FHWA
Bridge Scour Workshop

1. Introductions / Opening Comments
2. Overview of bridge scour
3. Long Term Degradation
4. Contraction Scour
5. Pier Scour
6. Abutment Scour
7. Comprehensive bridge scour example
8. Wrap-up and questions

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

Schedule

Day 1

10:00 - 11:00	Introductions and Opening Comments
11:00 – 12:00	Bridge Scour Overview
12:00 - 1:00	Lunch Break
1:00 – 2:00	Long Term Degradation (LTD) and Stream Stability
2:00 – 3:30	Contraction Scour

Day 2

10:00 – 11:00	Pier Scour
11:00 – 12:00	Abutment Scour
12:00 - 1:00	Lunch Break
1:00 – 2:30	Bridge scour comprehensive example
2:30 – 3:00	Wrap-Up and Questions

Housekeeping

- We are recording each session and plan to make the recordings publicly available
- You should have received a PDF file with the presentation slides
- Please mute yourself when not speaking
- Please engage and ask questions (voice, Chat pod, or email)
- We greatly appreciate your feedback
- A certificate for professional development hours (PDHs) will be provided

Disclaimers

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FHWA Bridge Scour Workshop

Introduction

Bridge Scour POWER HOUR

U.S. Department of Transportation
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Workshop Agenda

1. Introduction

- Instructors
- Workshop objectives
- Resources for training
- FHWA Bridge Scour Program
- Bridge scour analysis review
- Common pitfalls in computing scour

Instructors

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Workshop Objectives

- Provide an FHWA Bridge Scour Program update
- Present an overview of bridge scour analyses
- Provide a ‘refresher’ on correct methods for computing scour
- Highlight FHWA’s resources for computing scour
- Demonstrate practical applications of scour analyses
- Introduce new bridge scour tools
- Answer questions

Poll Questions

- What is your background with Bridge Scour Analyses?
- What type of hydraulic modeling training have you had?
- Have you taken the NHI training course on ‘Stream Stability and Scour’ (#135046)?

Resources for Bridge Scour Analyses
Reference Manuals

- HEC-18 (2012 5th Edition) – Evaluating Scour at Bridges
- HEC-20 Stream Stability at Highway Structures
- HEC-23 Bridge Scour and Stream Instability Countermeasures (2009 3rd Edition) (Volume 1 and Volume 2)
- HDS-7 Hydraulic Design of Safe Bridges (2012)
- Two-Dimensional Hydraulic Modeling for Highways in the River Environment – Reference Document (2019)

Resources for Bridge Scour Analyses
Training Courses

- NHI Training Course 135046 – Stream Stability and Scour at Highway Bridges *(Virtual option coming soon)*
- NHI Training Course 135048 – Countermeasure Design for Bridge Scour and Stream Instability *(Virtual option coming soon)*
- NHI Training Course 135095/135095V - Two-Dimensional Hydraulic Modeling of Rivers at Highway Encroachments
- NHI Training Course 135041 – HEC-RAS (1D) River Analysis System

Resources for Bridge Scour Analyses

Questions ?

FHWA Bridge Scour Program Update

- Scour Evaluations vs. Scour Assessments
- Plans of action for Scour Critical Bridges
- Scour Program Updates

Guidance for Hydraulic Design Standards
(new bridges)

- Guidance:
  - 23 CFR 625.3(a)(1) – NHS routes
  - 23 CFR 625.4(d)(1)(v) – AASHTO LRFD specs
  - 23 CFR 625.3(a)(2) – Non-NHS follow State Stds

  - 23 CFR 650.115 – applies to all Federal-aid projects
  - 23 CFR 650.117(b)(1)

Guidance for Scour Evaluations
(existing bridges)

- Guidance:
  - 23 CFR 650.313(e)
  - MBE 4.2.6
  - TA 5140.23
  - HEC-18 (10.1)

Risk-Based, Data-Driven Scour Program

- In 2011, FHWA implemented a risk-based, data-driven NBIP
- April 9, 2012 memo, applying risk to the Scour Program
  - Scour evaluation element
    - Scour evaluation vs. Scour assessment
  - Scour critical element
  - Unknown foundation element

Risk-Based, Data-Driven Scour Program

- In 2011, FHWA implemented a risk-based, data-driven NBIP
- April 9, 2012 memo, applying risk to the Scour Program
  - Scour evaluation element
    - Scour evaluation vs. Scour assessment
  - Scour critical element (requires a Plan of Action)
  - Unknown foundation element (requires a Plan of Action)

Scour Evaluation

- Scour Evaluation should be used to determine a structure’s susceptibility to scour for existing structures and all new bridge designs
- Scour Evaluation typically includes:
- Using the principles in HEC-18, HEC-20, and HEC-23
    - Including Hydraulic modeling (HEC-RAS or SRH-2D)
    - Calculating scour depths with HEC-18 eqtns (or FHWA Hyd. toolbox)
    - Comparing those scour depths to existing foundation depths (existing bridge)
    - Or, using those scour depths and working with Structural and Geotech engineers to determine the optimal foundation type and depth (new bridge)

Guidance for Plans of Action for Scour Critical Bridges

- Guidance:
  - 23 CFR 650.313(e)
  - MBE 4.2.6
  - TA 5140.23
  - HEC-18 (10.1)

Upcoming and Recent Scour Program Updates

- FHWA is anticipating the publishing of the updated NBIS regulations soon.
- New and developing (*) FHWA TechBriefs
  - Hydraulic Considerations for Shallow Abutment Foundations
  - Scour Considerations within AASHTO LRFD Design
  - *Scour Design within AASHTO LRFD Limit States (not yet published)
  - *Embankment Protection at Deep Abutment Foundations (being developed)

Upcoming and Recent Scour Program Updates (continued)

- Update to the following HEC/HDS manuals (associated training courses also planned):
  - Recently published:
    - HEC-25
  - Under development:
    - HEC-16
    - HEC-23
    - HDS-2
    - HDS-7
  - Planned update:
    - HEC-18
    - HEC-20
    - HEC-22
    - HEC-24

Questions ?

Bridge Scour Analysis Review

- Hydraulic modeling
  - Assumptions
  - Flood events
  - Modeling approach
- Extraction of hydraulic variables (location and type)
- Bed material gradation and sample locations
- Long term degradation and stream stability assessment
- Contraction scour
  - ✓ Approach and contracted section locations and width
  - ✓ Live-bed vs. clear water assessment

Bridge Scour Analysis Review

- Pier scour
  - ✓Pier dimensions, orientation and angle of attack
  - ✓Pier configuration and complex pier geometry
  - ✓Location where depth and velocity values were extracted
  - ✓Location of piers and potential for channel to migrate
- Abutment scour
  - ✓Location of abutments relative to main channel
  - ✓Channel migration potential
  - ✓Application of abutment scour depth to determine the scour elevation
- Total scour results review (Multi-disciplinary review)

Common pitfalls in computing bridge scour

- Assuming hydraulic modeling results are good (without review)
- Missing the worse case scour condition
- Incorrectly locating the approach section for contraction scour
- Incorrectly defining the width of flow transporting sediment
- Misinterpreting a live-bed vs. clear water scour condition
- Mis-applying tributary inflow immediately upstream of bridge

Common pitfalls in computing bridge scour

- Using maximum hydraulic values rather than averaged values
- Not considering future channel migration potential
- Using insufficient or inaccurate gradation information
- Incorrectly interpreting scour depths to elevations

Bridge Scour Analysis Review

Questions ?

FHWA
Bridge Scour Workshop

Overview of Scour

U.S. Department of Transportation
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Scour and Stream Stability Analysis and Evaluation

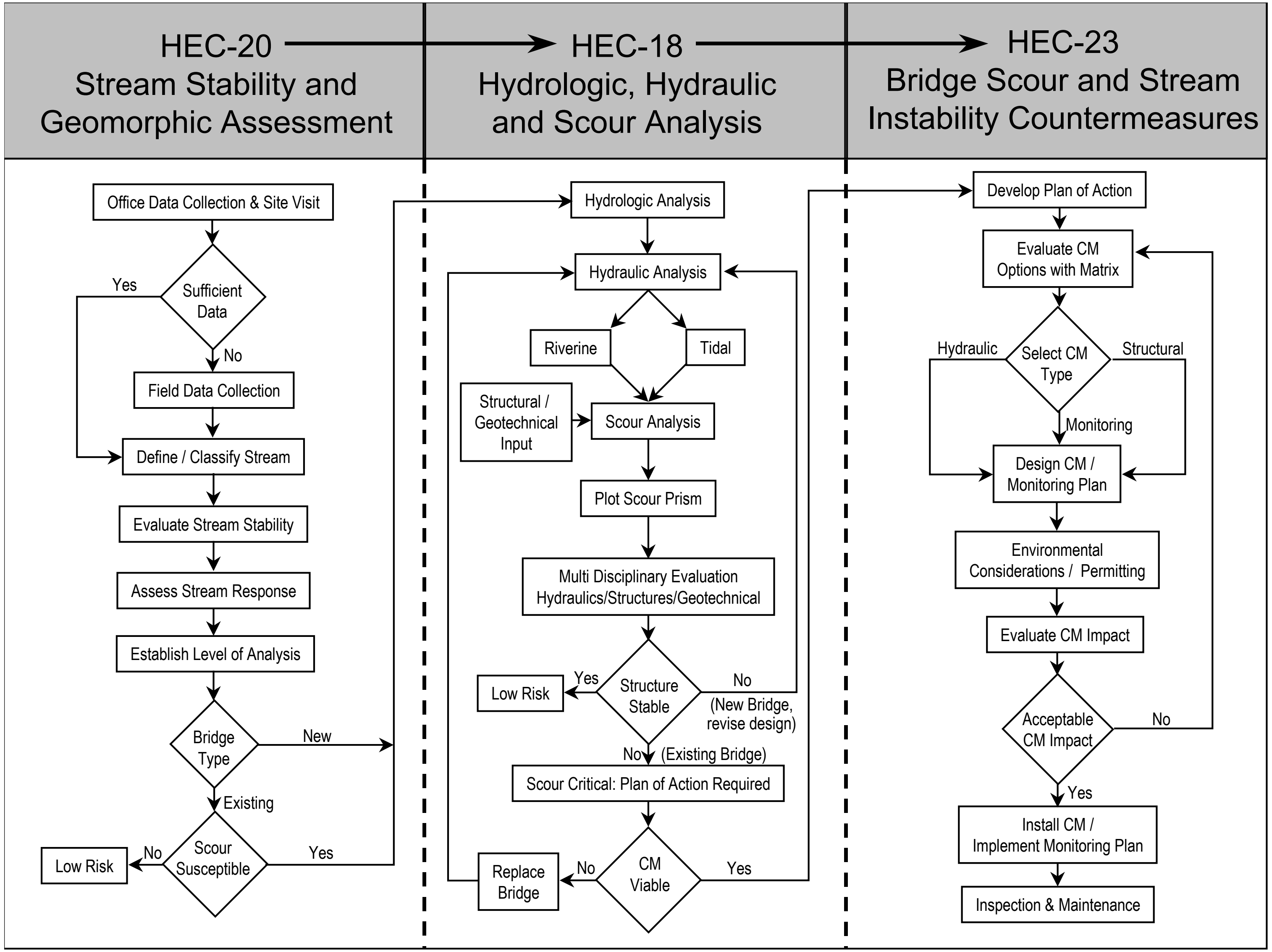


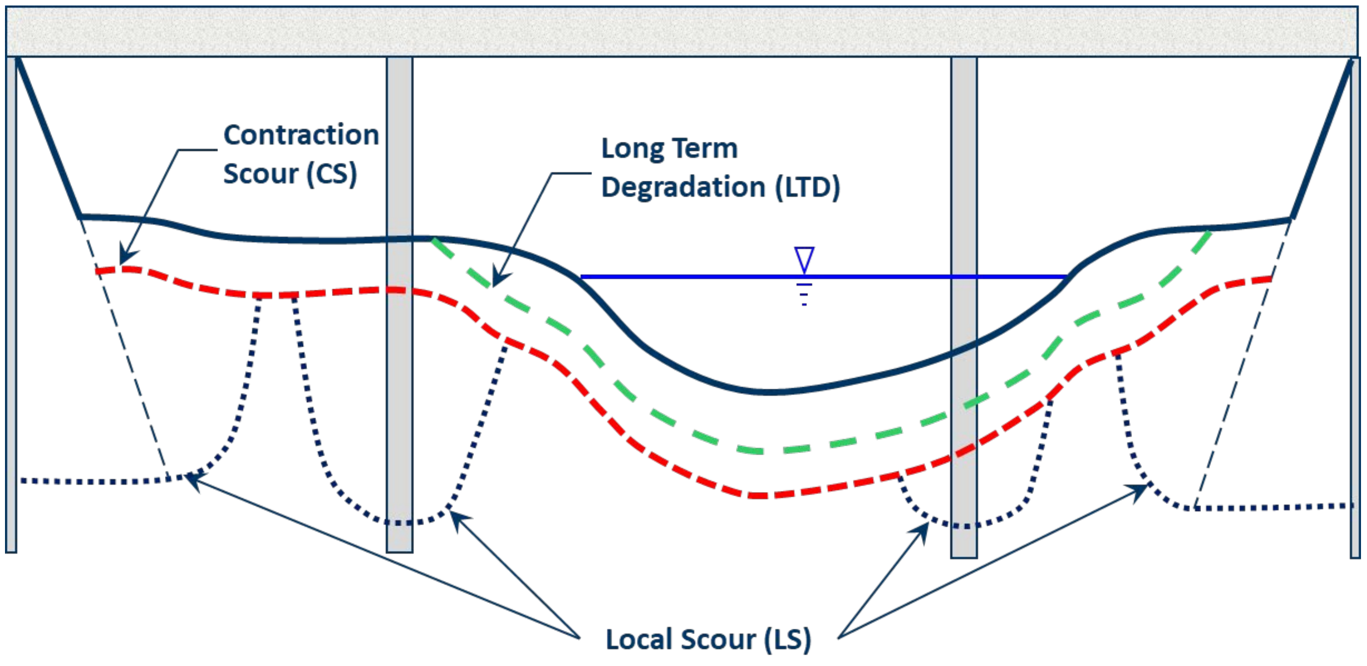
Image source: FHWA

Worst-Case Scour

- Floods Smaller than the Scour Design or Check Floods can Cause Deeper Scour
  - Flow approach angles change
  - Tailwater conditions change
- Evaluate several key discharges to assess worst case condition
  - Bankfull discharge or other mid-range flow
  - Incipient Overtopping
  - Q100
  - Q500
  - Other unique flow scenarios (project specific)

Total Scour

- Long-term Degradation
- Contraction Scour
- Local Scour
  - Pier
  - Abutment
- Lateral Migration



Total Scour = LTD + CS + LS

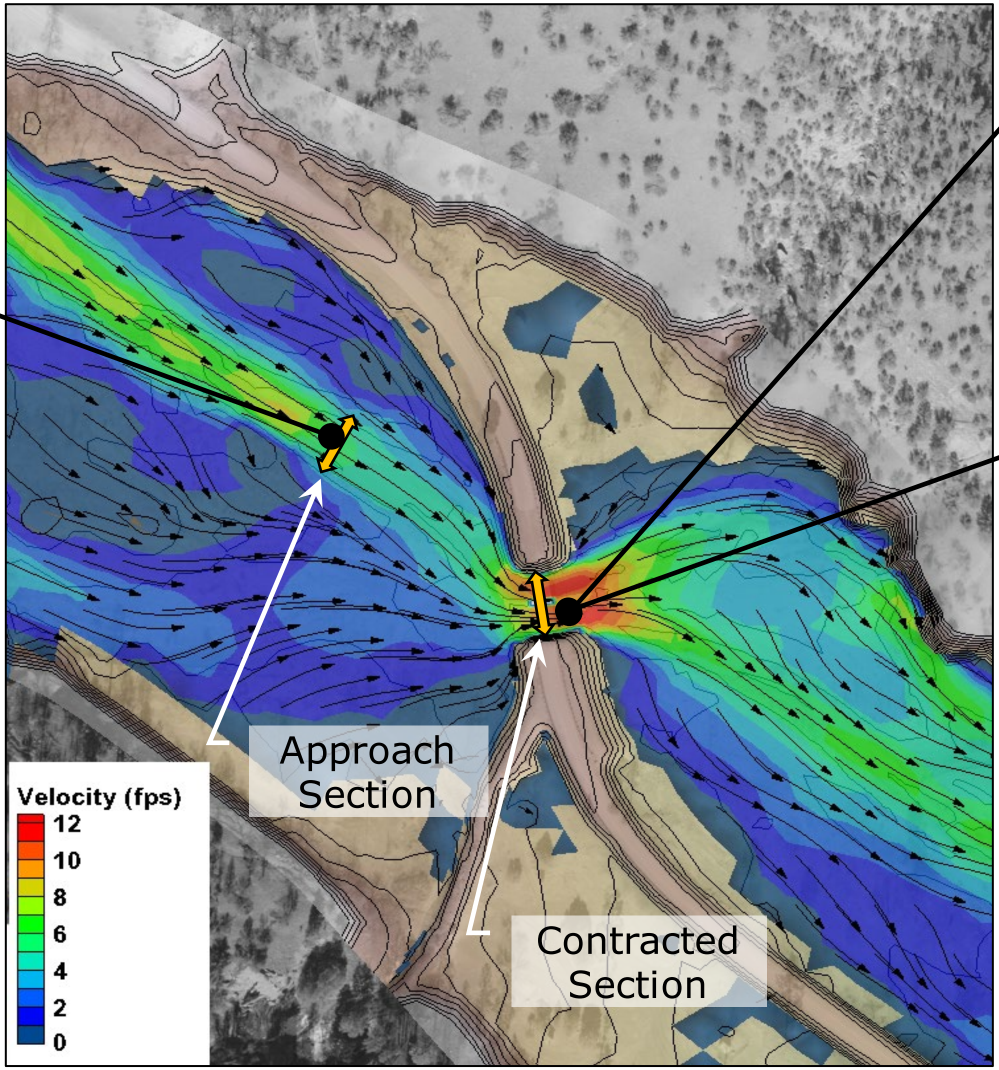
Image source: FHWA

Sediment Sampling for Bridge Scour Analyses

Sample Type / Location	Type of Analysis	Notes
Approach Section channel bed surface material	Gradation Analysis (d50) (Wolman count or sieve analysis)	The d50 is used to determine if clear-water or live-bed conditions exist for each flow scenario
Contracted Section channel bed surface material	Gradation Analysis (d50) (Wolman count or sieve analysis) Critical Shear for cohesive material	The d50 is used to compute clear-water scour depth potential
Contracted Section channel subsurface materials (each layer within the potential scour prism)	Gradation Analysis (d50) Critical Shear for cohesive material	The d50 is used to compute clear-water scour depth potential if scour exceeds the surface layer depth
Contracted Section overbank material	Gradation Analysis (d50) Critical Shear for cohesive material	Only needed if overbank contraction scour needs to be computed or if there is a relief bridge
Approach Section overbank material	Gradation Analysis (d50)	Only needed if overbank material is expected to be mobile (no vegetation) and overbank contraction scour needs to be computed, or if there is a relief bridge

Sediment Sampling for Bridge Scour Analyses

Approach Section
Channel Bed Gradation
(d50)
(Used for Live-Bed
Conditions)



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Contracted Section:
Channel Bed Gradation (d50)
(Used for Clear-Water Conditions)

Contracted Section:
Multiple material gradations needed
to capture total scour depth

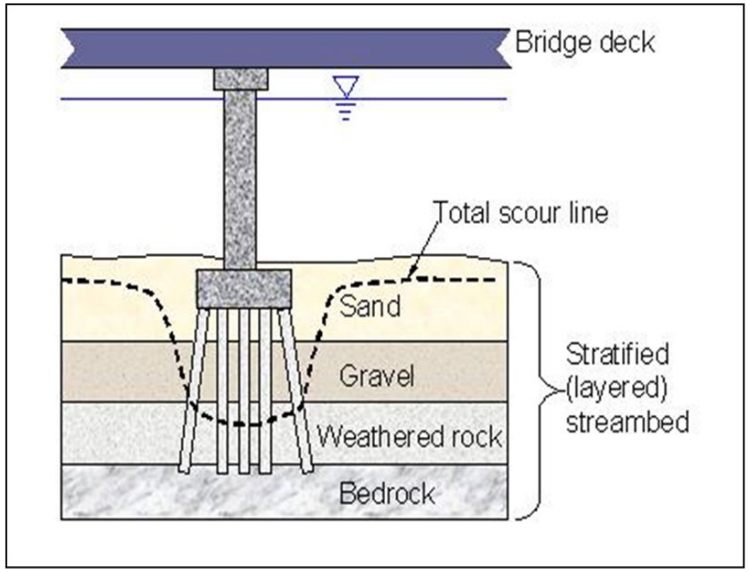


Image source: FHWA

Sediment Sampling for Bridge Scour Analyses

Non-Cohesive Materials

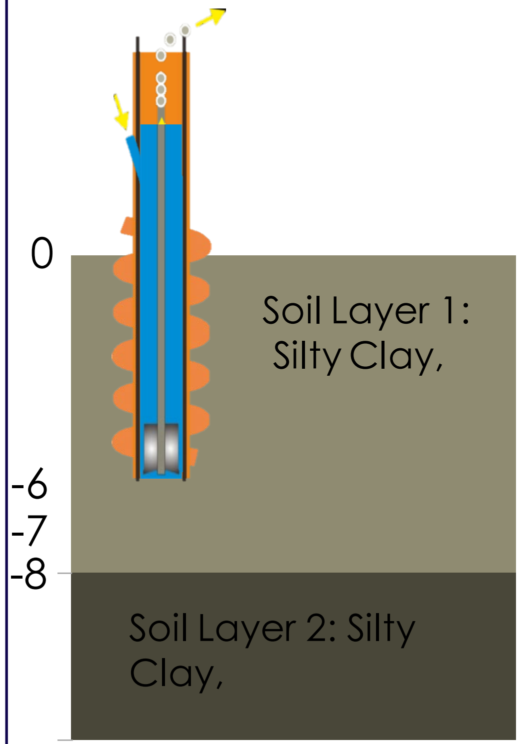
Grab sample (or boring) with sieve analyses
(finer materials)
or
Wolman Count
(coarser materials)

Gravelometer

Image source: FHWA

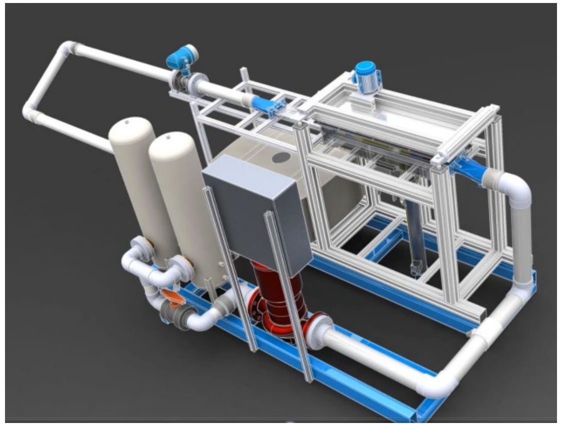
Cohesive Materials

Boring sample with ISTD or ESTD



In-Situ Scour Testing Device

Image source: FHWA



Shelby Tube Sample and
Ex-Situ Scour Testing Device

Image source: FHWA

Questions ?

Computing Hydraulic Parameters for Scour Analysis

1D vs 2D Hydraulic Modeling

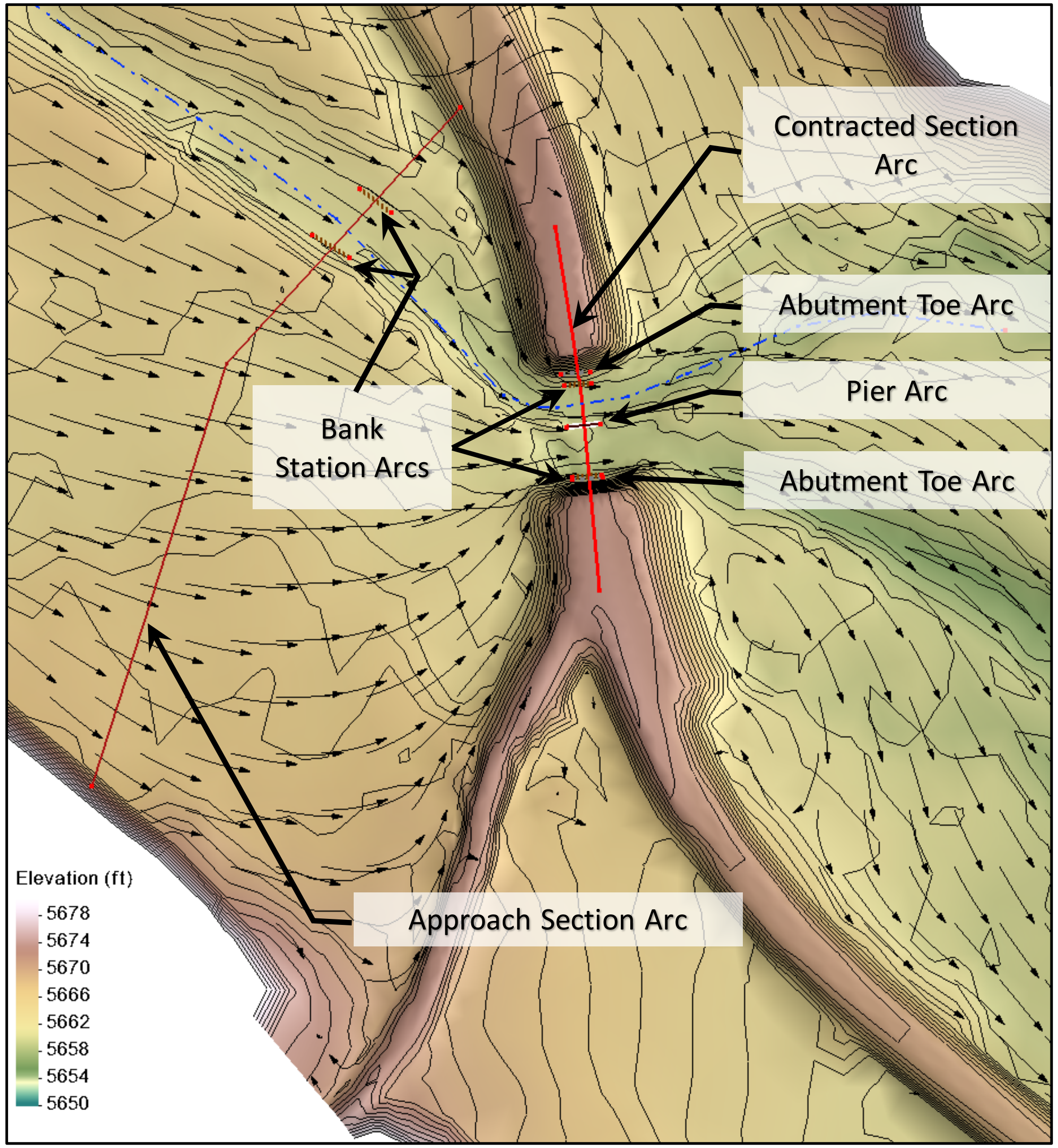
Hydraulic Variables	1D Modeling	2D Modeling
Flow direction	**Assumed** by user	**Computed**
Flow paths	**Assumed** by user	**Computed**
Land use roughness	**Assumed** constant between cross sections	Roughness values at individual elements used in computations.
Ineffective flow areas	**Assumed** by user	**Computed**
Flow contraction and expansion through bridges	**Assumed** by user	**Computed**
Flow velocity	**Averaged** at each cross section	**Computed** at each element
Flow distribution	**Approximated** based on conveyance	**Computed** based on continuity and momentum
Water Surface Elevation	**Assumed** constant across entire cross section	**Computed** at each element
Flow splits	Based on **Averaged** constant Energy Grade Line	**Computed** based on continuity and momentum

Bridge Scour Analysis Tools

- SMS/SRH-2D (v13.1)
  - Community version free to all
  - ‘Pro’ version licenses provided to all FHWA/DOT staff
  - ‘Pro’ version licenses free to anyone in an official review role
- SMS/SRH-2D Bridge Scour Tutorials
  - Introduction to Bridge Scour Tool (Aquaveo Learning Center)
  - FHWA Bridge Scour Overview and Tutorials (contact FHWA RC)
- SMS Bridge Scour Workflow Instructions (Aquaveo website)
- Potential for future use with HEC-RAS 2D raster results

Bridge Scour Tool (SMS)

- Efficient, effective, and consistent means of extracting hydraulic variables for bridge scour analysis
- Uses arcs to define the approach and contracted sections, bank stations, piers, and abutments
- Extracts main channel averaged hydraulic parameters
- Extracts overbank averaged hydraulic parameters
- Adjusts for bridge and pier skew



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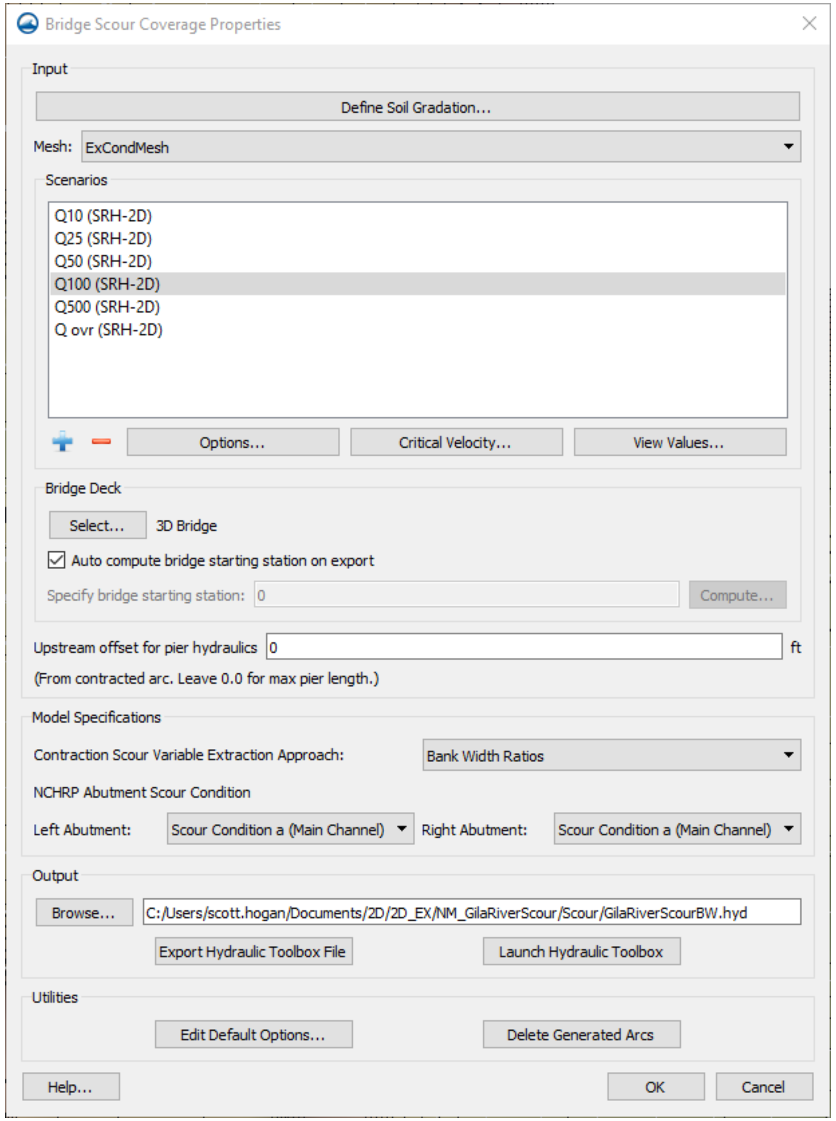
Bridge Scour Tool (SMS) (cont'd)

- Prompts for supporting data
  - Channel bed gradation
  - Pier shape and type
  - Abutment type and scour condition
- Can extract values for multiple flows
- Extracts channel geometry
- Extracts bridge geometry (when present)
- Generates a Hydraulic Toolbox input file
- View values allows preview of variables or use in other applications



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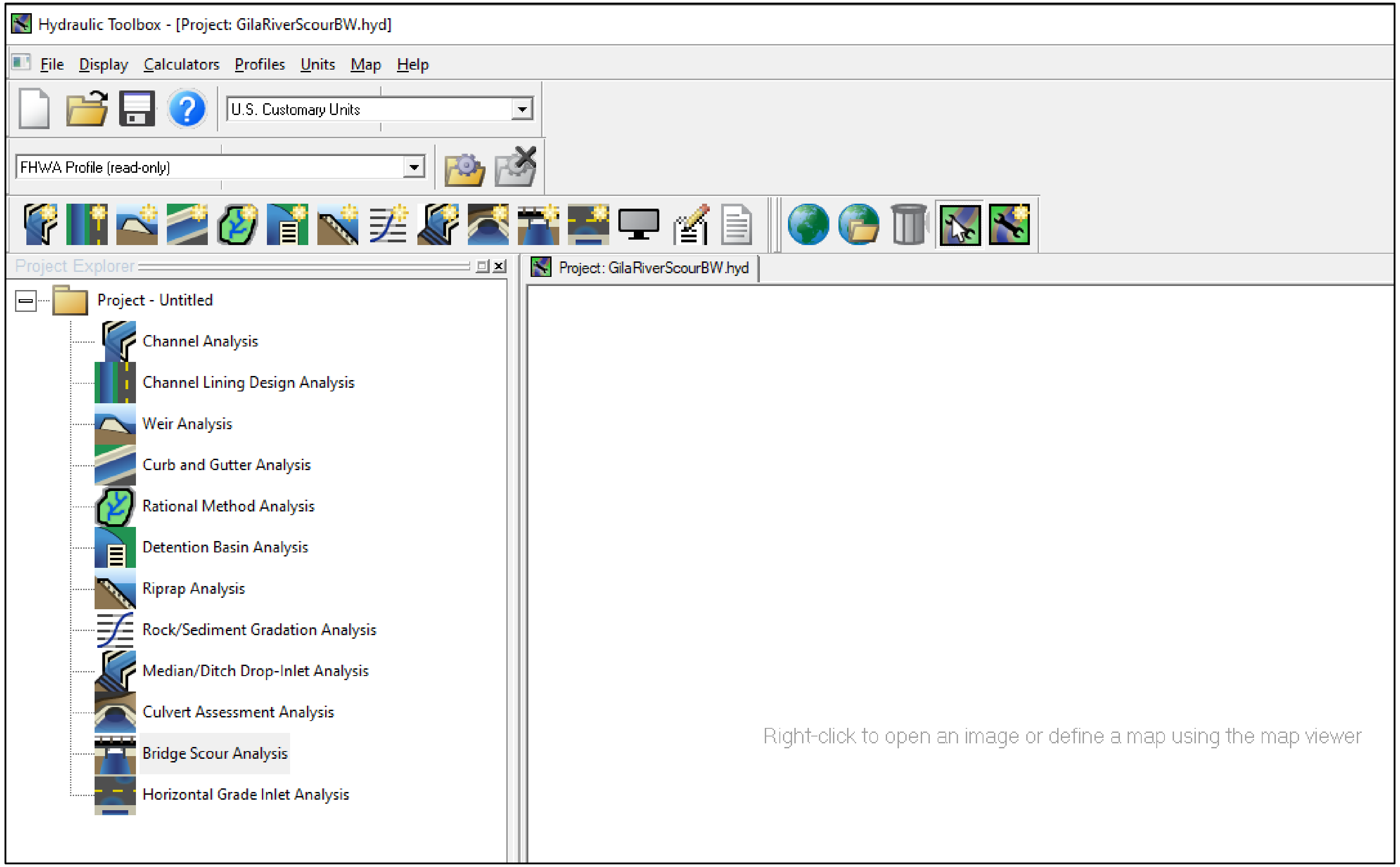
Bridge Scour Analysis Tools

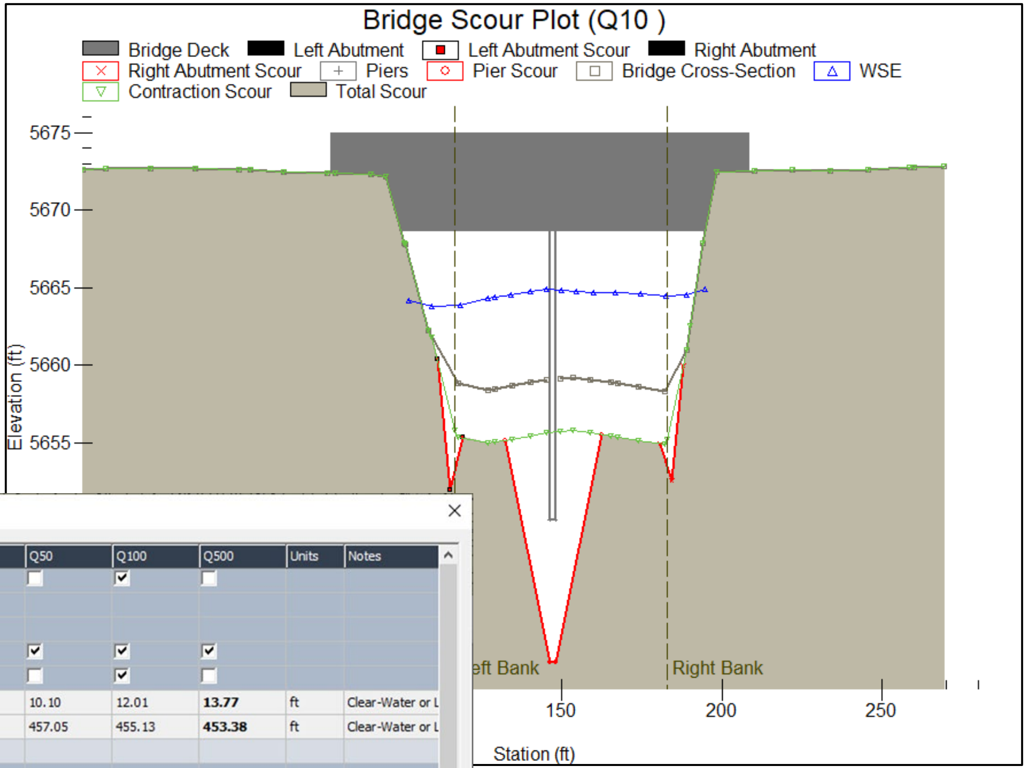
FHWA Hydraulic Toolbox (v5.1.1) (May 3, 2021)



Bridge Scour Analysis Tools

FHWA Hydraulic Toolbox ([v5.1.1])

- Includes calculators for each scour component (based on HEC-18)
- Summary Table provides scour estimates and elevations for multiple flow events
- Scour Plots display all results in the Summary Table



Bridge Scour Summary Table

Parameter	Q10	Q50	Q100	Q500	Units	Notes
Scenario	☐	☐	☑	☐		
Bridge Geometry						
Bridge Cross-Section						
WSE	☑	☑	☑	☑		
Contraction Scour	☐	☐	☑	☐		
Clear Water Contraction Scour Depth	5.13	10.10	12.01	**13.77**	ft	Clear-Water or L
Applied Contraction Scour Elevation with LTD	462.01	457.05	455.13	**453.38**	ft	Clear-Water or L
Approach Cross-Section						
Local Scour at Piers						
Plot Pier Scour	☐	☐	☑	☐		
Piers						
Pier Name	Pier 1	Pier 1	Pier 1	Pier 1		
Pier Scour Depth	19.21	20.93	21.49	**21.88**	ft	Computation Me
Total Scour at Pier	19.21	20.93	21.49	**21.88**	ft	
Total Scour Elevation at Pier	442.80	436.11	433.64	**431.50**	ft	
Piers						
Pier Name	Pier 2	Pier 2	Pier 2	Pier 2		
Pier Scour Depth	19.21	20.93	21.49	**21.88**	ft	Computation Me
Total Scour at Pier	19.21	20.93	21.49	**21.88**	ft	
Total Scour Elevation at Pier	442.80	436.11	433.64	**431.50**	ft	
Local Scour at Abutments						

Plot Cross Section | ☑ Color-Filled Plots | OK | Cancel

Side note: FHWA discourages the use of HEC-RAS Hydraulic Design Bridge Scour calculator.

- Significantly outdated
- Not correctly used by most

Bridge Scour Analysis Tools

Questions ?

Bridge Scour Analysis Example
West Fork Gila River, New Mexico (Existing Condition Bridge)

- Reach length
  ~ 1 mile
- Valley width
  ~ 800 ft
- Avg. slope
  ~ 0.003 ft/ft
- Bridge config.
  90 ft (2-span)
  Pier width=1.6 ft
- Channel bed
  D_{50} = 9mm (.0303 ft)

Image source: FHWA

Bridge Scour Example - Mapping

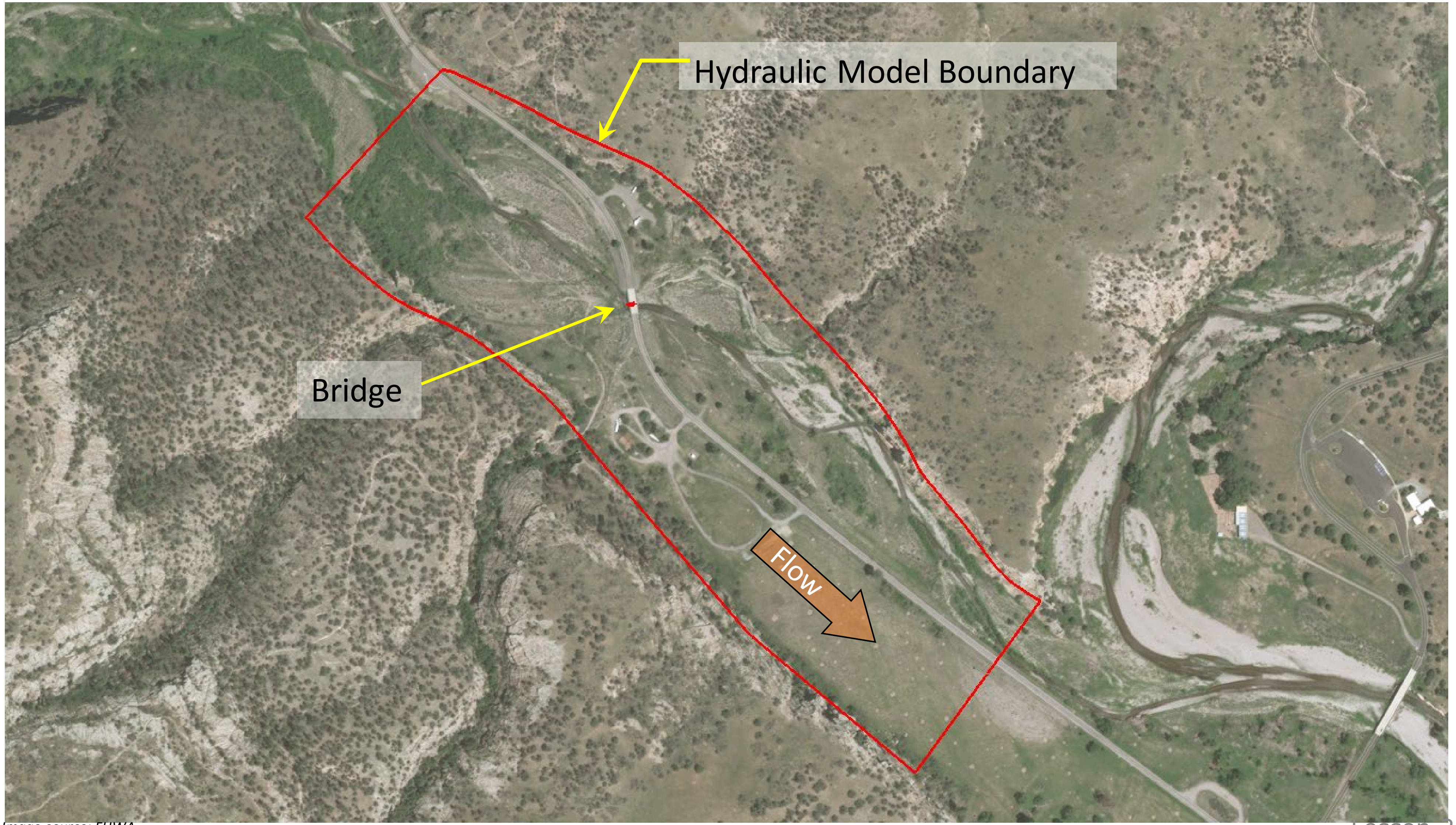


Image source: FHWA

Bridge Scour Example – SRH-2D Mesh

Image source: FHWA

# of mesh elements

~ 5,000

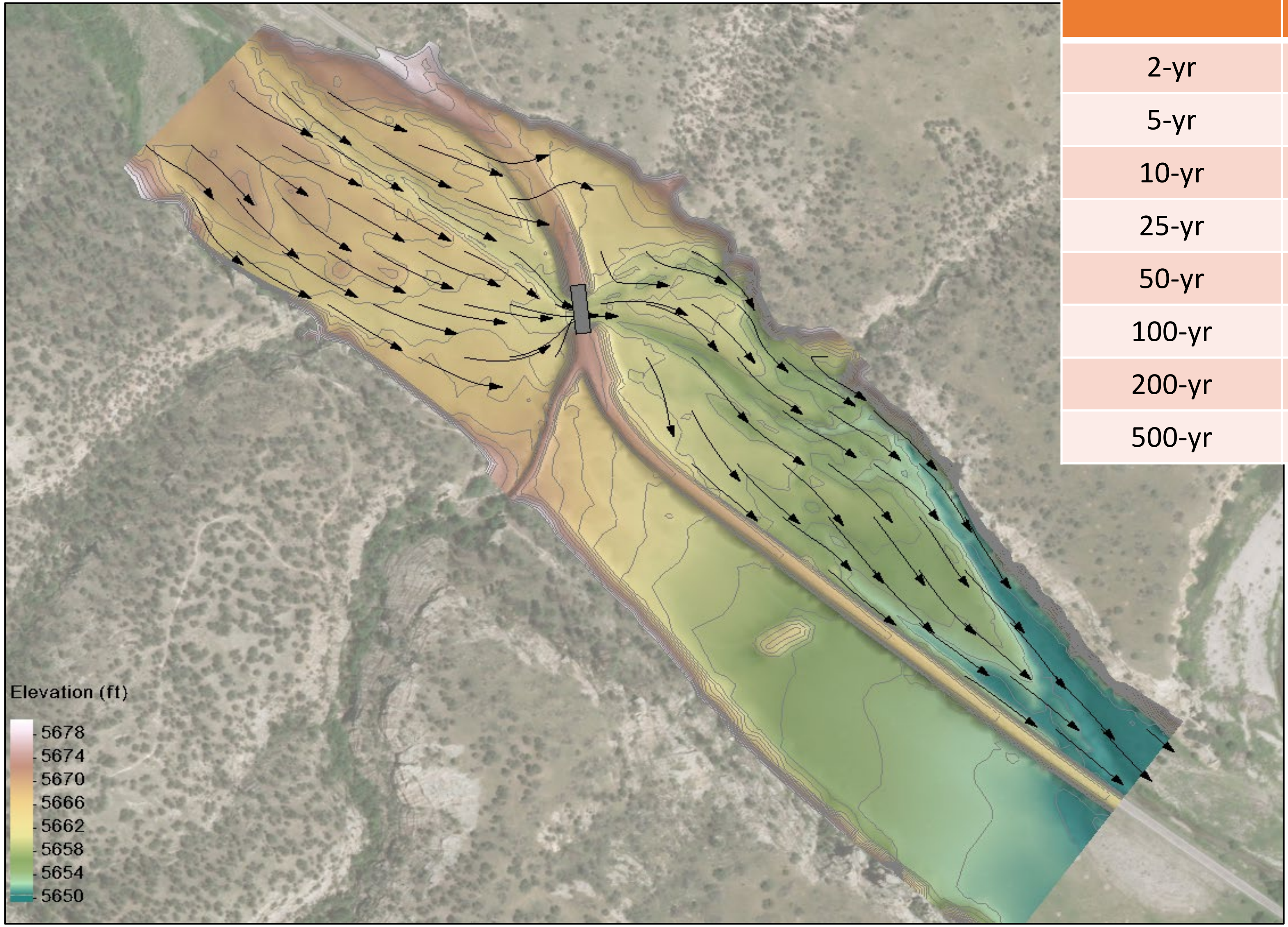
Size of mesh elements

~ 1.5ft to 50ft

Model run time

~ 40 seconds

Bridge Scour Example – Boundary Conditions

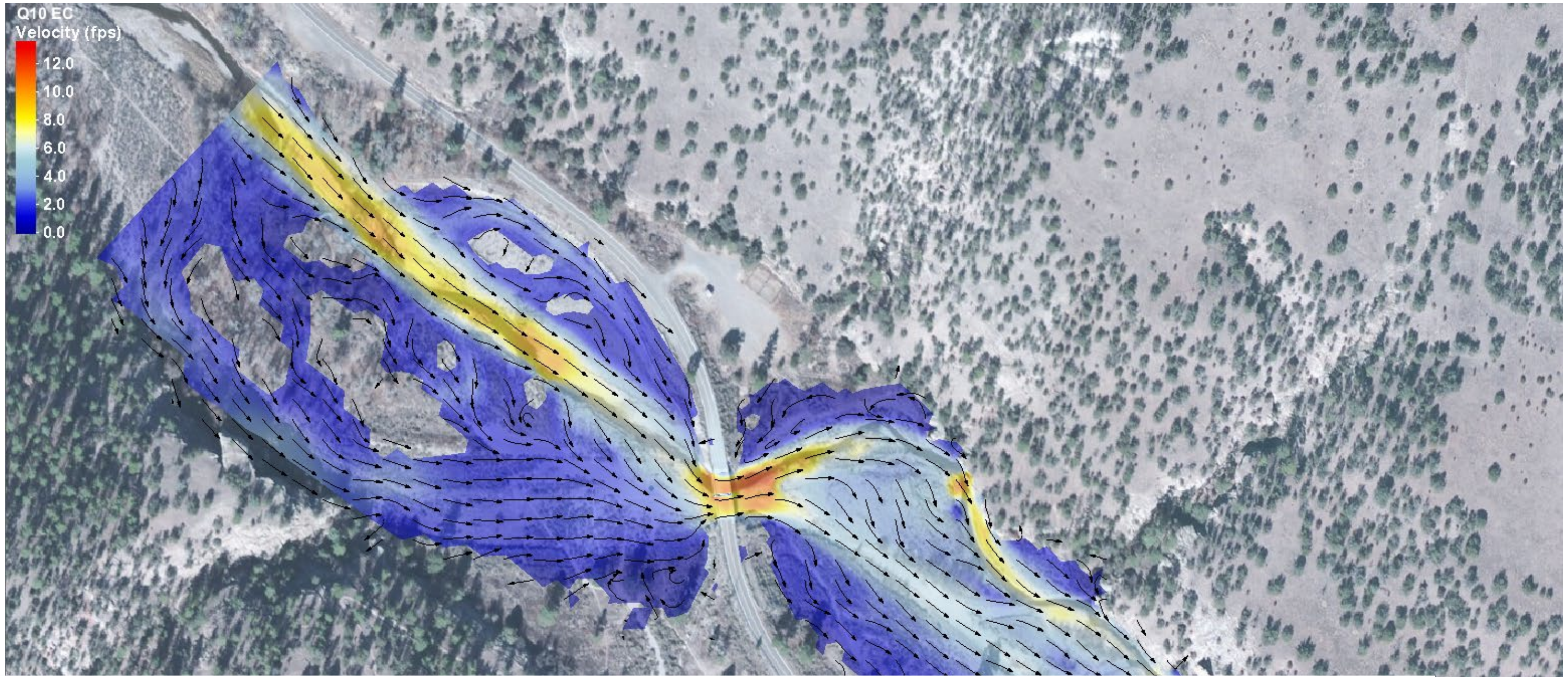


Flood Event	Peak Discharge (cfs)
2-yr	624
5-yr	1,643
10-yr	3,439
25-yr	6,550
50-yr	9,901
100-yr	14,344
200-yr	19,000
500-yr	26,000

Image source: FHWA

Bridge Scour Example – 2D Model Results

Q10 Velocities and WS Profile



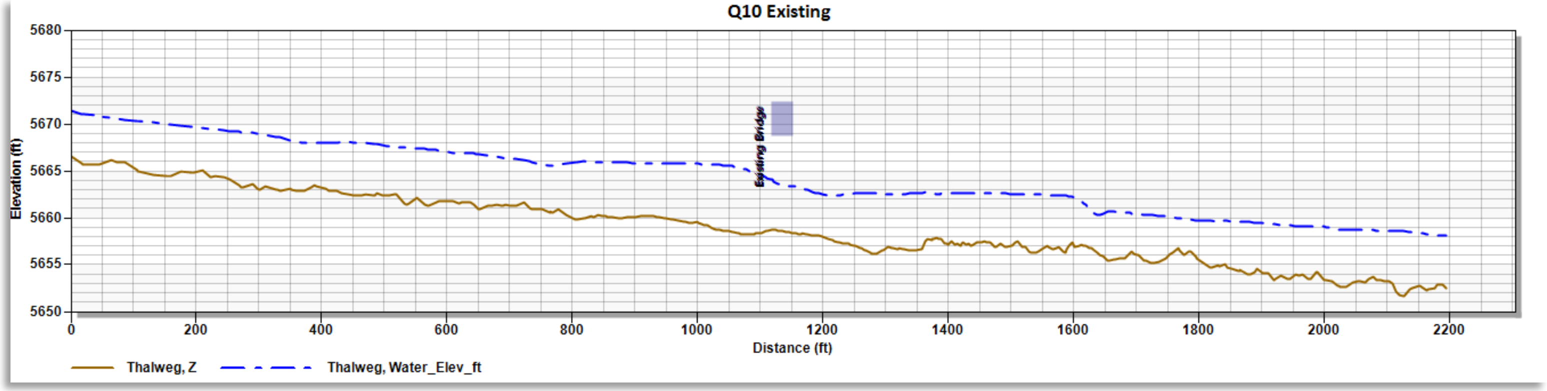
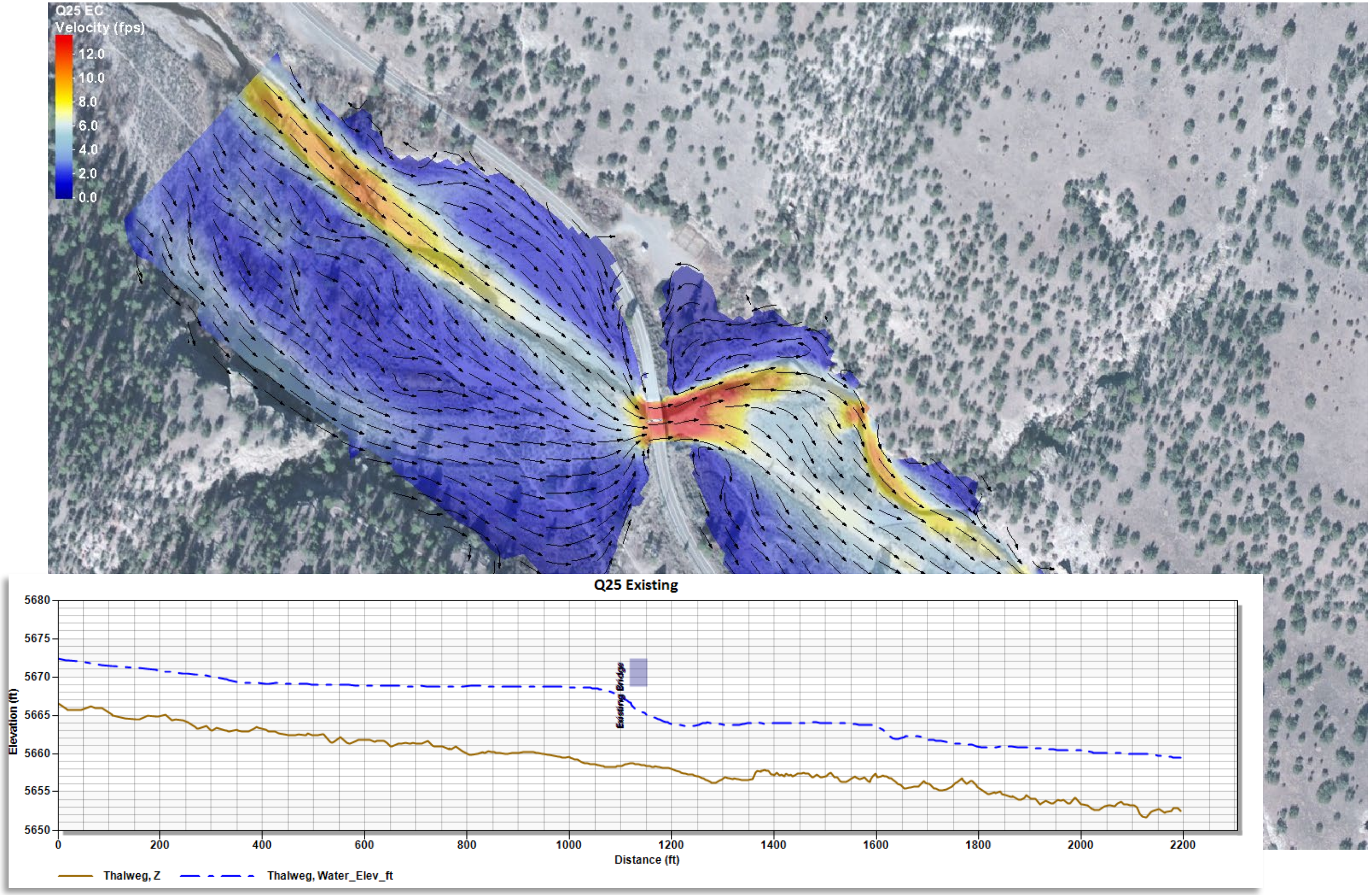


Image source: FHWA

Bridge Scour Example – 2D Model Results

Q25 Velocities and WS Profile



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Bridge Scour Example – 2D Model Results

Q50 Velocities and WS Profile

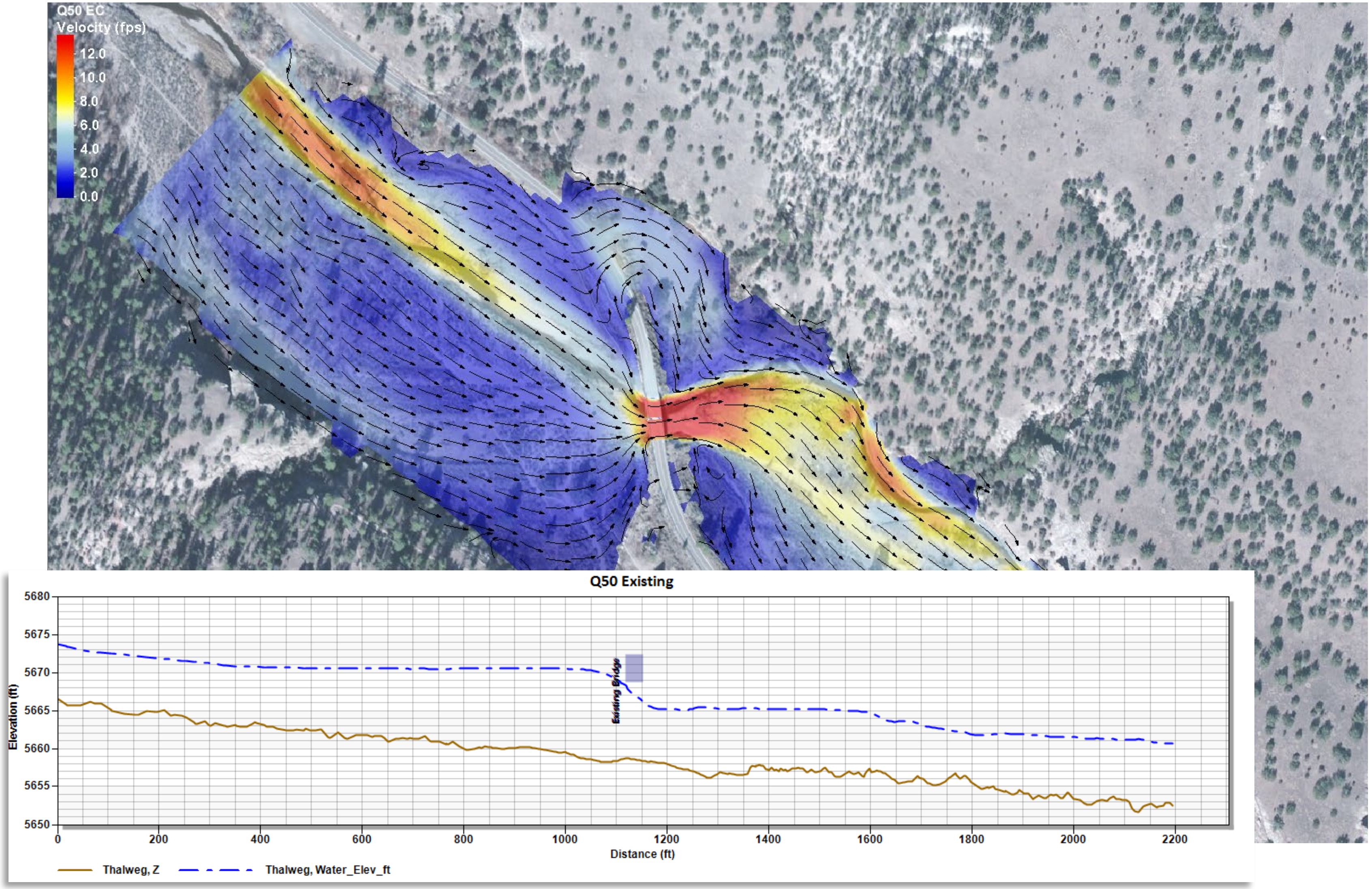


Image source: FHWA

Bridge Scour Example – 2D Model Results

Q100 Velocities and WS Profile

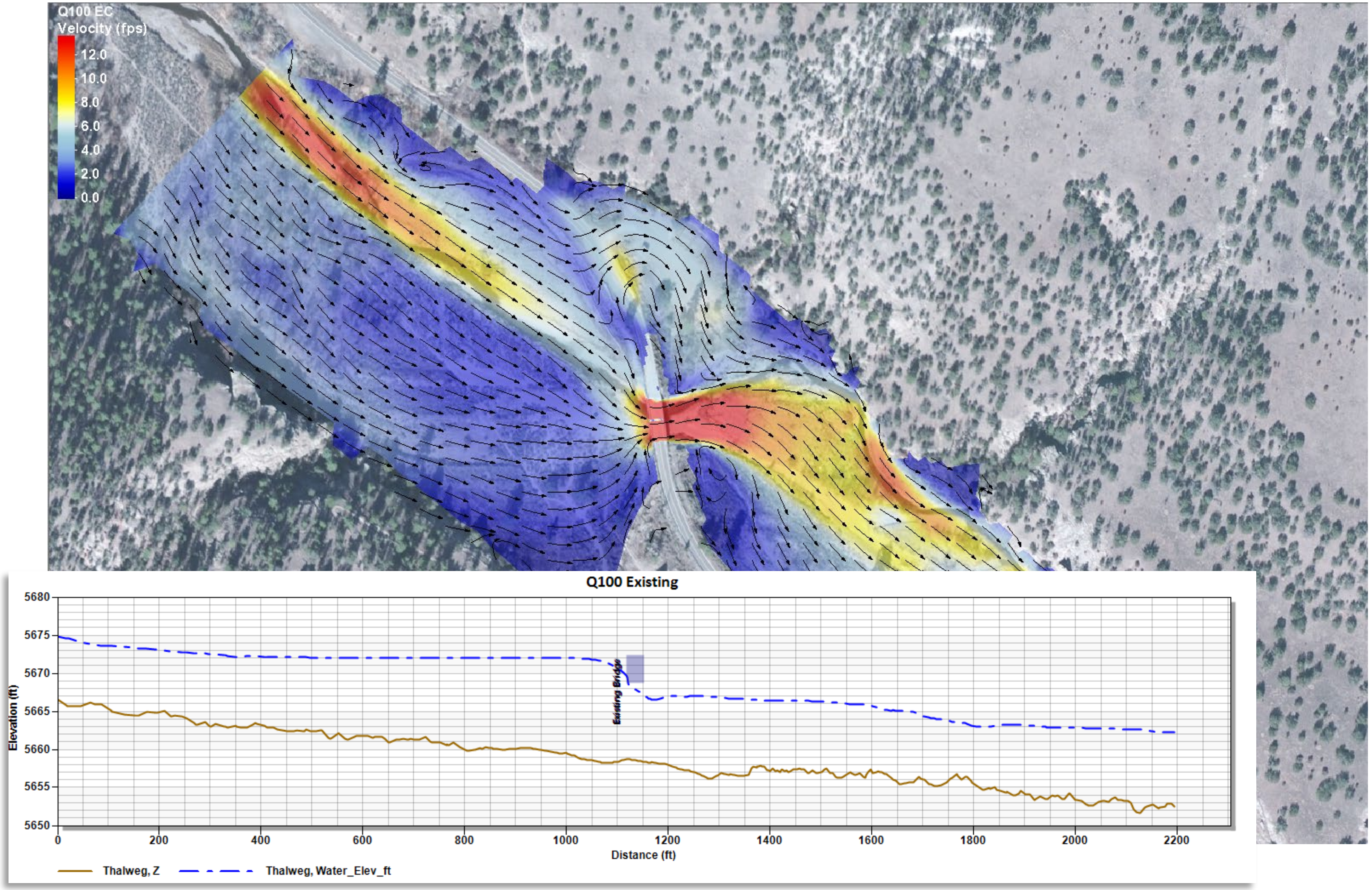
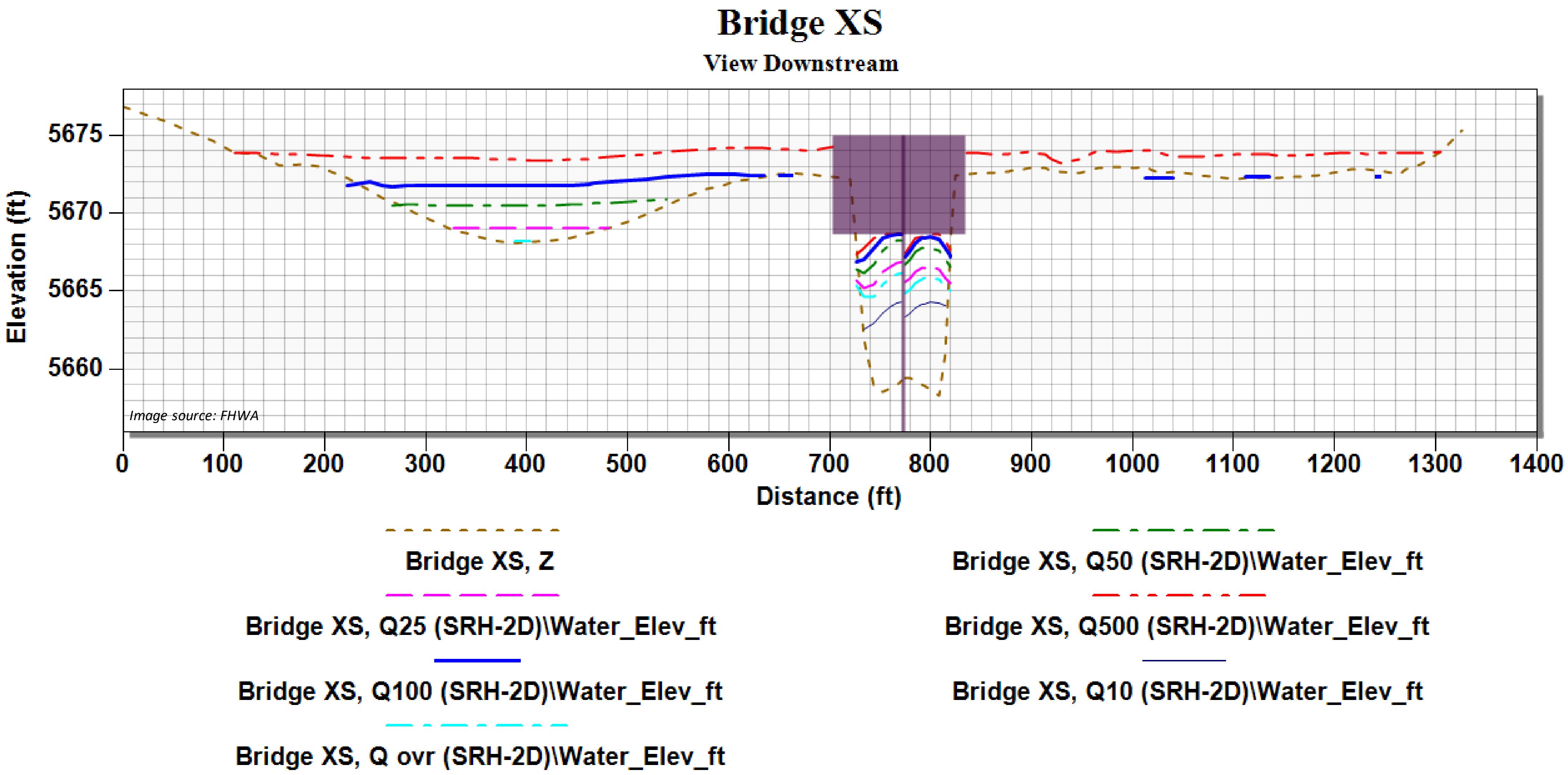


Image source: FHWA

Bridge Scour Example – 2D Model Results

Bridge Cross Section (view downstream)



Bridge Scour Example – 2D Model Results

Bridge Cross Section (view downstream)

Bridge Scour Summary Table

Parameter	Q10	Q25	Q50	Q100	Q500	Q ovr	Units
Scenario	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	
Bridge Geometry							
Bridge Cross-Section							
WSE	[x]	[x]	[x]	[ ]	[x]	[ ]	
Contraction Scour	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	
Applied Contraction Scour Depth	3.45	6.74	8.82	7.78	**12.88**	5.64	ft
Contraction Scour Depth and Long Term Degradation (LTD)	3.45	6.74	8.82	7.78	**12.88**	5.64	ft
Clear Water Contraction Scour Depth	3.45	6.74	8.82	7.78	**12.88**	5.64	ft
Live Bed Contraction Scour Depth	3.96	10.23	13.30	14.55	**16.58**	7.98	ft
Applied Contraction Scour Elevation with LTD	5654.90	5651.61	5648.88	5645.27	**5642.32**	5652.71	ft
Approach Cross-Section							
Local Scour at Piers							
Plot Pier Scour	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	
Piers							
Pier Name	Pier 1	Pier 1	Pier 1	Pier 1	Pier 1	Pier 1	
Pier Scour Depth	14.08	13.26	13.60	13.83	**15.89**	13.44	ft
Total Scour at Pier	14.08	13.26	13.60	13.83	**15.89**	13.44	ft
Total Scour Elevation at Pier	5640.82	5638.35	5635.28	5631.45	**5626.43**	5639.27	ft
Local Scour at Abutments							
Abutment scour currently cannot be computed with pressure flo...							
Left Abutment							
Plot Left Abutment Scour	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	
Abutment Scour Depth	8.96	11.82	14.61	16.73	**21.70**	10.64	ft
Total Scour at Abutment	8.96	**11.82**	0.00	0.00	0.00	10.64	ft
Total Scour Elevation at Abutment	5651.95	5649.70	5647.37	5645.79	**5641.81**	5650.64	ft
Right Abutment							
Plot Right Abutment Scour	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	
Abutment Scour Depth	6.95	10.64	12.77	15.08	**20.58**	9.77	ft
Total Scour at Abutment	6.95	**10.64**	0.00	0.00	0.00	9.77	ft
Total Scour Elevation at Abutment	5652.55	5649.37	5647.57	5645.96	**5642.45**	5650.06	ft

Image source: FHWA

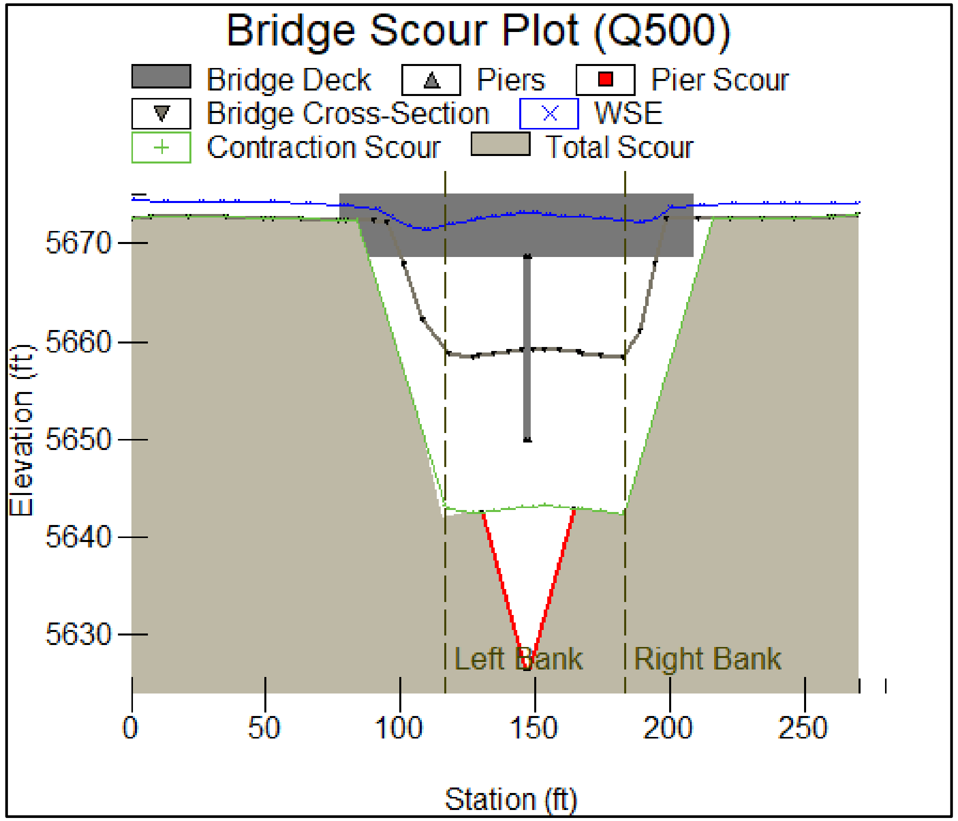


Image source: FHWA

Bridge Scour Example Project

Questions ?

FHWA Bridge Scour Workshop

Long Term Degradation

Bridge Scour POWER HOUR

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Long-term Degradation and Stream Stability – Overview

- The three levels of analysis
- Factors influencing long-term bed elevation changes
- Identifying stream instability trends

Assessment Procedures

- Information on long-term degradation and stream instability can be found in HEC-18, HEC-20, and HEC-16.
- HEC-18 and HEC-20 outline a three-level approach:

Level 1: Application of simple geomorphic concepts and other qualitative analysis

Level 2: Application of basic hydrologic, hydraulic, and sediment transport engineering concepts

Level 3: Application of mathematical or physical modeling studies

Level 1 – Qualitative Geomorphic Analysis

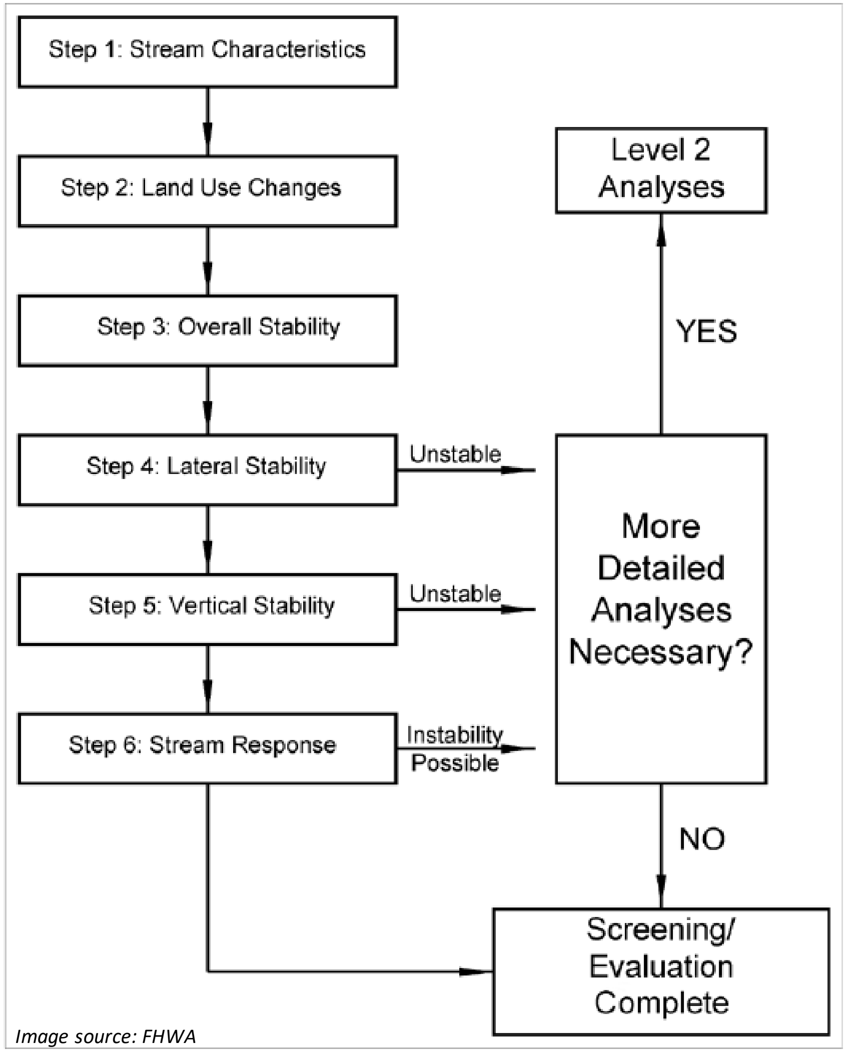


Figure 4.1. Flow chart for Level 1: Qualitative Geomorphic Analyses.

Level 2 – Basic Engineering Analysis

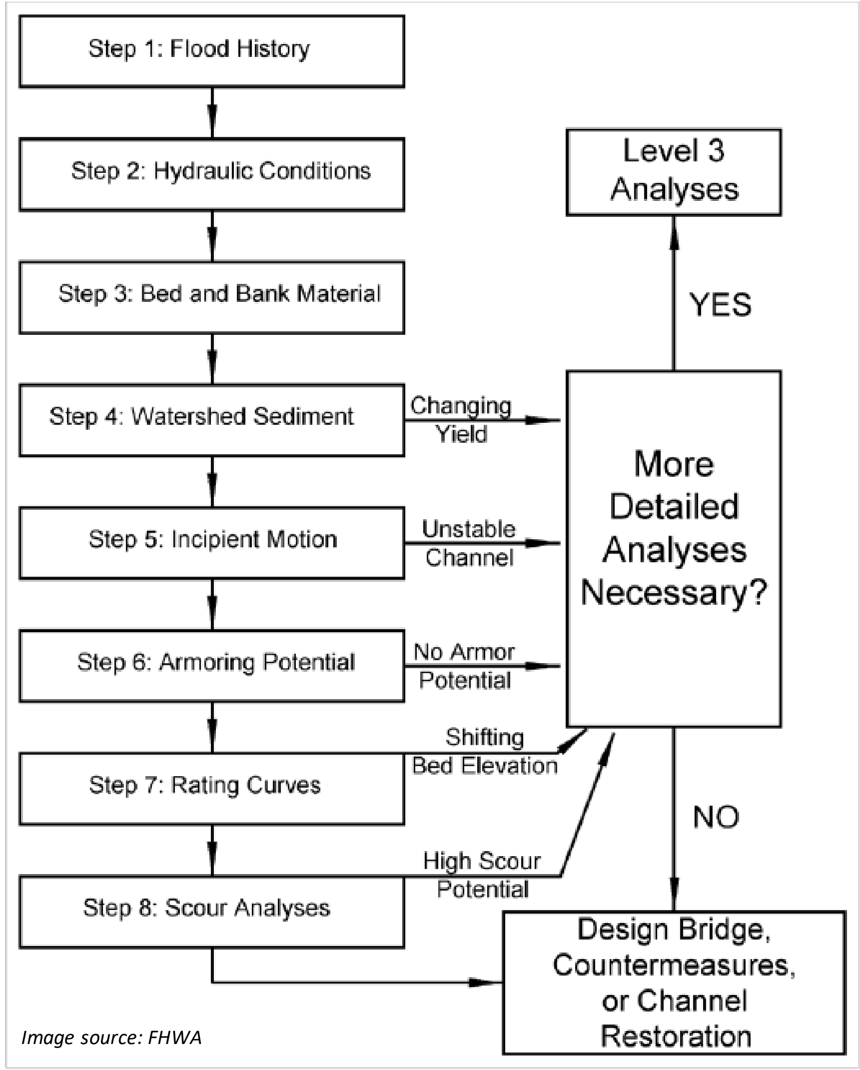


Figure 4.4. Flow chart for Level 2: Basic Engineering Analyses.

Level 3: Mathematical & Physical Models

Computer Models:

- USACE HEC-RAS
- GSTARS
- FLUVIAL
- SMS/SRH-2D
- MD SWMS
- CHARIMA
- MEANDER

Physical Models:

Image source: FHWA

Level 1 – Qualitative Geomorphic Analysis

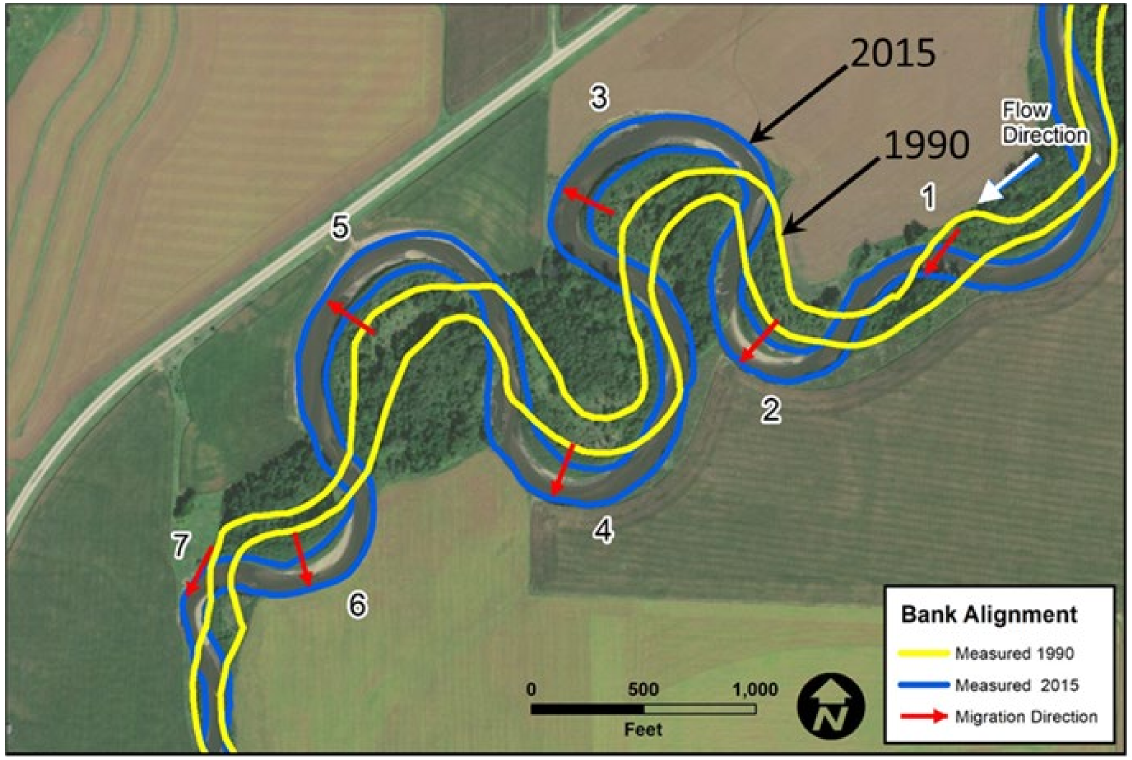
Data Needed:

- Photos, Bridge Inspections, and Stream Reconnaissance
- Topographic, Geographic, Soils, & Land-Use Maps
- Aerial Photographs
- Climatological & Stream Gage Data
- Soils & Sedimentation Data
- Other As-built, Basin, Project, or Special Reports

Channel Migration and Widening

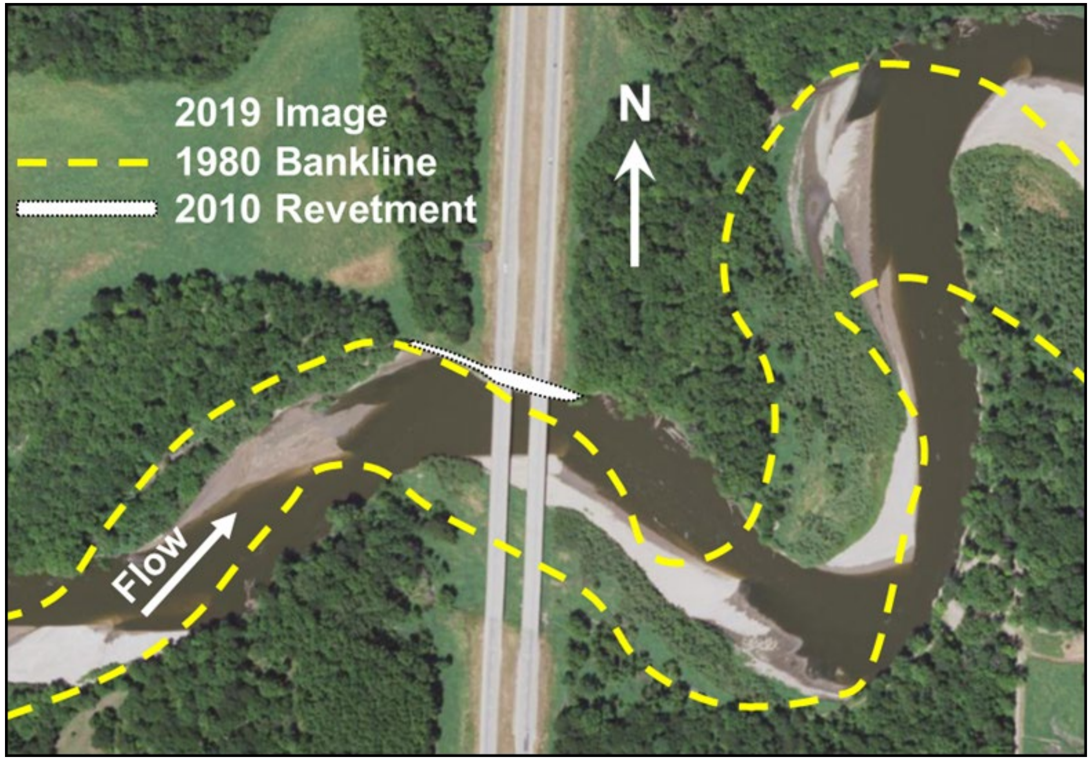
Long-term changes to channel bank locations and channel alignment due to natural or man induced causes.

Migrating toward roadway.



Maple River, IA. *Image source: Original image from National Agriculture Imagery Program (NAIP)*

Migrating toward abutment. Changing flow alignment at piers.



Wapsipinicon River, IA. *Image source: USDA*

Channel Migration and Widening - Tools

Stream Reconnaissance

- Eroding banks
- Trees in channel
- Compare Aerial Images
  - Google Earth
  - Farm Service Agency
  - USGS
- Compare Maps (USGS)

Image source: Map Data © 2019 Google

Middle Fork Clarks River, US 641 at Murray, KY

Channel Migration and Widening - Tools

Aerial imagery comparisons are used to identify historic trends in channel alignment and channel widening. Overlays of channel banks can be created easily in GIS software or even PowerPoint.

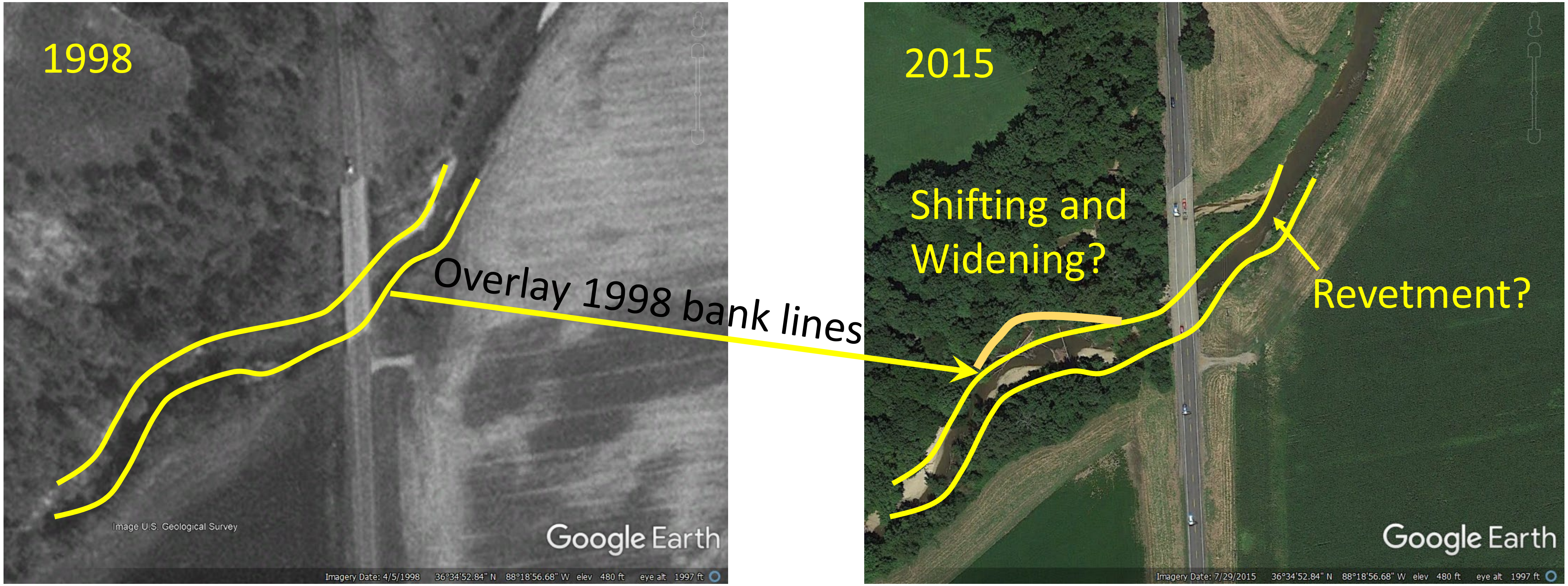


Image source: Map Data © 1998 Google

Image source: Map Data©2015 Google

Middle Fork Clarks River, US 641 at Murray, KY

Channel Migration and Widening - Tools

USGS map comparisons are also used to identify historic trends.

https://ngmdb.usgs.gov/topoview/

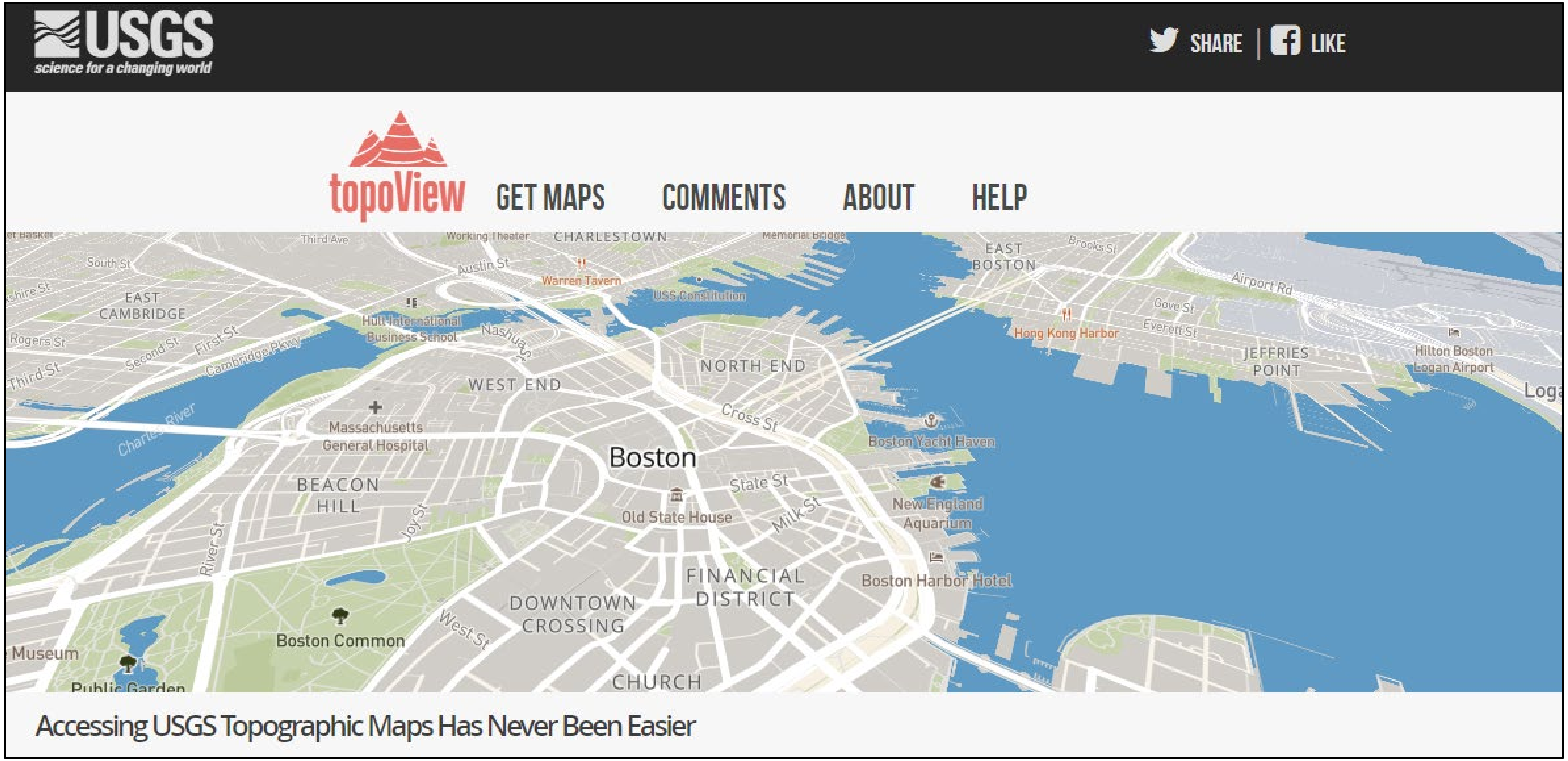


Image source: USGS

Channel Migration and Widening - Tools

USGS map near Murry, KY from 1930s to Present

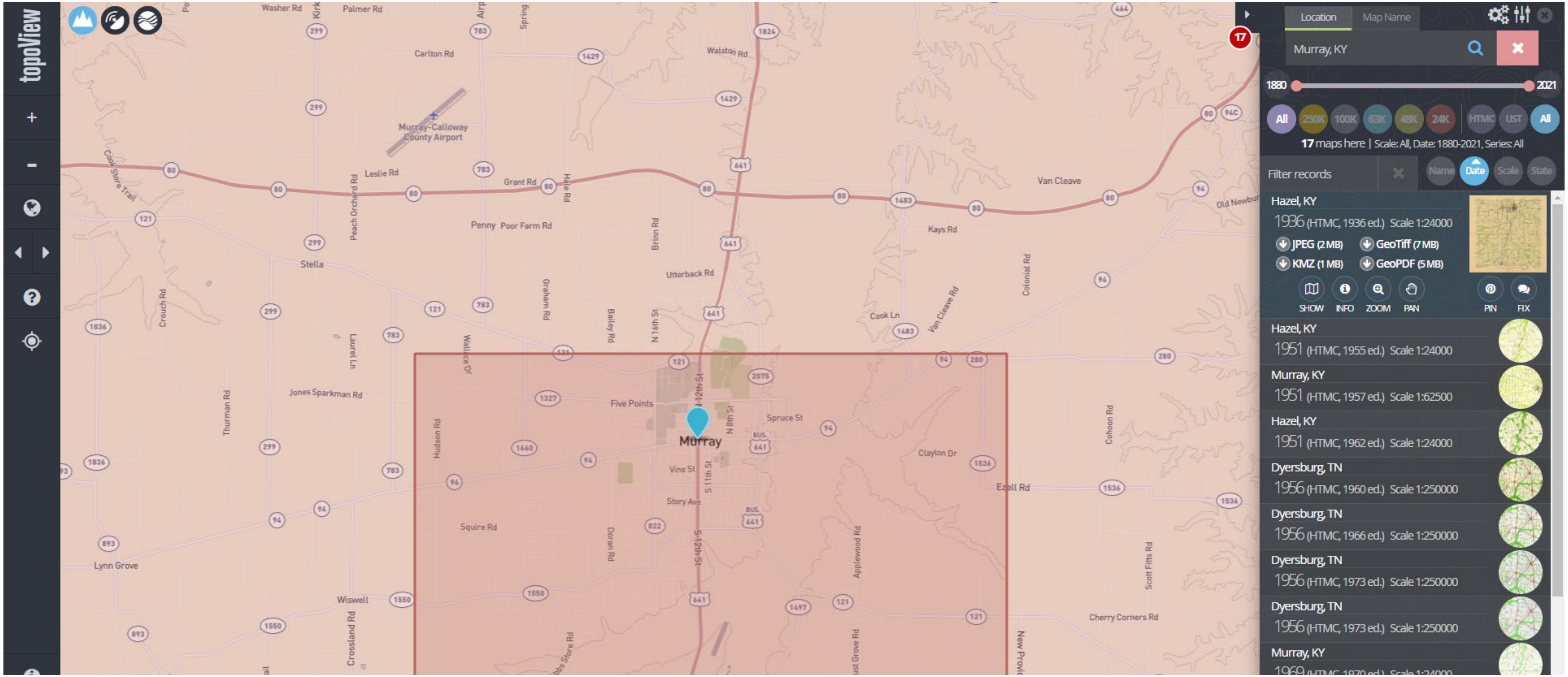


Image source: USGS

Channel Migration and Widening - Tools

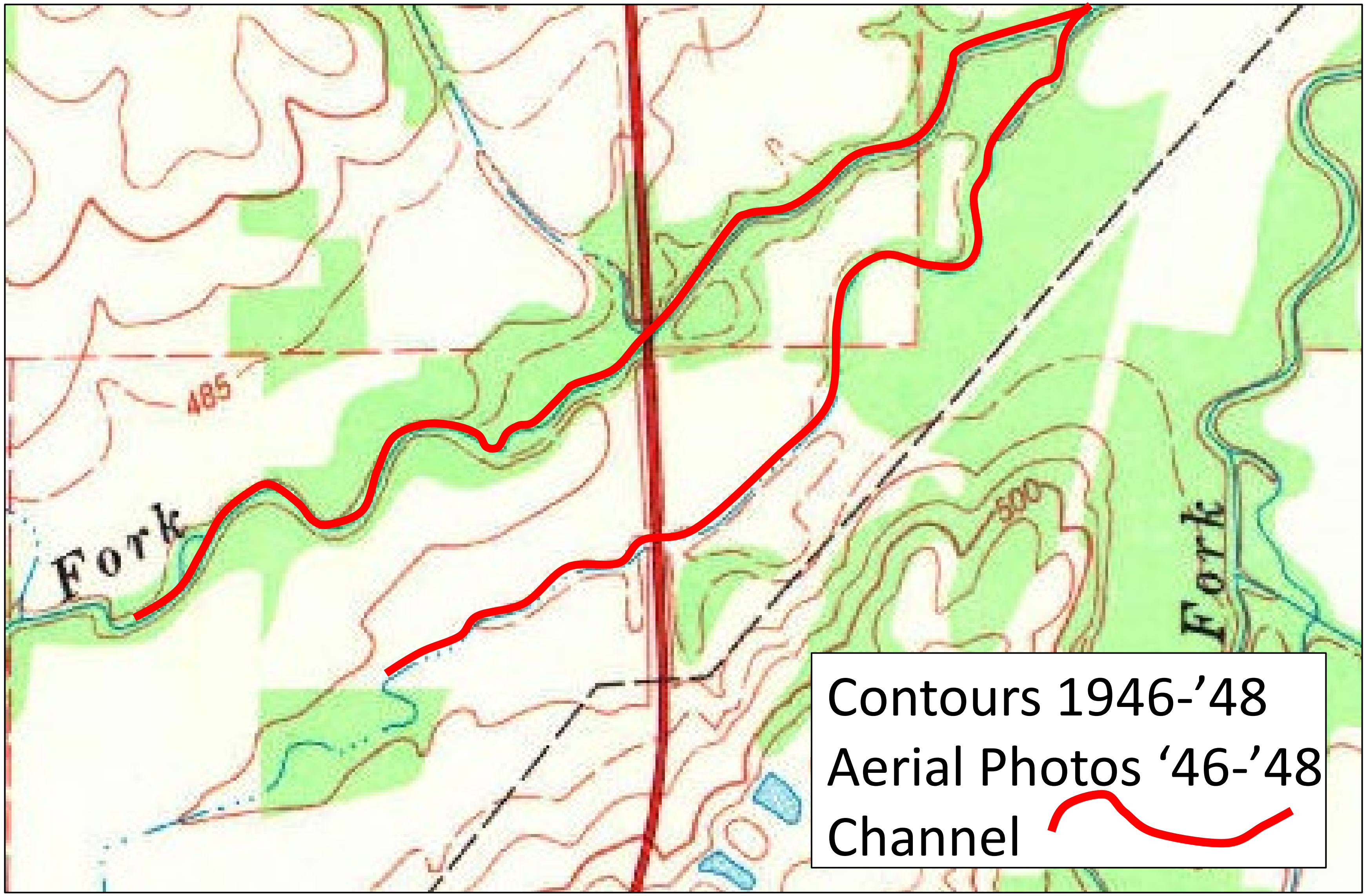


Image source: USGS

1940s Channels traced

Channel Migration and Widening - Tools

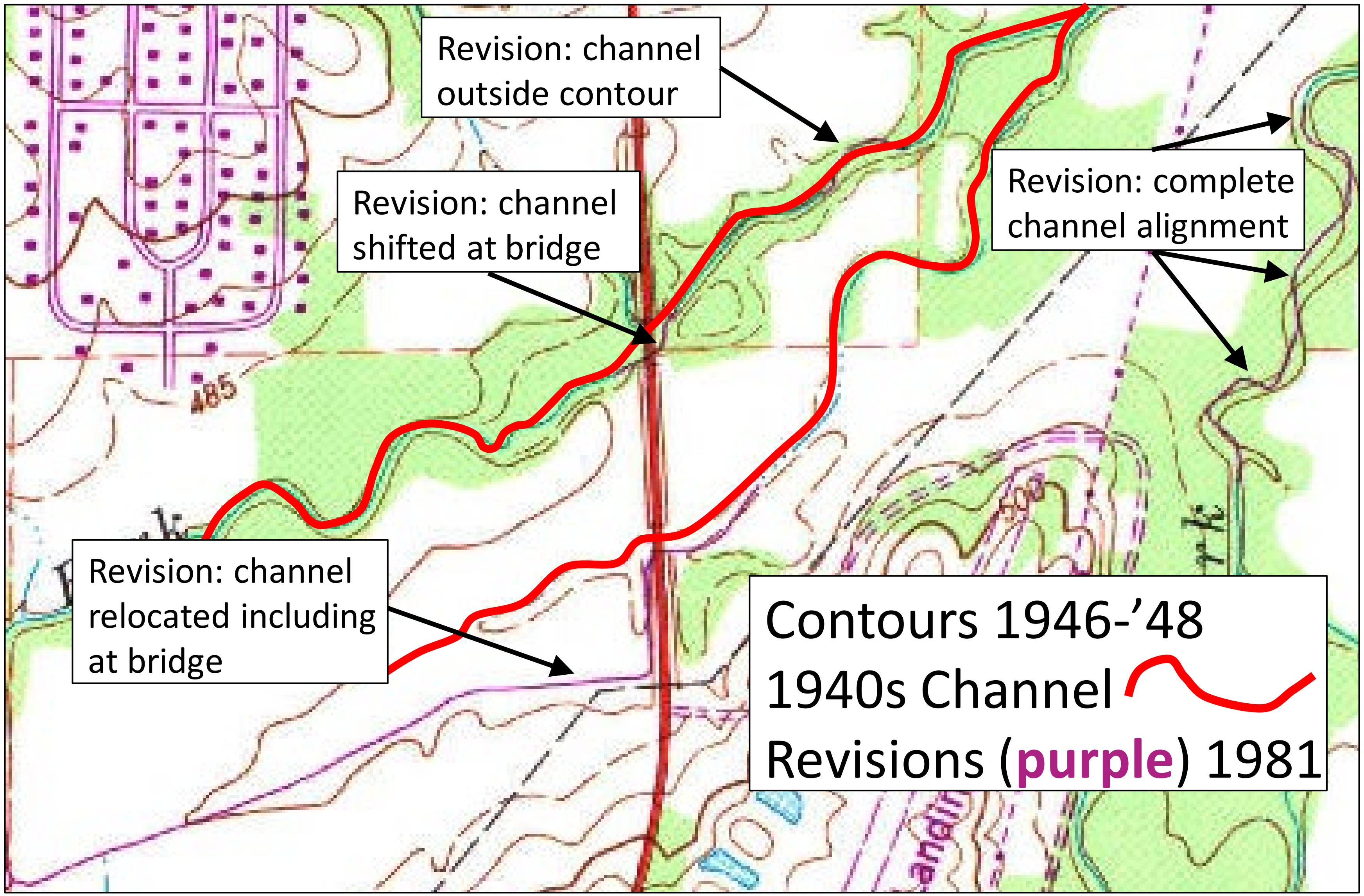


Image source: USGS

USGS maps often include revisions

Channel Migration and Widening - Tools

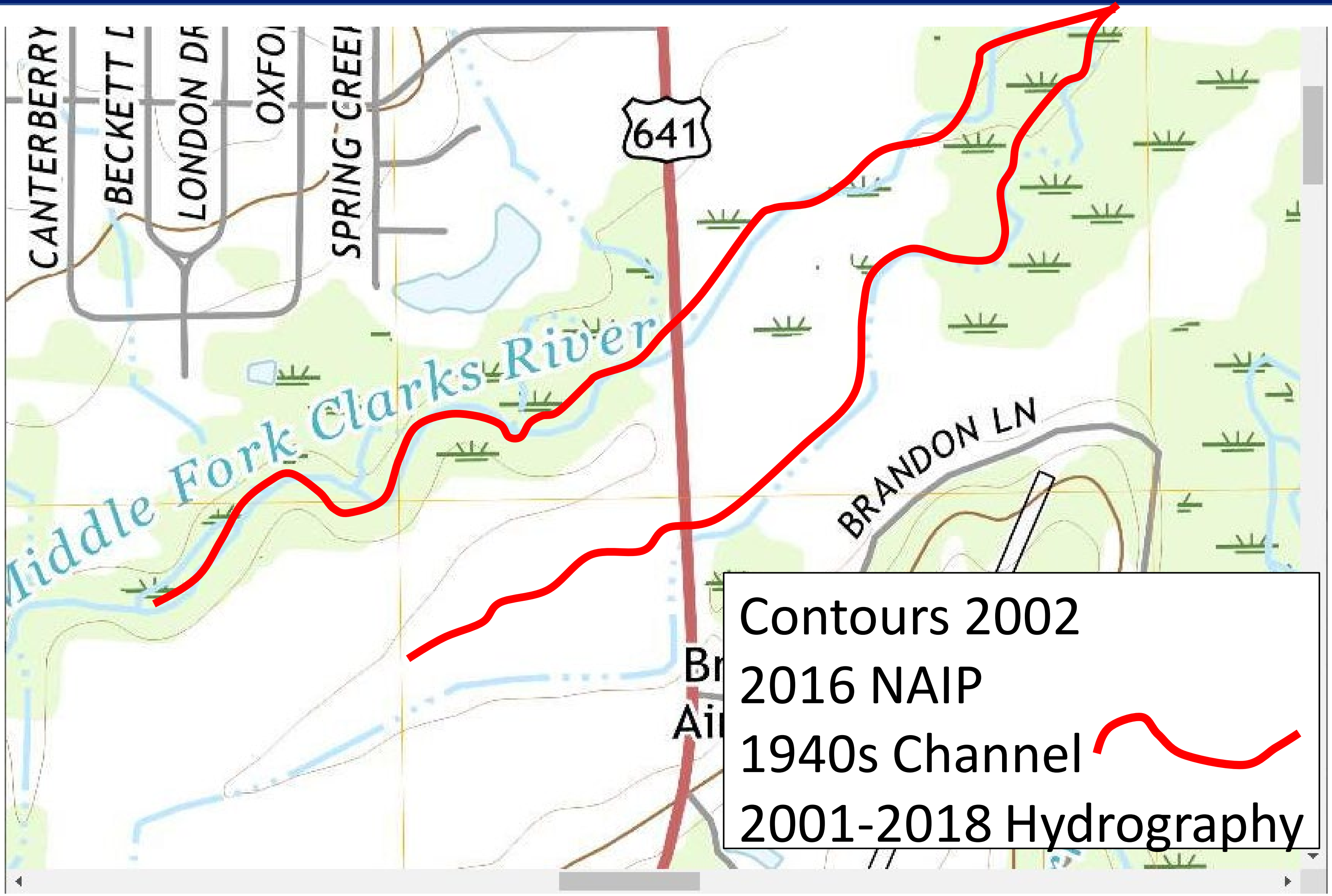


Image source: USGS

Comparisons between time periods show historical channel movement. Further movement should be expected in the future.

Aggradation and Degradation

Long-term elevation changes due to natural or man induced causes

Image source: FHWA

Aggradation:

River bed rise due to excess sediment deposition

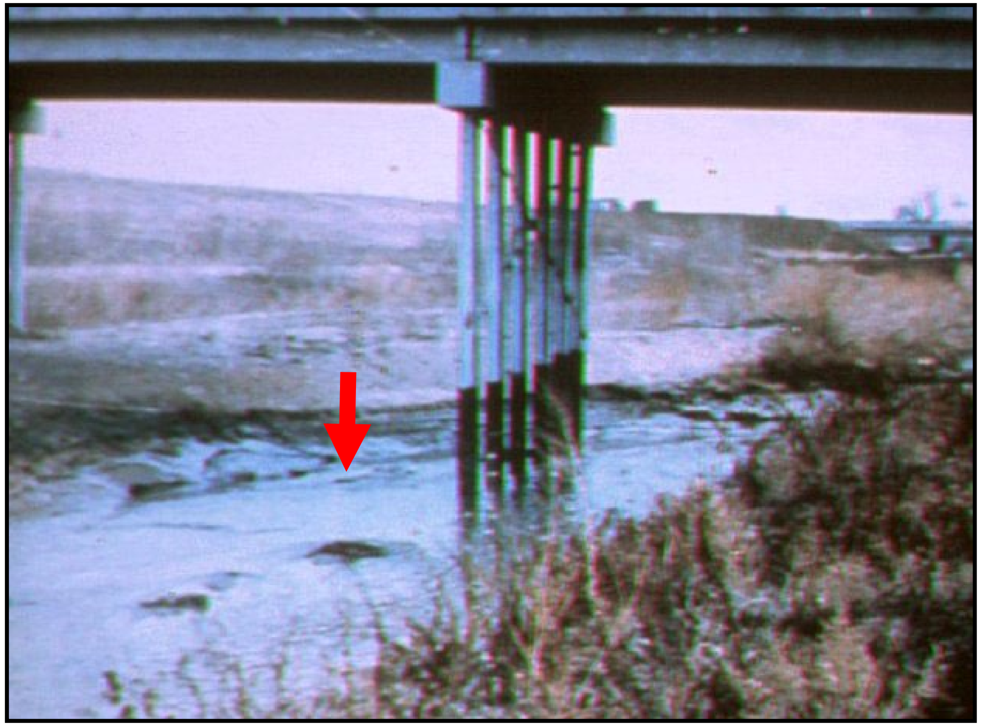


Image source: FHWA

Degradation:

River bed lowering due to long-term erosion

Lane's Equilibrium Concept

$$Q_S \; D_{50} \, \alpha \, Q \, S$$

where:

Q_S = Sediment transport rate

D_{50} = Median sediment size

Q = Discharge

S = Bed Slope

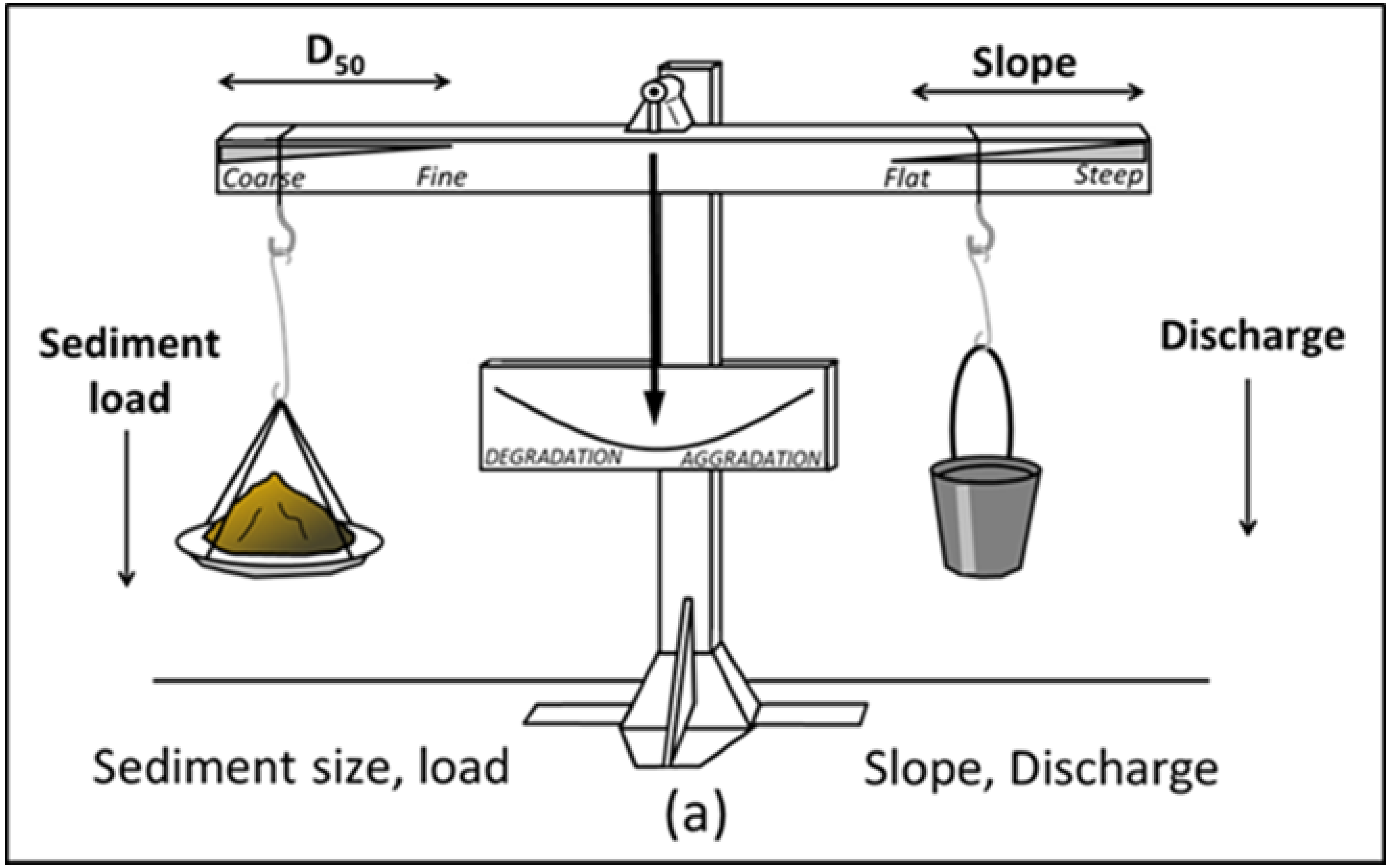


Image source: Johnson et al. (2019) after E.W. Lane

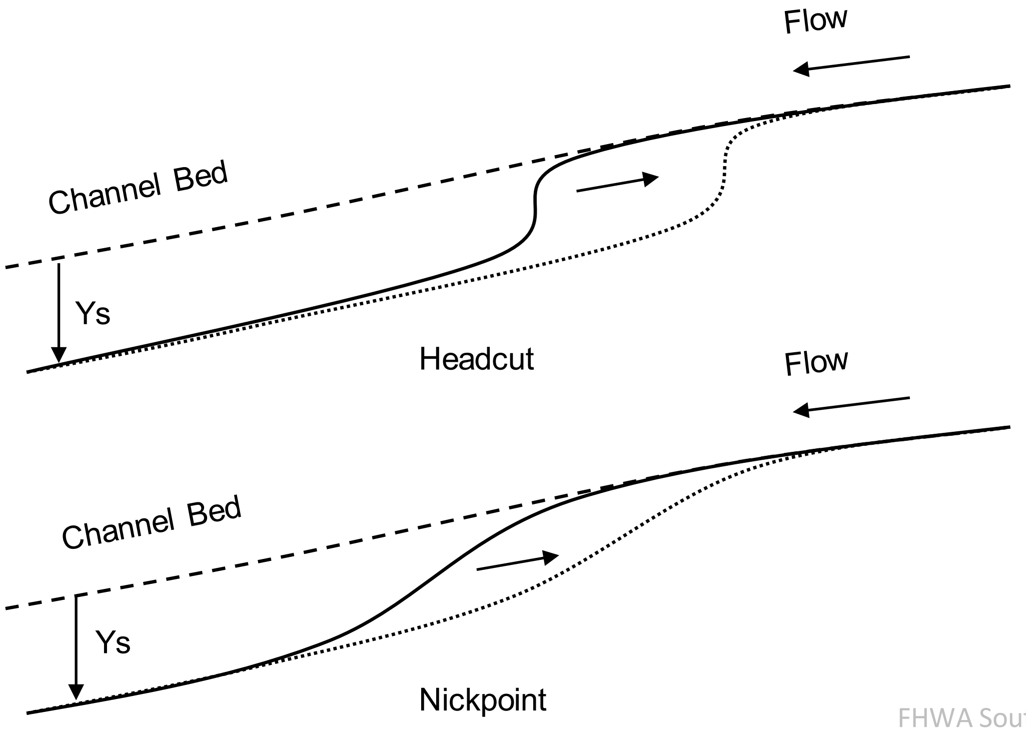
Factors Influencing Long-term Bed Elevation Changes

- Dams & reservoirs
- Channel Alterations
- Streambed mining
- Base level changes
- Watershed changes
- Urbanization
- Water use
- Natural Causes

Vertical Stability - Tools

Field Evidence

- Head cuts
- High, failing banks
- Exposed utilities



Direct Evidence

- Bridge inspections: channel profiles, foundations exposed or undermined

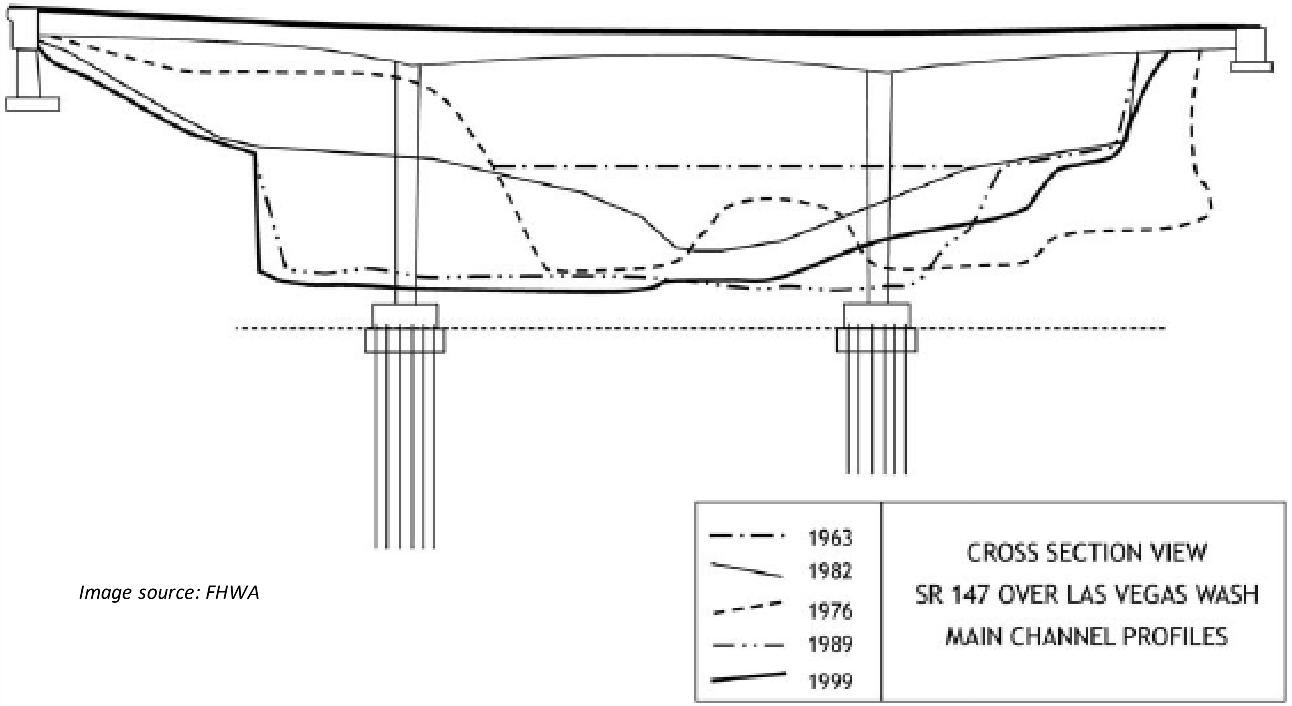
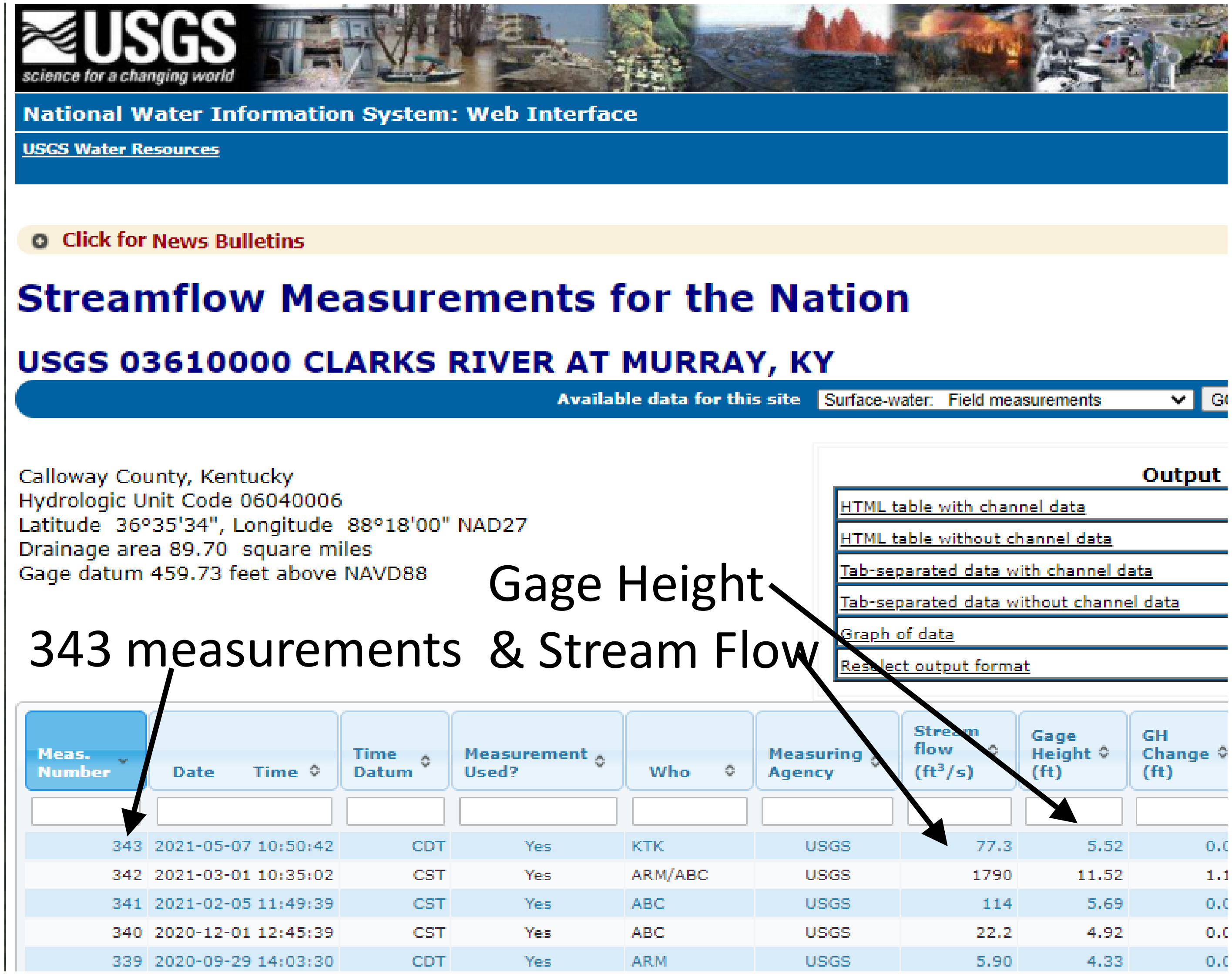


Image source: FHWA

Vertical Stability: Tools - Specific Gage Plots


USGS science for a changing world

National Water Information System: Web Interface

USGS Water Resources

Click for News Bulletins

Streamflow Measurements for the Nation

USGS 03610000 CLARKS RIVER AT MURRAY, KY

Available data for this site Surface-water: Field measurements

Calloway County, Kentucky
Hydrologic Unit Code 06040006
Latitude 36°35'34", Longitude 88°18'00" NAD27
Drainage area 89.70 square miles
Gage datum 459.73 feet above NAVD88

Output
- HTML table with channel data
- HTML table without channel data
- Tab-separated data with channel data
- Tab-separated data without channel data
- Graph of data
- Reselect output format

Meas. Number	Date Time	Time Datum	Measurement Used?	Who	Measuring Agency	Stream flow (ft^3/s)	Gage Height (ft)	GH Change (ft)
343	2021-05-07 10:50:42	CDT	Yes	KTK	USGS	77.3	5.52	0.0
342	2021-03-01 10:35:02	CST	Yes	ARM/ABC	USGS	1790	11.52	1.1
341	2021-02-05 11:49:39	CST	Yes	ABC	USGS	114	5.69	0.0
340	2020-12-01 12:45:39	CST	Yes	ABC	USGS	22.2	4.92	0.0
339	2020-09-29 14:03:30	CDT	Yes	ARM	USGS	5.90	4.33	0.0

Image source: USGS

Evidence at Gages

USGS repeats flow and stage measurements at gages to maintain the rating curves.

Specific gage plots track changes in stage with time. For low flows the stage and bed elevation are closely tied.

Vertical Stability: Tools - Specific Gage Plots

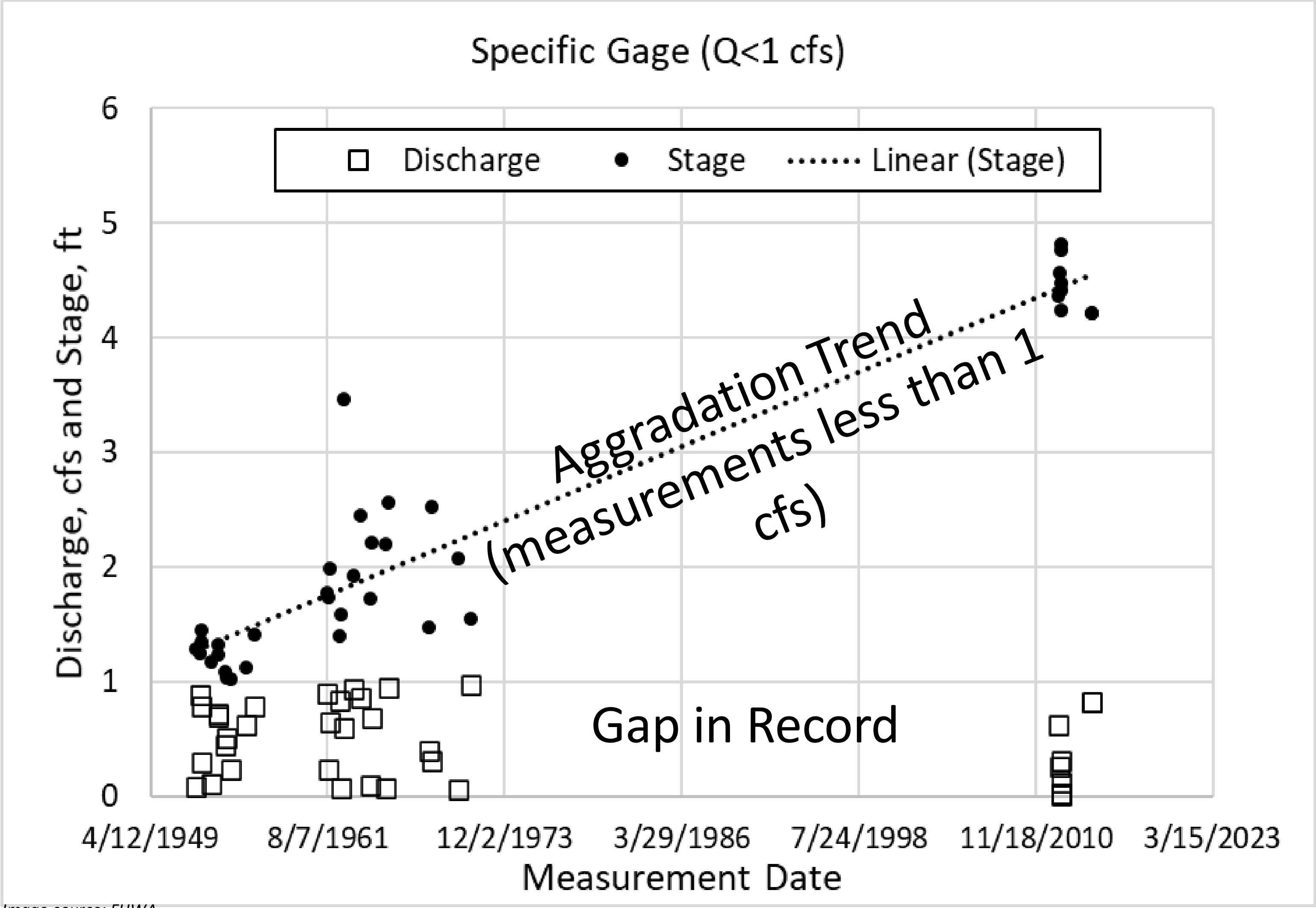


Image source: FHWA

Evidence at Gages

USGS repeats flow and stage measurements at gages to maintain the rating curves.

Questions ?

Key Points:

- Select the level of analysis based on complexity, uncertainty, and structure importance.
- Reviewing bridge inspection channel profiles is a good first step to identify bed elevation change and, potentially, channel shifting.
- Historical aerial photography and USGS maps are useful in identifying channel migration trends.
- Other methods are described in HEC-20.

FHWA Bridge Scour Workshop

Contraction Scour

Bridge Scour POWER HOUR

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

Workshop Agenda

1. Introduction
2. Overview of bridge scour
3. Long Term Degradation
4. **Contraction Scour**
5. Pier Scour
6. Abutment Scour
7. Comprehensive example with bridge scour tools
8. Wrap-up and questions

Contraction Scour Overview

- Definition of contraction scour
- Types of contraction scour
- Critical velocity / critical velocity index
- Pressure scour (vertical contraction scour)
- Steps to compute contraction scour

What is Contraction Scour?

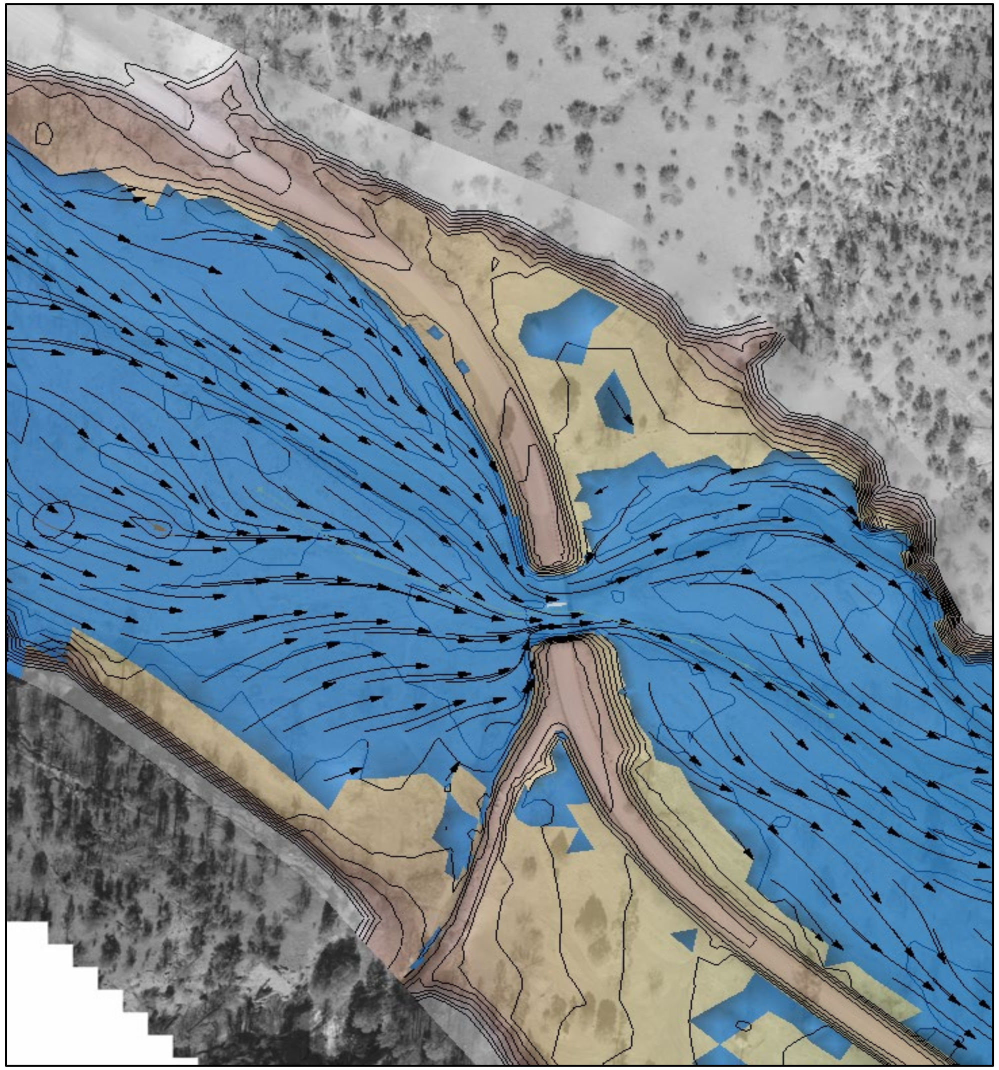


Image source: FHWA

- General lowering of the streambed across bridge opening
- Caused by a constriction in the channel or overbank areas that forces flow into the main channel
- The constriction increases the unit discharge, velocity, shear stress, and sediment transport capacity
- Scour may not be uniform in depth
- Scour may be cyclical (erosion and refilling)

Types of Contraction Scour

Two types of contraction scour

- **Clear water** – No transport of bed material sediment from upstream. The area of the contracted section increases until the velocity of the flow is equal to the critical velocity of the bed material

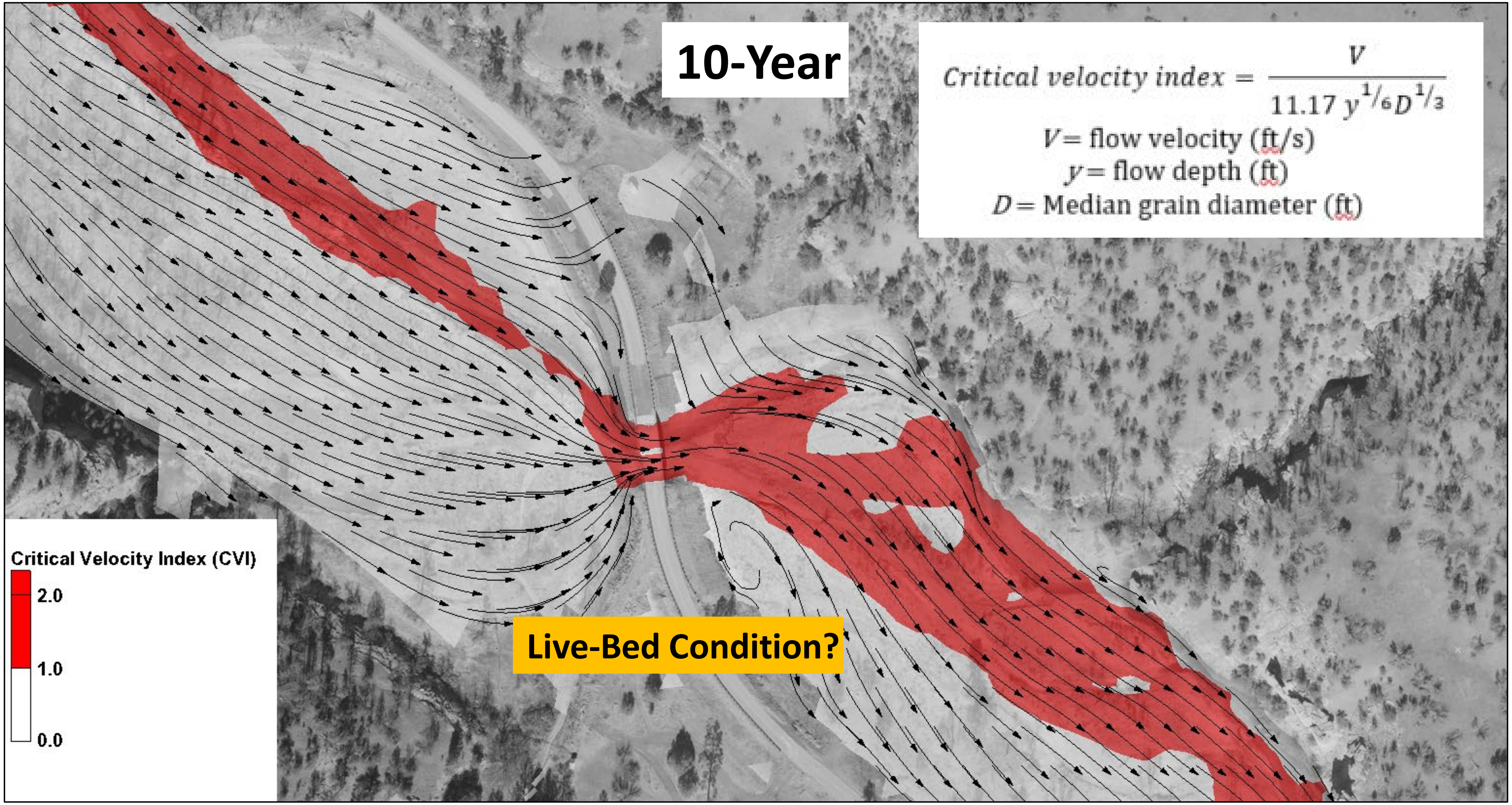
- **Live-bed** – Bed material from the riverbed upstream is transported into the crossing

Types of Contraction Scour

How do you know which one to use, clear-water or live-bed?

- Compare the average velocity (V_1) and the critical velocity (V_c) for bed material transport at the approach section
  - If $V_1 > V_c \rightarrow$ live-bed is most likely
  - If $V_1 < V_c \rightarrow$ clear-water is most likely
- Compute clear-water scour using the bed material gradation (D50) at the bridge
- For live-bed conditions, compute contraction scour for live-bed and clear-water scour and use the lesser of the two. In some cases, the bed material size at the bridge location may result in armoring that can limit scour depths.

Critical Velocity Index

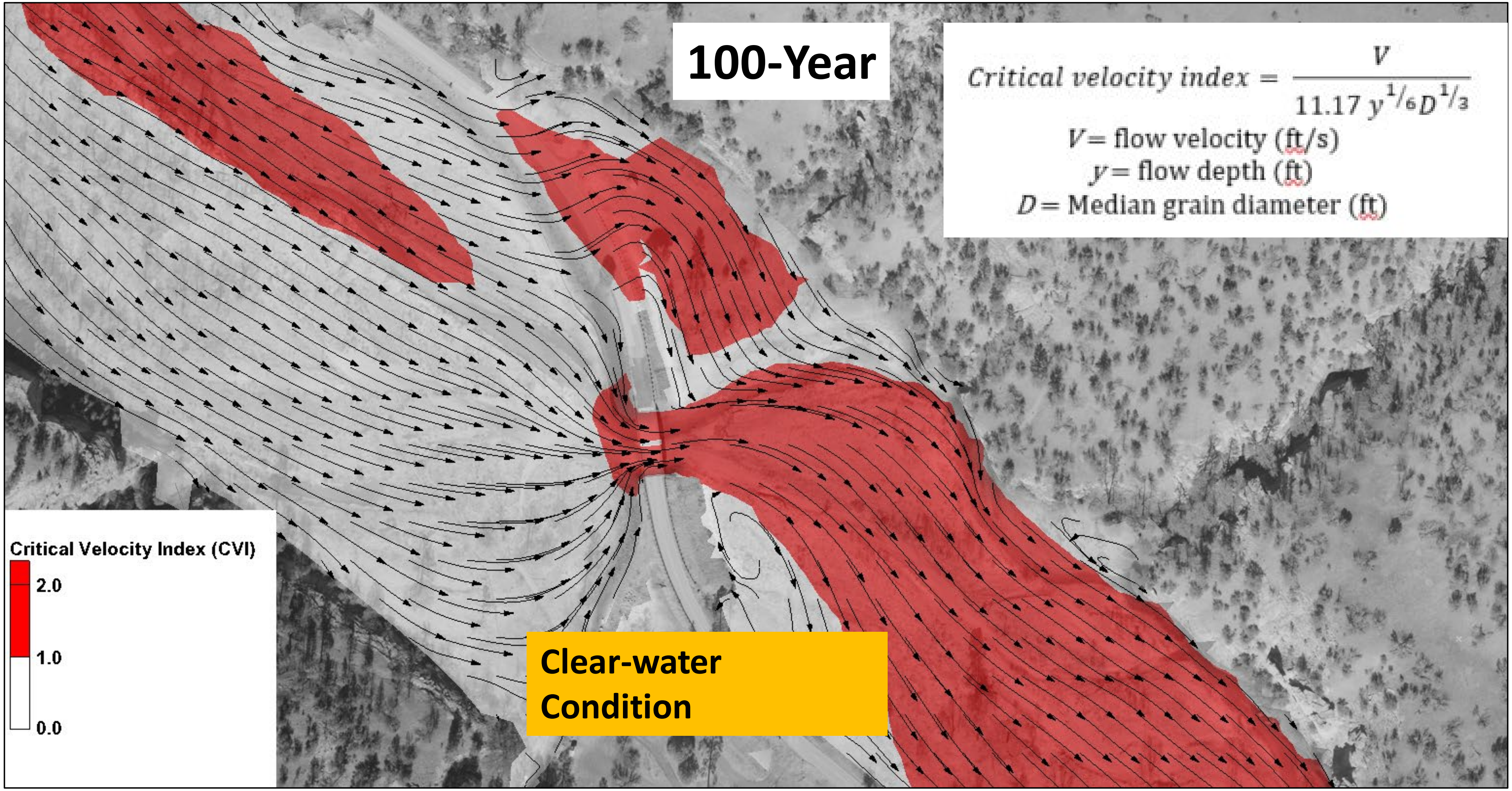


$$\text{Critical velocity index} = \frac{V}{11.17\, y^{1/6} D^{1/3}}$$

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

Image source: FHWA

Critical Velocity Index



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

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

Image source: FHWA

Computing Contraction Scour

How do we compute contraction scour?

- Locate the appropriate locations and widths for the approach section and contracted section
- **Approach Section location:**
  - Upstream of where overbank flow is diverted into the main channel
  - Width represents the flow that would likely transport sediment (toe to toe (of slopes) or between tops of banks)
  - Avoid locally higher velocity locations, as they result in underestimating contraction scour

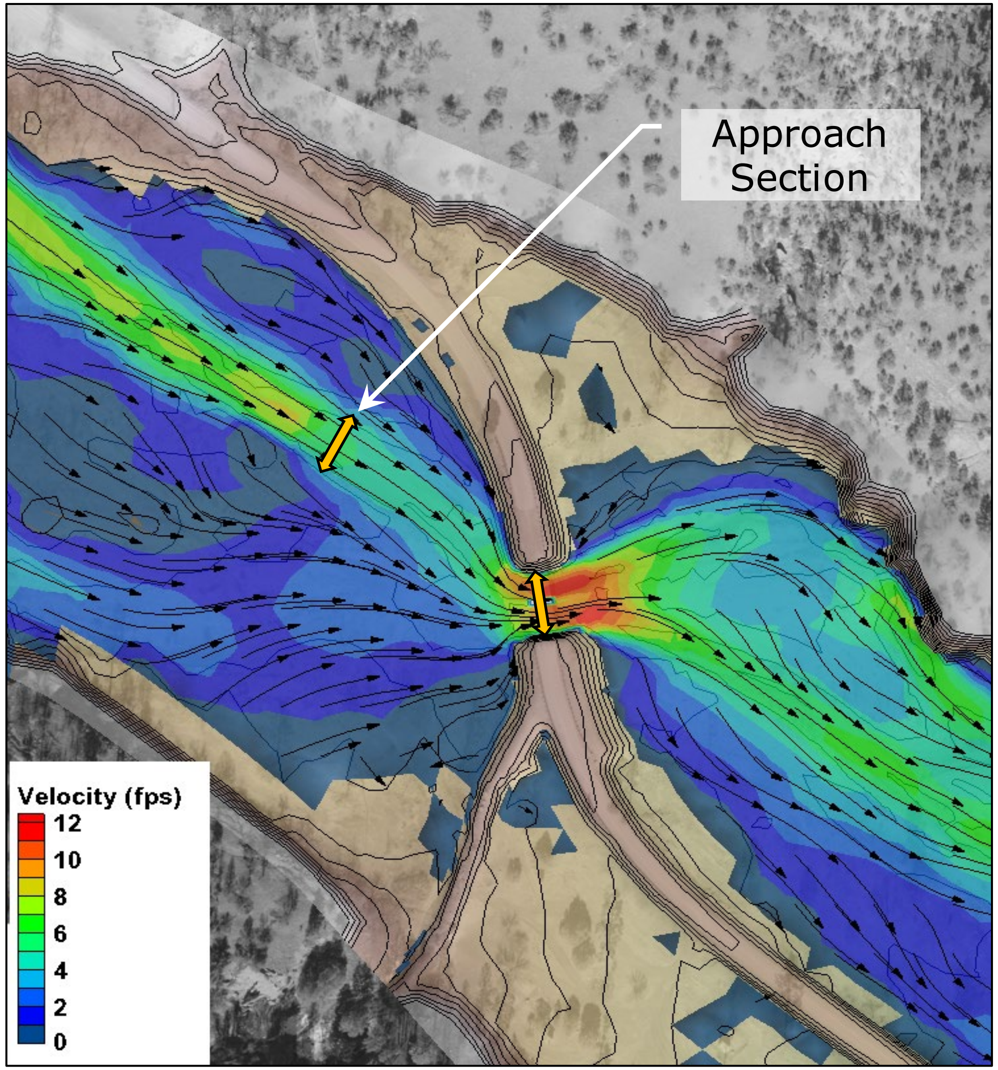


Image source: FHWA

Computing Contraction Scour

- **Contracted Section location:**
  - Where flow is most contracted through the bridge
  - Width should be consistent with the approach section reference (i.e. toe to toe (of bank slopes))
  - Width should exclude effective width of piers
  - Width needs to be adjusted for skew

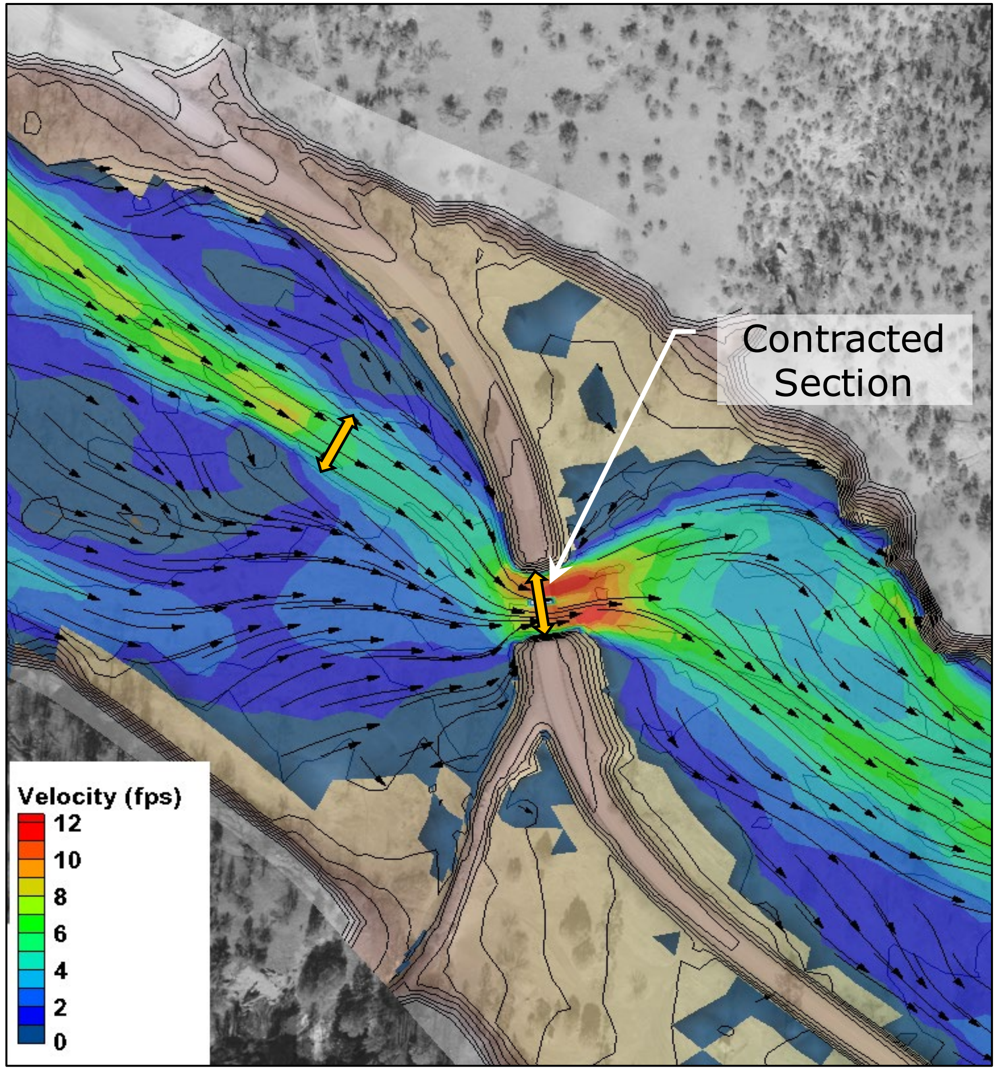


Image source: FHWA

Computing Contraction Scour

- **Main channel vs overbank contraction scour:**
  - Separate processes / separate computations
  - If the main channel can migrate to either abutment, the channel scour is used and the floodplain contraction scour is typically ignored.
  - Main channel contraction scour is likely live-bed scour, but clear-water scour may occur
  - Overbank contraction scour is predominantly clear-water scour when the overbanks are vegetated (i.e. secondary and relief structures)

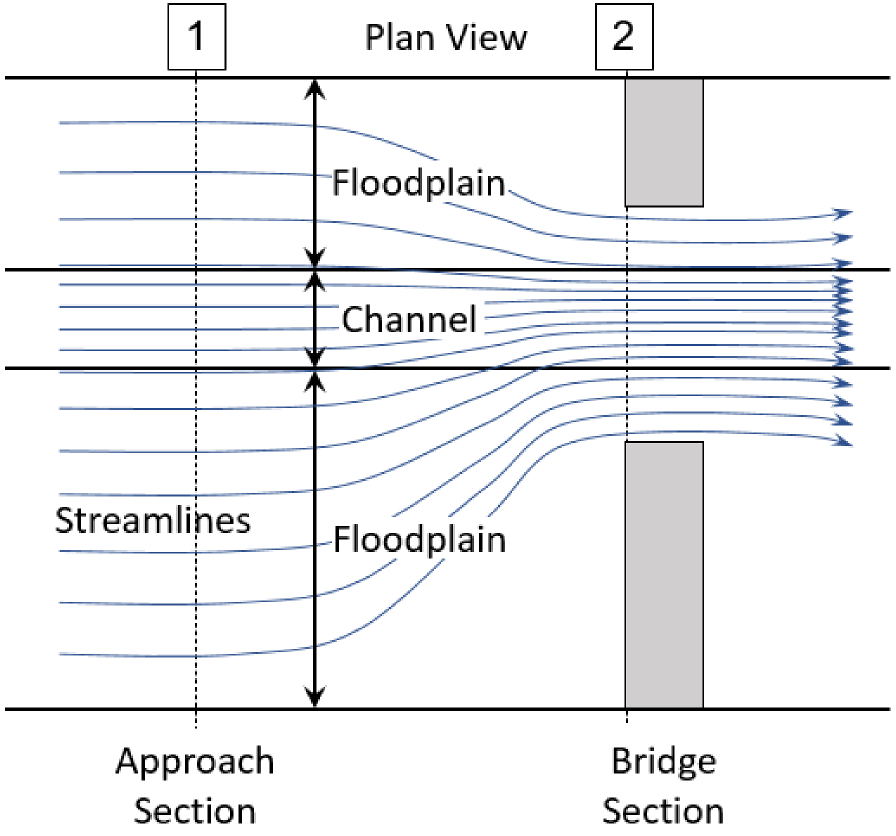


Image source: FHWA

Computing Contraction Scour

Computation steps:

- Perform hydraulic analysis for governing flow conditions (Qbankfull, Q50, Qovertopping, Q100, Q500)
- Extract average depth, average velocity, width and discharge from the **approach section**
- Obtain the bed gradation at the **approach section** (d50)
- Extract average depth, average velocity, width and discharge from the **contracted section**, adjusted for skew and pier width
- Obtain the bed gradation at the **contracted section** (d50)

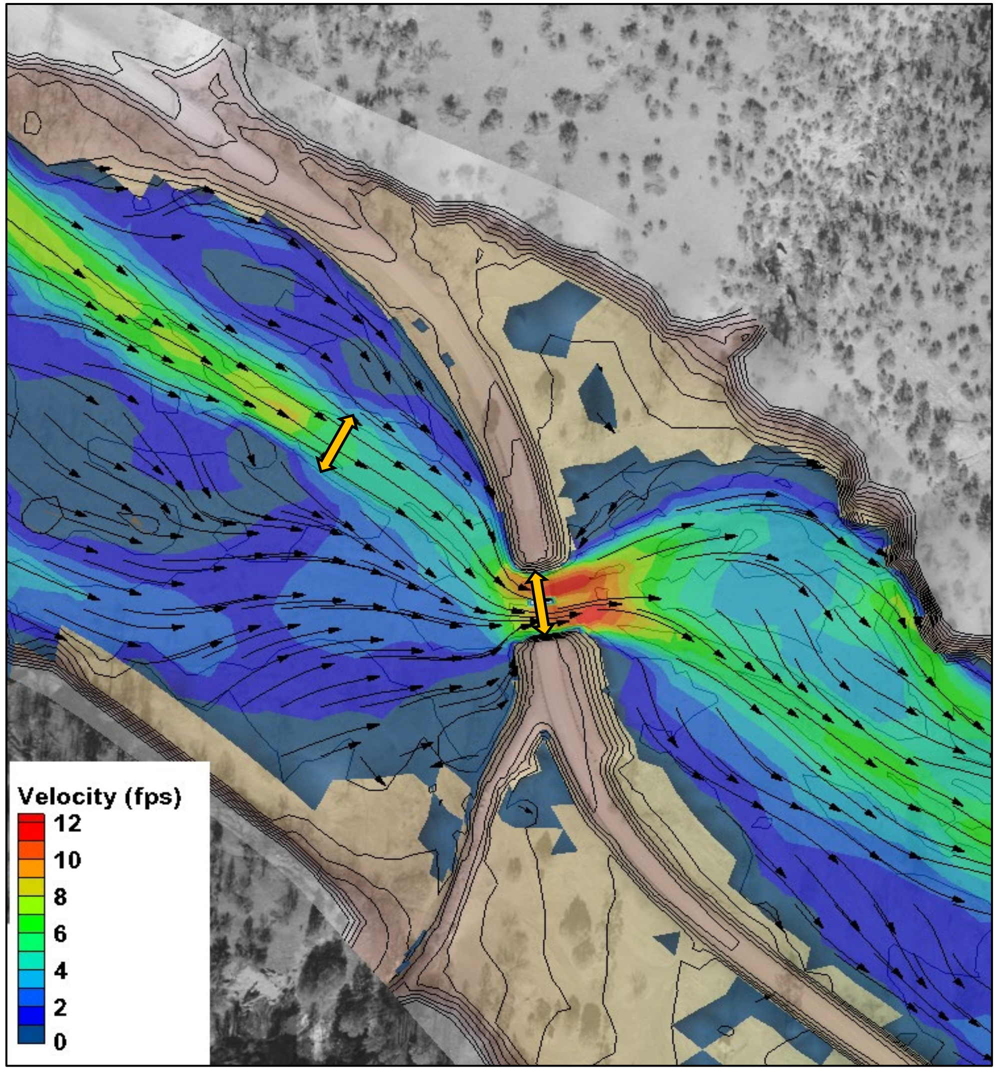


Image source: FHWA

Computing Contraction Scour

Computation steps:

- Compute critical velocity at the approach section and compare to average velocity to determine scour condition
- Compute contraction scour for the main channel, for each flow event, and repeat for overbank areas as necessary
- Compute pressure scour if pressure flow exists

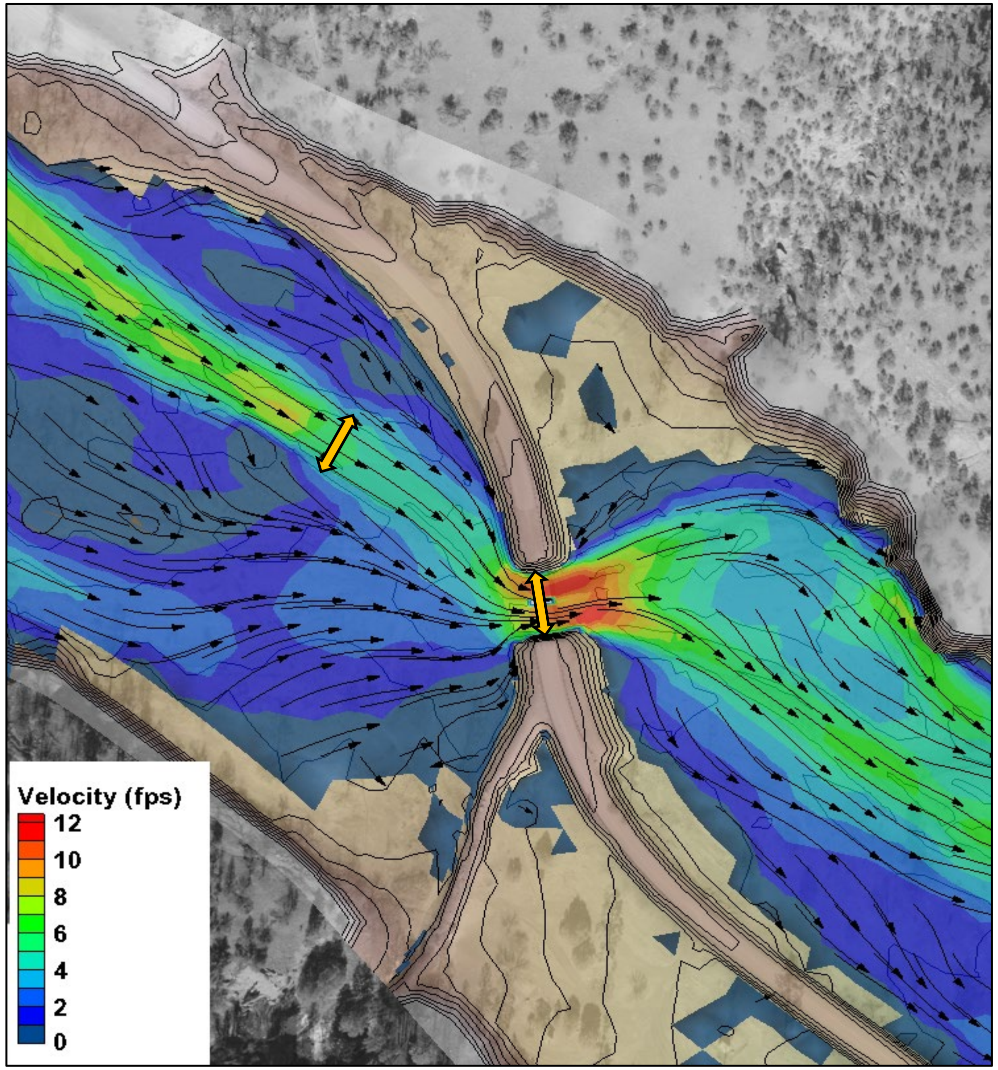


Image source: FHWA

Bridge Scour Equations

Critical Velocity $V_c = Kuy_1^{1/6}D^{1/3}$

Live Bed Condition

HEC-18 (2012) Eqs. 6.2 and 6.3

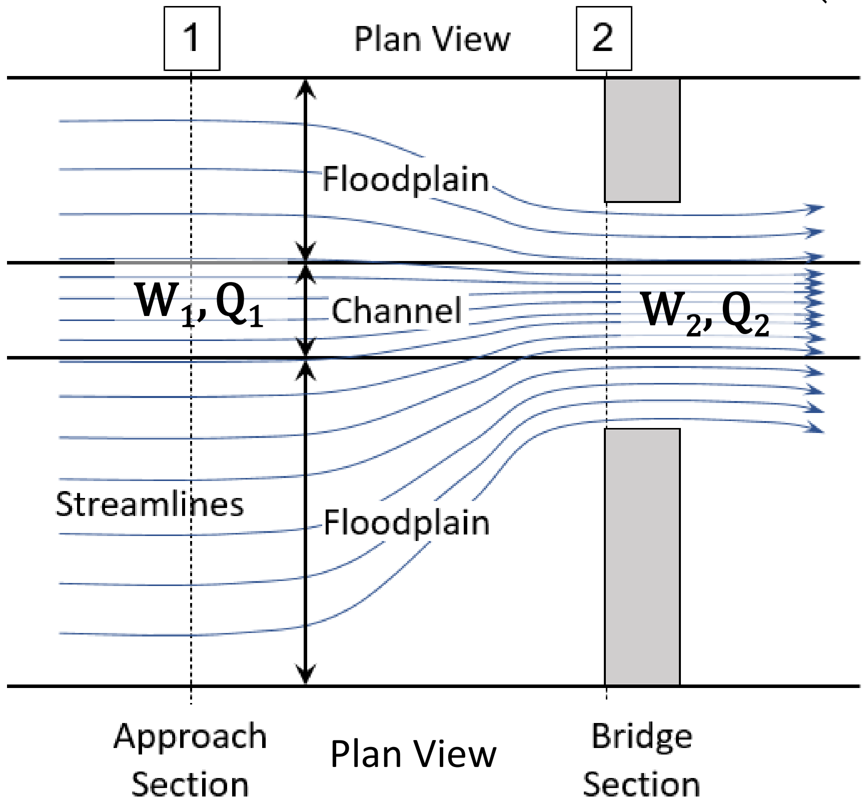
Clear Water Condition

HEC-18 (2012) Eqs. 6.4 and 6.5

Contraction Scour

$$y_s = y_2 - y_0 = y_1\left(\frac{Q_2}{Q_1}\right)^{6/7}\left(\frac{W_1}{W_2}\right)^{k_1} - y_0$$

$$y_s = \left(\frac{K_u Q_2^{\,2}}{Dm^{2/3} W_2^{\,2}}\right)^{3/7} - y_0$$



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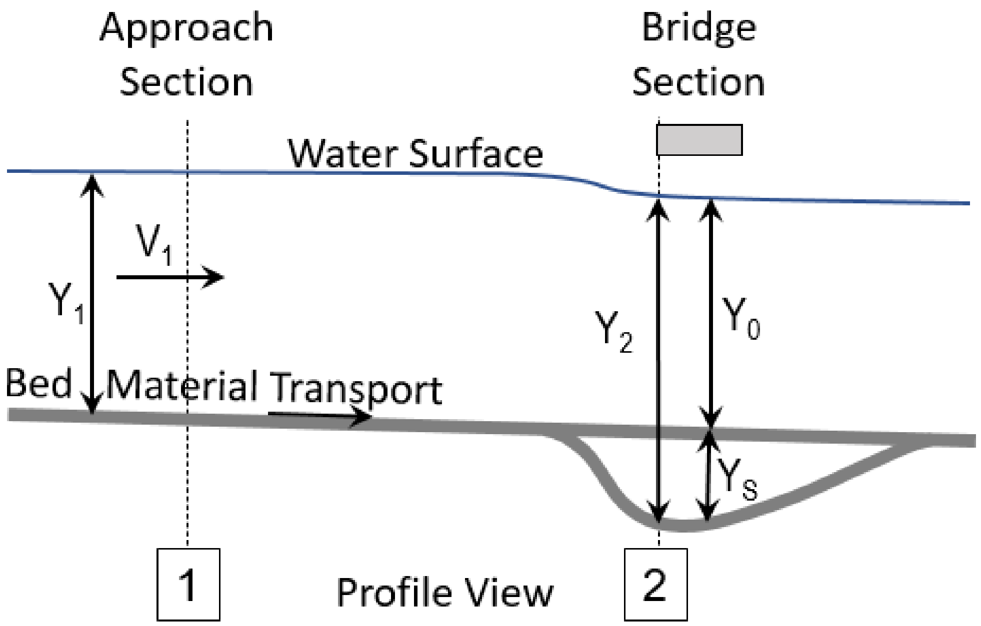


Image source: FHWA

Pressure Scour (Vertical Contraction Scour)

Computation steps:

1. Determine the flow through the bridge opening
2. Compute horizontal contraction scour, y_2
3. Assess low chord elevation and vertical bridge opening (h_b)
4. Assess the flow depth at the upstream bridge face (h_u)
5. Compute flow separation thickness (t)
6. Compute the pressure scour depth (y_s)

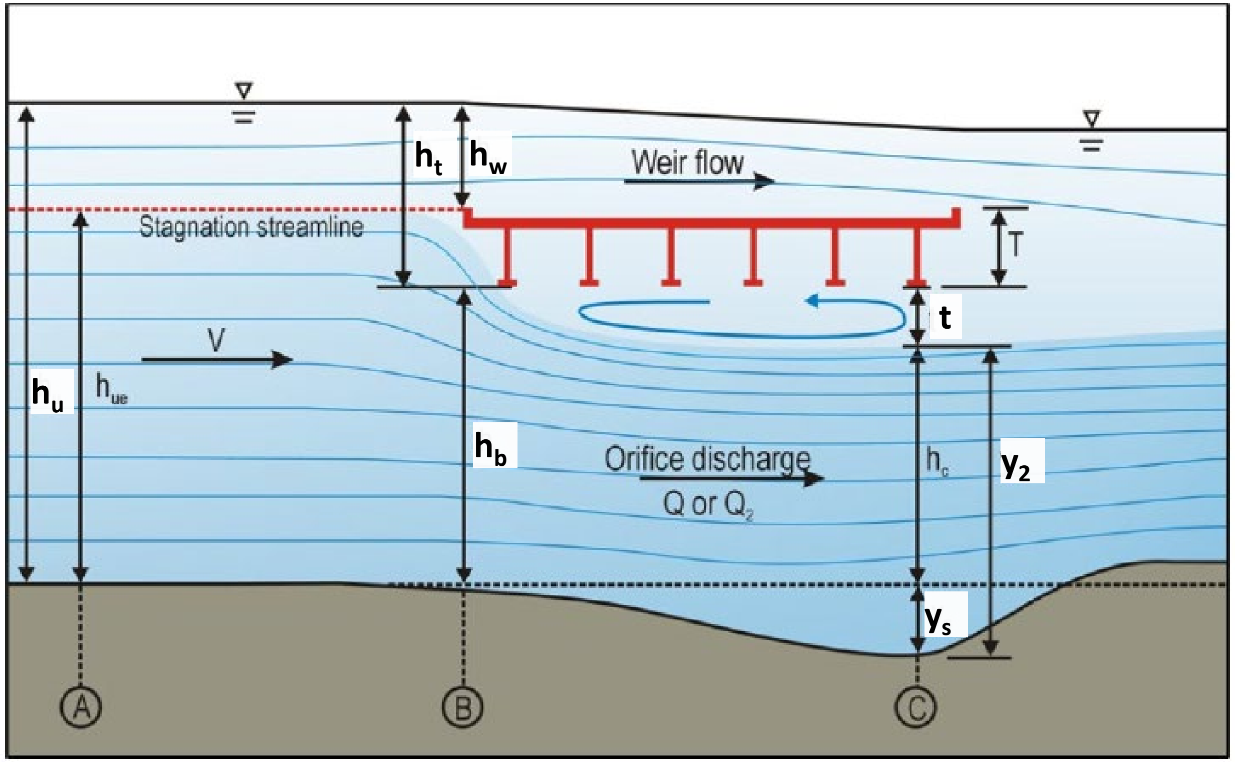


Image source: FHWA

$$\frac{t}{h_b} = 0.5\left(\frac{h_b \cdot h_t}{h_u^2}\right)^{0.2}\left(1 - \frac{h_w}{h_t}\right)^{-0.1}$$

(HEC-18 Eq 6.16)

$$y_s = y_2 + t - h_b$$

(HEC-18 Eq 6.14)

Cohesive vs. Non-cohesive Contraction Scour

The HEC-18 contraction scour in cohesive materials is used for cohesive channel bed or when a cohesive layer is exposed from live-bed or clear-water non-cohesive scour.

Computation steps:

- Determine τ_c, the critical shear stress for the cohesive bed or cohesive layer.
- Determine y_1, the upstream average flow depth.
- Determine V_2, the average velocity in the contracted area.
- Use HEC-18 Equation 6.6 to compute ultimate scour.
- Ultimate scour assumes sufficient time to develop. HEC-18 includes a method to compute long-term cohesive scour from a sequence of scouring events.

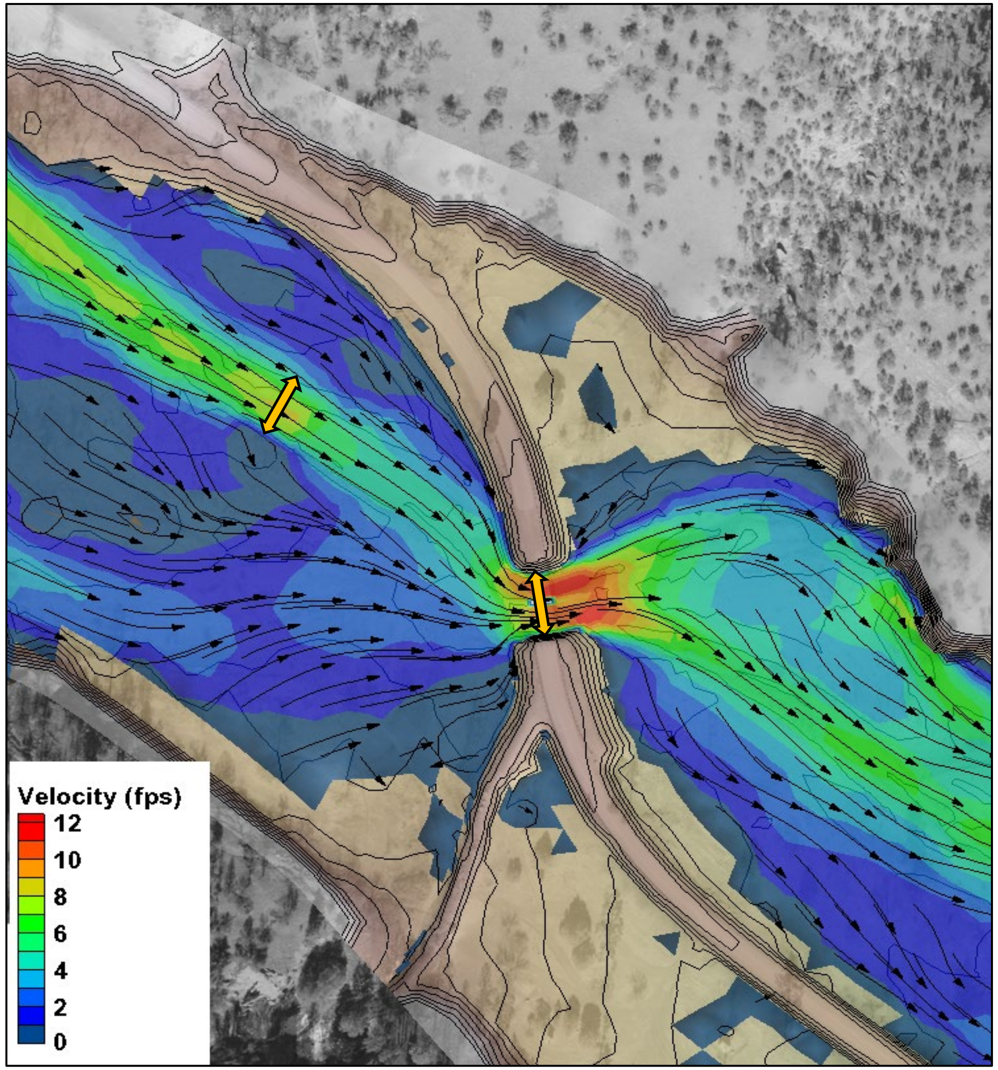


Image source: FHWA

Contraction Scour Example

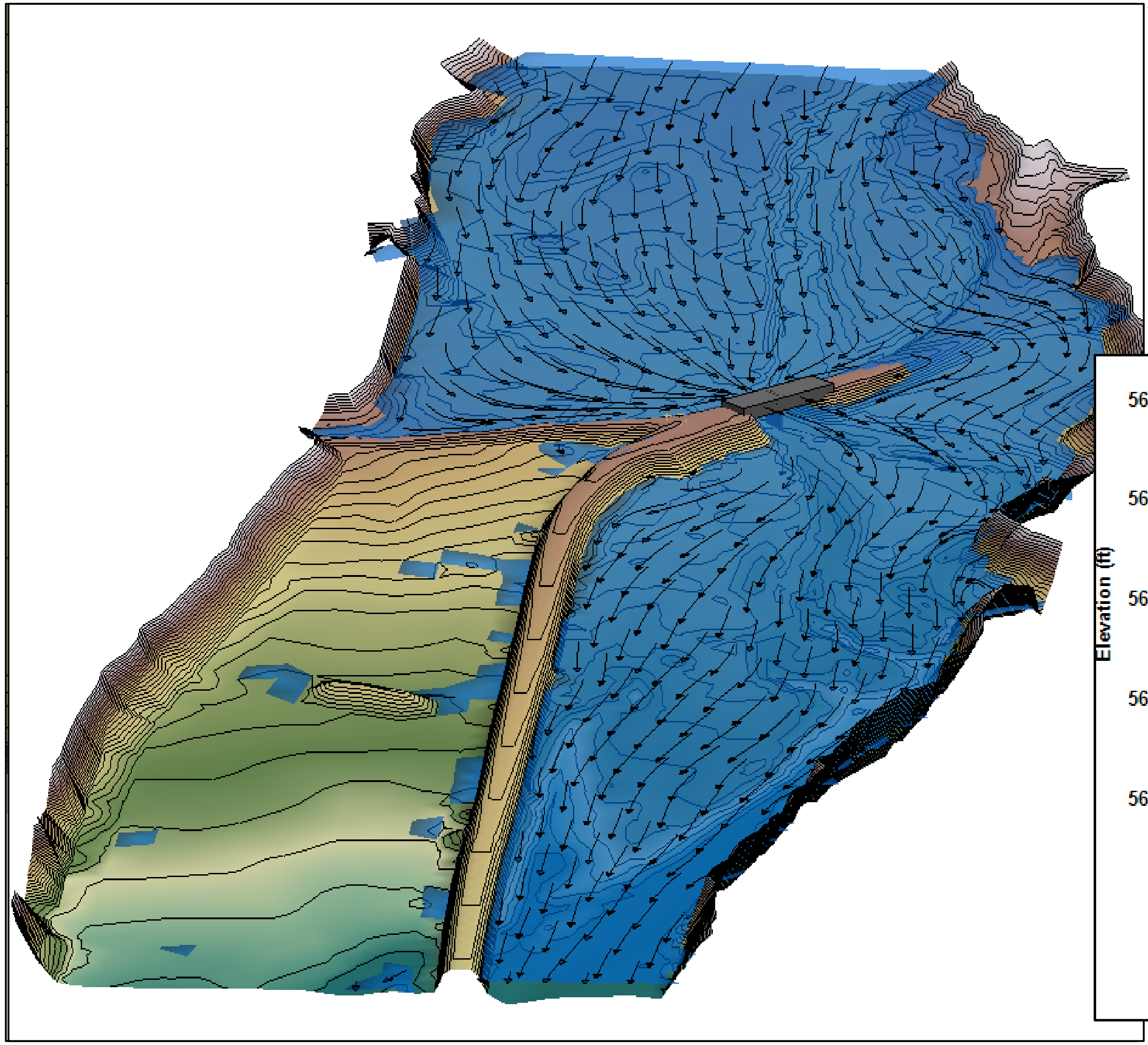
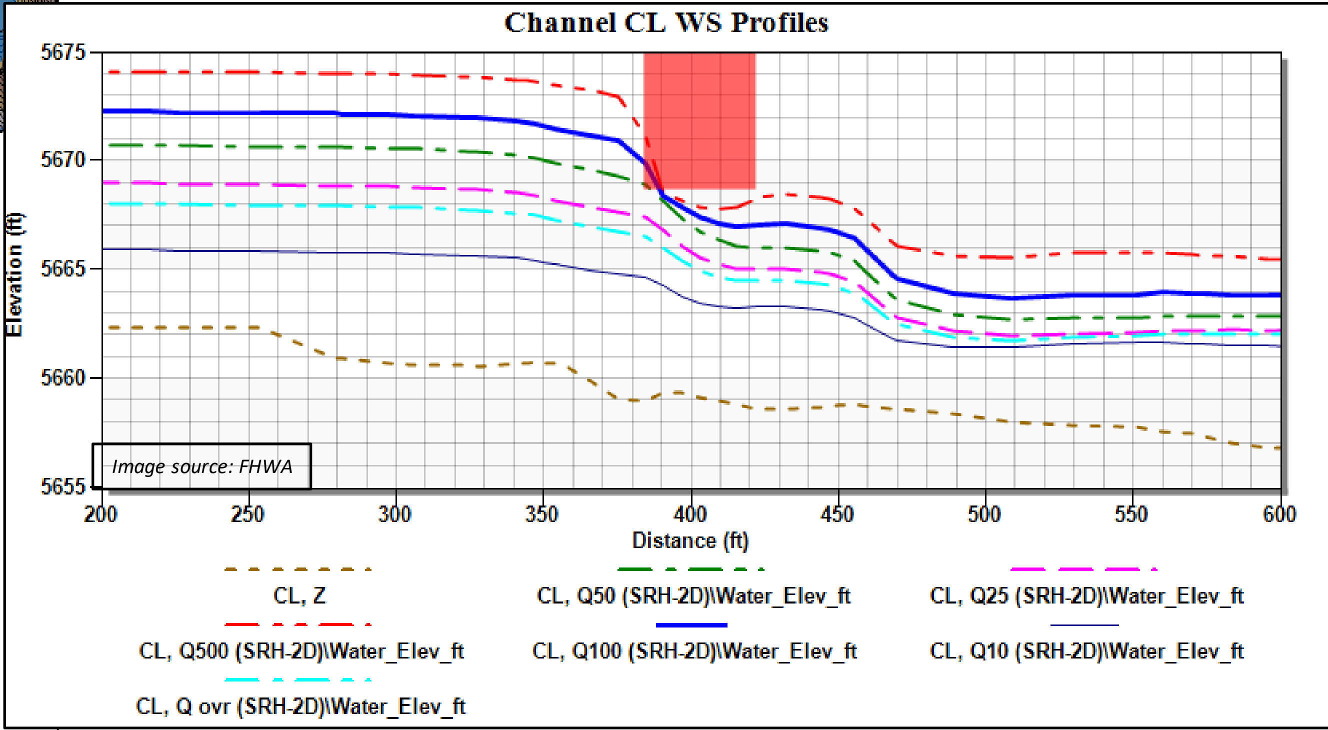


Image source: FHWA

Computation steps:

- Perform hydraulic analysis for a range of flow conditions (Q10, Q25, Q50, $Q_{overtopping}$, Q100, Q500)



Contraction Scour Example (Q100)

Computation steps:

- Extract EGL slope (0.011 ft/ft), average depth, y_1 (11.6 ft), average velocity, V_1 (4.3 fps), width, W_1 (50 ft) and discharge, Q_1 (2530 cfs) from the **approach section**
- Obtain the bed gradation at the **approach section** (D_{50}) (0.0303 ft ~ 9mm)
- Compute critical velocity at the approach section (5.5 fps) and compare to average velocity to determine scour condition (4.3 fps)
  - ➢ Clear water condition for Q100

View Values *(From SMS Bridge Scour Tool for Q100)*

APPROACH SECTION HYDRAULIC PARAMETERS:

Entire approach cross section:

Energy grade line slope at the approach section (ft/ft)	★ 0.0105266
Total flow in the approach section (cfs)	12215.8
Total flow area of the approach section (ft^2)	5194.32
Total wetted perimeter of the approach section (ft)	629.637

Main channel (approach):

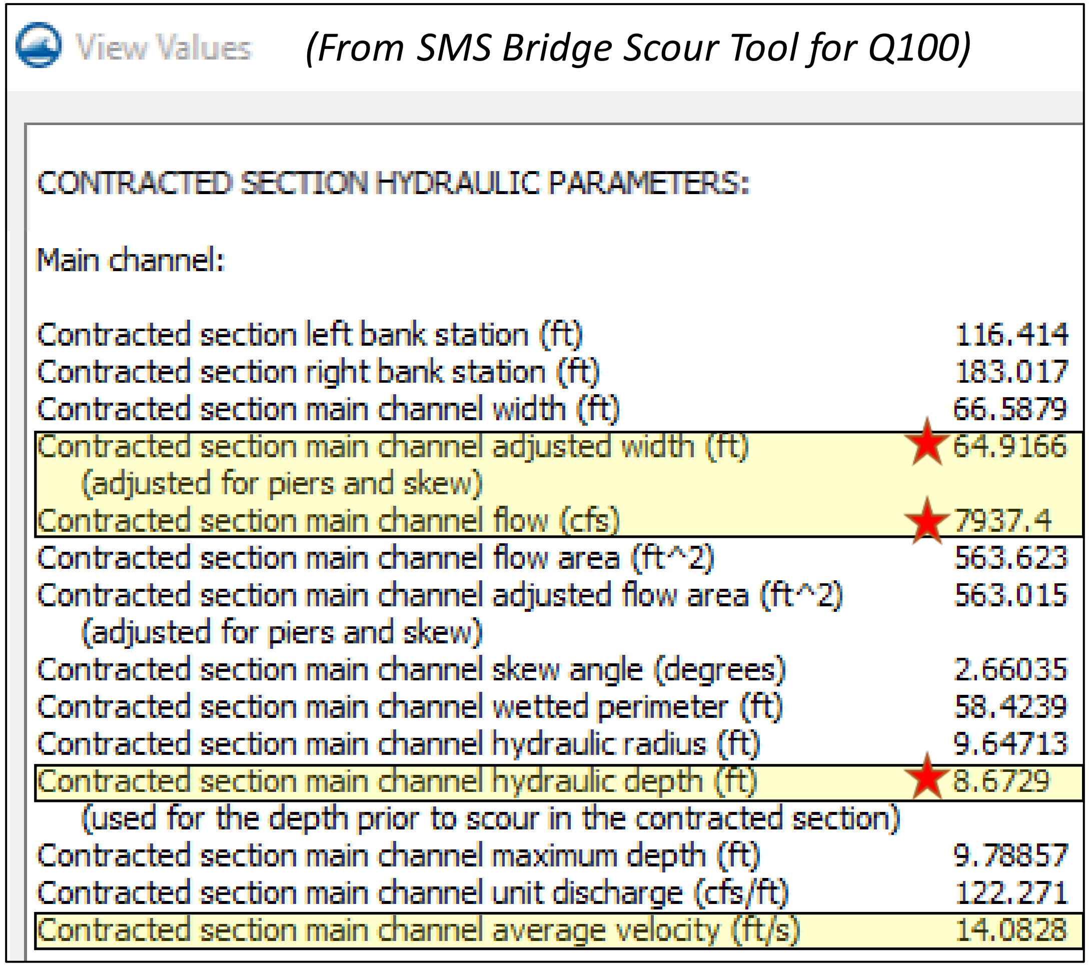
Approach section left bank station (ft)	135.946
Approach section right bank station (ft)	185.998
Approach section main channel width (ft)	★ 50.0519
Approach section main channel flow (cfs)	★ 2530.18
Approach section main channel flow area (ft^2)	582.377
Approach section main channel wetted perimeter (ft)	36.8993
Approach section main channel hydraulic radius (ft)	15.7829
Approach section main channel hydraulic depth (ft)	★ 11.6355
(used for average depth upstream of contraction)	
Approach section main channel maximum depth (ft)	12.3779
Approach section main channel unit discharge (cfs/ft)	50.5512
Approach section main channel average velocity (ft/s)	★ 4.34458
Approach section critical velocity (ft/s)	★ 5.51525

Image source: FHWA

Contraction Scour Example

Computation steps:

- Obtain the bed gradation at the **contracted section** (D_{50}) (0.0303 ft ~ 9 mm)
- Extract average depth, y_0 (8.7 ft), width, W_2 (64.9 ft), and discharge, Q_2 (7937 cfs), from the **contracted section**, adjusted for skew and pier width
- If pressure flow exists, the average depth upstream of the bridge deck is needed (13.7 ft) (for rapid drawdown, reference the WSEL prior to the drawdown)


View Values *(From SMS Bridge Scour Tool for Q100)*

CONTRACTED SECTION HYDRAULIC PARAMETERS:

Main channel:

Contracted section left bank station (ft)	116.414
Contracted section right bank station (ft)	183.017
Contracted section main channel width (ft)	66.5879
Contracted section main channel adjusted width (ft) (adjusted for piers and skew)	64.9166
Contracted section main channel flow (cfs)	7937.4
Contracted section main channel flow area (ft^2)	563.623
Contracted section main channel adjusted flow area (ft^2) (adjusted for piers and skew)	563.015
Contracted section main channel skew angle (degrees)	2.66035
Contracted section main channel wetted perimeter (ft)	58.4239
Contracted section main channel hydraulic radius (ft)	9.64713
Contracted section main channel hydraulic depth (ft) (used for the depth prior to scour in the contracted section)	8.6729
Contracted section main channel maximum depth (ft)	9.78857
Contracted section main channel unit discharge (cfs/ft)	122.271
Contracted section main channel average velocity (ft/s)	14.0828

Image source: FHWA

Contraction Scour Example

Computation steps:

- Compute contraction scour for the main channel, for each flow event, and repeat for overbank areas as necessary
- Compute pressure scour if pressure flow exists

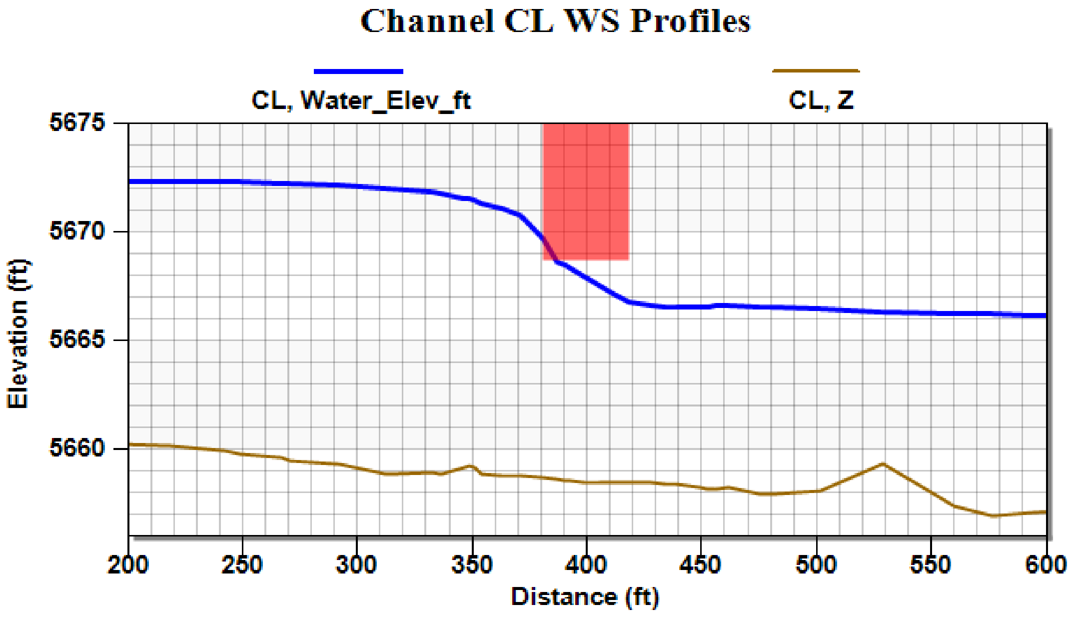


Image source: FHWA

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	11.64	ft	
D50	9.235440	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	4.34	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	5.24	ft/s	
Contraction Scour Condition	Clear Water		
Clear Water Input Parameters			
Discharge in Contracted Section	7937.40	cfs	
Bottom Width in Contracted Section	58.94	ft	Width should exclude pier wi...
Depth Prior to Scour in Contracted Section	9.55	ft	
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.010527	ft/ft	
Discharge in Contracted Section	7937.40	cfs	
Discharge Upstream that is Transporting Sediment	2530.18	cfs	
Width in Contracted Section	58.94	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	50.05	ft	
Depth Prior to Scour in Contracted Section	9.55	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	11.544300	mm	
Average Depth in Contracted Section after Scour	21.16	ft	
Scour Depth	11.61	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.99	ft/s	
Fall Velocity	1.40	ft/s	
Average Depth in Contracted Section after Scour	27.92	ft	
Scour Depth	18.37	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.7187	lb/ft^2	
Shear Required for Movement of D50 Particle	0.1212	lb/ft^2	
Recommendations			
Recommended Scour Depth	11.61		

Without pressure flow

Contraction Scour Example

Computation steps:

- Compute contraction scour for the main channel, for each flow event, and repeat for overbank areas as necessary
- Compute pressure scour if pressure flow exists

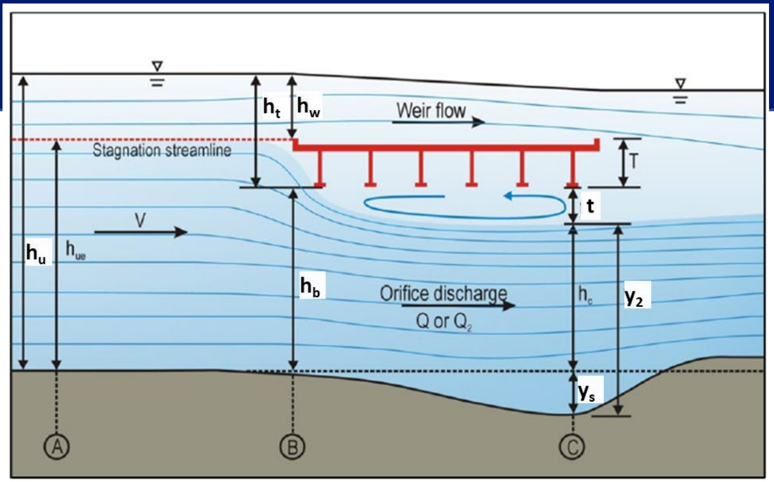
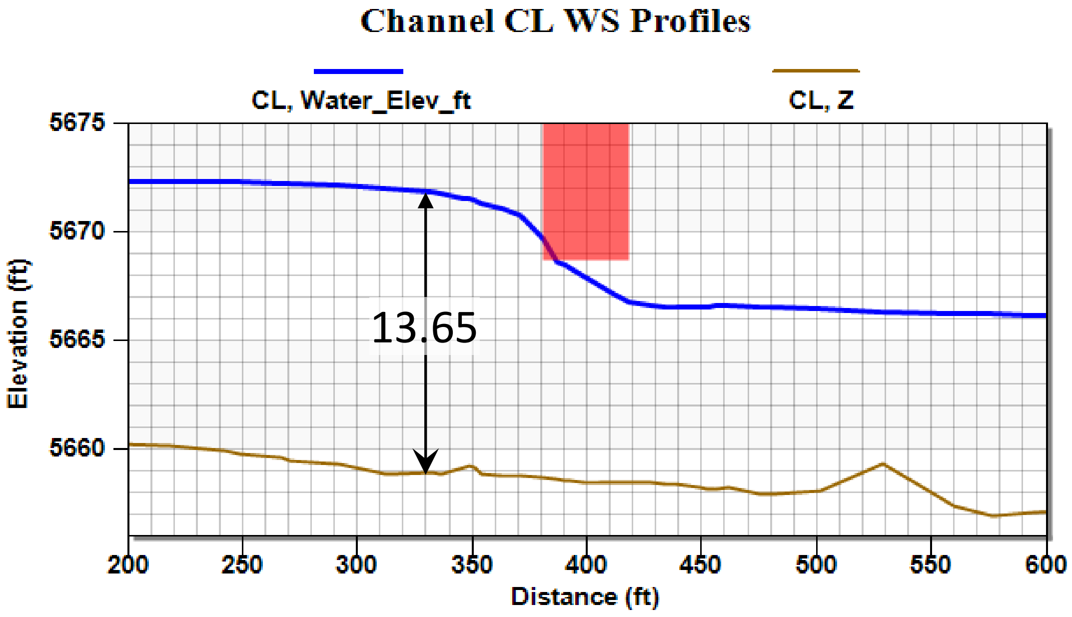


Image source: FHWA



Contraction Scour

Computation Method: Pressure Flow

Parameter	Value	Units	Notes
Input Parameters for Scour Condition			
Upstream Channel Flow Depth	11.64	ft	
Average Velocity Upstream	4.34	ft/s	
D50	9.235440	mm	0.2 mm is the lower limit for non…
Results of Scour Condition			
Critical velocity above which bed material of size D and s…	5.24	ft/s	
Contraction Scour Condition	Clear Water		
Input Parameters for Bridge Scour			
Width of the Contracted Section	58.94	ft	
Flow through bridge opening	7937.40	cfs	
Depth Prior To Scour At Upstream Bridge Face	13.65	ft	To be measured between WSE a…
Vertical Size of Bridge Opening Prior to Scour	10.30	ft	To be measured between low ch…
Deck Thickness	6.00	ft	
Results			
Diameter of Smallest Non-moving Particle	0.037875	ft	
Average Depth In Contracted Section	21.16	ft	
Flow Separation Thickness	3.68	ft	
Scour Depth	14.53		

With pressure flow

Image source: FHWA

Contraction Scour Example

Computation steps:

- Review contraction scour results for all events

Bridge Scour Summary Table

Parameter	Q10	Q25	Q50	Q100	Q500	Q ovr	Units
Contraction Scour	☐	☐	☐	☐	☑	☐	
Applied Contraction Scour Depth	4.08	7.26	9.48	11.61	**14.16**	6.11	ft
Contraction Scour Depth and Long Term Degradation (LTD)	4.08	7.26	9.48	11.61	**14.16**	6.11	ft
Clear Water Contraction Scour Depth	0.00	7.26	9.48	11.61	**14.16**	6.11	ft
Live Bed Contraction Scour Depth	4.08	0.00	13.87	**18.37**	17.50	0.00	ft
Applied Contraction Scour Elevation with LTD	5654.27	5651.09	5647.01	5643.82	**5640.10**	5652.24	ft

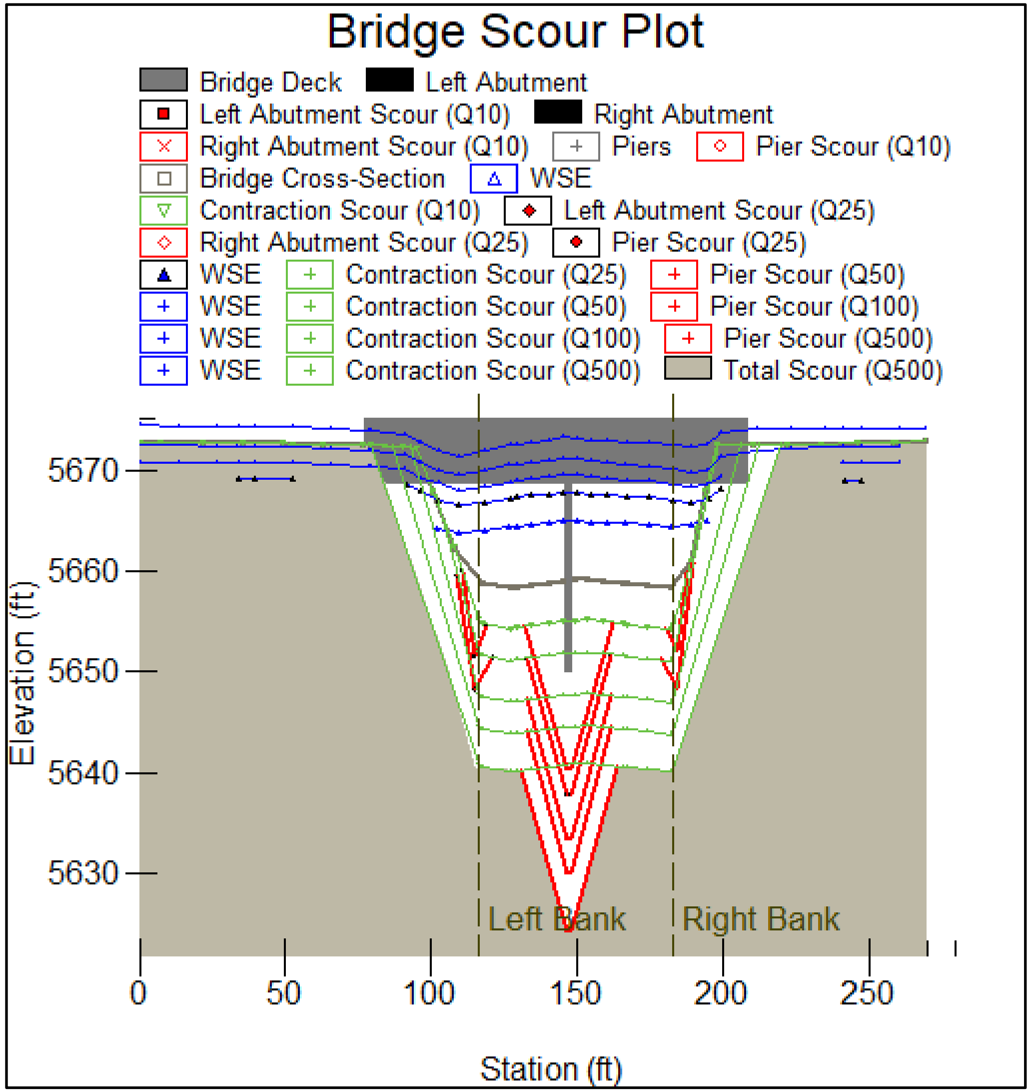


Image source: FHWA

Contraction Scour Review

Questions ?

Key Points:

- Carefully locate the approach and contraction sections
- Assign bank stations/channel width based on sediment transport
- Use consistent approach in assigning bank stations at both sections
- Extract average hydraulic parameters for contraction scour
- Review live-bed vs. clear-water scour condition
- Evaluate pressure flow conditions

FHWA
Bridge Scour Workshop

1. Introductions / Opening Comments
2. Overview of bridge scour
3. Long Term Degradation
4. Contraction Scour
5. **Pier Scour**
6. **Abutment Scour**
7. **Comprehensive bridge scour example**
8. **Wrap-up and questions**

Bridge Scour POWER HOUR

Day 2

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

Schedule

Day 2

10:00 – 11:00	Pier Scour
11:00 – 12:00	Abutment Scour
12:00 - 1:00	Lunch Break
1:00 – 2:30	Bridge scour comprehensive example
2:30 – 3:00	Wrap-Up and Questions

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- *The contents of this presentation do not have the force and effect of law and are not meant to bind the public in any way. This presentation is intended only to provide information to the public regarding existing requirements under the law or agency policies.*
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FHWA Bridge Scour Workshop

Pier Scour

Bridge Scour POWER HOUR

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

Workshop Agenda

1. Introductions and Opening Comments
2. Bridge Scour Overview
3. Long Term Degradation and Stream Stability
4. Contraction Scour
5. **Pier Scour**
6. Abutment Scour
7. Comprehensive example with bridge scour tools
8. Wrap-Up and Questions

Pier Scour – Overview

- Pier scour processes
- Factors that influence pier scour potential
- Calculate pier scour

Pier Scour Equations for Range of Conditions

- Detailed information on can be found in HEC-18.
- HEC-18 includes pier scour equations for:
  - Sand bed channels
  - Coarse bed channels
  - Cohesive and erodible rock materials
  - Complex pier geometry
  - Debris accumulations
- Surface sample and geotechnical exploration at/around pier location
- Equations applied sequentially for layers

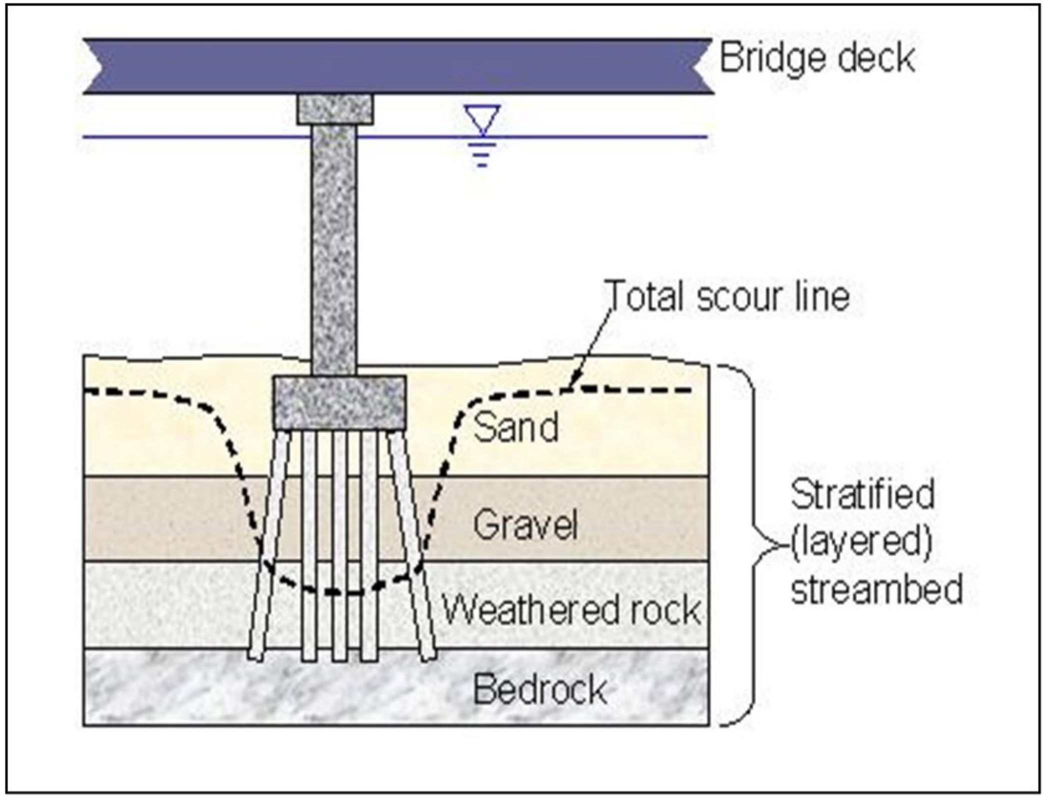
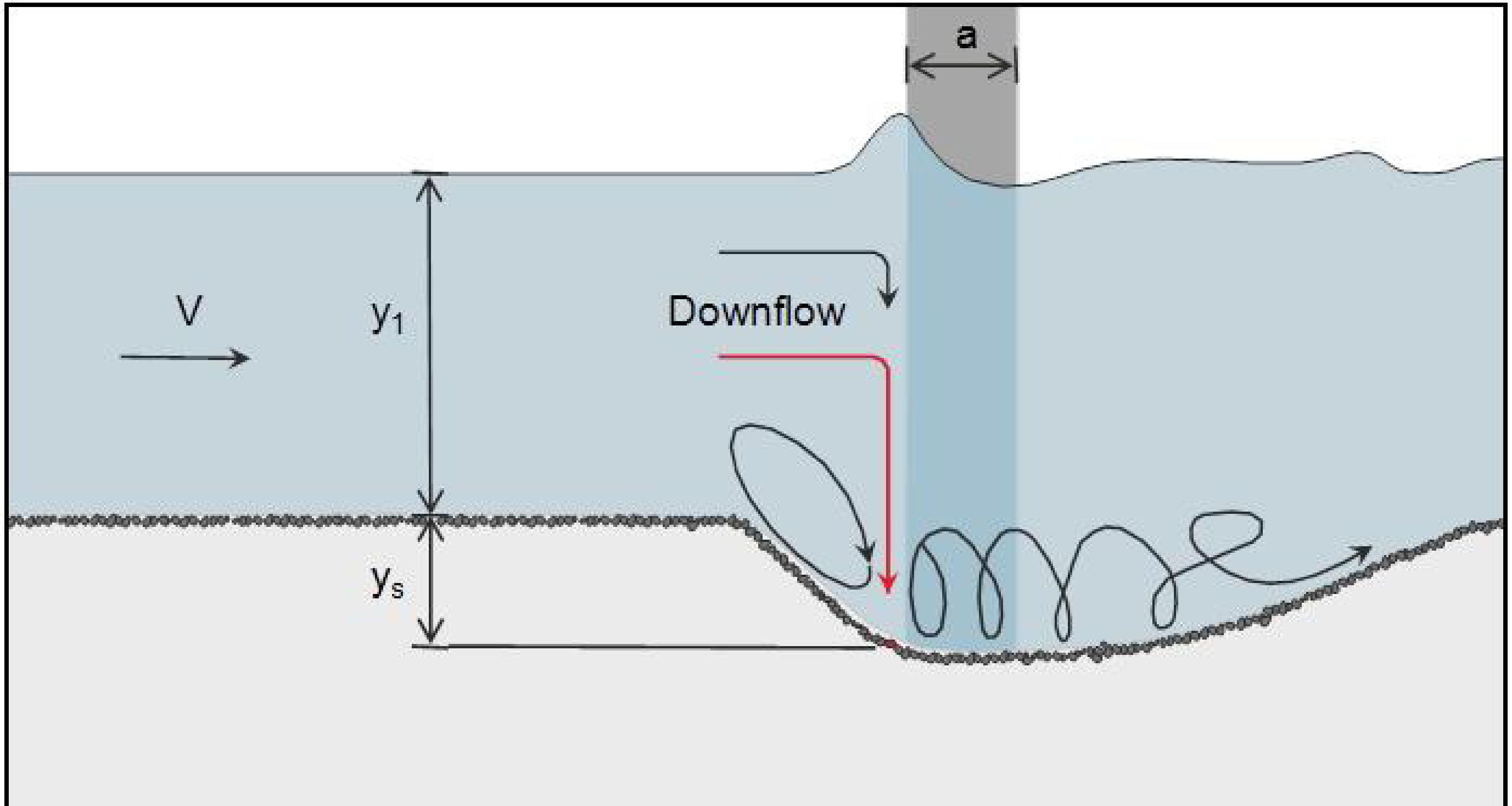


Image source: FHWA

Definition Sketch

1. Pier width, a
2. Velocity, V
3. Flow Depth, y_1
4. Scour depth, y_s

Velocity and Depth are for the flow approaching the pier. The location is close to the pier but outside the influence of the pier.



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The maximum velocity location, often identified as the location with the highest unit discharge, q, is selected to account for potential channel shifting. (q = V*y)

Example Pier Scour

- Large piers
- Cobble and boulder bed over (erodible) glacial till
- Deep scour

Image source: FHWA

Pier Foundations exposed from channel migration

- Formerly a floodplain pier
- Channel shifting
- Pier scour geometry is the footing and exposed piling
- Note debris accumulations

Image source: FHWA

Maximum Expected Scour – Single Cylindrical Pier

- $y_s/a < 2.4$ for Froude No. $<= 0.8$
- $y_s/a < 3.0$ for Froude No. > 0.8

$$Fr = \frac{V}{\sqrt{gy}}$$

HEC-18 Pier Scour Equation

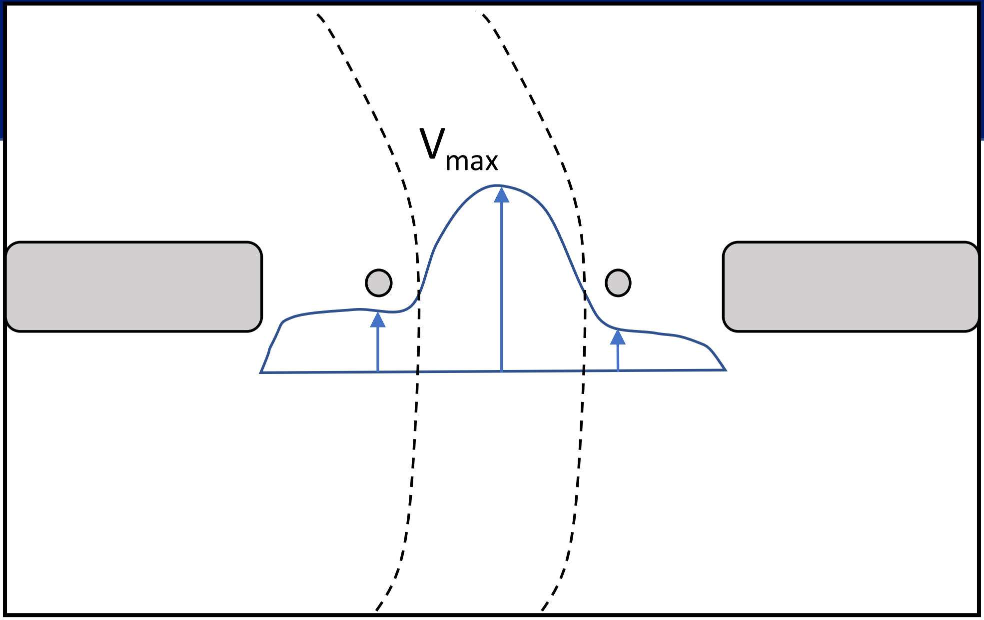
$$\frac{y_s}{a} = 2.0 K_1 K_2 K_3 \left(\frac{y_1}{a}\right)^{0.35} Fr^{0.43}$$

(Equation with variables grouped)

$$y_s = \frac{2.0}{g^{0.215}} K_1 K_2 K_3 a^{0.65} V^{0.43} y^{0.135}$$

K_1, K_2, and K_3 are correction factors

Use V_{max} for piers that channel can shift to.



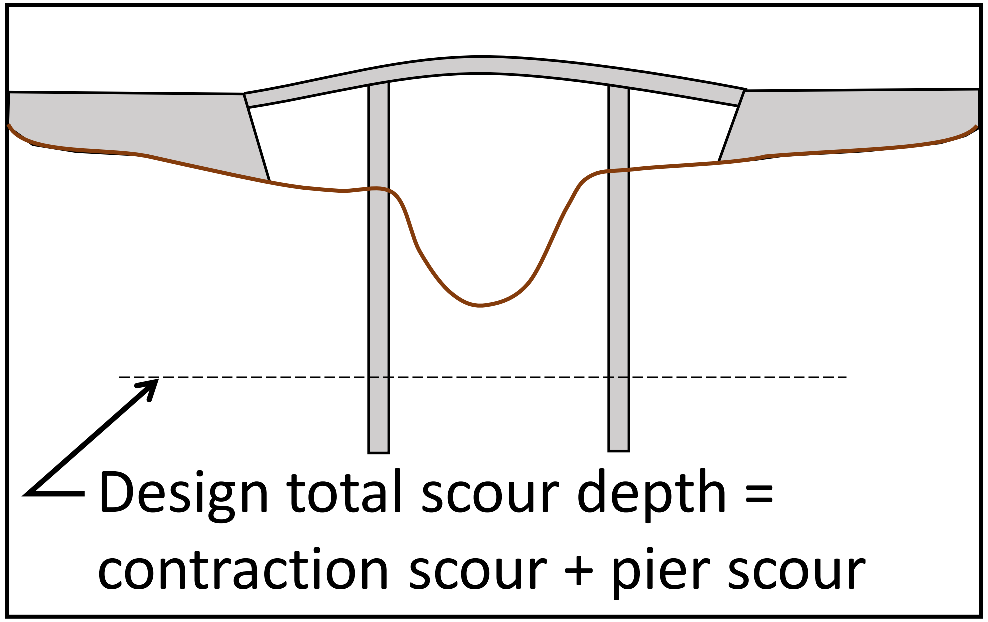


Image source: FHWA

K_1 Pier Shape Factor

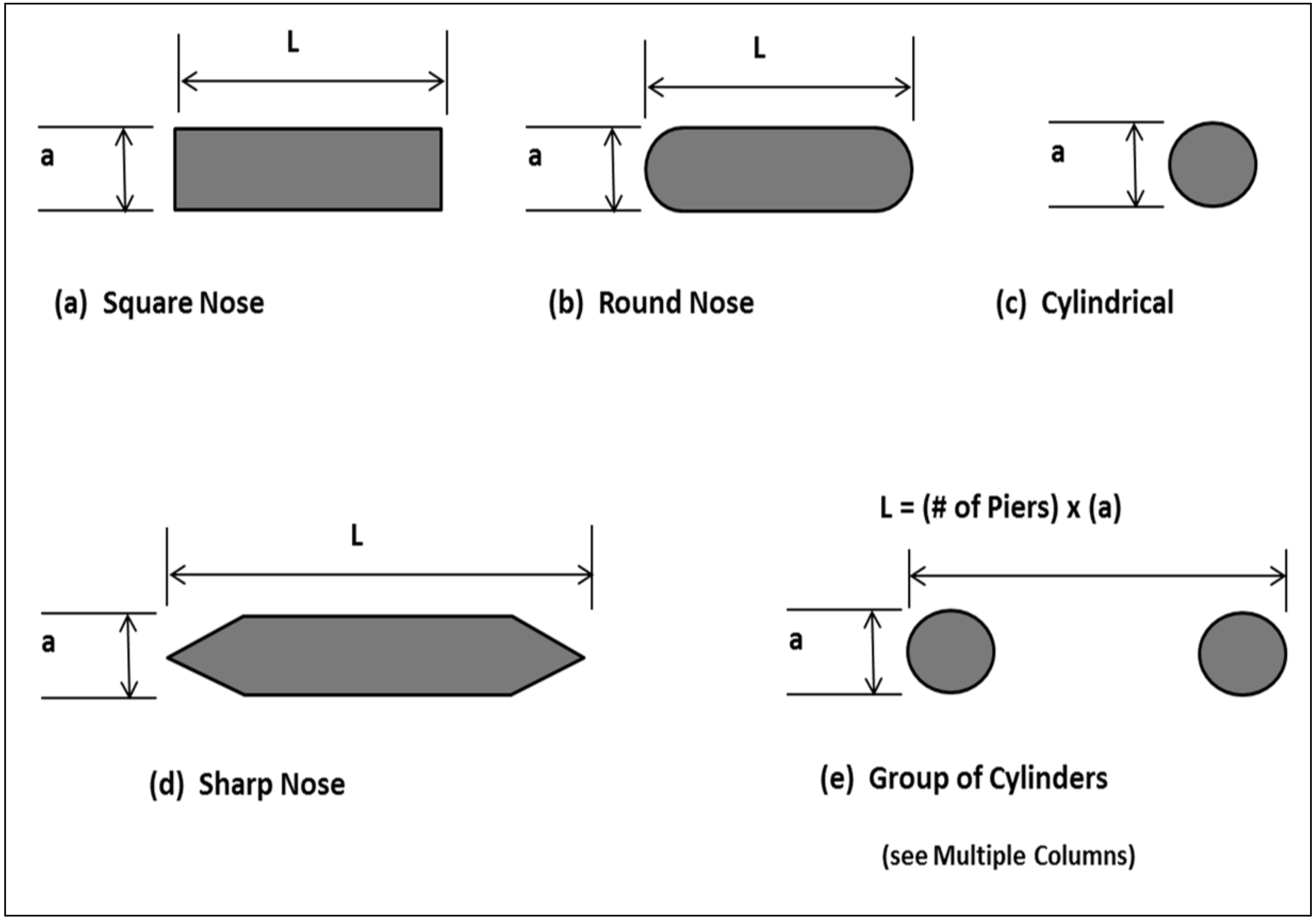


Image source: FHWA

Table 7.1. Correction Factor, K_1, for Pier Nose Shape.

Shape of Pier Nose	K_1
(a) Square nose	1.1
(b) Round nose	1.0
(c) Circular cylinder	1.0
(d) Group of cylinders	1.0
(e) Sharp nose	0.9

Table Source: HEC-18

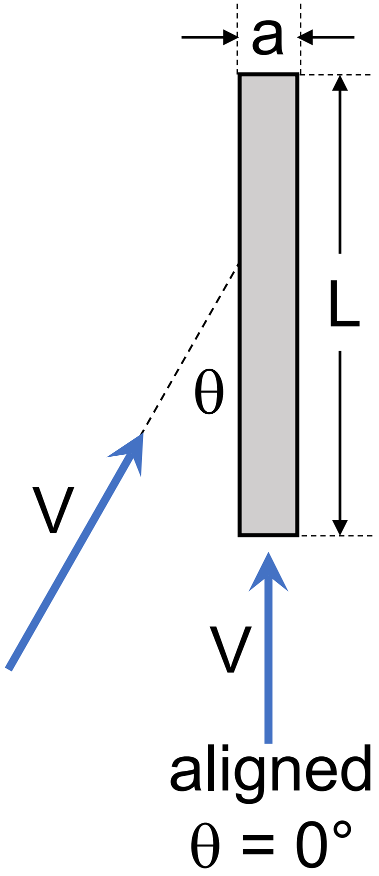
A single cylindrical pile maintains the same shape and total obstruction for any angle of attack and channel alignment changes.

K_2 Angle of Attack Factor

Table 7.2. Correction Factor, K_2, for Angle of Attack, θ, of the Flow.			
Angle	L/a=4	L/a=8	L/a=12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.75	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0

Angle = skew angle of flow
L = length of pier (Also limit L/a to a maximum of 12)

Table Source: HEC-18



$$K_2 = \left(\cos\theta + \frac{L}{a}\sin\theta\right)^{0.65}$$

K_3 Bed Condition Factor

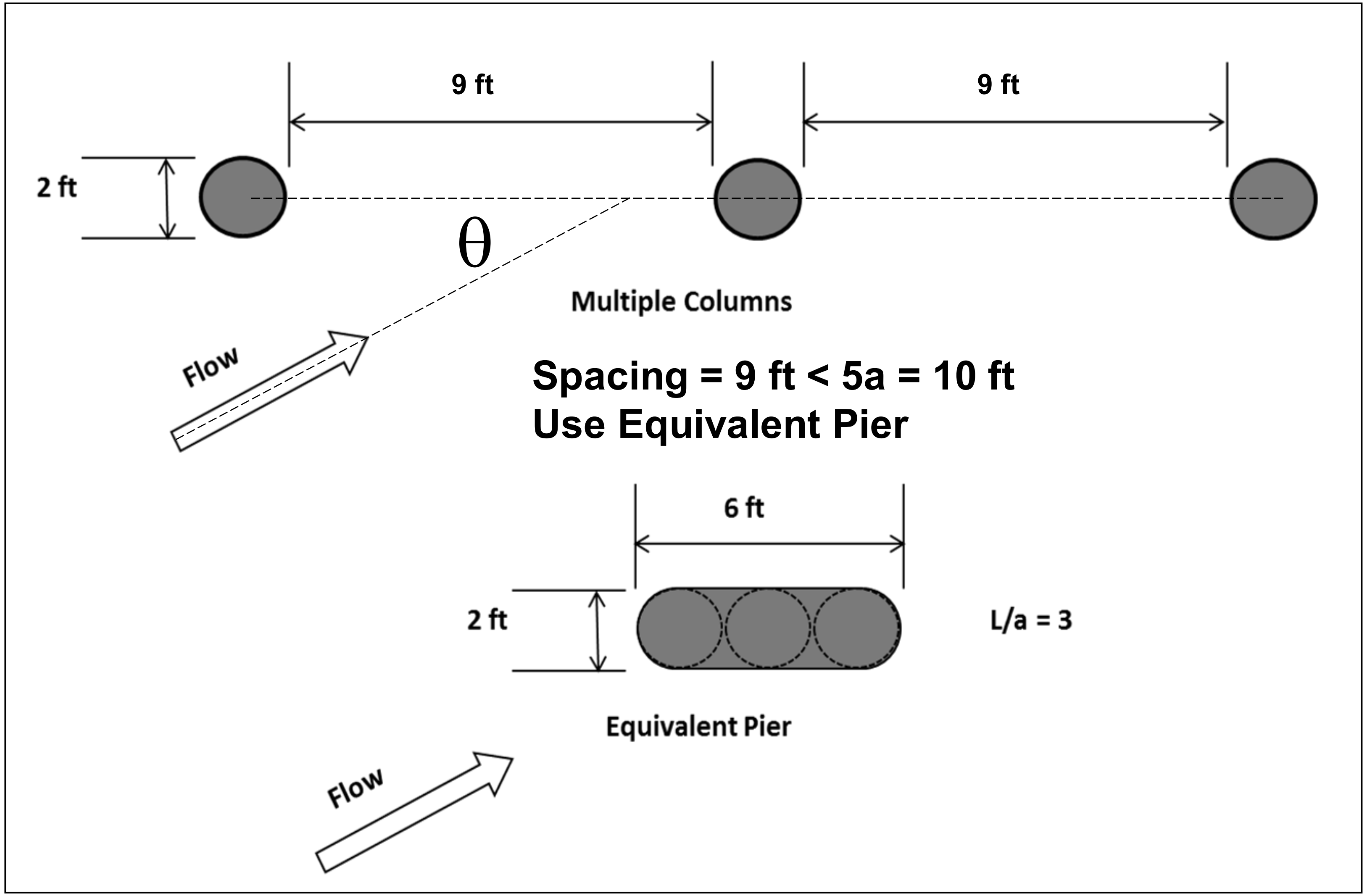
Bed Condition	**Dune Height (ft)**	**K_3**
Clear-Water Scour	N/A	1.1
Plane Bed and Antidune Flow	N/A	1.1
Small Dunes	$10 > H \geq 2$	1.1
Medium Dunes	$30 > H \geq 10$	1.2 to 1.1
Large Dunes	$H \geq 30$	1.3

Table Source: Table 7.3 HEC-18

K_3 almost always equals 1.1

Multiple Columns Skewed to the Flow

- Use the HEC-18 equation with $K_1 = 1.0$
- Spacing < 5a, use equivalent pier
- Spacing > 5a, use single column and $K_2 = 1.2$
- Consider debris



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Additional Information in HEC-18

- Pier Scour in Coarse Bed Materials (Section 7.11)
- Pier Scour in Cohesive Materials (Section 7.12)
- Pier Scour in Erodible Rock (Section 7.13)
- Pier Scour with Debris (Section 7.7)
- Complex Pier Geometry (Section 7.5)

Pier Scour with Debris


Image source: FHWA

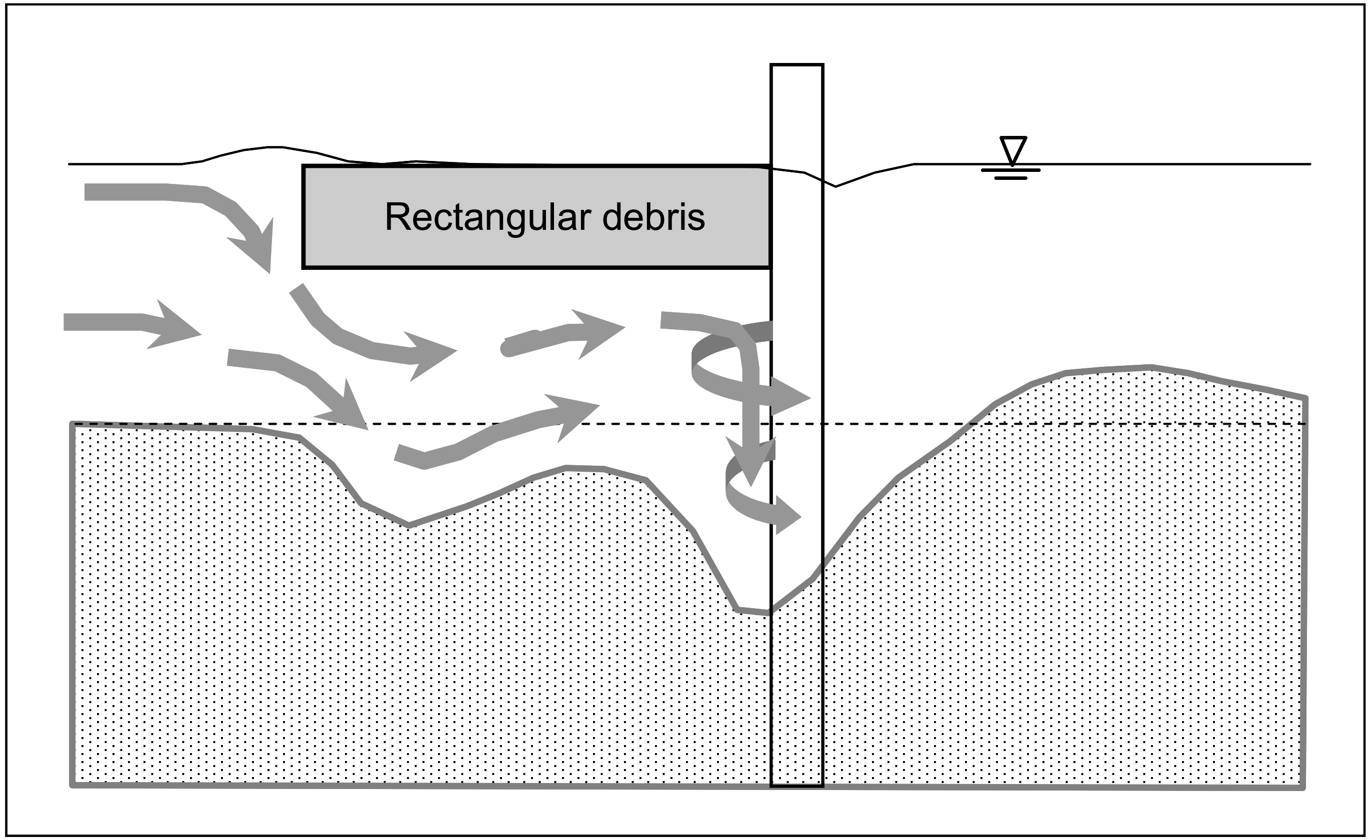


Image source: FHWA

Worst case pier scour with debris occurs when flow plunging under the debris hits the pier and the two scour holes overlap.

Complex Pier Scour

- Pier Stem
- Pile Cap
- Pile Group

(any can add to scour)

Exposure can come from long-term degradation, lateral migration, contraction scour, or scour from a higher element.

Calculations progress in sequence from higher to lower elements.

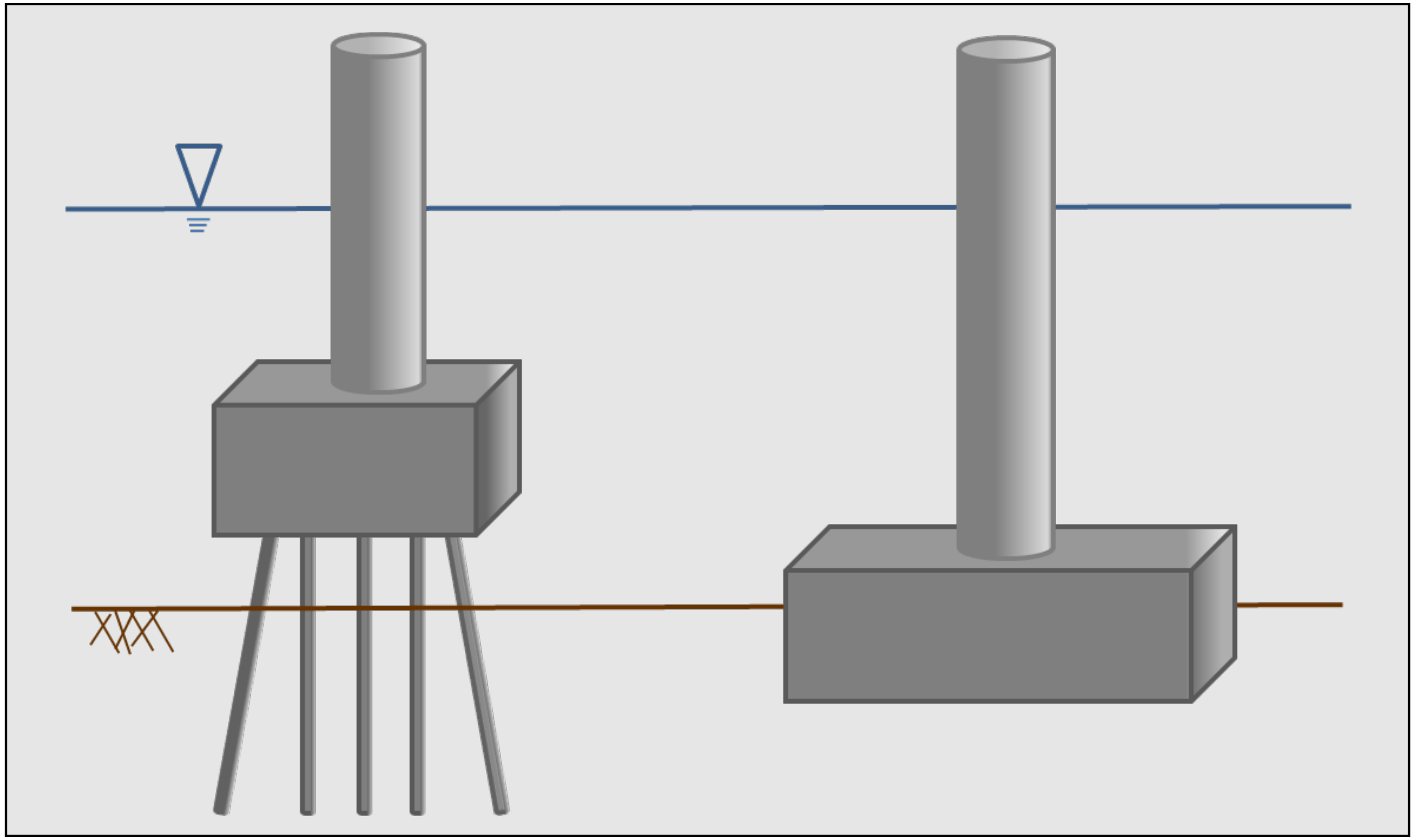


Image source: FHWA

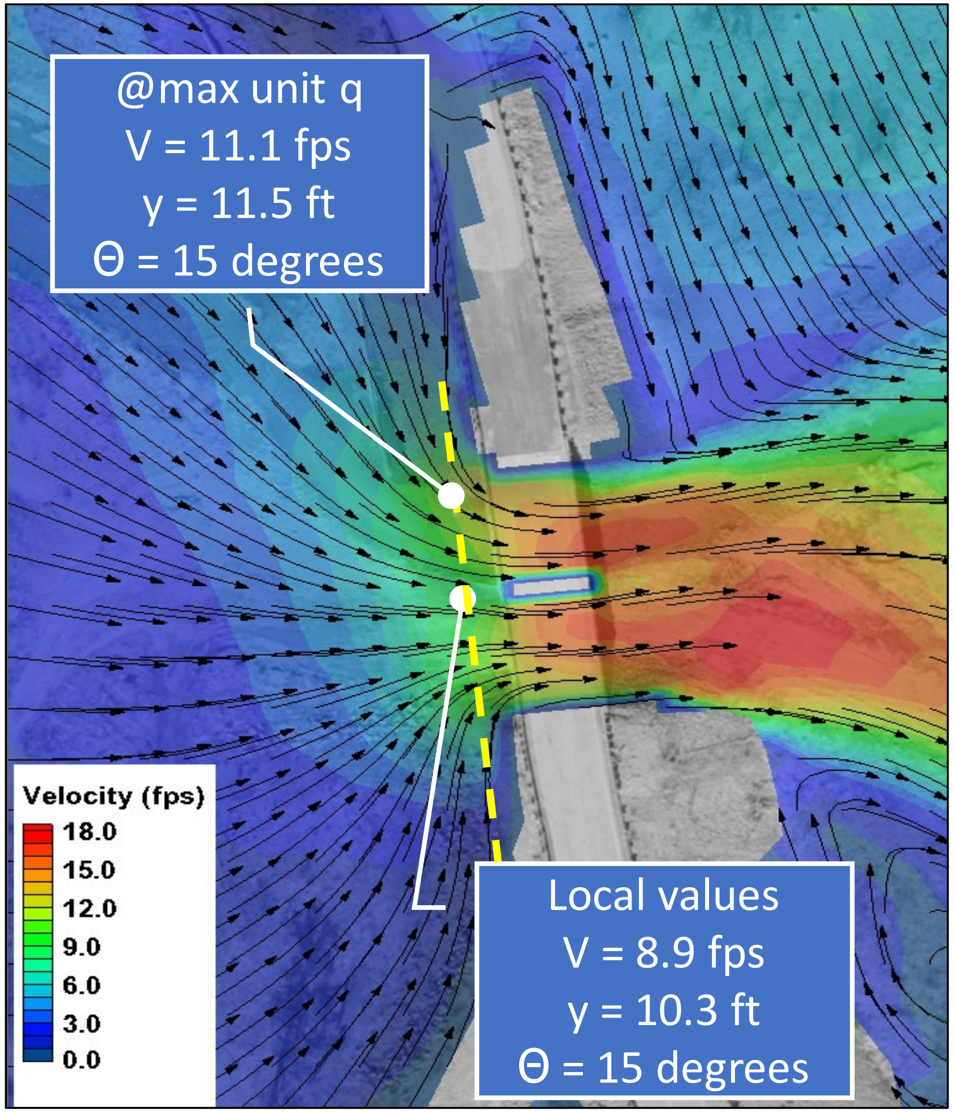
Case 1: Pile cap bottom exposed

Case 2: Pile cap bottom not exposed

Pier Scour Example (Q100)

Using either equation on Lesson 5 Slide 9, calculate the pier scour for these conditions:

- Velocity u/s of pier = 8.9 fps (11.1 at max q)
- Pier width = 1.6 feet
- Pier length = 24 ft
- Depth u/s of pier = 10.3 feet (11.5 at max q)
- Pier shape: Square nose
- Pier L/a = 16. Angle of attack = 15 degrees
- Bed condition: plane bed



Pier Scour Example (Q100)

$$Fr = \frac{V}{\sqrt{gy}} = \frac{11.1}{\sqrt{32.2 * 11.5}} = 0.58$$

$$\frac{y_s}{a} = 2.0 K_1 K_2 K_3 \left(\frac{y_1}{a}\right)^{0.35} Fr^{0.43}$$

$$\frac{y_s}{1.6} = 2.0 * 1.0 * 2.5 * 1.1 \left(\frac{11.5}{1.6}\right)^{0.35} (0.58)^{0.43} = 8.63$$

$$y_s = 1.6 * 8.63 = 13.8\ ft$$

Pier Scour

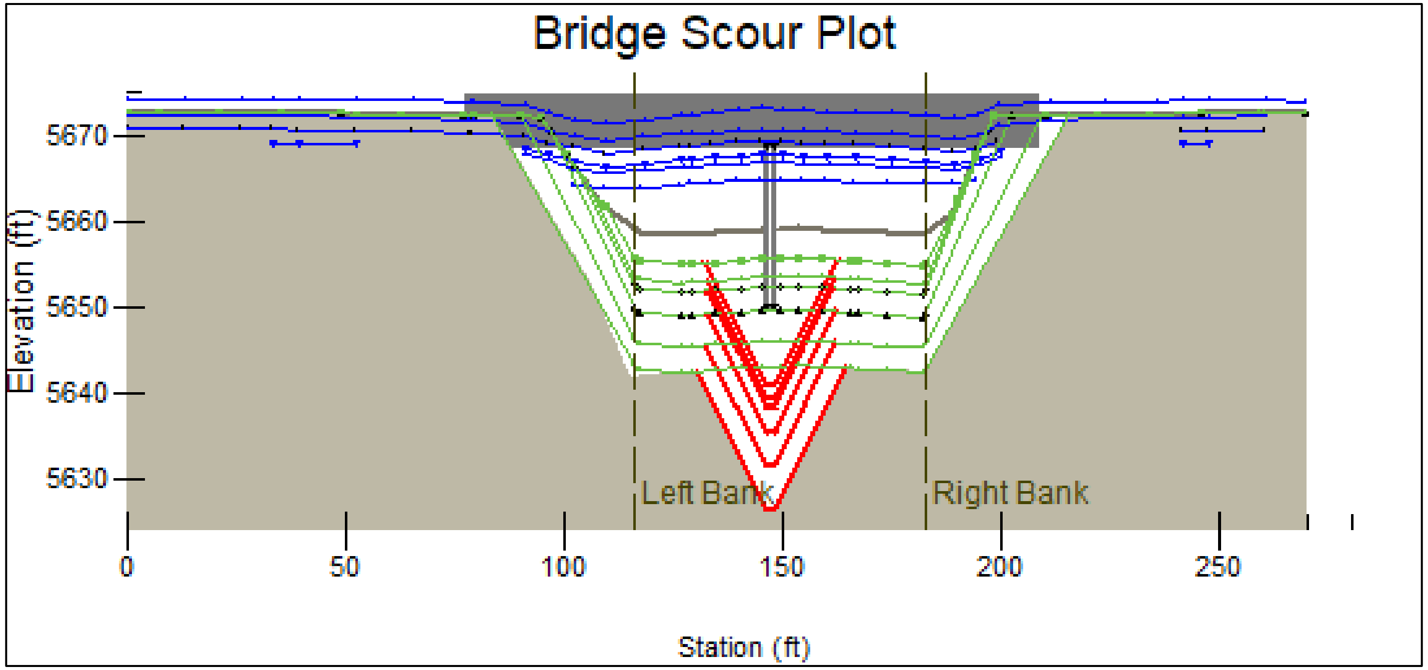
Computation Method: HEC-18

Parameter	Value	Units
Input Parameters		
Pier Shape	Square Nose	
Bed Condition	Plane Bed and Antidu...	
Depth Upstream of Pier	11.52	ft
Velocity Upstream of Pier	11.14	ft/s
Width of Pier	1.60	ft
Length of Pier	24.00	ft
Angle of Attack	15.00	Degrees
Results		
Froude Number Upstream	0.58	
Correction Factor for Pier Nose Shape (K1)	1.00	
Correction Factor of Angle of Attack (K2)	2.49	
Pier Length to Pier Width (L/a)	12.00	
Correction Factor for Bed Condition (K3)	1.10	
Scour Depth	13.83	ft
Scour Hole		
Angle of Repose	44.00	degrees
Use the Pier Width as the Bottom Width of Scour Hole	☑	
Scour Hole Bottom Width	1.60	ft
Scour Hole Top Width	28.15	ft

Pier Scour Example (Q100)

- Compute pier scour for a range of events
- Review the results for all events

	Q10 (SRH-...	Q25 (SRH-...	Q50 (SRH-...	Q100 (SRH...	Q500 (SRH...	Q ovr (SRH...	Units
Local Scour at Piers							
Plot Pier Scour	☑	☑	☑	☑	☑	☑	
Piers							
Pier Name	Pier 1	Pier 1	Pier 1	Pier 1	Pier 1	Pier 1	
Pier Scour Depth	14.08	13.26	13.60	13.83	**15.89**	13.44	ft
Total Scour at Pier	14.08	13.26	13.60	13.83	**15.89**	13.44	ft
Total Scour Elevation at Pier	5640.82	5638.35	5635.28	5631.45	**5626.43**	5639.27	ft



Pier Scour Review

Questions ?

<u>Key Takeaways:</u>

- Use material gradation representative of channel in vicinity of the pier
- Consider multiple channel bed layers
- Evaluate pier scour for a range of flow conditions (Use worst case)
- Consider changes in channel alignment and location for design
- Use cylindrical piers where there is potential for channel migration
- Consider the impacts of debris on scour potential

FHWA
Bridge Scour Workshop

Abutment Scour

Bridge Scour POWER HOUR

U.S. Department of Transportation
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Workshop Agenda

1. Introduction
2. Overview of bridge scour
3. Long Term Degradation
4. Contraction Scour
5. Pier Scour
6. **Abutment Scour**
7. Comprehensive example with bridge scour tools
8. Wrap-up and questions

Abutment Scour Overview

- Define abutment scour and scour conditions at abutments
- Highlight the NCHRP abutment scour approach and types of abutment scour
- Determine the abutment scour condition and parameters
- Steps to compute abutment scour using the NCHRP approach

What is Abutment Scour

- Local scour resulting from the flow obstruction caused by an abutment / embankment
- Contracting flow accelerates and forms a vortex

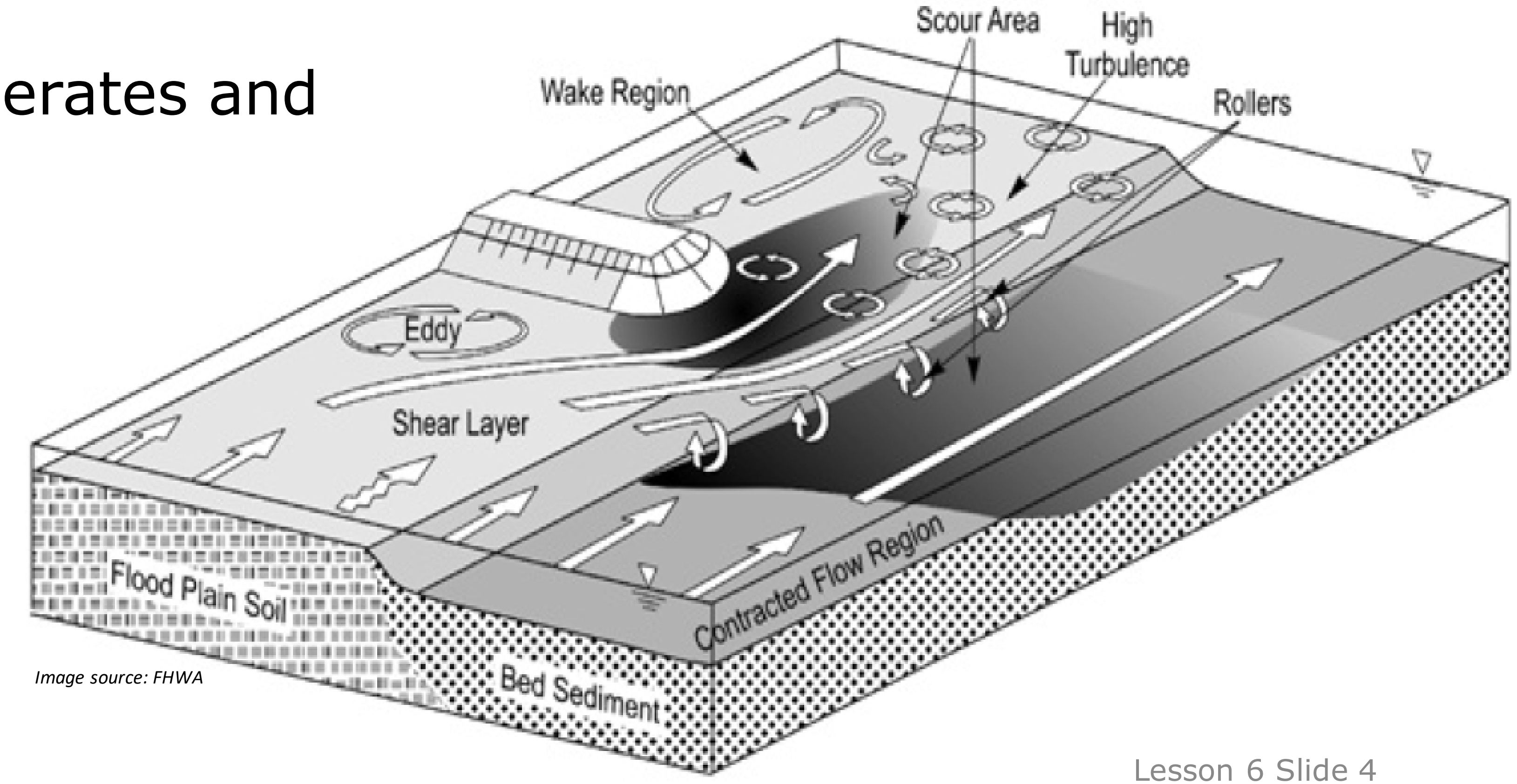


Image source: FHWA

NCHRP Approach

- FHWA recommends using the NCHRP approach
- The HIRE and Froehlich methods will be archived in the next version of HEC-18
- Abutment scour is computed by multiplying contraction scour by an empirically derived amplification factor
- Amplification factors were developed for two abutment configurations and two location scenarios

Live-Bed Contraction Scour – HEC-18 Eq.6.2

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

Live-Bed Contraction Scour – HEC-18 Eq.6.2

k_1 ~ 6/7

$Q_2/W_2 = q_{2c}$

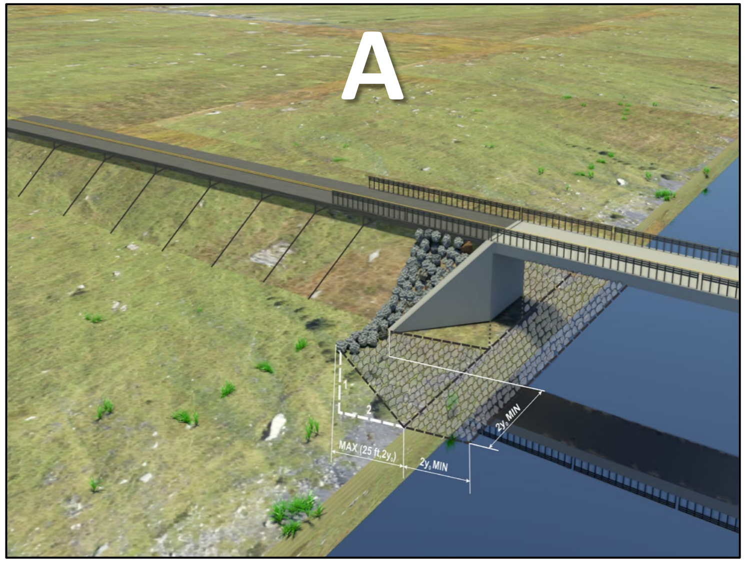
$Q_1/W_1 = q_1$

$$y_{max} = \alpha_{A/B}\boldsymbol{y_1}\left(\frac{\boldsymbol{q_{2c}}}{\boldsymbol{q_1}}\right)^{6/7}$$

NCHRP Abutment Scour – HEC-18 Eq. 8.3

$\alpha_{A/B}$ = Amplification factor for livebed or clear water conditions

Abutment Scour Scenarios (Location)



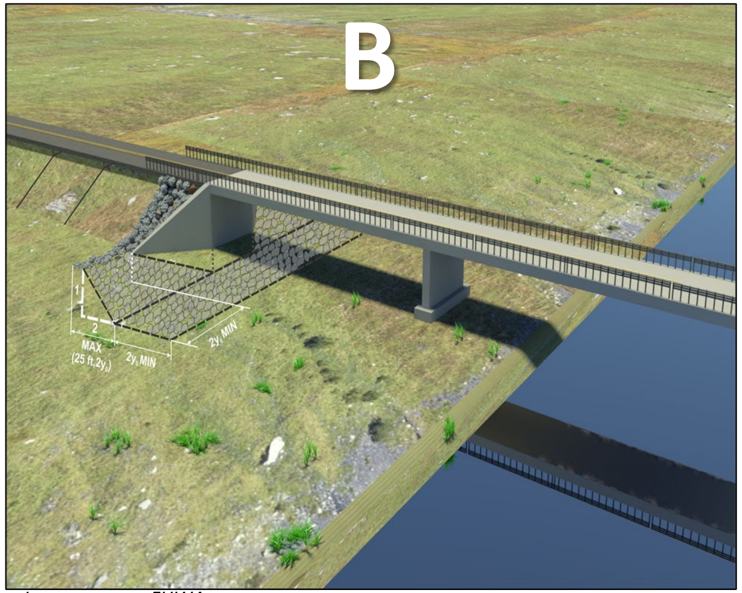


Image source: FHWA

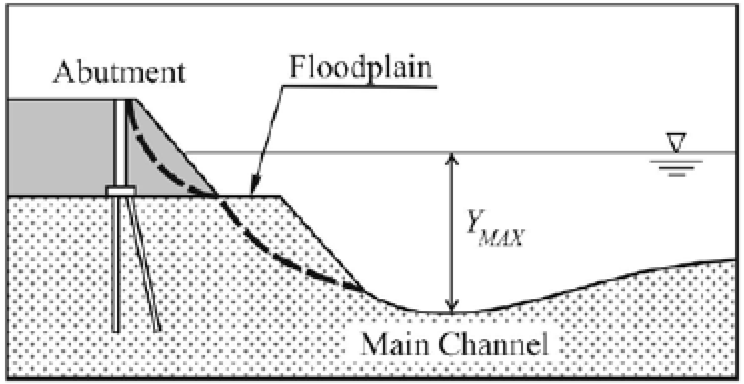
Scour Condition A:

- The abutment is located **near the channel** bank or the channel may migrate into the abutment over the life of the bridge
- Main channel hydraulic parameters are used to compute abutment scour

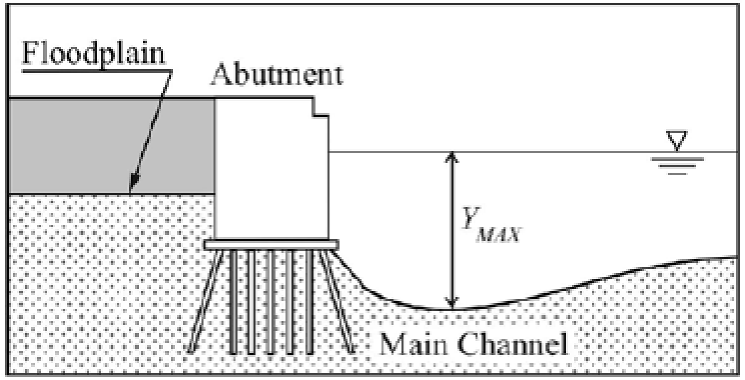
Scour Condition B:

- The abutment is **set back from the channel** bank far enough that it will not be in contact with the channel over the life of the bridge
- Overbank hydraulic parameters are used to compute abutment scour

Abutment Scour Scenarios (Abutment Type)



Spill-through abutments (sloped)



Wingwall abutments (vertical)

Image source: FHWA

NCHRP Approach Amplification Factor

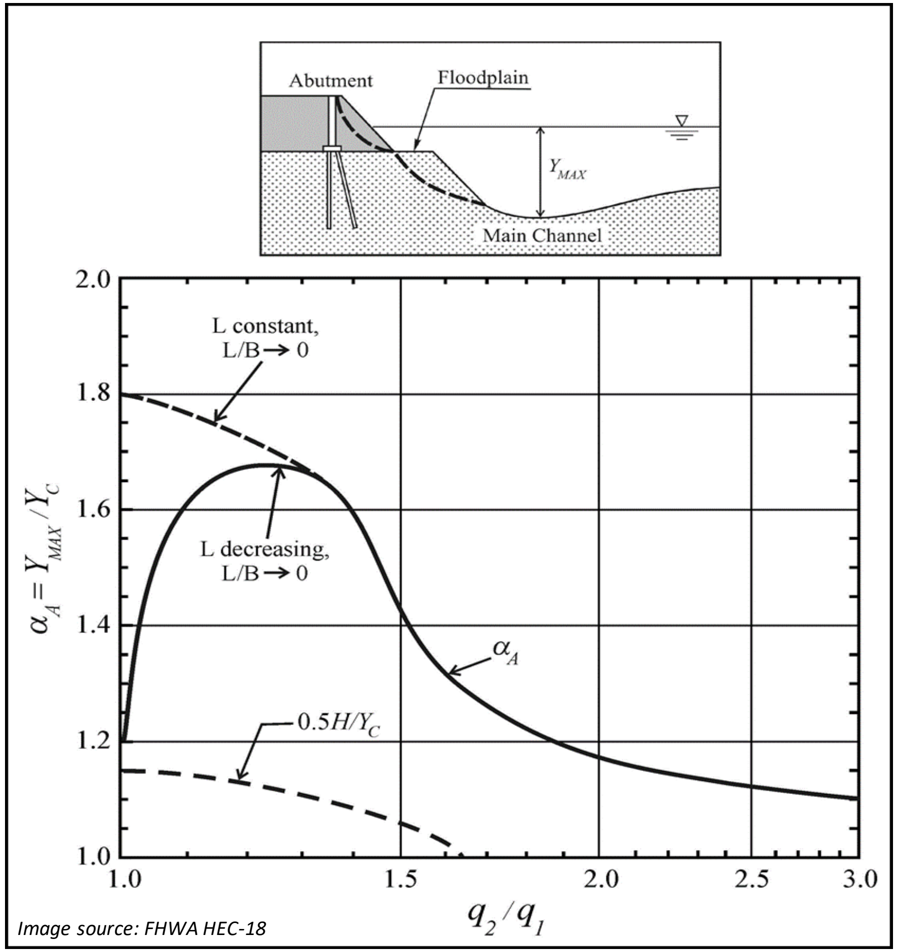


Figure 8.9. Scour amplification factor for spill-through abutments and *live-bed conditions (Scour Condition A)*

Four reference curves in HEC-18 (2012)

(Note the clarifications in Figure Captions)

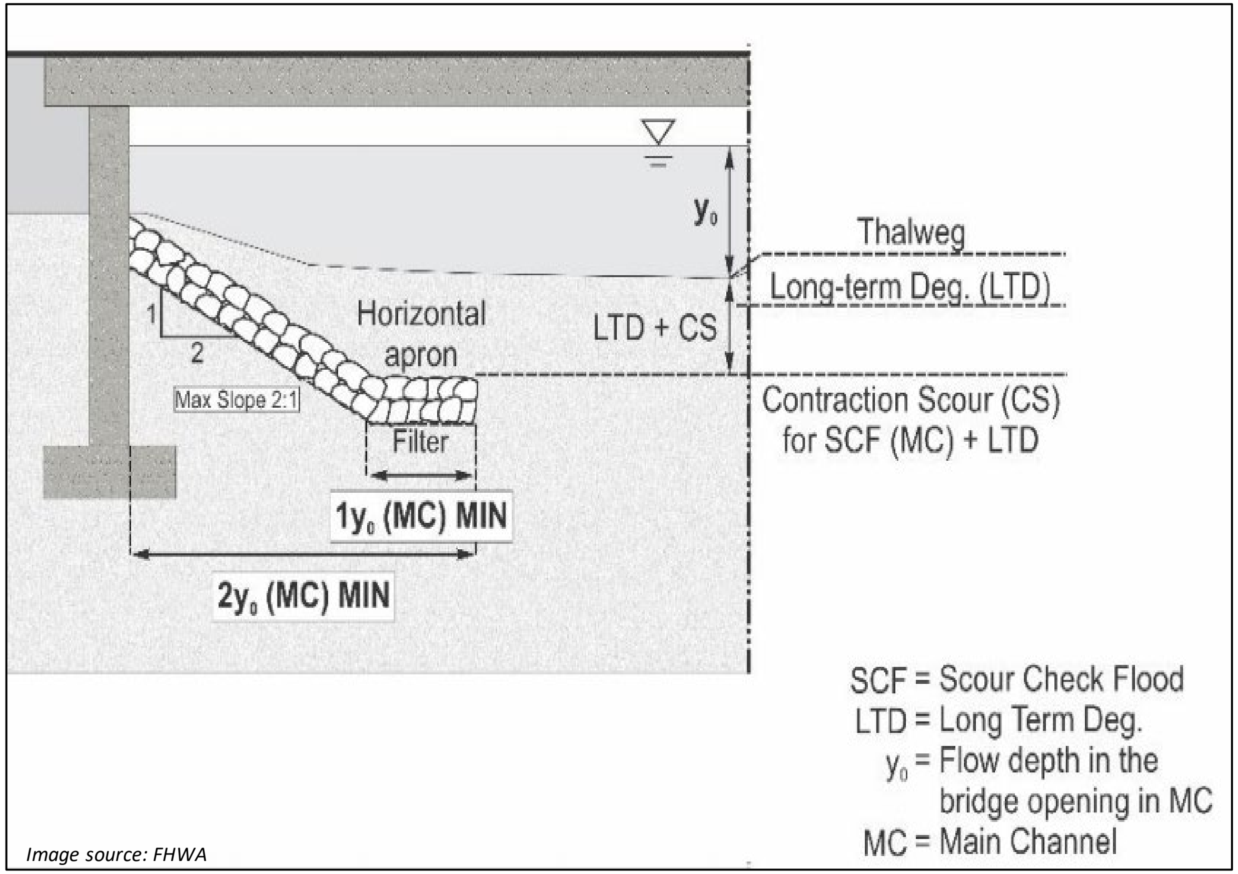
- Scour Condition A, spill-through abutments (Figure 8.9)
- Scour Condition A, vertical abutments/wingwalls (Figure 8.10)
- Scour Condition B, spill-through abutments (Figure 8.11)
- Scour Condition B, vertical abutments/wingwalls (Figure 8.12)

- When q_2/q_1 is low, contraction scour is small and flow separation and turbulence dominate the scour process
- When q_2/q_1 is large, contraction scour dominates the process and the amplification factor is small

Computing Abutment Scour (NCHRP Method)

Computation steps:

- Compute contraction scour for all flows first to assess scour condition and pressure flow conditions
- If pressure flow exists, abutment scour cannot be computed using current HEC-18 methods. An abutment scour countermeasure is required.



Abutment Scour Countermeasure (From FHWA 2018 Tech Brief (HIF-19-007), 'Hydraulic Considerations for Shallow Abutment Foundations')

Computing Abutment Scour (NCHRP Method)

Computation steps (cont'd):

- Determine Scour Condition (A or B)
  - For Scour Condition A, use main channel average hydraulic parameters to compute abutment scour
  - For Scour Condition B, use overbank average hydraulic parameters to compute abutment scour. (Most overbank scenarios will be a clear-water condition when vegetation is present.
- Compute unit discharges (q_1 and q_2) using hydraulic parameters from contraction scour
- Evaluate the amplification factor ($\alpha_{A/B}$) from HEC-18 Figures 8.9 – 8.12

Live Bed Condition

Contraction Scour

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

Abutment Scour

$$y_{max} = \alpha_{A/B} y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7}$$

Clear Water Condition

Contraction Scour

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

Abutment Scour

$$y_{max} = \alpha_{A/B} \left(\frac{q_{2f}}{K_u D_{50}^{1/3}}\right)^{6/7}$$

Ref: HEC-18 (2012) Equations 6.2-6.4, 8.3-8.6

Computing Abutment Scour (NCHRP Method)

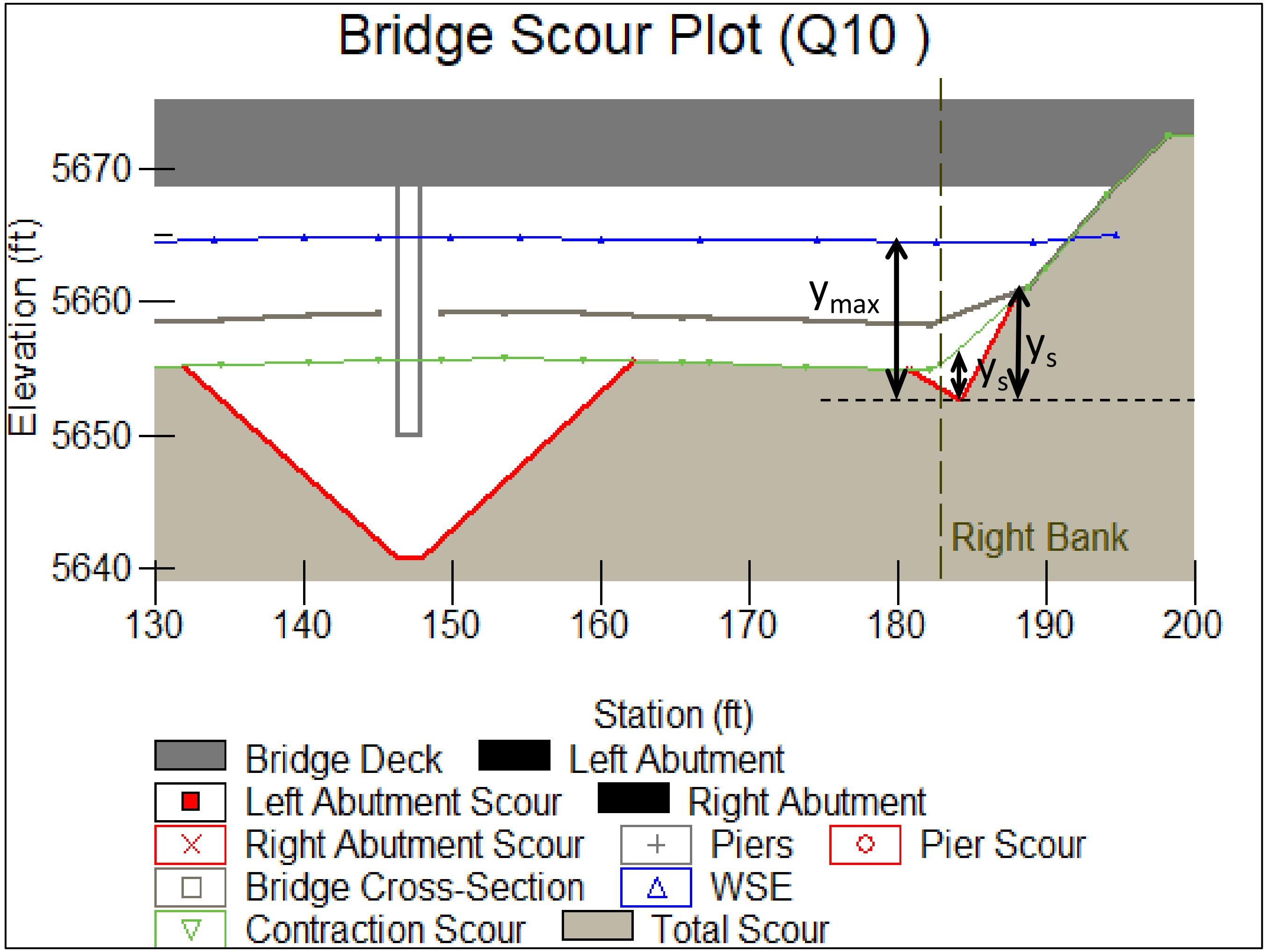


Image source: FHWA

Computation steps (cont'd):

- Identify an abutment toe location for reference. The equations will estimate a maximum flow depth including abutment scour.
  - The reference location is used to determine the abutment scour depth at that location. (Y_s is based on the selected location)
  - Y_s should always be reported with a location or the elevation at y_{max} should be given

Abutment Scour Example (Q25)

Computation steps:

- Compute contraction scour for all flows first to assess scour condition and pressure flow conditions
  - ➢ Clear-water scour for Q25
- Determine Scour Condition
  - ➢ Scour Condition A for both abutments (abutments will be impacted by main channel hydraulics)

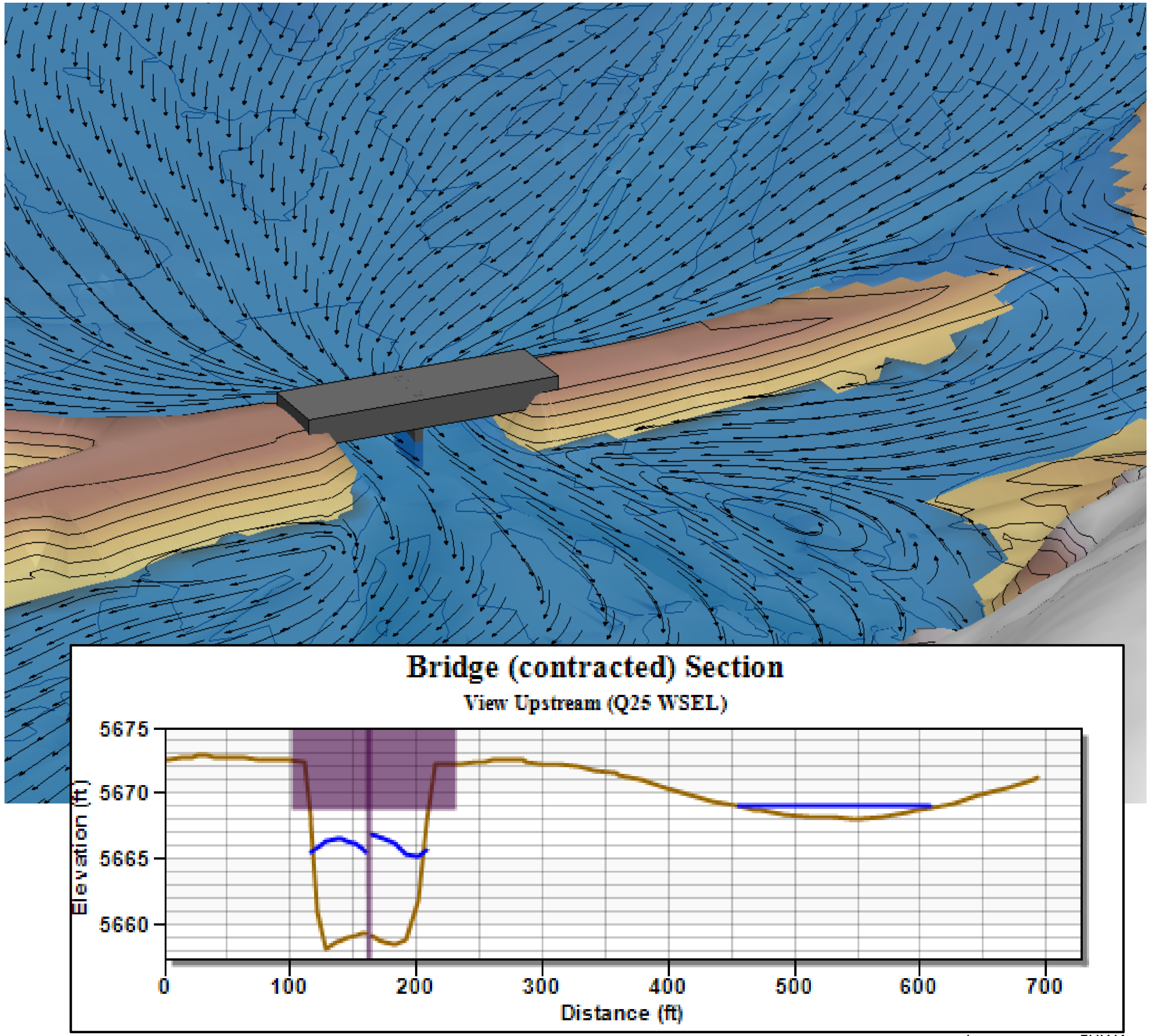


Image source: FHWA

Abutment Scour Example (Q25)

Computation steps (cont'd):

- Compute unit discharges using the hydraulic parameters from contraction scour
  - q_1 = Q1/W1 = 1875 cfs/50 ft = 37.5 cfs/ft
  - q_2 = Q2/W2 = 5167 cfs/58.5 ft = 88.4 cfs/ft
- Evaluate the amplification factor
  - q_2/q_1 = 88.4/37.5 = 2.36
  - From Figure 8.9, α_A = 1.14

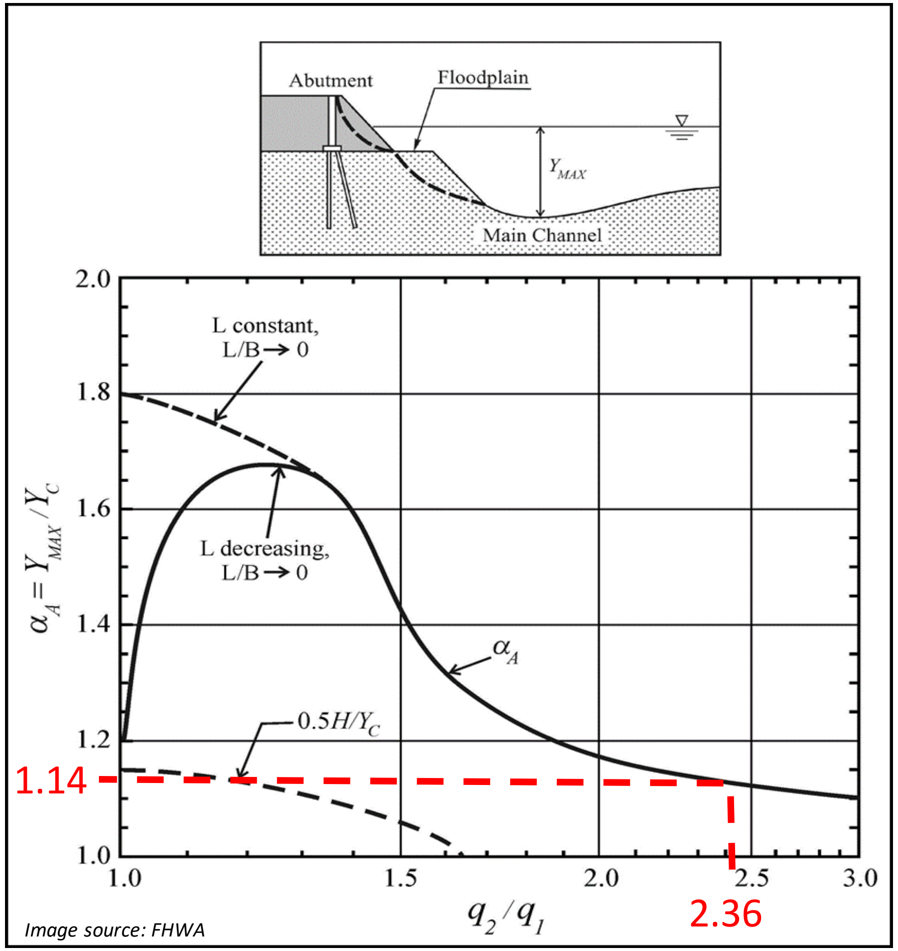


Figure 8.9. Scour amplification factor for spill-through abutments and *live-bed conditions (Scour Condition A)*

Abutment Scour Example (Q25)

Computation steps (cont'd):

- Identify the abutment toe reference location for each abutment and determine the flow depth prior to scour
  - Left = 5.2ft, Right = 6.9ft
- Compute the flow depth including contraction scour (Eq 8.6–Clear water scour)
  - $y_c = (q_2/K_u D_{50}^{1/3})^{6/7} = (88.4/(11.17*.0303^{1/3}))^{6/7} = 16.0$ ft
- Compute the maximum flow depth resulting from abutment scour
  - $y_{max} = \alpha_A y_c = 1.14\ (16.0) = 18.4$ ft
  - Abutment scour elevation = 5645.1 ft (same for both abutments in this case)

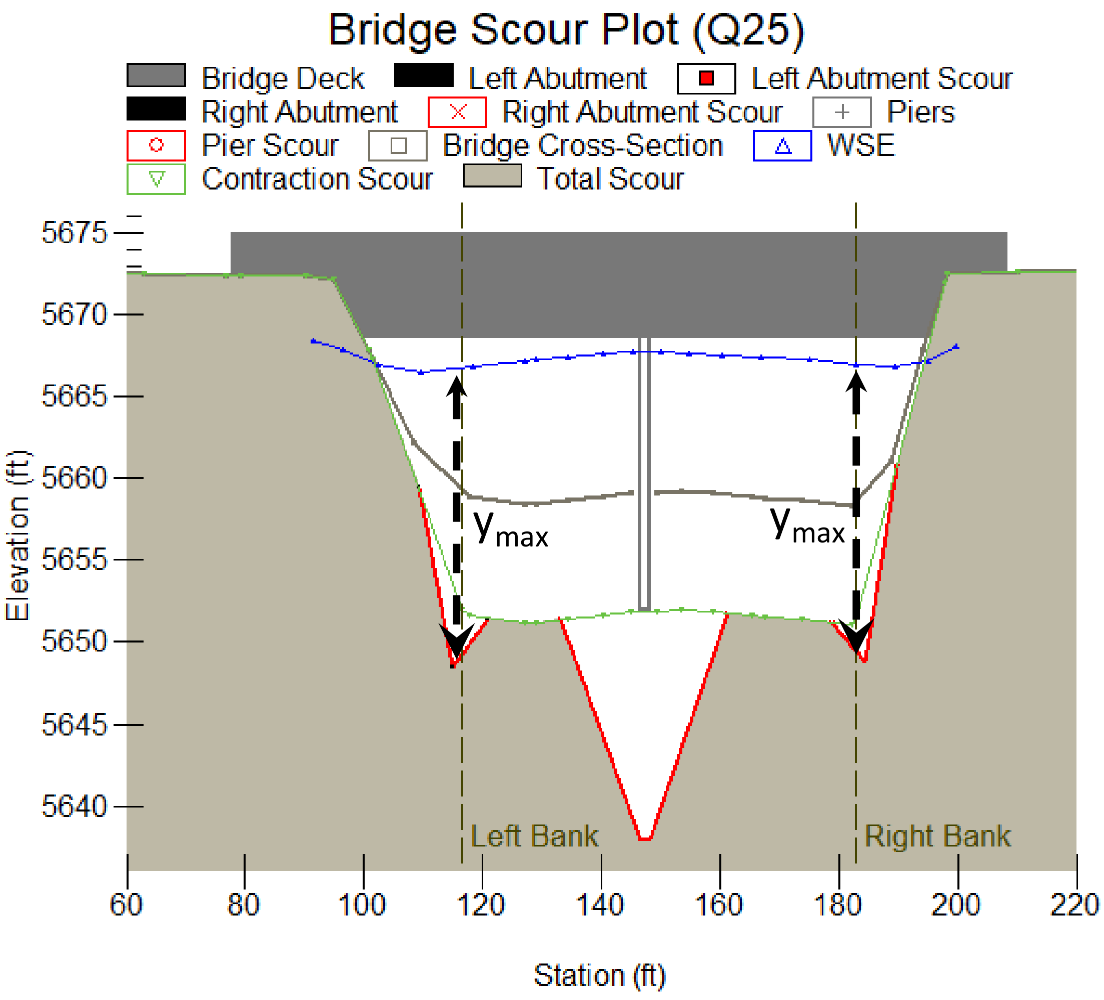


Image source: FHWA

Abutment Scour Example (Q100)

Computation steps:

- Pressure flow exists
- Abutment scour currently cannot be estimated with pressure flow conditions.
- An abutment scour countermeasure is required for pressure flow, with an apron placed at the depth of the computed pressure flow scour.
- See HEC-18 and the [Tech Brief: Hydraulic Considerations for Shallow Abutment Foundations]() for more information

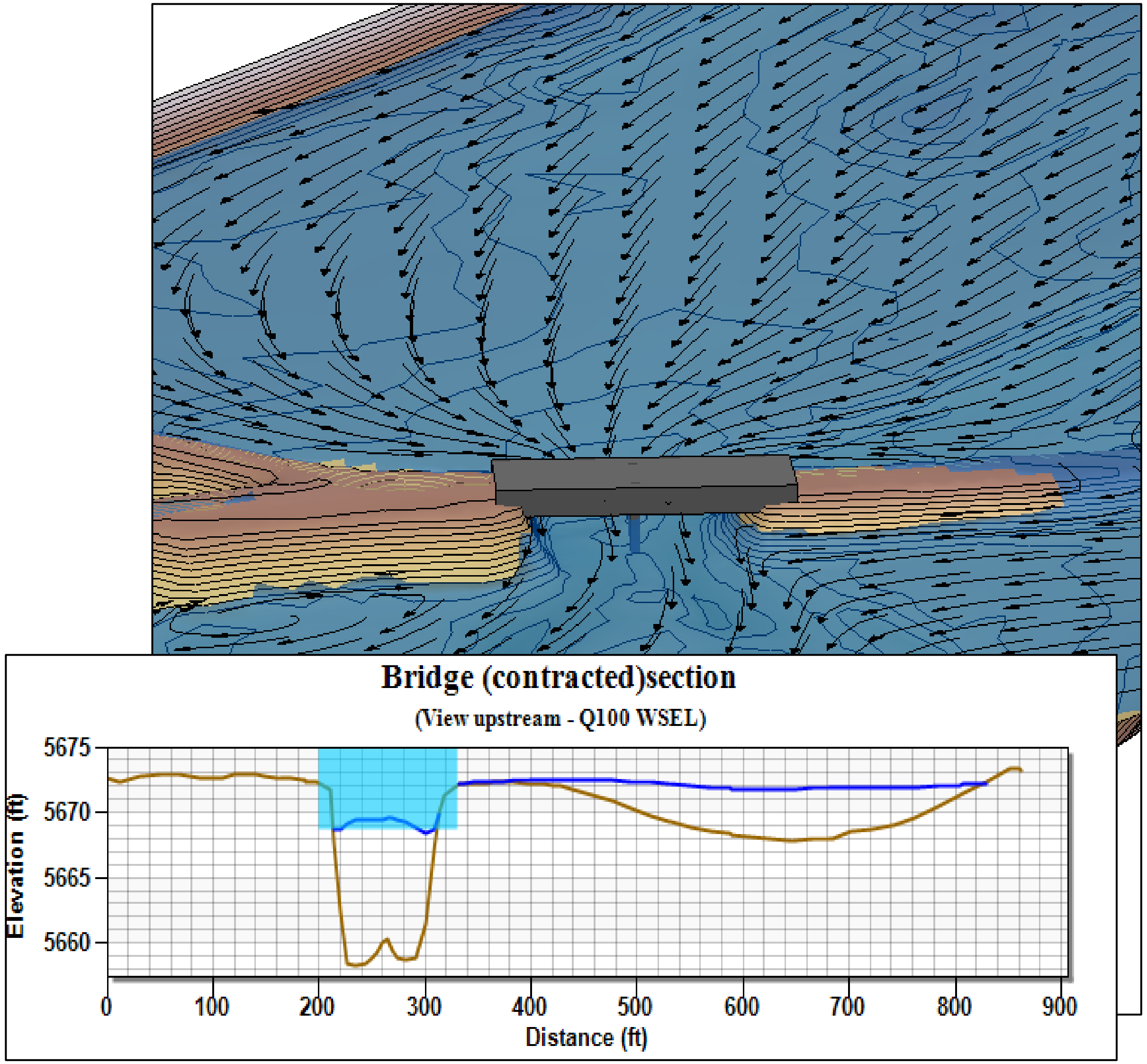


Image source: FHWA

Abutment Scour Example

Computation steps (cont'd):

- Review abutment scour results for all events

Bridge Scour Summary Table

Parameter	Q10	Q25	Q50	Q100	Q500	Q ovr	Units
Local Scour at Abutments							
Abutment scour currently cannot be computed with pressure flo...							
Left Abutment							
Plot Left Abutment Scour	☐	☐	☐	☐	☑	☐	
Abutment Scour Depth	9.34	13.04	16.19	18.40	**23.04**	12.12	ft
Total Scour at Abutment	9.34	**13.04**	0.00	0.00	0.00	12.12	ft
Total Scour Elevation at Abutment	5651.56	5648.48	5645.79	5644.16	**5640.47**	5649.17	ft
Right Abutment							
Plot Right Abutment Scour	☐	☐	☐	☐	☑	☐	
Abutment Scour Depth	7.33	11.26	14.35	16.75	**21.92**	10.30	ft
Total Scour at Abutment	7.33	**11.26**	0.00	0.00	0.00	10.30	ft
Total Scour Elevation at Abutment	5652.16	5648.75	5645.99	5644.32	**5641.10**	5649.54	ft

Image source: FHWA

Abutment Scour Review

Questions ?

<u>Key Points:</u>

- FHWA recommends using the NCHRP abutment scour method
- When evaluating the abutment scour condition, consider the channel migration potential over the life of the bridge
- For Scour Condition A use main channel average hydraulics
- For Scour Condition B use overbank hydraulics
- Clearly identify the abutment scour reference location when reporting a scour depth, or provide the abutment scour elevation
- Abutment scour currently cannot be estimated with pressure flow

FHWA Bridge Scour Workshop

Comprehensive Bridge Scour Example

Bridge Scour POWER HOUR

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

Workshop Agenda

1. Introduction
2. Overview of bridge scour
3. Long Term Degradation
4. Contraction Scour
5. Pier Scour
6. Abutment Scour
7. **Comprehensive example with bridge scour tools**
8. Wrap-up and questions

Disclaimers

- *The contents of this presentation do not have the force and effect of law and are not meant to bind the public in any way. This presentation is intended only to provide information to the public regarding existing requirements under the law or agency policies.*
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Comprehensive Bridge Scour Example

- Middle Fork Clarks River, near Murray KY
- 2-mile reach
- Main bridge and relief structure
- Flood flows
  - Q10 = 8,090 cfs
  - Q50 = 13,200 cfs
  - Q100 = 15,700 cfs
  - Q500 = 22,600 cfs
- Evaluate scour for existing conditions using the SRH-2D bridge scour tools and the Hydraulic Toolbox

Image source: Map Data@2019 Google

Comprehensive Bridge Scour Example

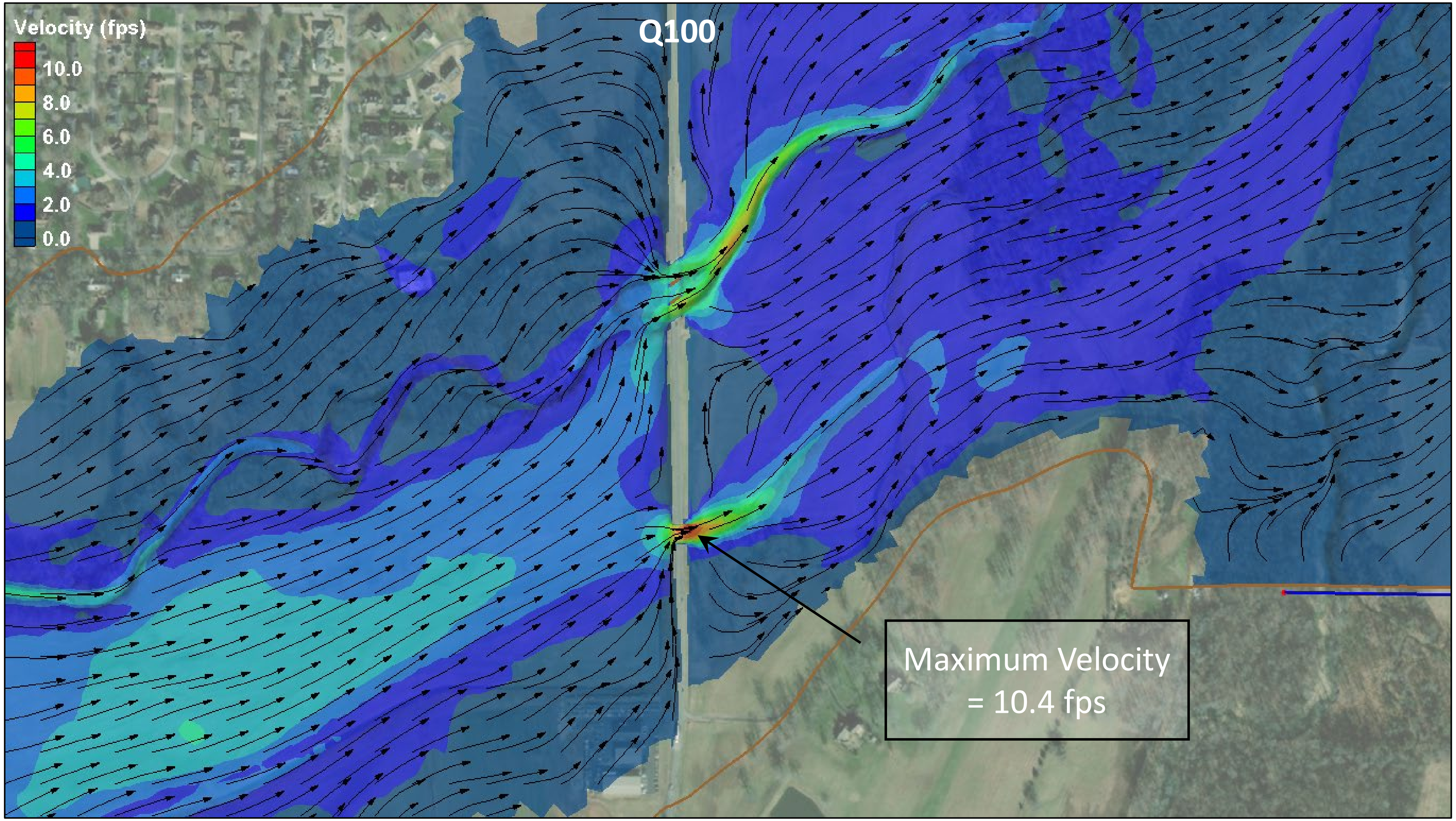
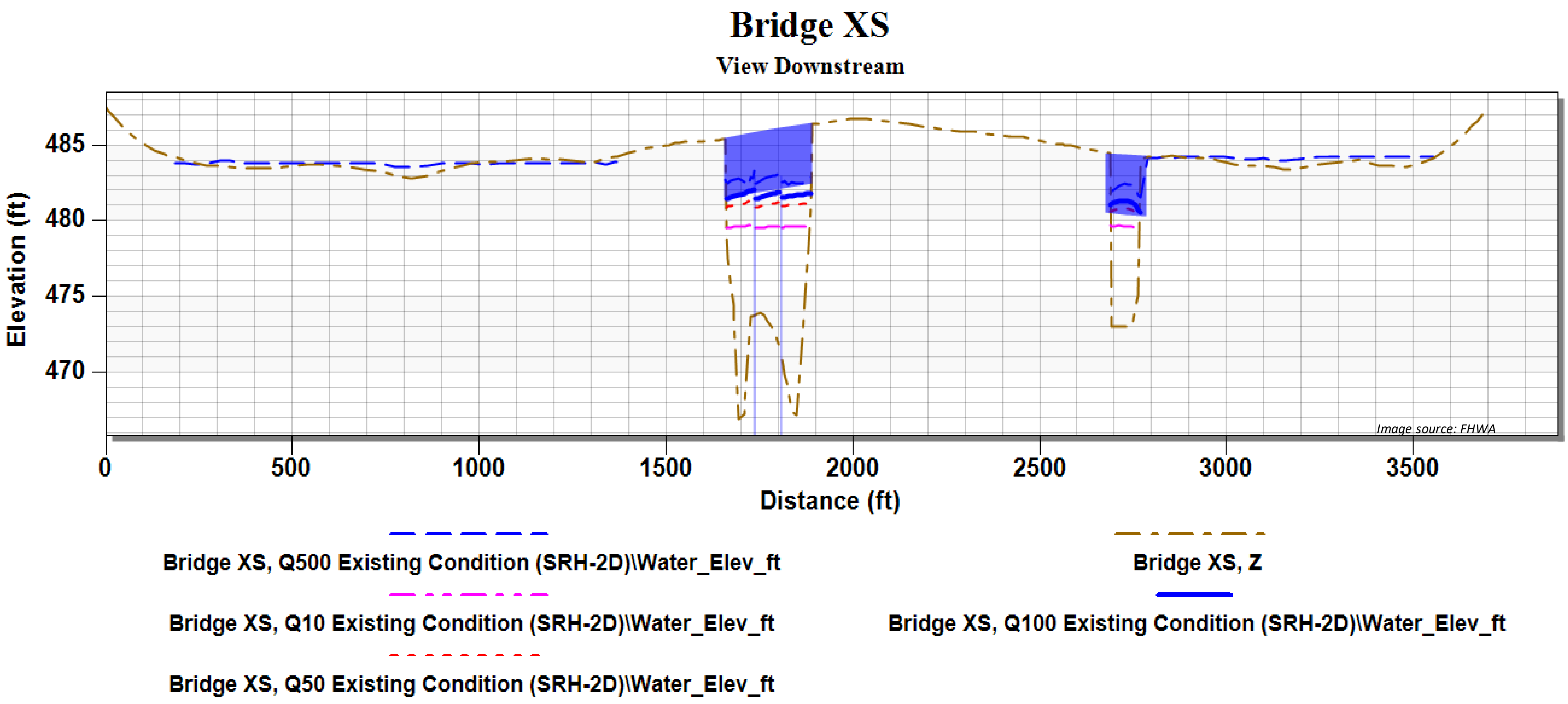


Image source: FHWA / Earthstar Graphics (Aerial Image)

Comprehensive Bridge Scour Example



Comprehensive Bridge Scour Example

- SMS/SRH-2D Demo
- Hydraulic Toolbox Demo

Comprehensive Bridge Scour Example

Questions ?

FHWA Bridge Scour Workshop

Bridge Scour POWER HOUR

Wrap-Up and Questions

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Wrap Up

Questions ?

- Bridge Hydraulic Design Standards and Policy
- Hydraulic modeling / analysis
- Long Term Degradation assessment
- Contraction Scour Analysis
- Pier Scour Analysis
- Abutment Scour Analysis
- Bridge Scour Tools

Wrap Up
Key Considerations in Computing Bridge Scour

- Verify hydraulic modeling approach and results
- Evaluate the worse case scour condition
- Locate the approach section for contraction scour appropriately
- Define the approach width of flow transporting sediment
- Closely review live-bed vs. clear water scour condition

Wrap Up
Key Considerations in Computing Bridge Scour

- Use averaged hydraulic values
- Consider future channel migration potential and degradation
- Collect bed gradation information in the appropriate locations
- Carefully interpret scour depths to design elevations
- Consider limitations of HEC-18 methods

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