Improving Design Guidelines for Rock Vanes and Other Flow Training Structures

Anne Lightbody, University of New Hampshire
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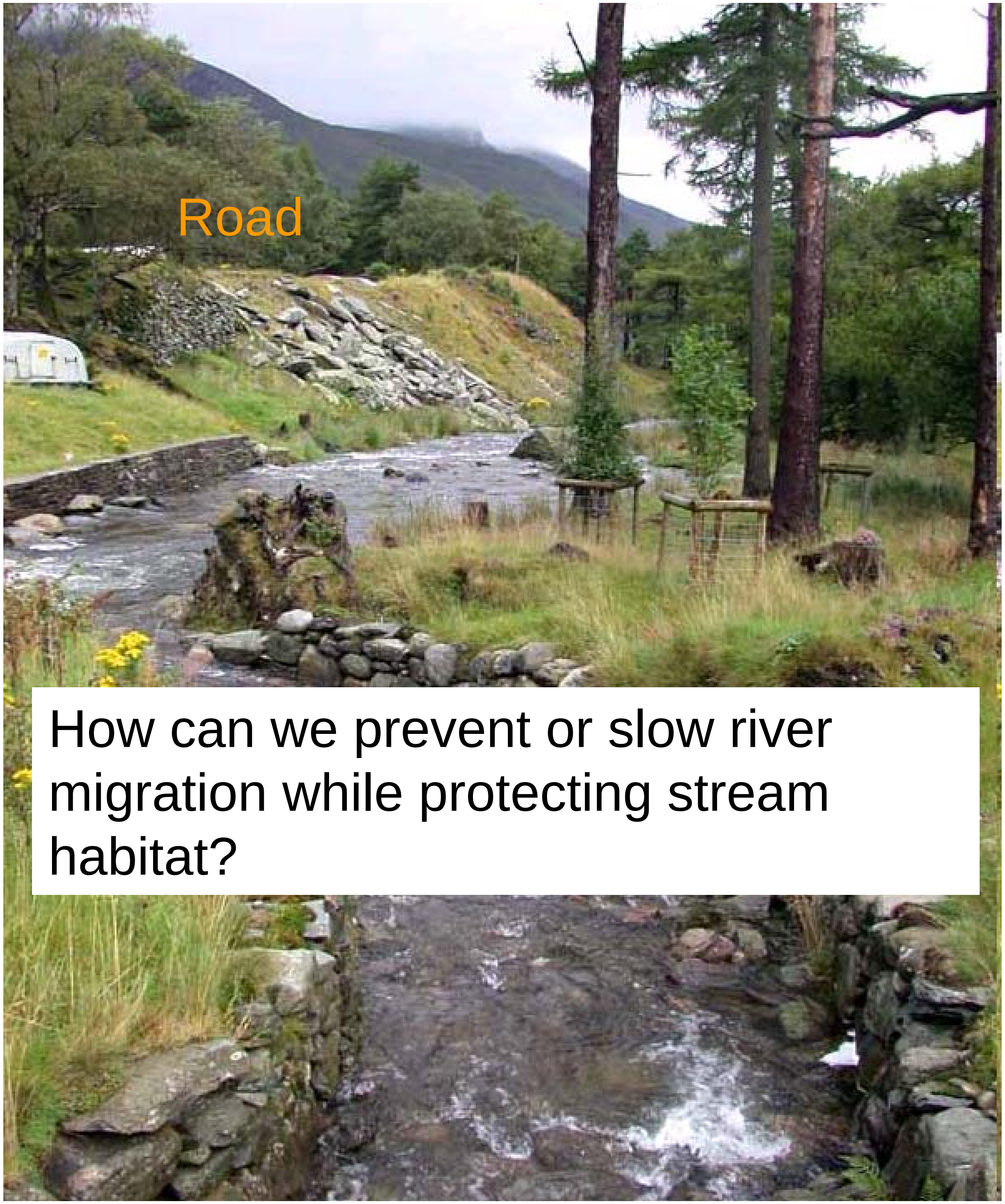
House

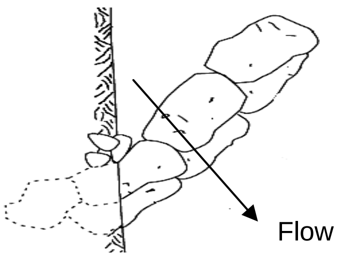


How can we prevent or slow river migration while protecting stream habitat?

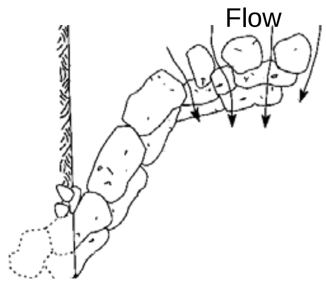
http://wales.fuzzup.net/images/fullsize/photos/stream-and-tree-along-a5-road-wales-welsh-uk-19.jpg

In-stream rock structures

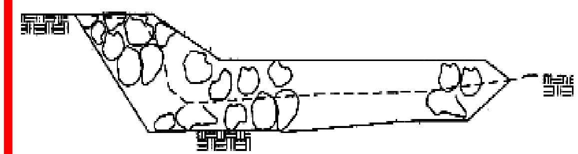
Rock vane



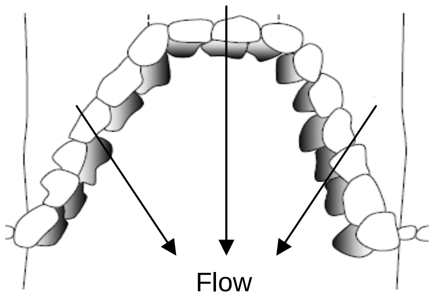
J-hook



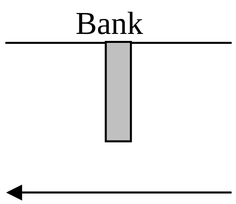
Bendway weir/stream barb



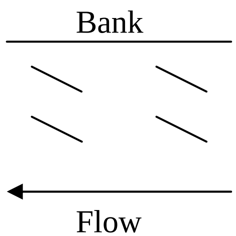
Cross vane



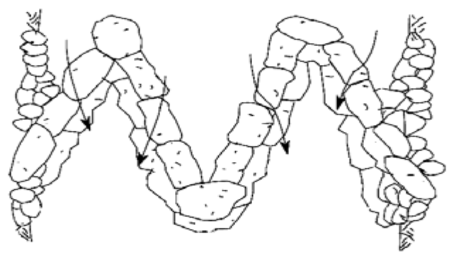
Spur dike/groyne



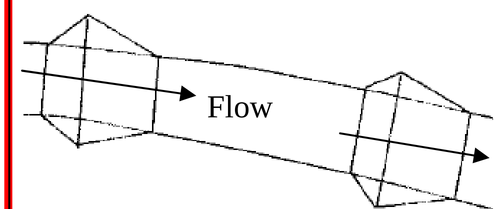
Submerged vane



W-weir



Constructed riffle



In-stream structure design

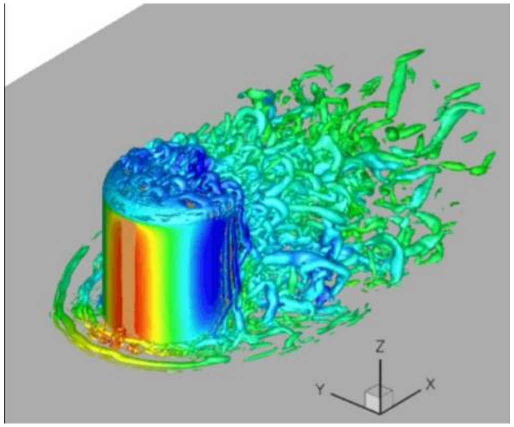
- Stream instability, degradation, aggradation, and local scour account for 60% of US highway bridge failures (Lagasse et al. 1995)
  - Riverbank failure and erosion put extra sediment into streams, which contributes roughly $16 billion annually in damages (USEPA 1994; ARS 2003).
- Over $1 billion spent every year since 1990 to improve river training, protect banks from erosion, and enhance aquatic habitat quality (Bernhardt et al. 2005).
- Despite the large investment, it is estimated that at least 50% of stream restoration projects fail (O'Neil and Fitch 1992).
- Overall, the emerging consensus (e.g., House 1996; Roni et al. 2002; Moerke and Lamberti 2004; Bernhardt et al. 2005) is that:
  - results of specific installations are often mixed and highly site-specific
  - existing research and monitoring practices for stream-restoration and river training strategies are inadequate
  - there is a strong need for a comprehensive evaluation of most river training and stream restoration methods

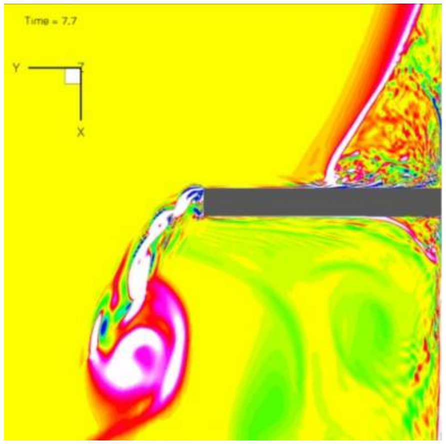
Three-dimensional flow patterns around in-stream structures

- Shingle Creek, Brooklyn Park, MN

Boils from submerged rock

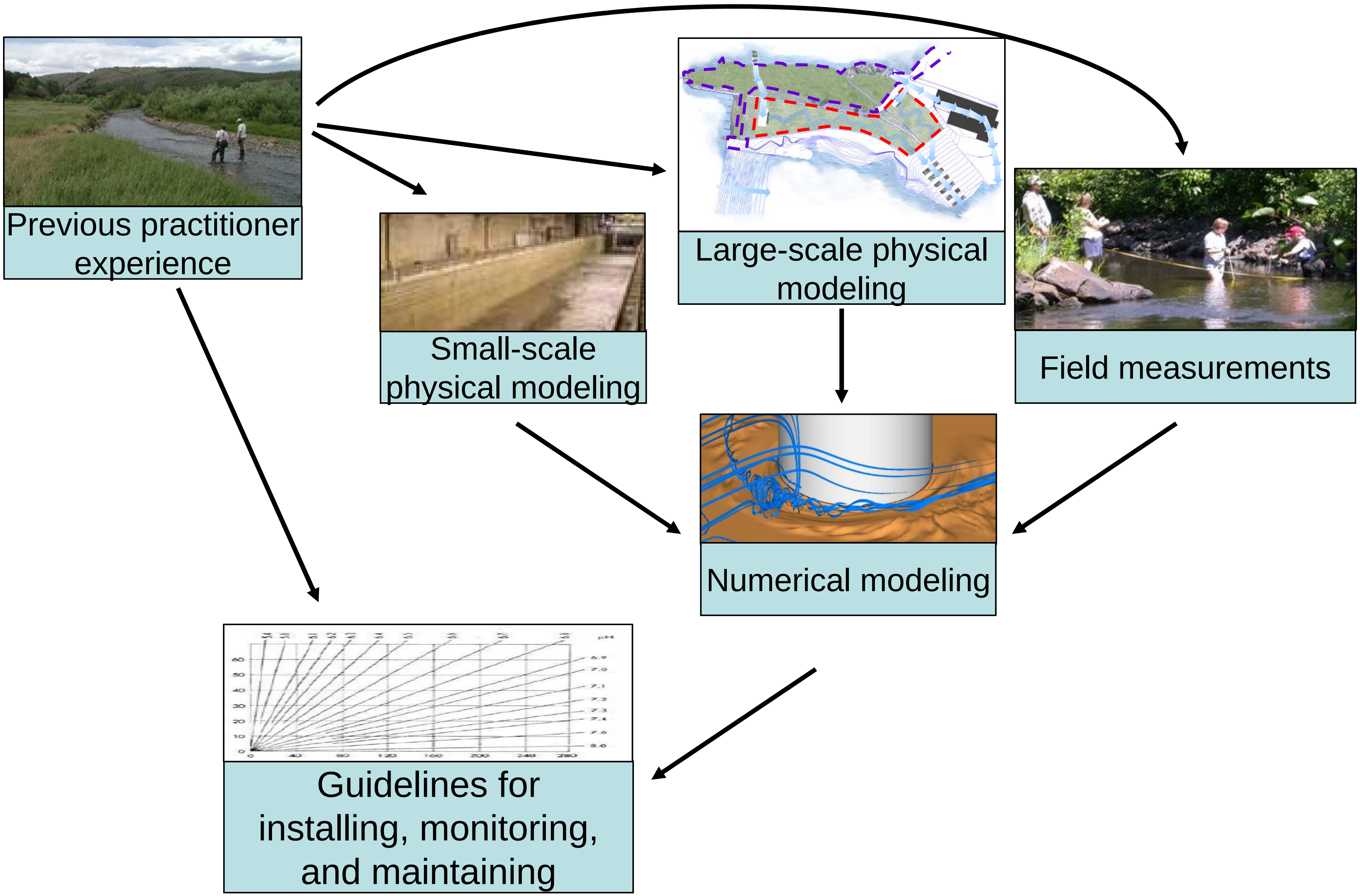
- Simulations by Fotis Sotiropoulos and Christian Escauriaza using the SAFL Virtual StreamLab (VSL) numerical model of flow around boulders and rectangular vanes





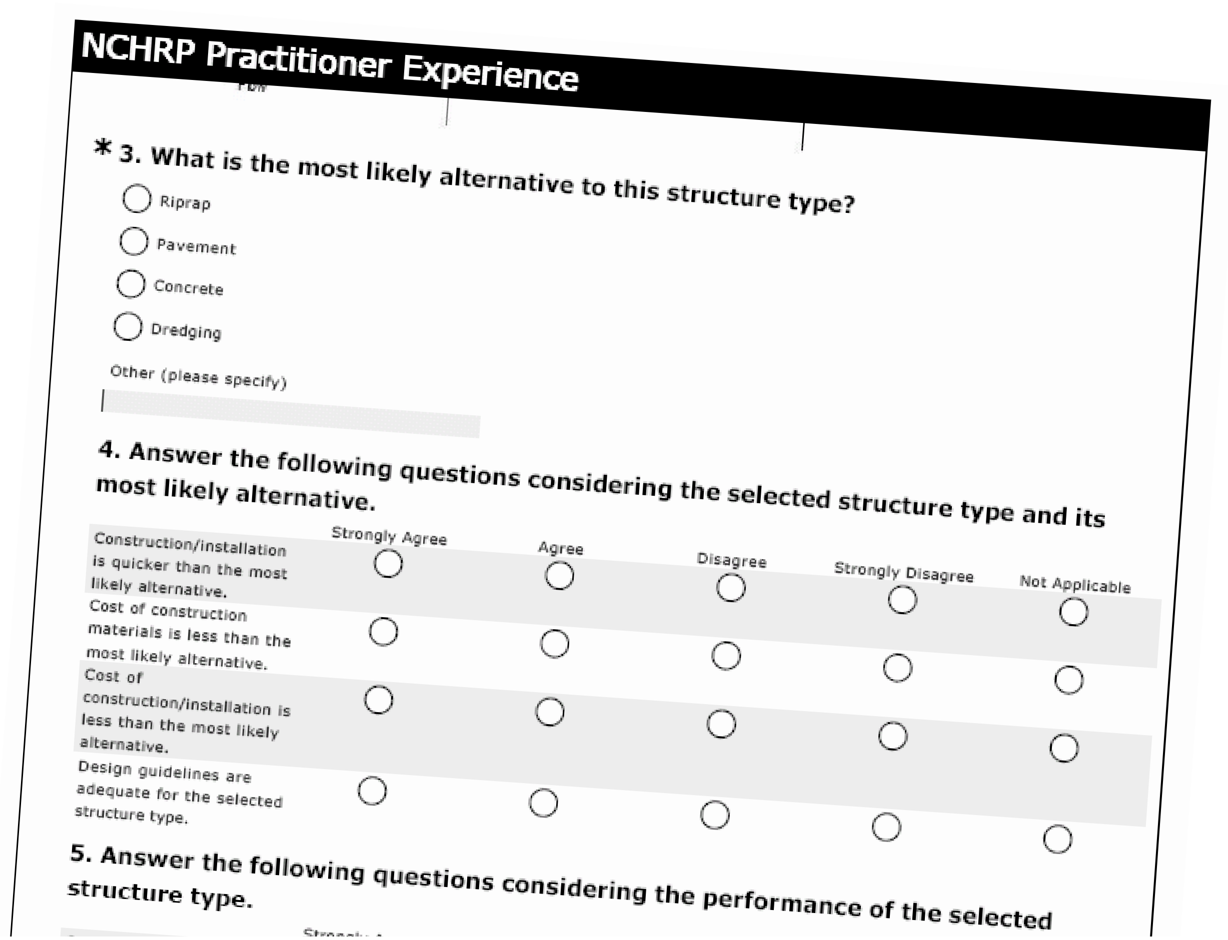
National Cooperative Highway Research Program (NCHRP) Project 24-33: Development of Design Guidelines for In-stream Flow Control Structures

PI: Fotis Sotiropoulos, SAFL; co-PI's: Anne Lightbody, SAFL; Panos Diplas, Virginia Tech



NCHRP practitioner survey (spring '09)

- 64 individuals (71% response rate)
  - 47% from DOT's, 28% from DNR's, 14% from USDA/NRCS,11% private consulting
  - 76% of USGS physiographic provinces



NCHRP Practitioner Experience

*** 3. What is the most likely alternative to this structure type?**

- Riprap
- Pavement
- Concrete
- Dredging

Other (please specify)

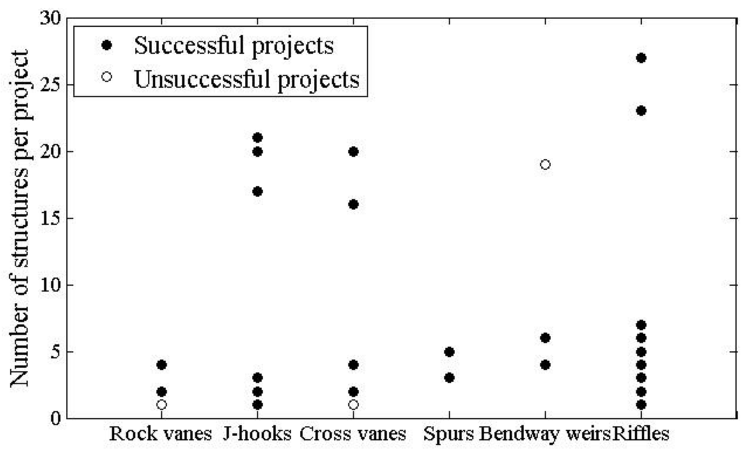
4. Answer the following questions considering the selected structure type and its most likely alternative.

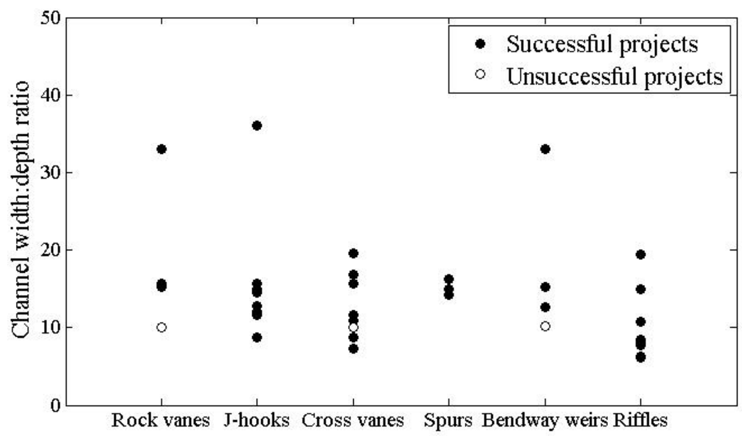
	Strongly Agree	Agree	Disagree	Strongly Disagree	Not Applicable
Construction/installation is quicker than the most likely alternative.	○	○	○	○	○
Cost of construction materials is less than the most likely alternative.	○	○	○	○	○
Cost of construction/installation is less than the most likely alternative.	○	○	○	○	○
Design guidelines are adequate for the selected structure type.	○	○	○	○	○

5. Answer the following questions considering the performance of the selected structure type.

NCHRP practitioner survey

- Summary info
  - 75% agreed structures (other than constructed riffles) halted further bank and bed scour
  - agreement on the need for quantitative predictive design guidelines
- Detailed project info





- Still collecting information – especially on UNSUCCESSFUL projects

“To the lab and beyond!”

Vermillion River, Empire Township, MN


Minneapolis, Minnesota, USA
St. Anthony Falls
Mississippi River
Outdoor StreamLab
Water Power Public Park
St. Anthony Falls
Laboratory

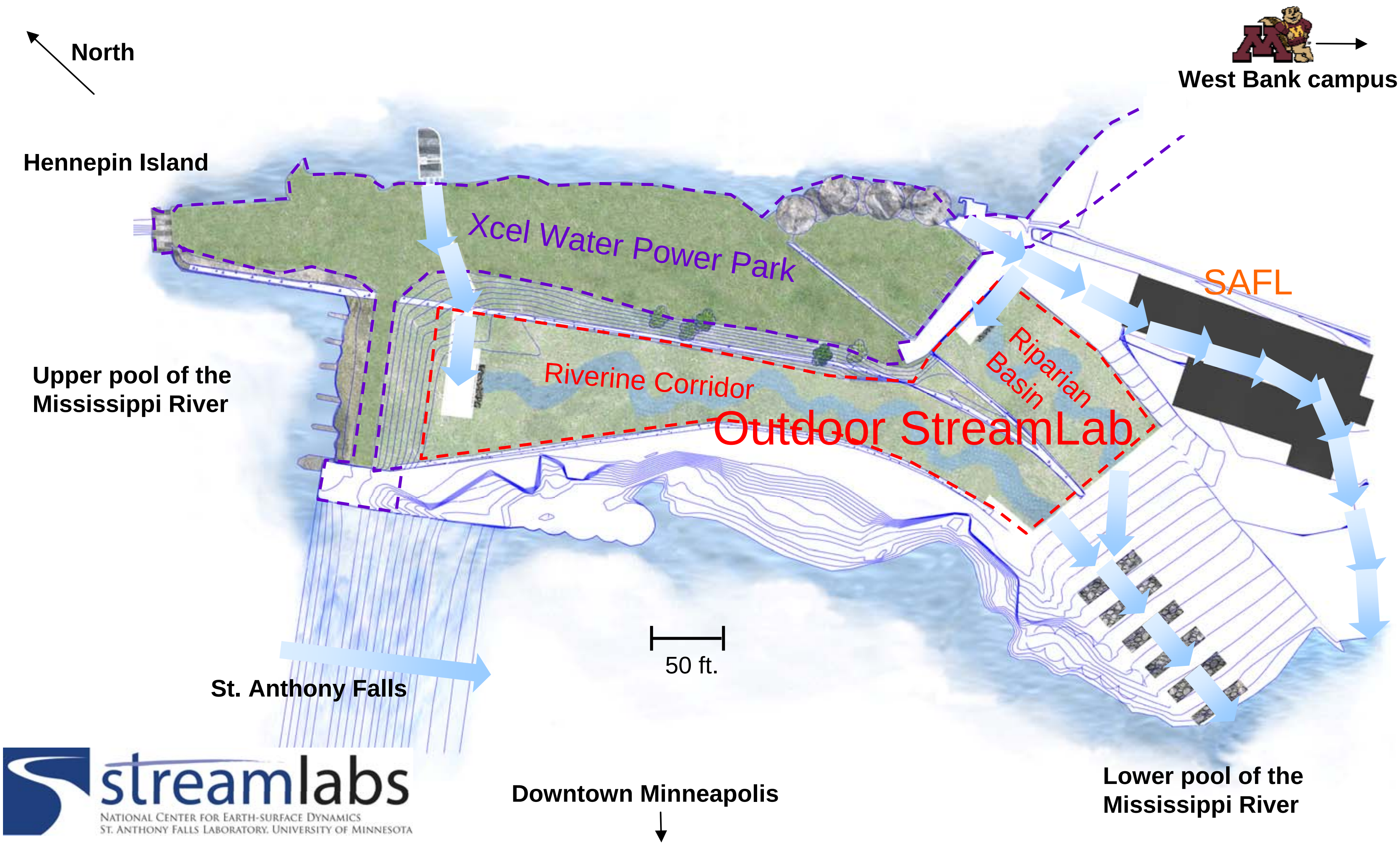
Outdoor StreamLab

Laboratory-quality data collection within a publicly visible field-scale experimental site

Outdoor StreamLab

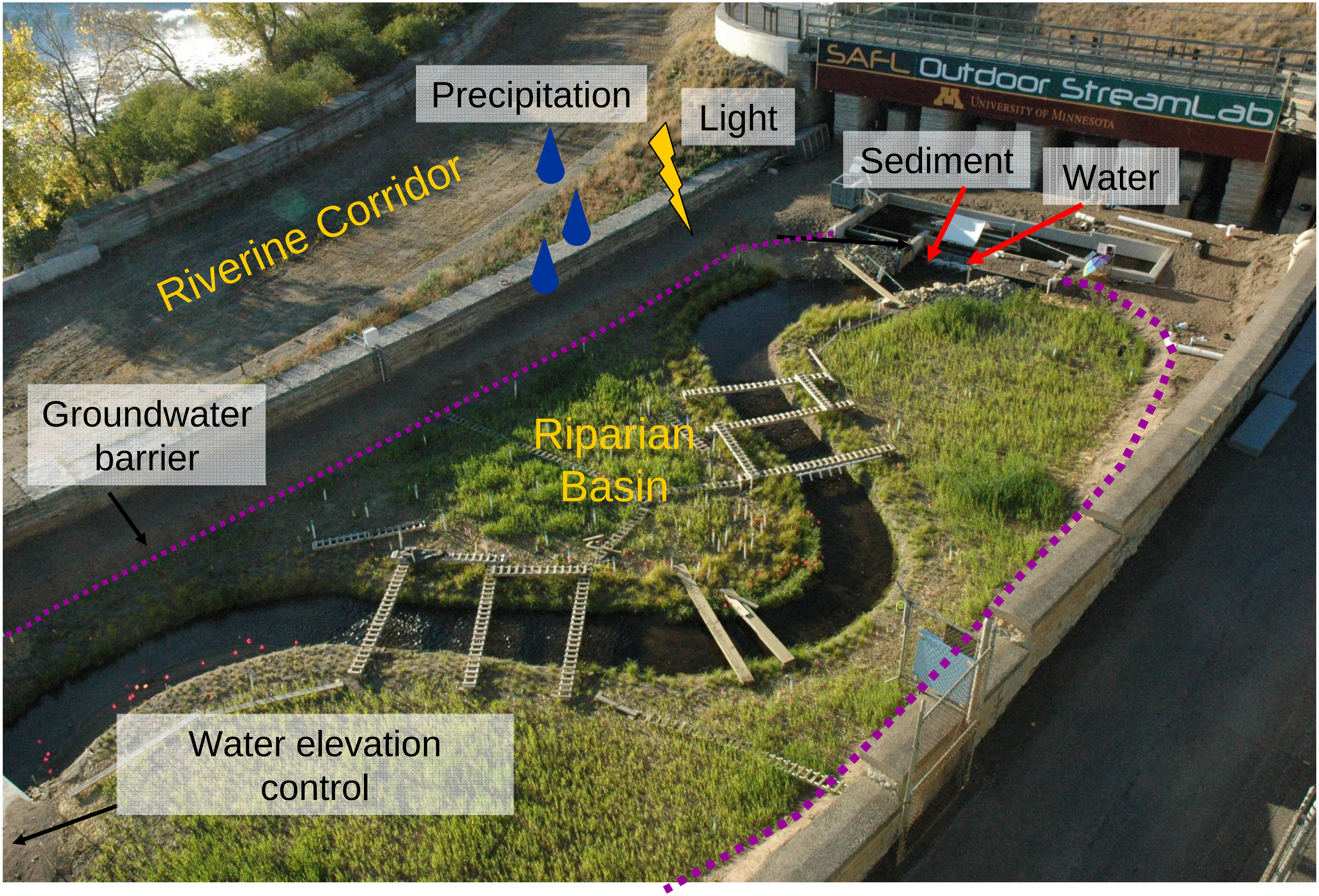
The Outdoor StreamLab is uniquely equipped to:

- Quantify processes from microscopic to basin scales
- Conduct field-scale experiments
- Impose and repeat hydrographs
- Provide verification for models and measurement techniques
- Enable highly visible formal and informal education
- Allow experimental study of processes influenced by organisms dependant on natural precipitation and sunlight

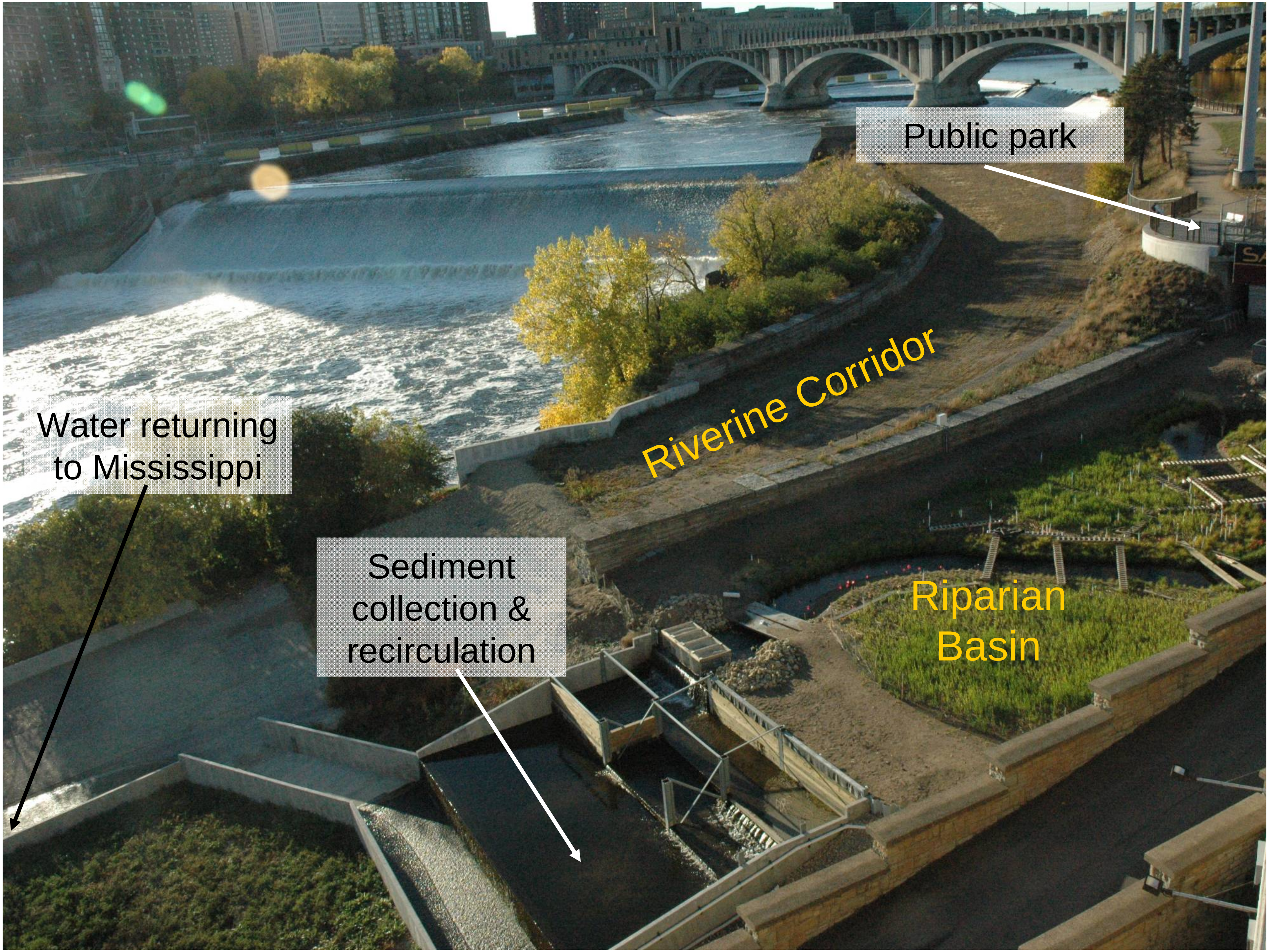


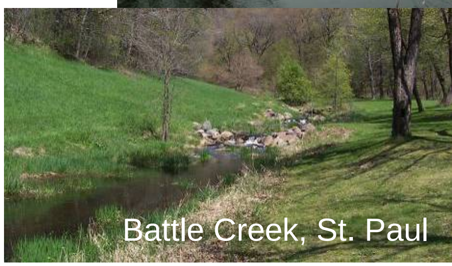
streamlabs
National Center for Earth-surface Dynamics
St. Anthony Falls Laboratory, University of Minnesota

University of Minnesota
Driven to Discover℠



Precipitation
Light
SAFL Outdoor StreamLab
University of Minnesota
Sediment
Water
Riverine Corridor
Groundwater barrier
Riparian Basin
Water elevation control

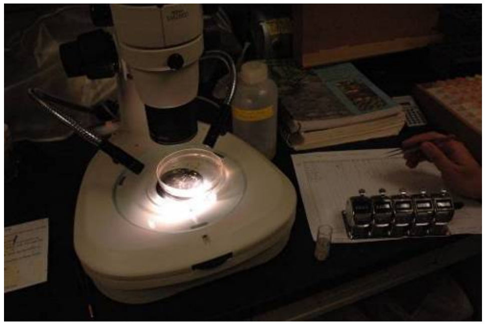

Public park
Riverine Corridor
Water returning to Mississippi
Sediment collection & recirculation
Riparian Basin



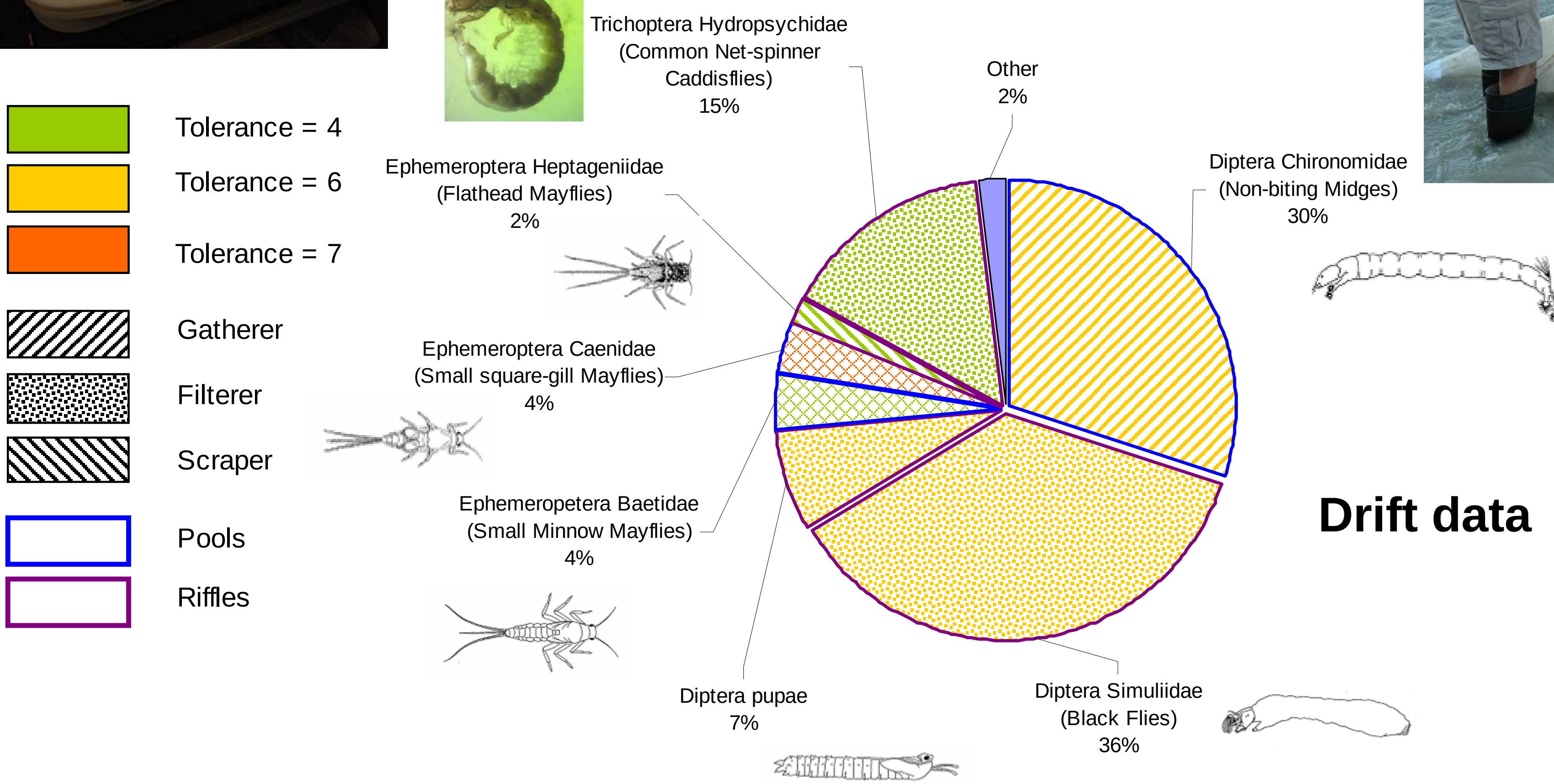
Water quality comparison

	Units	Site	Battle Creek	Browns Creek	Credit River	Eagle Creek	Fish Creek	Nine Mile Creek	Silver Creek	Outdoor StreamLab
Total phosphorus	mg/L	Mean	0.21	0.27	0.26	0.08	0.18	0.19	0.17	0.15
NO_x-N	mg/L	Mean	0.6	0.67	0.92	0.23	0.91	0.84	0.77	0.56
TSS	mg/L	Mean	50	78	50	20	39	105	74	29.3
Turbidity	NTU	Mean	9	12	13	6	13	19	11	8.5
Discharge	cfs	Mean	9.3	9.8	12.4	8.7	2.9	18.4	1.2	-
		Base	8	7	7	8	2	5	0.5	1.5
		Max	45	33	85	13	17	130	6.5	55

Data from Metropolitan Council Environmental Services



Macroinvertebrates



On average, $3/cm^2$ in riffles ≈ 500,000 in the stream

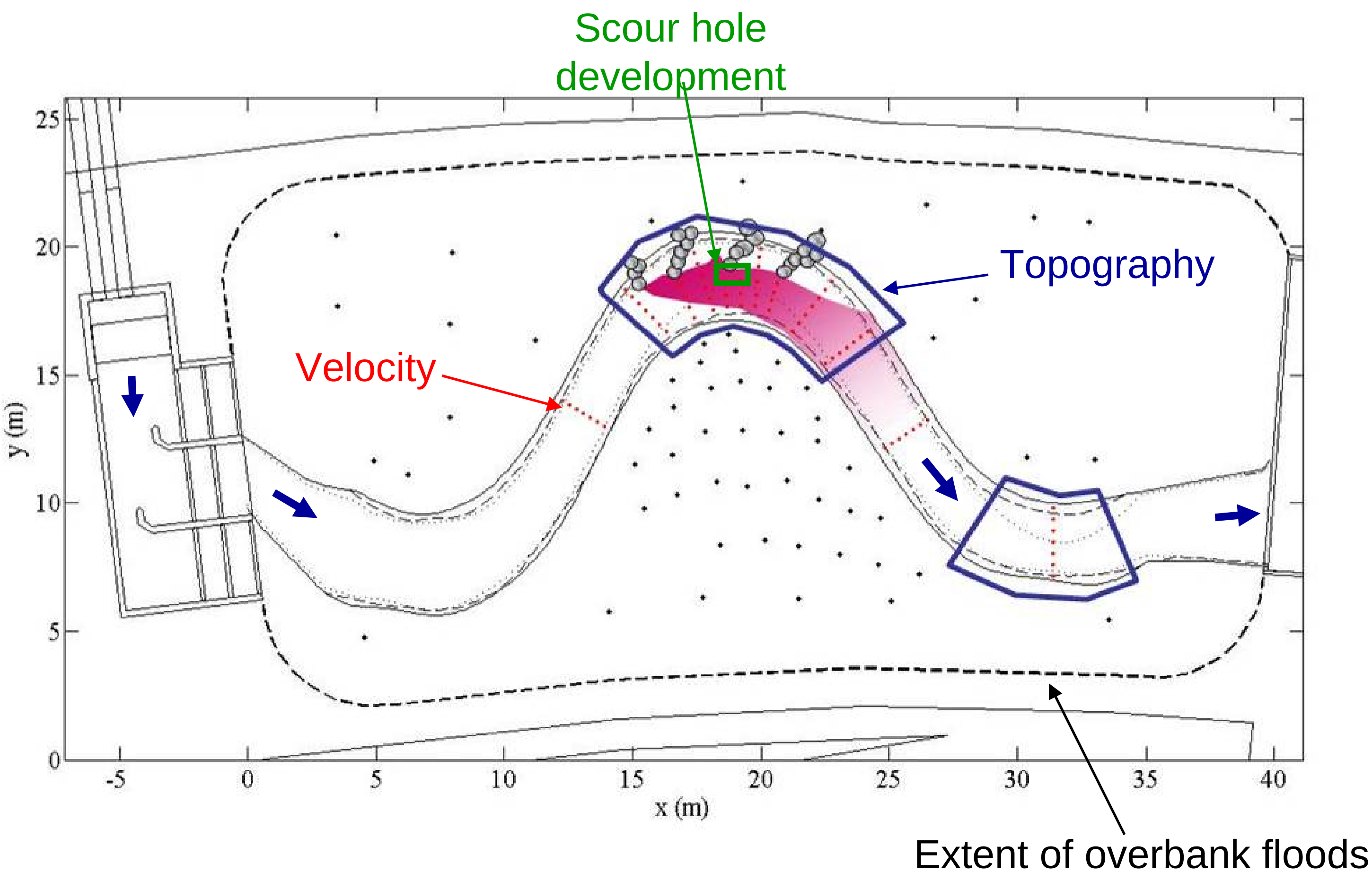
Field-scale laboratory measurements in the SAFL Outdoor StreamLab

Objectives:

1. effect of an array of structures on structure stability & bank erosion
2. installation and monitoring
3. data for validating the VSL numerical model around structure arrays at different flow rates

NCHRP SAFL Outdoor StreamLab measurements

(summer '09 &'10)

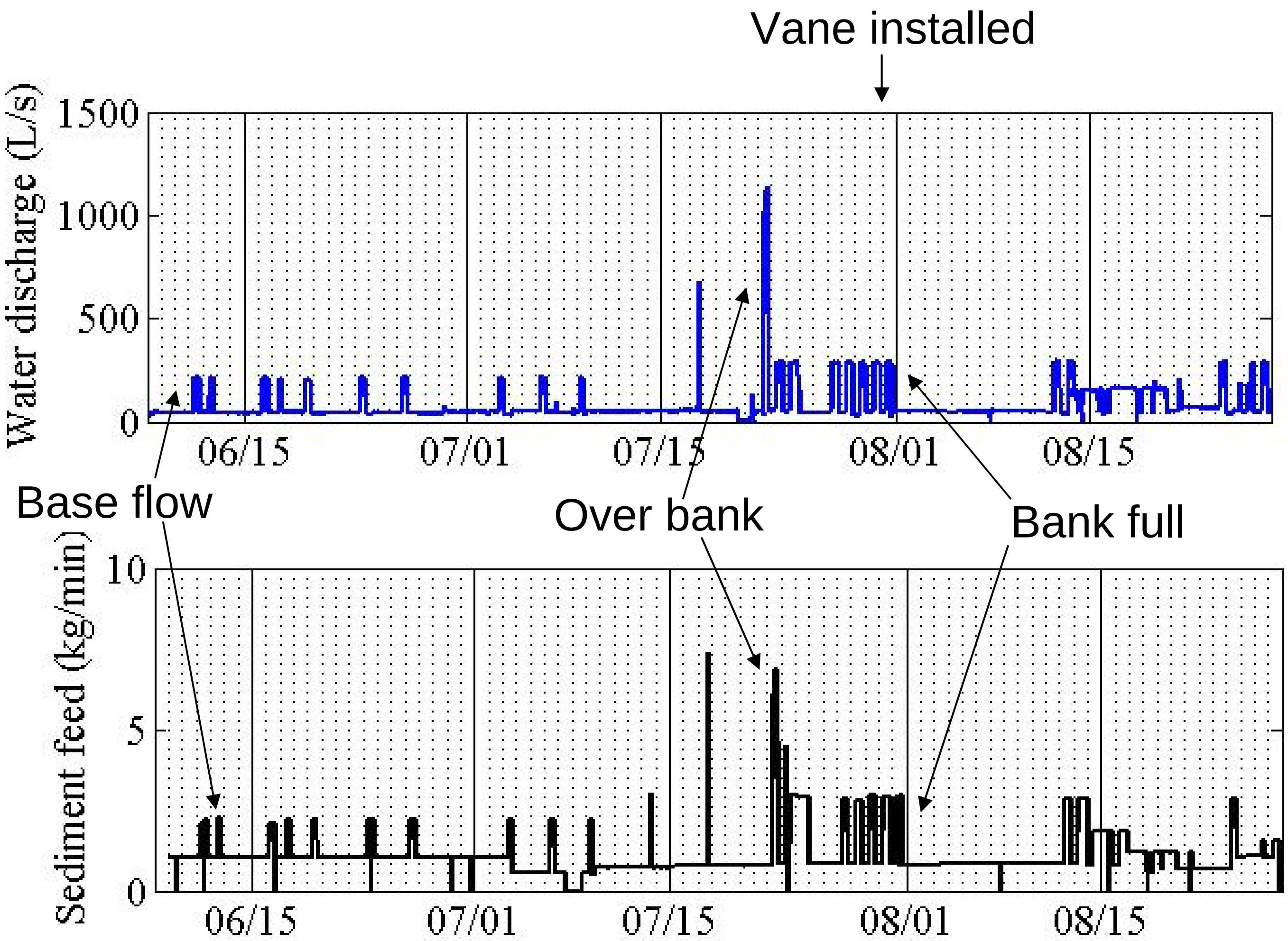


Rock vane added

- July 31, 2009, rock vane installed using recommended construction techniques (Maryland Department of the Environment, 2000; Lagasse et al., 2001; Rosgen, 2001; and Doll et al., 2003)

- Measurements repeated before and after vane installation

Water & sediment discharge



2009 OSL measurements

Base flow (44 L/s)

Bankfull flow (280 L/s)

Overbank flow (1200 L/s)

No structure

Single rock vane

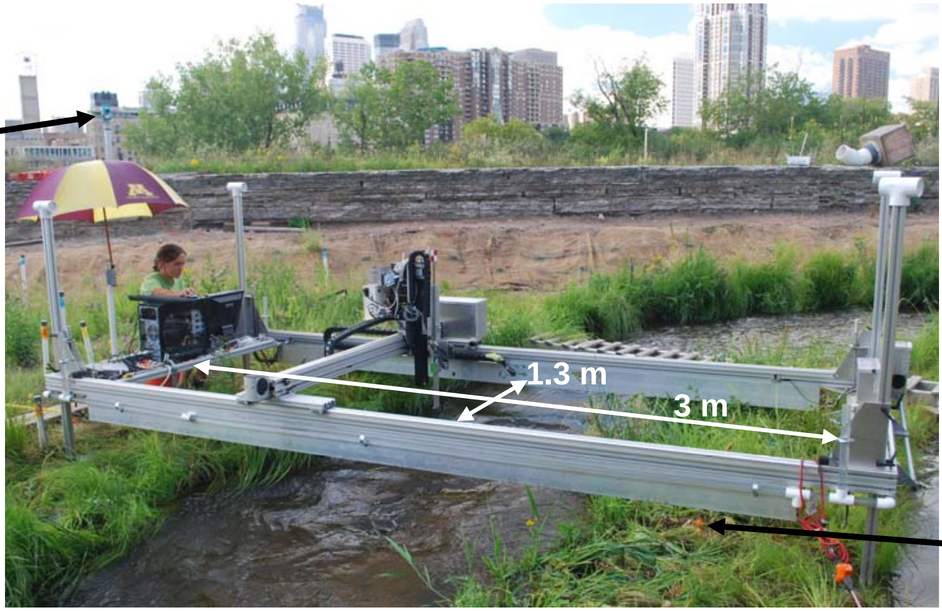
2009 OSL measurements

Overbank flow (1200 L/s)

Outdoor StreamLab high-resolution bathymetry measurements

- Mobile computer-controlled data acquisition (DAQ) system
- Position and control instruments to obtain topography, water surface elevation, velocity, temperature, dissolved oxygen, nitrate, etc.

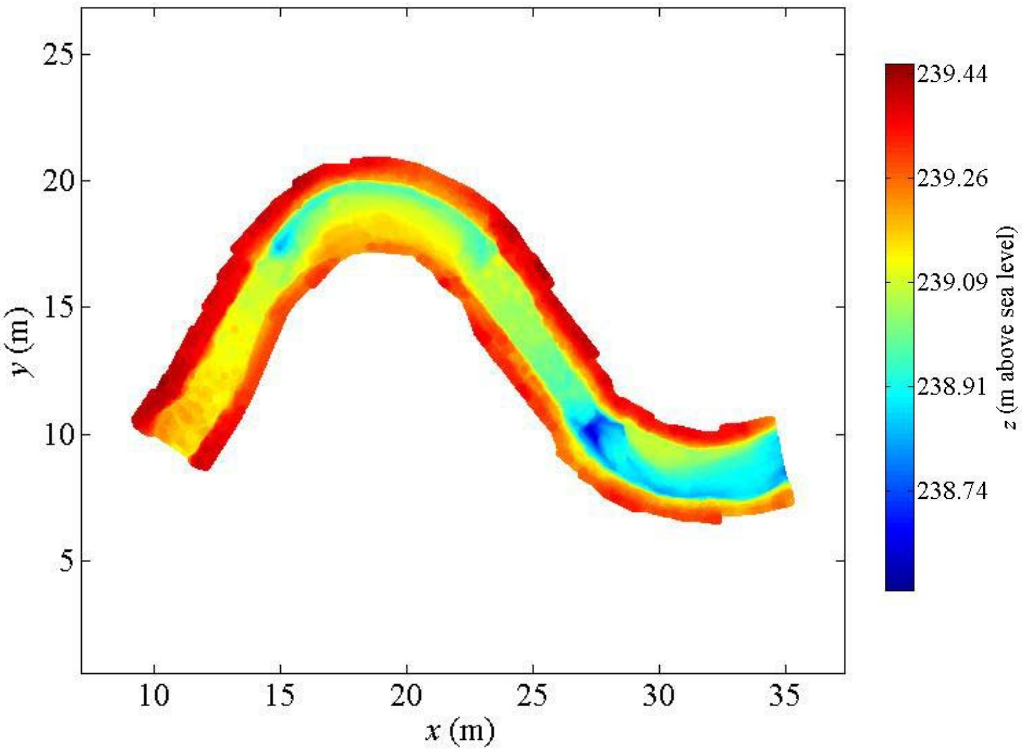
Total station to determine carriage position



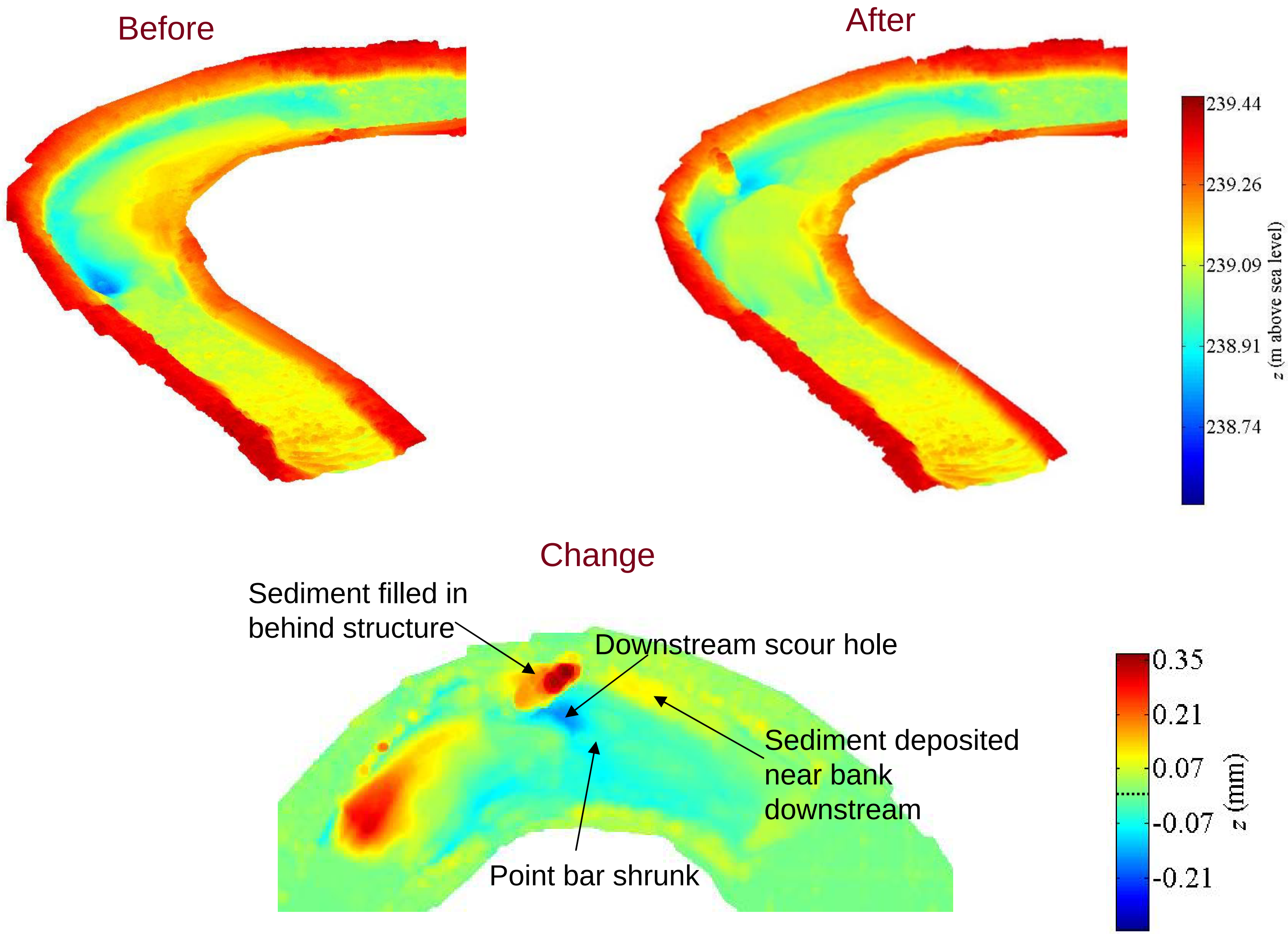
Fixed benchmarks for high-precision change detection

OSL bathymetry

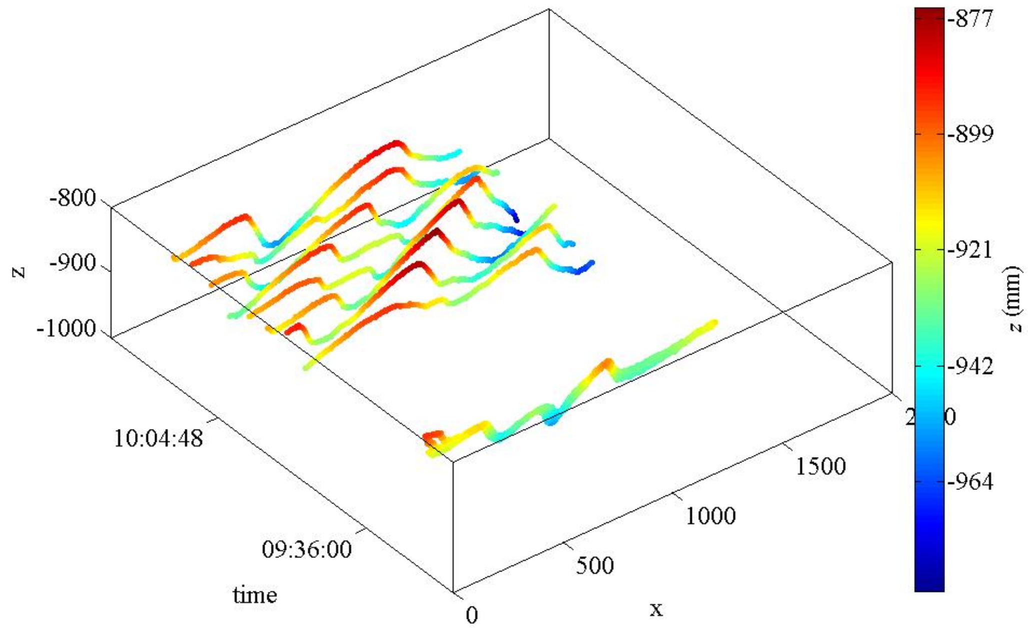
- cm-scale horizontal resolution; mm-scale vertical
- Continuous coverage of bed, banks, and water surface
- Bed grain size for roughness & sediment transport estimates



Effect of adding single rock vane

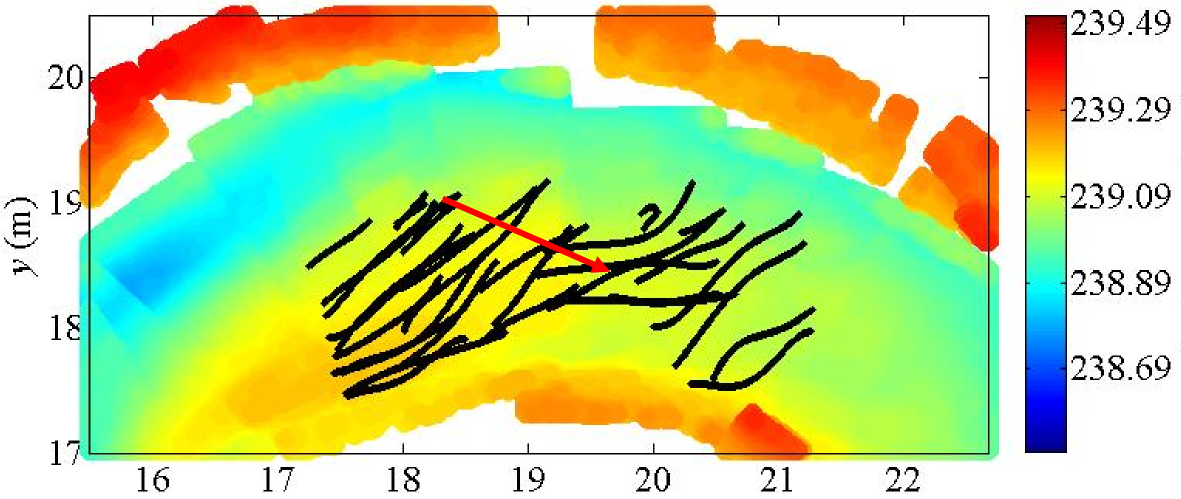


Sediment transport via bedforms

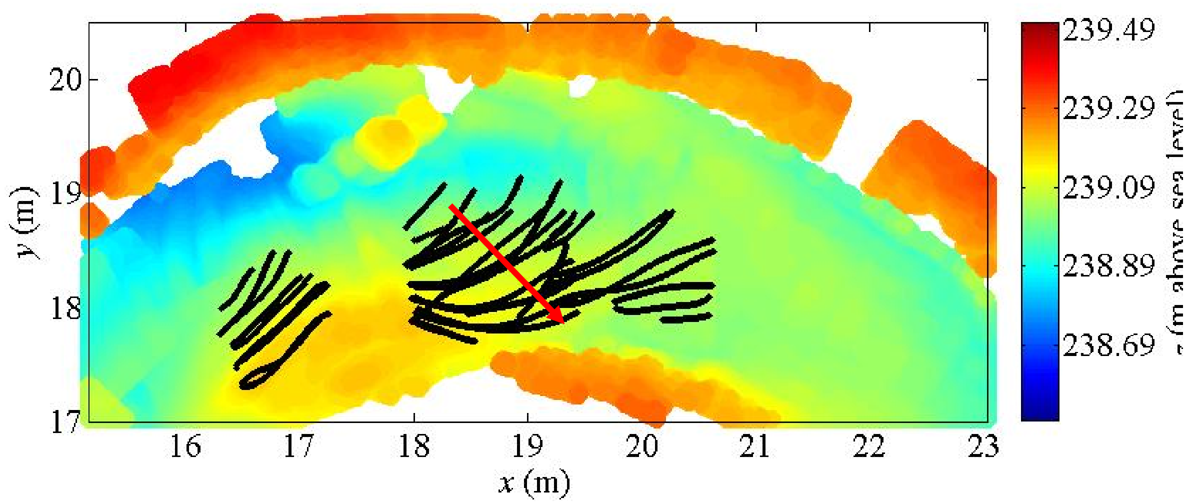


Bed form migration

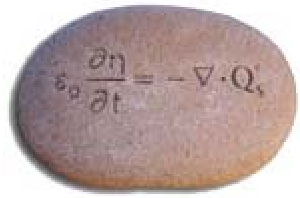
Prior to structure installation



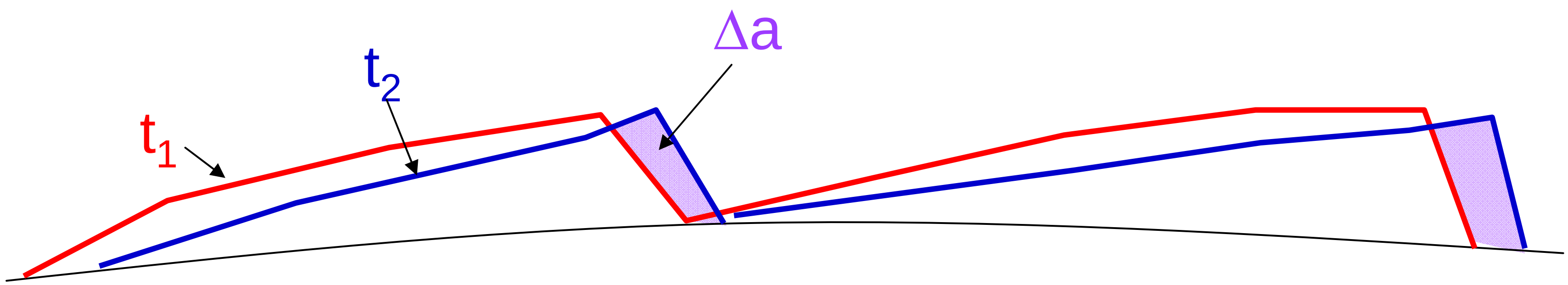
With rock vane



Sediment transport calculations



- Sediment topography integrated to obtain sediment flux



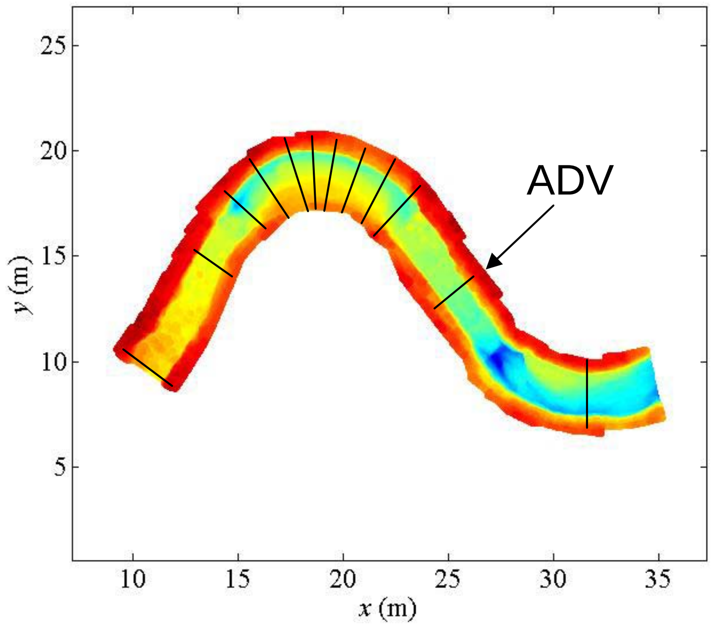
- Following Jerolmack and Mohrig (2005), the sediment flux per unit width in the direction of bedform motion:

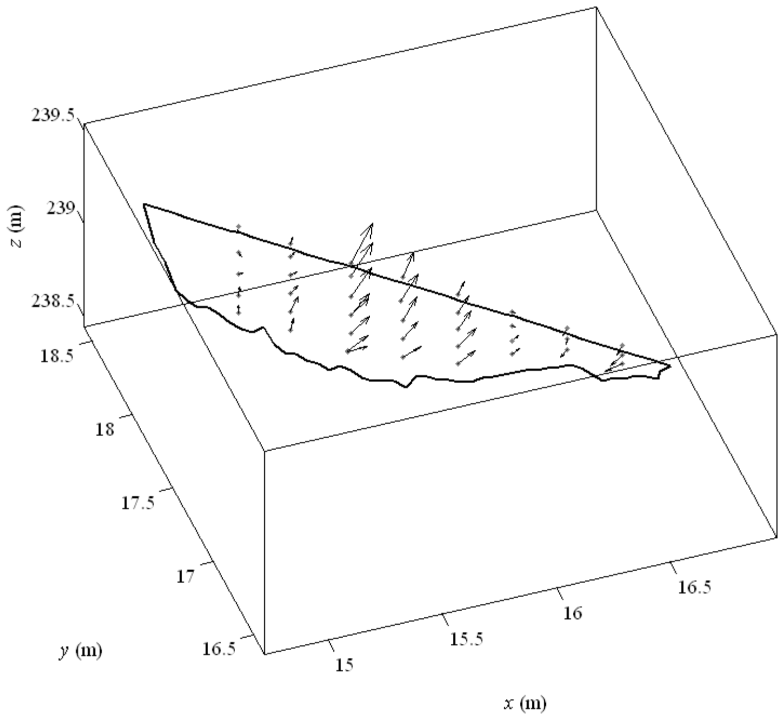
$$q_s = (1-\lambda)\frac{\Delta a}{\Delta t}$$

porosity; assumed constant: $\lambda = 0.35$

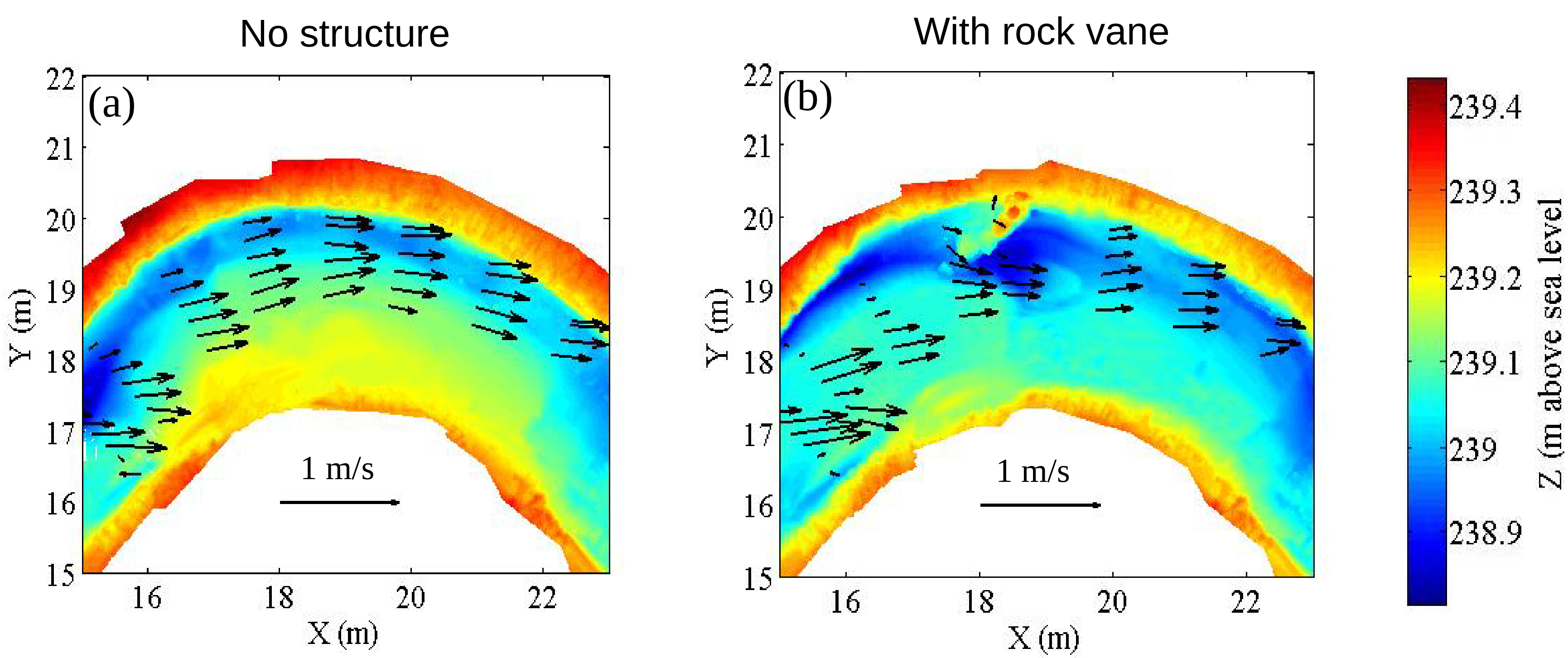
Velocity measurements

- 3-D 5-minute velocity records using acoustic Doppler velocimetry at 12 cross sections



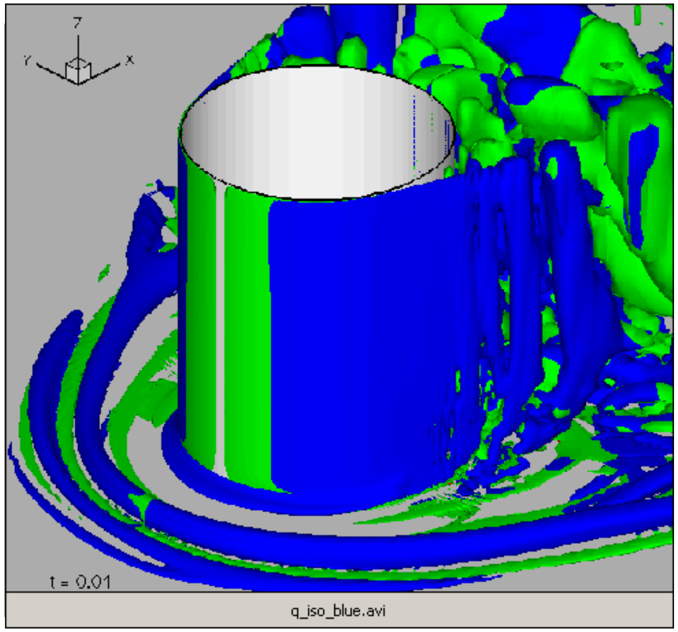


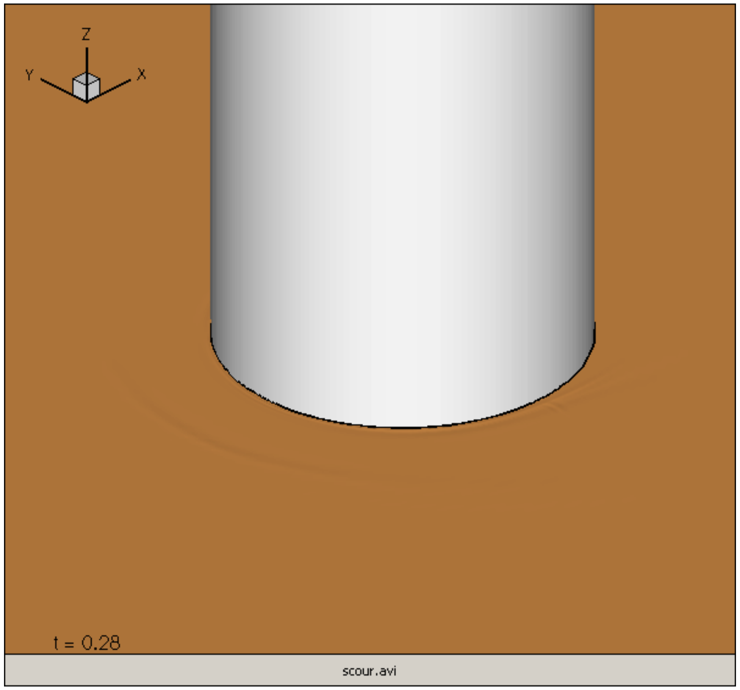
Depth-averaged velocity profiles



SAFL Virtual StreamLab

- State-of-the-art computational fluid dynamics (CFD) model developed by Fotis Sotiropoulos that is capable of simulating real-life hydraulic engineering flows using advanced numerical techniques and turbulence models
- Integrates a 2-D depth-averaged module, a 3-D steady module, and a full 3-D unsteady module with a highly advanced turbulence model capable of resolving unsteady vortices at full-scale conditions
- Can simulate sediment transport and scour past complex hydraulic structures using a physics-based approach

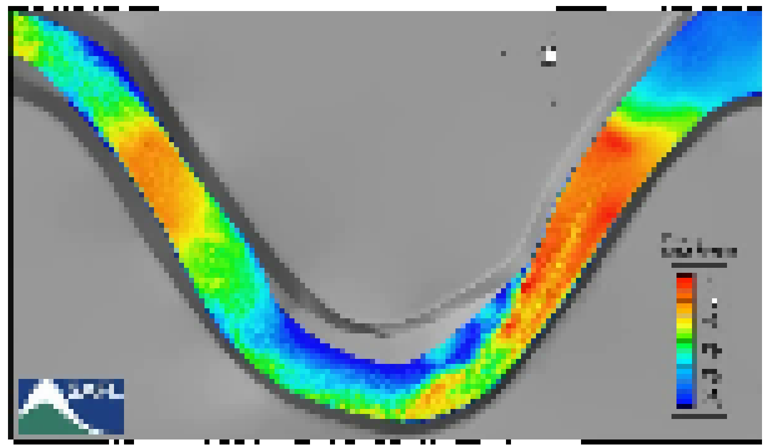




Virtual StreamLab simulations

Surface tracers

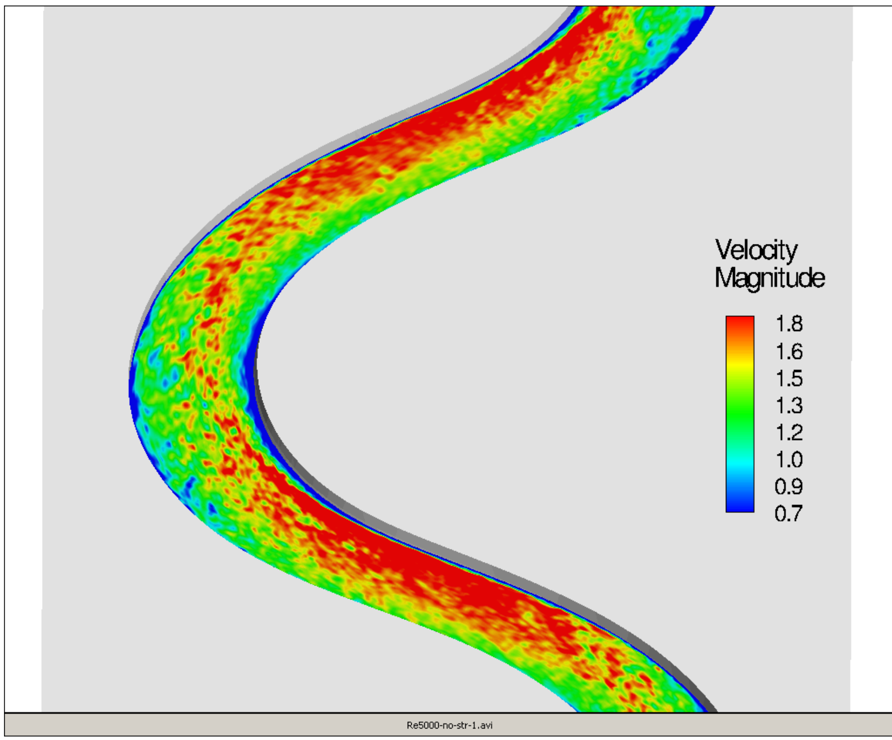
Modeled surface velocity



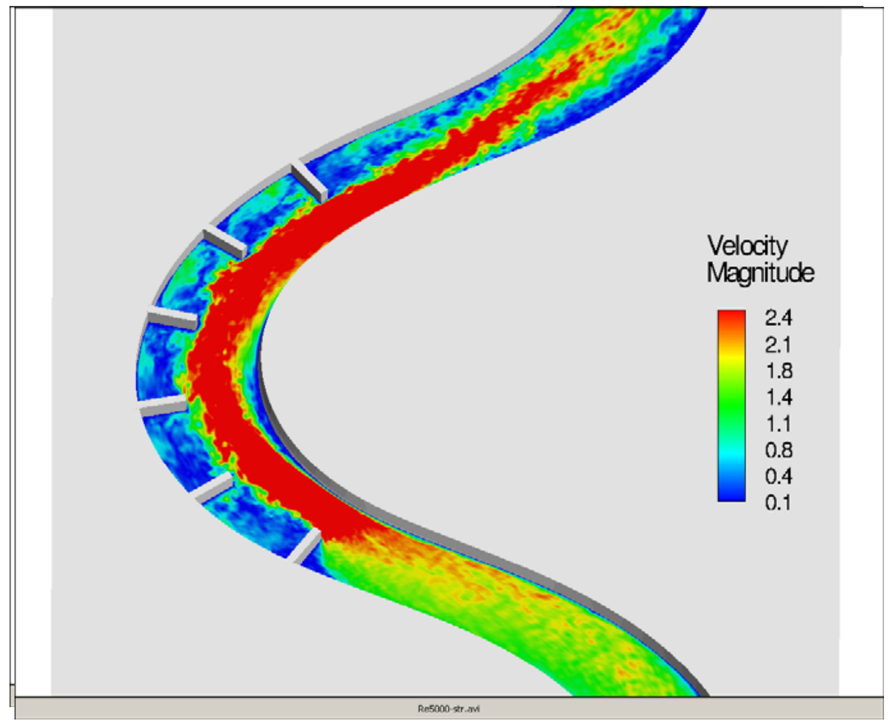
Virtual StreamLab simulations

- Preliminary LES simulations from Fotis Sotiropoulos and Seokkoo Kang (Re = 5000)

No structures

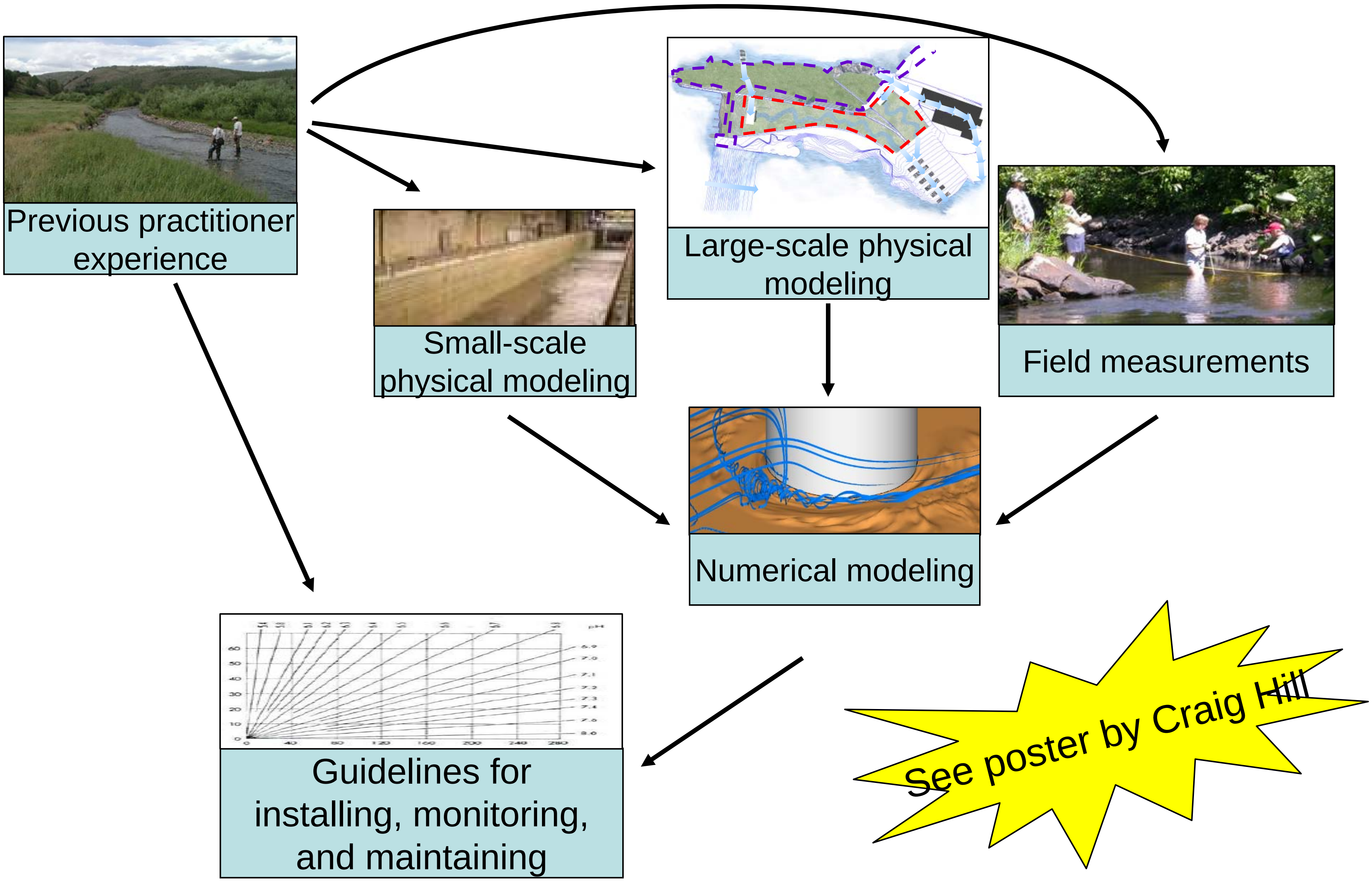


With structures



National Cooperative Highway Research Program (NCHRP) Project 24-33: Development of Design Guidelines for In-stream Flow Control Structures

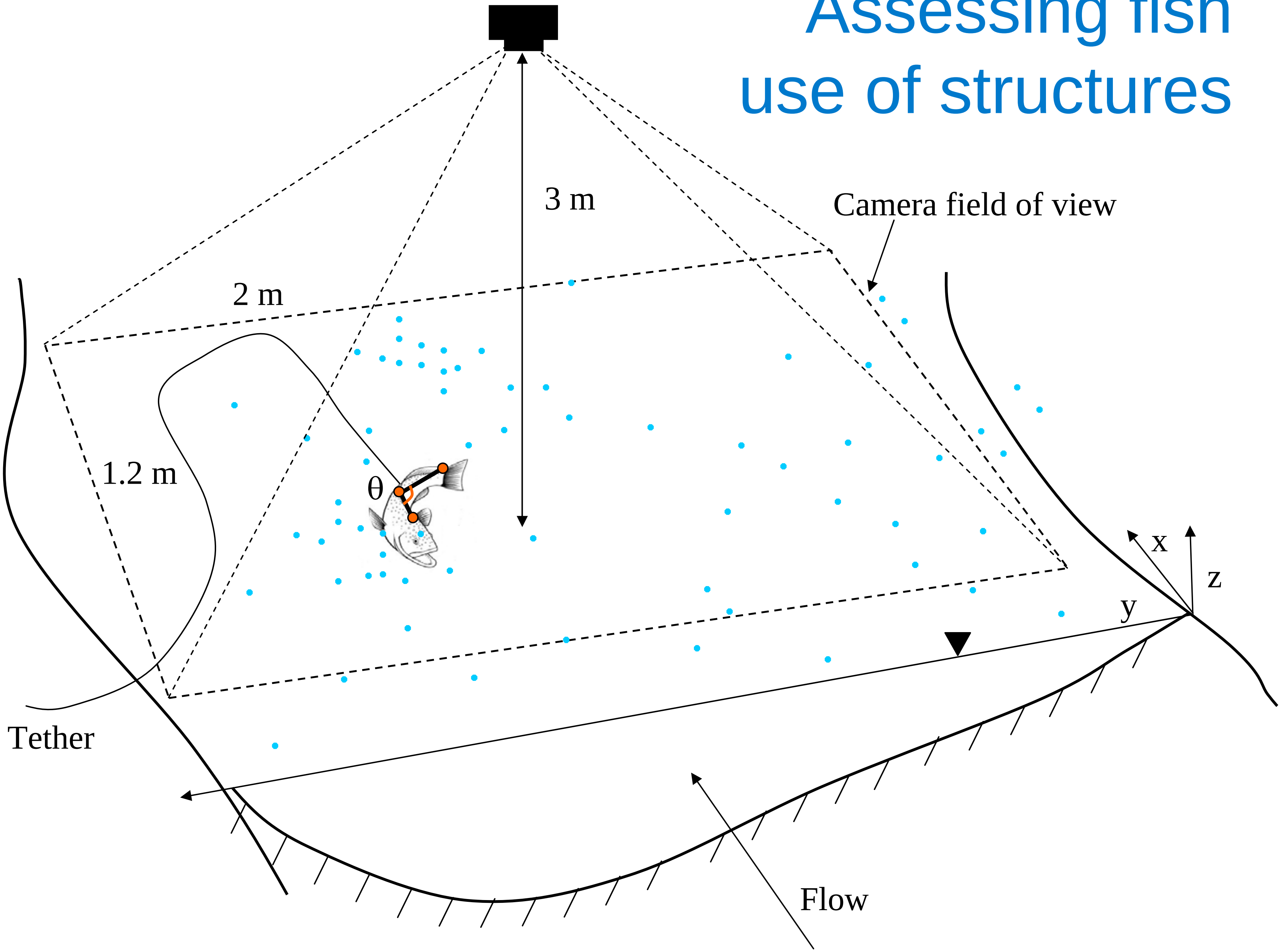
PI: Fotis Sotiropoulos, SAFL; co-PI's: Anne Lightbody, SAFL/UNH; Panos Diplas, Virginia Tech



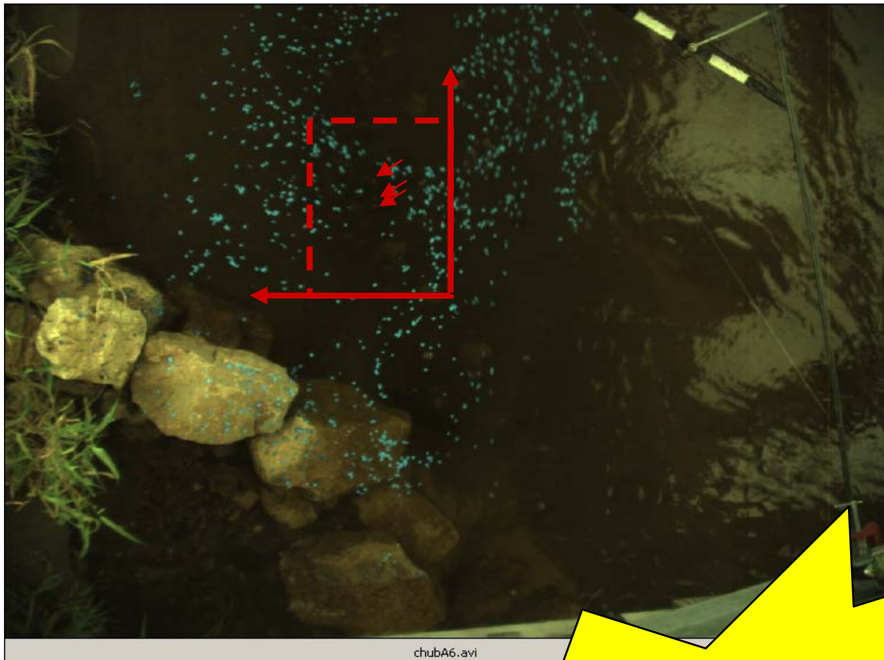
Developing guidelines with the Virtual StreamLab

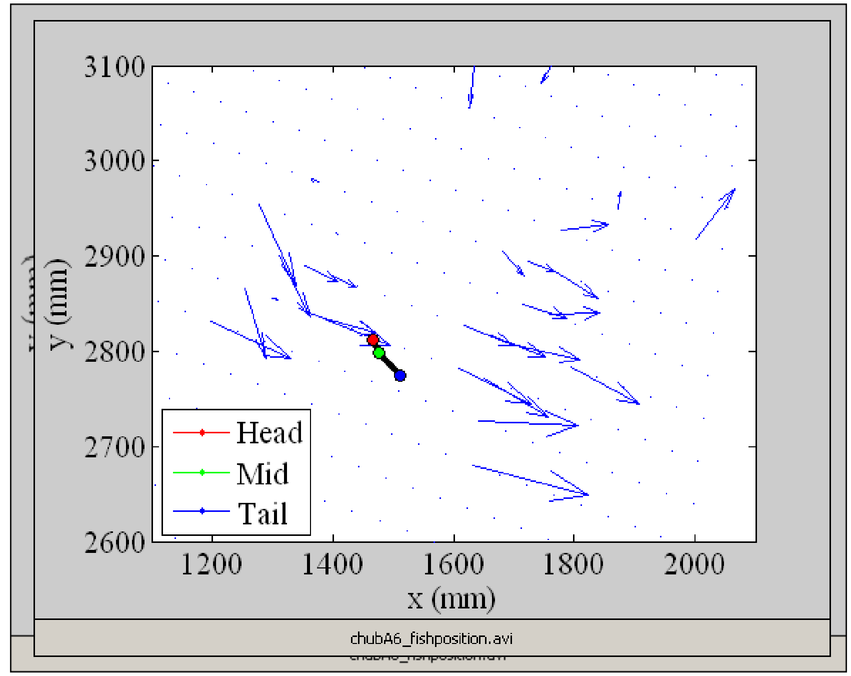
- Objectives:
  - Validate hydrodynamic & deformable bed model components using indoor laboratory flume, OSL, and field measurements
  - Use the VSL to extend the detailed laboratory and field measurements to an even wider range of channel configurations and flow rates
  - Determine, for a particular stream, what site-specific stream properties (e.g., curvature, slope, bed and bank material, channel morphology, etc.) must be measured, what structure or combination of structures is most appropriate, how it should be installed, how it should be monitored and maintained, and at what flow rate it will likely fail
  - Develop and test new structure types

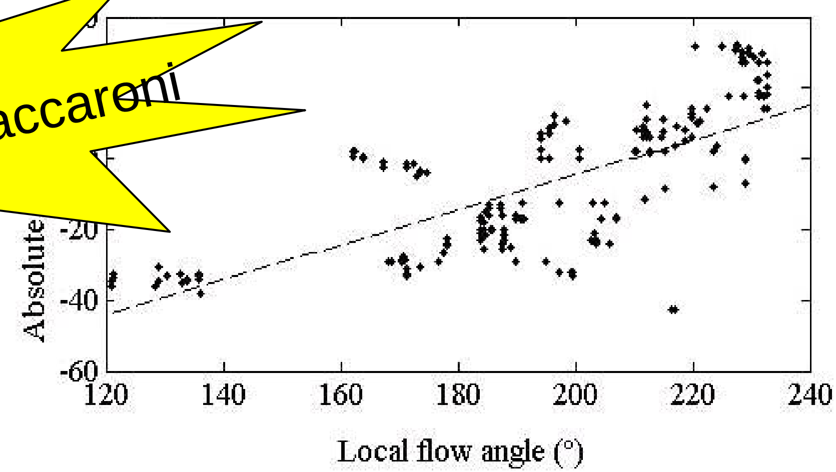
Assessing fish use of structures



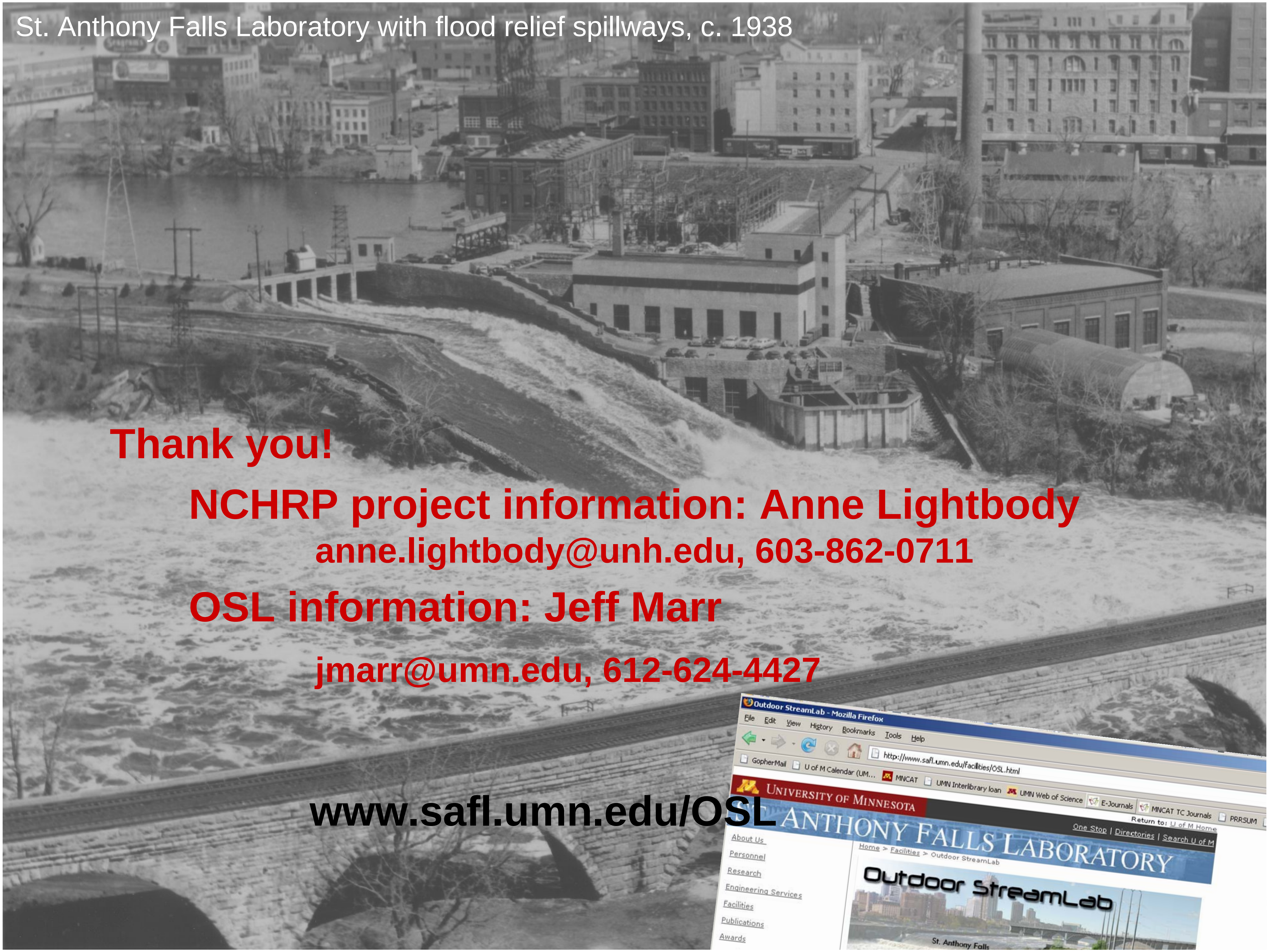
Simultaneous fish position & flow velocity measurements







See poster by Kristan Maccaroni



St. Anthony Falls Laboratory with flood relief spillways, c. 1938

Thank you!

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