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

Tess Wynn Thompson, Associate Professor
Lizzie Hickman, Graduate Assistant
Biological Systems Engineering, Virginia Tech
Funding provided by...
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.
Application

The cross vane is effective for stream reaches which...

- are slightly-to-moderately meandering/sinusoidal;
- are actively incising;
- would naturally possess a riffle-pool sequence (i.e., Beaugreg stream types AI-A4, B3-B4, C3-C4, F3-F4, and G3-G4);
- have a moderate to high gradient;
- have coarse bed material (large 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 headstands, 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 stream slope may exceed recommended values;
- are experiencing substantial change in their cross-sectional geometry, so additional structural stabilization measures may be required; and,
- have beds of very fine, mobile material (fine sand and/or silt), which increases the risk of structural failure by undercutting.

Illustration description. Single arm vane.

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.
Facts sheets and links to resources are on project web site

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
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.

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.

Low roughness (Manning’s n)

High roughness (Manning’s n)

Design of channels, pipes, etc. is STRONGLY affected by choice of “n”
Two SPSC systems on steep slopes were studied
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
Dye studies were conducted to determine average velocities

Dye injected at 10:15 AM
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.

Velocity = 0.05-0.11 fps
Discharge = 0.4-3.6 cfs
Measured roughness was 1-2 orders of magnitude higher than estimated values.

Velocity = 0.03-0.17 fps
Discharge = 0.12-2.0 cfs

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 \(h/\sigma_z\) to estimate roughness coefficient for design of SPSCs constructed on slopes >5%
   - \(\sigma_z\) 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**
Questions? Comments?
Improving the Success of Stream Restoration Practices

Stability of stream restoration practices and elements of practices

$217,322

Tess Wynn Thompson, Associate Professor, Bio. Systems Engineering
Eric P. Smith, Professor, Statistics
Virginia Tech
Funding provided by...
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?
Existing stream assessment protocols were summarized

<table>
<thead>
<tr>
<th>Assessment group ↓</th>
<th>Assessment Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pfankuch CSI</td>
</tr>
<tr>
<td>Bank Stability</td>
<td>✓</td>
</tr>
<tr>
<td>Bed Material</td>
<td>✓</td>
</tr>
<tr>
<td>Riparian Zone</td>
<td>X</td>
</tr>
<tr>
<td>Channel Pattern</td>
<td>X</td>
</tr>
<tr>
<td>Floodplain</td>
<td>X</td>
</tr>
<tr>
<td>Bedform</td>
<td>✓</td>
</tr>
<tr>
<td>XSection Survey</td>
<td>✓</td>
</tr>
</tbody>
</table>

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
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.
- ...

[Diagram of a river with a green landscape and a blue pathway, indicating the flow of energy and resistance to erosion.]
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!
Using discharge and velocity data, Manning’s $n$ was calculated and compared to common estimates.

<table>
<thead>
<tr>
<th></th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h/d_{84}$</td>
<td>$n = h/d_{84}$</td>
</tr>
<tr>
<td>$h/\sigma_z$</td>
<td>$n = h/\sigma_z$</td>
</tr>
<tr>
<td>NRCS (2006)</td>
<td>$n = 0.047(d_{50}*S)^{0.147}$</td>
</tr>
<tr>
<td>Anne Arundel County (2012)</td>
<td>$n = h^{1/6}/(21.6\log_{10}(h/d_{50})+14)$</td>
</tr>
<tr>
<td>Chow (1959)</td>
<td>tabular</td>
</tr>
<tr>
<td>Strickler’s relation</td>
<td>$n = 0.04d_{50}^{1/6}$</td>
</tr>
</tbody>
</table>

$h =$ water depth, $d_{50}$ and $d_{84} =$ weir particle size, $\sigma_z =$ std. deviation of protrusion height, $S =$ channel slope.
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 on 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 do I take from this if I am a practitioner:

- 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

What do I take from this if I am a regulator:

- 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