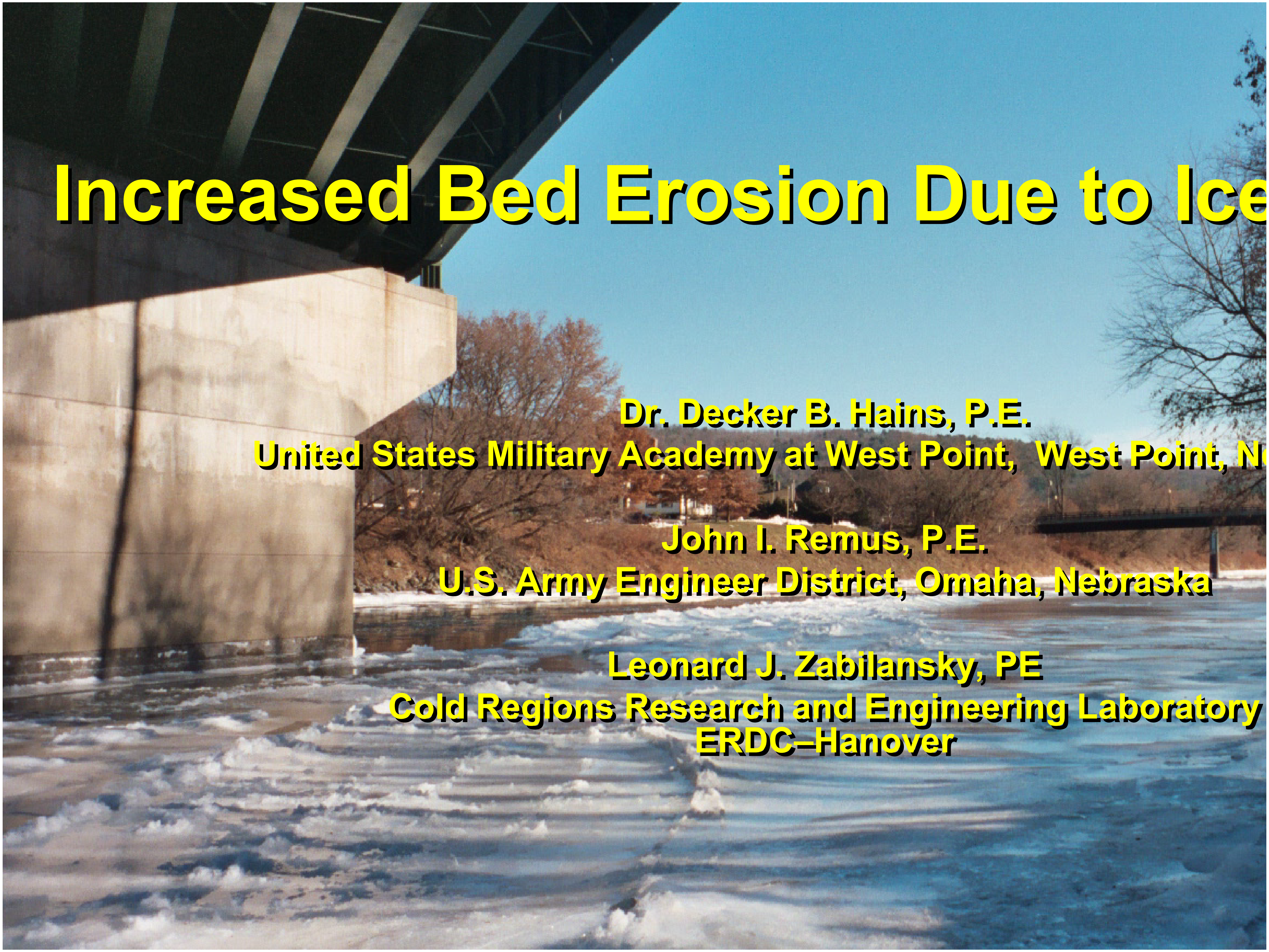

Increased Bed Erosion Due to Ice

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United States Military Academy at West Point, West Point, N

John I. Remus, P.E.
U.S. Army Engineer District, Omaha, Nebraska

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Bridge Street Bridge Late 60's

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What Happened?

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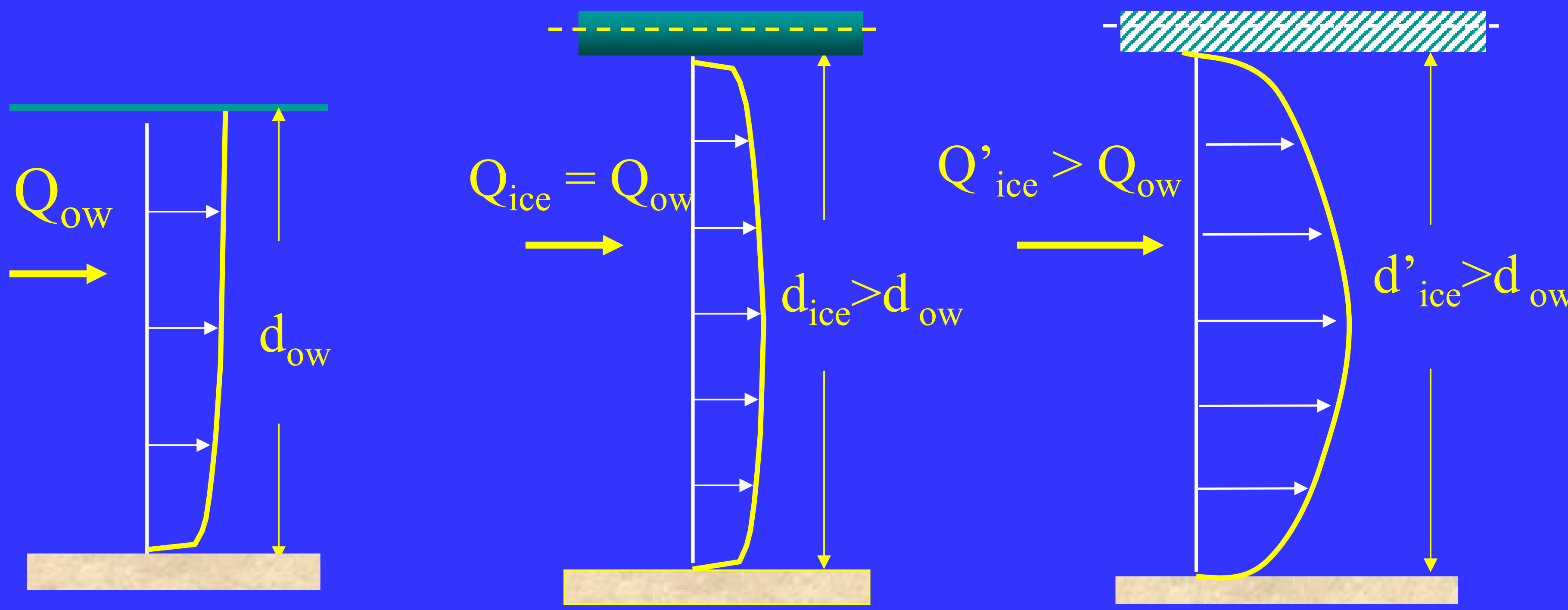
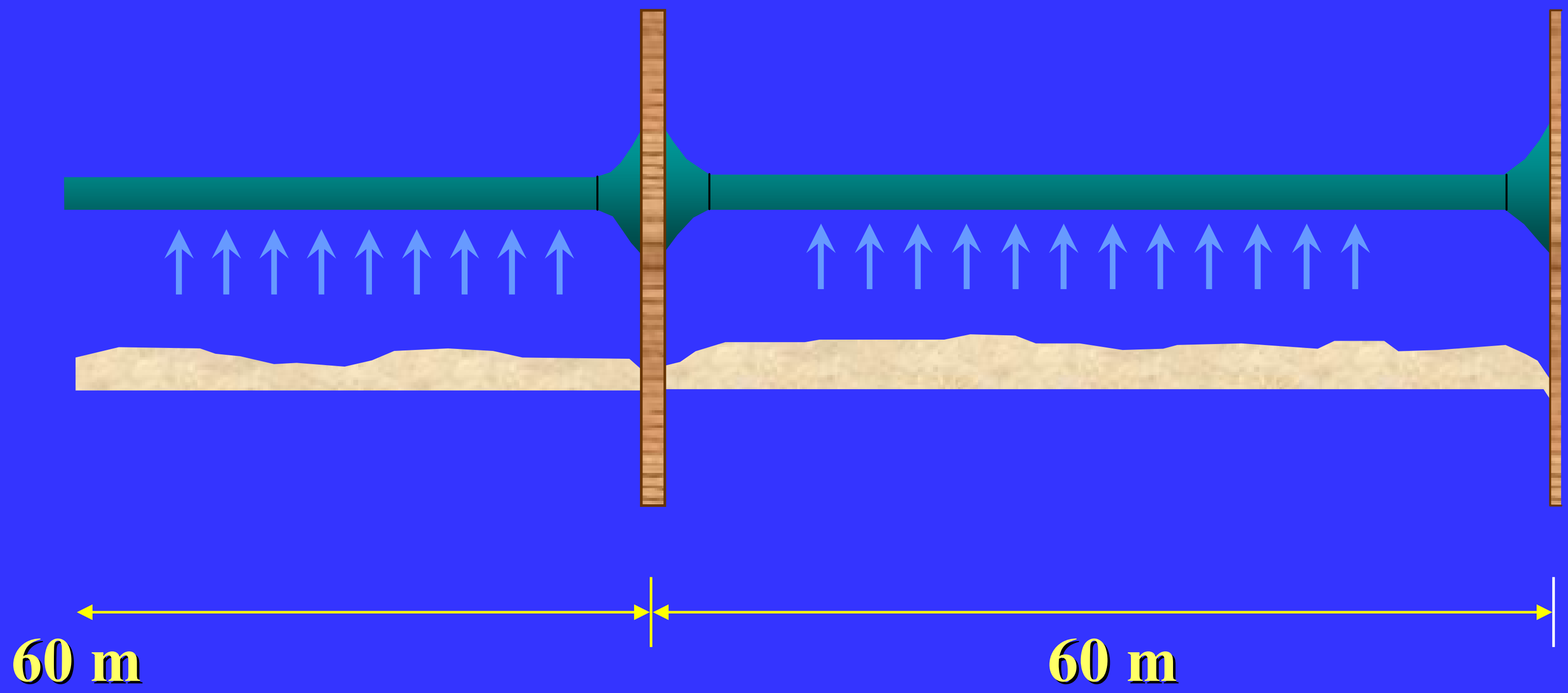
Open Water

Stationary-Floating Cover

Fixed Cover



Ice Cover Effects on Narrow Rivers
Initial Water Level



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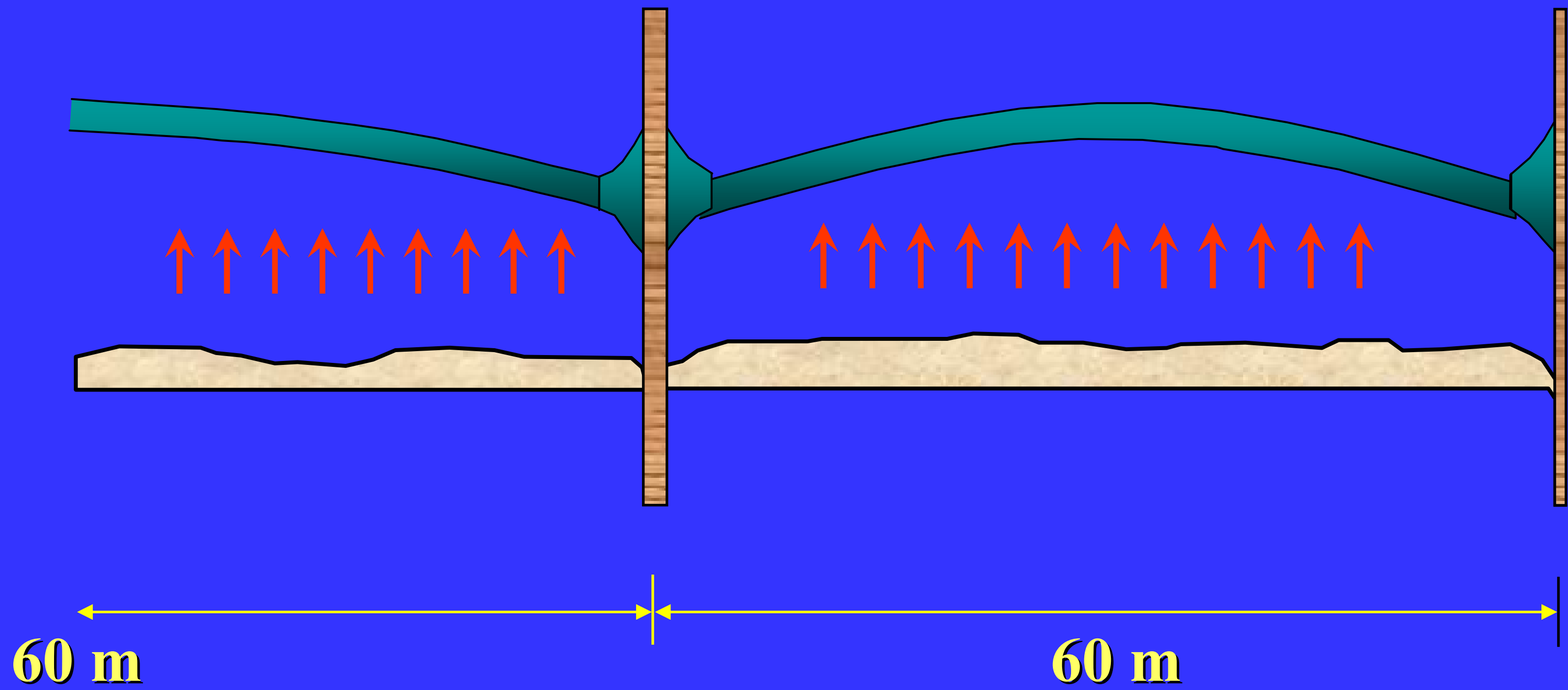
Ice Cover Effects on Narrow Rivers
Rising Water Level



Characteristic length (*l*) for 50 cm ice thickness (*h*)

Approximated by $16h^{3/4}$, l = 9.5 m

Radius of Influence (5*l) is >> Half the Span

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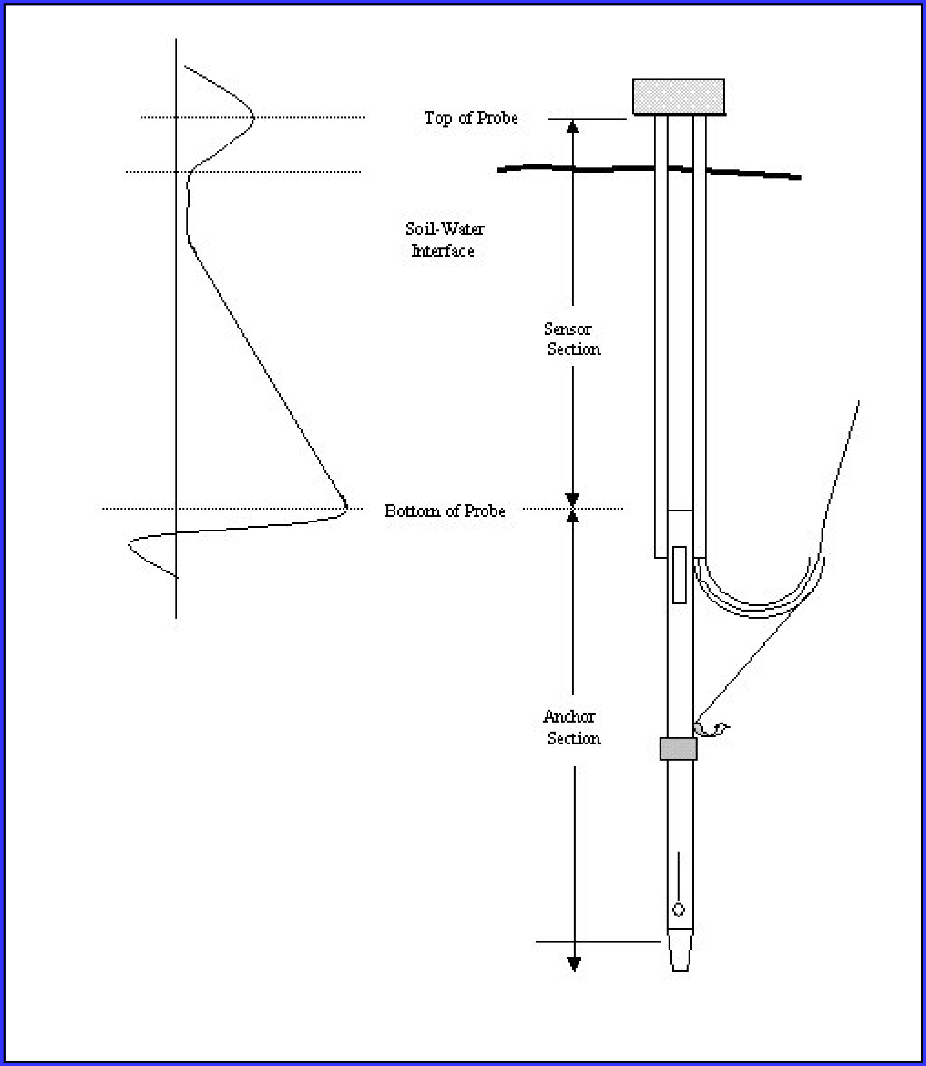
General Background

- Field Measurements
  - Scour probes using Time-Domain Reflectometry-independent of surface conditions
  - Stage must increase 2-4 times the ice thickness before break-up
  - Ice cover does not immediately respond to changes in stage
  - Increases above the freeze-up discharge but below the break-up threshold → increases in mean velocity

TDR Scour Probes



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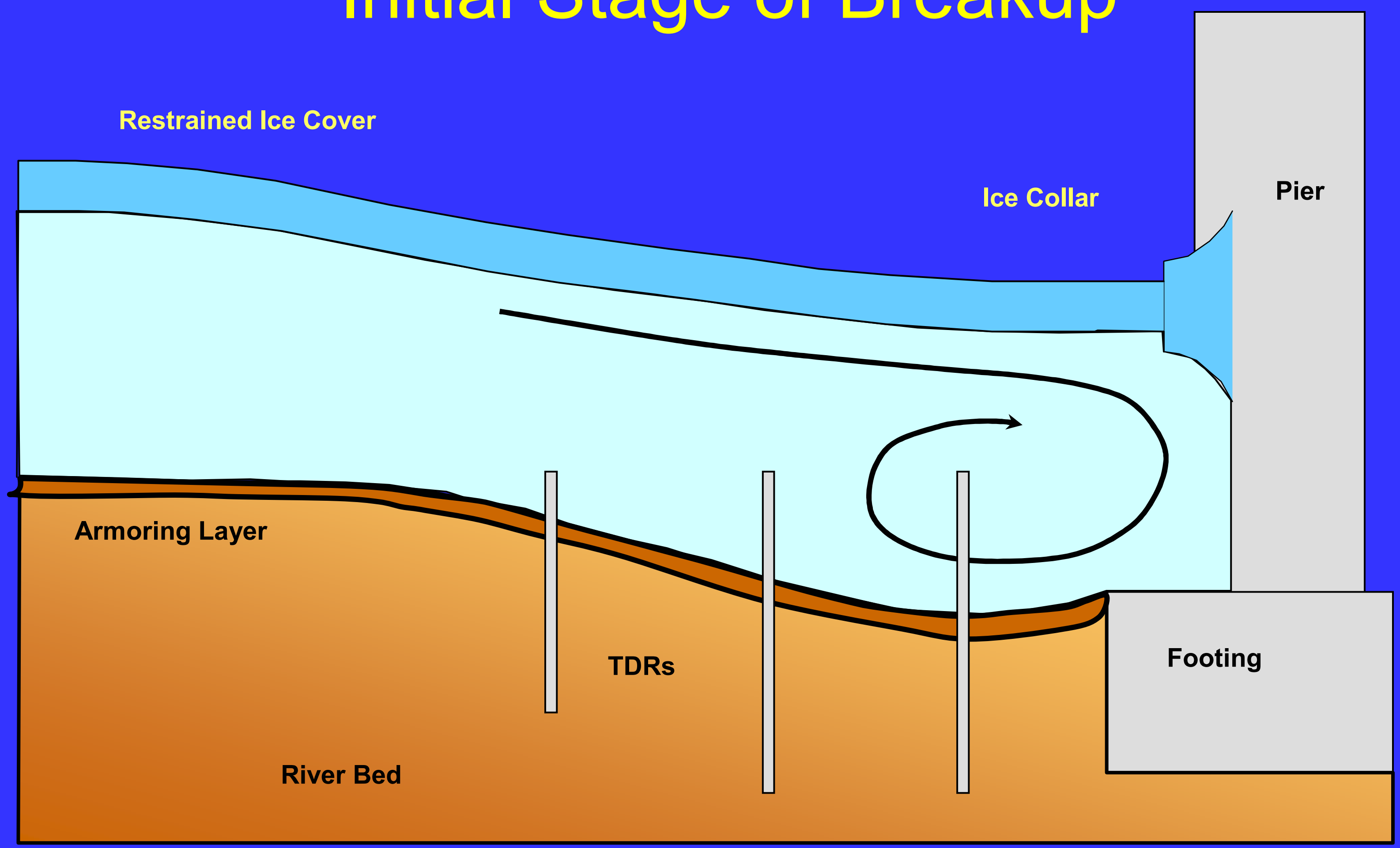
Ice Cover Rt. 5 Bridge

Scour Under an Ice Cover
Initial Stage of Breakup



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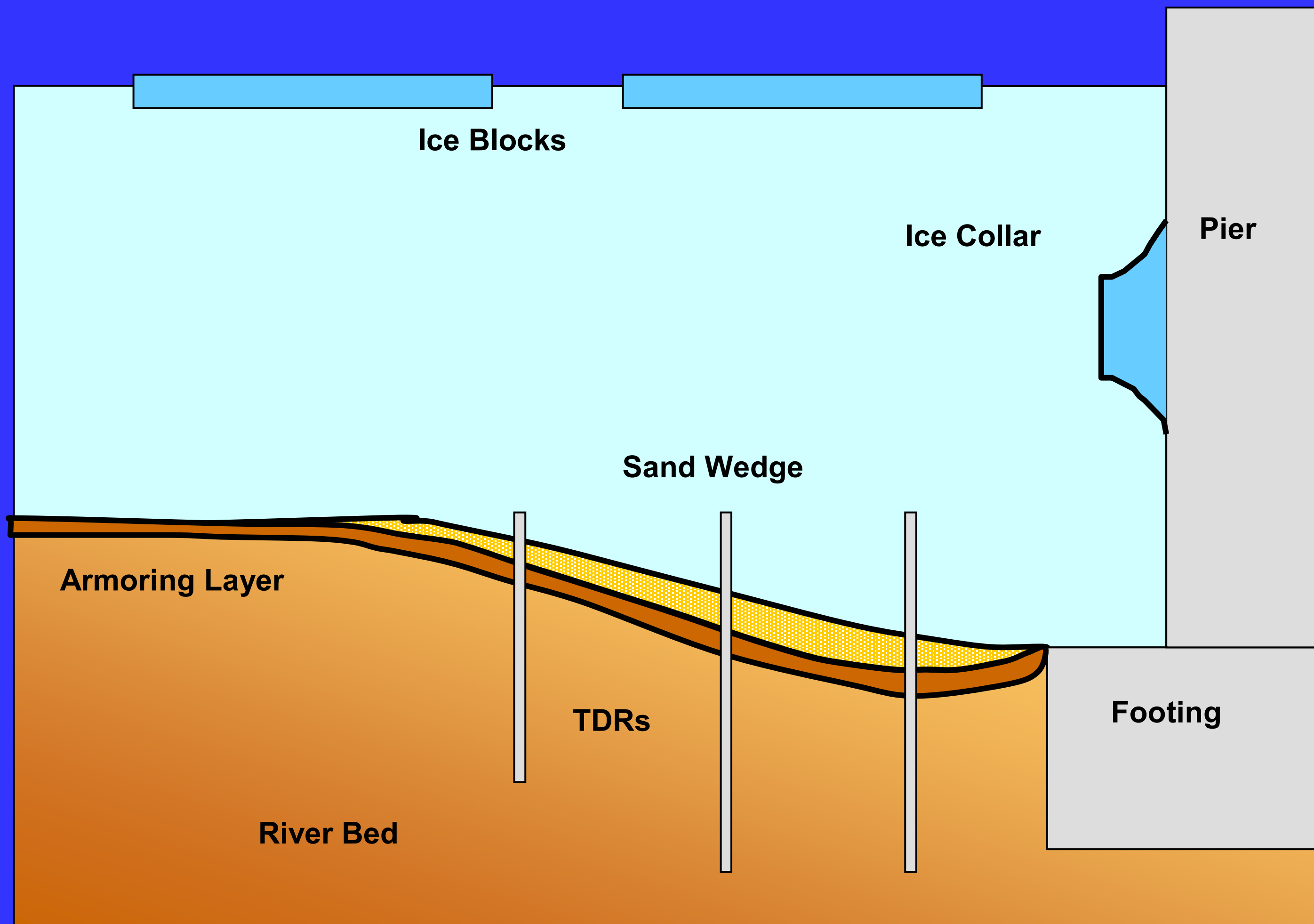
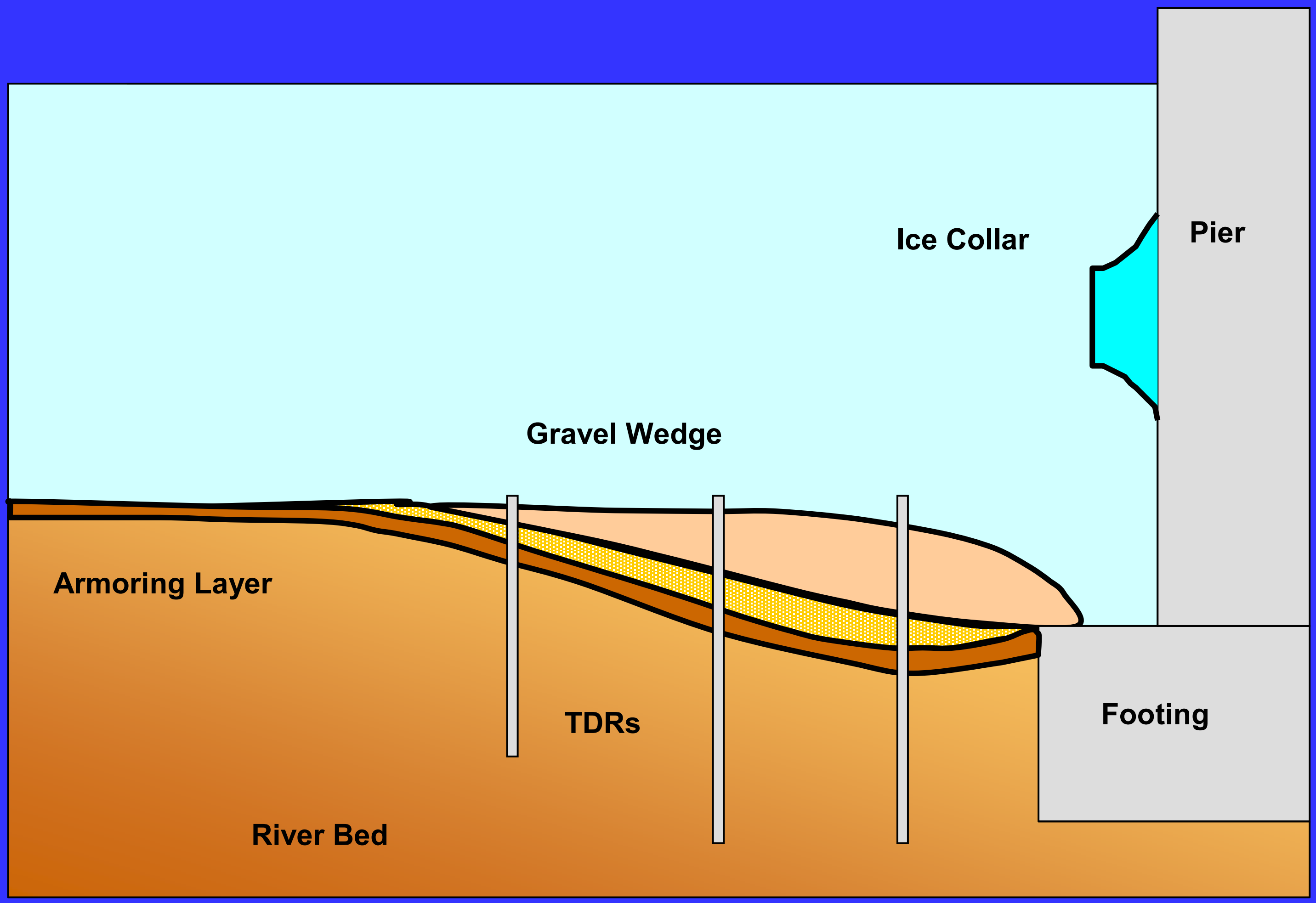
Scour Under an Ice Cover Immediately Following Breakup



Scour Under an Ice Cover
High Water Following Breakup



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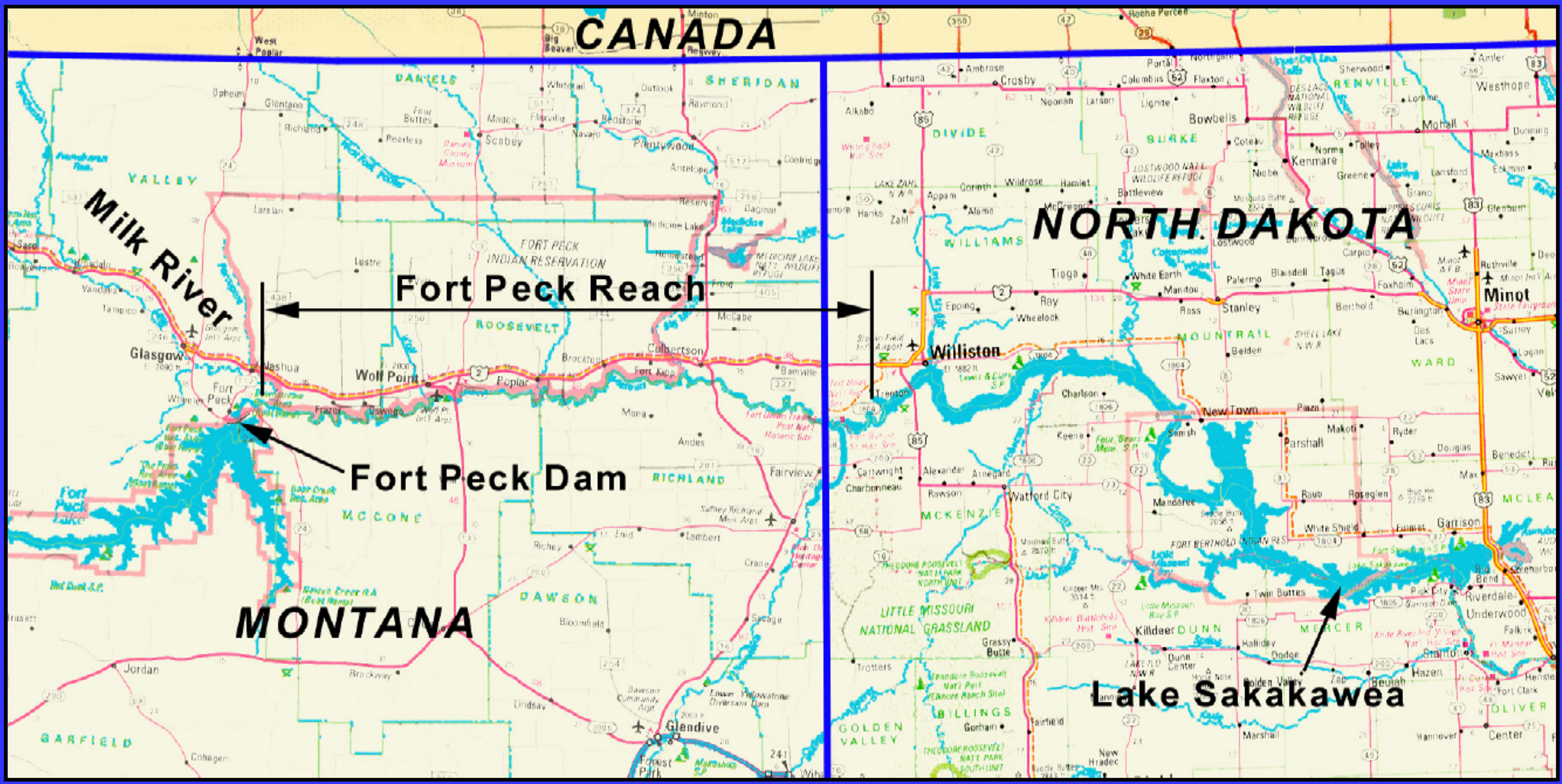
Fort Peck Reach of Missouri River



Five sites with periodic and continuous monitoring along the 170 mile reach

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Culbertson, Montana

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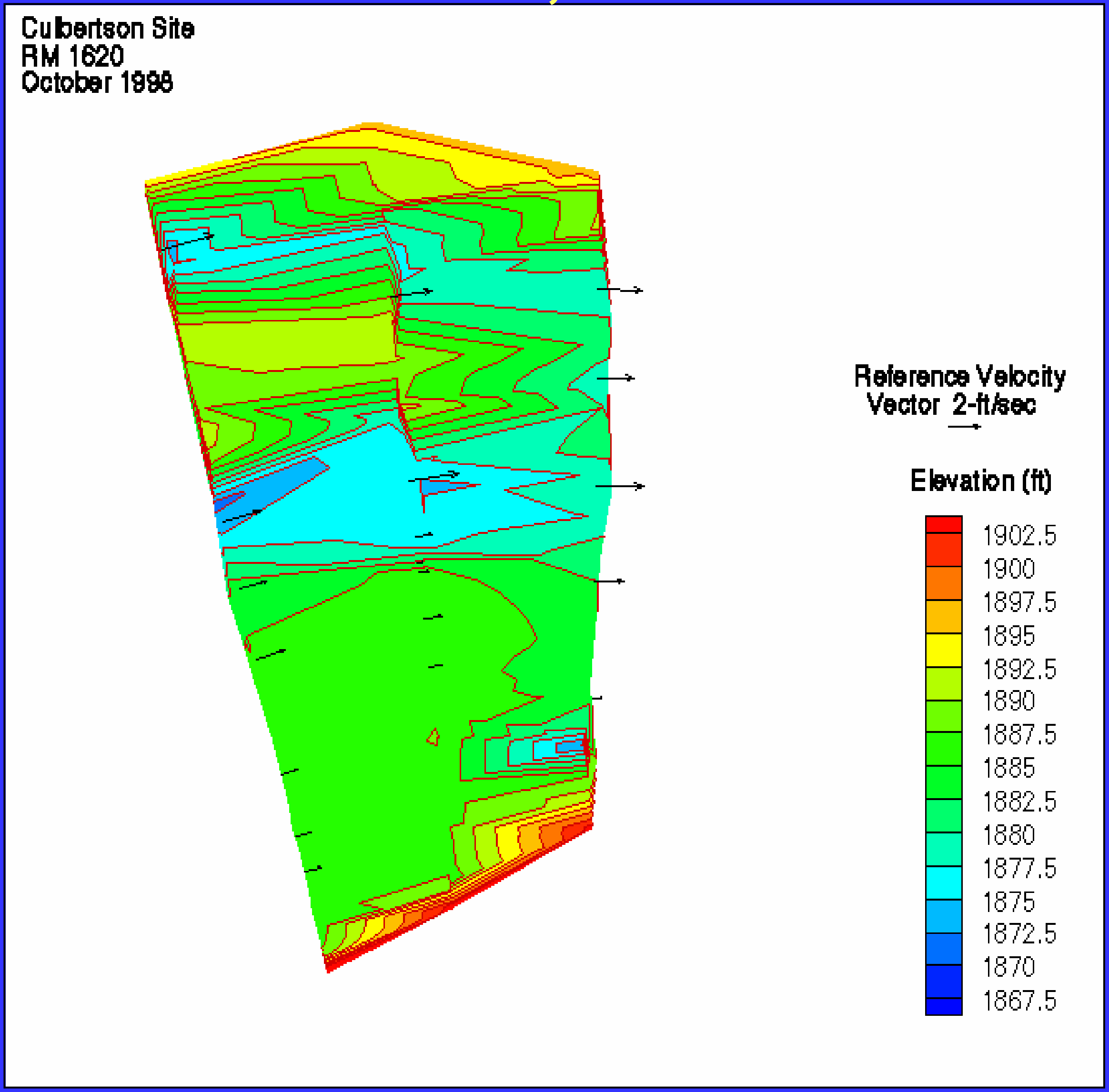
Culbertson, Montana



Culbertson, Montana

January

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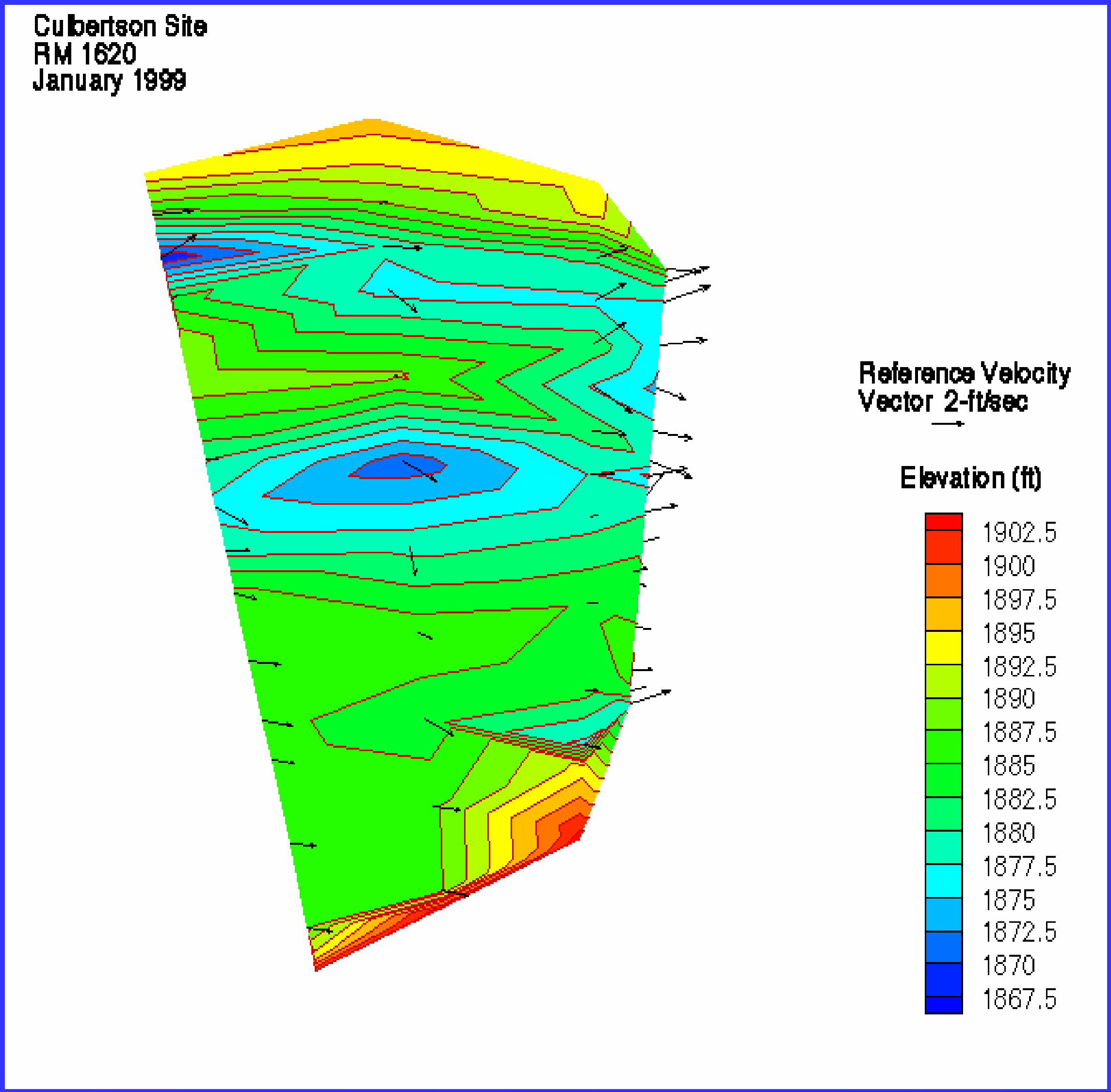
Culbertson, Montana



Culbertson, Montana

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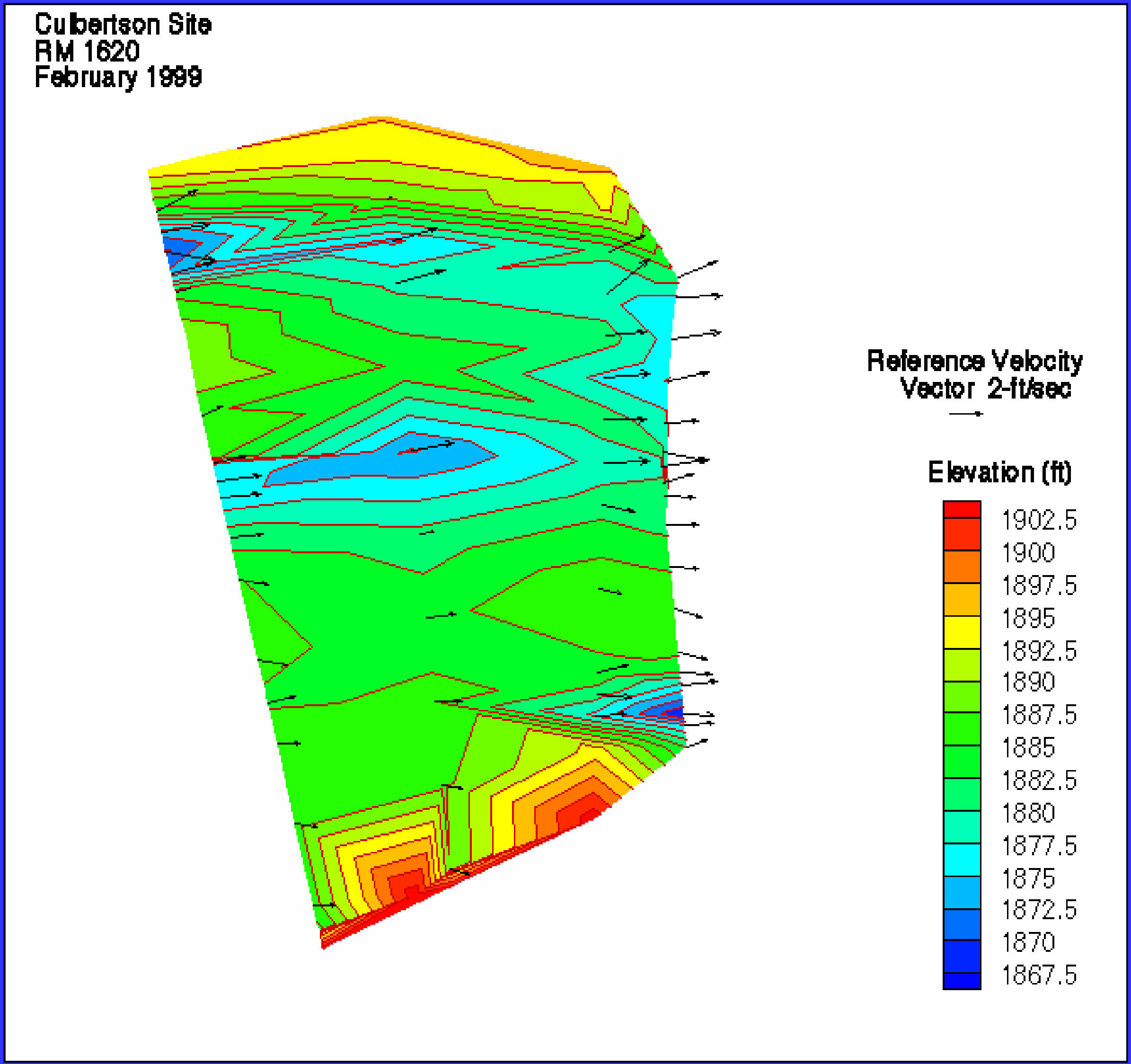
Culbertson, Montana



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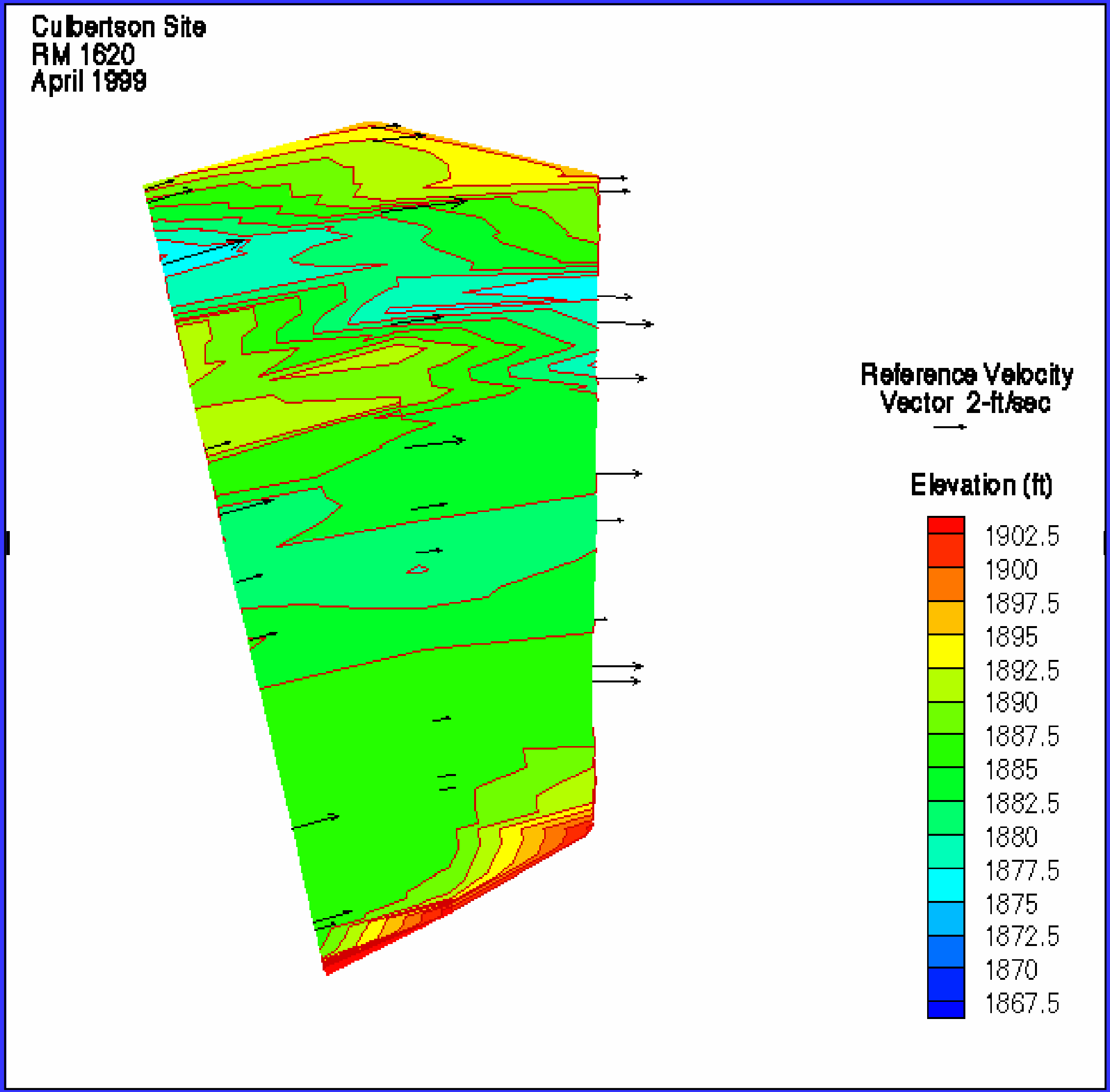
Culbertson, Montana

Culbertson, Montana

April

US Army Corps of Engineers

Culbertson, Montana



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Milltown Dam located 120 miles downstream of historic Butte and Anaconda copper mining operations.

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Testing Parameters

- Clear Water Scour
- Cylindrical Pier
- Smooth & Rough Cover
- One type of Uniform Sediment
  (d_{50} = 0.13 mm)
- Two Pressure Conditions
  - 3” of head
  - 6” of head

Effect of Flow Intensity: V/V_c

- Clear-water Scour- no sediment transport on the bed

$$V_c > V \geq 0.5\ V_c$$

- Live-bed Scour- sediment transport on the bed

$$V \geq V_c$$

- For the sediment in this study, V_c = 0.9 fps

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Test Conditions

Number of Tests	Cover Condition	Relative Cover Roughness
6	Open Water/Free Surface	N/A
5	Floating	Smooth
1	Floating	Rough
6	Fixed	Smooth
2	Fixed	Rough

Smooth Cover

Rough Cover

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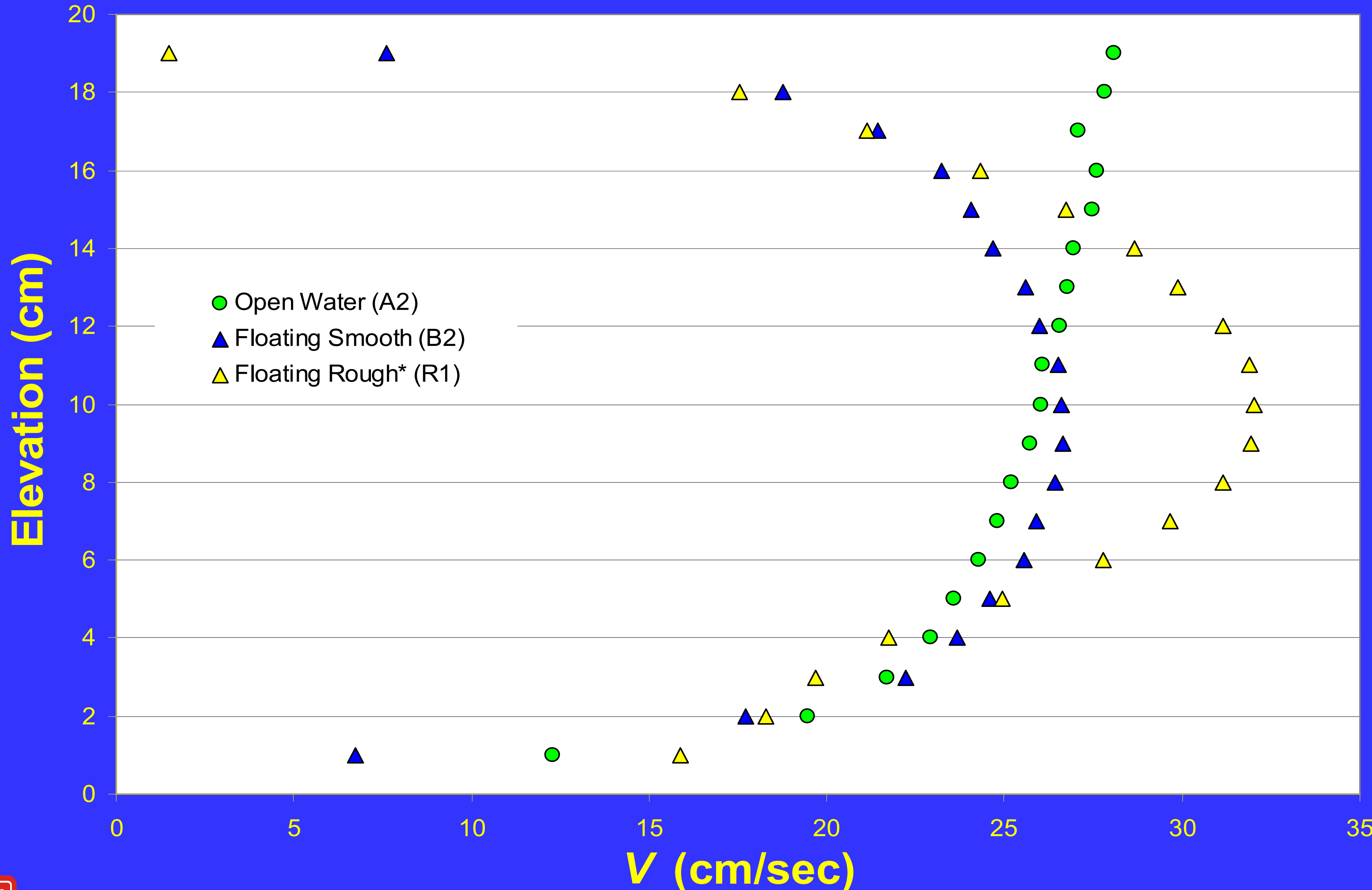
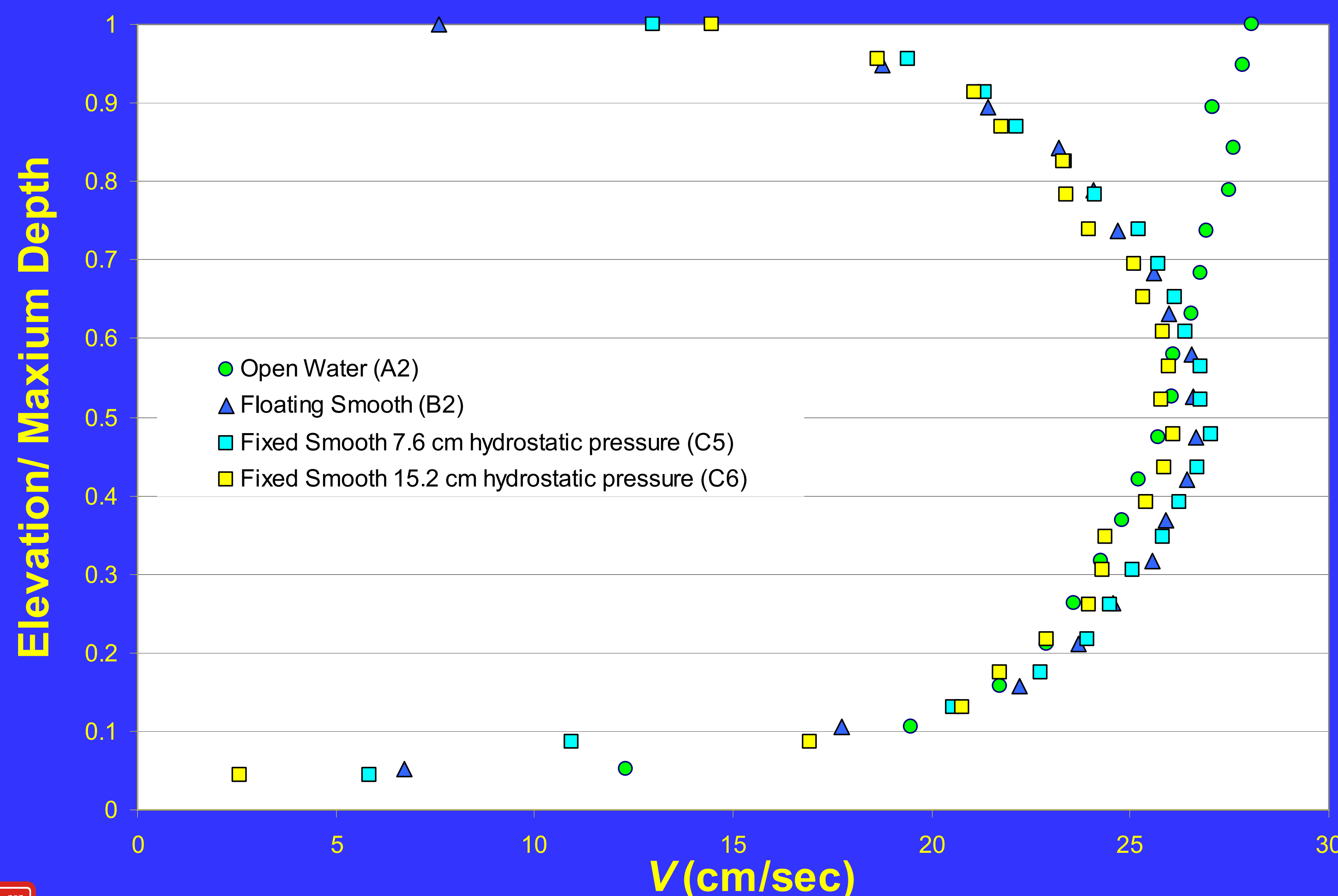
Velocity 1.96 cm/s, Vavg/Vc = 0.8589



Velocity 1.96 cm/s, Vavg/Vc = 0.8589



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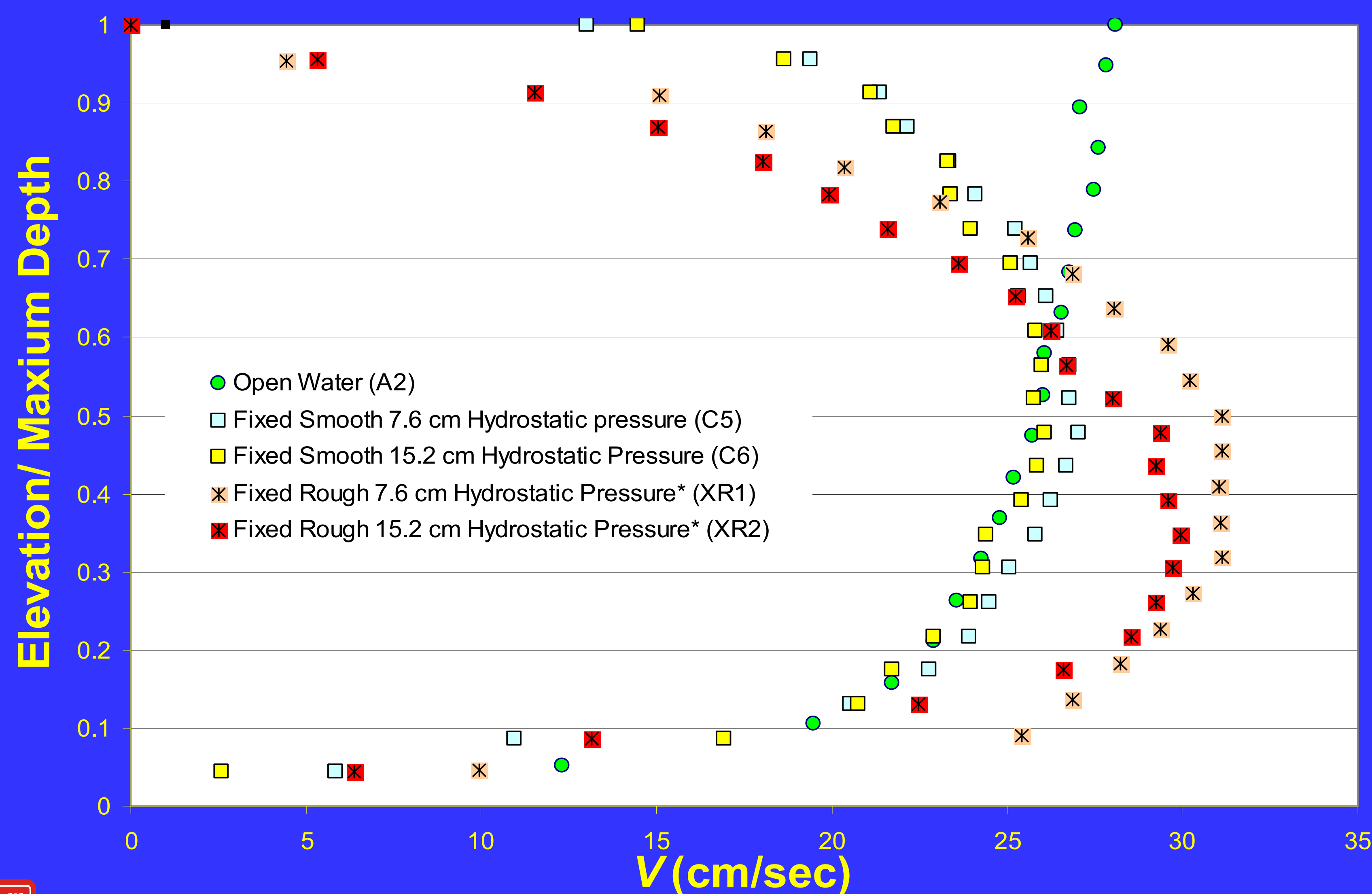
Velocity 1.96 cm/s, Vavg/Vc = 0.8589



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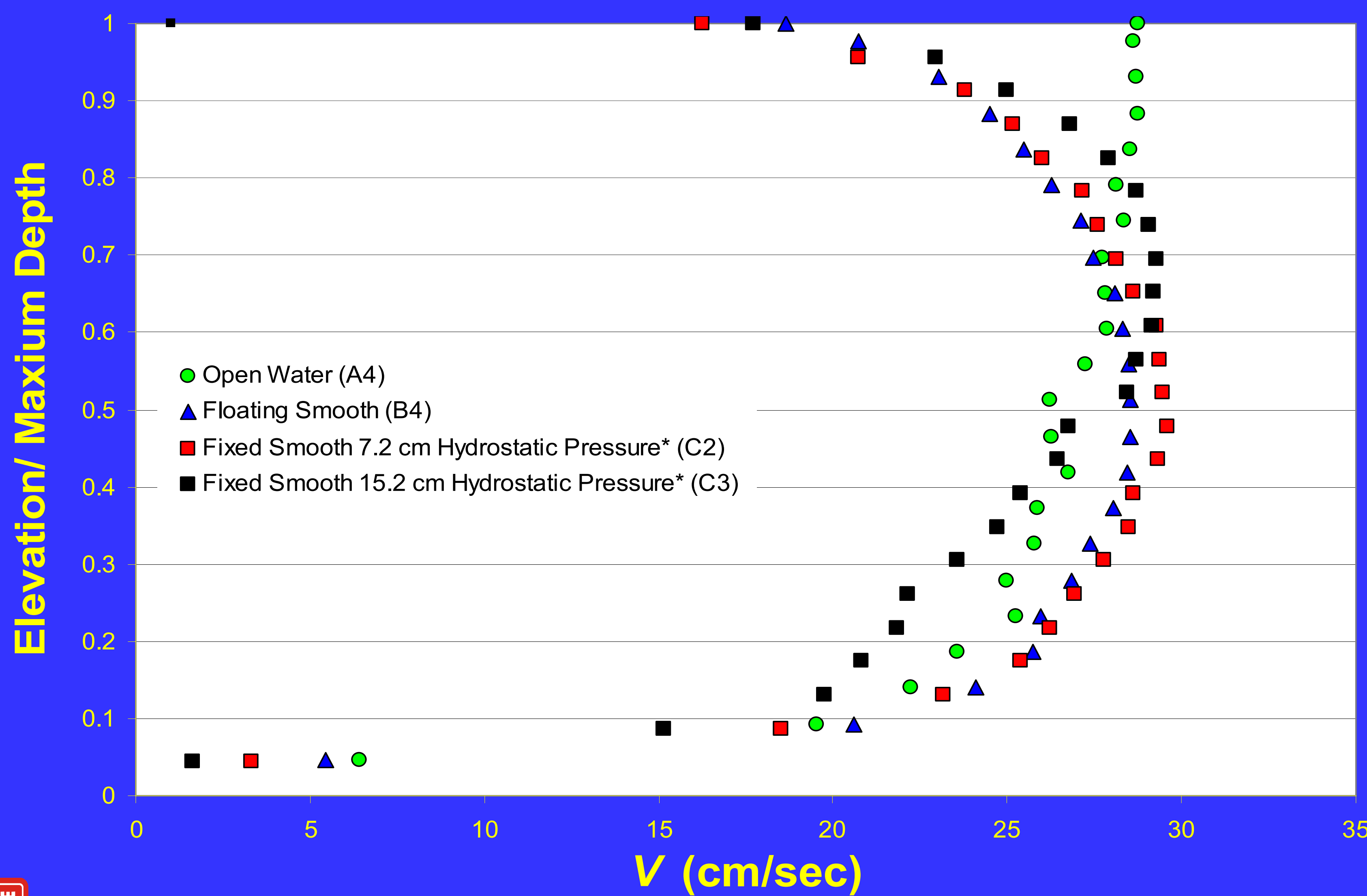
Velocity 2.12 cm/s, Vavg/Vc = 0.9278



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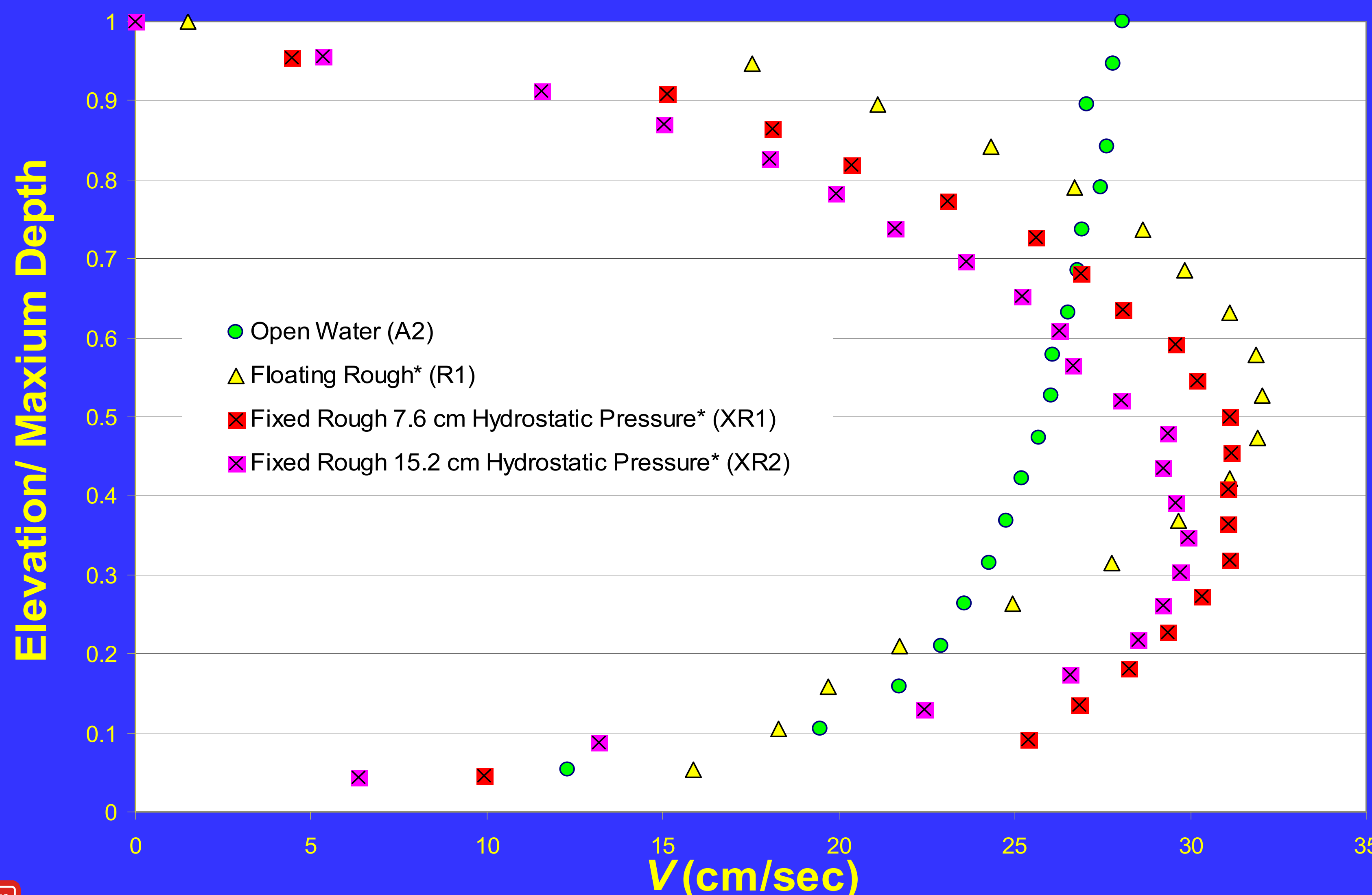
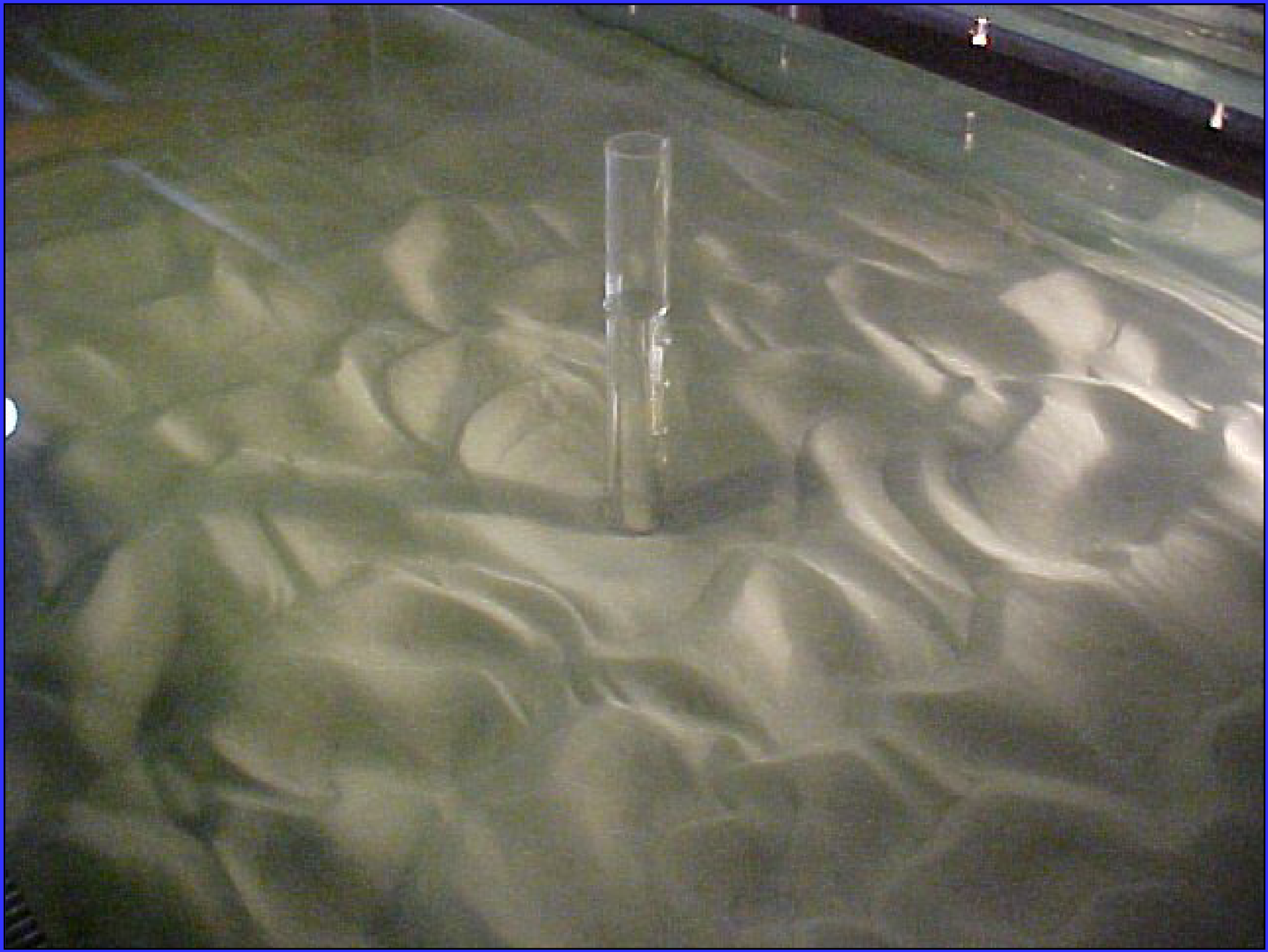
Velocity 1.96 cm/s, Vavg/Vc = 0.8589



Sample Scour Hole- Test C5

Sample Scour Hole- Test XR2



Conclusions

Ice Effects on Bed Erosion

•Ice cover can be a major factor in sediment transport and stability of contaminated sediment.

• Pressurized flow due to ice significantly increases mean velocity and the scour potential.

• Ice cover roughness increases turbulence, distorts the vertical velocity profile and increases bed shear.

• Existing theory and models do not adequately explain these field observations and flume experiments.

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Summary Results Grouped by V_{avg}

Test	Avg V [fps]	Ya [in]	Duration [h:mm]	Scour Depth [in]	Scour Depth [cm]	Notes
0.650 fps; V_{avg}/V_c = 0.7222						
A5	0.650	9	16:12	2.6875	6.826	
B3	0.650	9	18:10	2.7500	6.985	
0.700 fps; V_{avg}/V_c = 0.7777						
A6	0.700	8.5	13:13	2.8750	7.303	
B5	0.700	8.5	15:29	3.2500	8.255	
0.735 fps; V_{avg}/V_c = 0.8167						
A3	0.735	10	9:05	2.6875	6.826	
B1	0.735	10	19:49	3.2500	8.255	
C1	0.735	3	18:35	3.1250	7.938	
C4	0.735	6	18:55	3.1250	7.938	

Summary Results Grouped by V_{avg}

Test	Avg V [fps]	Ya [in]	Duration [h:mm]	Scour Depth [in]	Scour Depth [cm]	Notes
0.773 fps; V_{avg}/V_c = 0.8589						
A2	0.773	8	17:57	3.1875	8.096	
B2	0.773	8	22:08	3.2500	8.255	
R1	0.773	8	18:13	3.0000	7.620	Live Bed Scour
C5	0.773	3	15:39	3.2500	8.255	
C6	0.773	6	15:39	3.1875	8.096	
XR1	0.773	3	17:17	2.8750	7.303	Live Bed Scour
XR2	0.773	6	16:06	3.3125	8.414	Live Bed Scour
0.835 fps; V_{avg}/V_c = 0.9278						
A4	0.836	9	14:27	3.3125	8.414	
B4	0.836	9	17:46	3.3750	8.573	
C2	0.836	3	16:22	3.2500	8.255	Live Bed Scour
C3	0.836	6	20:16	2.8750	7.303	Live Bed Scour

Velocity Profile Comparisons- Summary

- Open water- logarithmic as expected
- Covered flows-
  - Zero velocity at boundaries (no slip condition)
  - Maximum velocity location is a function of-
    - Flow depth
    - Roughness of boundaries
    - Viscosity of fluid
  - Maximum velocity located near the middle for floating smooth cover
    → similar boundary roughness
  - Larger maximum velocity for rough cover → live-bed
- Pressurized flows- velocity shifts toward smoother boundary
  - Less scour for pressurized smooth cover → shifts toward cover
  - More scour for pressurized rough cover → shifts toward bed
  - Shifts more pronounced for larger V_{avg}/V_c and larger pressure head
  - Pressurized flows- V_{avg} not acceptable indicator for live-bed scour
- **Combined effect of roughness and pressure flow**