Stream Restoration Symposium 2019

Lessons Learned from Stream Restoration in Other Jurisdictions

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5 SMOOTH STONES RESTORATION INC

Toronto and Region Conservation Authority

NC State University Stream Restoration Program

Established: 1998

Mission: Advance the Science & Practice of Stream Restoration through

- Teaching
- Research
- Networking

www.ncsu.edu/srp

NC STATE UNIVERSITY Bio&Ag ENGINEERING Stream Restoration Program

NC State University A&T State University COOPERATIVE EXTENSION Empowering People · Providing Solutions

Sea Grant North Carolina

NC STATE UNIVERSITY

Objectives:

1. Educate designers, contractors, landowners, and resource managers about effective restoration
2. Educate students who will serve society in government, academia, and business
3. Develop and test effective technologies for restoration design, construction, and evaluation

Team of Professionals

- A team of faculty, staff, and students working to improve water quality and aquatic ecology through research, demonstration projects, and education.







Partnerships

- Many Disciplines
- Other Universities
- Agencies
- Private Sector
- Non-Profit Organizations

Program Components

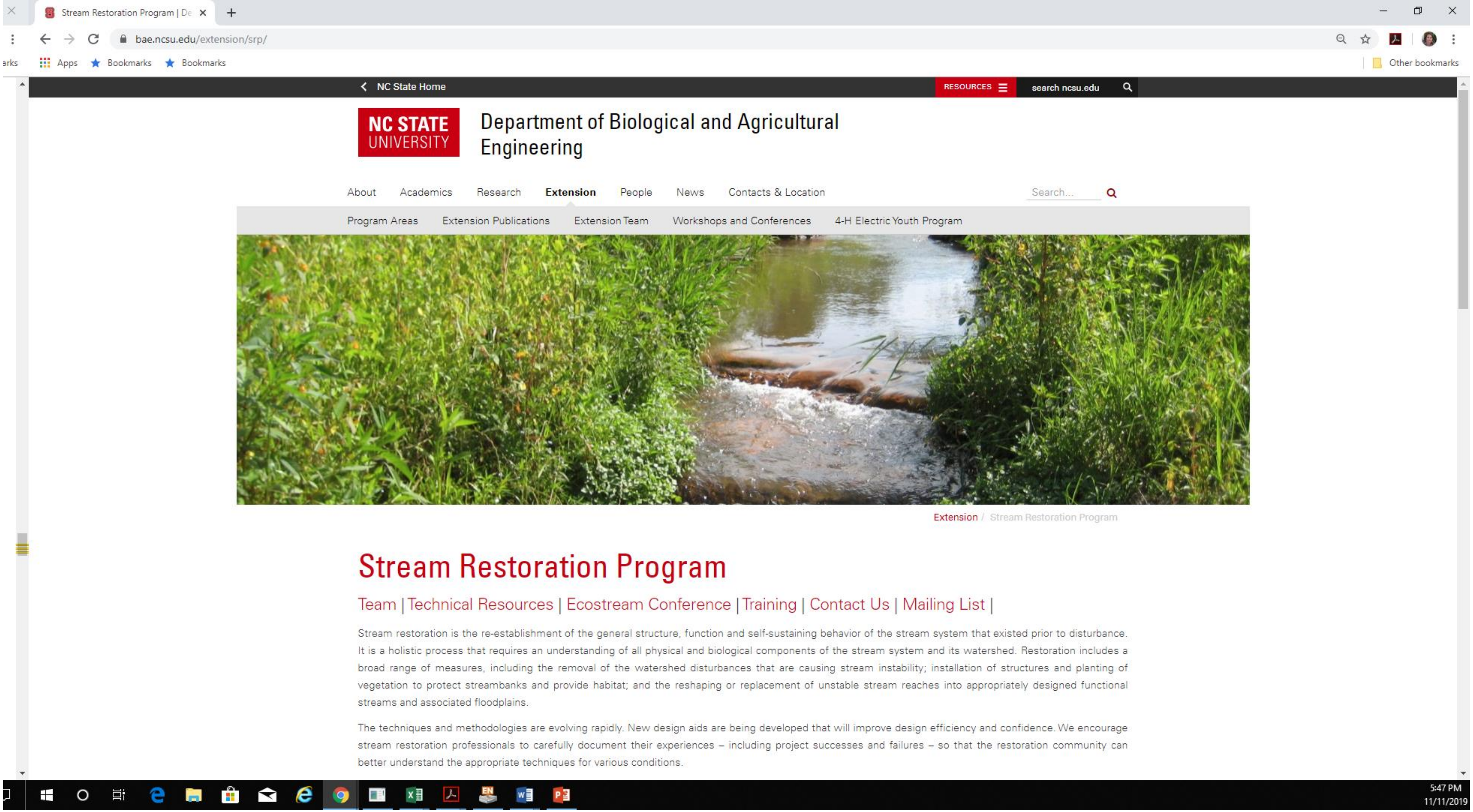
- Academic courses (campus and on-line)
- Professional development workshops & tours
- Technical Resources
- Southeast Regional Conference (biennial)
- Networking (e-mail list, web site)
- Demonstration Projects
- Research (Graduate and Undergraduate)

Academic Courses

- BAE 584 – Introduction to Fluvial Geomorphology (on-line)
- AES 443 – Environmental Restoration Implementation
- BAE 580 – Introduction to Land and Water Engineering (on-line)
- BAE 582 – Risk and Failure Assessment of Stream Restoration Structures (on-line)
- BAE 579 – Stream Restoration (Not currently offered)

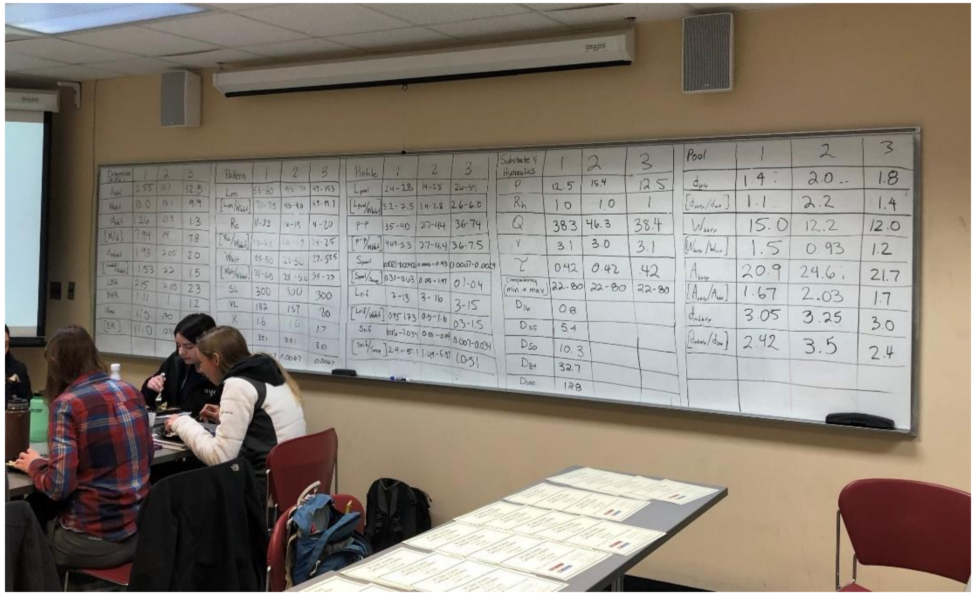


Web Site: *www.ncsu.edu/srp*



Training Courses

- Stream Assessment
- Stream Restoration
- Advanced Restoration Design
- AutoCAD for Stream Restoration
- Restoration Implementation & Evaluation
- Construction Certification for Contractors
- Vegetation Establishment & Monitoring
- Aquatic Macroinvertebrate Taxonomy
- Streambank Repair
- Hydraulic Design for Stream Restoration

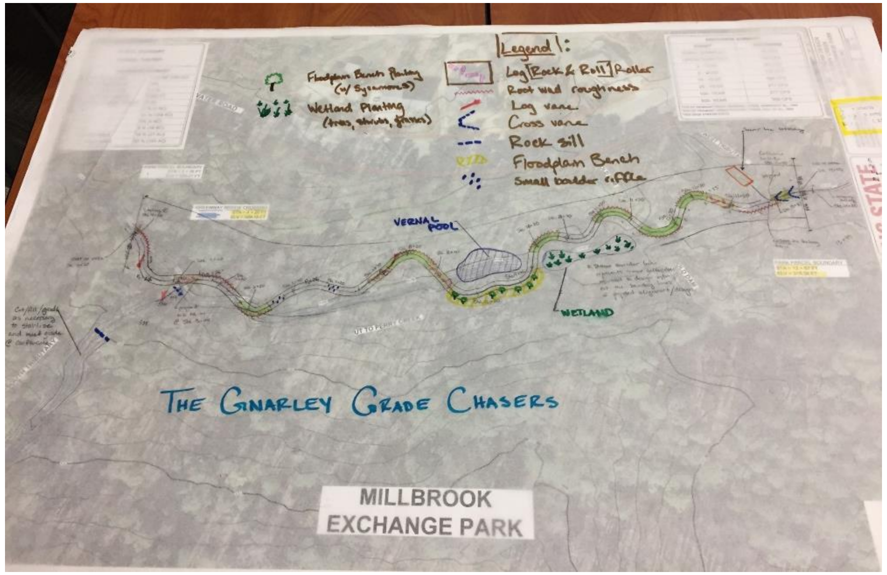


Training Courses: *www.ncsu.edu/srp*

Stream Restoration Program Training		
Workshop	**Location**	**Date**
RC 101 – Stream Morphology Assessment	Raleigh, NC	March 12-14, 2019
	Asheville, NC	October 9-11, 2019
RC 201 – Natural Channel Design Principles	Asheville, NC	May 22-24, 2019
RC 302 – HEC-RAS for Stream Restoration	Raleigh, NC	July 24-26, 2019
RC 303 – Multi-Dimensional Modeling for Stream Restoration	Raleigh, NC	August 27-29, 2019
RC 401 – Construction Practices for Stream Restoration	Kernersville, NC	March 26, 2019
	Kernersville, NC	March 27, 2019
Streambank Repair Workshops	Hendersonville, NC	March 13, 2019
	Asheville, NC	March 14, 2019
	Fayetteville, NC	April 30, 2019
Backyard Stream, Erosion Control, & Raingarden Clinics		
Surface Water Identification Training and Certification (SWITC)	Raleigh, NC	May 14-17, 2019
	Raleigh, NC	October 15-18, 2019

River Course Workshops

- 3-day modules on Assessment, Restoration, Advanced Design, & Implementation/Evaluation
- “Hands-on” training for 30-35 professionals per session
- More than 5500 participants since 2000

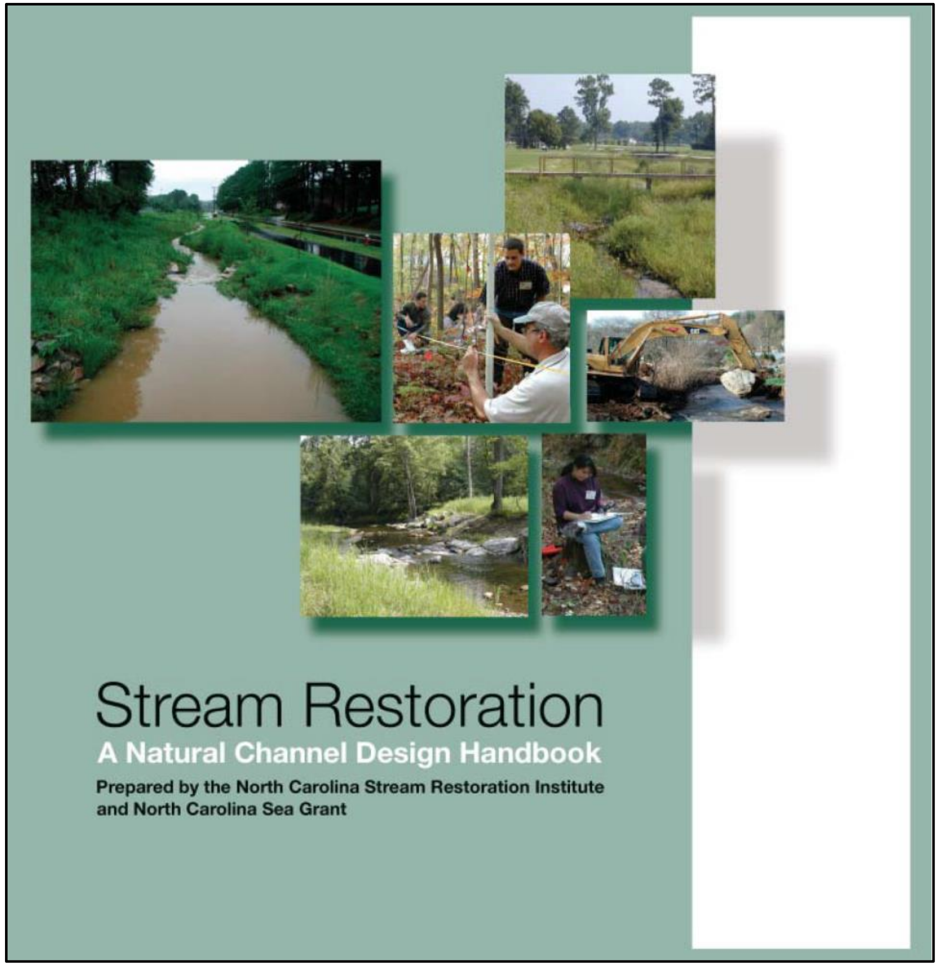


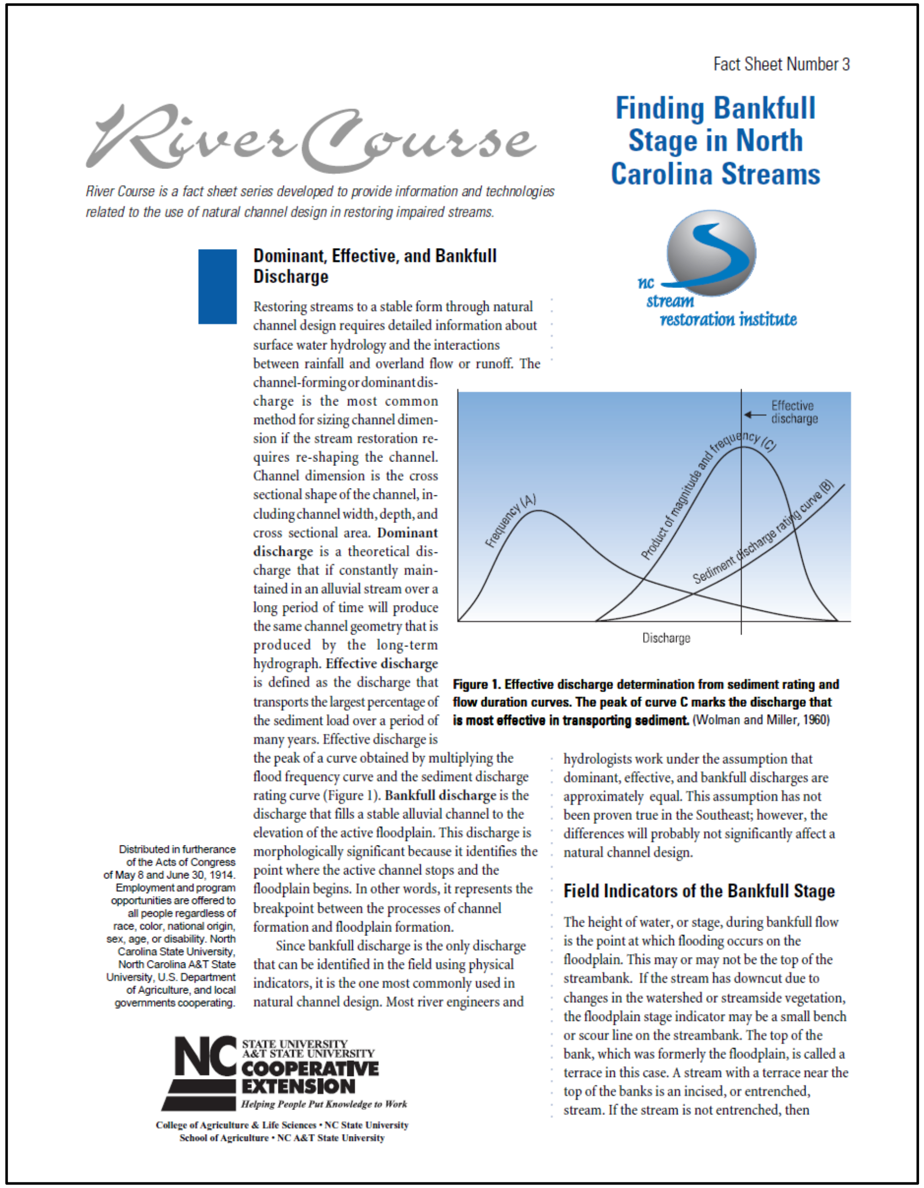
Construction (Certification)

- Partner with NC Ecosystem Enhancement Program (Mitigation Services)
- 3-day “hands-on” training for 40 contractors & construction supervisors
- Examination leads to certification

Technical Resources

- Fact Sheets
- Design Handbook
- Regional Curves for Hydraulic Geometry





Fact Sheet Number 3

RiverCourse

River Course is a fact sheet series developed to provide information and technologies related to the use of natural channel design in restoring impaired streams.

Finding Bankfull Stage in North Carolina Streams

nc stream restoration institute

Dominant, Effective, and Bankfull Discharge

Restoring streams to a stable form through natural channel design requires detailed information about surface water hydrology and the interactions between rainfall and overland flow or runoff. The channel-forming or dominant discharge is the most common method for sizing channel dimension if the stream restoration requires re-shaping the channel. Channel dimension is the cross sectional shape of the channel, including channel width, depth, and cross sectional area. **Dominant discharge** is a theoretical discharge that if constantly maintained in an alluvial stream over a long period of time will produce the same channel geometry that is produced by the long-term hydrograph. **Effective discharge** is defined as the discharge that transports the largest percentage of the sediment load over a period of many years. Effective discharge is the peak of a curve obtained by multiplying the flood frequency curve and the sediment discharge rating curve (Figure 1). **Bankfull discharge** is the discharge that fills a stable alluvial channel to the elevation of the active floodplain. This discharge is morphologically significant because it identifies the point where the active channel stops and the floodplain begins. In other words, it represents the breakpoint between the processes of channel formation and floodplain formation.

Since bankfull discharge is the only discharge that can be identified in the field using physical indicators, it is the one most commonly used in natural channel design. Most river engineers and hydrologists work under the assumption that dominant, effective, and bankfull discharges are approximately equal. This assumption has not been proven true in the Southeast; however, the differences will probably not significantly affect a natural channel design.

Figure 1. Effective discharge determination from sediment rating and flow duration curves. The peak of curve C marks the discharge that is most effective in transporting sediment. (Wolman and Miller, 1960)

Field Indicators of the Bankfull Stage

The height of water, or stage, during bankfull flow is the point at which flooding occurs on the floodplain. This may or may not be the top of the streambank. If the stream has downcut due to changes in the watershed or streamside vegetation, the floodplain stage indicator may be a small bench or scour line on the streambank. The top of the bank, which was formerly the floodplain, is called a terrace in this case. A stream with a terrace near the top of the banks is an incised, or entrenched, stream. If the stream is not entrenched, then

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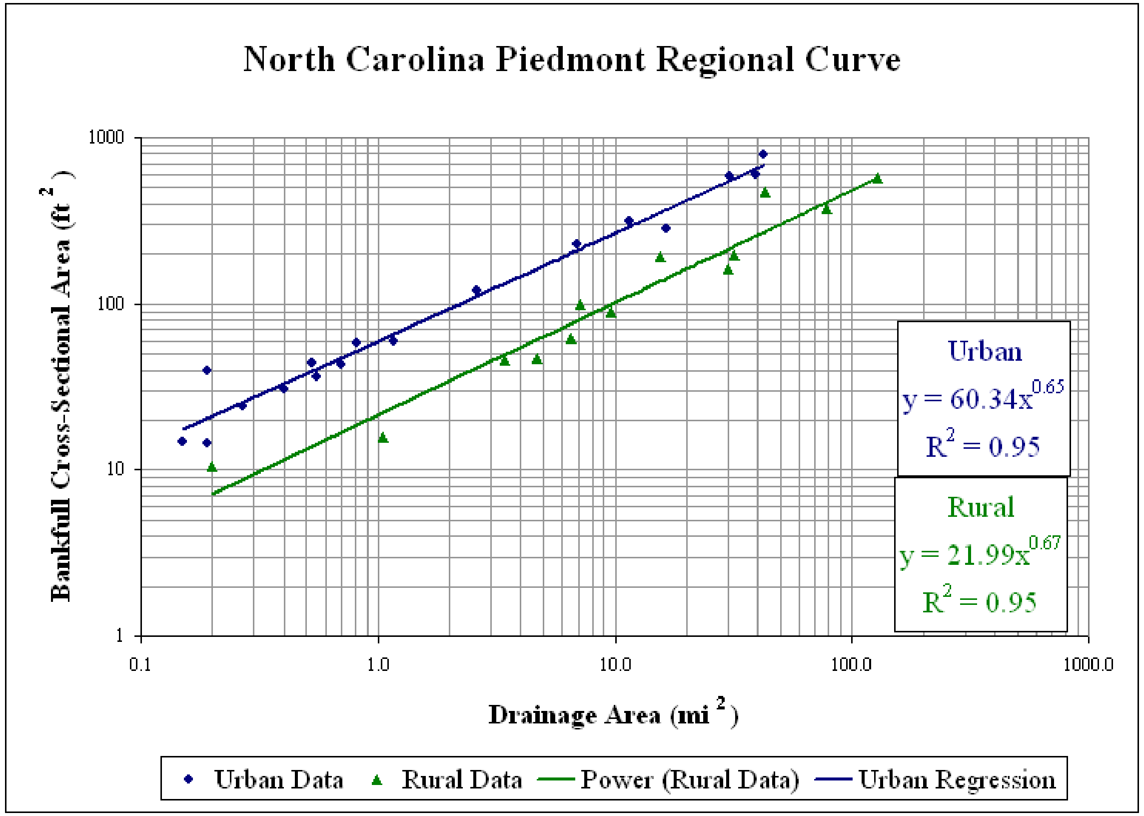
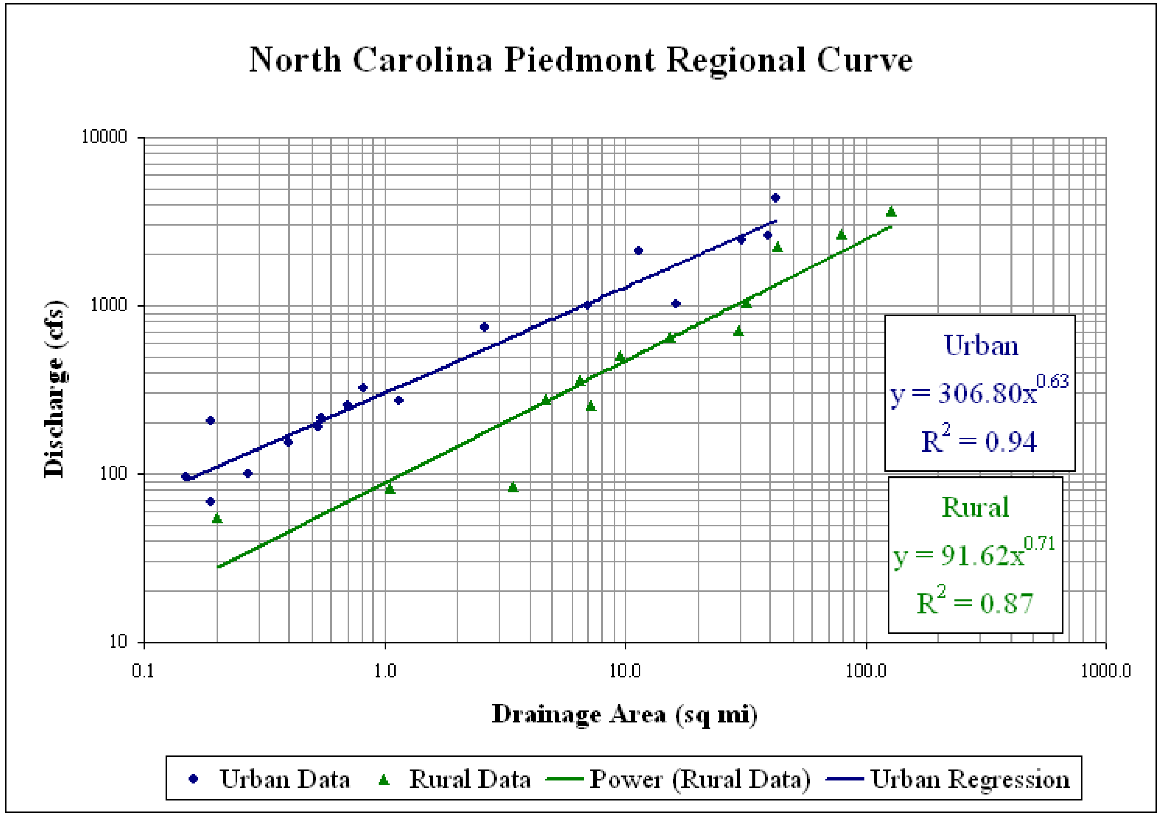
Hydraulic Geometry Regional Curves





Regional Conference - EcoStream

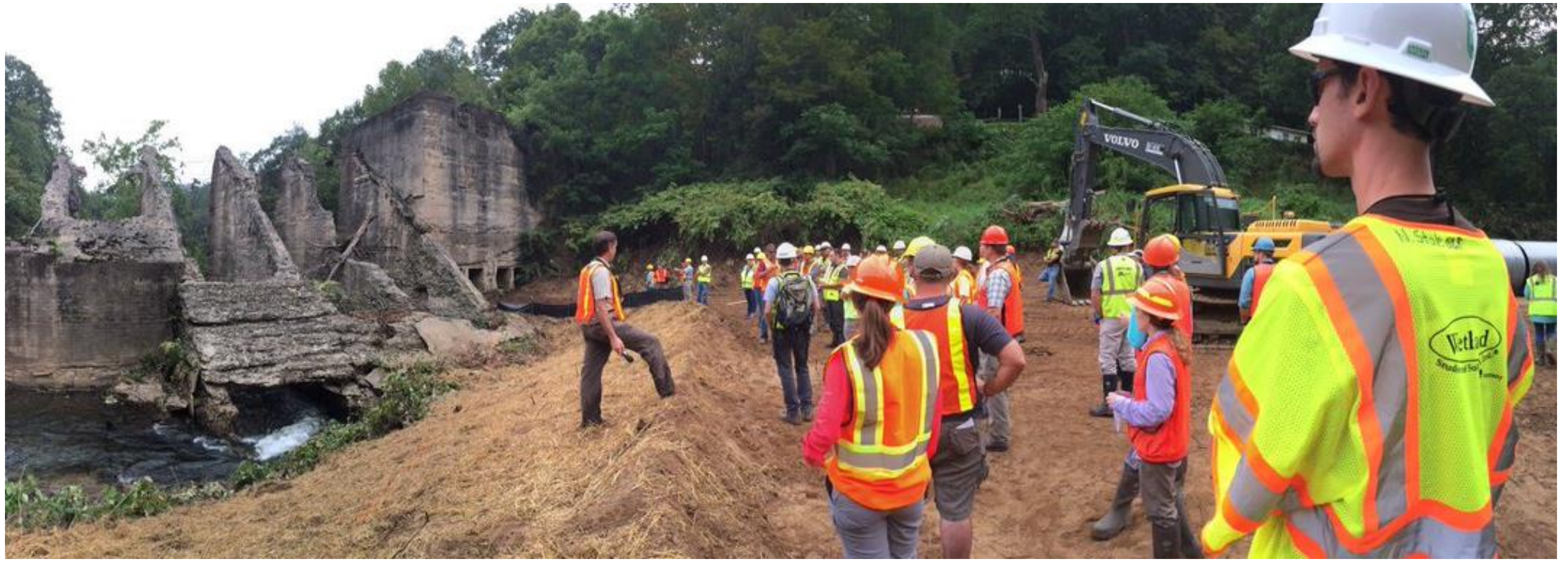
Purpose:

Exchange ideas and experiences

Promote research and advancement

Conference Includes:

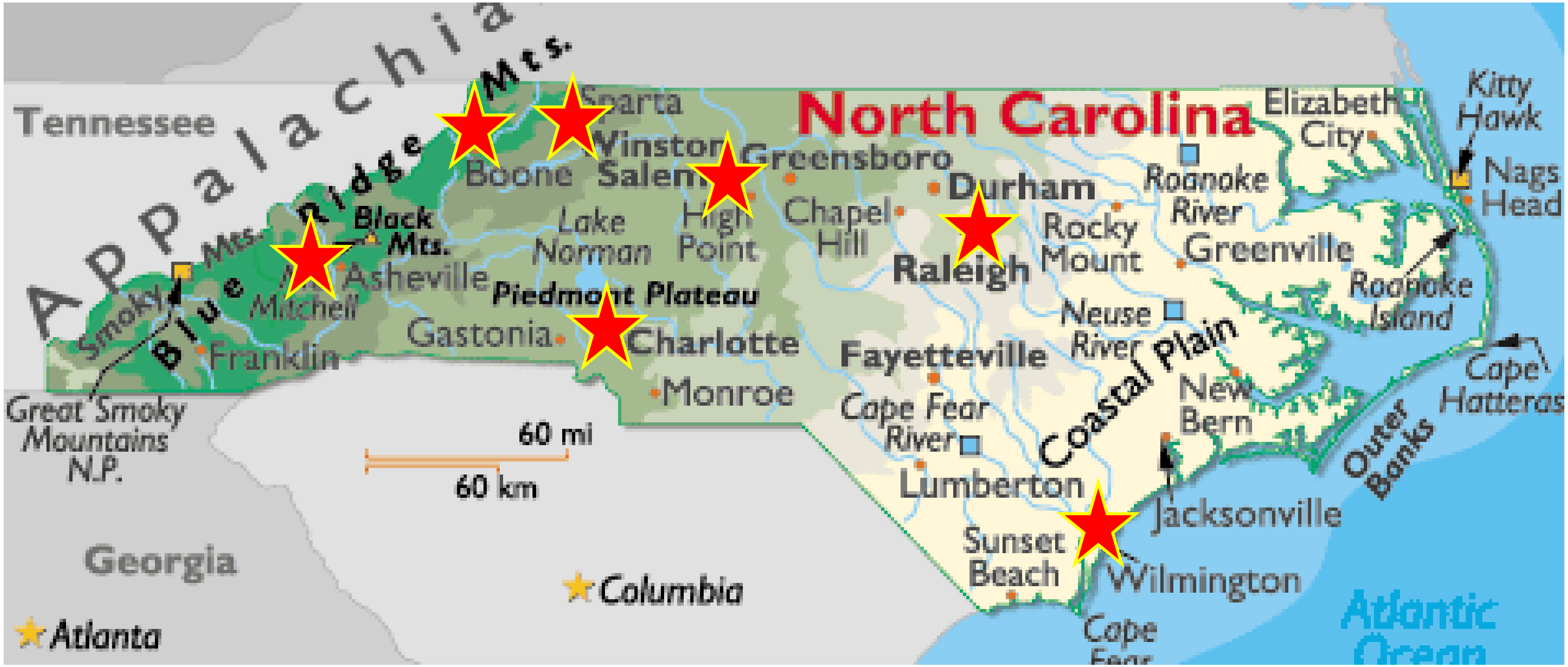
- Learning and Networking Opportunities
- Presentations & Posters
- Workshops
- Corporate Exhibits
- Field Tours



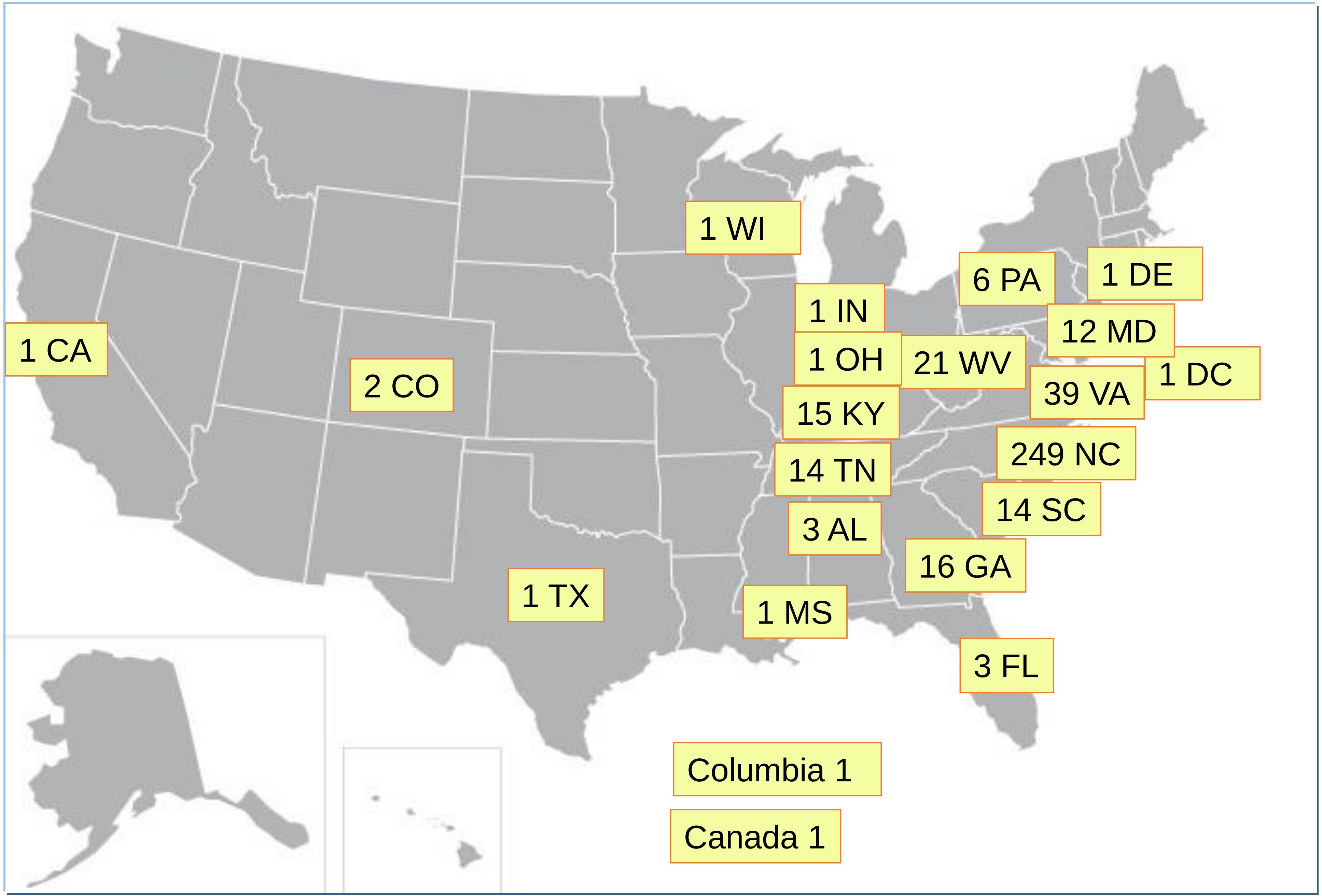
EcoStream
Stream Ecology and Restoration Conference

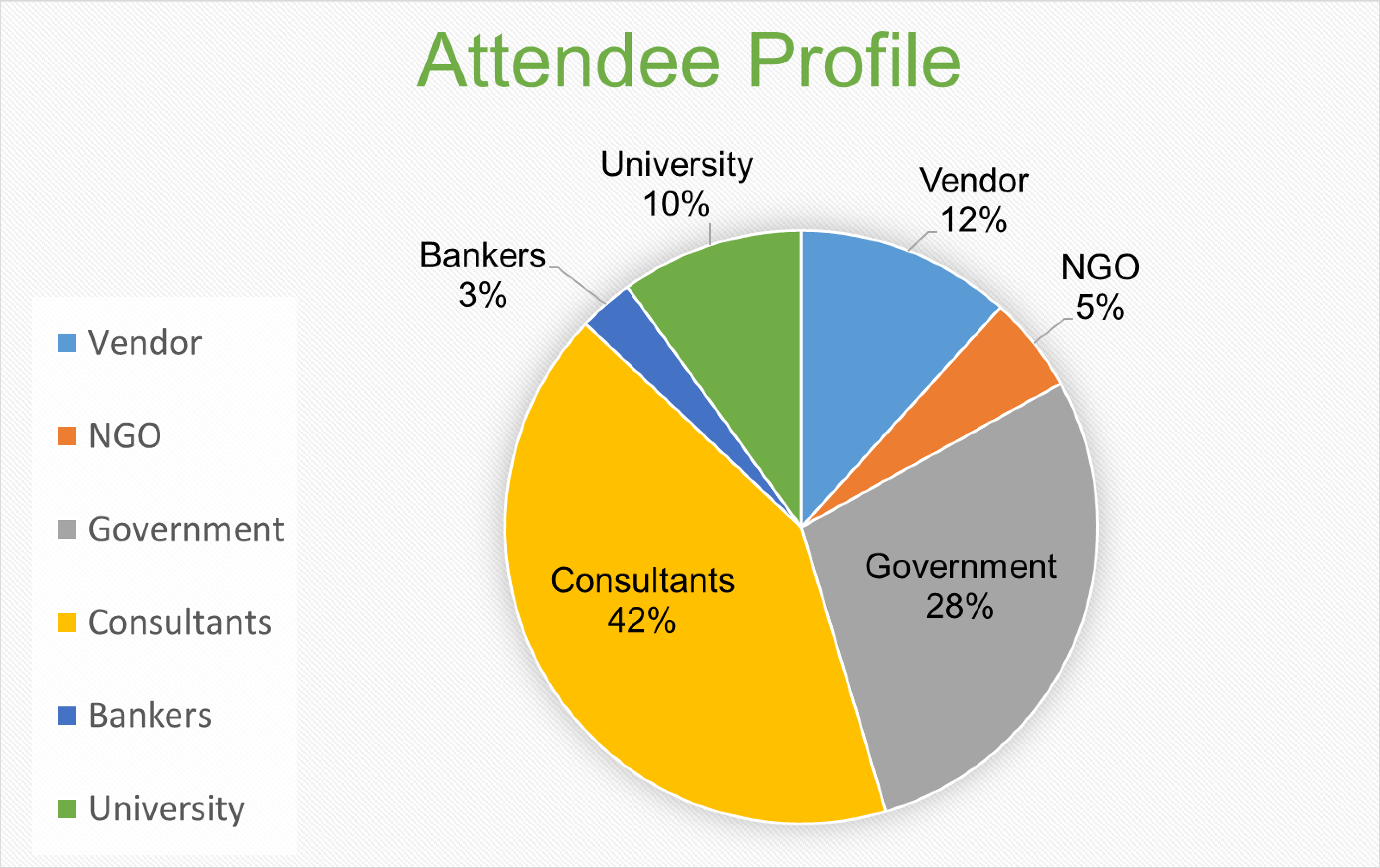
13 Conferences with Attendance of 150-500

- *Elkin* *1998*
- *Asheville* *1999*
- *Boone* *2000*
- *Raleigh* *2001*
- *Wilmington* *2002*
- *Winston-Salem* *2004*
- *Charlotte* *2006*
- *Asheville* *2008*
- *Raleigh* *2010*
- *Wilmington* *2012*
- *Charlotte* *2014*
- *Asheville* *2016*
- *Asheville* *2018*



401 Participants from 20 States & 2 Countries





Attendee Profile
University 10%
Vendor 12%
NGO 5%
Bankers 3%
Consultants 42%
Government 28%
Vendor
NGO
Government
Consultants
Bankers
University

Demonstration Projects

- Various watershed conditions
- Teaching & long-term evaluation

Rocky Branch, NC State University

Urban stream restoration & stormwater management (NC CWMTF, NC DENR 319, NC DOT, FEMA)

Design, Construction, Monitoring: 2001-2012

Stone Mountain State Park, Wilkes Co

Rural trout stream restoration (NC EEP, NC Div Parks & Rec)

Design, Construction, Monitoring: 1999-2007

Rendezvous Mountain State Forest

Rural high-gradient trout stream & wetland restoration (NC DFR, NC CWMTF)

Design, Construction, Monitoring: 2005-2009

North River

Rural Coastal Tidal Creek Restoration (NC CWMTF, NC EEP, Coastal Federation), 6,000-acre stream & wetland restoration

Design, Construction, Monitoring: 2008-2015

UT to Perry Creek, Millbrook Exchange Park

Urban Incised Channel – Test Innovative Grade Controls to Intercept Sediment Transport

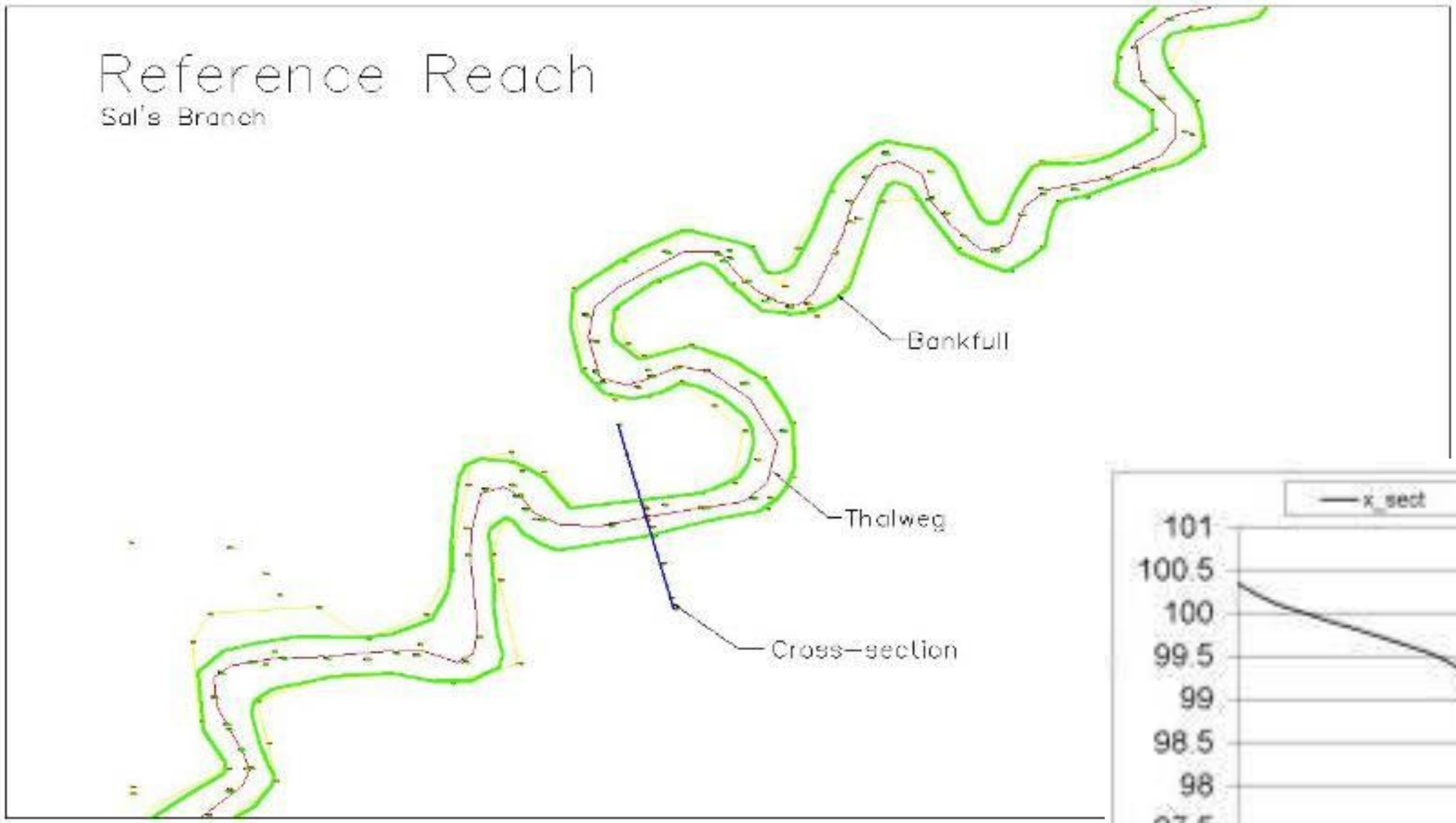
Design, Construction, Monitoring: 2017-2020

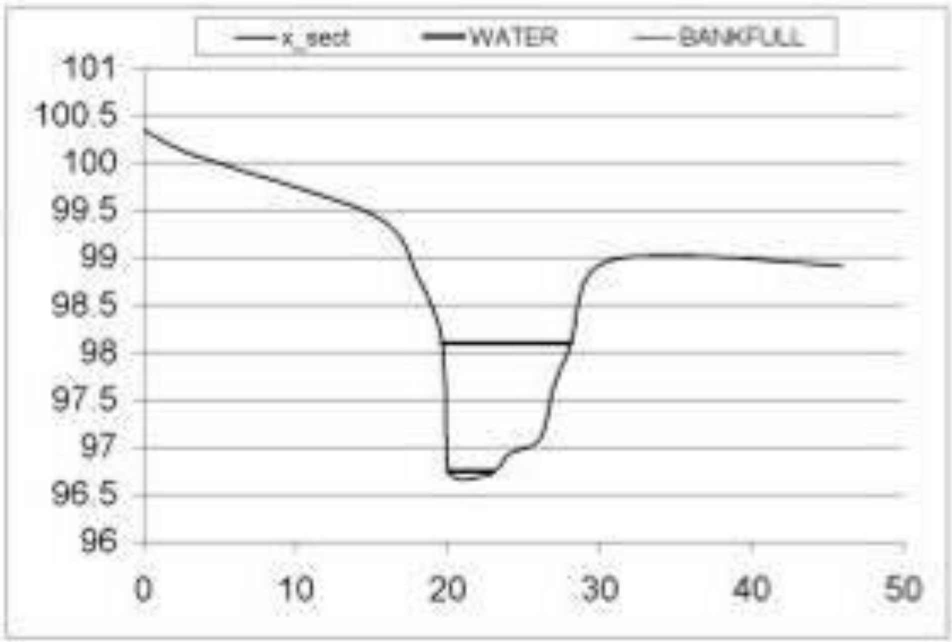
Research Projects

- Restoration Design
  - Hydraulic geometry relationships
  - Channel Morphology
  - Sediment transport
  - Innovative Design Techniques
- Restoration Effectiveness
  - Biological indicators
  - Eco-geomorphological Performance
  - Water quality impacts
  - Structure performance
  - Culvert impacts on fish passage

Hydraulic Geometry and Channel Morphology

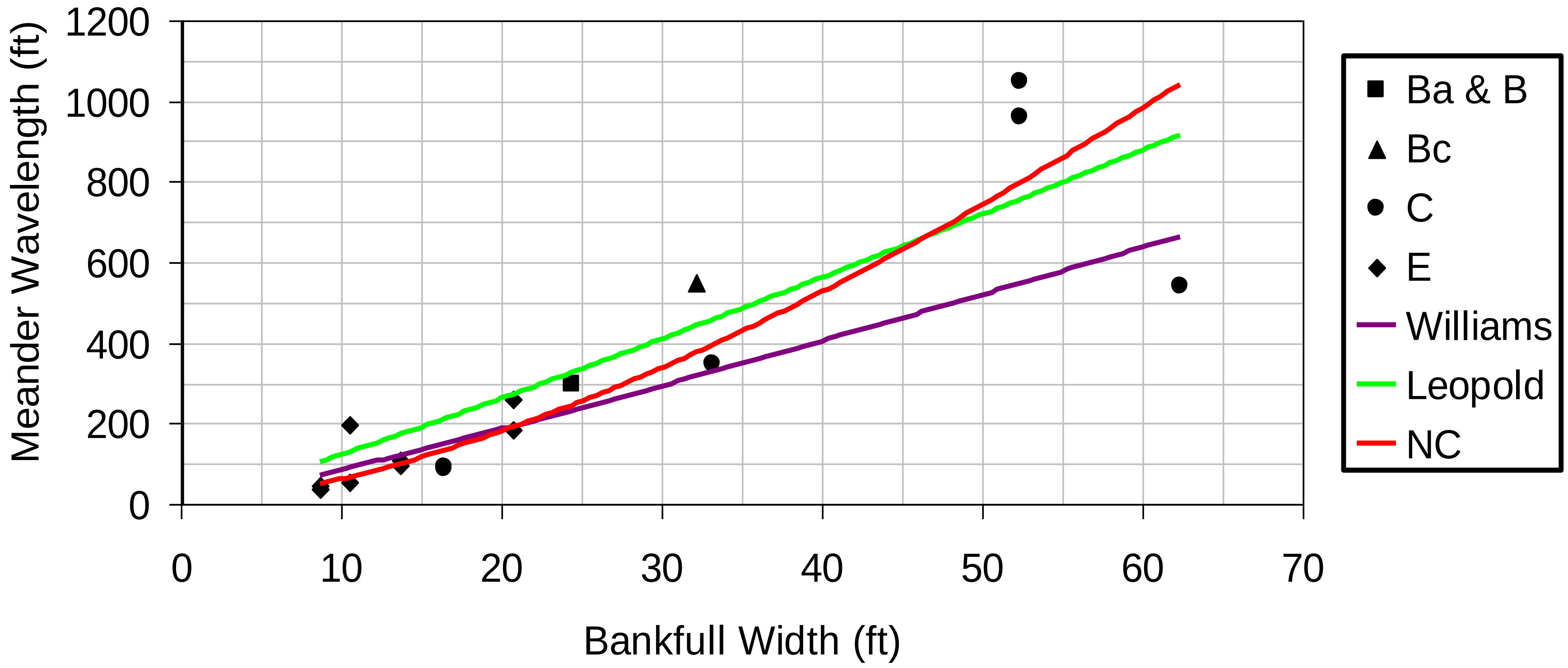
Geomorphology from Total Station Surveys





Hydraulic Geometry Relationships

Dimension, Pattern, & Profile related to
Discharge, Slope, & Bed Material



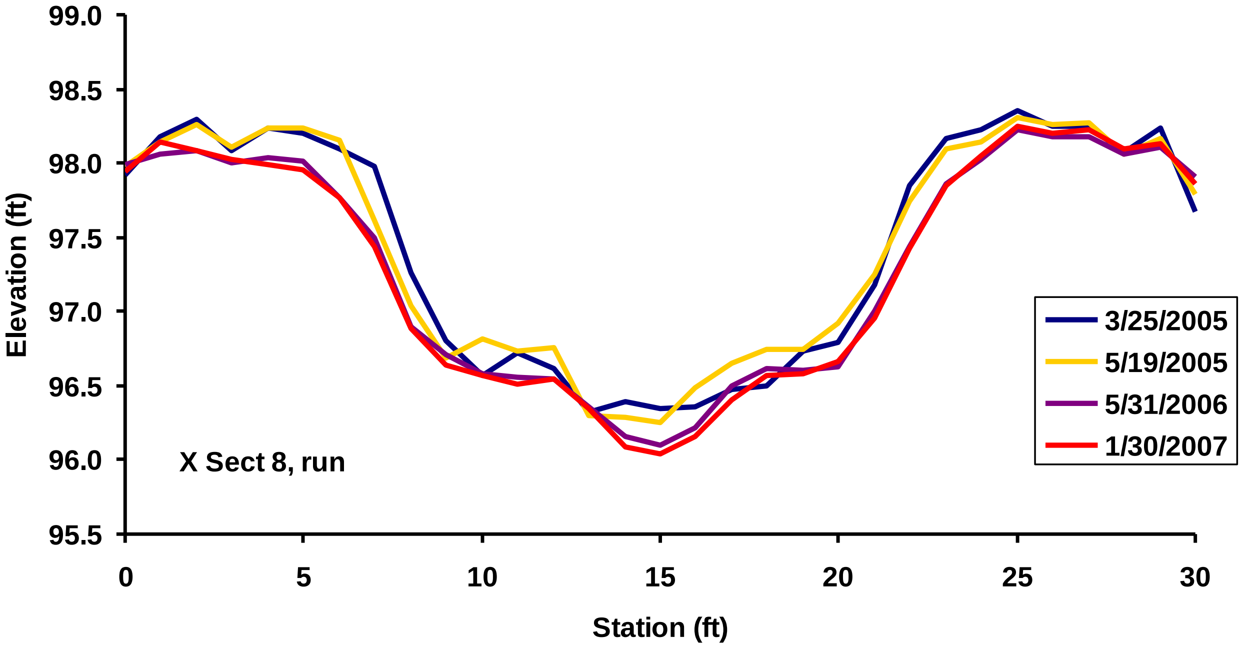
Clinton, 2001

Sediment Transport

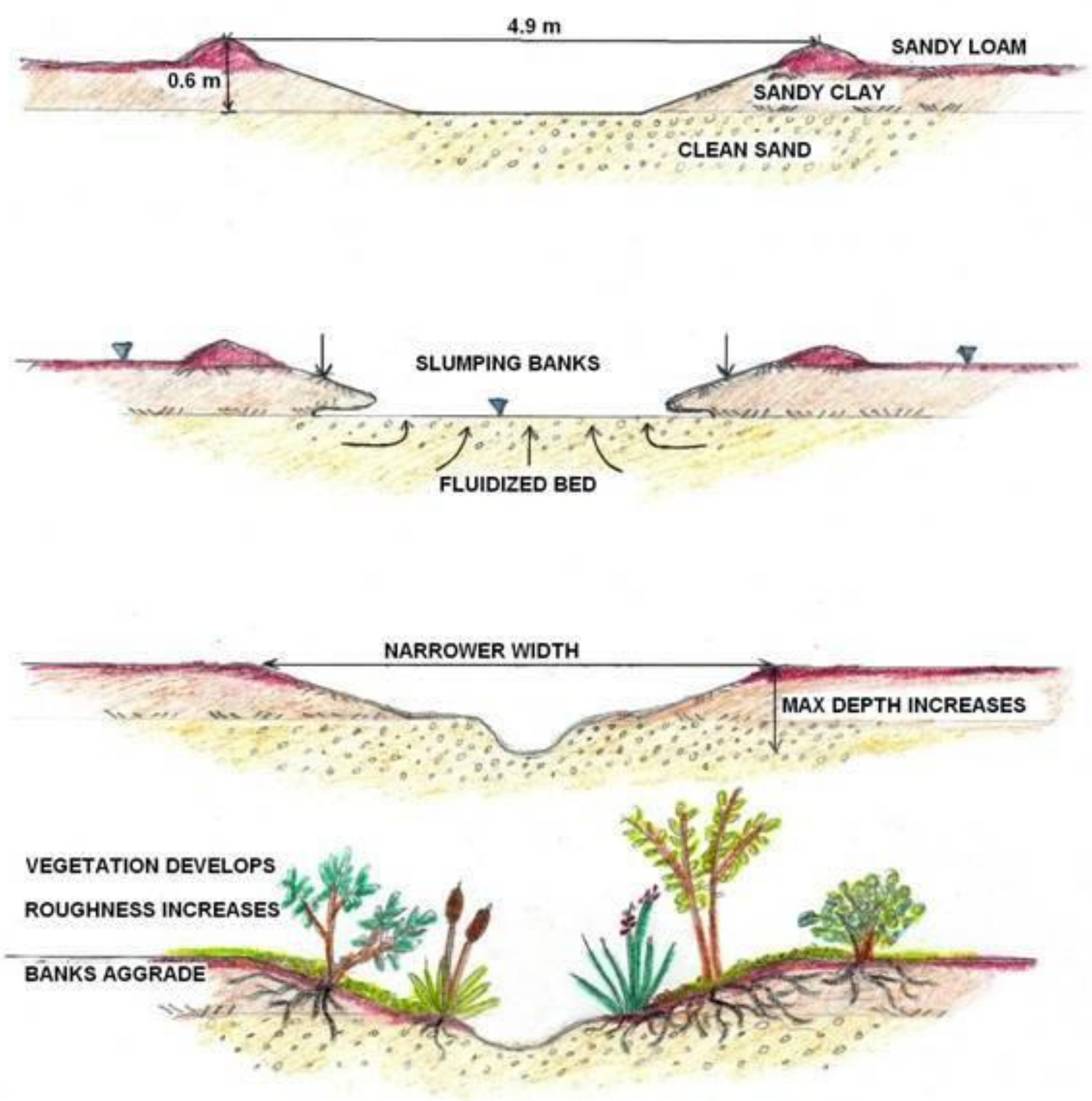
Monitoring and Modeling Sandbed Channel Development: Nick Lindow, PhD

Cove Creek Stream Restoration, Craven County

Cove Creek Monitoring



Cove Creek Dynamic Model

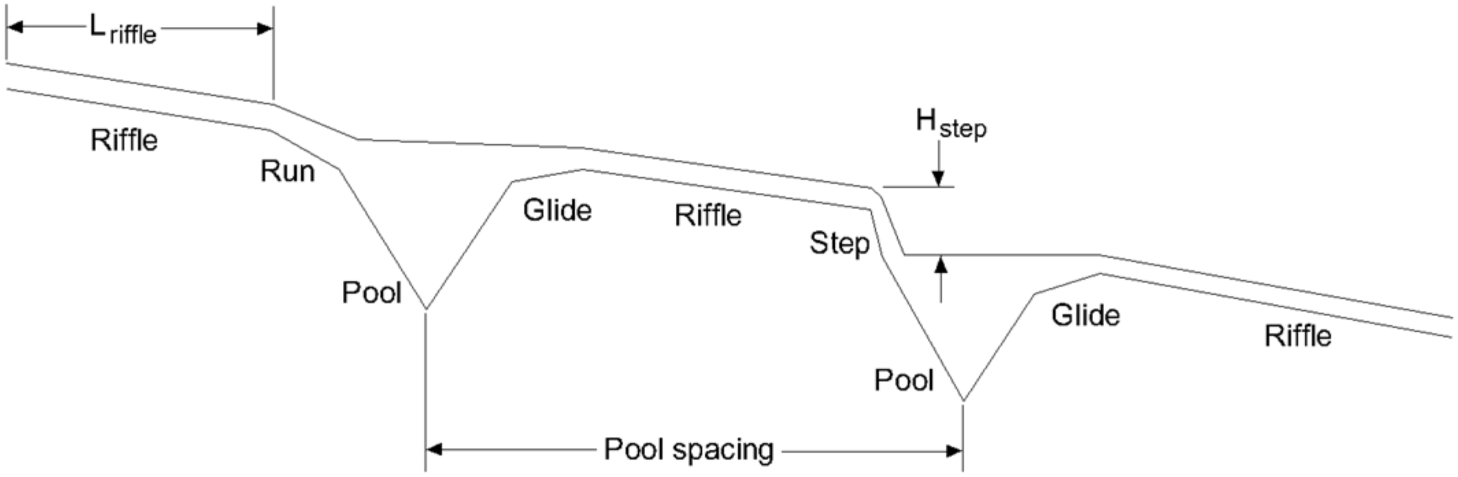


Channel Bedform Characterization

Morphology survey of two streams, Joyce Kilmer Wilderness Area, Western N.C.: Jason Zink, PhD 2012.

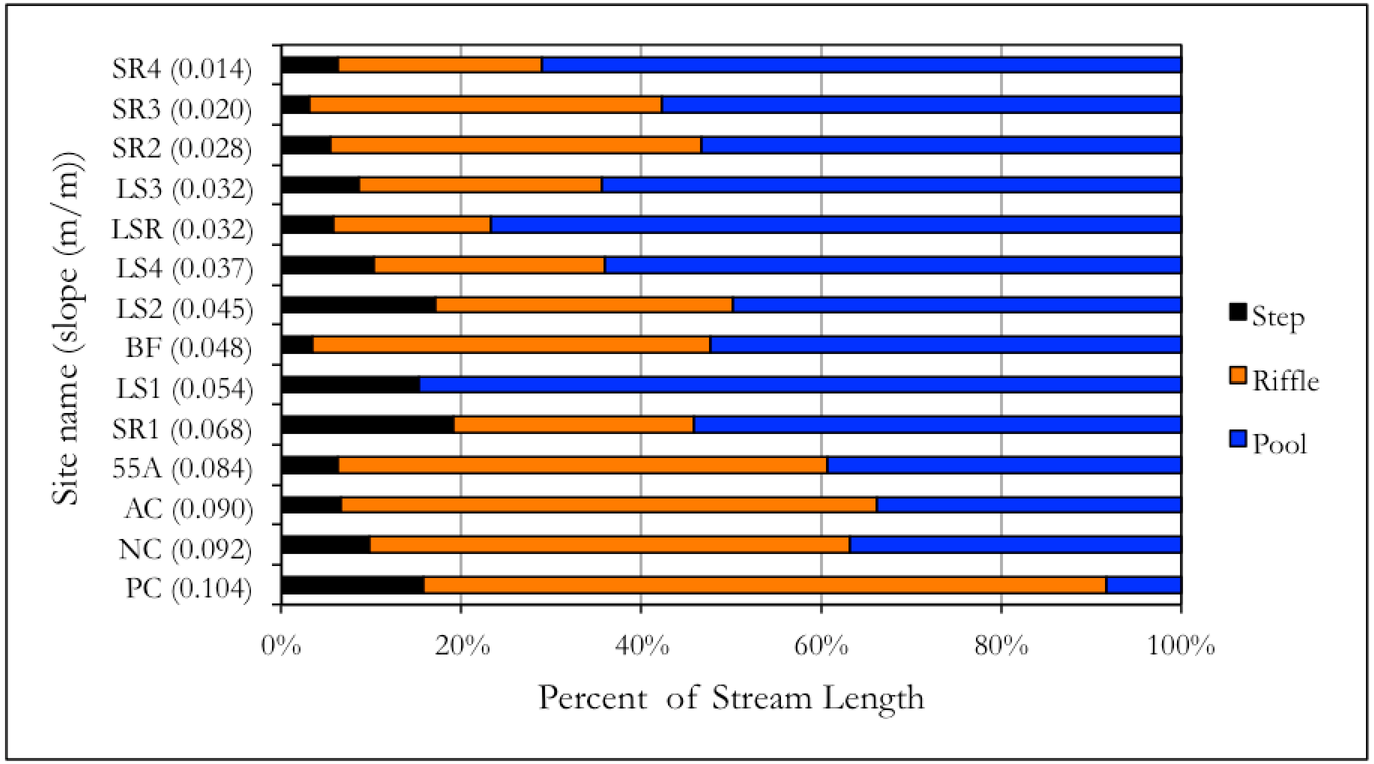
From longitudinal profile:

- length: pool, riffle
- slope: pool, riffle, reach
- height: step
- spacing: pool



Longitudinal Profile: Bedform Morphology

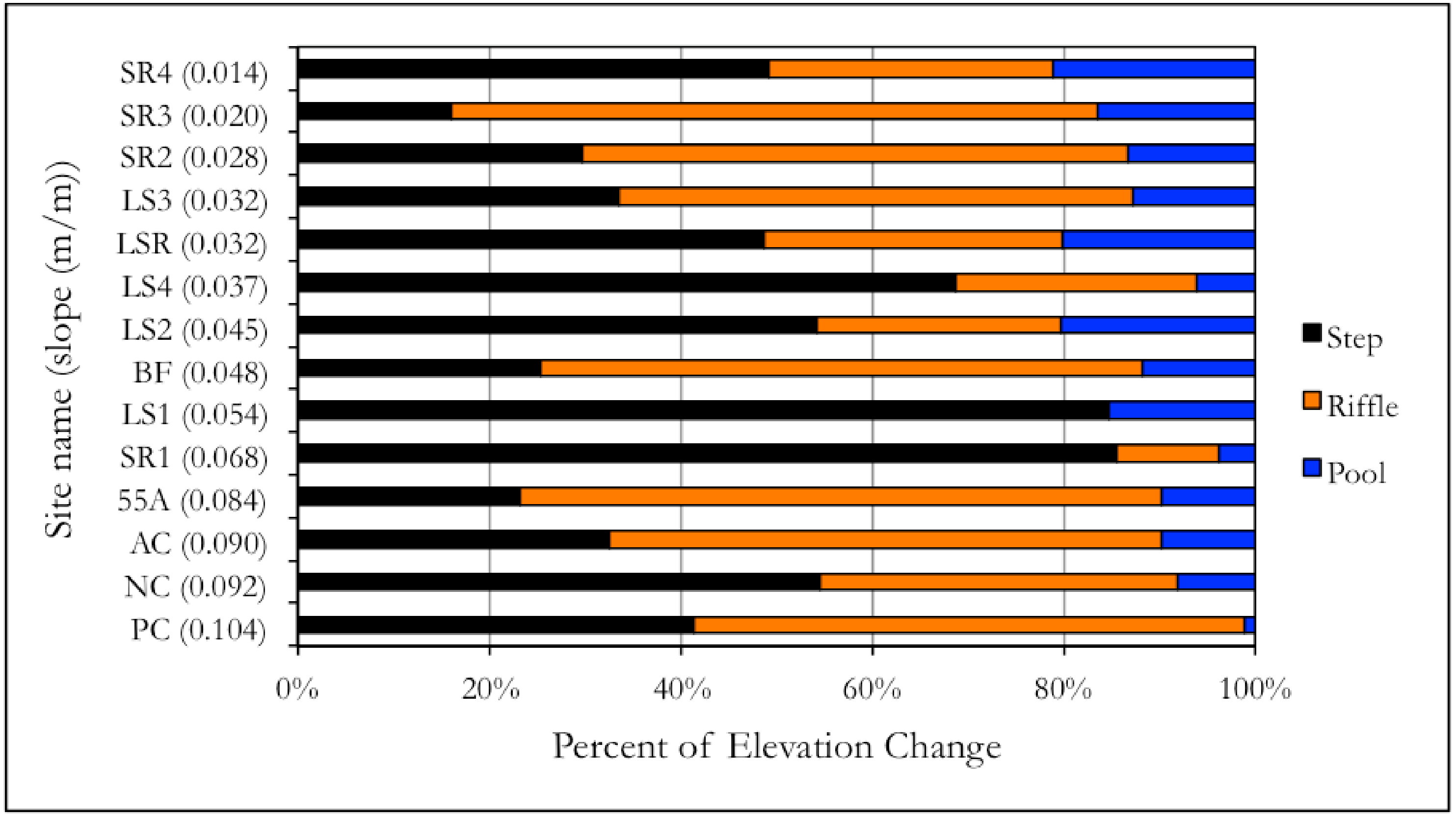
Percent of Stream Length Occupied by Steps, Riffles, Pools



Pools: >50% length for all streams with slope 0.07 ft/ft
Riffles/Steps: both exist across entire range of slopes
Most common sequence: step-pool-riffle

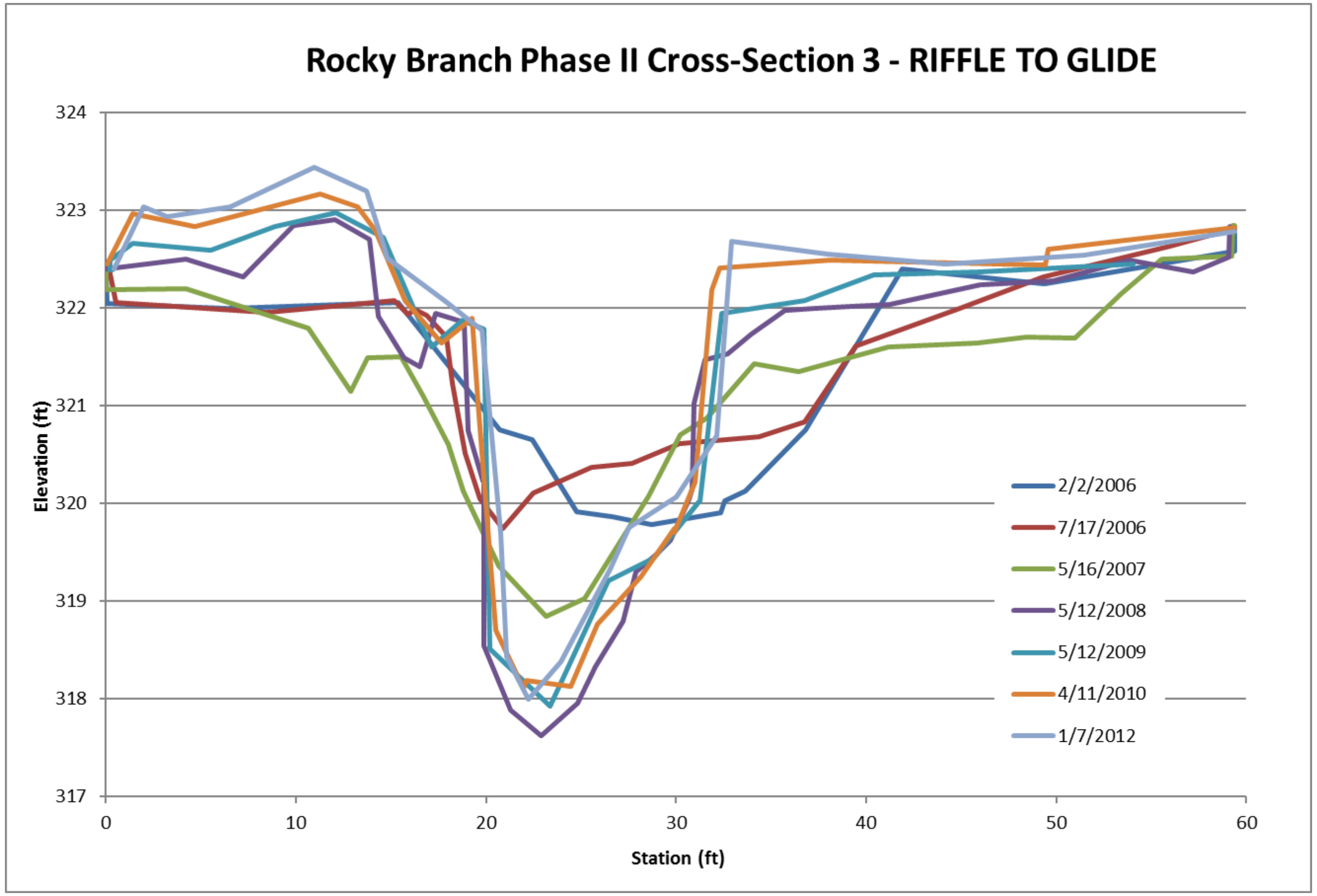
Longitudinal Profile: Bedform Morphology

Percent of Elevation Change by Steps, Riffles, Pools



Channel Adjustment

Use Post-restoration monitoring of stream restoration projects: Jonathan Page, PhD Candidate (2020)



XS 3 2006 Looking downstream

XS 3 2009 Looking downstream

NC Division of Mitigation Services Database of all Piedmont Restored Streams for Mitigation

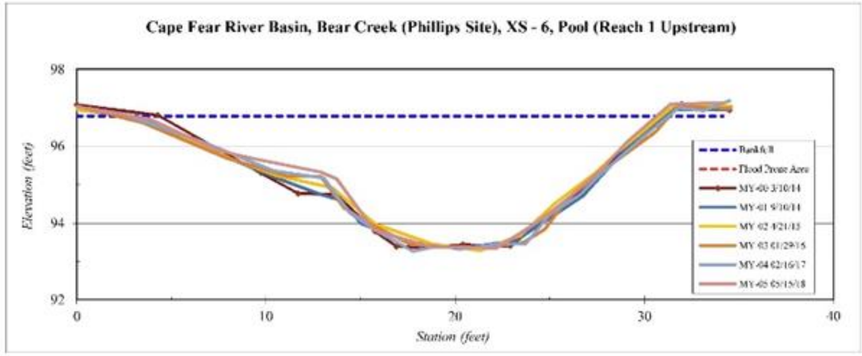
Level	Count
Site	122
Reach	312
XS	1,150 (Riffle = 651, Pool = 499)
MY	3,944 (Riffle = 2,200, Pool = 1,744)
D_{50}	754

River Basin:	Cape Fear
Site Name	Bear Creek (Phillips Site)
XS ID	XS - 6, Pool (Reach 1 Upstream)
Drainage Area (sq mi):	4.08
Date:	5/15/2018
Field Crew:	Perkinson, Keith

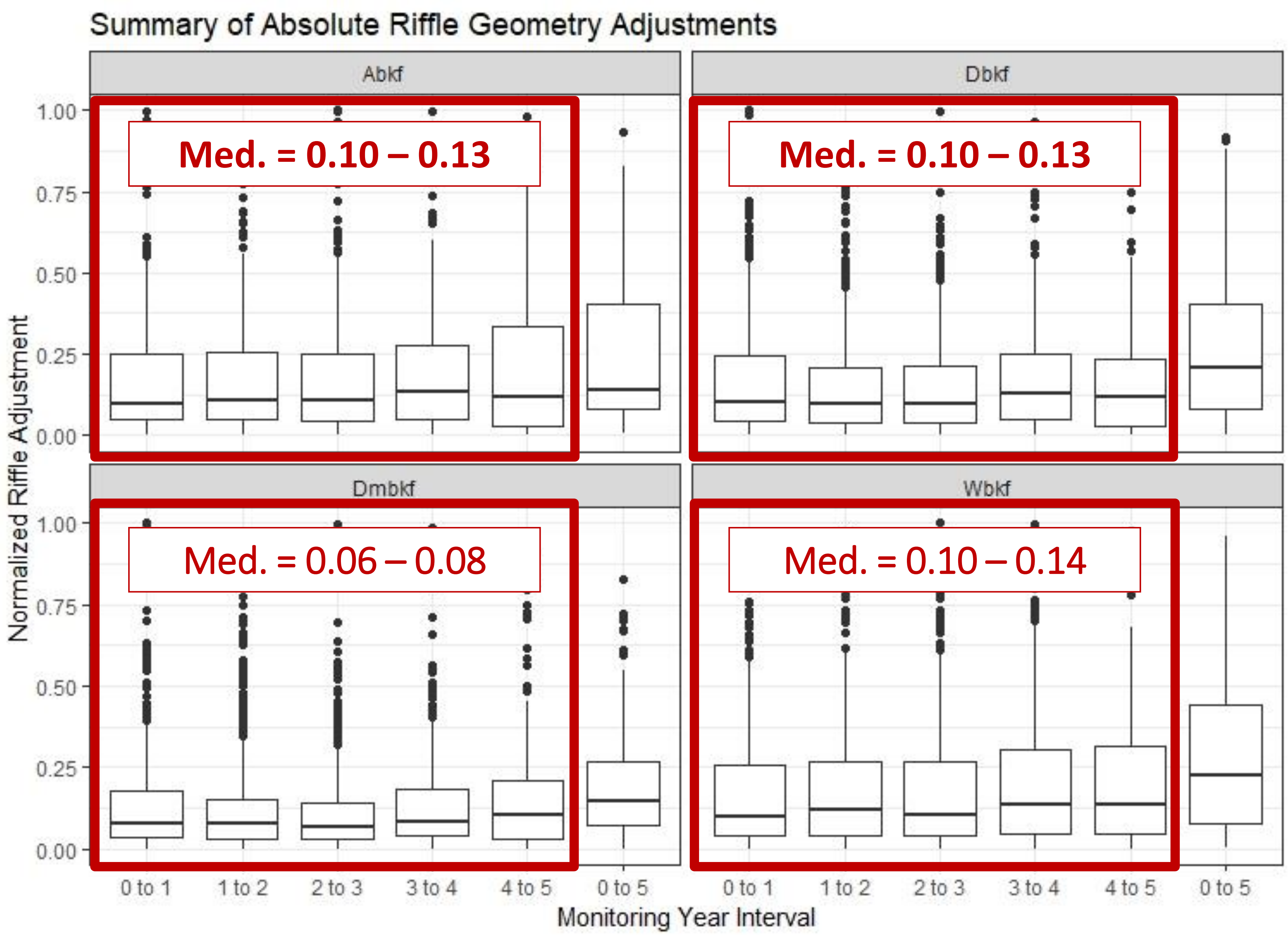
Station	Elevation
0.0	97.0
3.9	96.7
7.5	95.9
9.5	95.7
12.9	95.3
13.8	95.1
15.7	93.8
18.8	93.4
20.4	93.4
22.1	93.3
23.7	93.8
24.9	94.2
26.1	94.7
27.8	95.44
29.1	96.11
31.4	97.09
34.2	97.13

SUMMARY DATA	
Bankfull Elevation:	96.8
Bankfull Cross-Sectional Area:	51.1
Bankfull Width:	27.7
Flood Prone Area Elevation:	-
Flood Prone Width:	-
Max Depth at Bankfull:	3.4
Mean Depth at Bankfull:	1.8
W / D Ratio:	-
Entrenchment Ratio:	-
Bank Height Ratio:	1.00

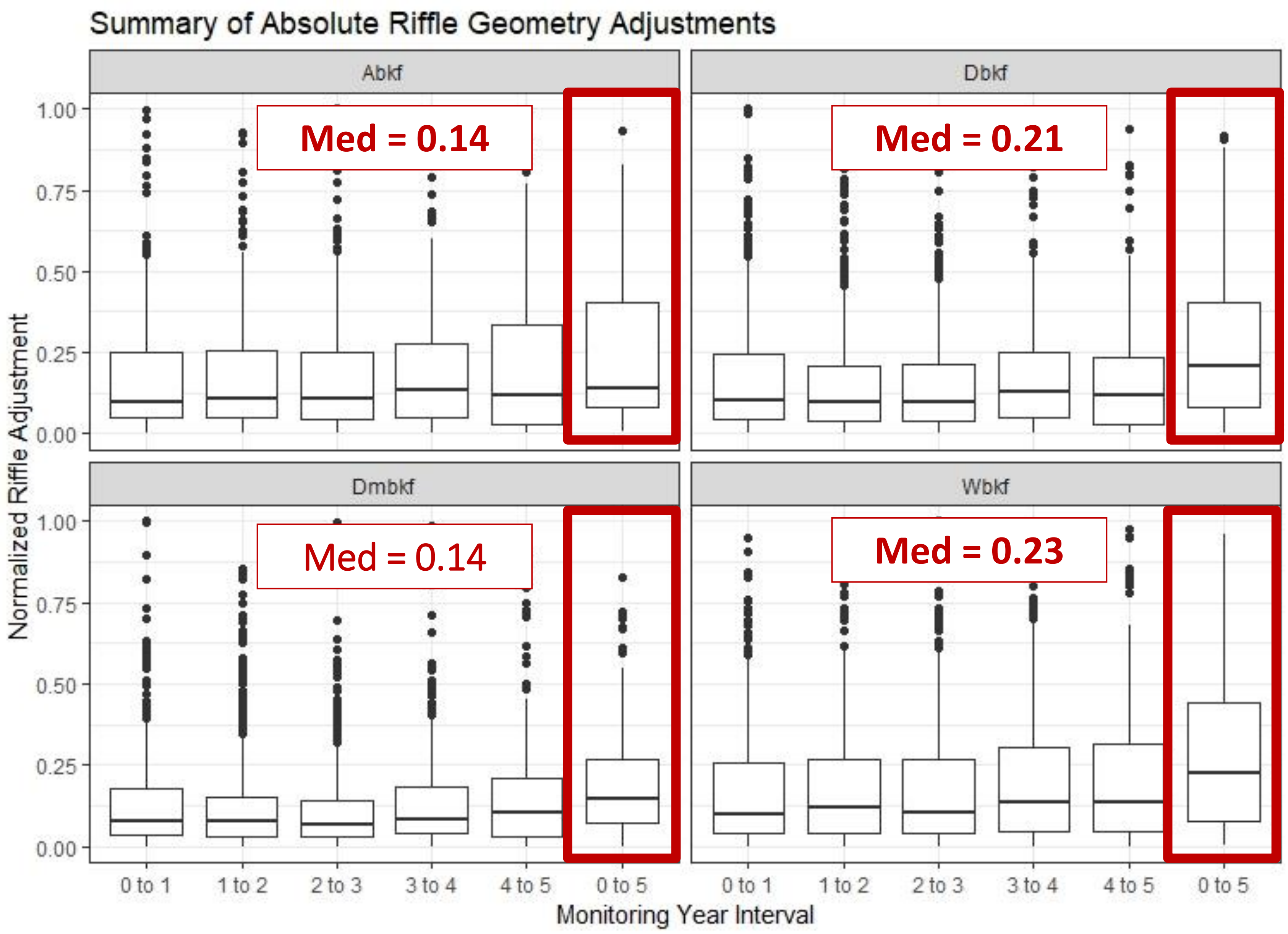
Stream Type	C



Absolute Adjustment in Riffle Cross Sections



Absolute Adjustment in Riffle Cross Sections



Water Quality Impacts

Purlear Creek restoration evaluation by Justin Spangler, MS 2007

Monitoring (14 sites)

Flow rate

Total Suspended Solids (TSS)

Total Phosphorus (TP)

Orthophosphate P (O-PO_4-P)

Total Nitrogen (TN)

Total Ammonium Nitrogen (NH_3-N)

Total Kjeldahl Nitrogen (TKN)

Organic Nitrogen (Org N)

Nitrate + Nitrite (NO_3-N)

Total Coliform

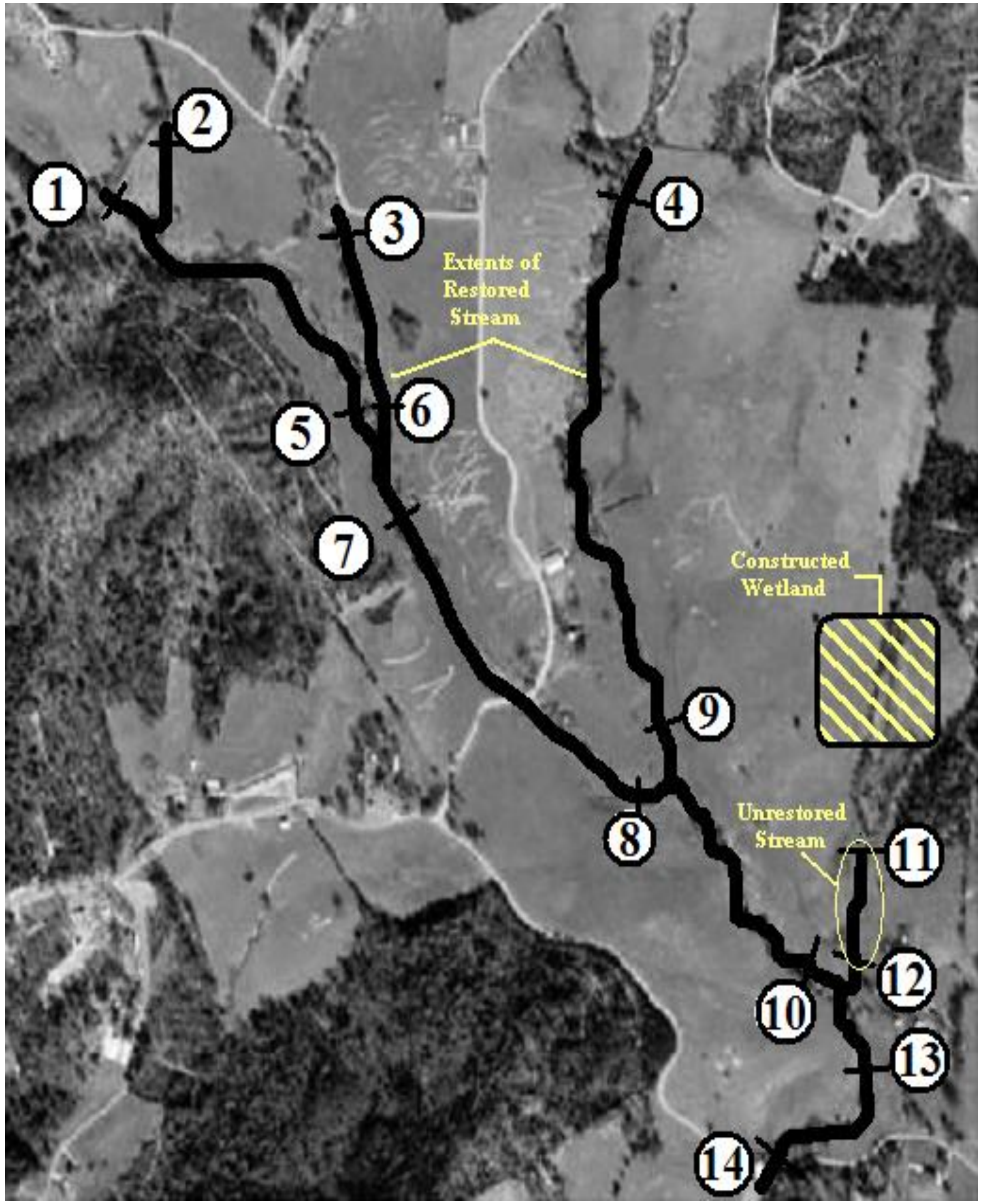
Escherichia Coli

Chloride (Cl)

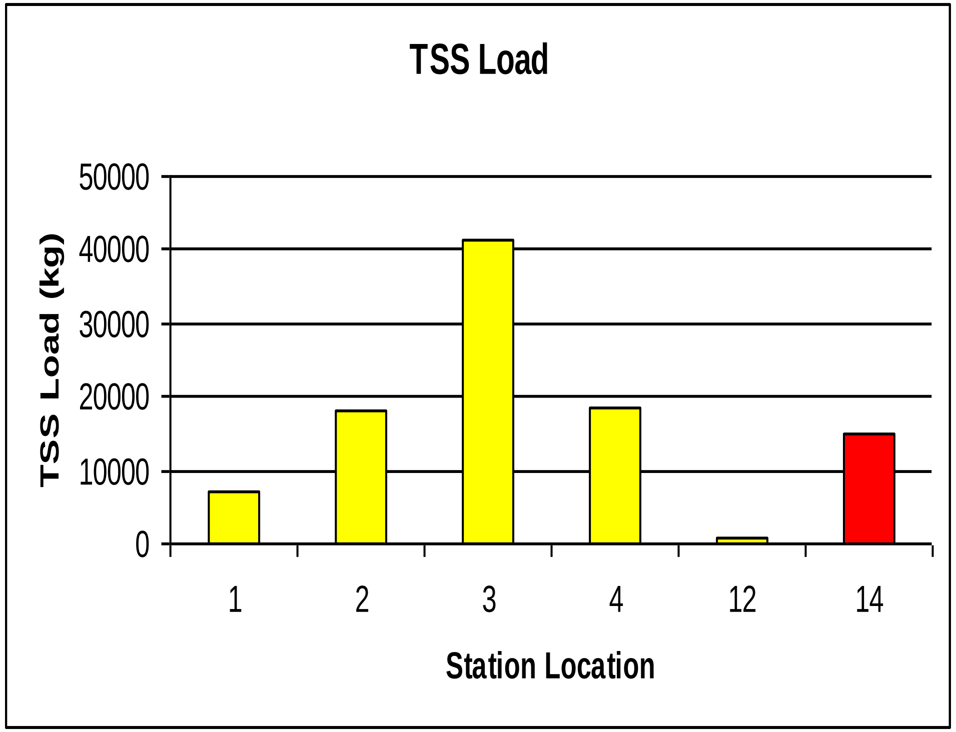
Temperature

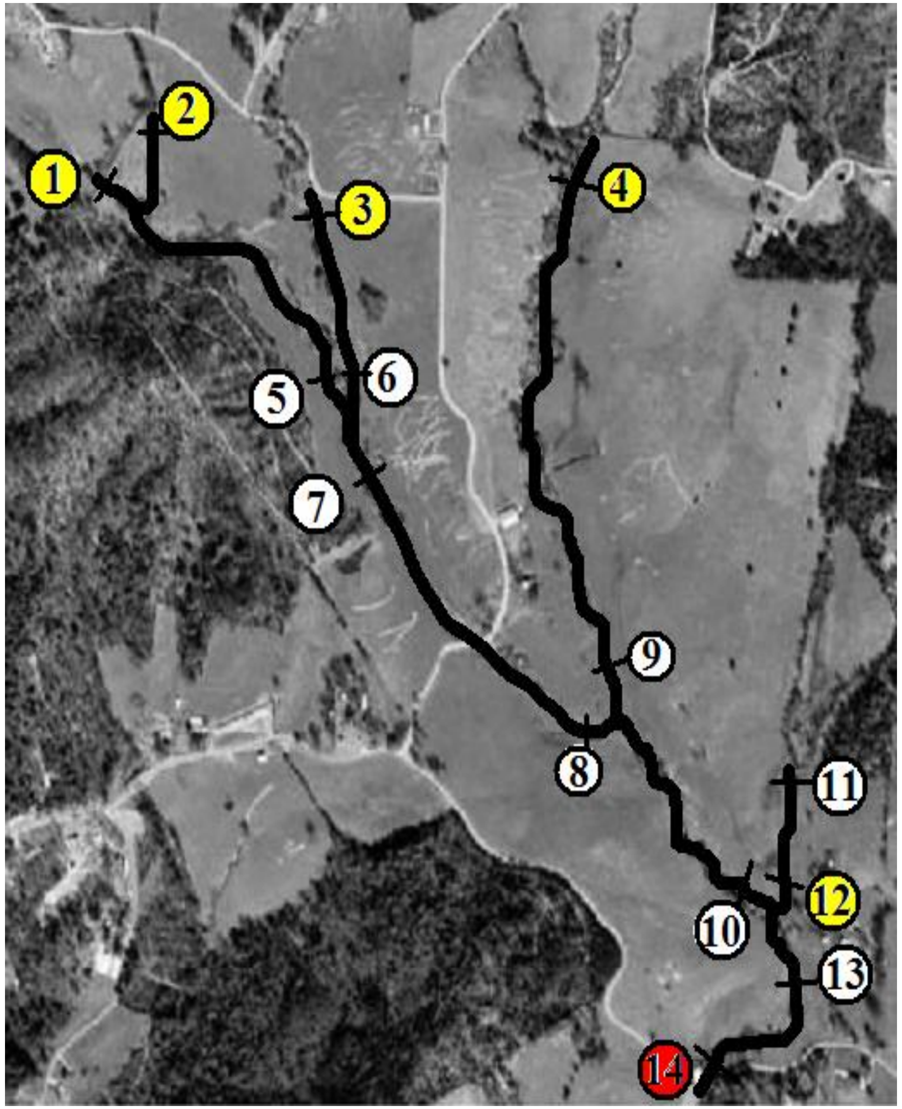
Dissolved Oxygen (DO)

pH



TSS Load





Total Inflow Load:

86 Mg

Total Outflow Load:

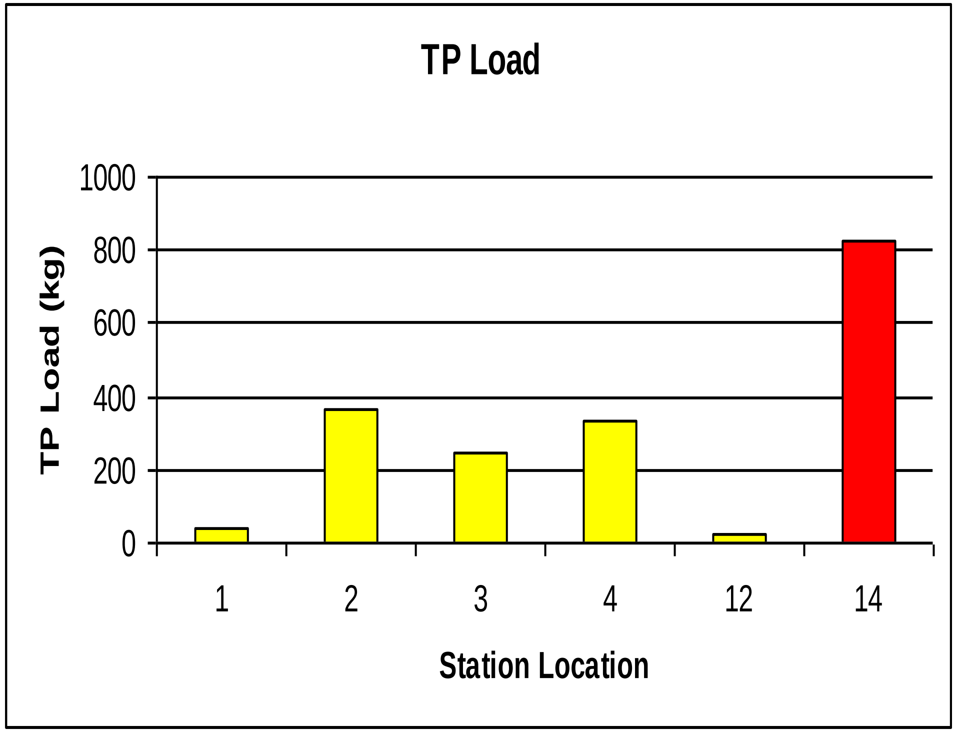
15 Mg

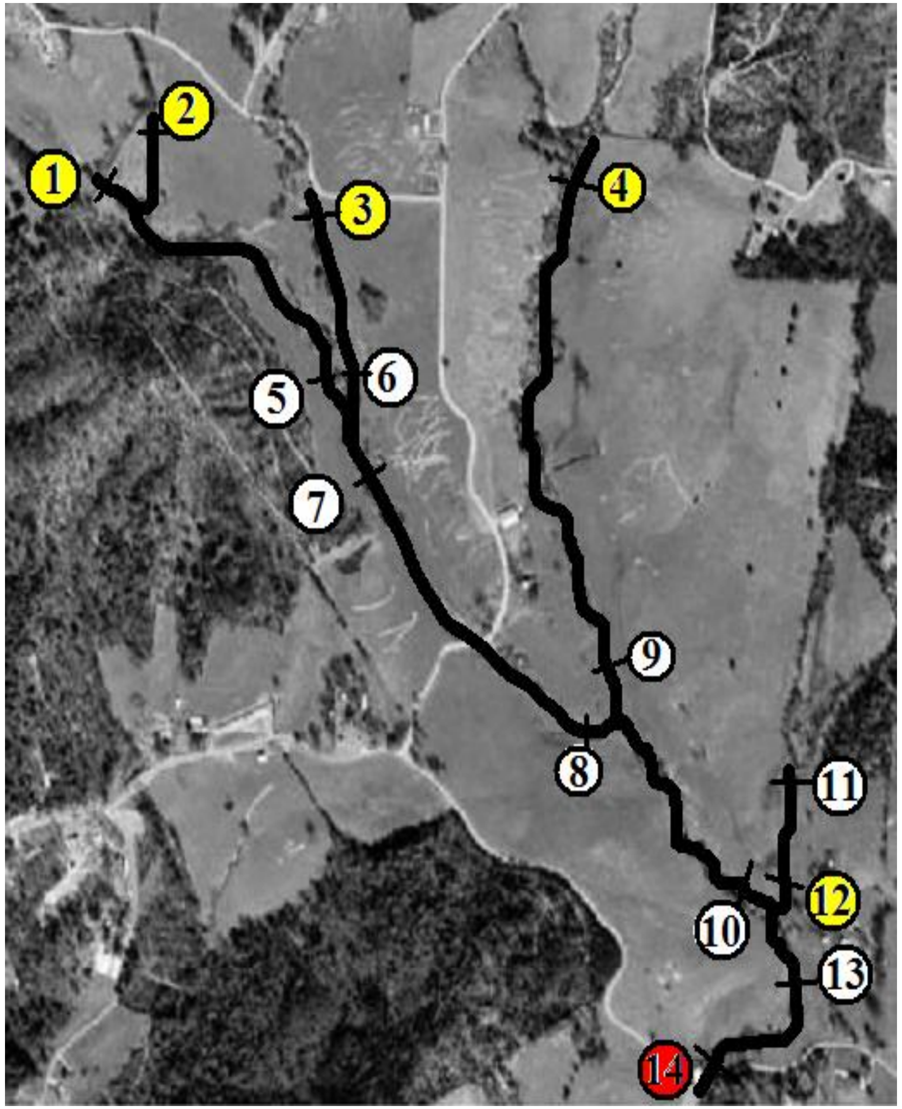
Decrease of:

71 Mg

83%

TP Load





Total Inflow Load:

1021 kg

Total Outflow Load:

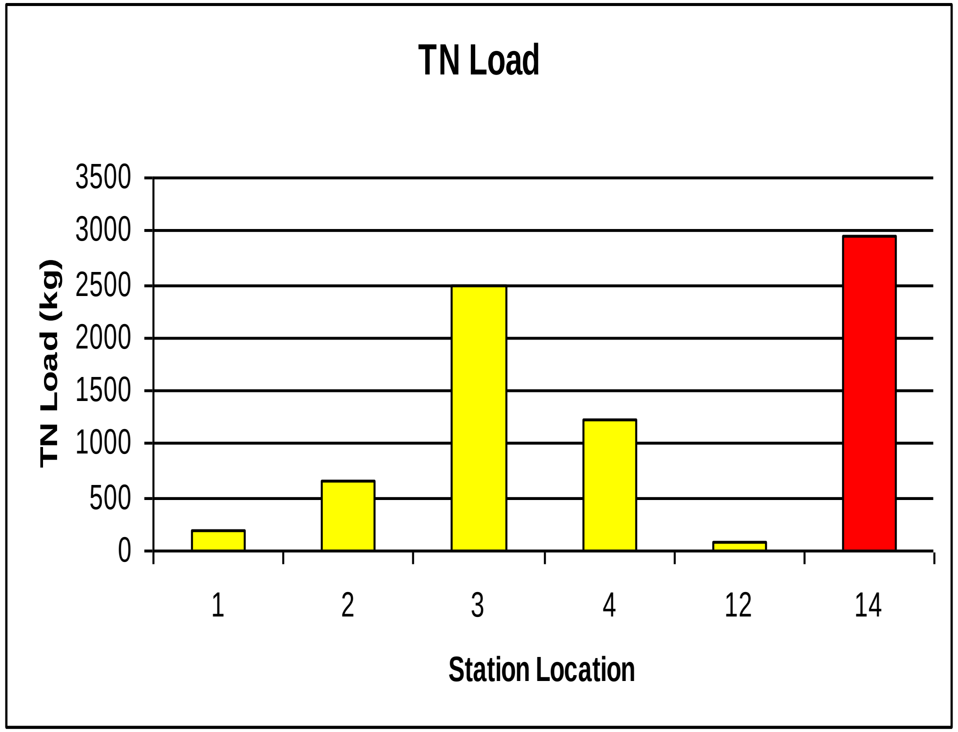
825 kg

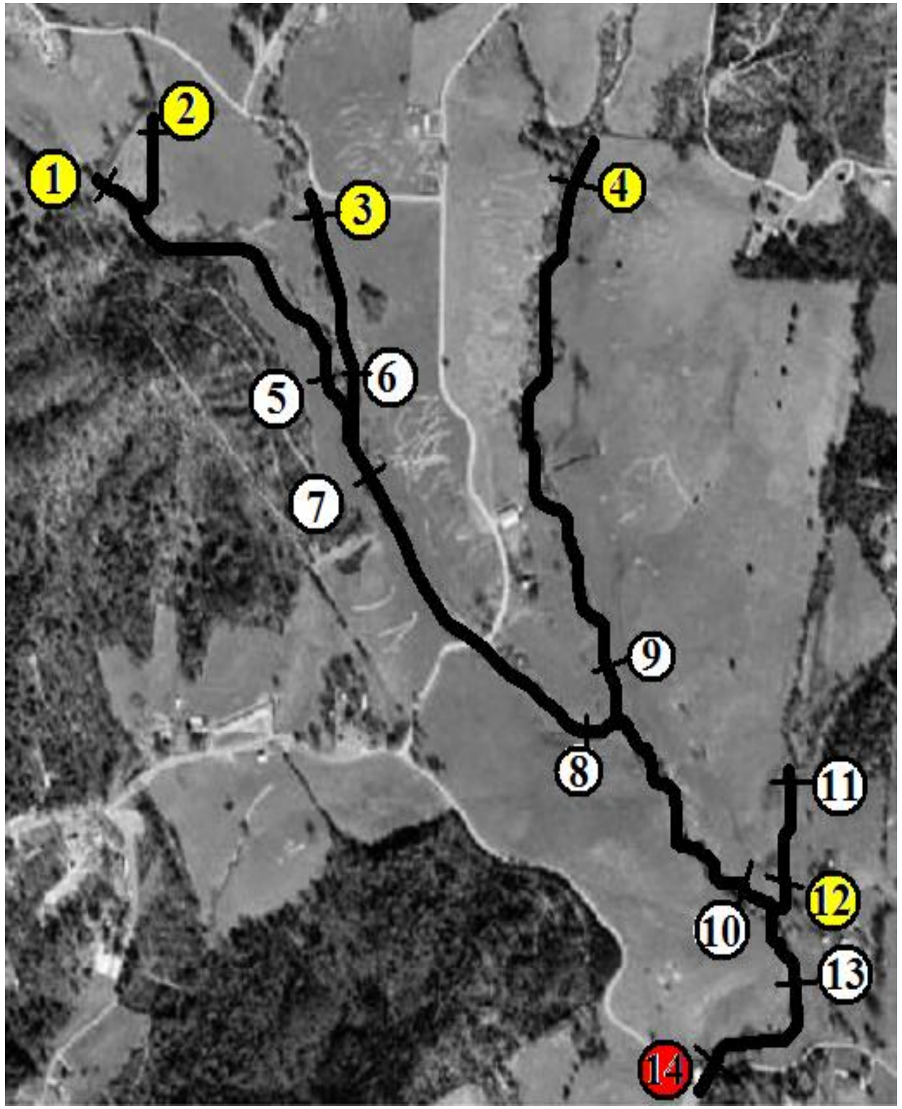
Decrease of:

196 kg

19%

TN Load





Total Inflow Load:

4660 kg

Total Outflow Load:

2965 kg

Decrease of:

1696 kg

36%

Structure Performance

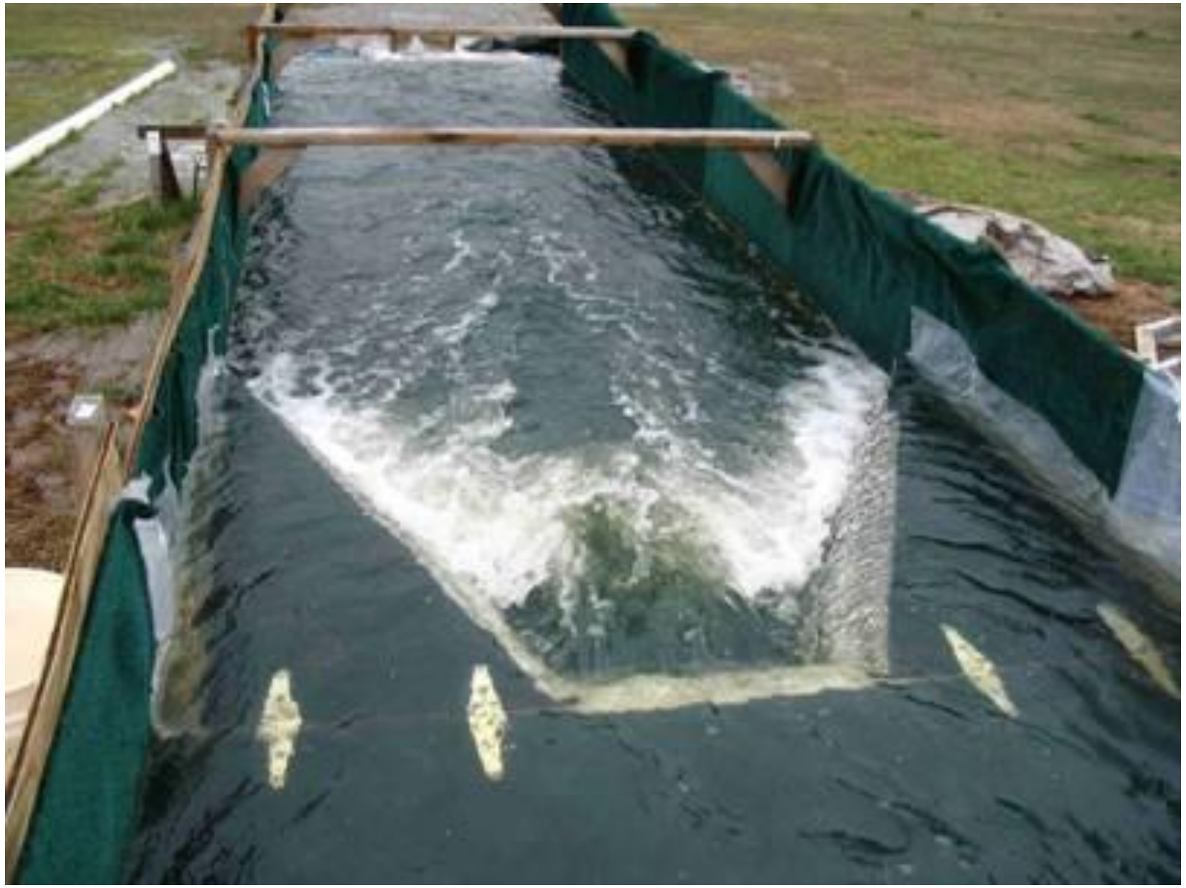
Rock Cross Vane Function & Performance: Paige Puckett, PhD, 2007

- 3 Factor, 3 Level Study

  Arm Angle (deg), Arm Slope (ft/ft), Drop (ft/bkfd)

- Response variable

  Flow Contraction = V_{center}/V_{outer}



Findings:

- Drop has the greatest impact on flow contraction.
- As drop decreases, slope effects are more predominant than angle effects.
- At higher drops, angle effects are more predominant than slope effects.

Failure Modes and Assessment

- 16 projects on 11 streams were assessed
- 6 failure indicators were observed:

  arms washed out
  header washed out
  head cut
  bank erosion at vane
  bank erosion downstream of vane
  insufficient scour pool development

Structure Rapid Assessment Tool

Crossvane #
Date/Time
Notes

score each indicator from 0-5 based on guidebook

Durability	primary	secondary
arm washout	drag + lift, moment to resist movement < moment to produce movement	arms do not tie into banks
		improper alignment
		insufficient backfill
		placed in a bend
		poor spacing of boulders
		undersized boulders
	undercutting (leads to tipping)	arms too steep
		drop too high
		improper alignment
		insufficient backfill
		no footers
		placed in a bend
		undersized cross vane
header washout	drag + lift, moment to resist movement < moment to produce movement	header too high
		insufficient backfill
		poor spacing of boulders
		undersized boulders

Banks	primary	secondary
bank erosion at vane	direct contact of flow with banks	arms do not tie into banks
		arms washed out
		exposed banks
		poor spacing of boulders
	flow directed at banks	improper alignment
		placed in a bend
	piping	insufficient backfill
		poor spacing of boulders
	side cutting	arms do not tie into banks
		arms too short
		arms washed out
		header too high
		improper alignment
		placed in a bend
		poor spacing of boulders
		undersized cross vane
	undercutting	arms too steep
		drop too high
		improper alignment
		insufficient backfill
		no footers
		placed in a bend
		undersized cross vane
downstream bank erosion	direct contact of flow with banks	arms too short

Results

INDICATOR	VANES	% OF VANES	PATH OCCURRENCES
F1. ARM WASHOUT	20	16.7	31
F2. SILL WASHOUT	4	3.3	4
F3. HEADCUT	60	50.0	161
F4. BANK EROSION	77	64.2	192
F5. DOWNSTREAM BANKS	39	32.5	65
F6. INSUFFICIENT POOL	52	43.3	69

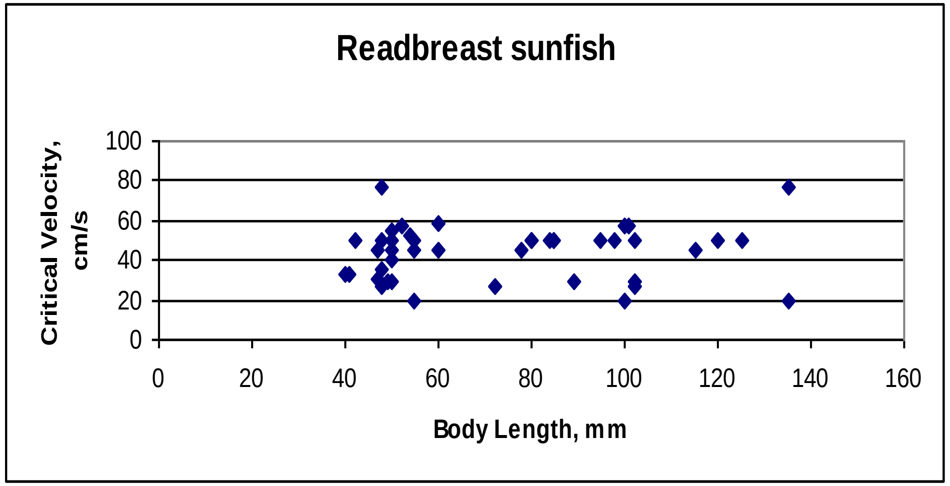
55 vanes showed indications of side-cutting from at least one of:

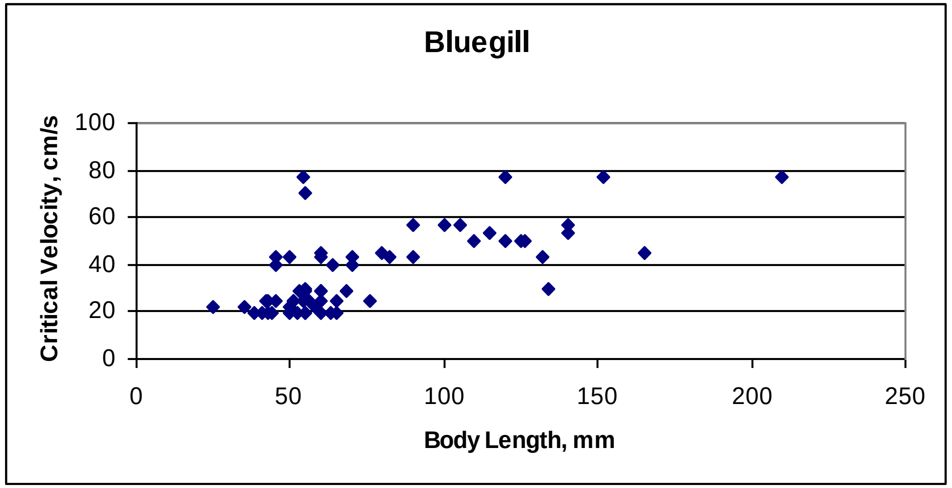
- Improper alignment
- Backed into a bend
- Poor boulder spacing
- Header installed too high
- Undersized vane

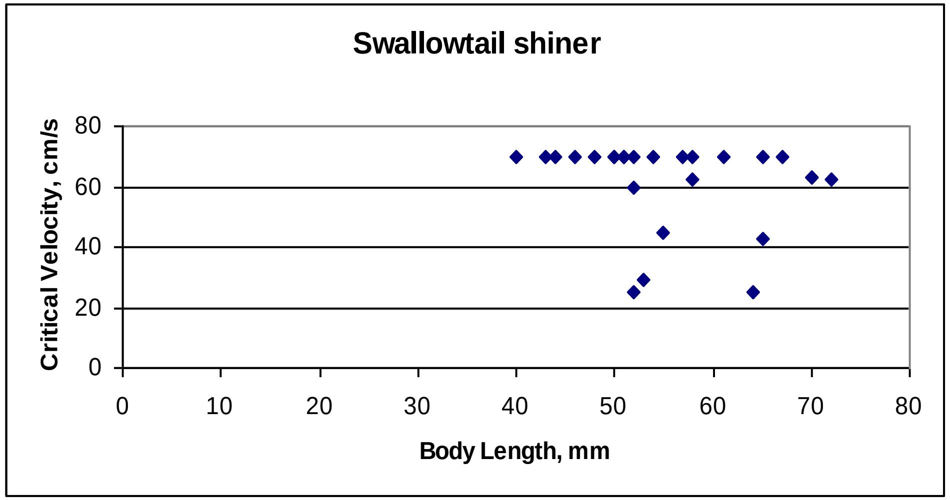
Culvert Impacts on Fish Passage

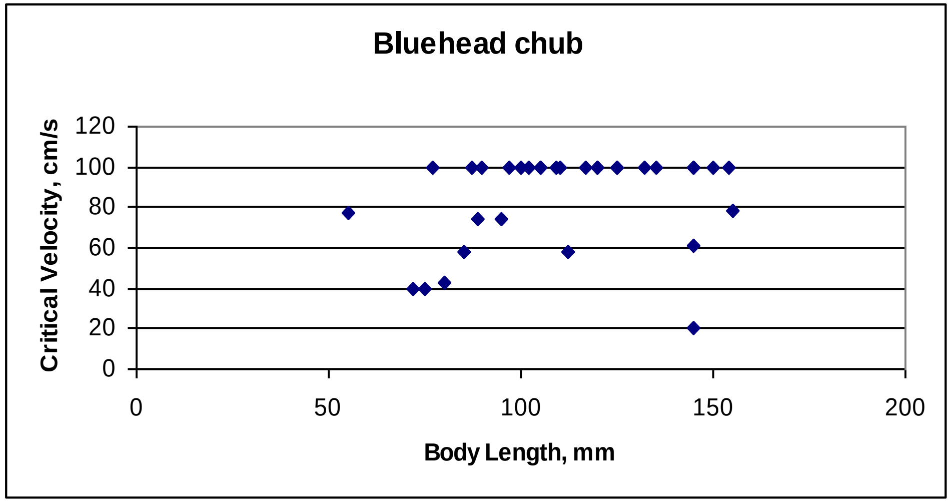
Fish Swimming Performance Measurement: Angela Gardner, MS, 2006

Critical Velocities Related to Body Length









Stream Restoration Assessment

Determine the ecological functional uplift achieved by stream restoration efforts. : Barbara Doll, PhD, 2013

Sampled Macroinvertebrates as restored streams and applied four rapid assessment tools at reference, degraded, and restored streams to:

- Determine what tools could be used to evaluate functional uplift
- Compare restored streams to degraded and high quality reference channels
- Identify factors (e.g. watershed, landscape and design) that influence the condition and function of restored streams

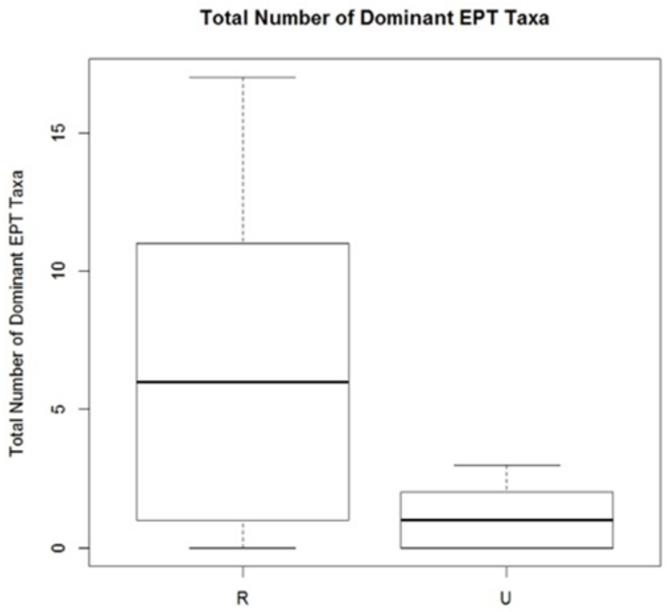

14.0'
VARIABLE
GREENWAY
MULCH
PA
POOL
RIFFLE
25
C-5

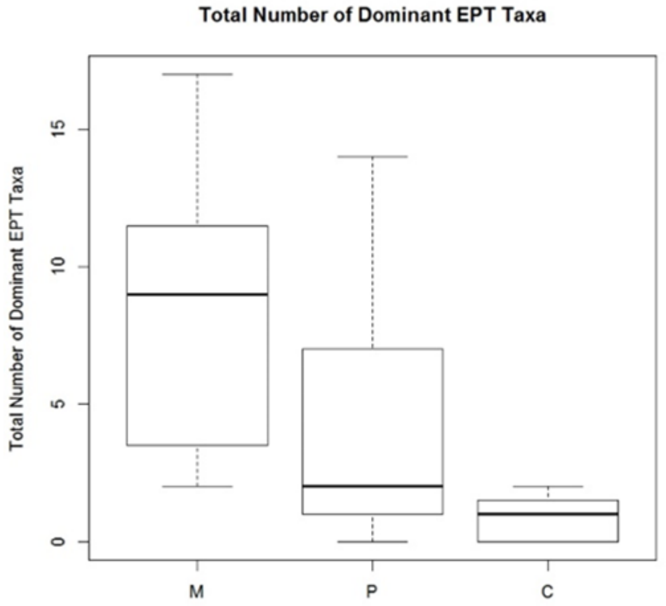
Statistical Regression Model (w/variable elimination)

Positive		Negative	
Basin Slope	1.66	CN	-1.42
ER	1.02	K	-0.46
D_{50}	0.81	[W/D]	-0.42
S_{valley}	0.74	T_c	-0.05
W_{bkf}	0.74		

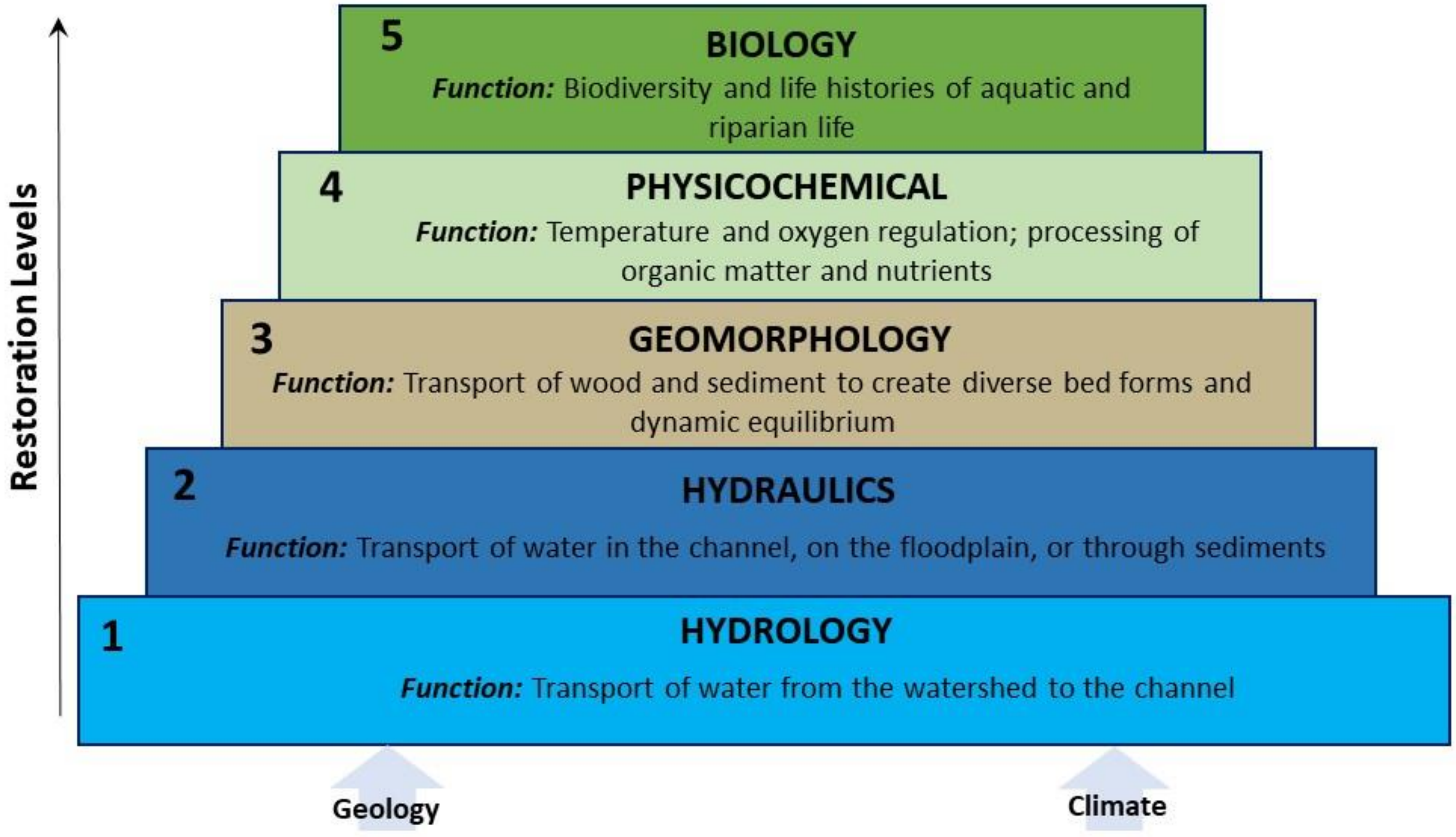
Larger streams in steeper valleys with coarse substrate and un-developed watersheds have more EPT taxa

Wider floodplain widths indicate higher EPT taxa numbers.





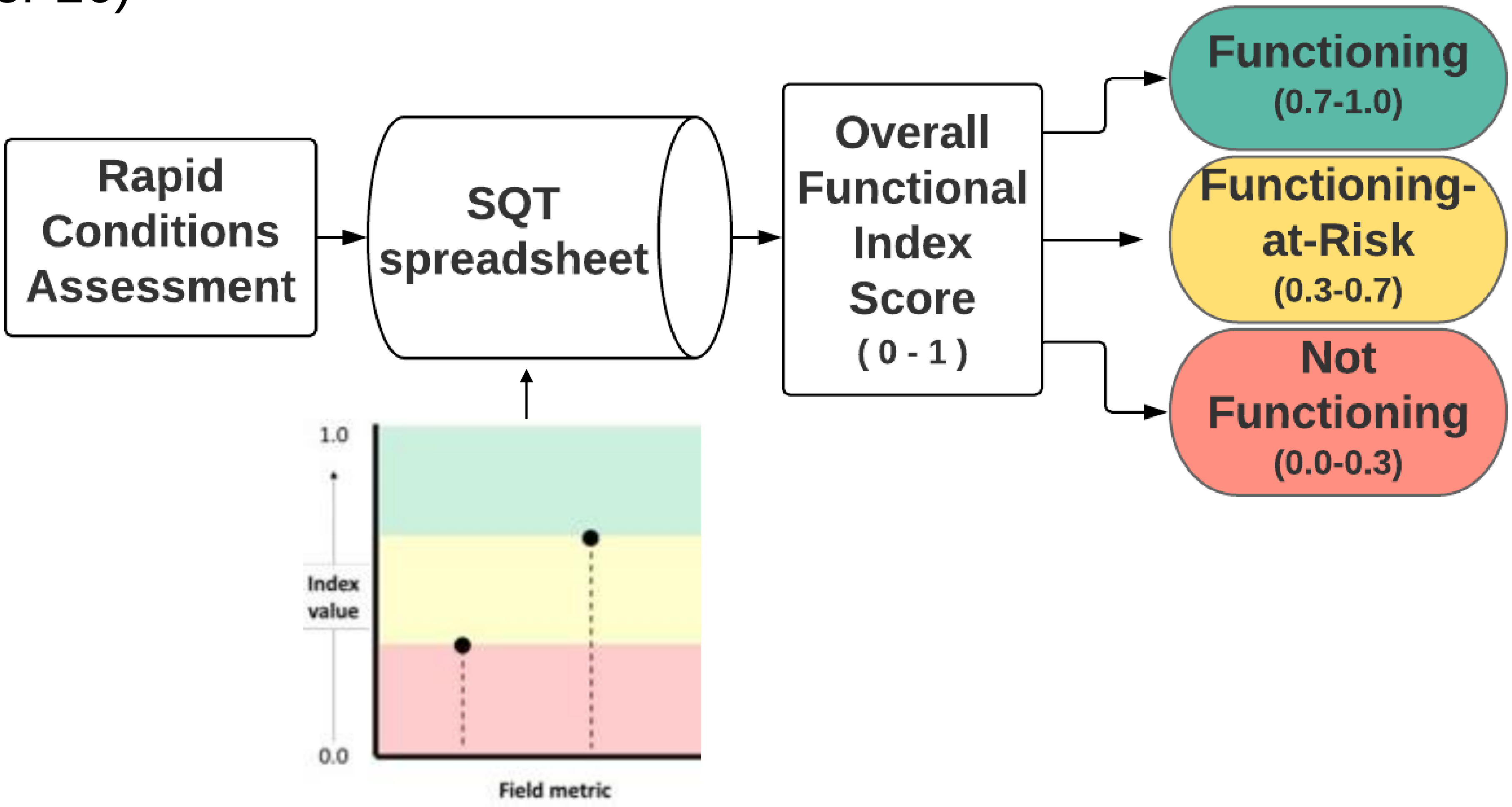
Stream functions pyramid framework



Adapted from Harman et al., 2012, *US EPA*

Evaluating the Stream Quantification Tool (SQT)

Evaluate the SQT for measuring ecological functional uplift for stream restoration efforts: Sara Donatich, MS, 2019 (defense November 26)



SFAM, Version 1.0, *US EPA*, 2018

Adapted from Harman et al., 2017

Functional Category	Measurement Method
Hydrologic	Curve Number
	No. of Concentrated Flow Points
	Soil Compaction
Hydraulic	Bank Height Ratio
	Entrenchment Ratio
Geomorphic	LWD Index
	Large Woody Debris Piece Count
	Erosion Rate
	Dominant BEHI/NBS
	Percent Streambank Erosion
	Canopy Coverage
	Buffer Width
	Basal Area
	Stem Density
	Pool Spacing Ratio
	Pool Depth Ratio
	Percent Riffle
	Aggradation Ratio
	Sinuosity
	Size Class Pebble Count Analyzer

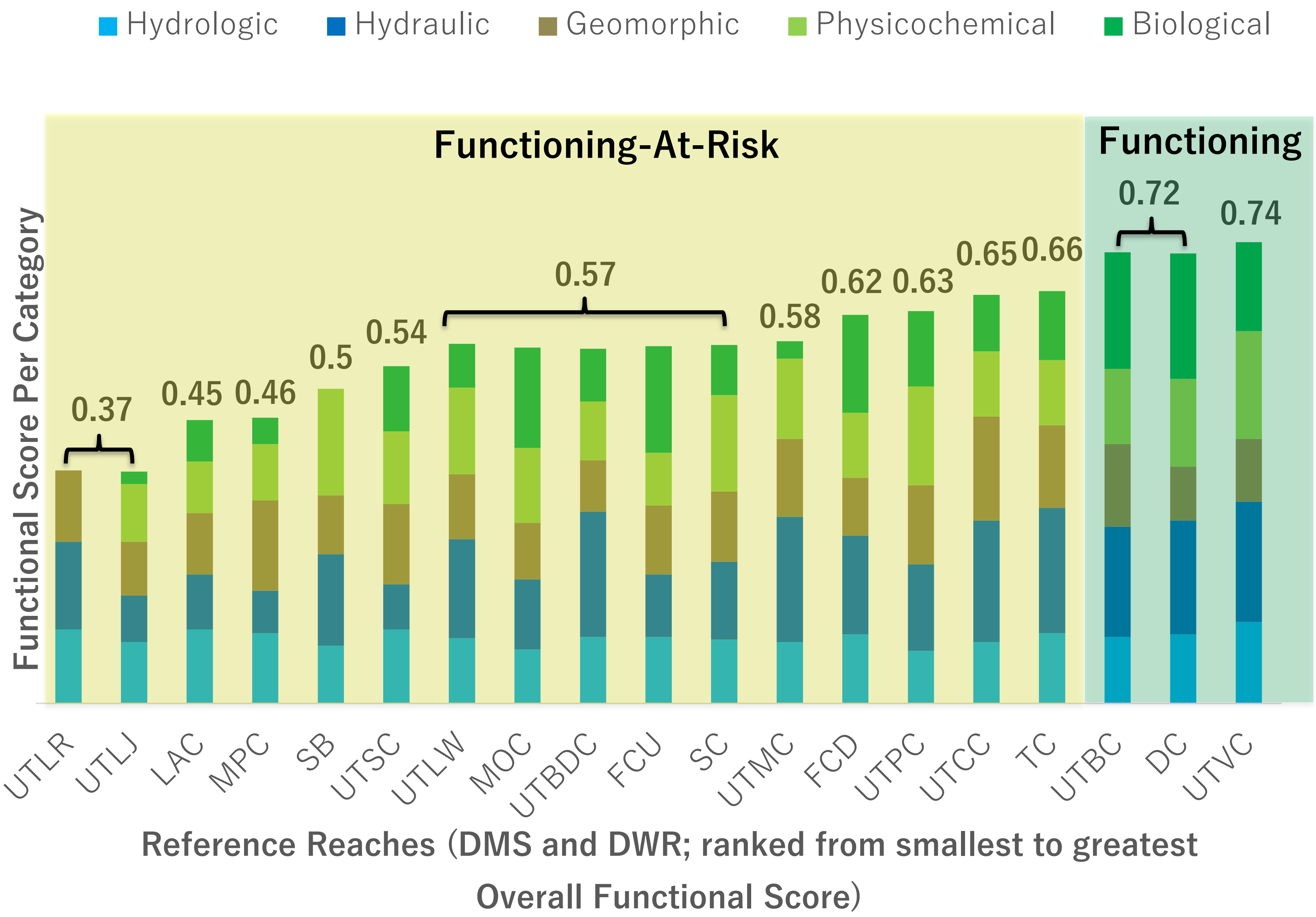
Functional Category	Measurement Method
Physico-chemical	Total Nitrogen
	Total Phosphorus
	Leaf Litter Processing Rate OR Percent Shredders
	Fecal Coliform
	Summer Daily Max. Temp.
Biological	NC Biotic Index for Macroinvertebrates
	EPT Index
	NC Index of Biotic Integrity for Fish

Restoration Potential	Watershed Catchment Assessment

<u>Total SQT Variables= 28</u>

Performance Standards are intended to represent high-quality "reference" streams

Reference Study Results

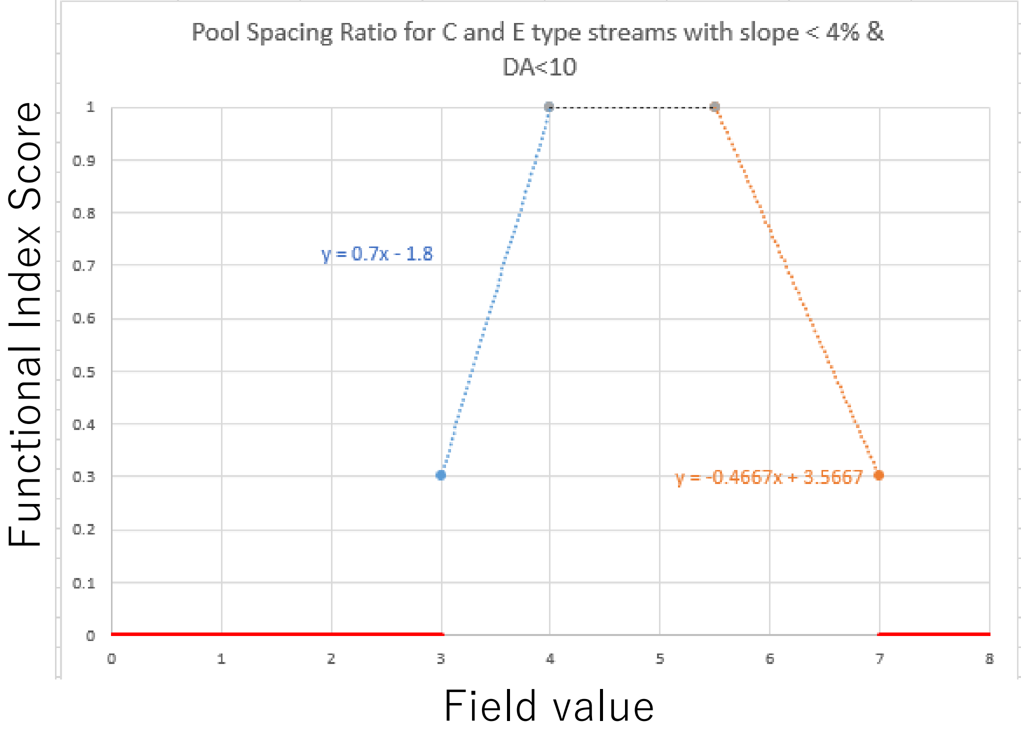


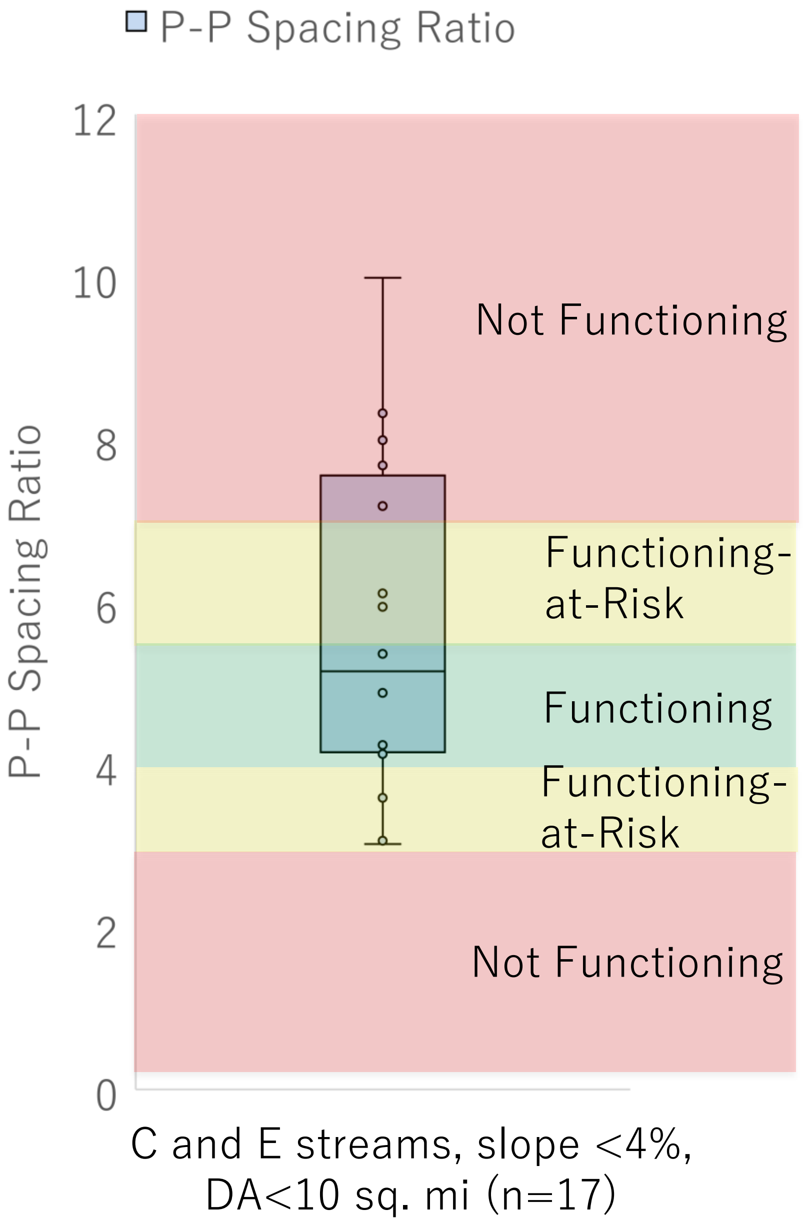
Reference Study Results

Pool-to-Pool Spacing Ratio (C and E streams)

Field Value			3 7			4 5.5	5.5
Index Value	0	0.29	0.3	0.69	0.7	1	1

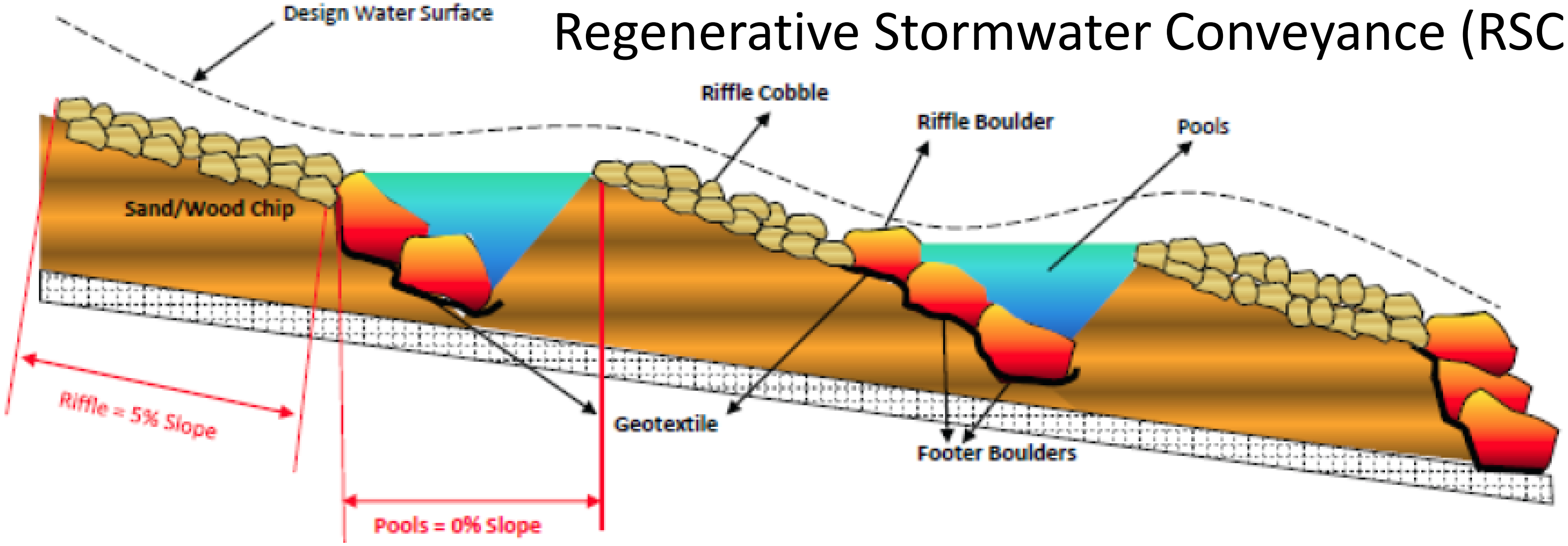
	Coefficients - Y = a * X + b	
	Field < 4	Field > 5
a	0.7	-0.4667
b	-1.8	3.5667



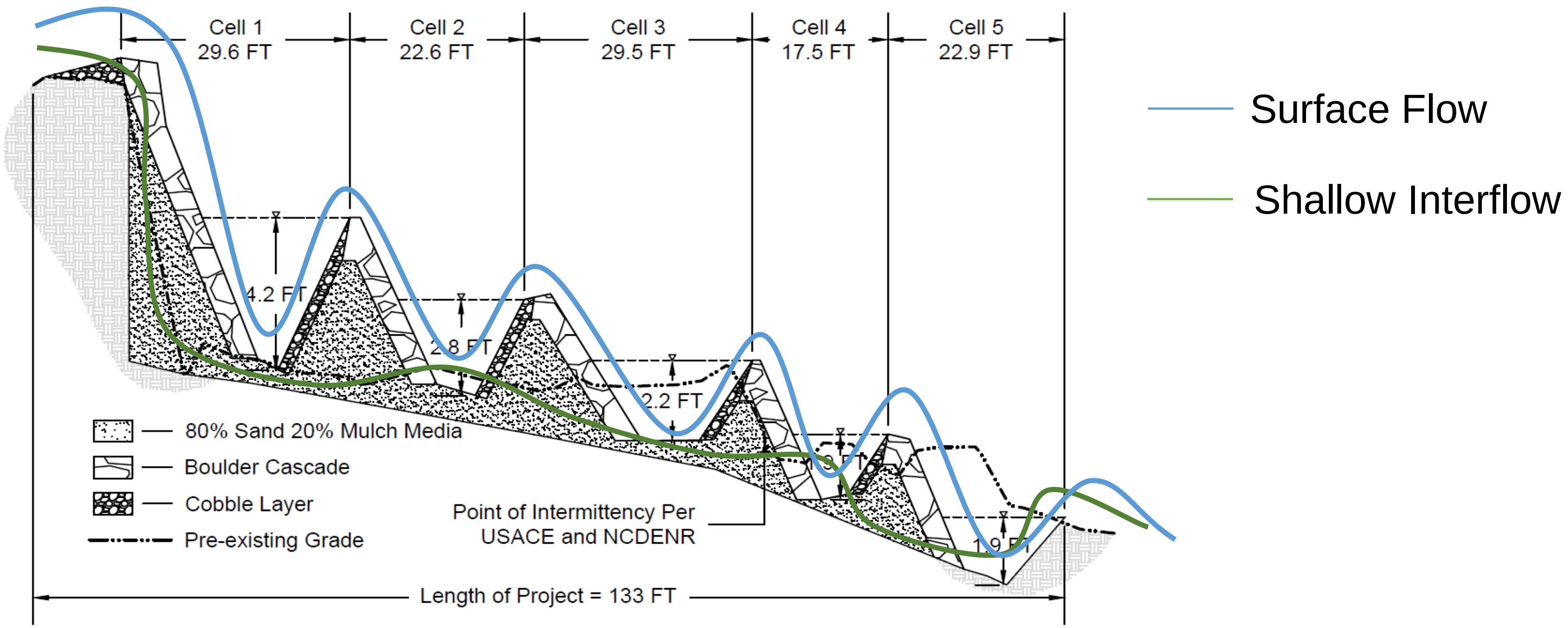


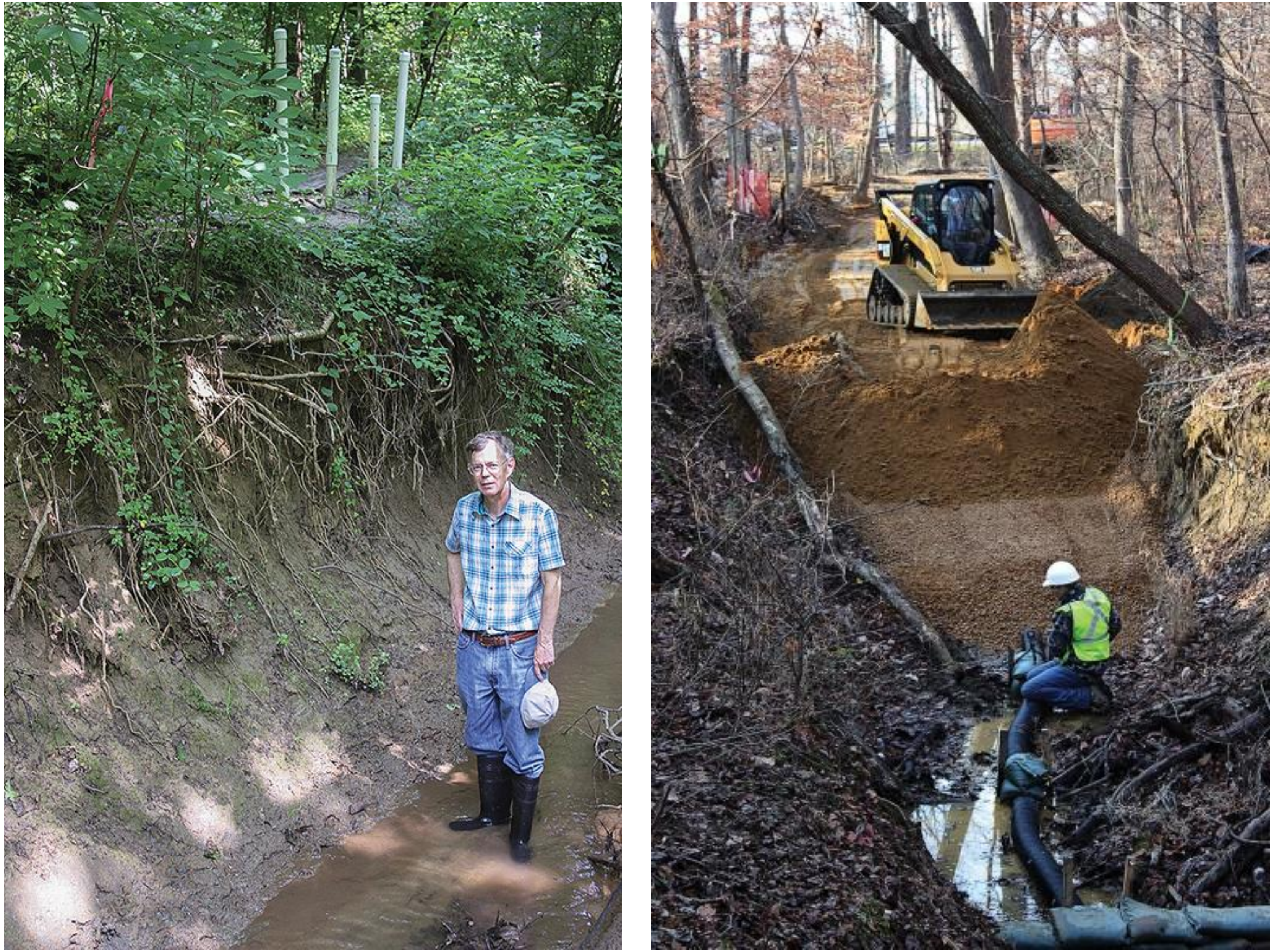
Evaluating Innovative Practices

Regenerative Stormwater Conveyance (RSC)



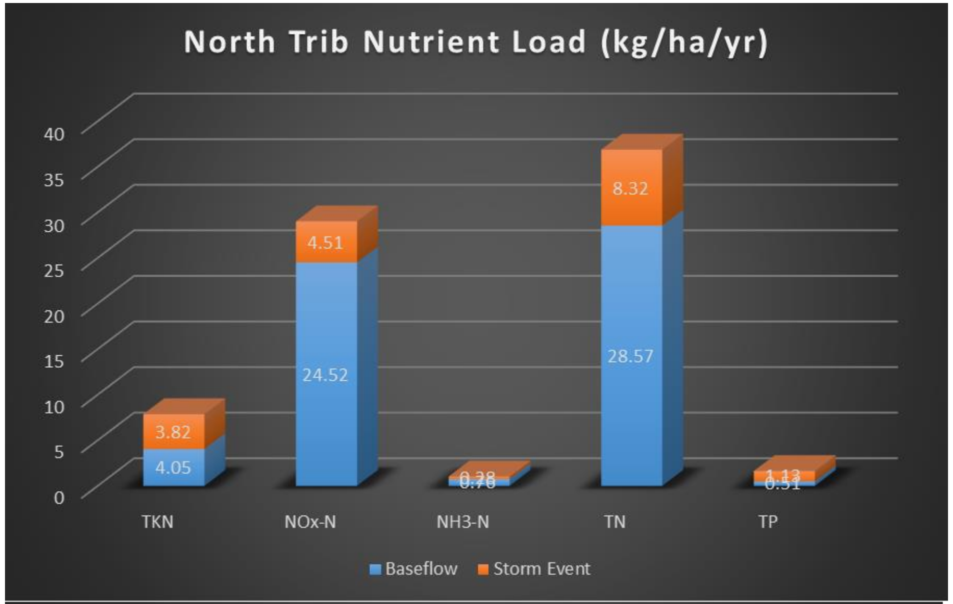
How RSC Works

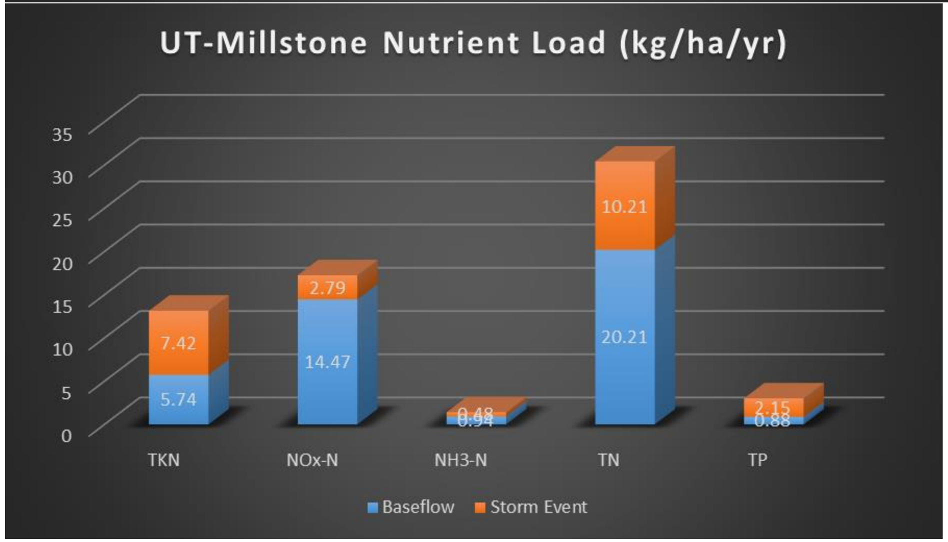




Mud Creek, Md. (http://www.bayjournal.com/article/researchers_examining_effectiveness_of_stream_restoration)

Millstone Creek: Test RSC in agricultural setting





Peer-Reviewed Publications

Doll, B.A., Jennings, G.; Spooner, J.; Penrose, D.; Usset, J.; Blackwell, J.; Fernandez, M. **2016**. Can Rapid Assessments Predict the Biotic Condition of Restored Streams? ***Water*** 8:143.

Doll, B.A.; Jennings, G.; Spooner, J.; Penrose, D.; Usset, J.; Blackwell, J.; Fernandez, M. **2016**. Identifying Watershed, Landscape, and Engineering Design Factors that Influence the Biotic Condition of Restored Streams. ***Water*** 8:151.

Doll, B.A.; Jennings, G.D.; Spooner, J.; Penrose, D.L.; Usset, J.L. **2015**. Evaluating the eco-geomorphological condition of restored streams using visual assessment and macroinvertebrate metrics. ***Journal of the American Water Resources Association***. 51:68–83.

Zink, J. M., and G. D. Jennings. **2014**. Channel Roughness in North Carolina Mountain Streams. ***Journal of the American Water Resources Association***. DOI: 10.1111/jawr.12180

McMillan, S. K., A. K. Tuttle, G. D. Jennings, and A. Gardner. **2014**. Influence of Restoration Age and Riparian Vegetation on Reach-Scale Nutrient Retention in Restored Urban Streams. ***Journal of the American Water Resources Association***. DOI: 10.1111/jawr.12205

Tuttle, A. K., S. K. McMillan, A. Gardner, and G. D. Jennings. **2014**. Channel complexity and nitrate concentrations drive denitrification rates in urban restored and unrestored streams. ***Ecological Engineering***. sciencedirect.com/science/article/pii/S0925857414004777

Tillinghast, E. D., W. F. Hunt, G. D. Jennings, and P. D'Arconte. **2012**. Increasing stream geomorphic stability using stormwater control measures in a densely urbanized watershed. ***Journal of Hydrologic Engineering*** 17(12):1381-1388.

Zink, J. M., G. D. Jennings, and G. A. Price. **2012**. Morphology characteristics of Southern Appalachian wilderness streams. ***Journal of the American Water Resources Association***. 48(4):762-773.

Tillinghast, E. D., W. F. Hunt, and G. D. Jennings**. 2011**. Stormwater control measure (SCM) design standards to limit stream erosion for Piedmont North Carolina. ***Journal of Hydrology*** 411(3-4):185-196.

Tullos, D. D., D. L. Penrose, G. D. Jennings, and W. G. Cope. **2009**. Analysis of functional traits in reconfigured channels: implications for the bioassessment and disturbance of river restoration. ***Journal of the North American Benthological Society***. 28(1):80-92.

Tullos, D. D., D. L. Penrose, and G. D. Jennings**. 2006**. Development and application of a bioindicator for benthic habitat enhancement in the North Carolina Piedmont***. Ecological Engineering*** 27(2006)228-241.

Future Work

- Continue teaching & training of students & professionals
- Long-term evaluation studies of restoration technologies & management practices
- Develop new design tools to increase engineering confidence in morphology based design
- Evaluate flood mitigation and environmental benefits of large-scale implementation of stream restoration

Stream Restoration Symposium 2019

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