Evaluating Cellular Containment Cells to control post-construction stormwater channel erosion

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Channel erosion processes

- Relevant in the contexts of construction sites and post-construction stormwater management
- Various types of water erosion
  - Raindrop
  - Sheet
  - Rill and gully
  - Channel
- Channel lining determine maximum velocities

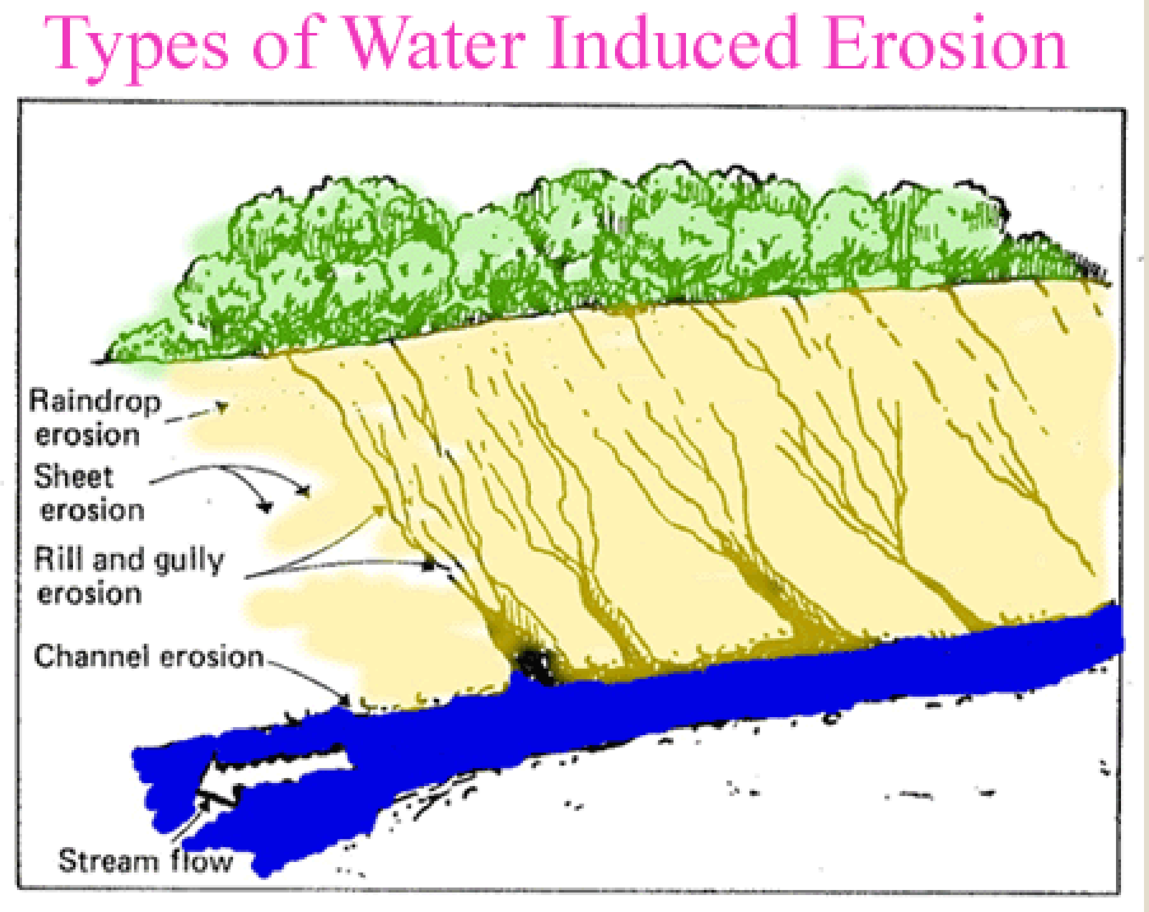


Fig. 1.3 Types of erosion. (Adapted from 1)

http://www.civil.ryerson.ca

Channel lining strategy

- Maximum anticipated velocity restricts the type of lining
- Earthen channel have lower velocity limits (most under 4 fps)
- Lined with igneous or metamorphic rock, channel velocity can reach 20 fps

Table 8–3 Maximum permissible canal velocities

	Mean velocity, for straight canals of small slope, after aging with flow depths less than 3 ft (0.9 m)					
	Clear water, no detritus		Water transporting colloidal silts		Water transporting noncolloidal silts, sands, gravels, or rock fragments	
Original material excavated for canals	ft/s	m/s	ft/s	m/s	ft/s	m/s
Fine sand (noncolloidal)	1.5	0.46	2.5	0.76	1.5	0.46
Sandy loam (noncolloidal)	1.75	0.53	2.5	0.76	2.0	0.61
Silt loam (noncolloidal)	2.0	0.61	3.0	0.91	2.0	0.61
Alluvial silt (noncolloidal)	2.0	0.61	3.5	1.07	2.0	0.61
Ordinary firm loam	2.5	0.76	3.5	1.07	2.25	0.69
Volcanic ash	2.5	0.76	3.5	1.07	2.0	0.61
Stiff clay (very colloidal)	3.75	1.14	5.0	1.52	3.0	0.91
Alluvial silt (colloidal)	3.75	1.14	5.0	1.52	3.0	0.91
Shales and hardpans	6.0	1.83	6.0	1.83	5.0	1.52
Fine gravel	2.5	0.76	5.0	1.52	3.75	1.14
Graded, loam to cobbles (when noncolloidal)	3.75	1.14	5.0	1.52	5.0	1.52
Graded silt to cobbles (when colloidal)	4.0	1.22	5.5	1.68	5.0	1.52
Coarse gravel (noncolloidal)	4.0	1.22	6.0	1.83	6.5	1.98
Cobbles and shingles	5.0	1.52	5.5	1.68	6.5	1.98

NRCS (2007)

Traditional lining strategies

- When strong shear forces are anticipated, lining strategies include
  - Concrete
  - Rip-rap
  - Flexamat ®
  - Gabion

Cellular confinement systems (CCS) alternative

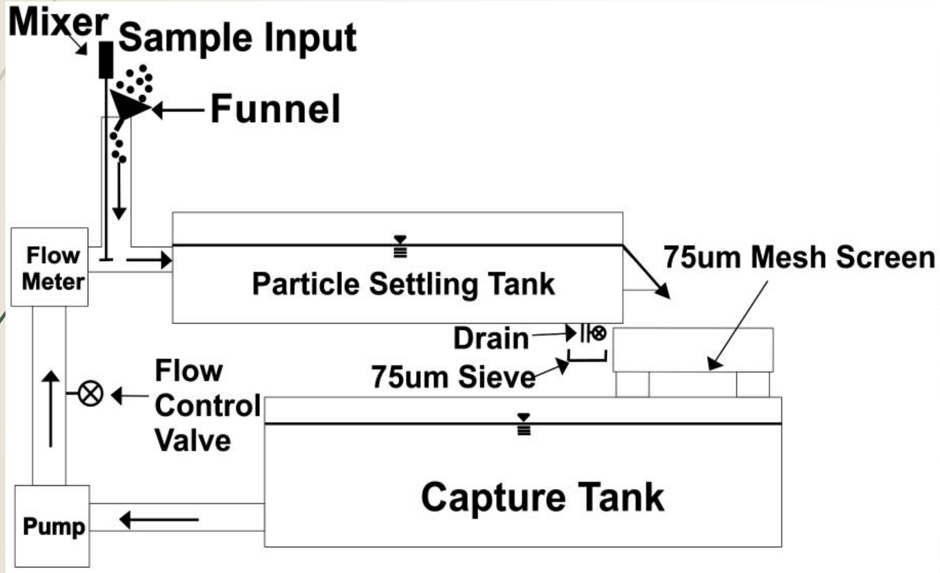
- CCS are constructed with HDPE plastic, forming grids
- CCS has been used for channel lining, soil improvement, slope stability, etc.
- CCS deployments normally involve use of media

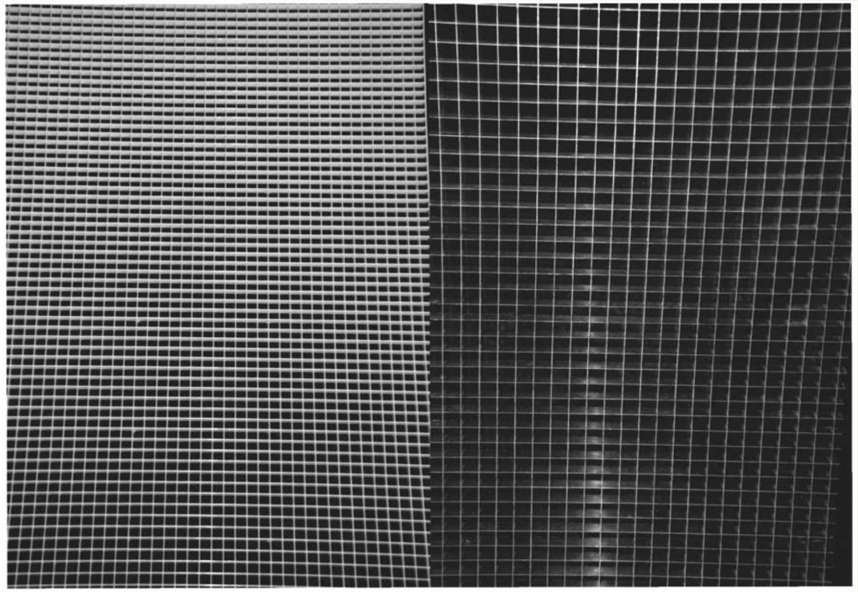
Cost issues

- Alternatives such as CCS, rip-rap, concrete, etc. for channel lining will have cost issues at location that are faraway from quarries
- On the other hand, vegetated channels require time before these can be established and resist shear forces
- A lower-cost alternative that can be rapidly deployed is desirable

Related research – He and Marsalek (2014)

- Presented and evaluated a square bottom grid structure (BGS)
- Experiments evaluated improvement of particle settling rates



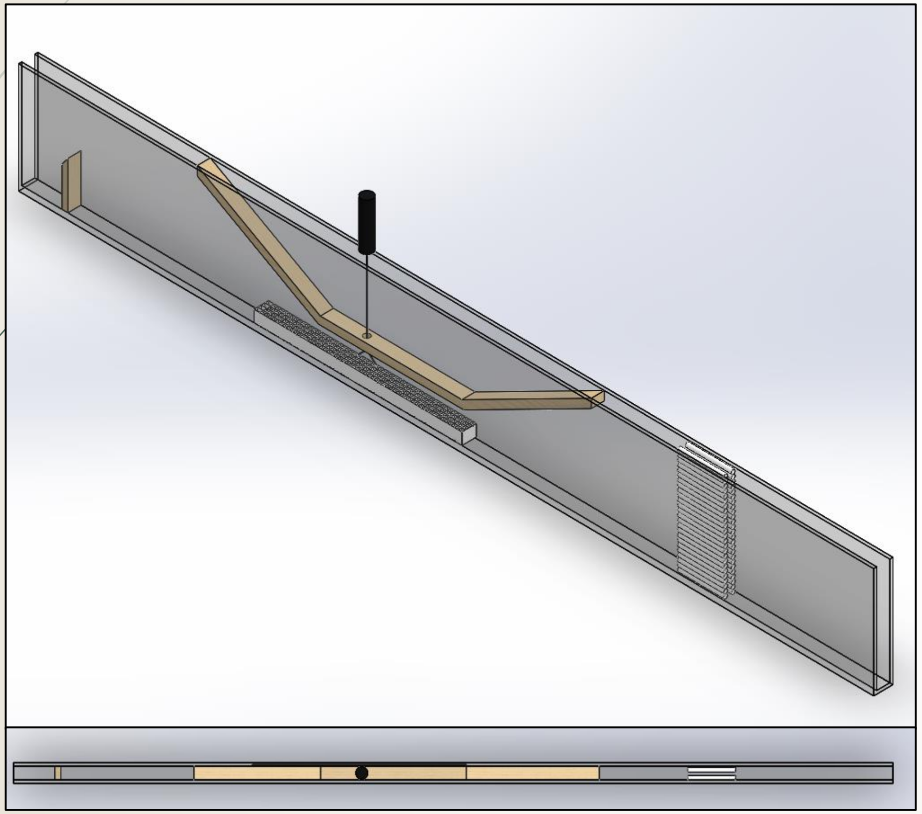


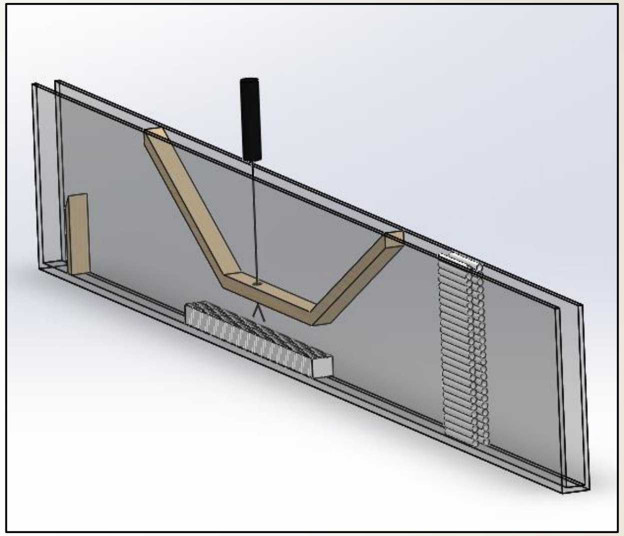
- Found 10-30% increase in particle removal efficiency when compared to the control. Not tested for erosion nor suspension.
- Stated efficiency more notable of BGS as flow rates increased

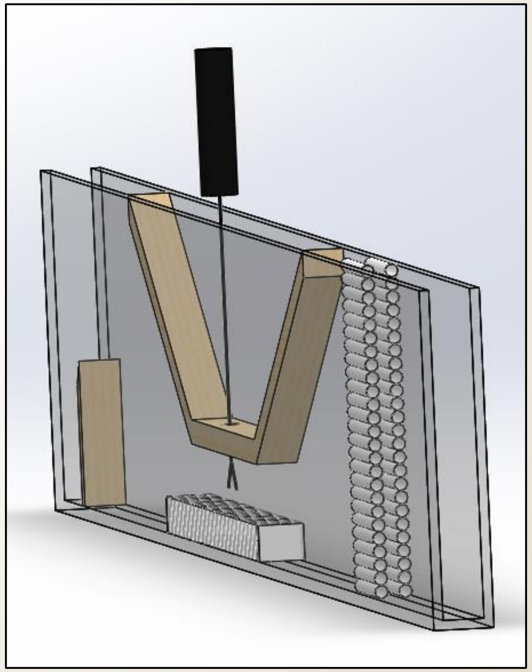
Phase 1 – Laboratory and CFD evaluation

Phase 1 – Laboratory evaluation

- Experimental apparatus
  - 10-m long acrylic-walled channel

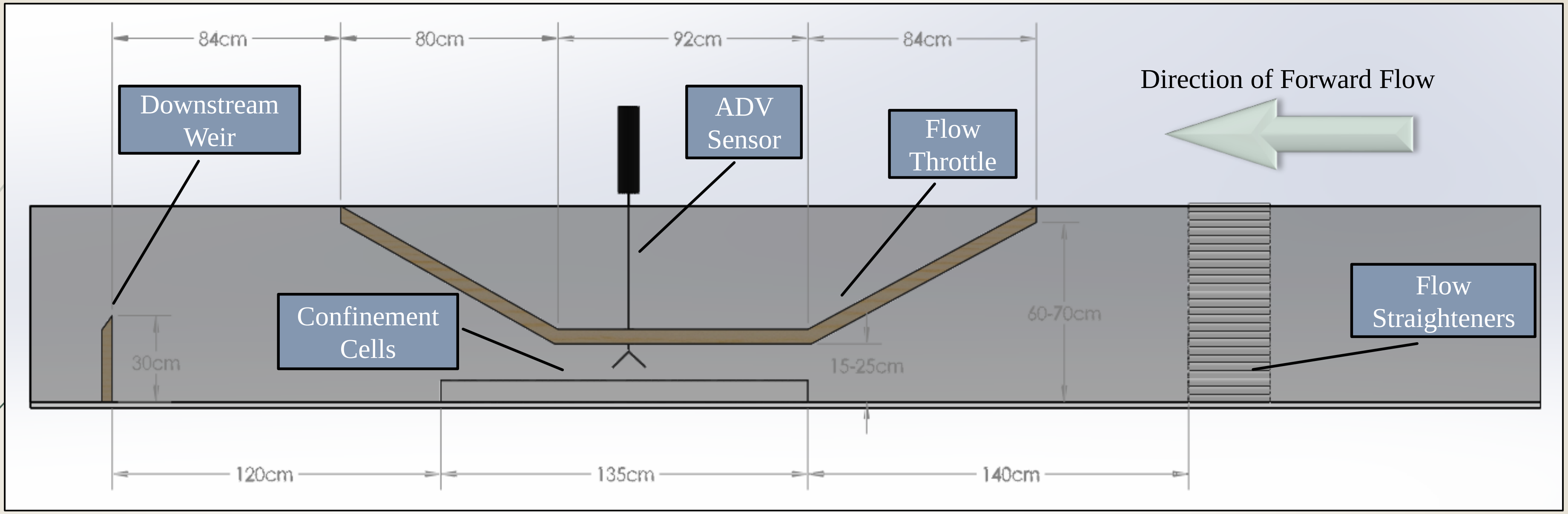


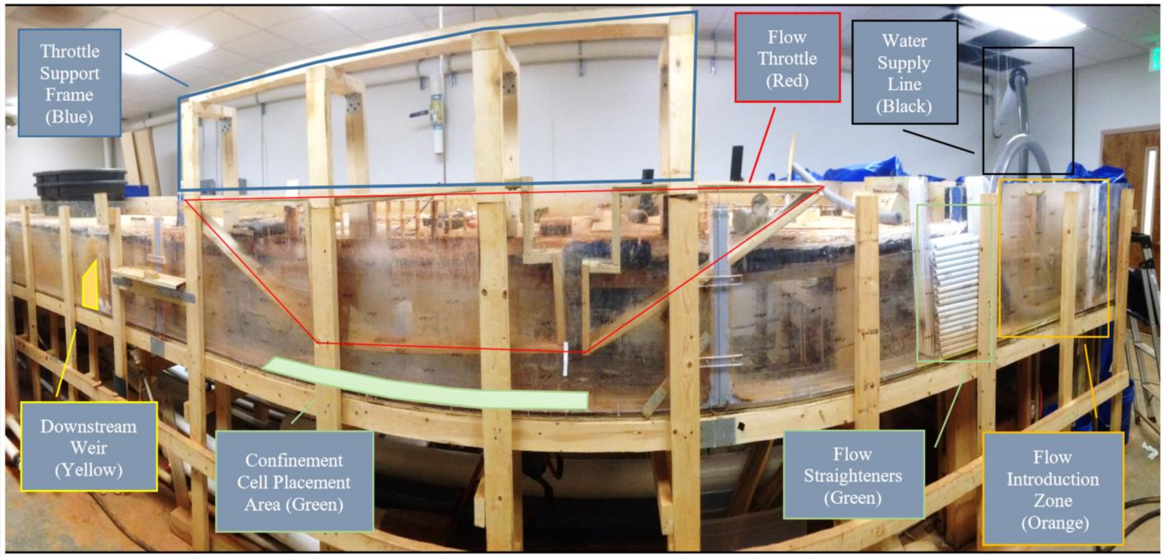




  - Constructed in order to provide placement of confinement cells in an area of high shear flow

Experimental Program





Experimental Program

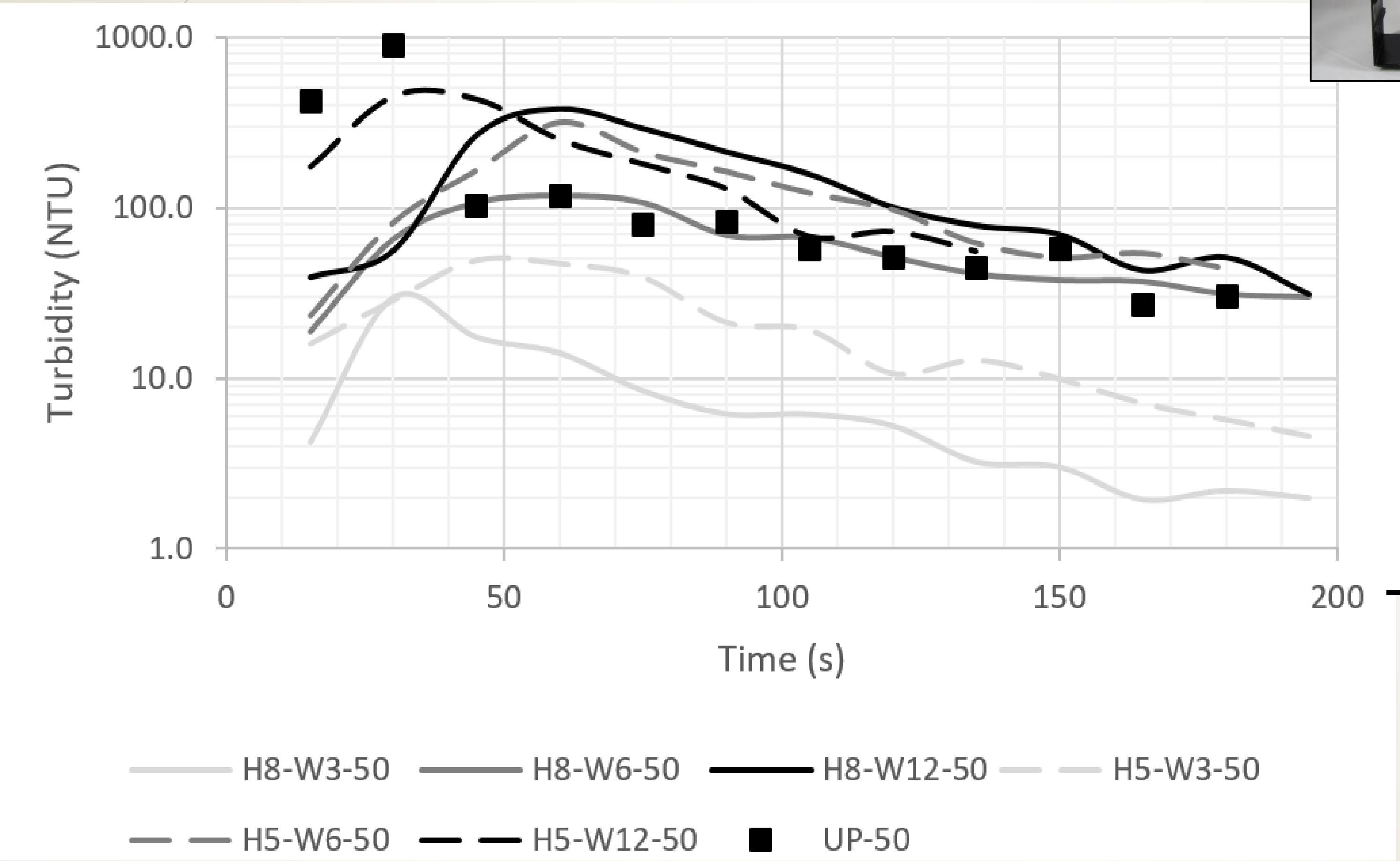
Experimental runs – typical results

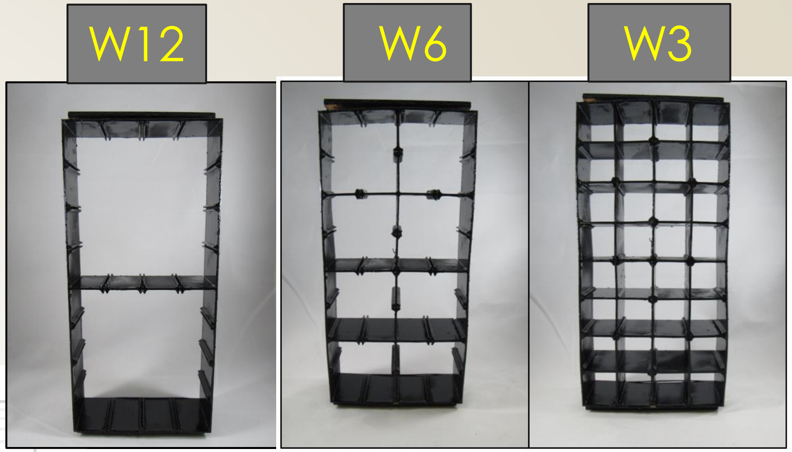
Unprotected, UP-50

Protected, H8-W12-50

Protected, H8-W3-50

Turbidity results, V_{flow}=0.50 m/s

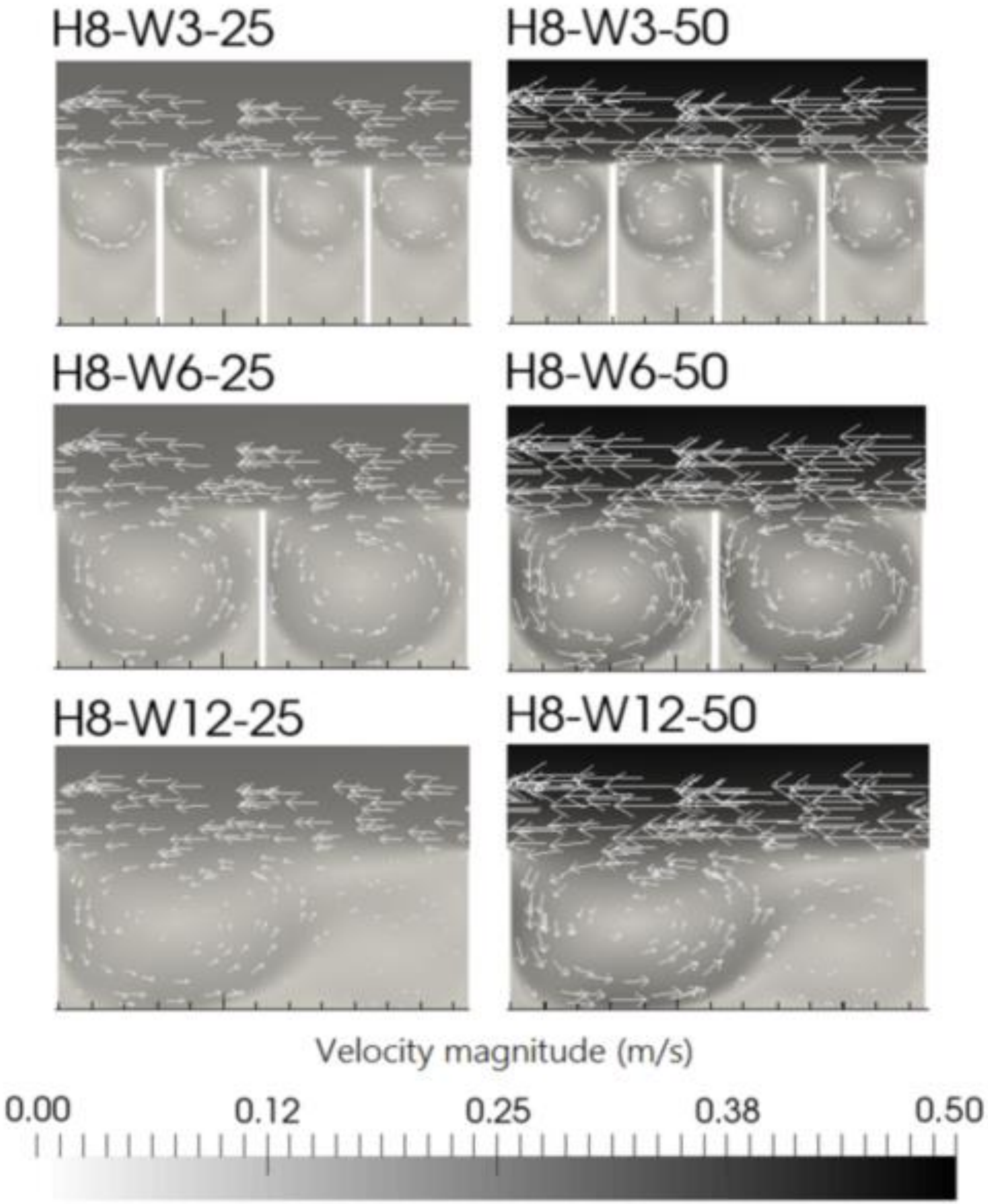




Config.	Peak	Avg.
UP-50	912.5	209.3
H5-W12-50	451.3	201.7
H8-W12-50	376.0	174.8
H5-W6-50	316.0	137.7
H8-W6-50	117.7	71.5
H5-W3-50	49.0	27.0
H8-W3-50	29.9	10.5

Numerical modeling results

- CFD modeling with OpenFOAM confirmed that more protective geometries had a much smaller shear stress at the bottom of cells



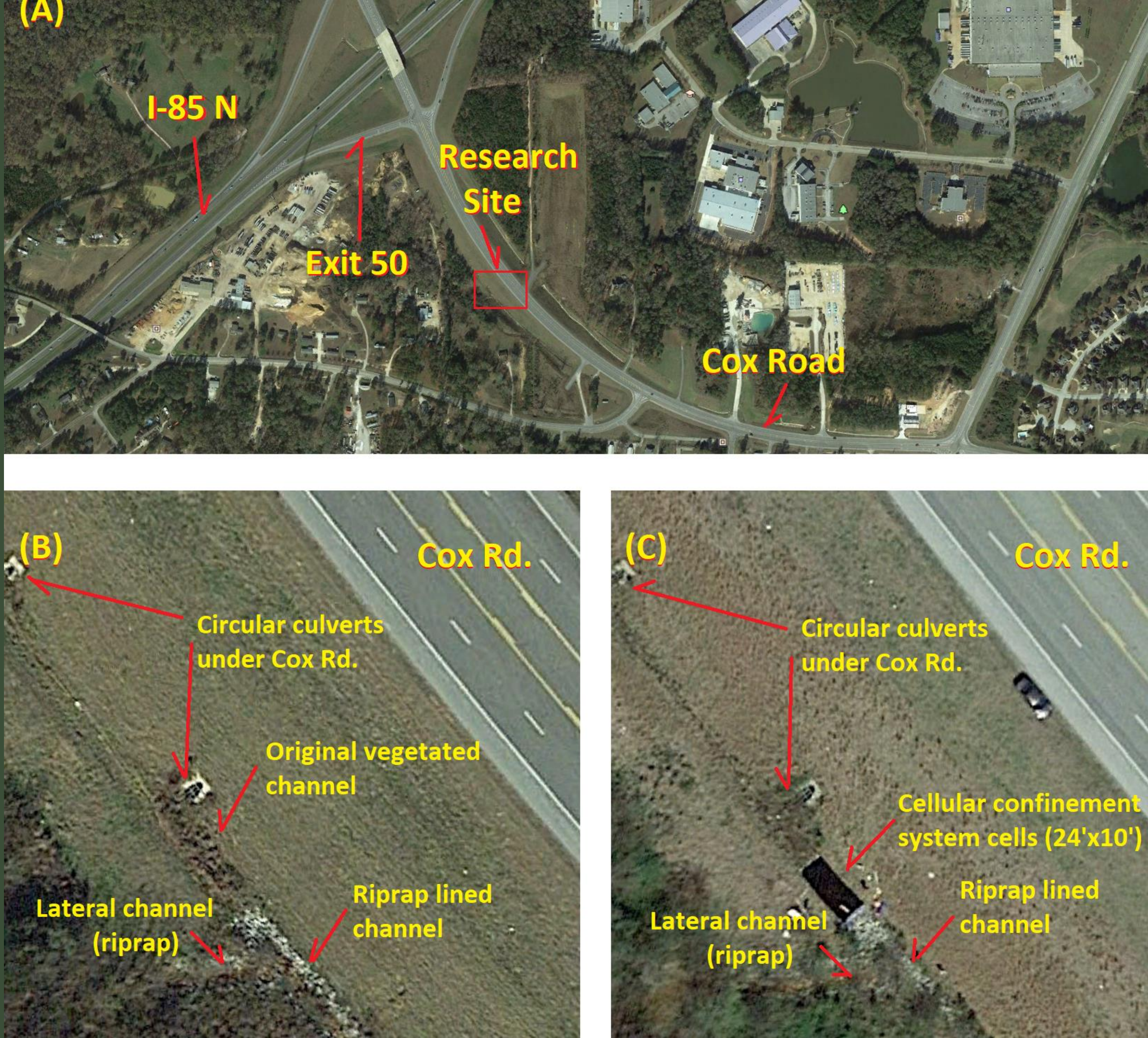
Phase 2 – Field test validation

- Alabama Water Resources Research Institute funded research focused on the development of a CCS-lined channel apparatus to study erosion
- Post-construction setting: With the cooperation with the City of Auburn, a site was selected for the study: drainage of Cox Rd. in Auburn, AL
- Channel initially lined either with rip-rap or vegetation
- Replacement for a 24-ft long section of empty CCS, 12-inch height, 11-inch wide

Research site location

Near exit 50, I-85N

Auburn, AL

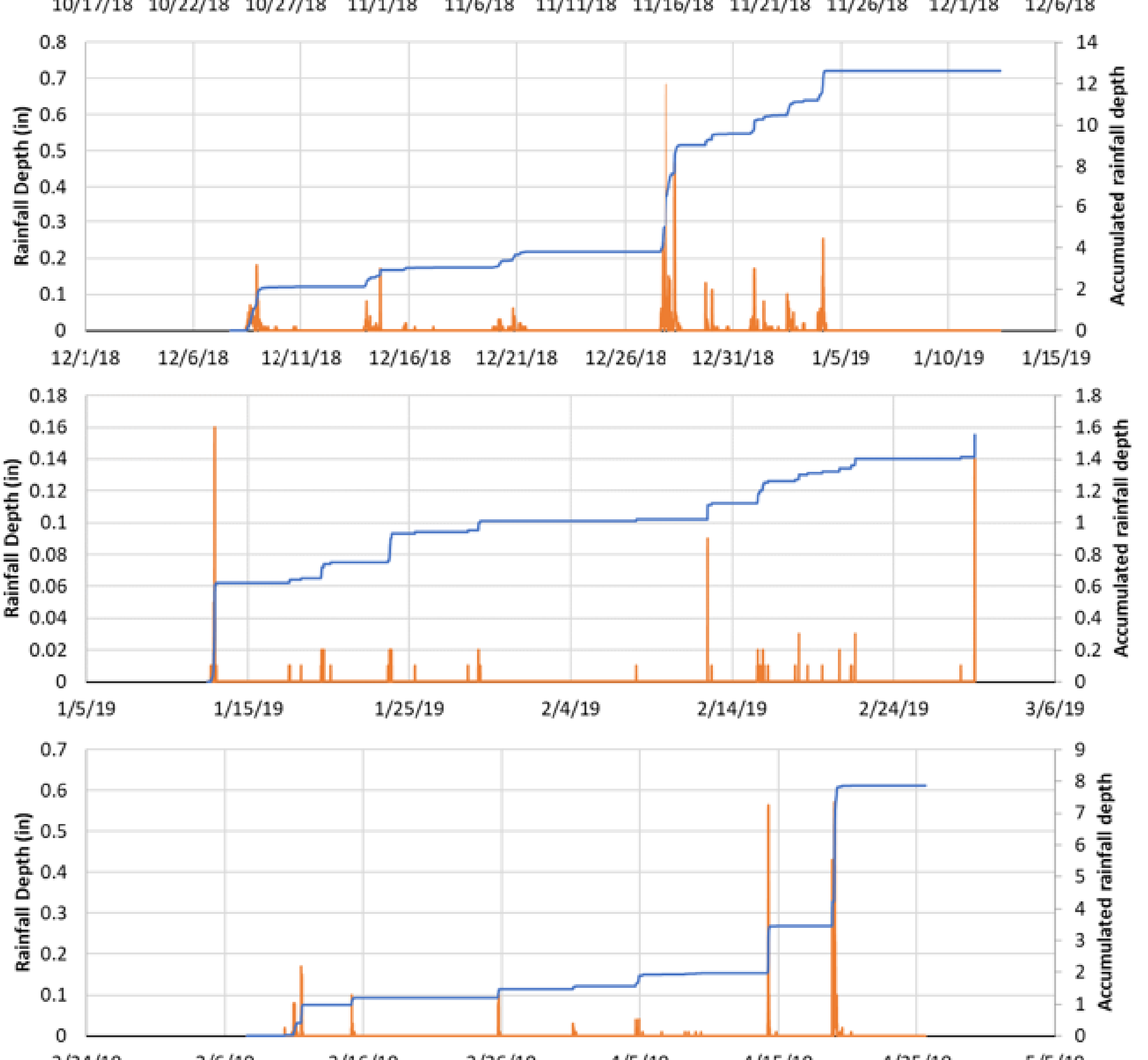


Rapid installation, no machinery

Upstream/downstream details – physical protection, flow metering

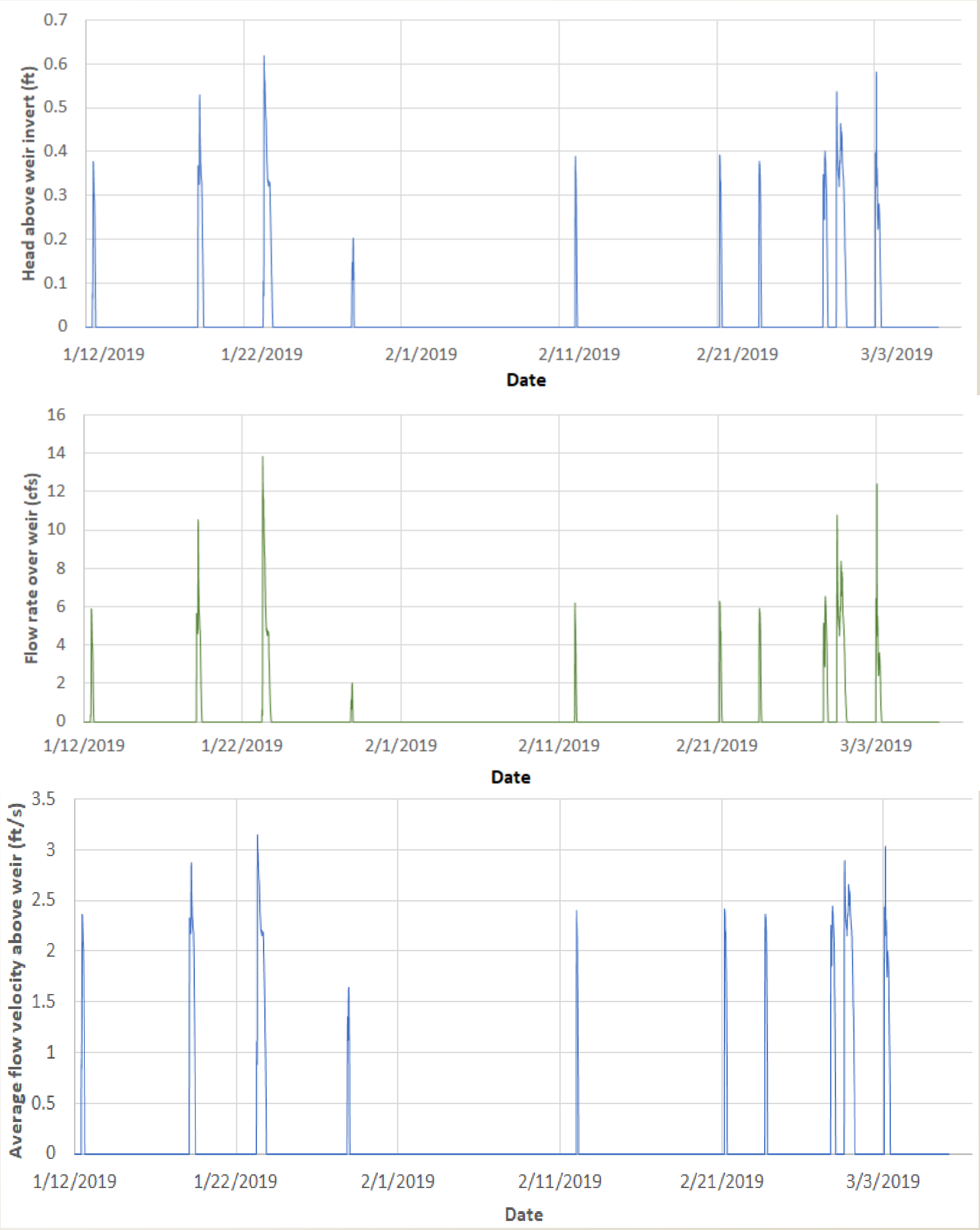
Hydrological characterization

- Rainfall measurement
- Head above the discharging weir
  - Flow rate measurement
- Flow velocities with current meter



Hydrological characterization

- 15-minute interval sampling for water levels above weir
- Head-discharge for broad crested weir helped to determine peak flows within CCS
- Key was to determine velocity over cells
- Current meter indicated velocities within cells always under 0.1 ft/s



Erosion assessment of field apparatus

- Based on turbidity samples
  - Upstream turbidity levels in the range of 60-90 NTU in most samples
  - Downstream turbidity levels either in the same level, sometimes 5-10 NTU lower
- Based on visual inspection
  - Removal of cells performed 4 months into experiments to inspect conditions of the channel bed
  - No signs of erosion noticed

Water quality characterization

- For three different rain events samples were taken upstream and downstream from apparatus
- Analysis performed at University of Alabama
- Results have indicated that when flows were active in the CCS water quality parameters improved as it passed through the cells
- Exception was the 3rd rain event studies
  - The first major flow event in four weeks
  - Hypothesis is that the contaminants captured downstream of the CCS were remnants of previous runoff organic matter that remained in the system but sloughed off due to the calm flow

Table 2. Water Quality Results

	Sample Name	UV_{254} (cm^{-1})	DOC (mg/L)	SUVA ($mg*L^{-1}*cm^{-1}$)	Alkalinity (mg/L $CaCO_3$)	COD (mg/L)	pH	Nitrate (mg/L NO_3-N)	Ammonium (mg/L NH_3-N)	Reactive Phosphorous (mg/L – PO_4 - P)	Total Phosphorous (mg/L – P)	TKN (mg/L)
October 2018	Middle	0.43	11.6	3.73	54	519	7.3	0.403	BDL	BDL	BDL	BDL
	Downstream	0.11	4.76	2.34	27.2	496	7.6	0.404	BDL	BDL	BDL	BDL
	Removal (%)	74 %	59%	37%	50%	4%	-	0%	-	-	-	-
December 2018	Upstream	0.37	11.3	3.29	40.8	126	7.2	0.406	0.086	0.393	0.446	BDL
	Middle	0.41	11.1	3.72	37.4	87	7.3	0.414	0.0625	0.412	0.453	BDL
	Downstream	0.21	7.96	2.67	25.5	109	7.1	0.300	0.062	0.274	0.296	BDL
	Removal (%)	43 %	30%	19%	38%	14%	-	26%	28%	30%	34%	-
June 2019	Upstream	0.65	14.5	4.47	78.2	68	7.6	BDL	0.052	BDL	0.195	BDL
	Middle	0.67	14.9	4.48	64.6	79	7.5	BDL	0.06	BDL	0.22	BDL
	Downstream	0.69	15.4	4.51	57.8	87	7.5	BDL	0.07	BDL	0.23	BDL
	Removal (%)	-7%	-6%	-1%	26%	-29%	-	-	-29%	-	-18%	-

***BDL – below detection limit**

Final remarks and future research

- It is believed that the tests show promising results for CCS to control erosion in channels
- Methods to improve anchoring and installation were devised during experimental period, certainly can be further improved
- Some questions still need further evaluation
  - Velocities associated with CCS use could be potentially higher, but field conditions were never above 4 fps
  - Quantification of capability of CCS to retain sediments could not be performed
  - Further evaluation of water quality characteristics would assess and quantify long-term performance of CCS.
  - CCS could be also be used to control channel erosion in in construction sites

Thank you!

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