Influence of Vegetation Density and Projected Area on Streambank Erosion

Nicole M. Czarnomski [1], Desiree Tullos [2], Andrew Simon [3], and Robert Thomas[3]

[1]Water Resources Engineering, Department of Geosciences, Oregon State University, Corvallis, Oregon; [2]Department of Biological and Ecological Engineering, Oregon State University, Corvallis, Oregon; [3]National Sedimentation Lab, USDA-ARS, Oxford, Mississippi

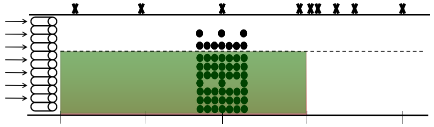
FRAMEWORK

Streambanks can be eroded by the sheering forces of water. If left unprotected, eroded material from streambanks can contribute large quantities of sediment to the channel, increasing sediment loads and putting a strain on water resource facilities. Vegetation along the toe of a streambank can slow down water and deflect flow away from banks, altering the forces applied to the bank surface and protecting banks against erosion. However, vegetation also introduces turbulence, roughening flow and introducing localized scour.

In this study, a scaled flume experiment was used to estimate the relative magnitude of difference in channel velocity and turbulence on the streambank due to changes in vegetation planform density (number of plants/horizontal area) and projected area (number of leaves/vertical area).

FLUME EXPERIMENTS

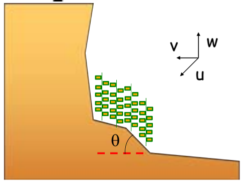
Experiments were conducted in a 6.05 × 0.61 × 0.61 m recirculating flume set at a fixed slope of 0.001 m/m. To simulate a 30° bank toe, a 4.88 m long, 0.45 m wide inclined insert was installed along one side of the flume immediately downstream of the flow straighteners. Bank and artificial vegetation was scaled by a Froude scaling factor of 4.35 from a prototype streambank representing the toe of a compound bank.



Planform view of flume; arrows indicate direction of flow, shaded region shows location of vegetation array. Cylinders represent flow straighteners used to help provide uniform flow characteristics. X's represent cross-sections where velocity measurements at 0.6 of depth were taken. O's represent locations of boundary velocity measurements. (Not drawn to scale.)

Measurements

In order to characterize the depth-averaged velocity , it was assumed that the von Kàrmàn-Prandtl law of the wall was valid and hence velocity was measured at ~0.6 × the flow depth (0.6d) at 7 cross-stream locations within the 9 cross-sections. Near-boundary velocity was measured at 7 or 9 cross-stream locations within 7 cross-sections. Velocities were measured over five minutes at 25 Hz with a 10 MHz Nortek acoustic Doppler velocimeter (ADV). Data were filtered and processed using the WinADV software.



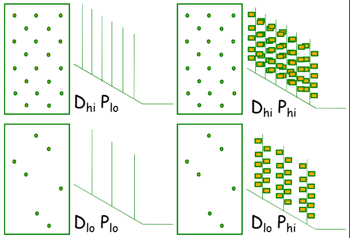
Example of a compound bank

Key variables:
- θ = angle of bank toe (°)
- u, v and w = velocity vectors in the streamwise, lateral, and vertical directions (m/s)
- P = cross-sectional area of plant (m²)
- D = vegetation planform density (#/m)
- Q = discharge (m³/s)

SAMPLING DESIGN

Vegetation was installed in two patterns: low density (D_{lo}) of 202 plants per m² and high density (D_{hi}) of 615 plants per m², which scale to 8 and 24 plants per m², respectively.

Vegetation was in two forms: low projected area (P_{lo}) and high projected area (P_{hi}). P_{lo} plants were made of 450 mm long, 4.54 mm diameter acrylic rods, scaled down from 2 m tall, 20 mm diameter woody stems. P_{hi} consisted of the same acrylic rods affixed with ten 28-gauge wire "branches" and ten 25 × 35 mm "leaves" made of contact paper (875 mm² total) spaced to reflect a pattern of projected area found by Wilson et al. (2006).



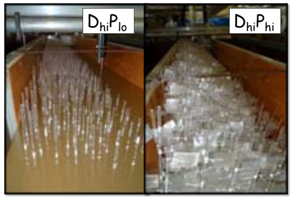
Fifteen experimental runs were conducted:

12 with vegetation

and

3 non-vegetated control runs.

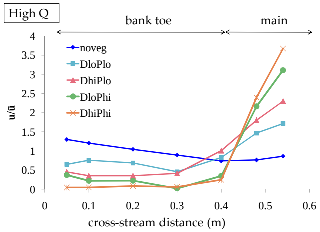
Run	D	P	Q (m³s⁻¹)
1	lo	lo	0.015
2	lo	lo	0.03
3	lo	lo	0.05
4	lo	hi	0.015
5	lo	hi	0.03
6	lo	hi	0.05
7	hi	lo	0.015
8	hi	lo	0.03
9	hi	lo	0.05
10	hi	hi	0.015
11	hi	hi	0.03
12	hi	hi	0.05

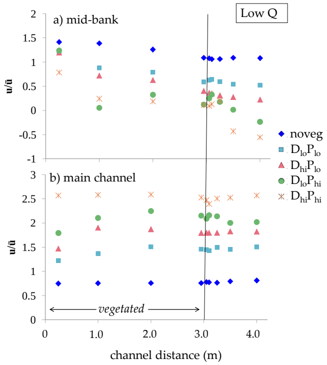


RESULTS – CHANNEL VELOCITY

Leading Question: What is the magnitude of change in channel velocity (u) created by increases in vegetation density (D) and projected area (P)?

- **Overall, at top and middle of bank toe, u decreased as D and P increased.** For example, in the figure below, the $D_{lo}P_{lo}$ condition decreased normalized u along the width of the bank toe by 34-50%, while all other combinations of D and P decreased normalized u by >50%.
- **At the bank toe-main channel margin, u decreased only as P increased.** On the bank toe-channel margin, with P_{lo} conditions u increased marginally despite density, but with P_{hi} they decreased by >50%.
- **In the main channel, average velocities increased by 50-75% with the introduction of vegetation.**
- **At the middle of the bank toe**, normalized u decreased to 30-67% more than the non-vegetated value after passing through the vegetation.
- **Within the upstream-most 2 m of the main channel**, normalized u increased by 22-26%, after which there was little change.



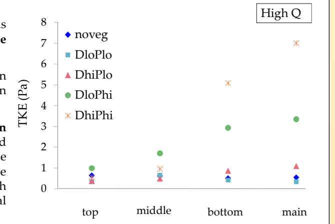


** Similar results were seen for all discharges, but not shown here.

RESULTS - TURBULENCE

Leading Question: How do increases in vegetation density (D) and projected area (P) influence turbulence intensity (TKE) at varying cross-sectional locations along the bank toe and main channel?

- Without vegetation, turbulence intensity was greatest at the **top of the bank toe** and lowest **at the bottom**, though overall differences were small.
- **At the top and middle of the toe**, once vegetation had been introduced, changing D had little effect on turbulence intensity when P was held constant .
- **At the bank toe-channel margin and in the main channel**, holding D constant and increasing P resulted in a more than three-fold increase in turbulence intensity. An increase in P corresponded to an increase in both lateral and vertical boundary velocities, with lateral velocity becoming more negative and vertical more positive (not shown).



CONCLUSIONS

- **Vegetation density (D) and projected area (P) are important to include when considering streambank hydraulics.** Both D and P decrease streamwise velocity along the bank toe and increase velocity in the main channel. They also alter turbulence patterns across the channel.
- **Plant form impacts turbulence, and thus erosion, along the bank toe.** Findings from this study suggest P is more influential than D in increasing turbulence along the already vulnerable bank toe. Higher turbulence may increase erosion and promote channel widening. Therefore, once plants leaf out in the spring, the risk of erosion along the bank toe-channel margin may increase.
- **Vegetation slows and redirects water.** This result supports findings from previous research. However, an important finding of this study are observations of a change in flow direction as P increases. This suggests that after leaf out occurs, patterns of scour and deposition may change. Increases in D did not have the same influence.
- **Future research.** This presentation is part of an ongoing study. Future efforts include exploration of an additional bank angle and a more detailed analysis of the channel hydraulics, including the drag forces associated with the plants and shear forces along the bank toe.

Top: $D_{hi}P_{hi}$ cross-section

Middle: $D_{lo}P_{hi}$, ADV

Bottom: ADV collecting velocity data.

REFERENCES CITED

Wilson, C. A. M. E., Yagci, O., Rauch, H.-P., and Stoesser, T. (2006). "Application of the drag force approach to model the flow-interaction of natural vegetation." Int. J. River Basin Mgmt., 4(2), 137-146.

ACKNOWLEDGEMENTS

Support for this research was provided by an NSF IGERT graduate fellowship (NSF award 0333257) in the Ecosystem Informatics IGERT program at Oregon State University and the USDA-ARS National Sedimentation Laboratory at Oxford, Mississippi. We are grateful for technical advice provided by Daniel Wren and technical assistance provided by Lee Patterson.

CONTACT INFORMATION: Nicole Czarnomski – czarnomn@geo.oregonstate.edu