Improving the Success of In-Stream Structures

Restoration Question 8: Stability

What design and construction factors are correlated with structural instability for certain site conditions?

$88,076

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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The project goal is to improve the application, design, and success of in-stream structures

1. Develop series of in-stream structure design fact-sheets
   a. Review design guidance, research literature
   b. Input from stream restoration designers and managers
   c. Surveyed designers and contractors
   d. Web site
2. Conduct flow studies of steep (slopes 5-10%) stormwater RSCs to evaluate current flow estimation methods

Photo courtesy of Ecotone, Inc.

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Fact Sheet Number 3

Stream Restoration Series
Cross Vane

Authors: Tess Thompson and Lizzy Merin

Alternate Names:

vortex (rock) weir; upstream-pointing chevron

Structure Type:

rigid structure; grade control structure; river training structure

The purpose of the cross vane is to provide grade control to an incising stream. It can also protect a streambank from undesirable erosion or migration in situations in which erosion is caused by flows being directed toward the bank face. By protecting the bank from fluvial erosion, this structure promotes the overall stability of the stream cross-section. It is also used to improve pool habitat and to direct flows to the center of the channel upstream of bridge crossings. The arms of the cross vane may be constructed either of wood (logs) or stone (boulders).

The regular cross vane is configured as though two single-arm vanes on opposite banks were connected across the center of the stream by a straight or semicircular crosspiece called the "vortex" section. Thus, the cross vane is a channel-spanning structure. The cross vane provides grade control in two ways. First, the footer rocks extend below the expected scour depth and thus prevent upstream migration of knickpoints. Second, the vane creates a "step" in the channel longitudinal profile, which allows lower bed slopes upstream and downstream of the vane, which in turn decreases the forces driving stream incision. The arms of the cross vane act as single-arm vanes, deflecting flows away from the bank and creating a new three-dimensional flow pattern which has a lower erosive potential (shear stress) near the bank. This causes a scour pool to form downstream of the vane, which can provide habitat for fish and other aquatic wildlife. The cross vane provides additional habitat benefits by inducing the deposition of gravel just upstream of the vane. In this way, a single cross vane creates a single riffle-pool structure while a series of cross vanes develops a riffle-pool sequence.

The design approach for the cross vane revolves around the selection of a structure design life (SDL), the period of time during which the vane is expected to remain structurally sound and functional. The SDL should be selected using a level of acceptable risk based on the project goals. The SDL is often specified by client needs or mitigation requirements, and reflects how long the vane needs to last. Projects where structure failure poses little risk to infrastructure or adjoining landowners should use a shorter SDL, such that normal stream bank erosion and channel migration can resume at a more natural rate when the structure eventually fails. Using the selected SDL, a structure design flow (SDF) is determined. If level of acceptable risk is provided in the form of a certain flow recurrence interval to be withstood by the vane, selection of SDL will be determined by the given SDF. For example, if local regulations require that all structures be designed to withstand a 100-

CAUTION: Cross vanes are costly and have a relatively high risk of structural failure due to their position within the stream itself, so they should be installed only when they are the best fit for the project goals for a particular stream.

0516/fact sheet 1

Application

The cross vane is effective for stream reaches which…

- are slightly-to-moderately meandering/sinuous;
- are actively incising;
- would naturally possess a riffle-pool sequence (i.e. Rosgen stream types A3-A4, B3-B4, C3-C4, F3-F4, and G3-G4);
- have a moderate to high gradient;
- have coarse bed material (small boulders/cobbles to coarse sand), which is mobile enough for scour pool formation; and,
- have few or no regions of stagnant water or backwater.

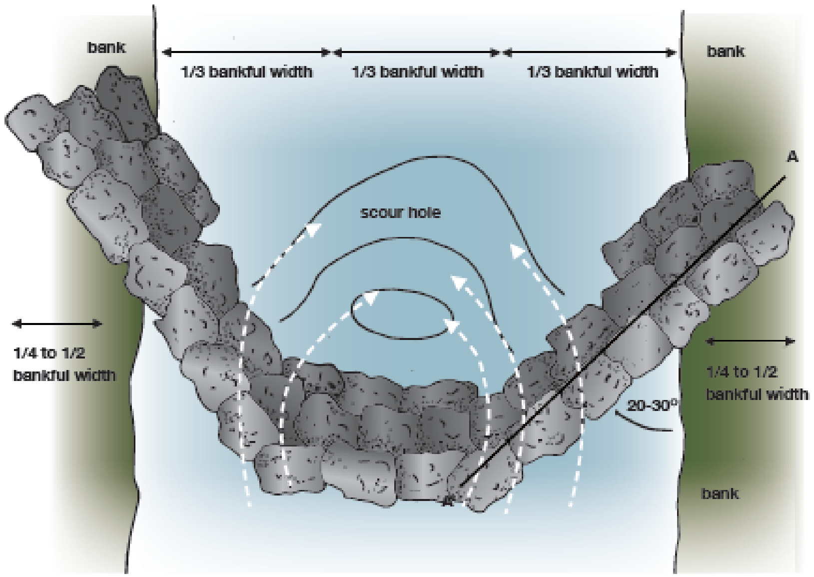
In streams with steep bed slopes and/or knickpoints, cross vanes can be used to safely reduce the bed elevation and to prevent streambank erosion. Cross vanes can also be used to induce a riffle-pool sequence and improve aquatic habitat.

Consider use of the cross vane carefully for stream reaches which…

- are deeply incised or have a low width to depth ratio, as the arm slope may exceed recommended values;
- are experiencing substantial change in their cross-sectional geometry, as additional structural stabilization measures may be required; and,
- have beds of very fine, mobile material (fine sands and/or silt), which increases the risk of structural failure by undercutting.

CAUTION: Use of log arms in streams with highly variable flows (especially those in urban settings) or for projects involving infrastructure protection is not recommended due to the lower durability of log arms. In addition, log arms are more easily undercut than rock vanes, so use caution when designing log arms for a stream with fine, mobile bed material.

Illustration description. Single arm vane.



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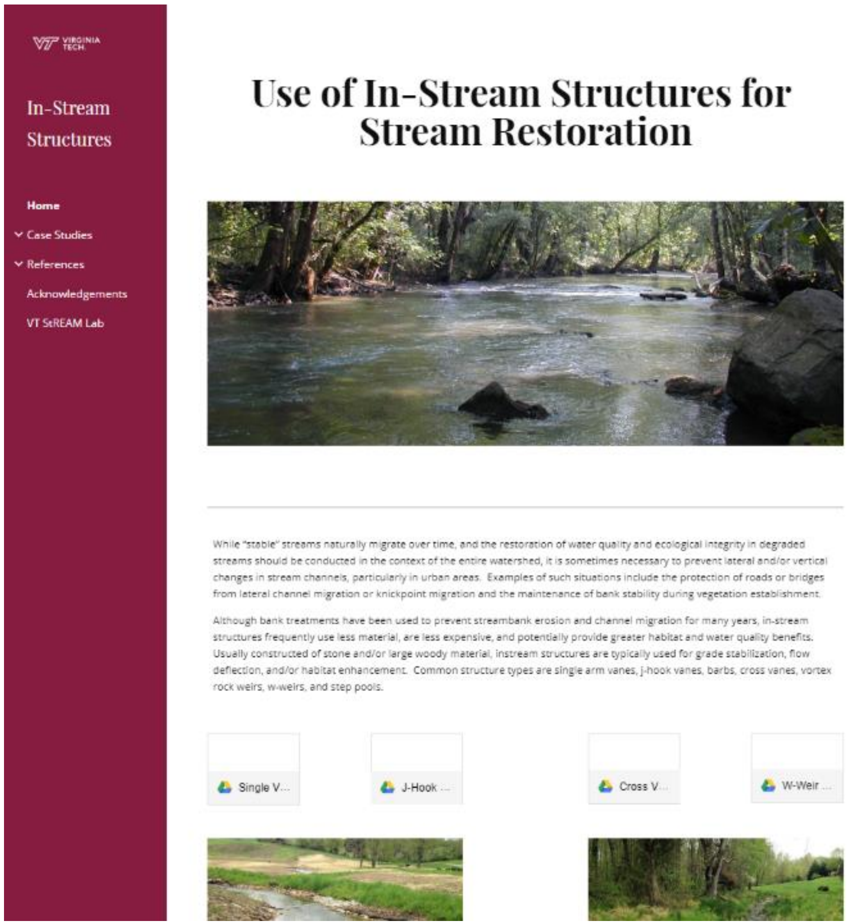
Facts sheets and links to resources are on project web site



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In-Stream Structures

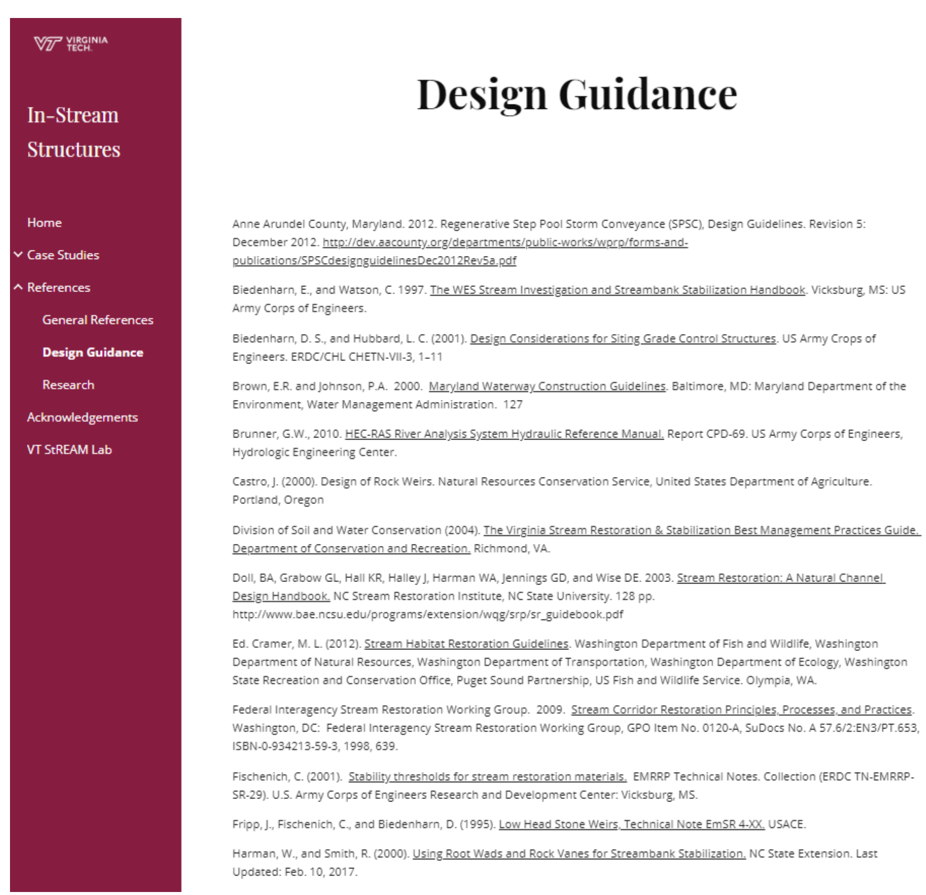
- Home
- Case Studies
- References
- Acknowledgements
- VT StREAM Lab

Use of In-Stream Structures for Stream Restoration

While "stable" streams naturally migrate over time, and the restoration of water quality and ecological integrity in degraded streams should be conducted in the context of the entire watershed, it is sometimes necessary to prevent lateral and/or vertical changes in stream channels, particularly in urban areas. Examples of such situations include the protection of roads or bridges from lateral channel migration or knickpoint migration and the maintenance of bank stability during vegetation establishment.

Although bank treatments have been used to prevent streambank erosion and channel migration for many years, in-stream structures frequently use less material, are less expensive, and potentially provide greater habitat and water quality benefits. Usually constructed of stone and/or large woody material, instream structures are typically used for grade stabilization, flow deflection, and/or habitat enhancement. Common structure types are single arm vanes, j-hook vanes, barbs, cross vanes, vortex rock weirs, w-weirs, and step pools.

Single V... J-Hook ... Cross V... W-Weir ...



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In-Stream Structures

- Home
- Case Studies
- References
  - General References
  - **Design Guidance**
  - Research
- Acknowledgements
- VT StREAM Lab

Design Guidance

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http://www.apps.bse.vt.edu/instreamstructures

Outcomes of practitioner survey and MSRA meeting:

- J-hook and cross vanes are most commonly used structures
- Rosgen, MDE, NRCS, and proprietary methods are most commonly used design guidance
- The majority of designers size rocks based on shear stress
- Roughly half of designers calculate the expected scour depth
- Visual assessment provides best assessment of structure success
- Projects are more successful when the designer (or someone familiar with the design) is on site during construction

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The project goal is to improve the application, design, and success of in-stream structures

1. Develop series of design fact-sheets
   a. Review design guidance, research literature
   b. Cross-vane, single arm vane, j-hook, w-weir
   c. Input from stream restoration designers and managers
   d. Web site with case studies

2. Conduct flow studies of steep (slopes 5-10%) stormwater RSCs to evaluate current flow estimate methods

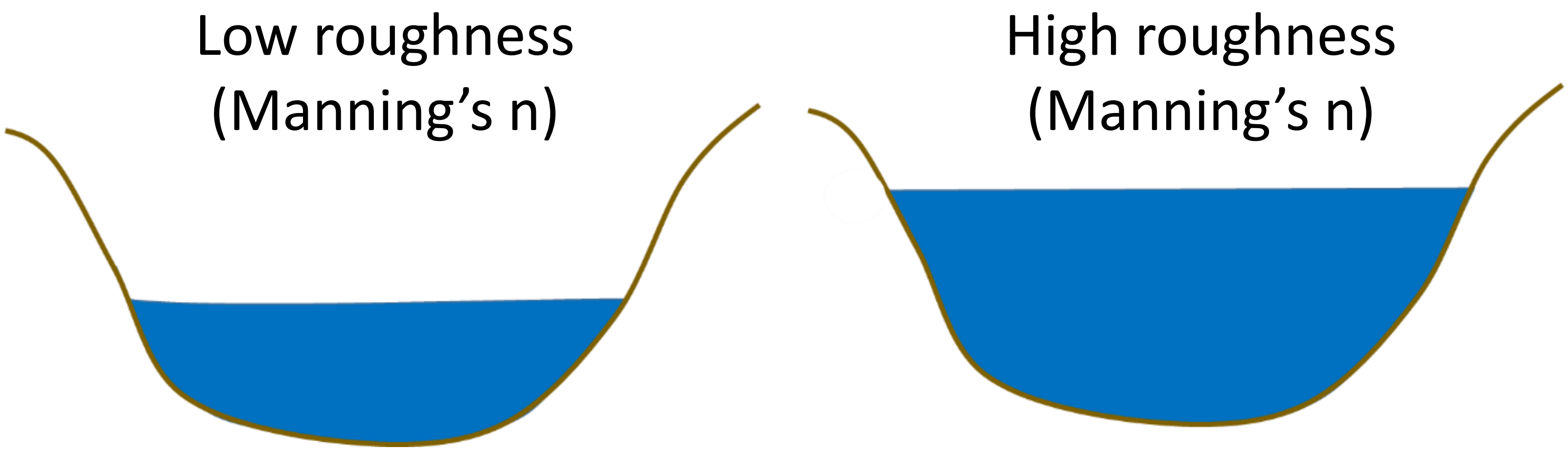
Regenerative stormwater conveyance
Regenerative step pool storm conveyance

The tools we use to calculate flow through RSC/SPSCs were developed for “regular” channels.

Fig. 3.10. Stream Corridor Restoration

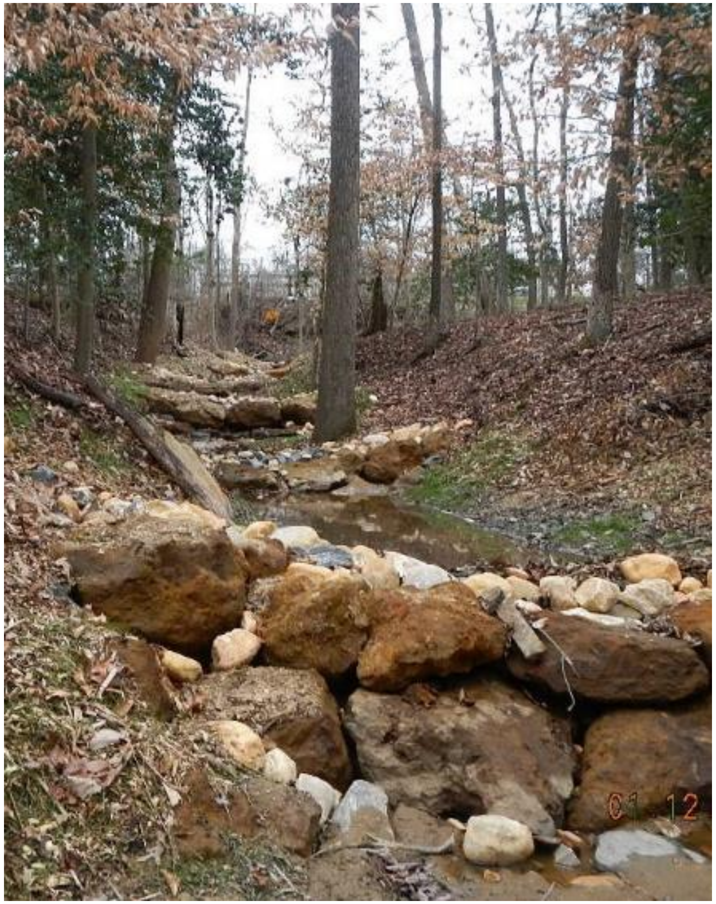
If flow depth or velocity is incorrectly estimated, channels may be over- or under-sized.

To pass a given discharge (cfs), more flow area is needed for a rougher channel



Design of channels, pipes, etc. is STRONGLY affected by choice of "n"

Two SPSC systems on steep slopes were studied



Broad Creek Park
Board of Education parking lot
Eastern Tributary RSC
Riva Rd
Annapolis Technology Park
Annapolis High School
Riva Rd
WHISKEY BOTTOM
Camp Woodlands entrance
Riva Rd
Broad Creek RSC
Gingerville Creek
Greek Orthodox church

Upstream and downstream compound weirs were installed for flow measurement

Three piezometers were installed to continuously recorded water levels.

1. Upstream
2. Mid
3. Downstream

Dye studies were conducted to determine average velocities

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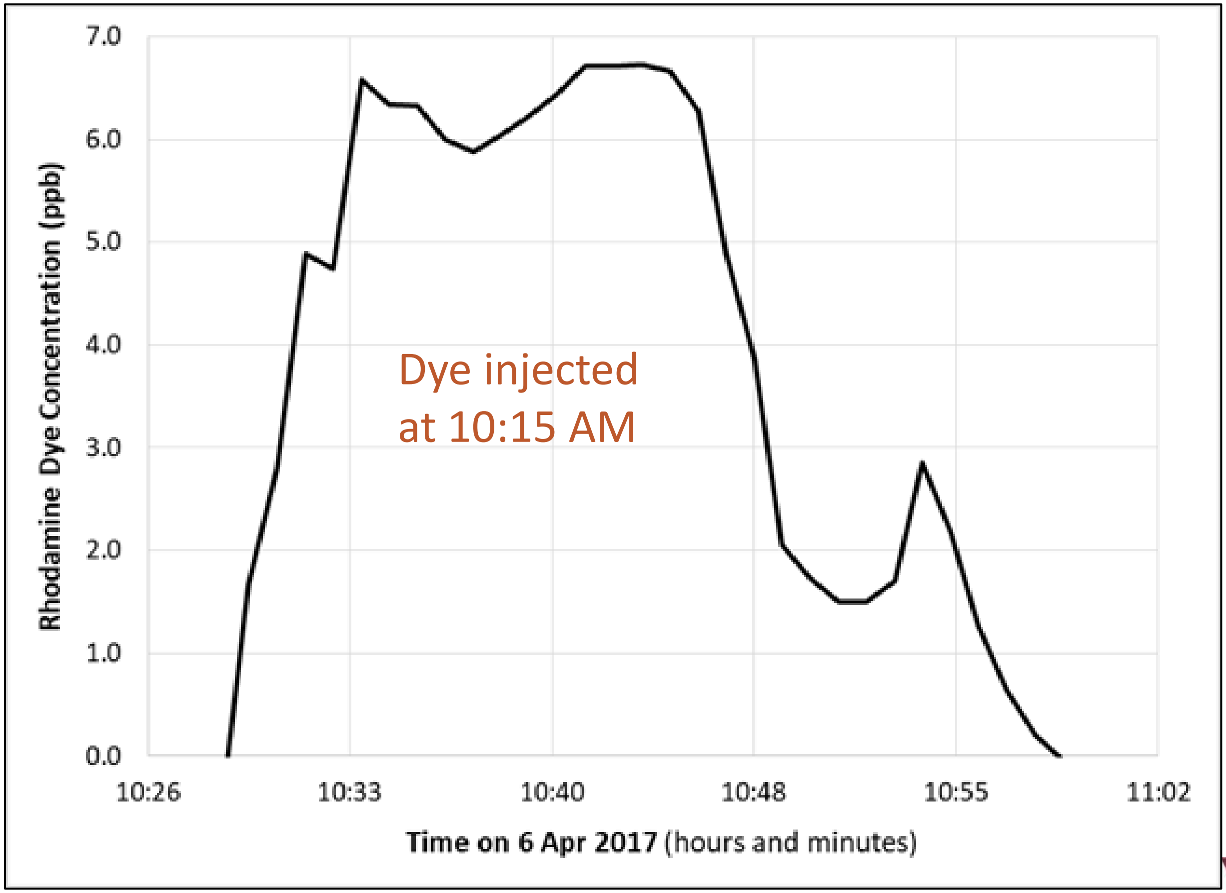
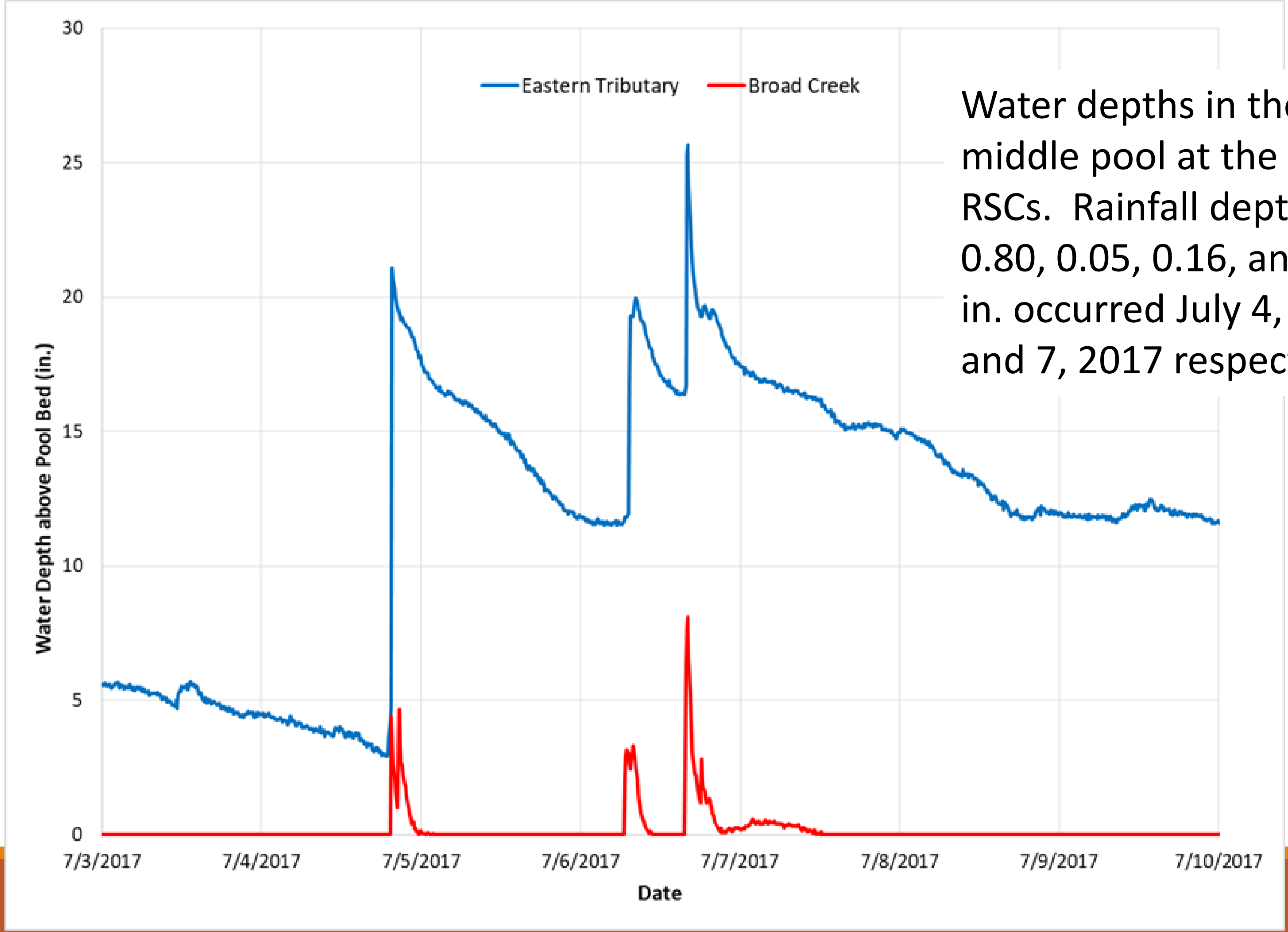
Dye studies were conducted to determine average velocities



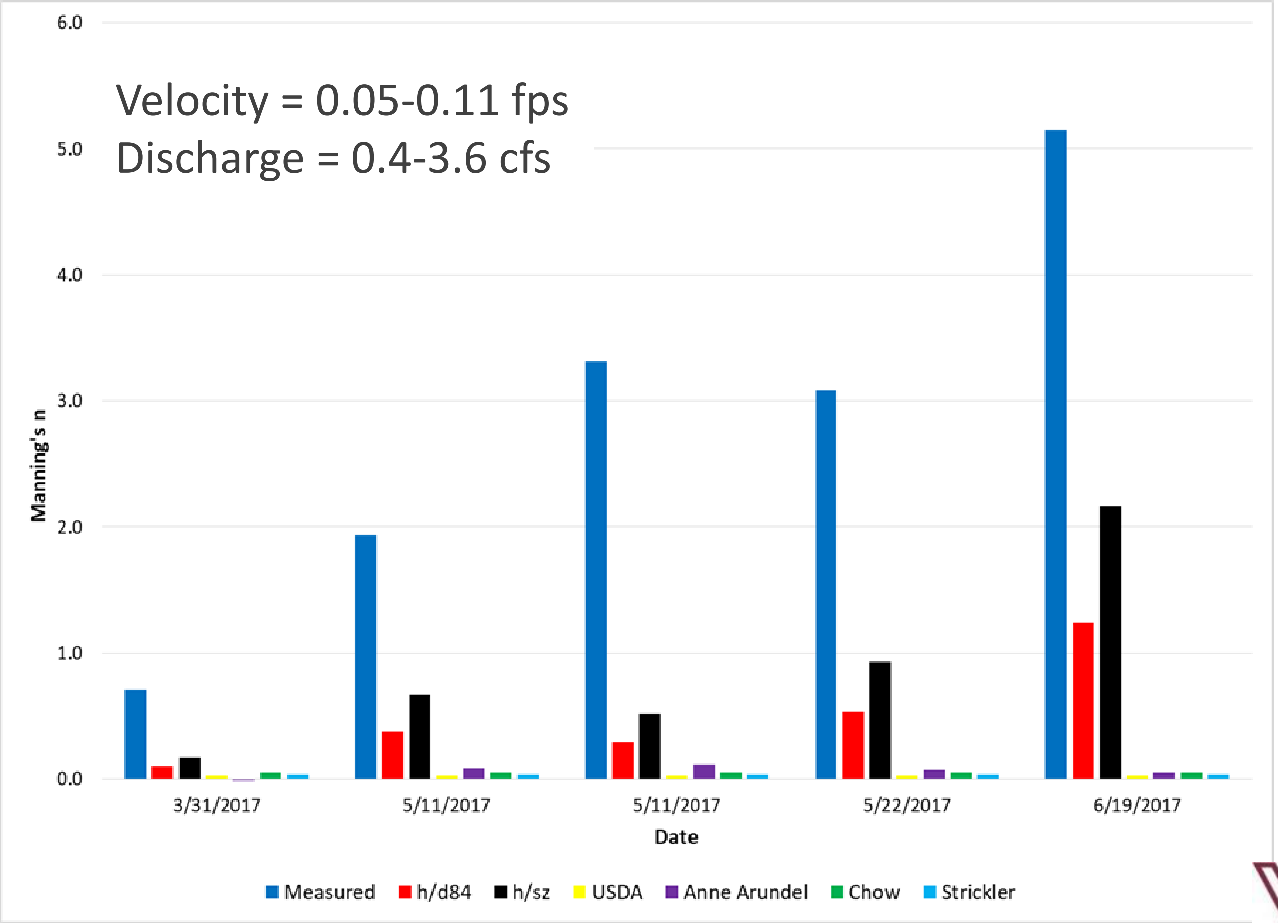
Controlled flow studies were also conducted

Flow in SPSCs peaked rapidly during storms and then slowly drained



Water depths in the middle pool at the study RSCs. Rainfall depths of 0.80, 0.05, 0.16, and 1.37 in. occurred July 4, 5, 6, and 7, 2017 respectively.

Measured roughness was 1-2 orders of magnitude higher than estimated values



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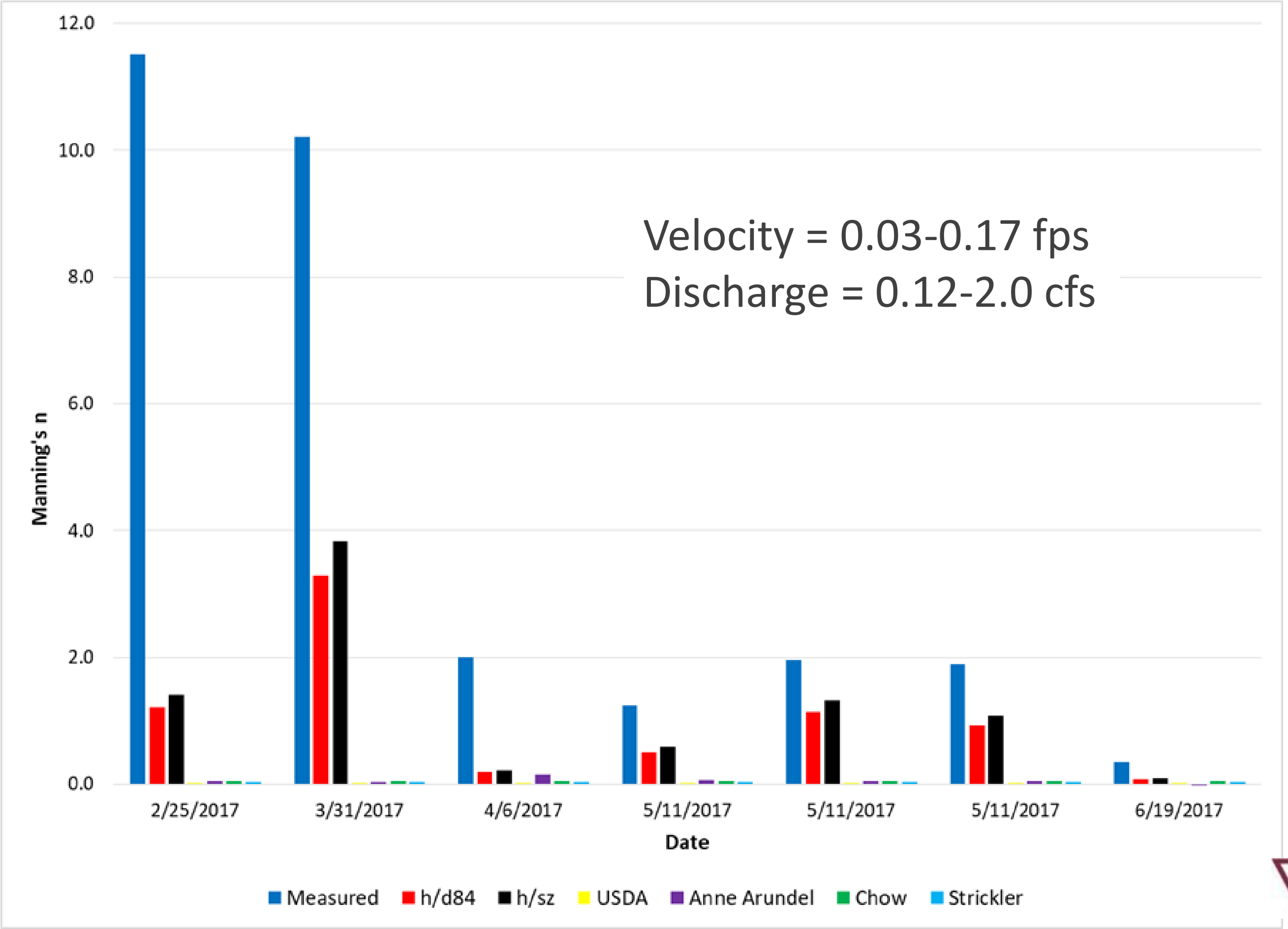

Broad Creek headwaters at Camp Woodlands

Cautions

- A lot of variability in roughness, due to difficulties measuring flows and changing conditions at the RSCs
- Measured flows were much lower than design flows
- Manning's n decreases as flow depth increases
- SPSCs constructed on steep slopes
- Flow occurs through and over rock weirs
- Difficult to define flow width or depth – irregular rock weirs

However…

- Similar Manning's n and similar variability reported in natural step-pool channels and other SPSC studies
- Weirs overtopped at even low flows
- The 100-yr design flows would never occur in these systems due to upstream infrastructure

Study Take-Aways:

1. **Flow through SPSCs is highly complex**
2. **Flow velocities are likely over-predicted and flow depths are likely under-predicted**
   - With current design guidance, rock sizes may be too large
   - With current design guidance, weirs may not be wide or deep enough
   - Recommend using flow depth/avg. rock height (h/σ_z) to estimate roughness coefficient for design of SPSCs constructed on slopes >5%
   - σ_z could be surveyed on multiple existing SPSCs with different size stone
3. **Based on observations**
   - Pools are storing and slowly releasing water
   - SPSCs effectively convey stormwater runoff without erosion
4. **Recommend considering how upstream infrastructure limits discharge in SPSC design to minimize over-design and cost**

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Questions?
Comments?

Improving the Success of Stream Restoration Practices

Stability of stream restoration practices and elements of practices

$217,322

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Eric P. Smith, Professor, Statistics

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United States Environmental Protection Agency

SHA
State Highway Administration

Maryland Department of Natural Resources

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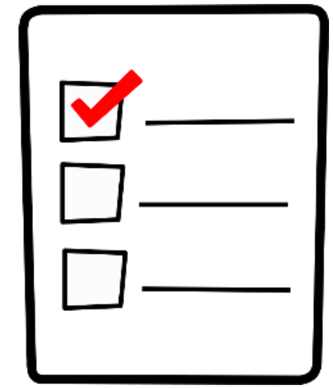
The overall project goal is to improve the overall application, design, and review of stream restoration projects

1. Treat prior projects as "experiments"
2. Quantify "success" of projects and individual structures
3. Evaluate correlation between "success" and watershed, site, and structure characteristics



4. Would 2-D modeling of structures identify potential design flaws?

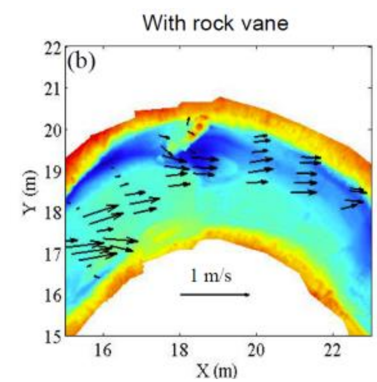


Image by Anne Lightbody, UNH

Existing stream assessment protocols were summarized

Assessment group ↓	Assessment Protocol								
	Pfankuch CSI	BEHI	NRCS SVAP	NCSU SPA	RCE	EPA RBP	NCSU EGA	RSAT	SFPF
Bank Stability	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bed Material	✓	✓	✓	X	✓	✓	✓	✓	✓
Riparian Zone	X	X	✓	X	✓	✓	✓	✓	✓
Channel Pattern	X	X	X	✓	X	✓	X	X	X
Floodplain	X	X	✓	✓	X	X	✓	X	✓
Bedform	✓	X	✓	✓	✓	✓	✓	✓	✓
XSection Survey	✓	X	X	X	✓	X	✓	✓	✓

BEHI: Bank Erosion Hazard Index; SVAP: Stream Visual Assessment Protocol; SPA: Stream Performance Assessment; RCE: Riparian, Channel, and Environmental Inventory; RBP: Rapid Bioassessment Protocols; EGA: Eco-Geomorphological Assessment; RSAT: Rapid Stream Assessment Technique; SFPF: Stream Functions Pyramid Framework

Project and structure "success" will be scored

Project Score

- Design score
  - Did the stream deviate from the original design?
  - Based on monitoring reports
- Functional score
  - Is the stream successfully moving water and sediment without degradation?
  - Based on field visit

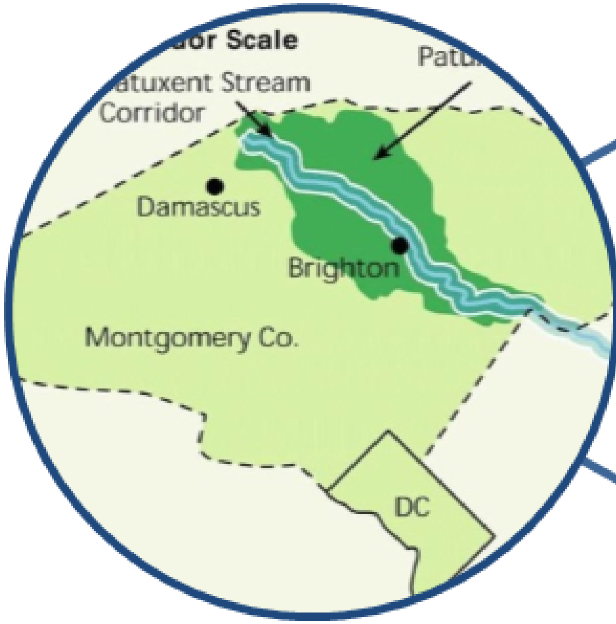
Project and structure "success" will be scored

Structure Score

- Field evaluation
  1. Not present
  2. Present, but not functioning as intended
  3. Present and functioning as intended
- Consider structure modifications noted in monitoring reports

123RF.com

Watershed-Scale Analysis



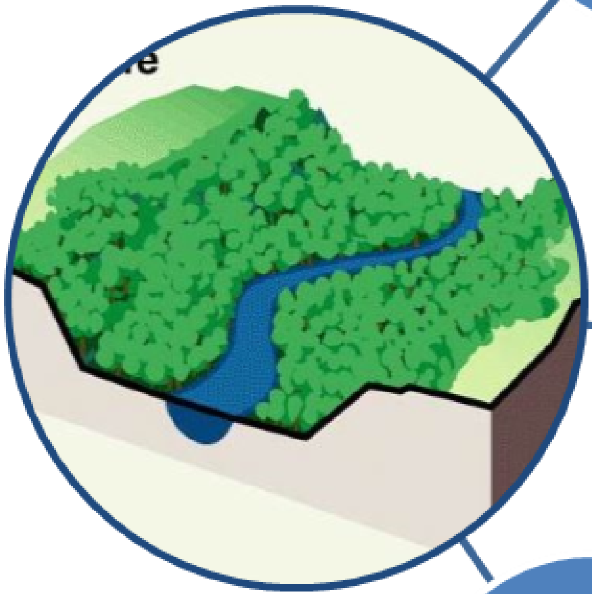
Flow Energy

- Watershed area
- Watershed landuse
- Landuse change since project construction
- Urban development age
- Watershed slope
- Channel slope

Erosion Resistance

- Geology/soils
- Riparian vegetation

Project-Scale Analysis



Flow Energy

- Stream order
- Design channel slope
- Floodplain width/bankfull channel width
- …

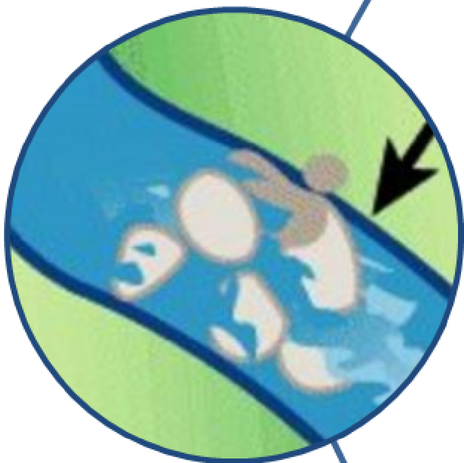
Erosion Resistance

- Soil layering
- Soil erodibility, K
- Bed sediment size
- Bank vegetation
- …

Design

- Design approach
- Project age
- Project length
- # structures/1000 ft.
- …

Practice-Scale Analysis



Flow Energy

- Bend radius of curvature/bankfull channel width
- Design bankfull width/depth
- …

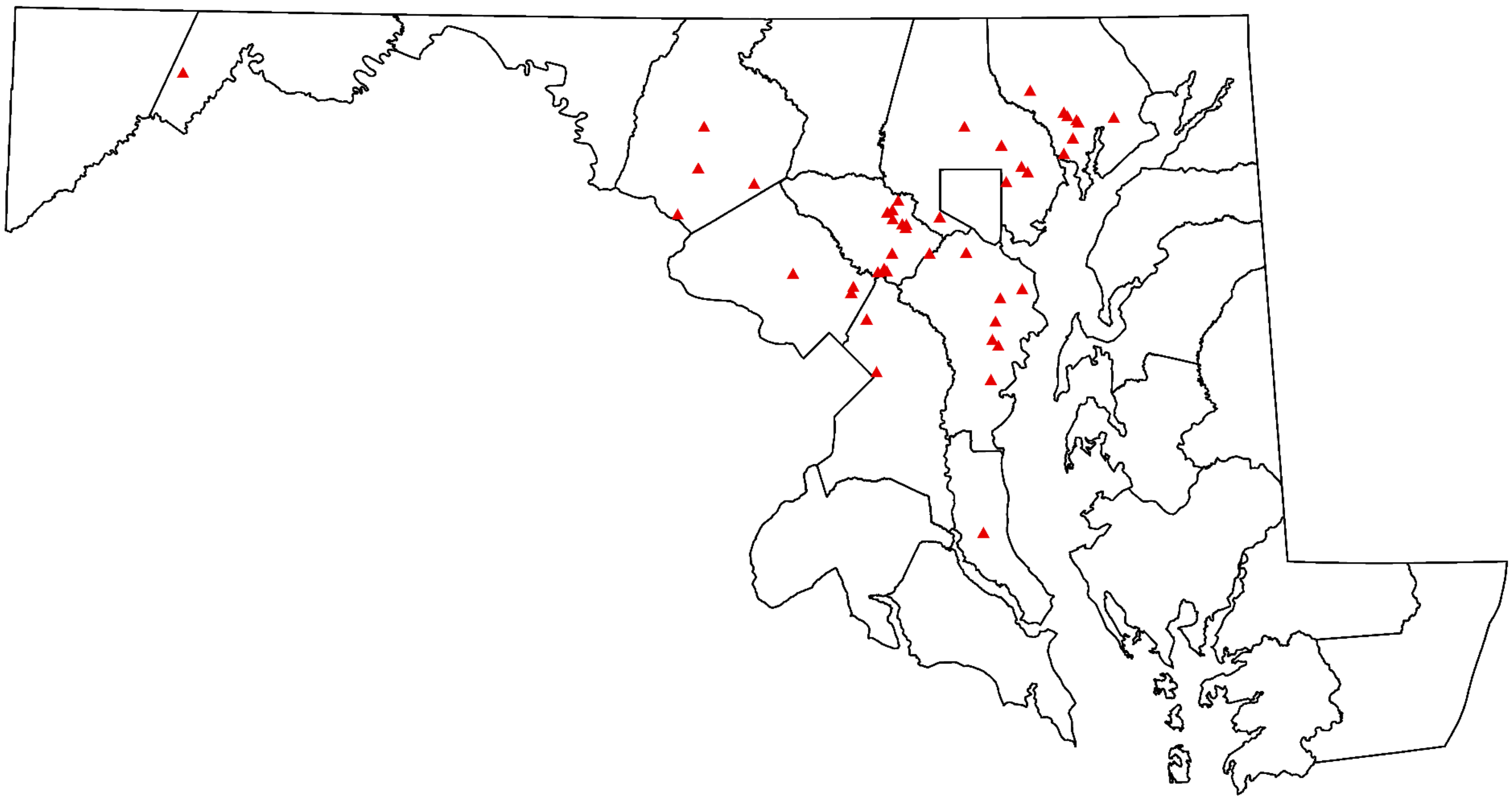
Erosion Resistance

- Bank angle from horizontal
- Bank vegetation
- Bed sediment size/structure rock size or log diameter
- …

Design approach

- Recurrence interval of practice design storm
- Vane vertical slope
- Key length/bankfull width
- Footer depth/bankfull depth
- Geotextile and backfill used
- …

Currently reviewing information for 50 projects, but could use more!




Questions?
Comments?

Using discharge and velocity data, Manning’s n was calculated and compared to common estimates

h/d_{84}	$n = h/d_{84}$	From studies of step-pool channels
h/σ_z	$n = h/\sigma_z$	
NRCS (2006)	$n = 0.047(d_{50}*S)^{0.147}$	
Anne Arundel County (2012)	$n = h^{1/6}/(21.6\log_{10}(h/d_{50})+14)$	
Chow (1959)	tabular	
Strickler’s relation	$n = 0.04{d_{50}}^{1/6}$	

h = water depth, d_{50} and d_{84} = weir particle size, σ_z = std. deviation of protrusion height, S = channel slope

Virginia Tech Translation Slides

What does this mean for me?

- Improving the Success of In-Stream Structures

  - Developed Fact Sheets for Cross Vanes, Single Vanes, J-Hook Vanes, and W-Weirs, available on website
  - Designed stone size based n scour, may need to verify scour depth more often

- Assessment of Steep RSC Channels
  - Measured Discharge and Velocity to evaluate roughness and hydrographs
  - Flow depths and roughness underpredicted and velocity over predicted in Design
  - Pool volumes release slower over time to extend hydrograph of storms, rising limb of hydrograph appears unaffected by structures for SPSCs constructed on slopes > 5%

What does this mean for me?

- <u>What do I take from this if I am a practitioner:</u>
  - Refer to Fact Sheets for improved application of vane structures
  - Verify scour and stone sizing of vane features
  - Evaluate weir and pool sizing more closely on steeper RSCs
- <u>What do I take from this if I am a regulator:</u>
  - Fact sheets can be useful to evaluate structure placement
  - Pool features provide attenuation in SPSC features
  - Stone sizing is likely conservative and stable

What does this mean for me?

- Improving the Success of Stream Restoration Practices

  - Evaluates Projects and Practices with Projects to Determine Success Criteria via Design Review and Site Monitoring Efforts
  - Looks at Watershed Scale, Project Scale, and Practice Scale Influences

What does this mean for me?

- What do I take from this if I am a practitioner:
  - Comprehensive Assessment being performed to help target and evaluate restoration practices
- What do I take from this if I am a regulator:
  - Once complete, tool may provide guide to focusing questions and treatments based on observed positive and negative trends