The Feather River

A Case Study in Scour Analysis, Real-time Monitoring and Field Measurements of Active Scour

Western Bridge Engineers' Seminar
Phoenix, AZ
September 28, 2011

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Structure Maintenance & Investigation
Hydraulics Branch

Outline

- Background
- Advanced Scour Analysis
- Surprise Scour Event
- Scour Monitoring
- Mitigation

Location Map


Feather River
Route 20
Marysville
Yuba City
Yuba River

Br. No. 18-0009

- Built in 1947
- 24 Spans
- 2673 feet Long
- Founded on Spreadfootings & Steel Piles

1955 Flood

1955 Flood Damage in the Overbank

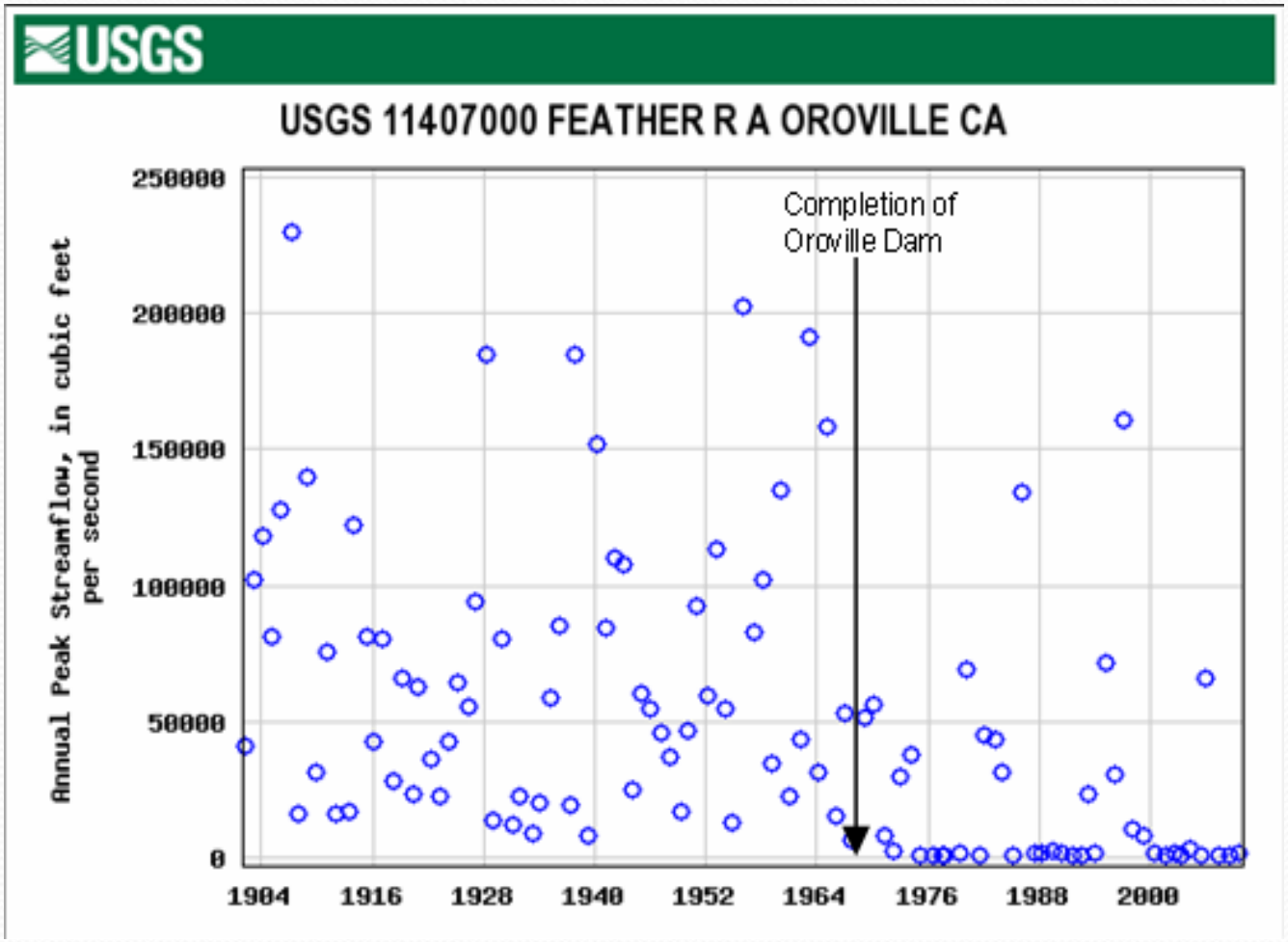
Controlling the Flow

- The flow in the Feather River is controlled upstream by the Oroville Dam which was completed in 1968.

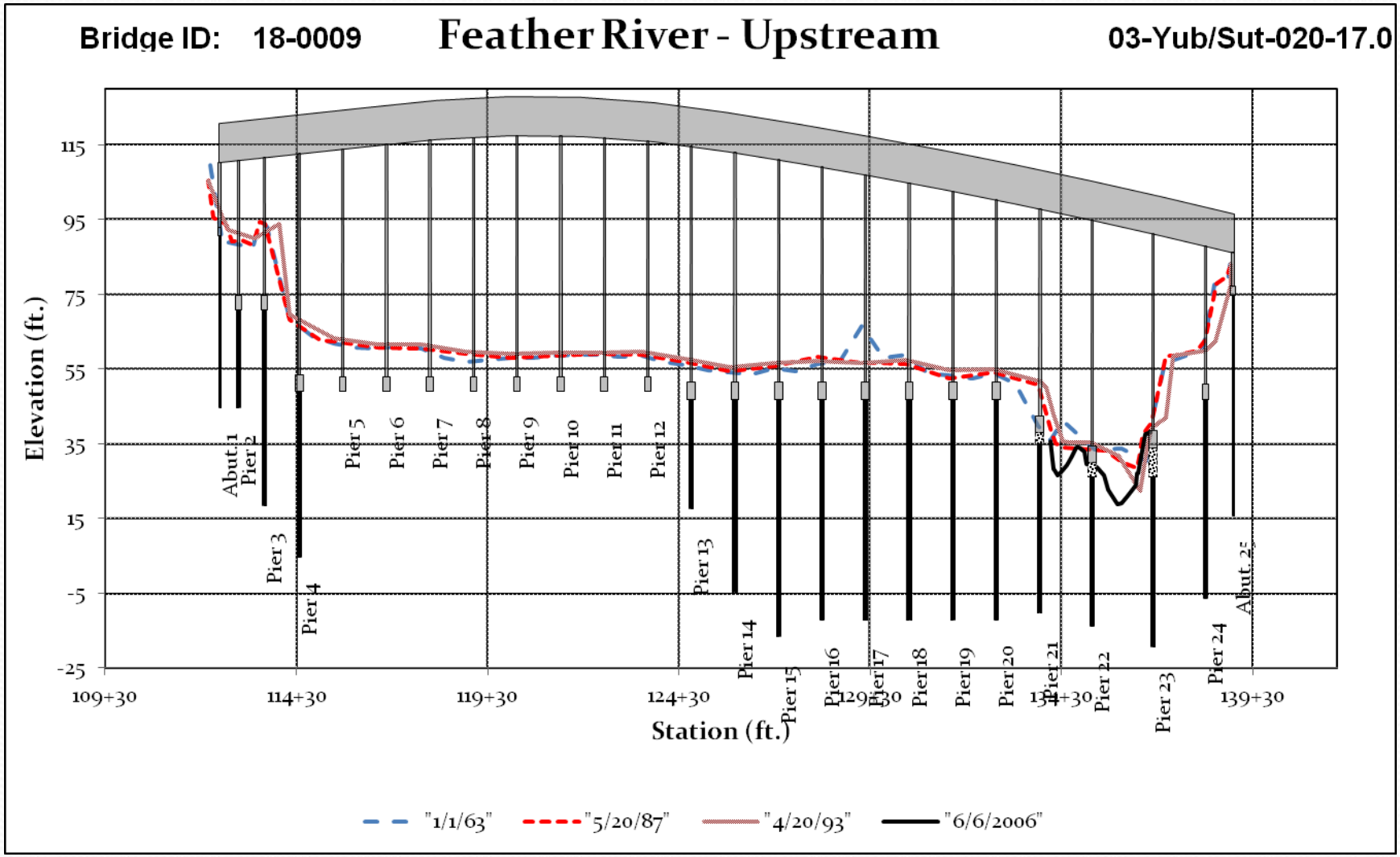
- Levees on both sides of the river, with the east levee set back approximately 2000 feet.

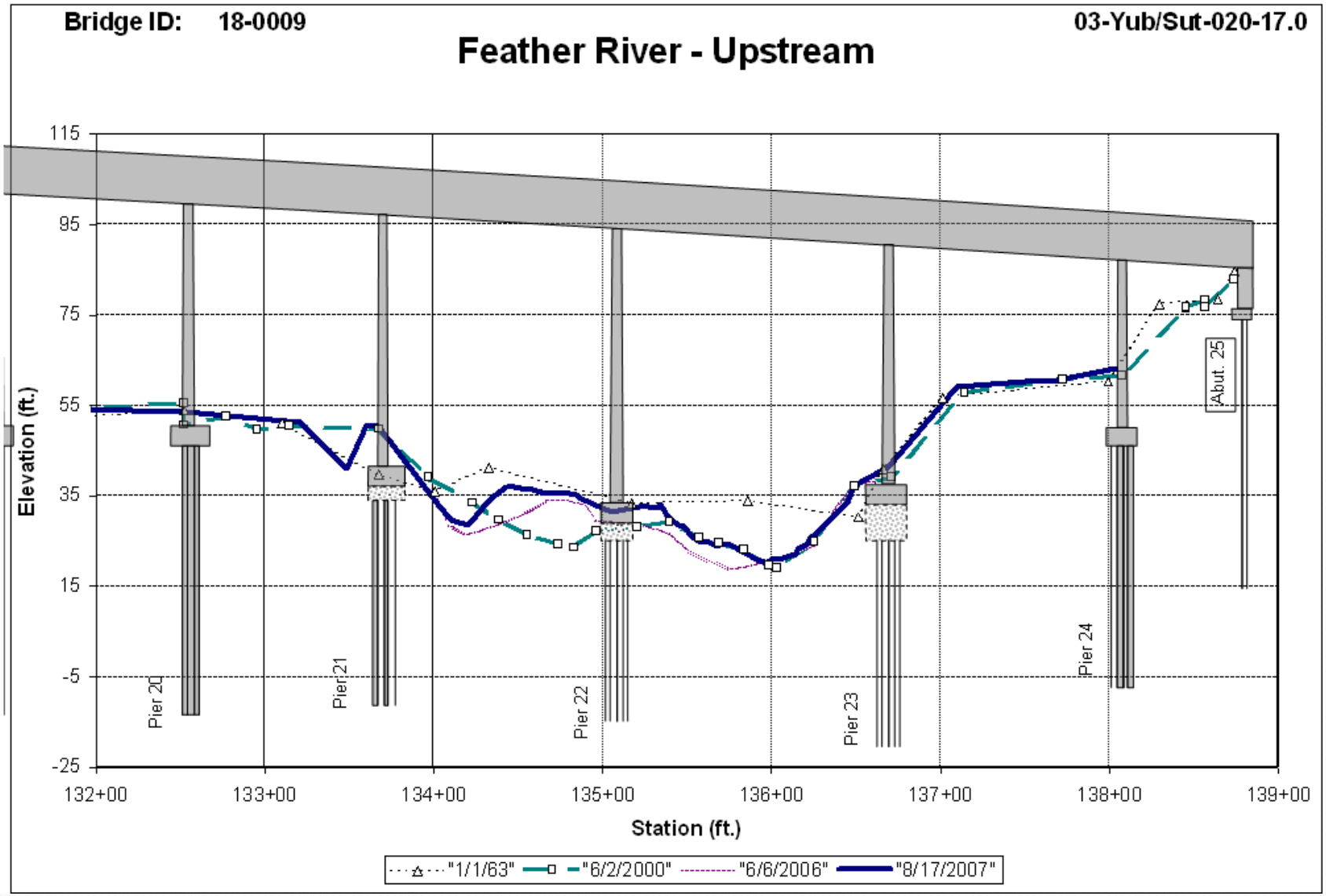
EFFECT OF OROVILLE DAM

- Maximum flows have been reduced
- High Flows are less frequent
- Significant Flows still occur



Historic Channel Cross-Sections





Cross-sections show the river has deepened about 14 ft in the main channel , but been laterally stable

1997 Major Flow Event

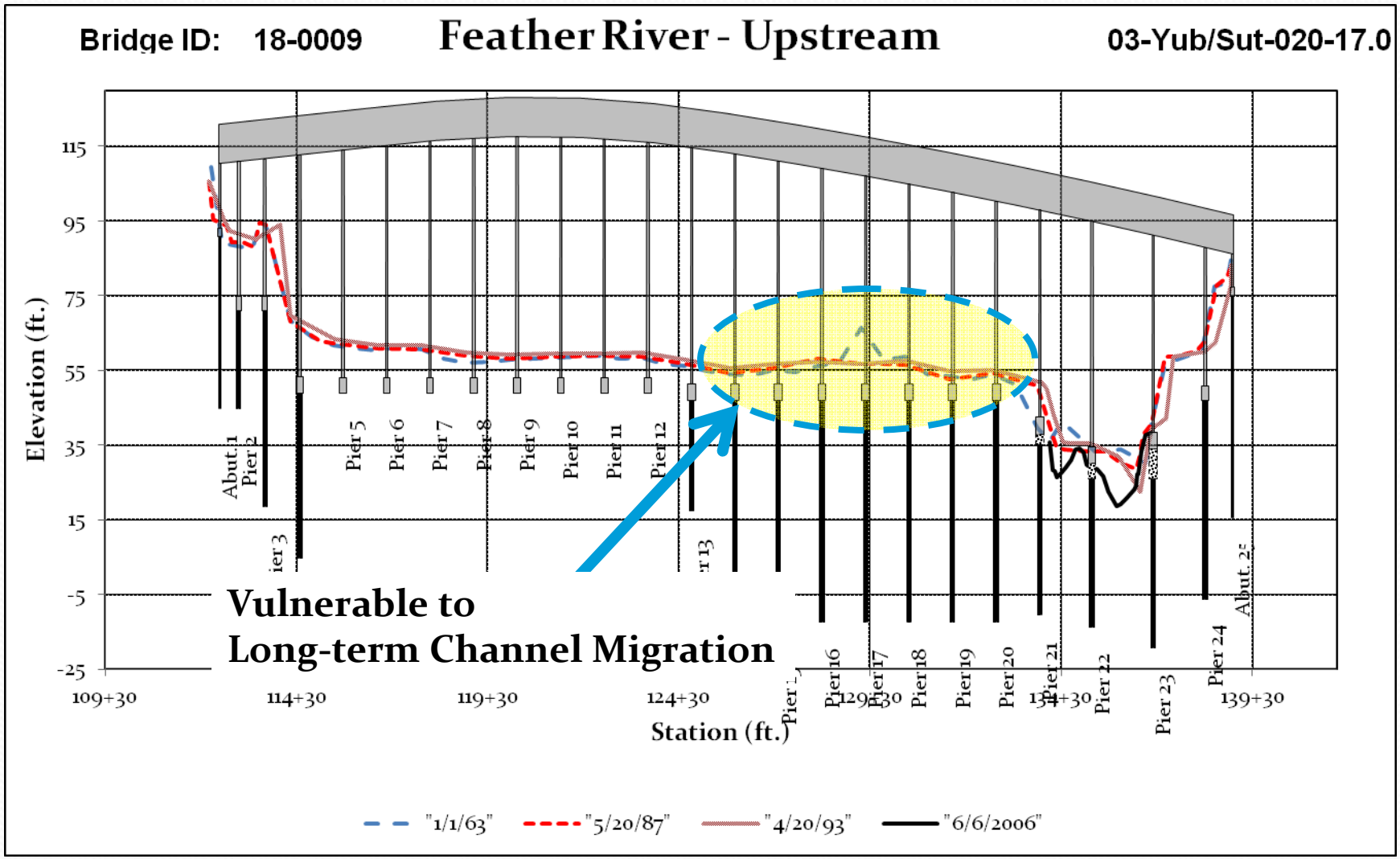
- A high flow (Approx. Q_{100}) in January 1997
  - Eroded a the east bank upstream of the bridge for an average distance of over 100 feet in width.
  - Accentuated the misalignment of the flow through the main spans of the bridge.
  - Pier 22 was undermined by approximately 1.5 feet based on June Dive inspection. Arguably, the scour depth was probably much larger during the flood and likely refilled during the subsequent months.

2002 Scour Evaluation

- Three Main Channel Piers
- Local piers scour = 20 ft
- Evaluated by Structural Ratings and Geotechnical Engineers
- All 3 Piers were Scour Critical and 113 Code = 3.
- Scour mitigation project for large rock around each of the 3 main channel piers programmed ($1.5 million).

Bank Erosion Concern

Bank erosion between 1998 and 2009


Bridge ID: 18-0009
Feather River - Upstream
03-Yub/Sut-020-17.0
Elevation (ft.)
115
95
75
55
35
15
-5
-25
109+30
114+30
119+30
124+30
129+30
134+30
139+30
Station (ft.)
Abut.1
Pier 2
Pier 3
Pier 5
Pier 6
Pier 7
Pier 8
Pier 9
Pier 10
Pier 11
Pier 12
Pier 13
Pier 16
Pier 17
Pier 18
Pier 19
Pier 20
Pier 21
Pier 22
Pier 23
Pier 24
Abut. 25
Vulnerable to
Long-term Channel Migration
"1/1/63"
"5/20/87"
"4/20/93"
"6/6/2006"

2007 Peer Review

Purpose was

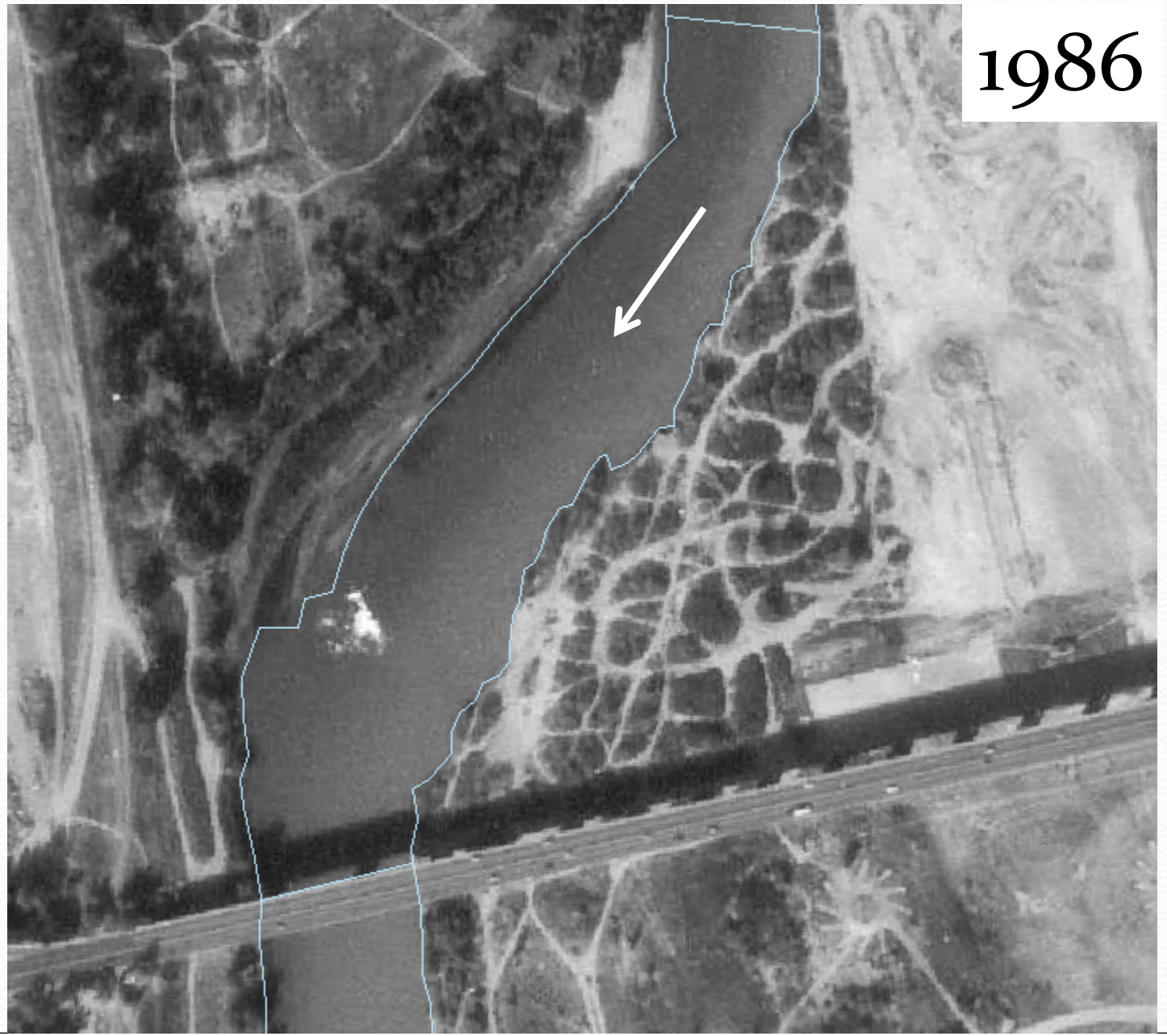
- To decide if proposed pier riprap was appropriate
- To decide if something should be done about upstream bank erosion

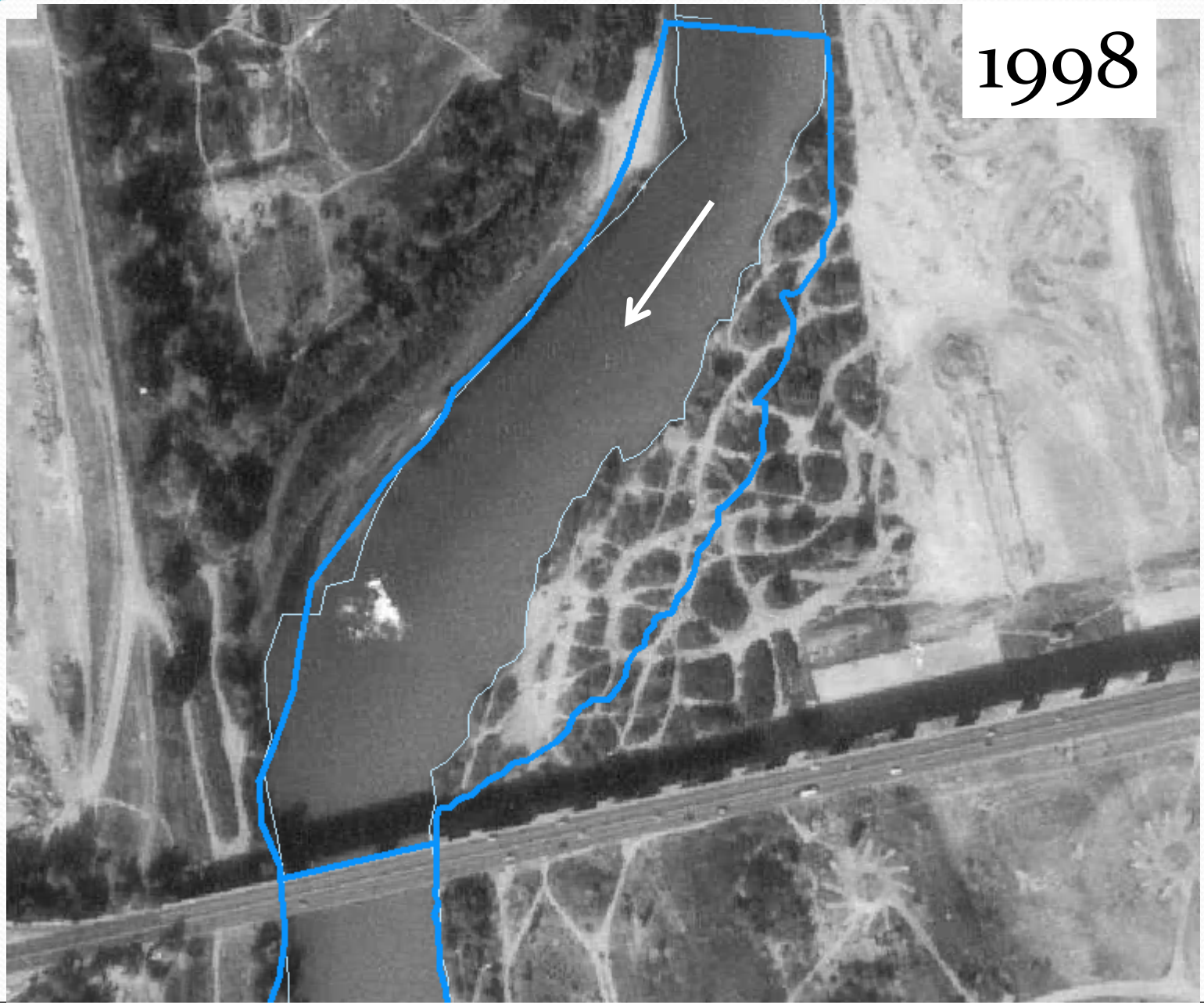
Decision ➔

- Riprap at Main channel piers was necessary
- More analysis was needed to determine the potential for scour problems due to bank erosion

Objectives of Advanced Analysis

1. Survey the channel and overbanks
2. Study the historic bank erosion patterns
3. Estimate rate and pattern of the bank erosion in the future
4. Develop a 2-D Hydraulic Model to access the flow velocity, direction and stresses
5. Predict the scour at the overbank piers


1986


1998

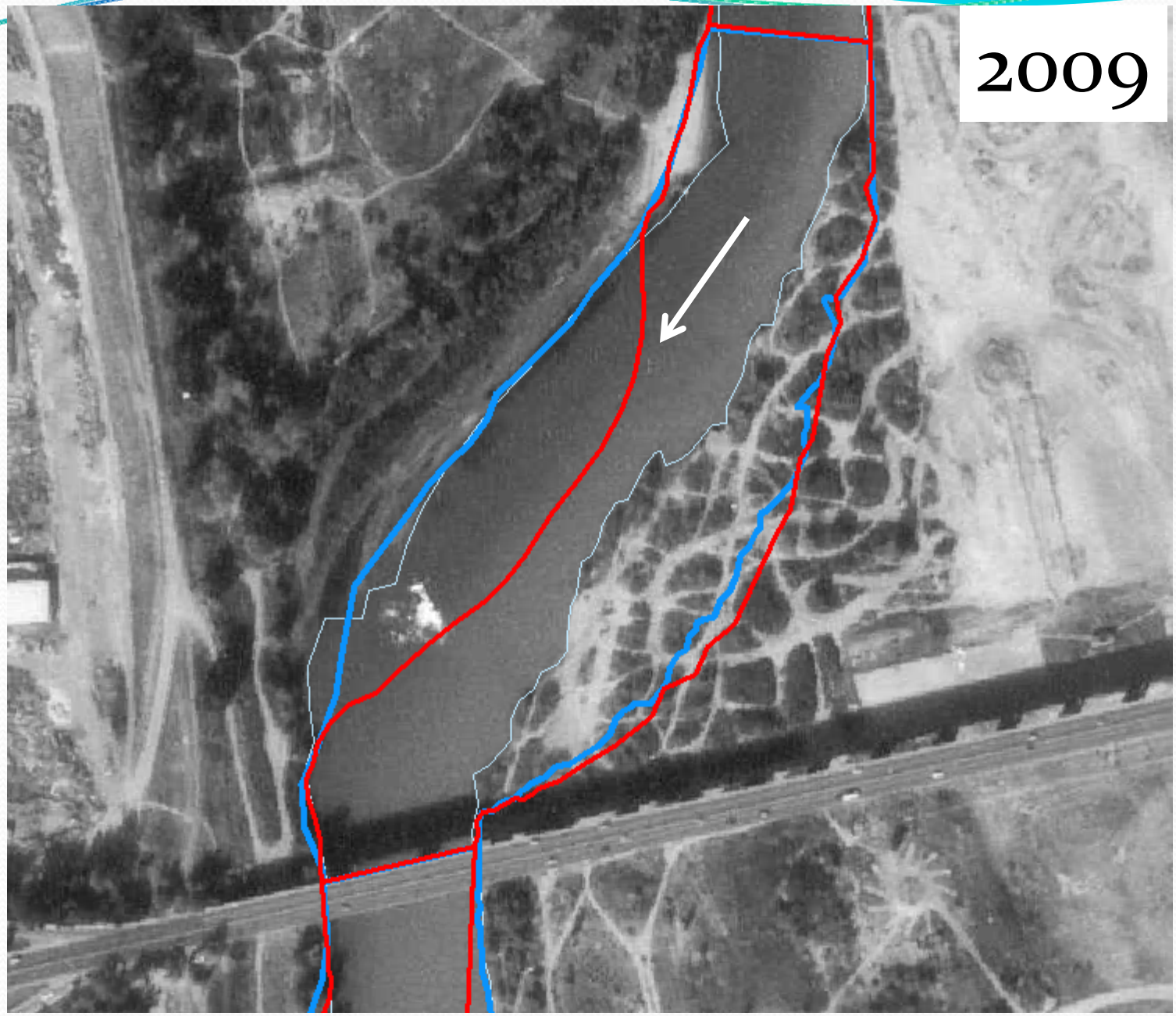
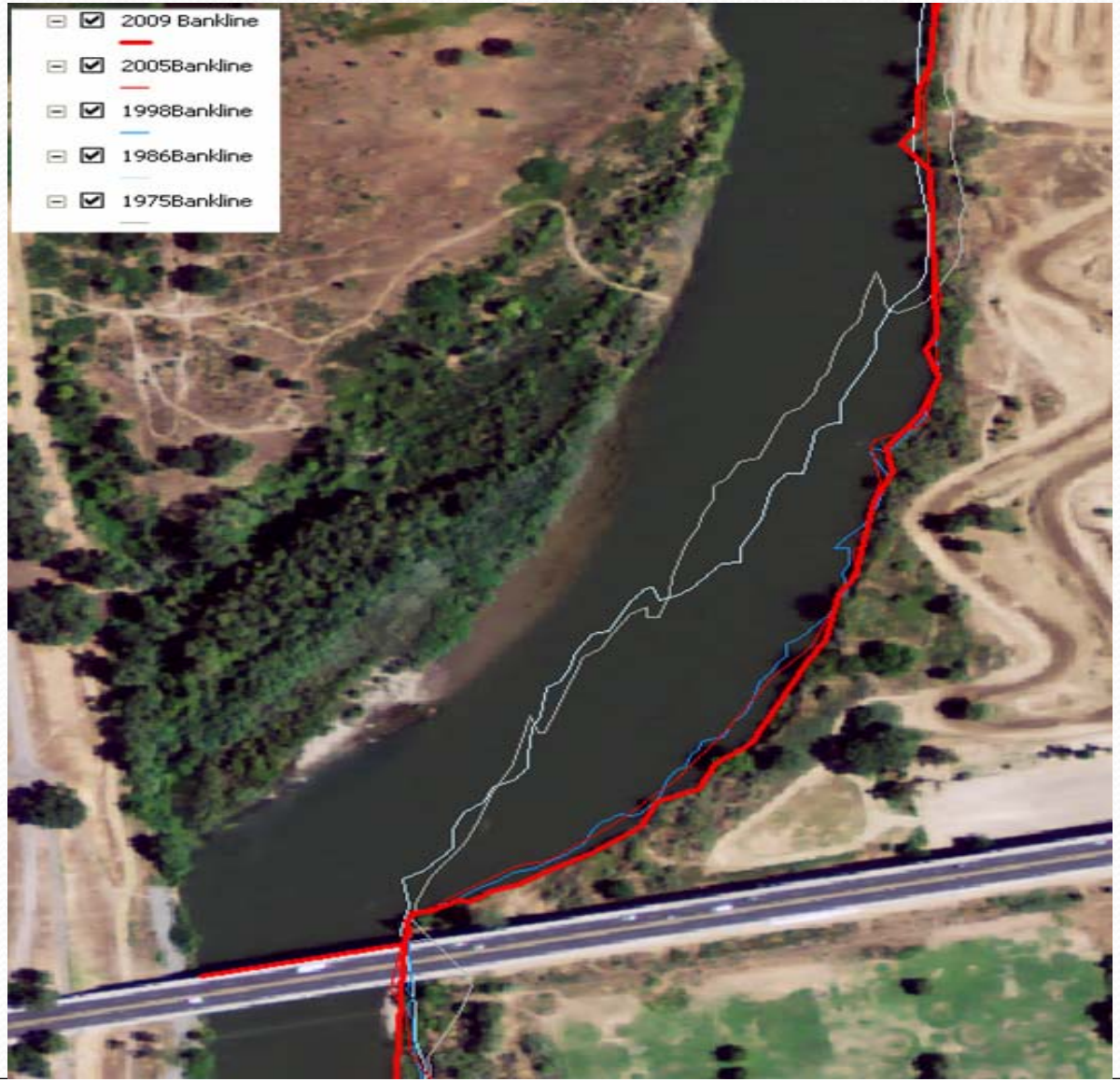

2009

Figure 10 – Erosion of the east bank from 1975 to 2009

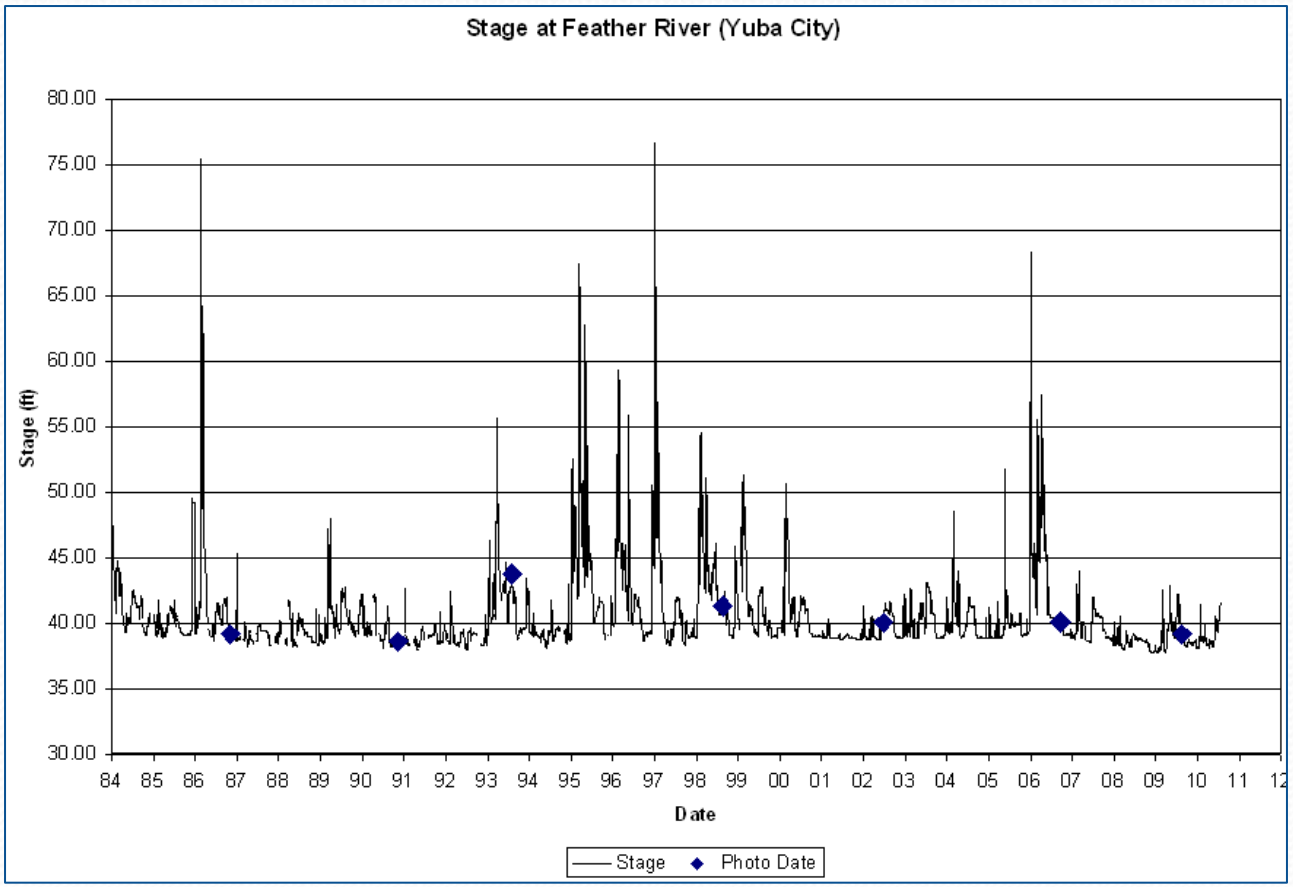



Bank Erosion from 1993 to 2009

It’s Just a Matter of Time

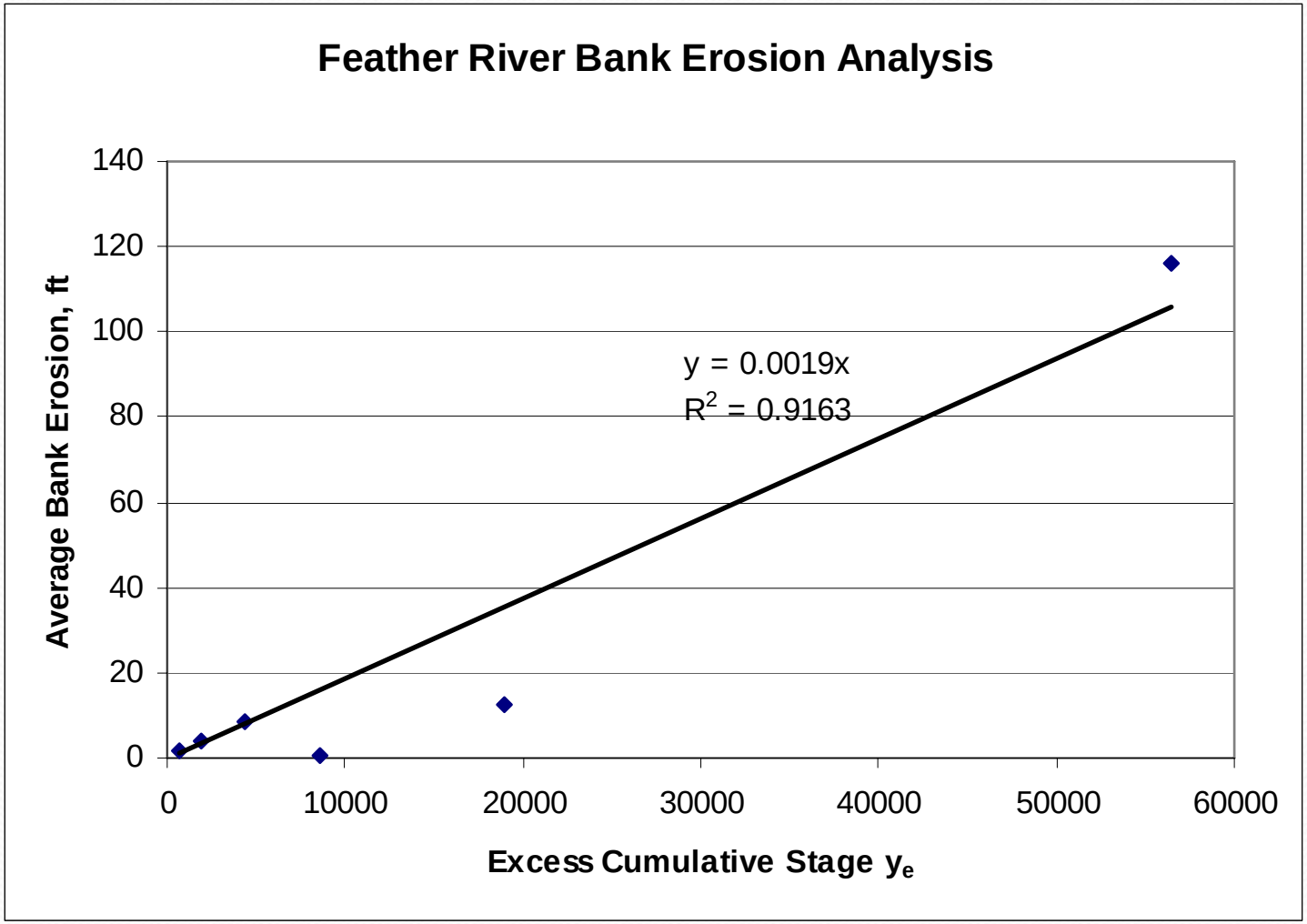
But How Long?

Historic Stages



Recognizing that $\Omega \propto y^{5/3}$ ➔ Need Cumulative Stage

Cumulative Stage – Erosion Rate Relationship



Cumulative Stage per time period

Start Date	End Date	y_{ce}
11/3/1986	11/12/1990	719
11/13/1990	8/13/1993	4392
8/14/1993	8/19/1998	56522
8/20/1998	6/21/2002	8555
6/22/2002	6/30/2005	1897
7/1/2005	8/18/2009	19006

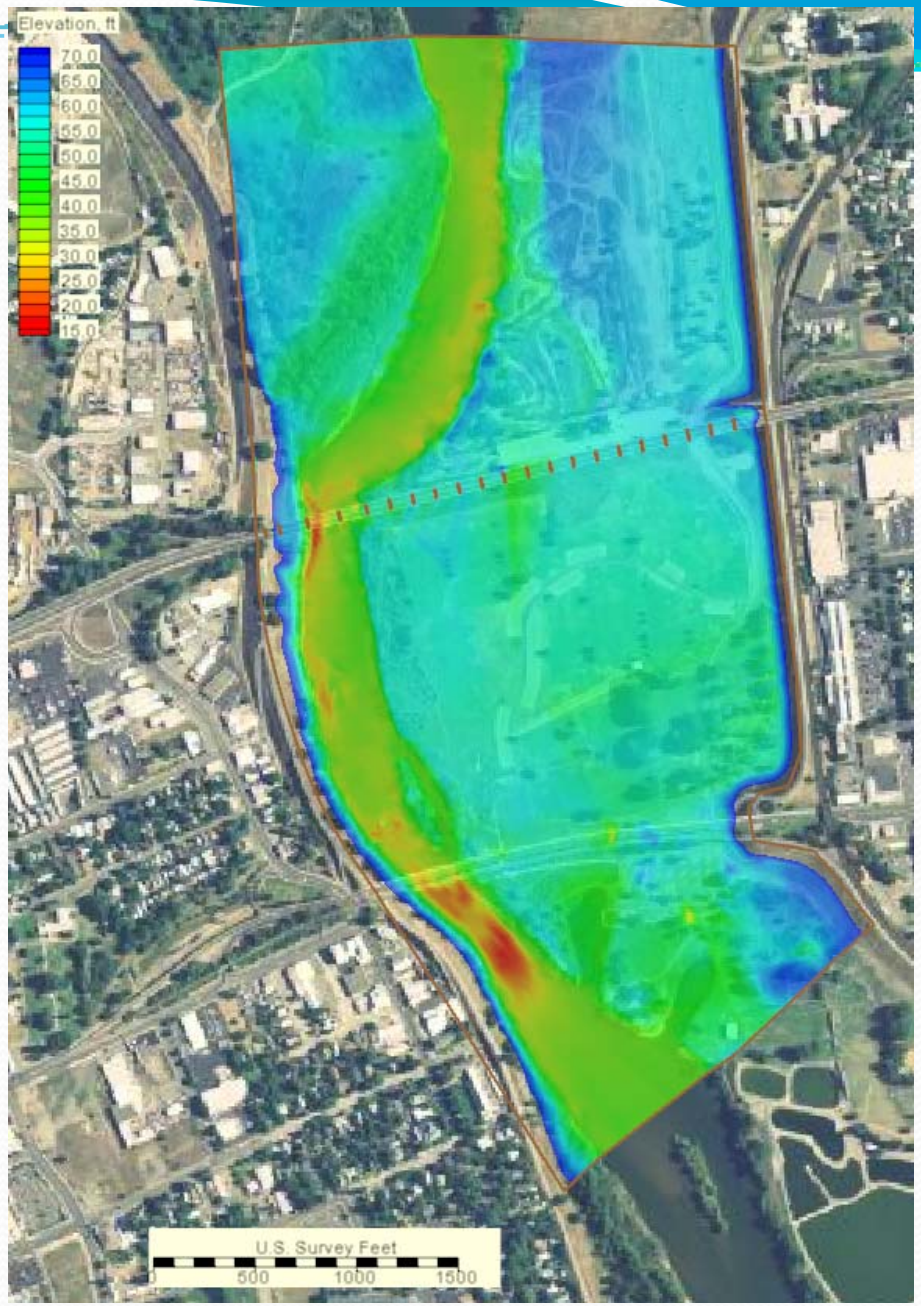
Pier No.	Distance from Bank to Pier Nose, ft	Required y_{ce}
16	285	150000
17	225	118400
18	165	86800
19	110	57900
20	80	42100
21	60	31600

Conclusions

1. A series of flows similar to those between 1993 – 1998 could reach Piers19-21
2. Local erosion rates could be even greater
3. Long-term Piers 16-21 are also vulnerable (possibly more)

Hydraulic Analysis

- Boat Survey
- GPS Survey
- Total Station Survey
- DEM Data

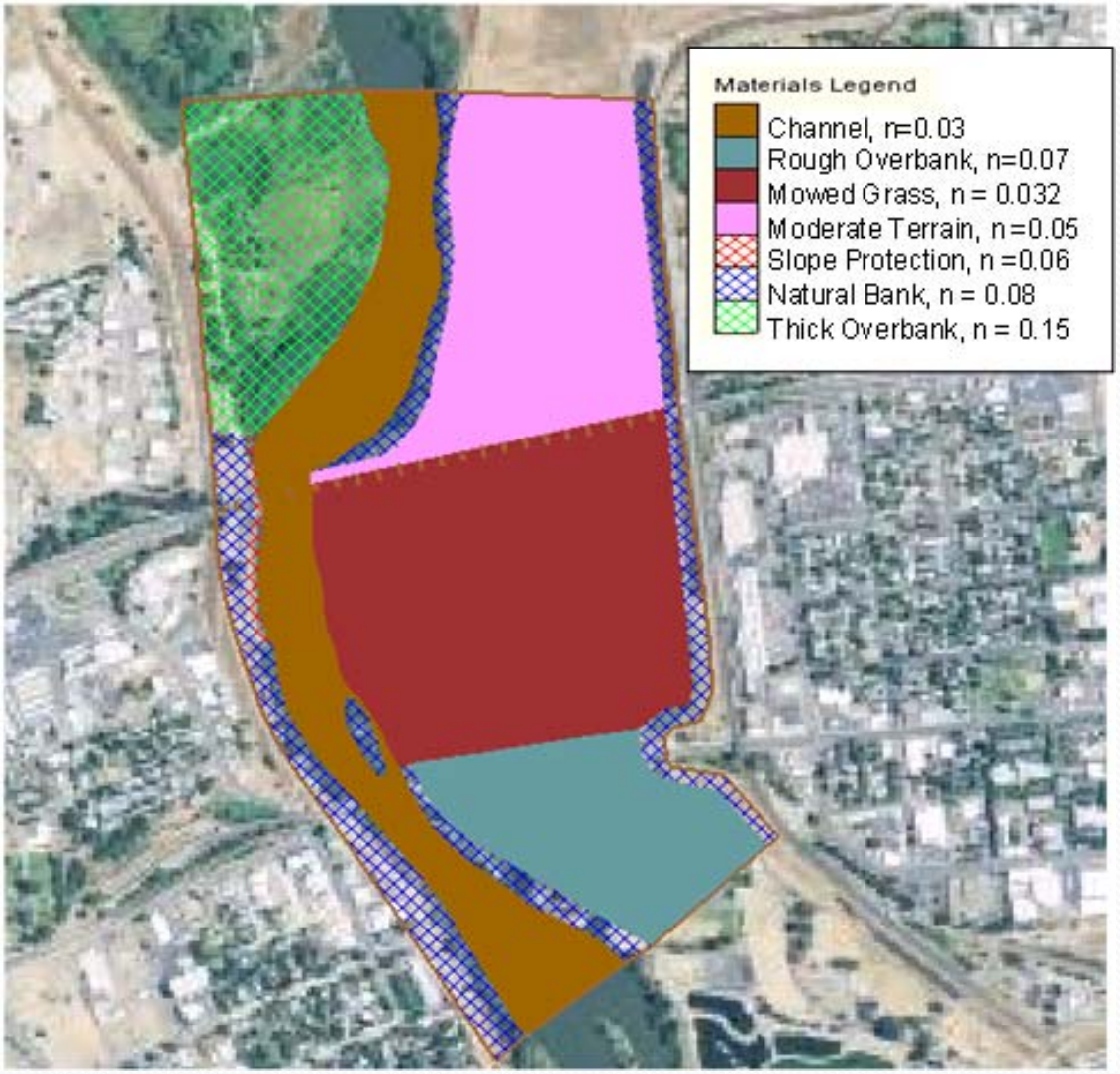

Elevation_ft
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
U.S. Survey Feet
0
500
1000
1500

2-D Model developed using Surface-Water Modeling System (SMS)

30,000 elements

Q = 160,800 cfs

WSEL = 71 ft

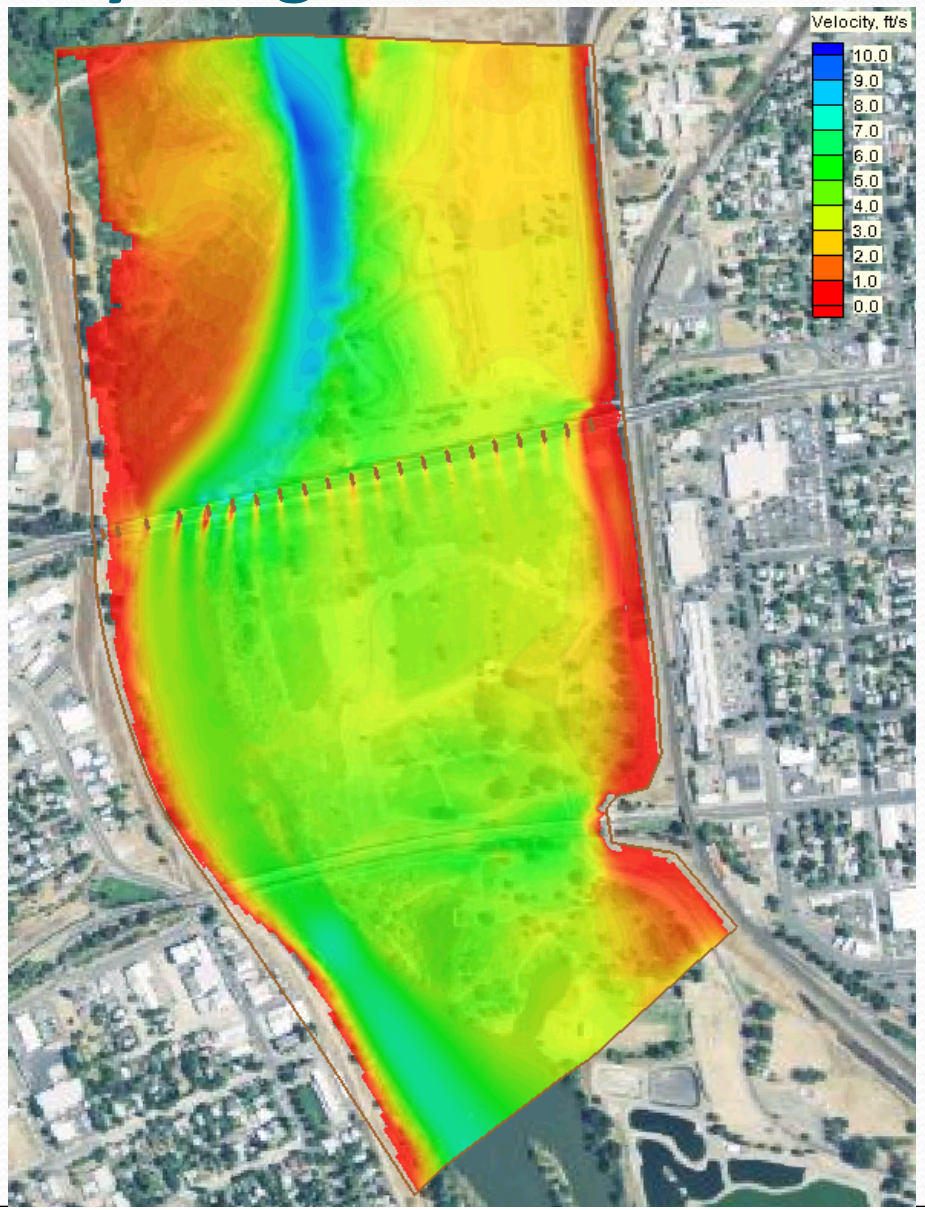


Velocity Magnitudes

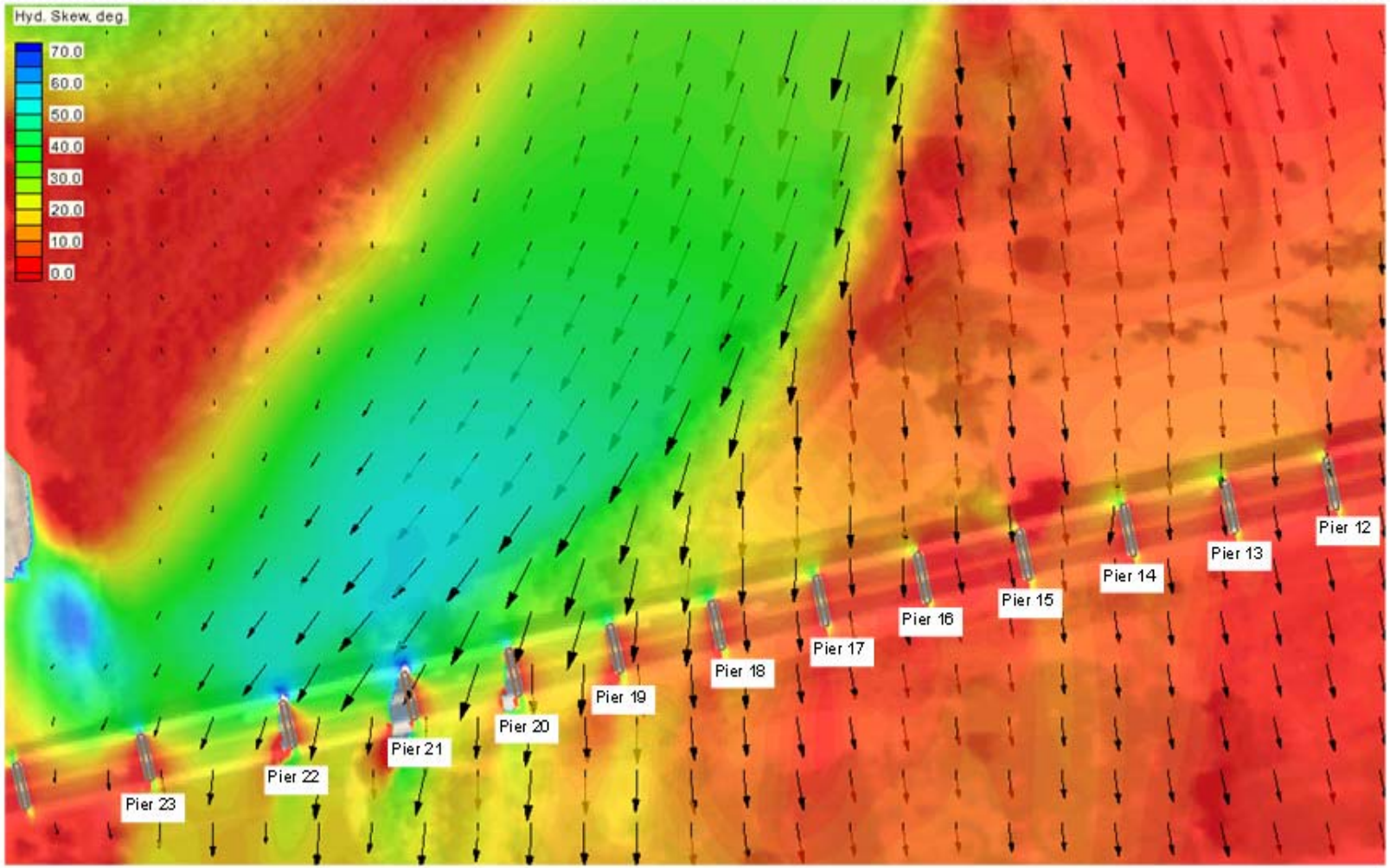
Peak Velocity = 9.5 ft/s

At Bridge, V = 3.5 – 6 ft/s

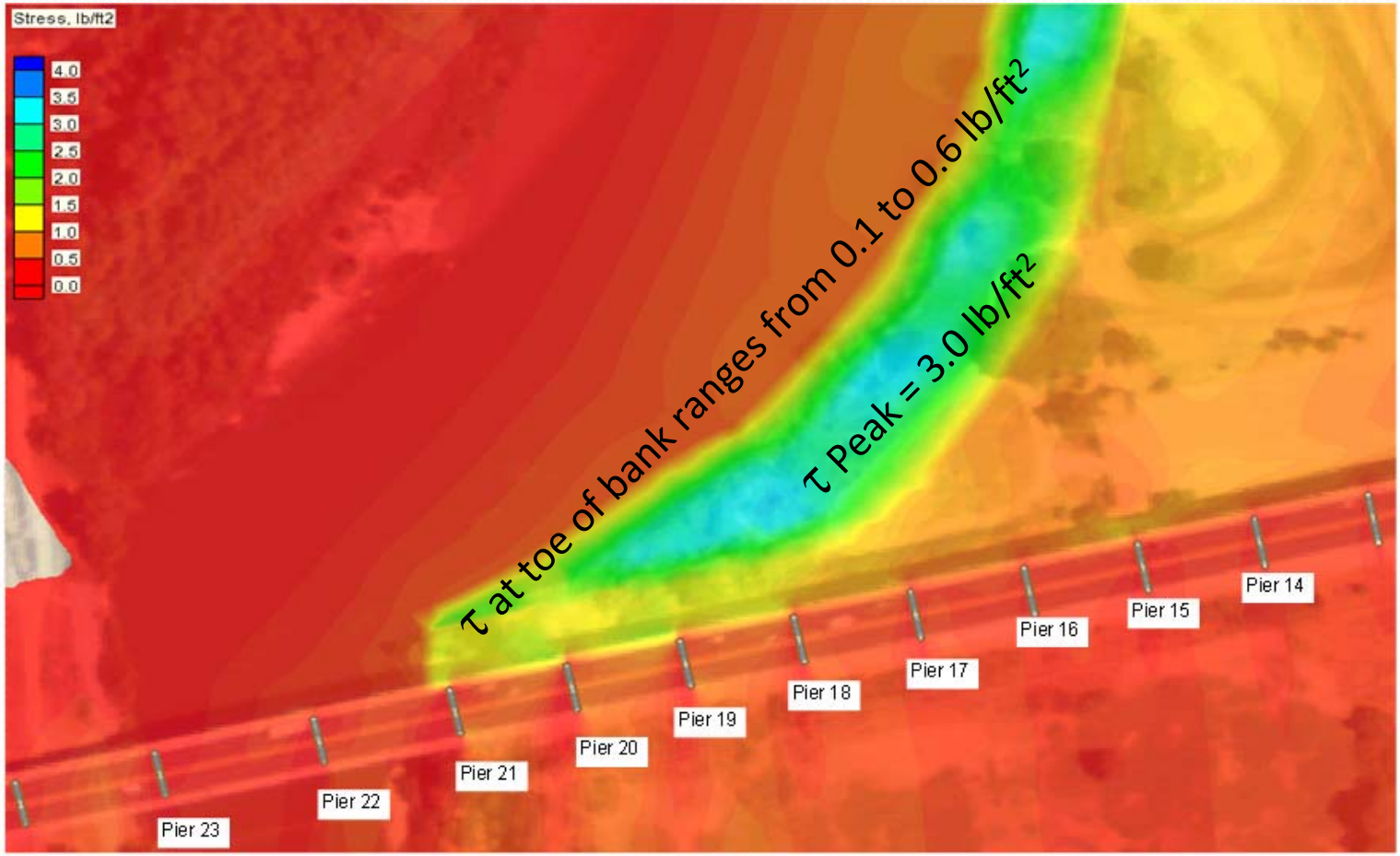
In the overbank, V = 3 to 6 ft/s



Hydraulic Skew – 40 to 50 degrees typical



Shear Stress along the East Bank



$$\tau = \gamma y S$$

where γ = weight of water,
y = depth
S = the Energy Slope

Critical Shear Stress for Various Grain Sizes

Class Name	D_{50}, in	τ_{cr}, lb/ft^2
Fine Sand	0.01	0.003
Medium Sand	0.02	0.004
Coarse Sand	0.08	0.006
Fine Gravel	0.3	0.06
Medium Gravel	0.6	0.12
Coarse Gravel	1.3	0.25
Small Cobbles	5	1.1
Large Cobbles	10	2.3

Banks are composed of loose sand with some medium gravel

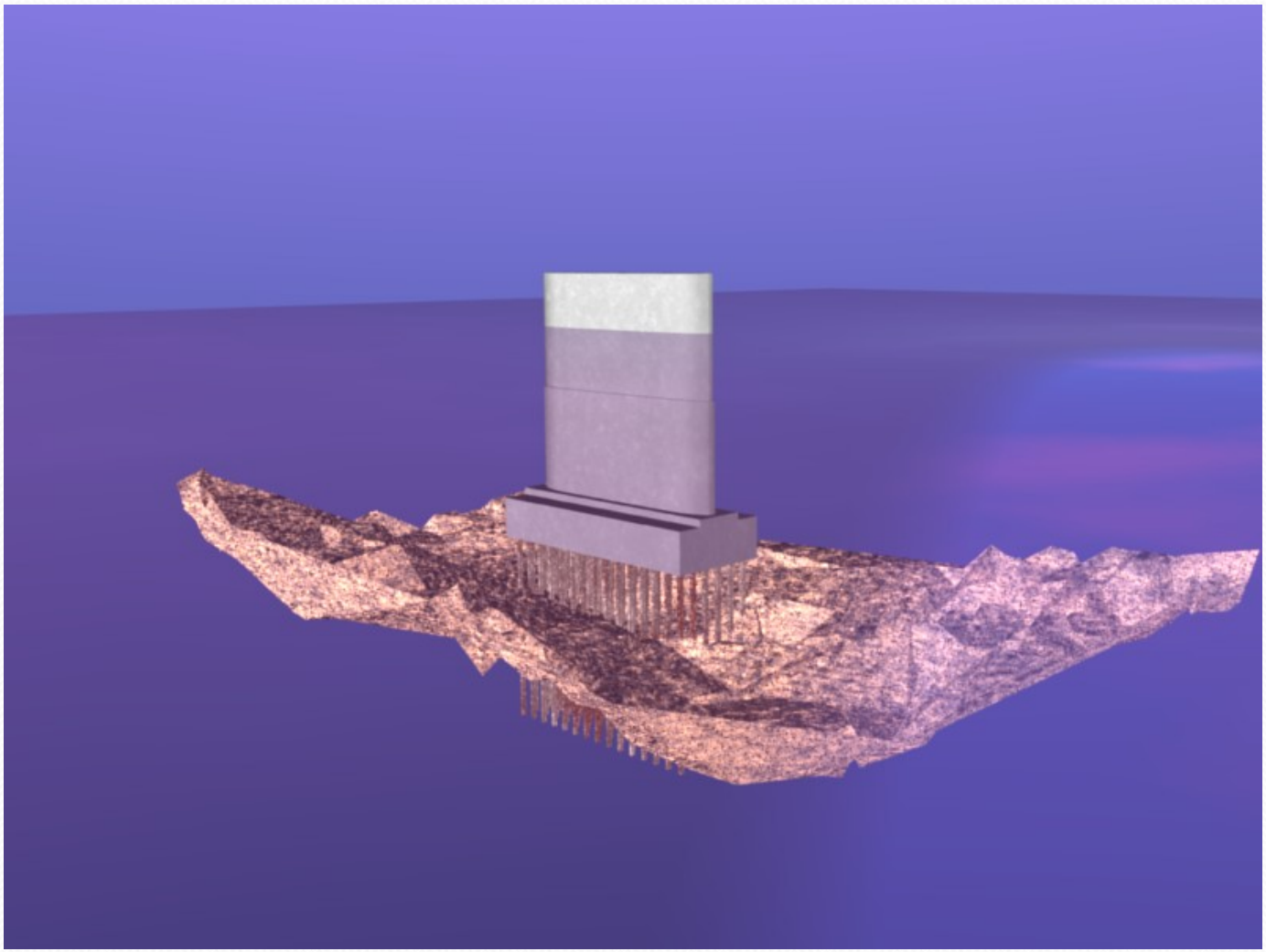
τ_{cr} = 0.12 1b/ft^2

➔ Stress at the bank will exceed τ_{cr} and easily erode the bank

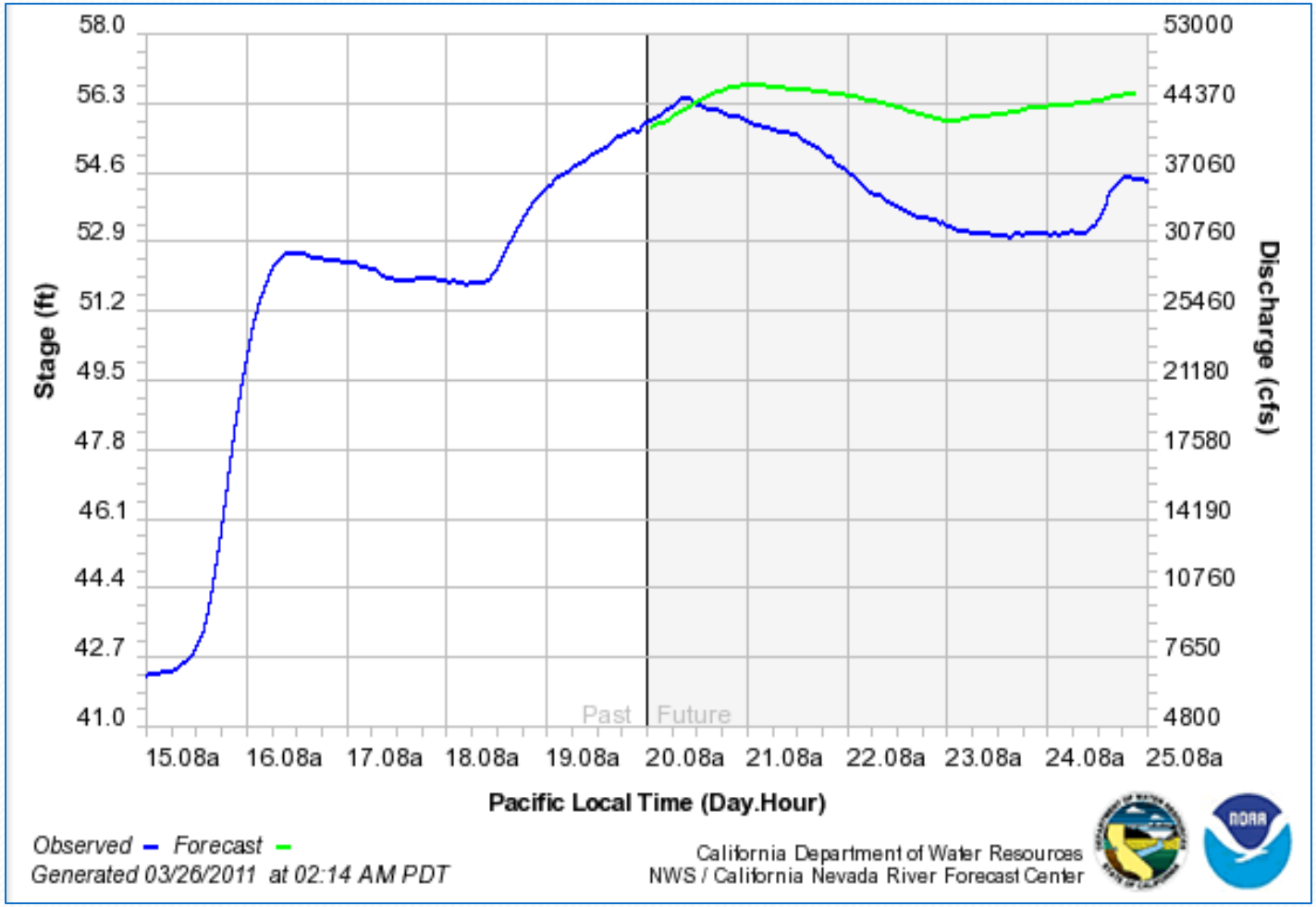
Advanced Study Recommendations

- Continue with Riprap Project for main channel piers
- Meet with outside agencies (City, County, USACE) to discuss interest in protecting the east bank
- Develop either a river training project or substructure retrofit or replacement project depending on cost/benefit analysis

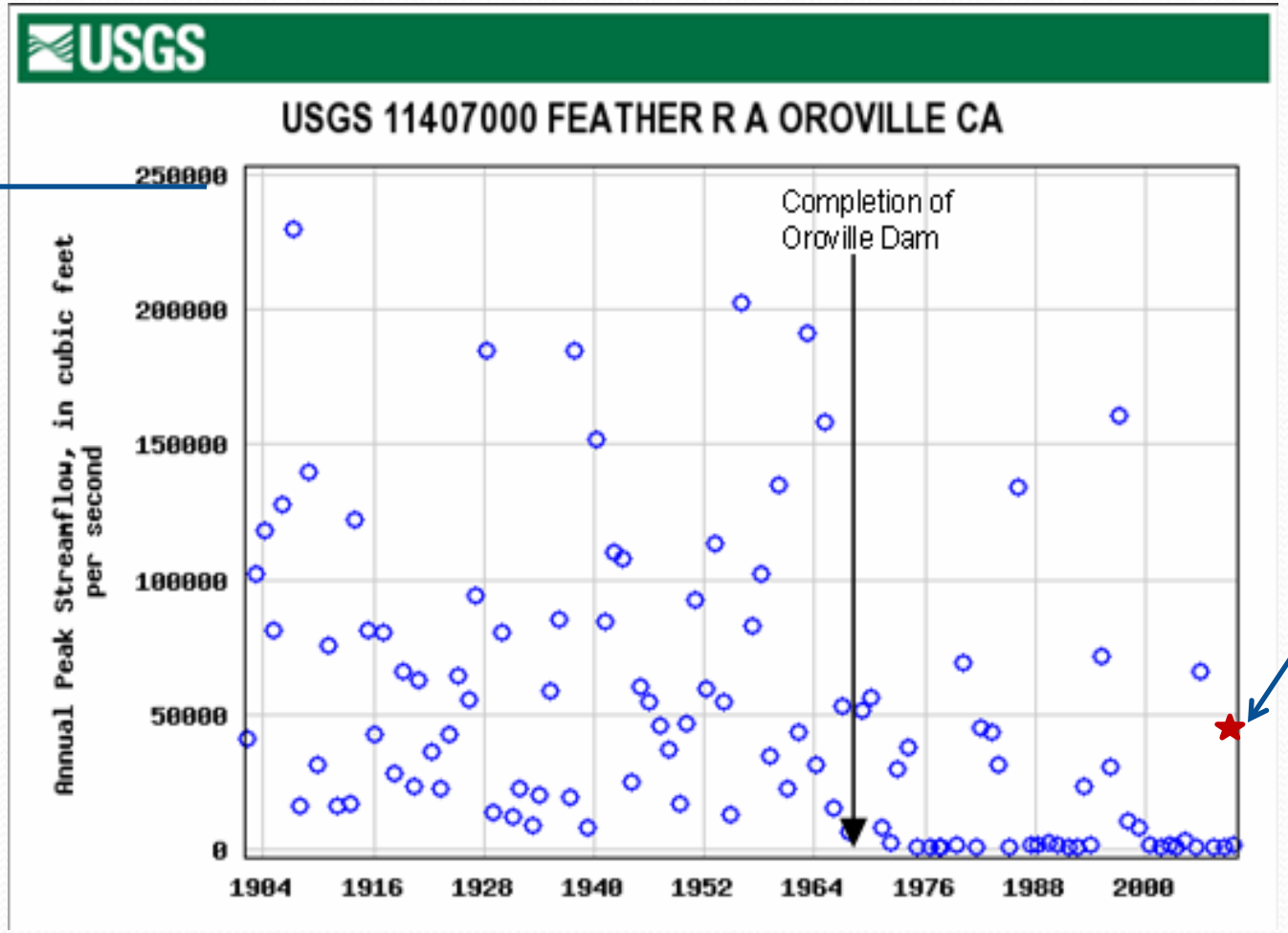
Real-time Scour Measurements during March 2011



March 2011 High Flow



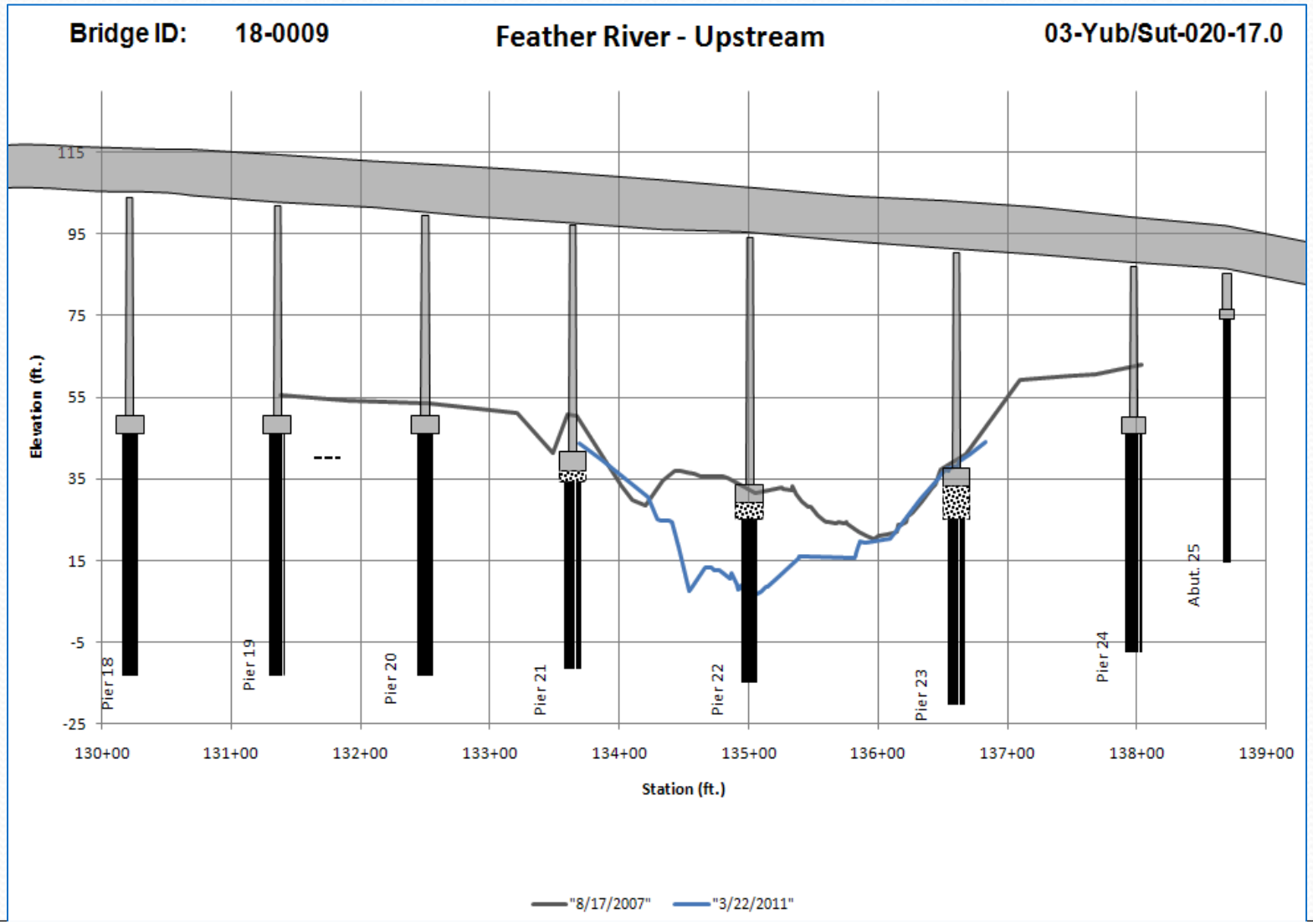
March 2011 - Relatively Small Flow Event



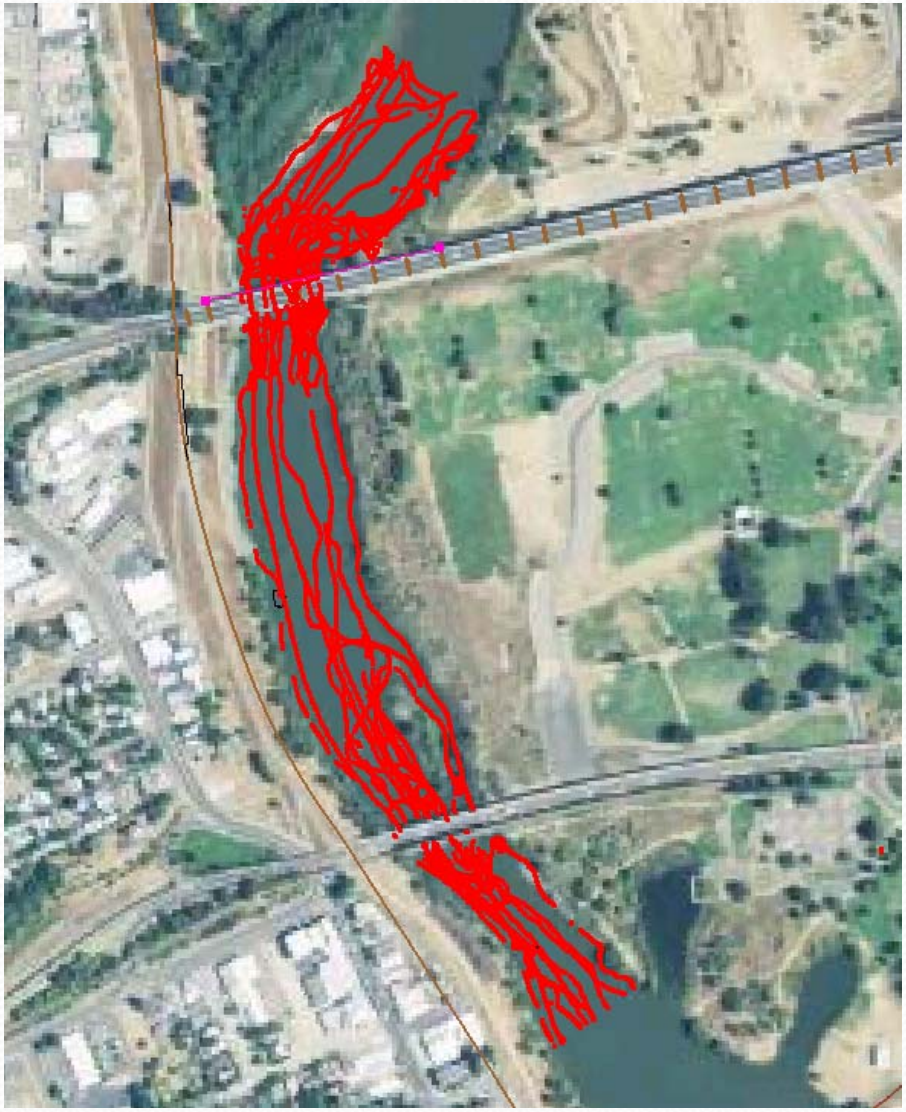
Sonar Survey on March 22, 2011

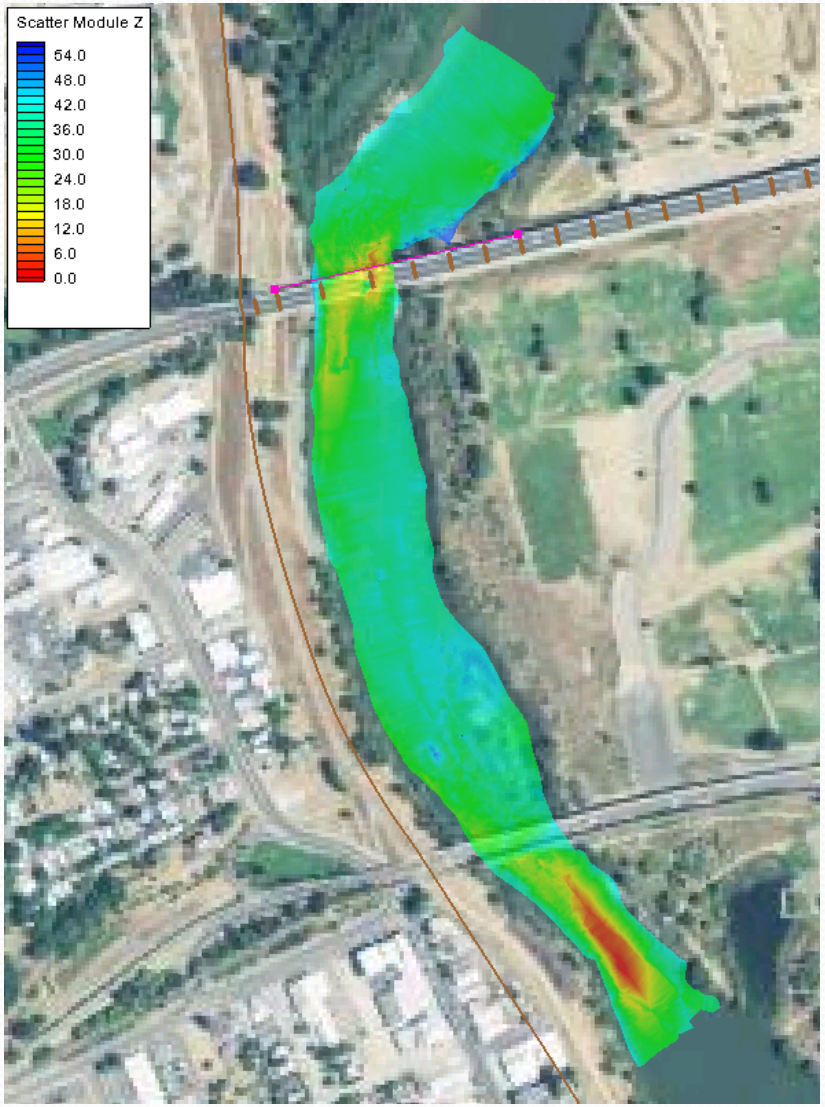
Change is X-Section

Approximately 30 feet change at Pier 22



Survey on March 28, 2011





Ba

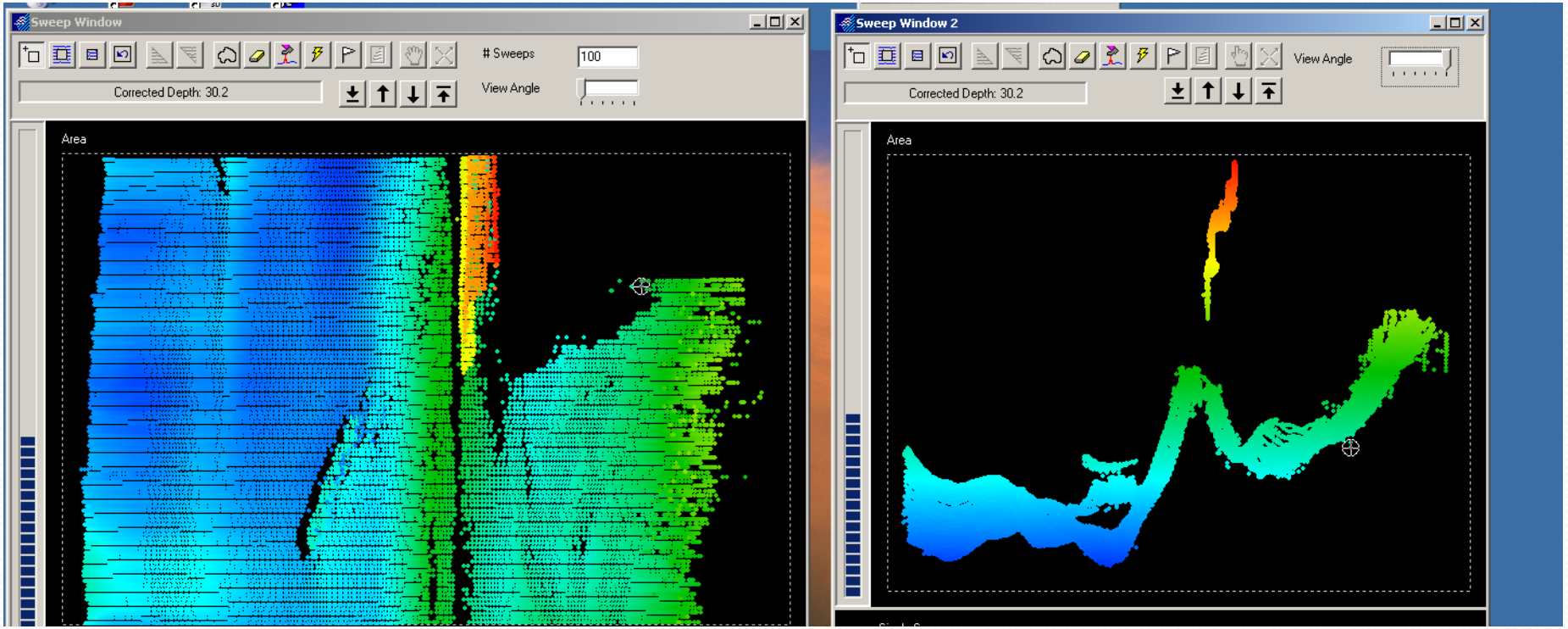
B

Emergency Peer Review Meeting

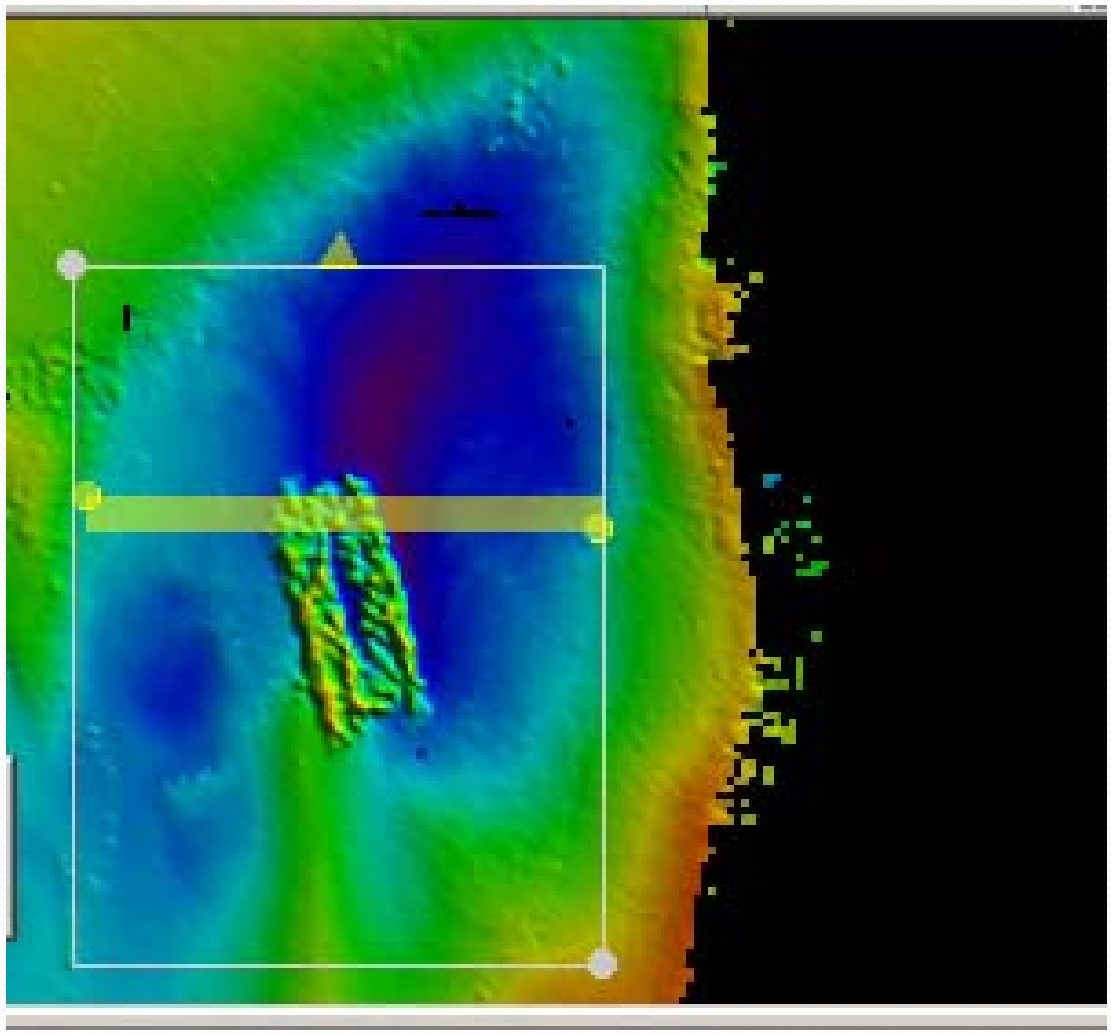
- Current Scour was approximately 5 feet above predicted 100-year Scour Elevation
- Pile Capacity was reduced to an unacceptable safety factor
- Structural Analysis indicated that the piles may be overstressed in compression at their maximum exposure length
- Recommendations:
  1. Multi-beam Sonar Survey
  2. Immediate Bridge Monitoring

Multi-beam Survey on March 30, 2011

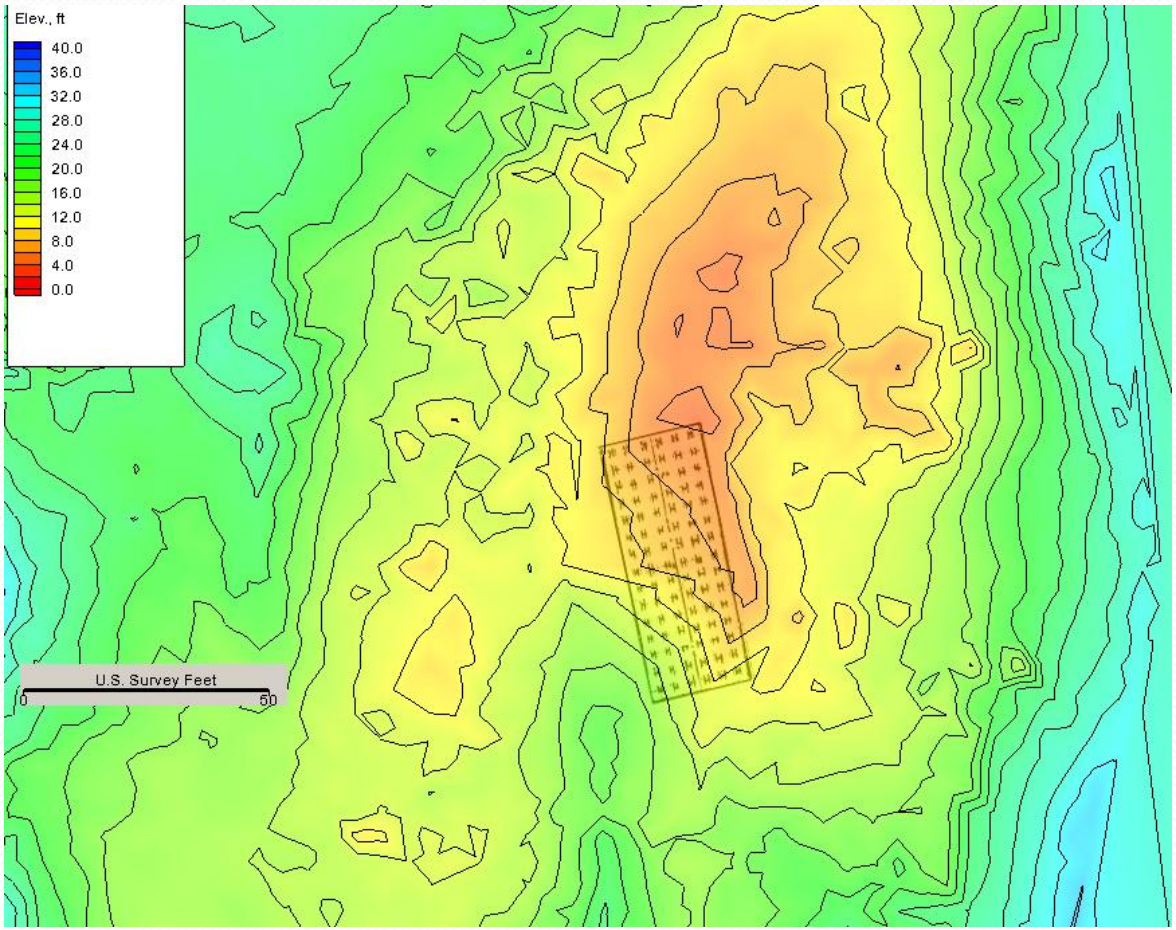
Multi-Beam Survey on March 30, 2011



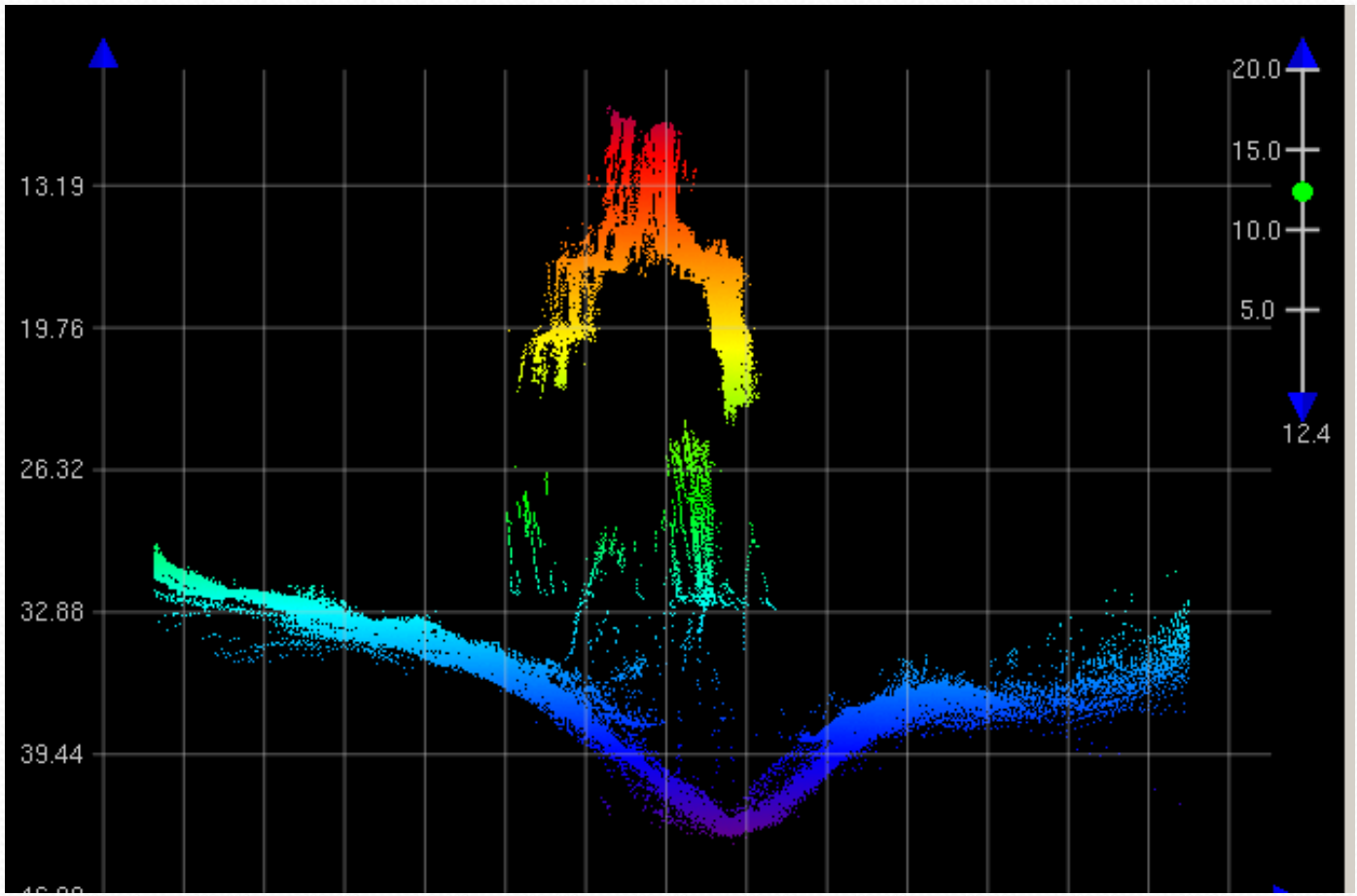
Multi-beam Bathymetry



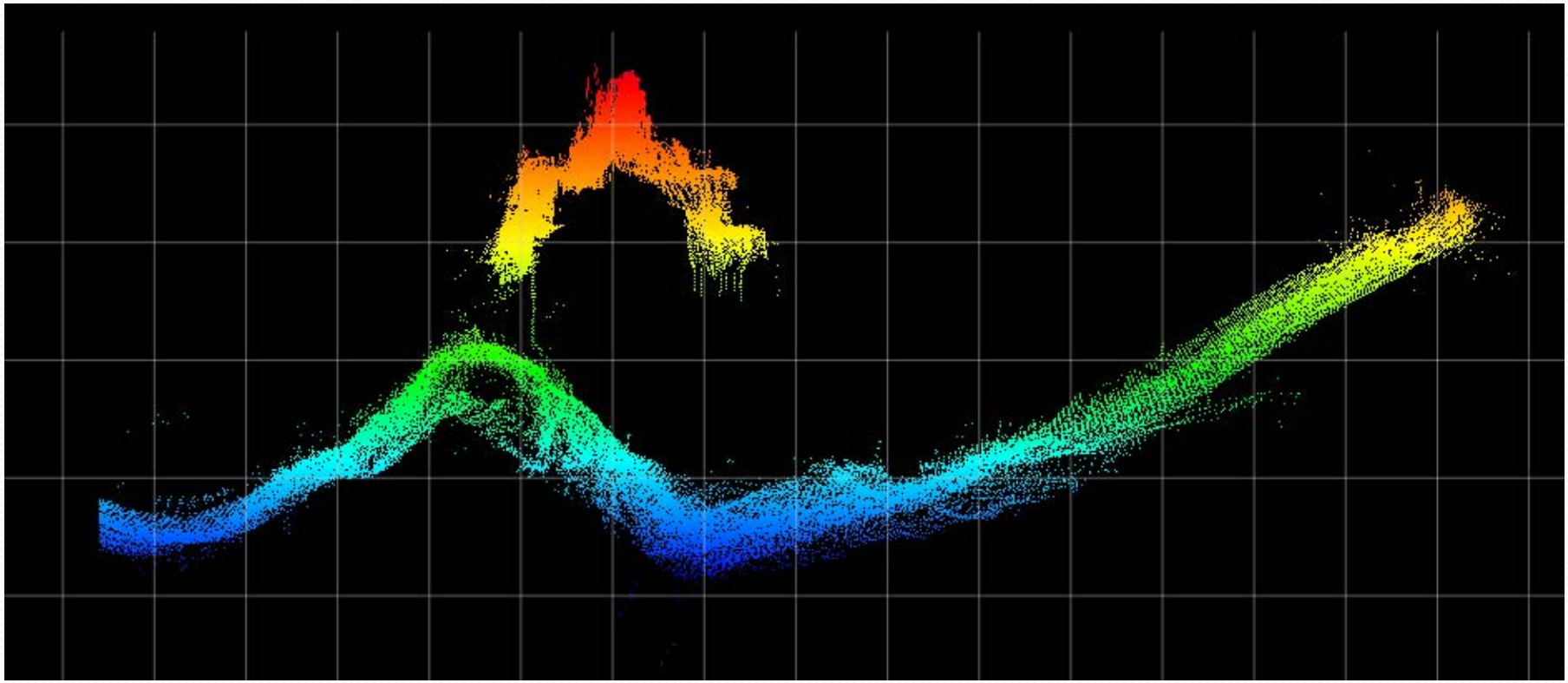
Multi-beam Bathymetry



Upstream Section



Downstream Section



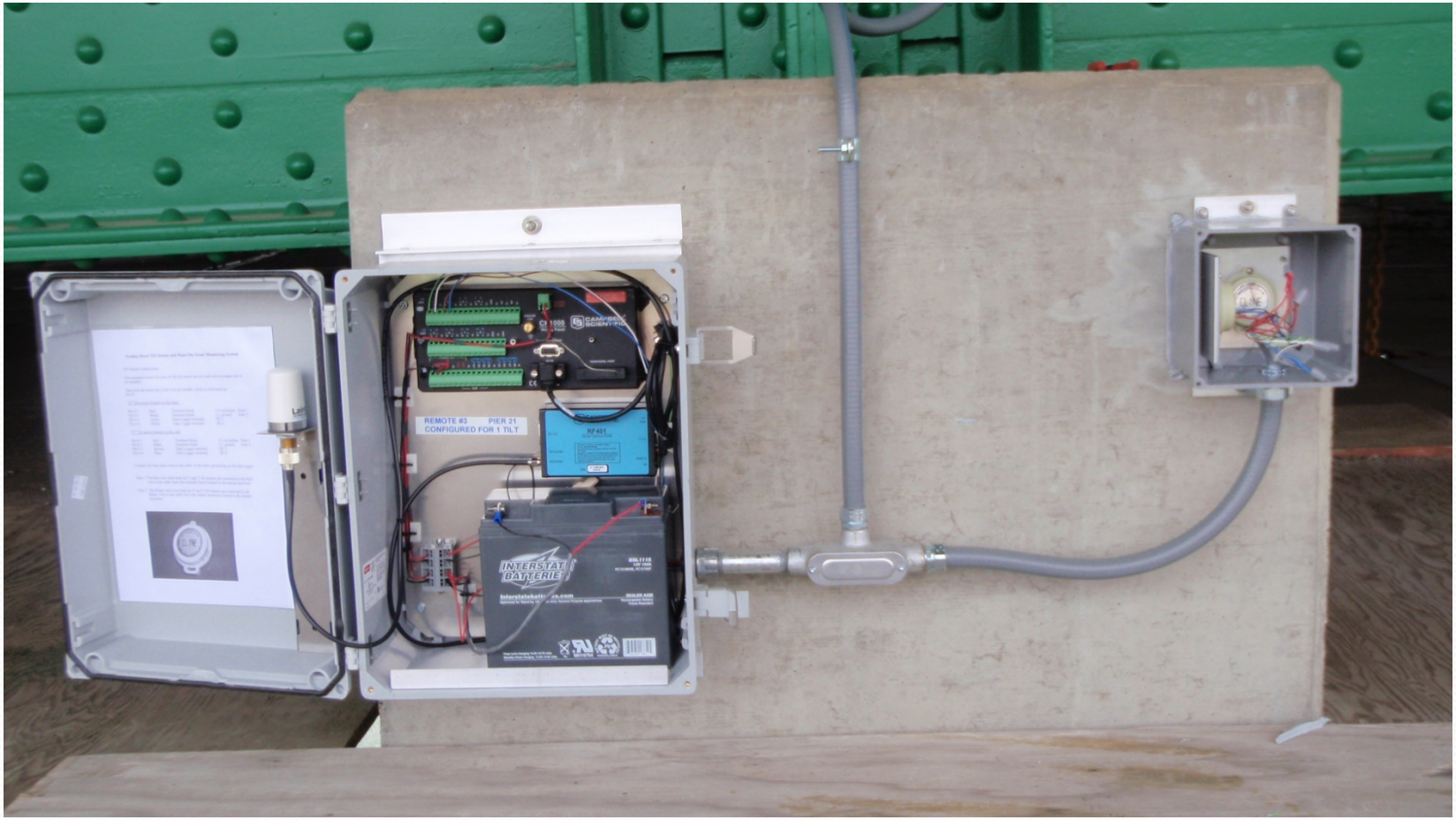
Multi-Beam Survey Conclusions

- Survey confirmed 30 feet of scour present at upstream side of the pier
- Less scour at the downstream, west side which explained by structure was not showing signs of distress
- Monitoring and Mitigation was still justified

Monitoring Strategy

- Immediate Around the Clock Deck Survey
- Temporary Tilt Sensor on Main Channel Pier
- 6 Biaxial Tilt Sensors on 5 Vulnerable Piers
- 12 Float-Out Alarm Sensors in the Overbank
- Data Hosted by Northwestern University with Text/Email Alarm notification

Tilt Sensors Instrumentation



Tilt Sensors Instrumentation

Float-out

Data Hosted by Northwestern University

INFRASTRUCTURE TECHNOLOGY INSTITUTE

Feather River Bridge #18-0009

STRUCTURAL HEALTH MONITORING

NORTHWESTERN UNIVERSITY Infrastructure Technology Institute

ABOUT THE PROJECT

Feather River Home
Feather River Documents
Scour Monitoring Home

LONG-TERM DATA

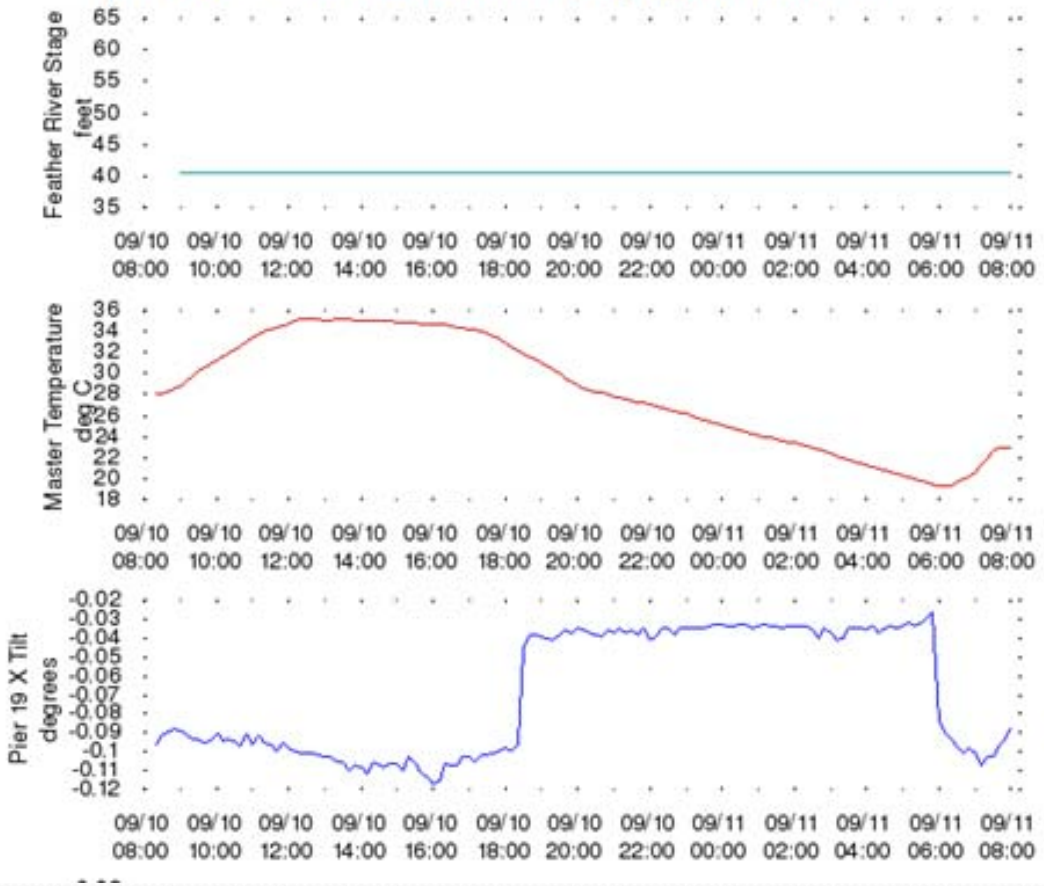
Past 24 Hours
Past 72 Hours
Past Week
Past Month
Past 90 Days
Entire Project
Custom Date Range

CONTACT US

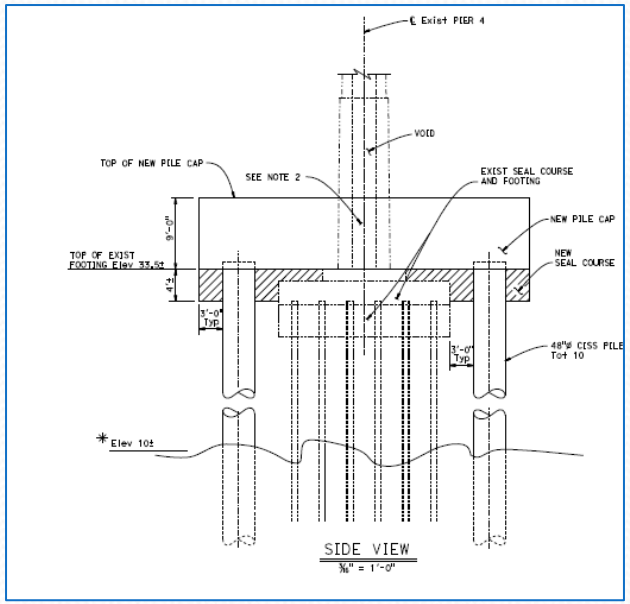
NU-ITI
2133 Sheridan Rd
First Floor
Evanston, IL 60208
Tel: 847-467-6684
dkosnik@northwestern.edu

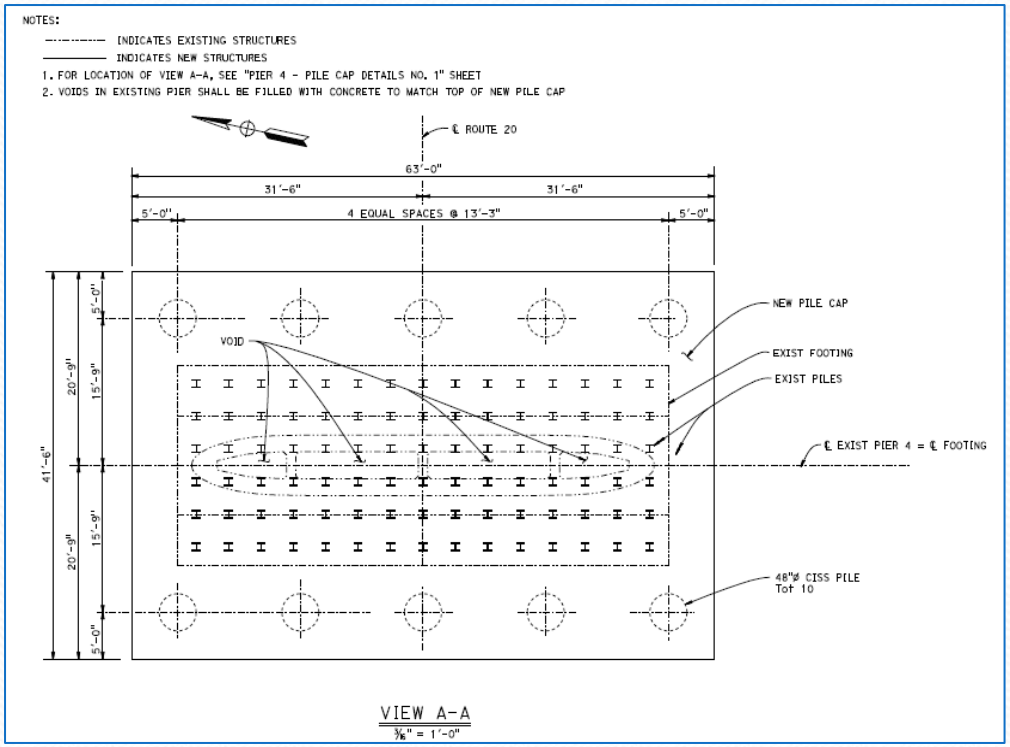
Hourly Data

past 24 hours -latest data taken Sun, Sep 11, 2011 08:00 PST

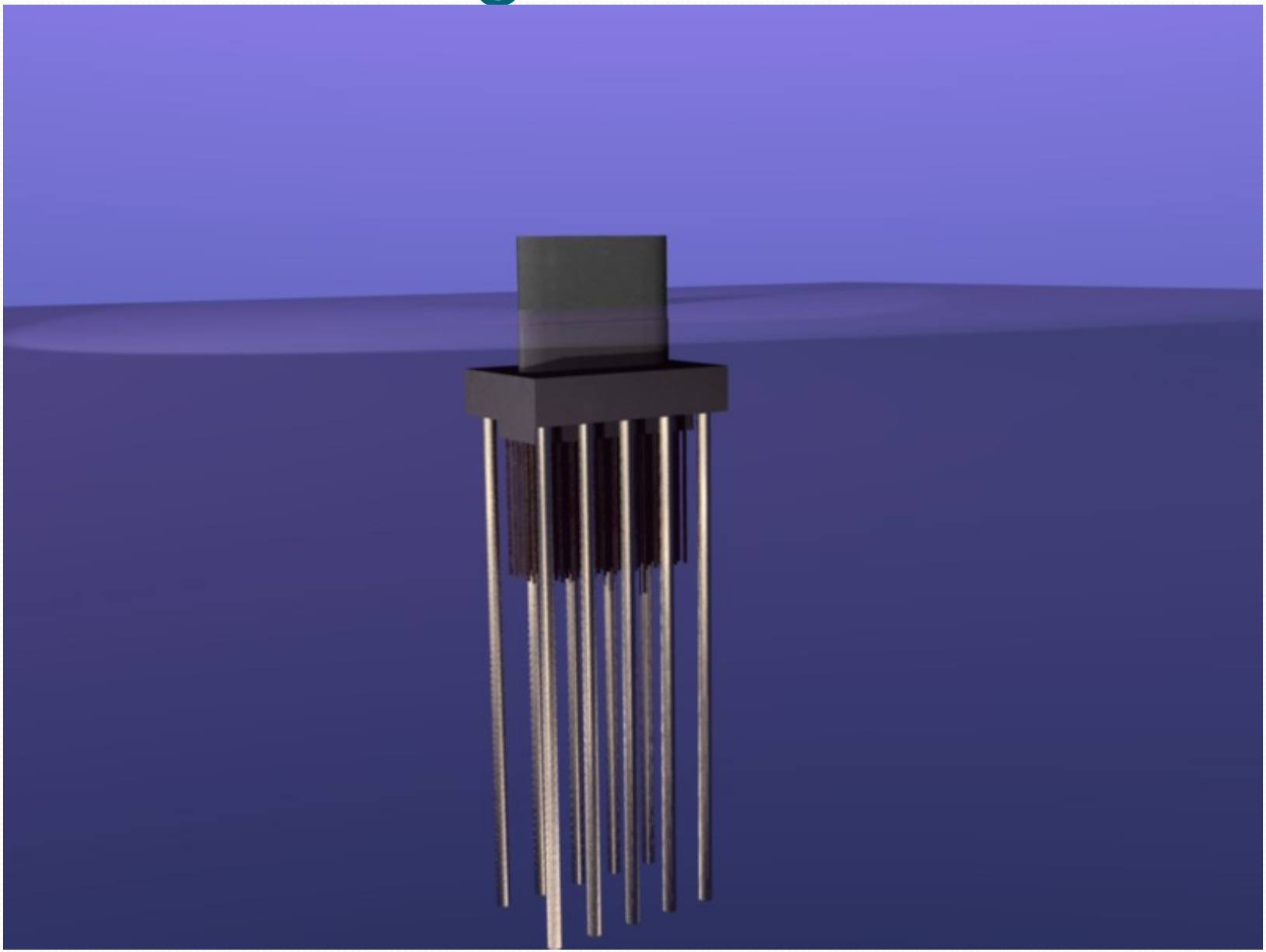


Supplemental Pile Retrofit Design

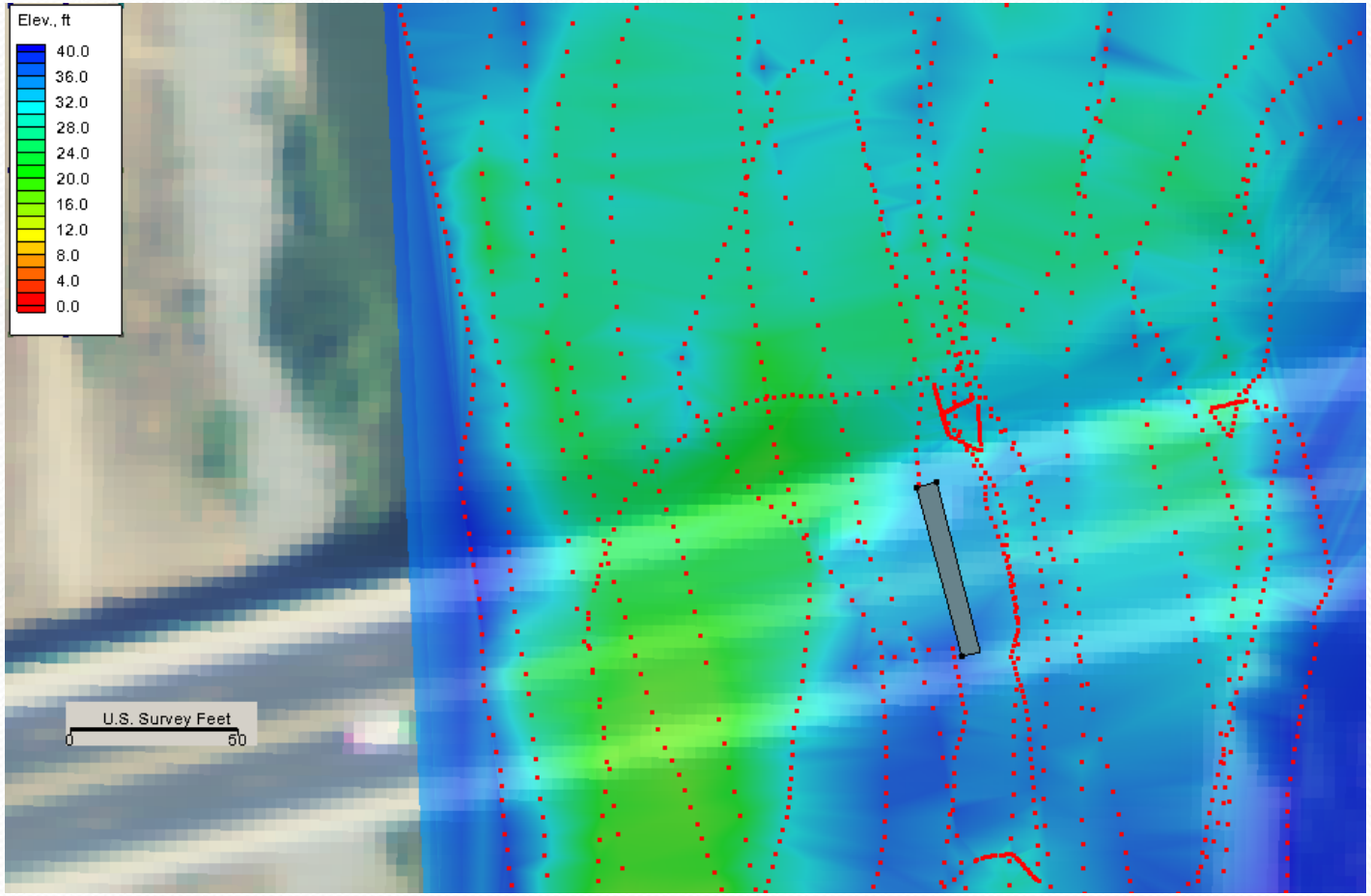




Retrofit Design



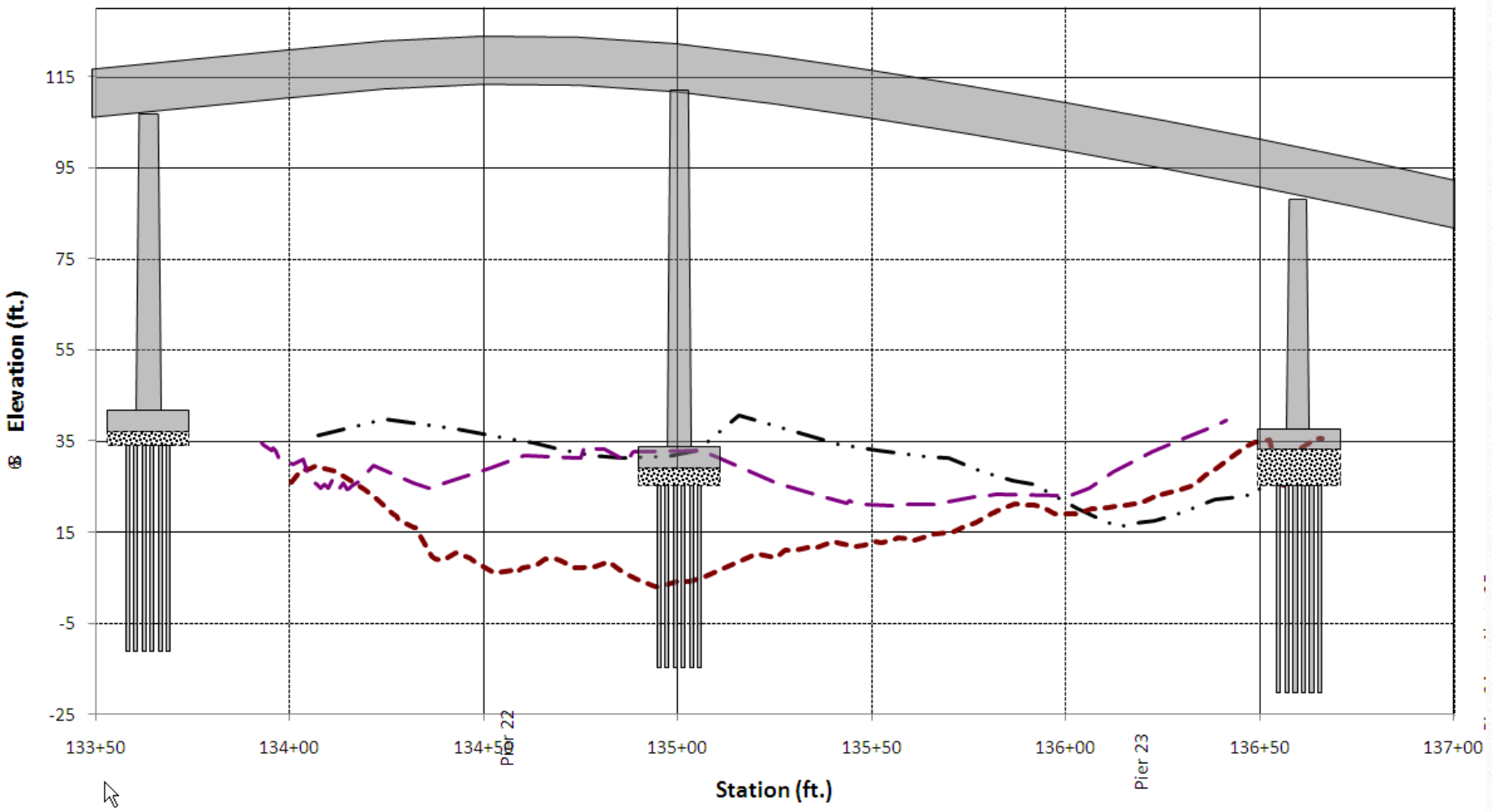
May 28, 2011 Re-Survey



Bridge ID: 18-0009

Feather River - Upstream

03-Yub/Sut-020-17.0



Lessons Learned

- It doesn't take a Q_{100} to create deep scour given long-term changes in the river morphology
- Having accurate bathymetry prior to flood events is of great value
- Recording scour during (or shortly after) the high flow event is critical to understanding the flows impact on the bridge
- 2-D Modeling is a valuable forensic and design tool for estimating hydraulic skew, velocities, etc.

Questions?