Laboratory Modelling of Sediment Dynamics to Promote Resilient Streams

Ryan G. R. Good, Andrew D. Binns, Bahram Gharabaghi
University of Guelph, School of Engineering
Guelph, Ontario, Canada

UNIVERSITY of GUELPH

IMPROVE LIFE.

Fundamentals of River Morphodynamics

- Erosion and deposition patterns are primarily a result of secondary flows (Blanckaert and Graf, 2004)
- Given a steady flow, the alluvial channel will stabilize to a dynamic equilibrium (Binns and da Silva, 2009)
- Bed forms will migrate downstream after dynamic equilibrium is reached (Whiting and Dietrich, 1993)
- Riparian vegetation and channel planform dynamics are closely related (Lanzoni and Seminara, 2006)
- Erodibility of the underlying geology can significantly impact the shape a meandering channel takes (Leopold and Langbein, 1966)

A highly sinuous tributary of the Amazon River (Google Earth, 2017)

Previous Work

- Abad and Garcia (2009 a,b) analyzed the impact of skewness on the hydrodynamics and bed morphodynamics in a channel with confined banks and an unconfined bed
  - Upstream-skewed channel produced a point bar just upstream of the apex
  - Downstream-skewed channel produced the deepest scour areas, which occurred downstream of the apex
- Blanckaert (2011)
  - Meander migration is driven by curvature-induced secondary flow, but limited by the presence of outer bank cells
  - Outer-bank cells are widest and strongest with steep banks (>30°)
  - Large, shallow rivers exhibit the most dynamic meandering behavior

Motivation

- Previous experimental research has focused on the development of bedforms and hydrodynamics in confined channels, little research into unconfined channels
- Simple sine-generated channels were often used in experiments, despite being less common than skewed channels in nature
- The effect of skewness on wide channels ($B/h>10$) had not been explored

Goal

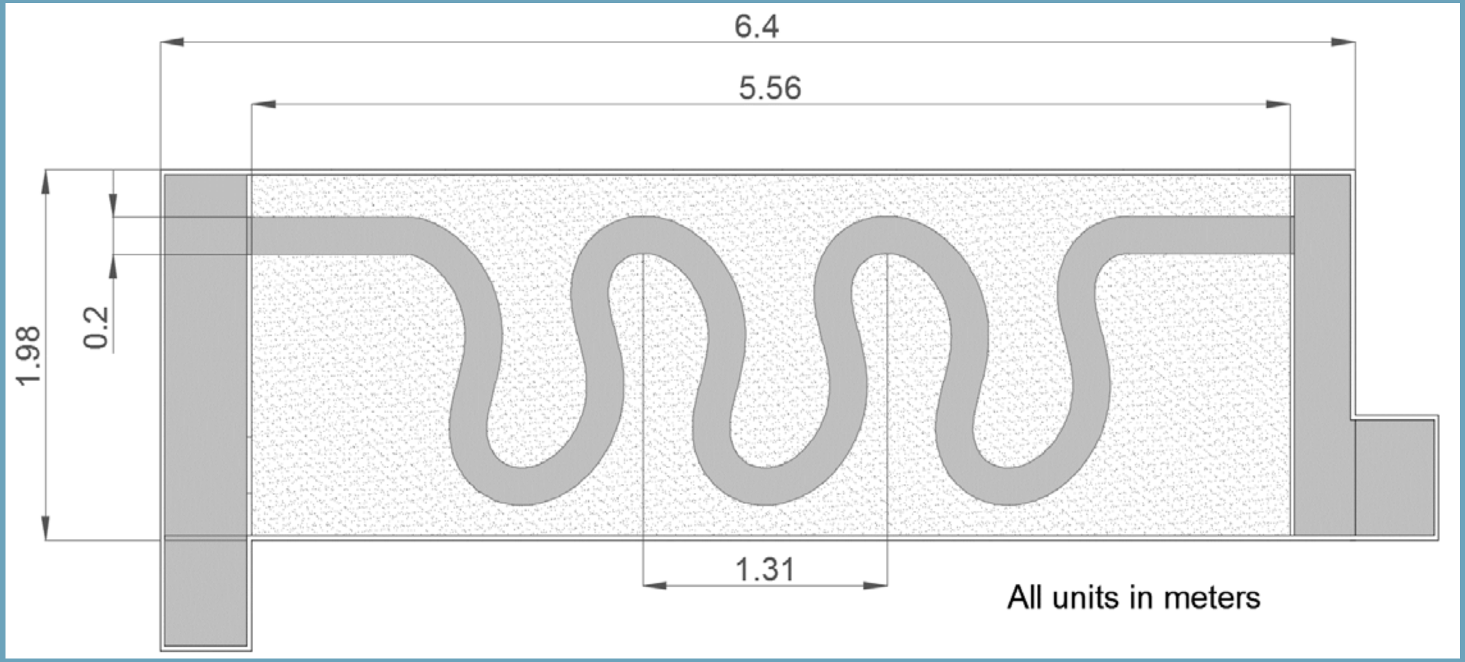
- Determine the effect bend orientation (skewness) has on the development of bedforms and the planform migration in a wide, unconfined alluvial channel

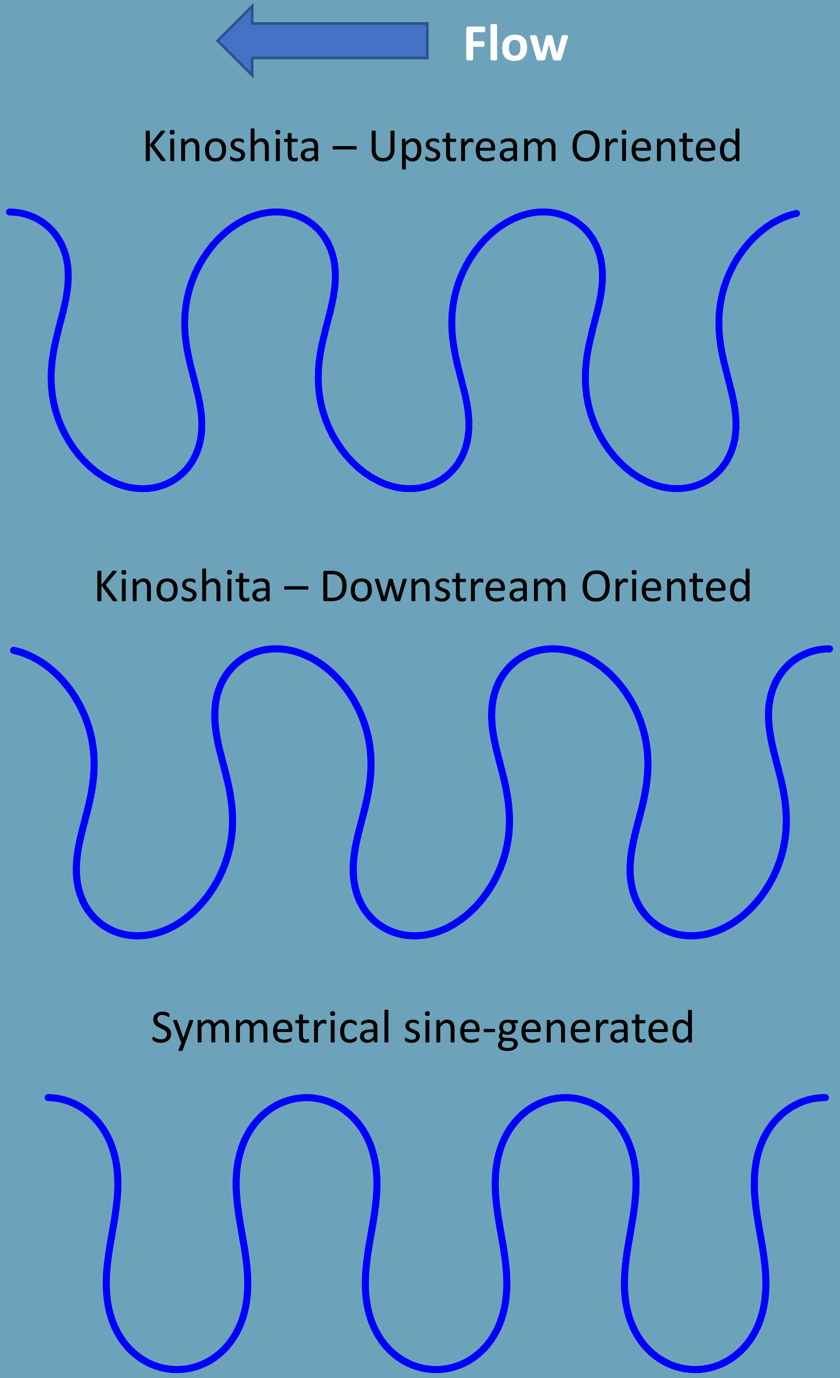
Applicability to Natural Channel Design and Resiliency

- Rivers naturally dissipate energy through many means – understanding these mechanics and applying them to channel designs can lead to better, less invasive stabilization practices

Experimental Setup

- Sediment was a unimodal medium sand with D_{50} = 0.8mm
- Sediment was collected at the outlet using a fine-mesh basket
- Water surface elevations were measured at each apex
- Flow data was collected using an ultrasonic flow meter





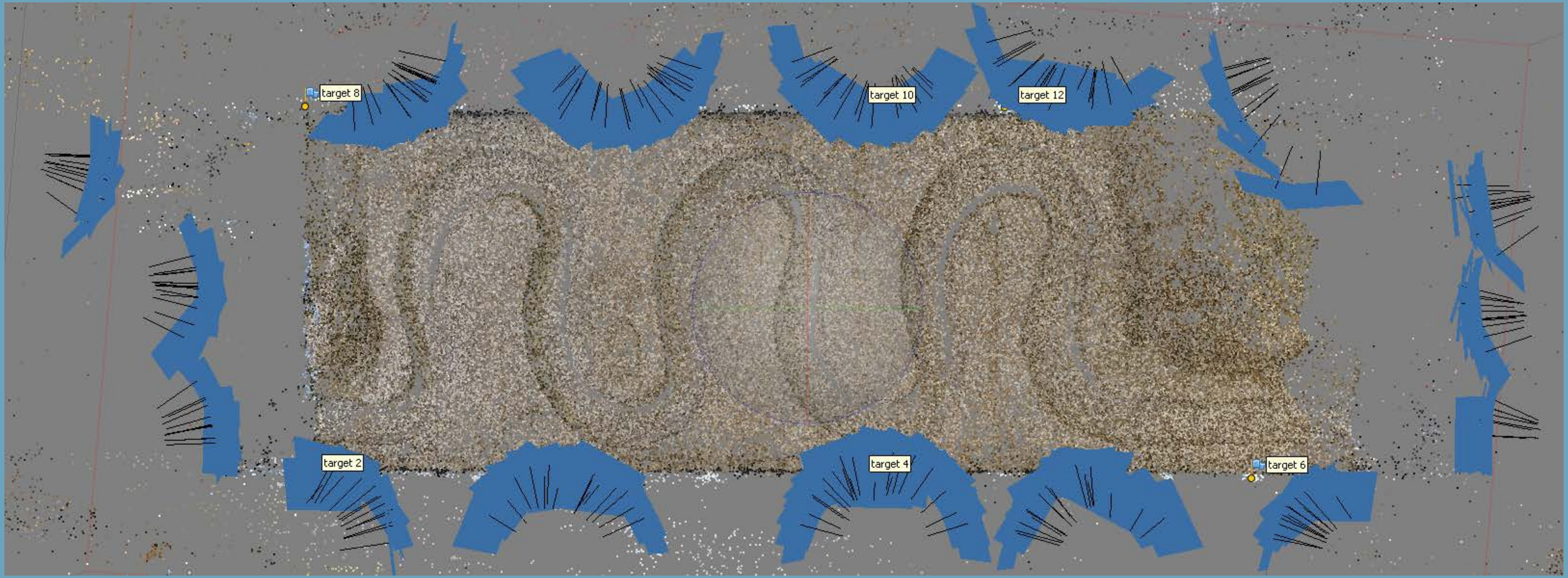
Experimental Conditions

- Each experiment was run for 2 hours with 10 minute time-steps
- The bed was saturated prior to the start of the experiments
- Flow was gradually increased and decreased at the beginning and end of each time-step, respectively, to minimize starting and stopping effects
- Slope was controlled to inlet and outlet weirs

Run	Channel Shape	Average Flow Rate (L/s)	Average Slope	Y/Y_{cr}	Re	Re_*	Fr	B (cm)	h_{av} (cm)	B/h	Sinuosity
1	Kinoshita – Upstream skewed	0.500	1/115	2.45	11200	54	0.365	20	2.06	9.7	2.6
2	Kinoshita – Downstream skewed	0.499	1/115	2.03	9792	49	0.339	20	1.98	10.1	2.6
3	Sinuous, not skewed	0.494	1/115	1.88	9467	48	0.326	20	1.98	10.1	2.7

Structure-from-Motion Photogrammetry

- Method was adapted from Morgan, Brogan and Nelson (2017)
- About 200 photos were necessary to achieve the recommended level of overlap
- Produced Digital Elevation Models (DEMs) with a resolution of about 1.25mm/pixel



Results

Initial Channel

Final Channel

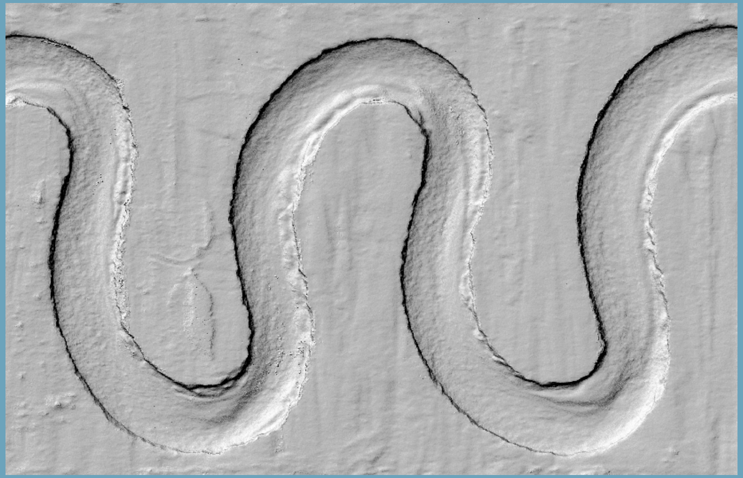
Time Lapse of First Time-Step

Flow

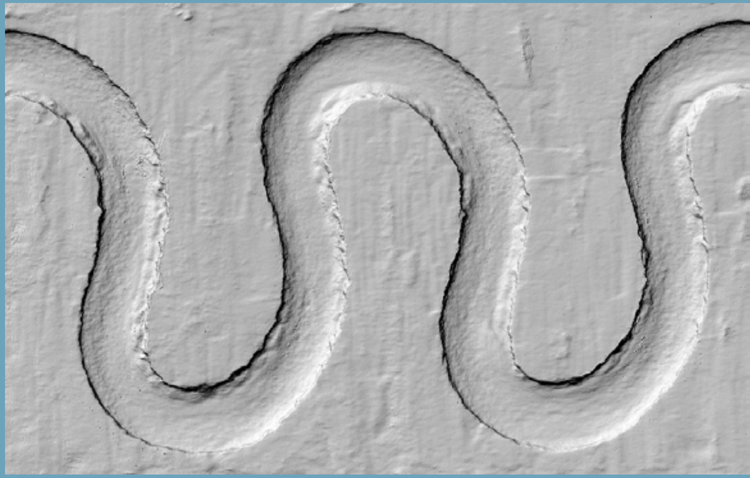
Results – DEM

- DEMs were exported from Agisoft Photoscan and analyzed in ArcGIS
- Point bars occurred upstream of the apex in the upstream-oriented channel
- Downstream-oriented channel had less-developed point bars positioned downstream of the apex

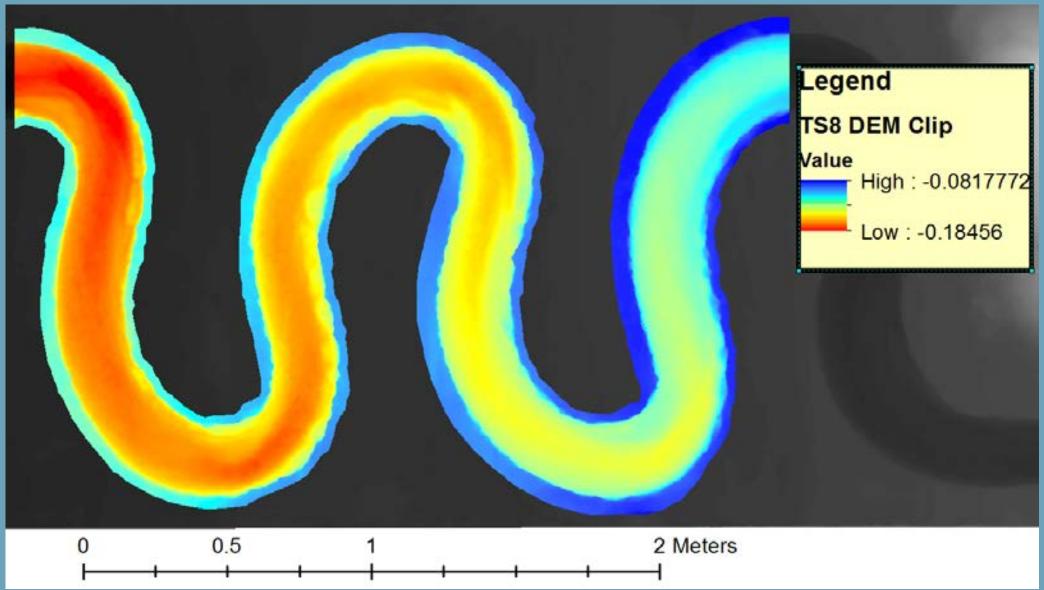
Upstream-Oriented



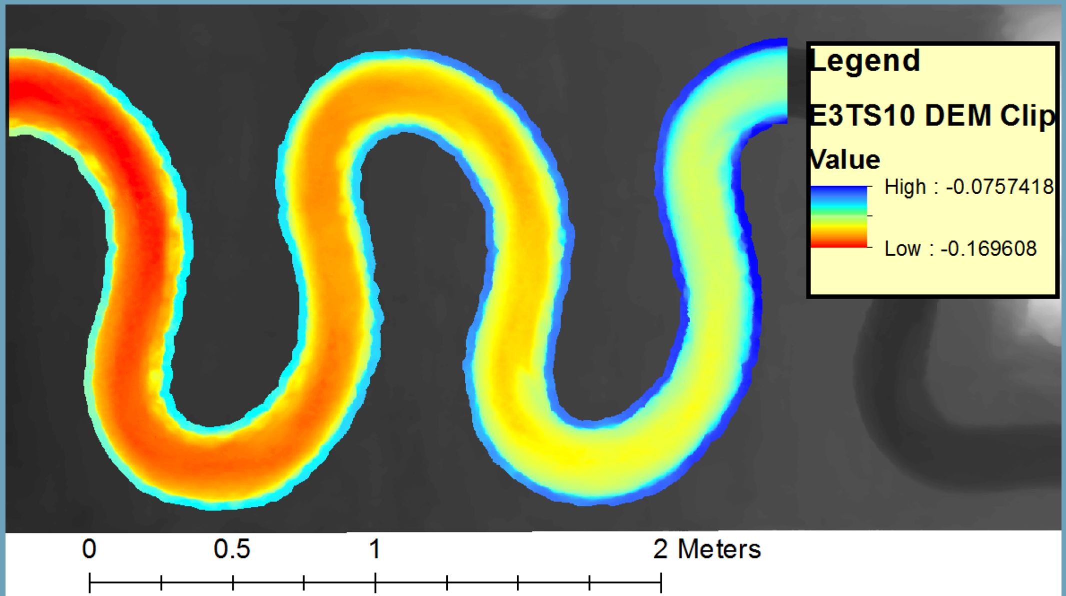
Downstream-Oriented



Upstream-Oriented (Run 1)



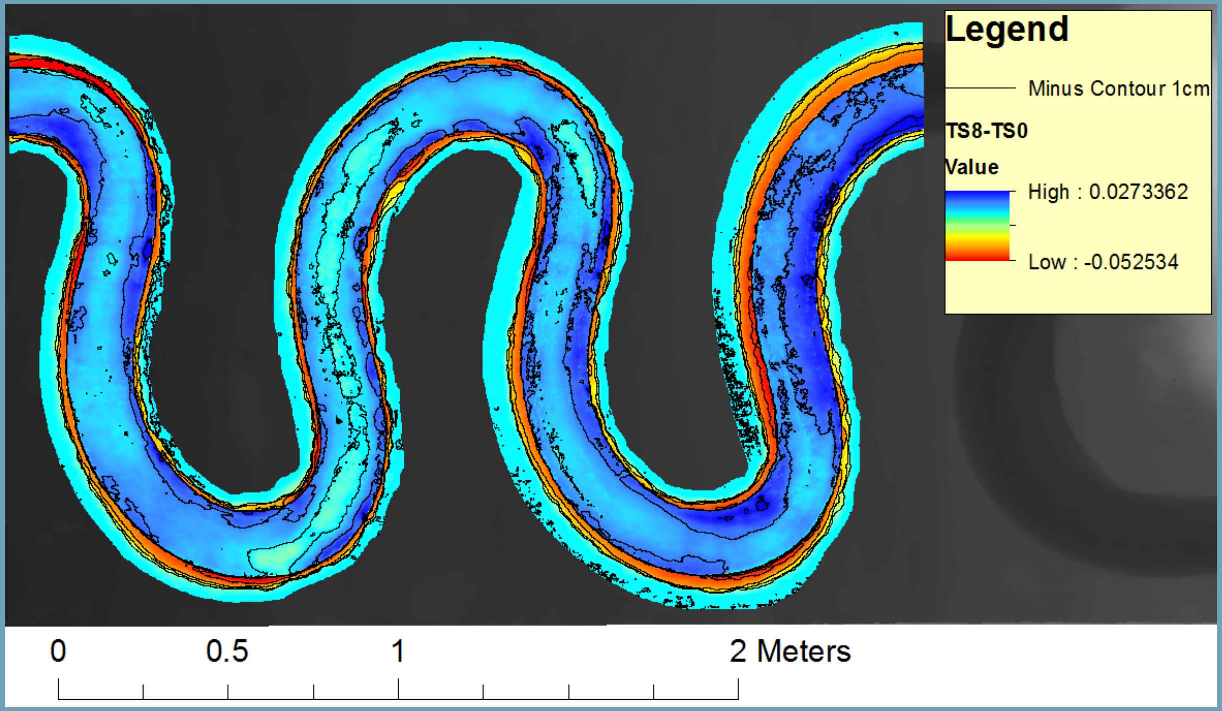
Downstream-Oriented (Run 2)



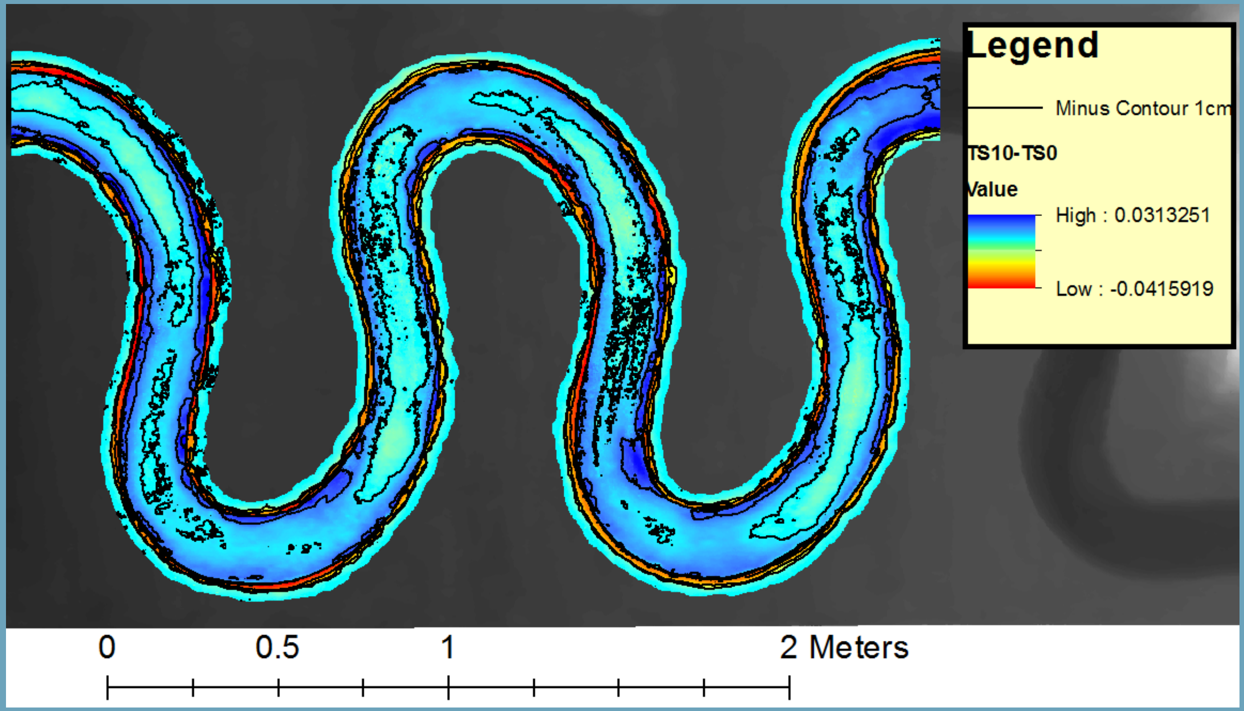
Results – Channel Elevation Difference

- Area of minimum channel adjustment in the upstream-oriented channel occurred at the upstream end of the point bars
- Downstream-orientation showed the most consistent, deepest scour areas in each meander

Upstream-Oriented



Downstream-Oriented

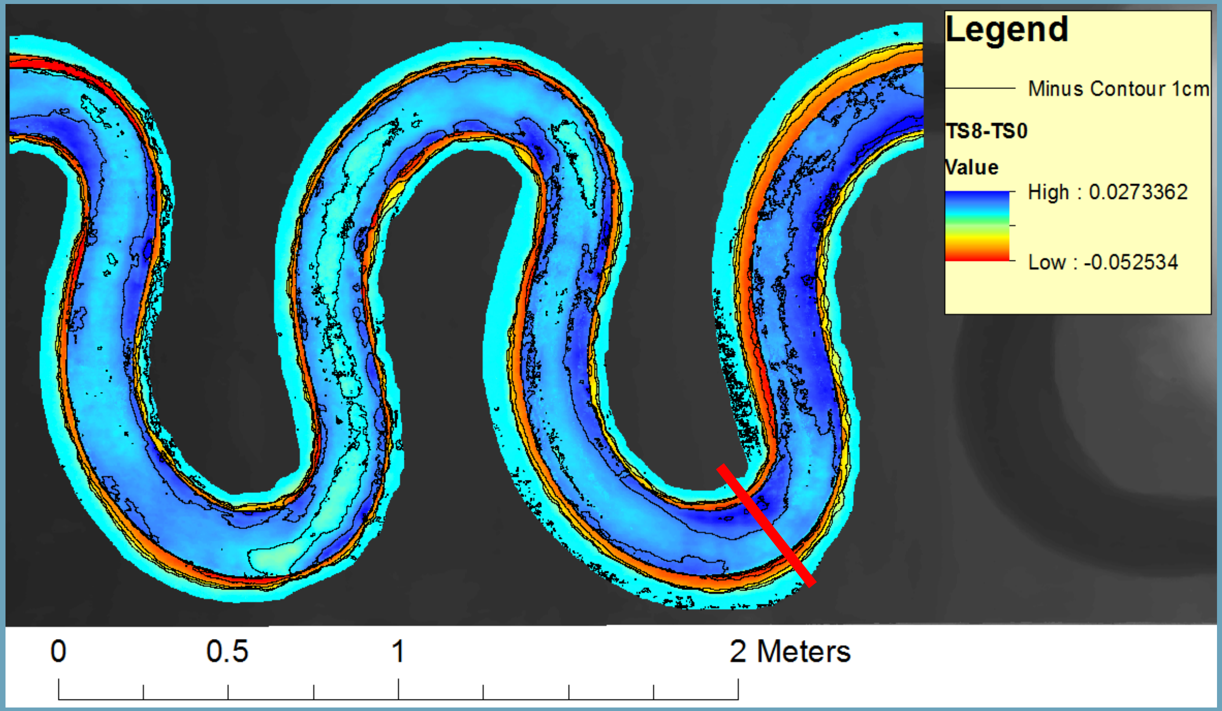


Flow

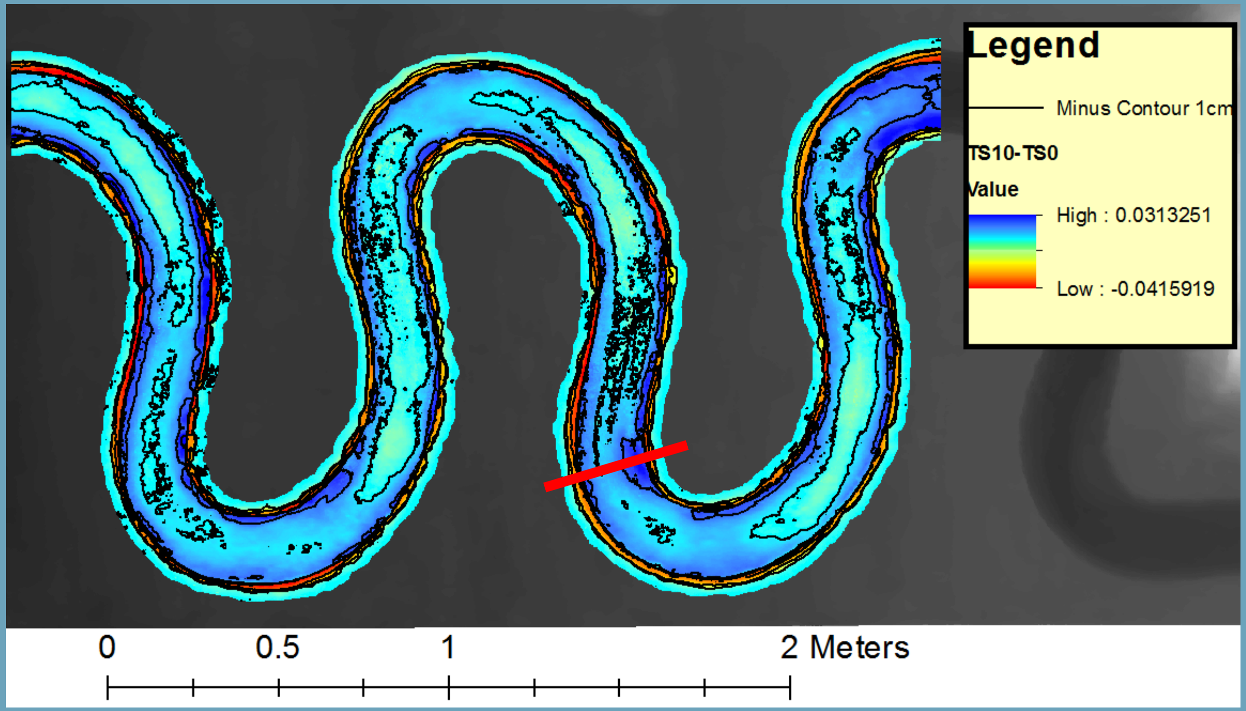
Results – Channel Elevation Difference

- Area of minimum channel adjustment in the upstream-oriented channel occurred at the upstream end of the point bars
- Downstream-orientation showed the most consistent, deepest scour areas

Upstream-Oriented (Run 1)



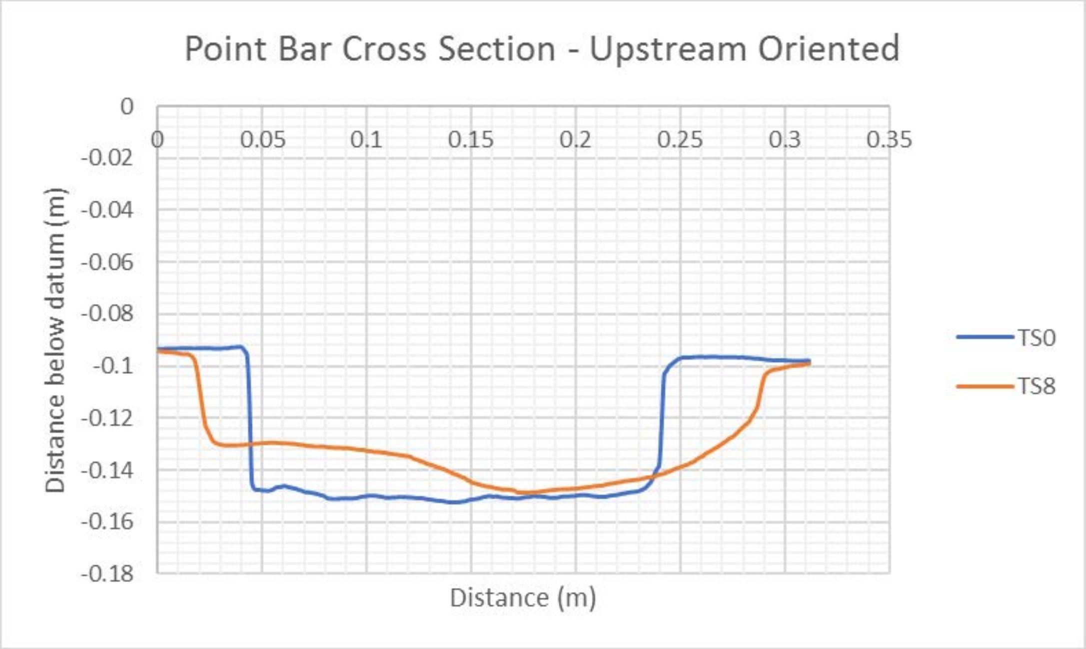
Downstream-Oriented (Run 2)

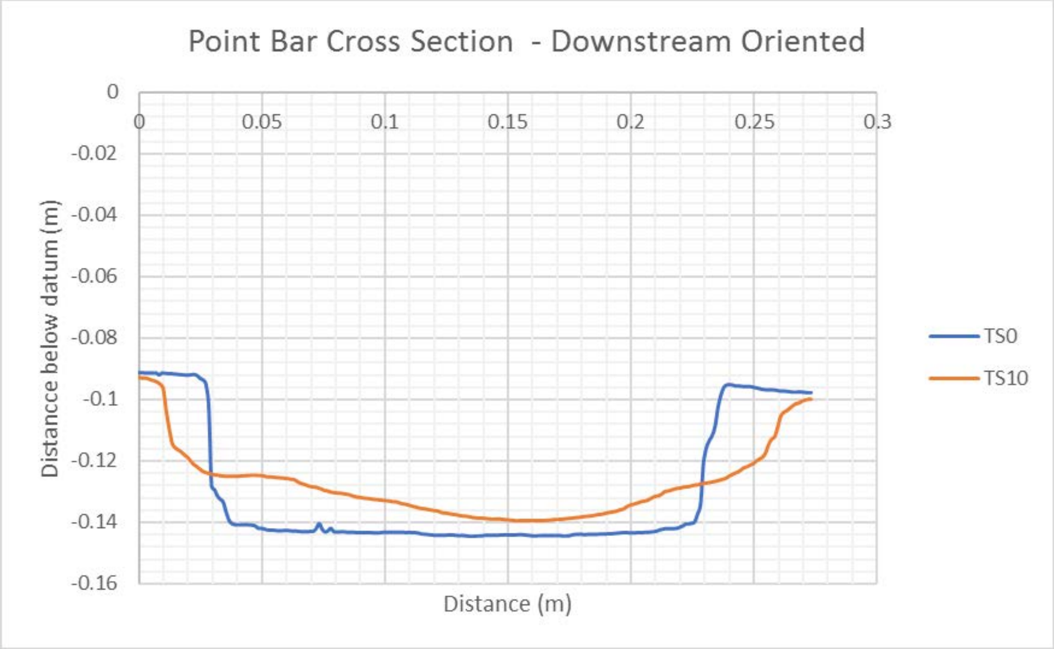


Flow

Results – Point Bar Cross Sections

- Bank slumping provided significant amounts of sediment to be deposited in the channel
- More distinct thalweg and point bar in the upstream-orientation

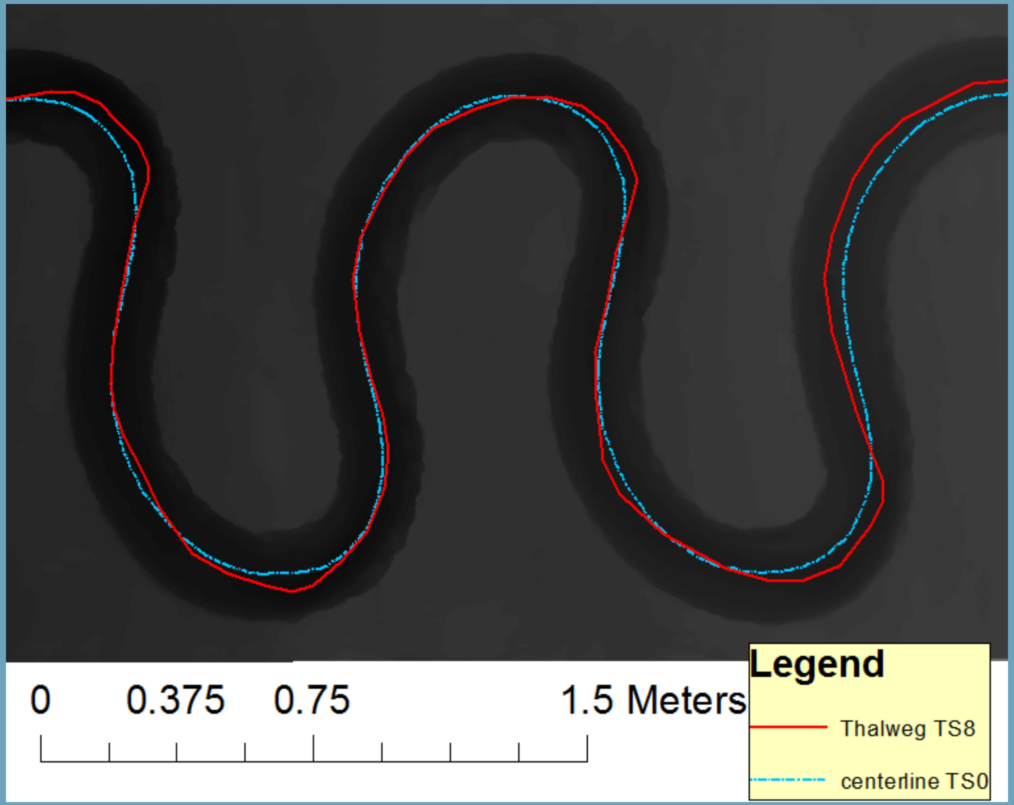




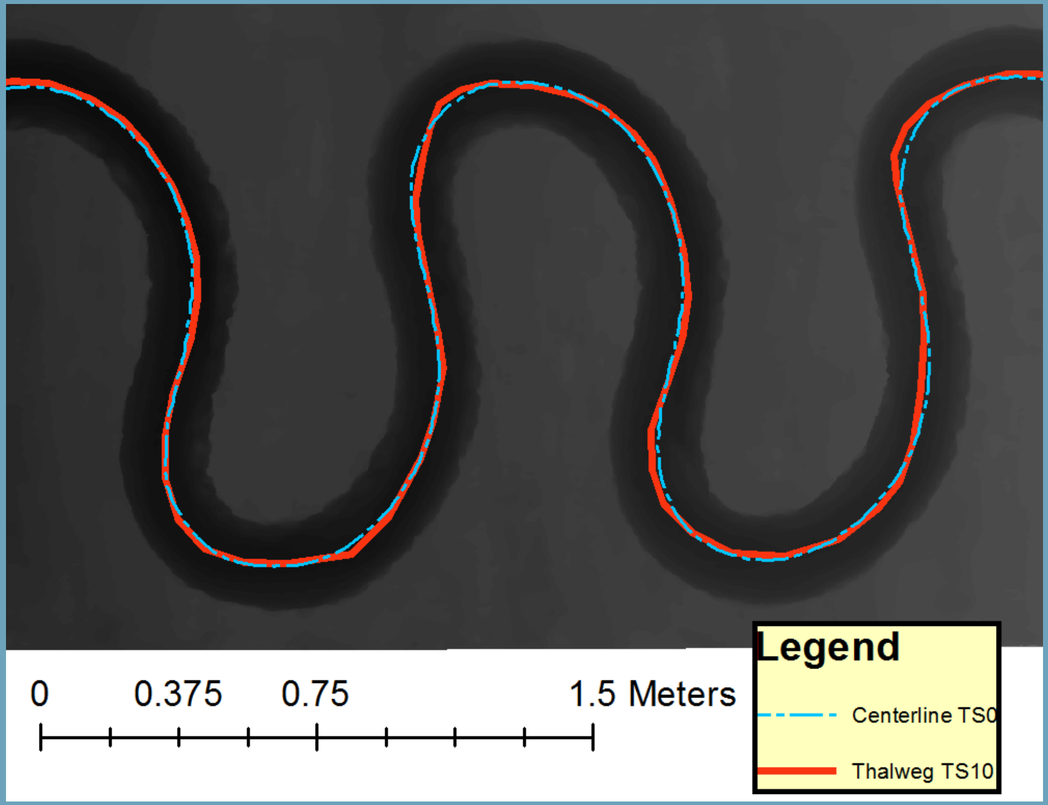
Results – Thalweg Adjustment

- The maximum deflection of the thalweg from the centreline occurred upstream of the apex in the upstream-orientation and downstream in the downstream-orientation

Upstream-Oriented

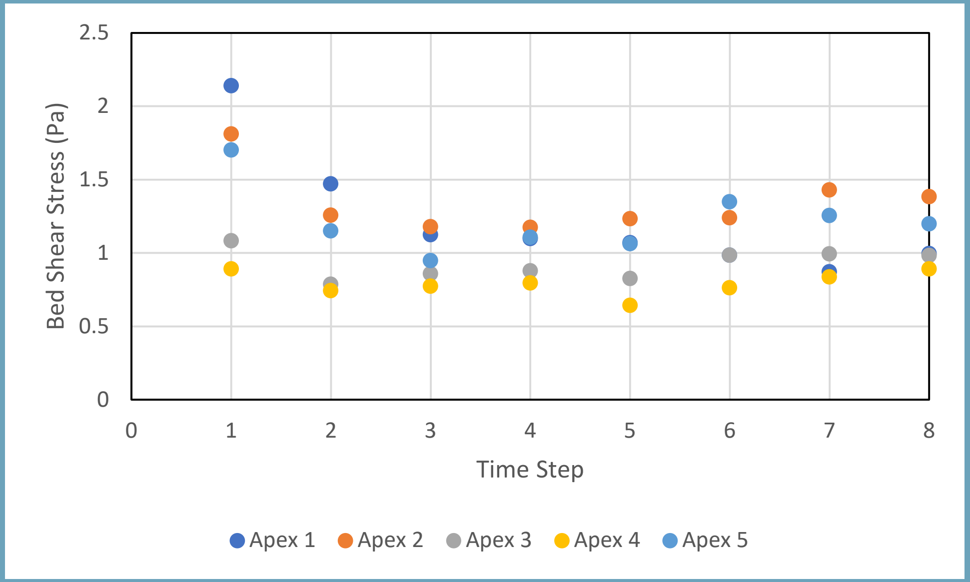


Downstream-Oriented

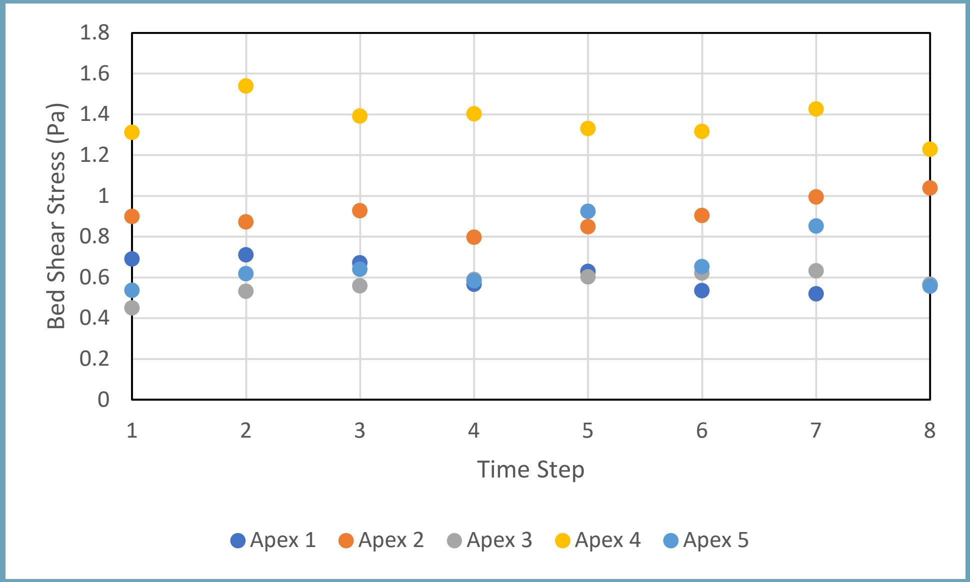


Bed Shear Stress Adjustment

- The upstream-oriented channel adjusted its geometry quickly to reduce bed shear stresses
- Selective transport of fine particles led to bed armouring and increased critical shear stress



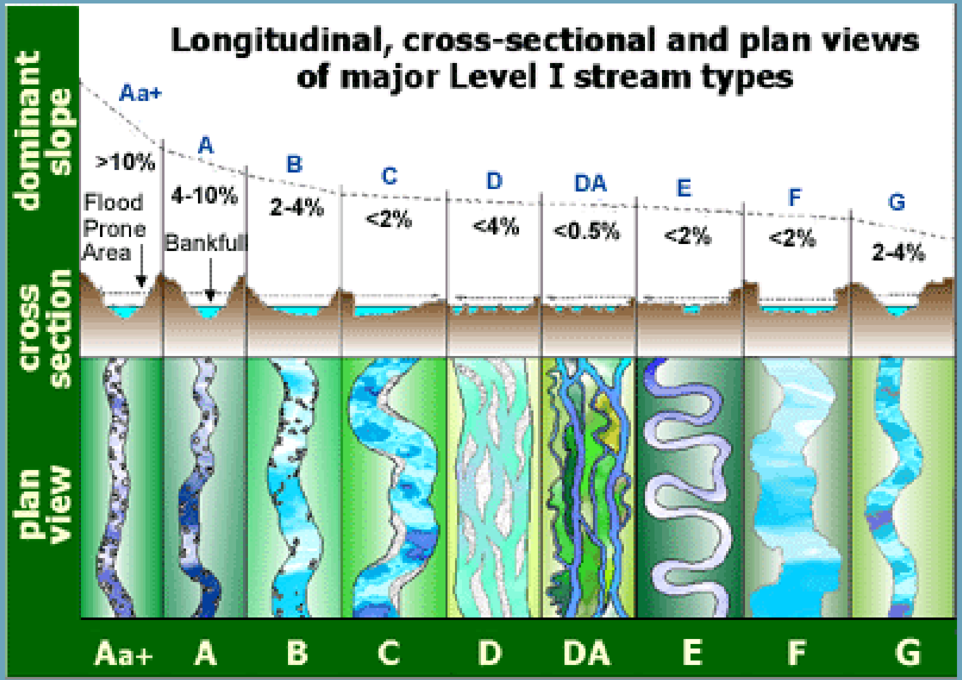
Upstream-oriented channel



Downstream-oriented channel

Implications for Channel Design

- Skewed channels have a higher flow resistance than non-skewed channels
  - Flow resistance dissipates energy and lowers energy grade line
- Erosion areas are concentrated downstream of the minimum radius of curvature
  - Less bank stabilization needed
- Downstream-skewed channels minimize bank erosion
  - Can prevent entrainment of contaminated bank sediment
- Can be a useful tool when re-aligning Rosgen C and E type channels



Rosgen Stream Classifications (from USEPA)

Conclusions & Recommendations

- Bed forms were most developed in the upstream-skewed orientation
- The downstream orientation had the most stable planform, and the symmetrical channel had the most dynamic planform
- Upstream-orientation adjusted to lower the bed shear stress

Recommendations:

- Collect additional water surface elevation data to correlate hydraulic conditions with morphological development
- Analyze morphological response under unsteady flow conditions

References

- Abad, J. D., & Garcia, M. H. (2009a). Experiments in a high-amplitude Kinoshita meandering channel: 1. Implications of bend orientation on mean and turbulent flow structure. *Water Resources Research*, *45*(2), W02401. https://doi.org/10.1029/2008WR007016
- Abad, J. D., & Garcia, M. H. (2009b). Experiments in a high-amplitude Kinoshita meandering channel: 2. Implications of bend orientation on bed morphodynamics. *Water Resources Research*, *45*(2), W02402. https://doi.org/10.1029/2008WR007017
- Binns, A. D., & da Silva, A. M. F. (2009). On the Quantification of the Bed Development Time of Alluvial Meandering Streams. *Journal of Hydraulic Engineering*, *135*(5), 350–360. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000025
- Blanckaert, K. (2011). Hydrodynamic processes in sharp meander bends and their morphological implications. *Journal of Geophysical Research: Earth Surface*, *116*(F1), F01003. https://doi.org/10.1029/2010JF001806
- Blanckaert, K., & Graf, W. H. (2004). Momentum Transport in Sharp Open-Channel Bends. *Journal of Hydraulic Engineering*, *130*(3). Retrieved from http://ascelibrary.org/doi/pdf/10.1061/(ASCE)0733-9429(2001)127:10(835)
- Google Earth 7.1.7.2606. 2017. 3°46'17.24"S 66°14'28.05"W, elevation 48m. Viewed on December 1, 2017.
- Lanzoni, S., & Seminara, G. (2006). On the nature of meander instability. *Journal of Geophysical Research: Earth Surface*, *111*(F4), F04006. https://doi.org/10.1029/2005JF000416
- Leopold, L. B., & Langbein, W. B. (1966). River Meanders. *Scientific American*, *214*(6), 60–73.
- Morgan, J. A., Brogan, D. J., & Nelson, P. A. (2017). Application of Structure-from-Motion photogrammetry in laboratory flumes. *Geomorphology*, *276*, 125–143. https://doi.org/10.1016/j.geomorph.2016.10.021
- Whiting, P. J., & Dietrich, W. E. (1993). Experimental studies of bed topography and flow patterns in large-amplitude meanders: 1. Observations. *Water Resources Research*, *29*(11), 3605–3614. https://doi.org/10.1029/93WR01755

Acknowledgements

- NSERC Discovery
- Christopher Sullivan
- Mostafa Elkurdy
- David Wright, Research Machinist, School of Engineering, University of Guelph
- Lafarge Canada Inc.

Questions?