Presenter Bio

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- Water Resources Engineer – Transportation Hydraulics & Water Resources
- Graduated from University of Guelph (2016) – Environmental Engineering (B.Eng. HONS)
- 7 years of industry tenure
  - Flood hazard assessment
  - Hydraulic structure (bridges, culverts, levees etc.)
  - Linear infrastructure (Light Rail, Heavy Rail, Highways/Roads)
  - Site Drainage & Stormwater Management
- Special interest in river hydraulics and hydraulic structures

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- Aaron Farrell, P.Eng. HDR inc.

Assessment of Riverine Scour for Design of a Major Bridge Crossing using 2-Dimensional Hydraulic Modeling

A Methodologic Comparison Case Study

HDR

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Acknowledgements

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- Robin Beebee, Ph.D. (HDR)
- Stanford Gibson, Ph.D. (USACE)

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Client:

- Metrolinx

Ontario Line Design Team:

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- Masoud Mansouri, P.Eng. (Thurber)

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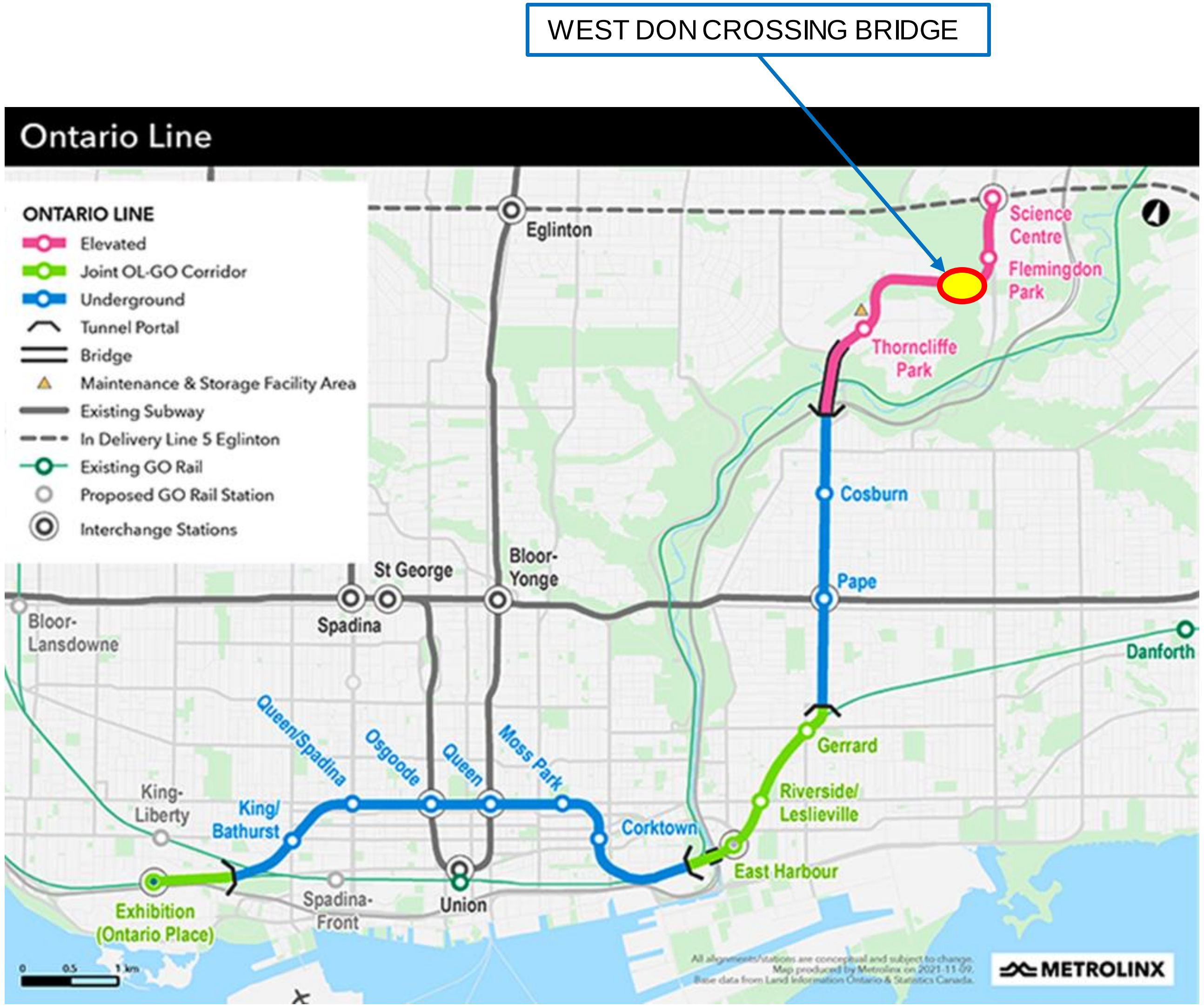
Aaron Farrell, P.Eng. (HDR)

CHI for hosting this event!

The Project



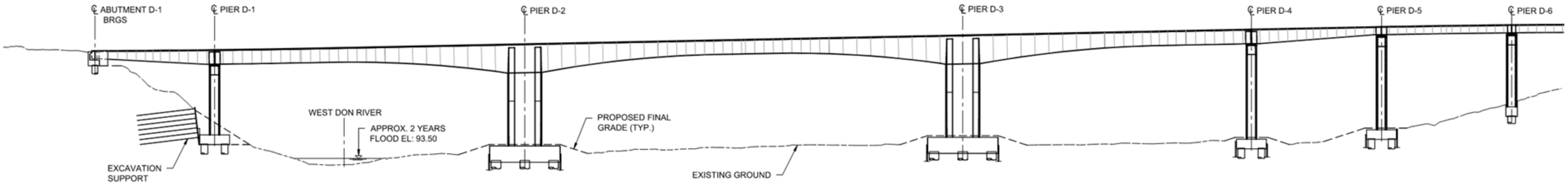
Ontario Line – a 15.6 km rapid transit line connecting downtown Toronto to the nearby suburbs to the Northeast.

One of the largest transportation project currently underway in North America

West Don Crossing

100% detailed design of a 400-meter-long bridge with one pier within the floodplain and one pier supported by the channel bank at the floodplain limit

Bridge hydraulics analysis involving drainage, stormwater management, flood hazard assessment and scour analysis

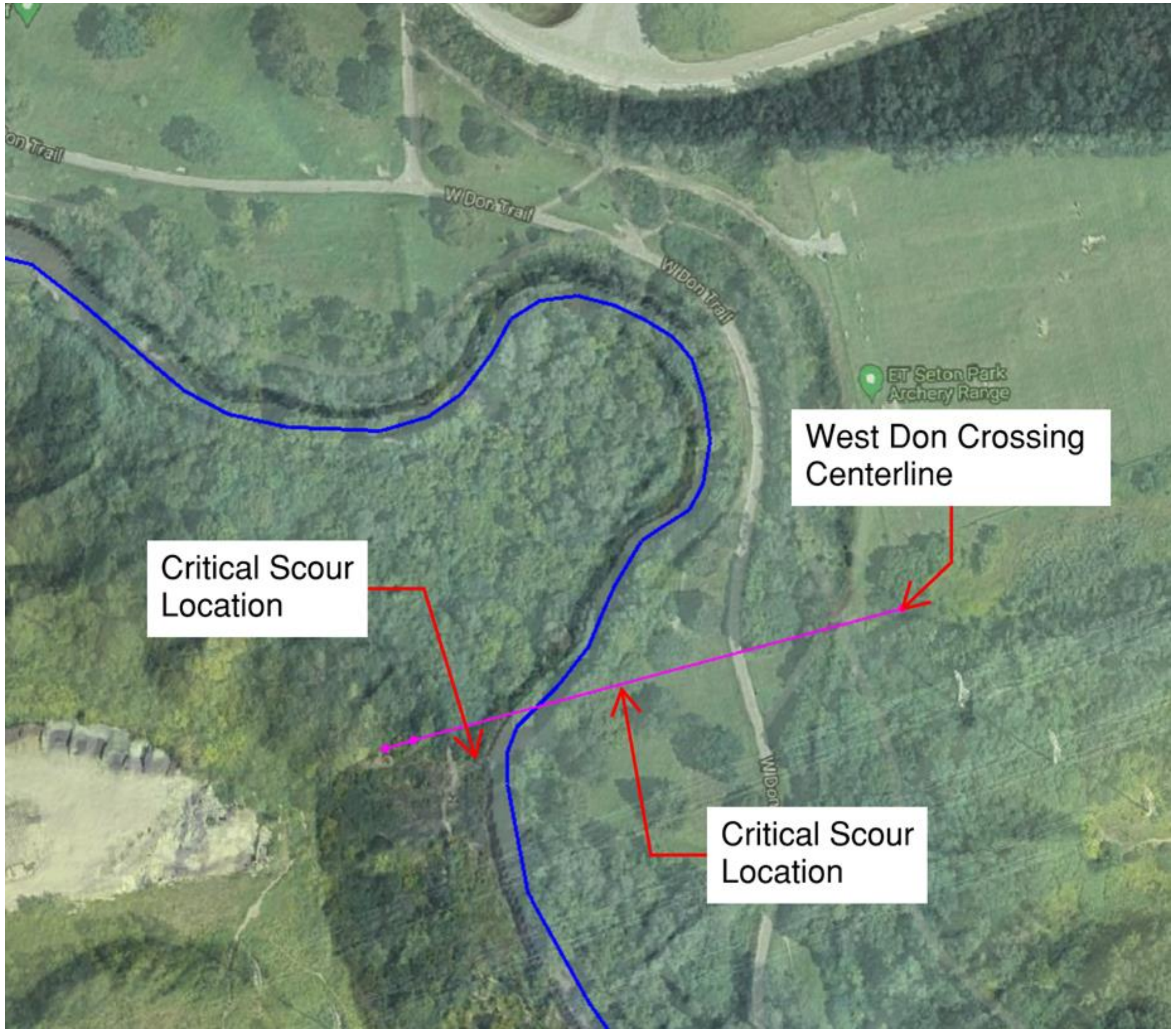


Scour Analysis

Scour assessment is a part of any detailed design of a structure with elements within the floodplain

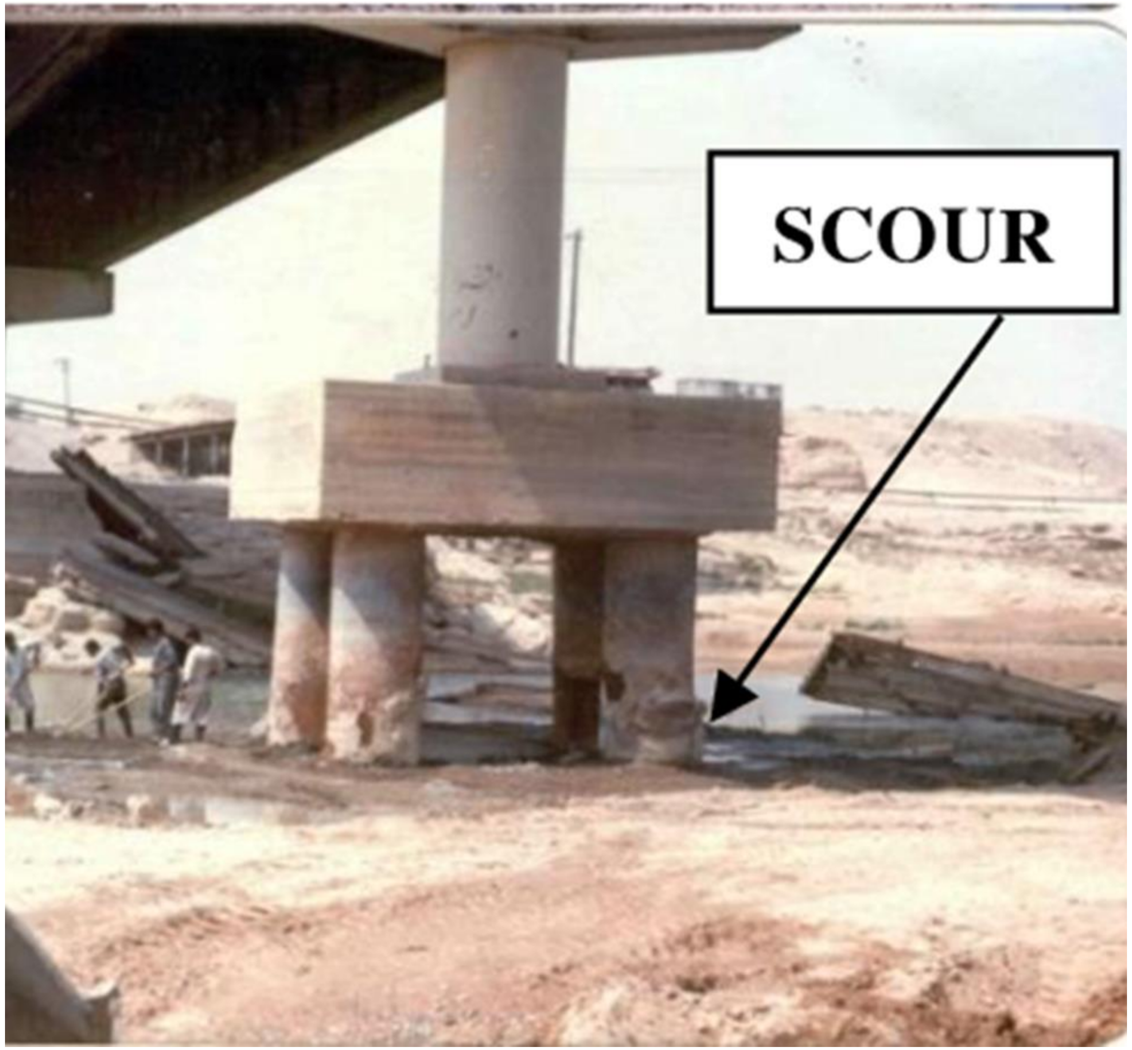
Types of Scour:

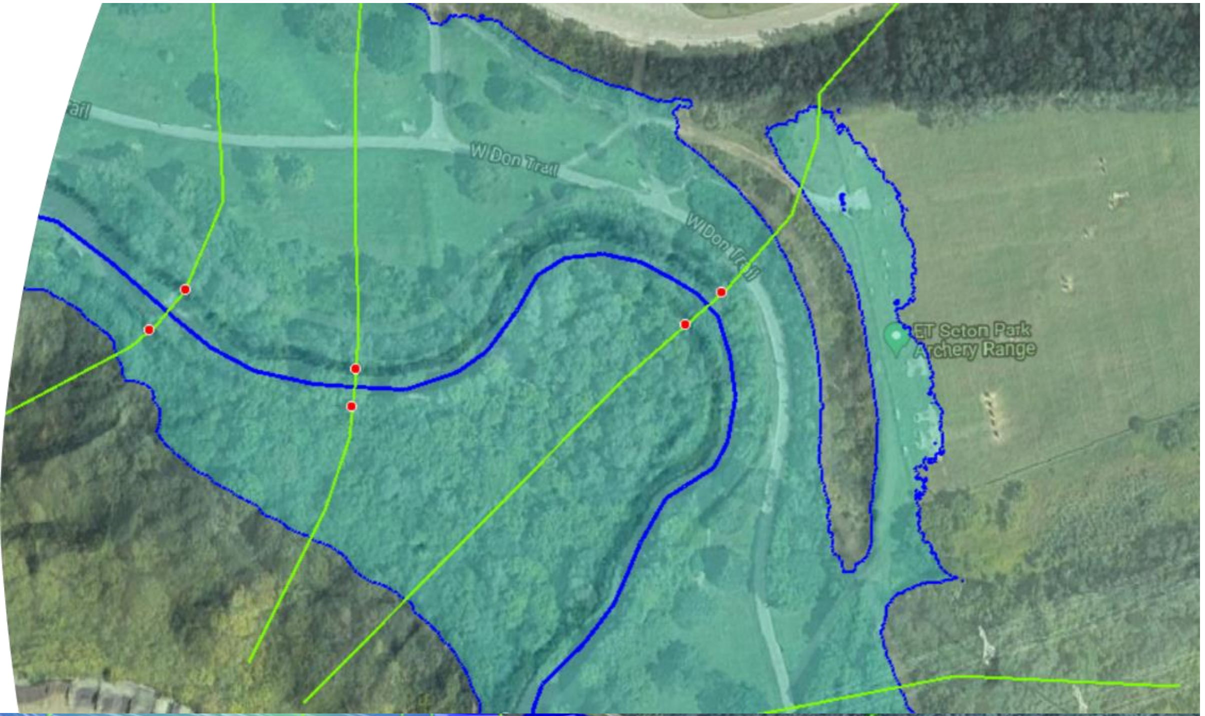
- Local Scour (Piers, Abutments)
- Contraction Scour (Channels, Overbanks)
- Bend Scour
- Long-Term Aggradation / Degradation

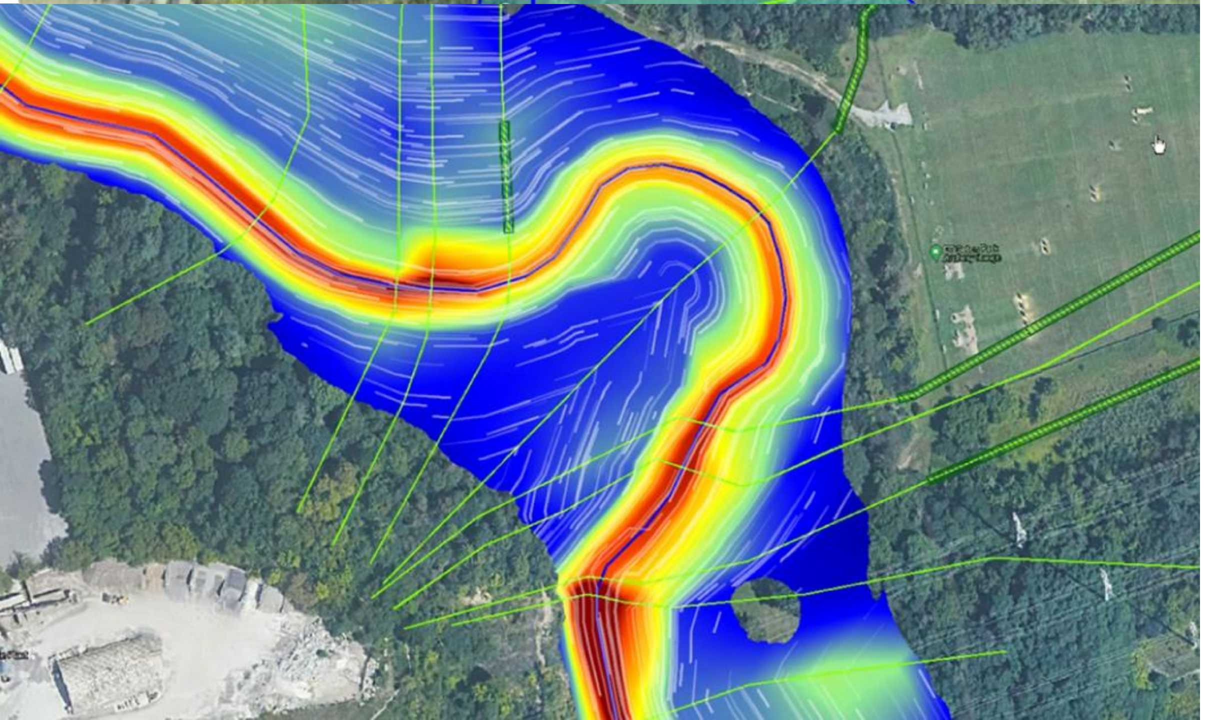


Why is this Important?

- The American Society of Civil Engineers cites riverine scour as the leading cause of bridge failure
- Overestimating scour can cause costly overdesign and unnecessarily disrupt the river system. Underestimating scour can have major implications for public safety
- Multidisciplinary problem – Structures, Geotech, Fluvial Geomorphology, Civil, Hydraulics
- A little bit of science and a LOT of engineering







Conventional 1D Modeling Approach

Base model provided by TRCA for flood hazard mapping

Flood hazard mapping model was updated to include the proposed grading, structure and additional cross sections

Results for velocities, depths, flow widths and angles were used to calculate scour

1D Scour Analysis

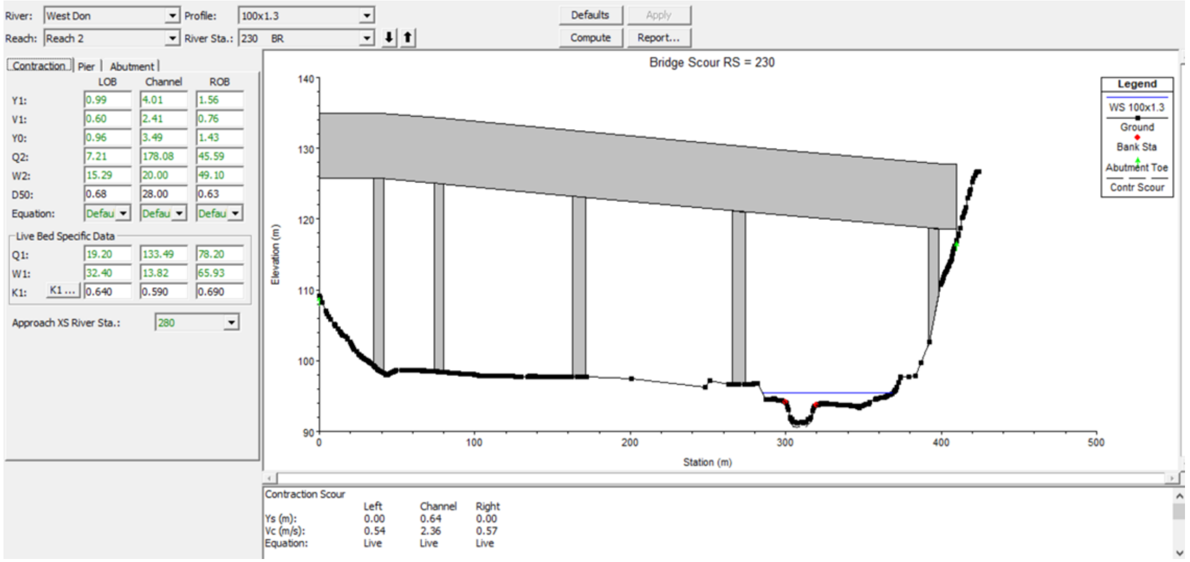
0.64 meters of contraction scour within the channel

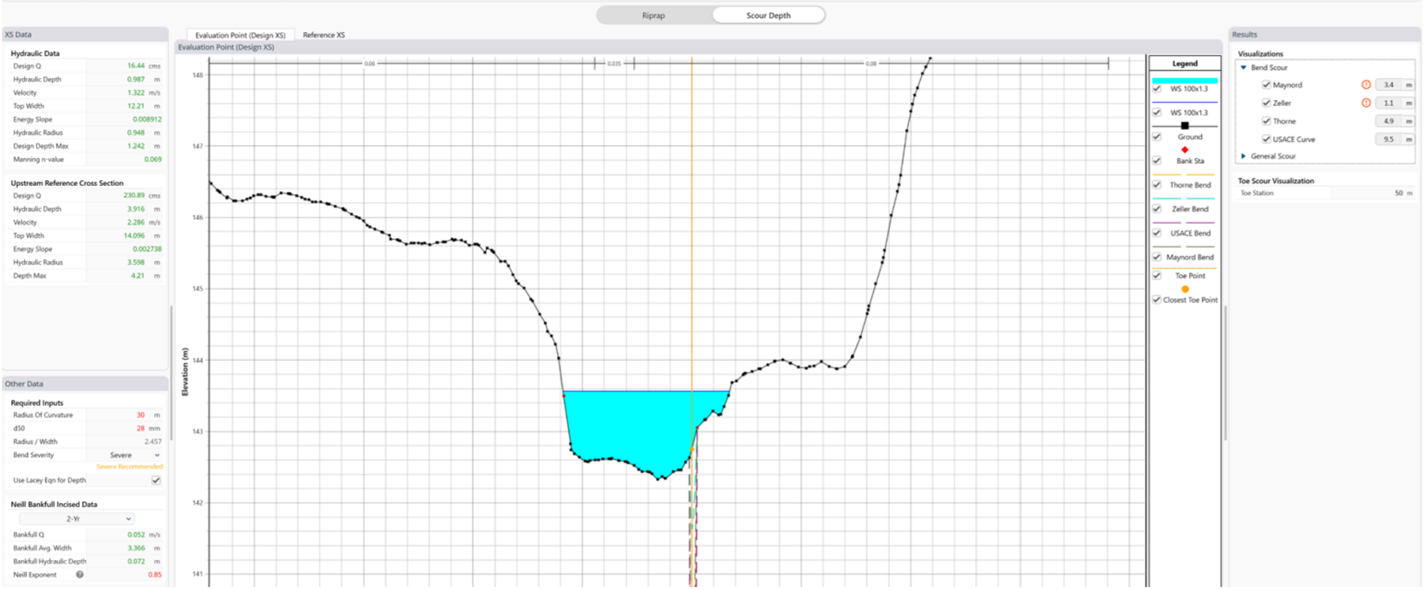
No contraction scour on the overbanks

Zero local scour since pier columns don’t appear to be inundated by the design flood – Is this accurate?

1.1m bend scour

Great! We’re done.





Is 1D Modeling Sufficient?

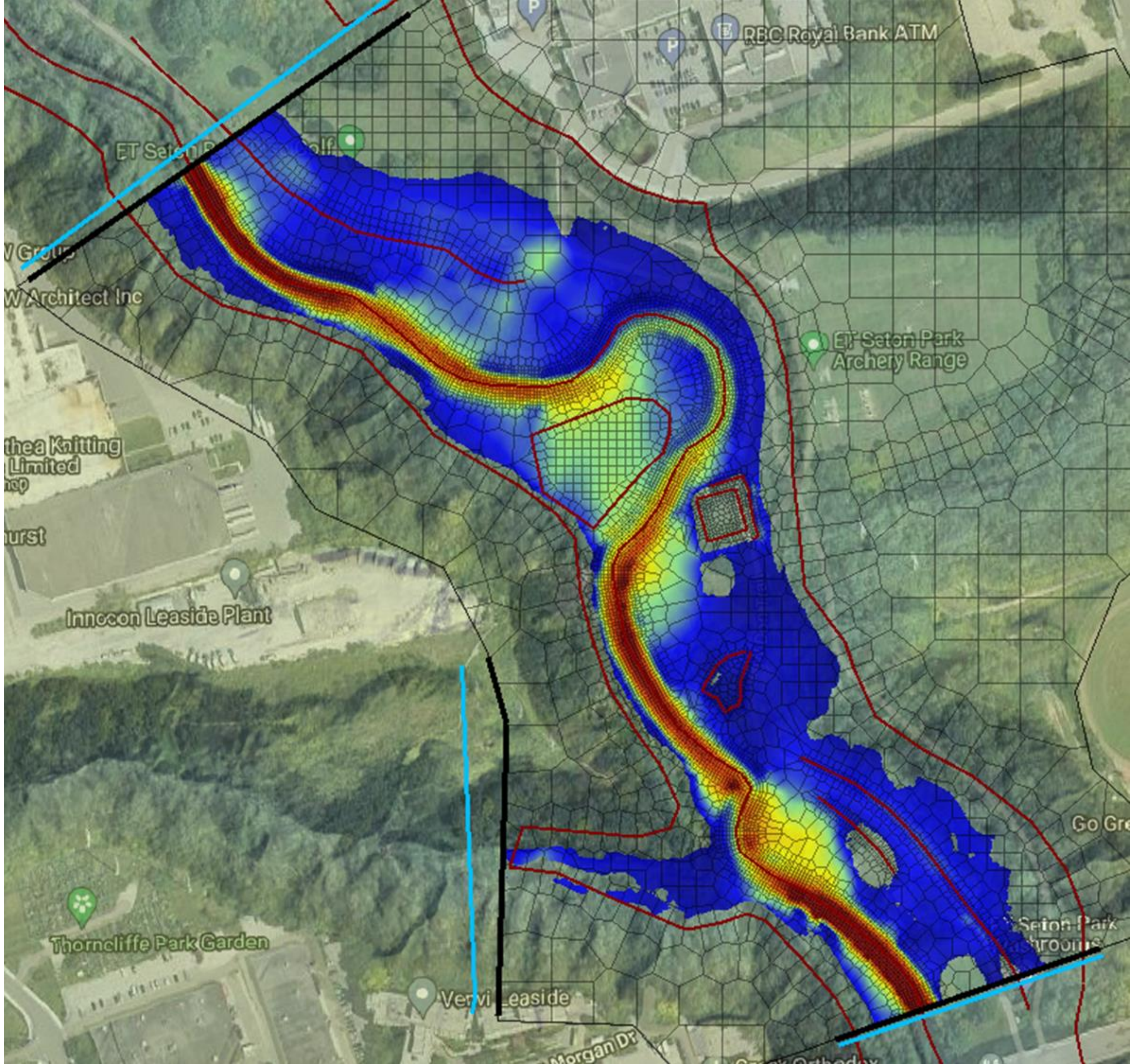

Time = 170
Net Height Change (m)
-0.08 -0.05 -0.02 0.01 0.04
Velocity (m s-1)
0.00 0.07 0.15 0.22 0.30
FLOW-3D
Max Scour Depth (m)
0 -0.02 -0.04 -0.06 -0.08 -0.1
0 950 1900 2850 3800
Time (sec)

Model Selection Criteria and Basis for 2D Modeling

- Aligning the hydraulic model with the intended application
  - Flood inundation modeling vs. Scour Analysis
  - Average hydraulic parameters vs local hydraulic parameters
- Requirement for detailed, high precision hydraulic results
- What model can give us the desired outputs?
- Other Considerations: size and scale of project, availability of expertise

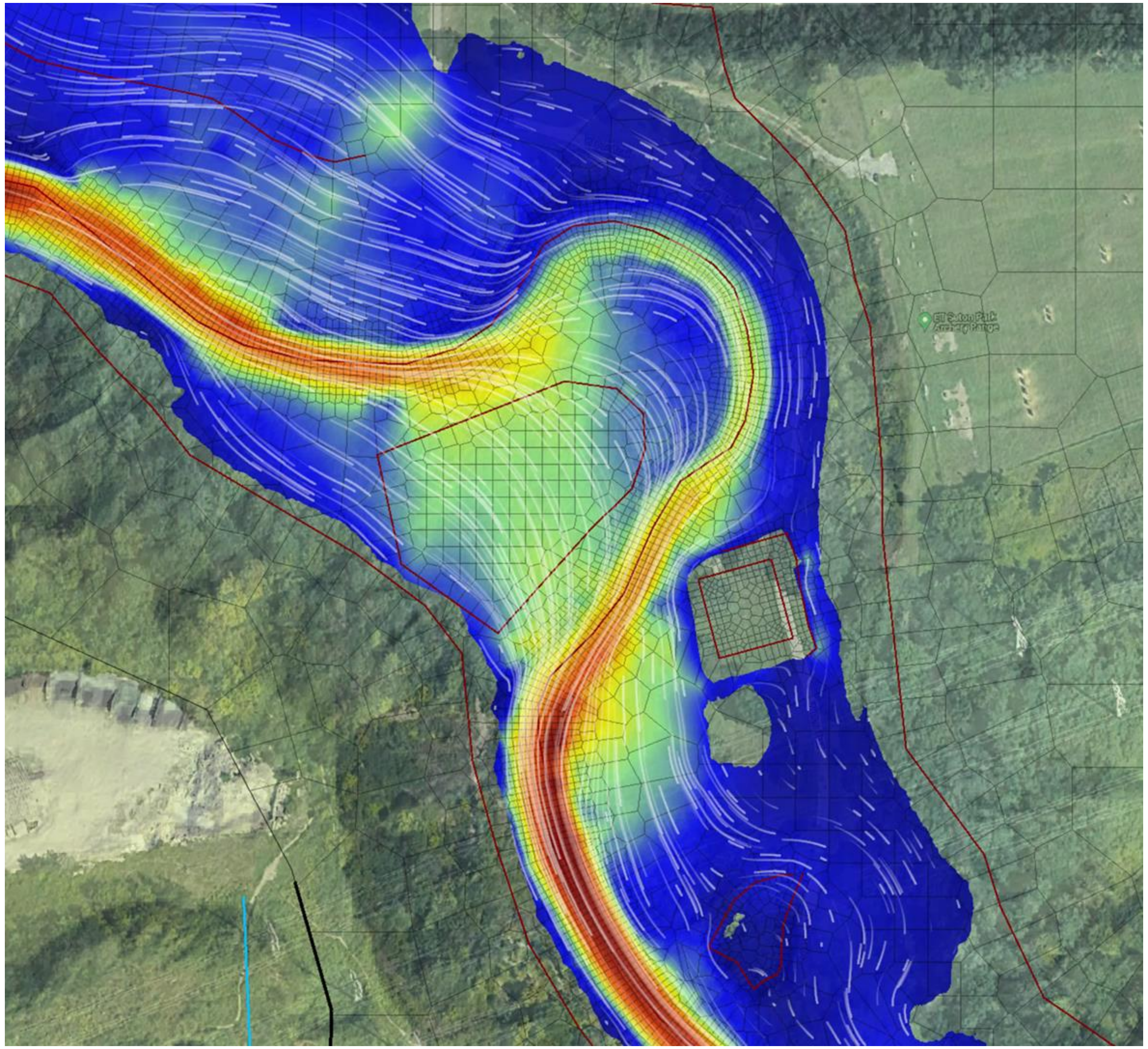
Development of 2D model

- 2D Mesh
- Refinement regions
- Flow specifics
- Boundary Conditions
- Pier footings



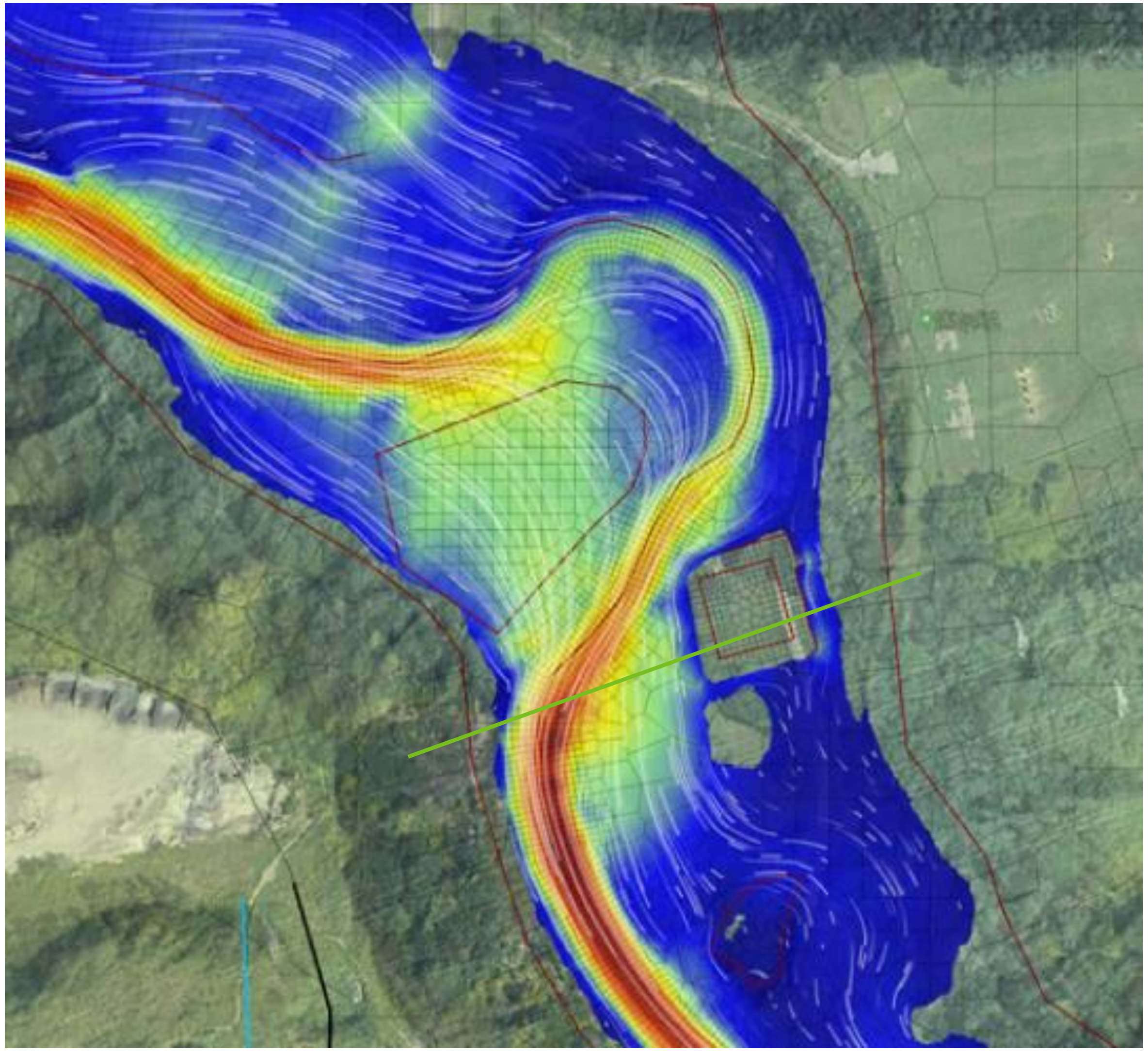
2D Hydraulic Results

2D Flow Tracers

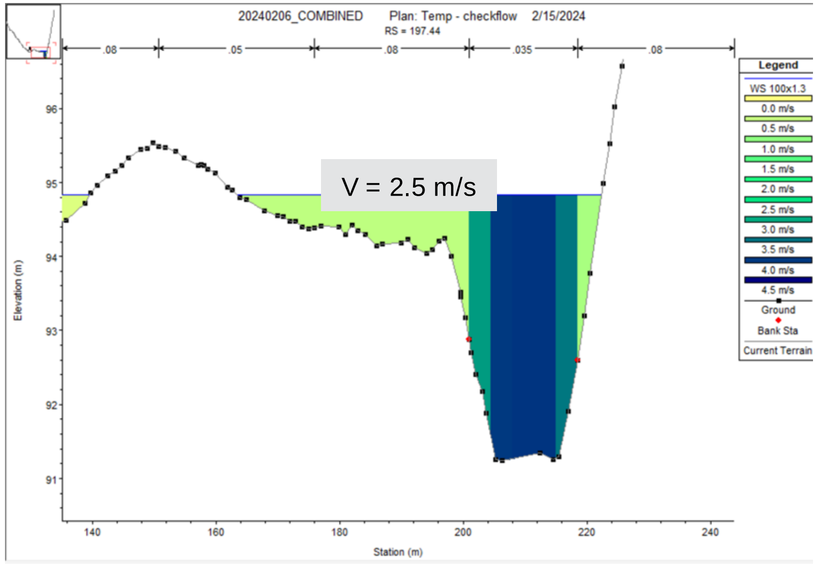


- Full momentum solution at work
- Flow patterns more representative of flow around bends
- Captures important and unique flow patterns and details for scour analysis
- Only provides depth-averaged velocities

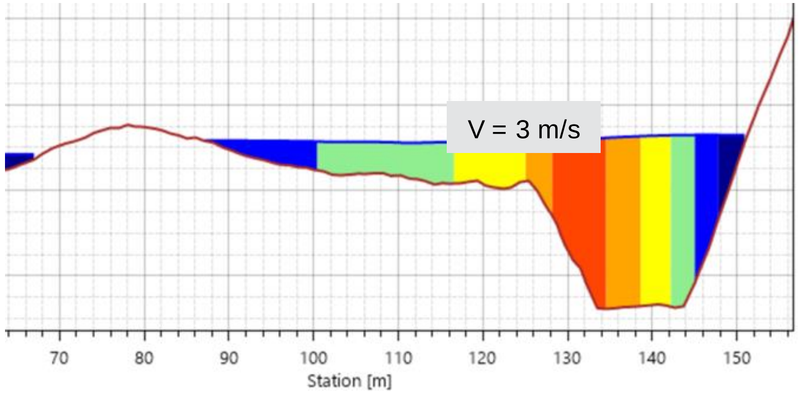
Comparison of Velocity Distributions



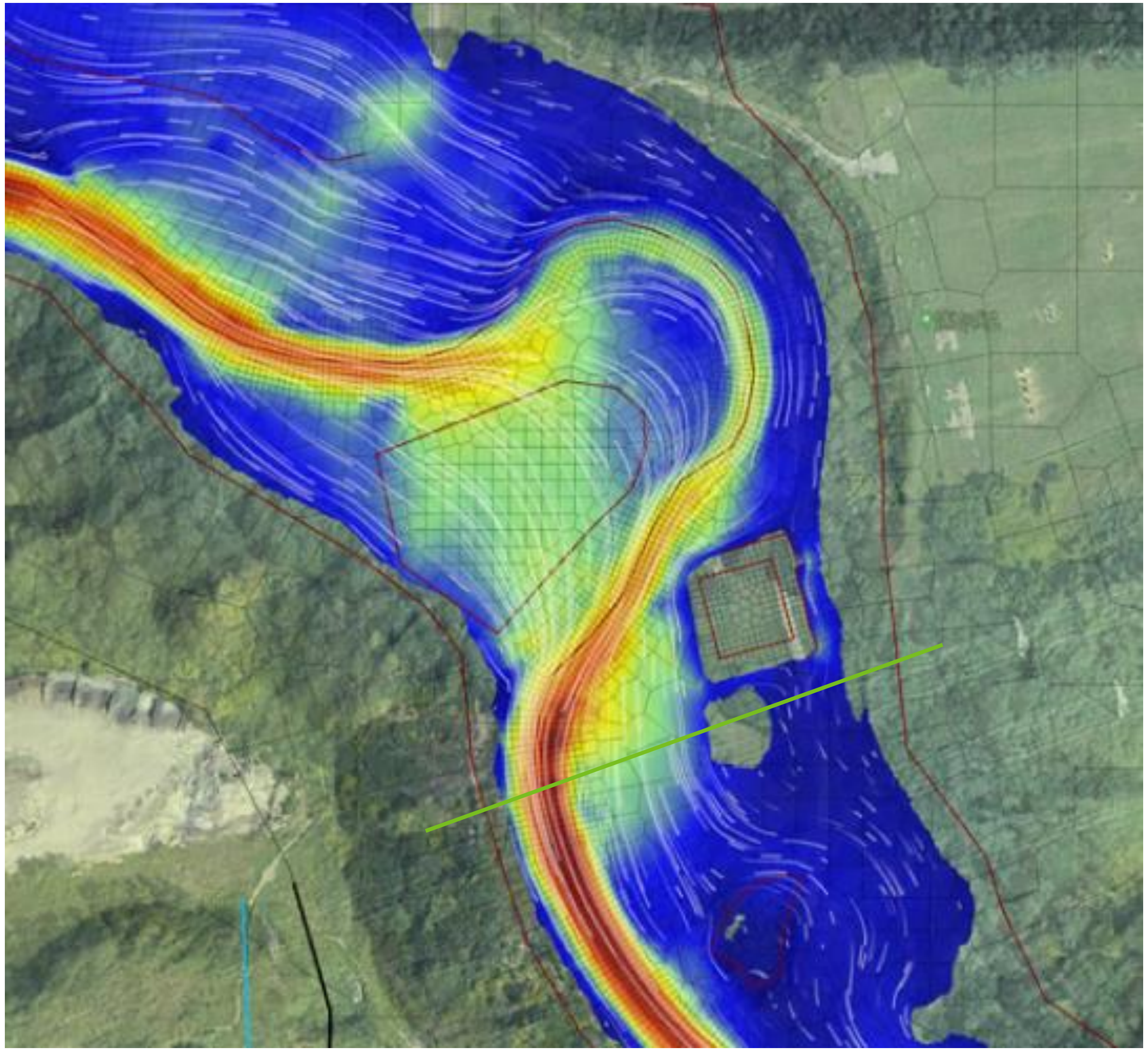
1D



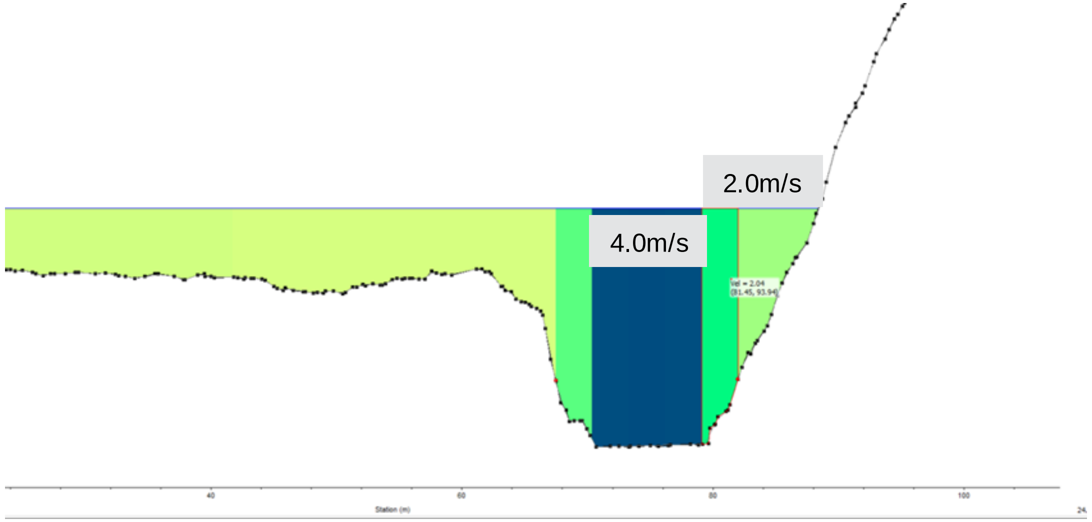
2D



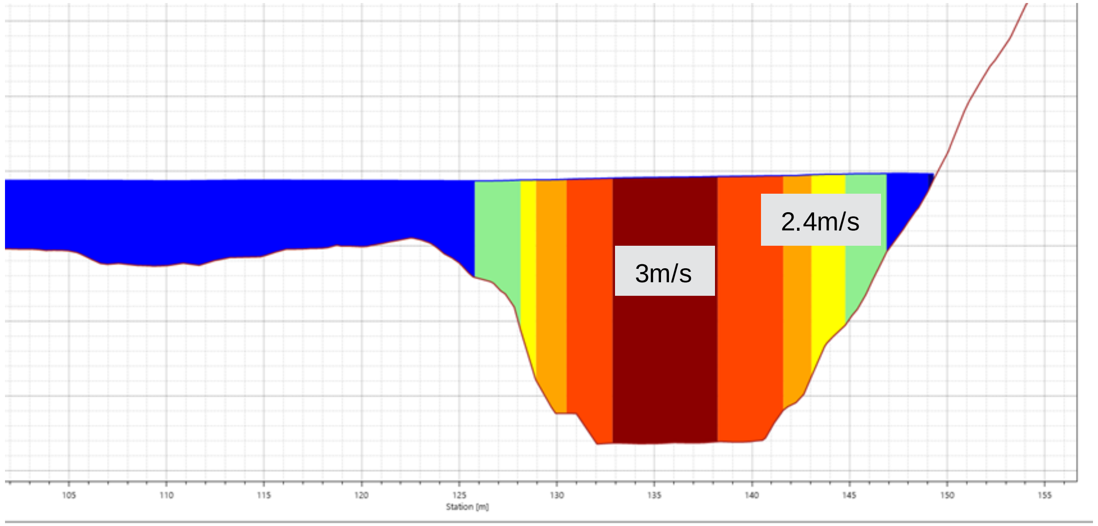
Comparison of Velocity Distributions



1D

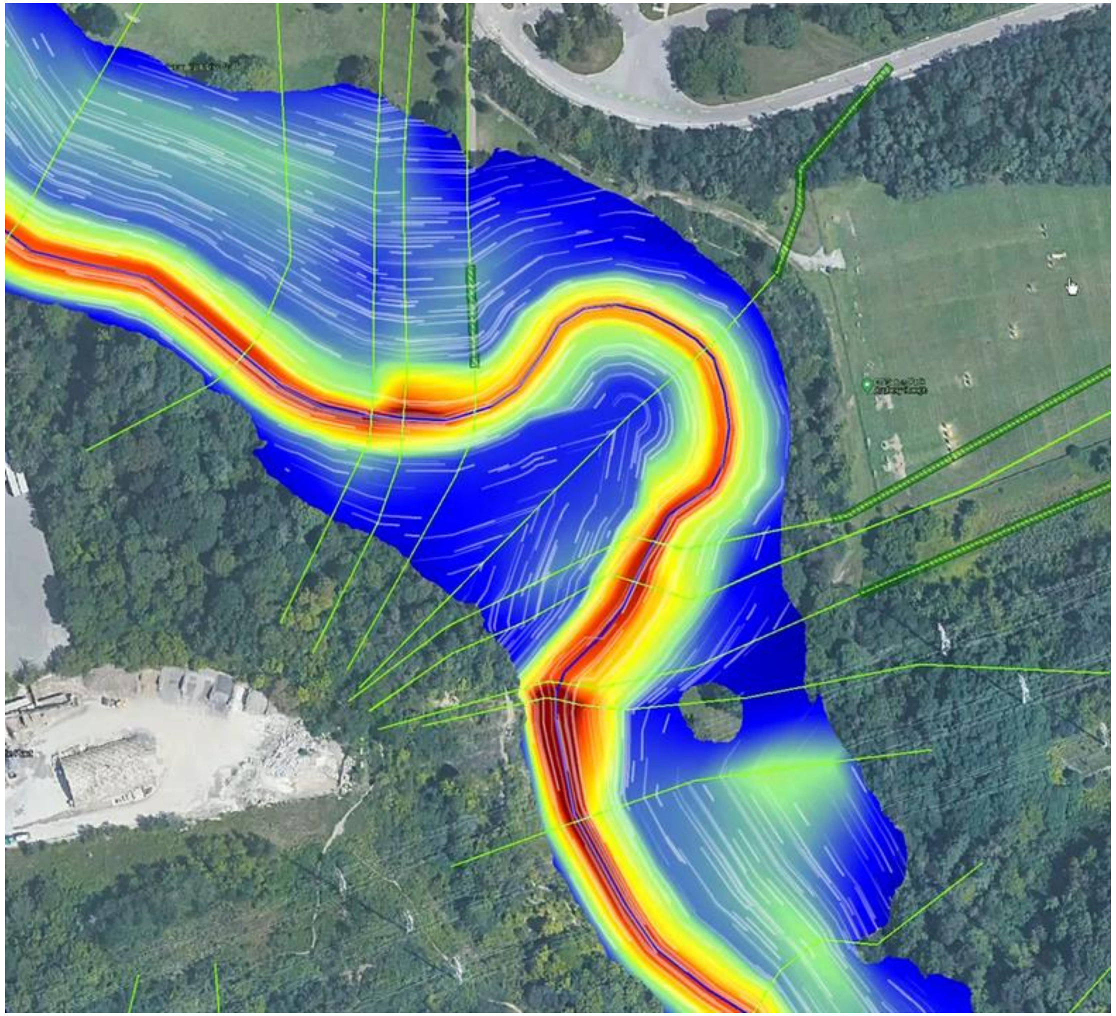


2D

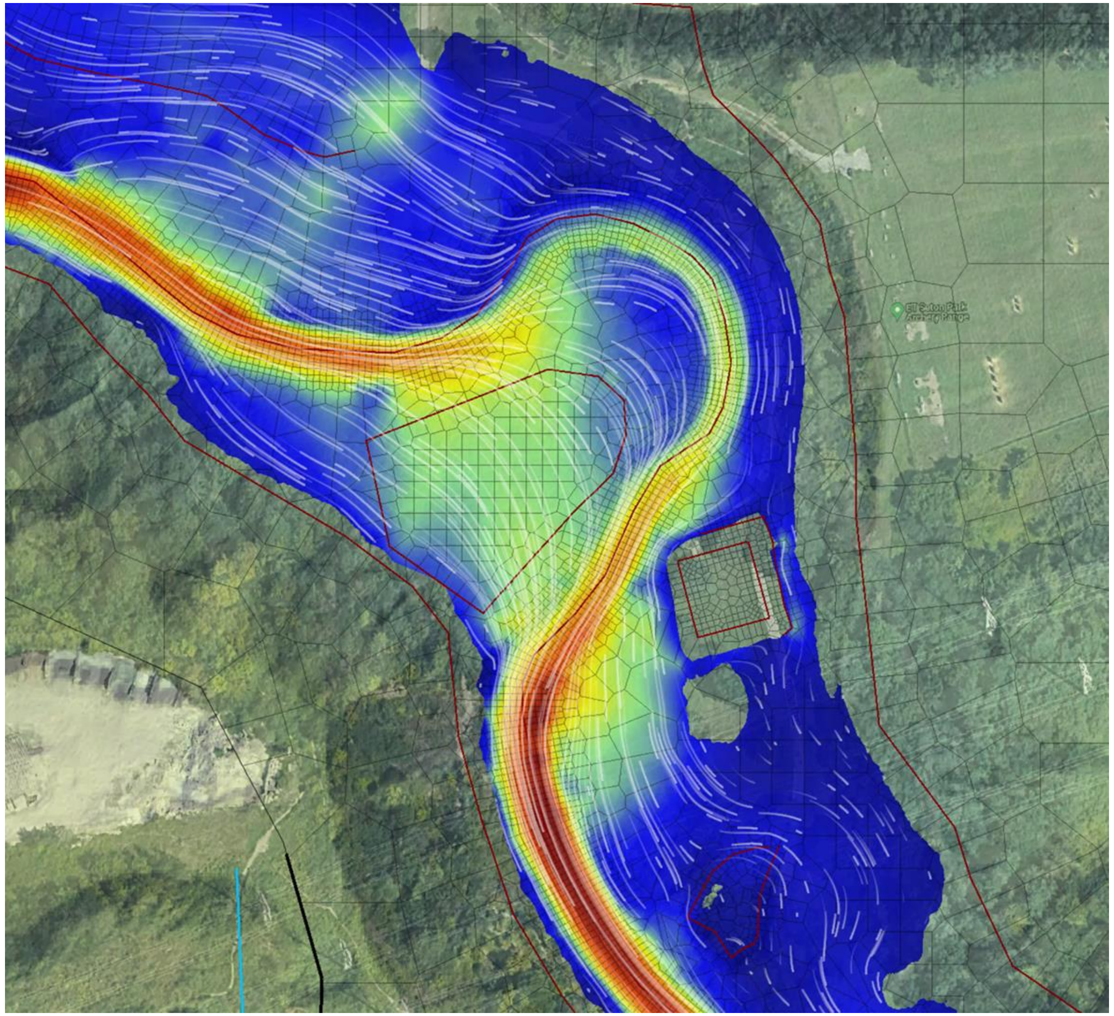


Result Comparison

1D Flow Tracers



2D Flow Tracers



1D vs 2D Modeling

Hydraulic Variables	One-dimensional (1D) Modeling	Two-dimensional (2D) Modeling
Flow direction	Assumed by user	Computed
Flow paths	Assumed by user	Computed
Channel roughness	Assumed constant between cross sections	Represented at each element
Ineffective (blocked) flow areas	Assumed by user	Computed
Flow contraction and expansion through bridges	Assumed by user	Computed
Flow velocity	Averaged at each cross section Assumed in one direction	Magnitude and direction Computed at each element
Flow distribution	Computed based on conveyance	Computed based on continuity
Water surface elevation	Assumed constant across cross sections	Computed at each element

Image Source: FHWA

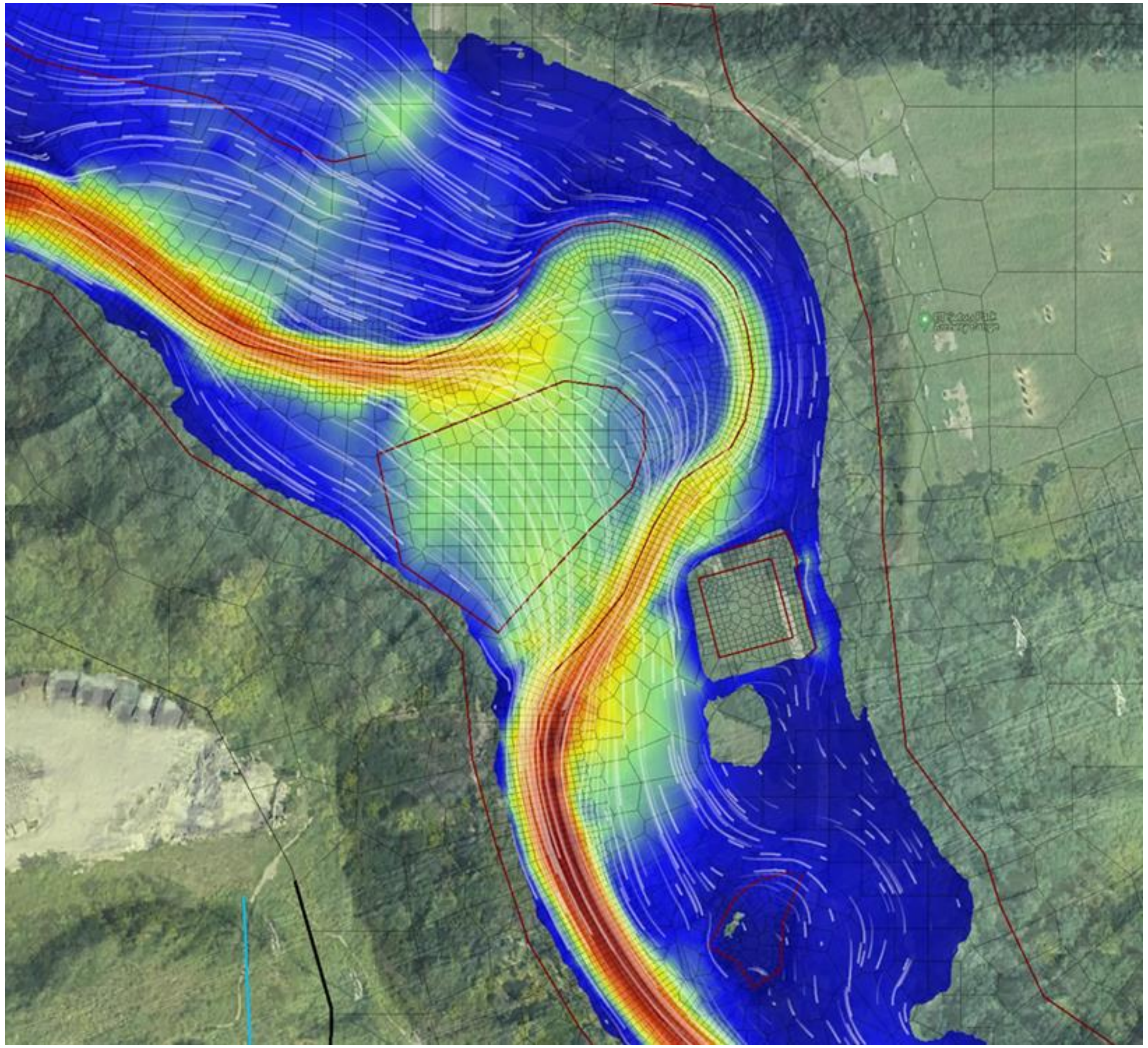
2D Scour Analysis
Contraction Scour

Much easier to measure flow widths carrying sediment

Zero contraction scour found in the 2D model (compared to 64cm in the channel via 1D)

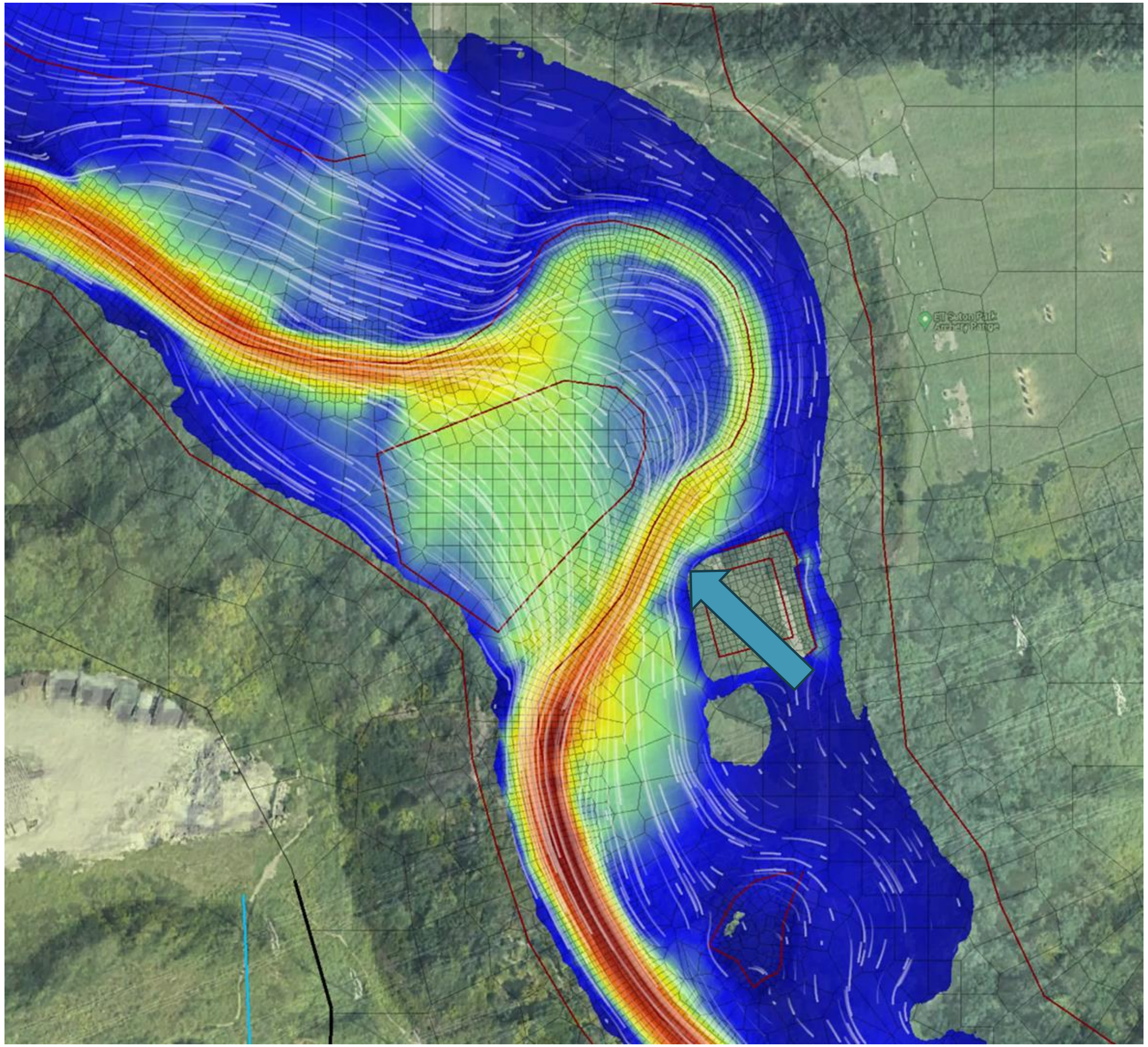
0.5m contraction scour at the left overbank not seen in 1D

Dramatically different result for slope stability calculations



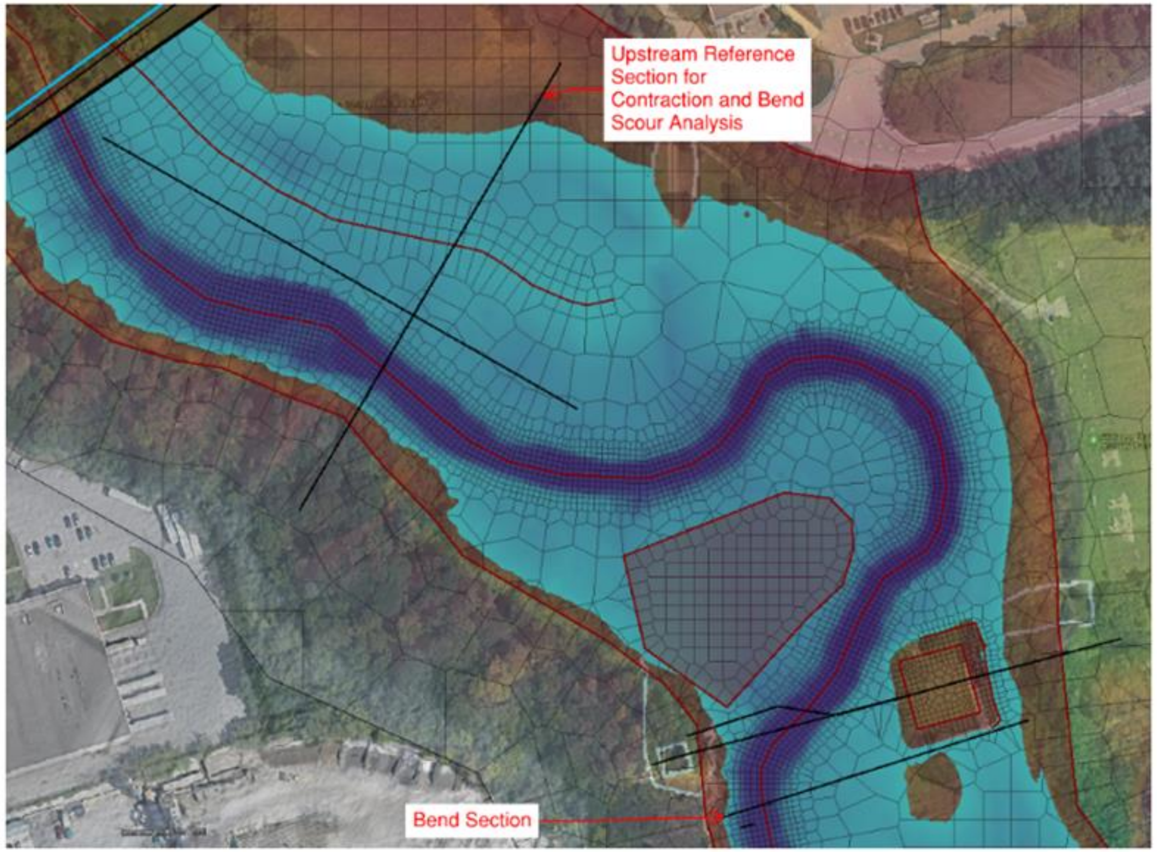
2D Scour Analysis
Local Scour

- 1D calculation may imply no local scour at the piers as pier columns are not inundated
- Looking closer at the results of the 2D model tells a different story
- Inside face of pier is at risk for experiencing local scour (0.25m)



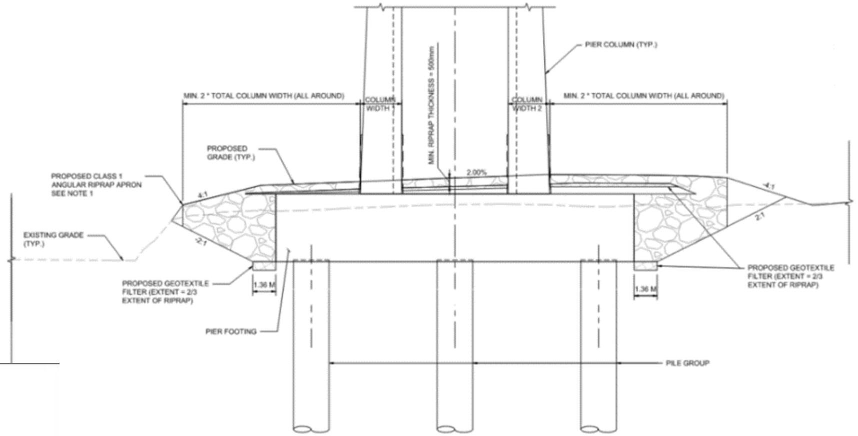
2D Scour Analysis
Bend Scour

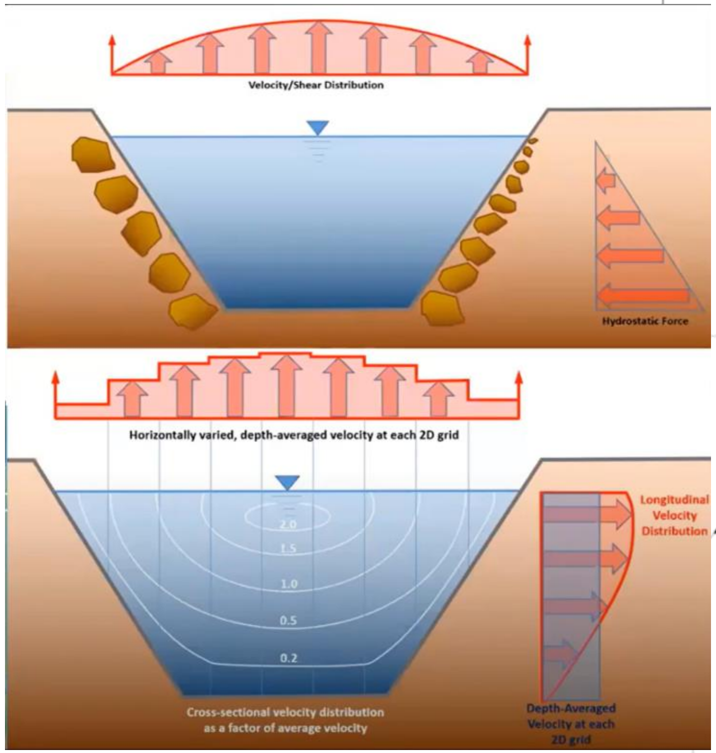
- Bend Scour calculation keyed to upstream reference section
- Equation developed for 1D analysis
- The more complex the geometry, the more uncertainty there will be in characterizing the scour with an upstream reference section
- 1D Bend Scour = 1.1m
- 2D Bend Scour = 1.2m

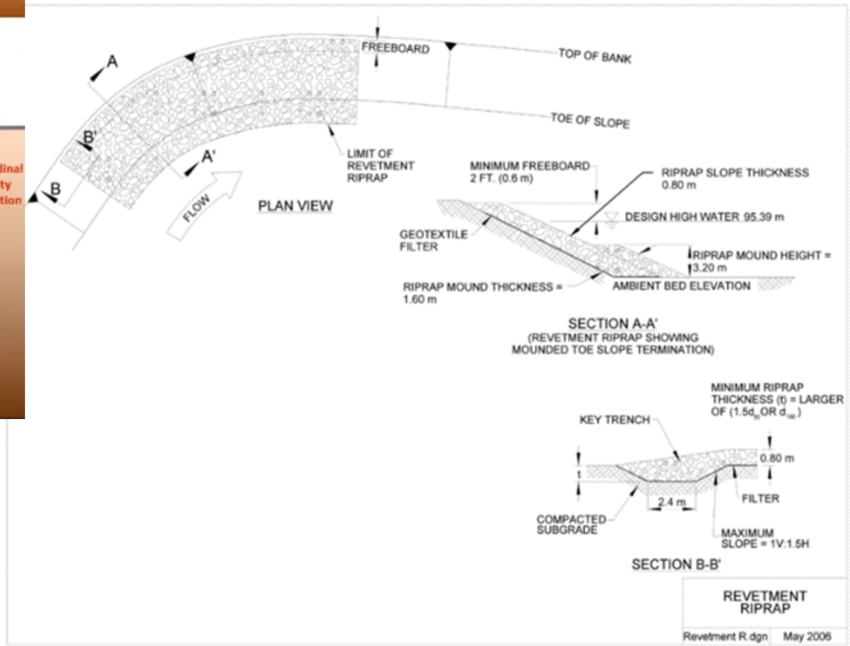


Countermeasure Design

- Riprap is the most common countermeasure
- Sizing riprap is heavily dependent on local velocity distributions and flow depth
- USACE riprap sizing method was developed for 1D hydraulic results, while others benefit from the 2D velocity distribution







Difference in Results

1D

- Contraction Scour – 0.64m (Channel)
- Local Scour – 0.0m
- Bend Scour – 1.1m (Zeller)
- Riprap size
  - Class 3 (Isbash)
  - Class 5 (USACE EM-1601)

2D

- Contraction Scour – 0.5m (LOB)
- Local Scour – 0.25m
- Bend Scour – 1.2m (Zeller)
- Riprap size
  - Class 5 (Isbash)
  - Class 5 (USACE EM-1601)

Summary

- 1D, 2D and 3D models have value in specific applications and appropriate model selection is key to accurate analysis
- 1D models are generally inferior to 2D models for determining local hydraulic characteristics at a high precision and spatial resolution in complex systems
- Some equations were developed with specific 1D assumptions
- 1D, 2D and even 3D models should be part of the engineer's toolkit for decision making