FDOT TRANSPORTATION SYMPOSIUM 2019

Advancements in Bridge Hydraulic and Scour Analyses with 2D Hydraulic Modeling

Scott Hogan (FHWA) and Carl Spirio (FDOT)

U.S. Department of Transportation
Federal Highway Administration

FHWA Every Day Counts Program (EDC) CHANGE

Collaborative

Hydraulics:

Advancing to the

Next

Generation of

Engineering

Image source: Earthstar Graphics / Other information: FHWA

FHWA Advancements in Hydraulic Modeling

Overview

- FHWA hydraulic modeling history
- 1D vs. 2D hydraulic modeling
- 2D hydraulic modeling applications
- 2D modeling resources
- What’s New?
- What’s Next?

Image by John Gussman

Why is FHWA concerned about bridge hydraulics?

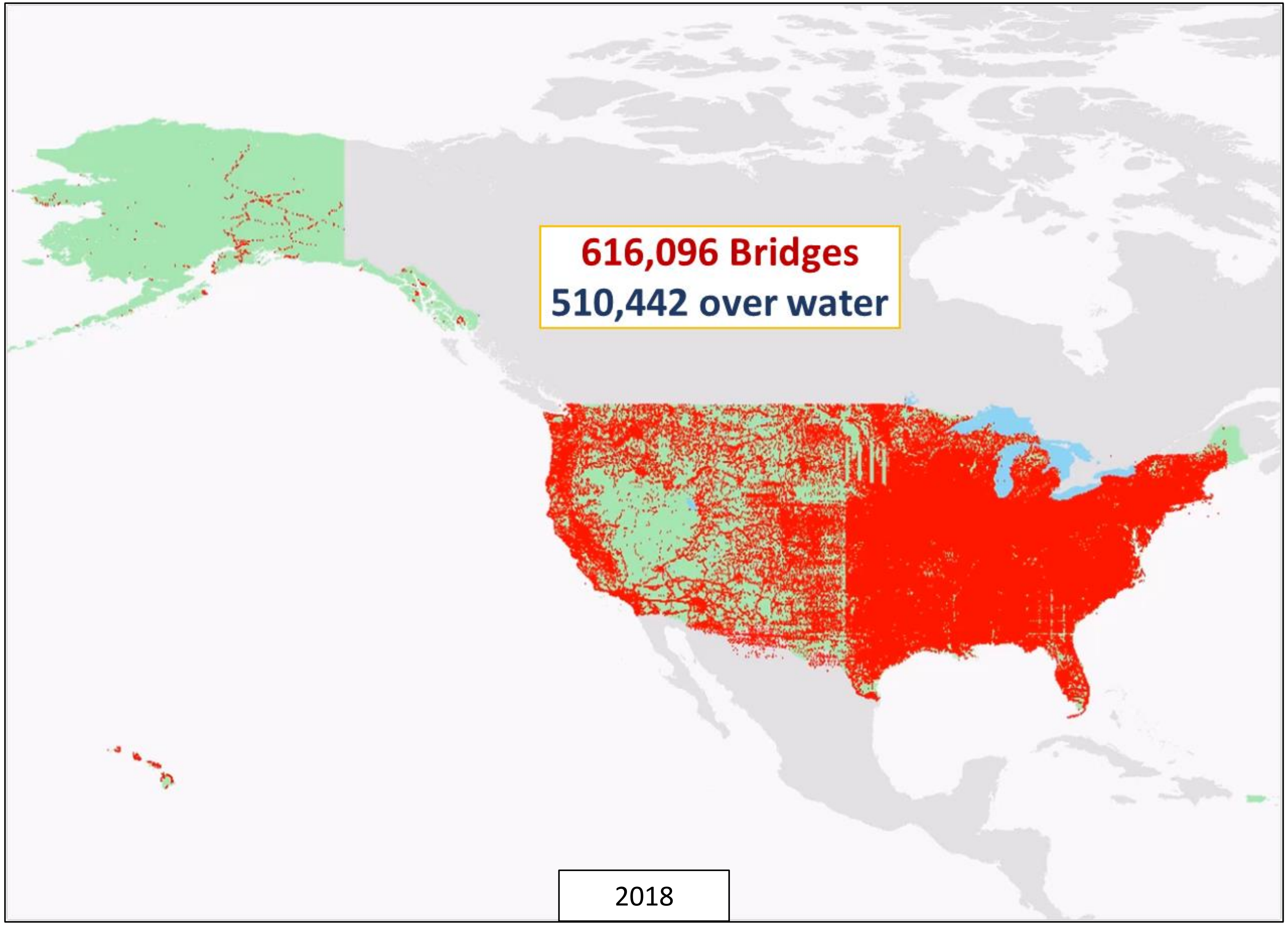


Image Source: FHWA

State DOT use of 2D Modeling:

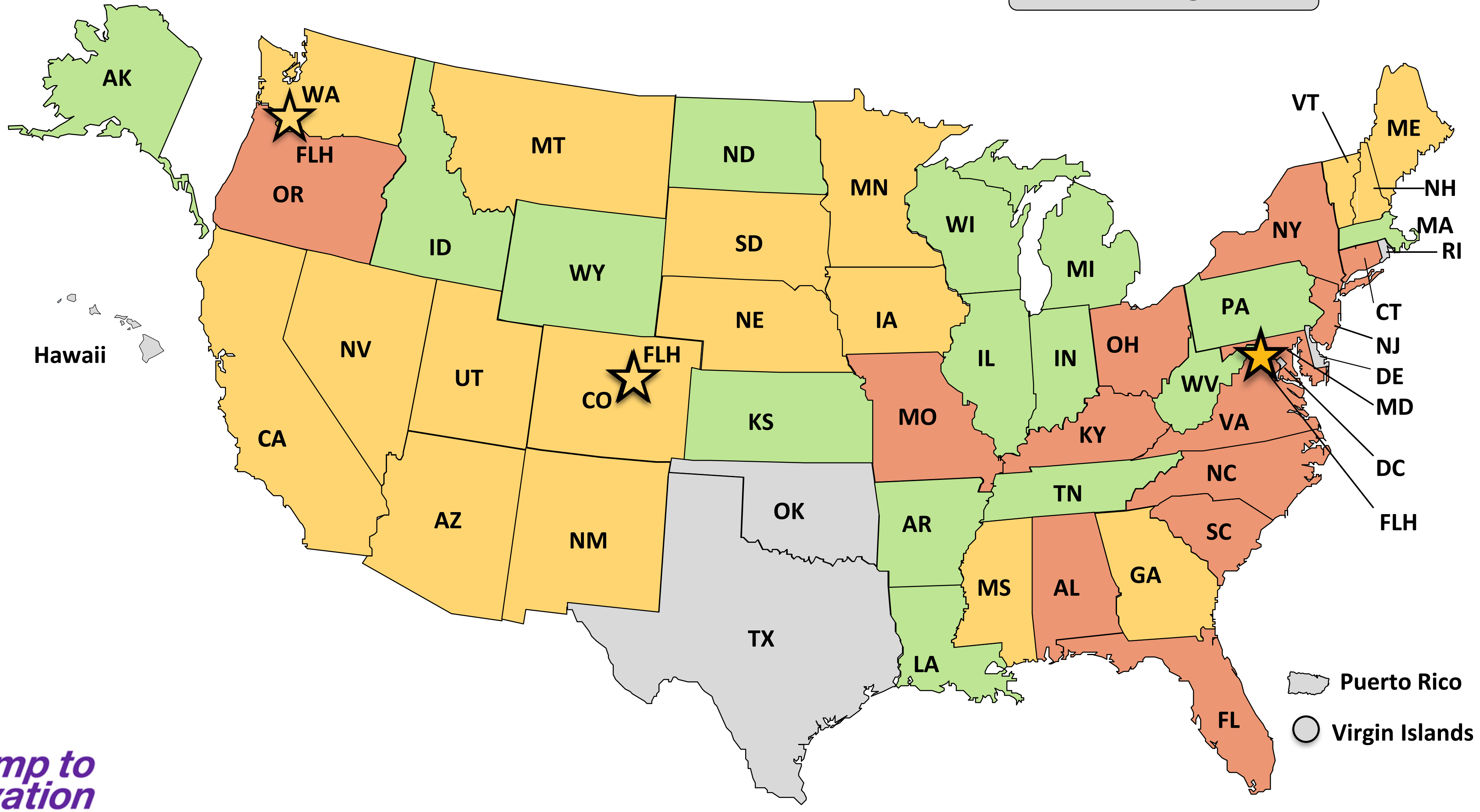
Estimate as of April 2019

Regular Use

Occasional Use

Limited Use

Not Using Yet



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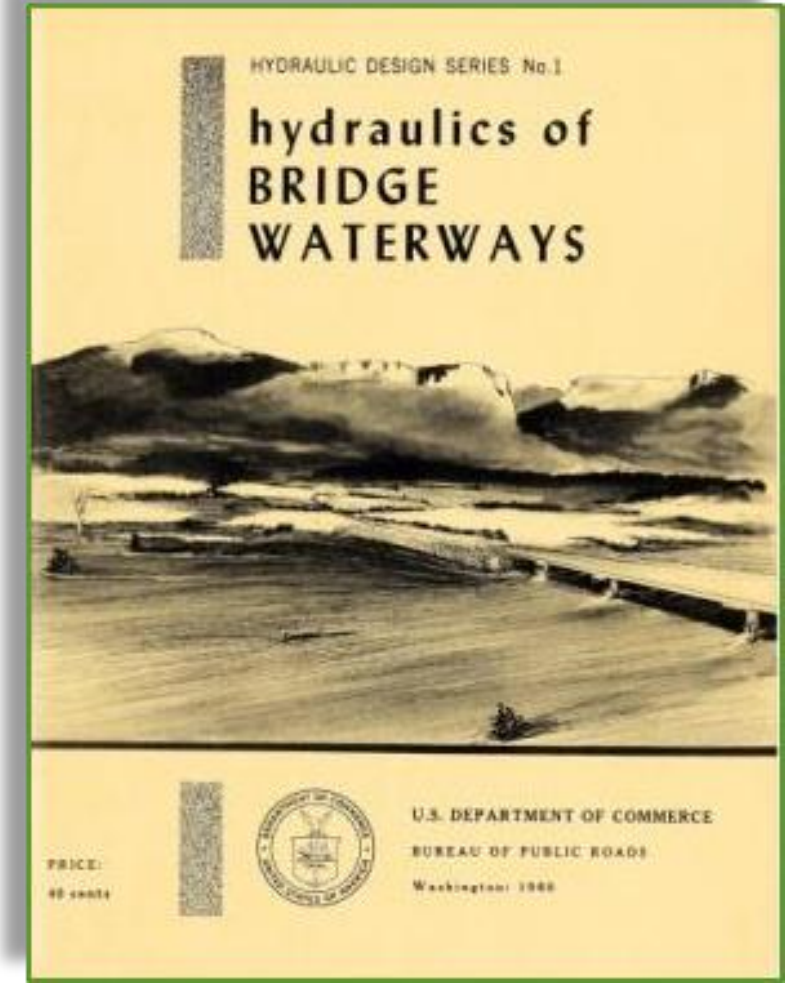
FHWA Hydraulic Modeling History



- **1957** First hydraulic bridge design
- **1960** FHWA introduced HDS-1 – basic analysis approach
- **1966** HEC-2 – Start of 1D modeling (step backwater)
- **1988** First 2D modeling by FHWA/USGS – with FESWMS
- **1996** HEC-RAS (1D) was released
- **2012** FHWA recommended 2D modeling for all but the simplest bridge hydraulics (HEC-18 / HDS-7)
- **2013** FHWA partnered with USBR (SRH-2D)
- **2014-16** Hydraulic structures added to SRH-2D
- **2017** EDC-4 CHANGE initiative to promote 2D modeling
- **2019** EDC-5 CHANGE continued development

Image Source: FHWA

SRH-2D Hydraulic Model

- USBR Partnership
- Model features and capabilities
  - Steady and unsteady flow
  - Sub- and supercritical flow
  - Multiple boundary conditions
  - Normal/critical depth rating curves
  - Internal boundary conditions
- Hydraulic structures
  - Bridge pressure flow with overtopping
  - Bridge piers and blocked obstructions
  - 1D (HY-8) and 2D culvert hydraulics
  - Weirs and Gates
- Other features
  - Depth dependent roughness
  - Sediment Transport

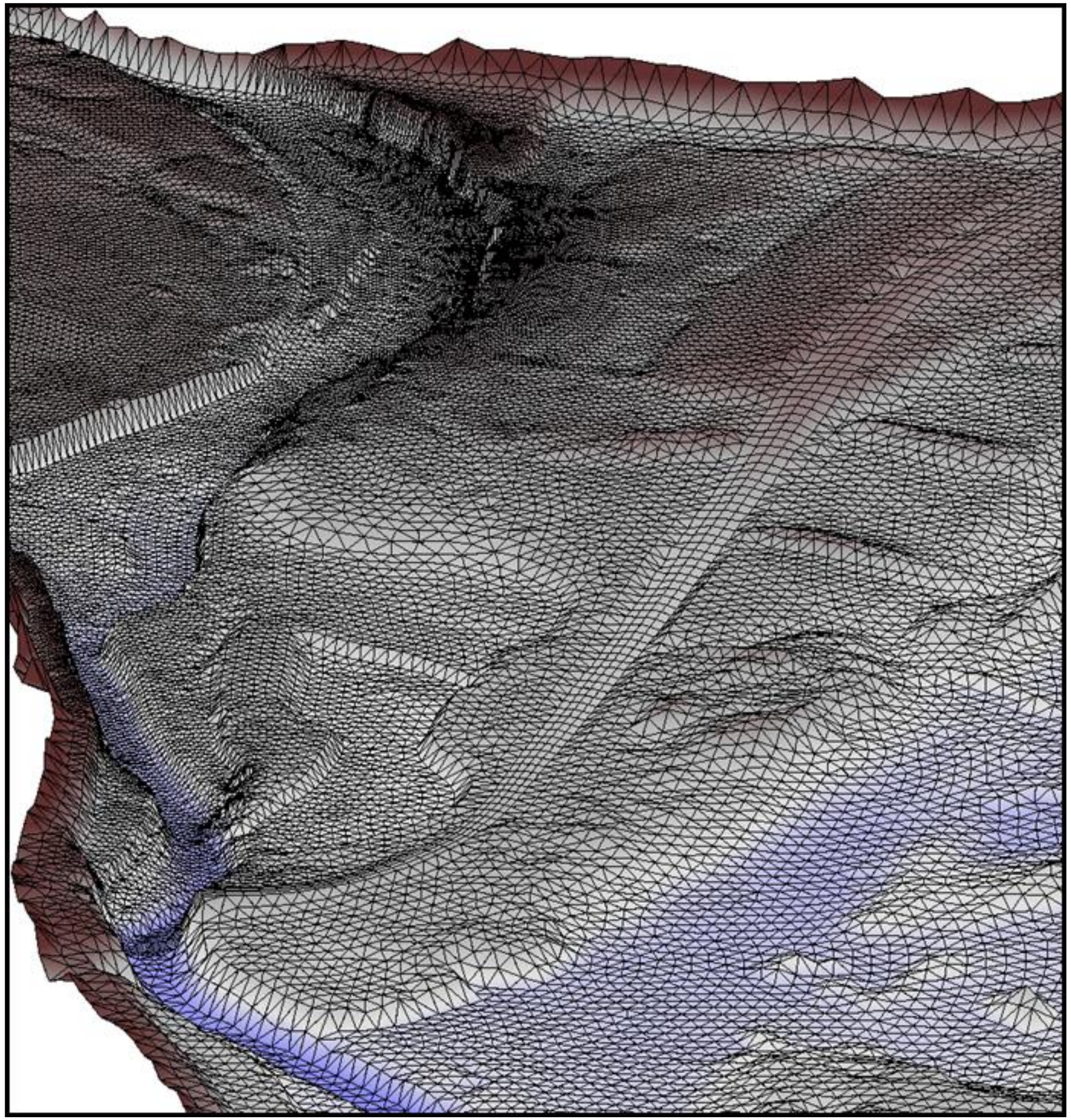
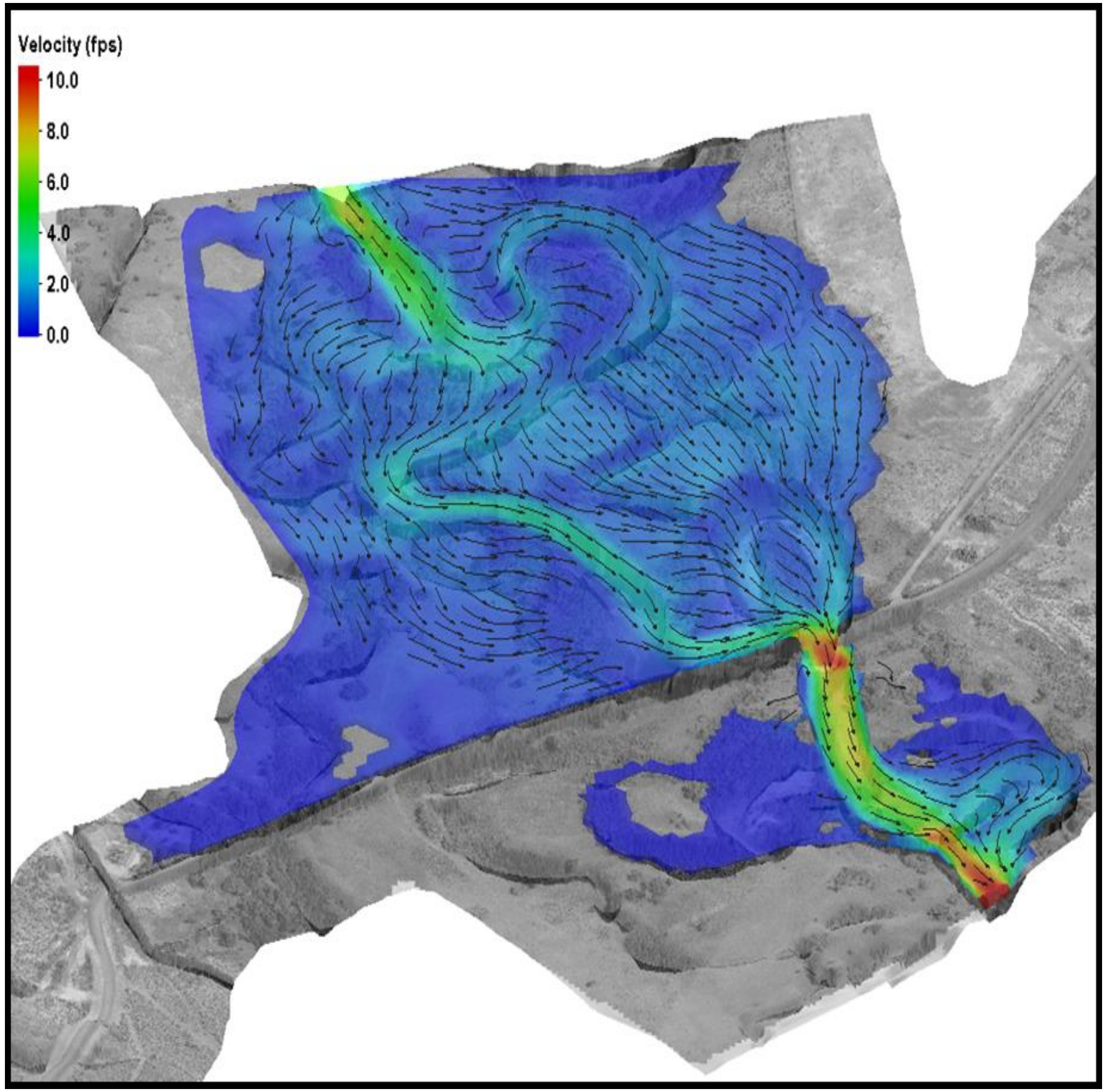


Image Source: FHWA

SMS Graphical User Interface

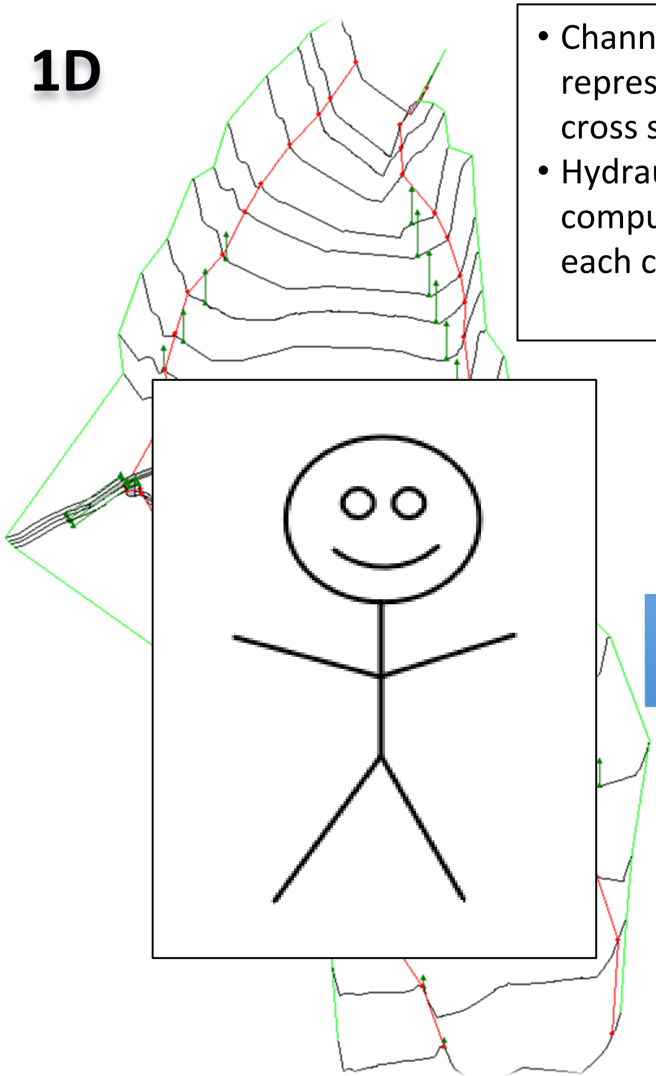


- Aquaveo support and partnership
- Full service package
  - Pre-processing
  - Model Execution
  - Model Review
  - Results Summary
- LiDAR processing features
  - Data filtering and transformation
- 2D Mesh development
- Presentation graphics and visualizations
- Tutorials and User's guide
- Technical Support
- **Free community version**
- 'Pro' version has additional analysis tools

Image Source: Nevada Department of Transportation

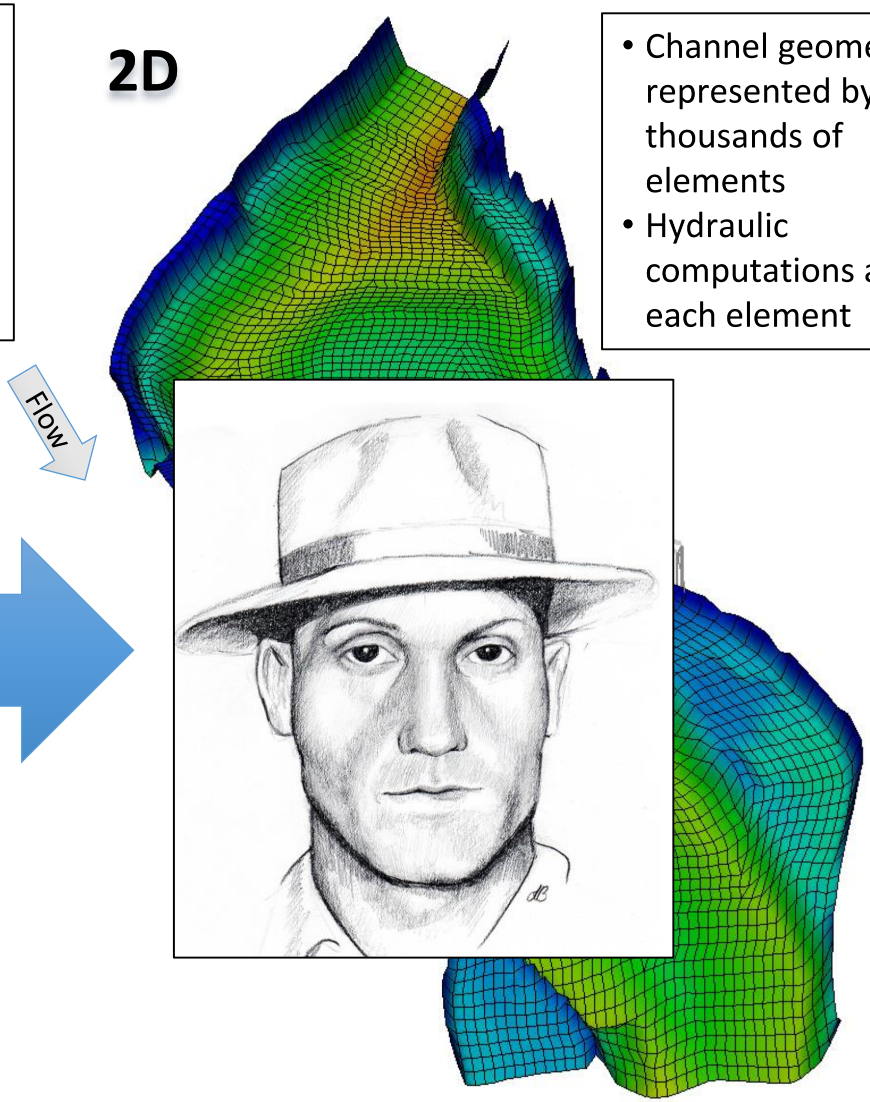
1D versus 2D Modeling

1D



- Channel geometry represented by cross sections
- Hydraulic computations at each cross section

2D



- Channel geometry represented by thousands of elements
- Hydraulic computations at each element

Image Source: New Hampshire DOT/ Wikimedia Commons stick figure by Jleedev / CC by 2.0 1940 mugshot | by Ask A Forensic Artist

1D versus 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	Assumed 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	Assumed based on conveyance	Computed based on continuity
Water surface elevation	Assumed constant across cross sections	Computed at each element

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Why use 2D hydraulic modeling?

- Flow paths/flow splits are directly computed
- Multiple openings are more accurately represented
- Continuity is preserved across the channel
- Flow distribution is computed based on continuity and momentum
- Water surface is computed across the channel
- Overtopping and pressure flow are more accurately represented
- More accurate bridge scour assessment

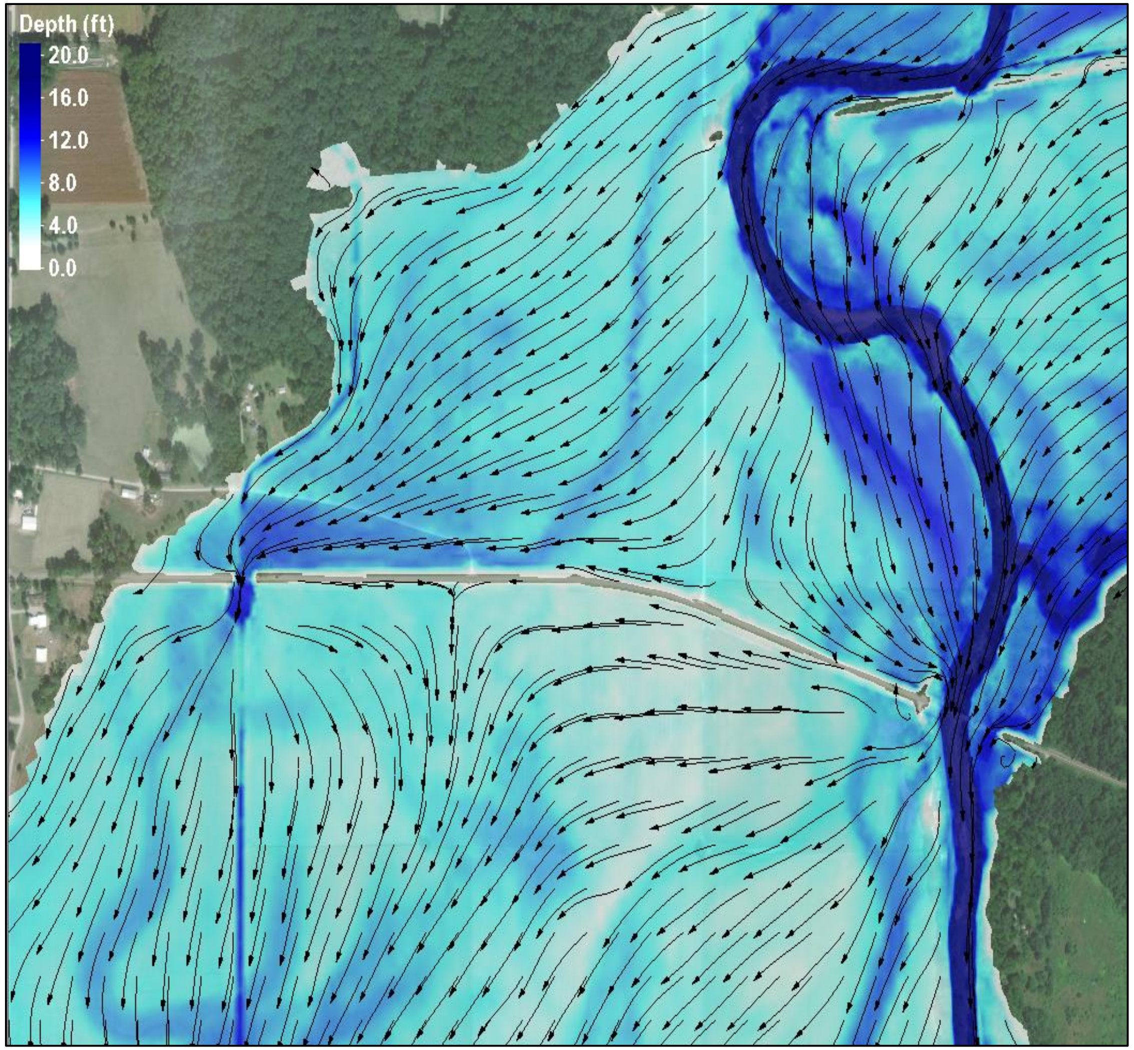

Image source: Earthstar Graphics / Indiana Department of Transportation

Consequences of 1D Modeling Assumptions

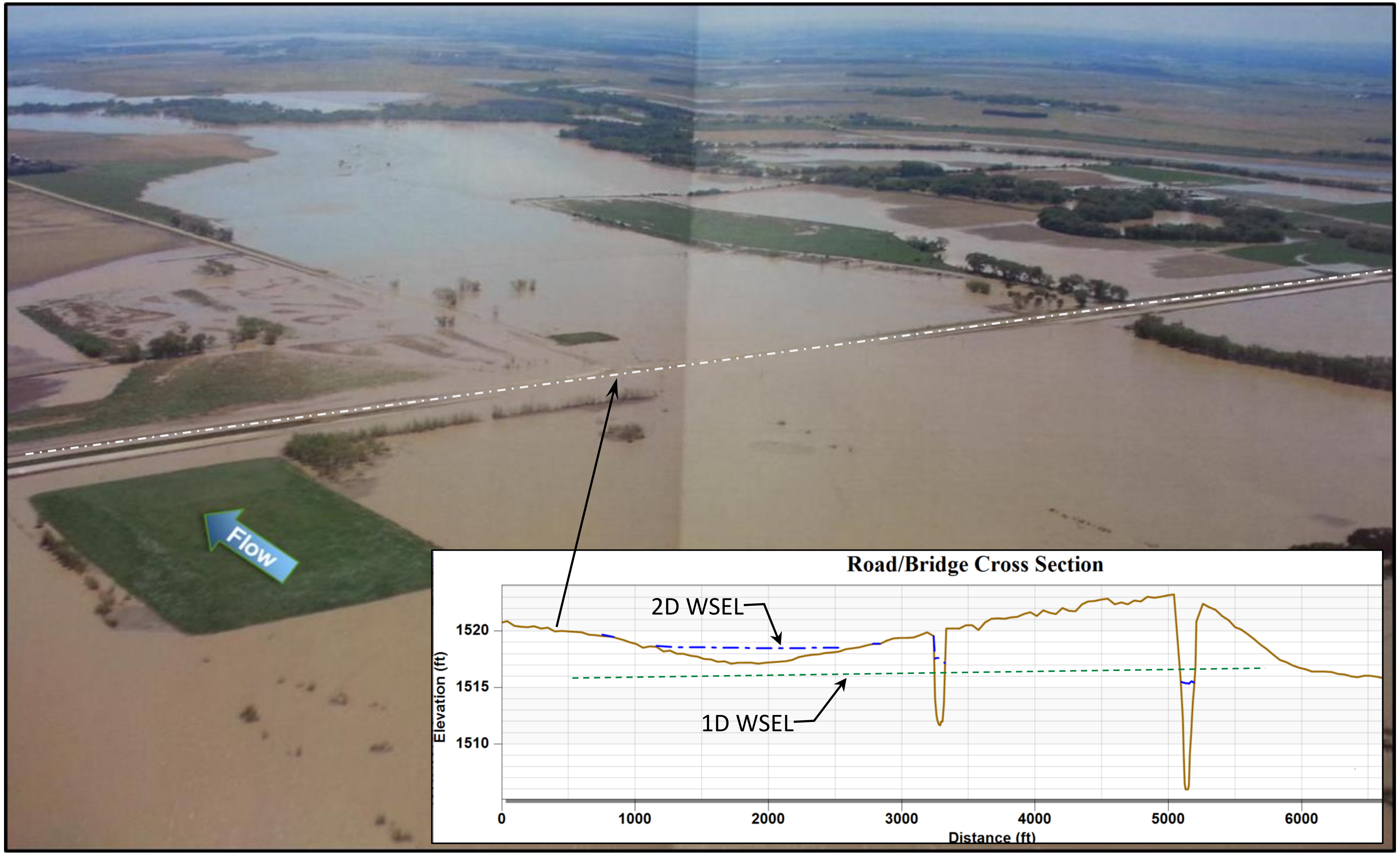

Image Source: Nebraska Department of Transportation

Benefits of 2D Hydraulic Modeling

More accurate representation of flow

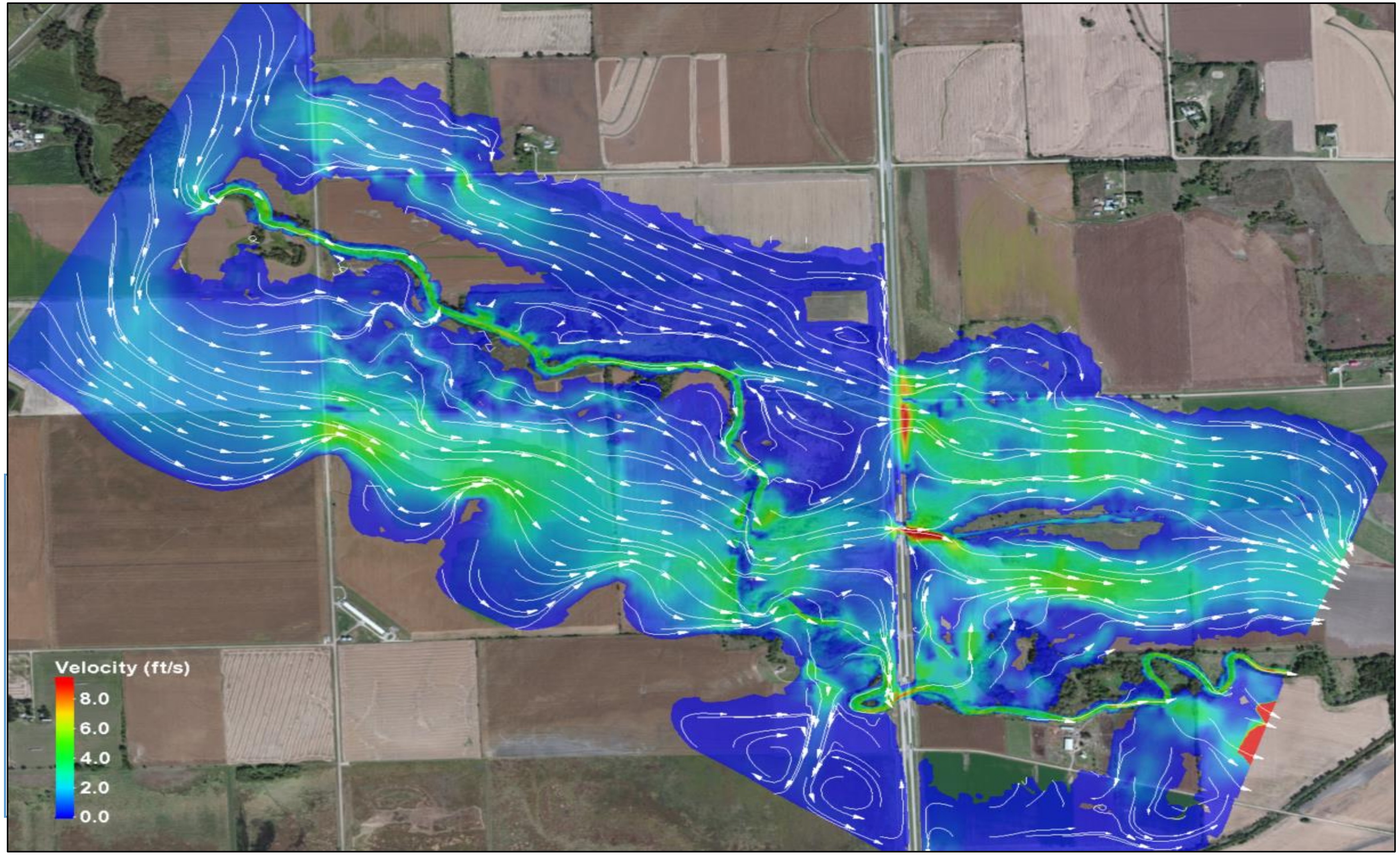

Image Source: Nebraska Department of Transportation / Earthstar Graphics (Aerial Image)

Benefits of 2D Hydraulic Modeling

Graphical Visualizations

Image Source: Nebraska Department of Transportation/ Earthstar Graphics (Aerial Image)

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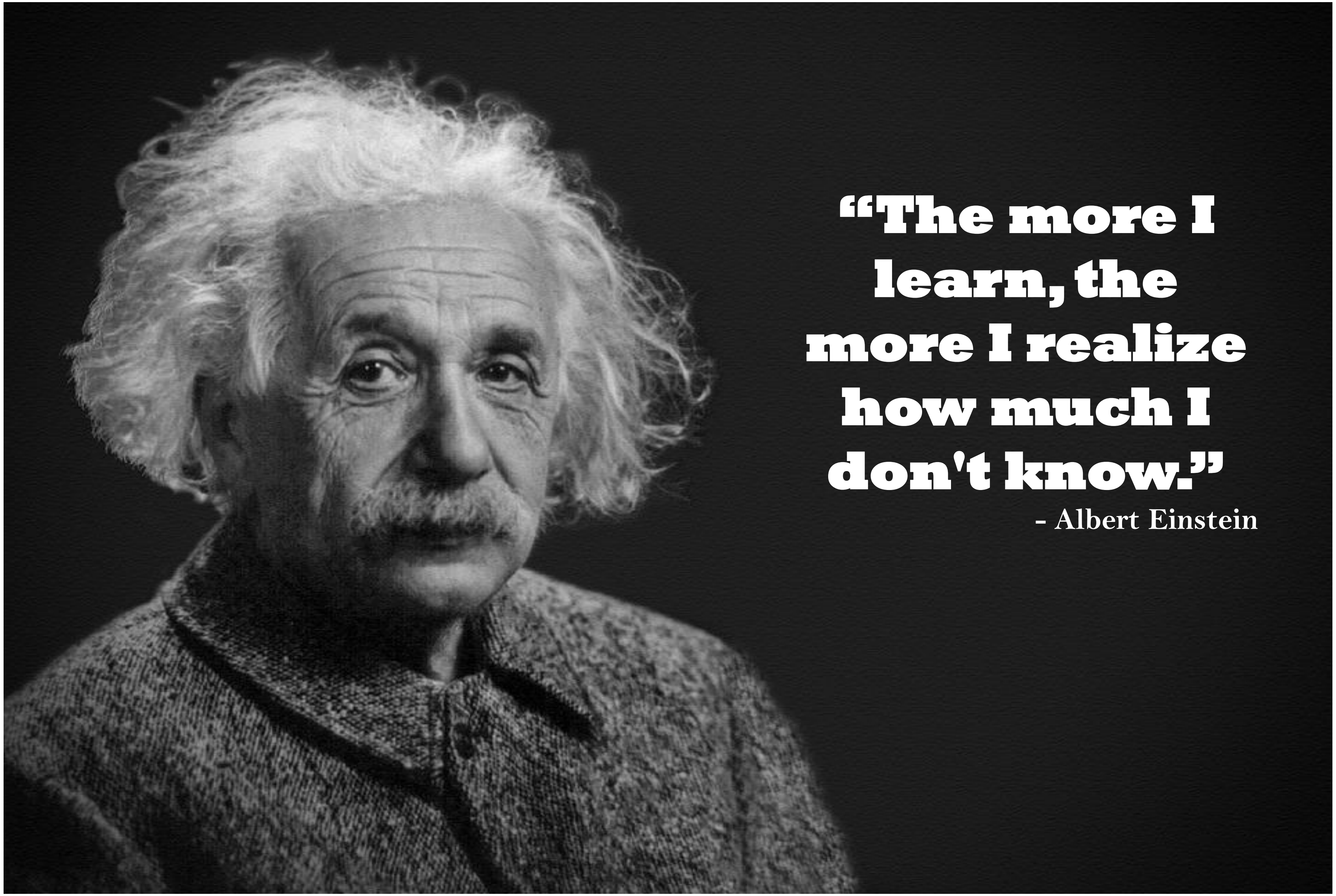

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2D Hydraulic Modeling Applications

- Multiple hydraulic structures
- Skewed bridges
- Complex floodplain flow
- Multiple flow paths
- Wide floodplains
- Undefined flow paths
- Super-elevation around bends
- Bank protection design
- Channel stabilization design
- Bridge scour evaluation
- Habitat impact assessment

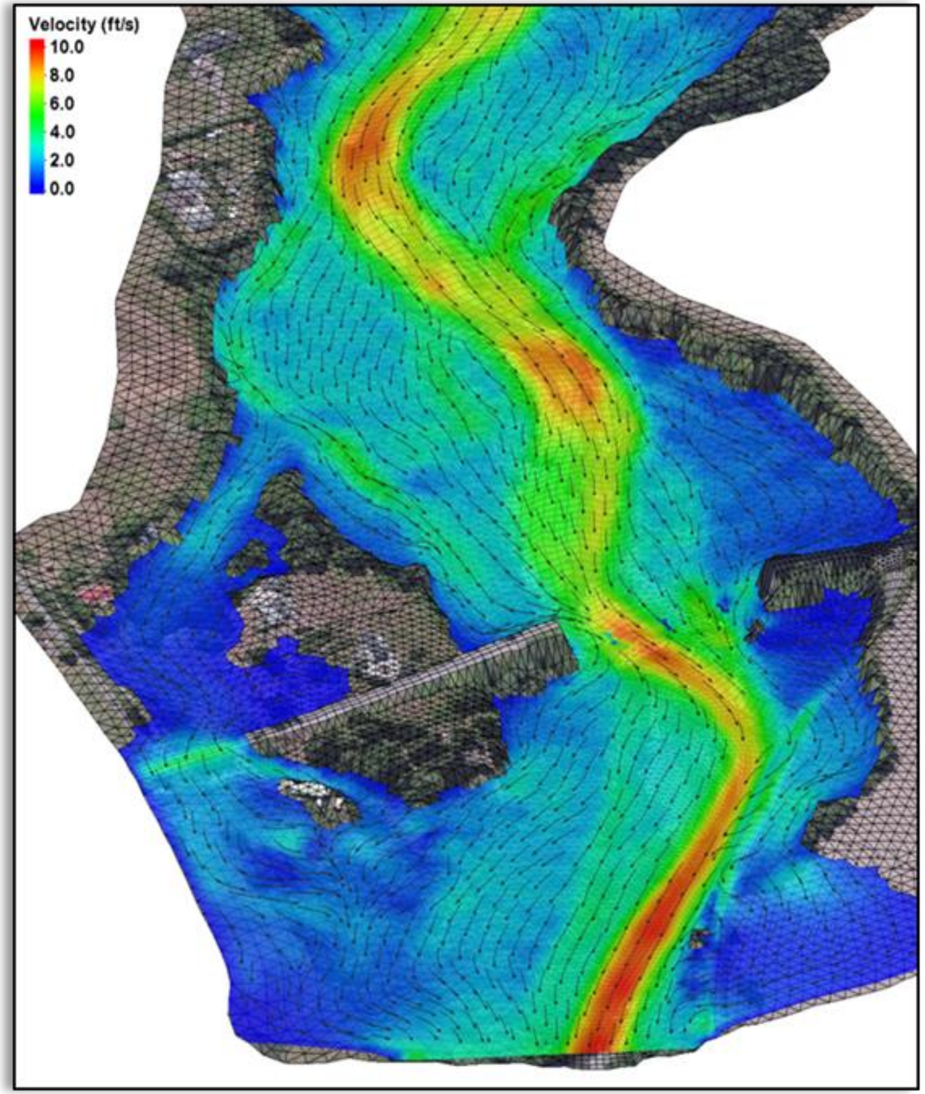

Image Source: Washington Department of Transportation

Multiple Structures

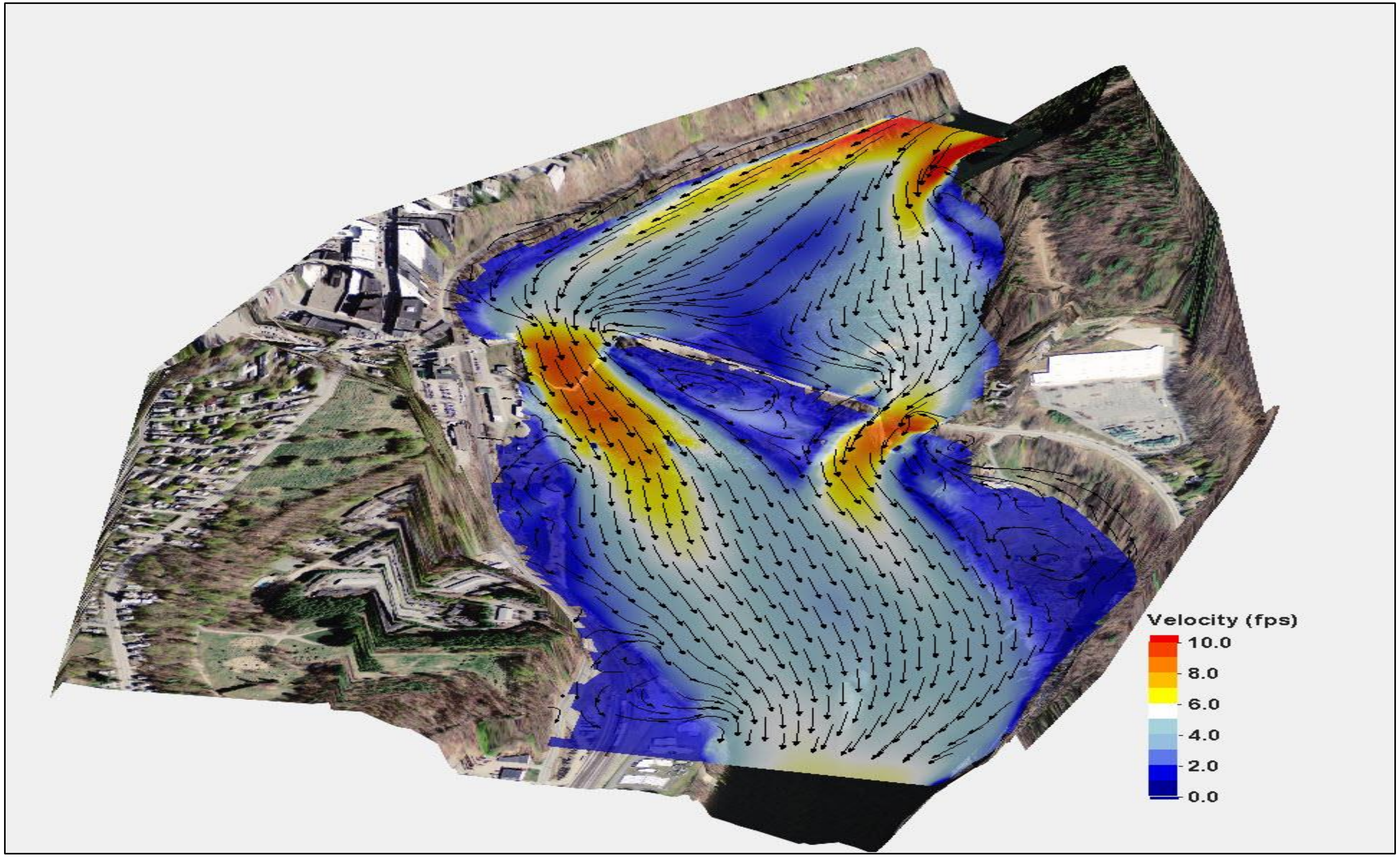

Image Sources: New Hampshire Department of Transportation / Earthstar Graphics (Aerial Image)

Skewed Bridges

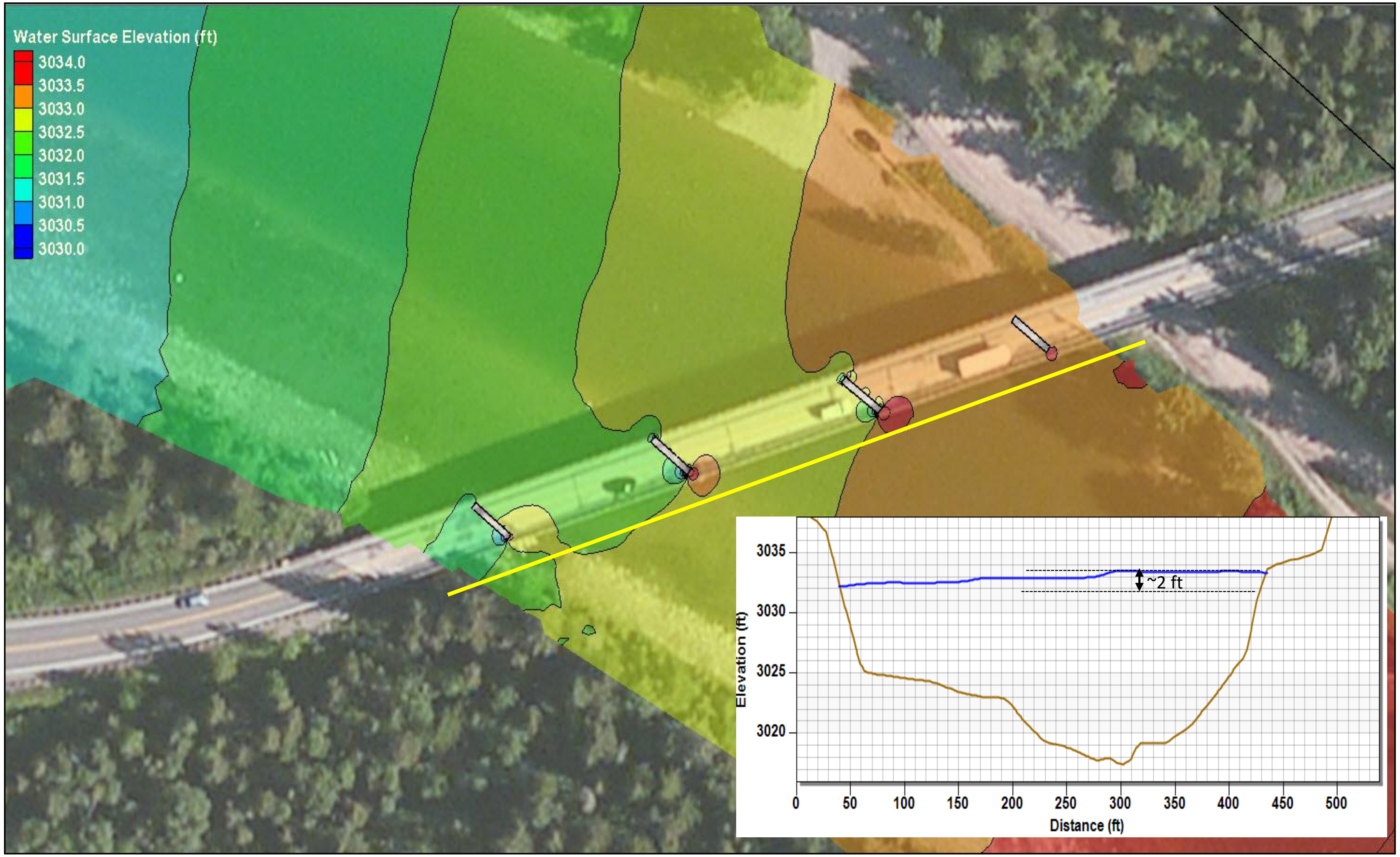

Image Sources: Montana DOT / Earthstar Graphics (Aerial Image)

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Complex Floodplain Flow

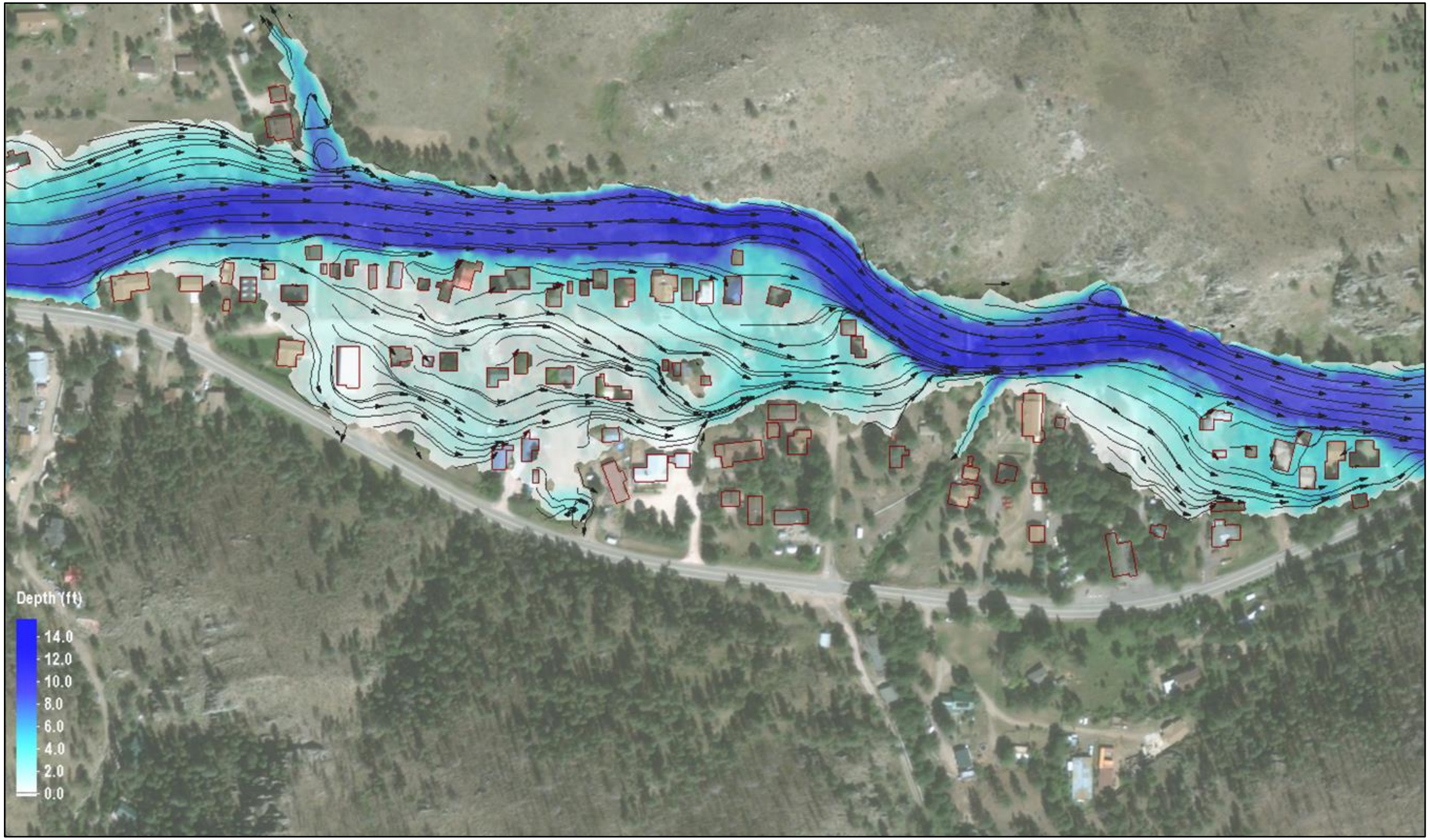


Image Sources: Larimer County Colorado

Multiple Flow Paths

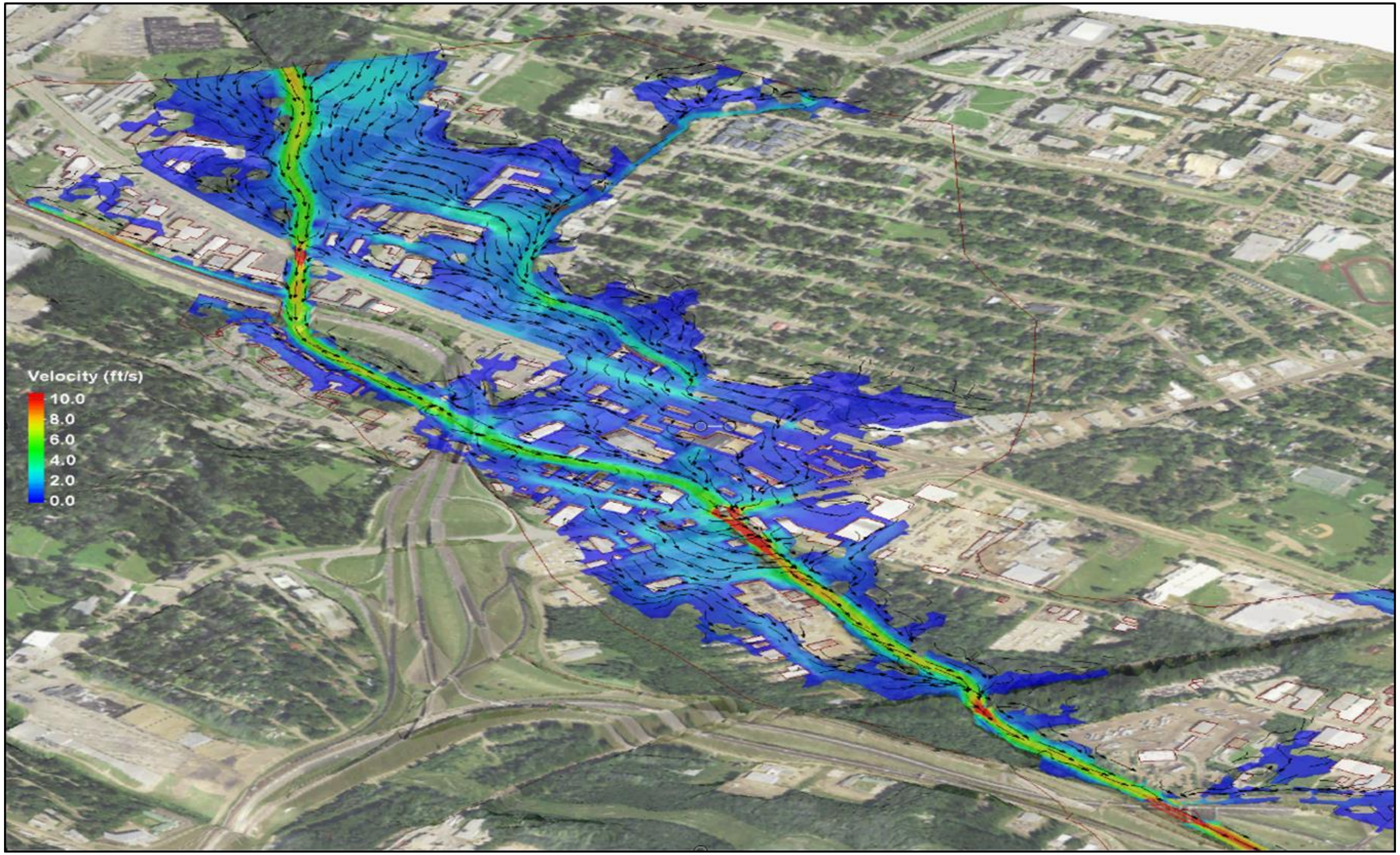


Image Sources: Mississippi Department of Transportation / Earthstar Graphics (Aerial Image)

Wide Floodplains

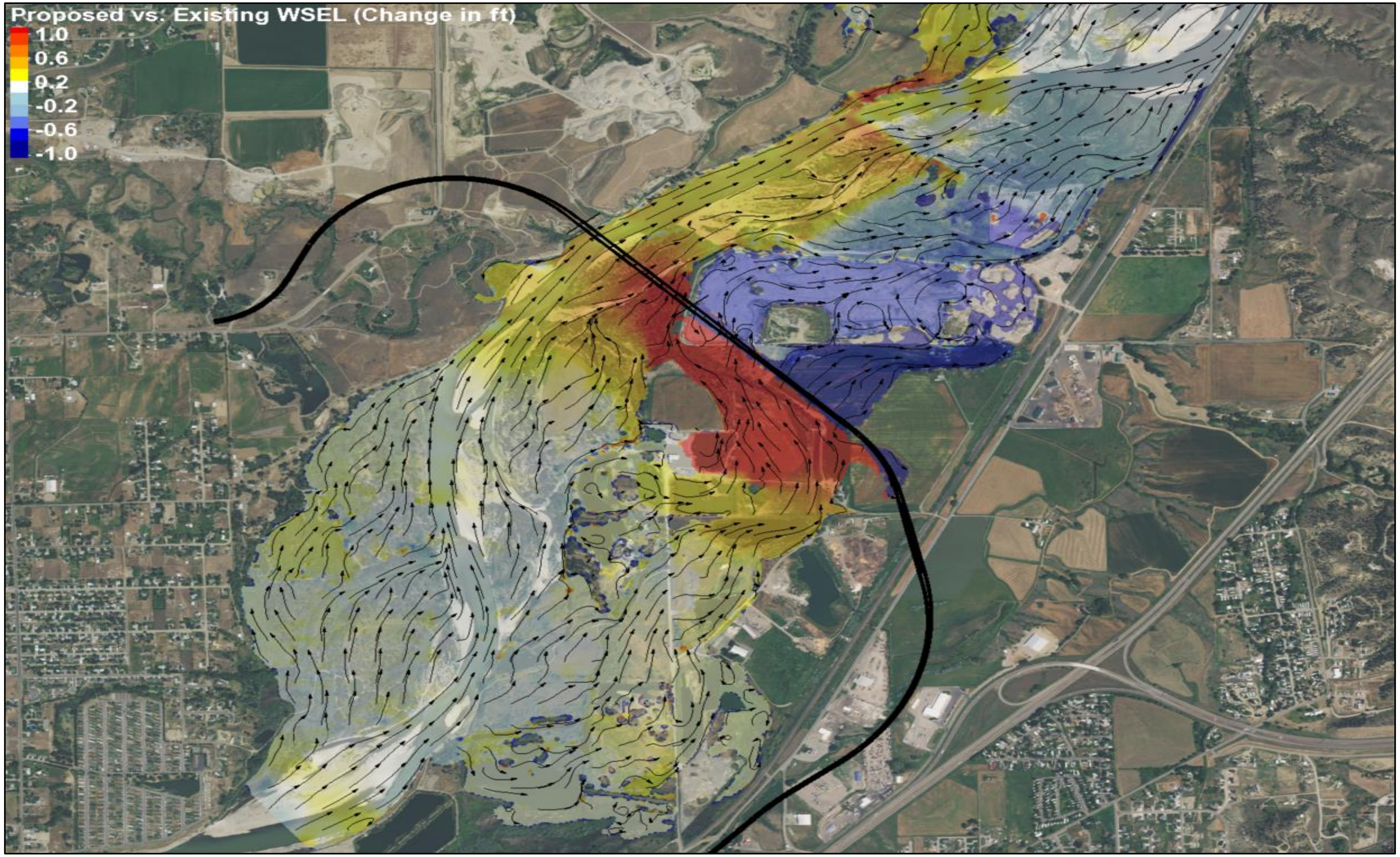


Image Sources: Montana DOT / Earthstar Graphics (Aerial Image)

Undefined Flow Paths

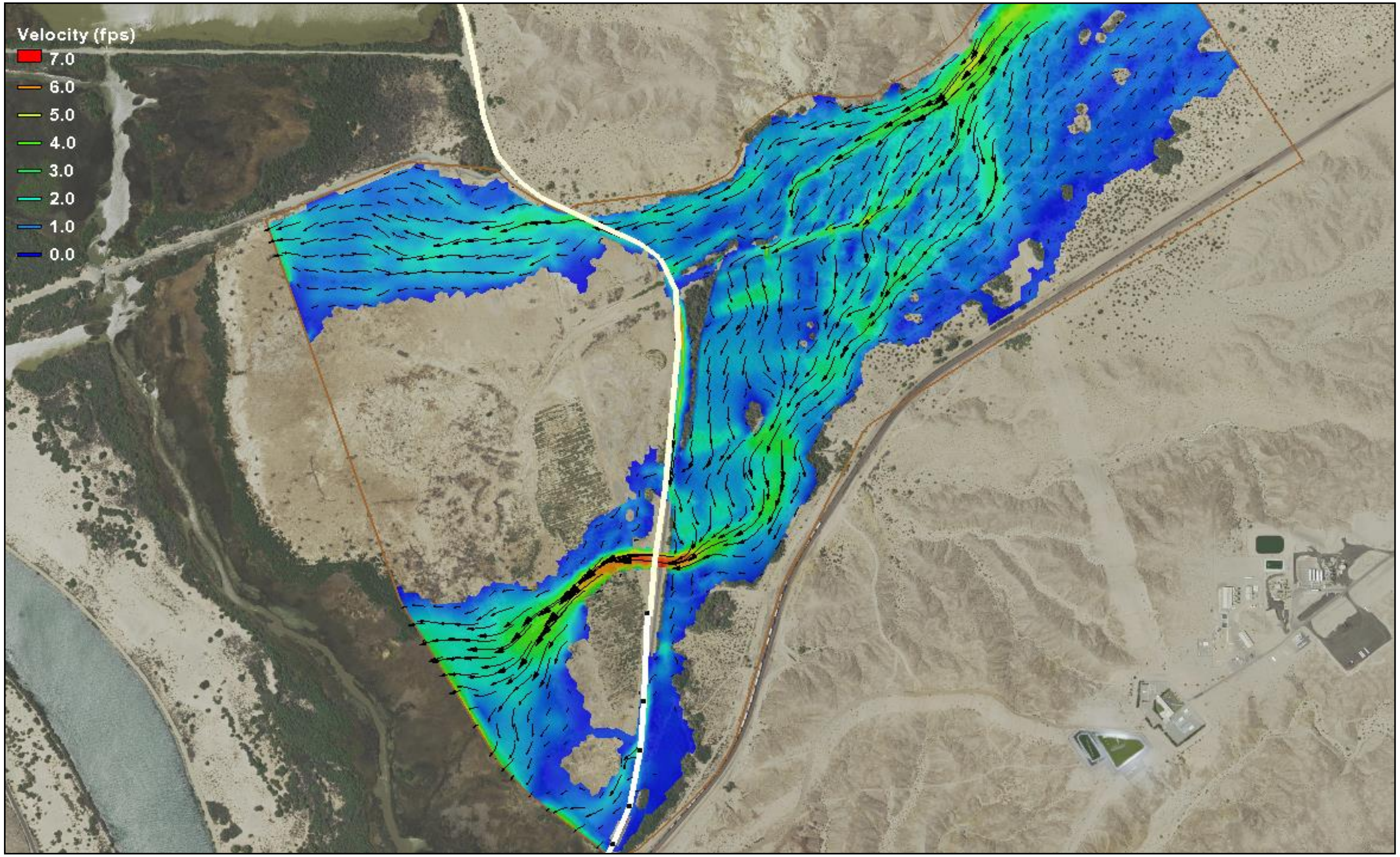


Image Sources: FHWA / Earthstar Graphics (Aerial Image)

Super-elevation of Flow Around Bends

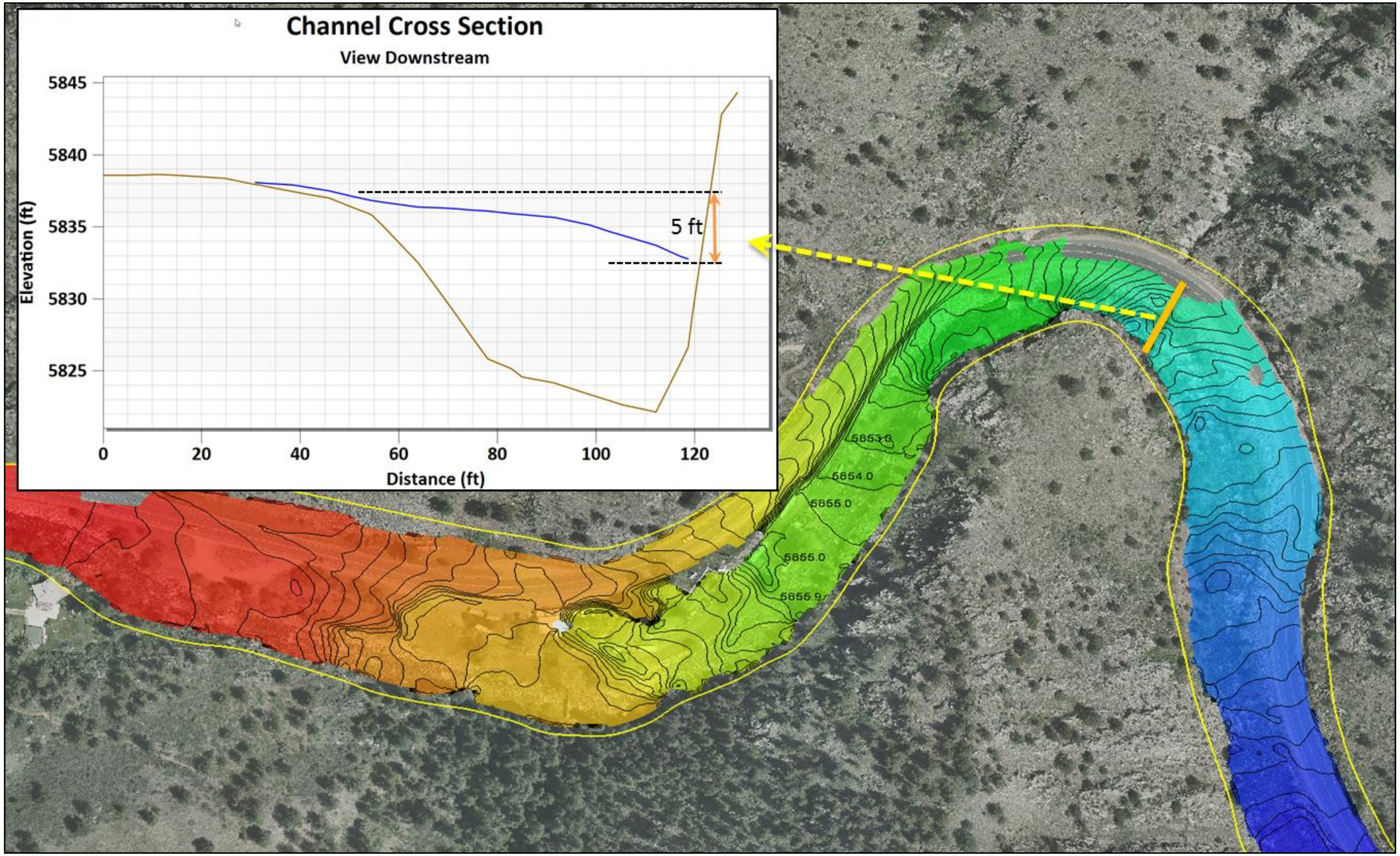


Image Sources: CDOT / Earthstar Graphics (Aerial Image)

Improved Bank Protection Design Approaches

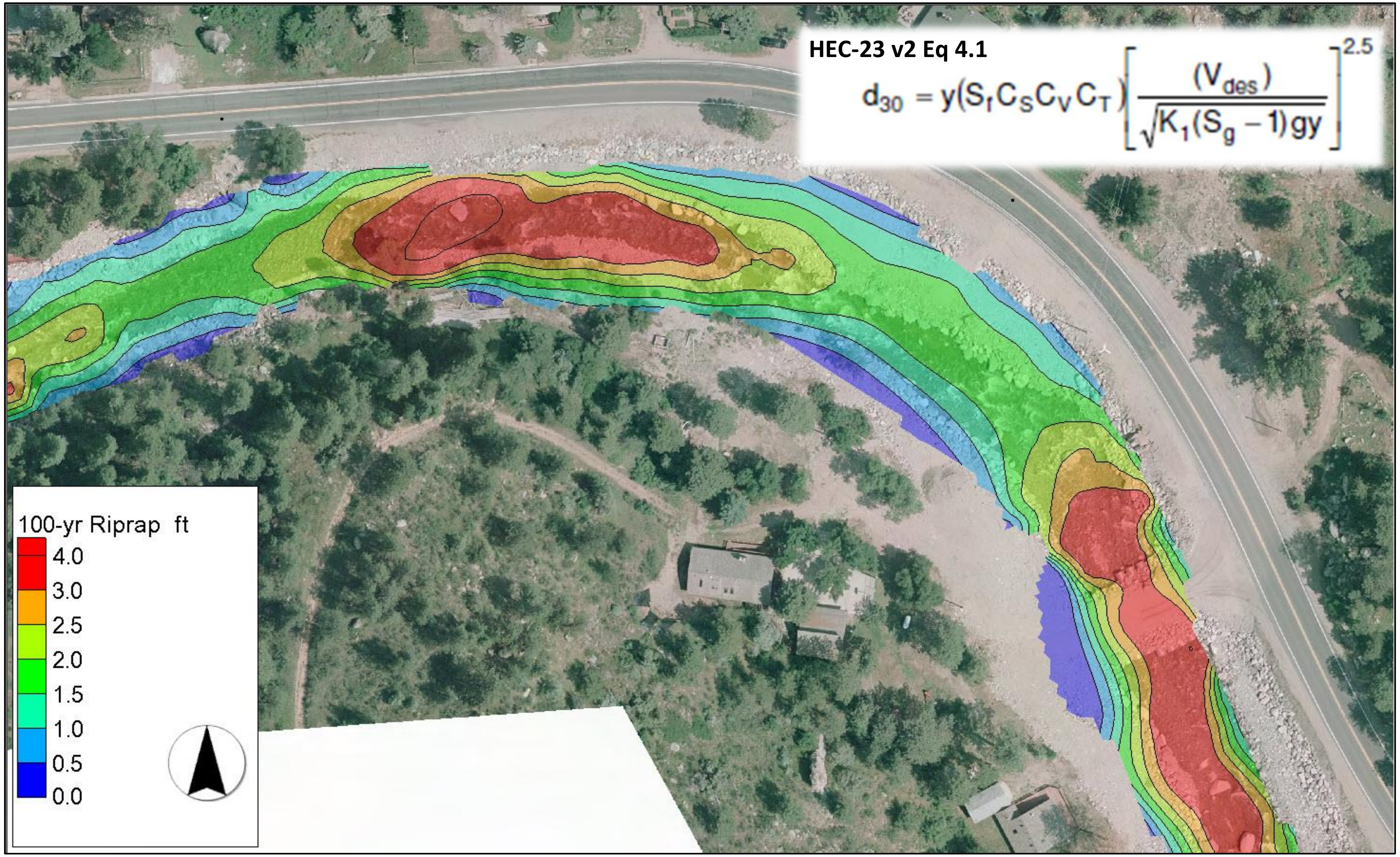


Image Sources: FHWA/ CDOT / Earthstar Graphics (Aerial Image)

Channel Stabilization Design

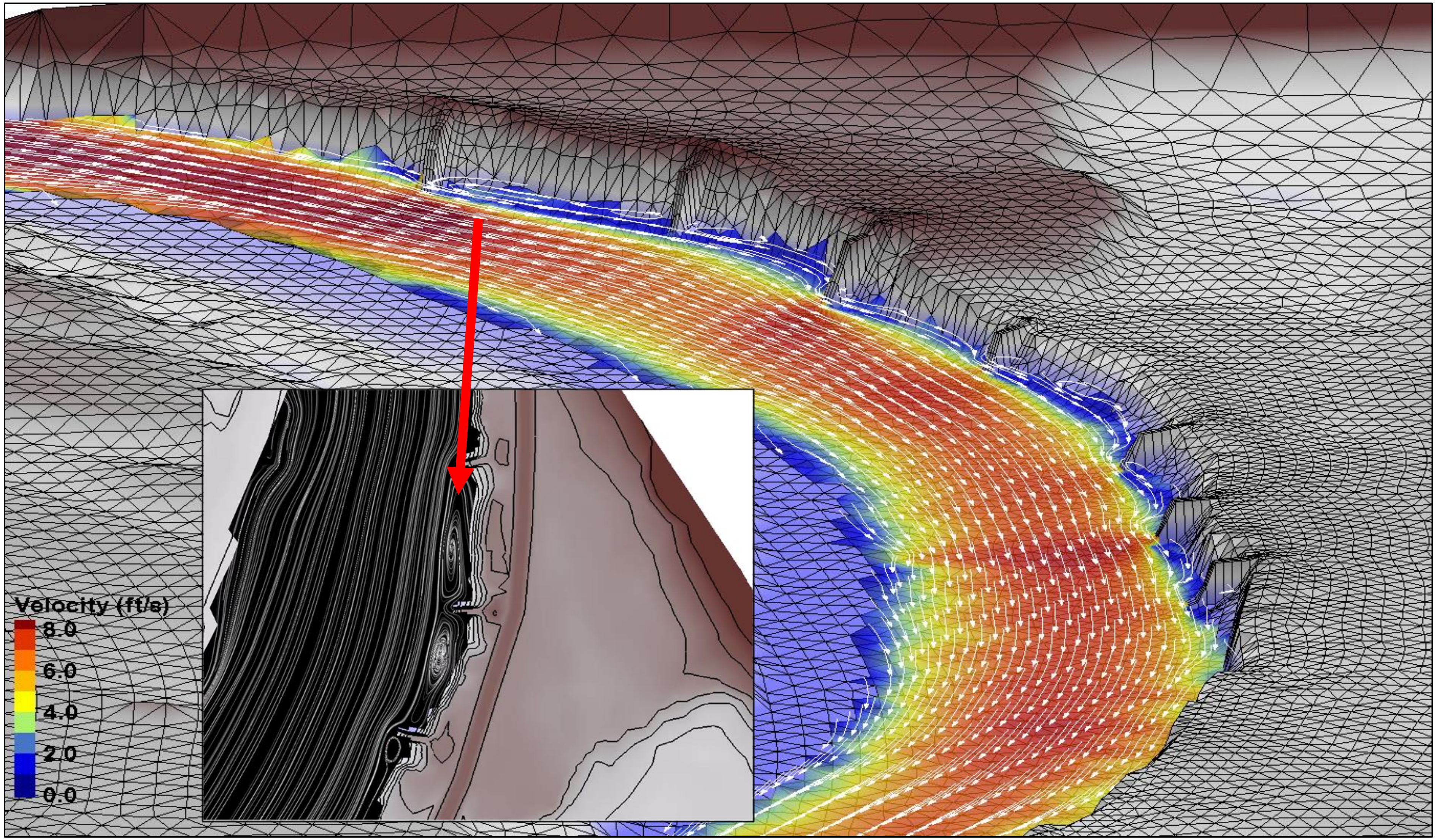
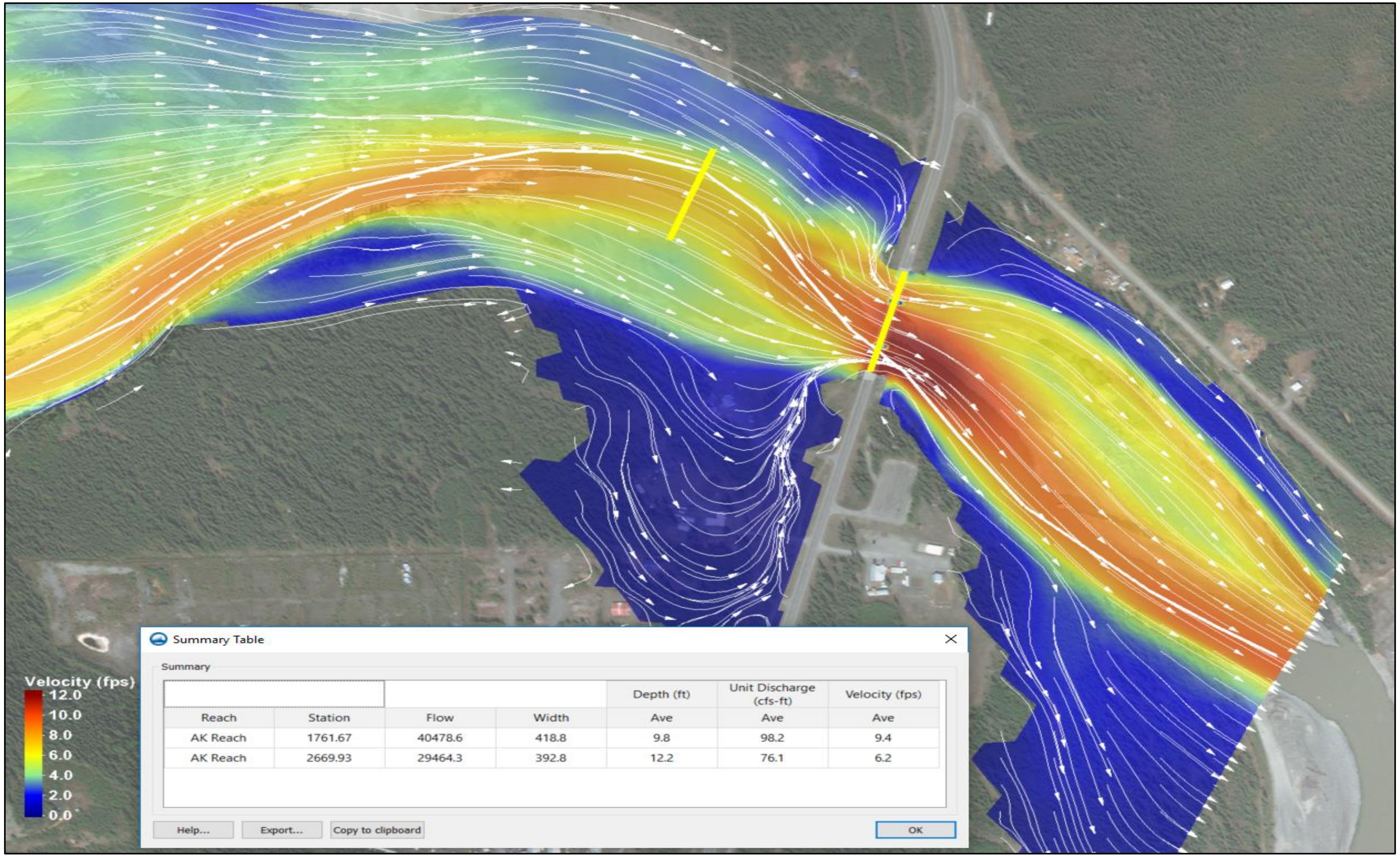


Image Sources: FHWA

Bridge Scour Evaluation



				Depth (ft)	Unit Discharge (cfs-ft)	Velocity (fps)
Reach	Station	Flow	Width	Ave	Ave	Ave
AK Reach	1761.67	40478.6	418.8	9.8	98.2	9.4
AK Reach	2669.93	29464.3	392.8	12.2	76.1	6.2

Image Sources: Alaska DOT/ WFL / Earthstar Graphics (Aerial Image)

Habitat Analysis and Impact Assessment

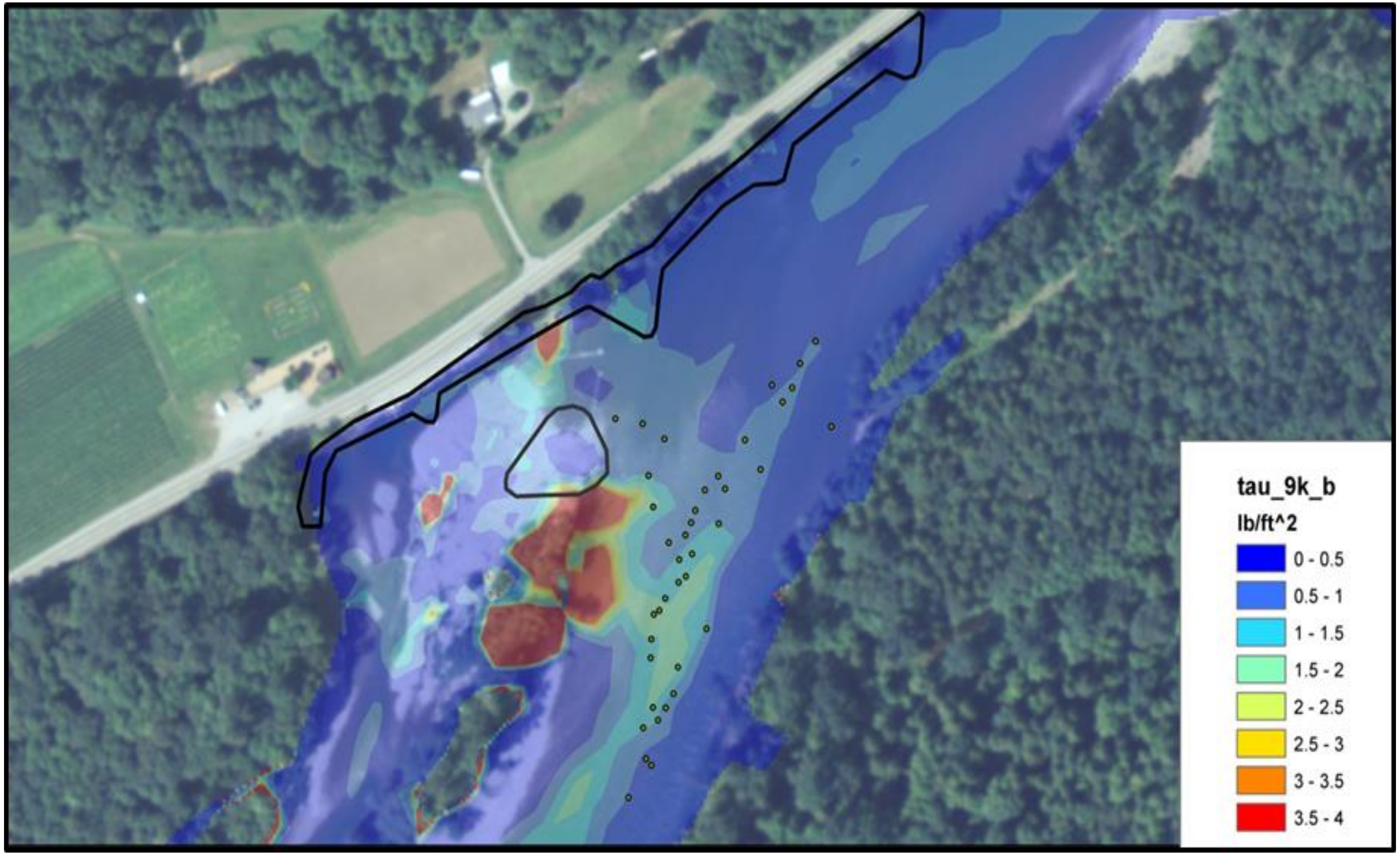
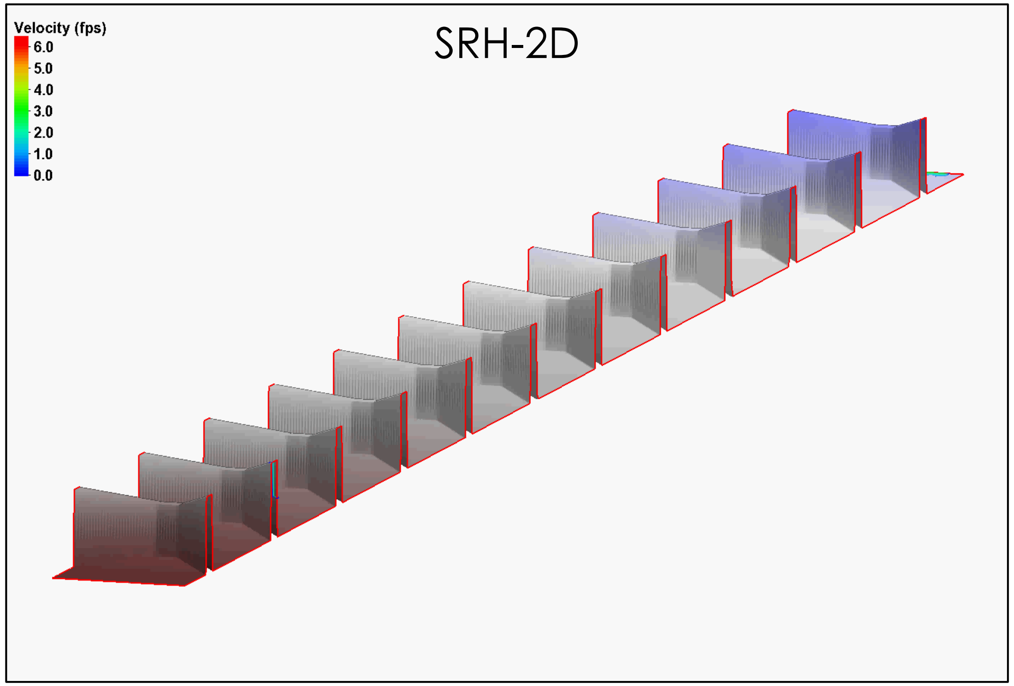
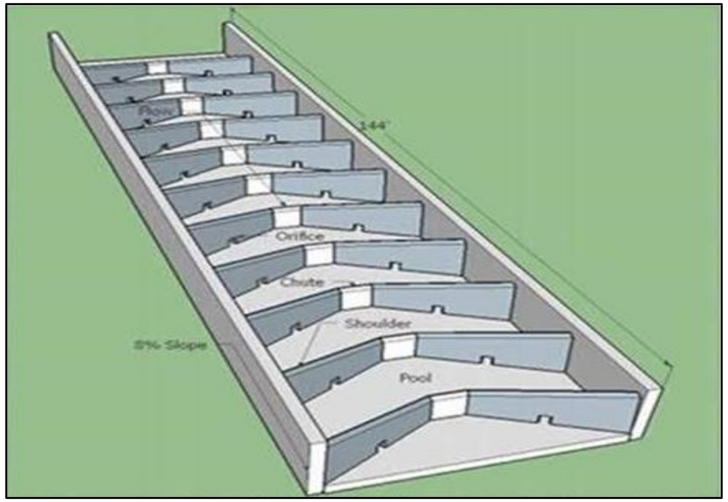


Image Sources: Kramer / Timm et al.

Fish Passage Design





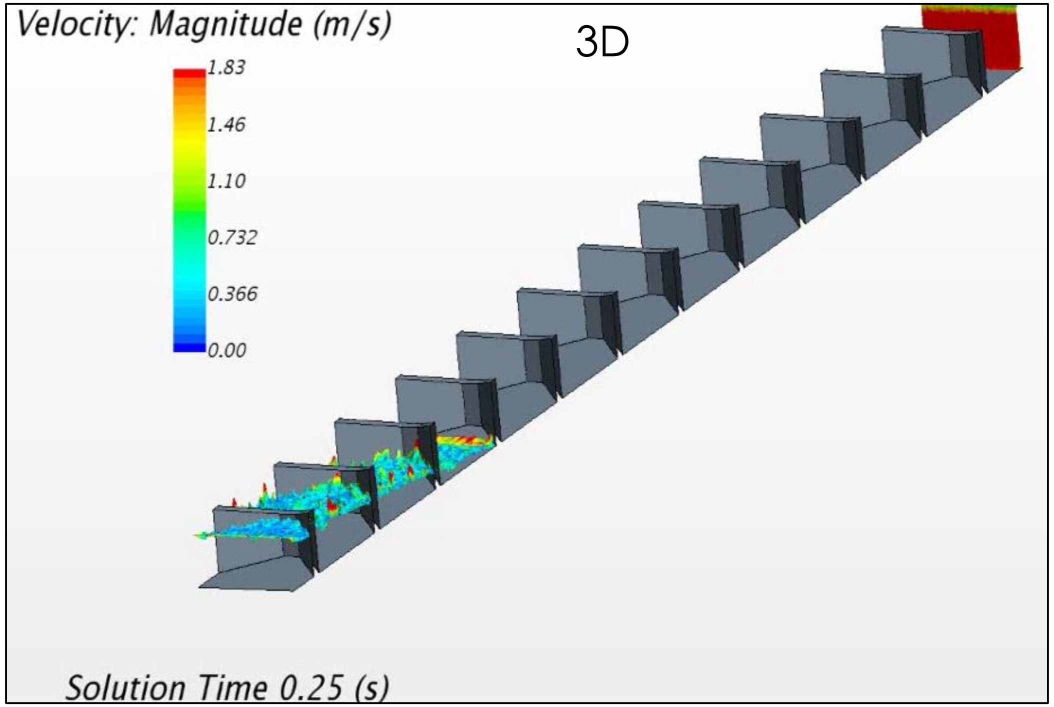


Image Sources: FHWA / Oregon Department of Transportation

Urban Drainage Analysis

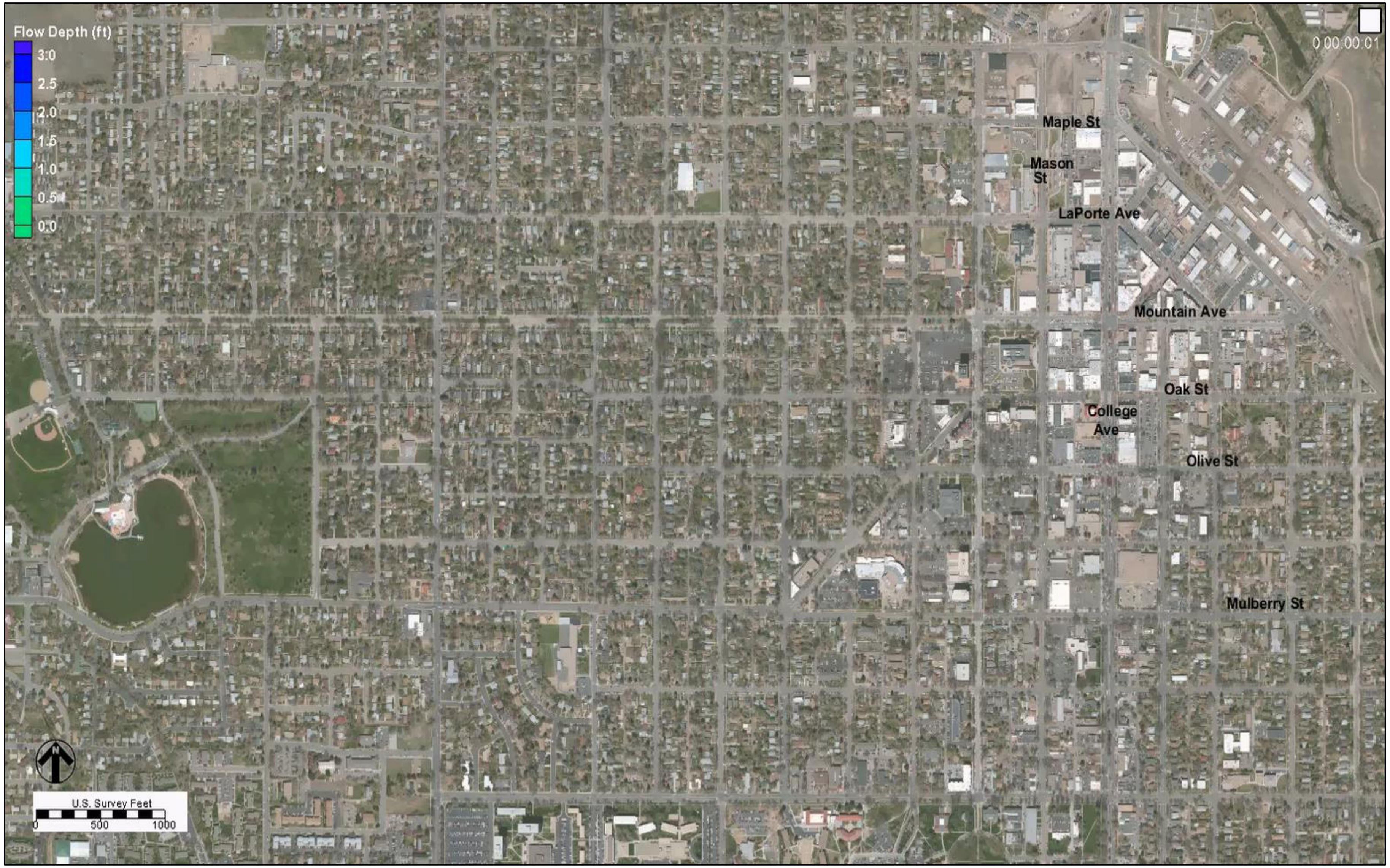


Image Sources: City of Fort Collins, Colorado

2D Hydraulic Modeling and Scour References

www.fhwa.dot.gov/engineering/hydraulics *(Search FHWA Hydraulics)*

- Two-Dimensional Hydraulic Modeling for Highways in the River Environment (FHWA, ETA summer 2019)
- Hydraulic Design of Safe Bridges – HDS-7 (FHWA, 2012)
- Evaluating Scour at Bridges – HEC-18 (FHWA, 2012)

2D Hydraulic Modeling Resources

www.fhwa.dot.gov/engineering/hydraulics *(Search FHWA Hydraulics)*

Training

- 2D hydraulic modeling course (NHI#135095)
- Advance online training (NHI#135095A & B)
- YouTube video tutorials *(Search FHWA SRH-2D July 2017)*
- 2D Hydraulic Modeling User's Forum webinars (contact Scott Hogan)

2D Hydraulic Modeling Resources

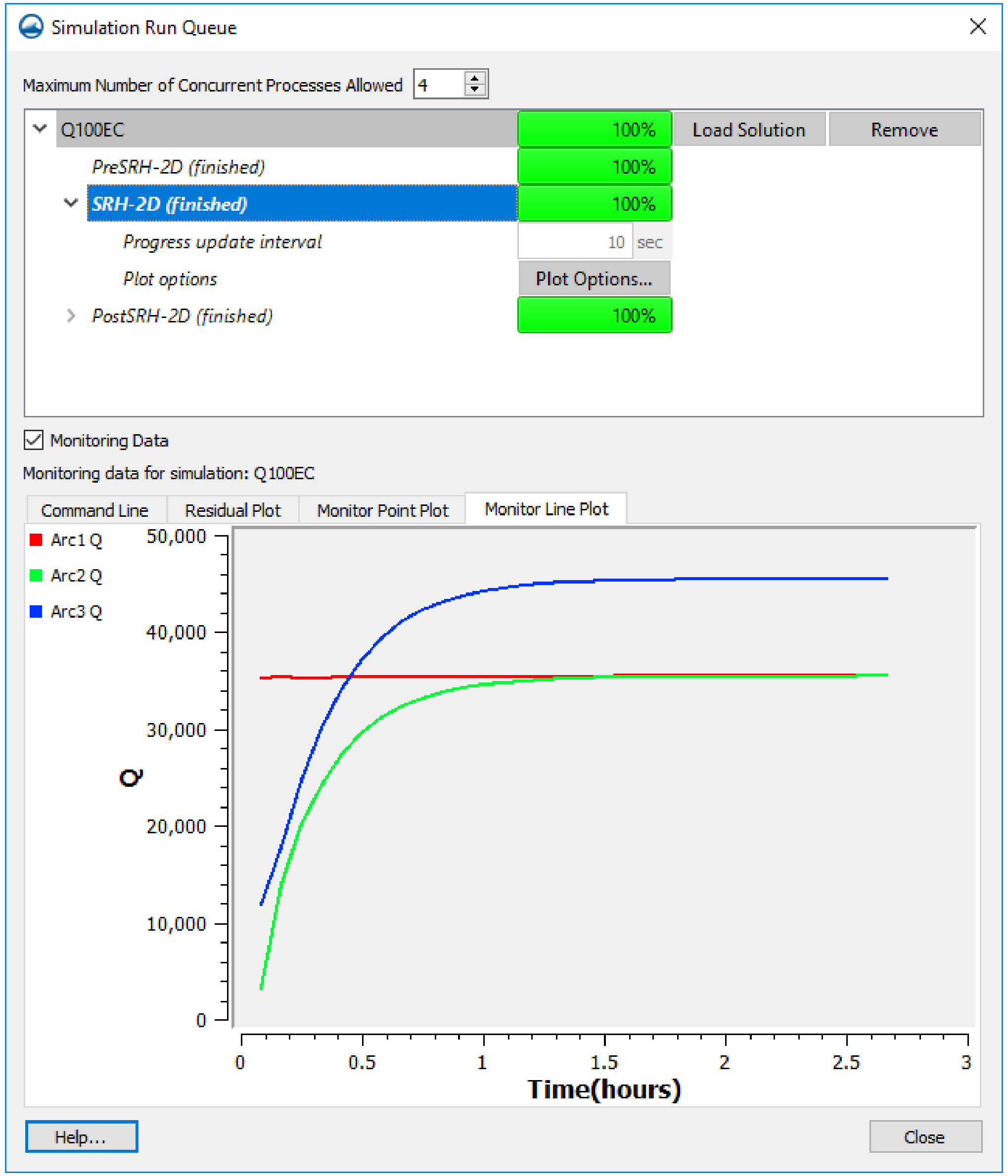
www.fhwa.dot.gov/engineering/hydraulics *(Search FHWA Hydraulics)*

Other Information (contact Scott Hogan):

- Examples of graphical visualization tools
- Sample scope of work for 2D modeling
- Model review checklist and comment form
- 2D Hydraulic Modeling Fact Sheet
- Case studies (example applications)
- College level curriculum for 2D hydraulic modeling COMING SOON

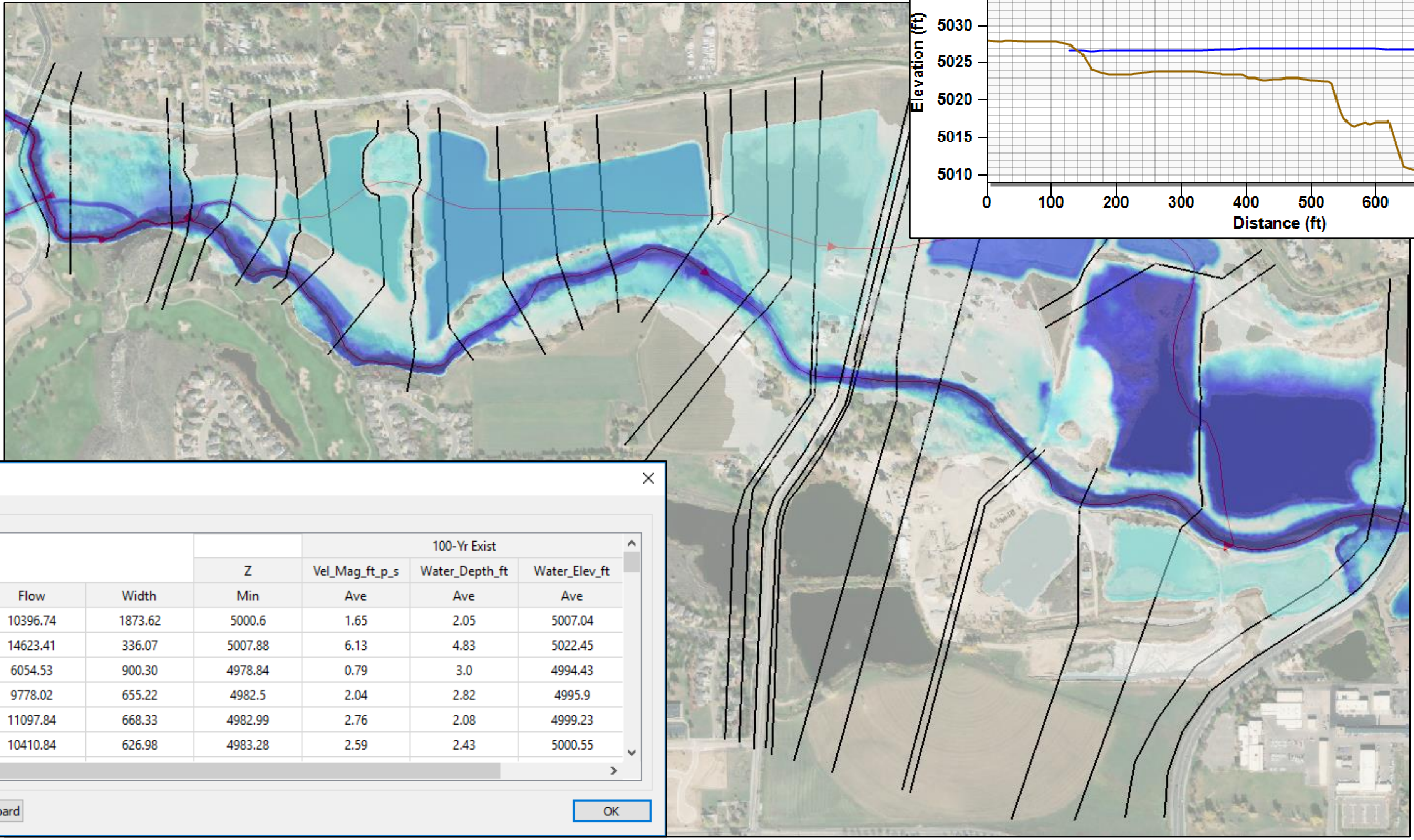
What's New?

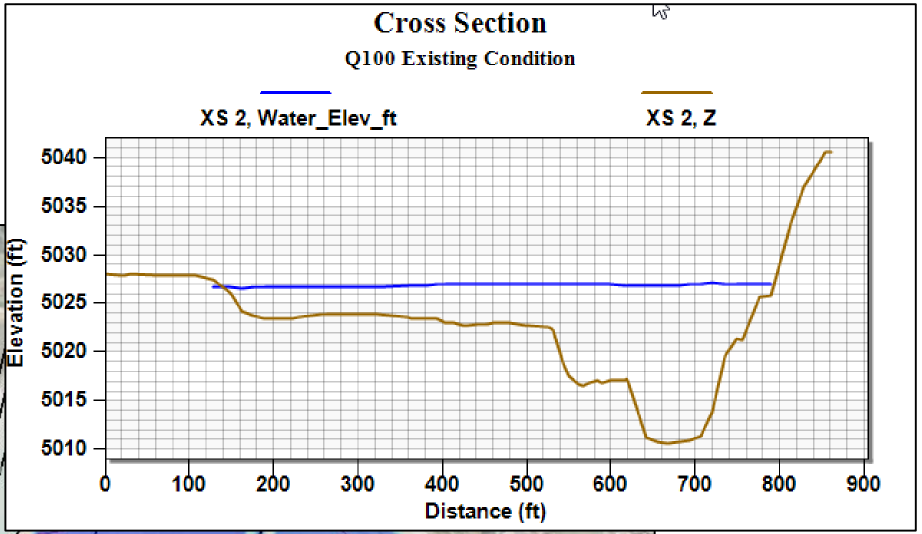
- Simulation 'dashboard'
- Concurrent simulations
- Simulation queue
- Summary tables
- Plotting features
- Bridge scour analysis tools



What's New ?

Hydraulic Summary Tables and Plotting Features





Summary Table

Summary

					100-Yr Exist		
				Z	Vel_Mag_ft_p_s	Water_Depth_ft	Water_Elev_ft
Reach	Station	Flow	Width	Min	Ave	Ave	Ave
Main Channel	-4780.84	10396.74	1873.62	5000.6	1.65	2.05	5007.04
Main Channel	-871.049	14623.41	336.07	5007.88	6.13	4.83	5022.45
Main Channel	313.626	6054.53	900.30	4978.84	0.79	3.0	4994.43
Main Channel	1044.28	9778.02	655.22	4982.5	2.04	2.82	4995.9
Main Channel	1466.47	11097.84	668.33	4982.99	2.76	2.08	4999.23
Main Channel	1513.52	10410.84	626.98	4983.28	2.59	2.43	5000.55

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Image Sources: Larimer County, Colorado

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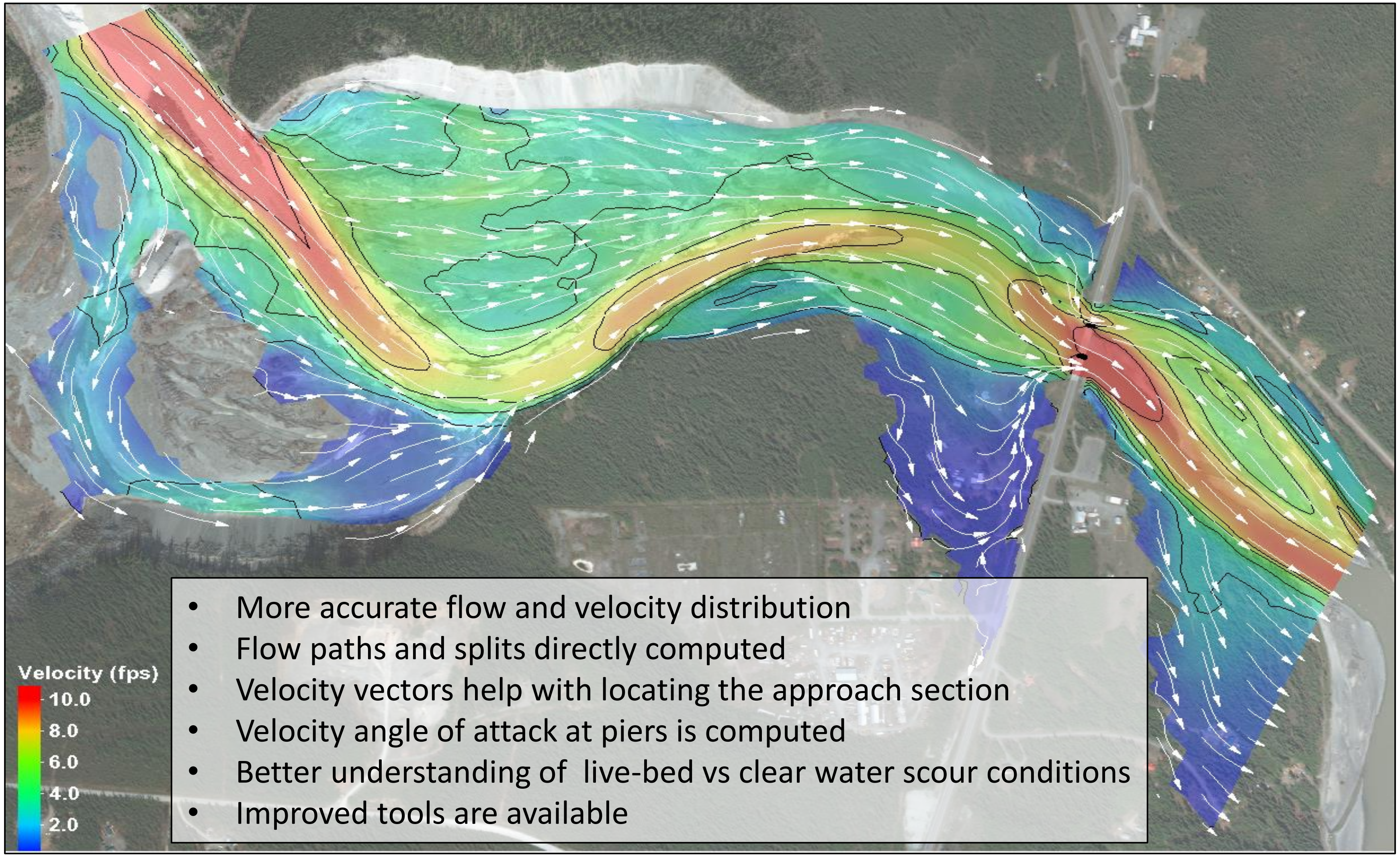
What's New ?

Improved Bridge Scour Evaluation with 2D Model Results

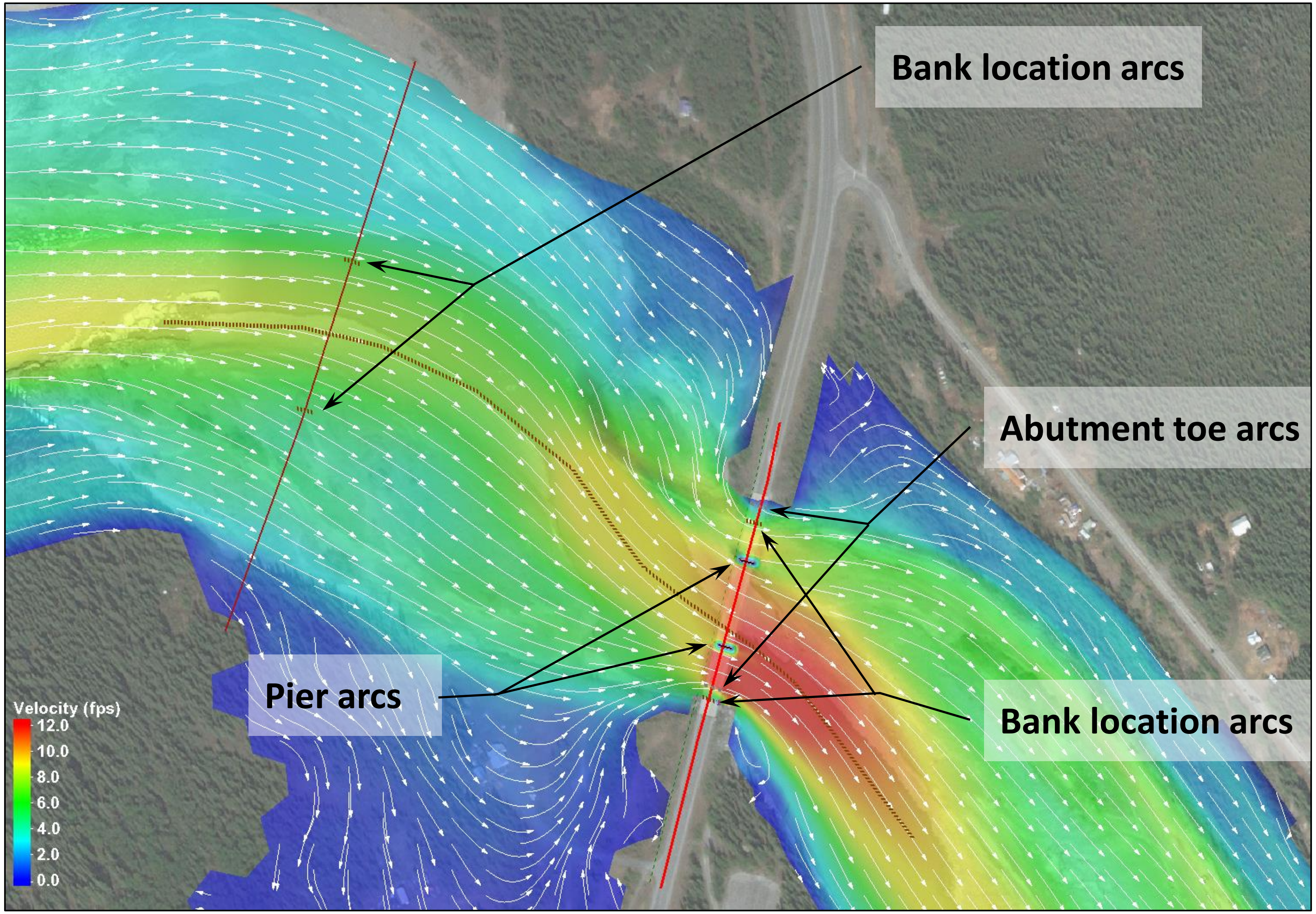


- More accurate flow and velocity distribution
- Flow paths and splits directly computed
- Velocity vectors help with locating the approach section
- Velocity angle of attack at piers is computed
- Better understanding of live-bed vs clear water scour conditions
- Improved tools are available

Image Sources: Alaska DOT/ WFL / Earthstar Graphics (Aerial Image)

What's New ?

Bridge Scour Tools in SMS / FHWA Hydraulic Toolbox Interface



User specifies:

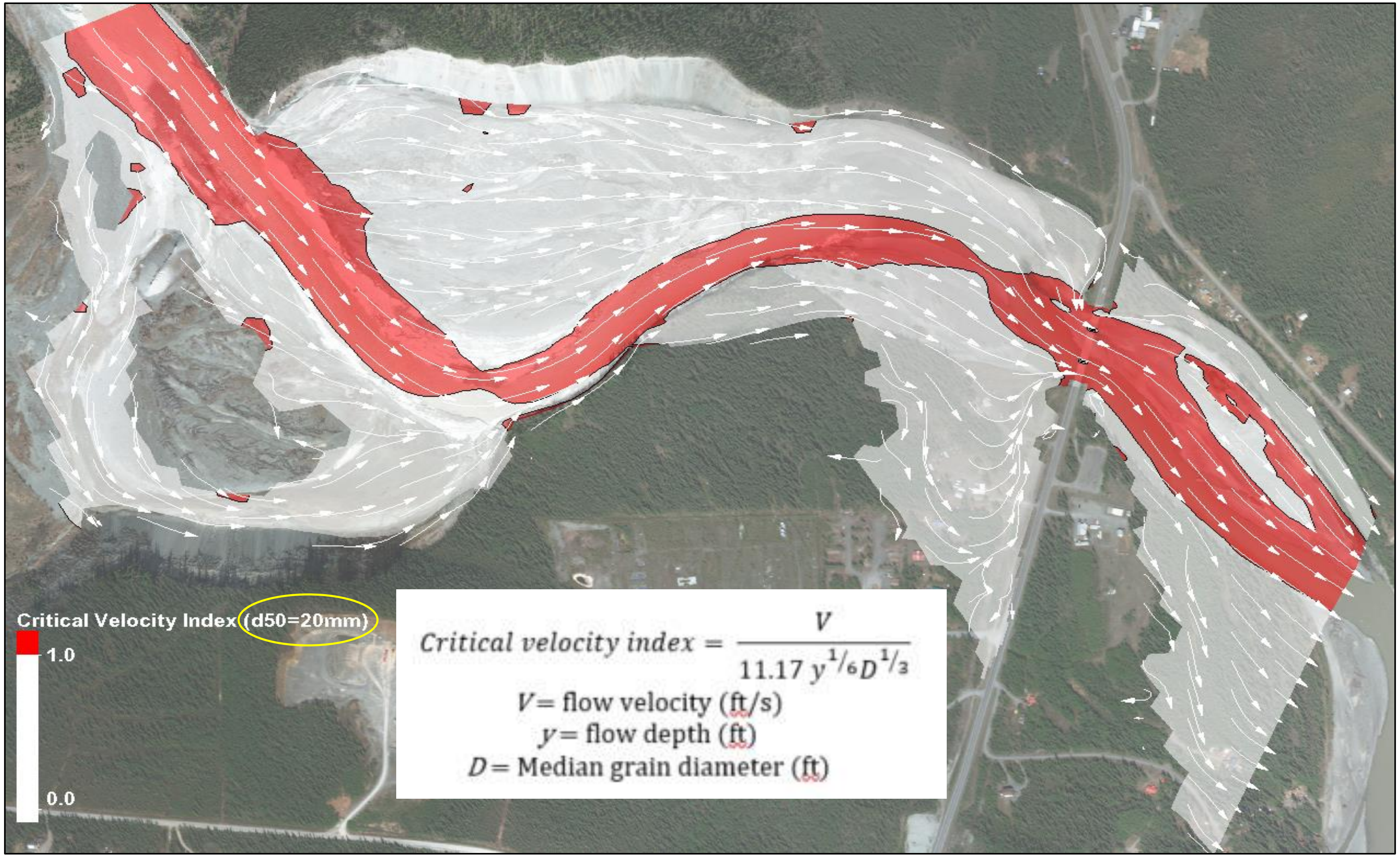
1) Channel centerline
2) Approach section
3) Contracted section
4) Bank locations
5) Pier locations, size and alignment
6) Abutment toe locations

Average hydraulic parameters and geometry are exported to the Hydraulic Toolbox

Image Sources: Alaska DOT/ Earthstar Graphics (Aerial Image)

What's New ?

2D Bridge Scour Analysis Tools – Critical Velocity Index with the Data Calculator



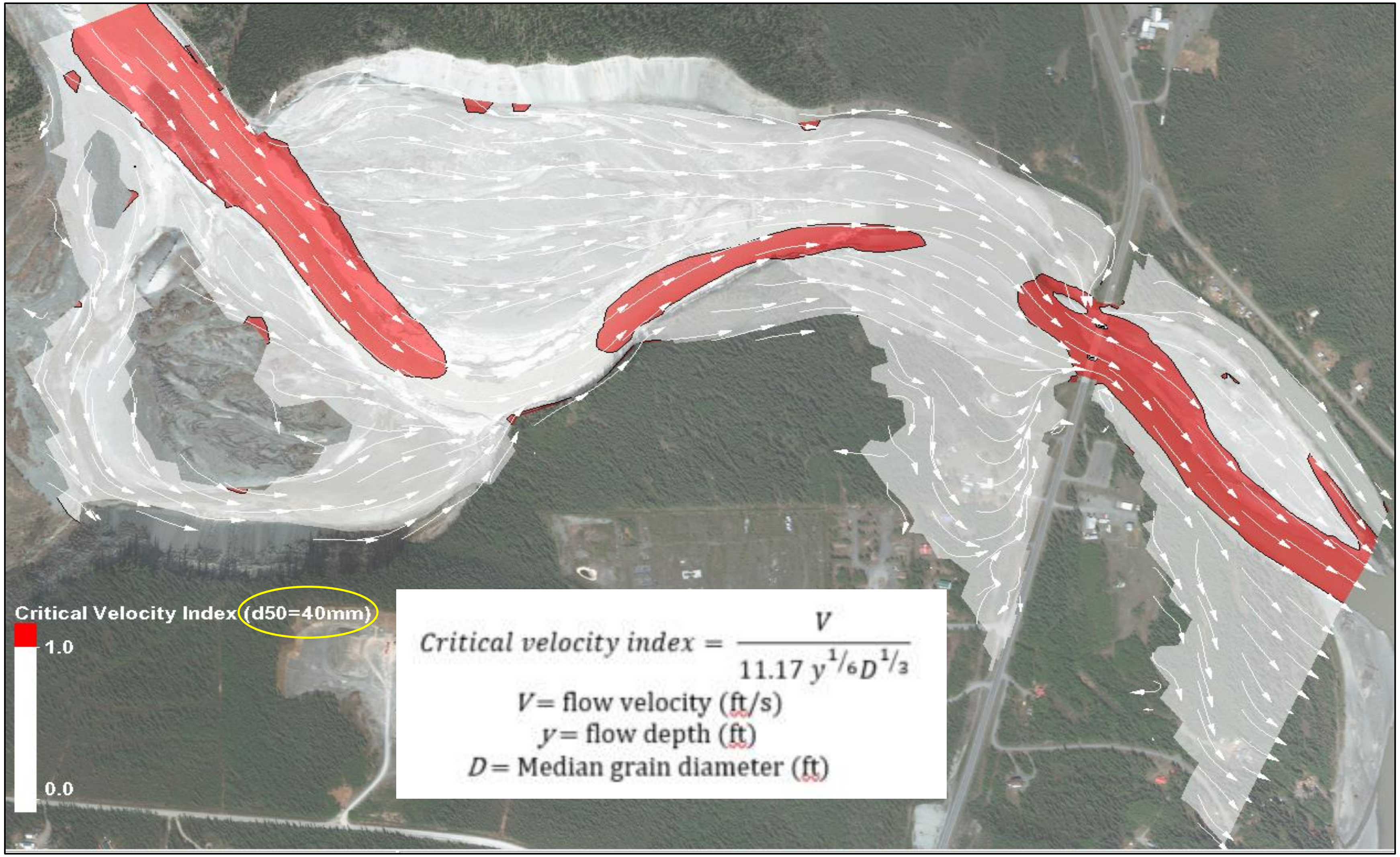
$$Critical\ velocity\ index = \frac{V}{11.17\, y^{1/6} D^{1/3}}$$

V = flow velocity (ft/s)
y = flow depth (ft)
D = Median grain diameter (ft)

Image Sources: Alaska DOT / Earthstar Graphics (Aerial Image)

What's New ?

2D Bridge Scour Analysis Tools – Critical Velocity Index with the Data Calculator



$$\text{Critical velocity index} = \frac{V}{11.17\, y^{1/6} D^{1/3}}$$

V = flow velocity (ft/s)
y = flow depth (ft)
D = Median grain diameter (ft)

Image Sources: Alaska DOT / Earthstar Graphics (Aerial Image)

What's New ?

Update FHWA Hydraulic Toolbox Scour Calculators

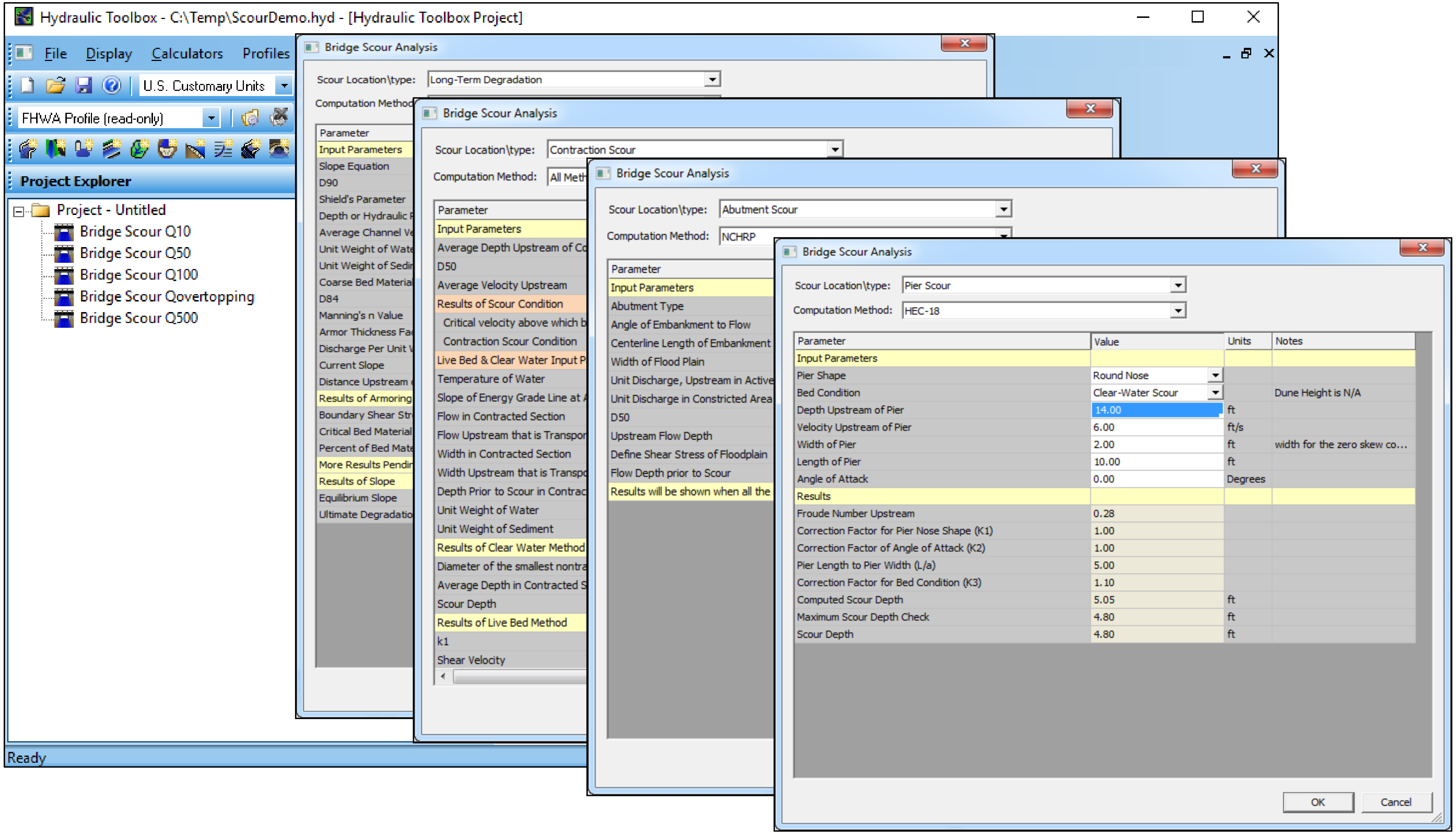


Image Sources: FHWA

What’s New ?

FHWA Hydraulic Toolbox Scour Summary Tables and Plots

Bridge Scour Summary Table

Parameter	Value	Units	Notes
Bridge Geometry			
Bridge Cross-Section			
Long Term Degradation			
Long Term Degradation (LTD)	3.00	ft	User-Specified Scour Depth
Minimum Channel Elevation with LTD	1114.07	ft	
Main Channel Contraction Scour			
Applied Contraction Scour Depth	3.92	ft	Contraction & Long Term Scour is applied method
Live Bed Contraction Scour Depth	3.92	ft	
Applied Contraction Scour Elevation with LTD	1110.15	ft	
Approach Cross-Section			
Local Scour at Piers			
Plot Pier Scour			
Piers			
Pier Name	Pier 1		
Pier Scour Depth	24.30	ft	Computation Method: HEC-18
Total Scour at Pier	31.22	ft	
Total Scour Elevation at Pier	1085.85	ft	
Piers			
Pier Name	Pier 2		
Pier Scour Depth	24.59	ft	Computation Method: HEC-18
Total Scour at Pier	31.50	ft	
Total Scour Elevation at Pier	1085.57	ft	
Local Scour at Abutments			
Left Abutment			
Plot Left Abutment Scour			
Abutment Scour Depth	12.35	ft	NCHRP Method
Total Scour at Abutment	12.35	ft	
Total Scour Elevation at Abutment	1101.72	ft	
Right Abutment			
Plot Right Abutment Scour			
Abutment Scour Depth	12.35	ft	NCHRP Method
Total Scour at Abutment	12.35	ft	
Total Scour Elevation at Abutment	1101.72	ft	

Plot Cross Section OK Cancel

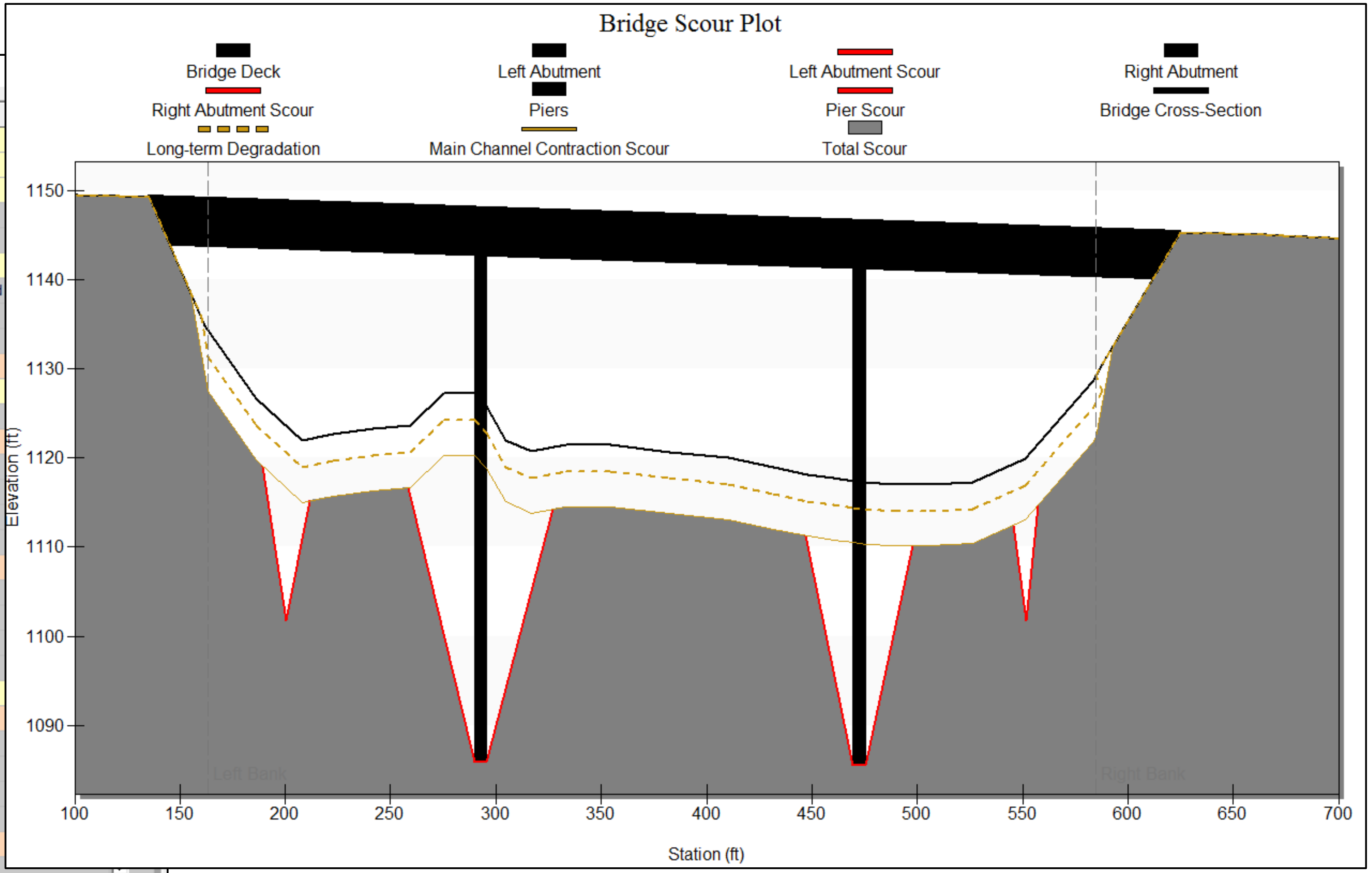


Image Sources: FHWA

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What's Next?

- 3D bridge profiles
- Multiple profile bridge scour analysis tools
- Bridge scour tutorials
- Bridge scour webinars
- Advanced 2D meshing tools
- 1D model export tools
- Floodplain mapping tools
- Floodway delineation tools

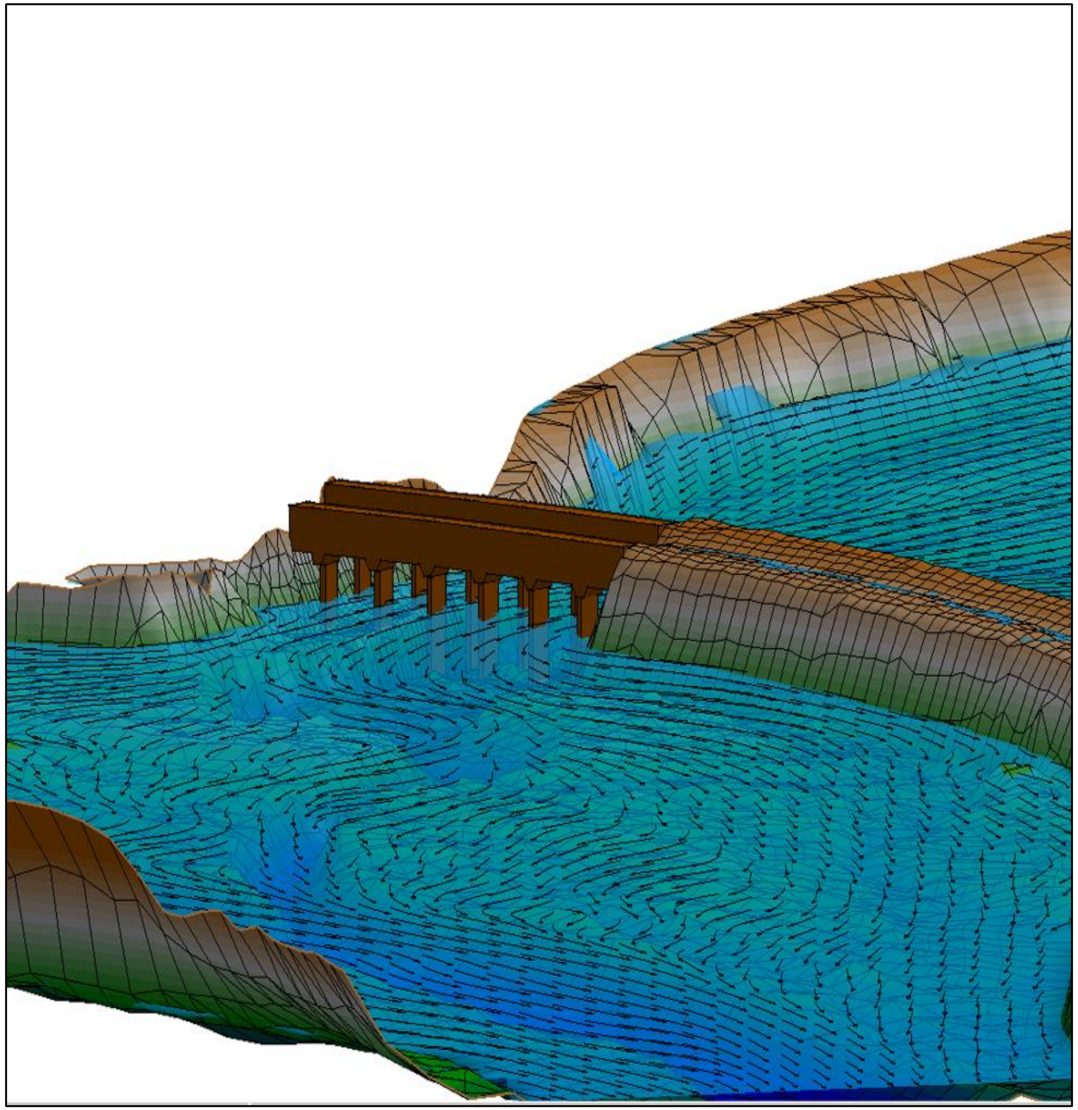

Image Sources: FHWA/Caltrans

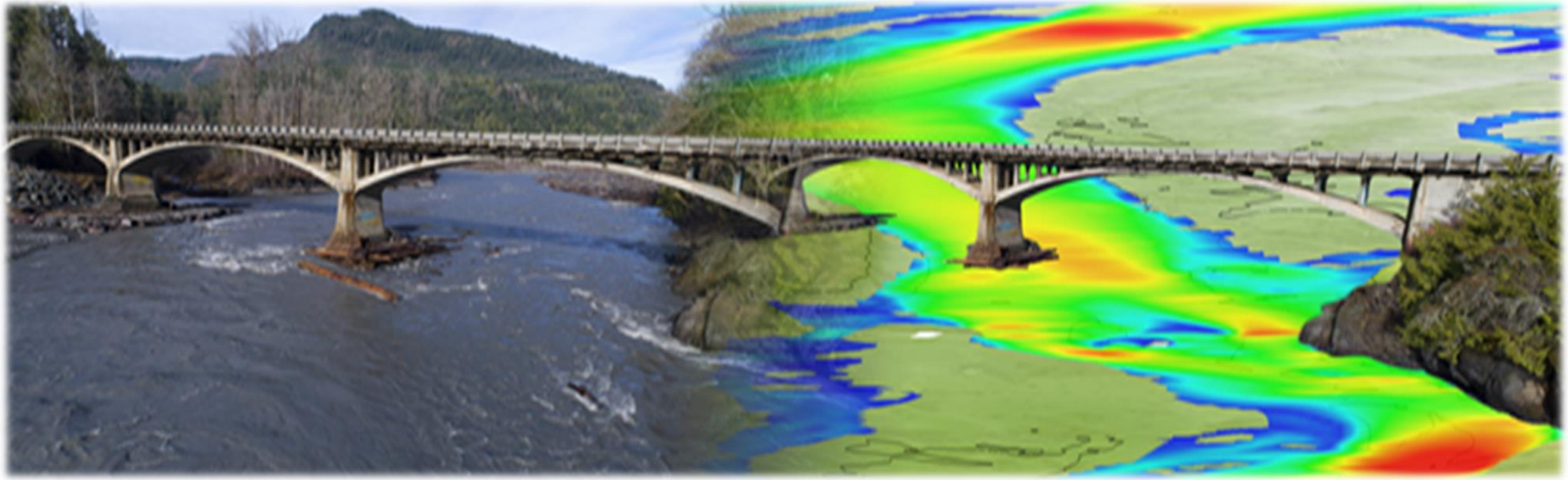

Image by John Gussman

THANK YOU!
Please contact us with any questions

Scott Hogan
FHWA Resource Center
Scott.hogan@dot.gov
(720) 575-6026

Laura Girard
FHWA Resource Center
laura.girard@dot.gov
(970) 217-3894

Carl Spirio
Florida Department of Transportation
Carlton.Spirio@dot.state.fl.us
(850) 414-4351

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