Streams and Structures Roadway Design and Bridge Conference

Texas Department of Transportation

April 16, 2025

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Overview of Fluvial Geomorphology and a Tale of Two Bridges

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Turn Around, Don't Drown

On average, over 50% of flood fatalities occur in vehicles

Our Subject

1. What is fluvial geomorphology?
2. Why does it matter to TxDOT?
3. What should I do now that I know what it is and why it matters?

Our Subject

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What is Fluvial Geomorphology?

Fluvial -- Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.

Geomorphology -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

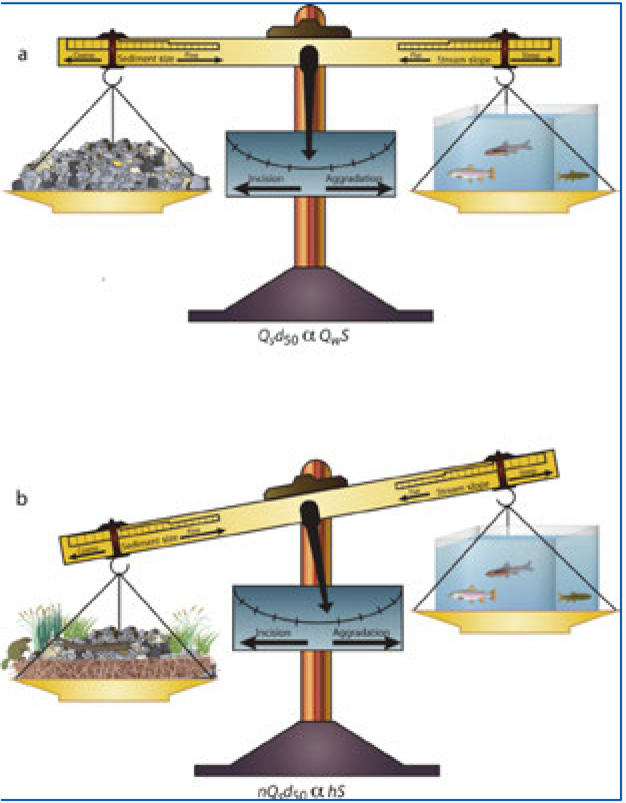
ERDC TN-EMRRP-SR-01

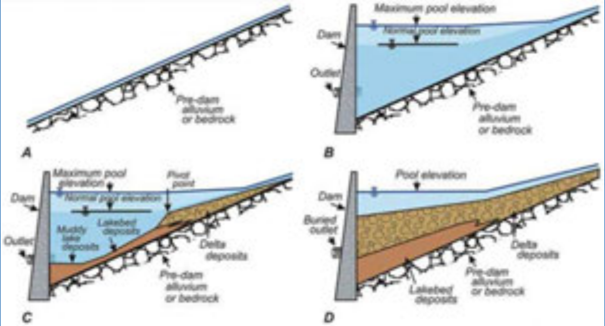
Stream Stability

Natural stream systems are dynamic. They continually adjust their cross-section, grade, planform, and resistance. A stable stream maintains average values for these parameters over an engineering time scale, and they display no trend.

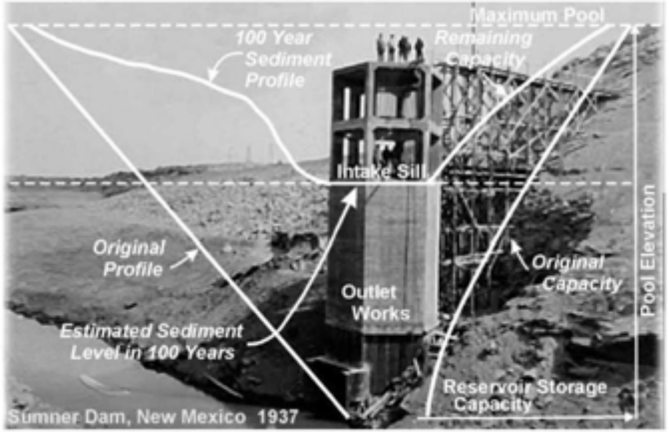
The Meandering Ucayali River, Peru

Channels Carry Water and Sediment





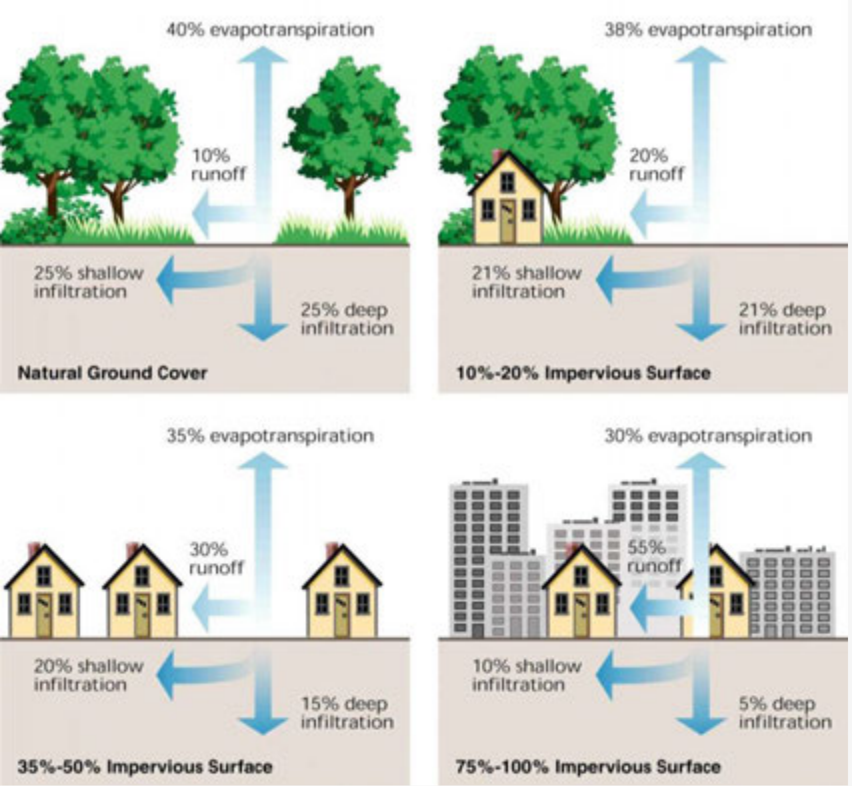
l. Channel degradation resulting from lack of upstream sediment source, downstream from Sumner Dam near Fort Sumner, NM.



Schematic of locating the outlet works intake to account for reservoir sedimentation.

f. Reservoir sedimentation has buried the outlet at Sumner Dam near Fort Sumner, NM.

Changes in Land Use = Changes in Stream Power



Effects of Channelization

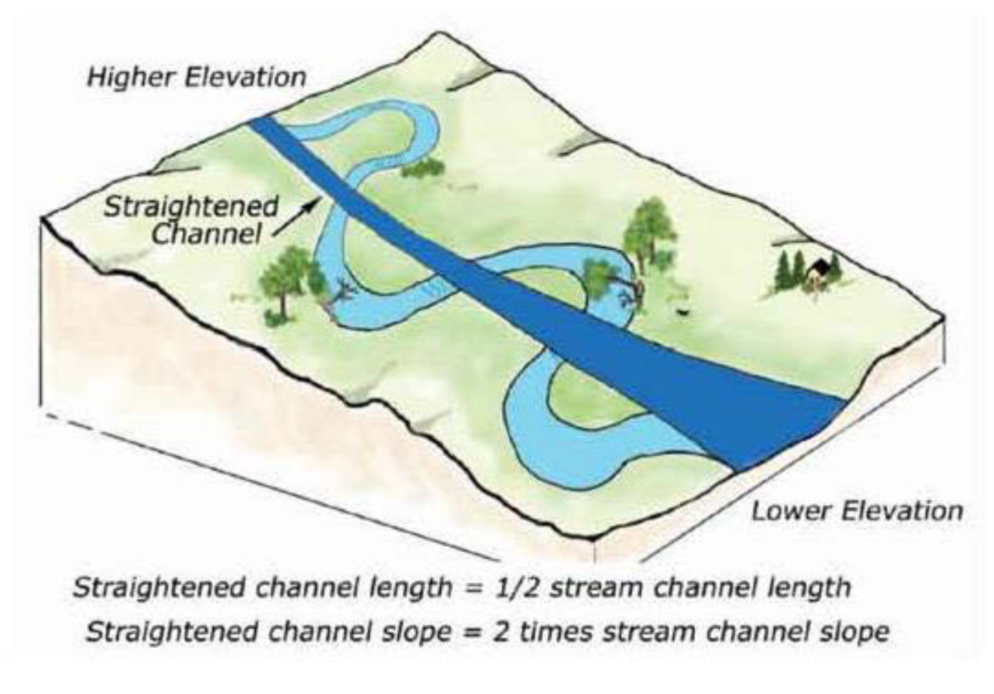
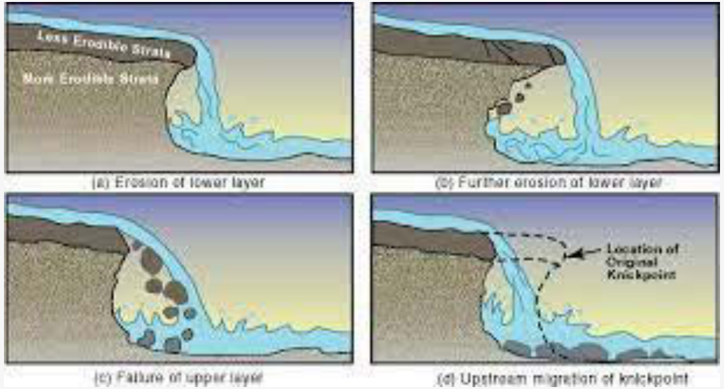
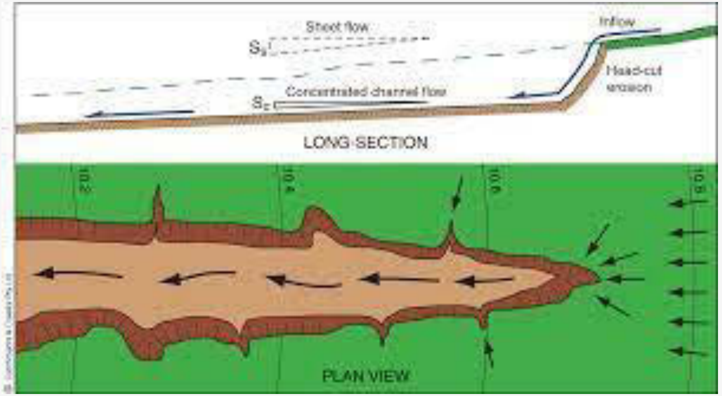


Figure 11. Walla Walla River (1964 flood showing meanders in a channelized section near Milton-Freewater). (OSU Archives)

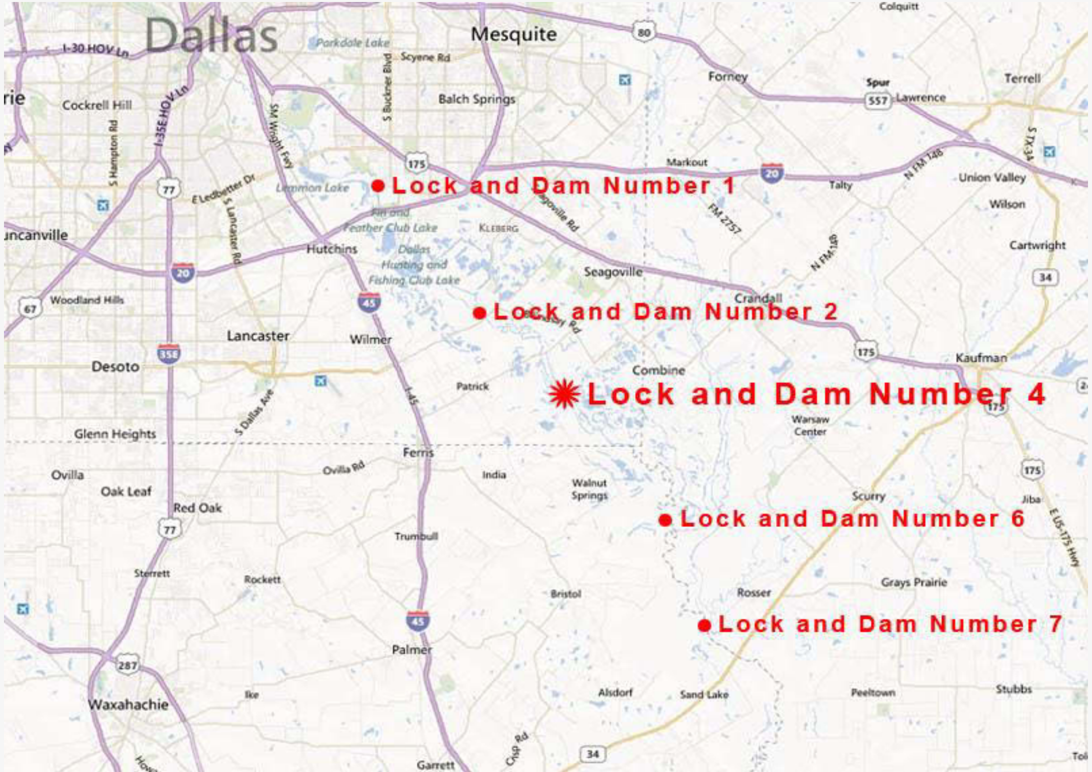
Headcuts


Less Erodible Strata
More Erodible Strata
(a) Erosion of lower layer
(b) Further erosion of lower layer
(c) Failure of upper layer
Location of Original Knickpoint
(d) Upstream migration of knickpoint


Sheet flow
Inflow
Head-cut erosion
Concentrated channel flow
LONG-SECTION
PLAN VIEW

Migrating Headcut Example: Trinity River Lock and Dam No 4

Constructed 1910-1913



Migrating Headcut Example: Trinity River Lock and Dam No 4

2005

2009

Migrating Headcut Example: Trinity River Lock and Dam No 4

2011

2013

Migrating Headcut Example: Trinity River Lock and Dam No 4

2015

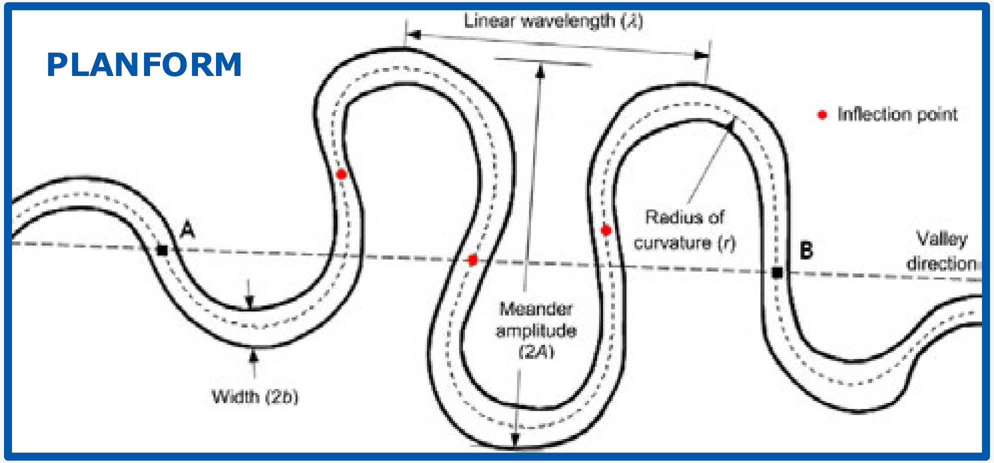
2017

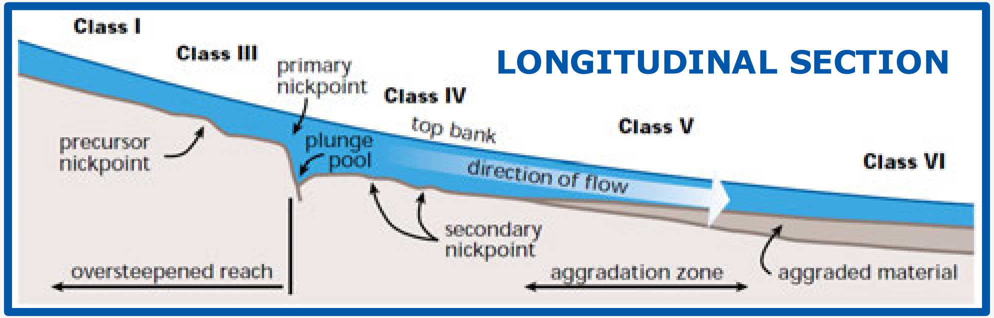
Migrating Headcut Example: Trinity River Lock and Dam No 4

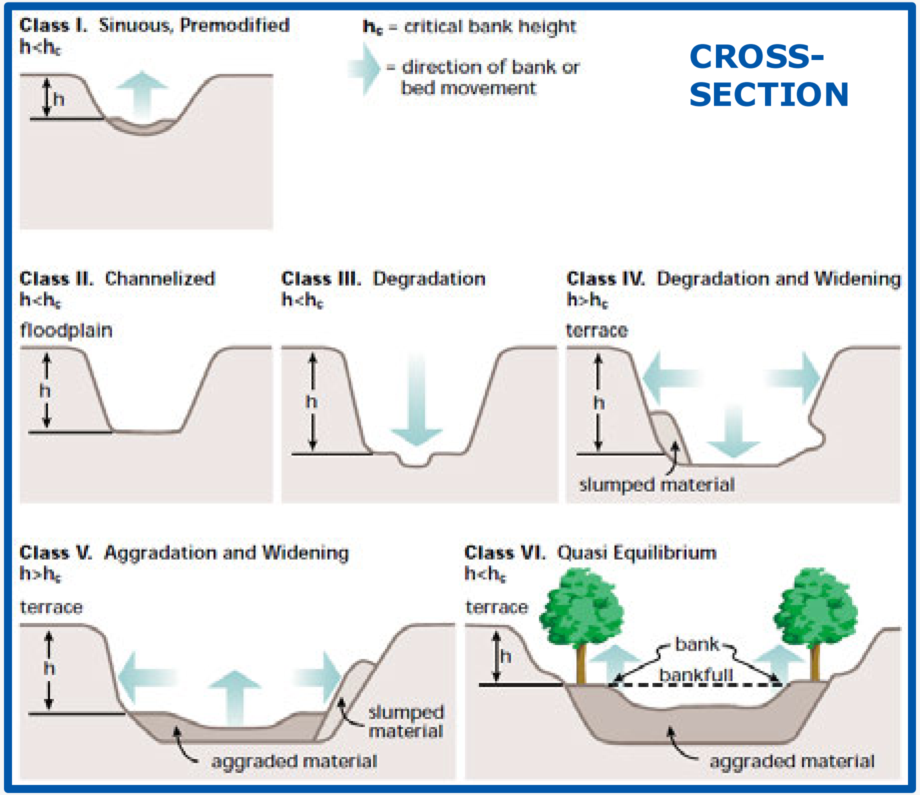
2005

2017

Hydraulic Geometry







Our Subject

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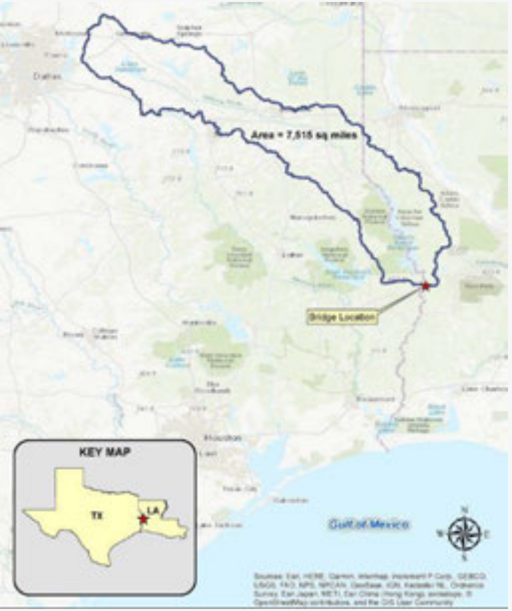
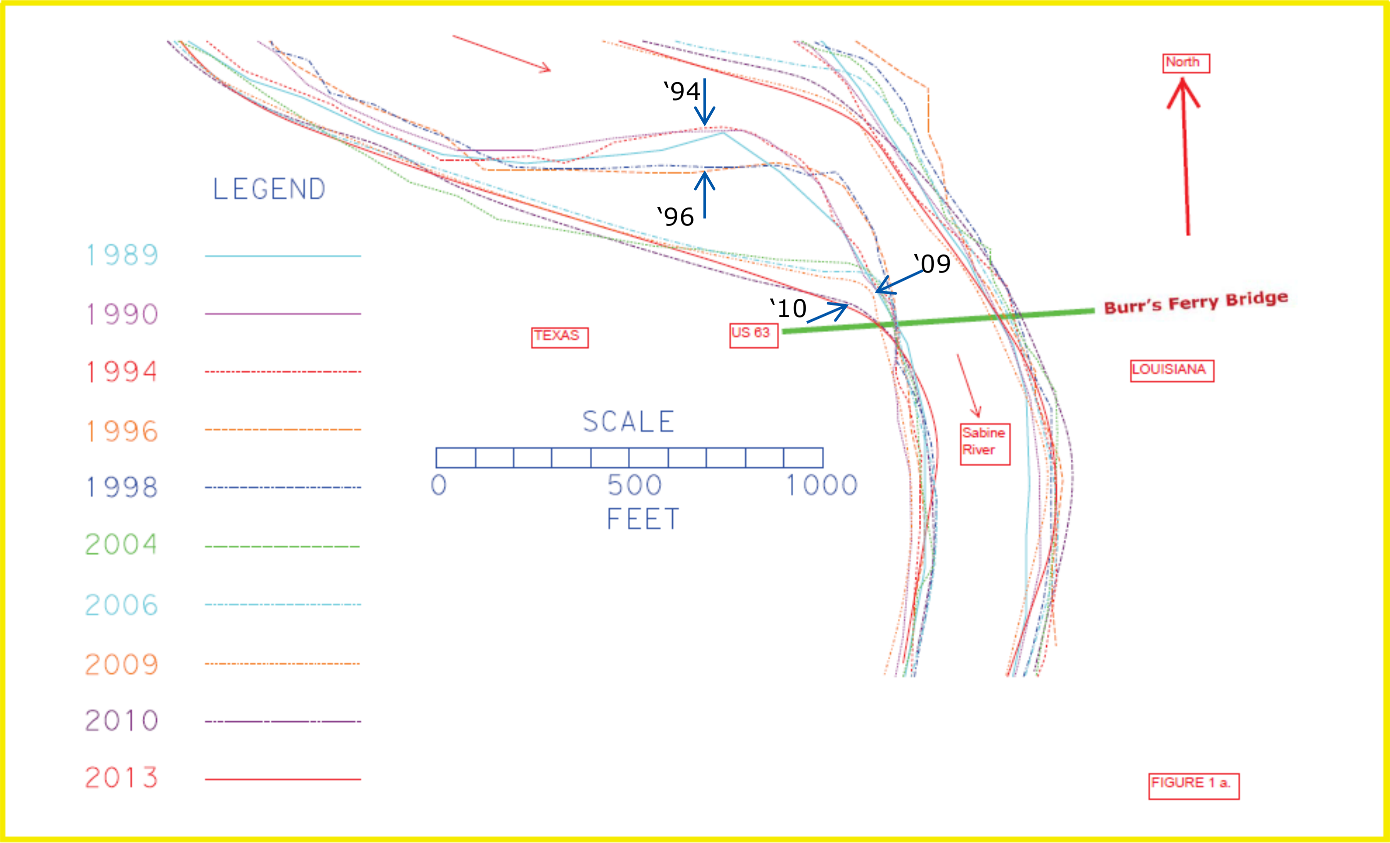
2. **Why does it matter to TxDOT?**
3. What should I do now that I know what it is and why it matters?

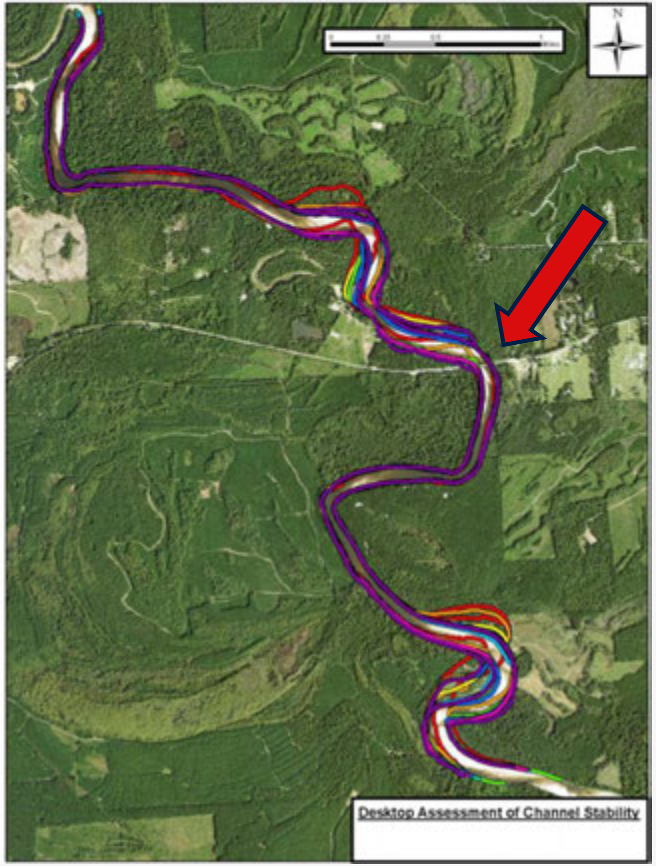
Bridge on the Sabine River

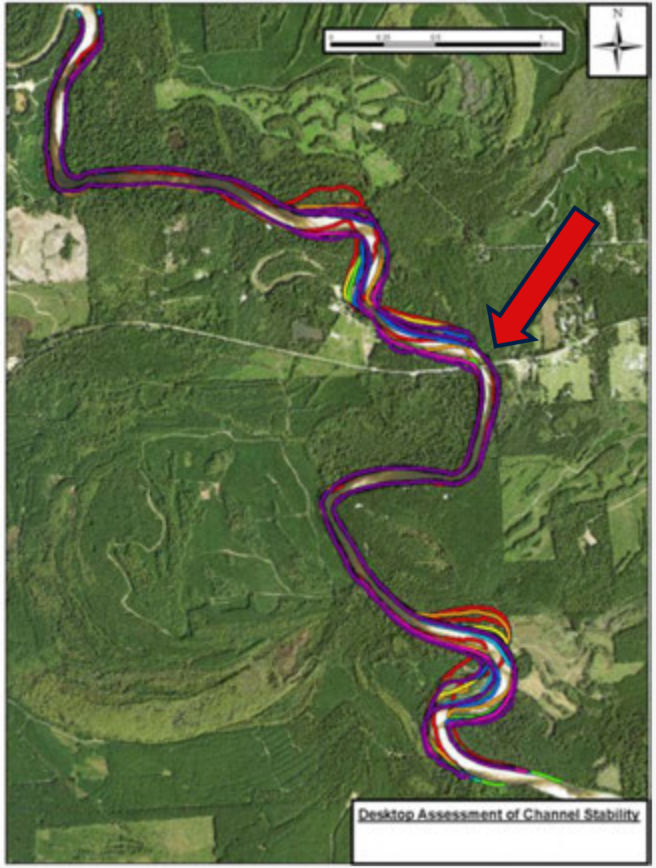
- SH68 (LA 8) bridge constructed in 1937
- Toledo Bend Reservoir is 10.5 river miles upstream, constructed in 1966
- USGS gage 08026000 (Sabine River near Burkeville, TX) in continuous operation since 1956

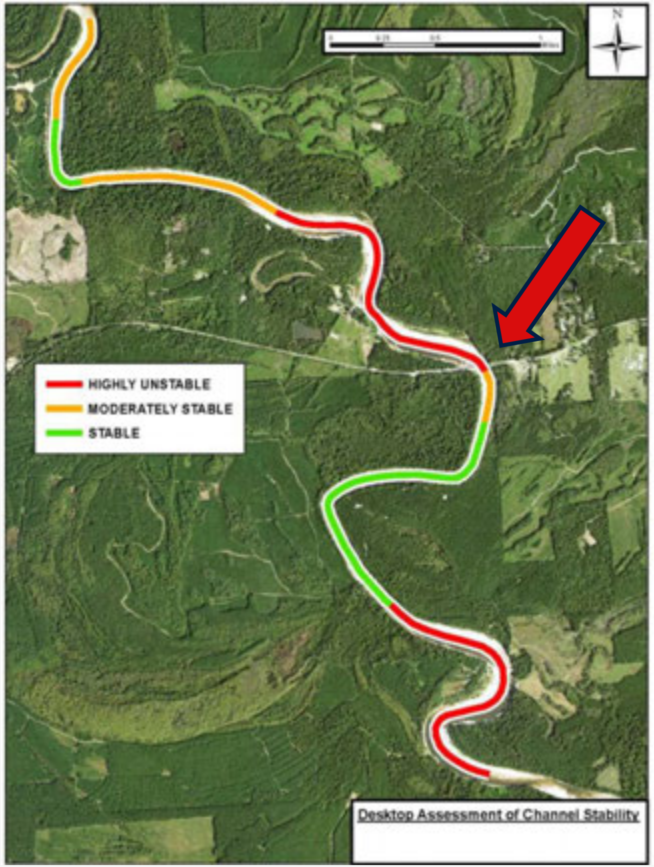
Migration of Sabine River Channel 1989 – 2013

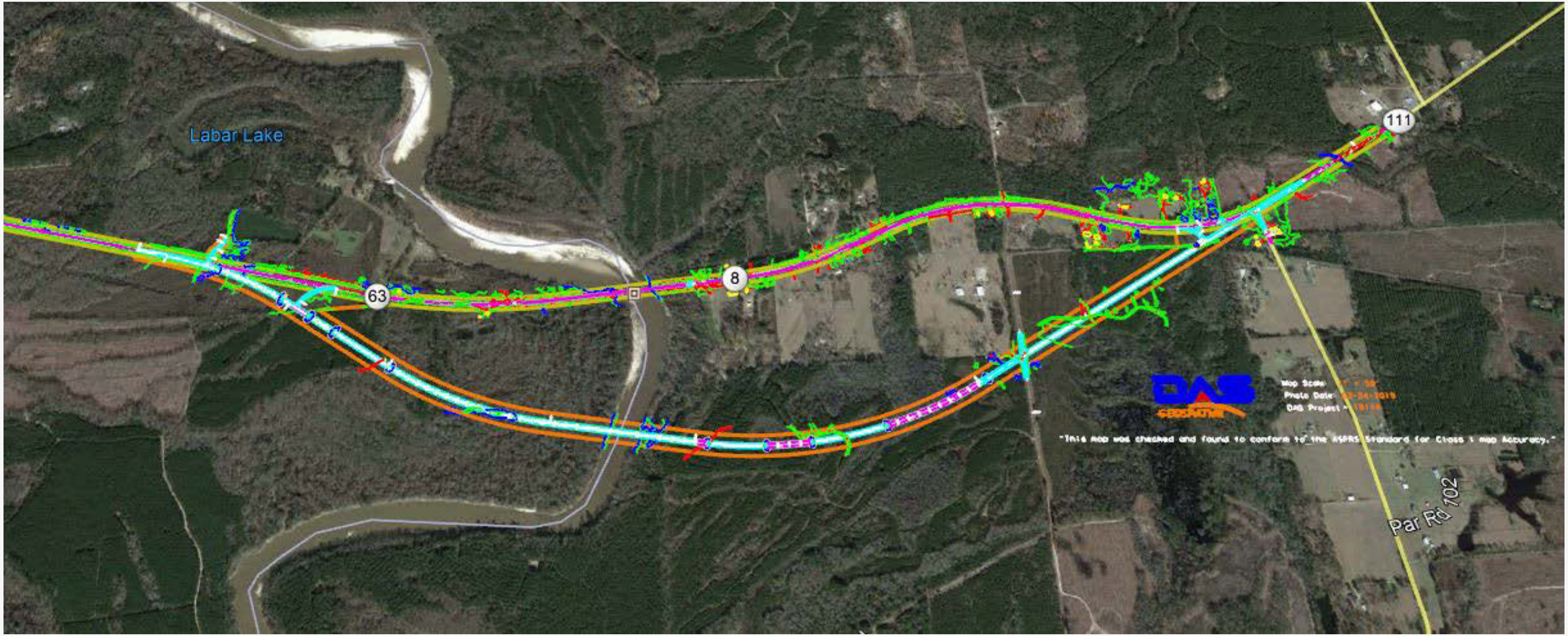





N
Desktop Assessment of Channel Stability


N
Desktop Assessment of Channel Stability

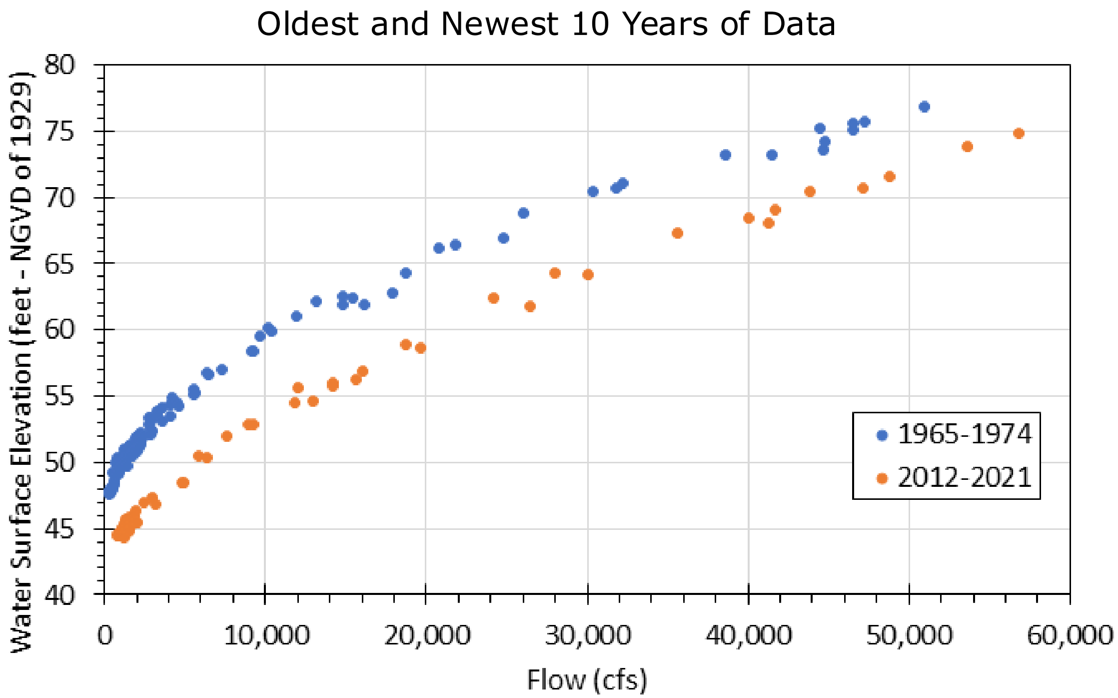

N
HIGHLY UNSTABLE
MODERATELY STABLE
STABLE
Desktop Assessment of Channel Stability


Labar Lake
63
8
111
DAS
Map Scale:
Photo Date:
DAS Project
"This map was checked and found to conform to the ASPRS Standard for Class 1 map Accuracy."
Par Rd 702

Bridge on the Trinity River

- Bridge constructed in 1997
- Lake Livingston is 0.5 river miles upstream, constructed in 1968
- USGS gage 08026000 (Trinity River near Goodrich, TX) attached to US 59 bridge (11.4 river miles downstream of FM 3278) in continuous operation since 1965

Helpful information sent by our friends at TWDB



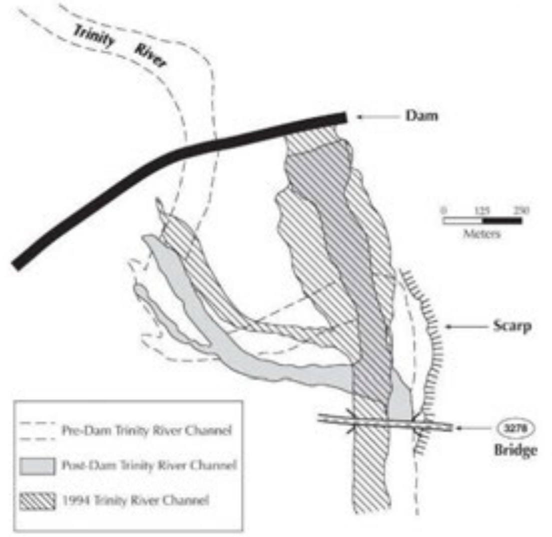
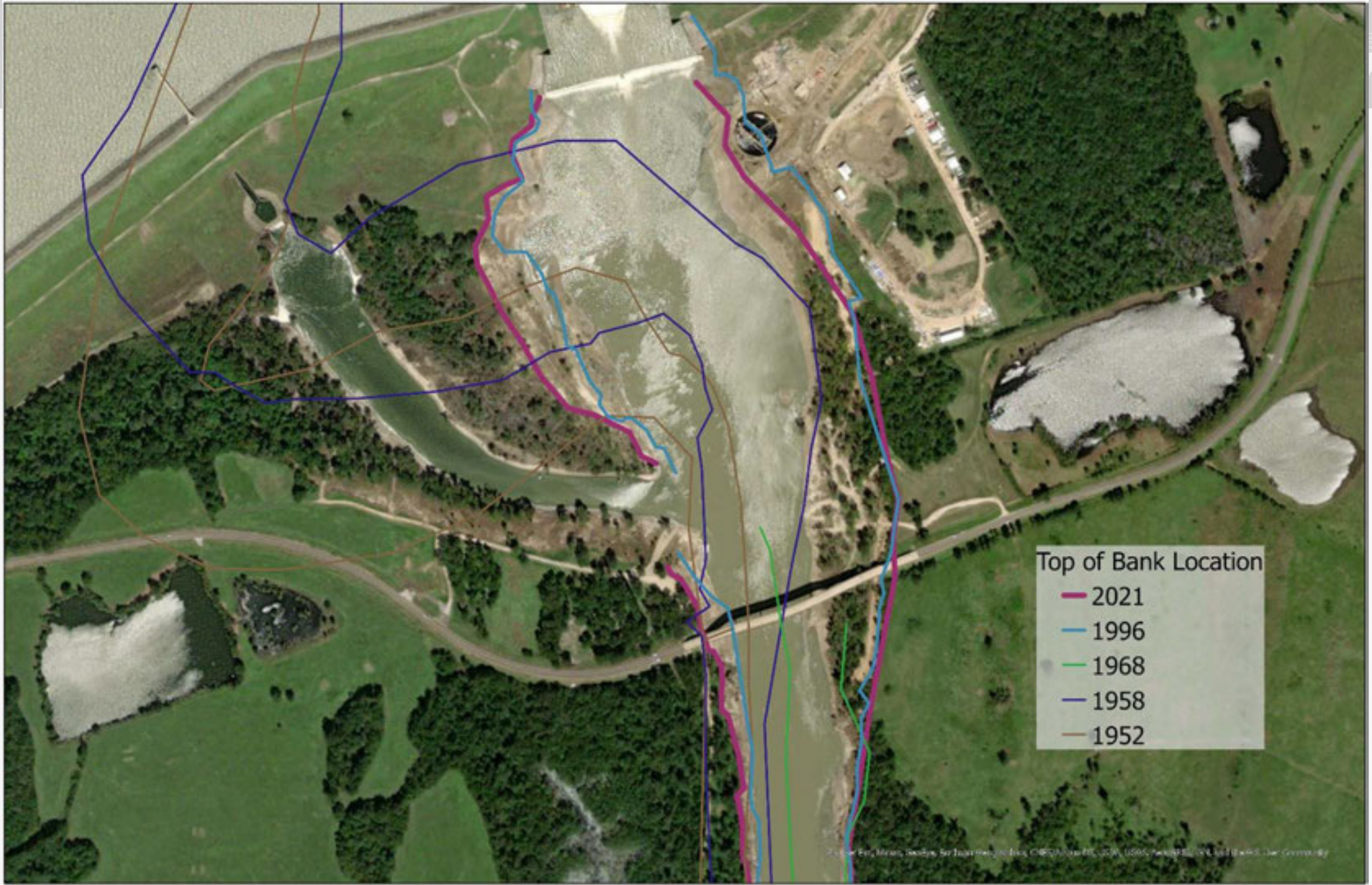


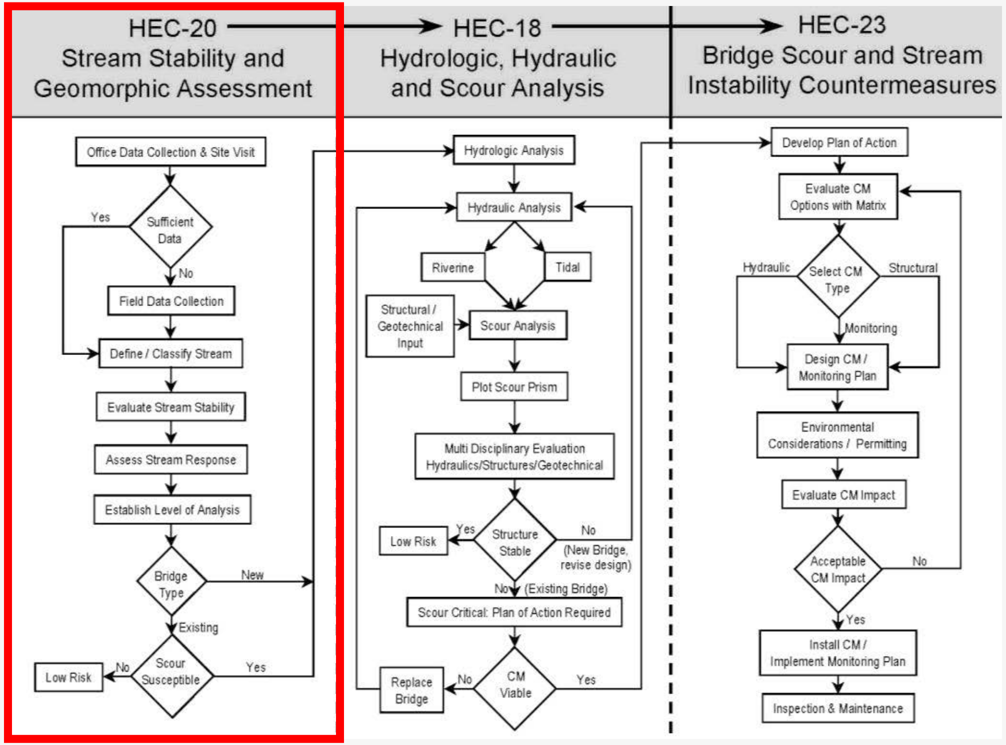
Figure 3. Channel changes at Camilla, just downstream of Livingston dam.

Table 1. Field evidence of channel responses at cross-sections from Livingston Dam to Romayor

Cross-section	Geomorphic response	Field evidence or indicators
Camilla	Channel scour Floodplain surface scour	Flood stains of gray channel-bottom clays on trees; undermining of boat ramps Exposed tree roots indicate at least 1.29 m of vertical stripping *Taxodium distichum* (bald cypress), which germinates near river level, now well above water levels


Top of Bank Location
2021
1996
1968
1958
1952

Fluvial Geomorphology in Relation to Scour



Three Thoughts and a Big Take-Away

1. It is often said that there is only one natural lake in Texas
2. Texas is one of the fastest-growing States in the US
3. Texas has more bridges than any other State in the US

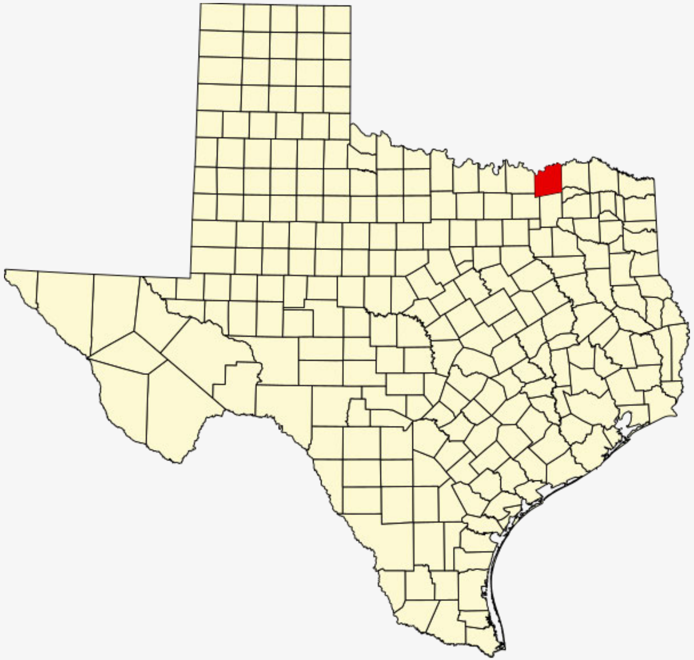
Texas Water Development Board has shared that they estimate that around 95% of streams in Texas are disturbed.

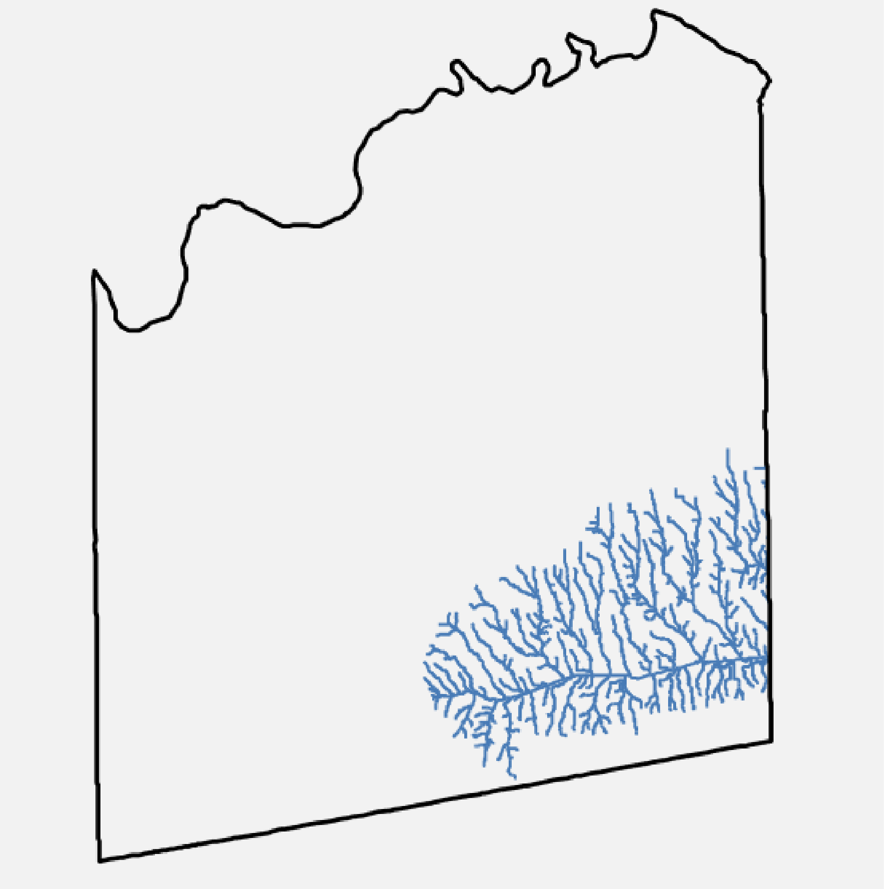
FM 68 at North Sulphur River

Katie Vick
Paris District

April 16, 2025

Location





North Sulphur River – A History

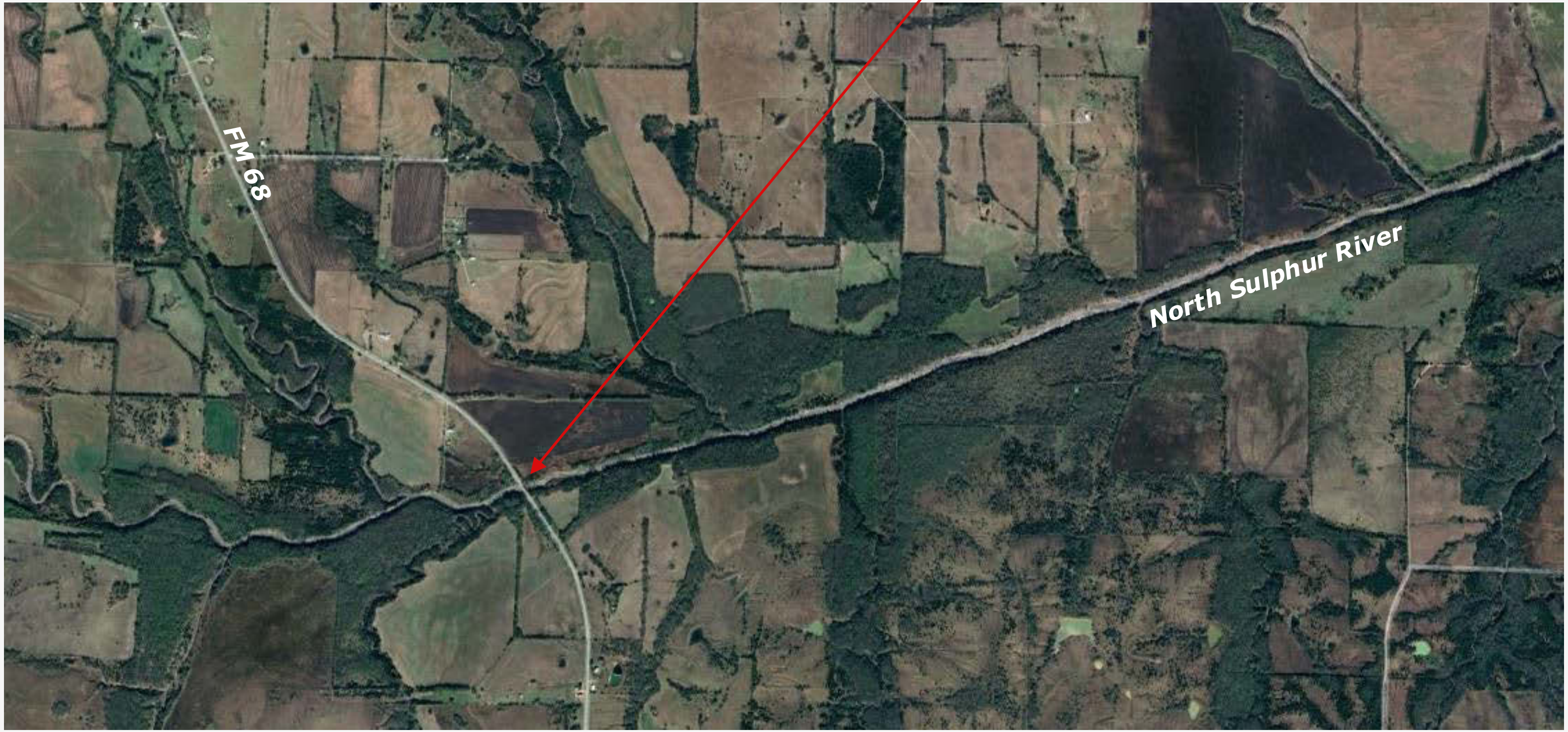
- In the 1920's the North Sulphur River bottom, then known as Sulphur Creek, was a swamp. When the creek flooded, it would cause damage to adjacent farmland and crops but also created rich farmland.
- Cotton and row-crop farming were quite profitable in Fannin County.
- The Fannin, Lamar, Delta County Levee Improvement District No. 3 was created in May 1928 with the intent to protect adjacent farmland using levees.
- A Dallas engineering firm was given the project, and instead of levees, channelization and straightening of the channel and main tributaries was proposed.
- Report noted "This will cause high velocity and subsequent erosion, and will result in the substantial enlargement to the section as cut."

North Sulphur River – A History

- Construction was completed by early 1929 that straightened 18.6 miles of the upper reaches of the main channel with a total fall of 120 feet.
- The original channel was 16’ wide and 10’ deep.
- The current channel at FM 68 crossing is 200’ wide and 40’ deep.

Location

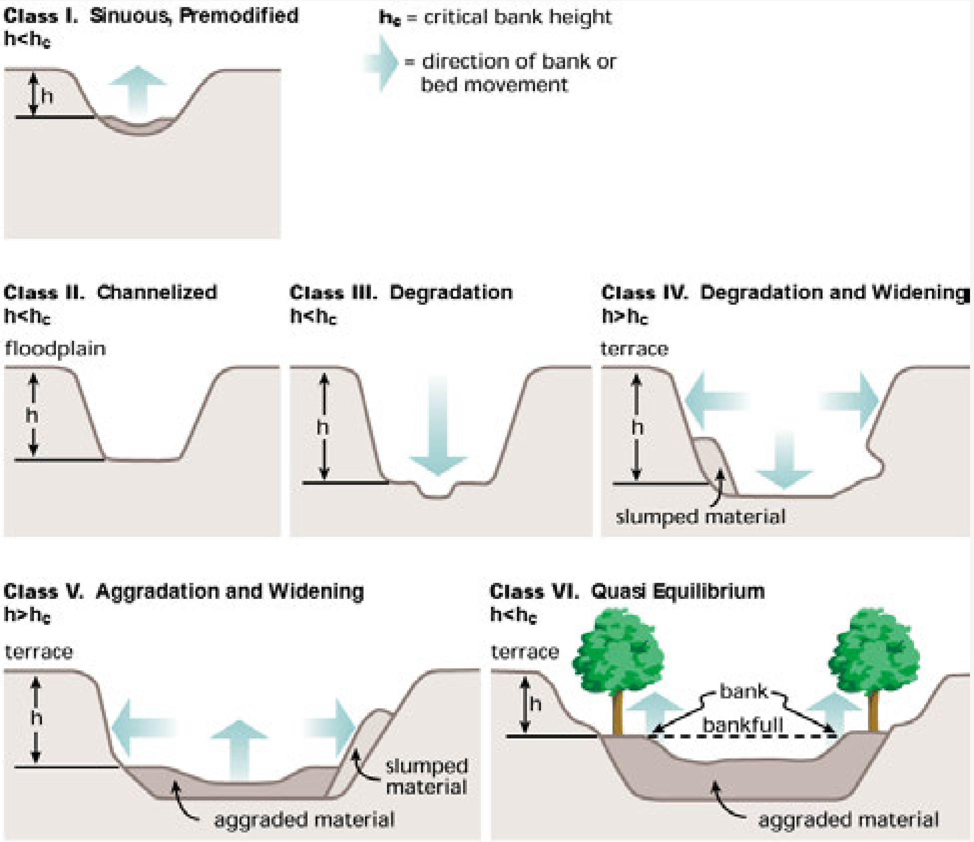
Project Location



Existing FM 68 Bridge

- Built in 1943 at 200’ long with spread footing foundations
- Lengthened in 1979 to 280’ and foundations replaced with drilled shafts
- As of 2022 inspection, there was up to 20’ of drilled shaft exposure at interior bents and increasing encroachment of the north channel bank into the north abutment
  - 8’-10’ of the channel degradation was through shale

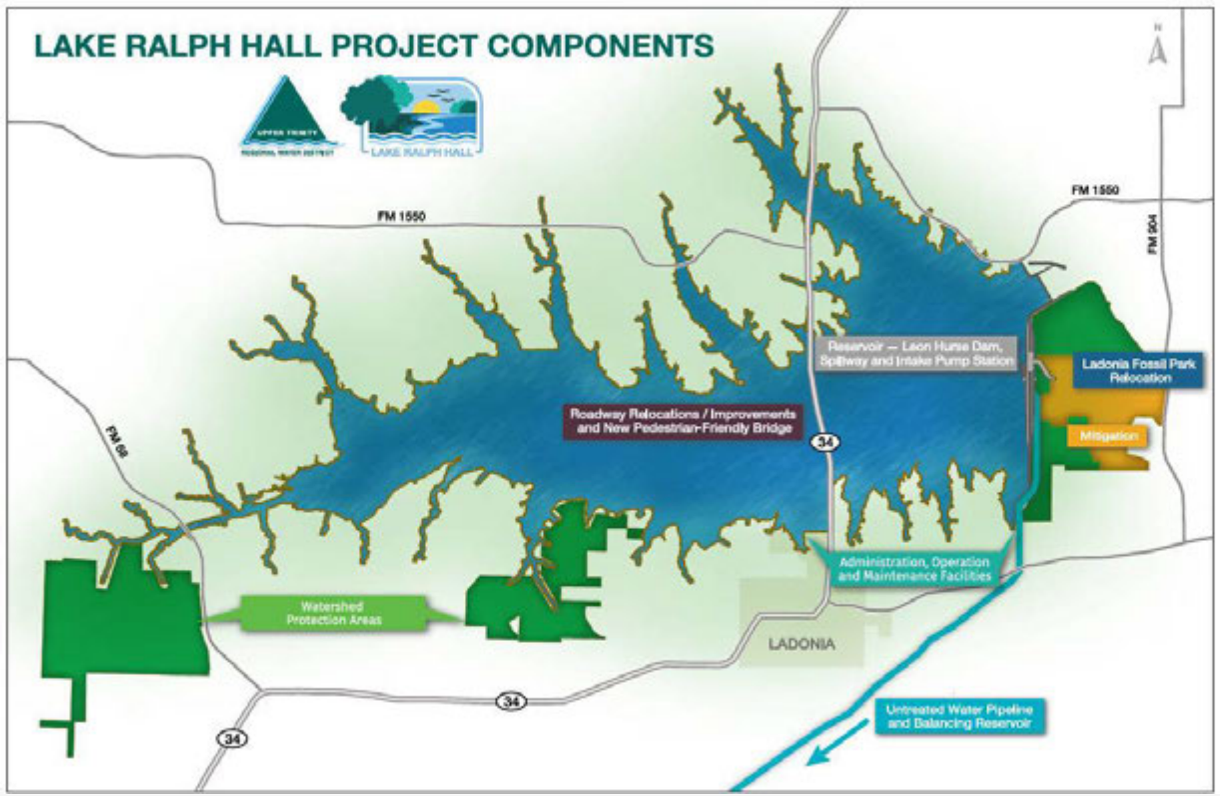
Channel Evolution Model



Challenges – Erosion: How much more?

Texas Imagery Service, TxDOT – Statewide Planning Map

Challenges – Lake Ralph Hall



LRH Project Overview Map https://lakeralphhall.com/resources/library/

Site Visit – 1/9/2024

- Participants - TxDOT Paris District, TxDOT DES H&H, Huitt-Zollars, Inc., WEST Consultants, Inc.
- Observations
  - Exposed bedrock (shale) in the riverbed showed active signs of weathering.
  - Bed material varies in thickness, 1′ – 3′, and is composed of predominantly well-sorted fine-grained silt and clay, likely from the slaking of the shale. Bars and the presence of a sinuous channel within the main channel are evident.
  - Over 8′ of riverbed degradation observed since bridge was lengthened in 1976.
  - Channel is actively widening. Shale is exposed on channel banks. Soil on top of shale shows signs of slumping, typical of oversaturation and sudden drawdown (flash flooding).

Site Visit – 1/9/2024

- Observations, cont'd.
  - Trees located along bank edges are failing due to bank erosion in vicinity of bridge. Channel conditions farther upstream and downstream appear more stable with stable bank vegetation.

Analysis - Degradation

- Dominant erosion mechanism is slaking of exposed weathering shale
  - Primarily controlled by wet/dry cycles
- Potential channel degradation was estimated using 3 techniques
  - SRICOS Analysis per TxDOT (2023)
  - Allen et al. (2002) analysis: Long-term Degradation of the Shale at the Thalweg
  - Historical Cross-Section Overlay (2 in/yr until 2001, then 0.6 in/yr)
- Agreement of the 3 methods provides support for considering 9' as the best estimate of future degradation over 50 years (not considering the effects of Lake Ralph Hall).

Predicted degradation over 50 years (existing conditions)	Low Estimate (ft)	Median Estimate (ft)	High Estimate (ft)	Comment
SRICOS (50-year scour event)	8.0	9.0	11.5	(Rounded to nearest ½ ft)
Allen et al. (2002)	9.0	9.2	9.3	
Historical Regression	6.8	8.7	10.6	Low and high estimates correspond to +/- standard error for rate estimate
Averages:	**7.9**	**9.0**	**10.5**	(Note that none of the results of the 3 methods include the influence of the future lake.)

Table 3. Summary results of vertical scour and degradation estimates
Technical Memorandum: Geomorphic Evaluation and Scour Analysis, FM 68 Bridge Replacement, North Sulphur River, Fannin County, Texas (2024)
WEST Consultants, Inc.

Analysis – Channel Widening/Meandering

- Aerial photographs were collected from the past 74 years (since 1950), and the top edges of the channel bank visible on the photographs was digitized and georeferenced.
  - 1950, 1956, 1981, 1996, 2001, 2005, 2012, 2022
- The meander belt was delineated based on observance of peaks and troughs in historical imagery, which estimates the limits to which the river will migrate laterally.

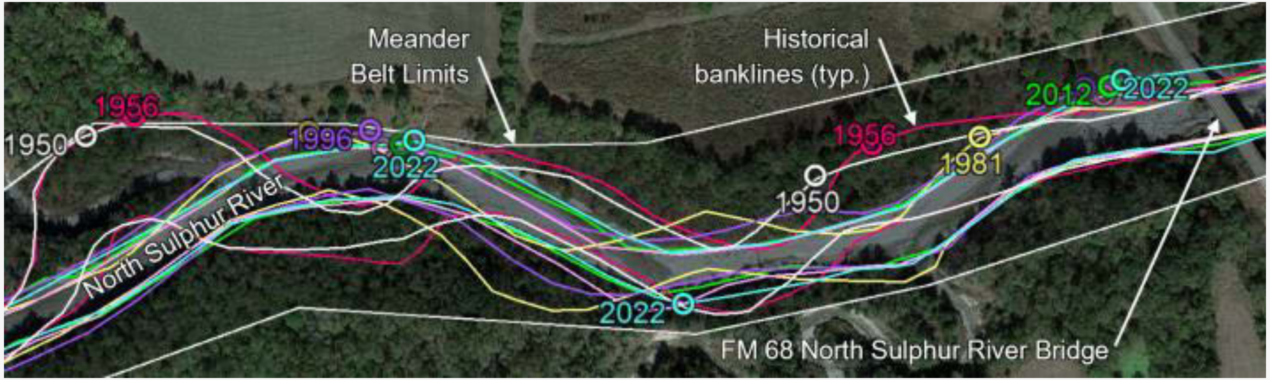


Figure 5. Channel top width bank lines since 1950, just upstream of bridge site
Technical Memorandum: Geomorphic Evaluation and Scour Analysis, FM 68 Bridge Replacement, North Sulphur River, Fannin County, Texas (2024)
WEST Consultants, Inc.

Analysis – Channel Widening/Meandering

- Meander rates over the years were determined at three locations upstream of the project location, and plotted on a chart.

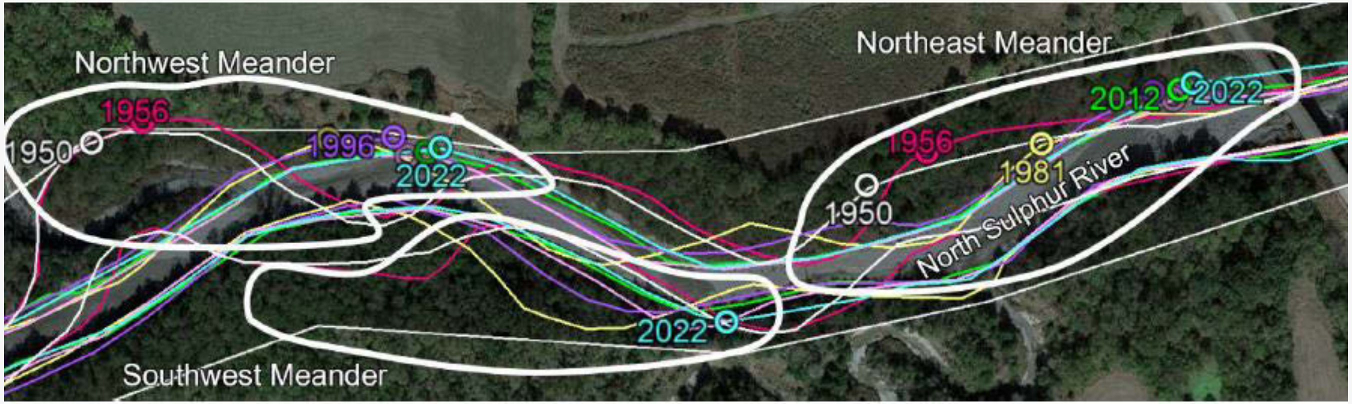


Figure 6. Analyzed meander migration rate locations
Technical Memorandum: Geomorphic Evaluation and Scour Analysis, FM 68 Bridge Replacement, North Sulphur River, Fannin County, Texas (2024)
WEST Consultants, Inc.

Analysis – Channel Widening/Meandering

- The observed meander rates were at a maximum of 12 ft/yr observed between 1950 and 1990, with values of 3 ft/yr in recent years.

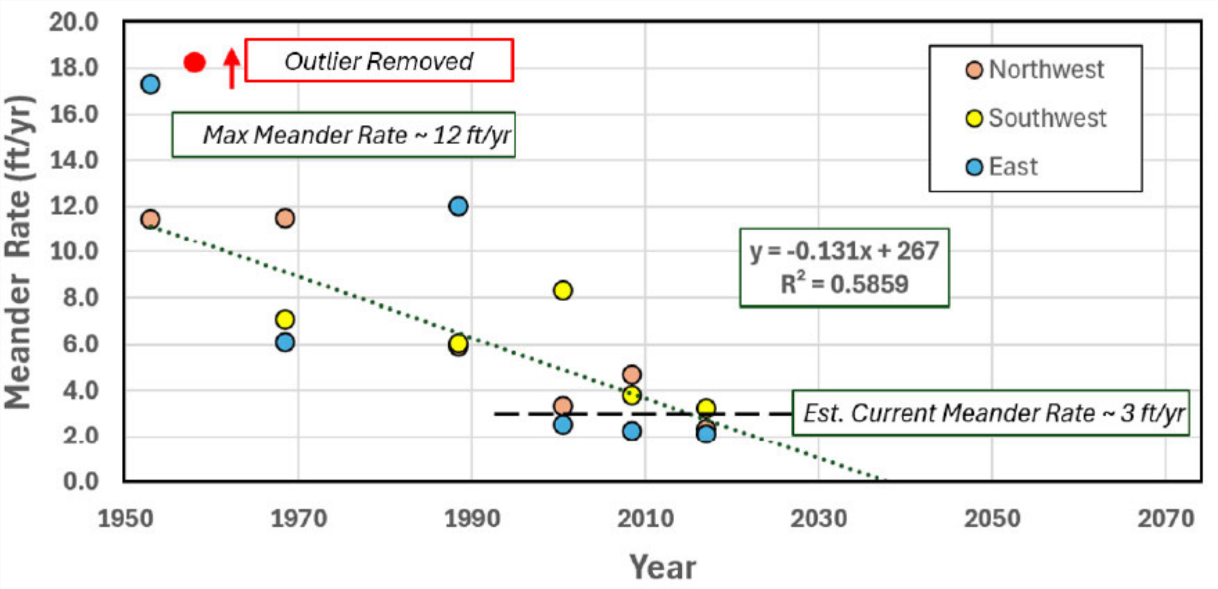


Figure 6. Analyzed meander migration rate locations
Technical Memorandum: Geomorphic Evaluation and Scour Analysis, FM 68 Bridge Replacement, North Sulphur River, Fannin County, Texas (2024)
WEST Consultants, Inc.

Lake Ralph Hall Effects

- Once the lake is filled, the riverbed at the bridge site is expected to be submerged for longer periods of time with reduced number of wet/dry cycles.
- To determine the degree to which the estimated scour will be reduced, the annual exceedance probability plot prepared by FNI (2020) for the Leon Hurse Dam was utilized.

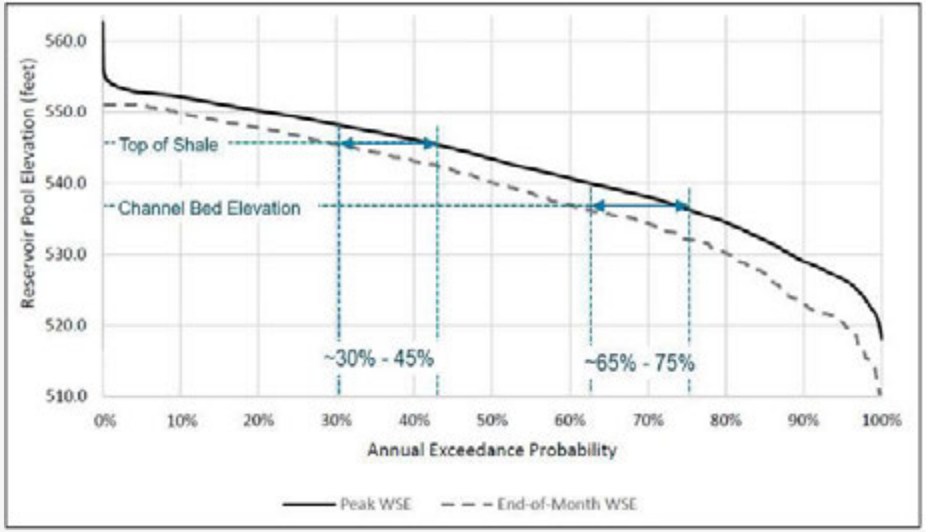


Figure 8. FNI (2020) Basis of Design Report for Leon Hurse Dam Figure 2.12

Technical Memorandum: Geomorphic Evaluation and Scour Analysis, FM 68 Bridge Replacement, North Sulphur River, Fannin County, Texas (2024)
WEST Consultants, Inc.

Conclusions

- The channel bed degradation rate has slowed from 2 in/yr to 0.6 in/yr. This decline in rate may be attributed to progressively lower hydraulic gradient and reduced stream power, and the development of a protective layer of sediment over the shale.
- The scour analysis indicates an expected degradation of ~9′ in the absence of Lake Ralph Hall.
- The presence of Lake Ralph Hall is estimated to reduce the estimated degradation of the shale by as much as 65%-75% and reduce the lateral erosion in the channel banks by 30%-35%.

Conclusions

- A 300′ meander belt was estimated for purposes of determining the proposed bridge length. It was recommended for the bridge to span this belt by at least 50′ on each end.

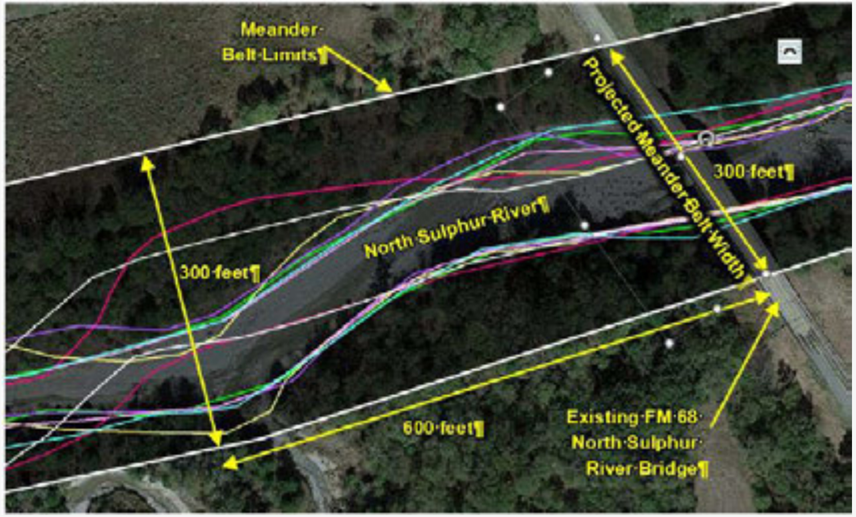
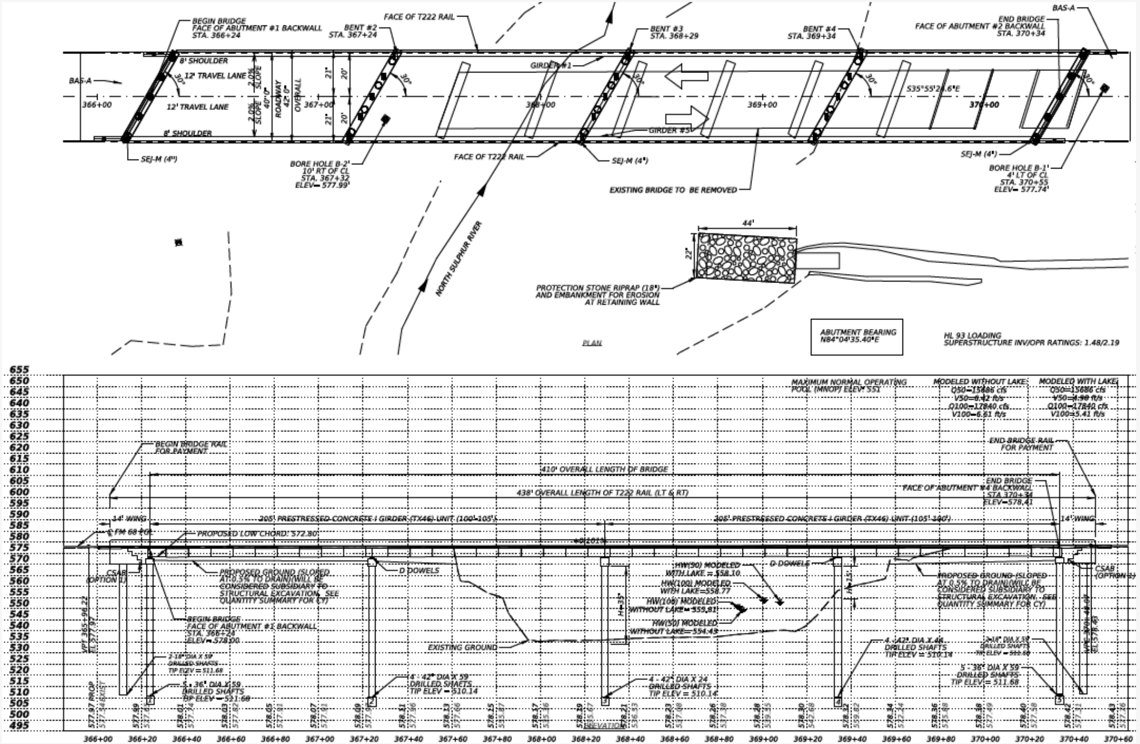


Figure 9. Projected meander belt width
Technical Memorandum: Geomorphic Evaluation and Scour Analysis, FM 68 Bridge Replacement, North Sulphur River, Fannin County, Texas (2024)
WEST Consultants, Inc.

Proposed Bridge

- The proposed bridge was designed at 410’ span to sufficiently span the estimated meander belt.



FM 787 at Trinity River

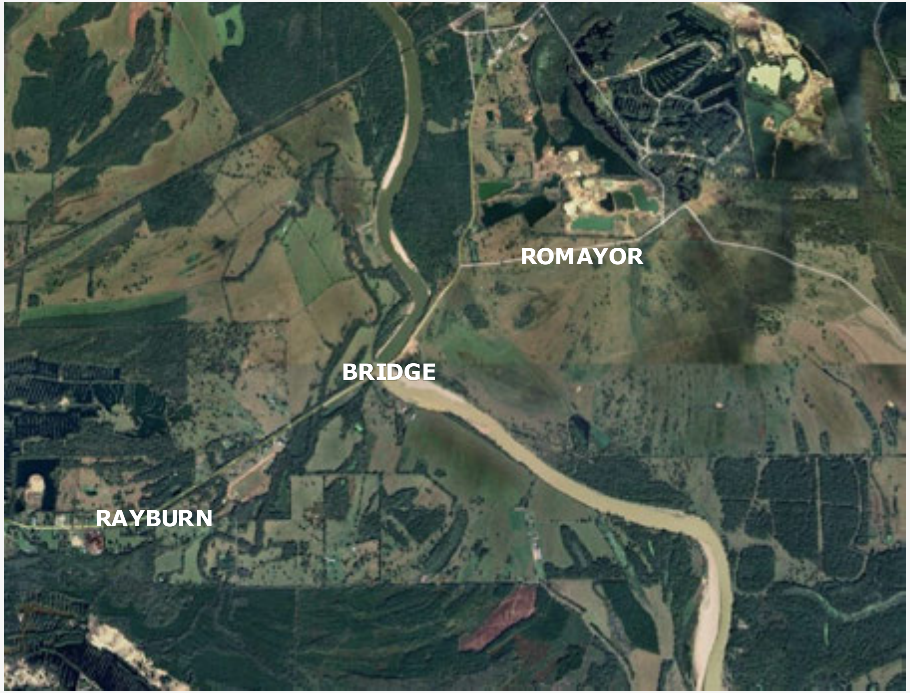
Lisa Collins
Beaumont District

Texas Department of Transportation

April 16, 2025

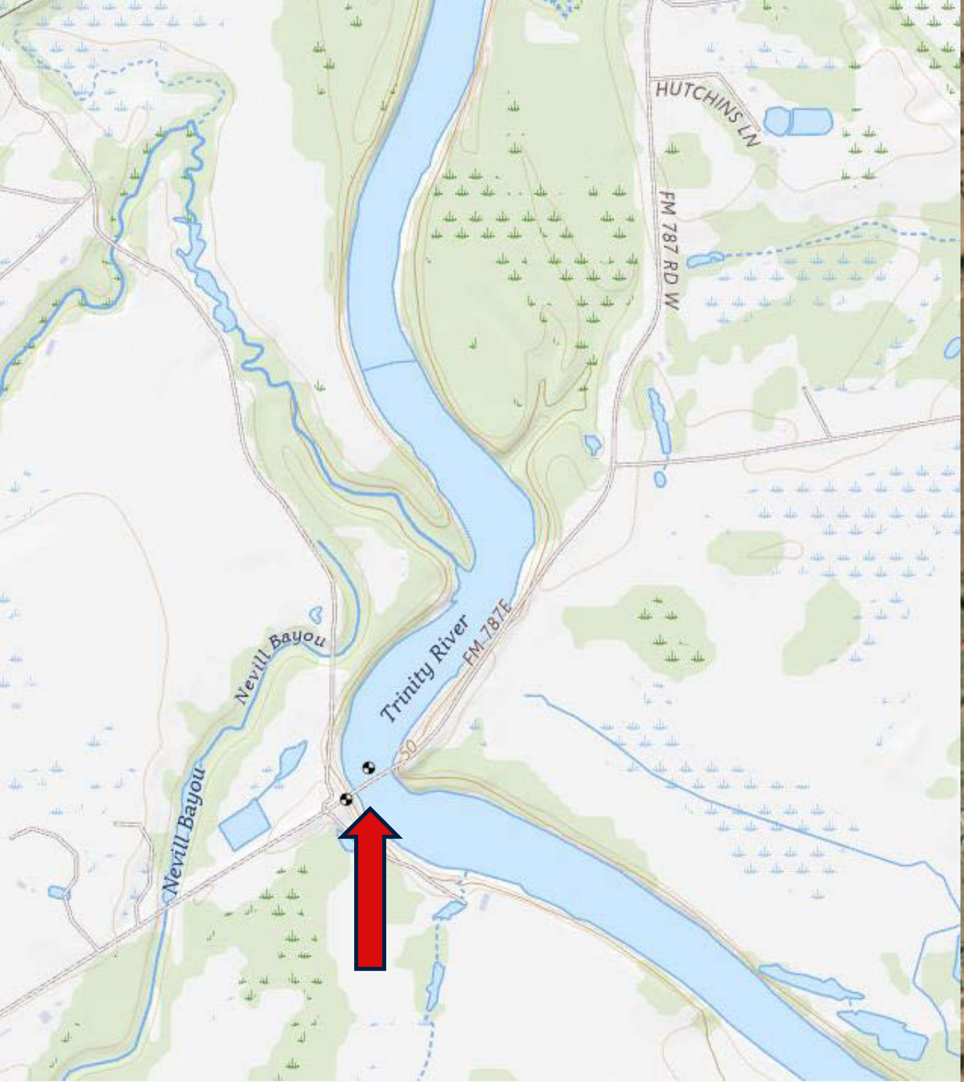
FM 787 @ Trinity River

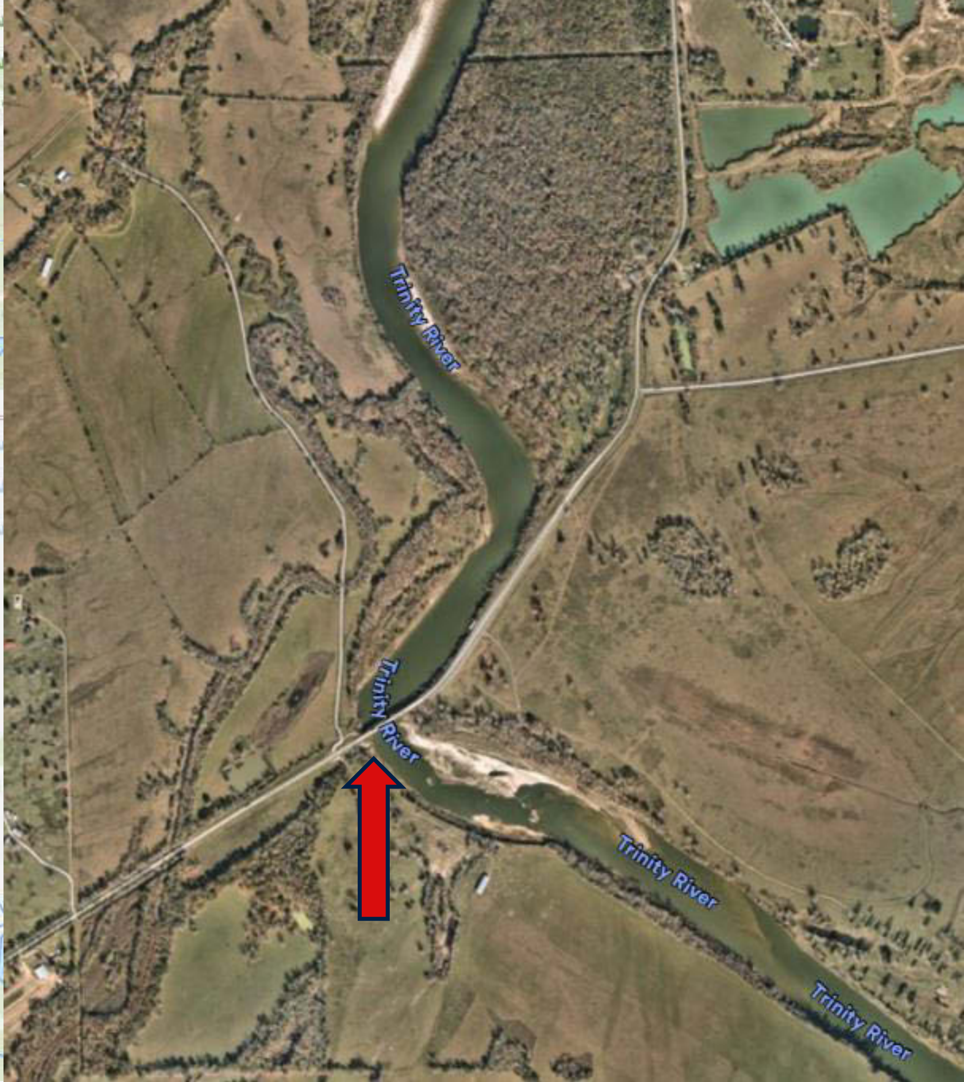
- Liberty County
- Initial crossing built in **1920**
- Connects communities of Romayor and Rayburn (detour is 40 miles)
- Agricultural communities, historically



FM 787 @ Trinity River – Overview of Area

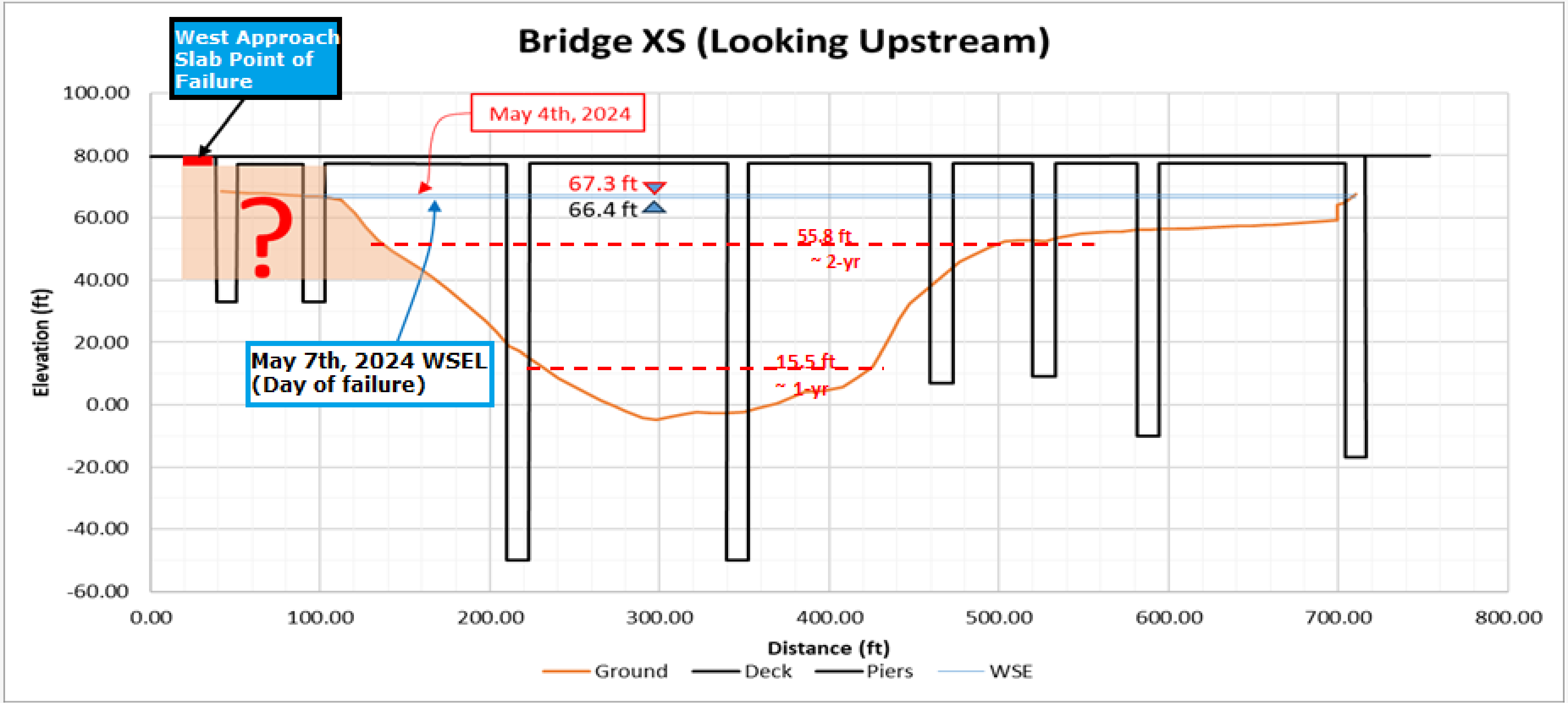
- Mixture of mostly crops, wetlands, and forest
- Entirely within the regulatory floodway
- Mixture of freshwater forested/shrub wetlands and freshwater emergent wetlands
- Just south of Lake Livingston Dam (31 river miles downstream)


HUTCHINS LN
FM 787 RD W
Trinity River
FM 787E
Nevill Bayou
Nevill Bayou
50


Trinity River
Trinity River
Trinity River
Trinity River

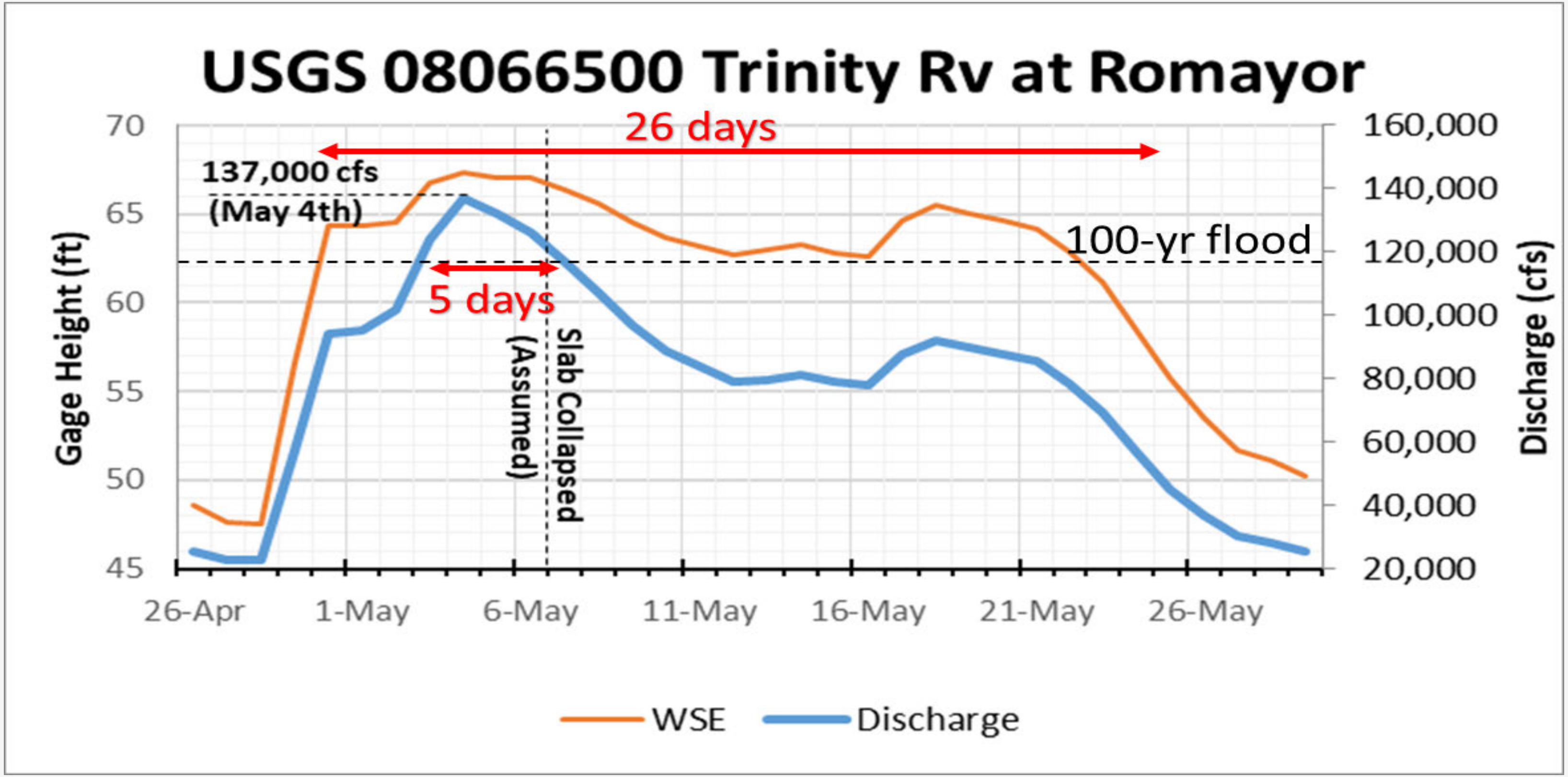
May 7, 2024 - collapse of west approach slab

May 7, 2024 – Trinity River Bridge experienced Partial Collapse



BIG FLOODING in May 2024 (!)

Hurricane Harvey: 92,800 cfs
(~ 10-yr event)

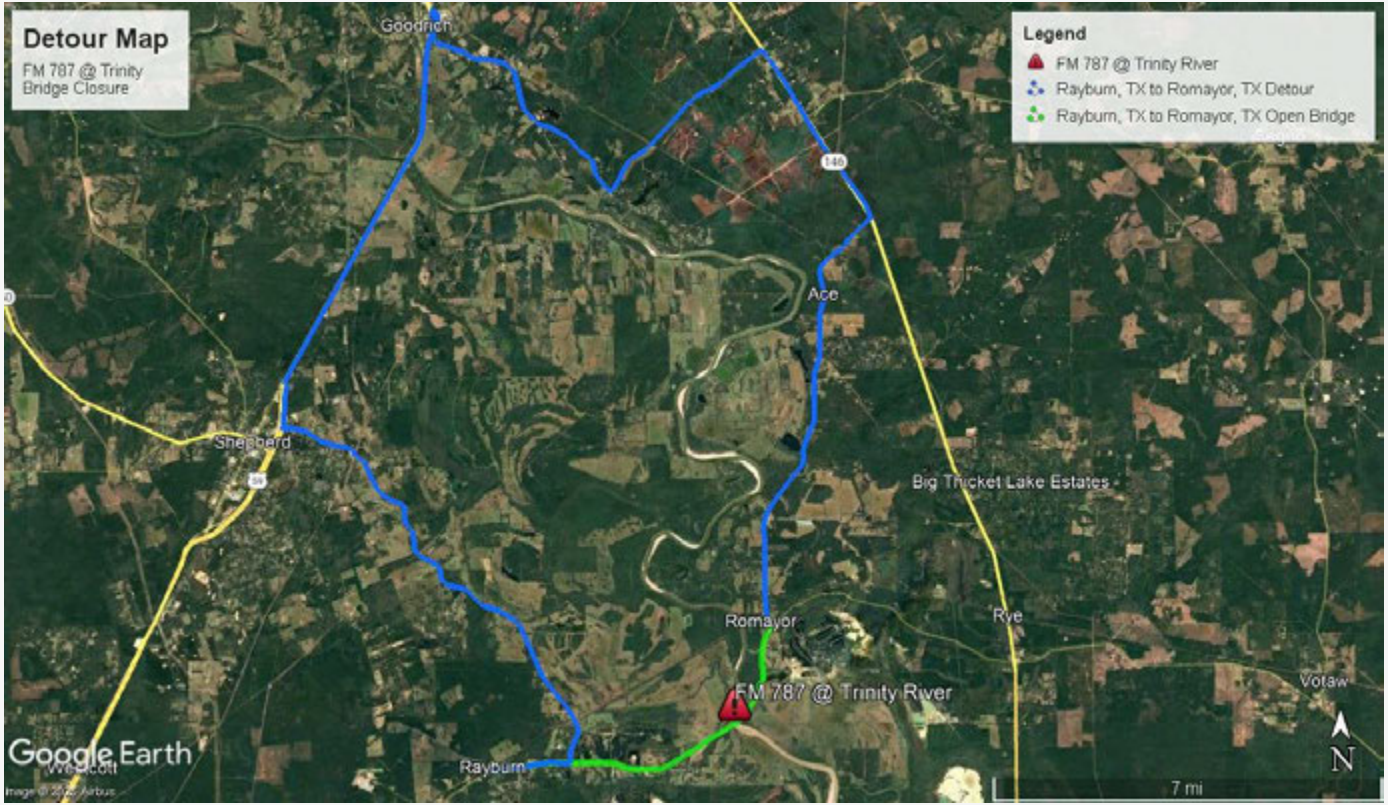



N
NE
E
330
0
30
60
90
36°NE (T) 30°25'28"N, 94°51'4"W ±13ft ▲ 84ft
FM 787 at Trinity River
Beaumont District Bridge
15 May 2024, 17:34:40


E
SE
S
90
120
150
180
210
144°SE (T) 30°25'28"N, 94°51'5"W ±32ft ▲ 78ft
FM 787 at Trinity River
Beaumont District Bridge
15 May 2024, 17:32:48


North West Elevation
157°SE (T) 30°25'32"N, 94°50'57"W ±13ft ▲ 85ft
FM 787 Trinity River
Beaumont District Bridge
12 Jun 2024, 18:35:22

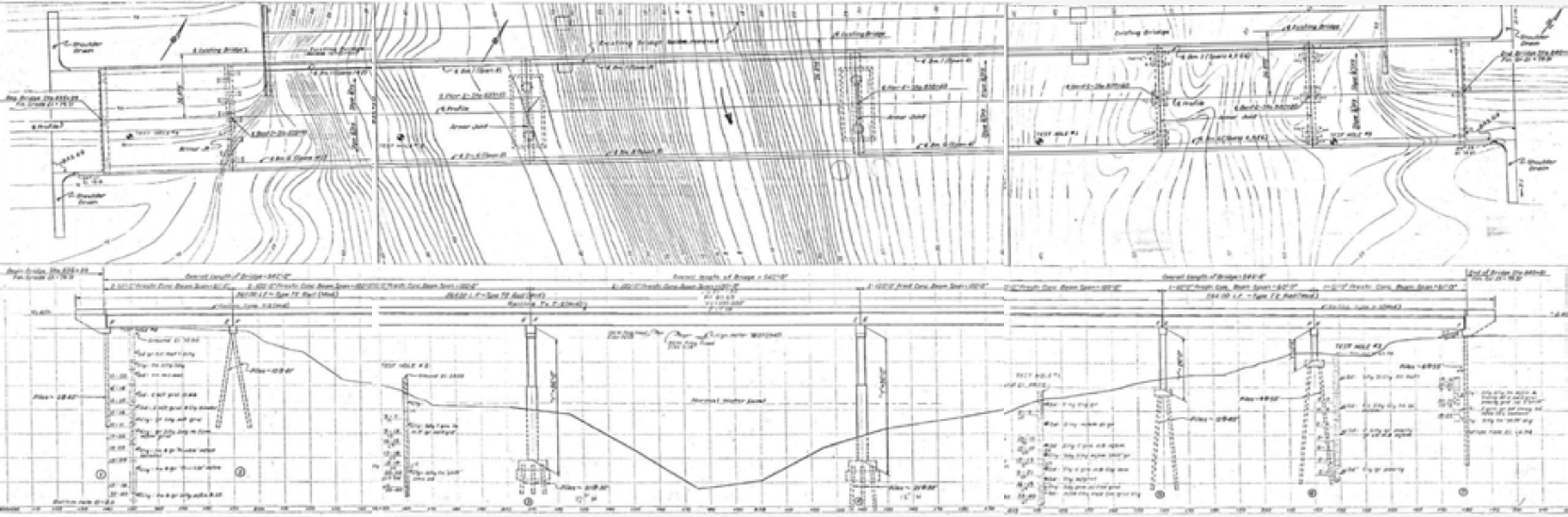
40 MINUTE DETOUR (!)



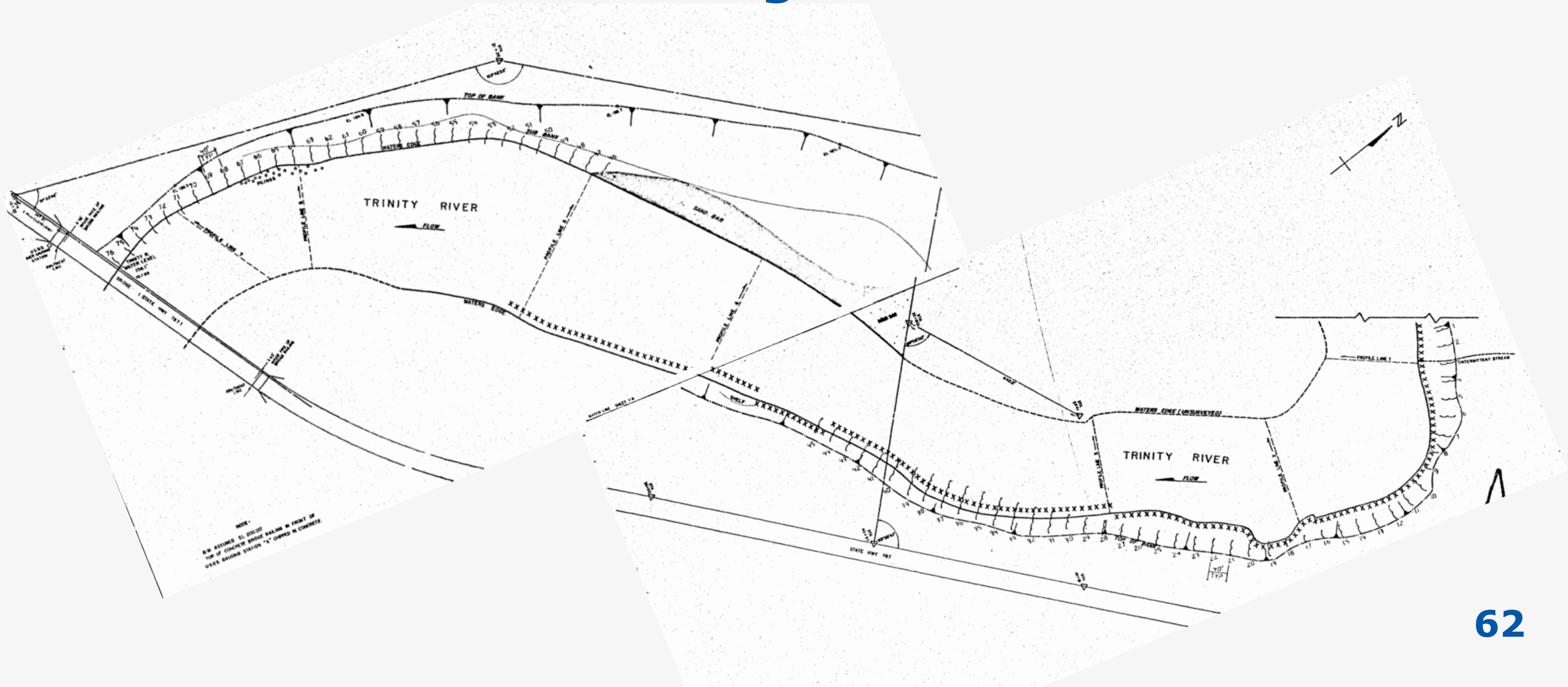
1971 – Lake Livingston Constructed

1976 – Current FM 787 Bridge Constructed

542′ long, 6 spans (51′-120′-130′-160′-120′-60′-61′)



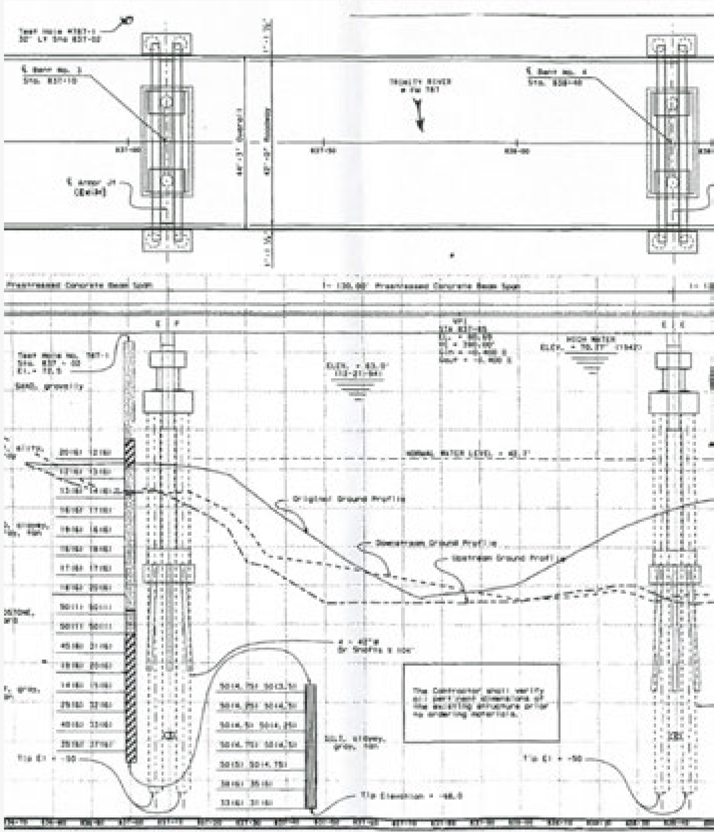
1986 – "Construct Permeable Jetty Panels" AKA River Training



1986 – "Construct Permeable Jetty Panels"

1986 – "Construct Permeable Jetty Panels"

1995 – Straddle Bents added at Bents 3 and 4



2001 – Bridge Lengthening, added 122′ Span to the East

2022 – Added 1000’ of Sheet Pile Wall along East Approach Added Bent Encasement Protection at Bents 6 and 7

2022 – Added 1000' of Sheet Pile Wall along East Approach Added Bent Encasement Protection at Bents 6 and 7

Timeline of FM 787 @ Trinity River

- **1920** – Original bridge constructed (truss)
- **1971** – Lake Livingston (including Dam) constructed
- **1976** – Truss structure replaced with concrete span bridge
- **1986** – Scour/ erosion repair project
- **1995** – Scour/ erosion repair project
- **2001** – Scour/ erosion repair project
- **2017** – Hurricane Harvey
- **2018** – Scour/ erosion repair from Hurricane Harvey
- **2019** – Tropical Storm Imelda
- **2022** – Scour/ erosion repair from Tropical Storm Imelda
- **2024** – Unnamed flood event & bridge failure
- **2025** – Emergency bridge repair complete
- **2029** – FM 787 Re-Route Project to begin

2005 Research Article

- Sediment loads in the Trinity River after construction of the Lake Livingston Dam were significantly less than before
- At the FM 787 crossing, chronic scour and significant bank erosion were noted
- Channel had exposed sandstone bedrock (no bed material left)

Earth Surface Processes and Landforms
Earth Surf. Process. Landforms **30**, 1419–1439 (2005)
Published online in Wiley InterScience (www.interscience.wiley.com). **DOI:** 10.1002/esp.1203

Channel adjustments of the lower Trinity River, Texas, downstream of Livingston Dam

Jonathan D. Phillips,[1*] Michael C. Slattery[2] and Zachary A. Musselman[1]
[1] *Tobacco Road Research Team, Department of Geography, University of Kentucky, Lexington, KY 40506-0027, USA*
[2] *Department of Geological Sciences, Texas Christian University, Fort Worth, TX, USA*

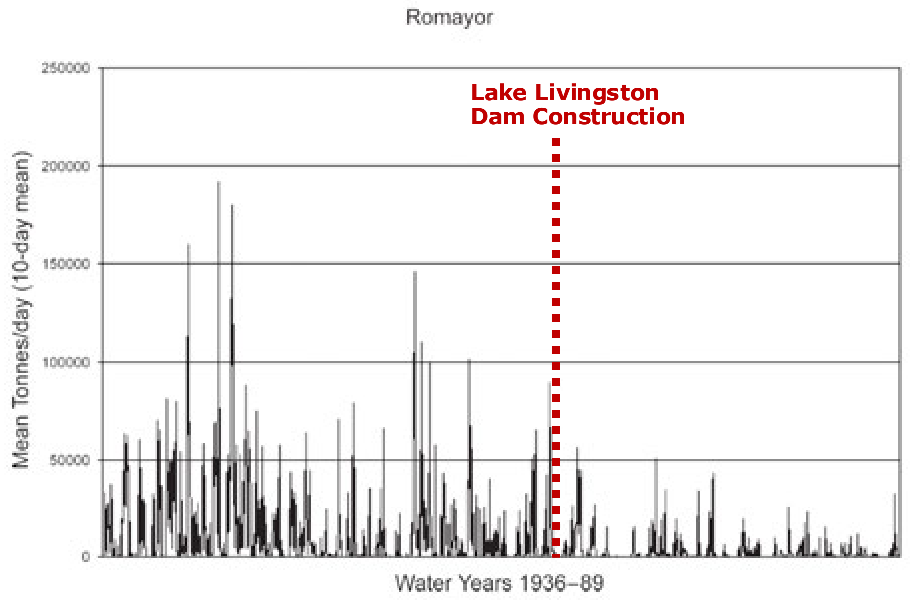


Figure 2. Sediment loads as 10-day means at the Romayor gaging station. Data from the Texas Water Development Board. Samples were taken with a point sampler (the Texas Sampler); results are multiplied by 2·37 to calibrate with depth-integrated samples as described by Phillips *et al.* (2004).

Texas Department of Transportation

2017 Research Article

Geomorphic Signature of a Dammed Sandy River: The Lower Trinity River Downstream of Livingston Dam in Texas, USA

Submitted to *Geomorphology*

By Virginia B. Smith[1,*] and David Mohrig[2]

[1]Department of Civil and Environmental Engineering, Villanova University, Villanova, PA 19085

[2]Department of Geological Sciences, the University of Texas at Austin, Austin TX, USA, 78712

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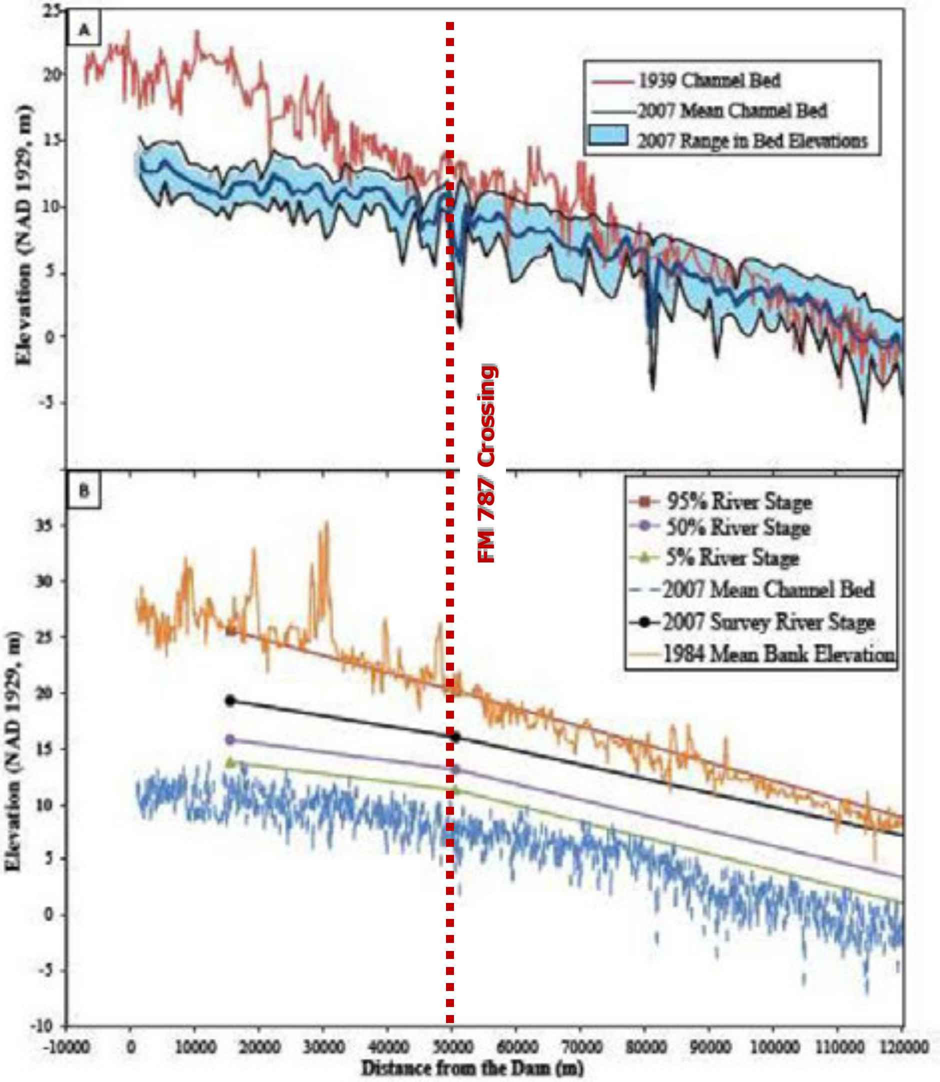
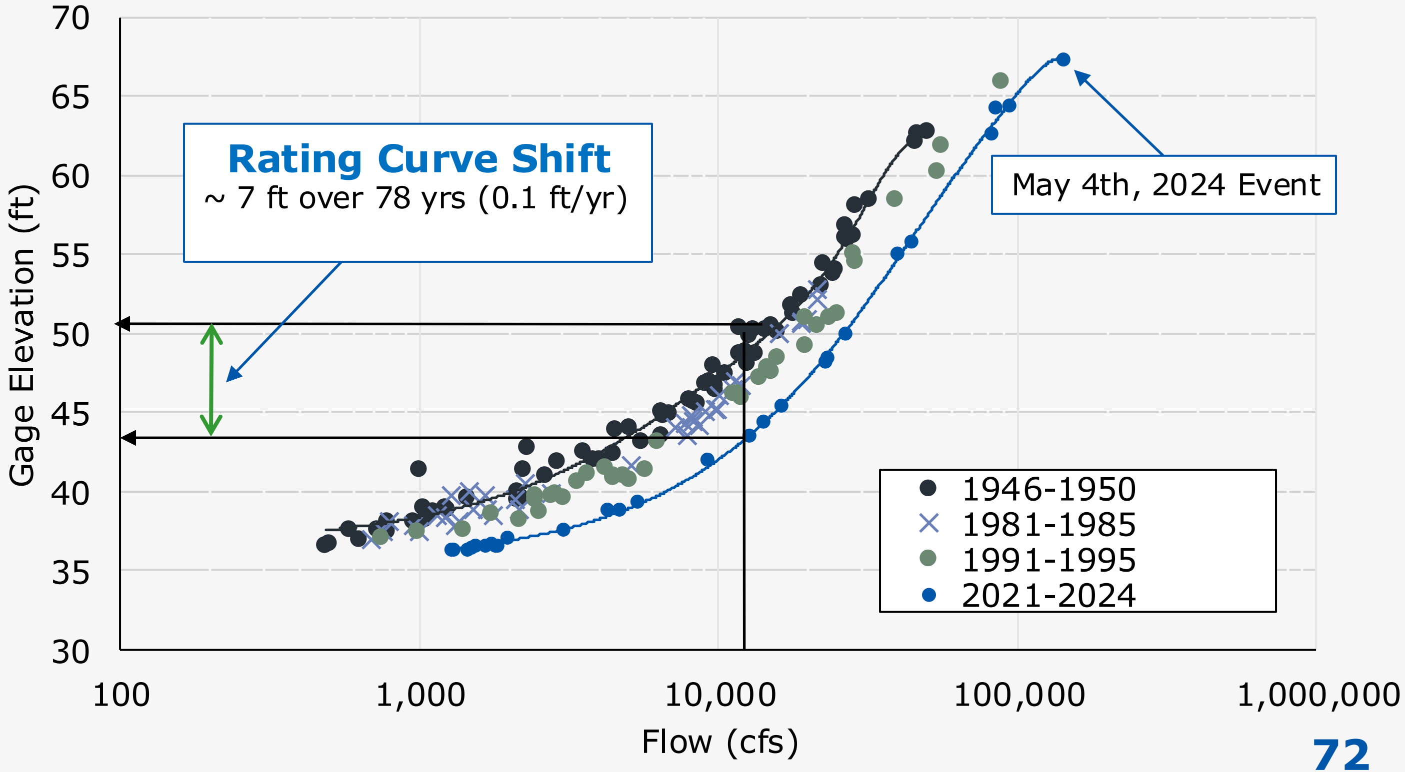
- Though most streams eventually stabilize downstream of a dam, the sandy nature of the Trinity River allows continuous adjustment
- Reach of impacts from dam construction continues to grow over time, but may take more than 100 years to realize impact to the coastal zone at Trinity's delta

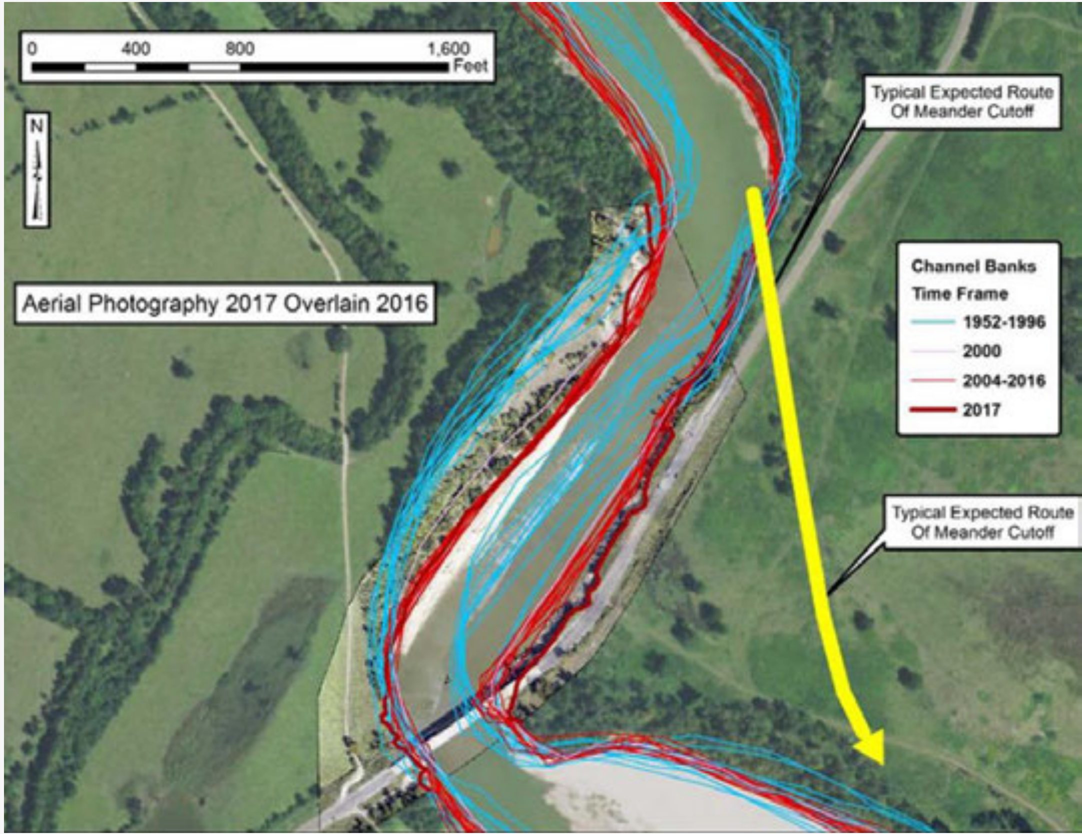


Channel Degradation/Widening – Rating Curve Shift



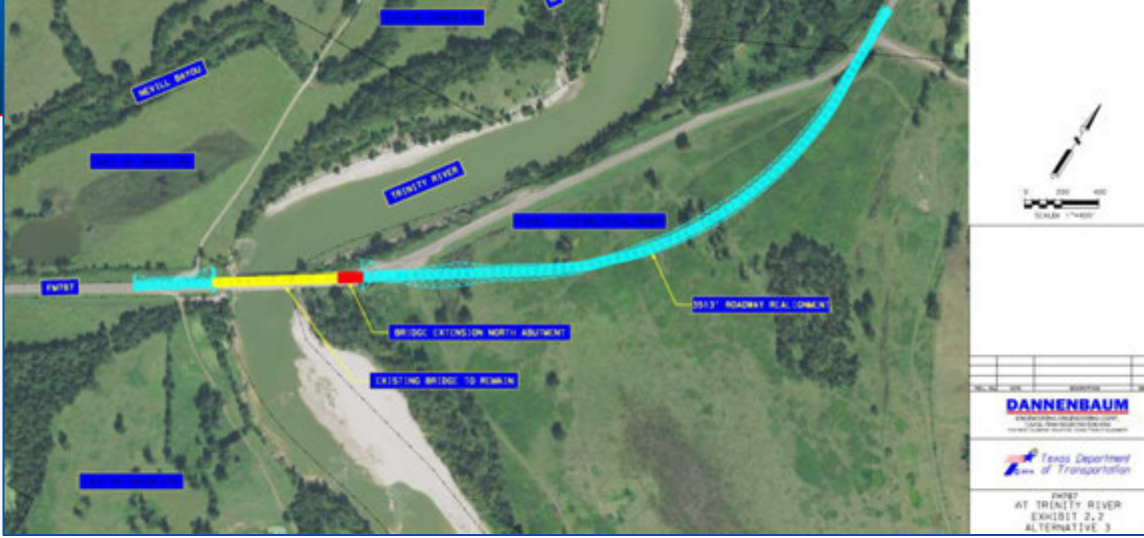
2018 River Migration Assessment

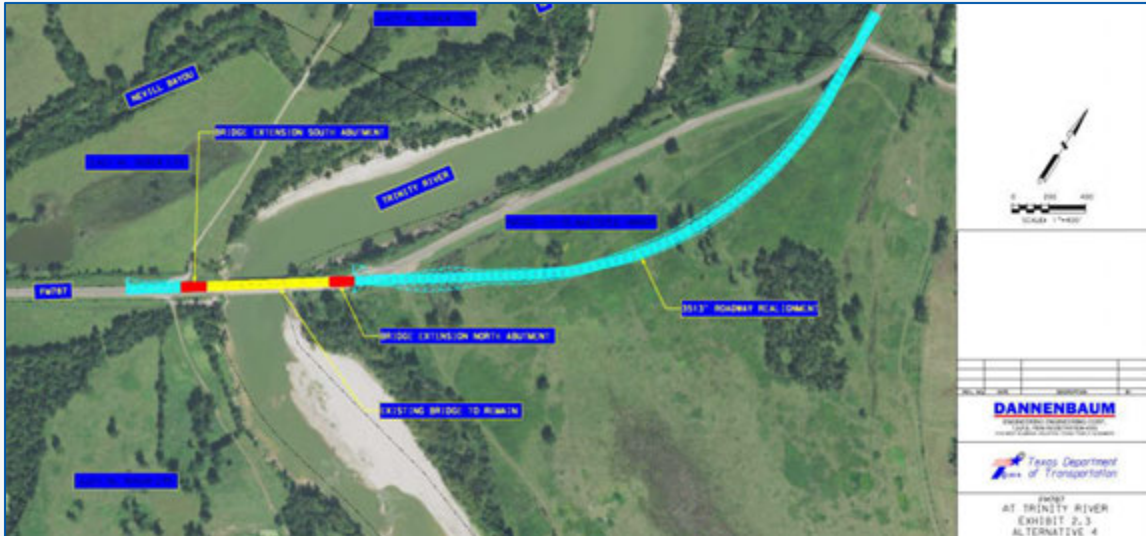
- Evaluated stability of channel based upon historical aerial imagery
- Determined that erosion pressure at abutments of the existing bridge will continue to increase over time
- Recommended relocating crossing



2018 River Migration Assessment

- Recommended two options for crossing to remain in place
- Both alternatives would extend bridge and relocate eastern approach roadway





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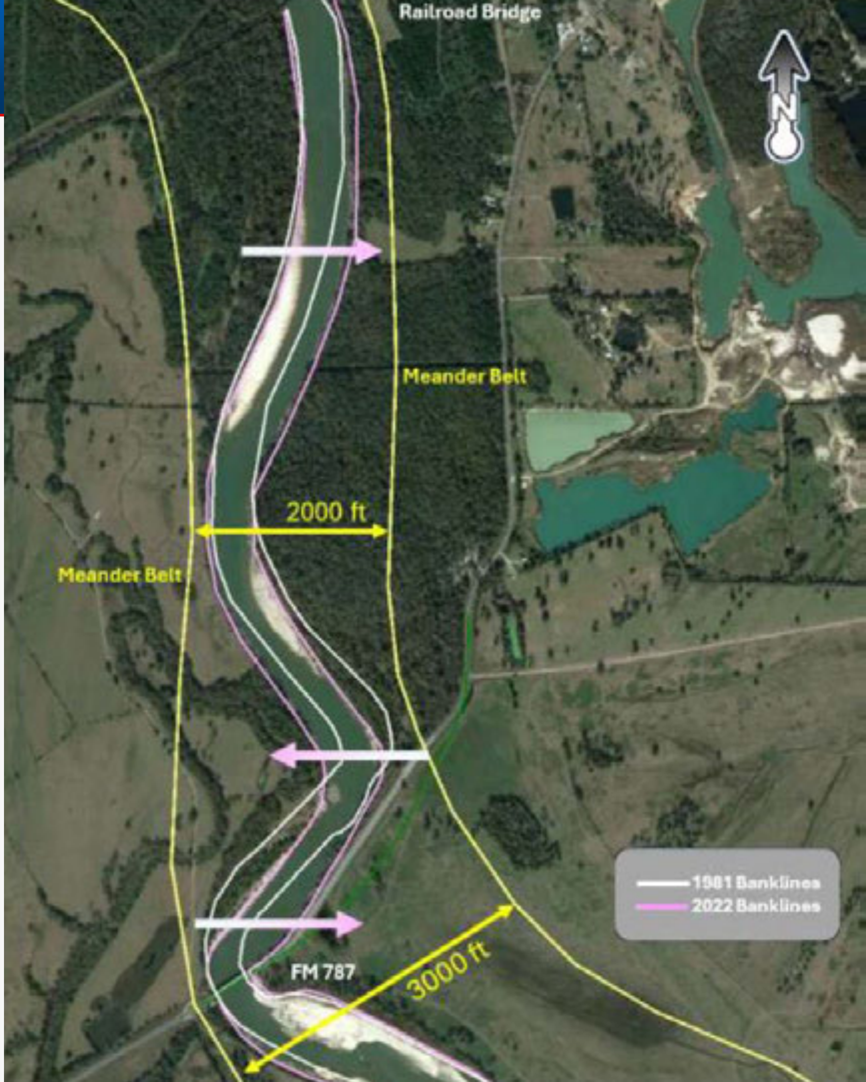
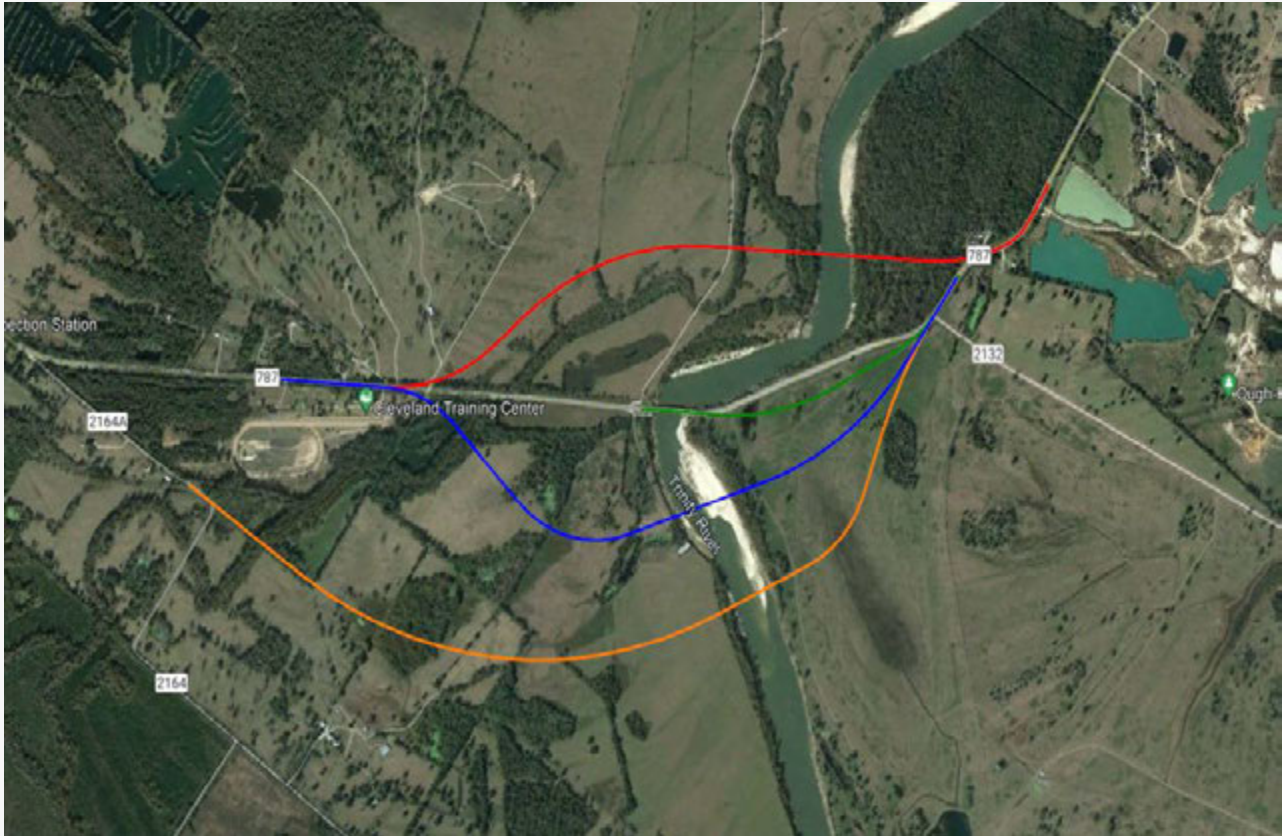
Current River Migration Assessment

- Evaluating risk and anticipated channel evolution (as with 2018 study)
- Consideration of meander belt
- Consideration of 4 alternatives



What's Next for FM 787?

- Looking for an alternate location to cross the Trinity River on FM 787
- Fluvial geomorphology study underway now – will use data to determine most stable location



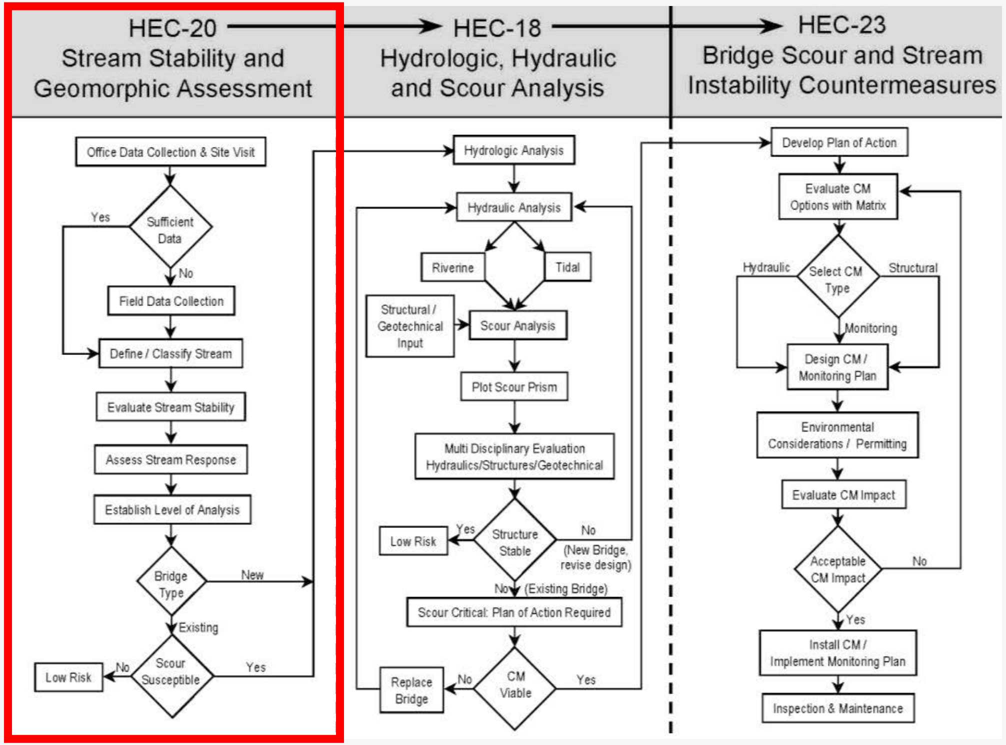
Emergency Repairs began September 2024

Bridge Open March 2025

Our Subject

1. What is fluvial geomorphology?
2. Why does it matter to TxDOT?
3. **What should I do now that I know what it is and why it matters?**

Fluvial Geomorphology in Relation to Scour



Historical Bank lines at the Bridge

- Aerial photograph from 2012 to 2021 shows the banklines.
- Extensive banklines indicate the greatest bank migration occurred from 2012 to 2017.
- Downstream bankline was stabilized after the channelization project in 2017.

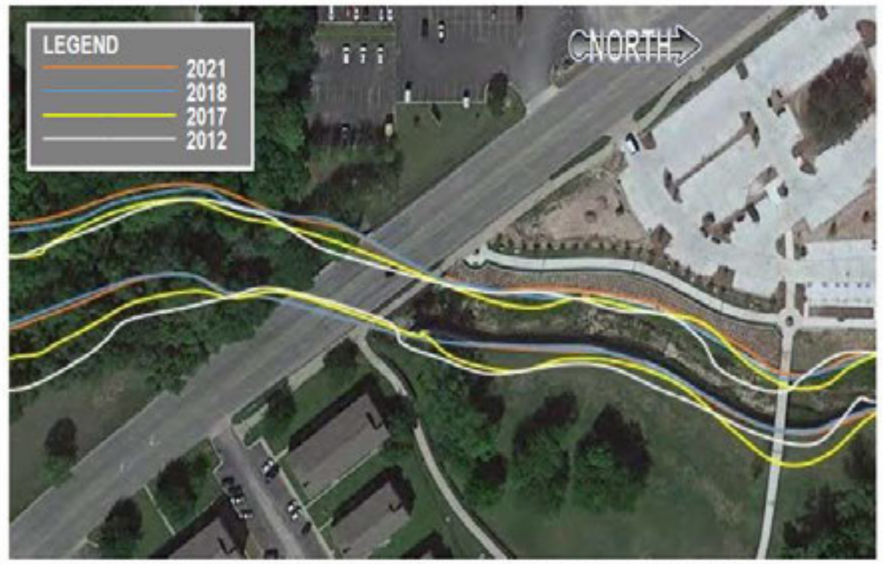


Image Source: FM 2552 at Black Warrior Branch Geomorphic Assessment Report- West Consultants

Historical Cross-Section Overlays

- Scour from as-built to 2012 = 2 ft.
- Scour from 2012 to 2014 = 0 (no difference)
- Scour from 2014 to 2016 = 2 ft.
  - Channel appears to have scour on right bank and scour on channel bottom.
- Scour from 2016 to 2020 = 3 ft.
  - Channel shown 3 ft of degradation at the thalweg.
- Scour from 2020 to 2021 = 1 ft. (not shown on the sketch)

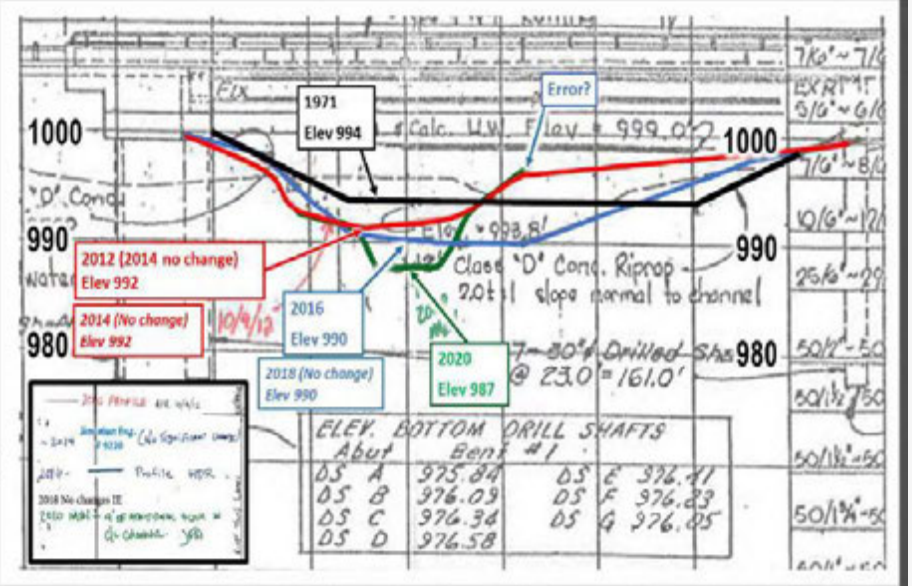


Image Source: FM 2552 at Black Warrior Branch Geomorphic Assessment Report- West Consultants

Historical Streambed Profile

- Streambed profile provides perspective of the accelerating rate of long-term scour at the bridge.

- It took 45 years to scour 4 feet but it only tool six years to scour another 7 feet.

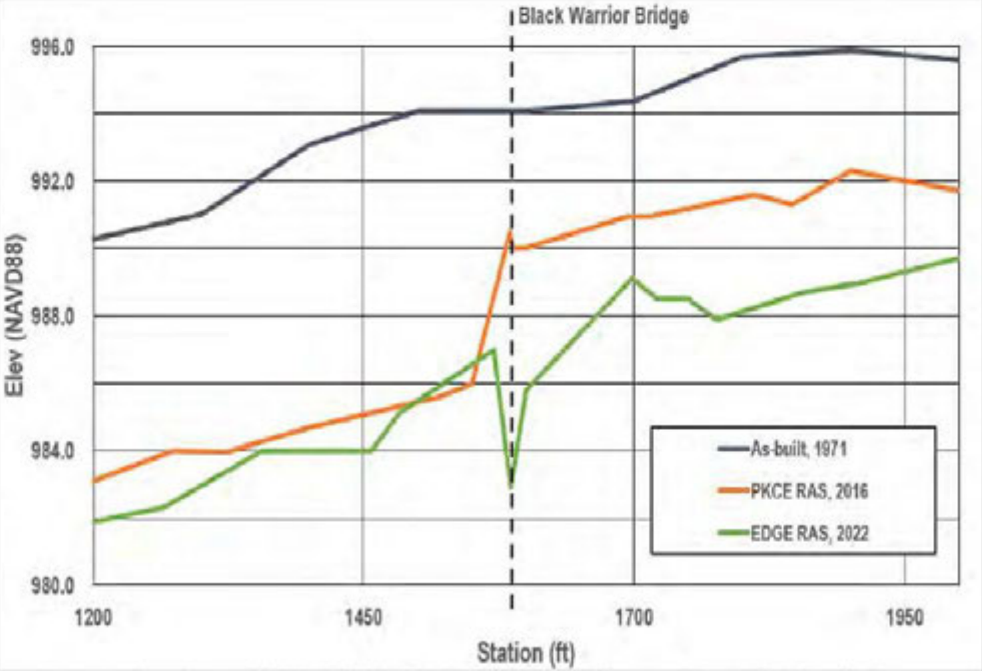


Image Source: FM 2552 at Black Warrior Branch Geomorphic Assessment Report- West Consultants

Bridge on the Trinity River

- Bridge constructed in 1997
- Lake Livingston is 0.5 river miles upstream, constructed in 1968
- USGS gage 08026000 (Trinity River near Goodrich, TX) attached to US 59 bridge (11.4 river miles downstream of FM 3278) in continuous operation since 1965

When we create a hard point, we create a soft point

A Few Additional Considerations

- When we create a hard point, we create a soft point
- Feeding the stream vs abutment armoring
- Sediment transport is highest at peak flows, aggradation/deposition tends to occur on the receeding limb of flood flows

3. What should I do now that I know...?

- Desktop evaluation:
  - Look at site images from online street views, bridge inspection photos
  - Use historic aerials to look for changes in planform
  - Look at bridge inspection channel cross-sections
  - Other sources of information
- Reach out to DES-H&H!

THANK YOU! + Questions?

The Meandering Ucayali River, Peru

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