Impacts of River Restoration on Bridges

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THE UNIVERSITY OF ARIZONA

CIVIL ENGINEERING ENGINEERING MECHANICS 1905

River Restoration

- River restorations is to return rivers to its natural hydrological and ecological functionalities, and enhance river’s recreational values.
- River restoration often needs to stablize incised main channel and return flows to floodplain to enrich riparian areas.
- Depending on the restoration objective, the ultimate measures of restoration success can be stream stability, water quality, riparian health, or instream habitat.

Bridges on Incised Channel

- **Urban runoff** and **climate changes** causes more severe storms on rivers in arid and semi-arid regions, bed degradation and bank erosion causes the pier of the North Shore bridge exposed 20-30 feet.

North Shore Bridge on Las Vegas Wash

Bridges on Aggraded Channel

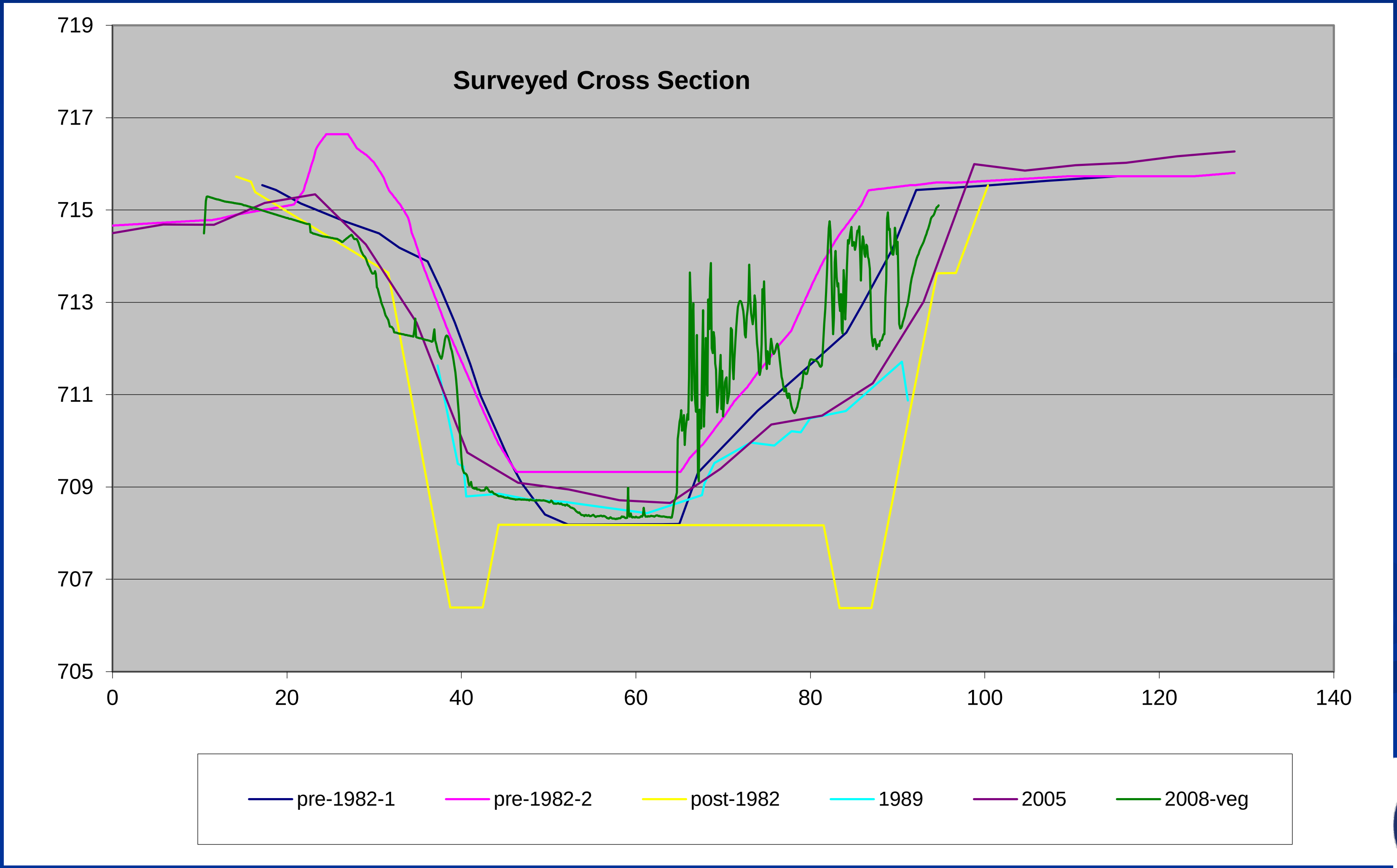
- Stream restorations often overlook the flood capacity of bridge and culvert infrastructures and over-emphasize the recovery of riparian vegetation
- The consequence is excessive sedimentation in the channel and significantly reduces the geometry of cross sections near the bridge/culverts and causes the reduction of flow conveyance for those bridges/culverts

Congress Street Bridge on Santa Cruz River

Over Vegetated Bridge Section

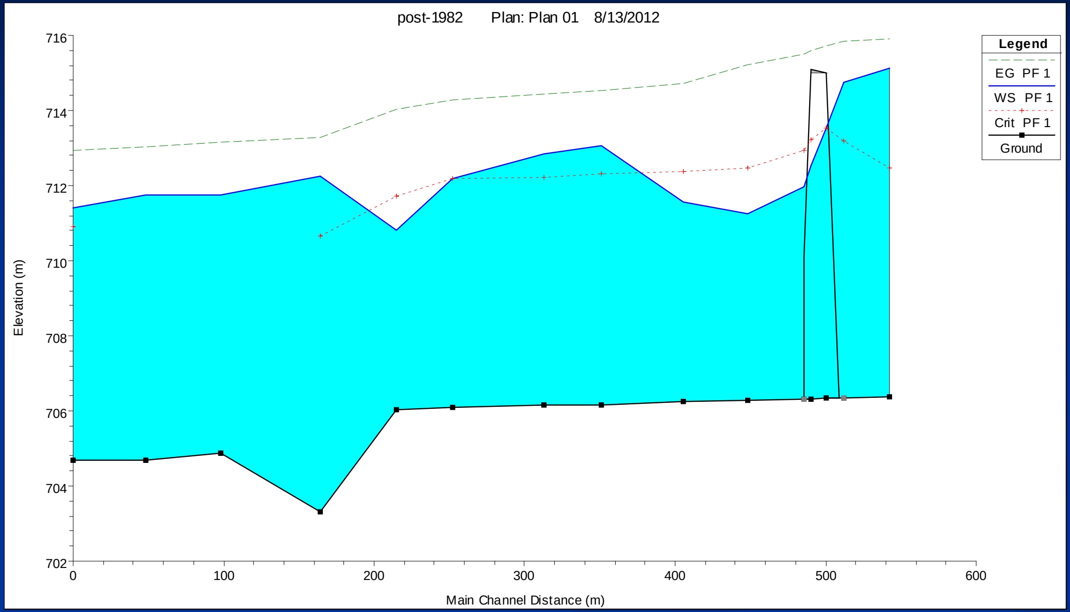
Twin Peak Bridge on Santa Cruz River

Surveyed Cross Sectional Changes

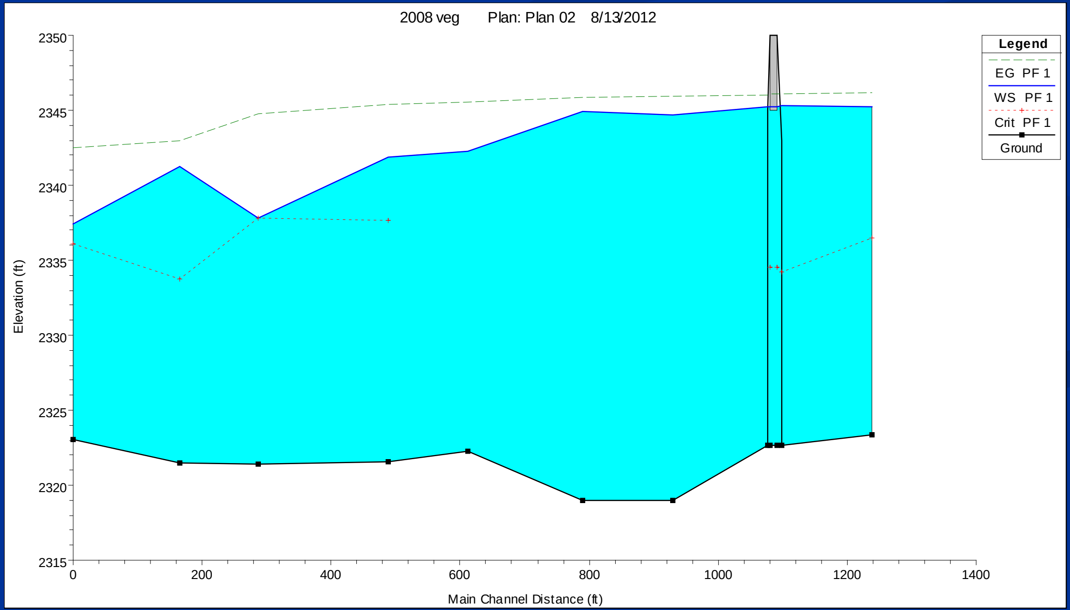


HEC-RAS Simulated Flow Profile

Post – 1982
Construction
Design
Q = 60,000 cfs

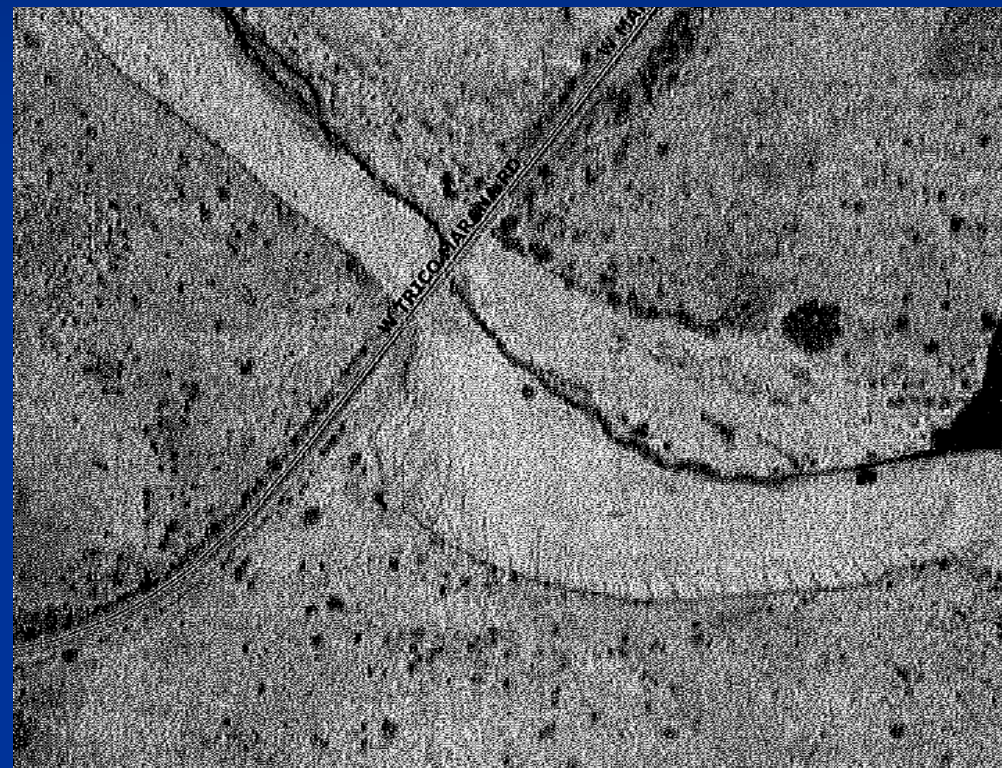


2008 Vegetated
channel
Capacity
Q = 27,000 cfs



Bridges in River Meander

- In addition of erosion/deposition, **river planform is evolving,** especially meandering channels are migrating gradually as bank erodes and sand bars form.
- As channel planform evolves at the upstream/downstream reaches, flow path can be switched to the left or right of the bridge section that **undermine the abutments.**



Trico – Marana Bridge on Santa Cru
River (1996)

Bridges in River Meander

Trico – Marana Bridge on Santa Cruz River (2010)

Restoration for Bridges

Therefore, to ensure the safety and functionality of bridges, river restoration should consider the impacts of flow variability on sediment transport, local scour, and river planform changes. Three basic types of restorations are classified:

- stabilize bridge/culvert crossings due to unfavorable erosion
- restore conveyance of culvert/bridges from excessive deposition and vegetation growth
- re-align flow paths under bridge/culvert crossings

A reliable computational model for flow and sediment transport is essential to evaluate the impacts of river modifications on river morphodynamics.

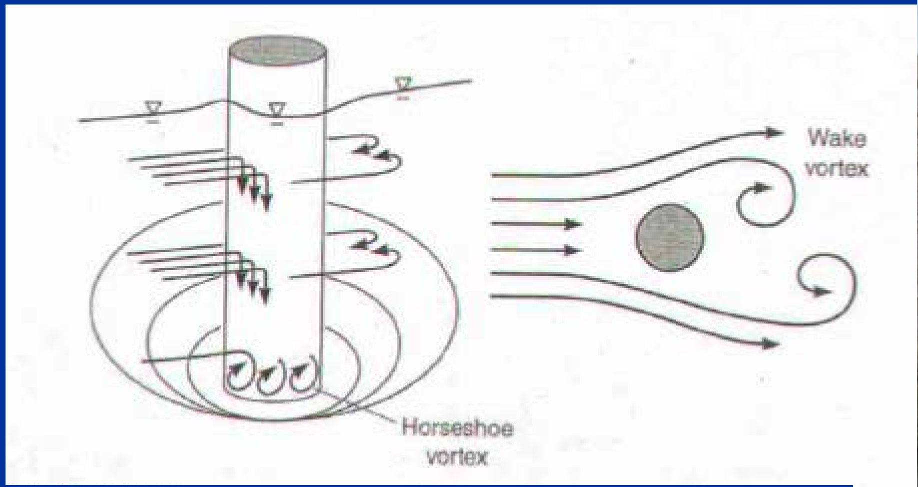
Computational Hydraulic and River Engineering Two-dimensional Model – CHRE2D

- Two-dimensional depth-averaged variable-density hydrodynamic model, where flow density is a function of sediment concentration (Duan, JHE, 2004; Yu and Duan, JHR, 2012; Yu and Duan, JHE, 2014)
- Flow field solution was enhanced by including the simulation of channel curvature induced secondary currents
- Sediment transport simulation is developed for multiple-grain sized sediment mixture (Duan and Nanda, JH, 2006)
- Non-equilibrium sediment transport model is adopted which enable the simulation of channels in non-equilibrium state
- Bank erosion module can simulate fluvial processes including meandering migration as a result of bank erosion (Duan and Julien, ESPL, 2005; Duan, JHE, 2005)

Bridge Contraction/Local Scour

Local scour occurred because of increased flow velocity or shear stress either due to increased flow discharge (e.g. tributaries) or narrowed cross section (e.g. contraction due to bridge piers).

Below is a picture of scoured bridge piers at the North Shore bridge on the Las Vegas Wash. The channel has incised about 50ft in the past 20 years.

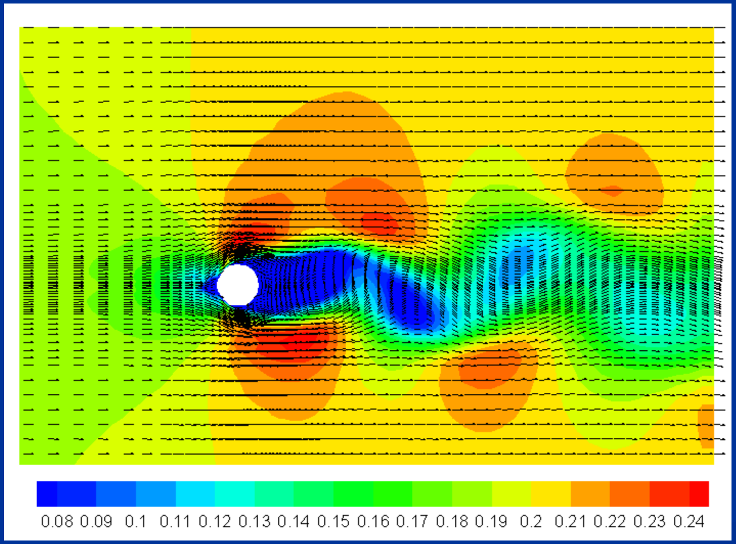


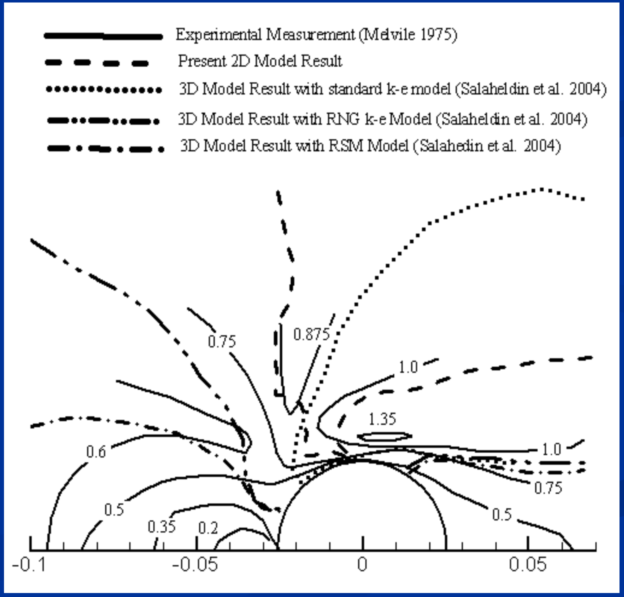
Schematic representation of scour around a bridge pier

North shore bridge over the Las Vegas wash (2003)

Prediction of Bridge Scour

- Empirical relations for clear water and live bed scour prediction, also available in HEC-RAS and HEC-18 models
- Advanced computational models (e.g., 3D. RANS, LES) models to simulate local scour. But, the current computational models still reply on empirical relations of sediment transport. An advanced model may not yield better accurate results than a simplified 1D or 2D model (Hummel and Duan, 2012; Duan 2005).





Bed shear stress prediction from 2D and 3D models (Duan 2005)

Bank Erosion

Various types of bank erosion in the natural rivers

Bank Erosion Rate (Duan, JHE, 2005)

Therefore, the rate of bank erosion of cohesive bank material, M, can be

$$M = \frac{\Delta B}{\Delta t} = eE\left(1 - \frac{\tau_{bc}}{\tau_{b0}}\right)^{\frac{3}{2}} \sqrt{\tau_{b0}} \qquad \text{(Eq.2.9.34)}$$

in which

$$E = \sin\overline{\beta}\sqrt{\frac{C_L^{'}}{3\rho_s}}\left(1 - \frac{C}{C_*}\cos\overline{\beta}\right)$$

Basal Erosion Factor

$$e = \frac{\dfrac{H-Y}{\tan\beta_c} - \dfrac{H^{'}}{\tan\beta}}{\dfrac{H-H^{'}}{2\tan\beta} + \dfrac{\overline{\xi}}{\eta}}$$

Bank Geometry Factor

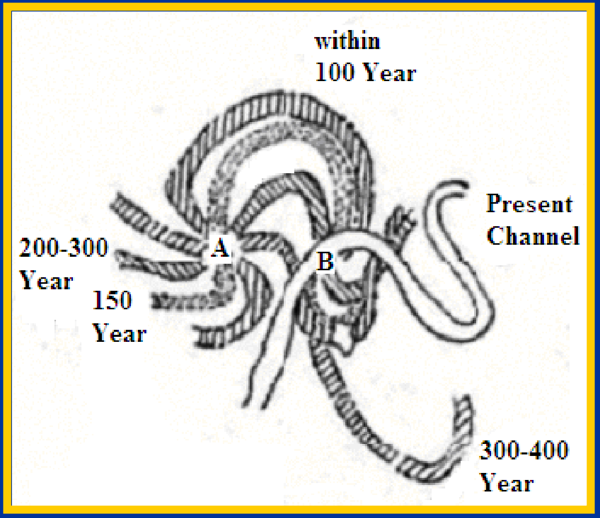
$$\eta(Q \geq Q_p) = \frac{1}{\alpha'\Gamma(\beta')}\int_{Q_p}^{\infty} \frac{1}{x}\left[\frac{\log(x) - \gamma}{\alpha'}\right]^{\beta'-1} e^{-\left\{\frac{\log(x)-\gamma}{\alpha'}\right\}} dx$$

Bank Failure Frequency Factor

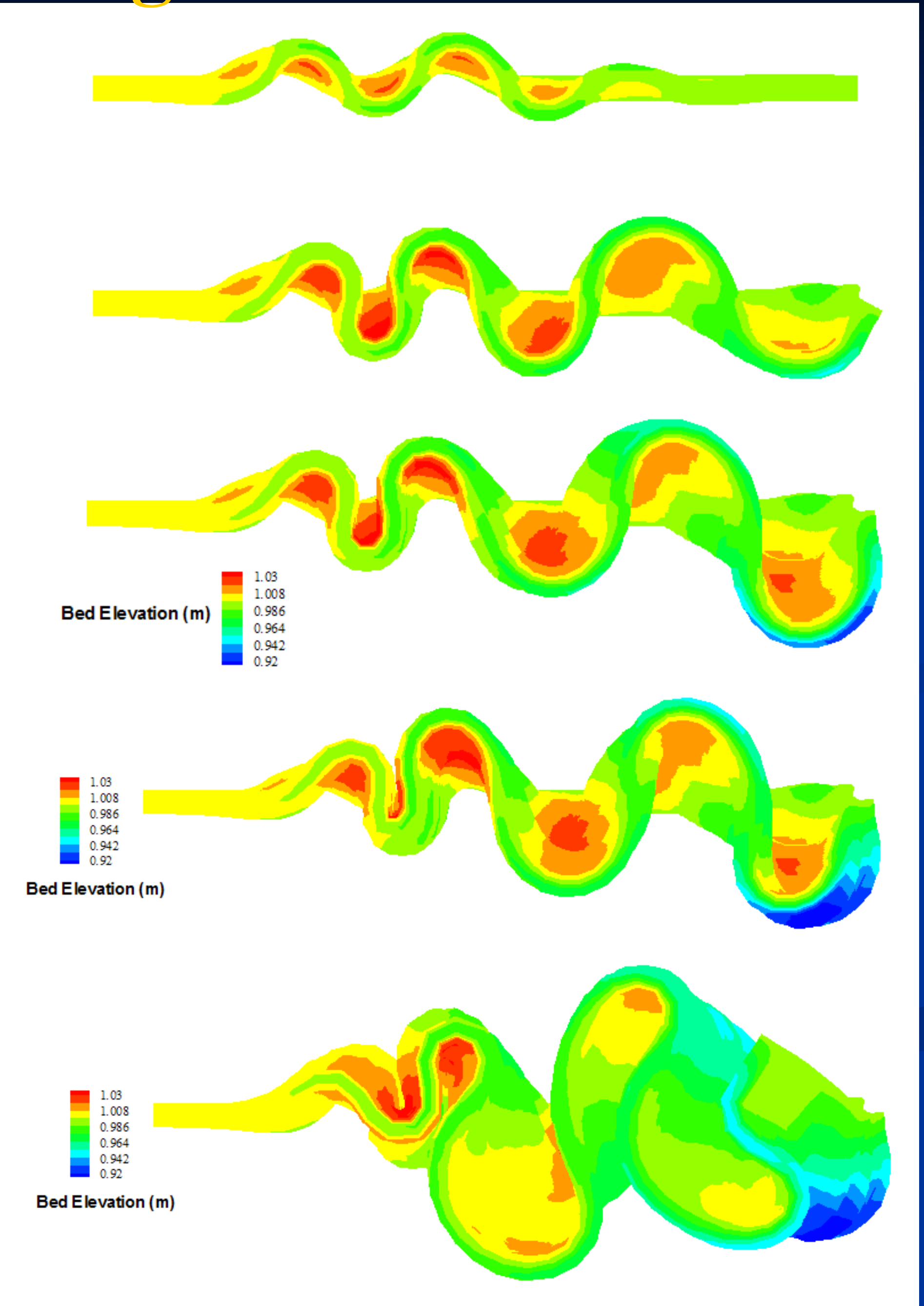
Eq.2.9.34 has been programmed in an excel sheet available at the course site. The users need to prepare input data of bank geometry and bank material to determine the bank erosion rate.

Simulation of Meandering Channel Evolution

The initial channel is a sine-generated with an initial angle of *30*. The discharge is *2.10 l/s*, and the width of channel is *0.4m*. The total length of the simulated channel is *13.2 m*. The mean sediment size is *0.45 mm*.



Yellow River



Simulation of Unsteady Flow Over Obstacle

Two-dimensional depth-averaged finite volume model for unsteady turbulent flow

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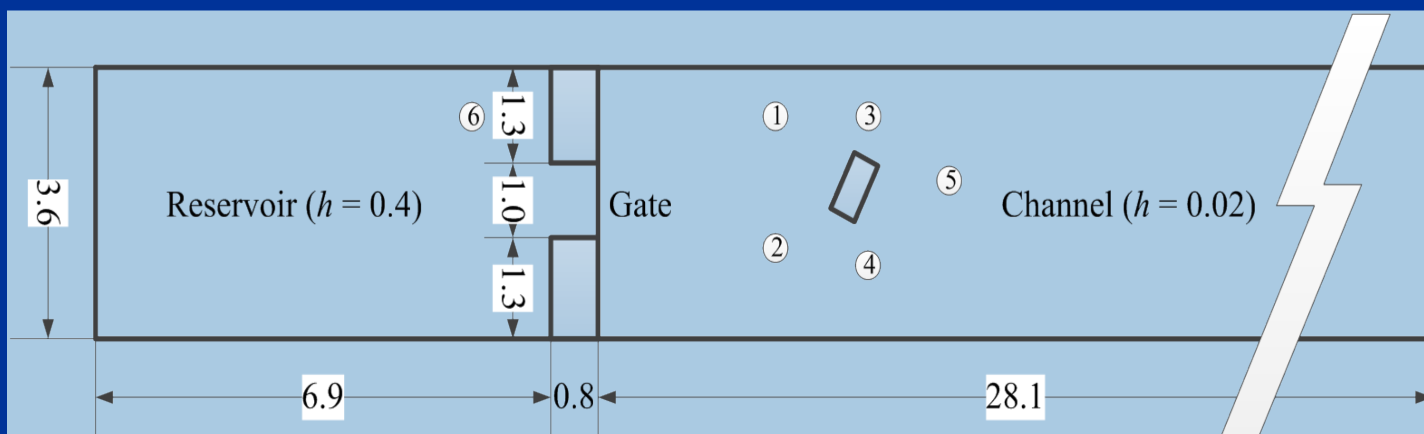
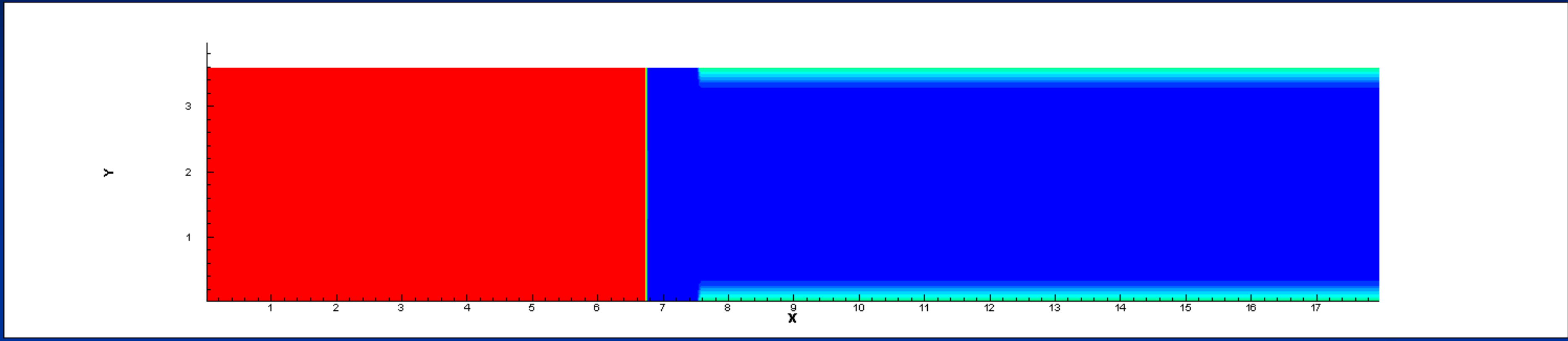
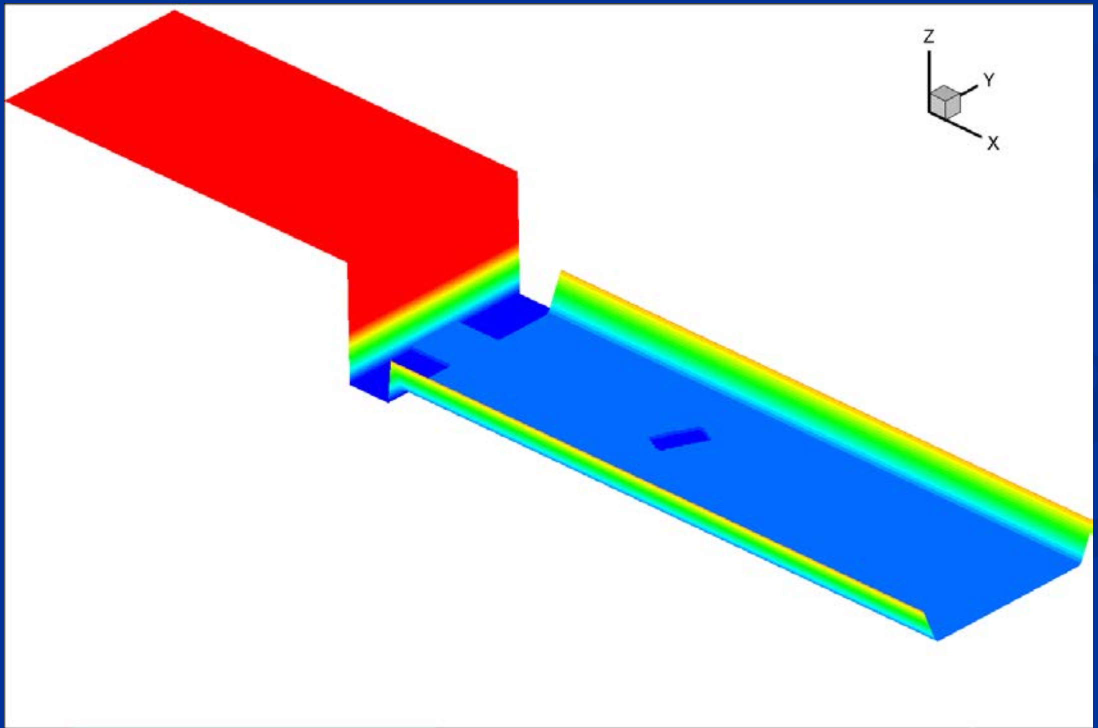


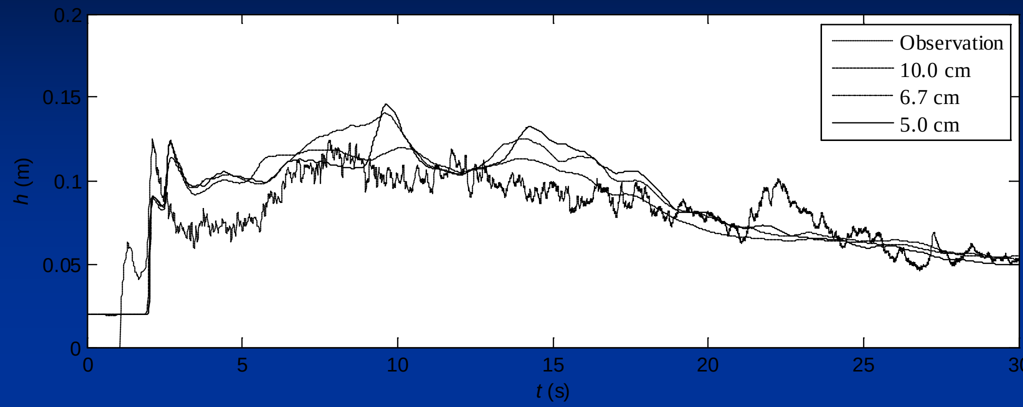
Experiment of Unsteady Flow Over Obstacle

Simulated Results

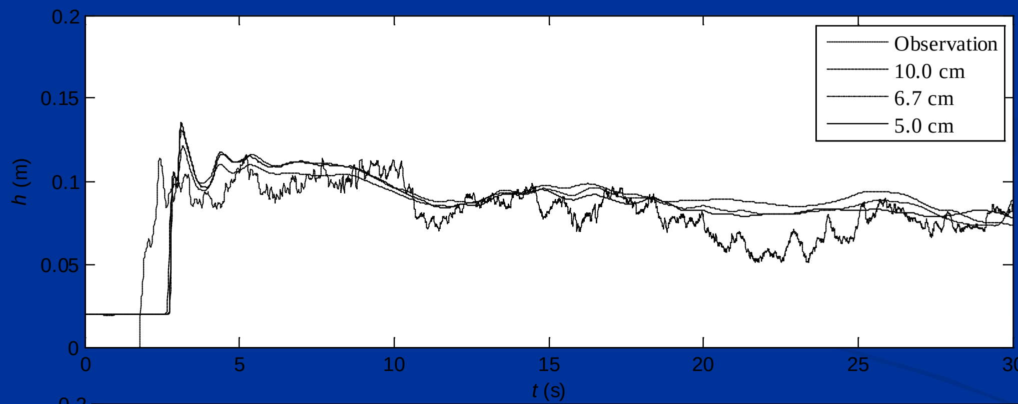




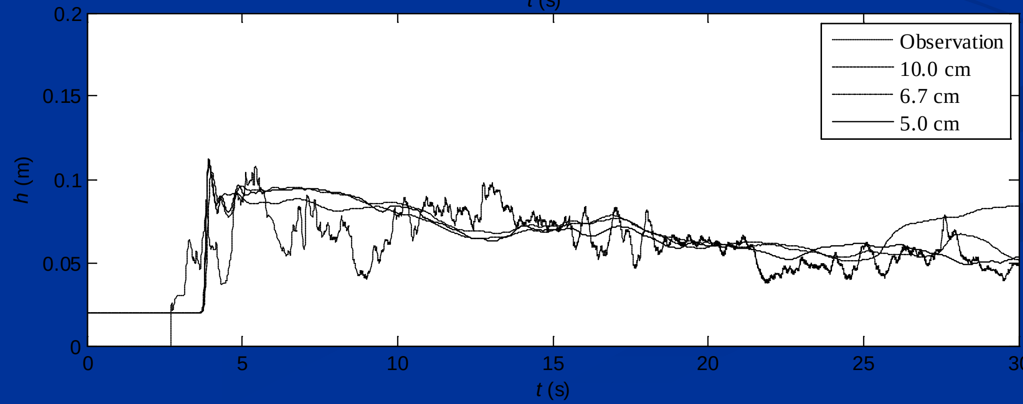
Gauge #1



Gauge #3



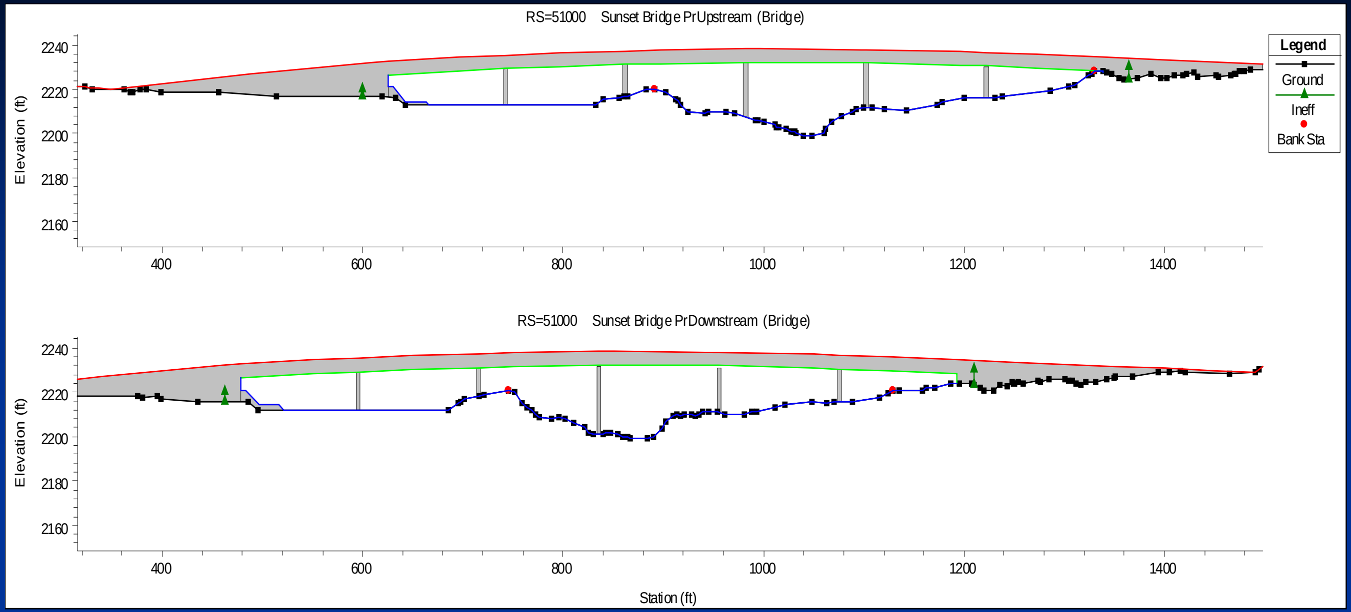
Gauge #5



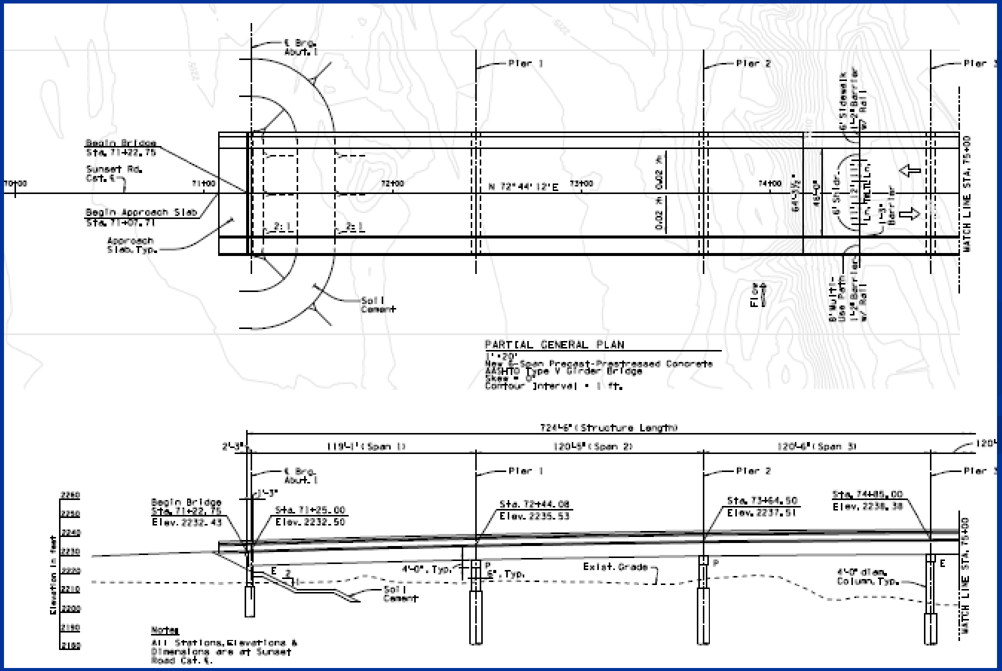
Proposed Sunset Road Bridge

Santa Cruz River

- Santa Cruz River at this reach is perennial from treated effluent. The base flow discharge ranges from 46 to 110 cfs.
- FEMA regulated 100-year design discharge is 60,000 cfs.
- Bridge scour calculation requires to use discharge 70,000 cfs as 100-year design flow.



Case 1C – Abutment scour at the toe and contraction scour in the main channel will cause bank collapse an widening of main channel.



Clear Water vs Live-bed

1. Flow at upstream section is capable of entraining sediment (V1> Vc), so live-bed.
2. **Most sediment on the floodplain with V*/ω >5.0, suspended/wash load – clear water on floodplain.**
3. **Most sediment in the main channel 2<V*/ω <2.5, live bed.**

Results

Flow and Geometry Condition		100-year design flow Q=70,000 cfs					
		Interim Geometry			Ultimate Geometry		
Pier Diameter (ft)		4	6	8	4	6	8
General/contraction Live-bed Scour	west floodplain	2.29	2.34	2.51	3.12	3.14	3.31
	channel	6.09	5.93	5.7	8.1	7.84	7.45
	east Floodplain	no flow					
Clear Water Scour	west floodplain	17.75	18.07	18.79	29.7	30.16	31.2
	channel	12.83	25.91	25.34	18.24	36.74	35.8
	east Floodplain	no flow					

Results of Max Scour Depth – Pima

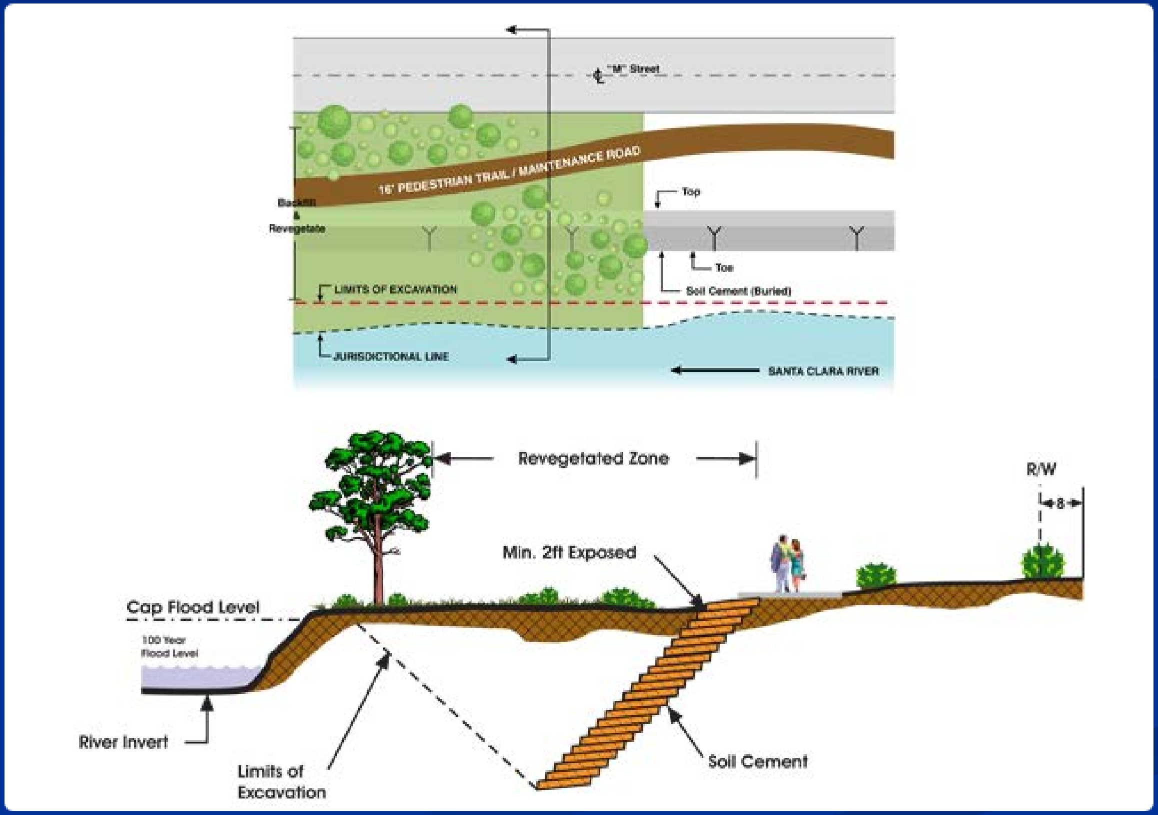
Flow and Geometry Condition		100-year design flow Q=70,000 cfs					
		Interim Geometry			Ultimate Geometry		
Pier Diameter (ft)		4	6	8	4	6	8
Max Pier Scour Depth (ft)	west floodplain	21.49	26.34	31.31	21.63	26.51	31.53
	channel	25.29	29.93	34.5	25.05	29.85	34.57
	east Floodplain	no flow					
Max Abutment Scour Depth (ft)	west	20.91	20.85	21.12	20.07	20.0	19.96
	east	no flow					

Counter Scour Measures

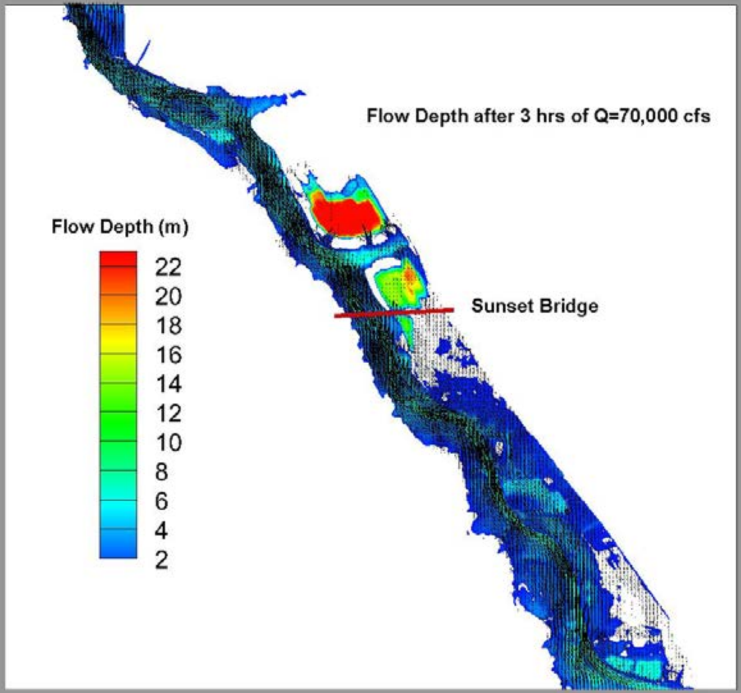
- Pima county guideline recommends soil cement for bank protection, so for abutment protection.
- PDOT requires soil cement for bank protection to place soil cement up to the erosion depth.

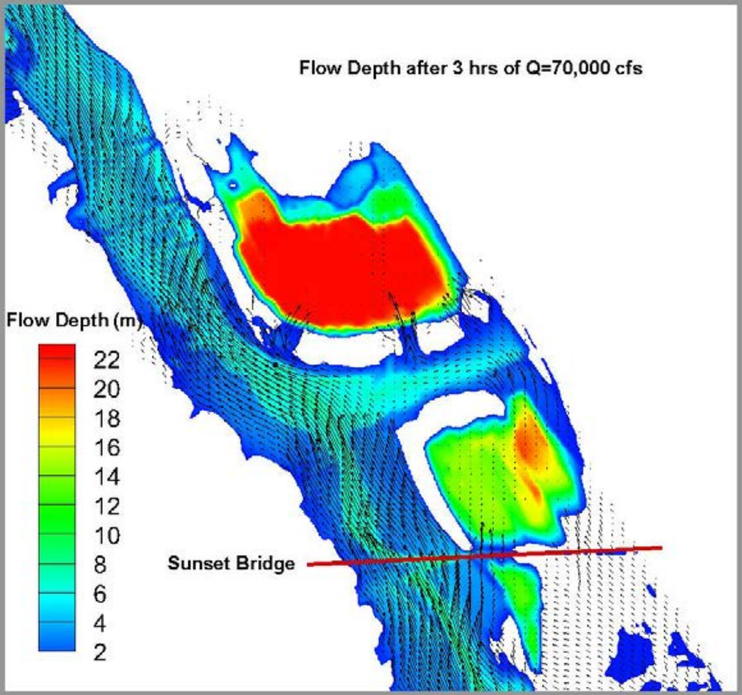
Counter Scour Measures

- For abutment protection, shall the soil cement to the contraction scour depth or the local scour depth ?
- Is soil cement possible a method to counter abutment scour?



Applications of CHRE2D Model to Sunset Rd Bridge





Conclusions

- Stream restoration needs to not only achieve ecosystem restoration goals but also ensure infrastructure's safety and sustainability.
- Impacts of stream restoration can be quantitatively evaluated using 2D advanced hydrodynamic and sediment transport model
- Additional researches on the contraction and local scour prediction in ephemeral streams are needed, especially scour development in a flash flood event.

NSF Funded: Flood Induced Scour Prediction using Bio-inspired Sensor Network

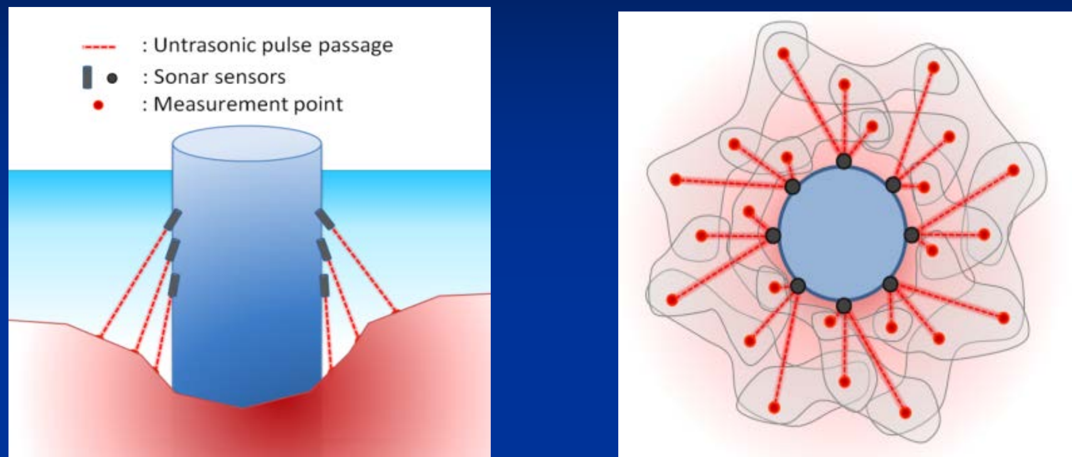


Fig.X Schematic of bio-inspired sonar sensor network: network topology and sensor grouping example

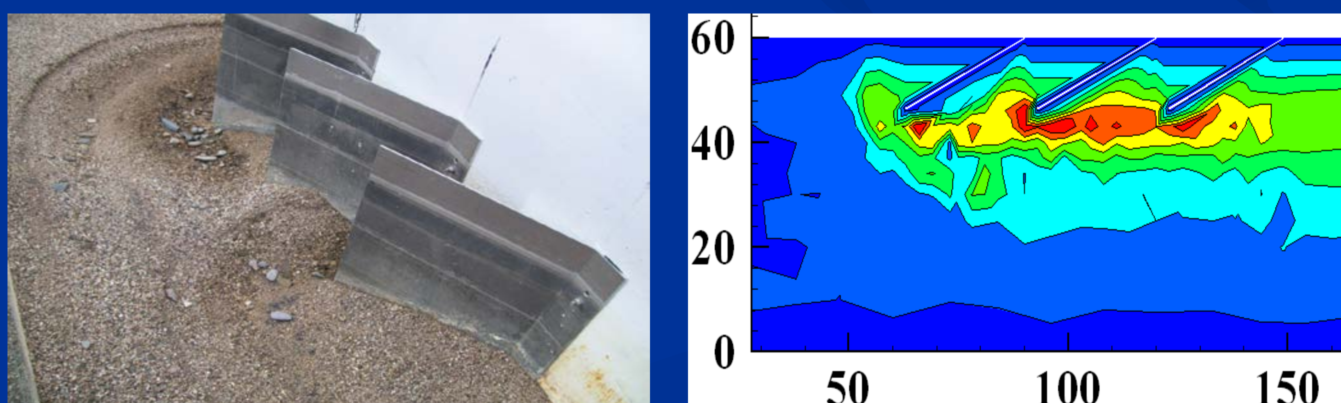


Fig.X Laboratory observed abutment scour and simulated shear stress distribution

Acknowledgement

- Pima County DOT, NSF CAREER award, NSF CMMI program, DOD DURIP, DOD standard research grants, USGS, Corps of Engineers, BOR, Pima County.
- Participating post-docs, students, visiting scholars: Deyu Zhong, Dong Chen, Li Chen, Jennifer Weller, Anu Acharya, Mary Yaeger, Li He, Shiyan Zhang, Ari Posner, Chunshui Yu, Yang Bai, Liu Lei, Khalid Asaki, Ryan Hummel, Jaeho Shim.