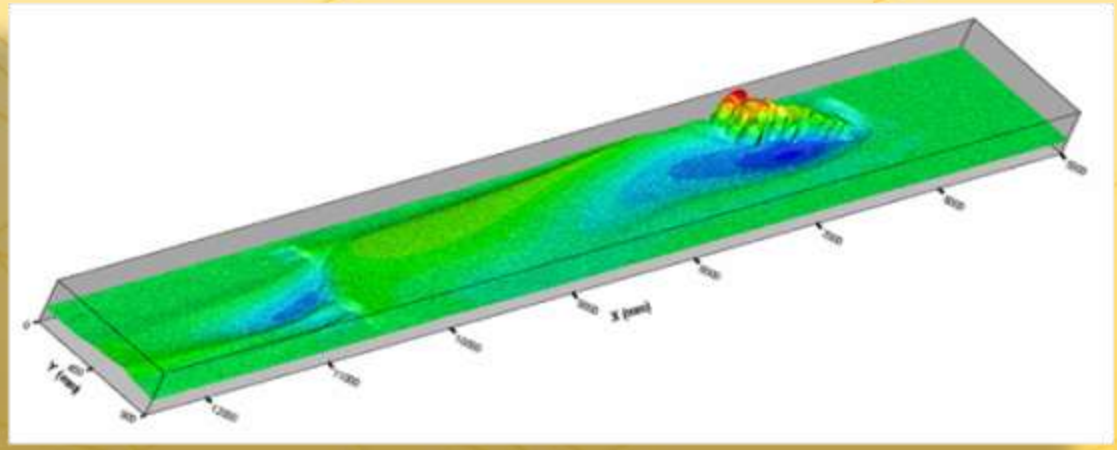
Turbulence, bed shear and scour measurements in the wake of small-scale stream restoration structures.



Craig Hill

St. Anthony Falls Laboratory

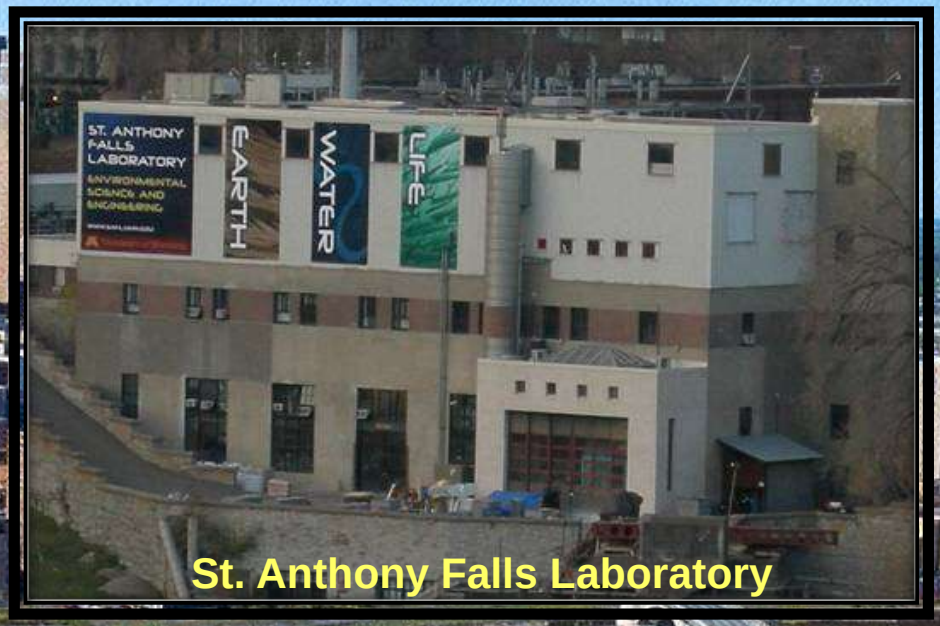
March 16-18, 2011

Nortek Technical Symposium, Newport, RI

UNIVERSITY OF MINNESOTA

St. Anthony Falls Laboratory

Minneapolis, Minnesota, USA



St. Anthony Falls

Mississippi River

St. Anthony Falls Laboratory

NCHRP Project No. 24-33:

(National Cooperative Highway Research Program)

Development of Design Methods for In-Stream Flow Control Structures

- Previous practitioner experience
- Field Observations
- Small scale physical models
- Large scale physical models
- Numerical modeling

- *Quantitative design guidelines for in-stream flow control structures*

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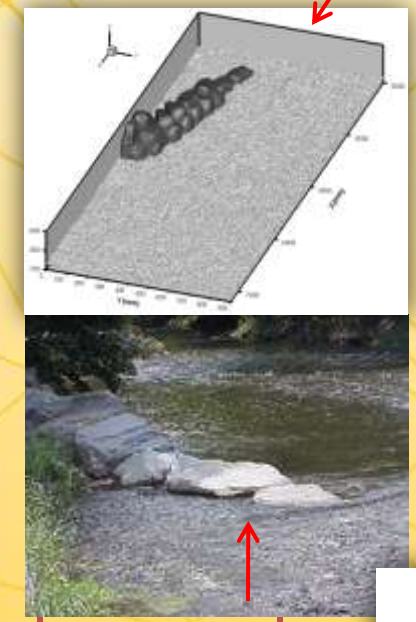
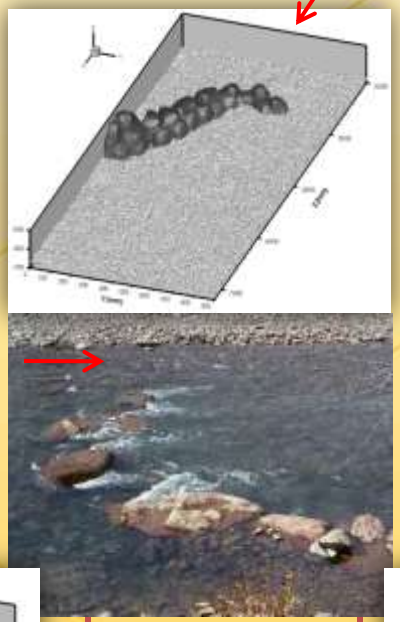
Small-scale stream restoration structures



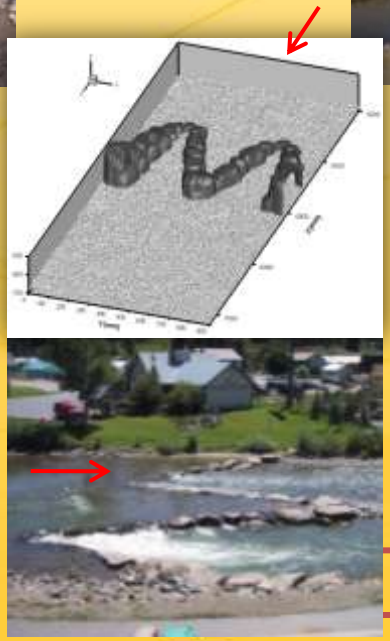
Rock Vane



J-hook Vane

Bendway Weir

Cross Vane



W-weir

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The SAFL/NCED Outdoor StreamLab

A Science-Based Approach to Stream Restoration

A unique field-scale facility for studying aquatic habitats under controlled laboratory conditions

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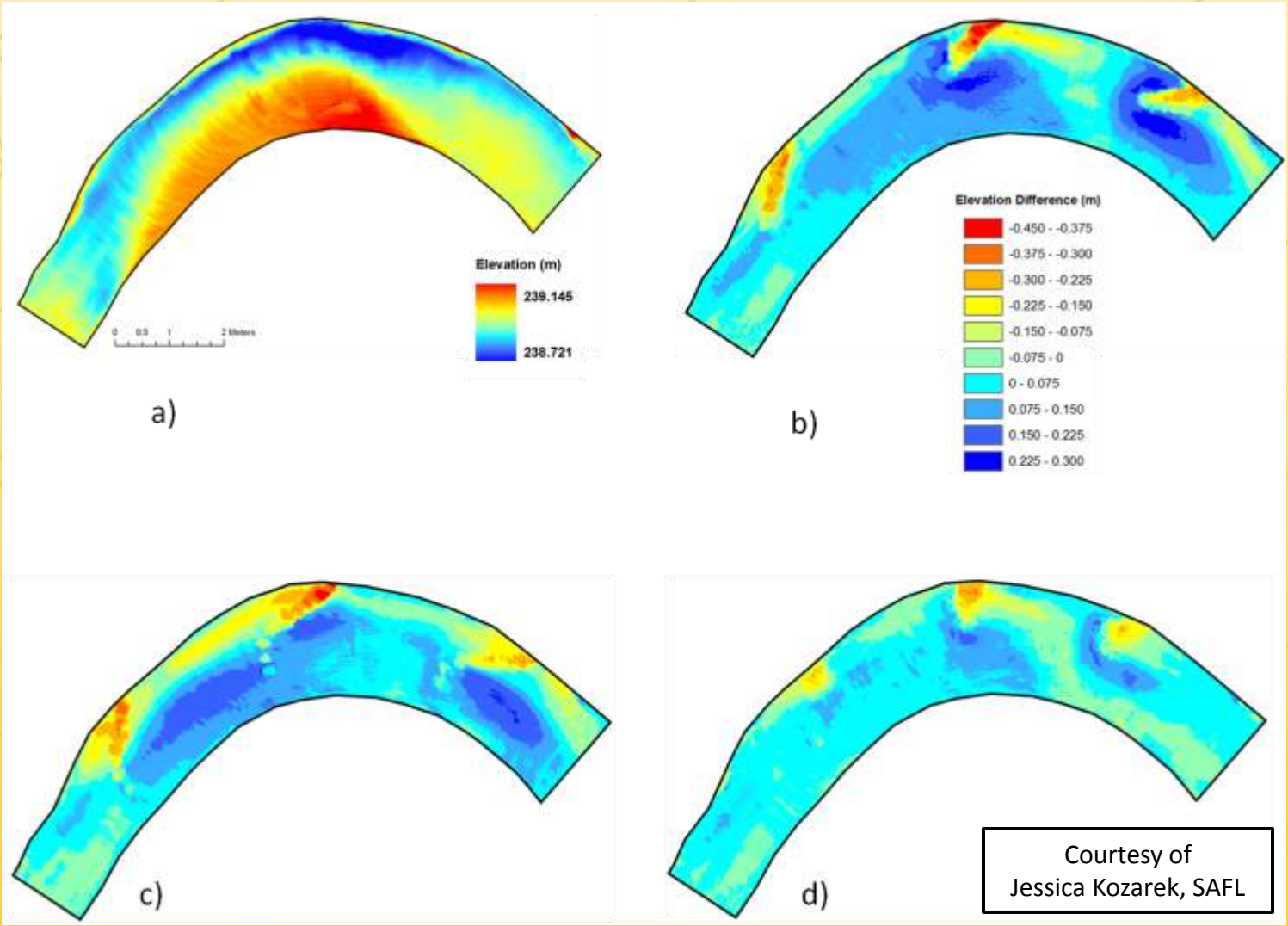
Turbulence induced scour from Outdoor StreamLab stream restoration structures



Courtesy of
Jessica Kozarek, SAFL

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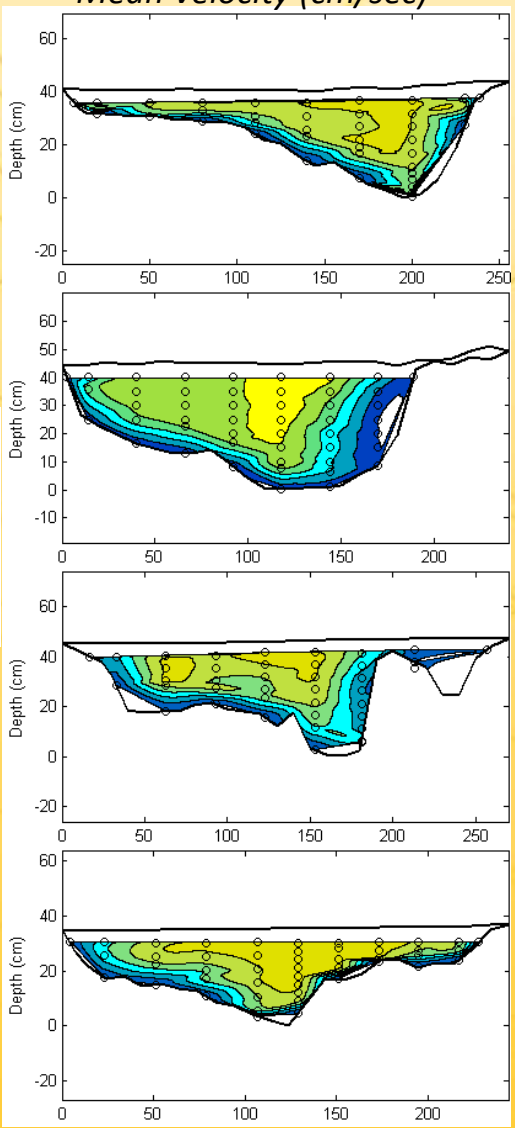
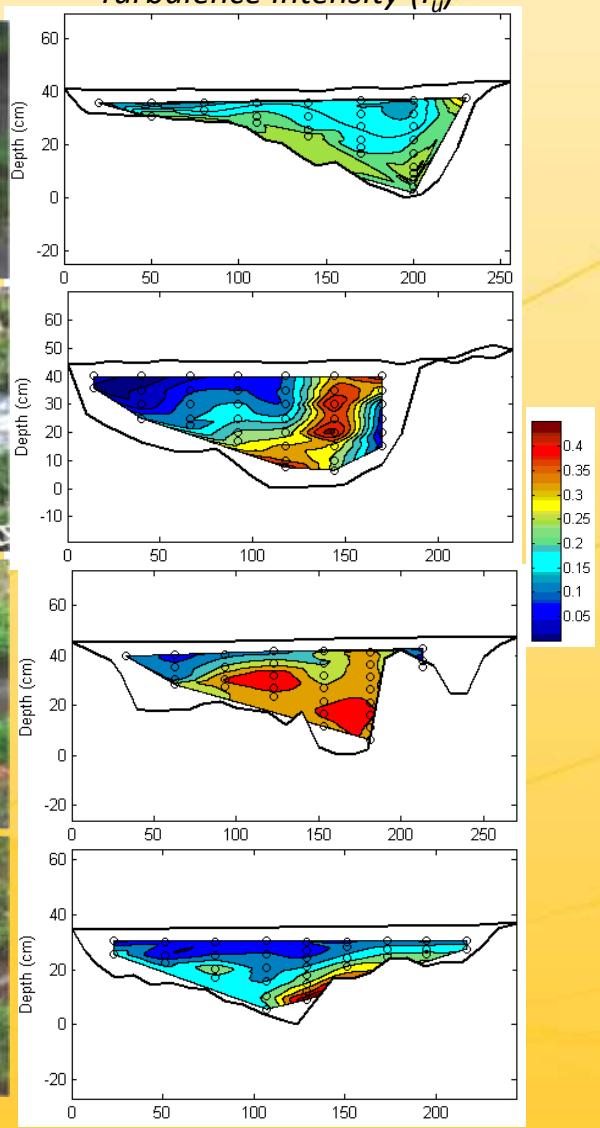
Mean flow and turbulence intensity

Mean Velocity (cm/sec)



Turbulence Intensity (I_u)



Courtesy of Jessica Kozarek, SAFL and Read Plott, Virginia Tech

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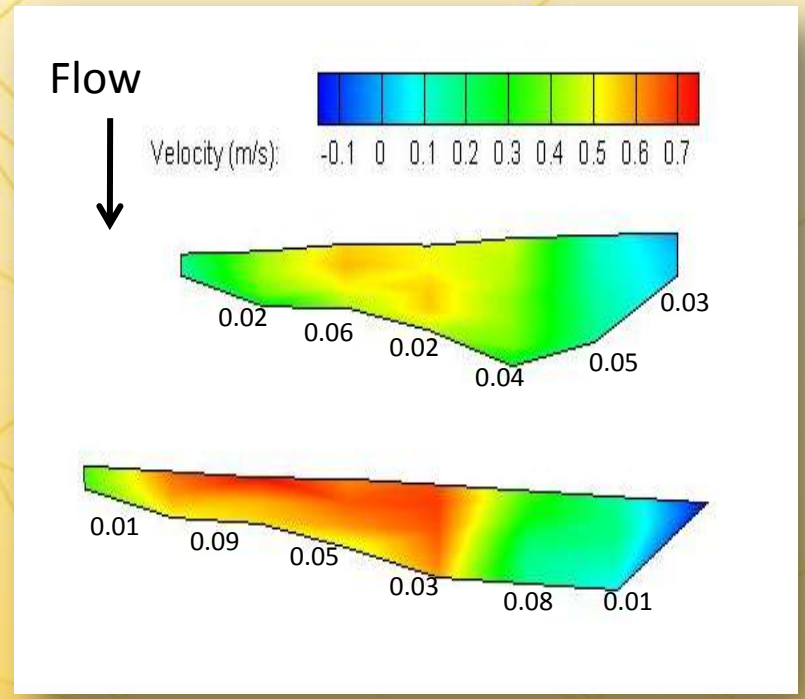
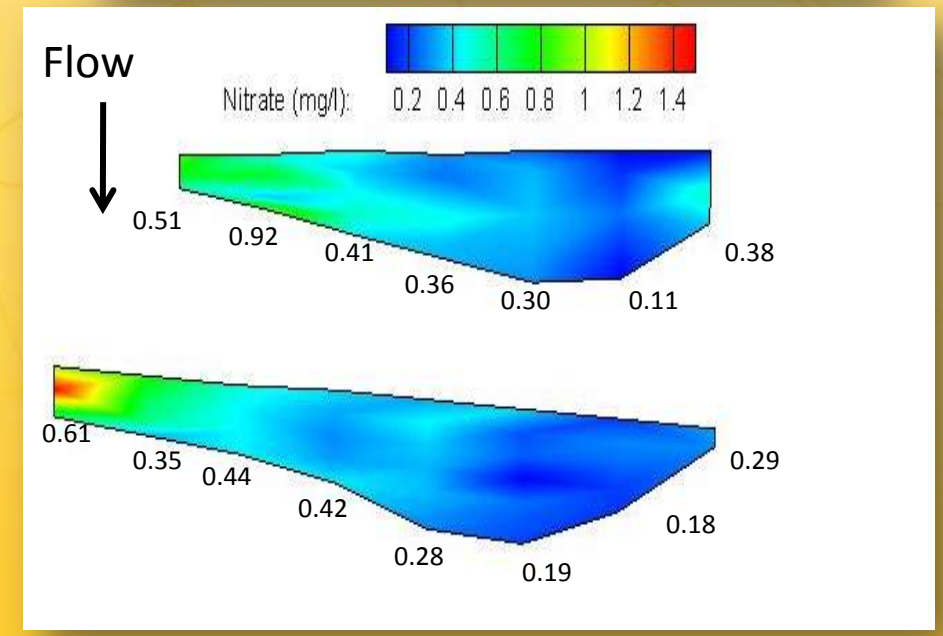
Correlating velocity measurements with Nitrate, Temperature, and Dissolved Oxygen





Courtesy of Kris Guentzel, SAFL

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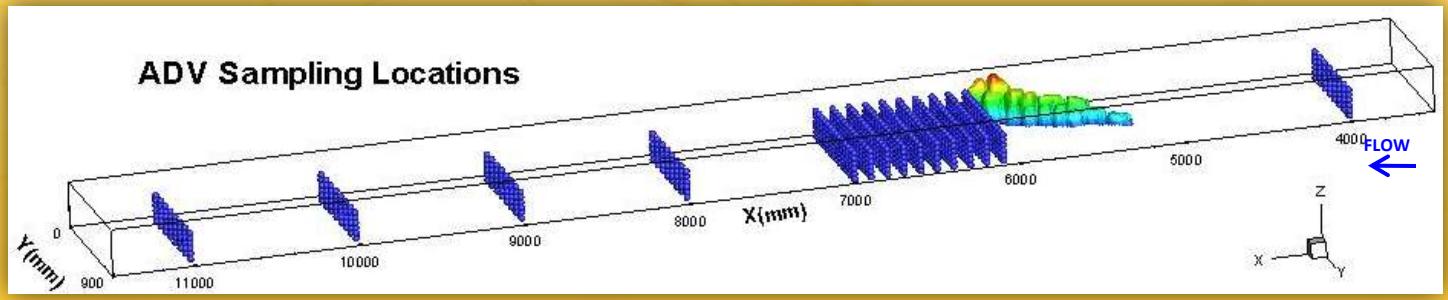
Small-scale experiments

- SAFL Tilting Bed Flume
  - 0.9m wide x 15m long
- Two phases
  - Phase 1: fixed bed (d_{50} = 6mm)
  - Phase 2: mobile bed (d_{50} = 1.8mm)
- Data Collection
  - high resolution topography
  - 3D velocity measurements (100Hz or 200Hz)
    - > 1000 measurement locations for each structure
  - "Time-lapse" bathymetry measurements
  - Water surface measurements
  - Discharge data
- Allows testing of numerous structures & arrangements

Data acquisition cart on the Tilting Bed Flume at SAFL.



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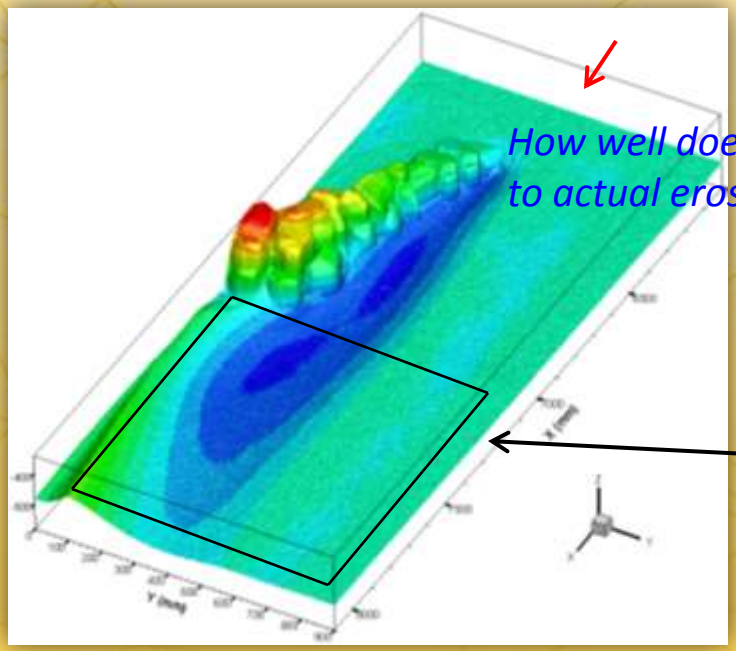
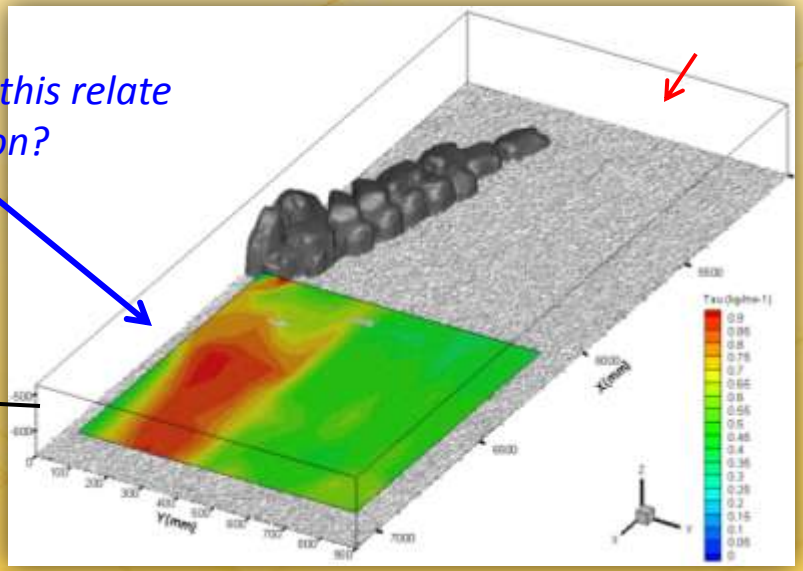
Estimating bed shear stresses

- Use velocity fluctuations for estimating bed shear stress values
- Turbulent Kinetic Energy (TKE) method vs. Reynold's Stress method.



How well does this relate to actual erosion?



TKE method

$$TKE = \frac{1}{2}\rho\left(u'^2 + v'^2 + w'^2\right)$$

$$\tau_b = C_1 \cdot TKE$$

where, C_1 = 0.19 (Biron 2004)

VS.

$$\tau_b = -\rho\overline{u'w'}$$

Reynold's Stress Method

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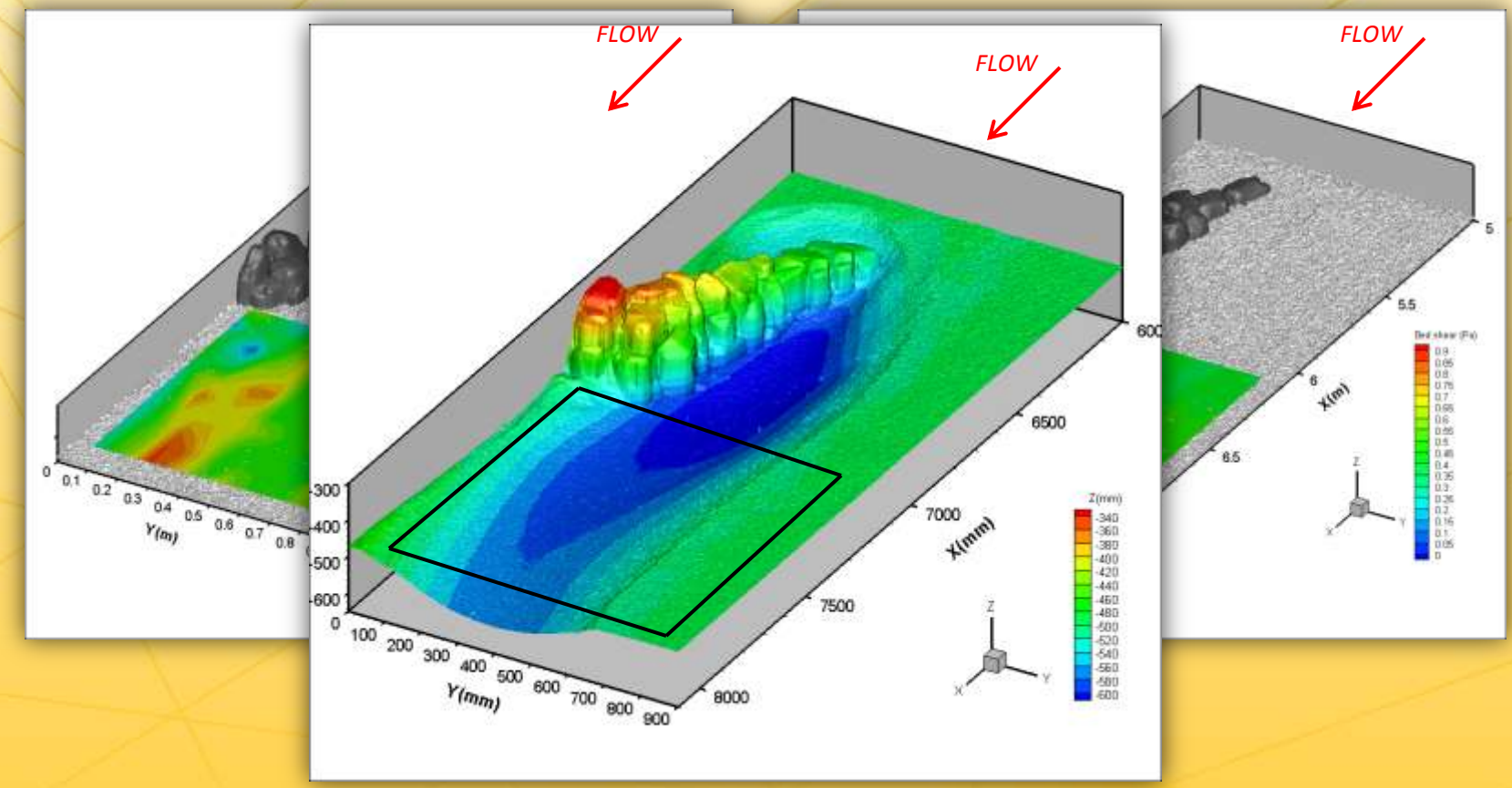
Rock Vane

Reynold's Stress Method

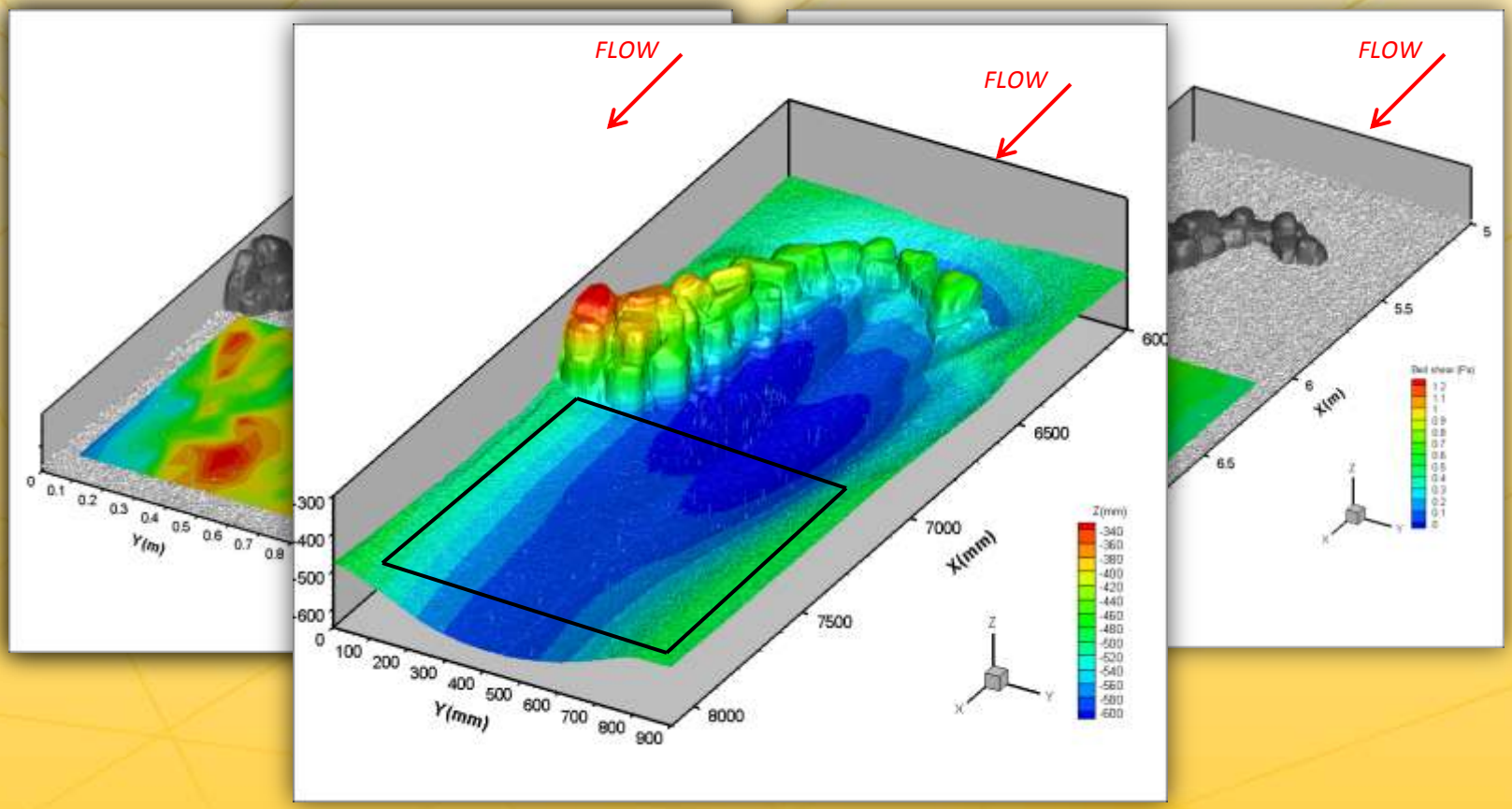
TKE method



J-hook Vane

Reynold's Stress Method

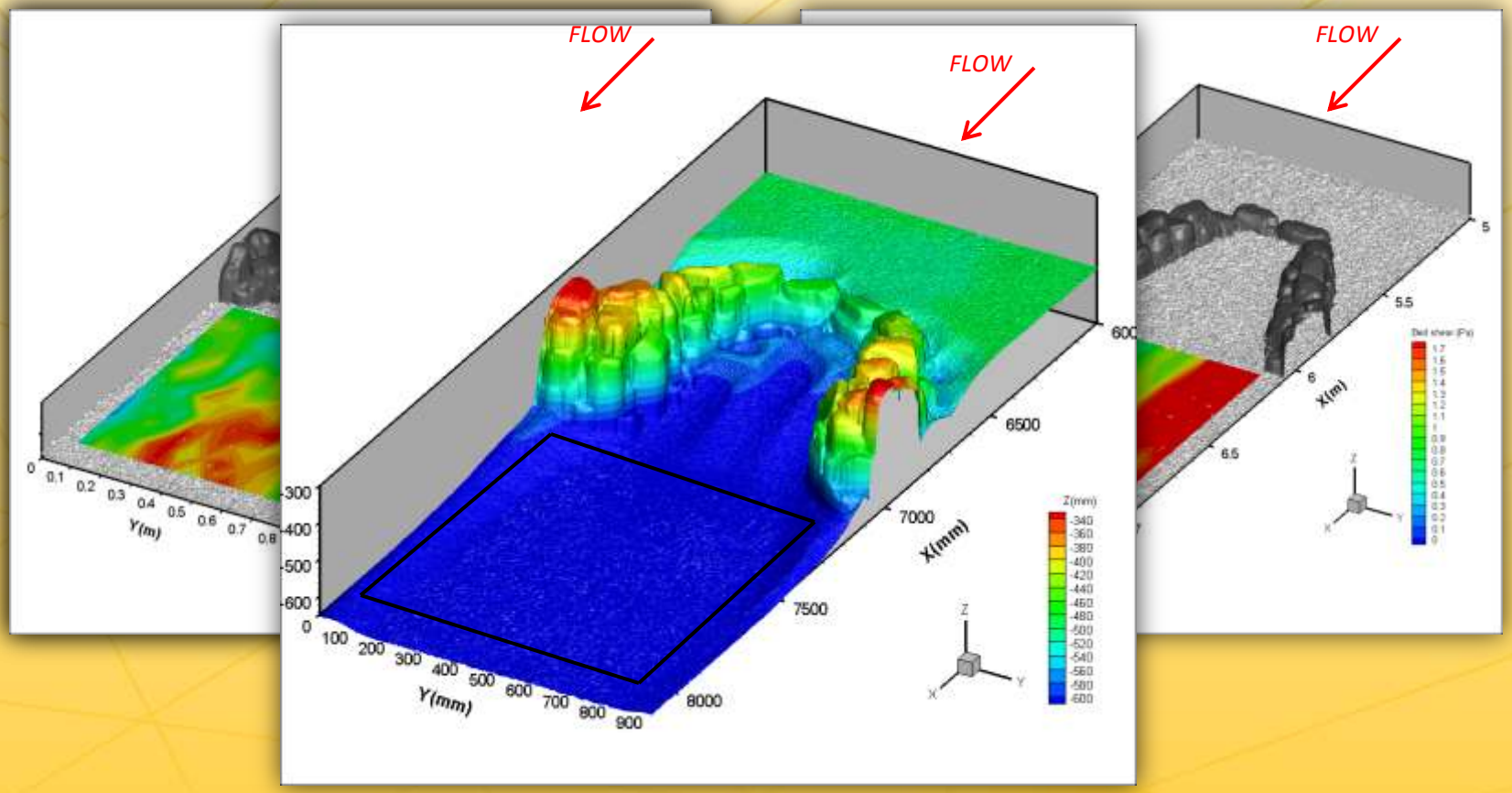
TKE method



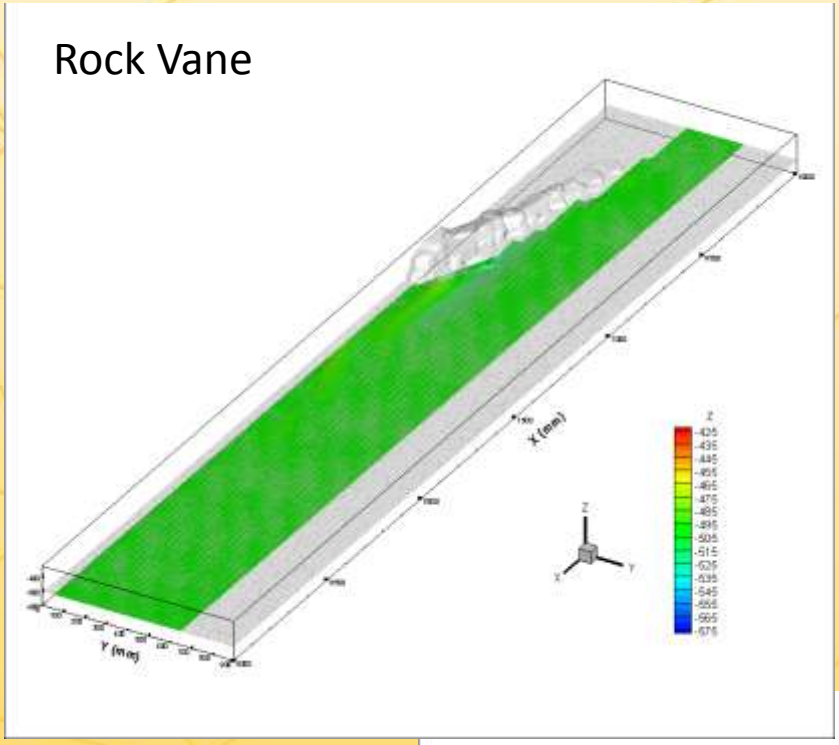
Cross Vane

Reynold's Stress Method

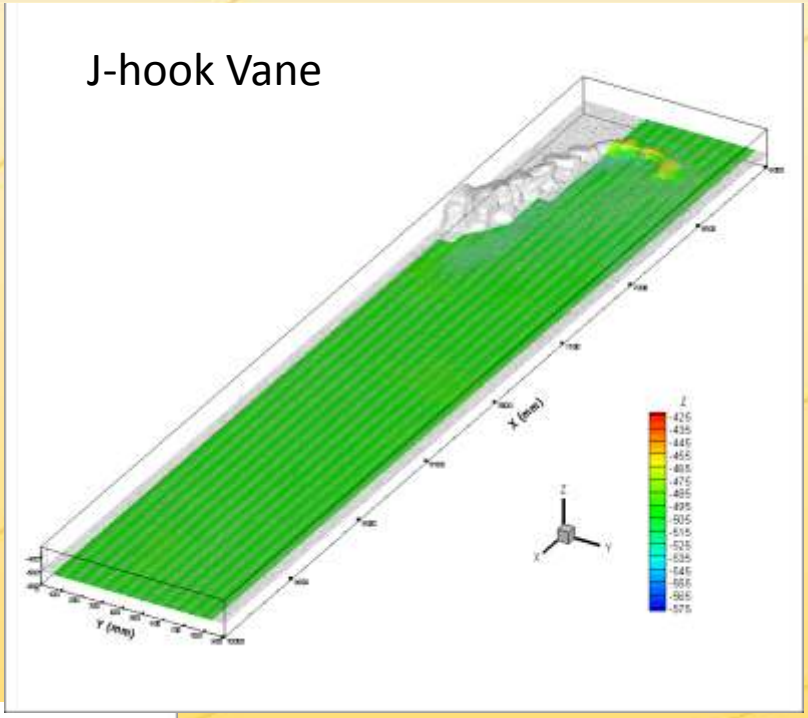
TKE method



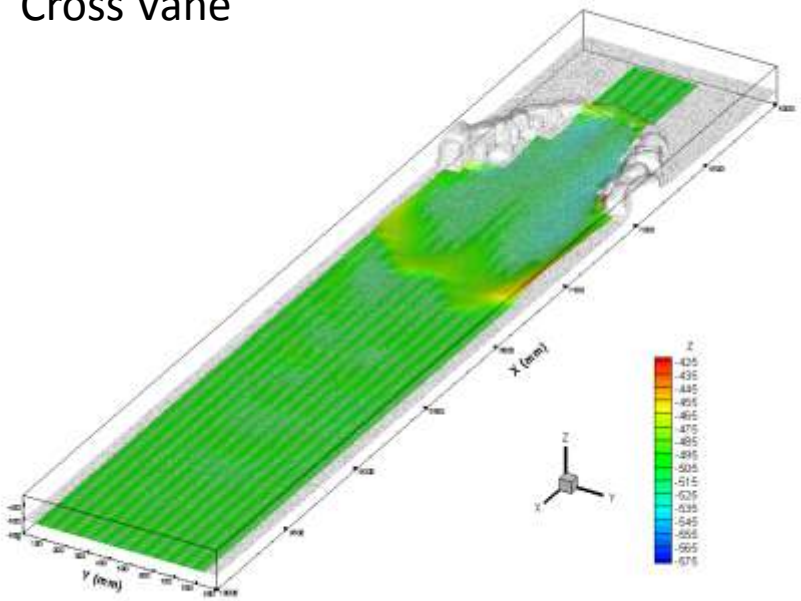
Rock Vane



J-hook Vane



Cross Vane



Animations of scour formation

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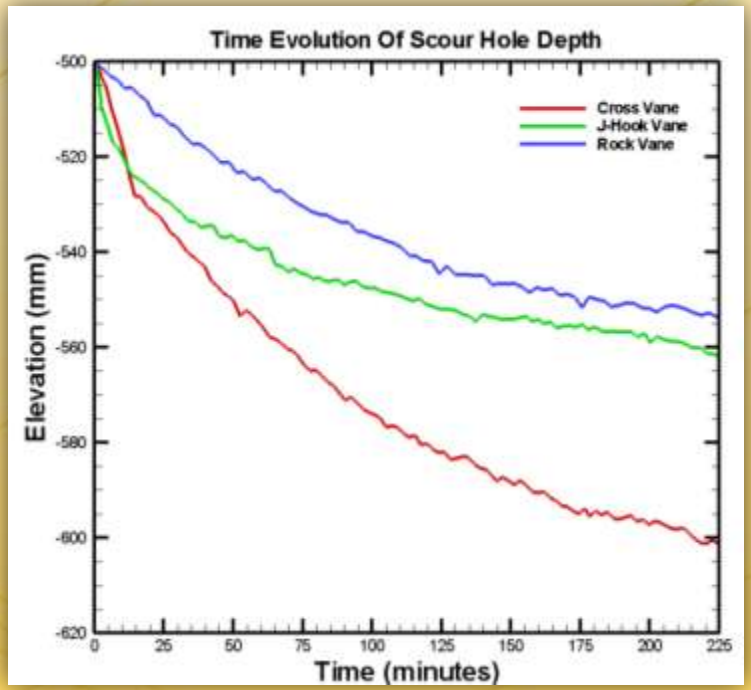
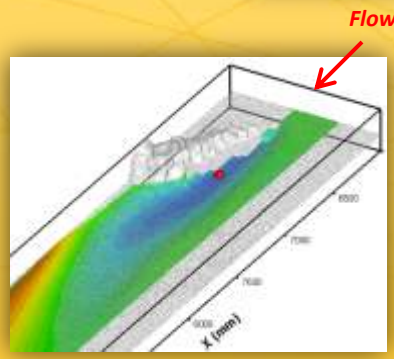
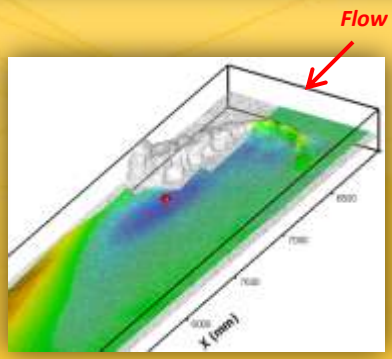
Time evolution of scour formation

- Cross vanes produce scour depths much greater than rock vane or J-hook vanes.
- Addition of "J" hook at the end of the vane arm shows added benefit for aquatic habitat.
- Rapid erosion and formation of scour hole indicate high risk for structure failure.

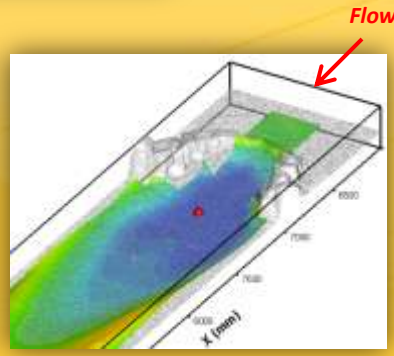




Rock Vane



J-hook Vane



Cross Vane

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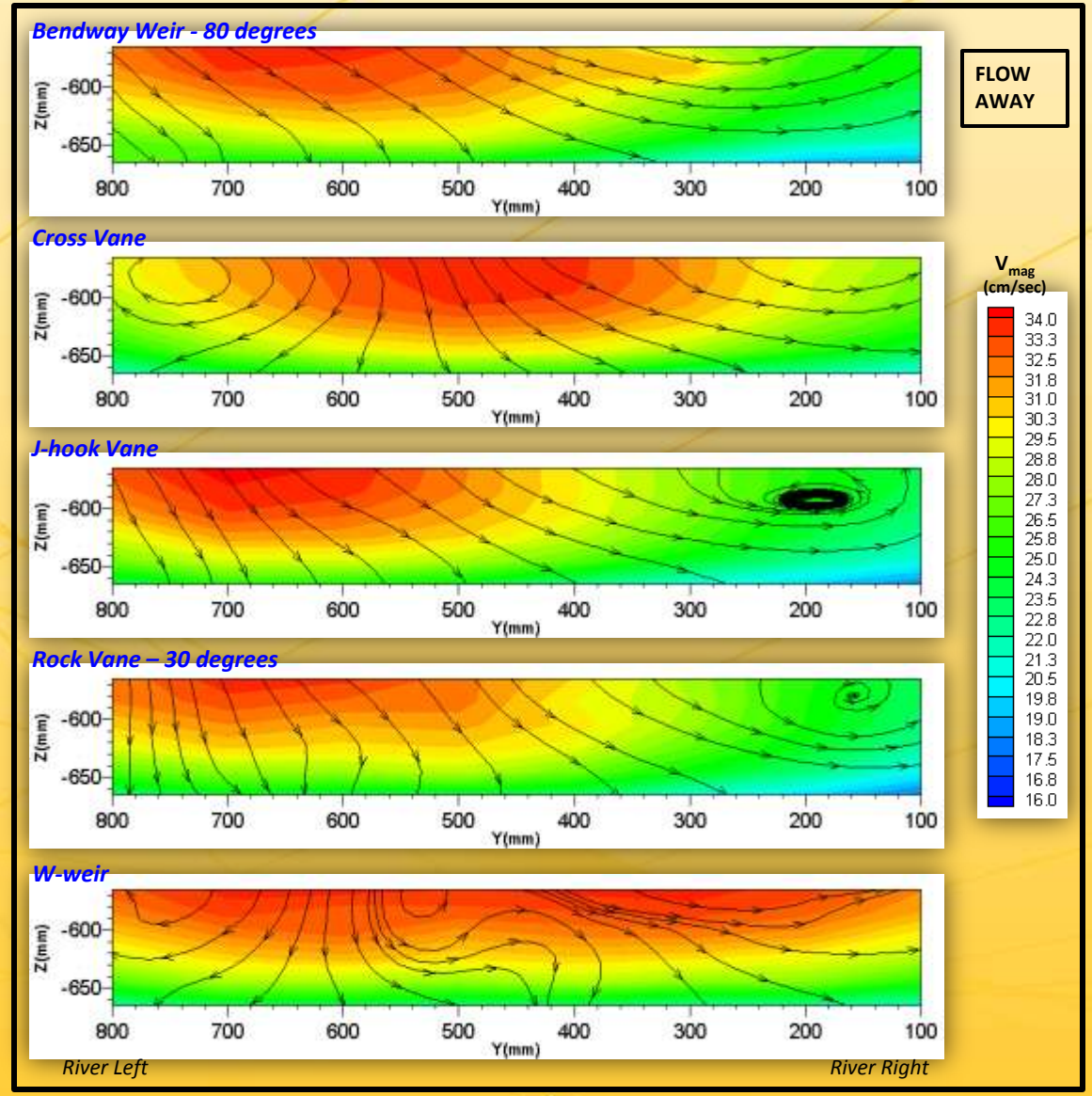
How far downstream do effects travel?

- Structures can have negative impacts on streambanks far downstream of their location.

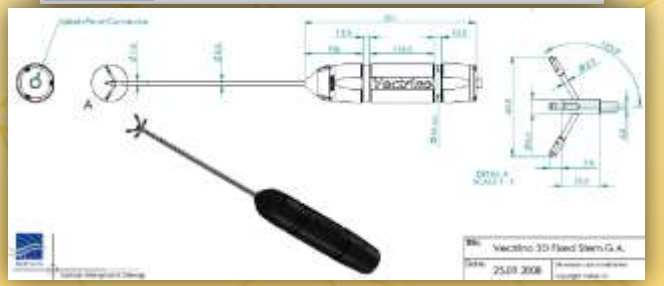
- Structure effects still exist 5 channel widths downstream of structure location in these flume studies.

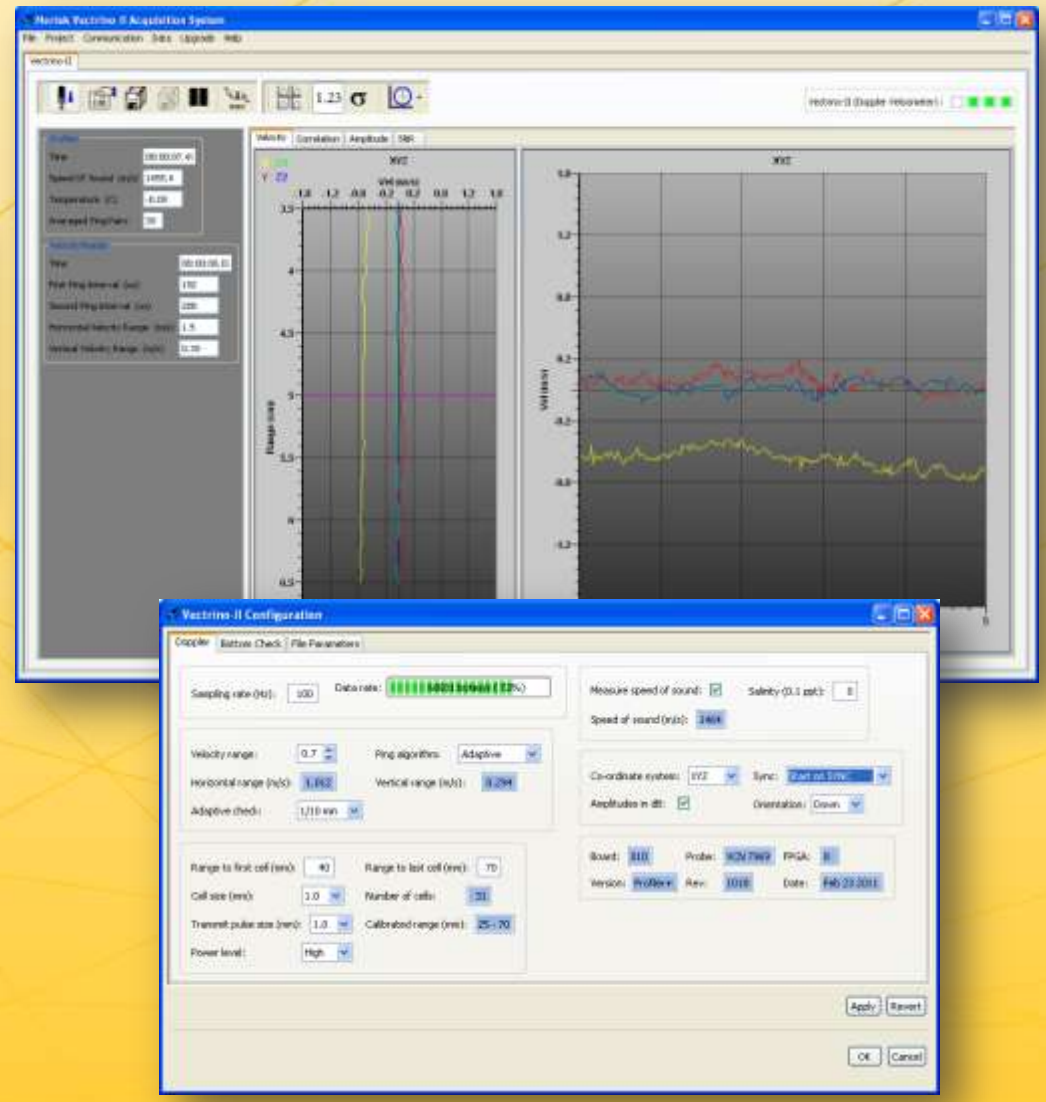
- Current work from Outdoor StreamLab suggests that riffles "reset" flow patterns.



Nortek Vectrino II Profiling Velocimeter

VECTRINO-II
PROFILING
VELOCIMETER





- *100 Hz maximum velocity sampling rate*
- *Simultaneous bottom tracking (10 Hz max)*
- *1-mm minimum cell size (recommended 30 cell max)*

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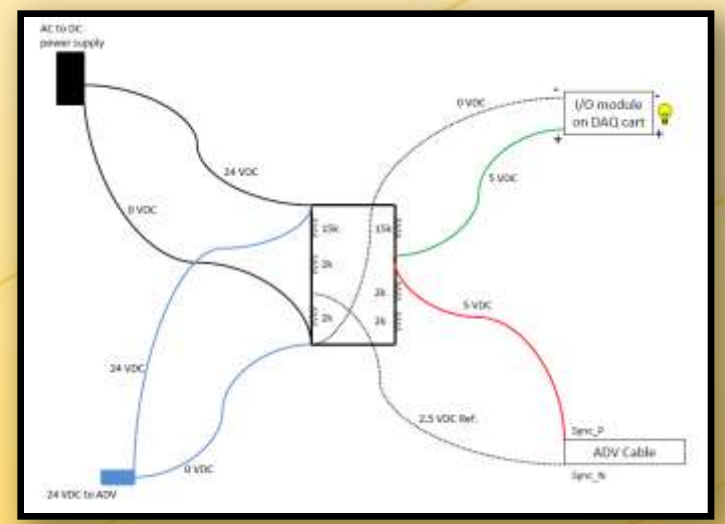
Nortek Vectrino II Profiling Velocimeter

SAFL Main Channel Data Acquisition Carriage with Vectrino II Velocimeter mount.



- *External sync pulse control allows continuous unattended data collection for long periods of time.*

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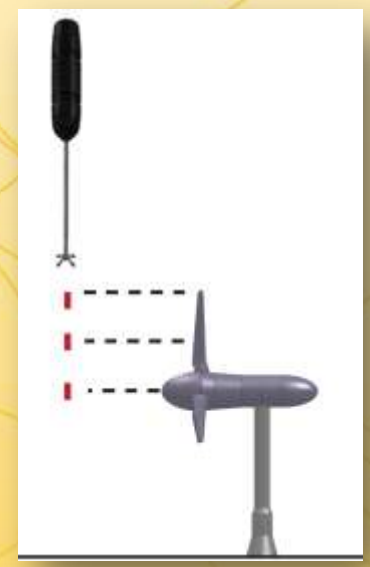
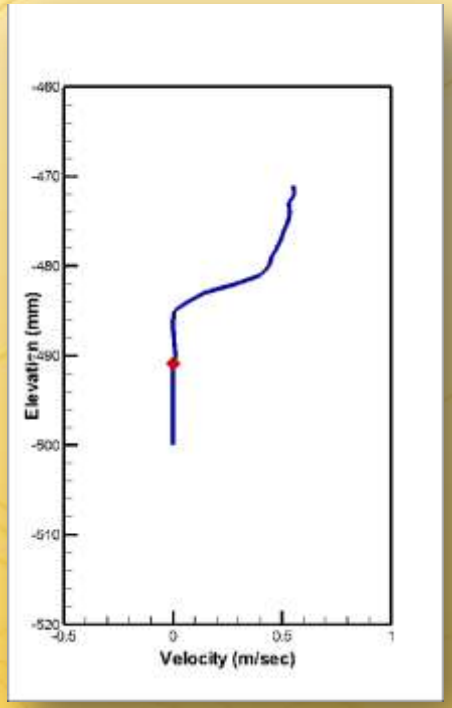
Nortek Vectrino II Profiling Velocimeter



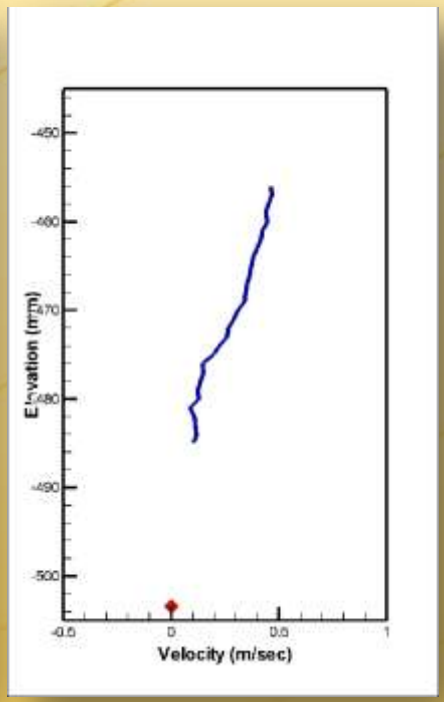
Turbine wake dynamics

Simultaneous bottom tracking

FLOW →



Scour hole formation under sampling location



Bedform migrating through sampling location

(1 second = 30 seconds real time)

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Summary

- Instream flow control structures used for stream restoration projects can effectively redistribute flow to protect the streambanks they are attached.
- Turbulence propagated far downstream may adversely affect streambank stability.
- Increased noise levels during high resolution velocimeter applications potentially over predict bed shear stress estimates.
- Rapid initiation of scour formation indicates the need for post-installation and after large storm event monitoring.

Acknowledgements

- Jessica Kozarek (OSL Manager), Kris Guentzel and Read Plott (graduate students), Engineers Jim Mullin and Chris Ellis, and the many other SAFL employees.
- The National Cooperative Highway Research Program (NCHRP).
- The Nortek staff for quick responses to all of my Vectrino II questions.

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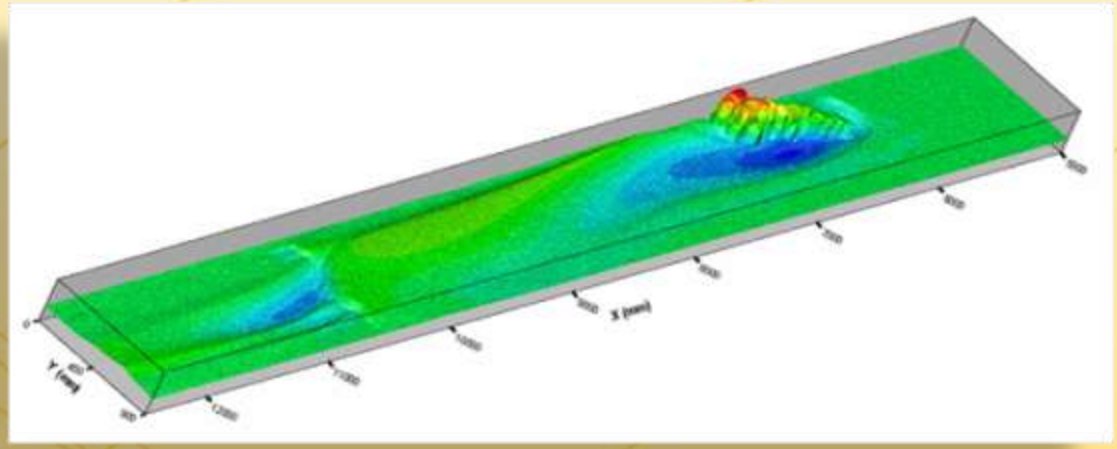

Thank you!

Questions?

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