Instream Structures in the Mid-Atlantic United States:

An Investigation of the Design, Project, and Watershed Factors that Affect Structure Success

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COLLEGE OF ENGINEERING
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
BIOLOGICAL SYSTEMS ENGINEERING
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MDOT
MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

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- Motivation
- Methods
- Results
- Conclusion
- Q/A

Instream structures have been present and evolving since the inception of stream restoration

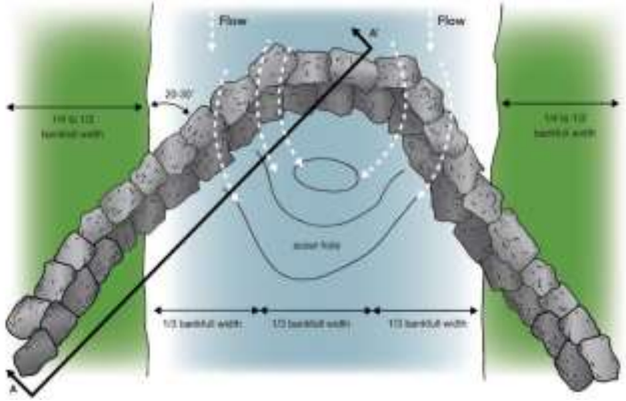
Structure failure is widely reported and there are no formal design standards.


Goal: evaluate existing instream structures with the aim of informing structure design

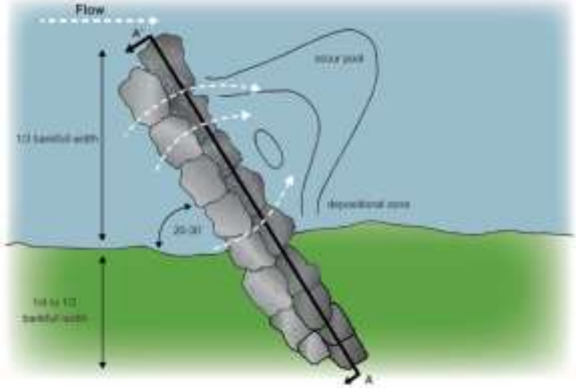
Methods

Six families of structures based on function

Bank Protection



Full Span Vanes



Partial Span Vanes

Constructed Riffles

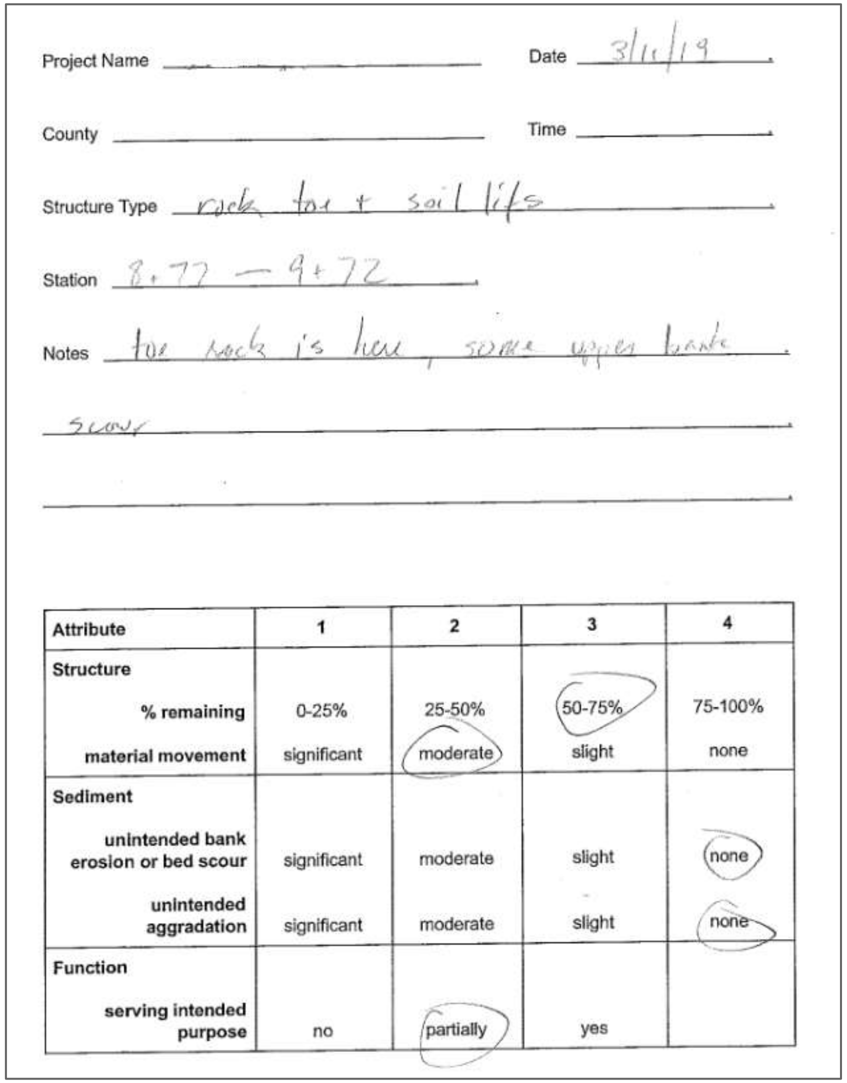
Regenerative Stream Conveyance (RSCs)

Step Pools

Structure assessment performance in the field

An overall structure score was determined by summing all subcategory scores.

		0	1	2	3
Stability	% remaining	0- 25%	25- 50%	50- 75%	75- 100%
	material movement	significant	moderate	slight	none
Sediment	unintended bank erosion/ bed scour	significant	moderate	slight	none
	unintended aggradation	significant	moderate	slight	none
		0	3	6	
Function	serving intended purpose	no	partially	yes	


Project Name ______ Date 3/11/19

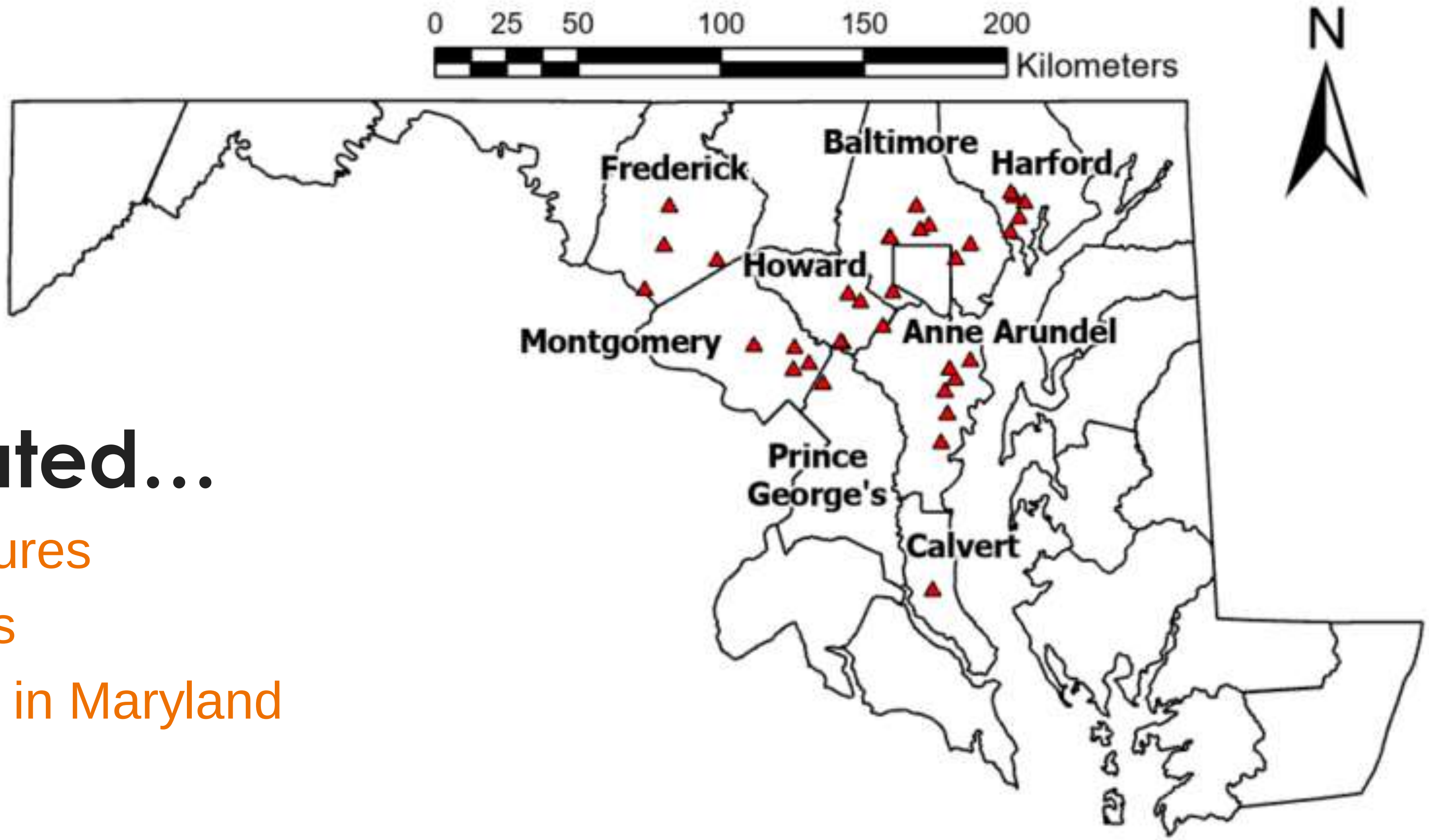
County ______ Time ______

Structure Type rock toe + soil lifts

Station 8+72 — 9+72

Notes toe rock is here, some upper bank scour

Attribute	1	2	3	4
Structure				
% remaining	0-25%	25-50%	50-75%	75-100%
material movement	significant	moderate	slight	none
Sediment				
unintended bank erosion or bed scour	significant	moderate	slight	none
unintended aggradation	significant	moderate	slight	none
Function				
serving intended purpose	no	partially	yes	



Evaluated…

536 structures

39 projects

8 counties in Maryland

Field assessments

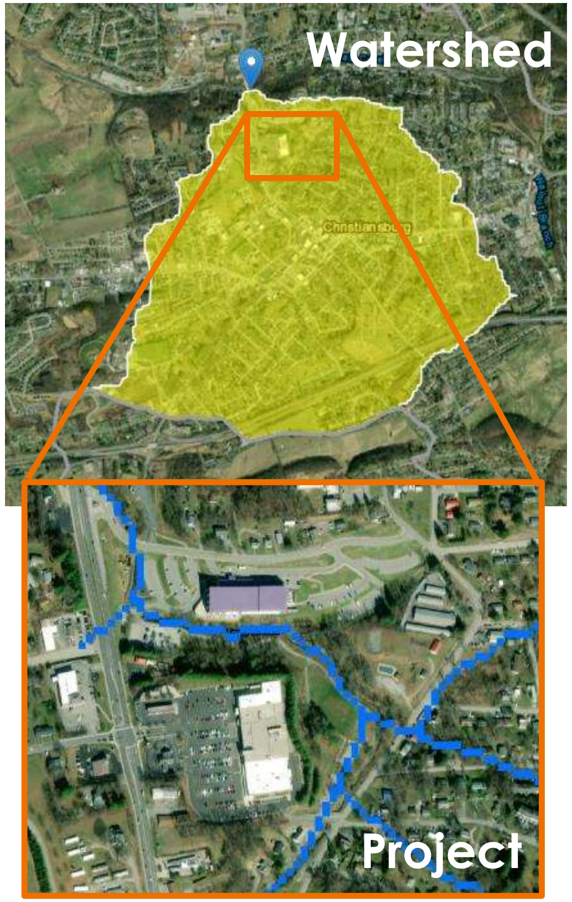
March 2019 and
January 2020

Collected variables

Watershed Scale

Flow Energy
- Watershed area
- Average watershed slope
- Land use
- BMP density
- Stream slope

Erosion Resistance
- Area-weighted soil erodibility (K)
- Length-weighted K of stream banks



Project Scale

Flow Energy
- Specific stream power
- Bankfull discharge
- Stream slope
- Floodplain width
- Sinuosity
- Bankfull channel dimensions

Erosion Resistance
- Bed sediment size
- Length weighted K of stream banks
- Up/downstream grade control

Design Approach
- Project age
- Project length
- Structure Density (#/1000ft)
- Rosgen channel type

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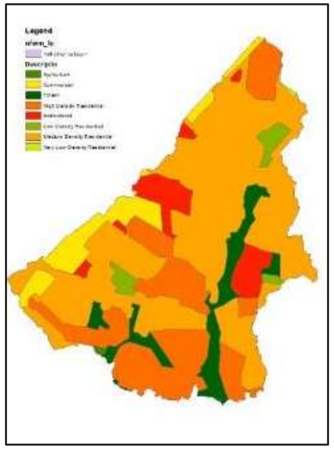
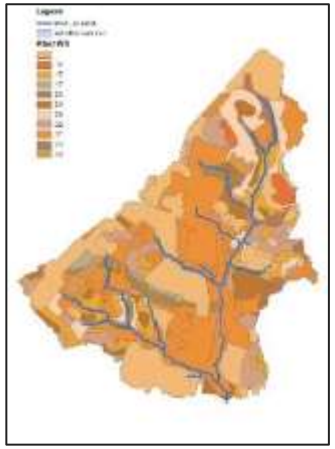
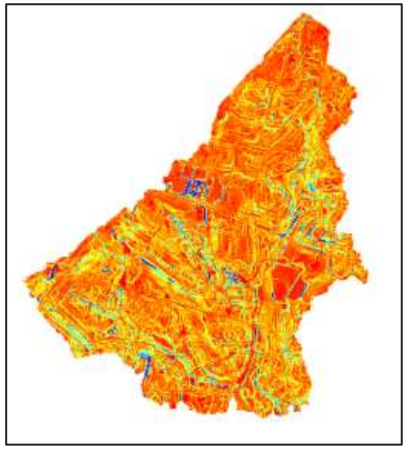
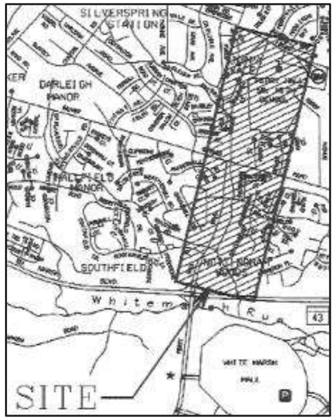
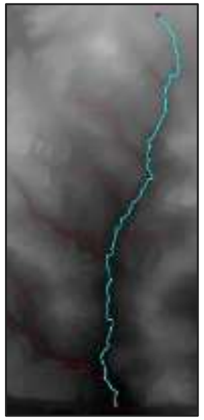
Structure-scale explanatory variables related to the design and placement of structures

https://www.wetlands.com/towne-branch

Watershed-level data was collected using ArcGIS

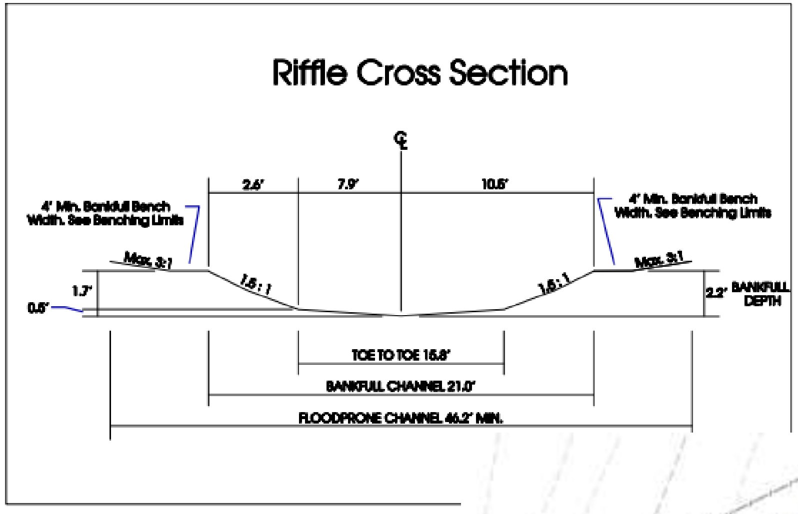


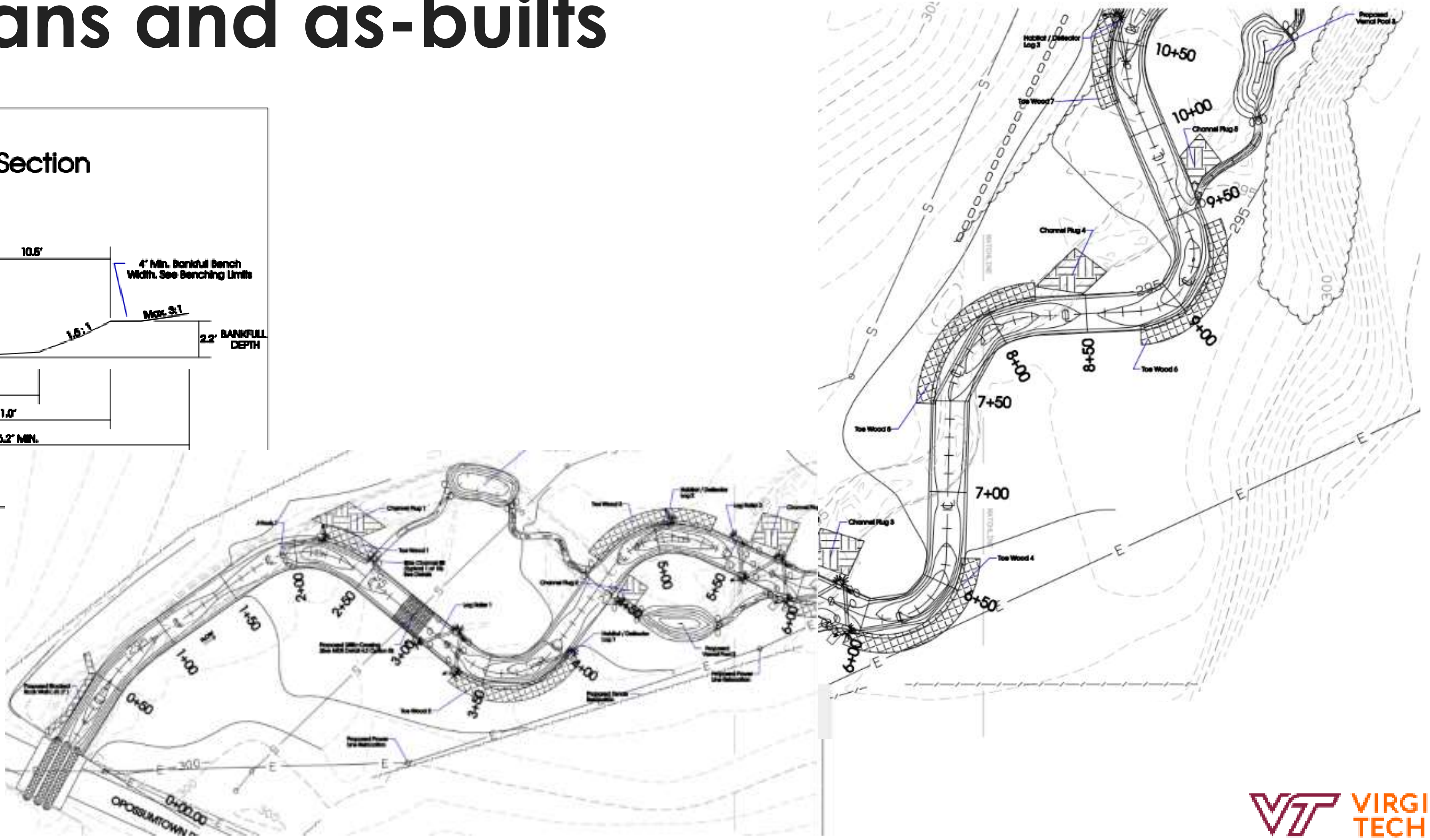

Elevation data
- 2m DEMs from Maryland iMAP

2010 land use data
- Maryland iMAP

Soils data
- NRCS web soil survey

Project-level data was collected from project design plans and as-builts





Structures were grouped by function and material

- Bank protection (n = 147)
- Full span vanes (n = 105)
- Partial span vanes (n = 68)
- Constructed riffles (n = 102)
- RSC weirs (n = 57)
- Step pools (n = 31)

- Rock
- Log
- Combination

Design explanatory variables depended on structure family and were scaled to channel size.

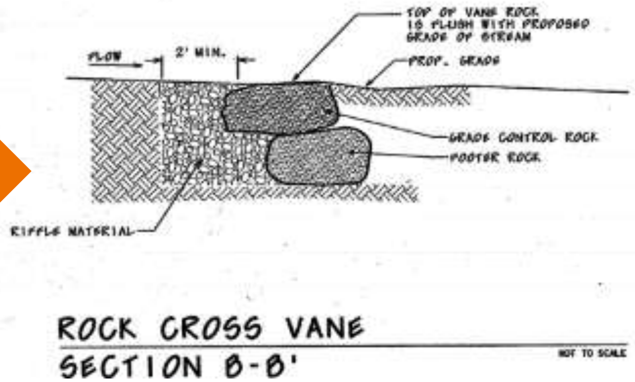
Structure-scale data was collected using a variety of data sources

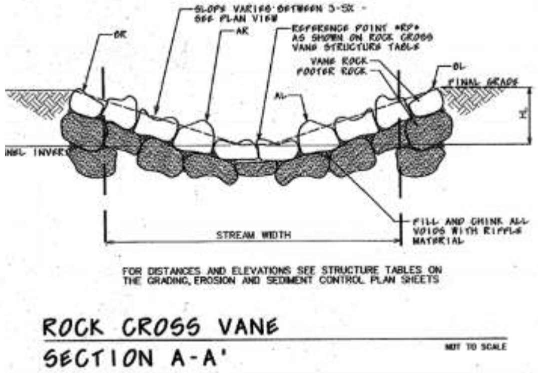
ROCK CROSS VANE STRUCTURE TABLE

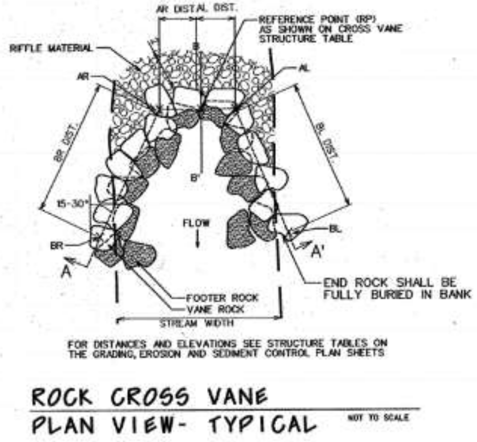
RP STATION	RP ELEVATION	AL DISTANCE	AR DISTANCE	BL DISTANCE	BR DISTANCE	HL HEIGHT	HR HEIGHT
12+10	467.5	3.3'	3.3'	26.0'	13.0'	1.3'	1.3'
14+37	462.6	3.3'	3.3'	28.0'	32.0'	1.3'	1.3'
14+90	462.0	3.3'	3.3'	31.0'	16.0'	1.3'	1.3'

Structure Table

Design Drawings

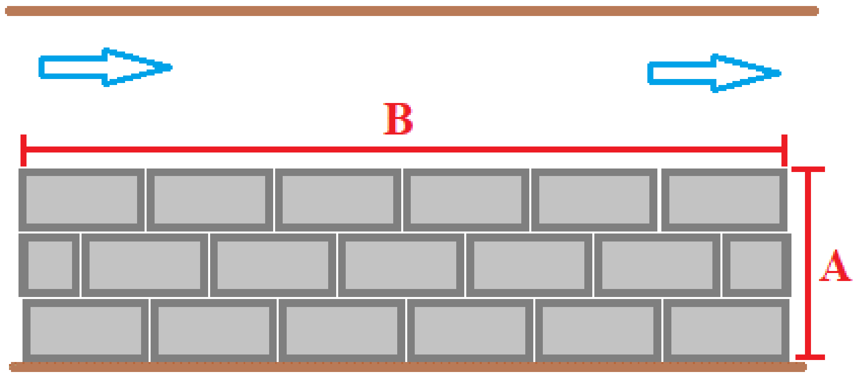






Bank protection structure-scale predictors related to…

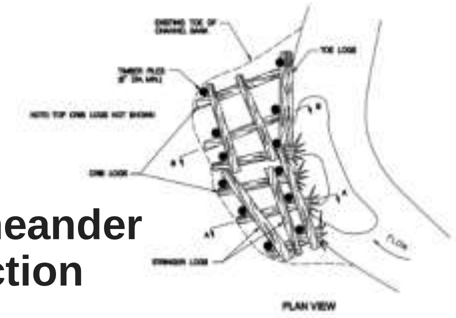
Top of Bank



Bed

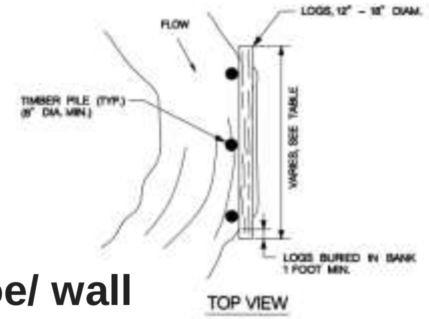
Wall height (A)
Wall length (B)

Type



Log meander protection

VS



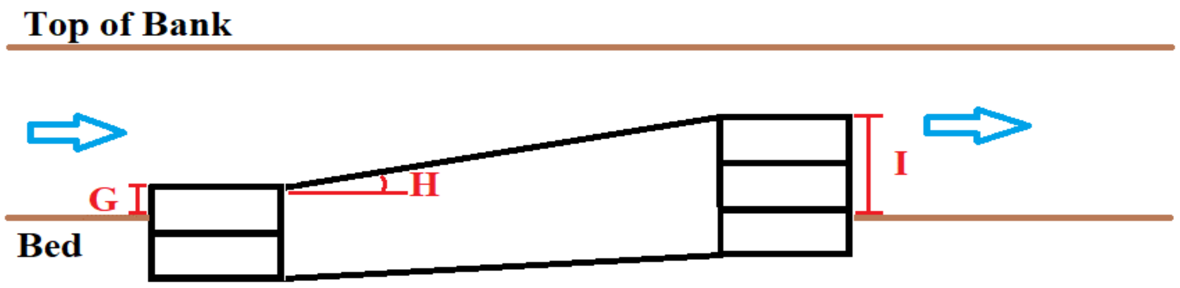
Log toe/ wall

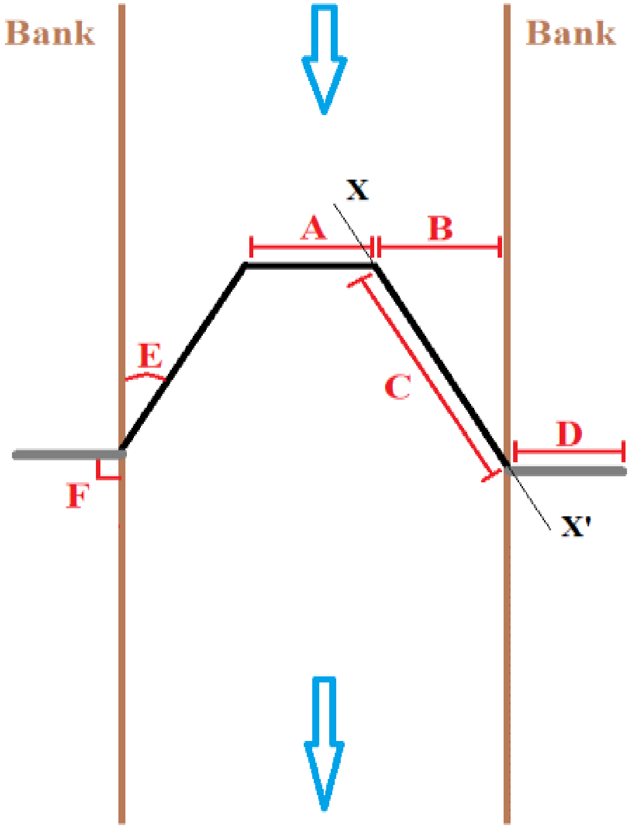
Imbricated rock wall

VS

Rock toe

Full span vane structure-scale variables relate to…





Type

Arm

- Length (B, C)
- Bank angle (E)
- Slope (H)
- Distance in channel (I)

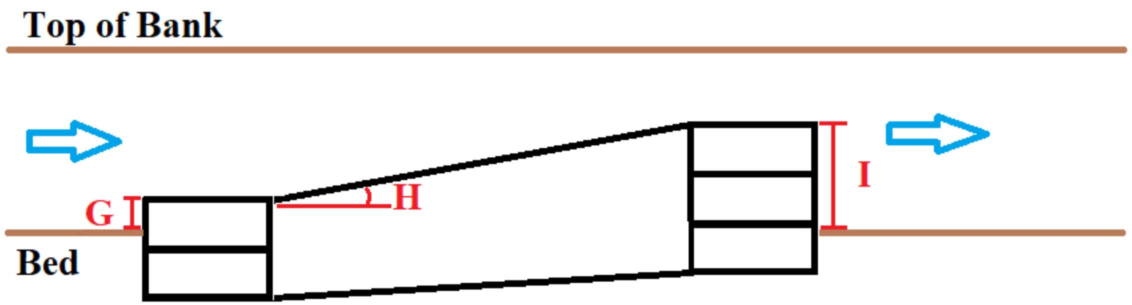
Sill

- Width (A)
- Protrusion (G)

Bank Key

- Distance (D)
- Bank angle (F)

Partial span vane structure-scale variables are almost the same as full span vanes



Type

Arm

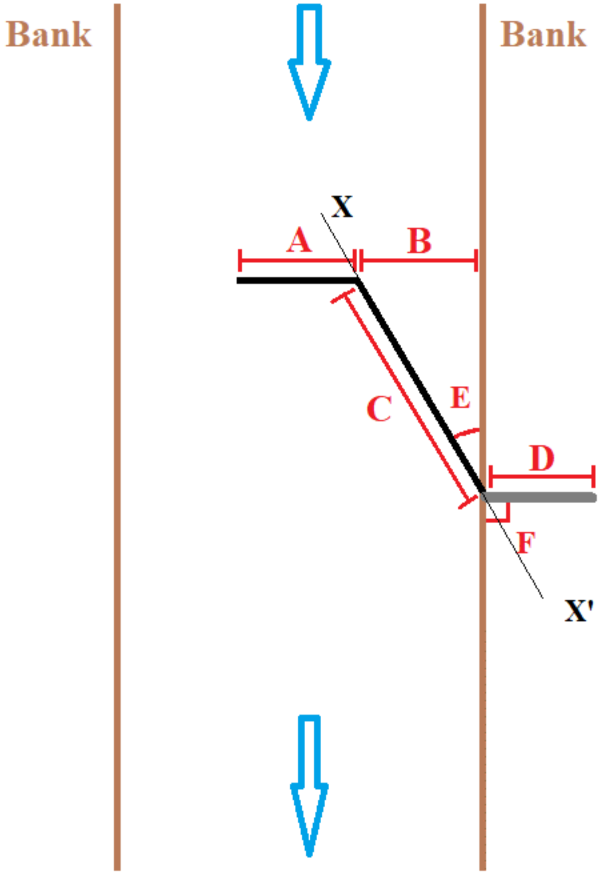
- Length (B, C)
- Bank angle (E)
- Slope (H)
- Distance in channel (I)

Sill

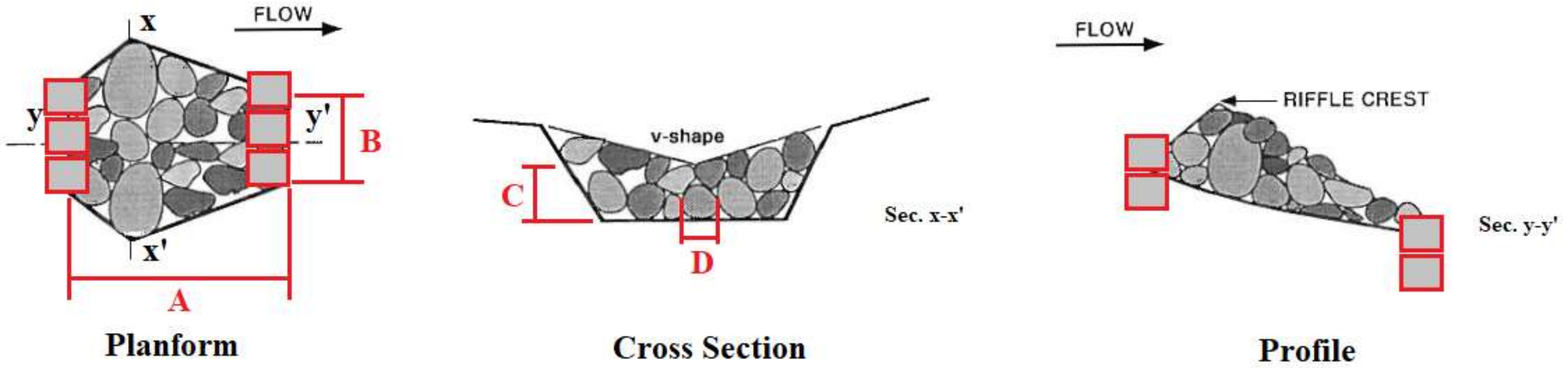
- Width (A)
- Protrusion (G)

Bank Key

- Distance (D)
- Bank angle (F)

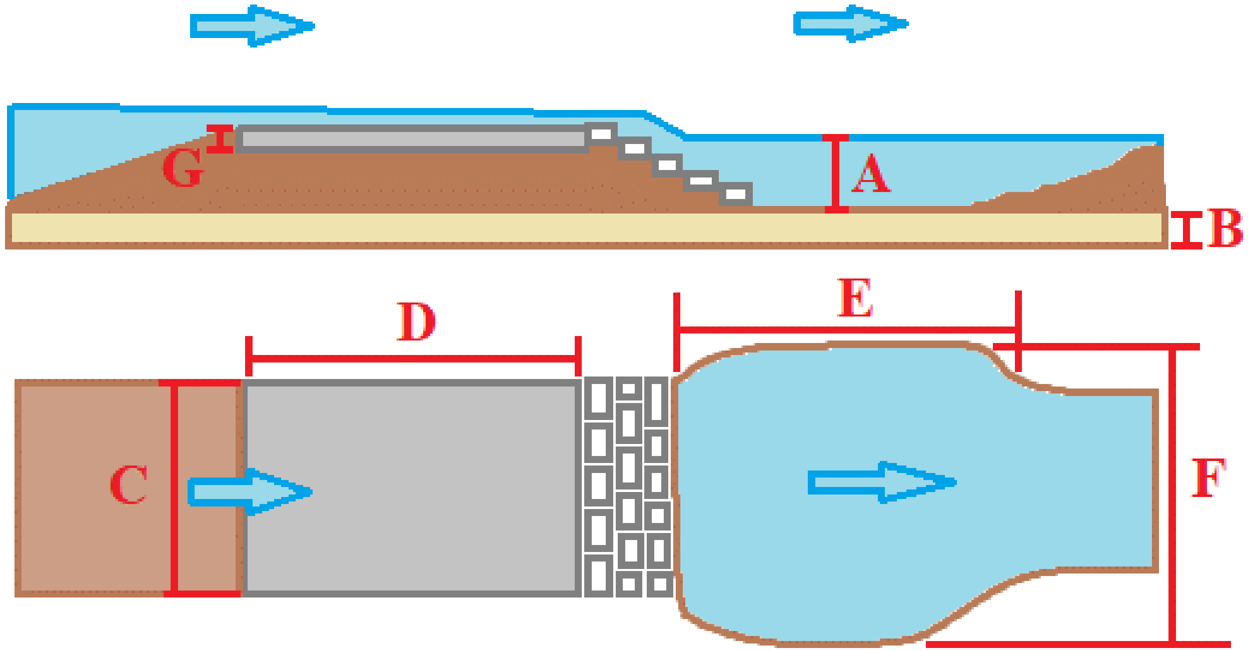


Constructed riffle structure-scale predictors relate to the dimensions and substrate



Length: width (G)
Substrate depth (C)
Substrate size (D_{50}) (D)

RSC structure-scale predictors relate to properties of the weir and pool



Weir

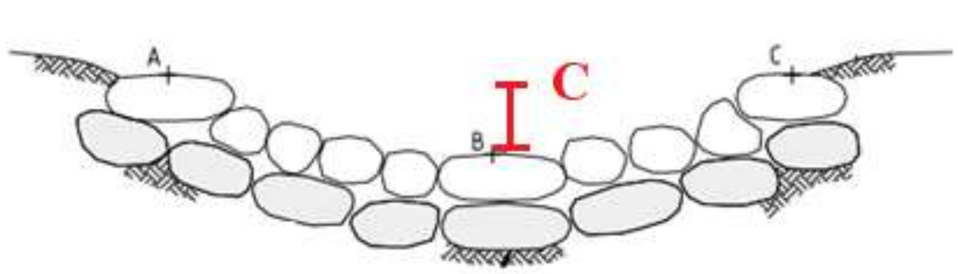
- Length: width (D:C)
- Slope
- Substrate size (D_{50})
- Substrate thickness (G)

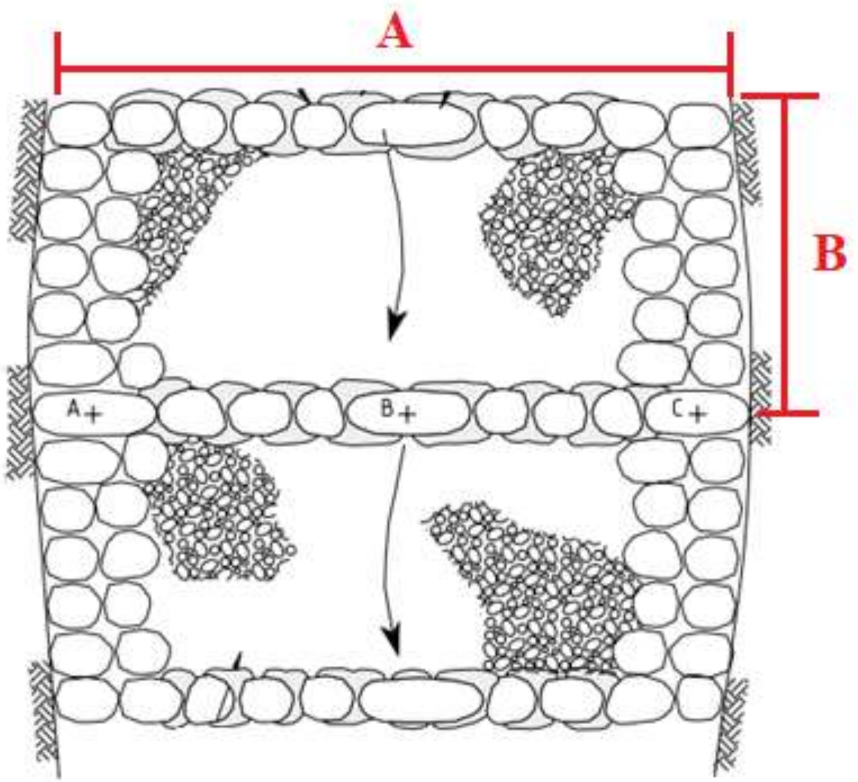
Pool

- Length: width (E:F)
- Depth (A)
- Perimeter

Infiltration Media Thickness (B)

Step pool structure-scale variables relate to the system, sill, and pool





System-wide

- Number of step-pools
- Total length
- Average step-pool slope
- Ratio of mean steepness

Sill width (A)

Pool

- Depth (C)
- Length: width (B:A)
- Substrate depth
- Substrate size (D_{50})
- Perimeter

Primary statistical analyses were performed in Rstudio and Excel

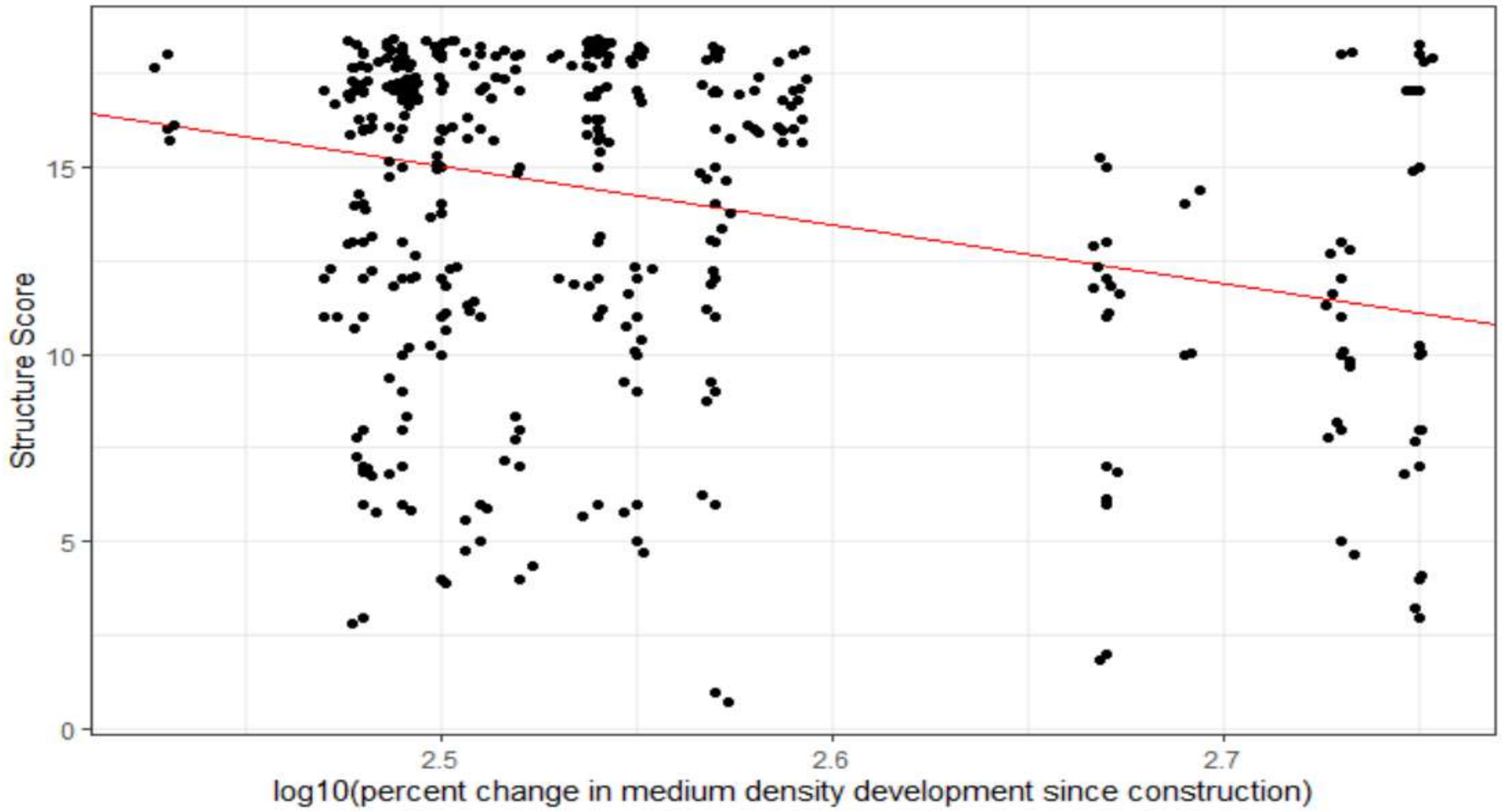
- **Structure Predictors**
  - Single and multiple linear regression
- **Watershed and Project Predictors**
  - Linear mixed-effects models
    - Dependent variable – fixed effect
    - Grouping variable – random effect - project

- **Mann-Whitney 2-sample tests**
  - Used to determine if there were significant differences between groups

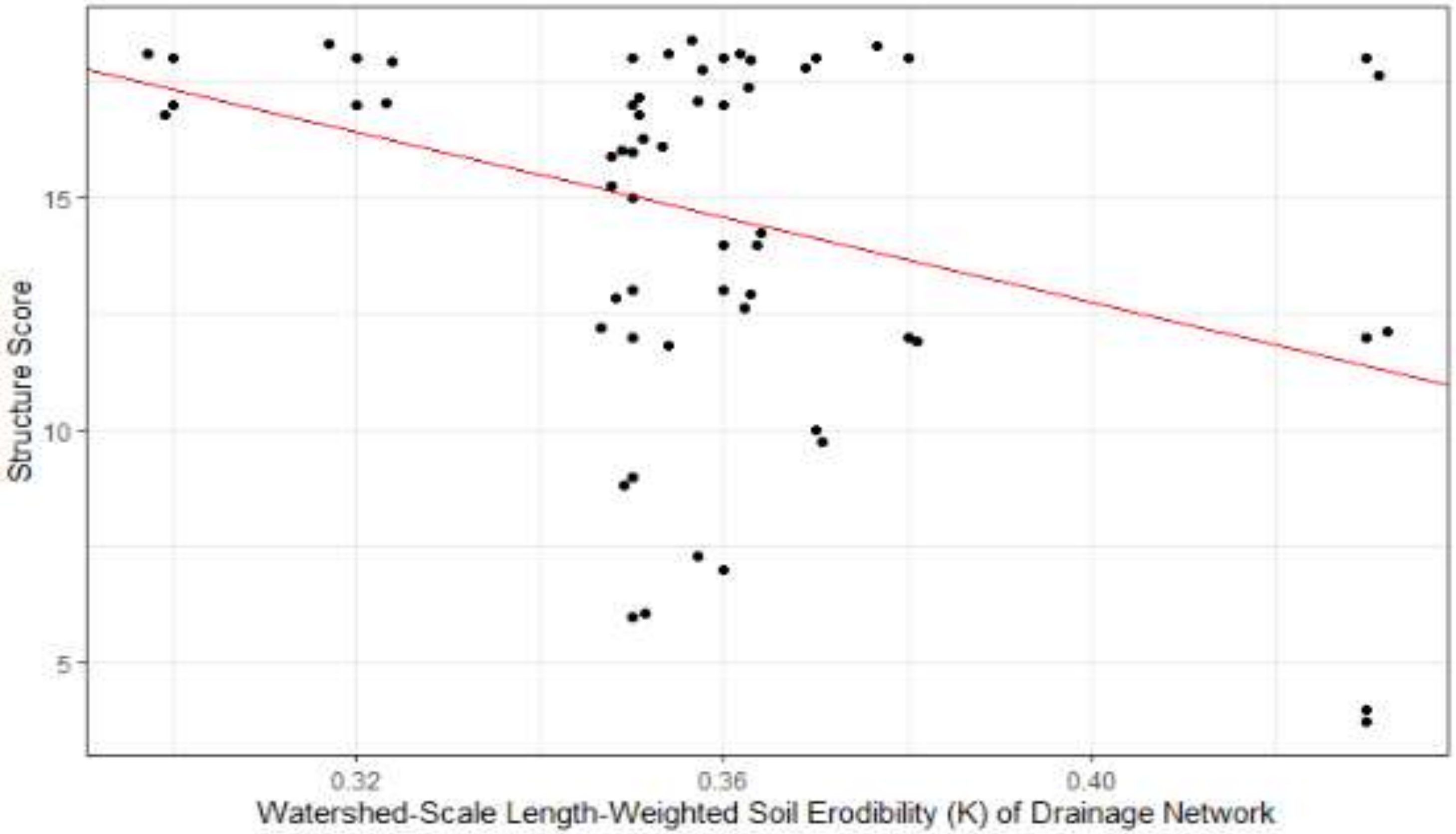
		0	1	2	3
Stability	% remaining	0- 25%	25- 50%	50- 75%	75- 100%
	material movement	significant	moderate	slight	none
Sediment	unintended bank erosion/ bed scour	significant	moderate	slight	none
	unintended aggradation	significant	moderate	slight	none
		0	3	6	
Function	serving intended purpose	no	partially	yes	


Results

Increased watershed urbanization is correlated to decreased structure performance



Log structure performance is negatively correlated to drainage network streambank erodibility



Rock bank protection performance negatively correlated to bankfull discharge

Restoration activities have a protective effect on nearby structures

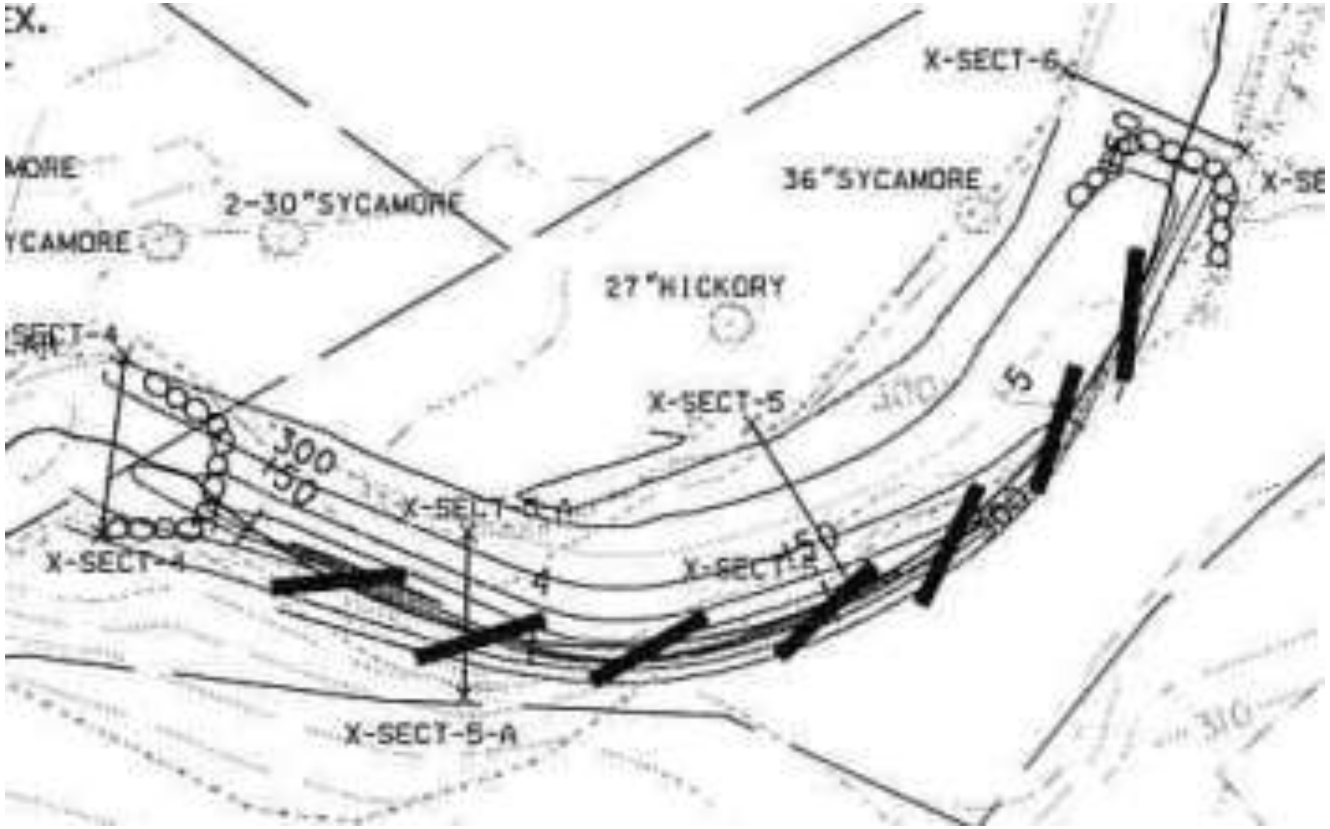
Rock bank protection

- Project length (+)*
- Structure density (+)*

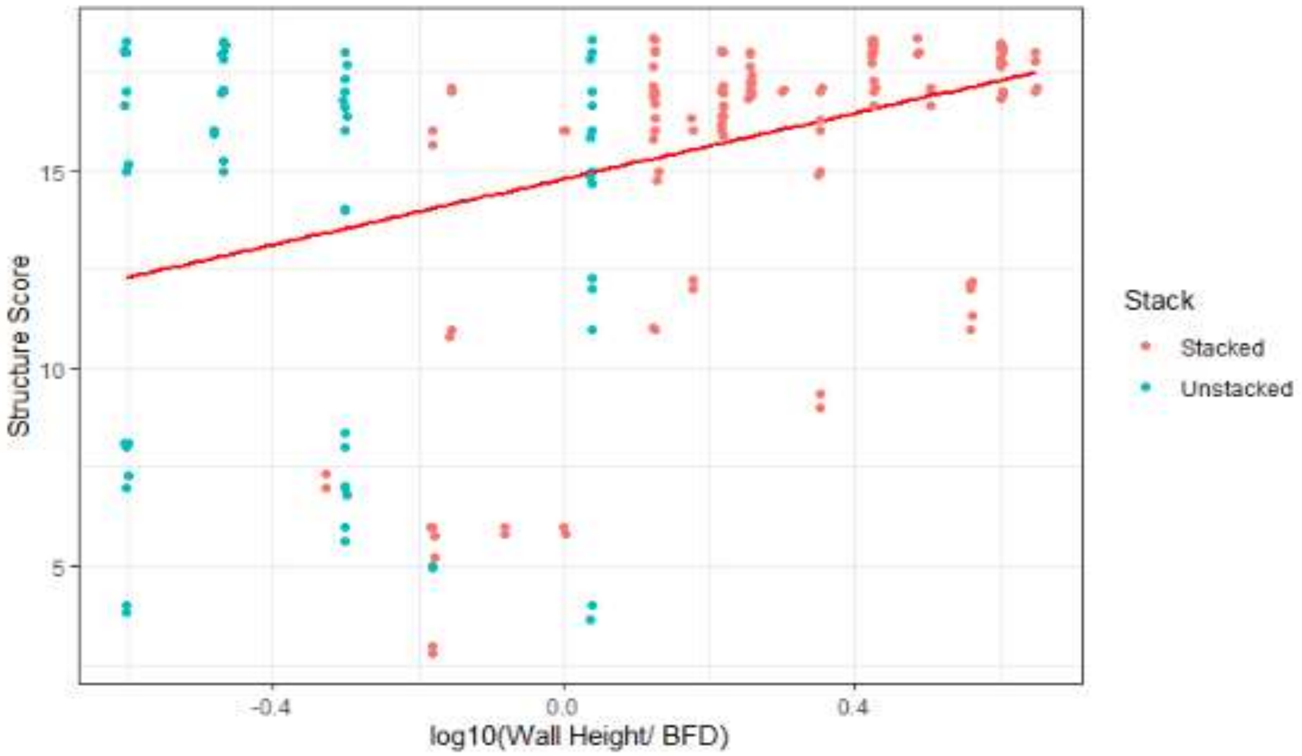
Log partial span vanes

- Proximity to other structures (+)

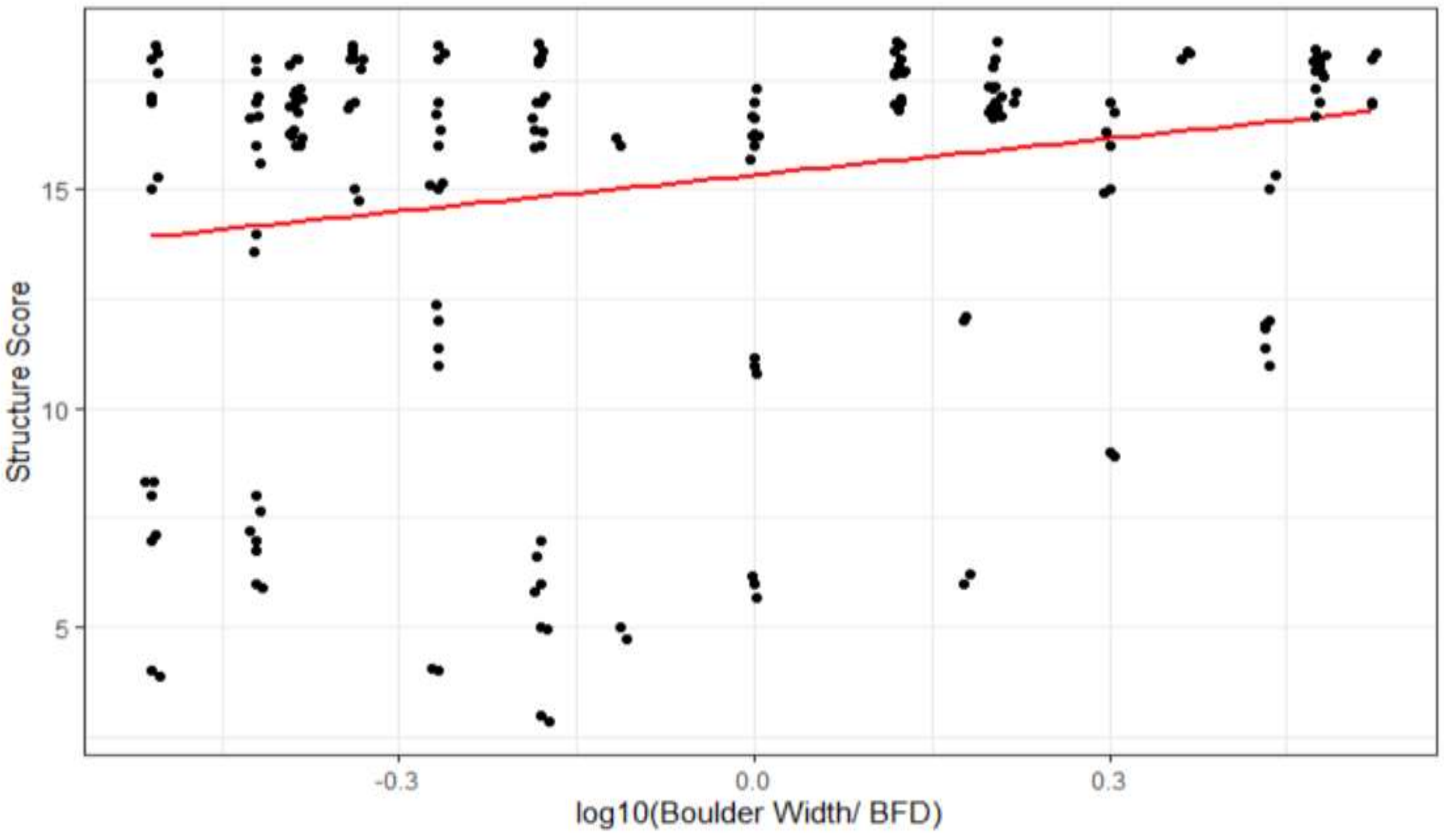
* 90% of variability explained by project



Rock bank protection performance was positively correlated to wall height



Rock bank protection performance was positively correlated to boulder size



Stacked bank protection performed better than unstacked bank protection

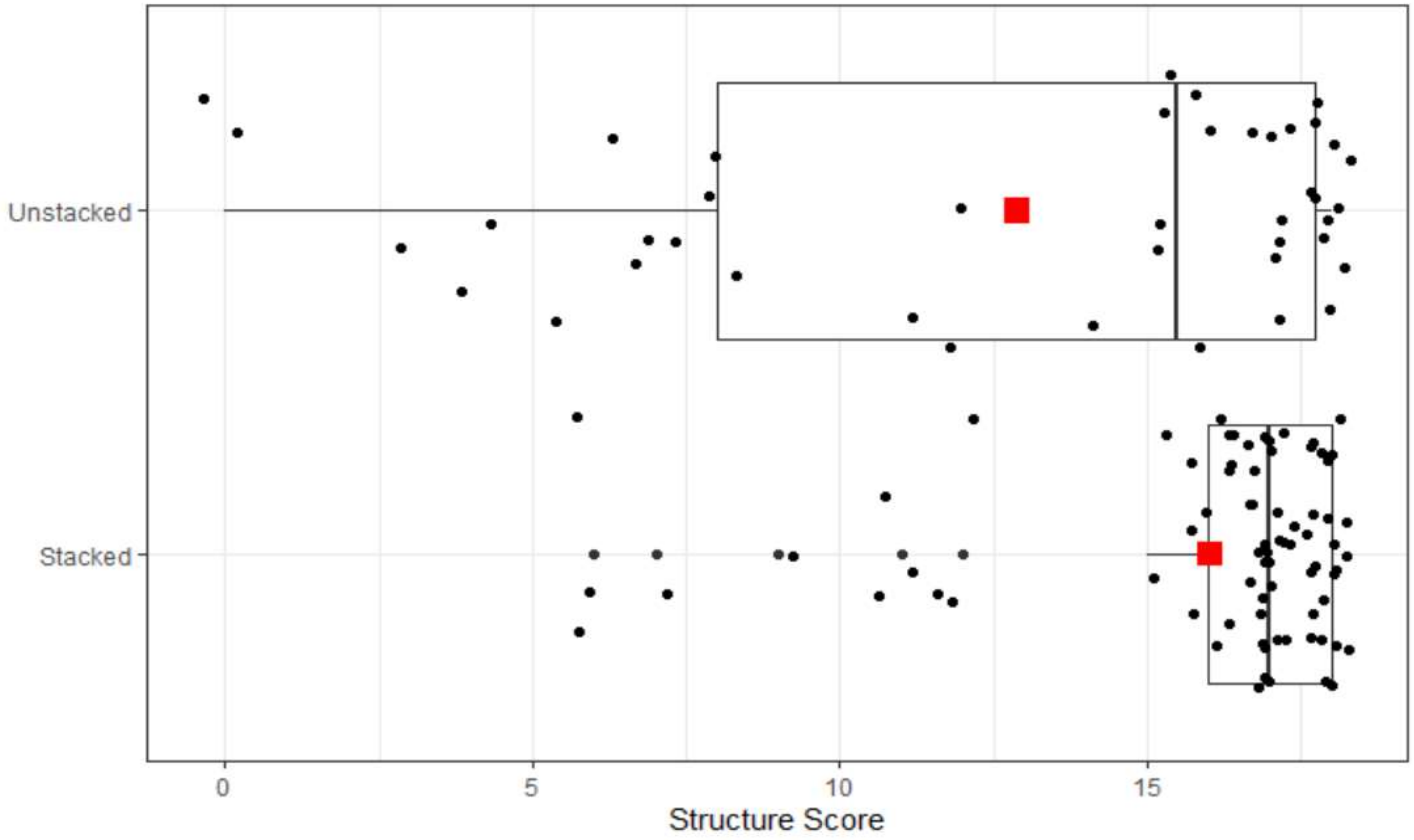
Stacked



Unstacked



Differences in performance



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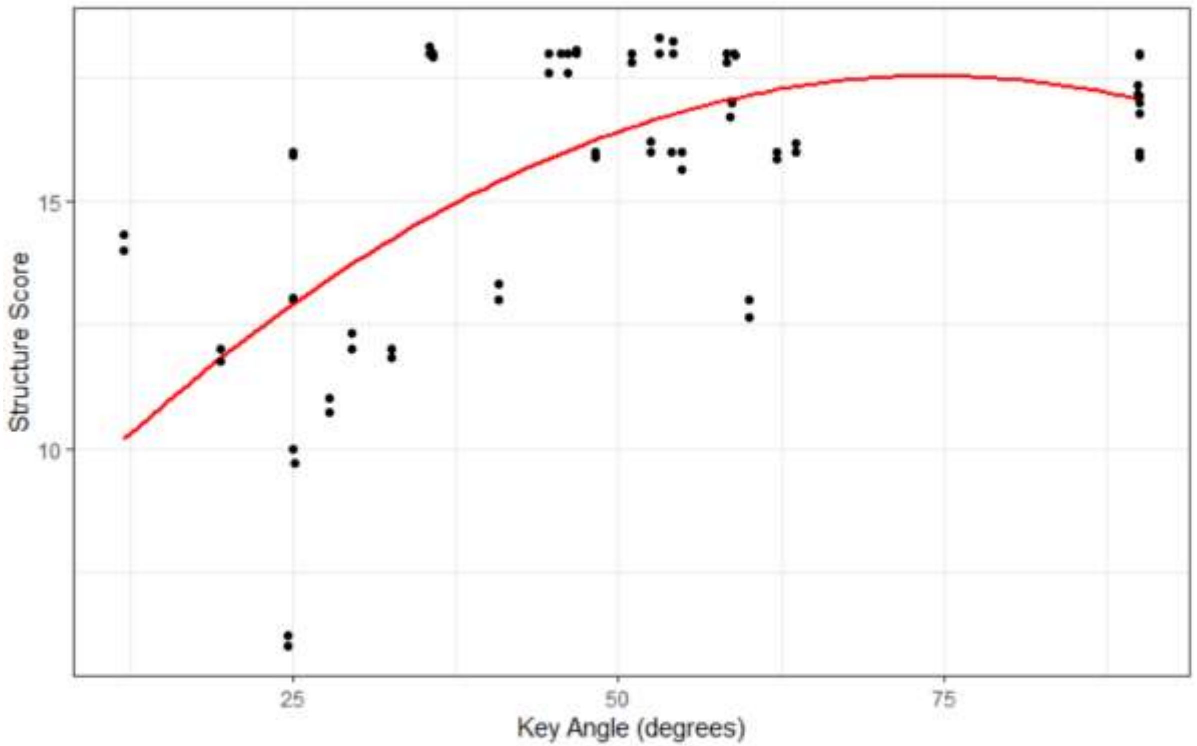
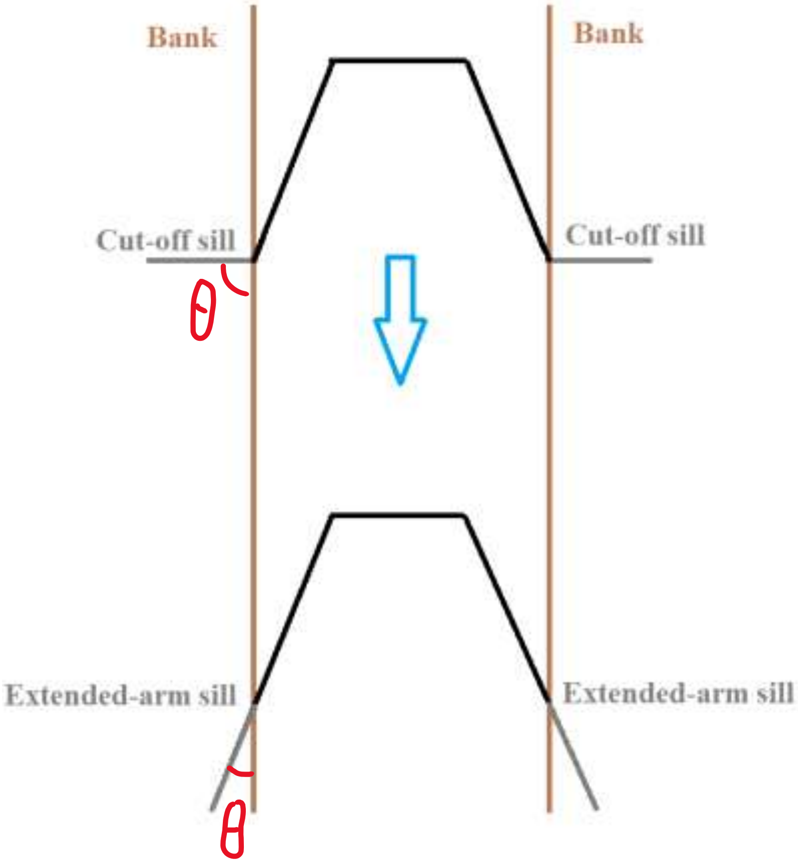
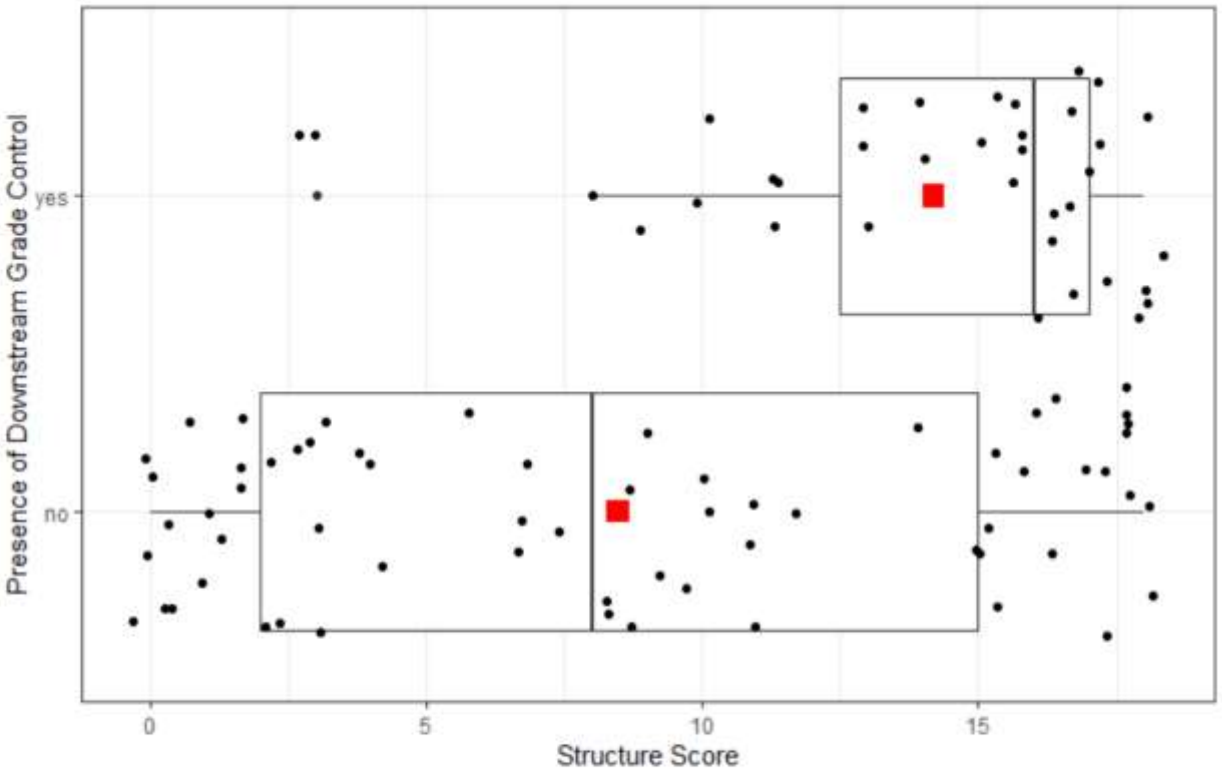
Full span vane key angles between 35 and 90 degrees correlated with increased performance

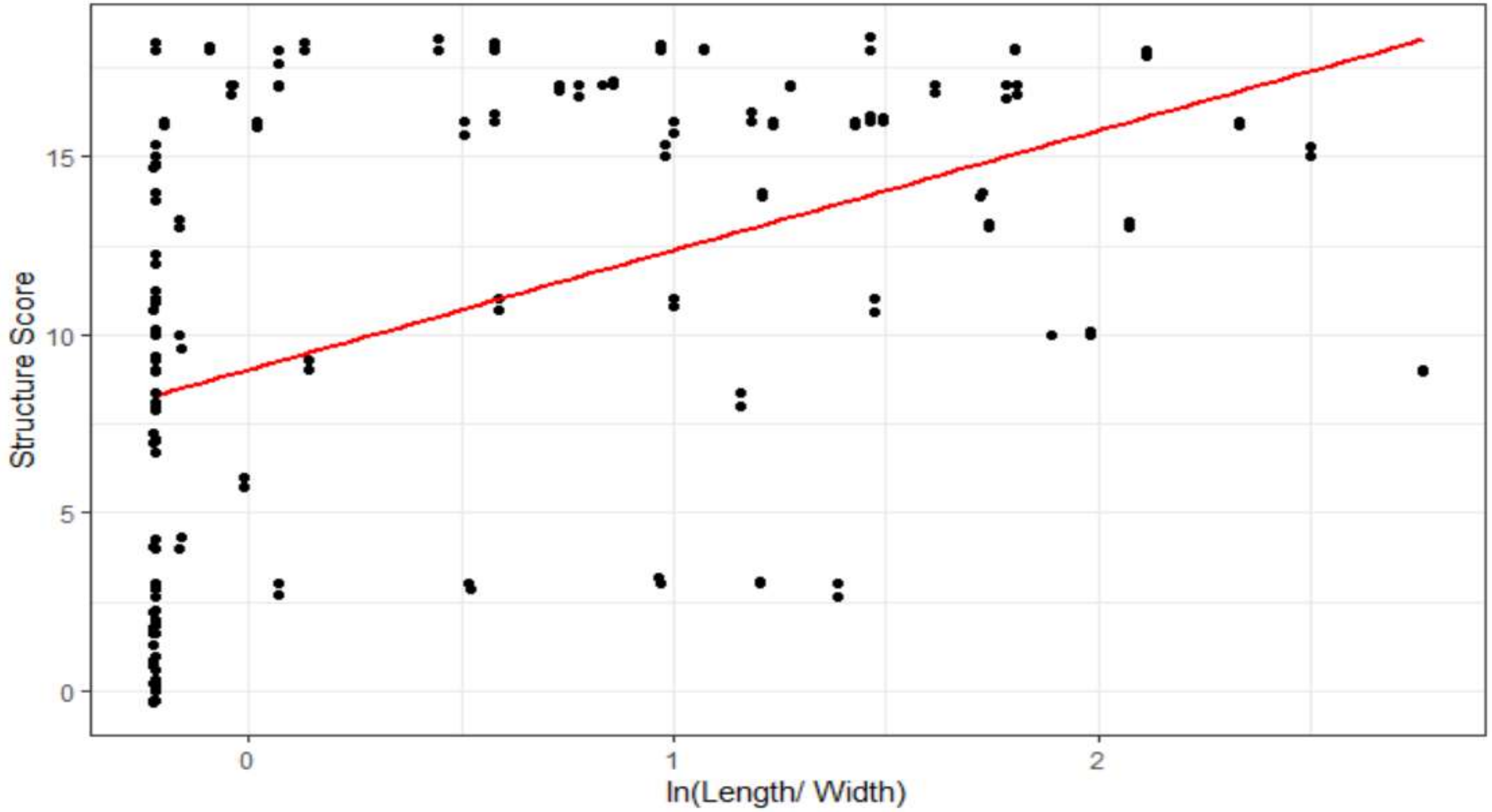




Structure score is positively correlated to downstream grade control for constructed riffles



Constructed riffle scores were positively correlated to the L:W and substrate depth



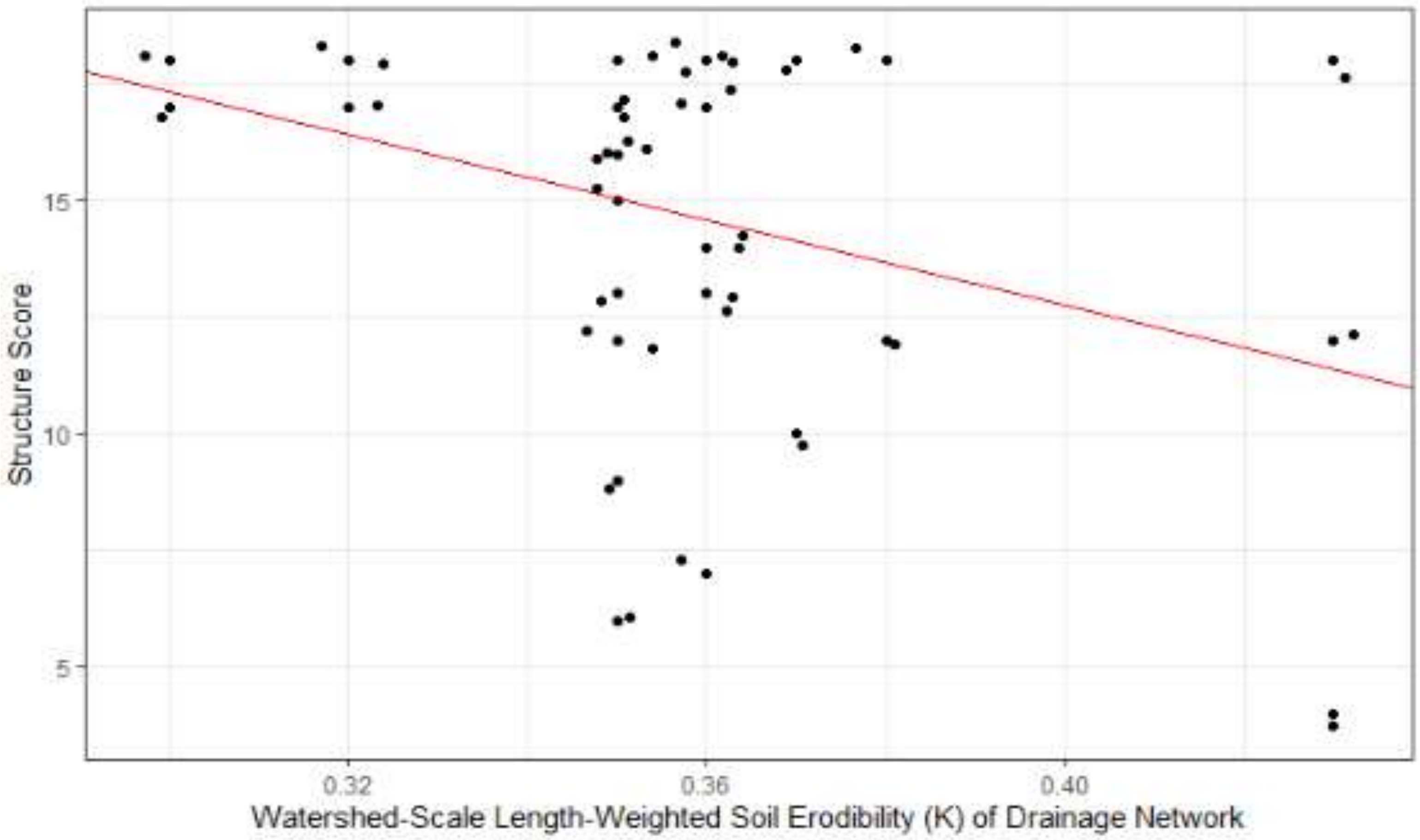

Conclusion

Structure performance is strongly influenced by individual project

- Design quality
- Construction quality
- Maintenance
- Weather during/immediately after construction

Structures performed well over a range of conditions

Example



Design recommendations

- Imbricated rock walls are more stable and provide a greater degree of bank protection than rock toe.
- Vanes should be constructed with bank keys to prevent flanking, ideally angled between 35 and 90 degrees.
- The stability of constructed riffles can be enhanced significantly using downstream grade control.

Study limitations

- Maintenance
- Design drawings vs. construction
- Did not assess ecological improvement/degradation
- Results are only applicable to the Mid-Atlantic US

Future work

- Assess the performance of additional instream structures (for example: BDAs)
- Determine the biological function/ ecosystem value of instream structures
  - Particularly FSV, PSV, RF, SP
- Evaluate structure placement and construction by modeling channel hydraulics and sediment transport

Questions?

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