Estimating Bridge Hydraulics and Scour

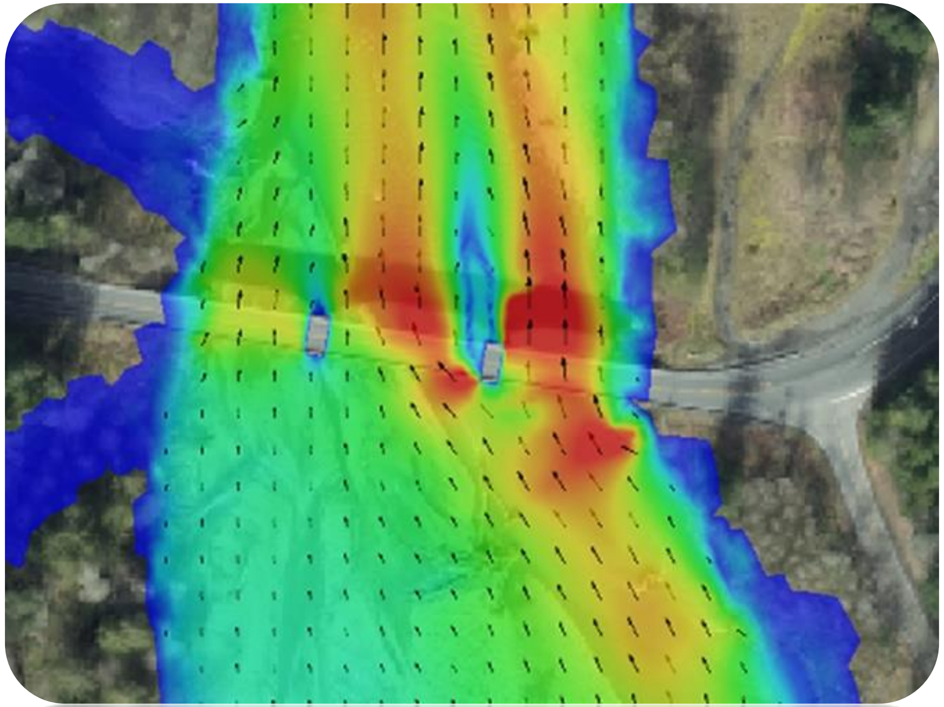

Image Sources: Casey Kramer

Australian Water School

Estimating Bridge Hydraulics and Scour Webinar

June 1st, 2021

Casey Kramer, P.E.

Australian Water School

NATURAL WATERS

Overview

- Type of Project
- Bridge Hydraulics
- Selecting the Most Appropriate Hydraulic Model
- Importance of Understanding Applicability and Limitations
- Bridge Scour Introduction
- Total Scour and Scour Components
- Other Considerations

Image Source: Casey Kramer

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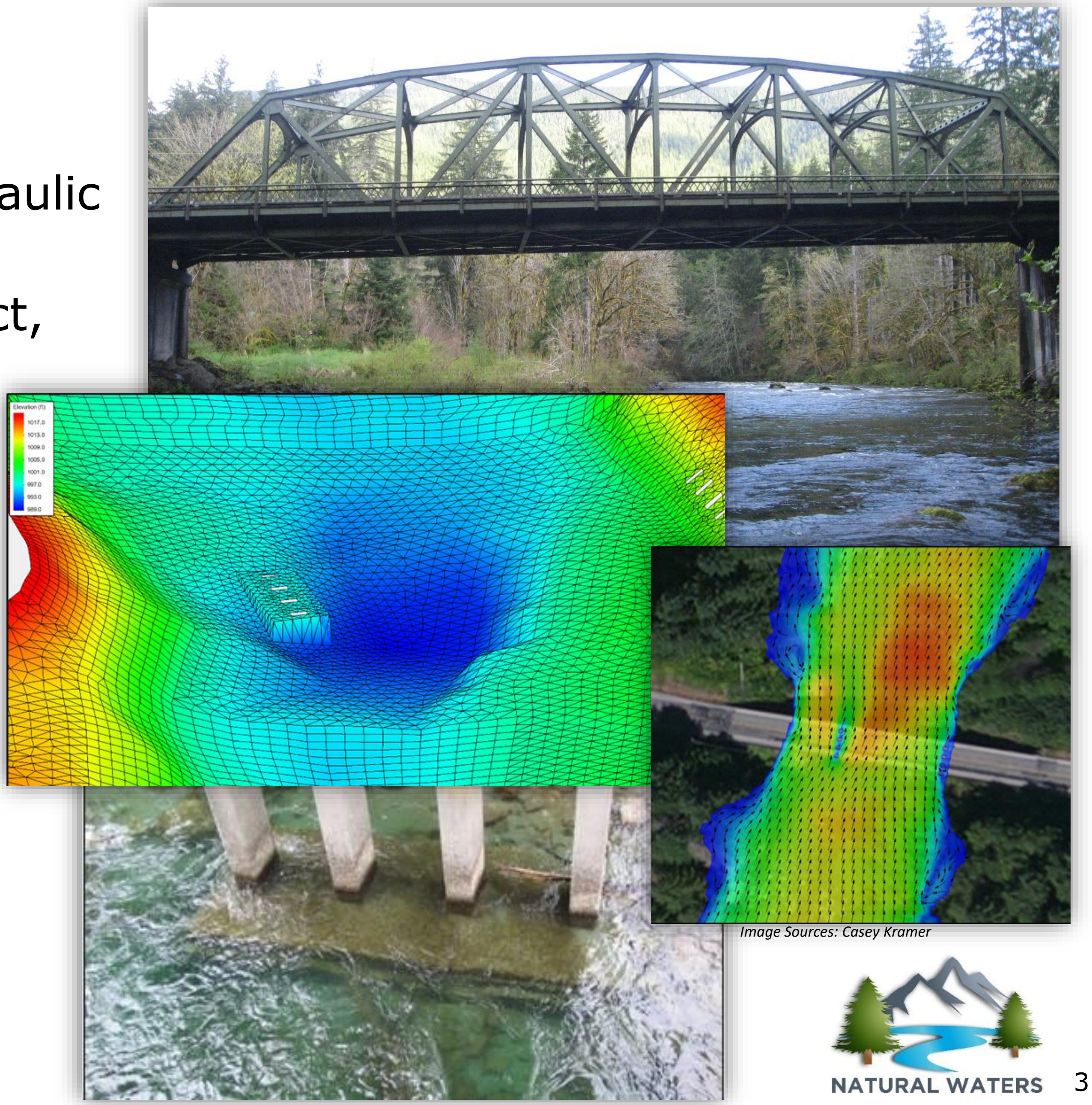
Type of Project

- Prior to a water crossing design or hydraulic modeling, the designer should clearly identify the type and goals of the project, for example:
  - Flood Inundation/Risk Mapping
  - Bridge Hydraulics
  - Bridge Scour
  - Scour Countermeasure Design
  - Etc.



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Bridge Hydraulics

- Aligning bridge hydraulic modeling with intended application
  - Appropriate losses as part of flood inundation modeling
  - Detailed bridge hydraulics for scour assessment

- Aligning bridge hydraulic modeling results to a given scour equation
  - Averaged hydraulic parameters
  - Localized hydraulic parameters

Image Sources: Casey Kramer

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Selecting Most Appropriate Hydraulic Model

- Some of the key questions in model selection should be:
  - What are the key hydraulic processes observed at the project site?
  - What hydraulic parameters were the scour equations originally developed for?
  - What model extents are needed to properly determine flow characteristics at project site?
  - What resolution is needed to adequately represent hydraulic processes necessary for the selected bridge scour equations?
  - What other model inputs are necessary?

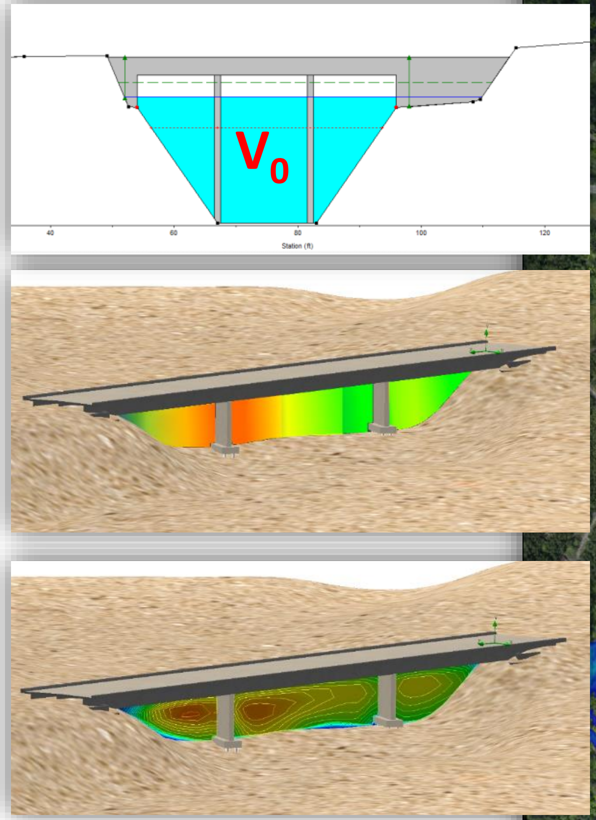
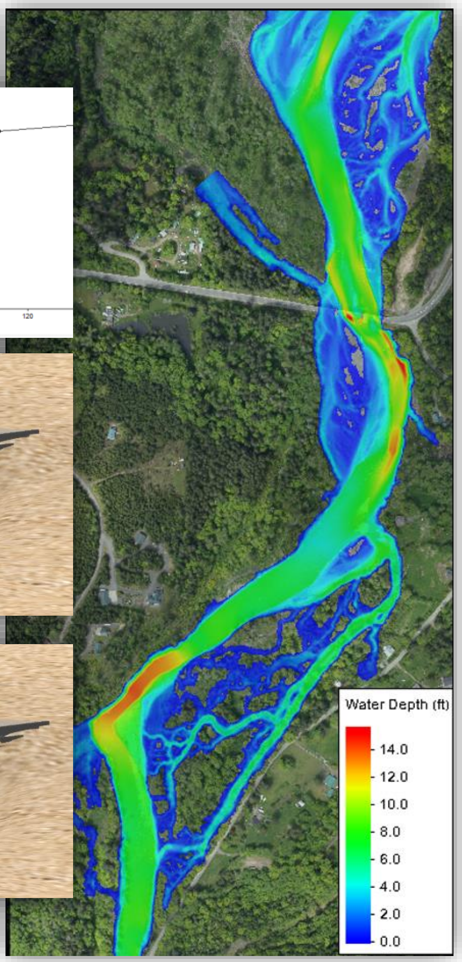


Image Sources: FHWA



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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

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Bridge Scour Introduction

- Most common cause of bridge failures
- Variety of reference documents
  - HEC 18 Evaluating Scour at Bridges (2012)
  - HEC 20 Stream Stability at Highway Structures (2012)
  - HEC 23 Bridge Scour and Stream Instability Countermeasures: Experience, Selection and Design Guidance (2009)
  - HDS 7 Hydraulic Design of Safe Bridges (2012)
  - Austroads (2019)

Image Sources: Casey Kramer

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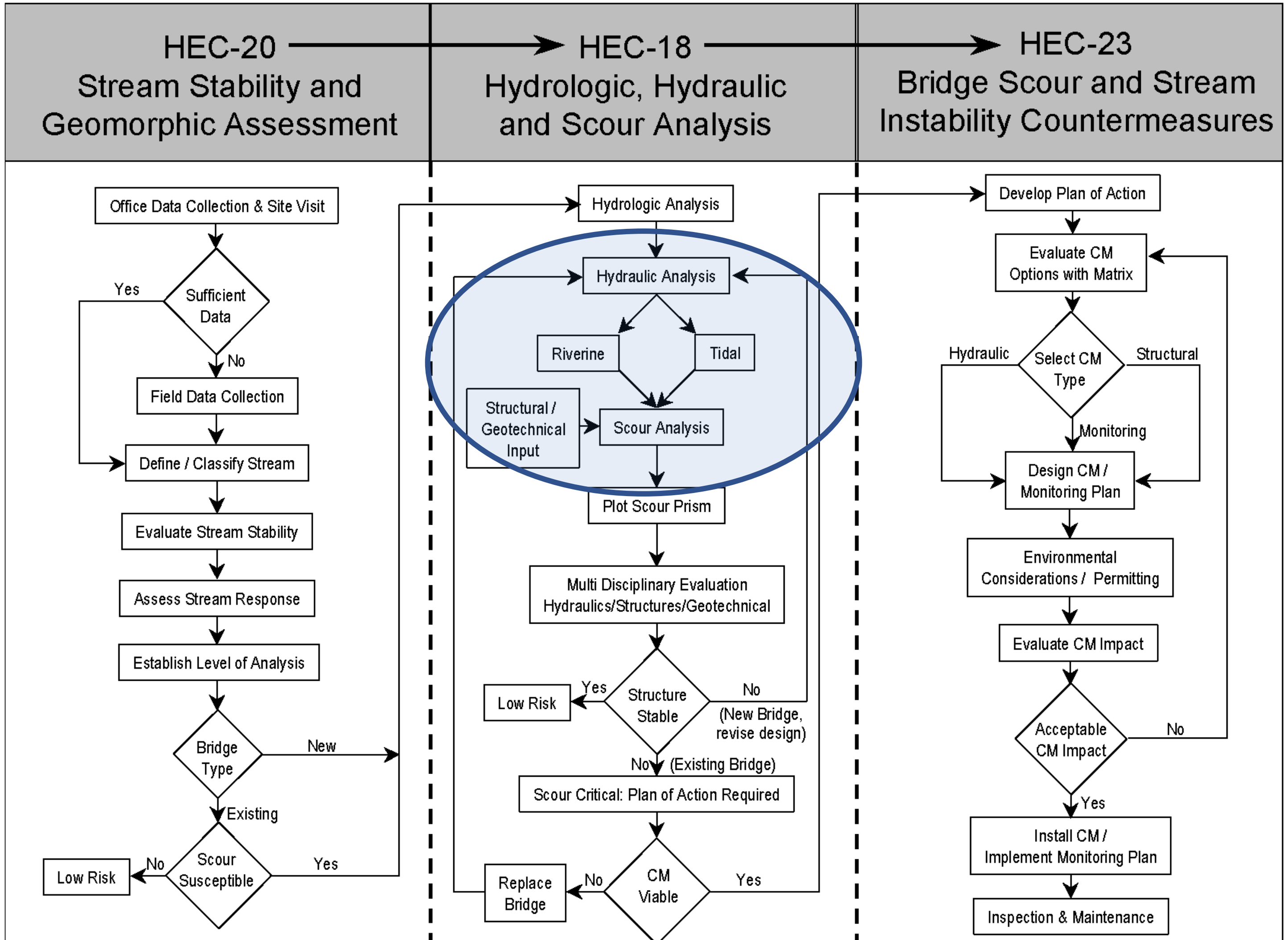
Bridge Scour Introduction



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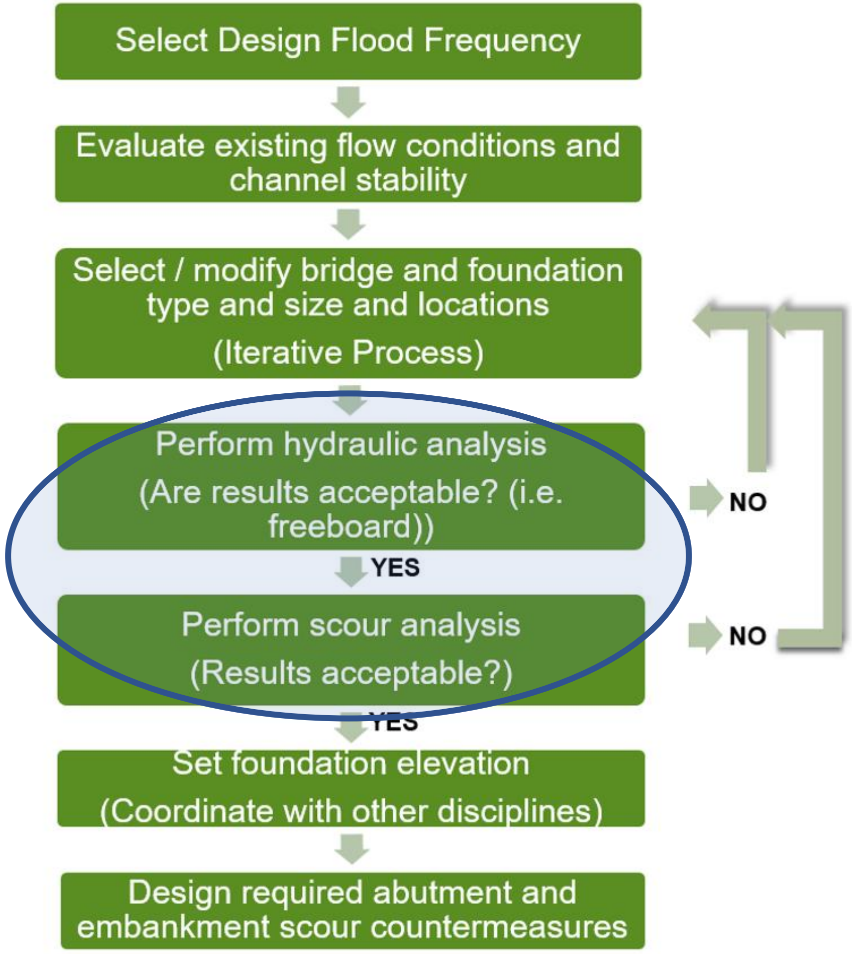

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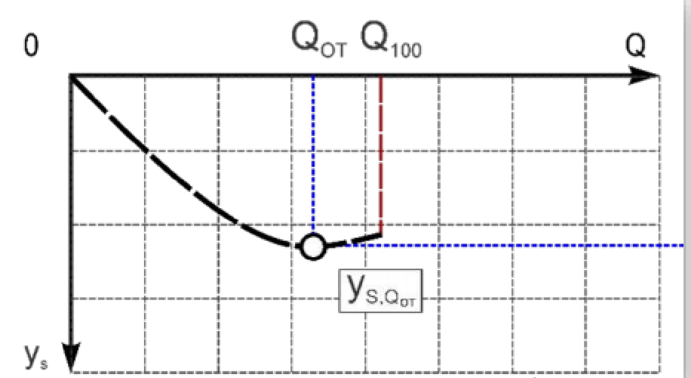
Worst Case Scour

- **Austroads –** "The aim of bridge design should identify the flood event that produces the highest velocities and worst case."
- **FHWA -** Worst Case Scour Depth – "The conditions (e.g., discharge, velocity, depth, tailwater, geometry, orientation, type of foundation, etc.) that would produce the maximum scour depth at a particular foundation element."
- **AASHTO** – Scour Design Flood – "The flood flow equal to or less than the 100-year flood that creates the deepest scour at bridge foundations…"



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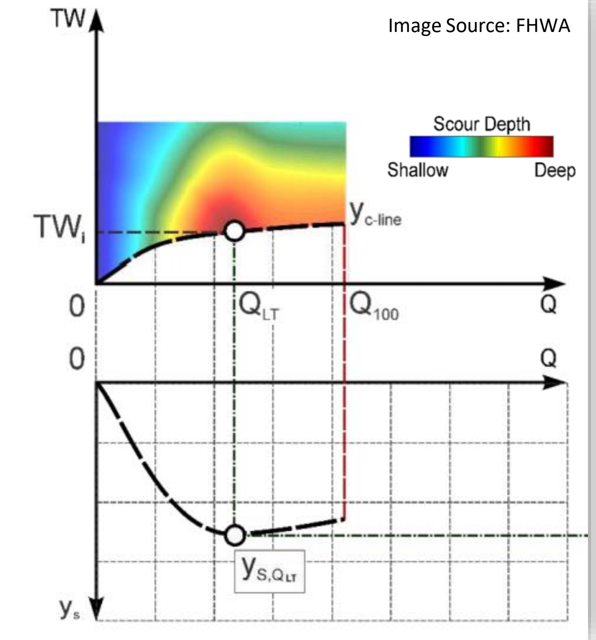

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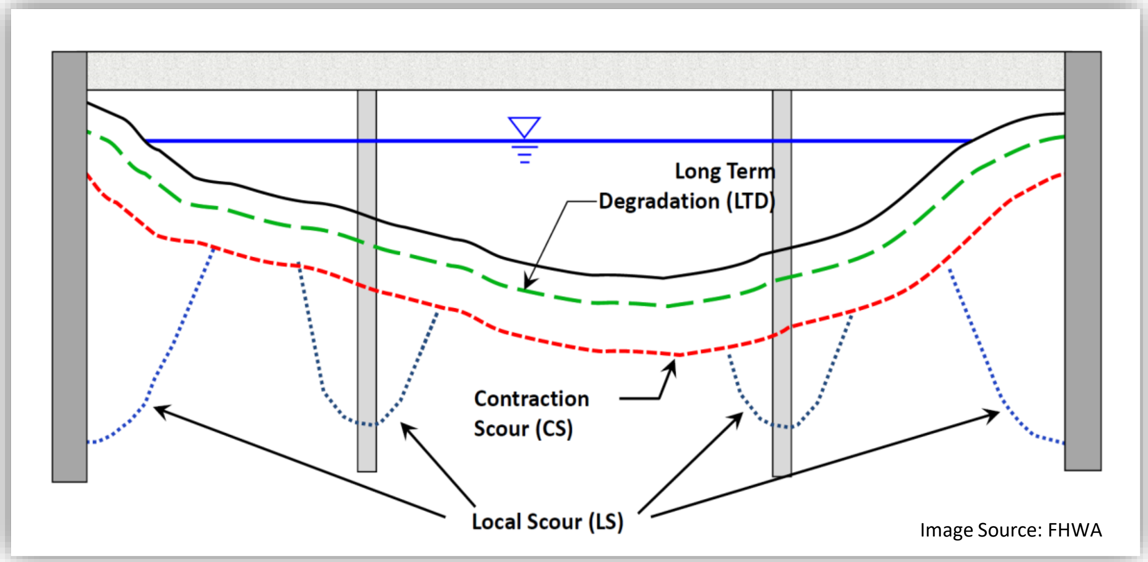
Total Scour and Scour Components

Potential lateral migration of a channel must be assessed when evaluating total scour

Total scour is comprised of three main components:

1. **Long-term degradation** of the riverbed
2. **General scour** at the bridge
    a. Contraction scour
    b. Other general scour
3. **Local scour** at the piers or abutments



Importance of Understanding Applicability and Limitations

- Designers need to understand key assumptions of various scour equations
- Applicability and limitations for each method may include:
  - Sediment Type/Size
  - Foundation Type/Size
  - Averaged or Local Hydraulic Inputs
  - Clear water or Live bed
  - Rivers are Dynamic!
  - Etc.

Image Source: Casey Kramer

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Lateral Migration

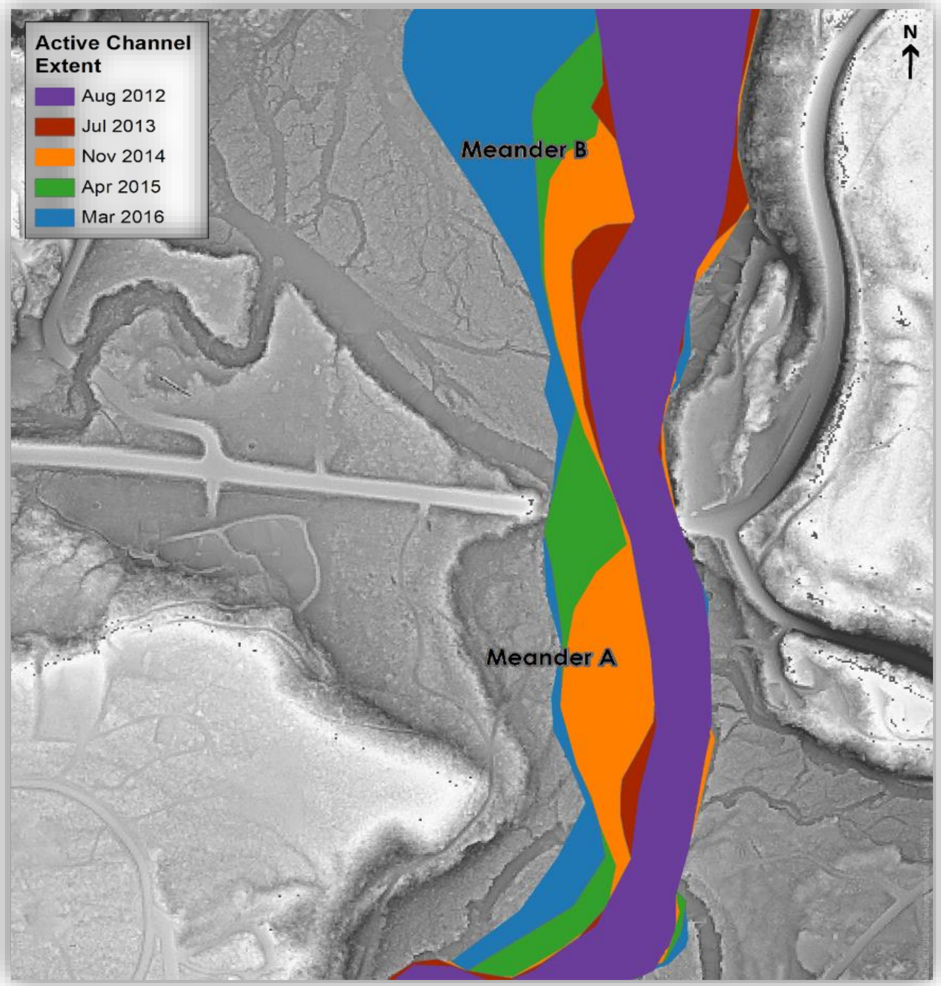


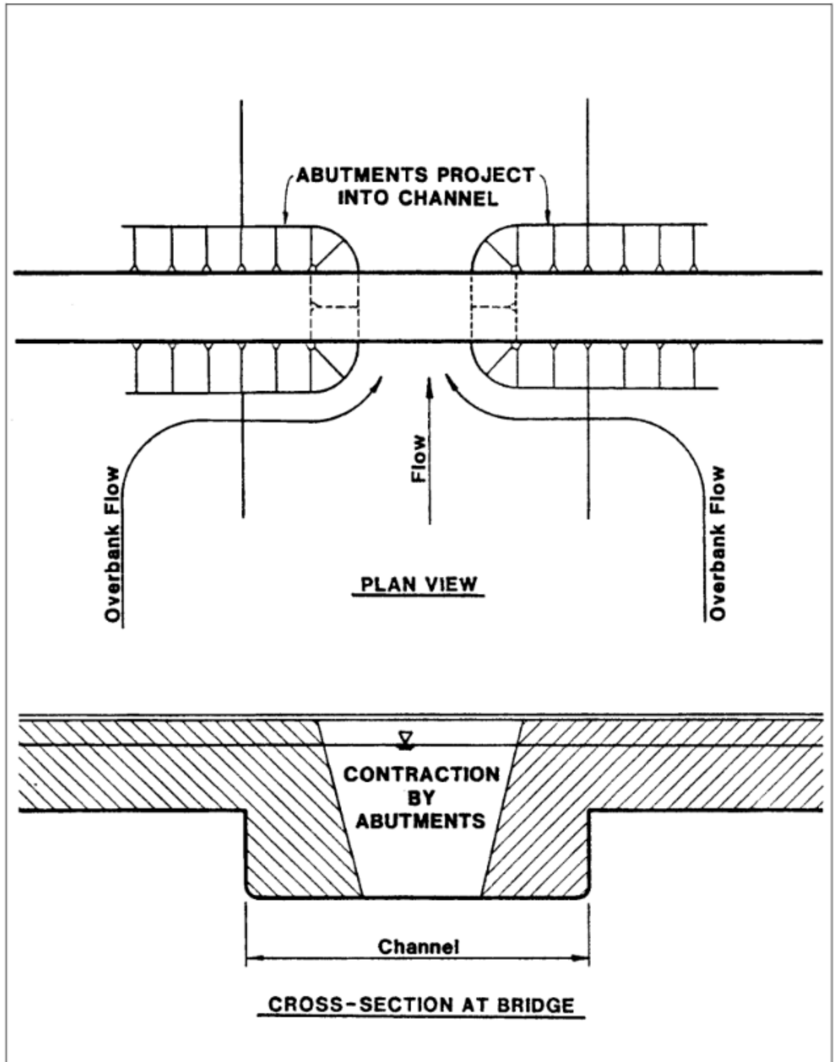
Image Source: Casey Kramer

Long-Term Degradation

- Downstream base level changes
- Dams and reservoirs
- Change in watershed land use
- Cutoffs of meander bends

Image Sources: Casey Kramer

Contraction Scour



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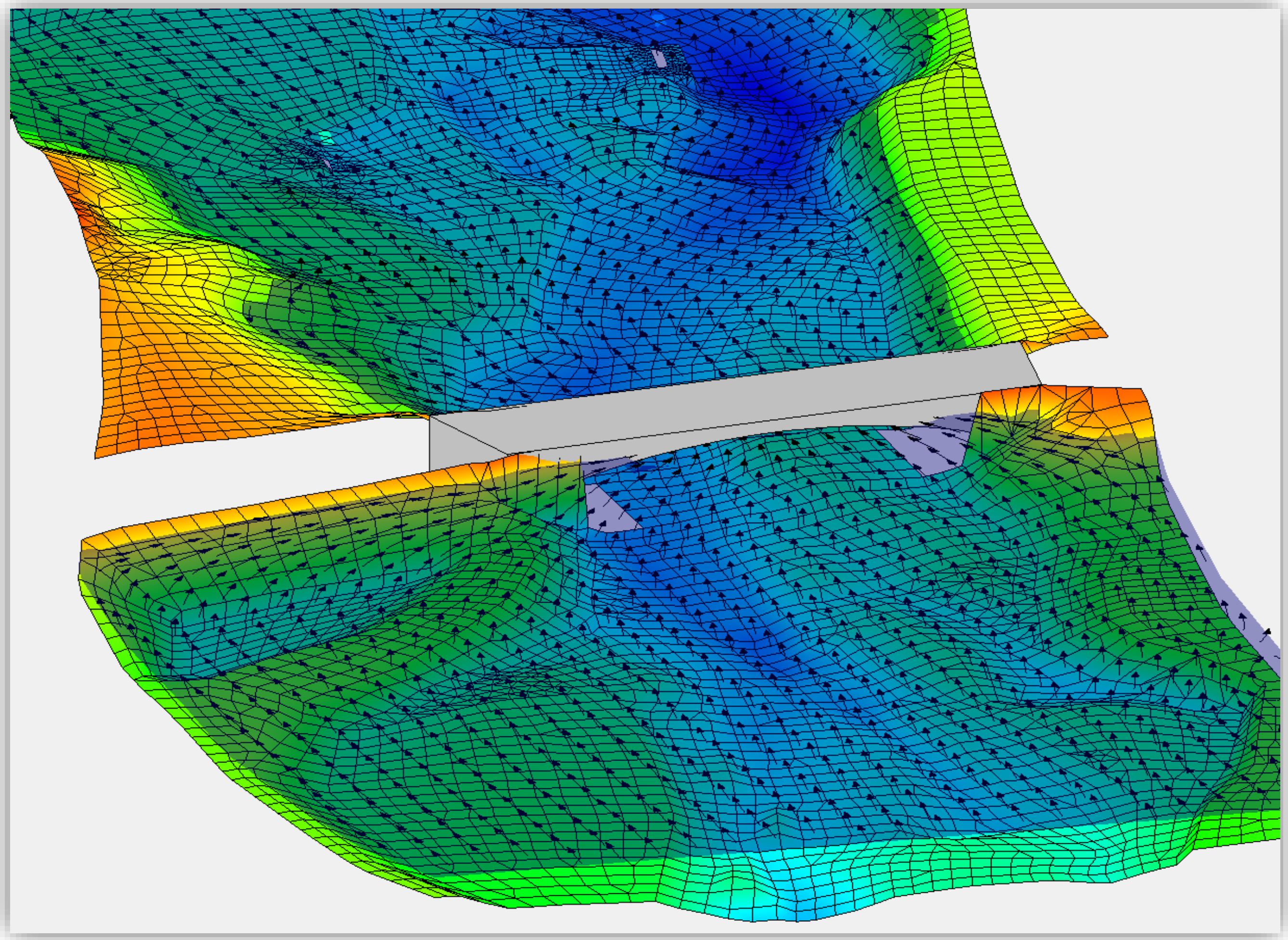

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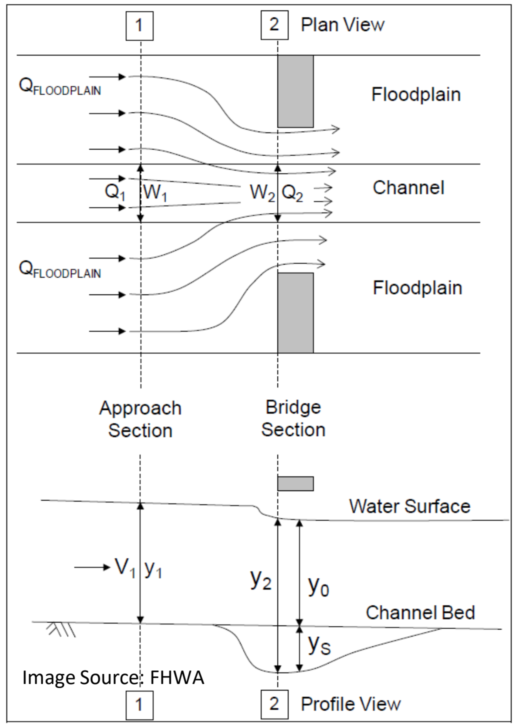
Contraction Scour

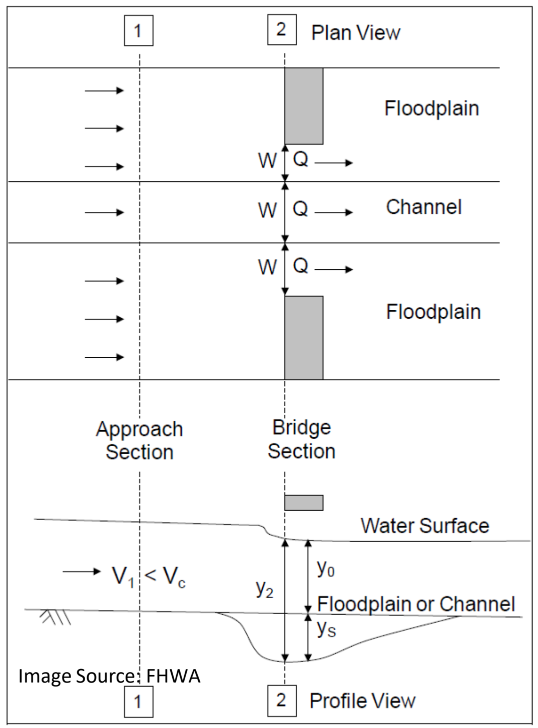
Critical Velocity $V_c = K_u y^{1/6} D^{1/3}$

Live Bed Condition



$$y_s = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} - y_0$$

Clear Water Condition



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$$y_s = \left(\frac{K_u Q^2}{Dm^{2/3} W^2}\right)^{3/7} - y_0$$

Ref: HEC-18 (2012) Equations 6.1-6.4

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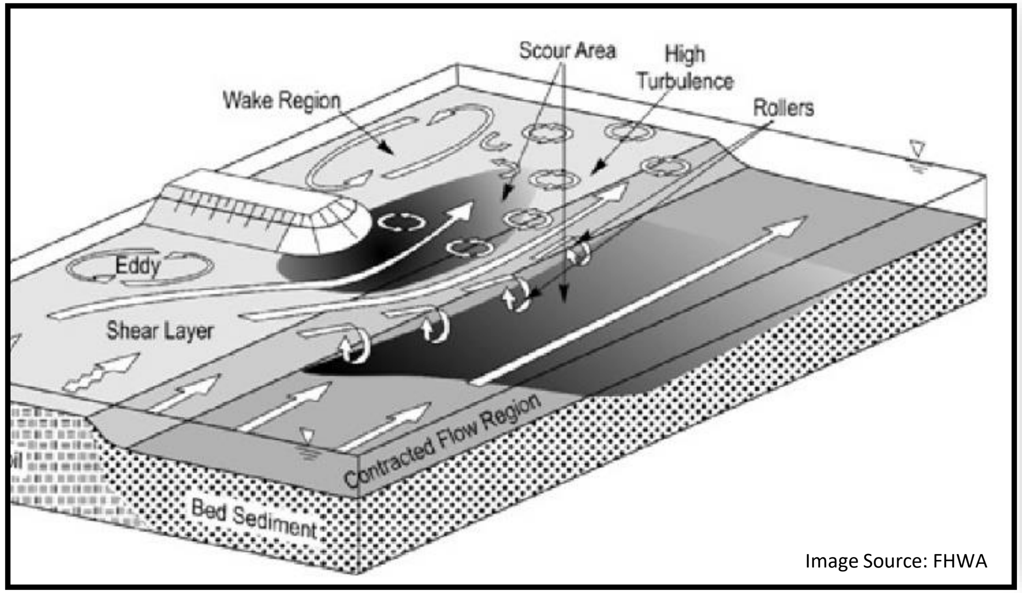
Abutment Scour



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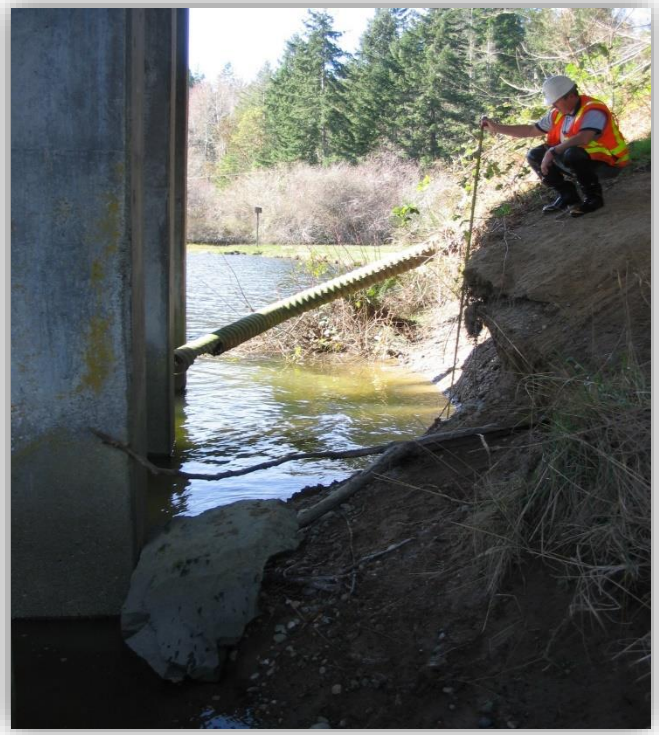

Image Sources: Casey Kramer

Abutment Scour



Image Sources: Casey Kramer

	Condition A	**Condition B**
	Live Bed Condition	**Clear Water Condition**
Abutment Scour	$y_{max} = \alpha_{A/B} y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7}$	$y_{max} = \alpha_{A/B} \left(\frac{q_{2f}}{K_u D_{50}^{1/3}}\right)^{6/7}$

Ref: HEC-18 (2012) Equations 8.3-8.6

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Local (Pier) Scour

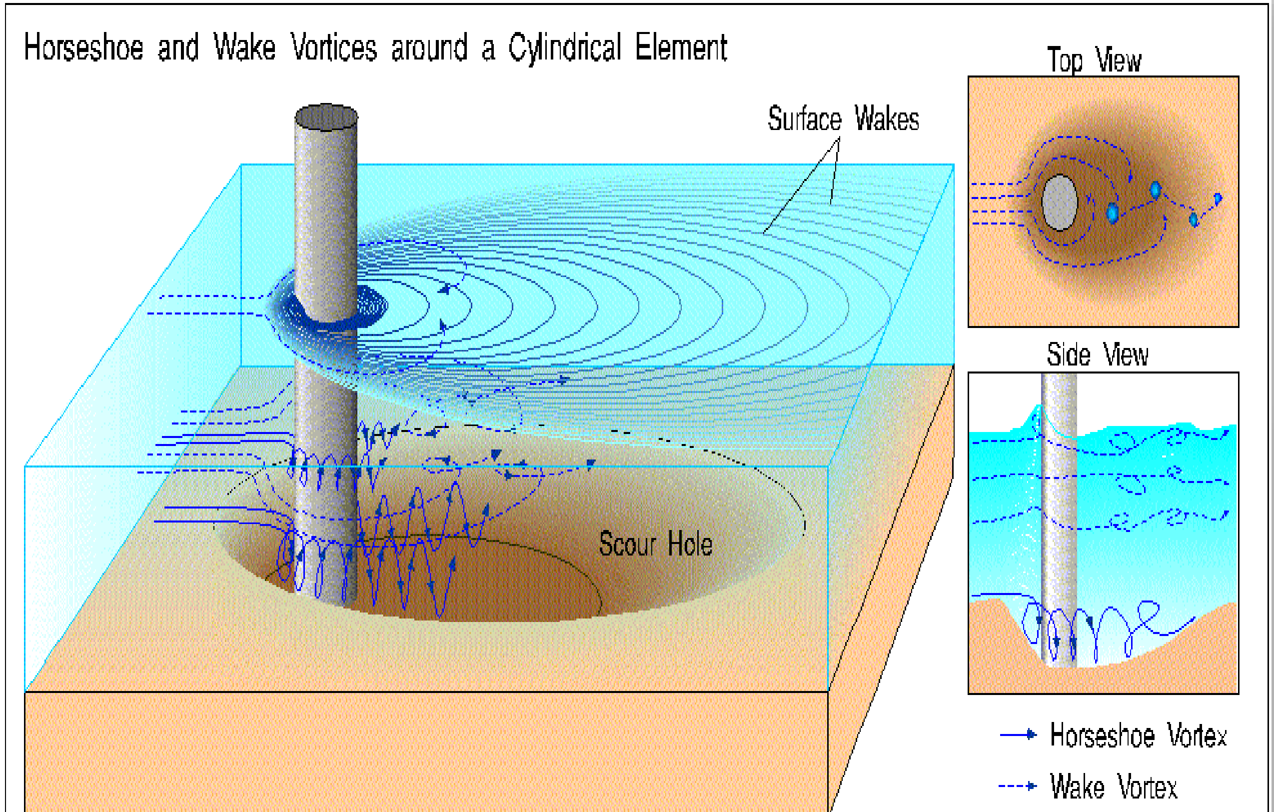

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Image Sources: Casey Kramer

Local (Pier) Scour

Image Sources: Casey Kramer

Pier Scour

$$y_s = 2.0\, K_1\ K_2\, K_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43}$$

$$Fr_1 = \frac{V_1}{(g y_1)^{0.5}}$$

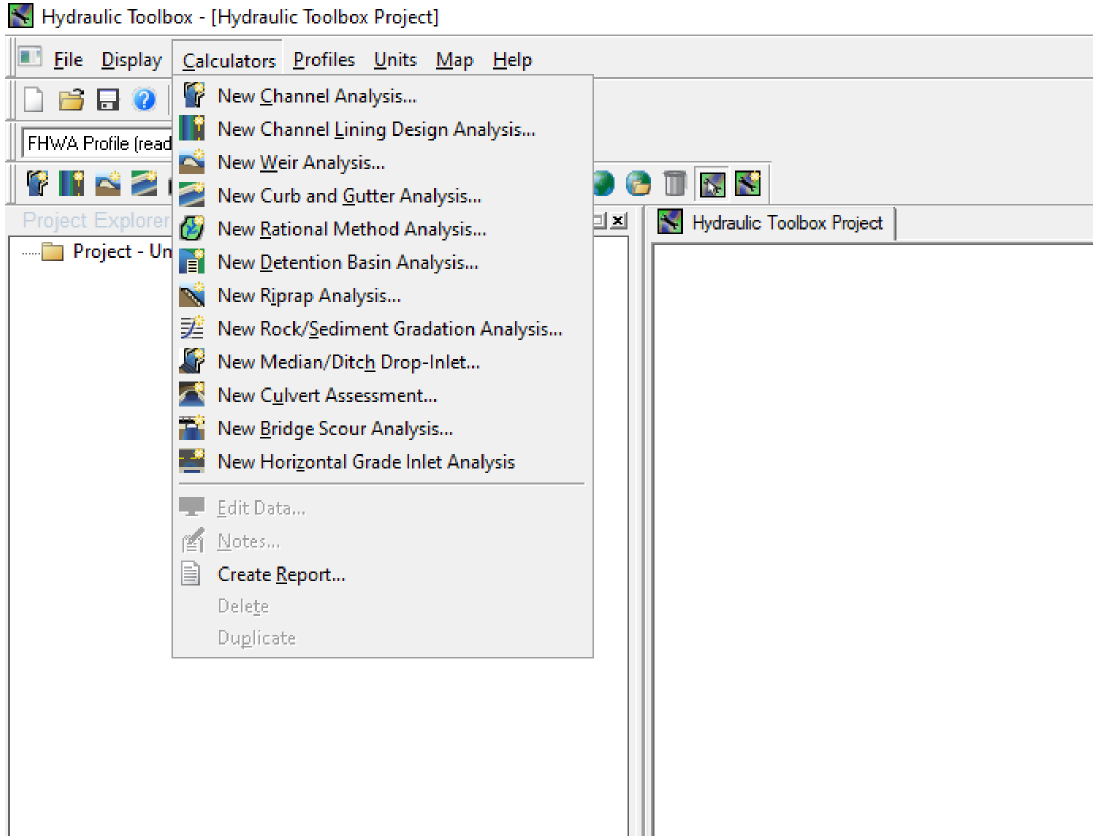
$y_s \leq$ 2.4 times pier width for $Fr \leq 0.8$

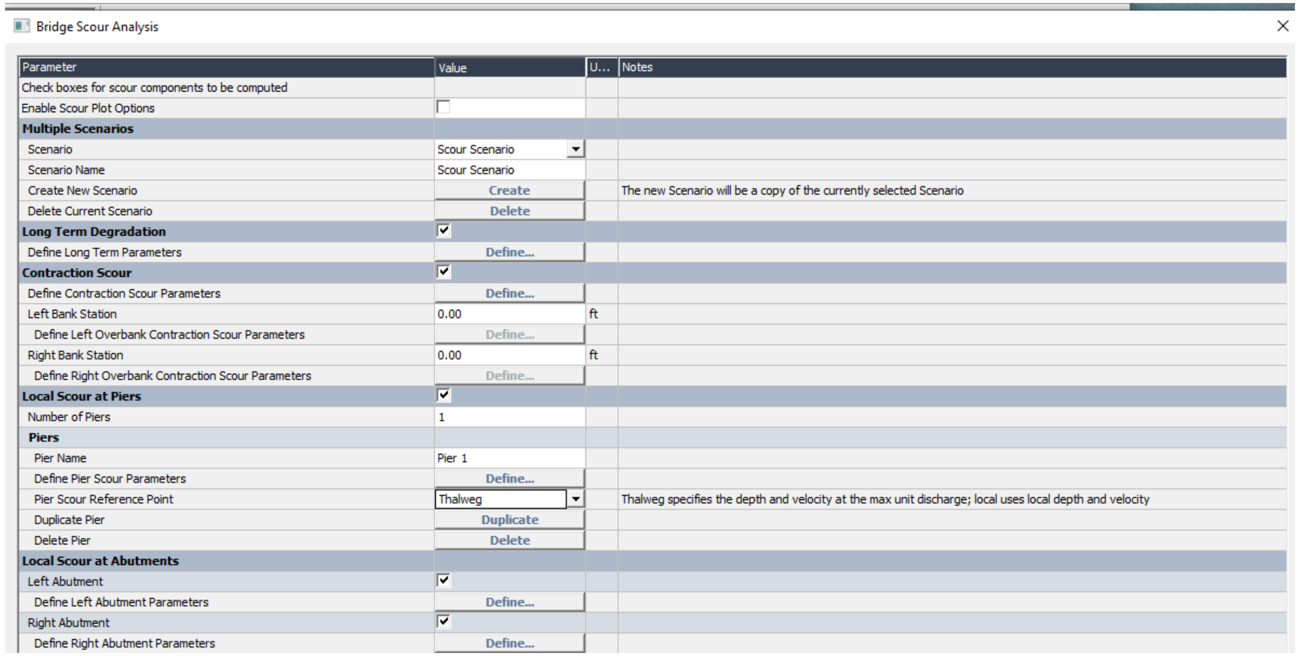
$y_s \leq$ 3.0 times pier width for $Fr > 0.8$

Ref: HEC-18 (2012) Equations 7.1-7.4

FHWA Hydraulic Toolbox

FHWA Hydraulic Toolbox Version 5.1.1





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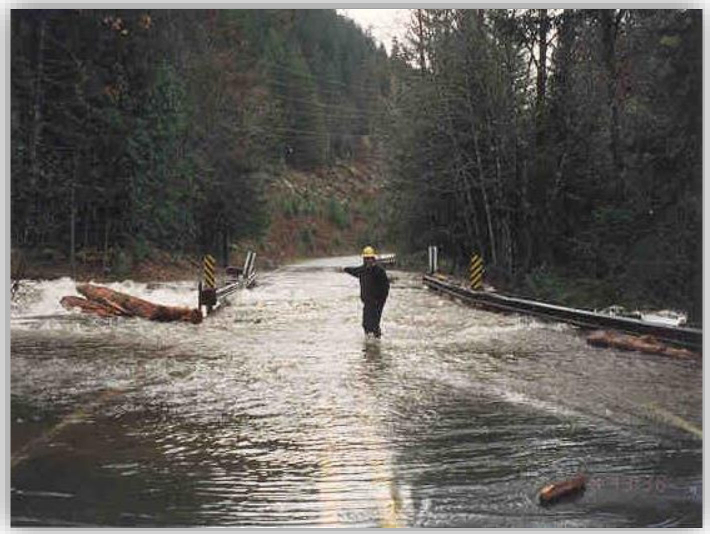
Freeboard and Pressure Flow



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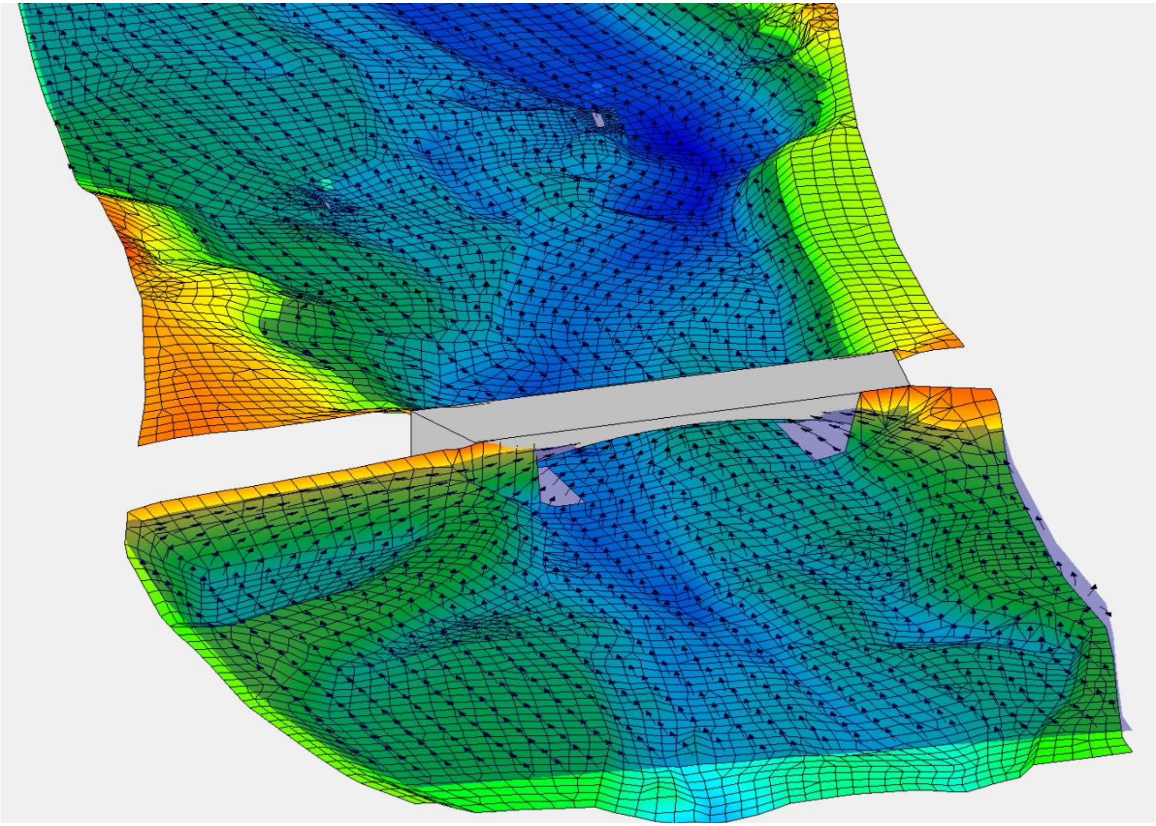
Freeboard and Pressure Flow



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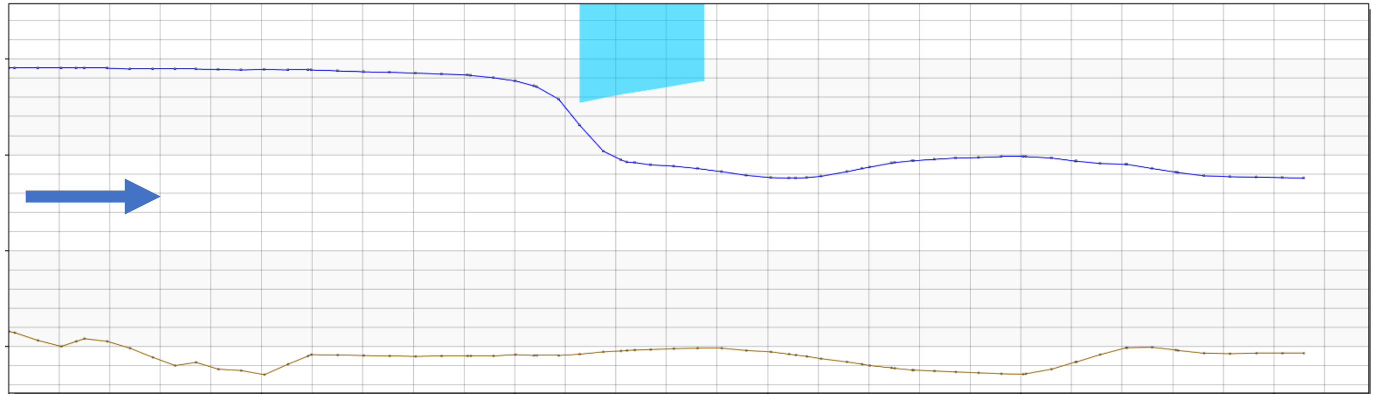

Debris

Image Sources: Casey Kramer

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Conclusions

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