - Brightness
  - Consolidation of particles
  - Bottom size distribution
  - Scouring and deposition
  - Aquatic vegetation

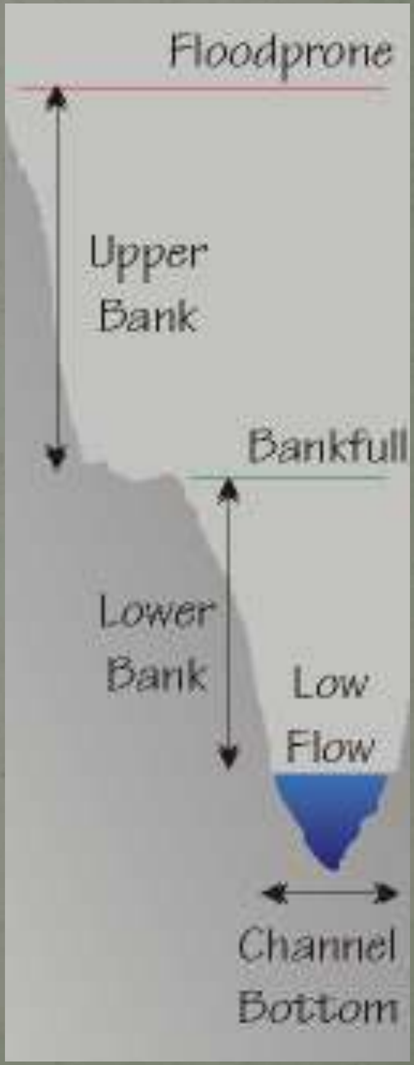


Image from: RiverMorph software

Phase III – Modified Pfankuch

- WHY?
  - Good summary of what you saw
  - Monitoring over time
  - Overall sediment supply rating variable (low, moderate, high, very high)
  - Determine appropriate dimensionless bedload and suspended sediment rating curves in FLOWSED model
    - FLOWSED – annual sediment yield

Valley Creek, PA

Phase III – Modified Pfankuch

- Tips
  - Keep doing it
  - Compare notes on the same reach with a friend
  - Don't be too hard – remember it is based on the whole reach not a single XS
  - Don't compensate based on stream type

Stream Type	A3	A4	B3	B4	C3	C4	E3	E4	F4	F5	G4	G5
Good	54-90	60-95	40-60	40-64	60-85	70-90	40-63	50-75	85-110	90-115	85-107	90-112
Fair	91-129	96-132	61-78	65-84	86-105	91-110	64-86	76-96	11-125	116-130	108-120	113-125
Poor	129+	132+	78+	84+	105+	110+	86+	96+	126+	131+	121+	126+

Phase III – BANCS Model

- **B**ank **A**ssessment for **N**on-point source **C**onsequences of **S**ediment
  - Bank Characteristics
    - **B**ank **E**rosion **H**azard **I**ndex (BEHI)
  - Flow Distribution
    - **N**ear **B**ank **S**tress (NBS)

Phase III – BANCS Model

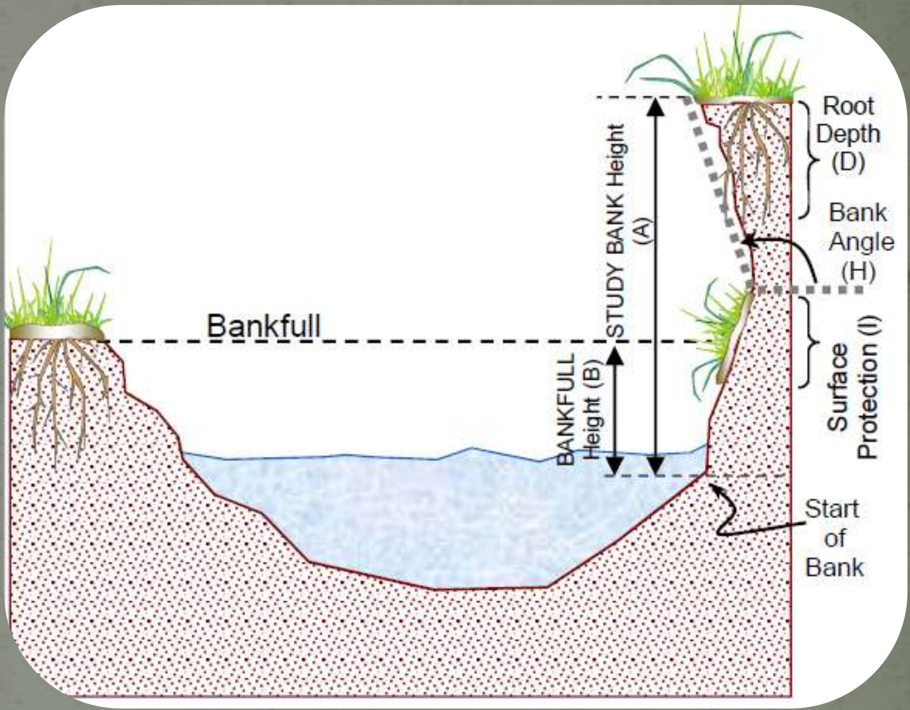
- WHY?
  - Estimate of annual erosion rate -> tons of sediment per year or annual sediment loss in cubic yards

Tinicum Creek, PA

Image by: Steve Woodmore
www.flickr.com/photos/stereoviews/4444168980/

Phase III – BANCS Model BEHI

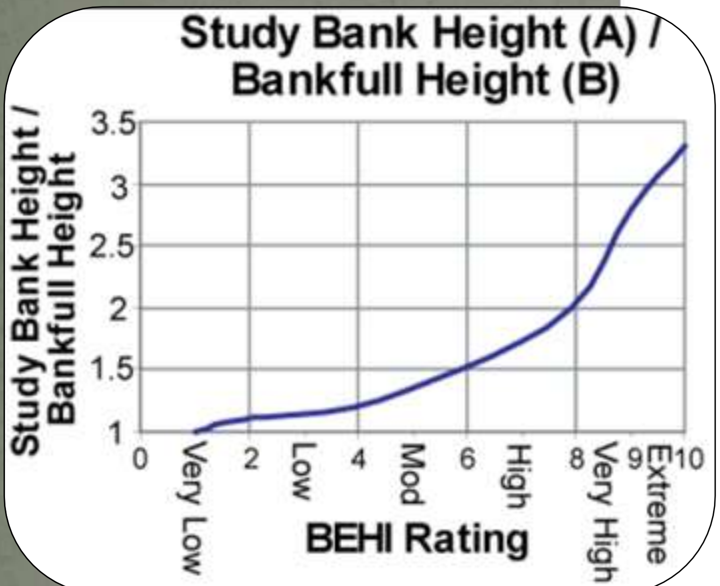
- Bank height/Bankfull height
- Root depth/Bank height
- Root density (%)
- Bank angle (degrees)
- Surface protection (%)



- Adjustments
  - Bank material (add 5-10 pts for sand or mix)
  - Stratification (add 5-10 points for unstable layers in bankfull)

Image from: “River Stability: Field Guide; Dave Rosgen, 2008.

Phase III – BANCS Model BEHI



Date: **9-15-10** Stream Type: **C4** Valley Type: **VIII**

						BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)						
Study Bank Height (ft) =	2.70 (A)	Bankfull Height (ft) =	1.00 (B)	(A) / (B) =	2.70 (C)	8.5
Root Depth / Study Bank Height (E)						
Root Depth (ft) =	0.50 (D)	Study Bank Height (ft) =	2.70 (A)	(D) / (A) =	0.19 (E)	7.5
Weighted Root Density (G)						
		Root Density as % =	5% (F)	(F) × (E) =	0.00926 (G)	10.0
Bank Angle (H)						
				Bank Angle as Degrees =	90 (H)	8.0
Surface Protection (I)						
				Surface Protection as % =	5% (I)	10.0

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: **5**

Stratification Adjustment

Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

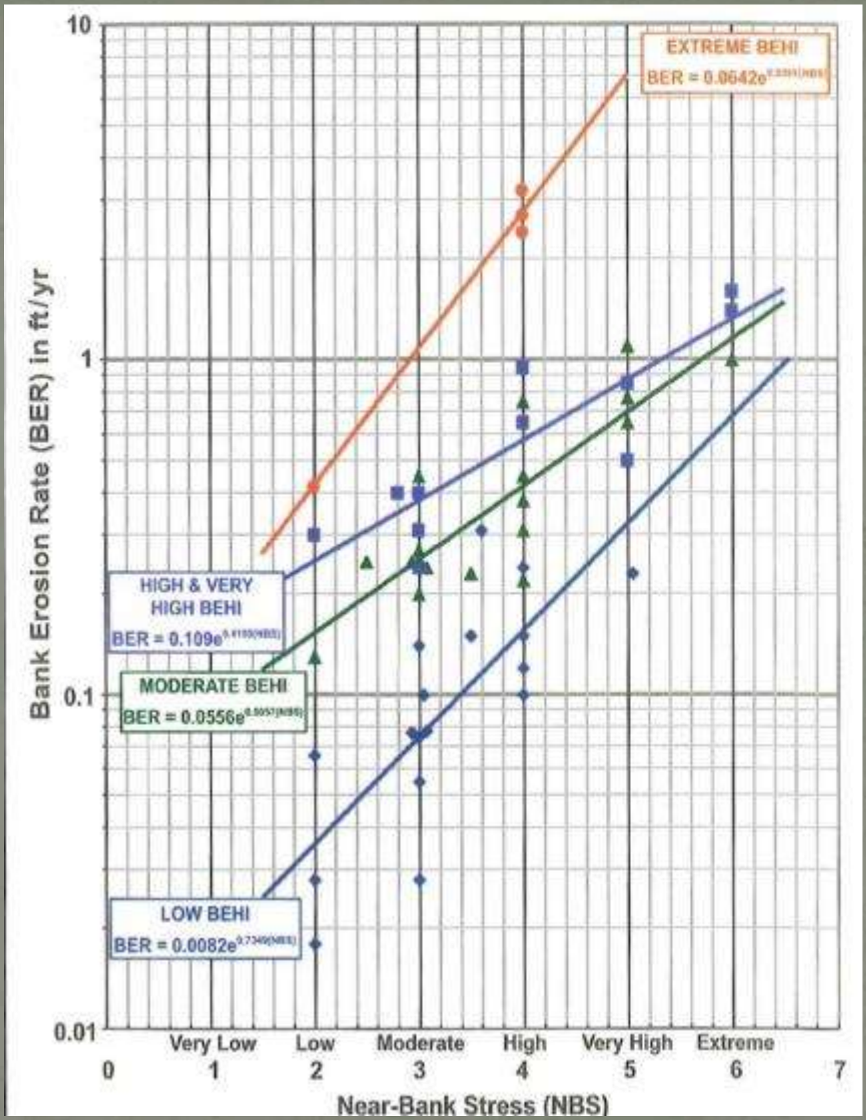
Adjective Rating and Total Score: **49.0**

Image from: "River Stability: Field Guide; Dave Rosgen, 2008.

Phase III – BANCS Model NBS

- Channel pattern
  - Transverse and/or central bars – High/Very High
  - Extensive deposition (continuous, cross channel) – Extreme
  - Chute cutoffs, down-valley meander migration, converging flow – Extreme
- Ratio of radius of curvature to bankfull width (R_c/W_{bkf})
- Ratio of pool slope to average slope (S_p/S)
- Ratio of pool slope to riffle slope (S_p/S_{rif})
- Ratio of near-bank maximum depth to bankfull mean depth (d_{nb}/d_{bkf})
- Ratio of near-bank shear stress to bankfull shear stress
- Velocity profiles

Phase III – BANCS Model
NBS



Annual Streambank Erosion Rates from Colorado USDA Forest Service data (1989)
(Rosgen, A Practical Method of Computing Streambank Erosion Rate)

Phase III – BANCS Model

Stream: **Nevada Creek** Location: **Reach 2**

Graph Used: **Yellowstone** Total Stream Length (ft): **1740** Date: **9/14/2010**

Observers: **Team 2** Valley Type: **VIII** Stream Type: **C4**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station (ft)	**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
1. **0**	**low**	**low**	**0.041**	**75.0**	**1.5**	**4.65**	**0.00298**
2. **125**	**mod**	**high**	**0.467**	**39.0**	**2.0**	**36.40**	**0.04494**
3. **164**	**mod**	**high**	**0.467**	**76.0**	**2.0**	**70.94**	**0.04494**
1720	**low**	**high**	**0.234**	**60.0**	**4.2**	**58.46**	**0.04692**
Sum erosion subtotals in Column (7) for each BEHI/NBS combination					Total Erosion (ft^3/yr)	**2492.18**	
Convert erosion in ft^3/yr to yds^3/yr {divide Total Erosion (ft^3/yr) by 27}					Total Erosion (yds^3/yr)	**92.30**	
Convert erosion in yds^3/yr to tons/yr {multiply Total Erosion (yds^3/yr) by 1.3}					Total Erosion (tons/yr)	**119.99**	
Calculate erosion per unit length of channel {divide Total Erosion (tons/yr) by total length of stream (ft) surveyed}					Total Erosion (tons/yr/ft)	**0.0690**	

Phase III – BANCS Model

- Tips
  - Take the time to calibrate your eye
  - Take actual measurements often to "check your eye"
  - Start new segments as often as you need to
  - Use the worst scenario for NBS

Valley Creek, PA

Phase III – BANCS Model

- Tips
  - Validate your predictions whenever you can
  - Make and validate predictions at full range of NBS and BEHI ratings
    - What's a natural erosion rate?

Valley Creek, PA

Phase III – Validate BANCS Bank Pins and Bank Profiles

- WHY?
  - Validate stream bank erosion prediction
  - Measure loss of sediment over time
  - Measure lateral erosion rate
  - Develop your own stream bank erosion curve

Smith's Run, PA

Phase III – Validate BANCS Bank Pins and Bank Profiles

- Tips
  - Two+ people
  - Know when not to use a bank pin
  - Use a long enough bank pin
  - Set toe pin out far enough
  - Detailed notes on location and procedure
  - Take bank pin elevation
  - Keep levels in your field bag
  - Be consistent how you line up rod on toe pin

Phase III –Validate Competency
Scour Chains

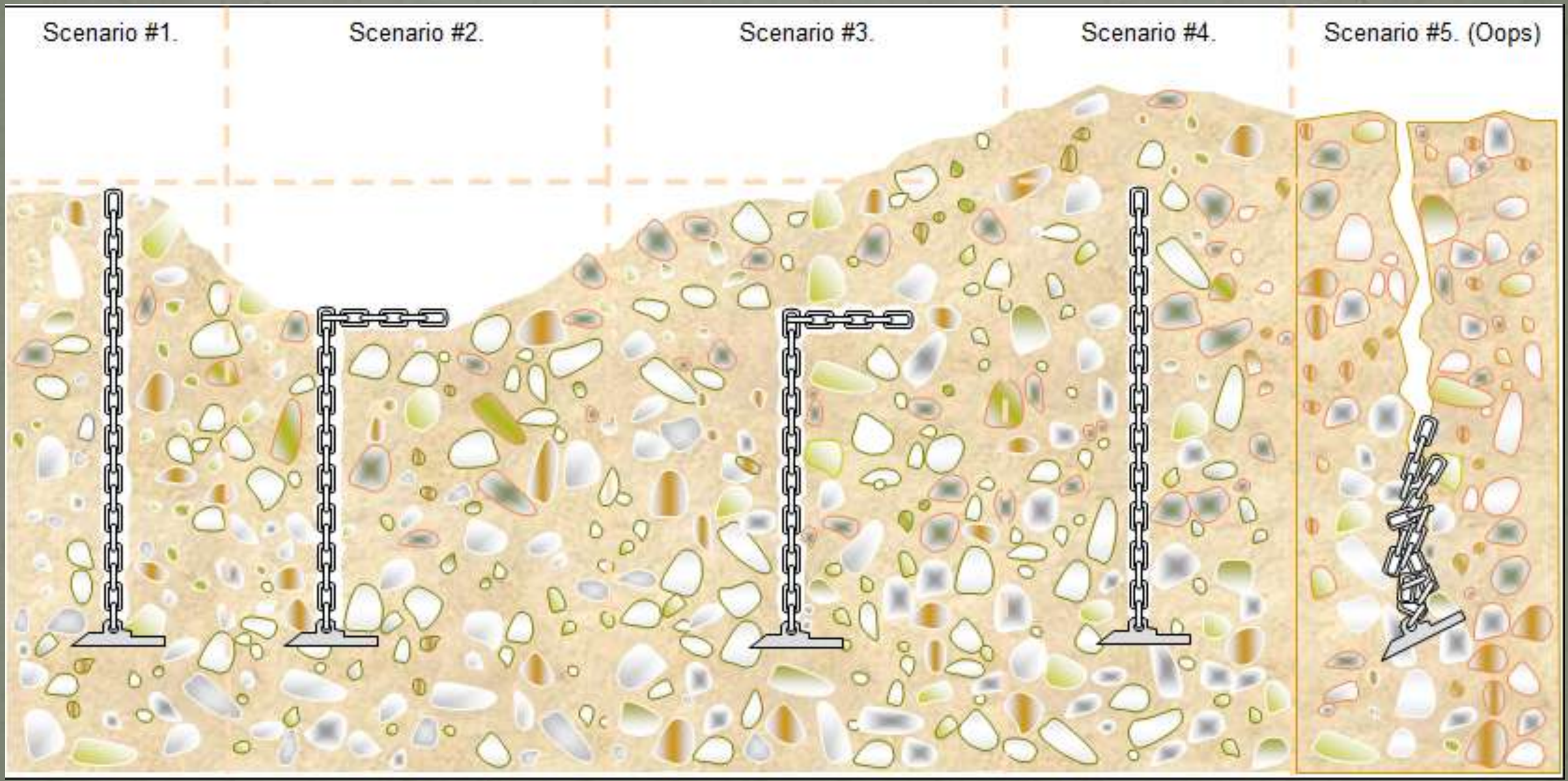


Image from: "River Stability: Field Guide; Dave Rosgen, 2008.

Phase III –Validate Competency Scour Chains

- Tips
  - Duckbill and chain v. sliding bead
  - Install at riffles and glides
  - Detailed notes and exact measurements for scour chain location
    - Monument end points
  - Want cross-section survey and pebble count at same location – do before
  - Tie flagging on the end
  - Isolate flow using bottomless metal trash can
  - Don’t over dig

Rosgen's Phase IV – Passive Recommendations

- DRN's 10 Commandments of Stream Restoration
  - If you can do nothing, do nothing
- Do NOT overlook this important step

Mill Creek, PA

Rosgen's Phase V – Conceptual Design

- Can the project meet your partners' needs and project objective?
  - Ecologically and economically
- What does the community think?
- What do the permitters think?

Mercer County, NJ

Rosgen's Phase VI – Preliminary NCD

- 88 steps
- Looks at existing and reference reach data for 145 variables!!
  - Most of these variables have three values (mean, min, and max)
  - So 318 values for existing and 318 for reference
- Then determine these 318 values for the proposed design based on data and design parameters

Rosgen's Phase VII – Structures

Sprogels Run, PA

Darby Creek, PA

Manatawny Creek, PA

Rosgen's Phase VII – Structures

Nevada Creek, MT

Darby Creek, PA

Rosgen's Phase VII – Structures

Nevada Creek, MT

Rosgen's Phase VIII – Finalize NCD and Monitoring Maintenance Plan

Rosgen's Phase IX– Construct NCD

Manatawny Creek, PA

Rosgen's Phase IX– Construct NCD

Darby Creek, PA

Rosgen's Phase X – Monitoring and Maintenance

Darby Creek, PA

Sprogels Run, PA

Darby Creek, PA

Crum Creek, PA

Summary and Final Tips

- Always know who has the field book and where it is
- The sooner you enter the data the better
- Waterproof cameras are a good investment
- Share the fun (and the not so fun too)

Darby Creek, PA

Looking for More Info...

- We need reference reaches
  - Please let me know

- Stream restoration webinar series
  - Registration to start soon

Maury River, VA

Thank you.

Emma B.L. Gutzler
Restoration Manager
emma@delawareriverkeeper.org
215.369.1188