Applied Fluvial Geomorphology

River Processes In the Metroplex

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HALFF

USDA Agricultural Research Service

BAYLOR UNIVERSITY 1845

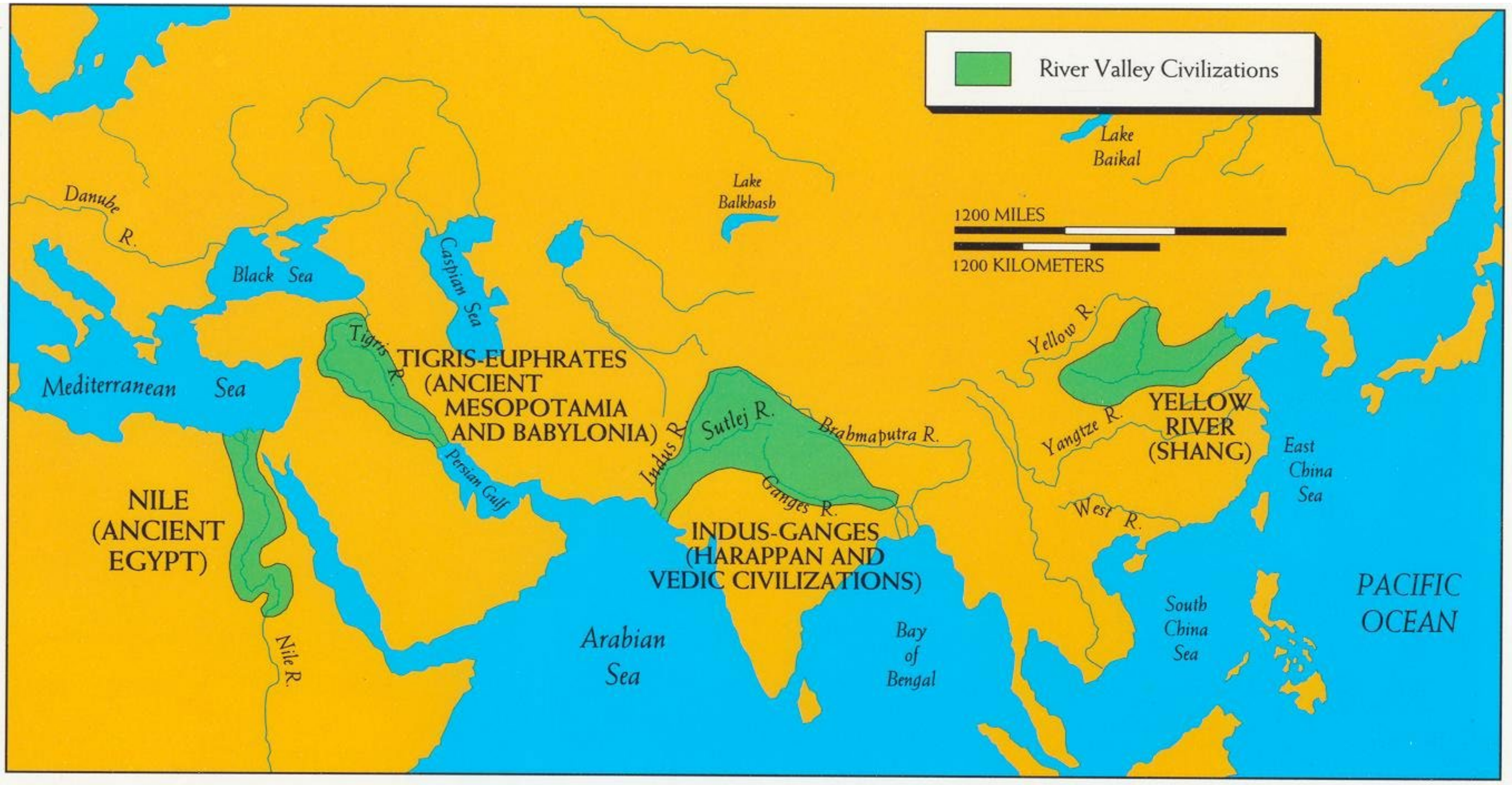
In nature's infinite book of secrecy, a little I can read.

Or What is Fluvial Geomorphology ?

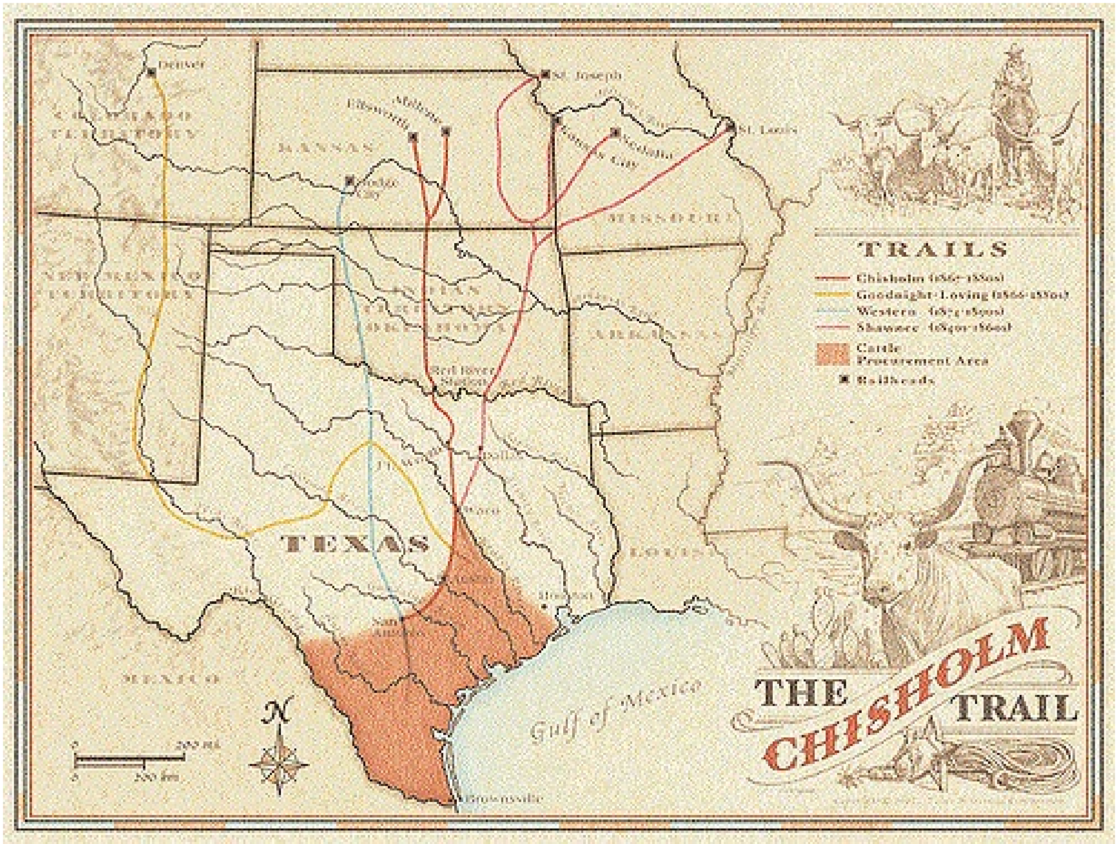
William Shakespeare

Our History began Near Rivers

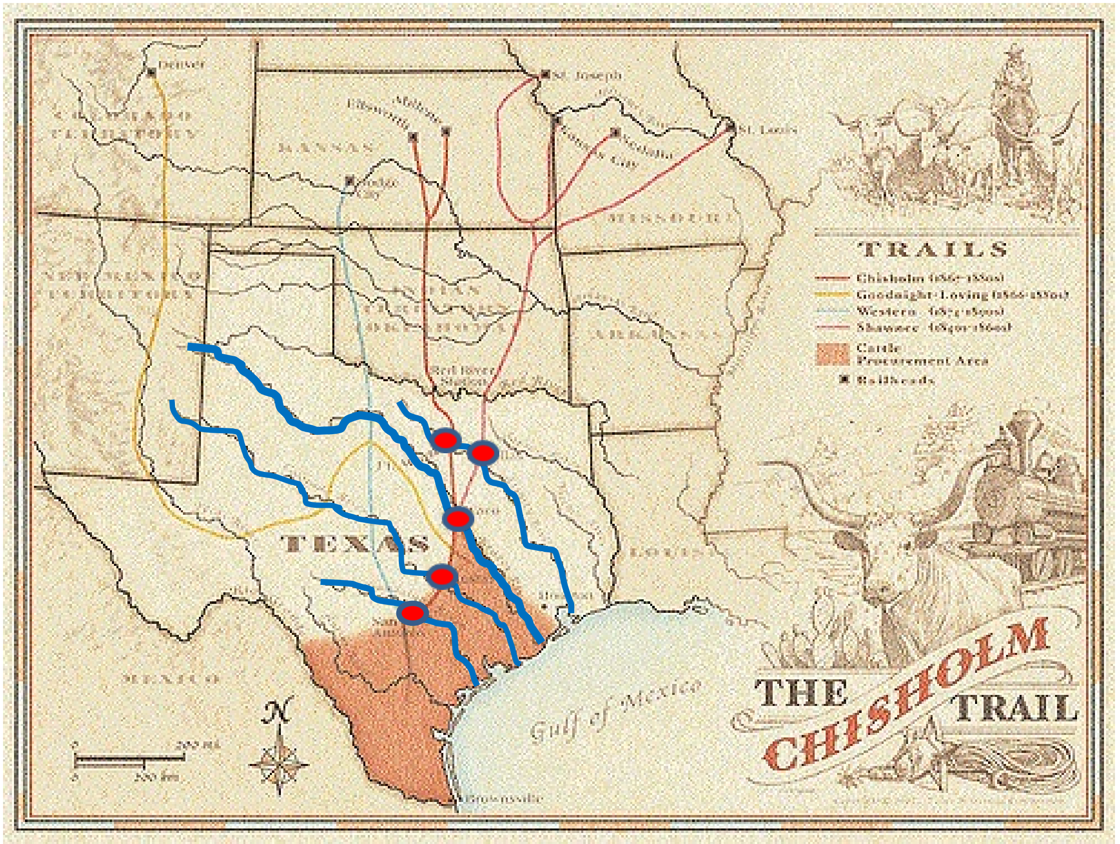
4.4 Million Years Ago
Floodplain
Ethiopia



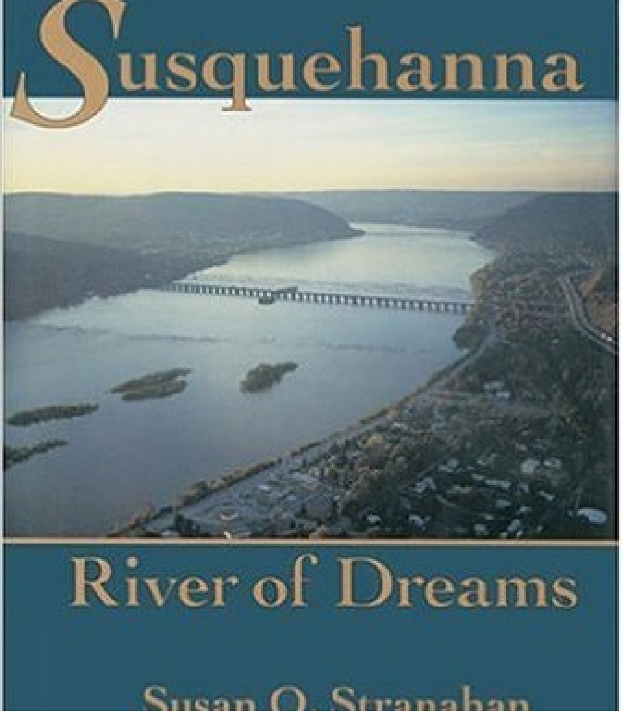
Our Cites Were Located by Cows and Rivers

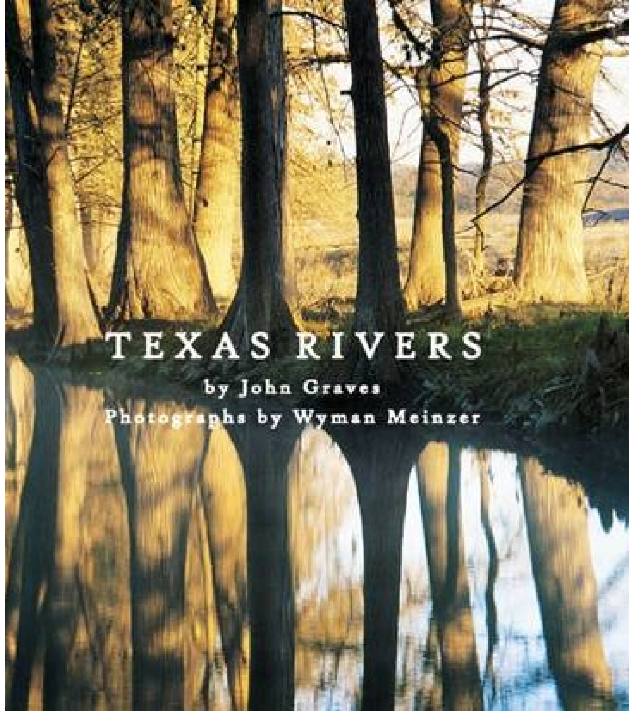


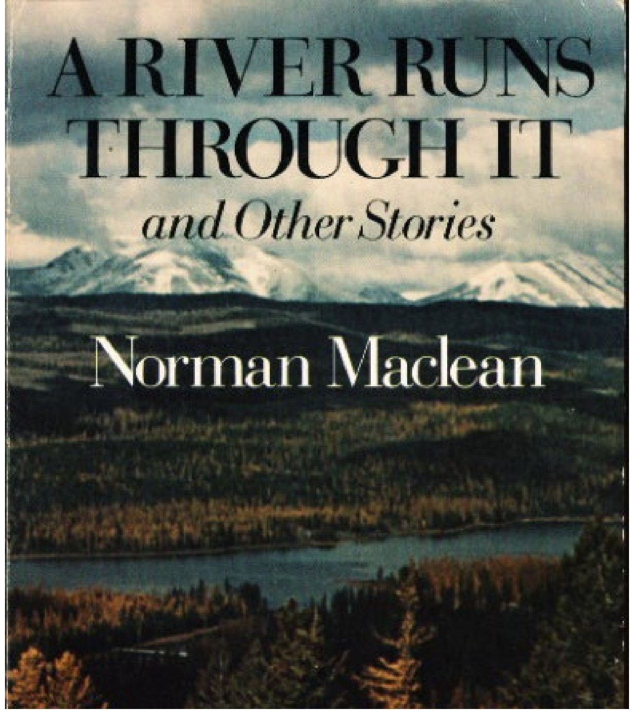
Our Cites Were Located by Rivers… and Cows

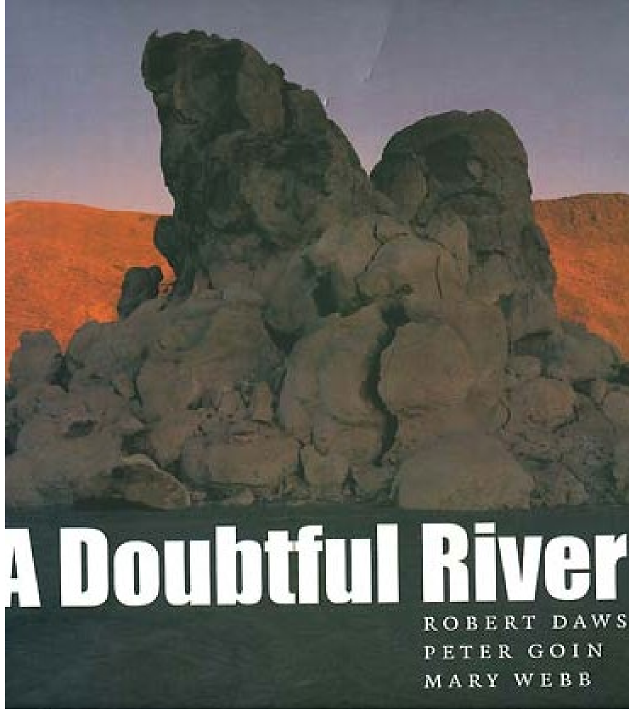


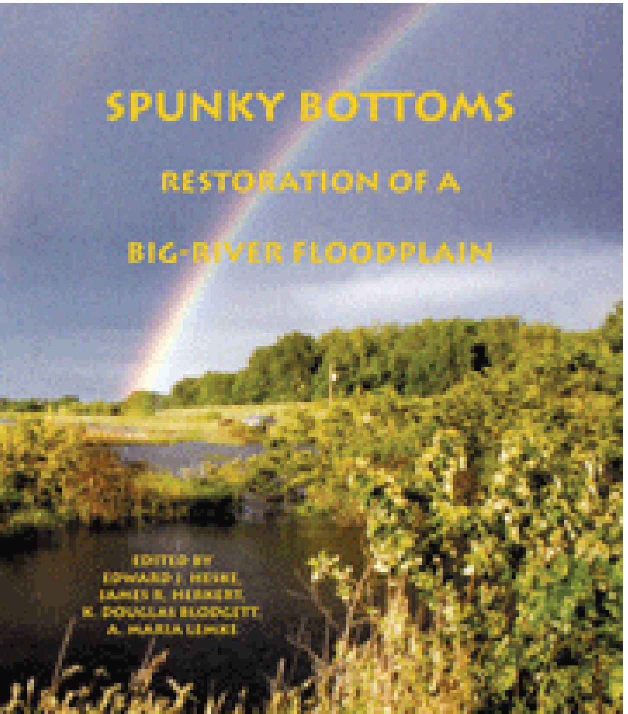
Hard Rock Crossings: Limestone and Rivers

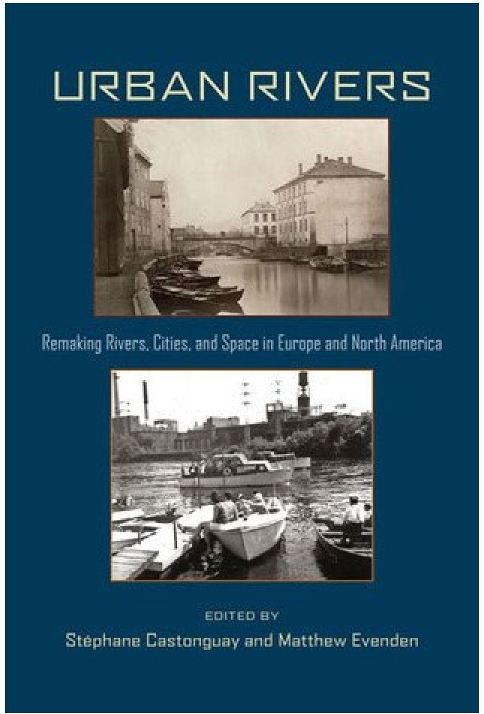












We wrote about rivers

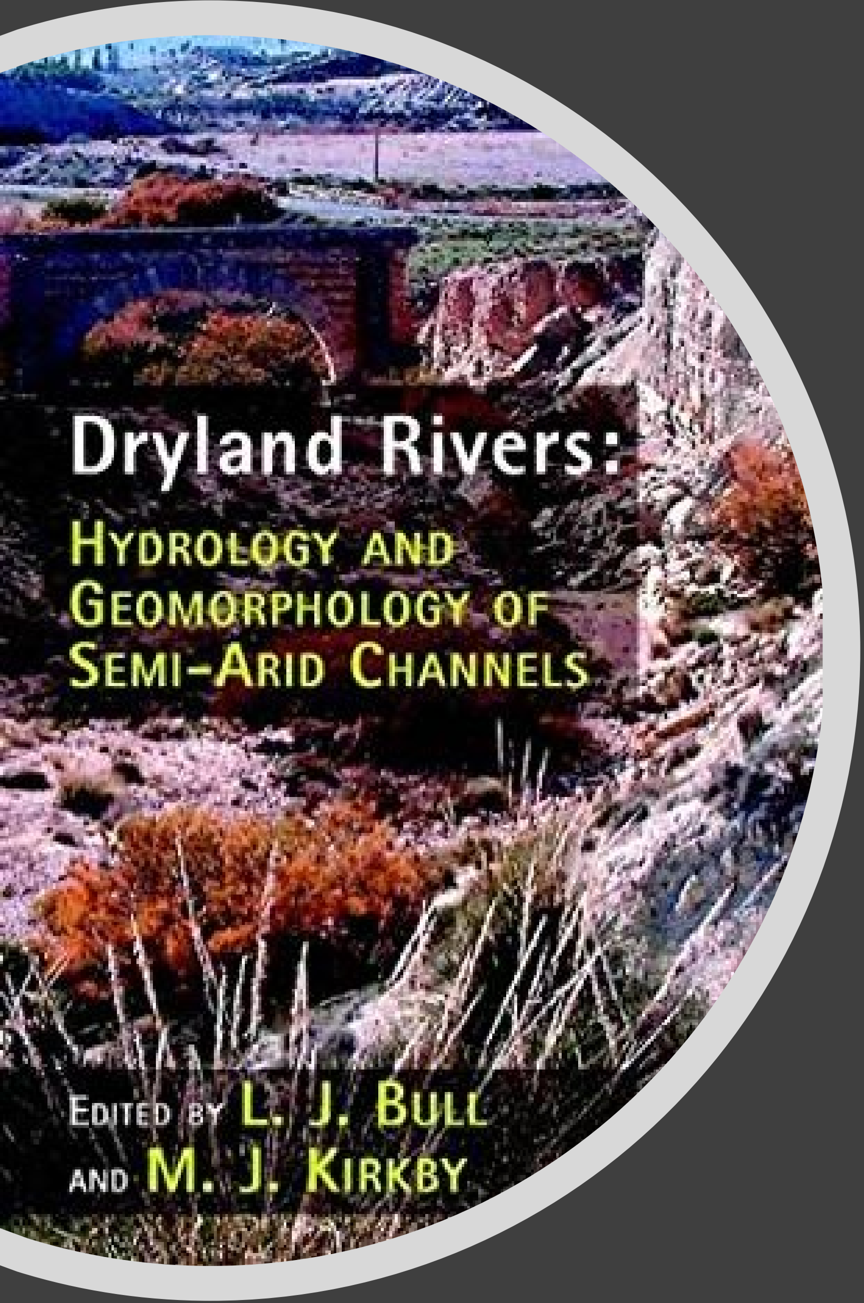
- *416 with River Names on Amazon*
- *Most Popular Hucklberry Finn*

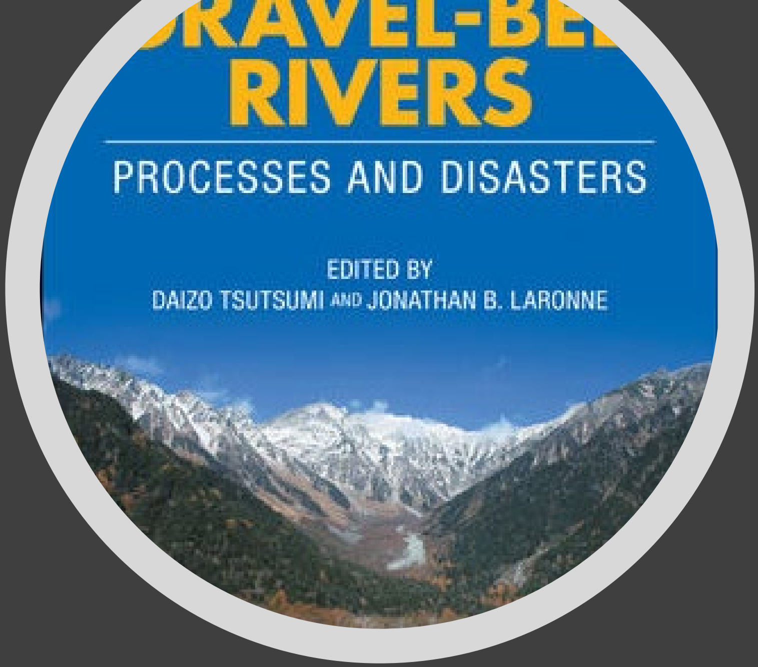


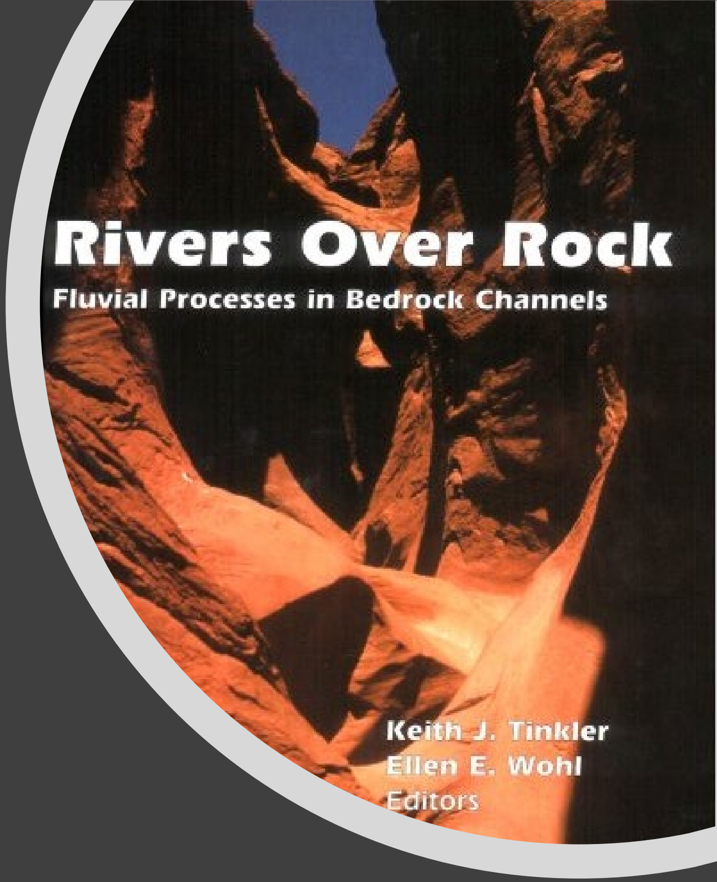


We started out with Natural Rivers

- *3.5 million miles streams in Continental US*
- *Log jams and beavers*



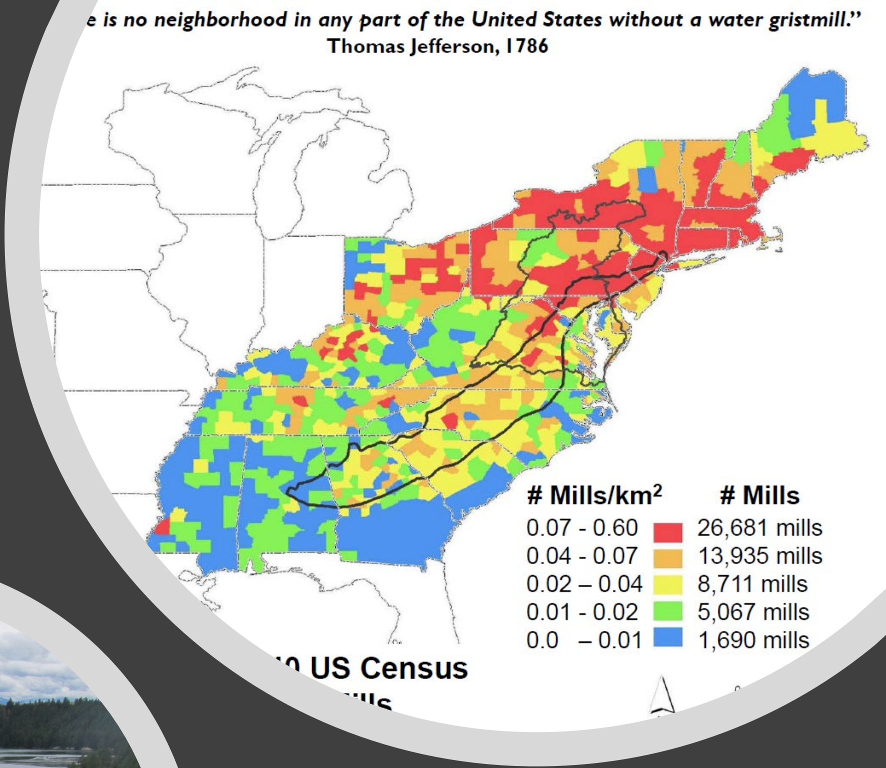




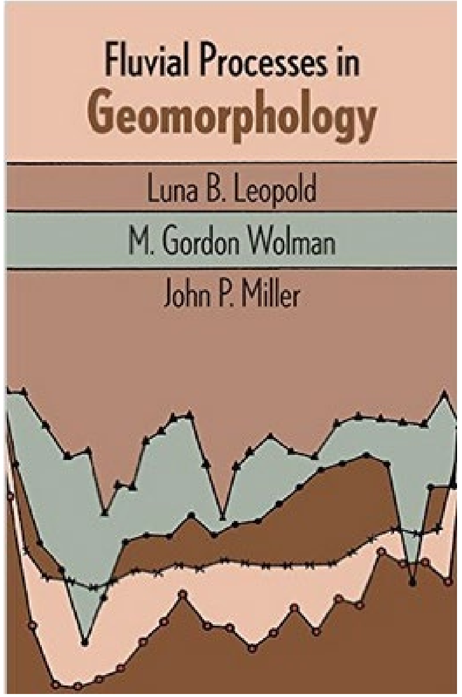
From Rock to Dryland Rivers

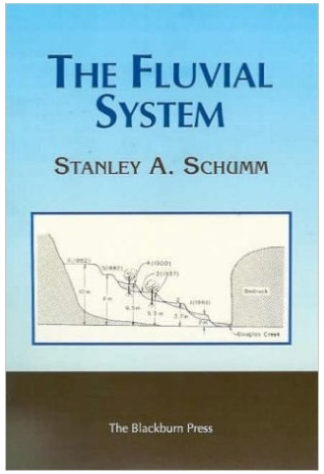
And…We began screwing things up

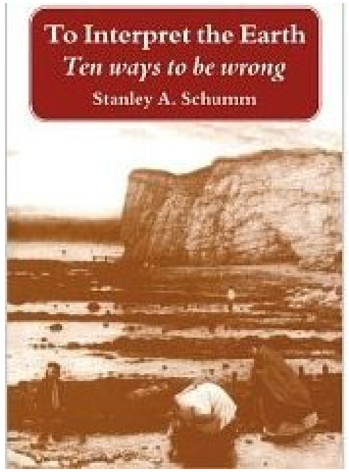
- Merritts, et. al, (2015) 65,000 mill dams
- 85,000 Dams
- 2,000,000 ponds
- 1997 channelized 20,000 miles

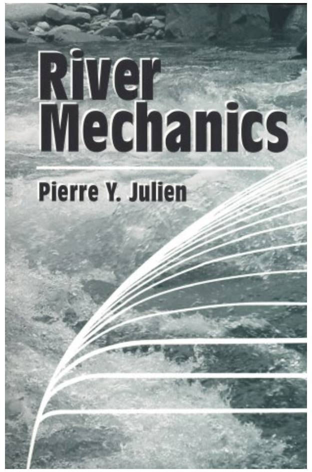


Studies began in detail in 1960's



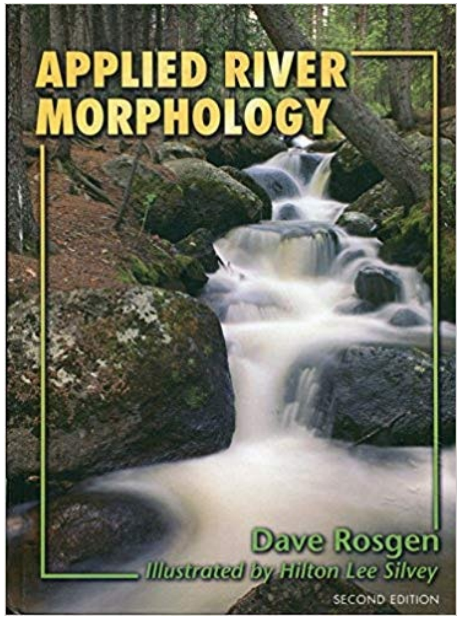


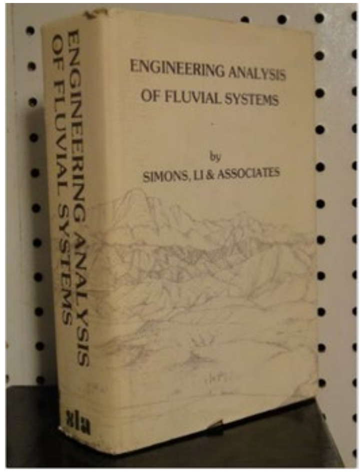


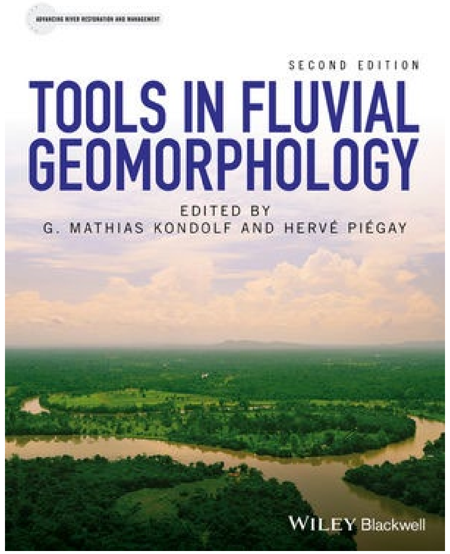


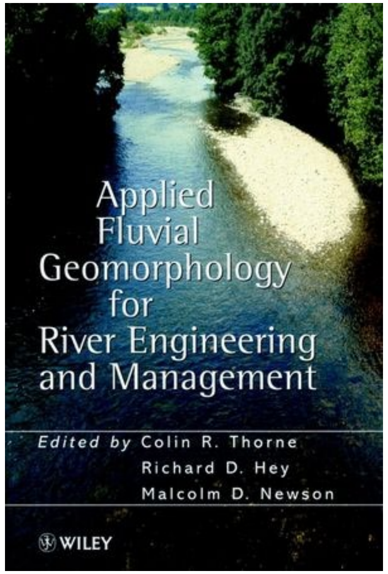
Then

APPLIED

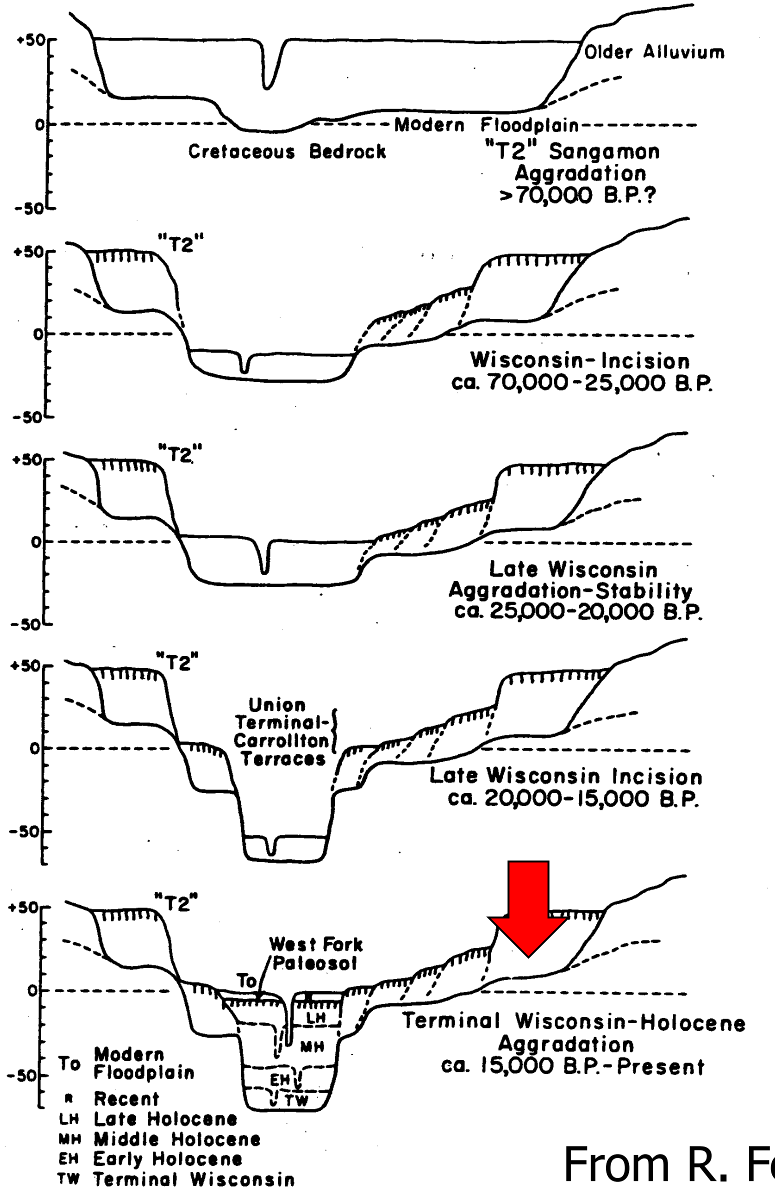








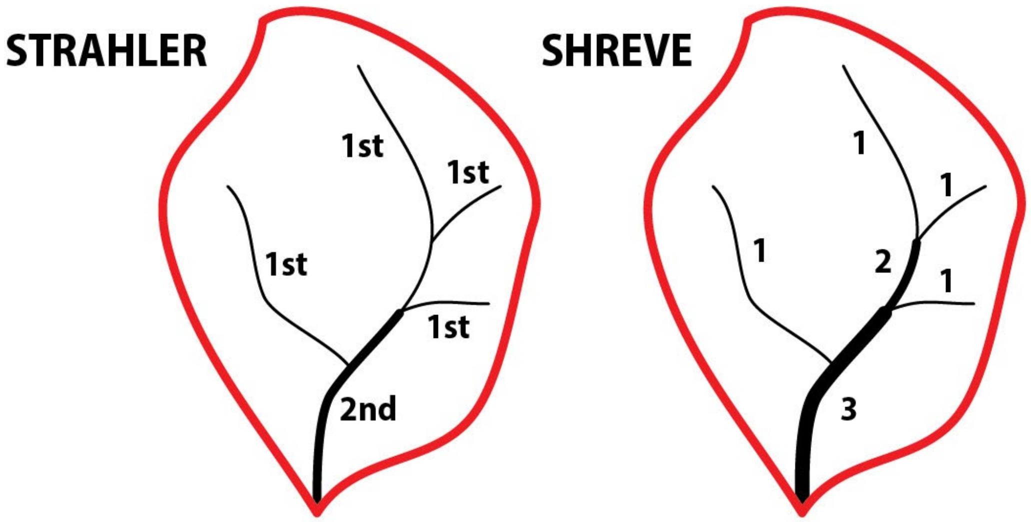
We found out rivers have a complex history



From R. Ferring (1990)

- Rivers and landscapes have a history
- Very complex
- We are looking at a very short period time (Clovis Points man at 10,000 years)
- But, recent changes can also be dramatic

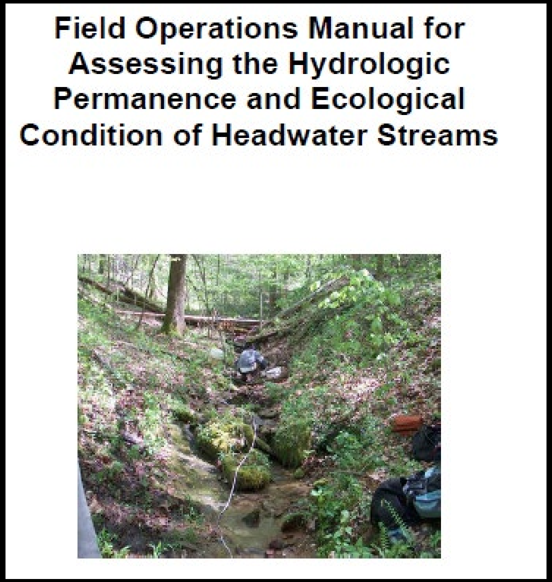
We Quantified Rivers and Found……

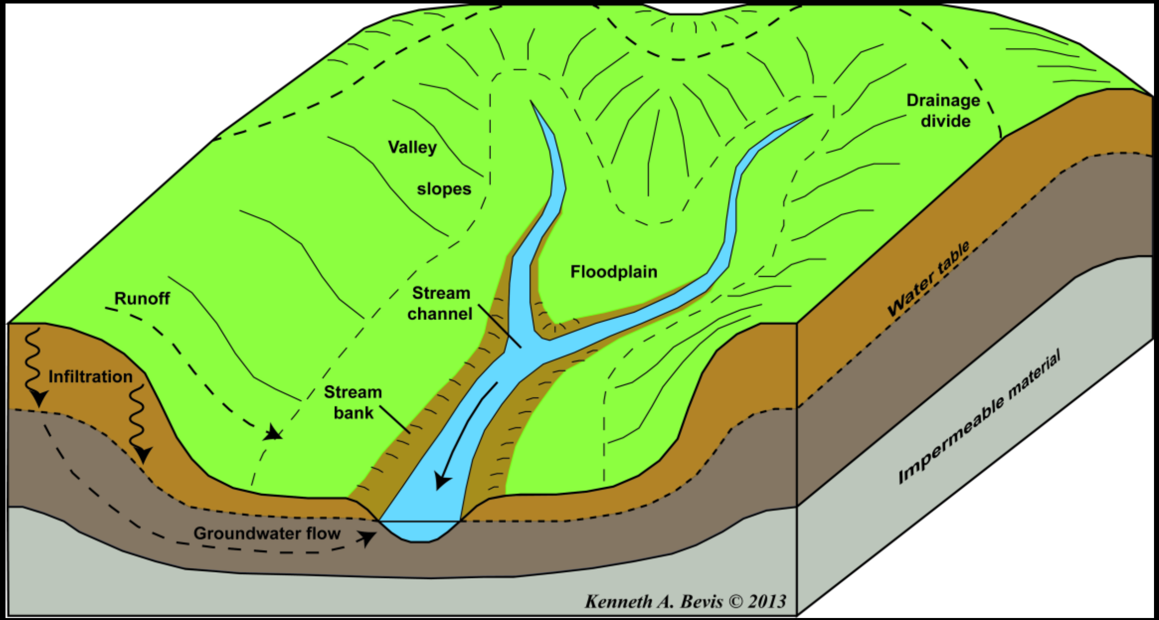


Order		Ave. Length	Total Length	Drainage Area
1	1,570,000	1.6	2,510,000	2.6
2	350,000	3.7	1,300,000	12.2
3	80,000	8.8	670,000	67
4	18,000	19	350,000	282
5	4,200	45	190,000	1,340
6	950	102	98,000	6,370
7	200	235	48,000	30,300
8	41	540	22,999	144,000
9	8	1,240	9,900	684,000
10	1	2,880	2,880	3,240,000

Of approximately 5,200,000 km of streams;

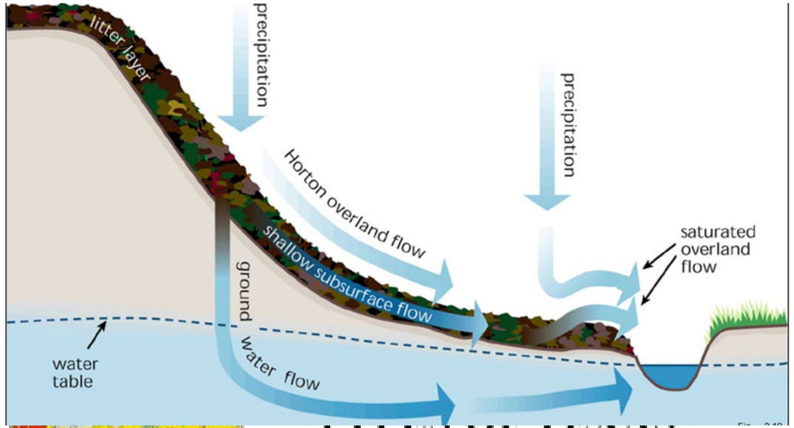
About 73 % by length 1-2 Order

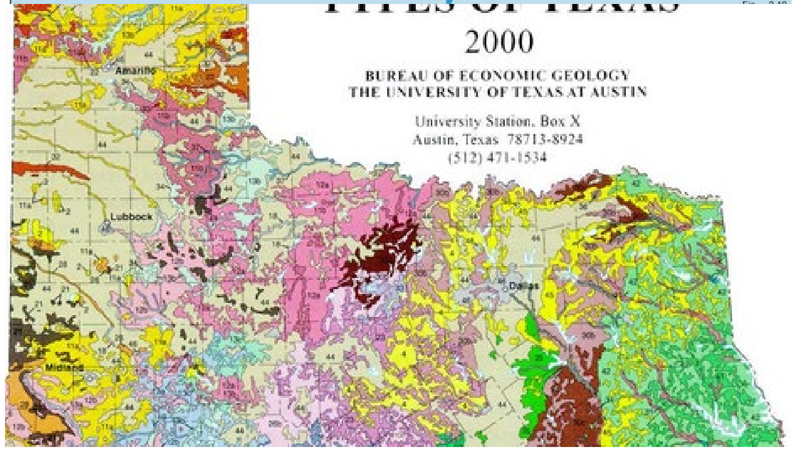


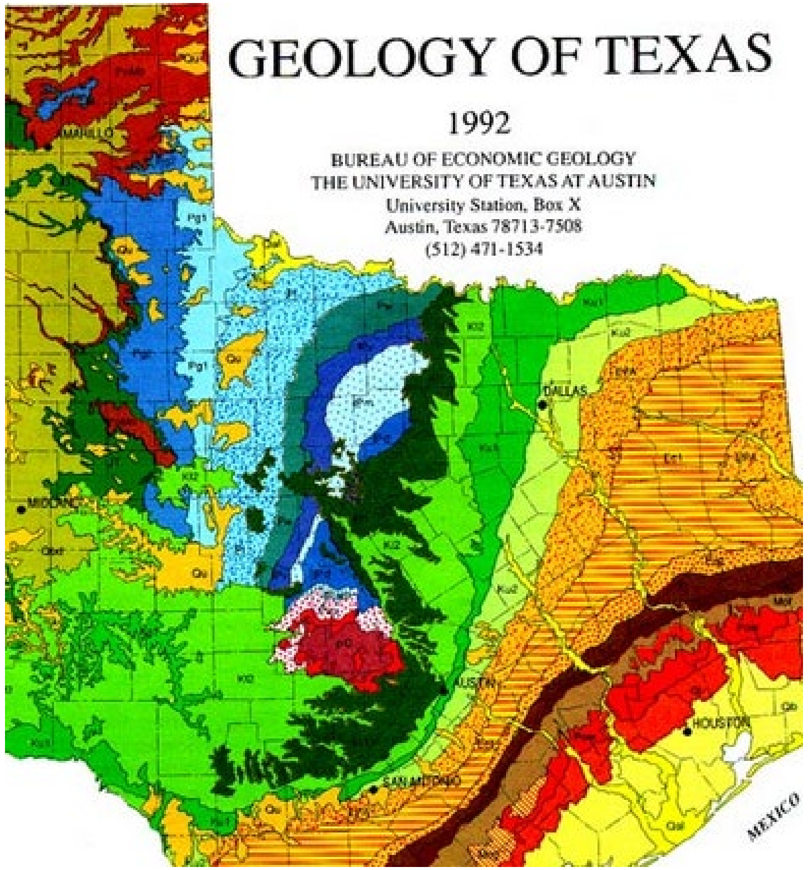


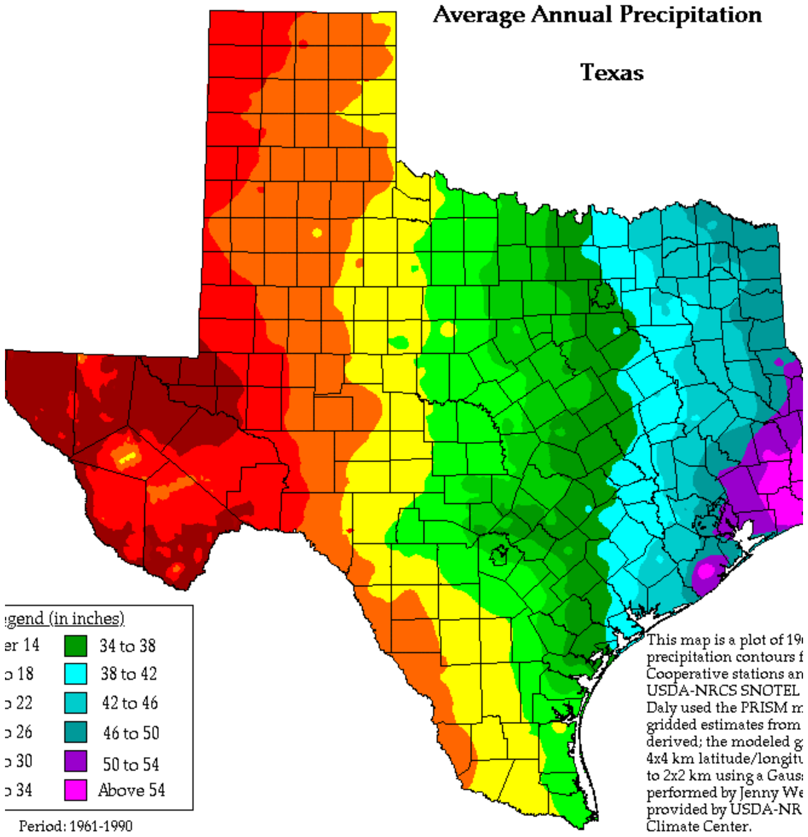
Most are Headwater Streams

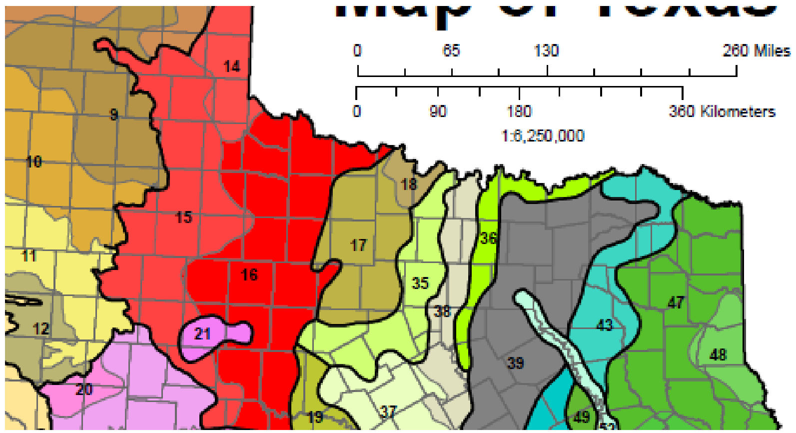
- Most are small and quite easy to screw up.
- About 2 million Headwater Streams











Processes tied to a Changing Climate

And Changing Land Use

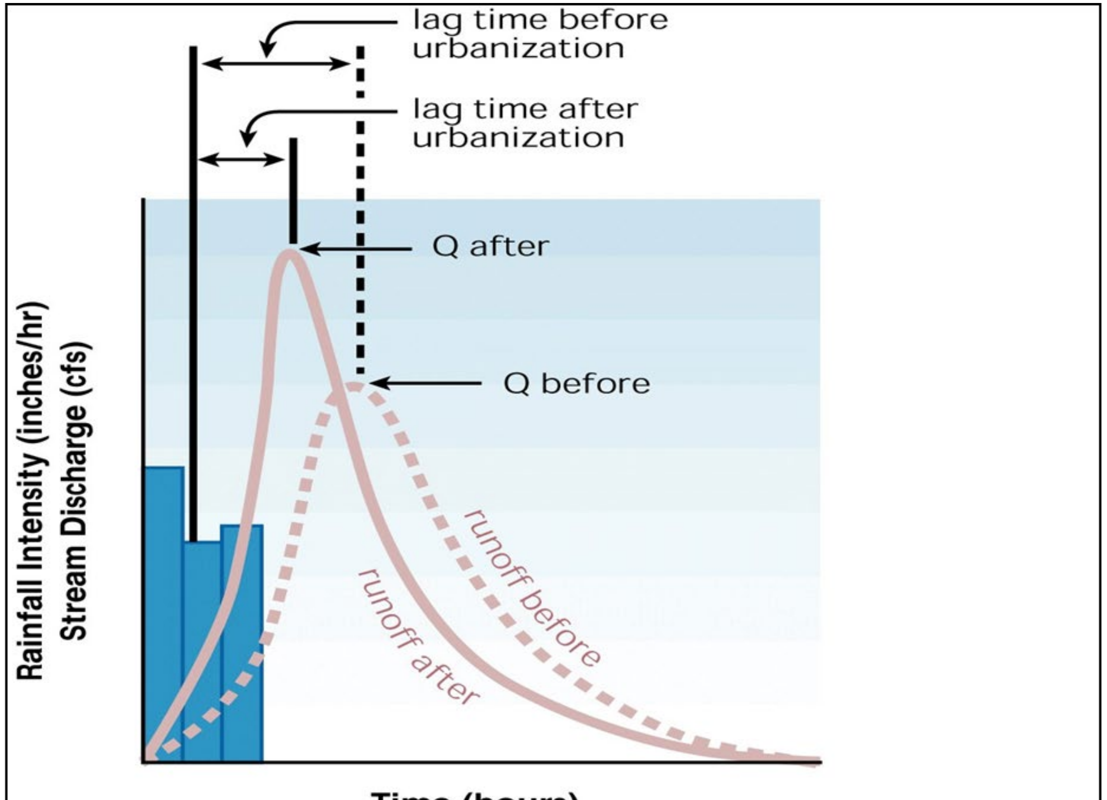
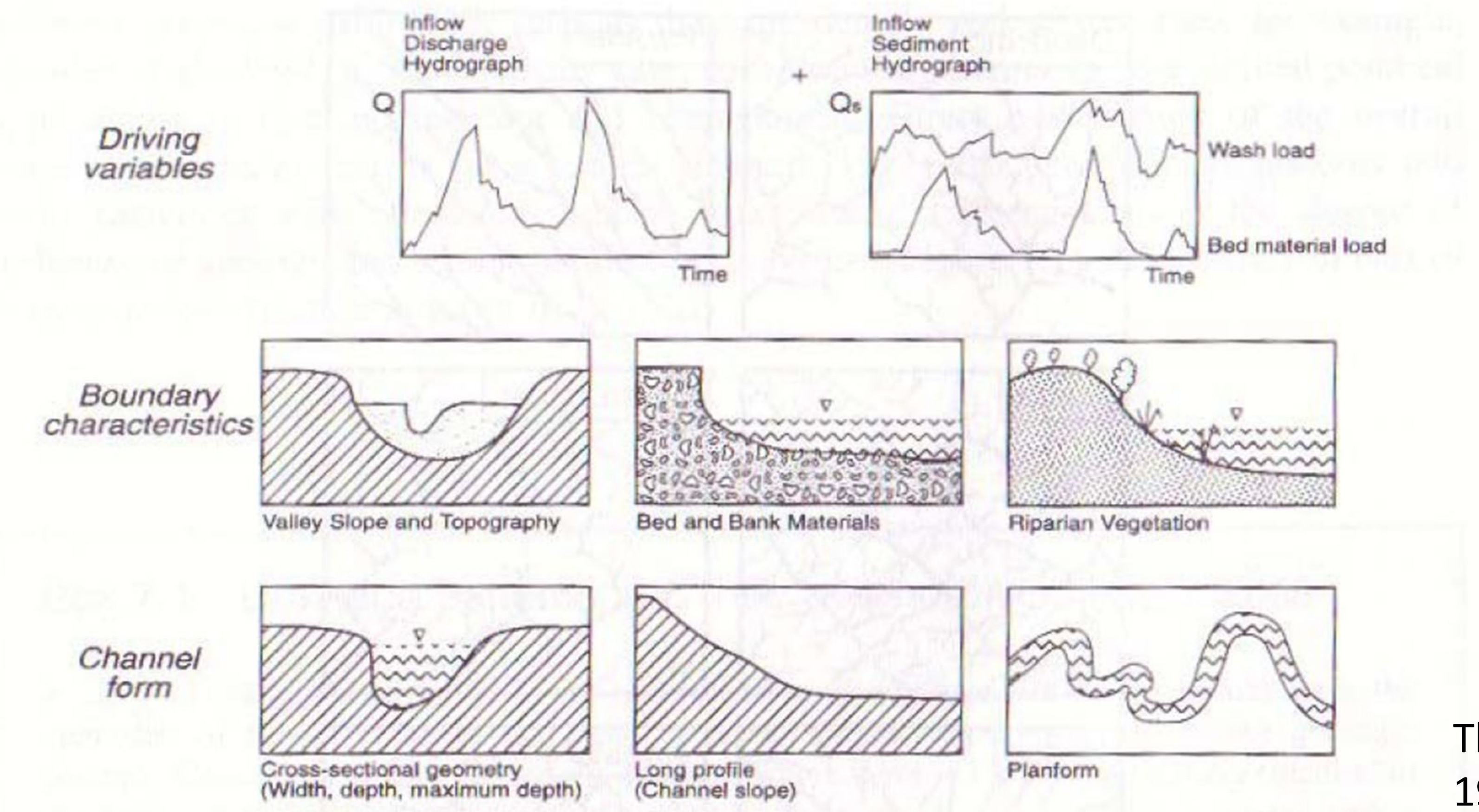


Figure 1.15

http://www.usda.gov/stream_restoration/Images/scrhimage/chap1/fig1-15.jpg

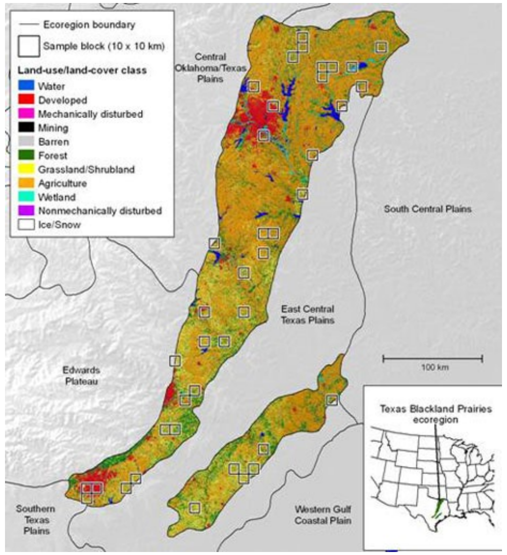
And Controlling Variables

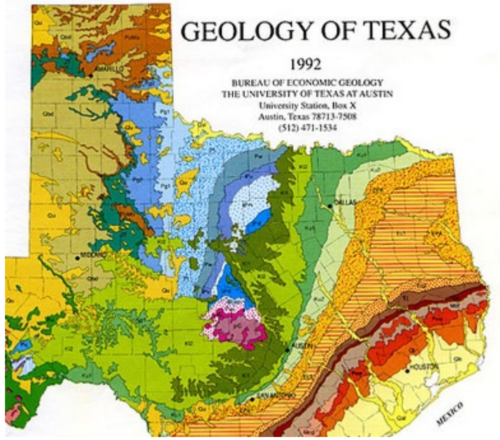


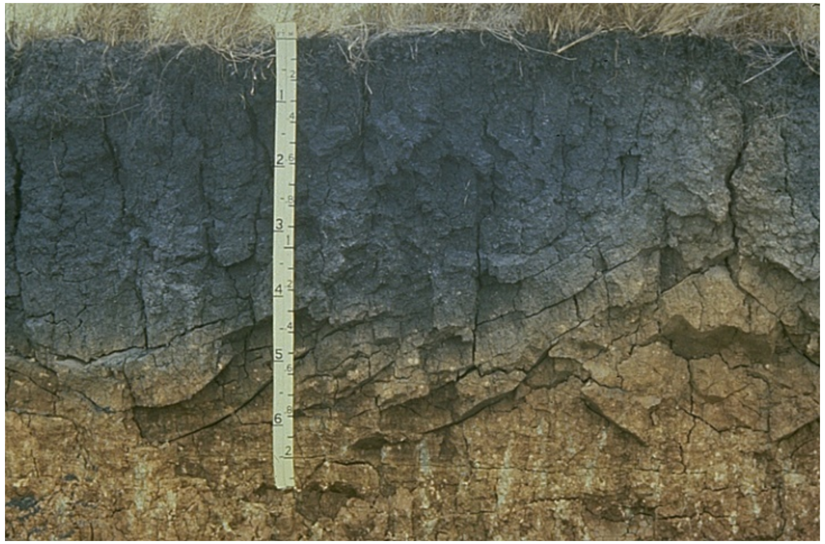
Thorne, 1997…Rosgen…1985

Example 1. Landuse Impacts in Blackland Prairie

- *Shale and Limestone*
- *Vertisols and Mollisols*
- *Home >40 percent States Population*
- *I-35 Growth Corridor*







Westward Migration: 1890-1955

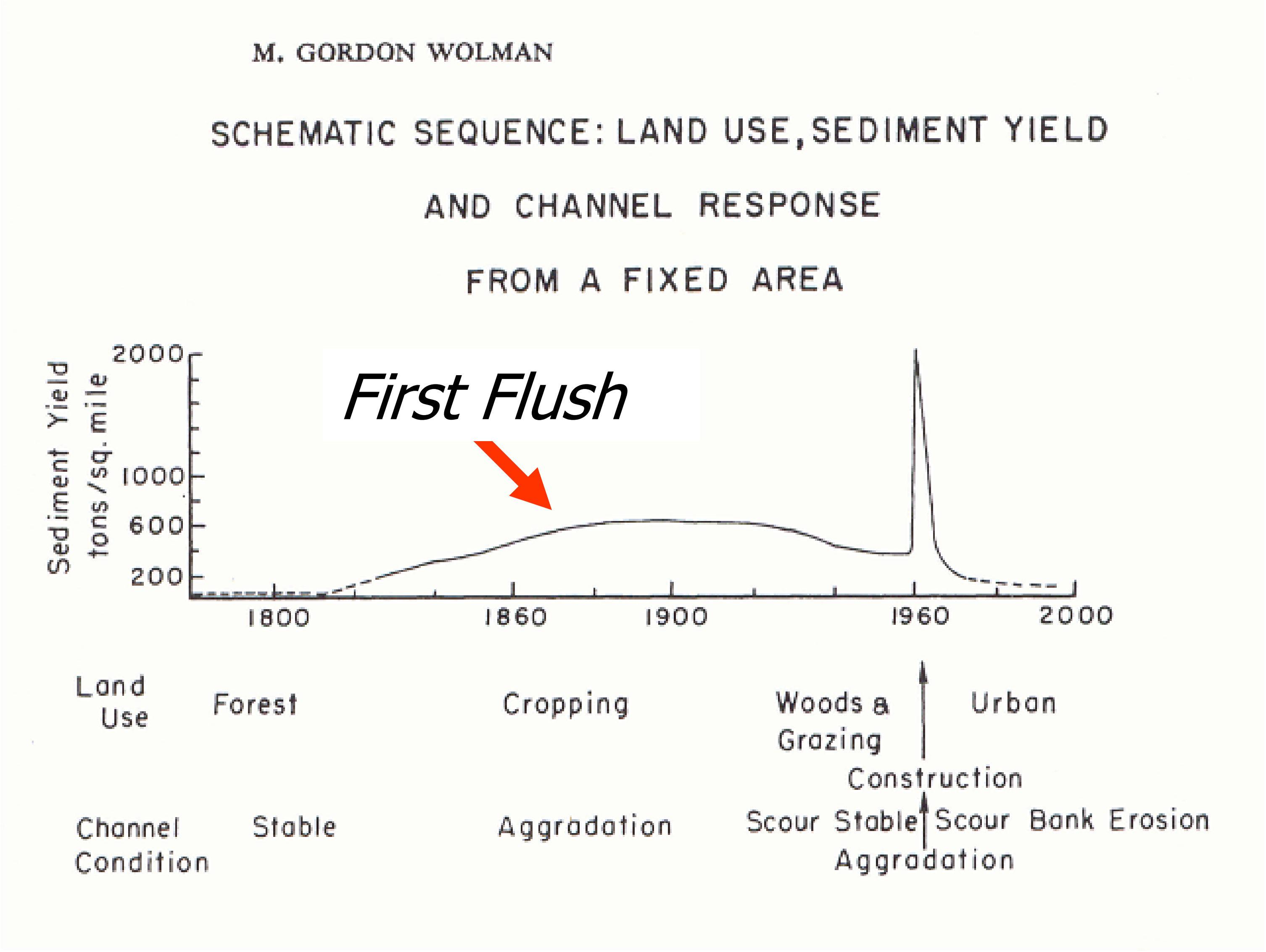
Clearing the Prairie

70

Runoff Curve Number

91

Wolman Revisited

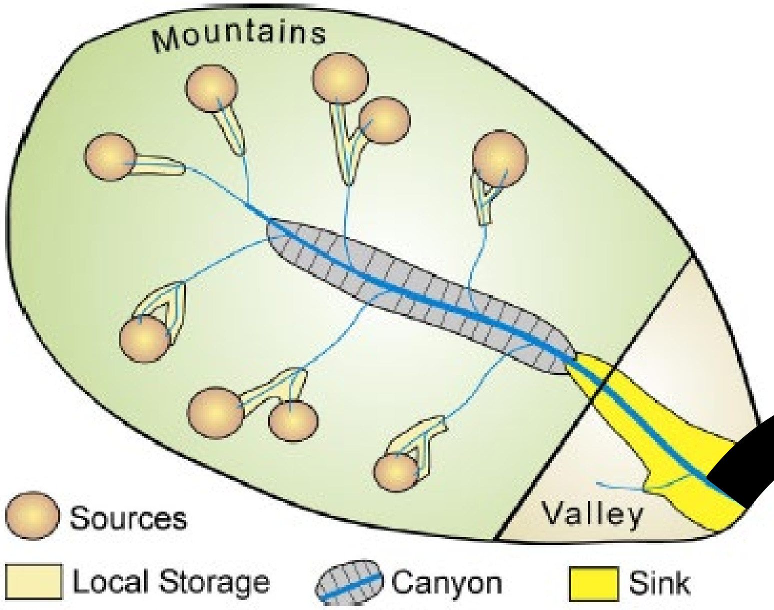


Landscape Metamorphosis

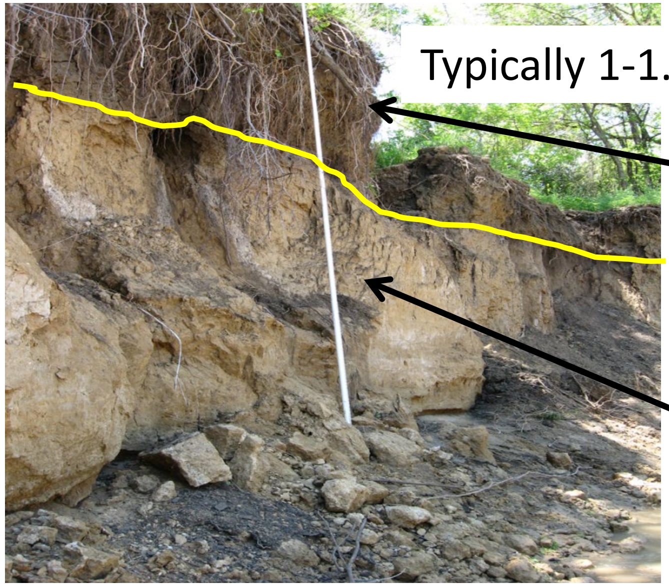
First Flush

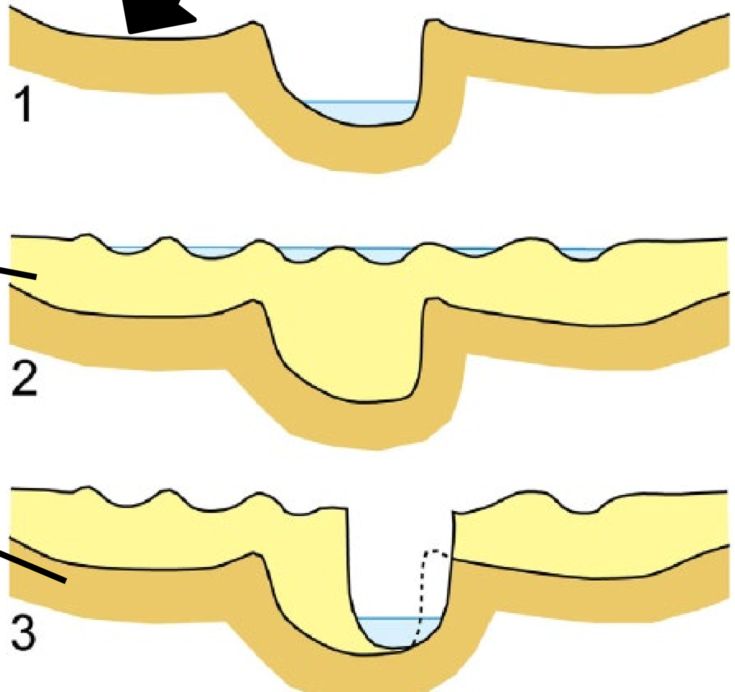
16 tons/acre crops versus .2 grassland

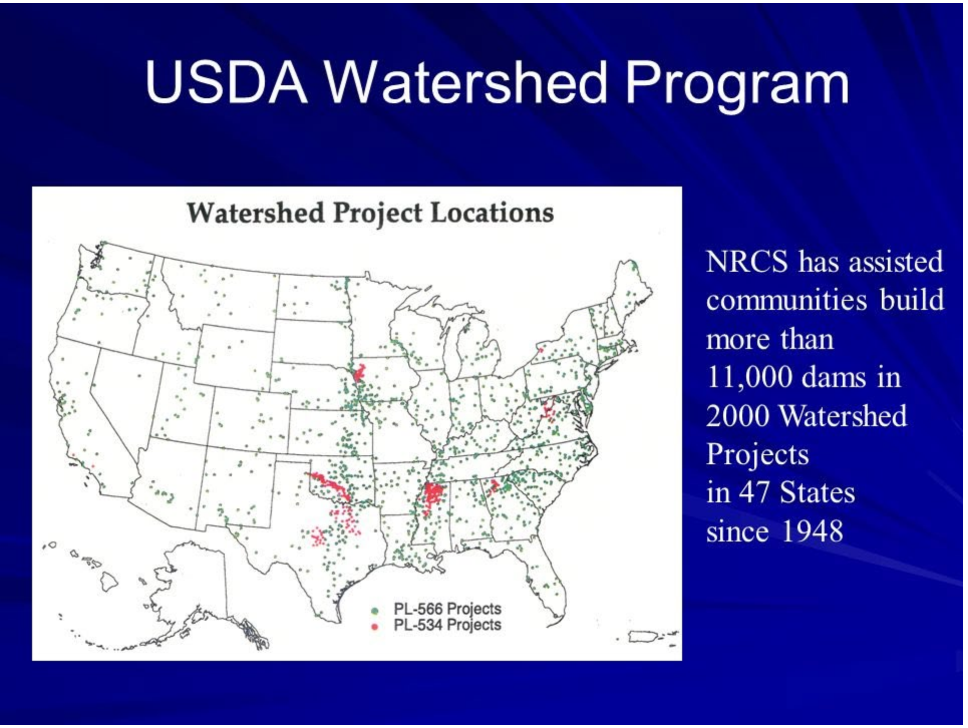
Post Settlement Alluvium= PSA

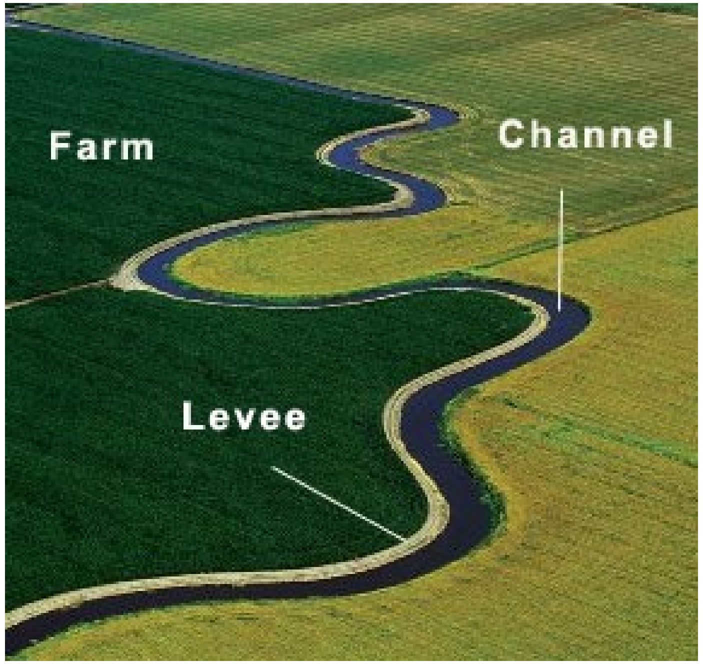


L.A. James / Anthropocene 2 (2013) 16–26



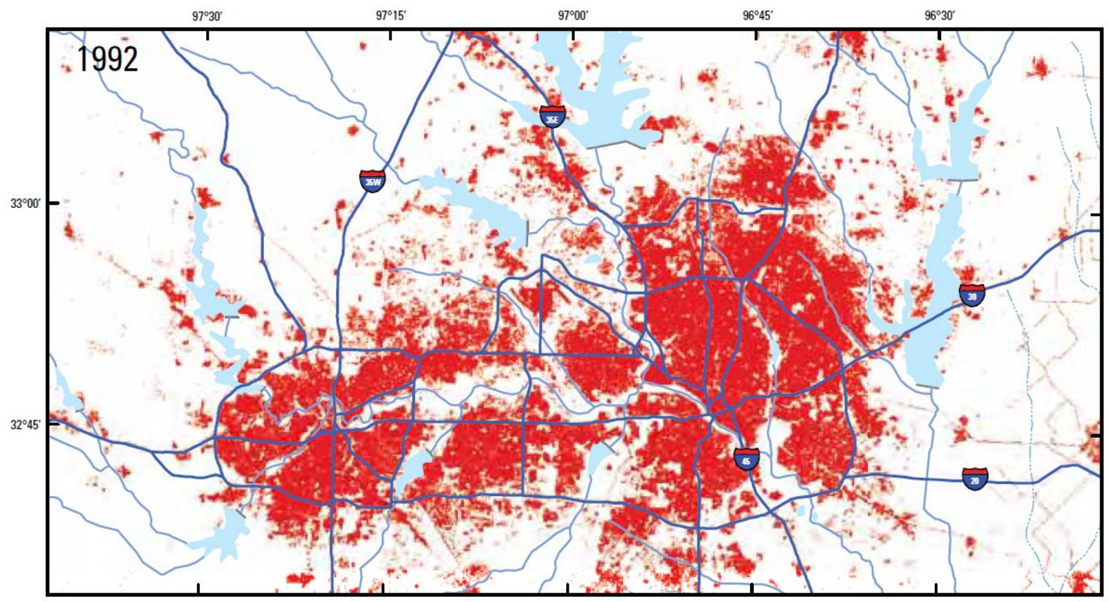




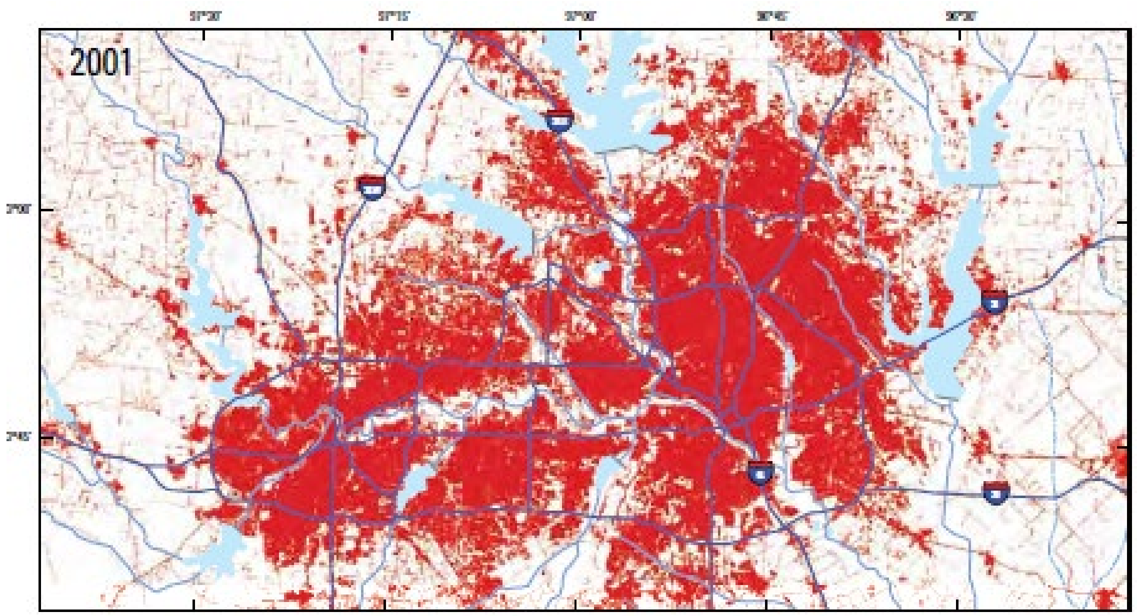


Post Flush Changes

10 Years



National Land Cover Dataset, 1992



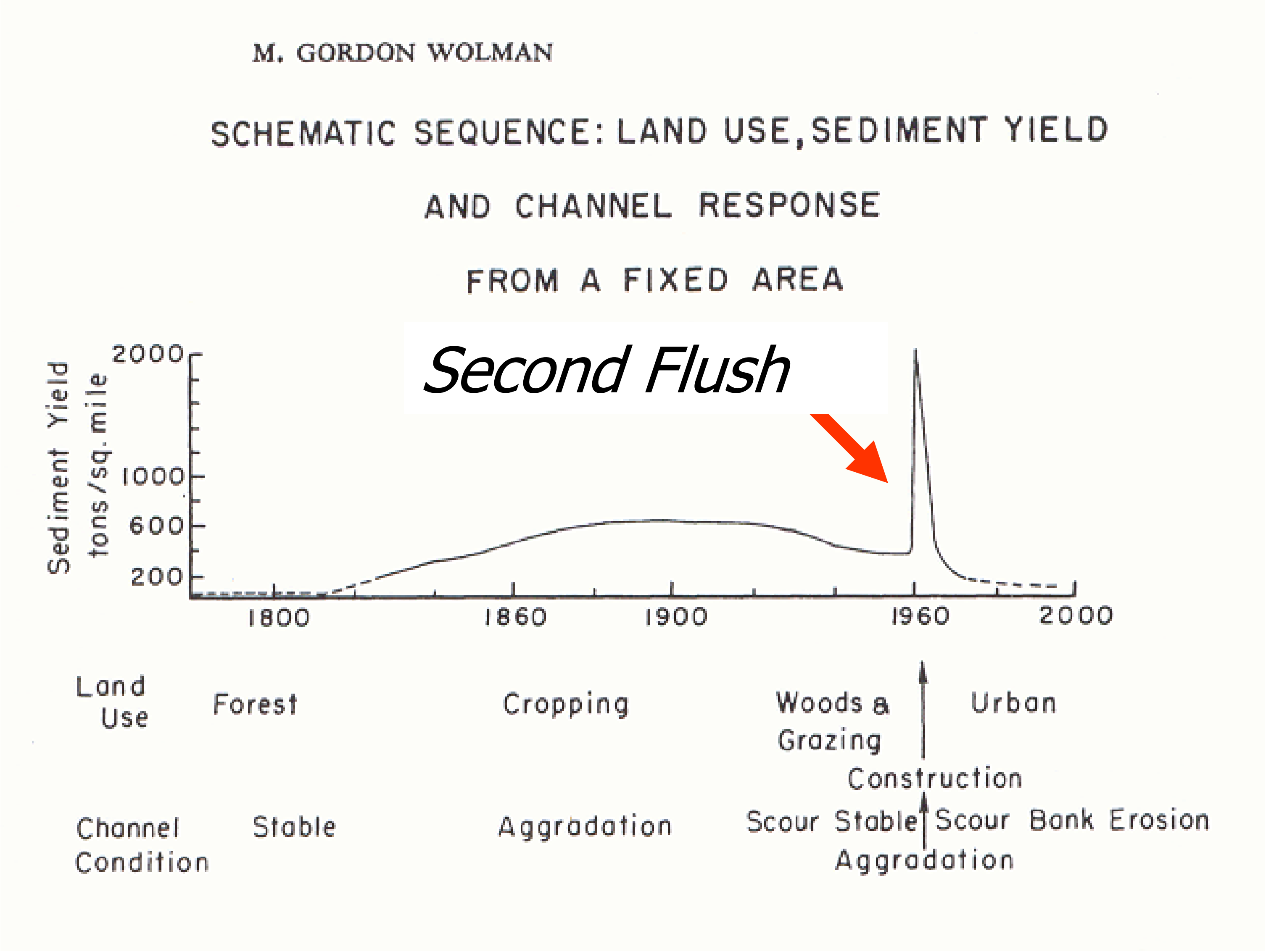
Growth up to 400,000 year in Texas.

For each 1000 people from 250-500 acres land; or up to 300 square miles

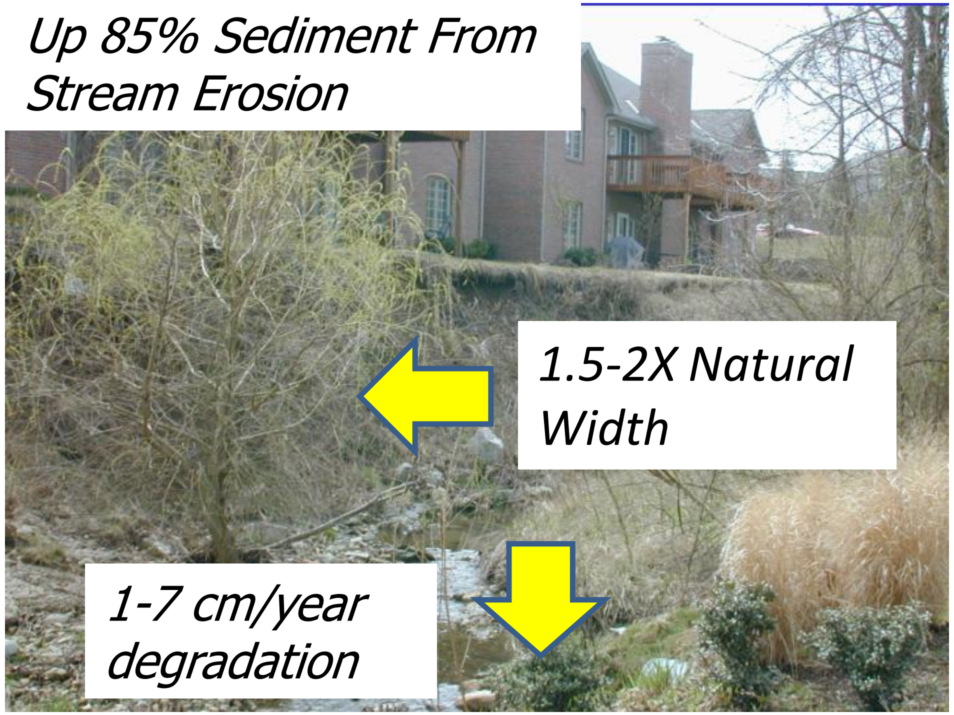
SIR 2006-5101

Urbanization

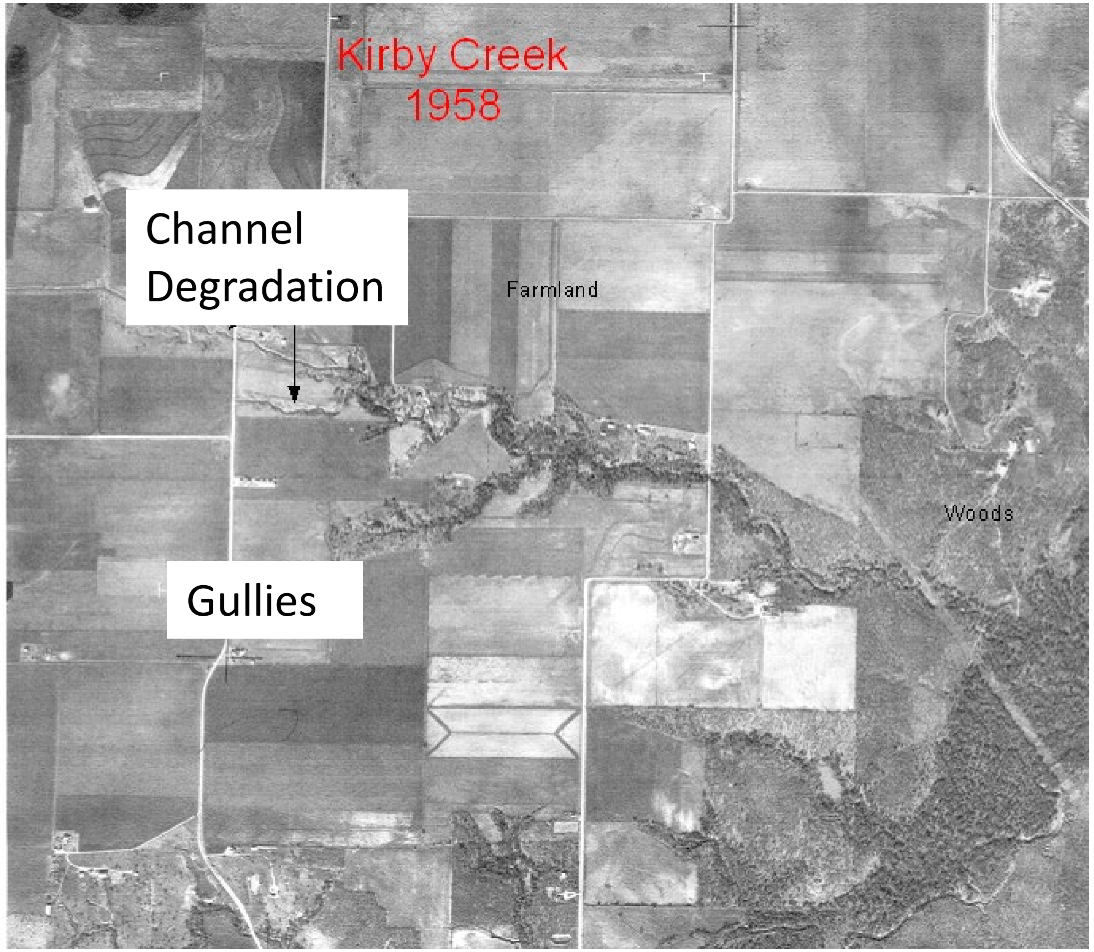
Wolman Revisited

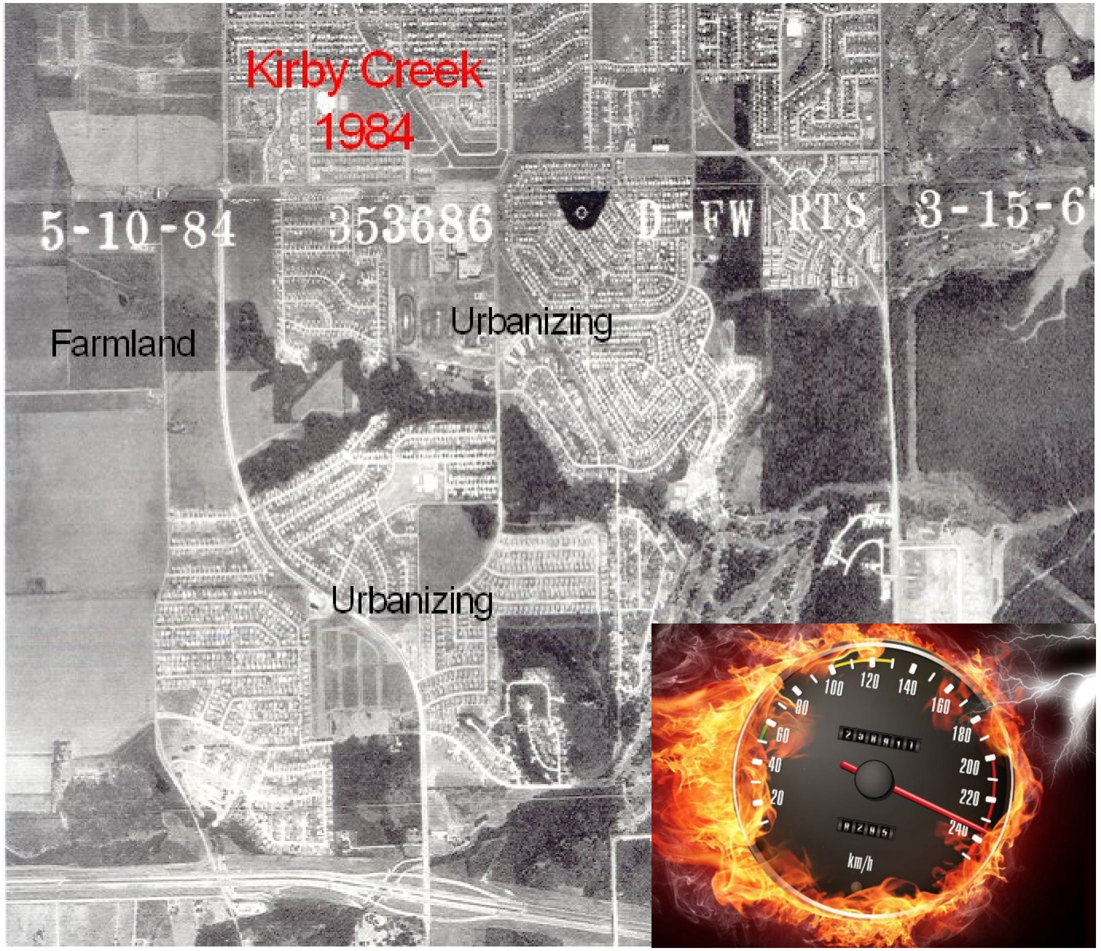


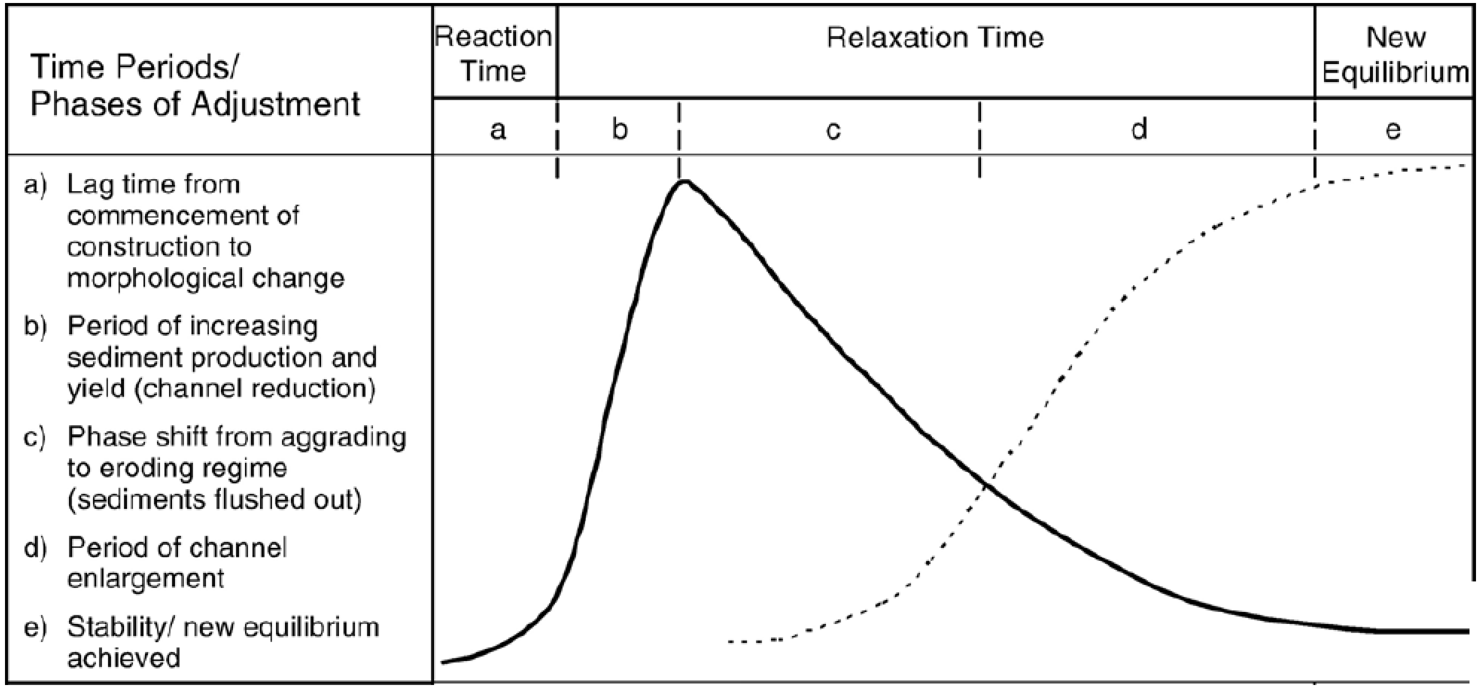
Second Flush



Urbanization Fast…Rivers React Slower







Reference	Location	Years from urban development →				Adjusted?*
	U.S.					
Graf 1975	Denver[1]	< 2				
Hammer 1972	Philadelphia[2]			> 4	~ 30	yes
Wolman 1967	Baltimore			5-7		
Leopold 1973	Maryland[1]		13	> 20 †		no
Fox 1976	Maryland[3]			1-50		no
Arnold et al. 1982	Connecticut[4]				> 40 †	no
Trimble 1997	S. California[5]				> 50	no
Chin & Gregory 2001	Fountain Hills, Arizona				> 30 ‡	no
Henshaw & Booth 2000	Puget Sound, Washington[6]				1-2 decades	6 yes; 6 no

Disturbance fast.....relaxation time slow 30-50 years+

Urban transformation of river landscapes in a global context

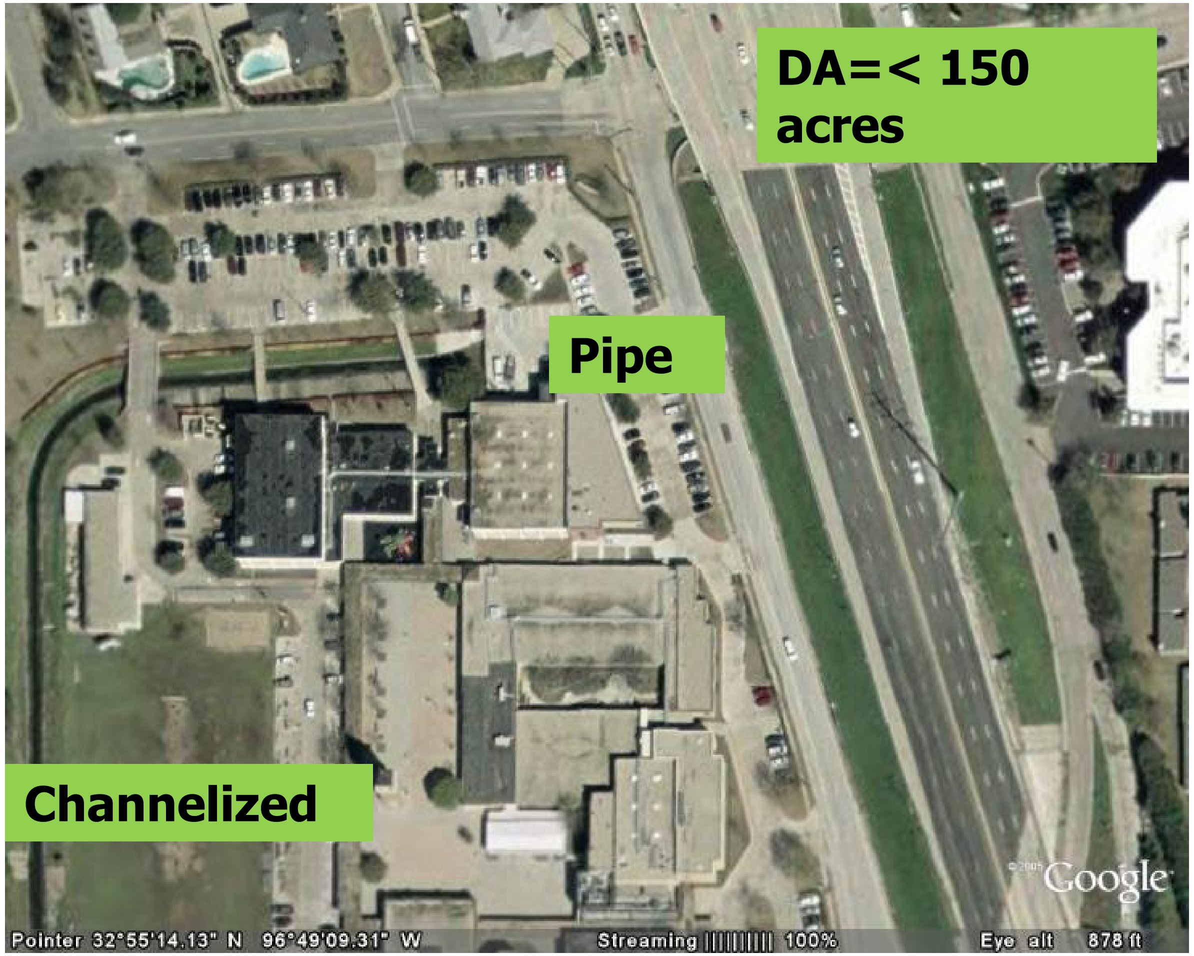
Anne Chin *

$T_{90} = 2.3/k$

k=.02-.11 *115-21 yrs.*

Julien (2014)

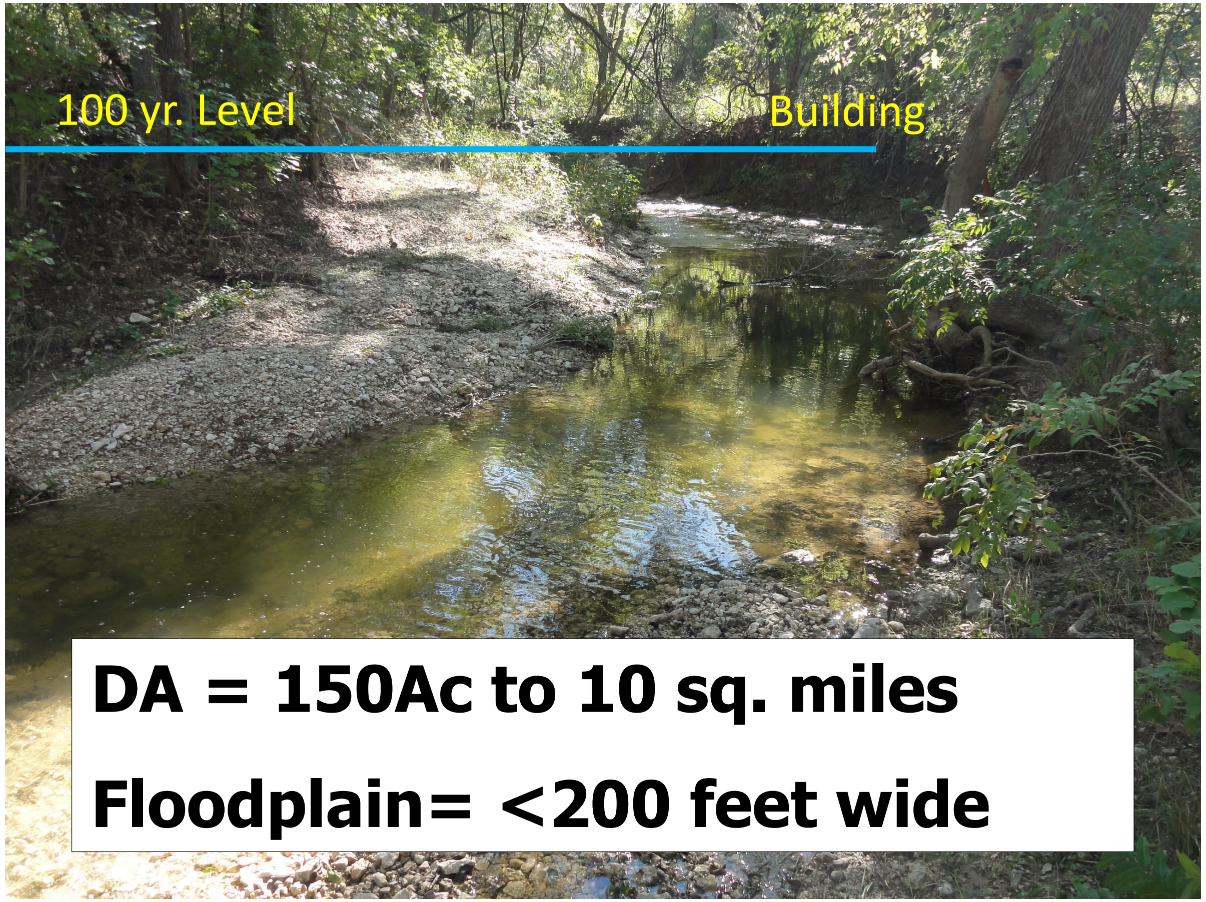
Hierarchy Impacts: Landuse and Streams Dallas: Type I

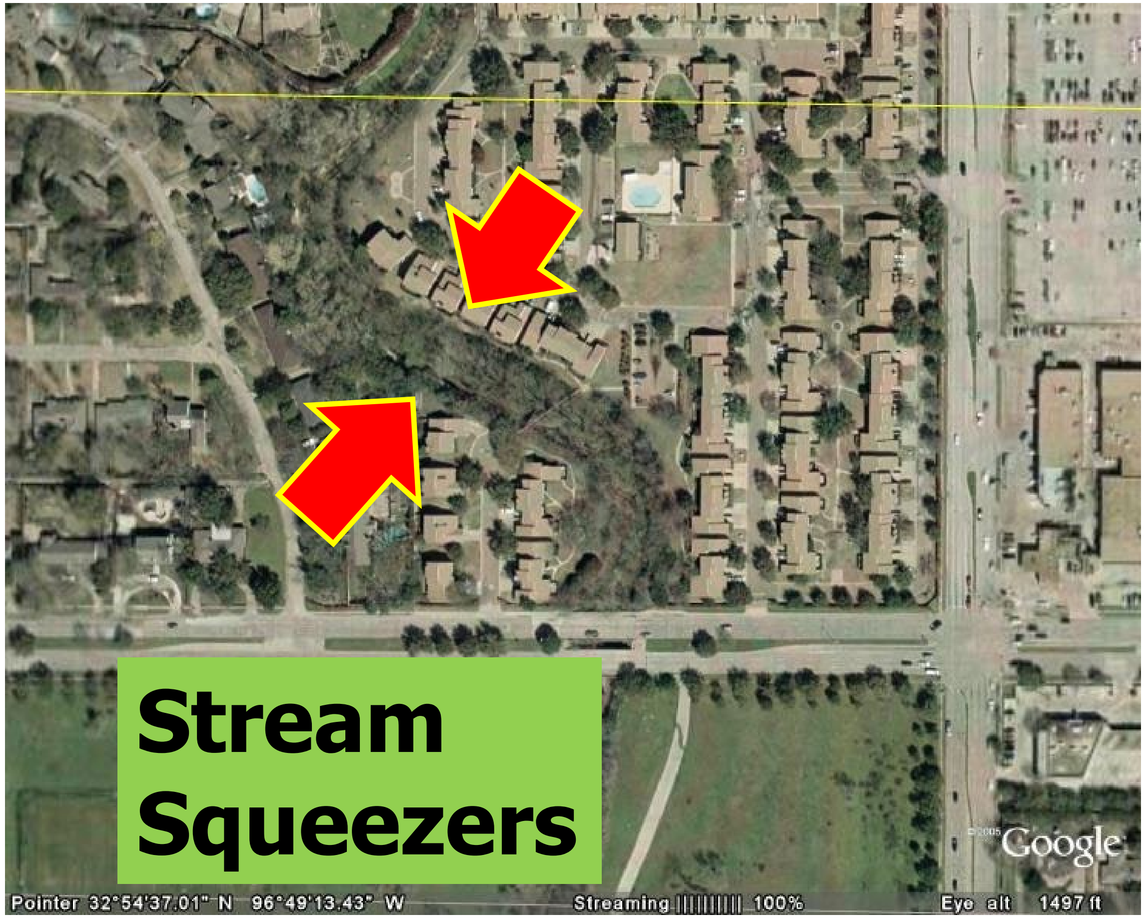


Type 1 Natural to Urbanized

Oops!!....Hill, et. al. (2018) indicates these small catchments are worth about INT $31 million/yr in ecosystem services ..yep covering up some $$$

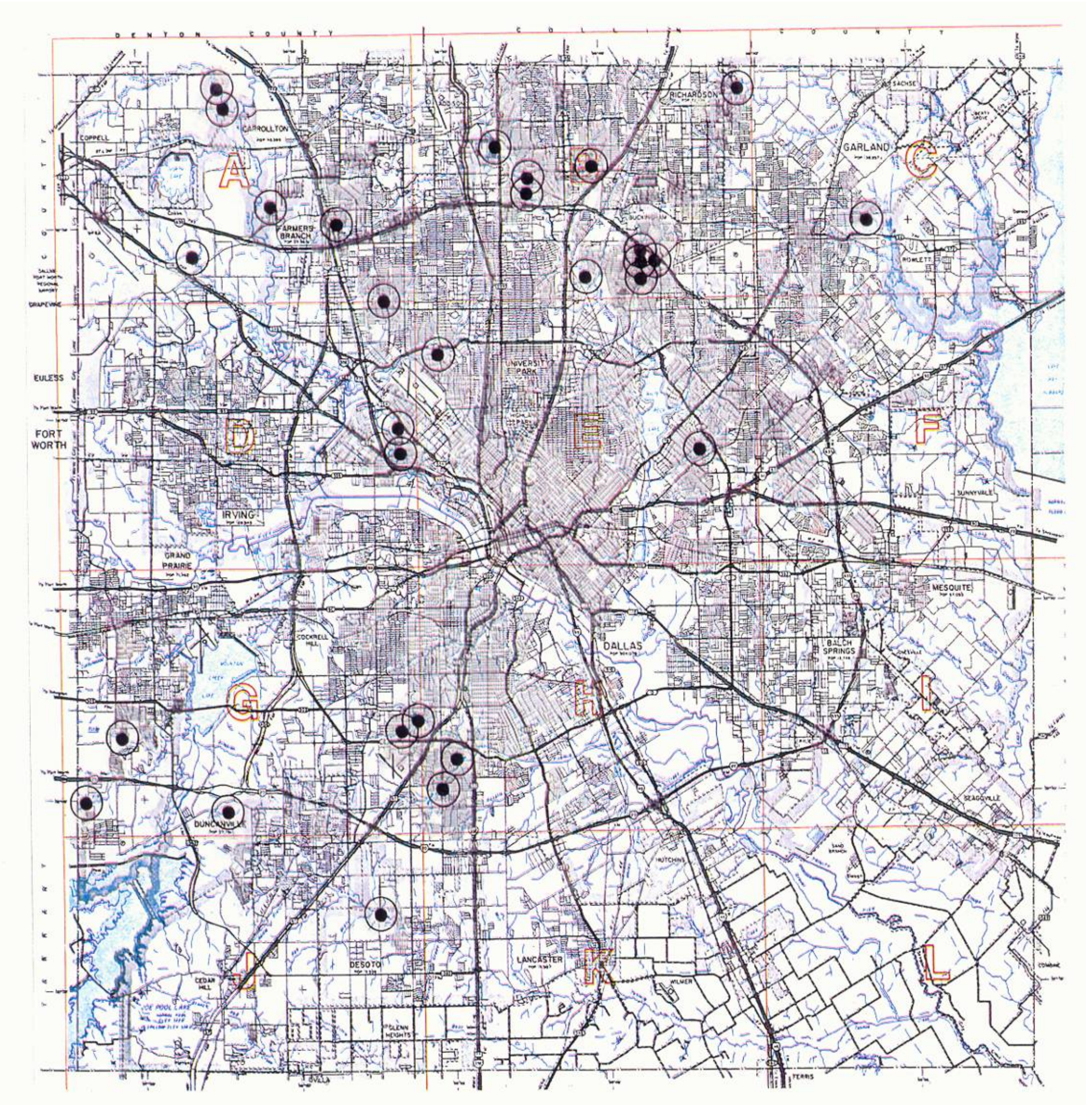
Type II: Natural to Urban






Top of Bank
32 ft. to House
Mean Dog
Soil
Laminated Silty Beds
Woodbine Formation
Sandier, More Resistant
Bed Woodbine Fm.
Woodbine Fm. In Channel Bed

Stream Bank Failures (1 Year)



Estimated Repair:
$300,000 per lot

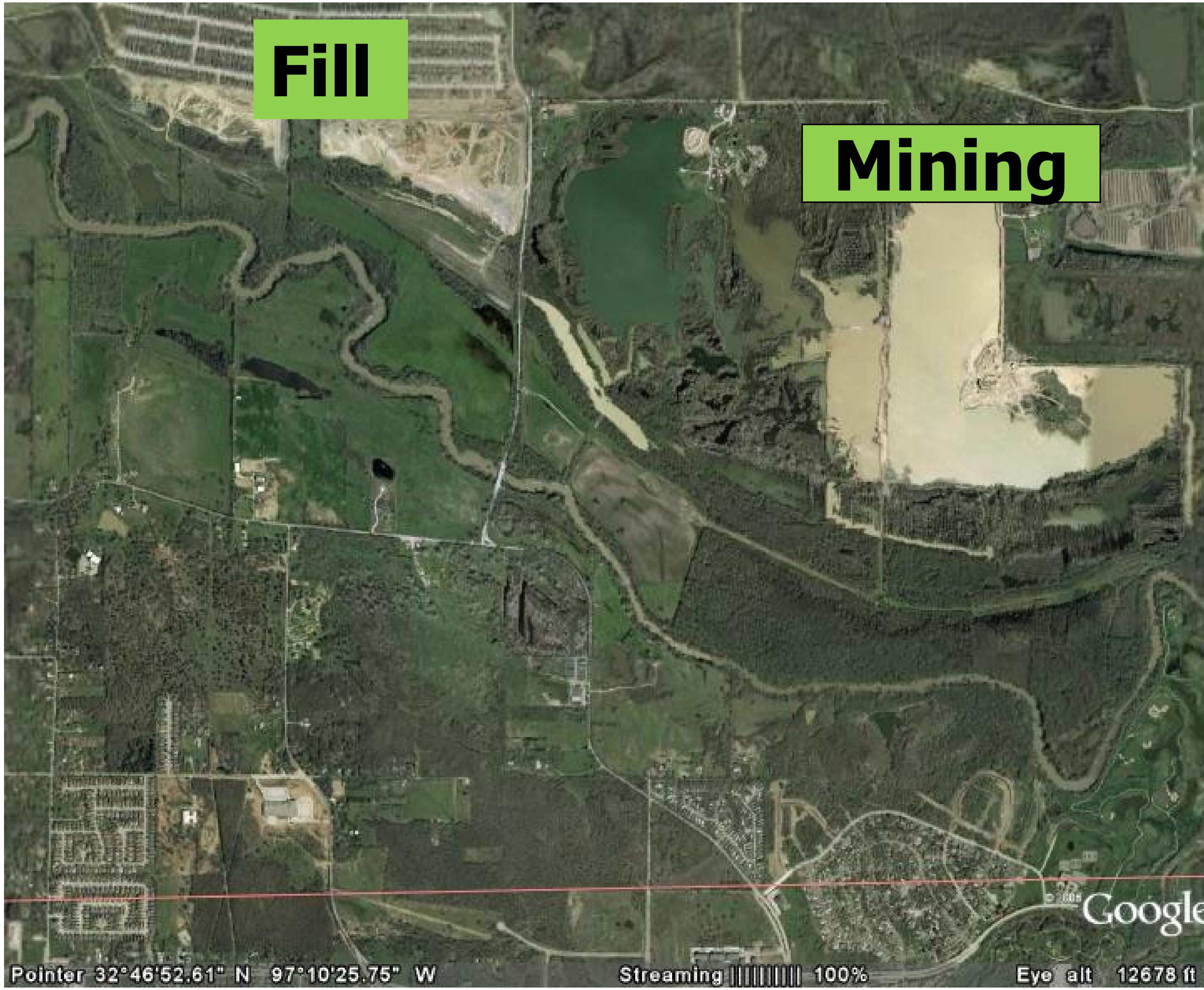
Reed and Associates

Type III

DA = 10 to 150 sq. miles

Floodplain= 200 to 1000 feet

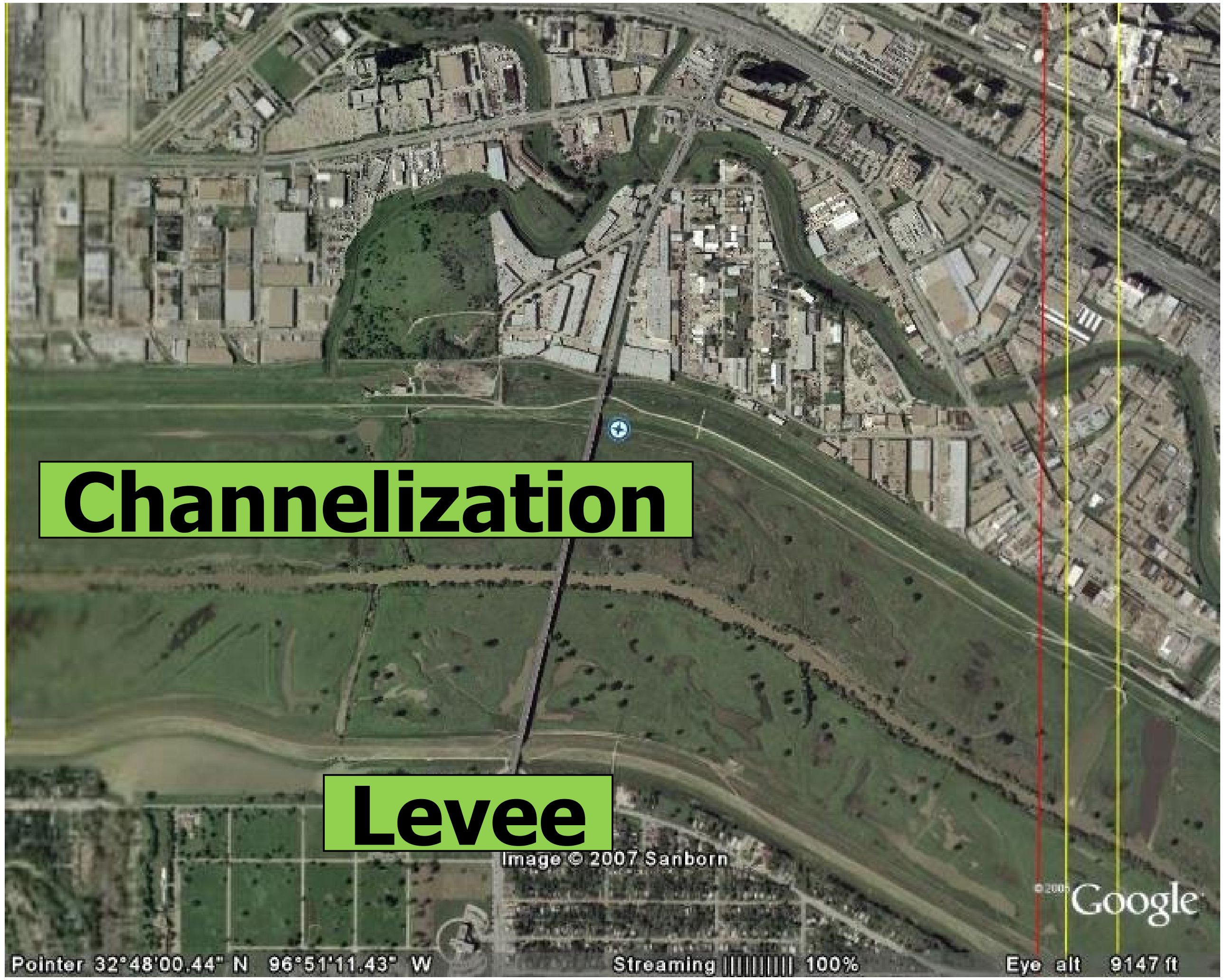
Type IV



DA = 150 sq. mi. +

Floodplain = 1000-6000′

Type IV



Channelization
Levee
Image © 2007 Sanborn
Google
Pointer 32°48'00.44" N 96°51'11.43" W
Streaming |||||||||| 100%
Eye alt 9147 ft

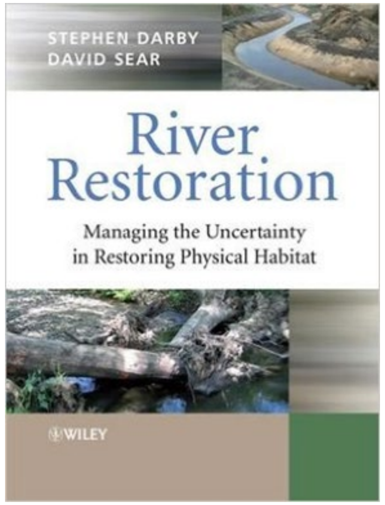
Dallas: Pre Levee

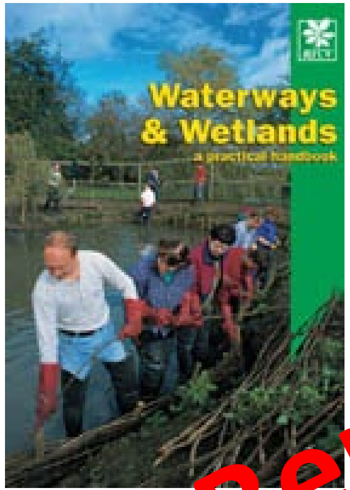
Improvement District—Central and Southern Section

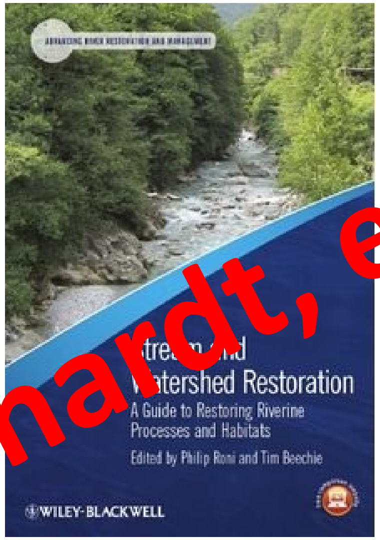
The district extends on the south to the curved highway crossing the district in the center of the photograph. The portion of the district along the railroads on the east to be developed industrially, the westerly portion for residential and suburban retail purposes.

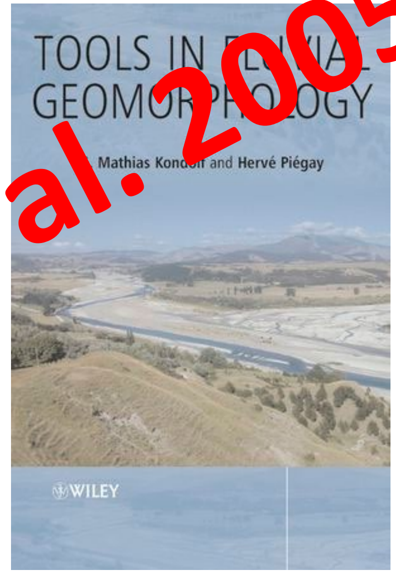
Old to Proposed

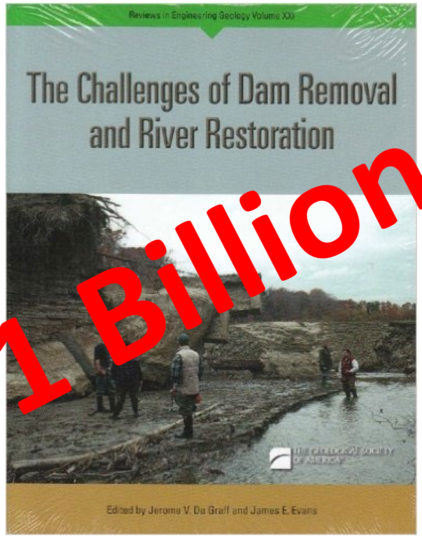
SO…We needed to figure out how to "fix" rivers?

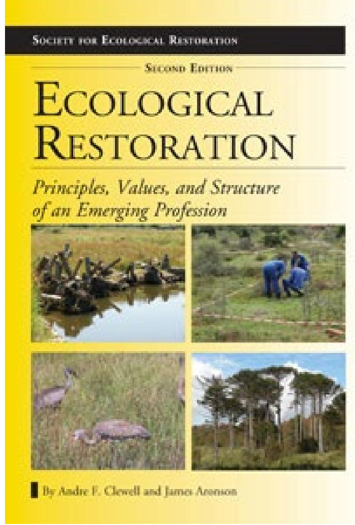


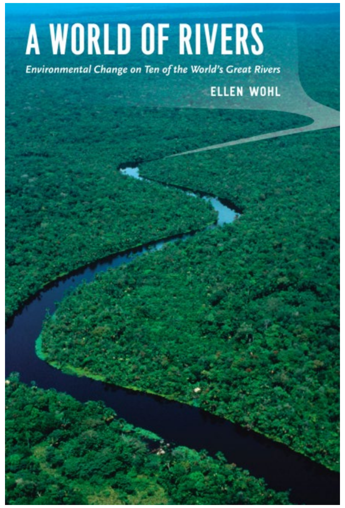






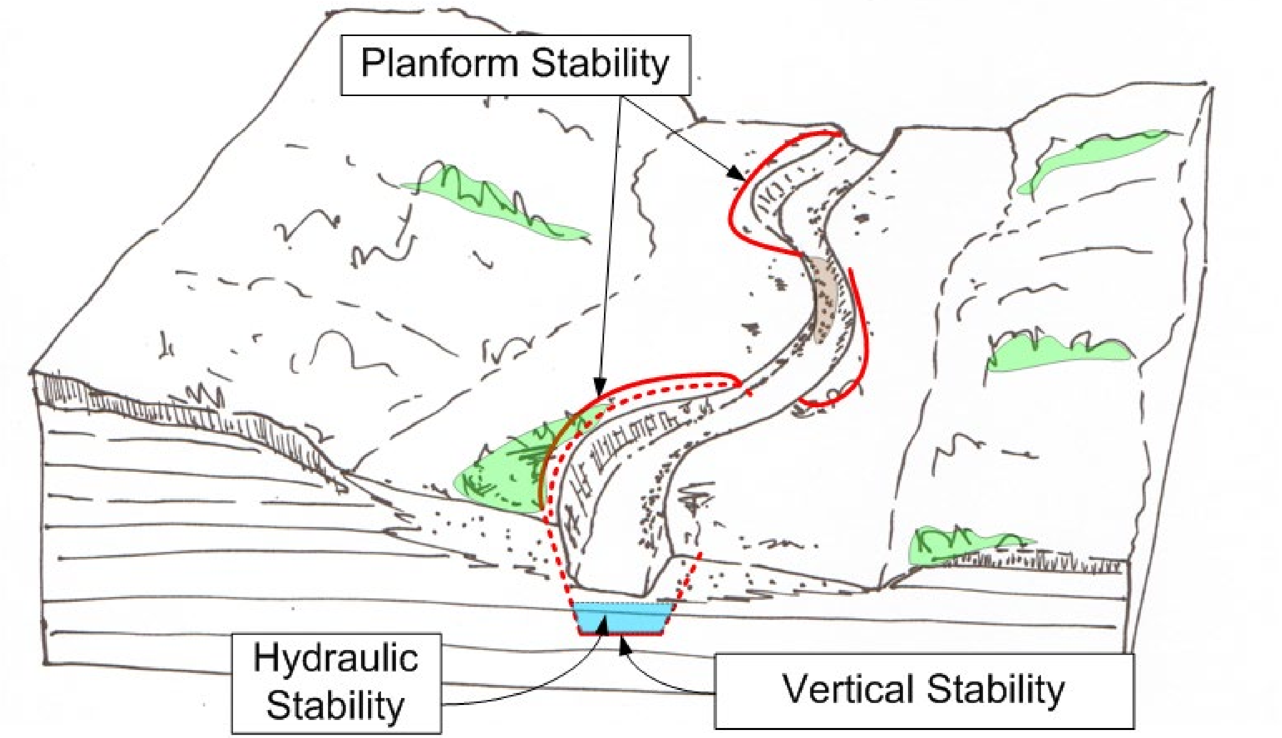






>1 Billion/year Bernhardt, et al. 2005

And we looked for Guidance…..



$QS \sim Q_s D_{50}$

TECHNICAL NOTES

USDA NATURAL RESOURCES CONSERVATION SERVICE COLORADO

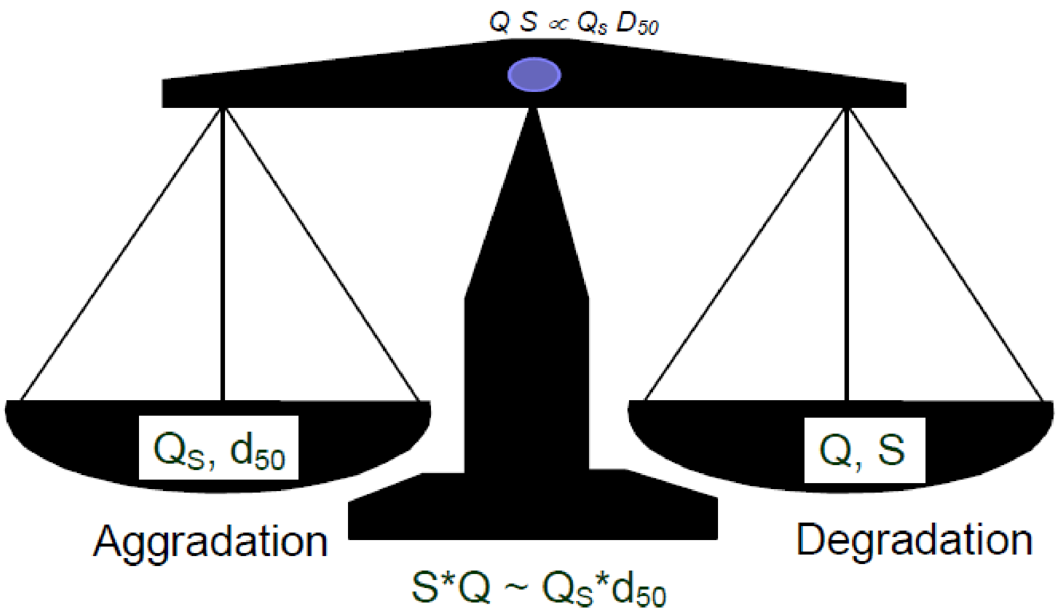
ENGINEERING – No 27.2 April 2013

GUIDANCE FOR STREAM RESTORATION

Illinois River, North Park, Colorado

NRCS Helping People Help the Land

Quantification: Lane



- Sediment Discharge (Qs)
- Median grain size of bed material (D50)
- Dominant Discharge or Streamflow (Q)
- Thalweg or Energy Slope (S)

And finally began to think about Ecosystems

Jennings, PhD, PE, Stantec 2015

What is a "healthy" stream ecosystem?

1. Bed stability & diversity
2. Sediment transport balance
3. In-stream habitat & flow diversity
4. Bank stability (native plant roots)
5. Riparian buffer (native streamside forest)
6. Active floodplain
7. Healthy watershed

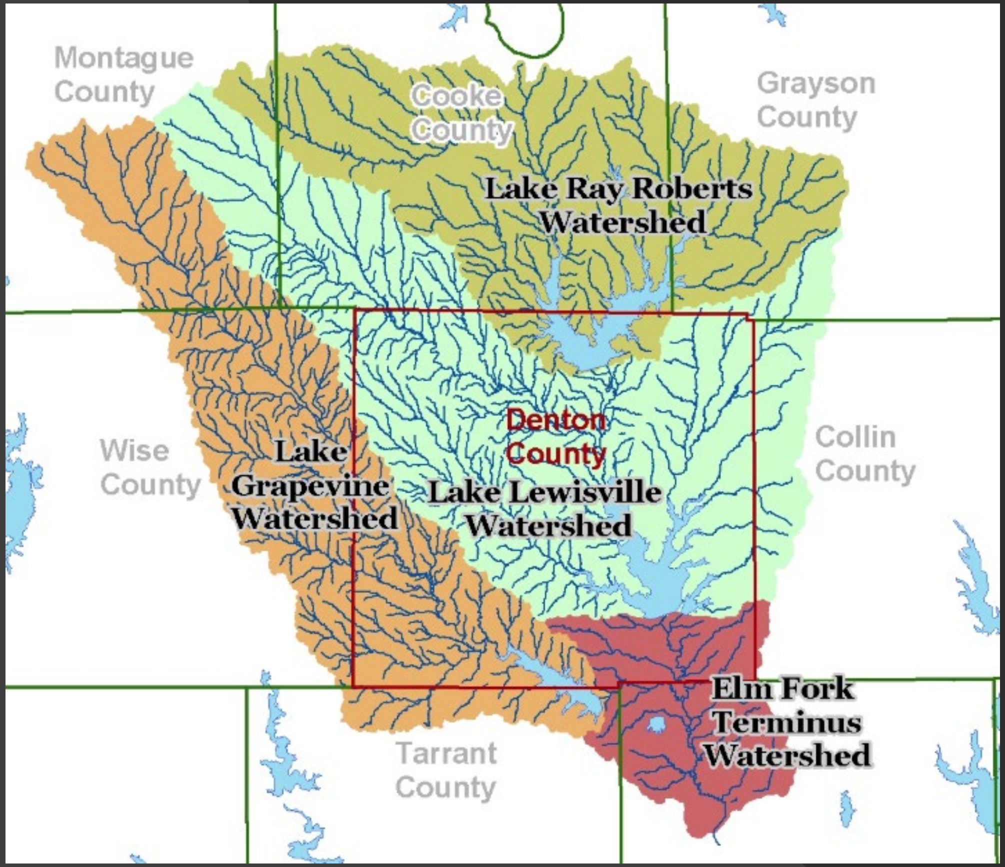
Agreement regarding the variables

Table 20. TXRAM Stream Metrics by Core Element

Core Elements	Metrics
Channel Condition	Floodplain Connectivity
	Bank Condition
	Sediment Deposition
Riparian Buffer Condition	Riparian Buffer
In-stream Condition	Substrate Composition
	In-stream Habitat
Hydrologic Condition	Flow Regime
	Channel Flow Status

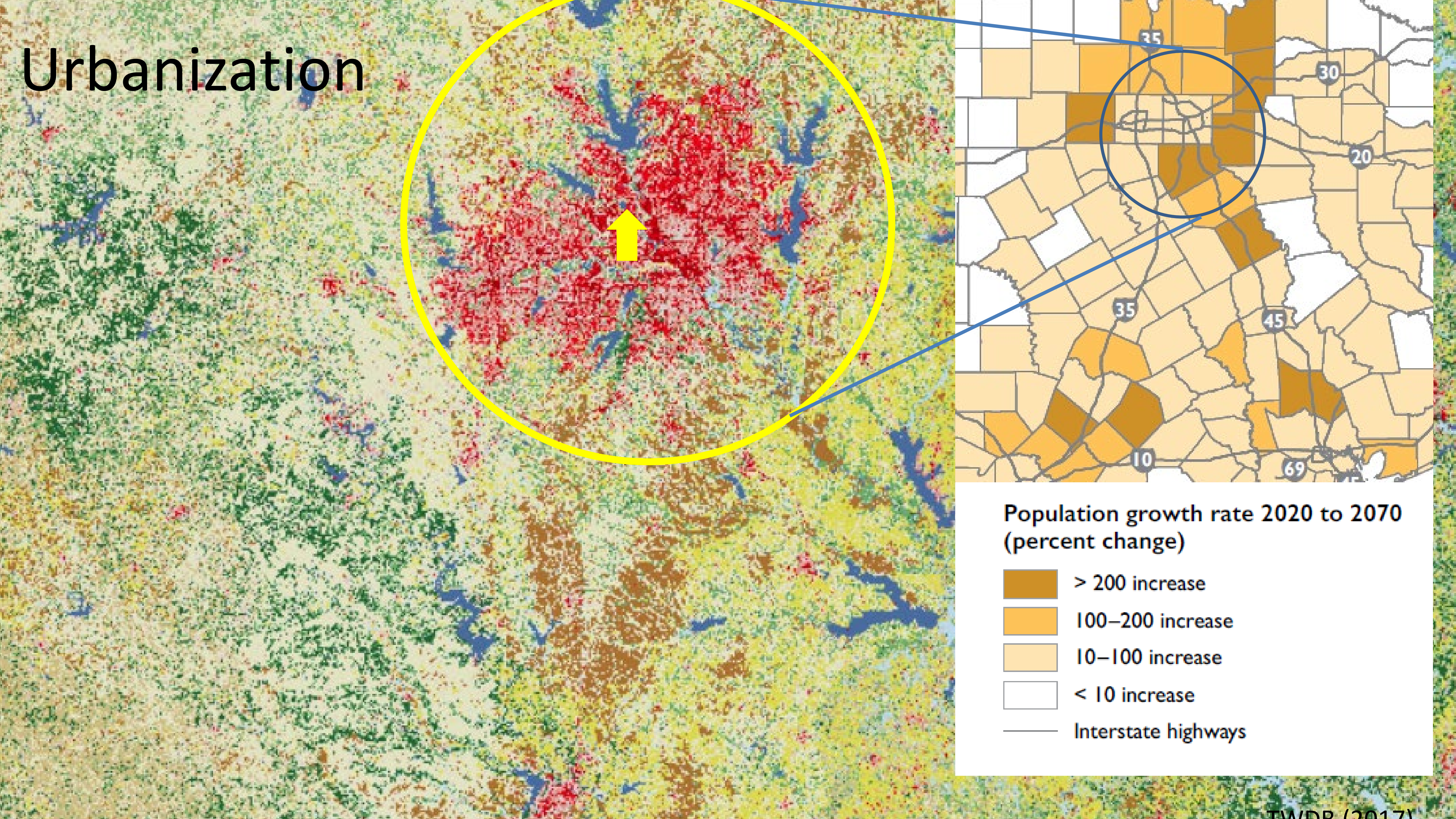
Example 2: Denton Creek; A River in Transition…

- Urbanization
- Dam
- Channelization
- Levee Construction
- Channel Erosion
- Homeowner Distress



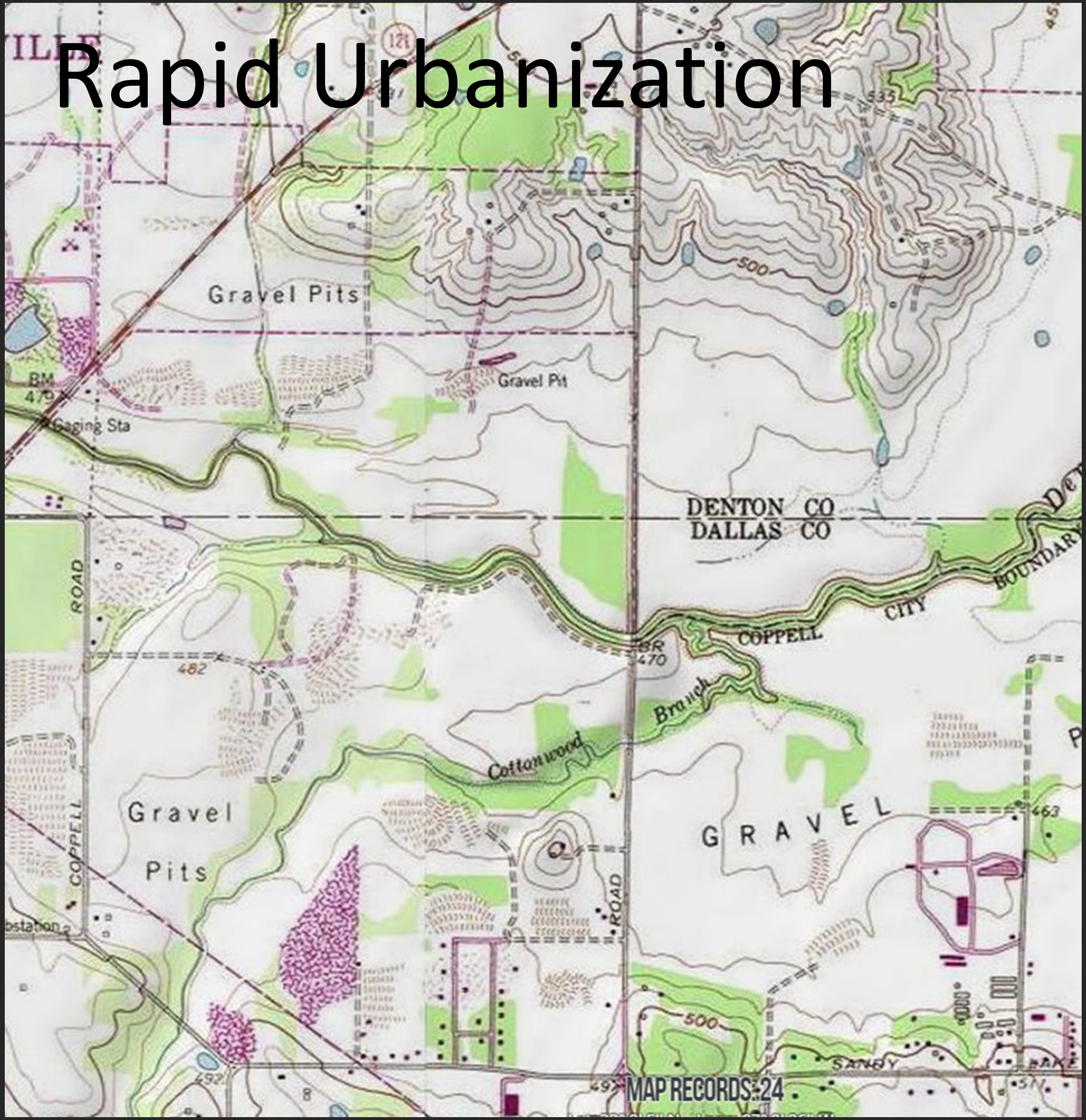
- This River has Had Everything Thrown At It.

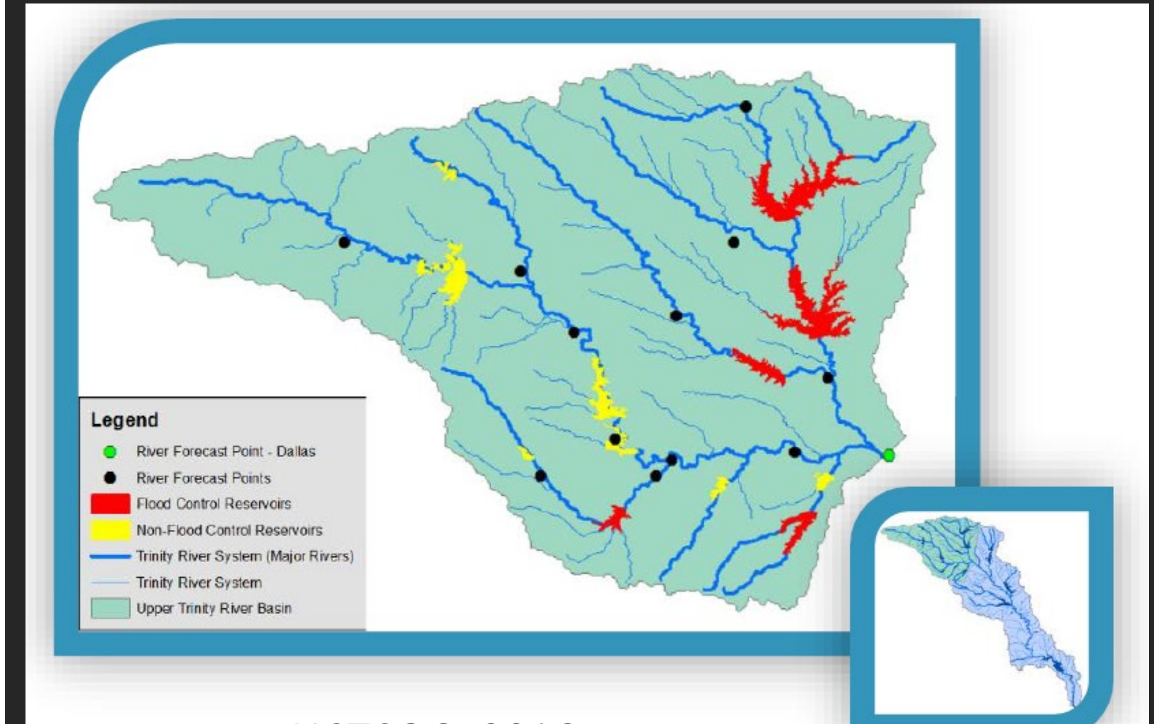
Urbanization



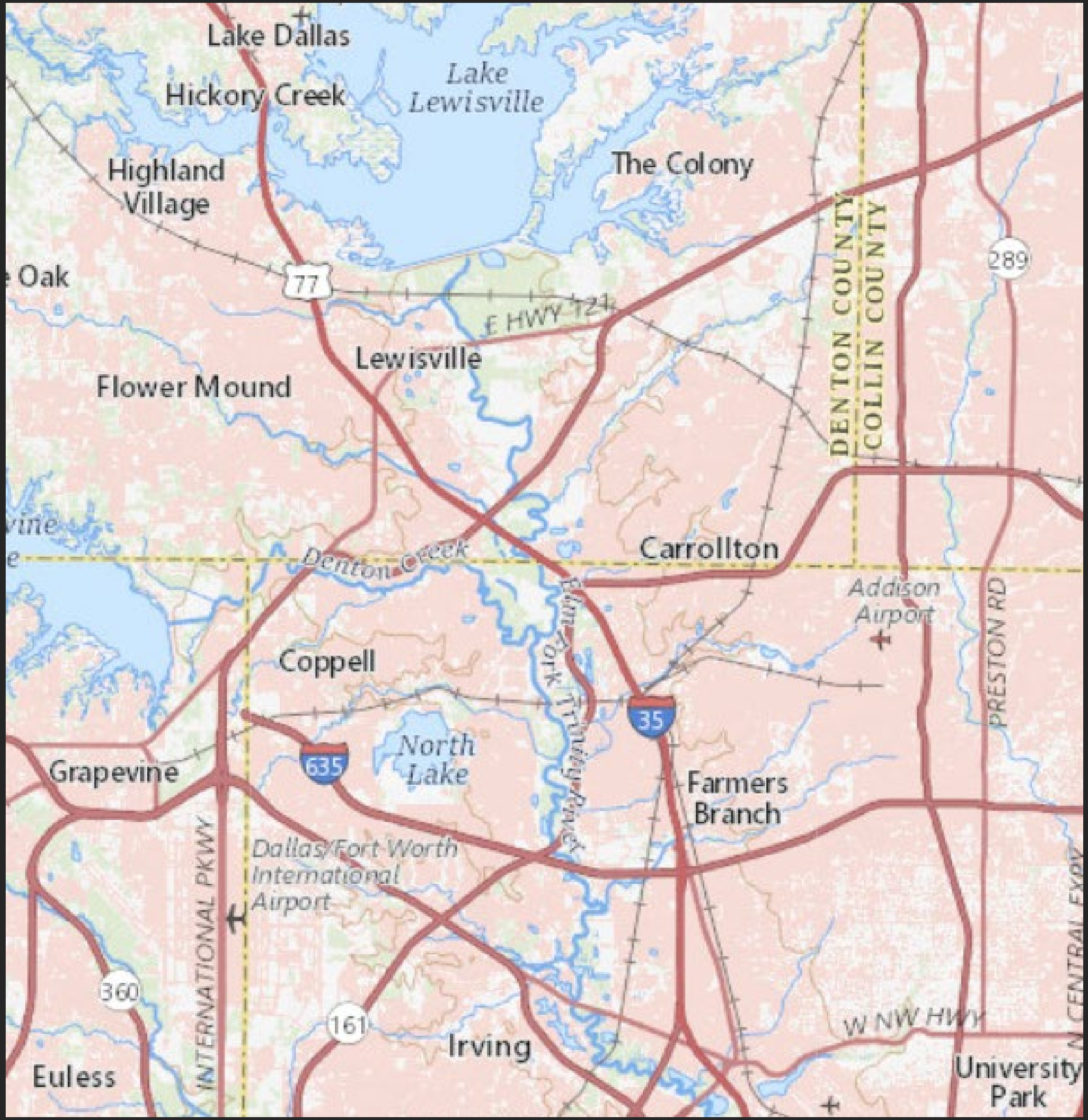
TWDB (2017)

Rapid Urbanization



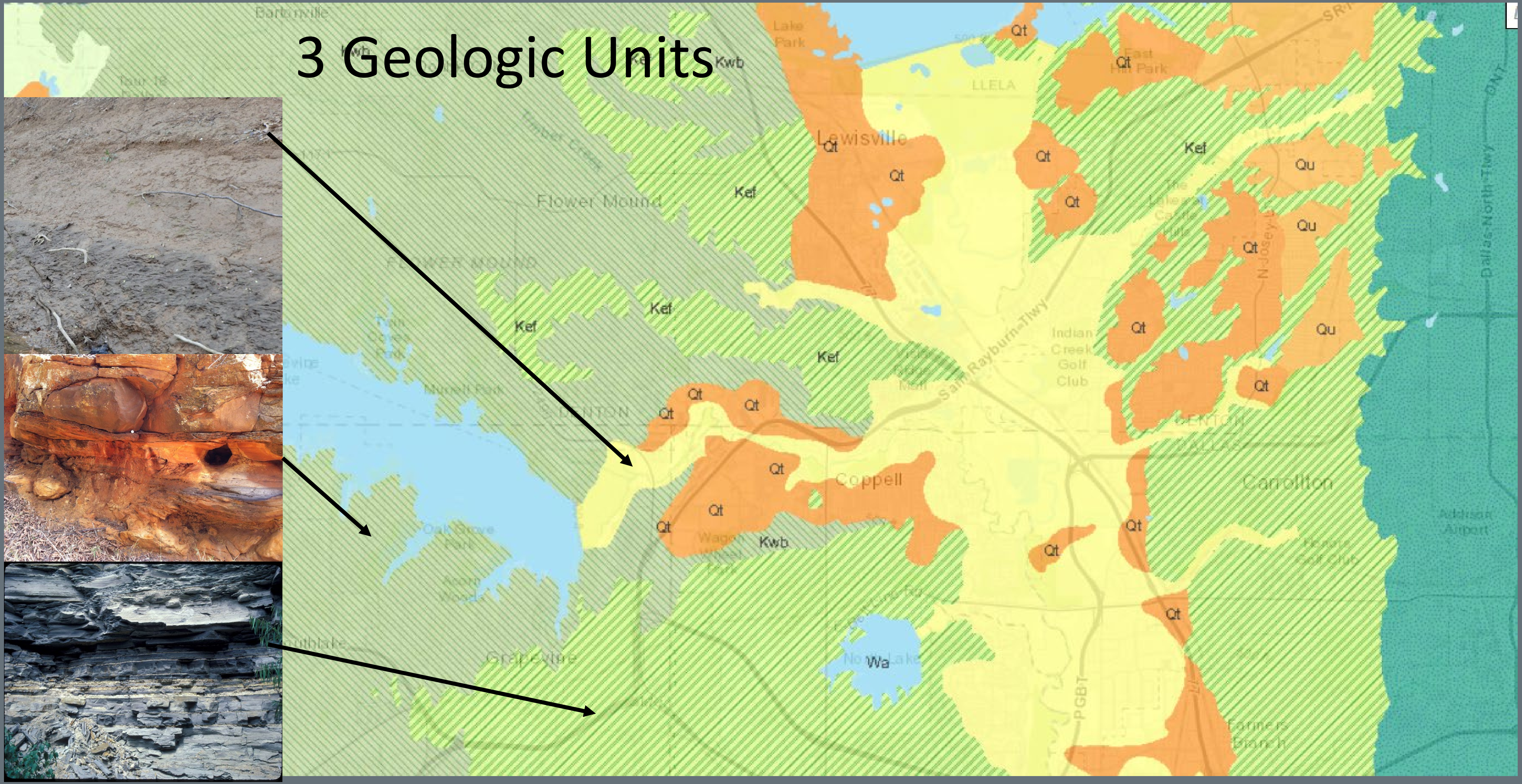


NCTCOG, 2016

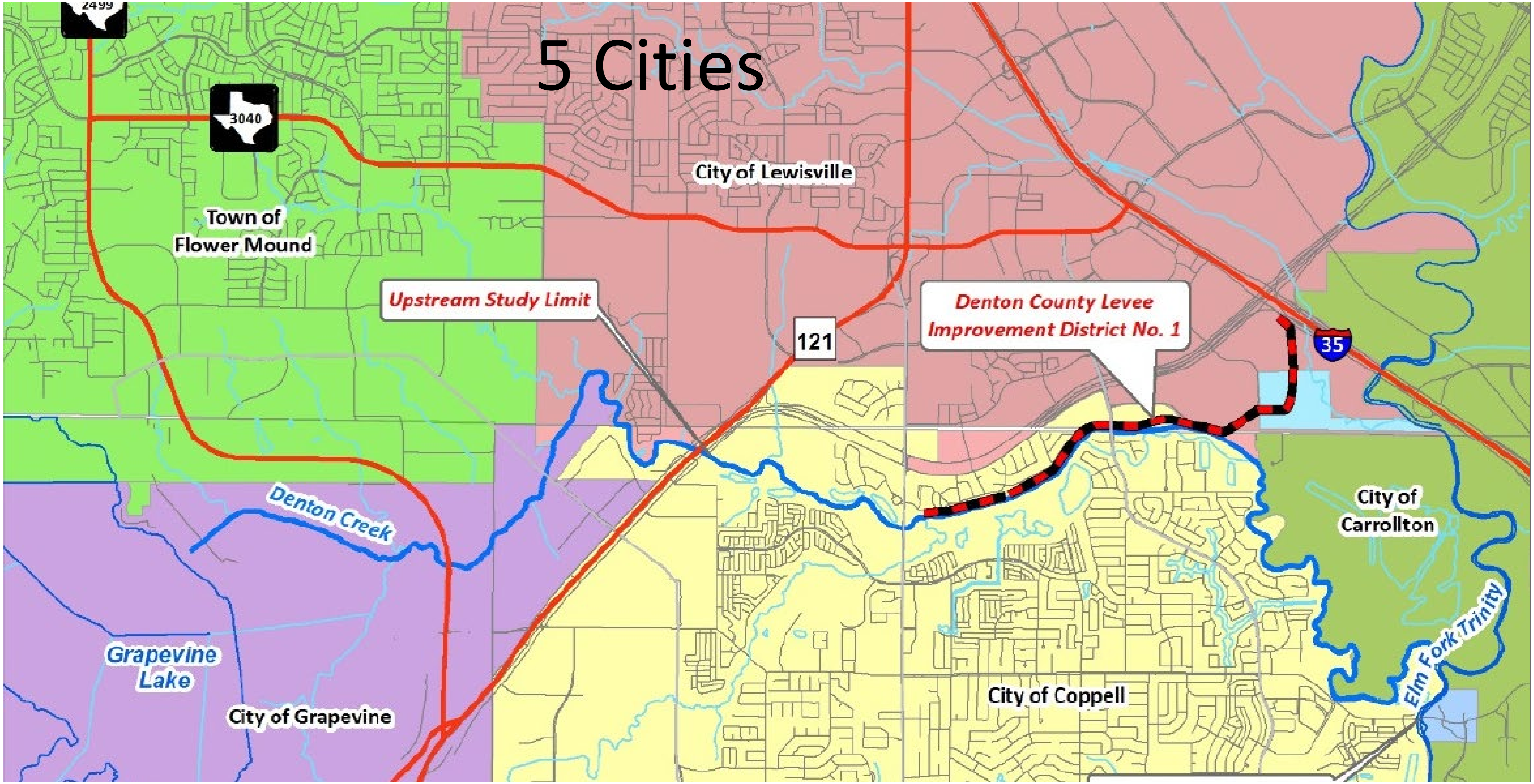


Four Dams

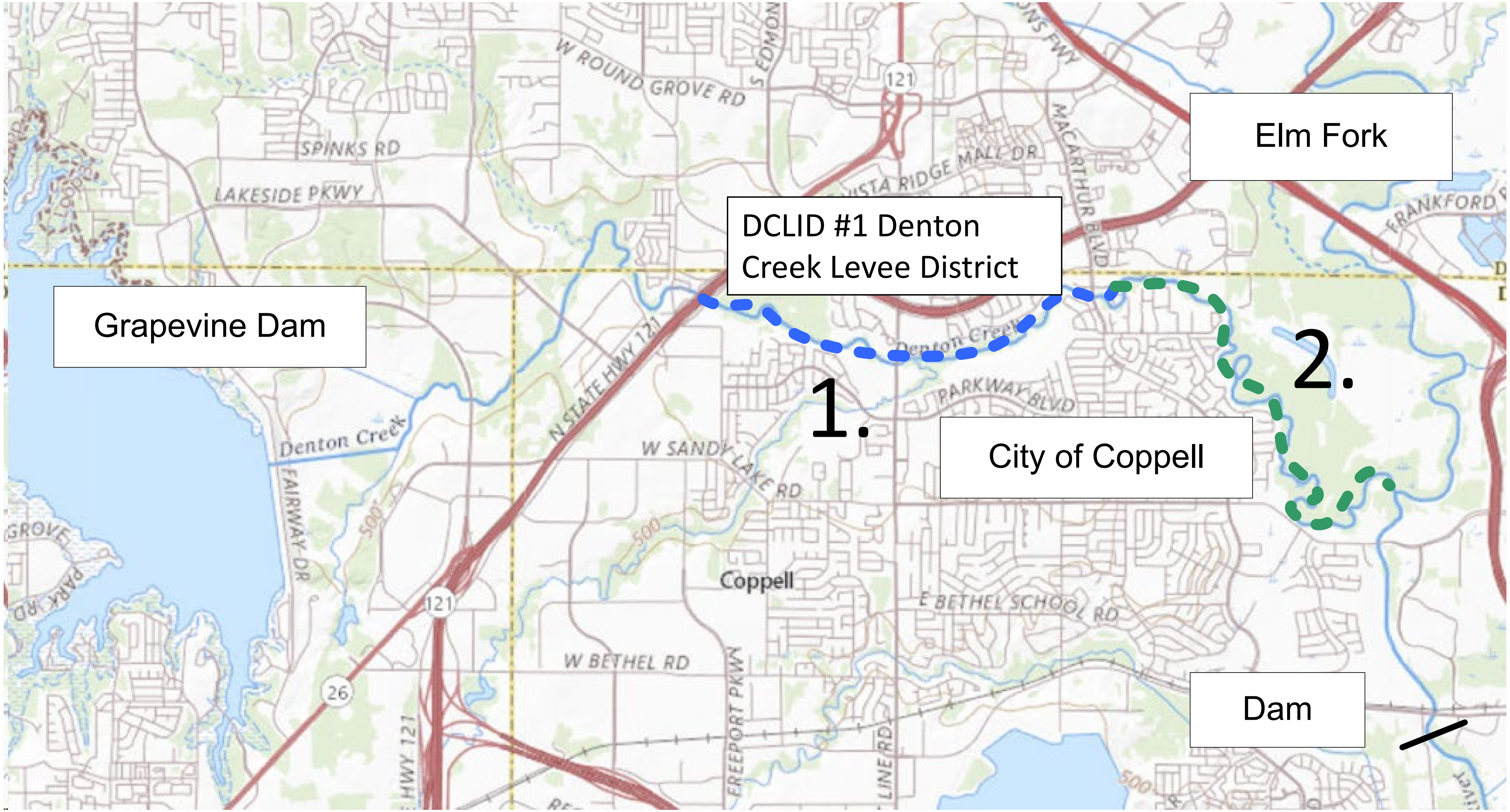
3 Geologic Units



5 Cities

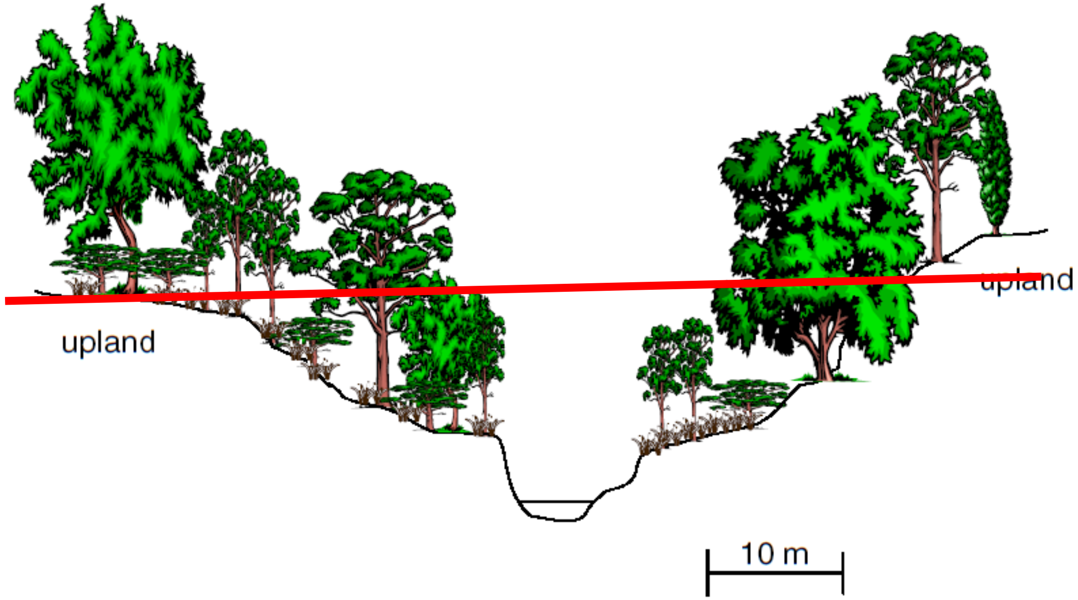


2499
3040
City of Lewisville
Town of
Flower Mound
Upstream Study Limit
121
Denton County Levee
Improvement District No. 1
35
Denton Creek
City of
Carrollton
Grapevine
Lake
City of Grapevine
City of Coppell
Elm Fork Trinity

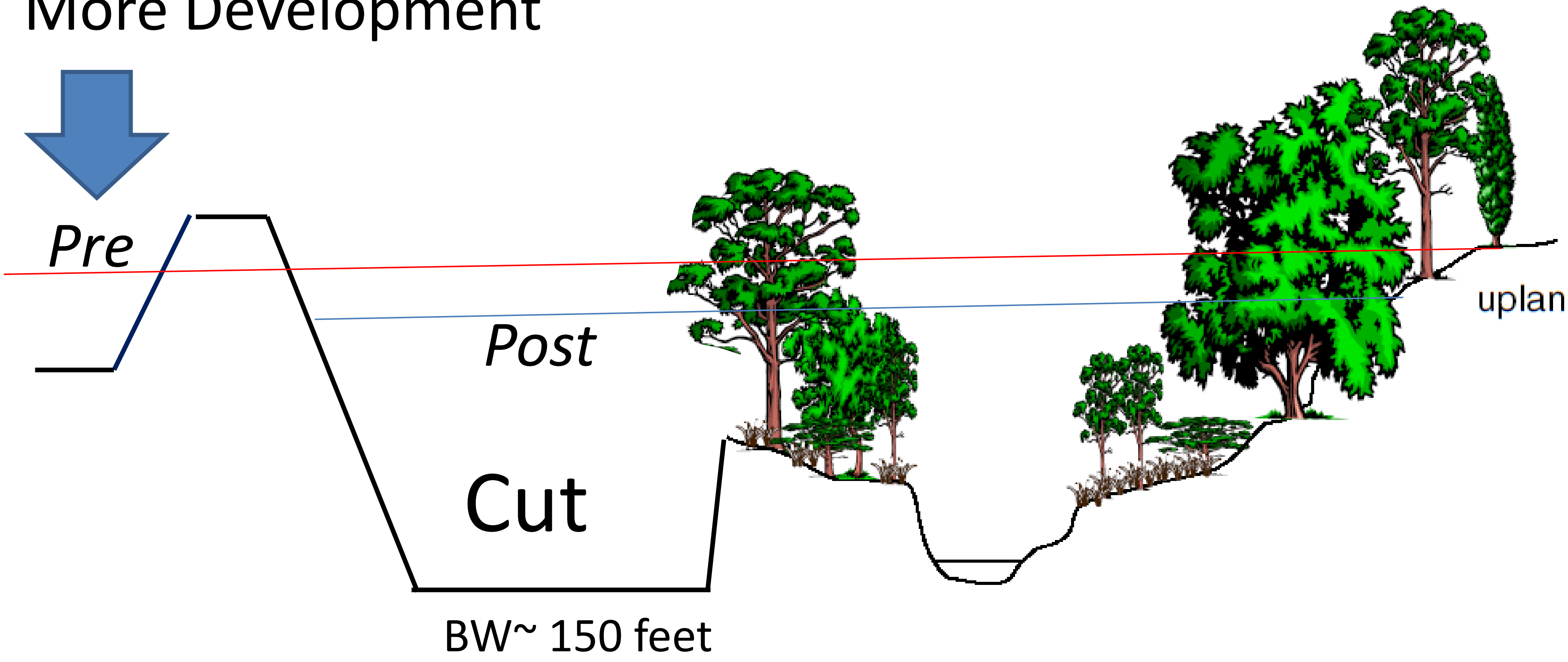


Elm Fork
DCLID #1 Denton Creek Levee District
Grapevine Dam
1.
2.
City of Coppell
Dam
W ROUND GROVE RD
SPINKS RD
LAKESIDE PKWY
VISTA RIDGE MALL DR
MACARTHUR BLVD
FRANKFORD
Denton Creek
PARKWAY BLVD
N STATE HWY 121
W SANDY LAKE RD
FAIRWAY DR
Coppell
E BETHEL SCHOOL RD
W BETHEL RD
FREEPORT PKWY
121
26


03/18/2017

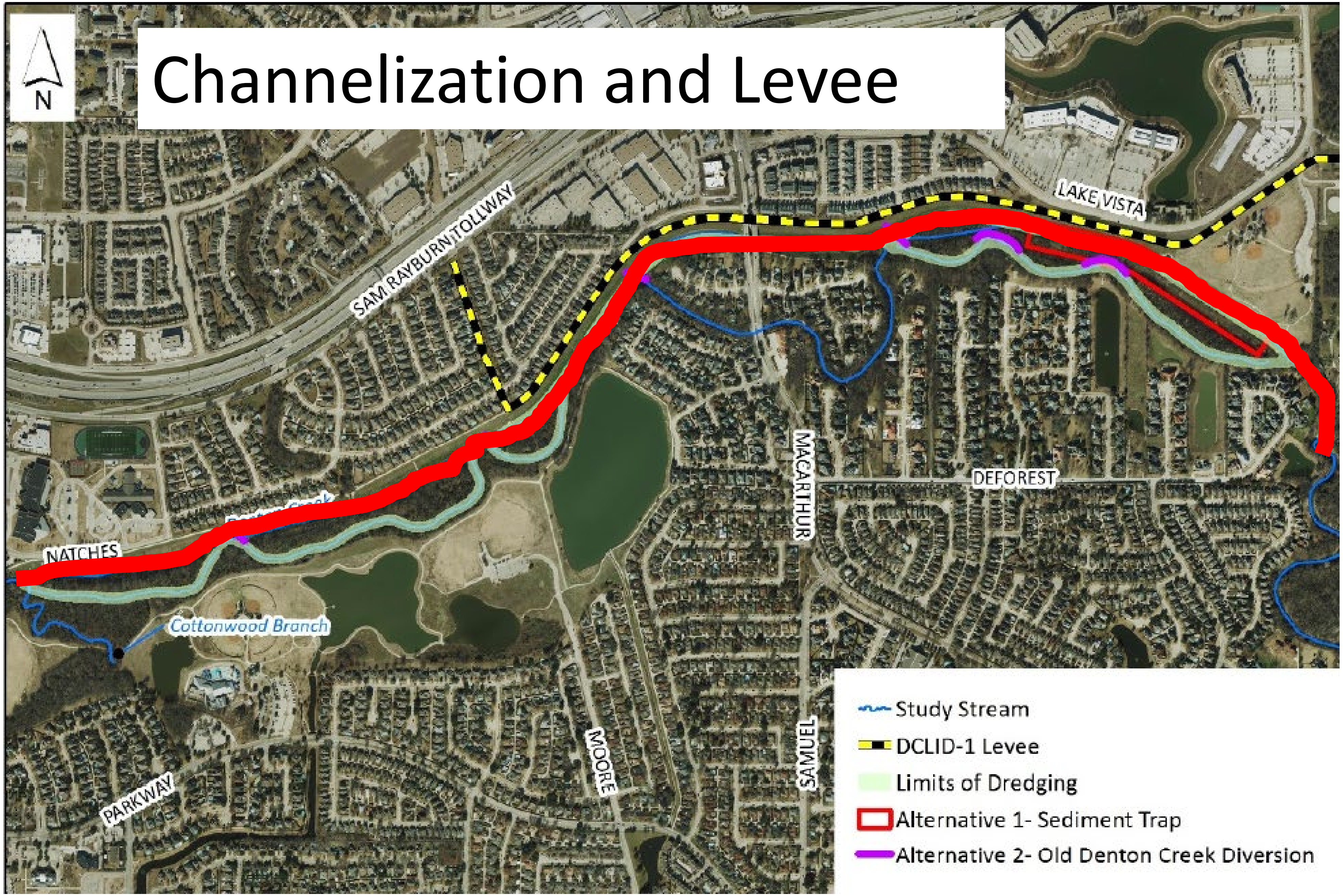

upland
upland
10 m

More Development

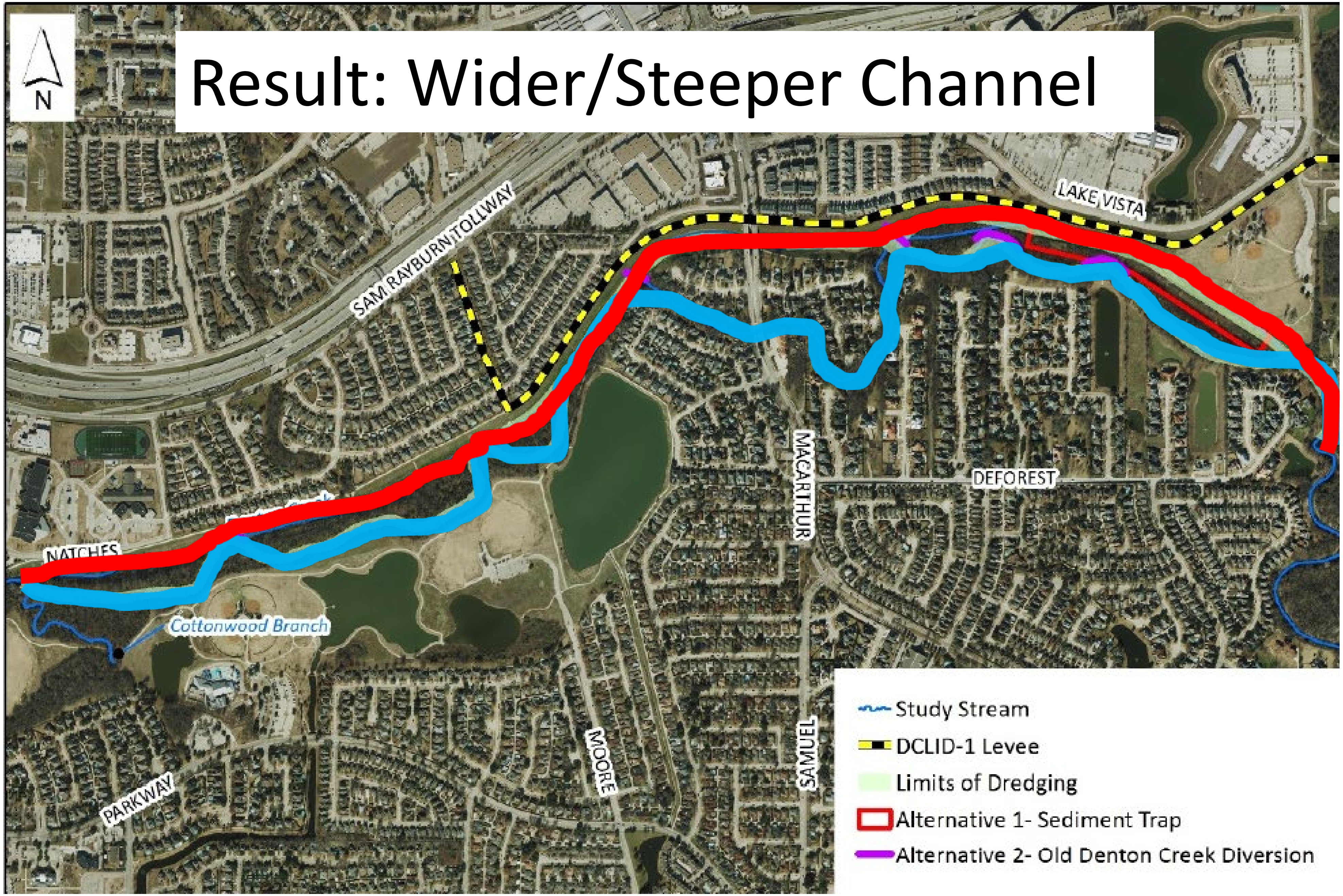


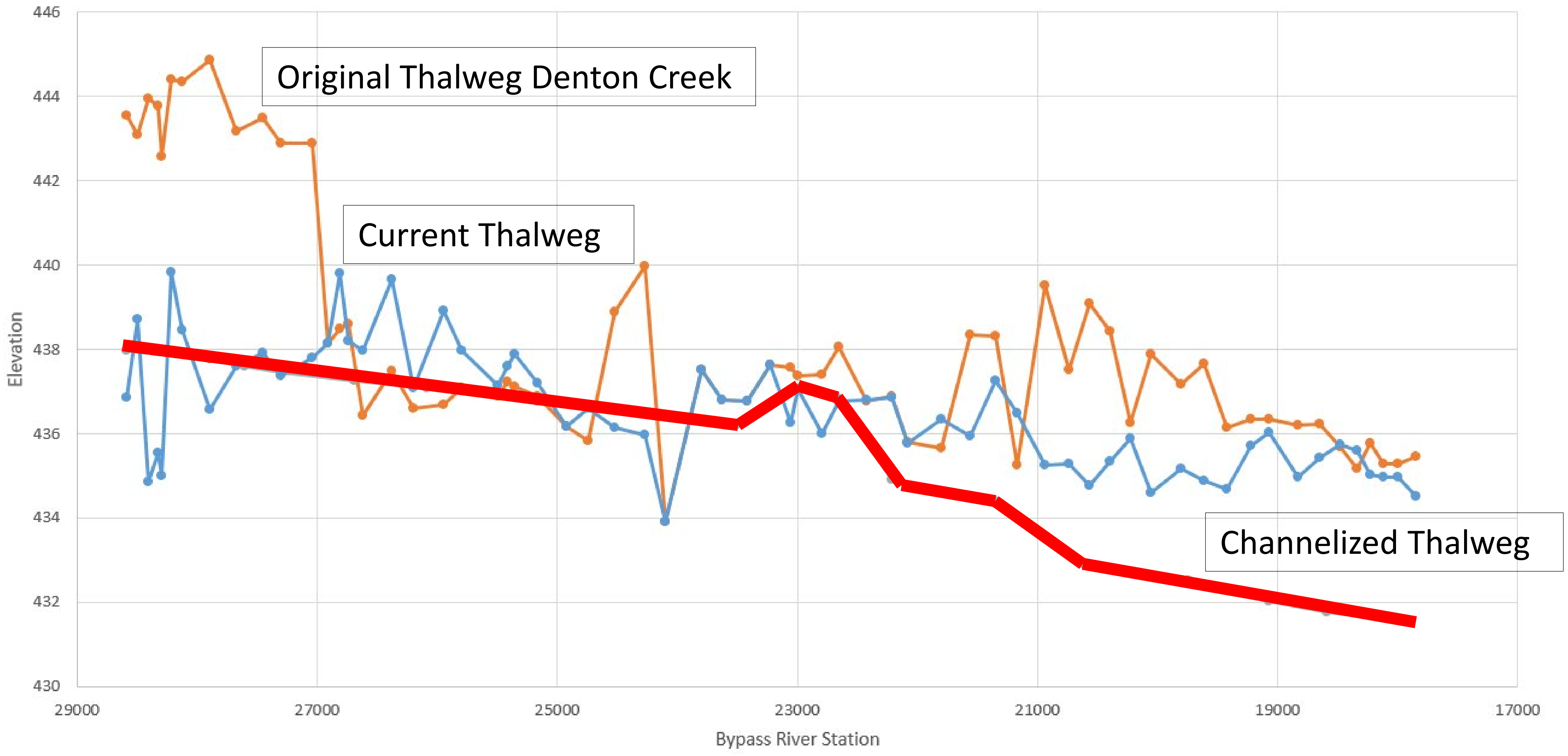
Original Channel

Channelization and Levee



Result: Wider/Steeper Channel

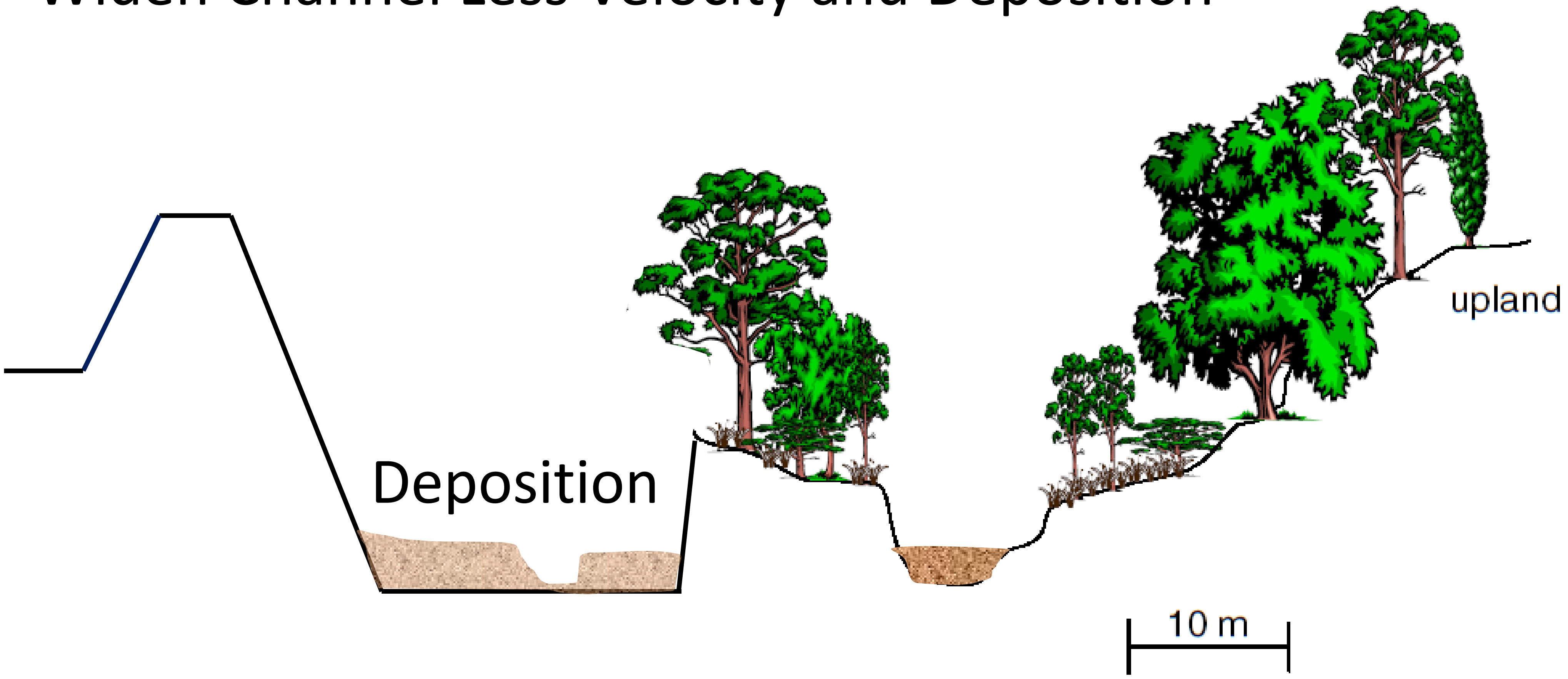


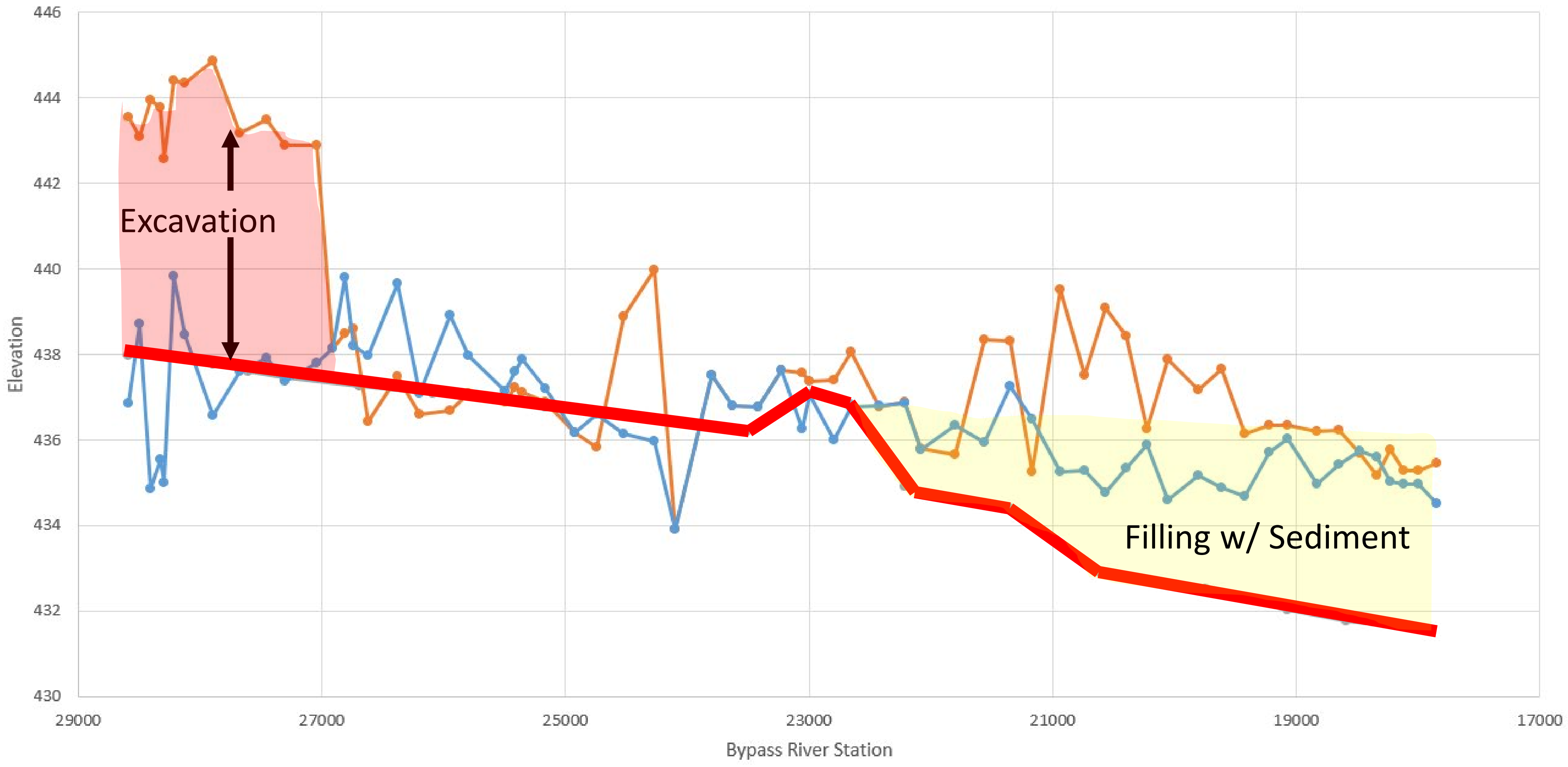


Source: Halff Assoc., 2017

Q=VA

Widen Channel Less Velocity and Deposition

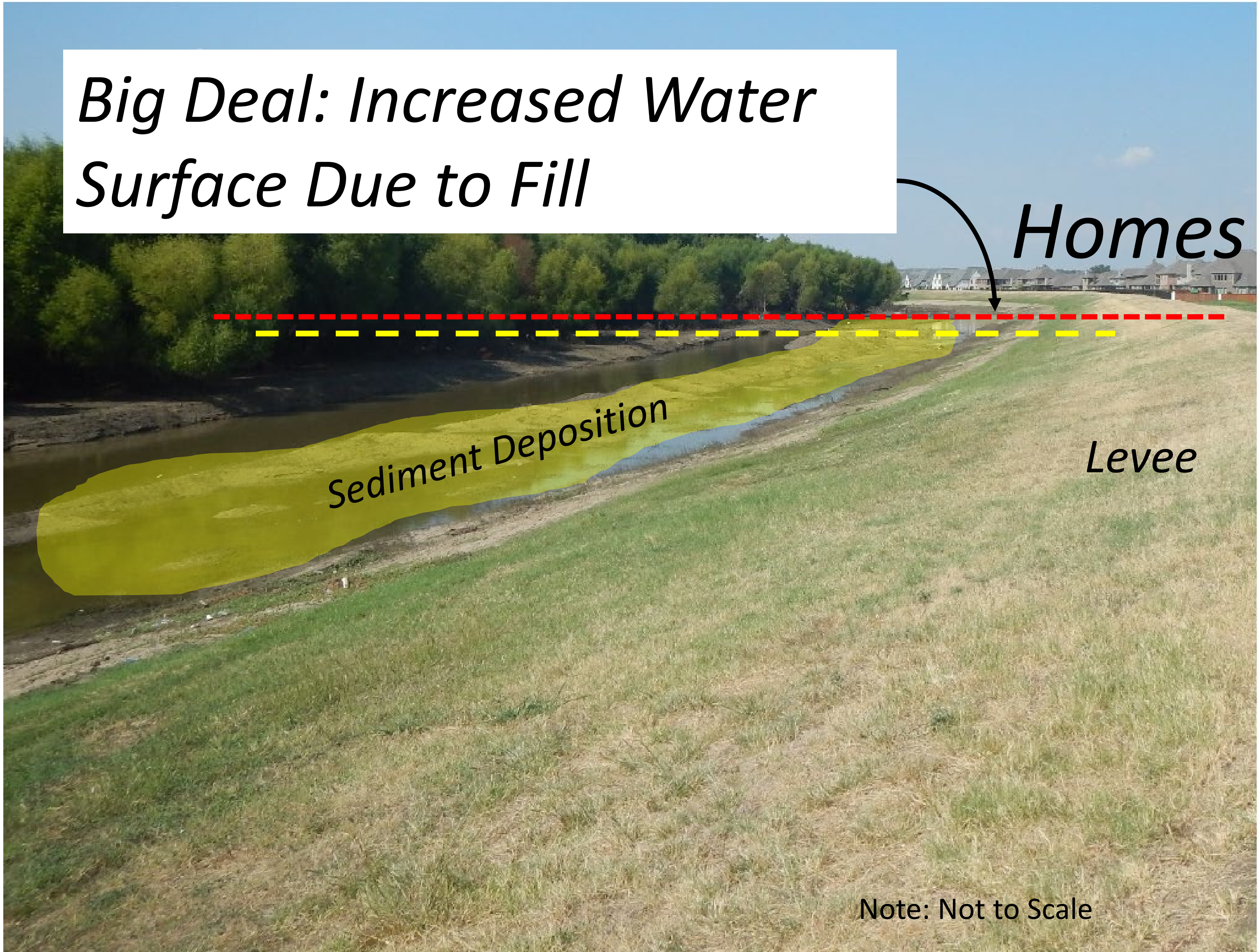




Source: Halff Assoc., 2017


Fill Sediment

Big Deal: Increased Water Surface Due to Fill

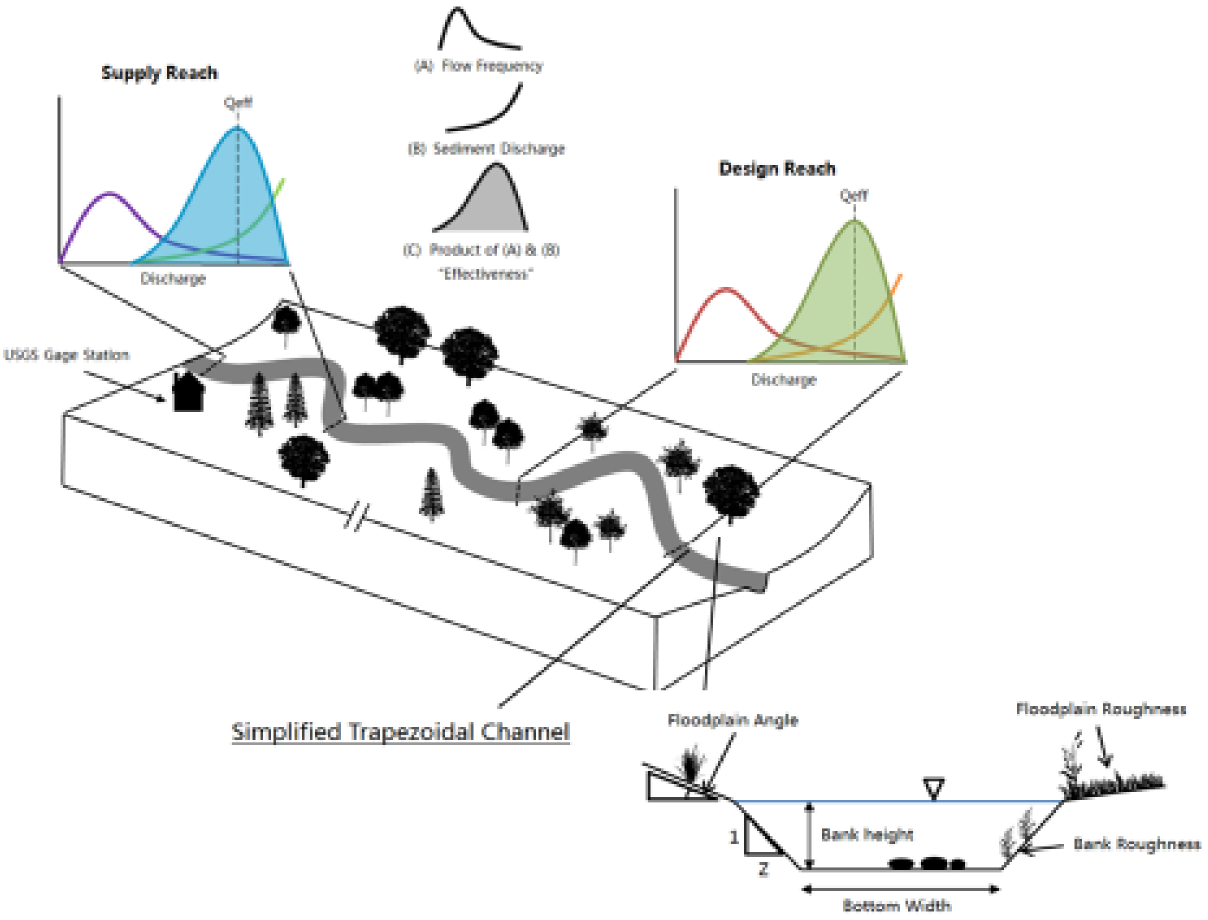


DREDGING 101

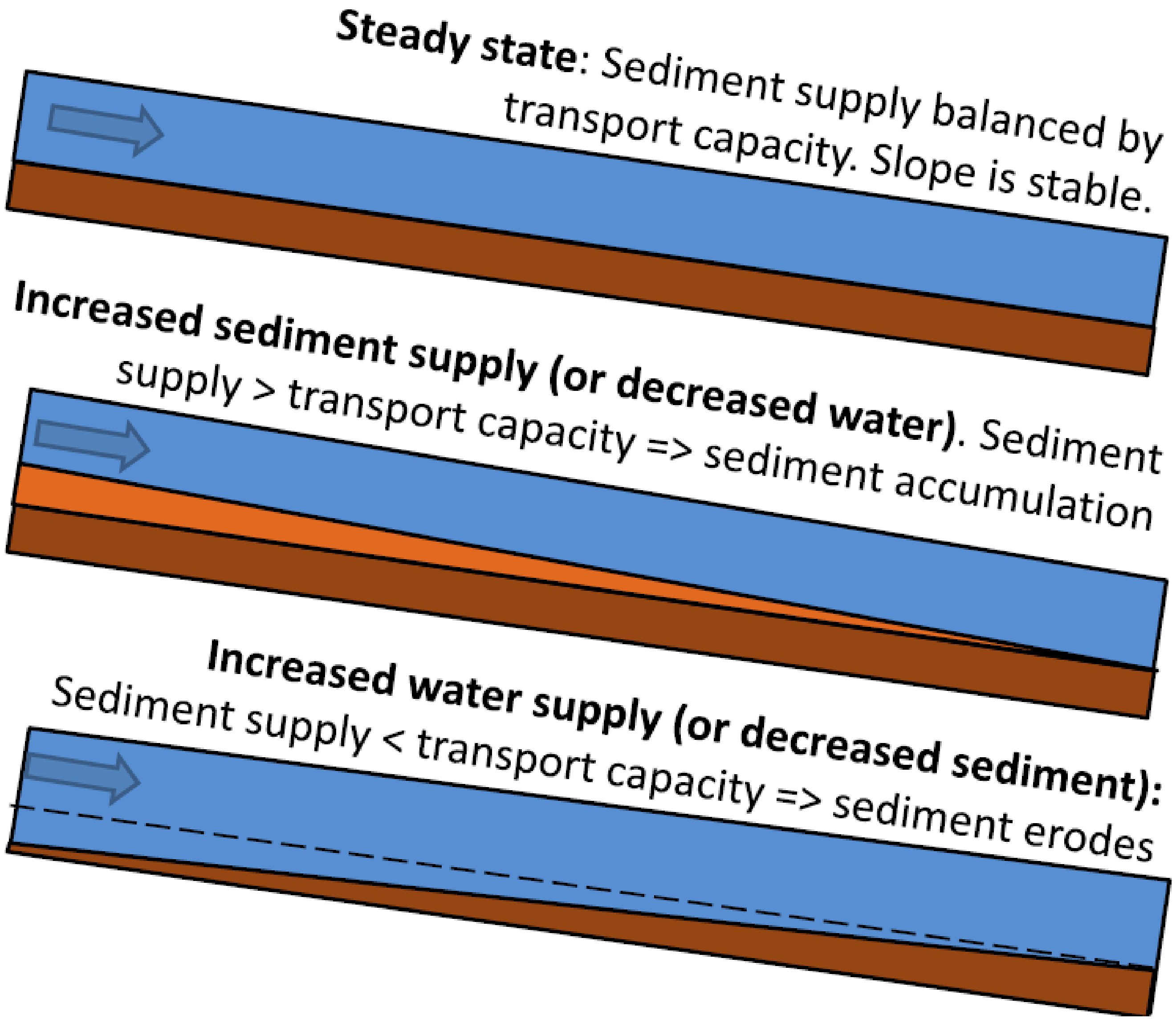
Recurring Costs $$$$

$$\text{Capacity/Supply Ratio(CSR)} = \frac{\int_{\text{time}} \text{Sediment transport capacity of Design Reach}}{\int_{\text{time}} \text{Sediment transport capacity of Supply Reach}}$$

Capacity Supply Analysis



Bledsoe and Stroth, CSU, 2017

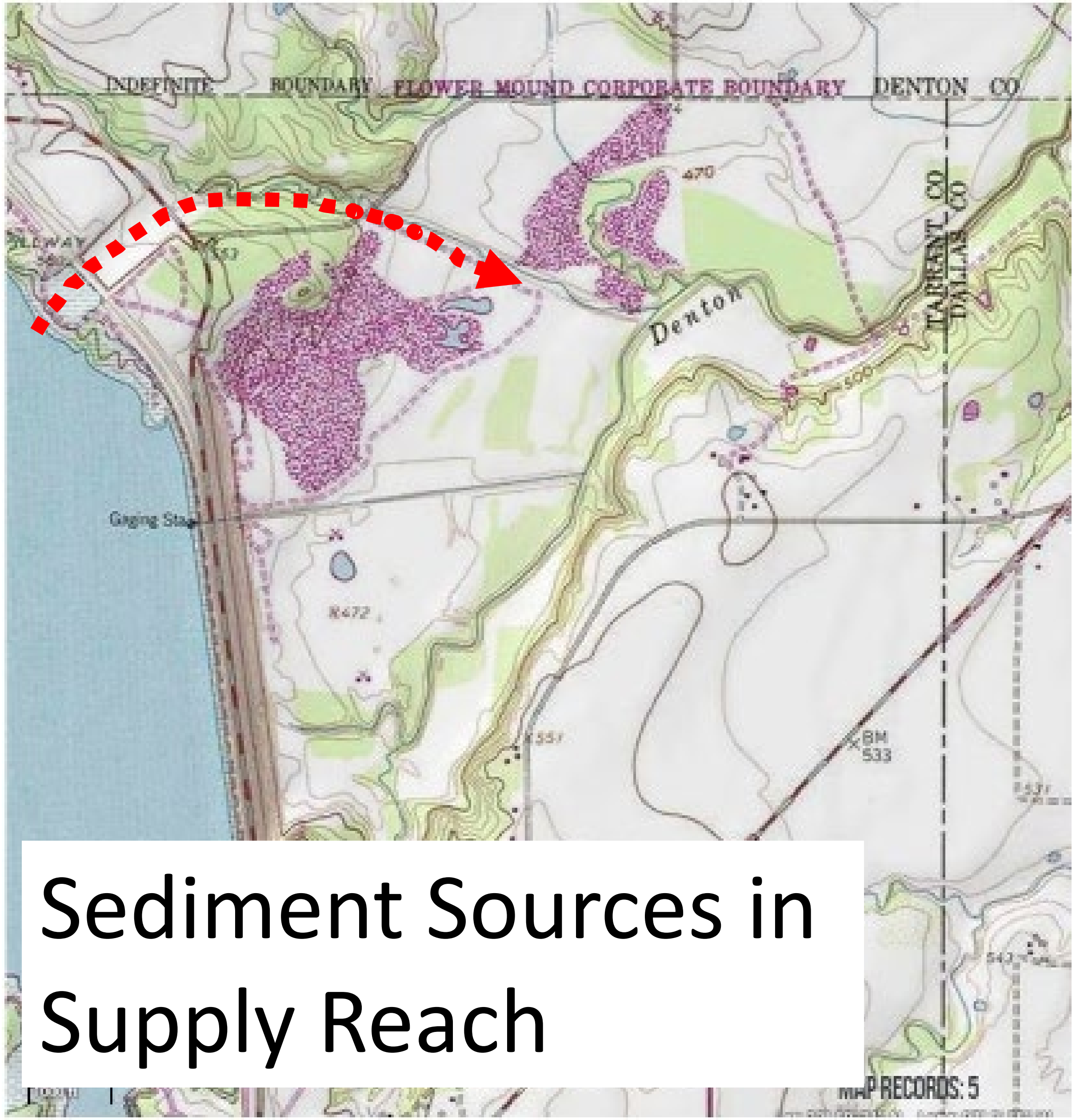


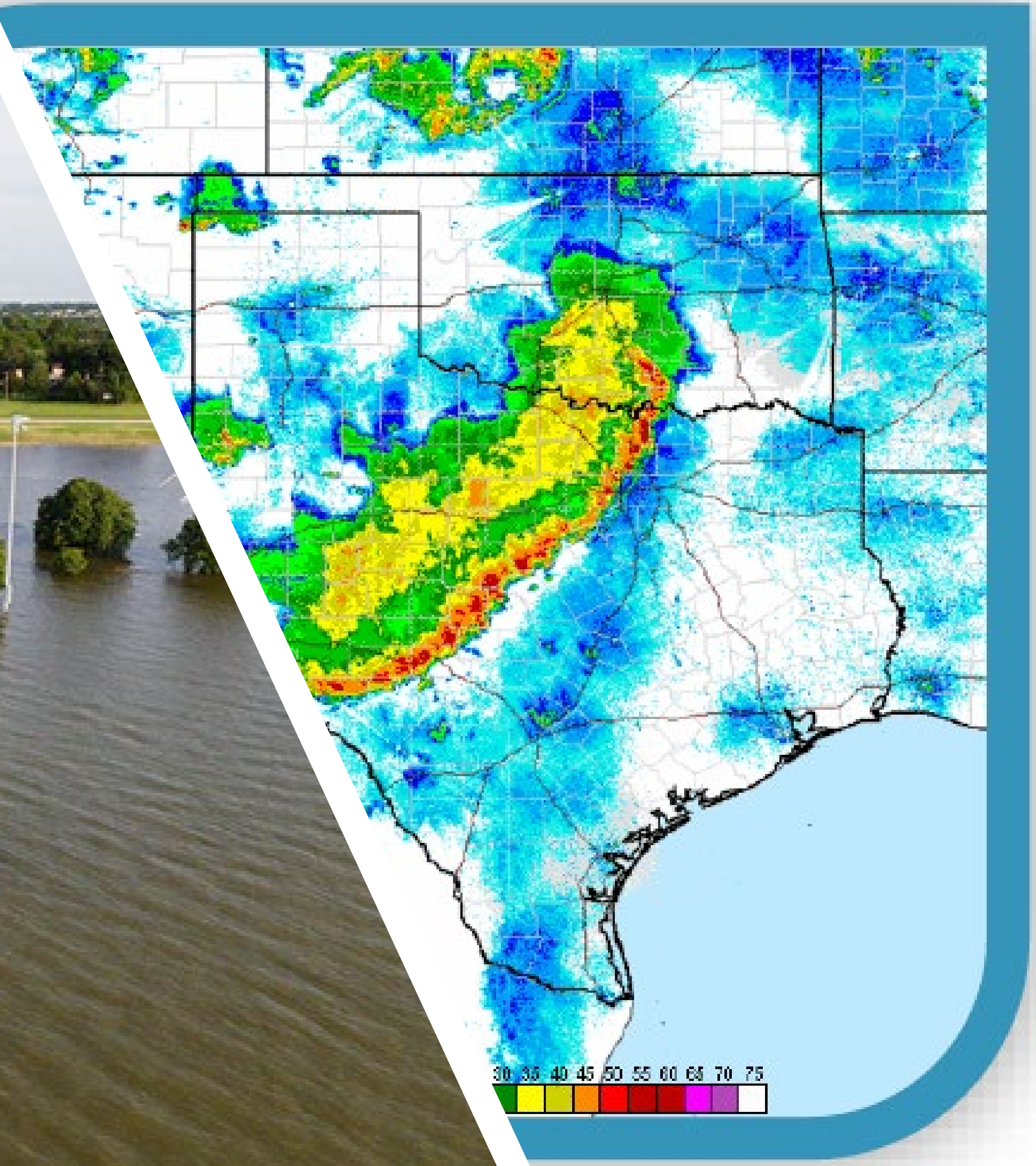
Steady state: Sediment supply balanced by transport capacity. Slope is stable.
Increased sediment supply (or decreased water). Sediment supply > transport capacity => sediment accumulation
Increased water supply (or decreased sediment): Sediment supply < transport capacity => sediment erodes

NCHRP 853

1. Emergency Spillway
2. Dam Release Channel/Denton Creek
3. Sediment Supply Reach
4. Levee District

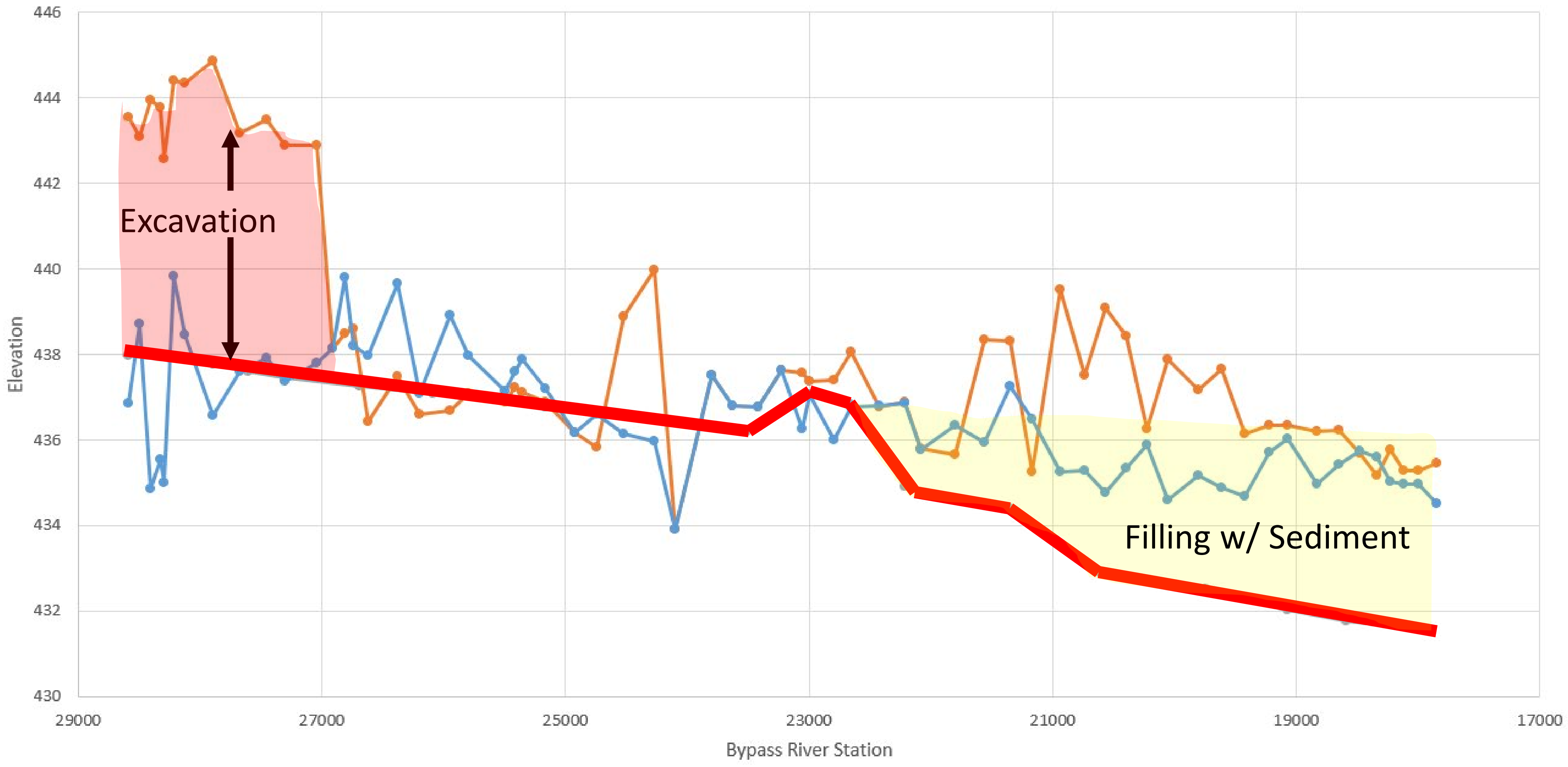
Sediment Sources in Supply Reach



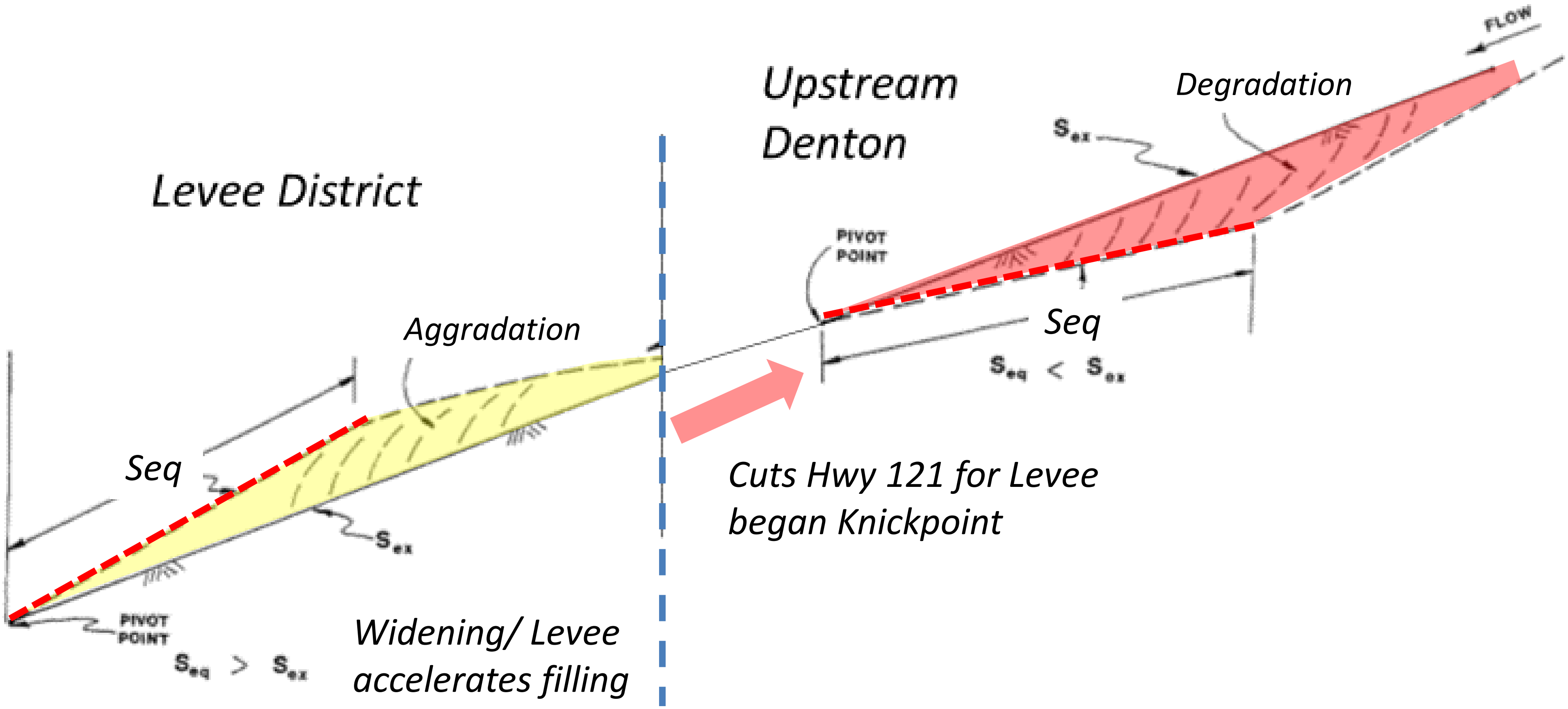

30 35 40 45 50 55 60 65 70 75


2014
2015

1. ~~Emergency Spillway~~
2. ~~Dam Release Channel/Denton Creek~~
3. Sediment Supply Reach
4. Levee District



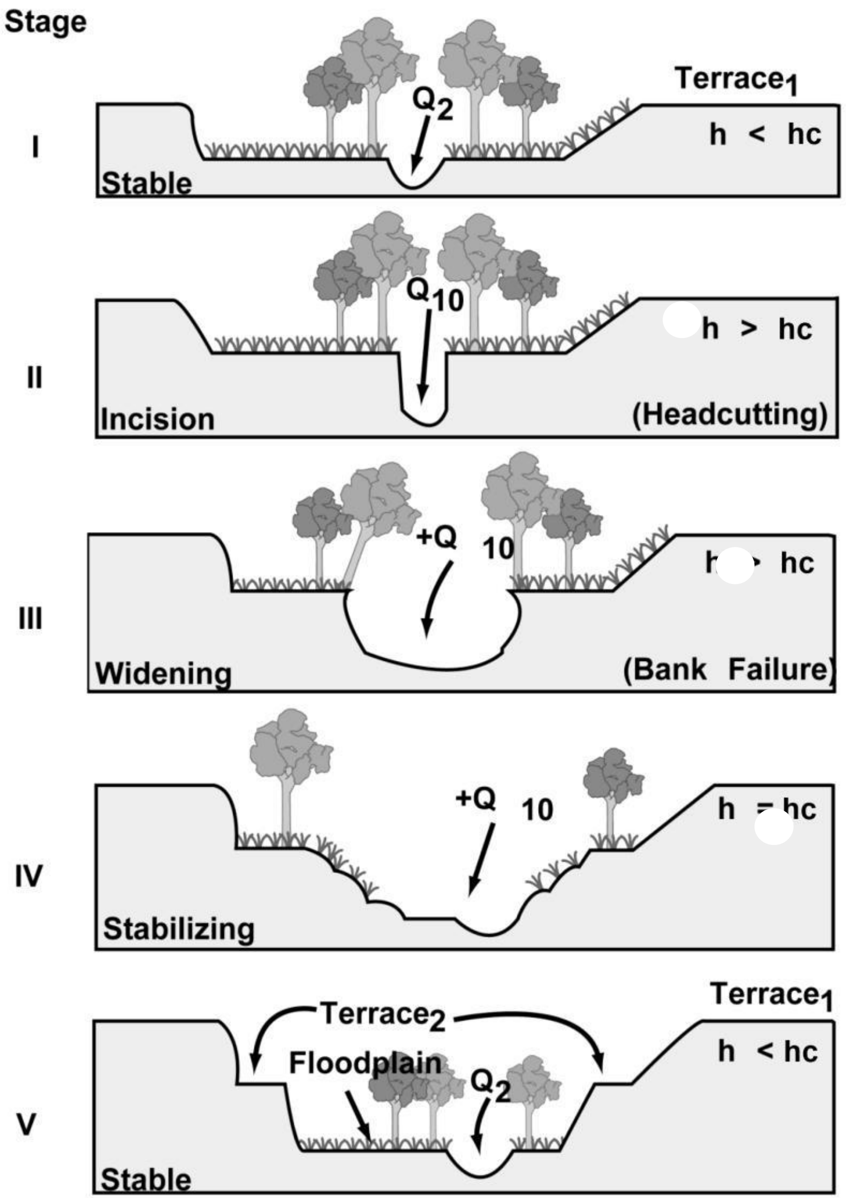
Source: Halff Assoc., 2017

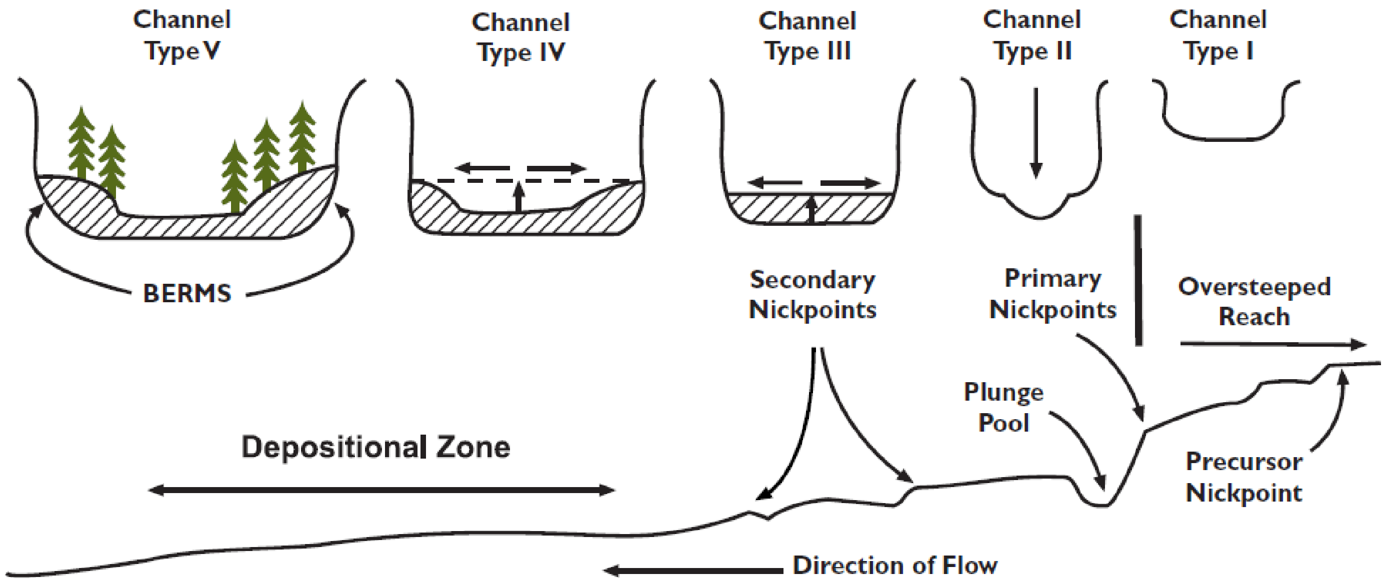


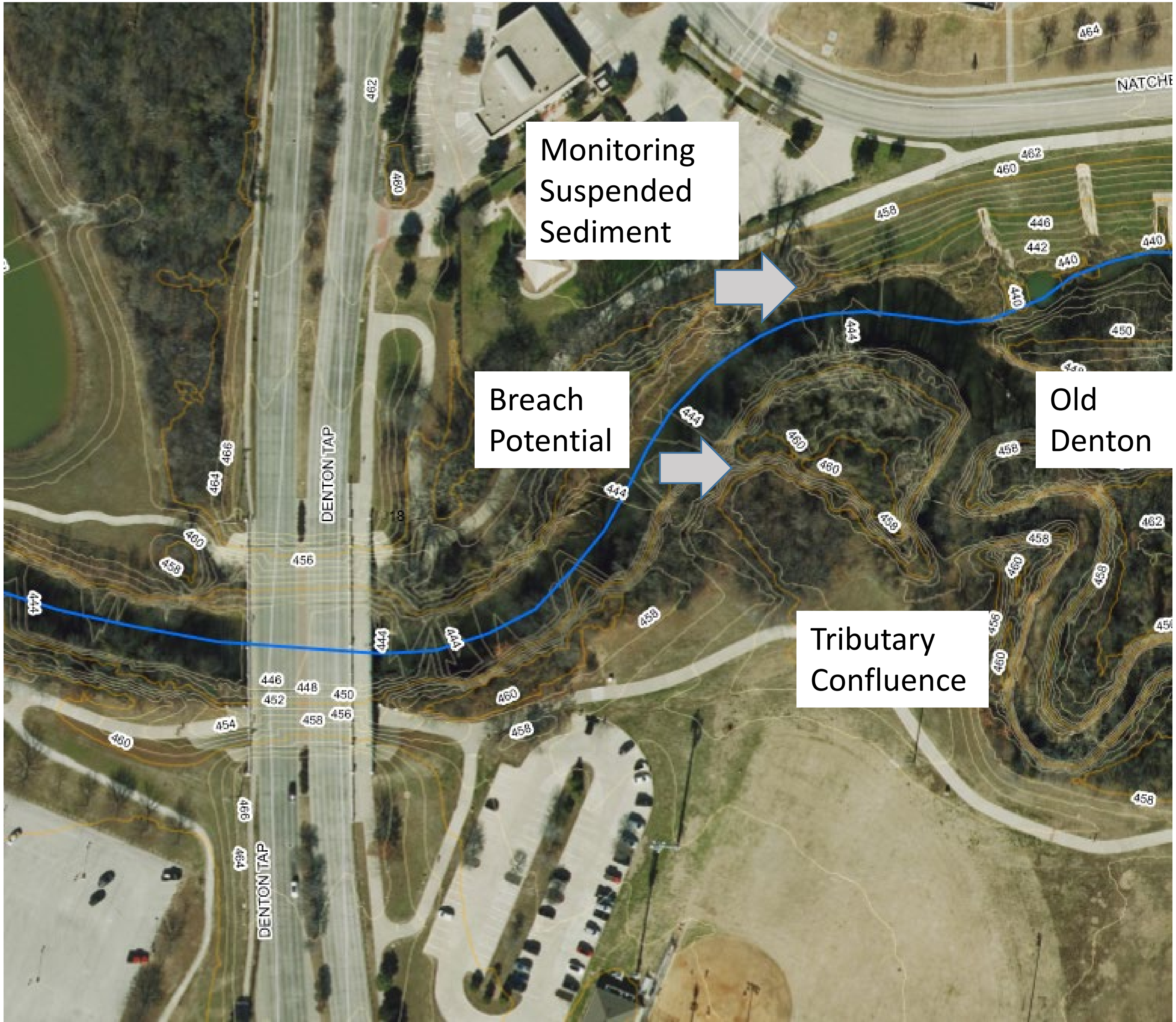
(Simons and Li, 1981)

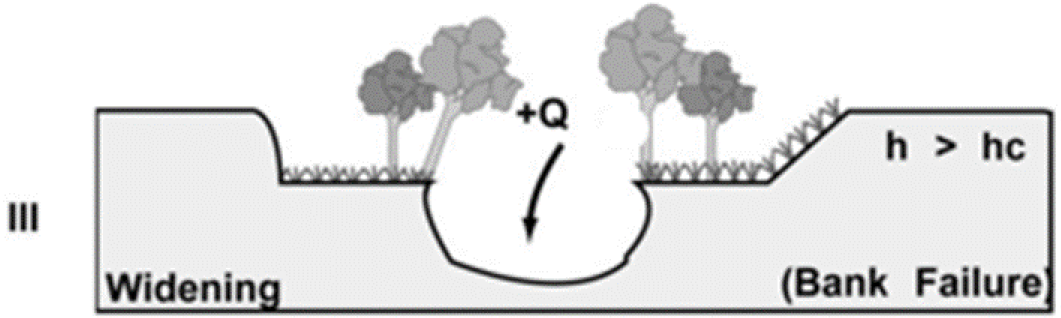
1. ~~Emergency Spillway~~
2. ~~Dam Release Channel/Denton Creek~~
3. Sediment Supply Reach
4. Levee District

Channel Evolution Model





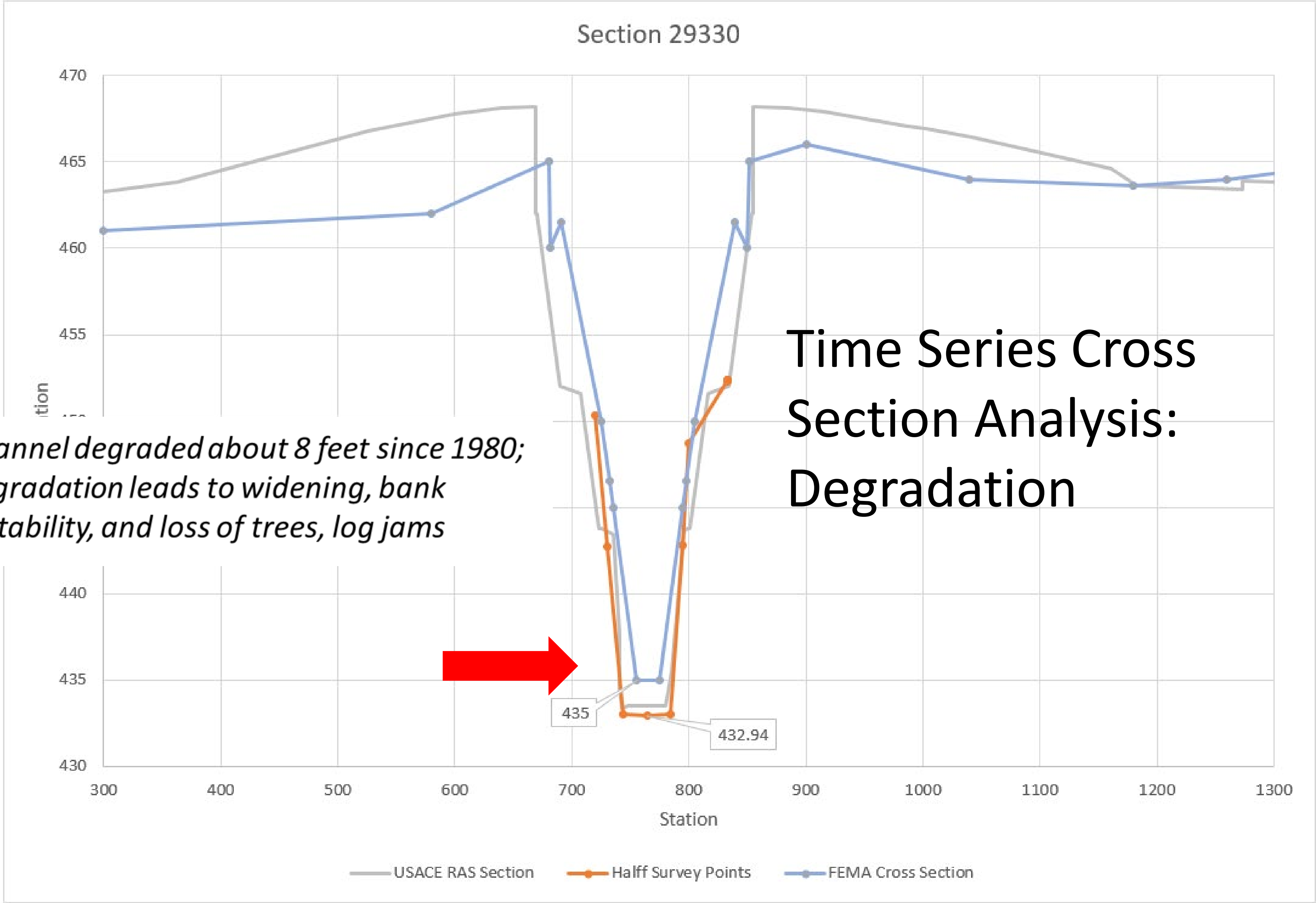

Monitoring Suspended Sediment
Breach Potential
Old Denton
Tributary Confluence
DENTON TAP
NATCHE

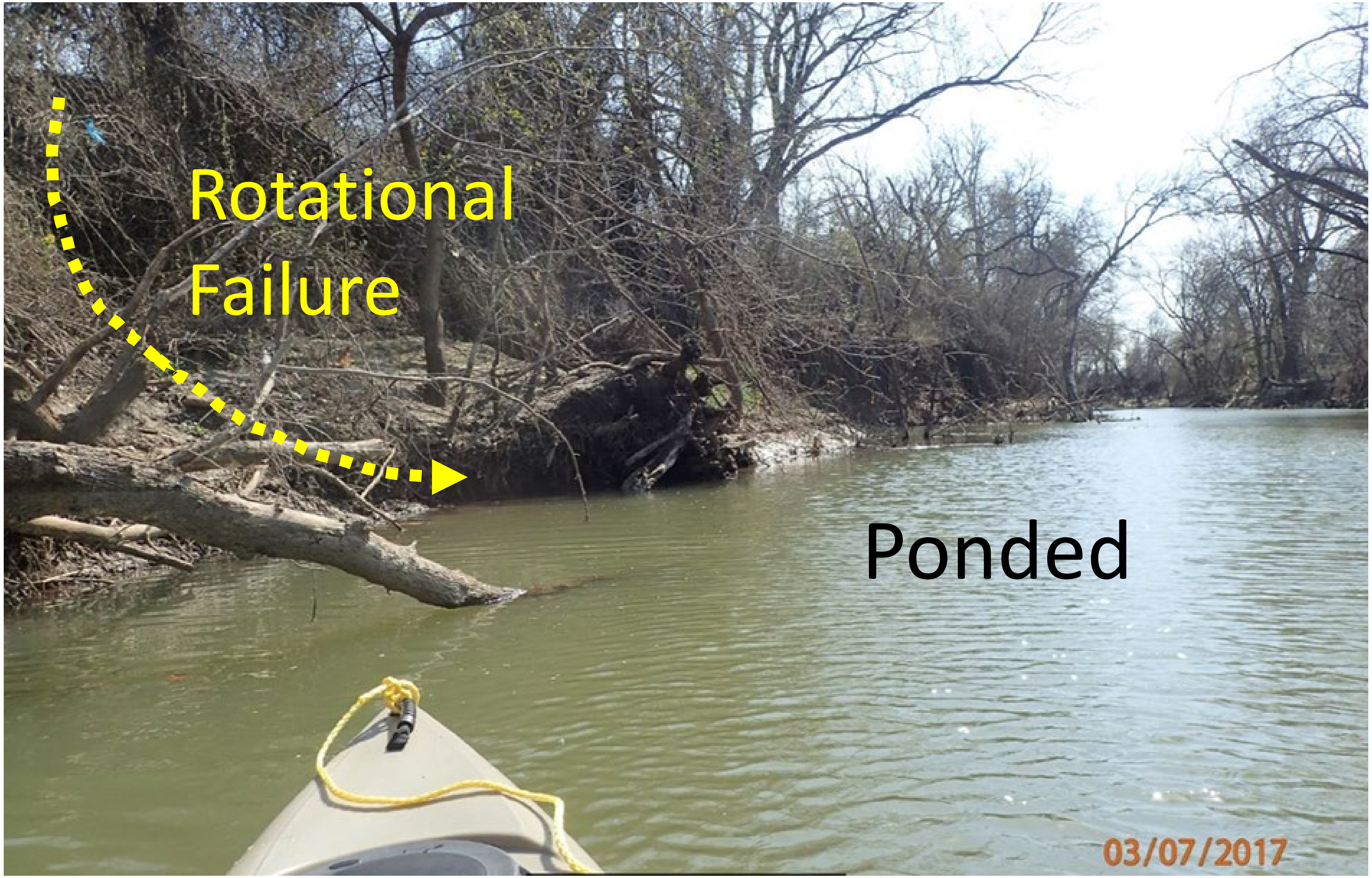


Upstream

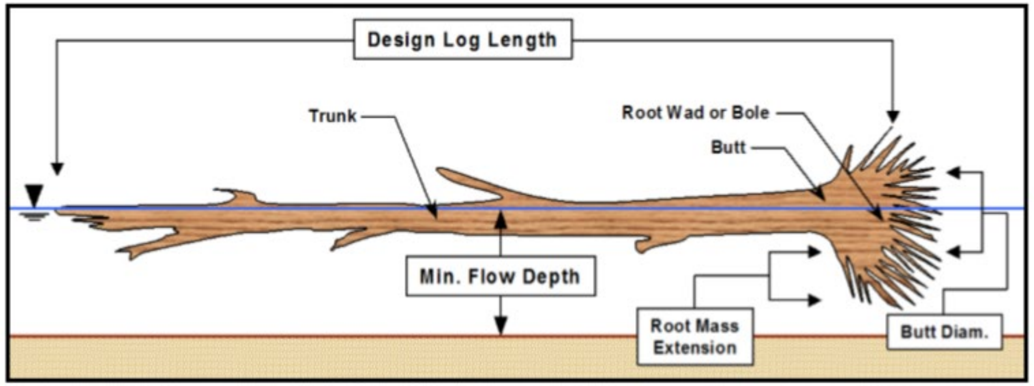
Time Series Cross Section Analysis: Degradation

Channel degraded about 8 feet since 1980; degradation leads to widening, bank instability, and loss of trees, log jams




Rotational
Failure
Ponded
03/07/2017

Tree Falls due to Toe Erosion and Degradation= Log Jams



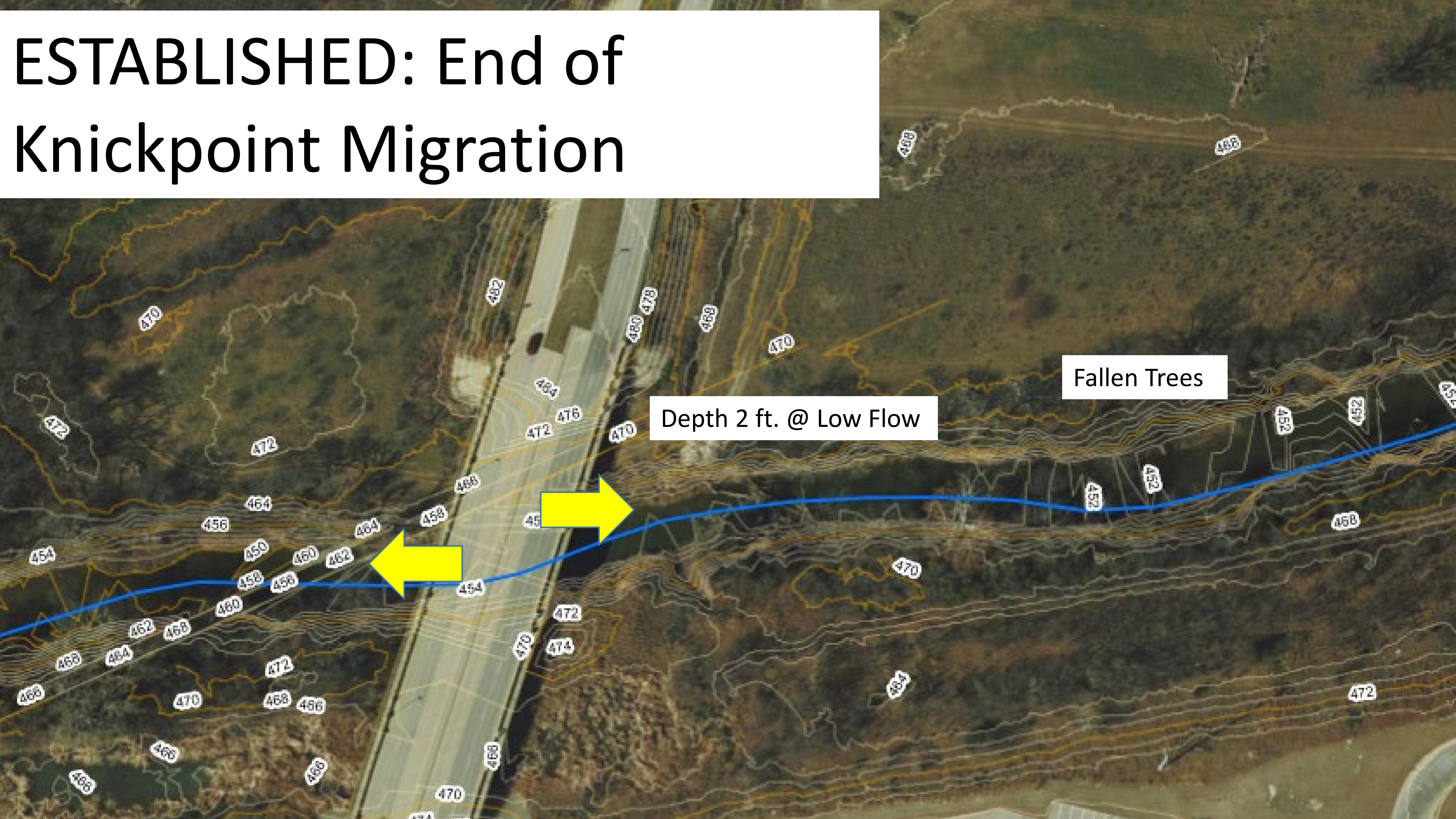
Comparison Widths Upstream and Downstream of Denton Tap

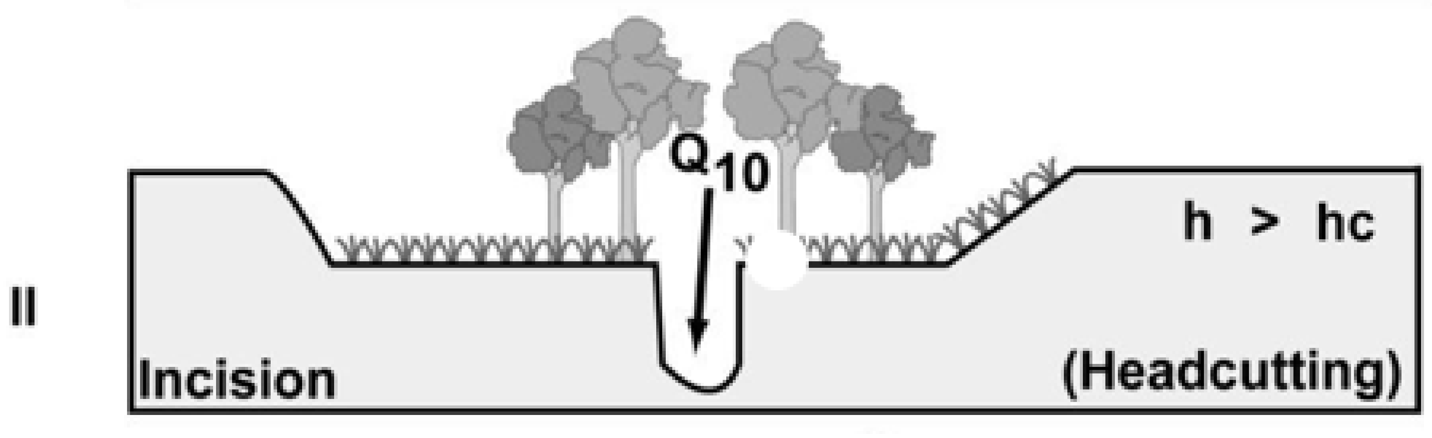
Old Denton Creek (Levee District)
Riparian to channel bottom, and narrower width, depth. (Fill from cutoff)

Denton Creek Upstream Denton Tap:
Wider, deeper, tree falls, undercut banks, Stage III CEM Model

1. Emergency Spillway
2. Dam Release Channel/Denton Creek
3. Sediment Supply Reach
4. Levee District

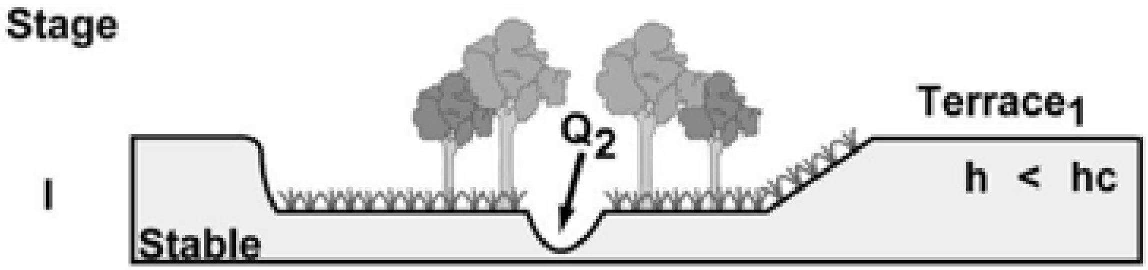
ESTABLISHED: End of Knickpoint Migration



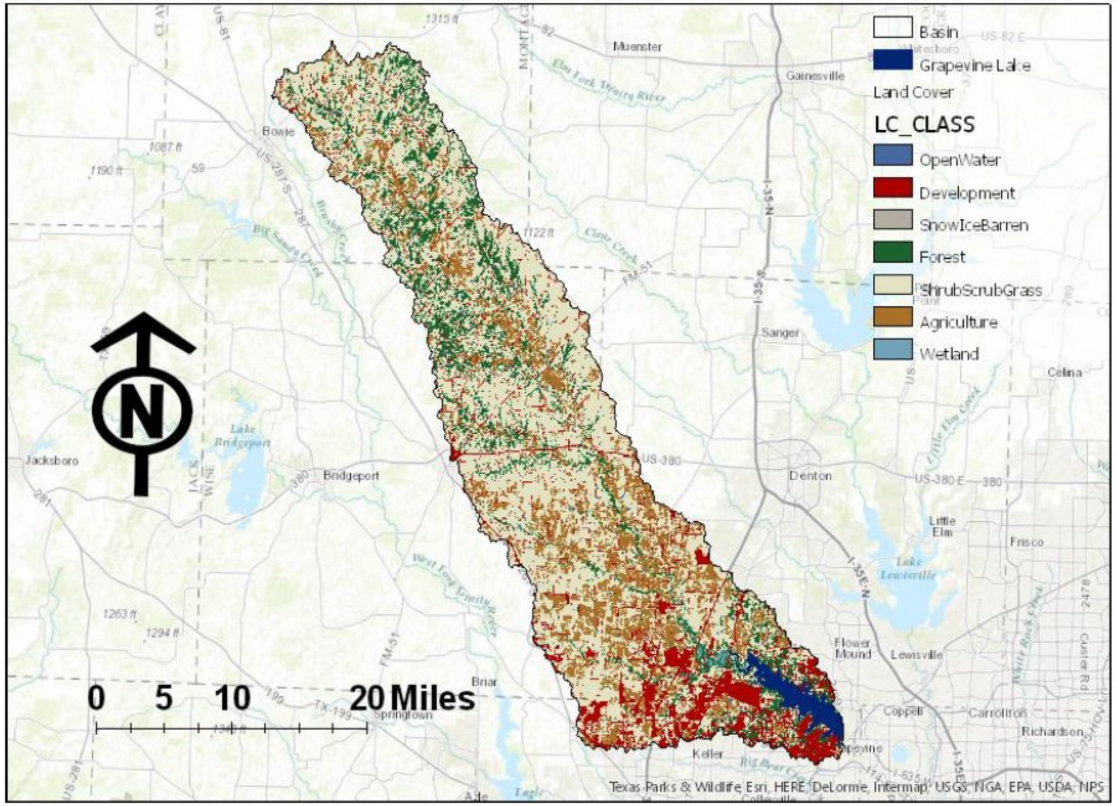


Downstream

View Upstream: Natural River



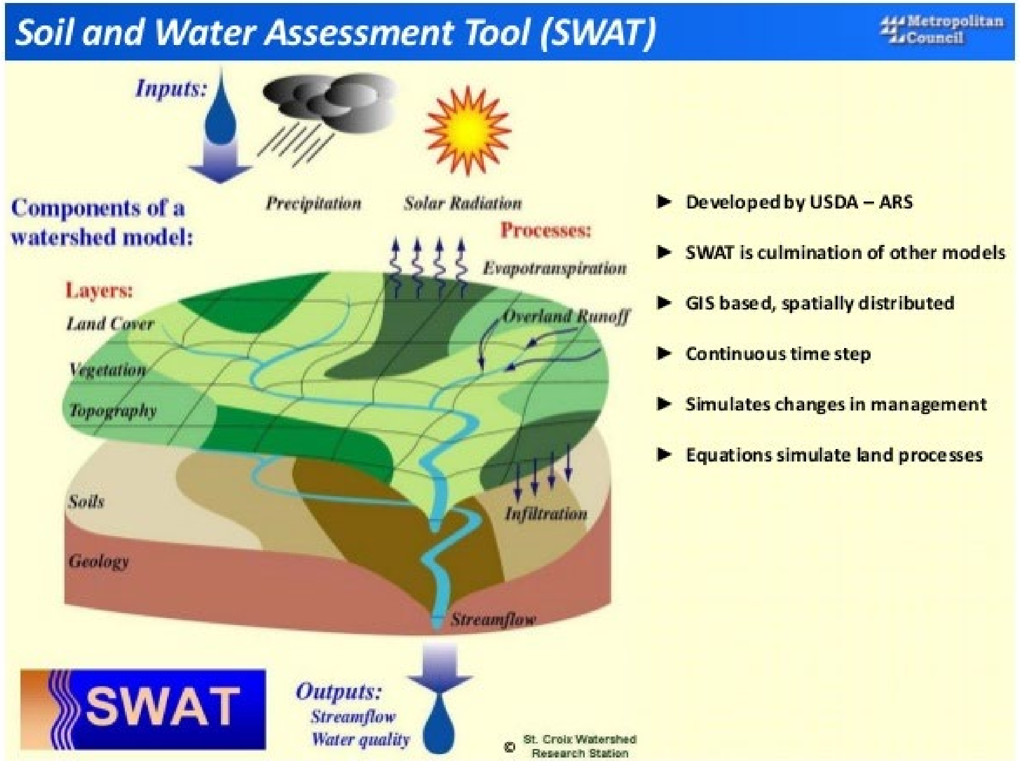
Looked at Watershed Future Q?

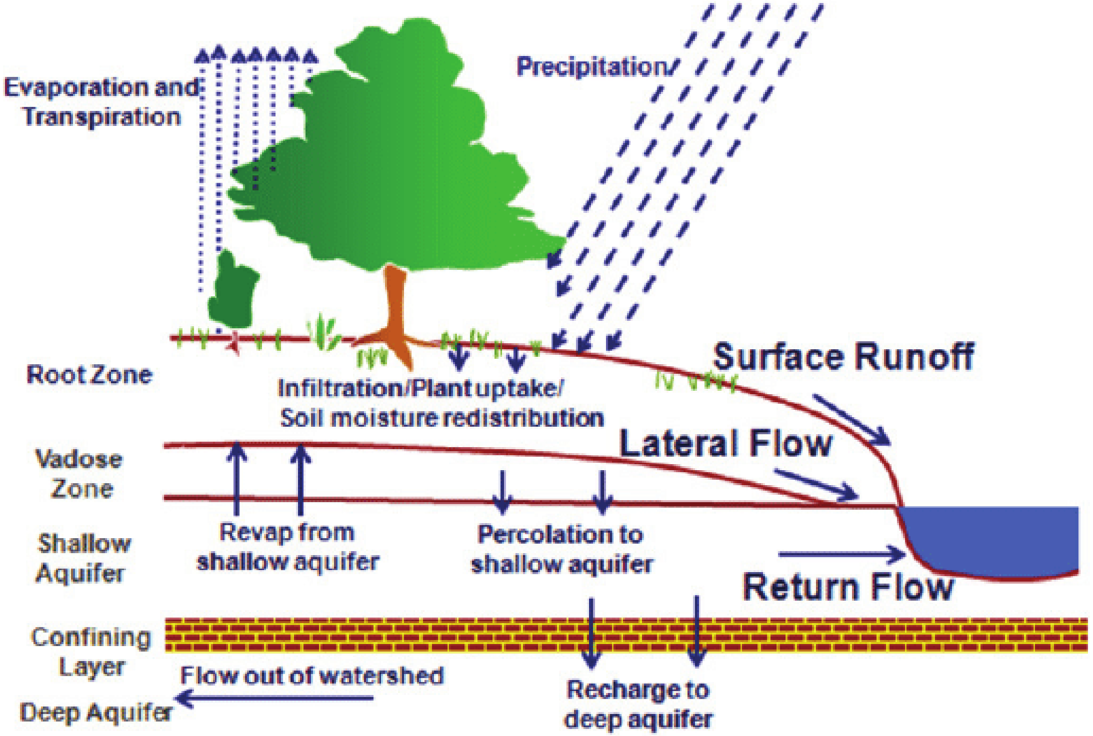


Land Cover	Area (%)	Area (km^2)
Agriculture	18.00%	323.88
Development	11.55%	207.88
Forest	13.80%	248.32
Open Water	2.05%	36.87
ShrubScrubGrass	54.12%	973.64
SnowIceBarren	0.15%	2.64
Wetland	0.33%	5.86

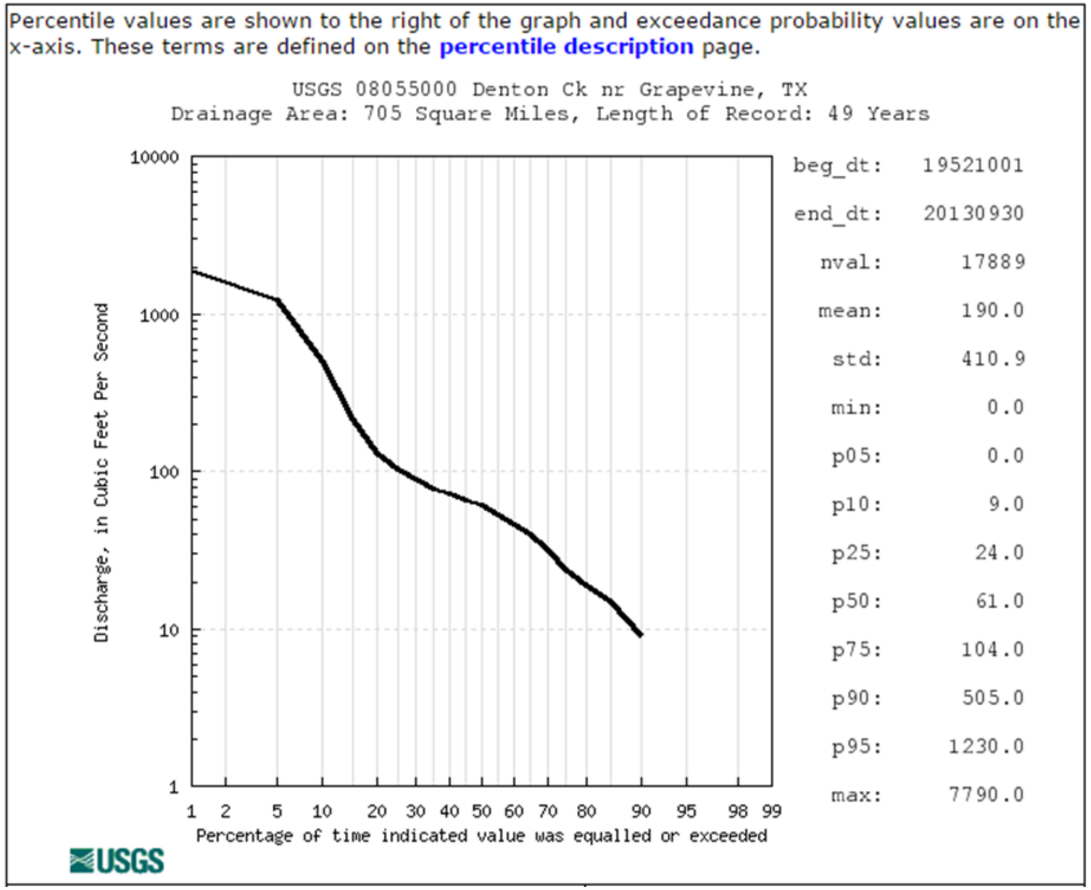
Mock (2016)

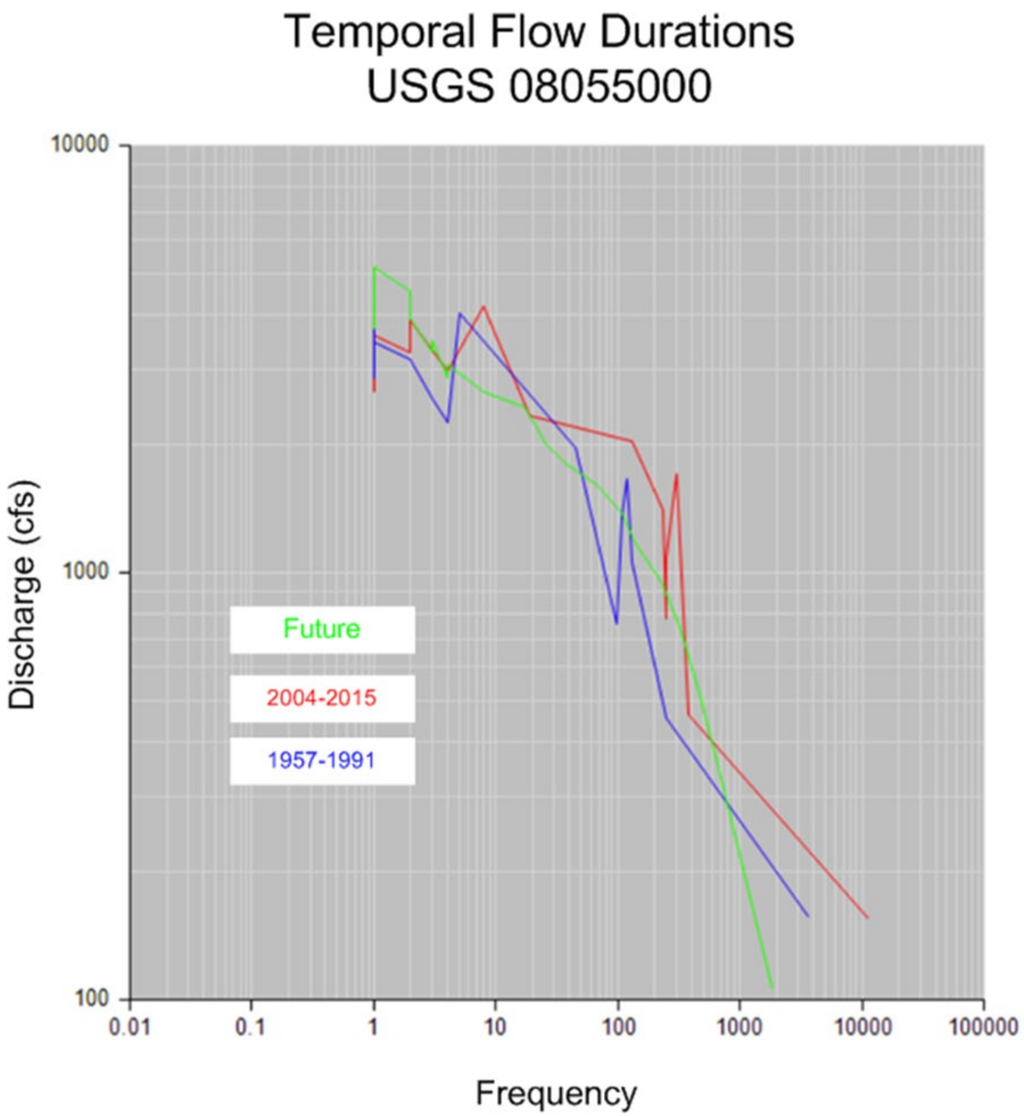
SWAT Model Run to Determine Future Discharge Change Land Use



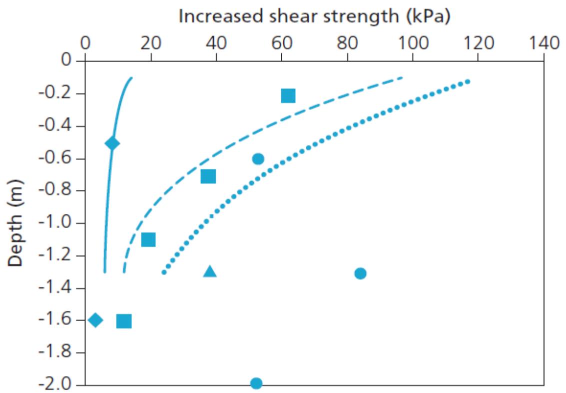


Q Flow Duration: Dam Operation Lessens Change

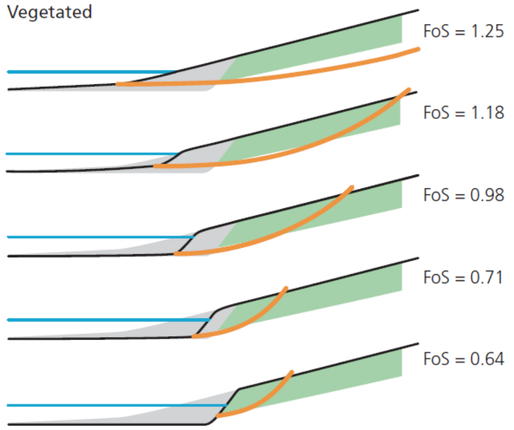




Looked At Erosion…Causes Tree Loss Widening……But What Rate?



Strength < Depth



Failure as Cut Toe

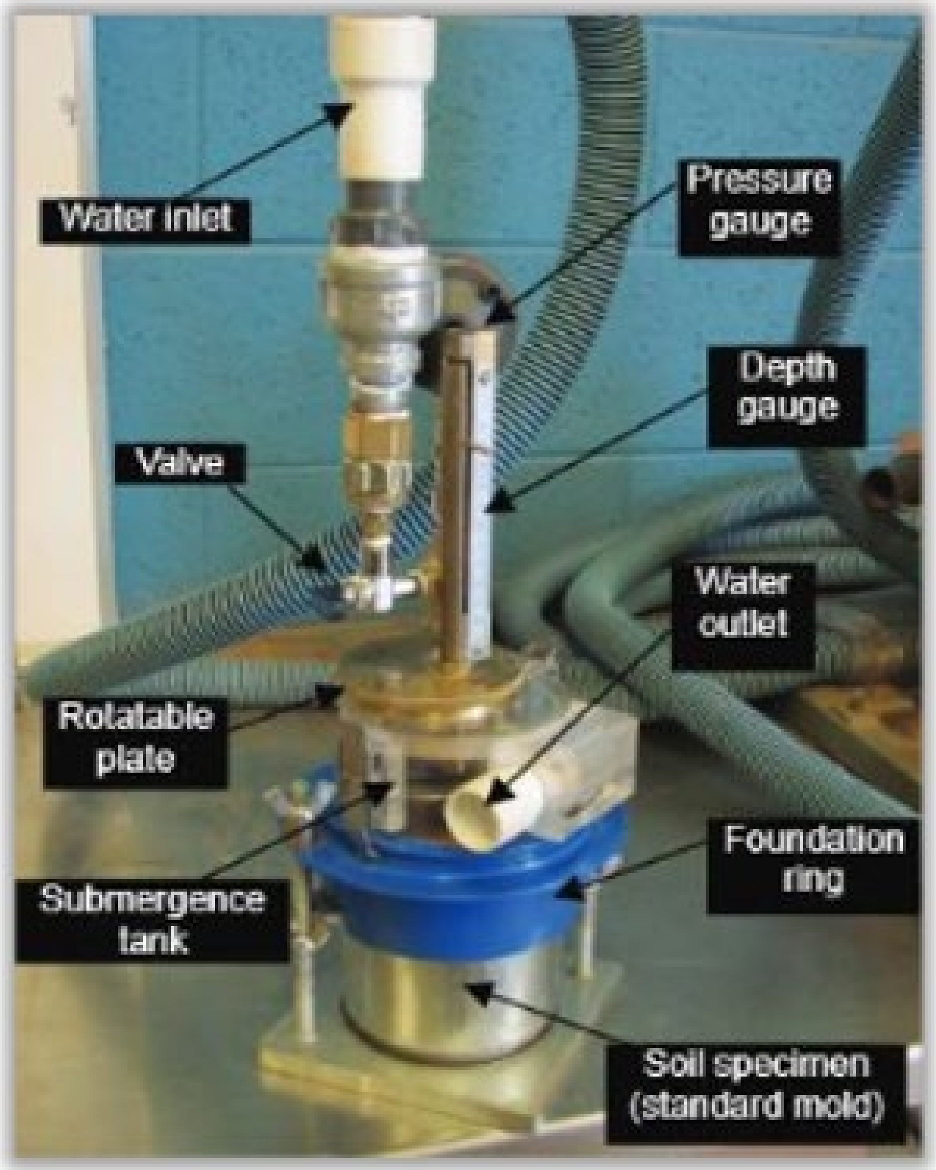
Rutherfurd (2007)

$$Erosion_{(cm/hr/Pa)} = Kd\ (Te - Tc)$$

Stream Force

"Te"=9810*R*S

Resisting: Erosion Rate and Critical Tractive Force



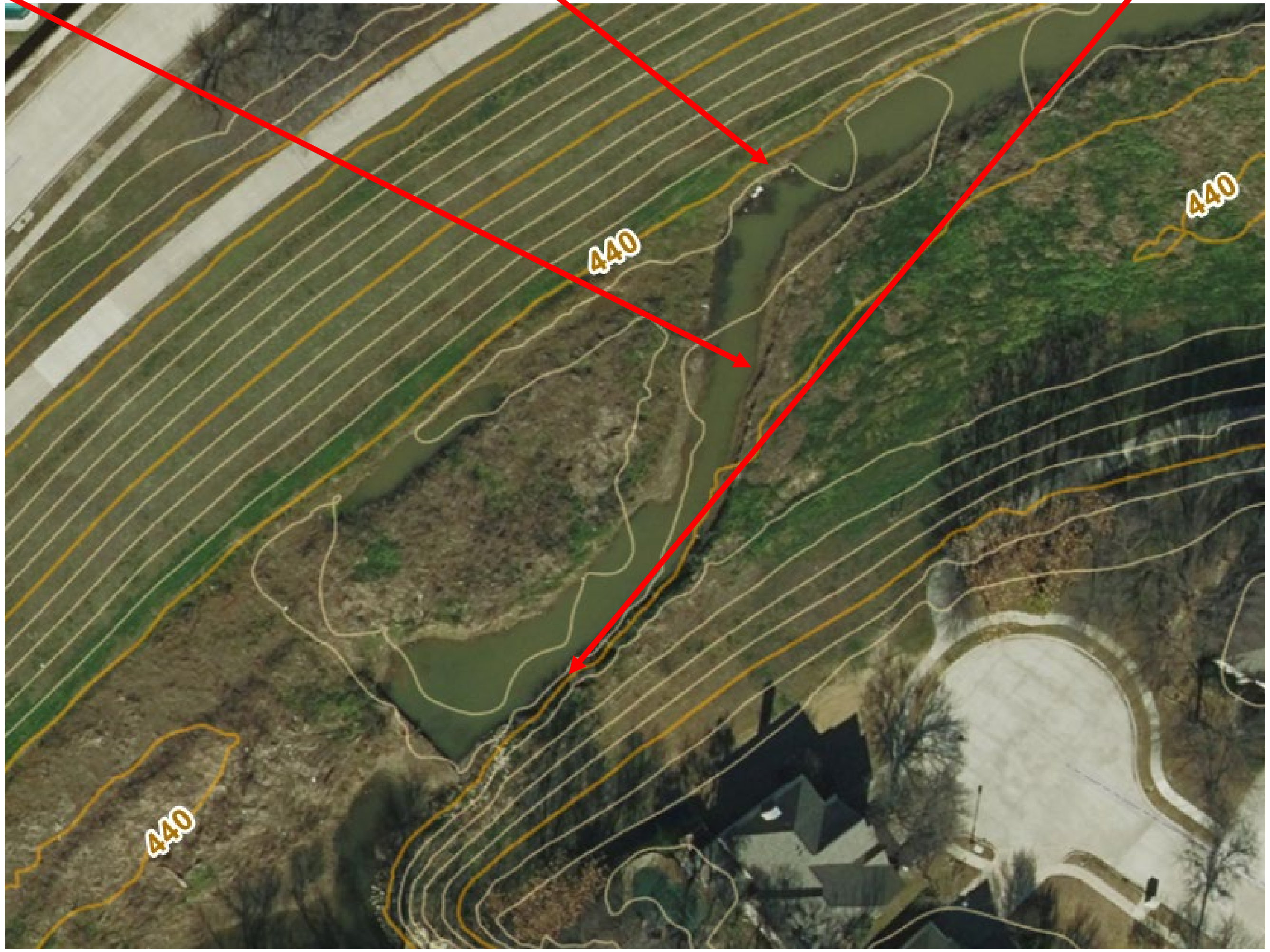
$$E = K_d(T_e - T_c)$$

JET TEST ERODIBILITY: RESULTS

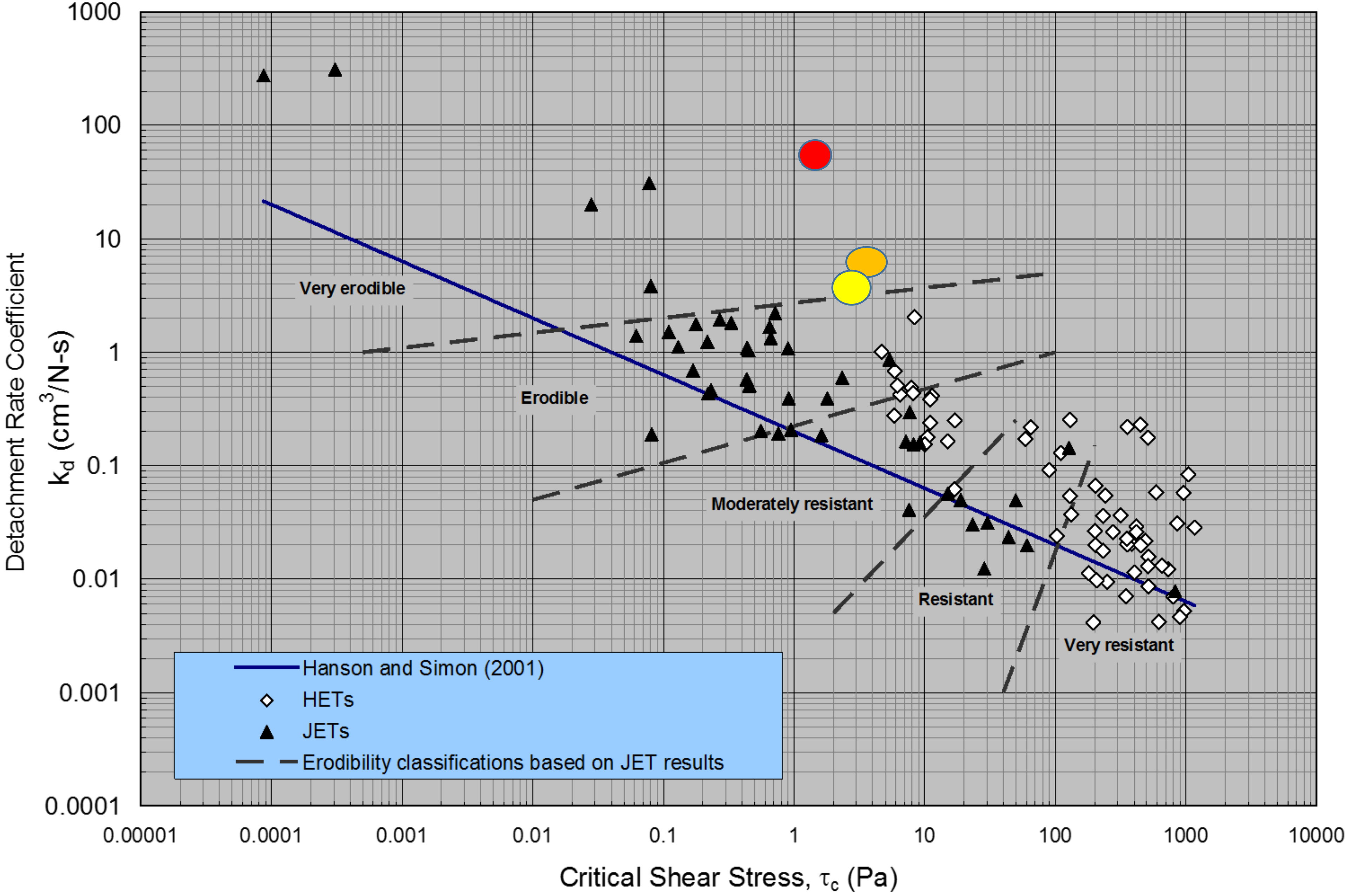
τ_c (Pa)	1.94
k_d (cm^3/N·s)	64.80

τ_c (Pa)	4.94
k_d (cm^3/N·s)	8.43

τ_c (Pa)	6.22
k_d (cm^3/N·s)	3.20

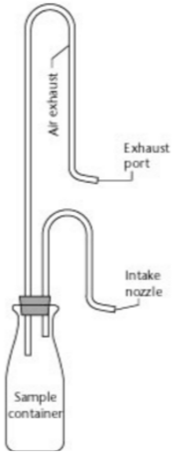


Channel: Highly Erodible

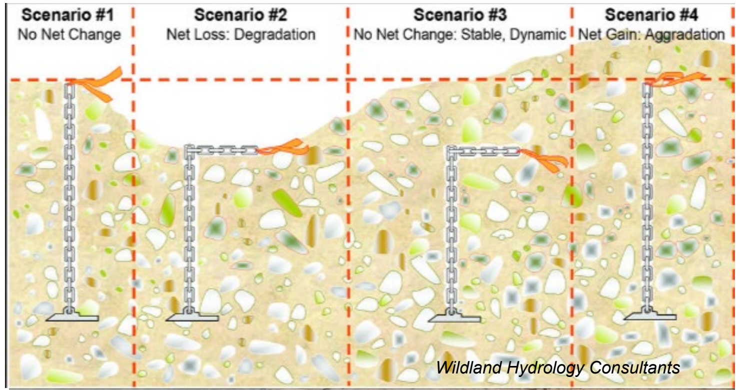


1000
100
10
1
0.1
0.01
0.001
0.0001
Detachment Rate Coefficient
k$_d$ (cm^3/N-s)
0.00001
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
Critical Shear Stress, τ_c (Pa)
Very erodible
Erodible
Moderately resistant
Resistant
Very resistant
Hanson and Simon (2001)
HETs
JETs
Erodibility classifications based on JET results

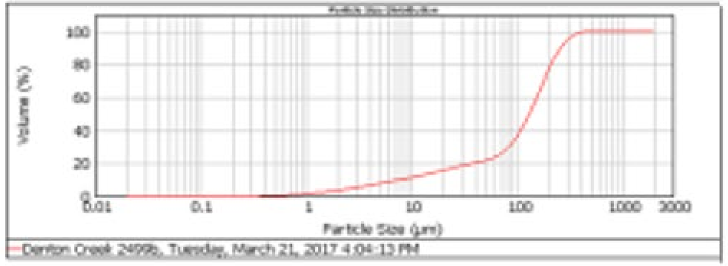
Looked at SEDIMENT: Fine Sand 0.176mm

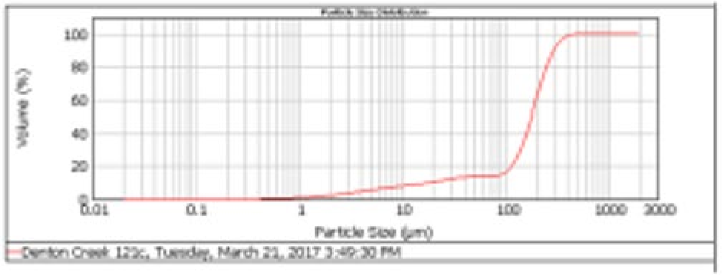


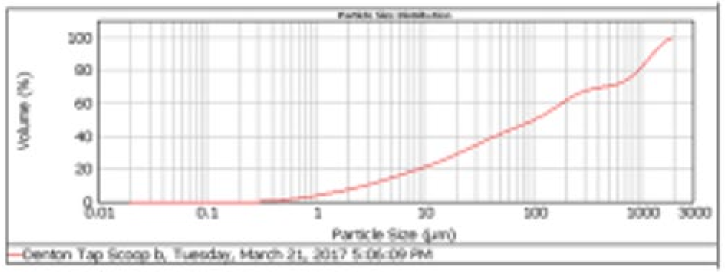
Rising stage sediment sampler and level recorder



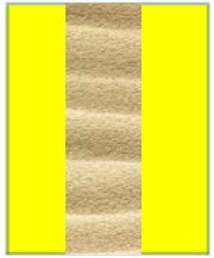
Scour Chains







Supply Reach

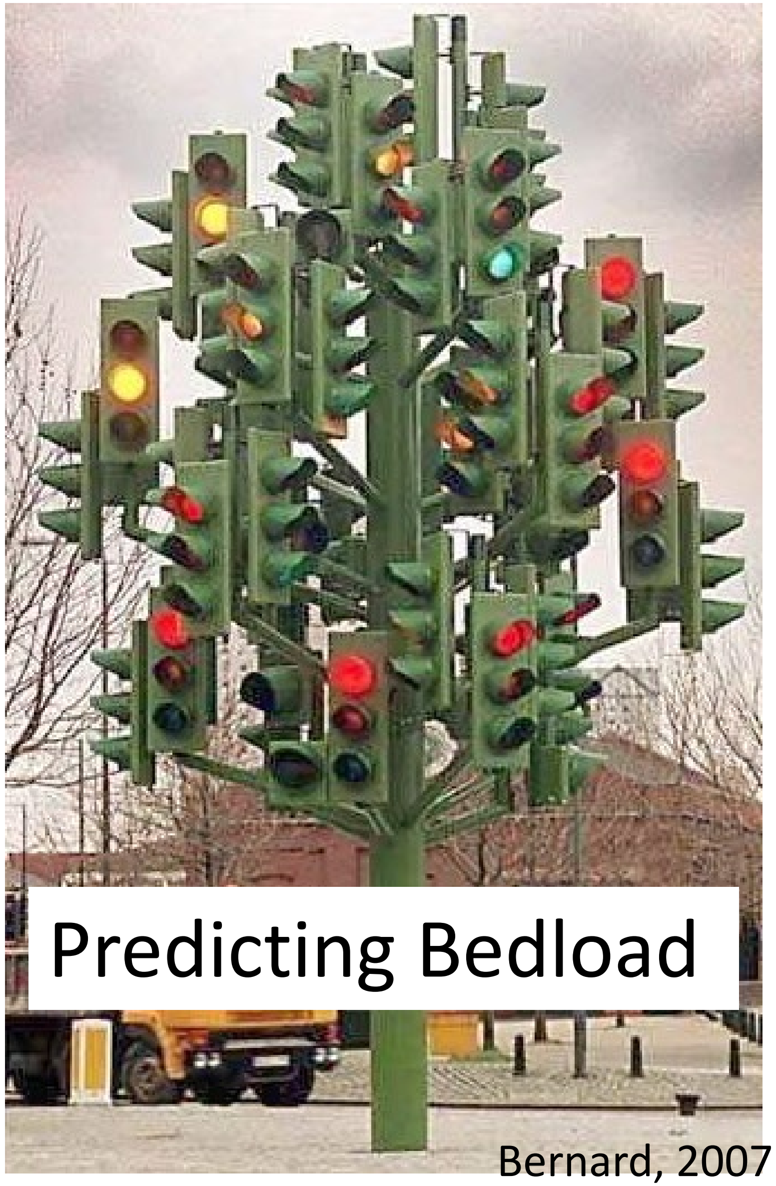


Levee Reach

Bedload Transport

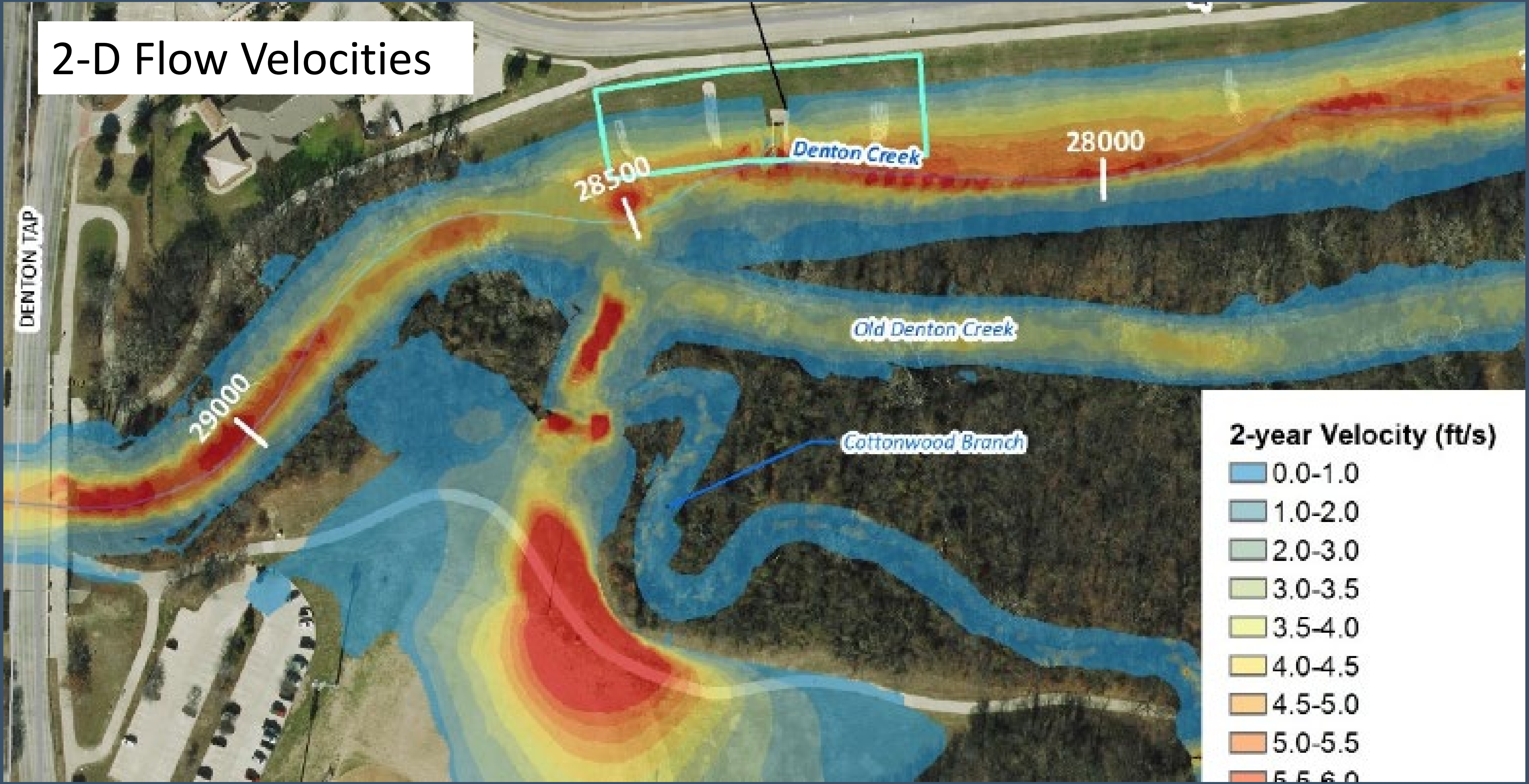
$$C = 7115 c_f \left(F_g - F_{g0}\right)^{1.978} S^{0.6601} \left(\frac{r}{D_{50}}\right)^{-0.3301}$$

CSR Uses Brownlie Equation (1981)



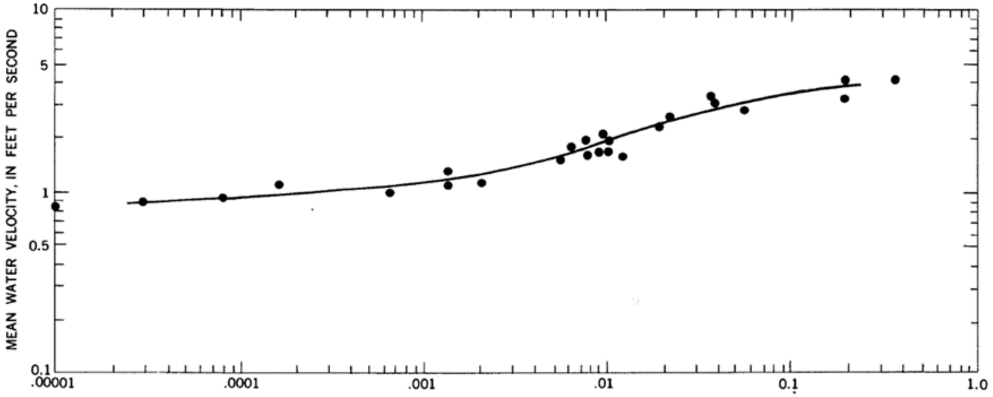
Bernard, 2007

2-D Flow Velocities



Scaled Sand Movement in Levee District

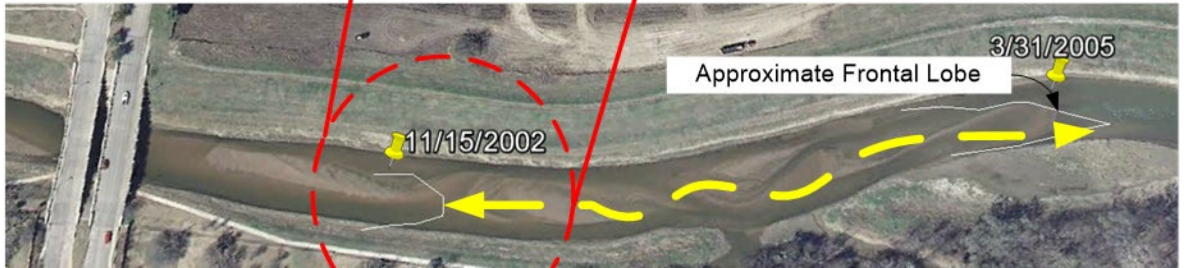
Literature Rates Support Assessment



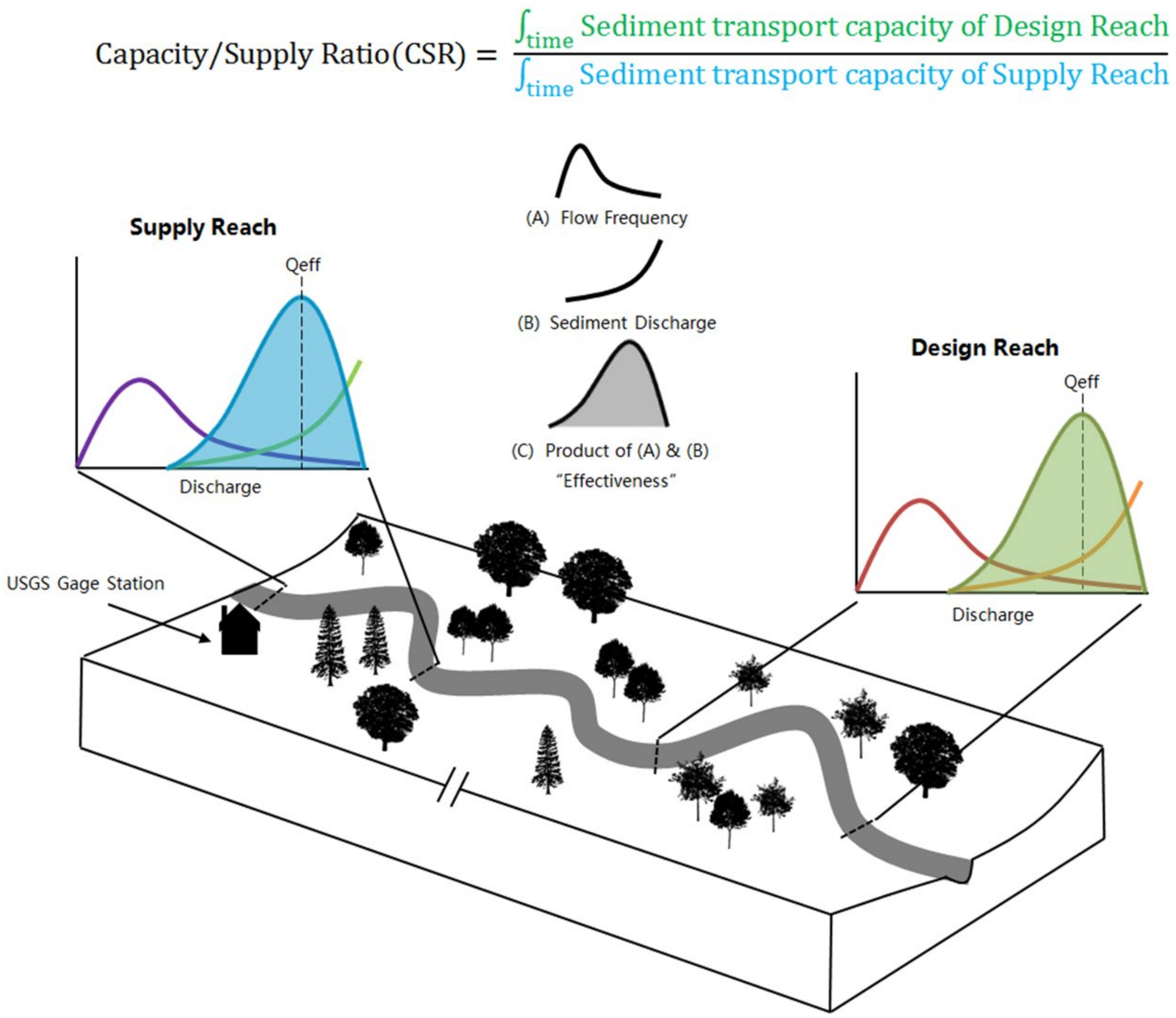
Mean Water Velocity and Mean Sand Speed 0.19mm (Leopold, 1963)

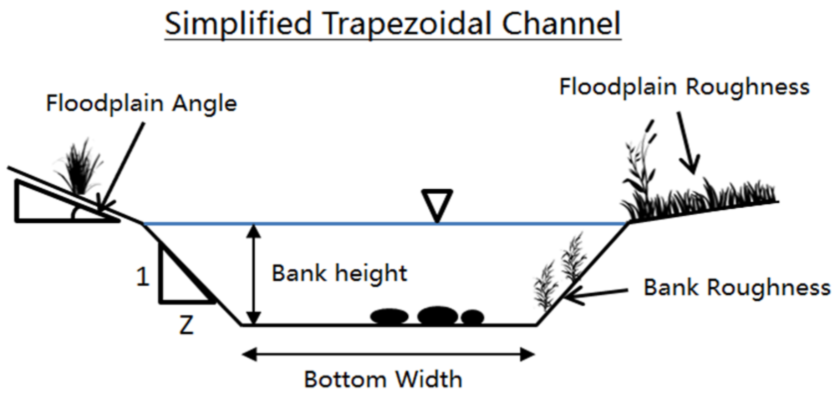
Mean Movement= 1.56 ft/day.
Std Dev. = 1.15
Minimum=0.47 ft/day
Maximum= 3.375 ft/day

Infers: Approximately 8 years to Fill from MacArthur to Old Denton



CSR Uses Brownlie Equation (1981)





water
MDPI

Article

Full Spectrum Analytical Channel Design with the Capacity/Supply Ratio (CSR)

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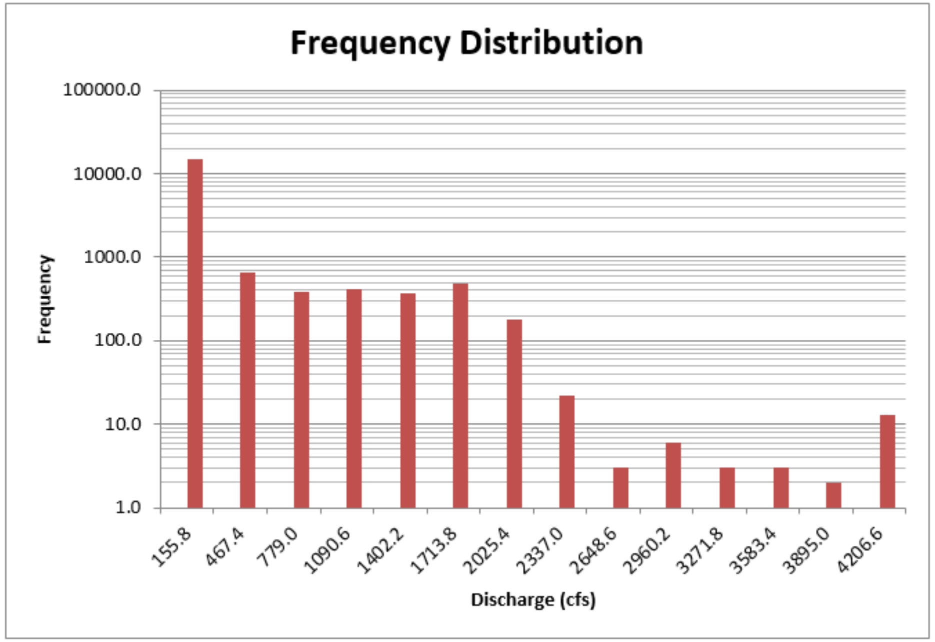
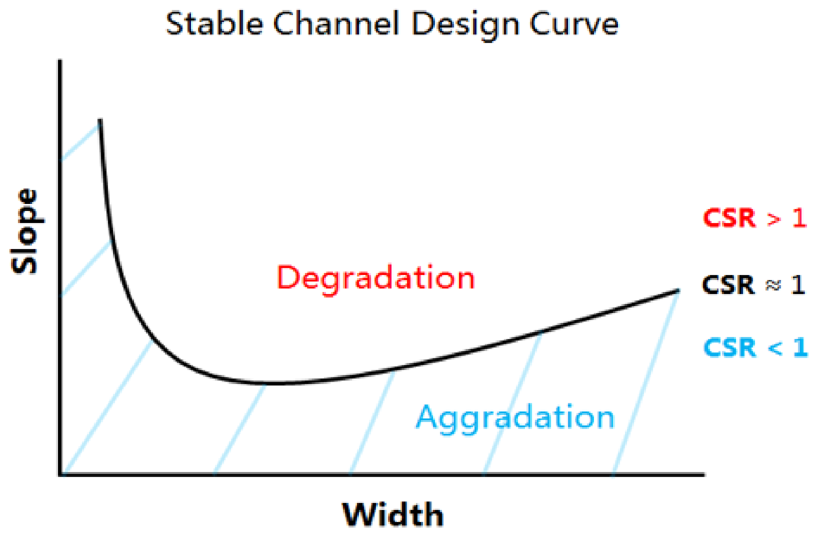
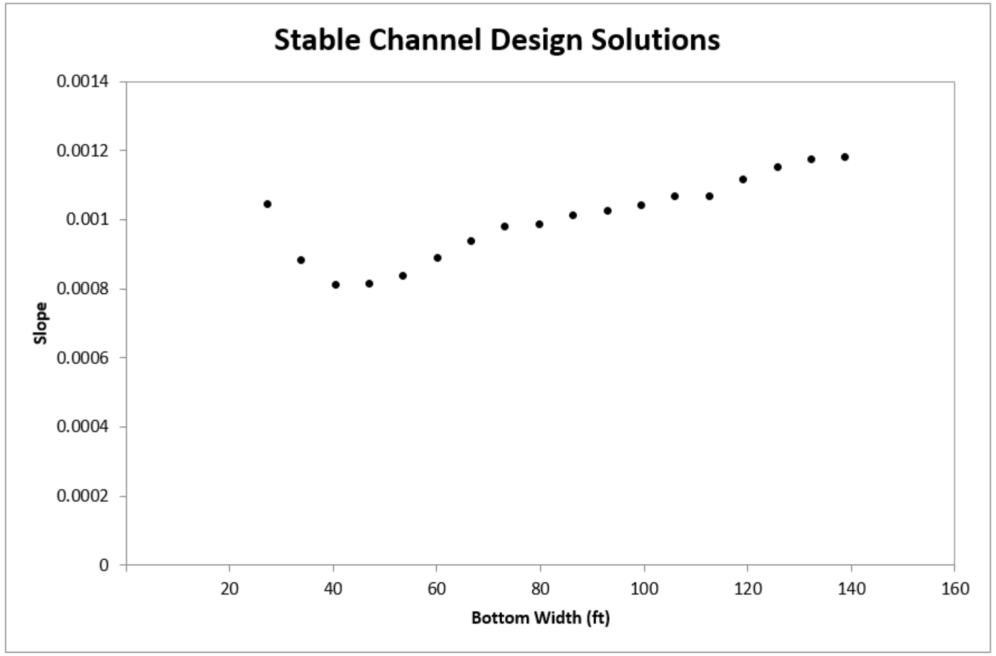
2. College of Engineering, University of Georgia, 507 Driftmier Engineering Center, Athens, GA 30602, USA

* Correspondence: bbledsoe@uga.edu; Tel.: +1-706-542-7249

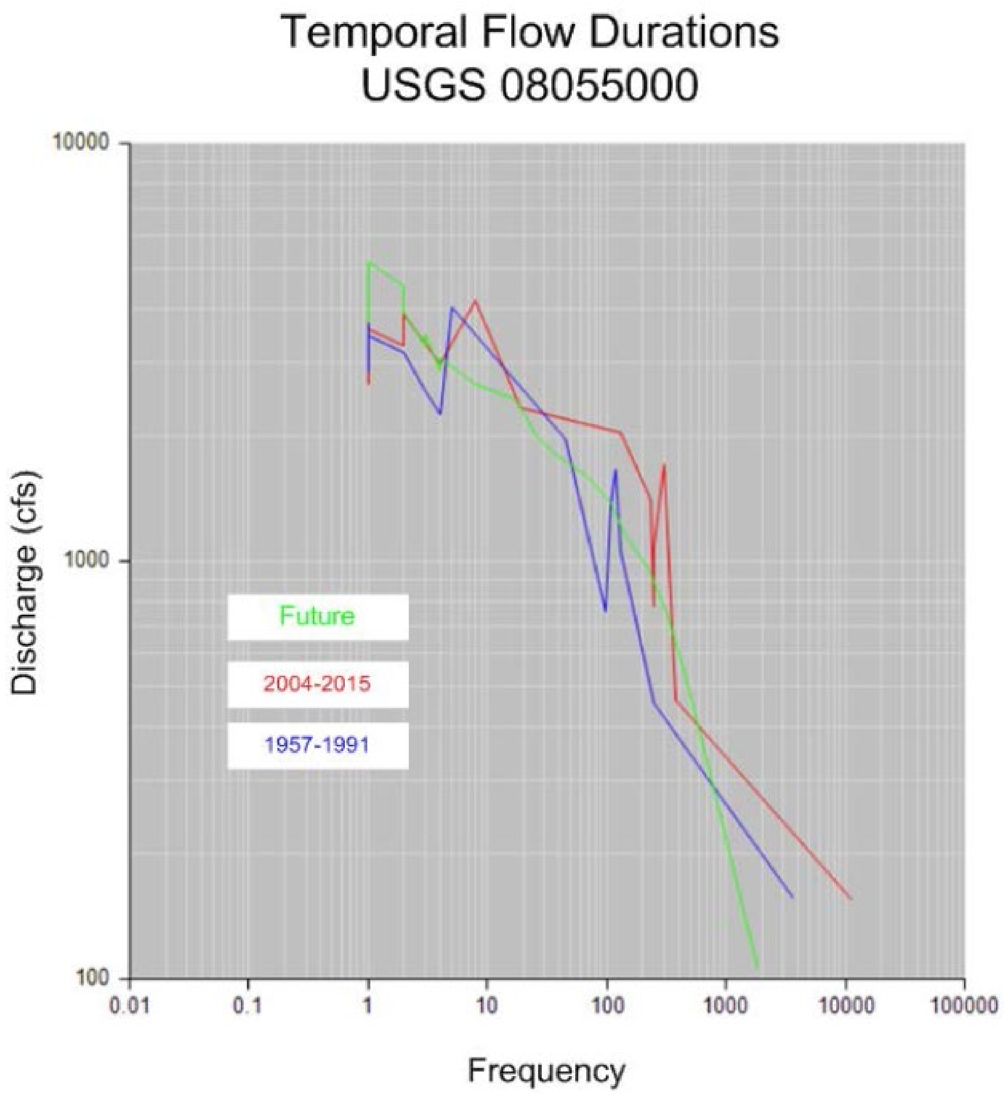


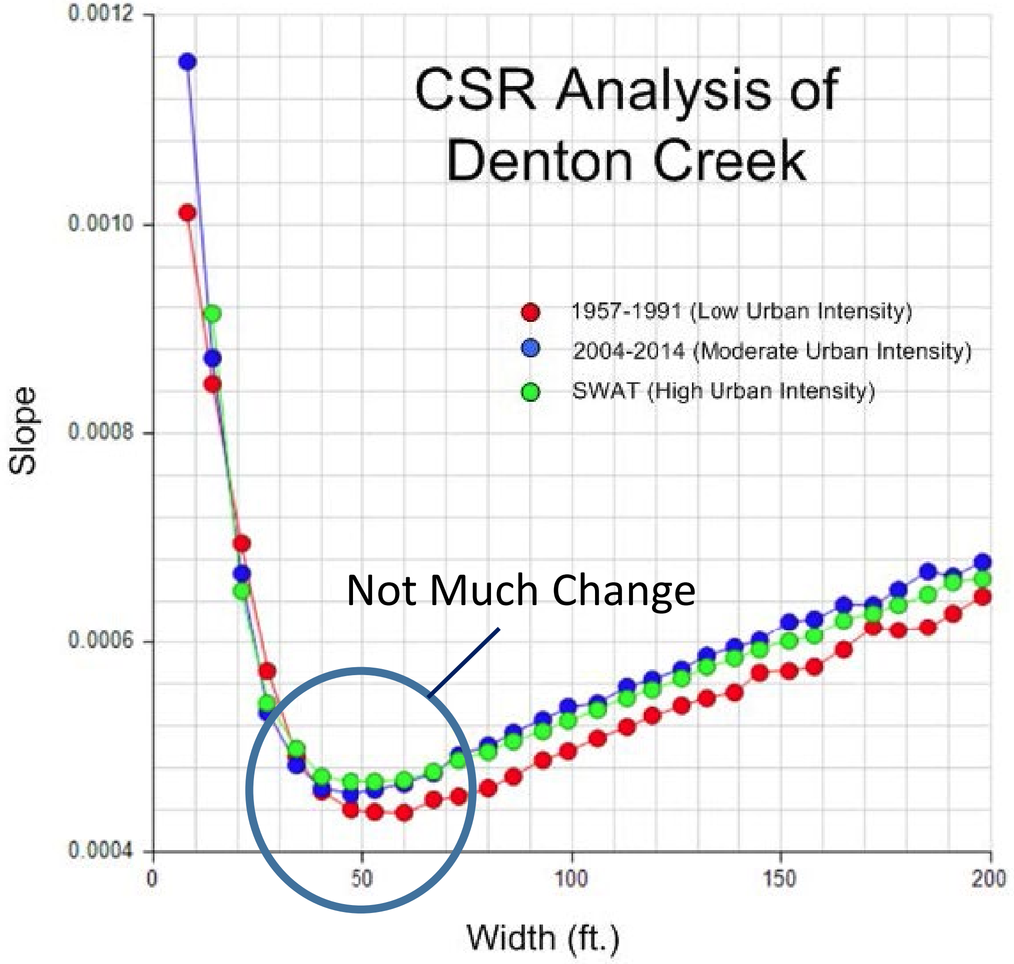


Summary from Supply Reach				
Discharge (cfs)	Probabilty	Qs (ppm)	Qs (tons/day)	Effectiveness
155.8	0.8483	693.7	291.8	247.54
467.4	0.0367	1239.1	1563.7	57.45
779.0	0.0215	1547.9	3255.8	69.95
1090.6	0.0232	4226.9	12446.7	289.05
1402.2	0.0204	4519.5	17110.8	349.38
1713.8	0.0275	4832.3	22360.6	615.87
2025.4	0.0102	5102.5	27903.8	284.88
2337.0	0.0012	5357.1	33802.9	41.72
2648.6	0.0002	5527.7	39530.2	6.65
2960.2	0.0003	5714.6	45674.8	15.37
3271.8	0.0002	5844.9	51633.7	8.69
3583.4	0.0002	5967.2	57734.2	9.72
3895.0	0.0001	6086.1	64004.9	7.18
4206.6	0.0007	6205.1	70476.6	51.39

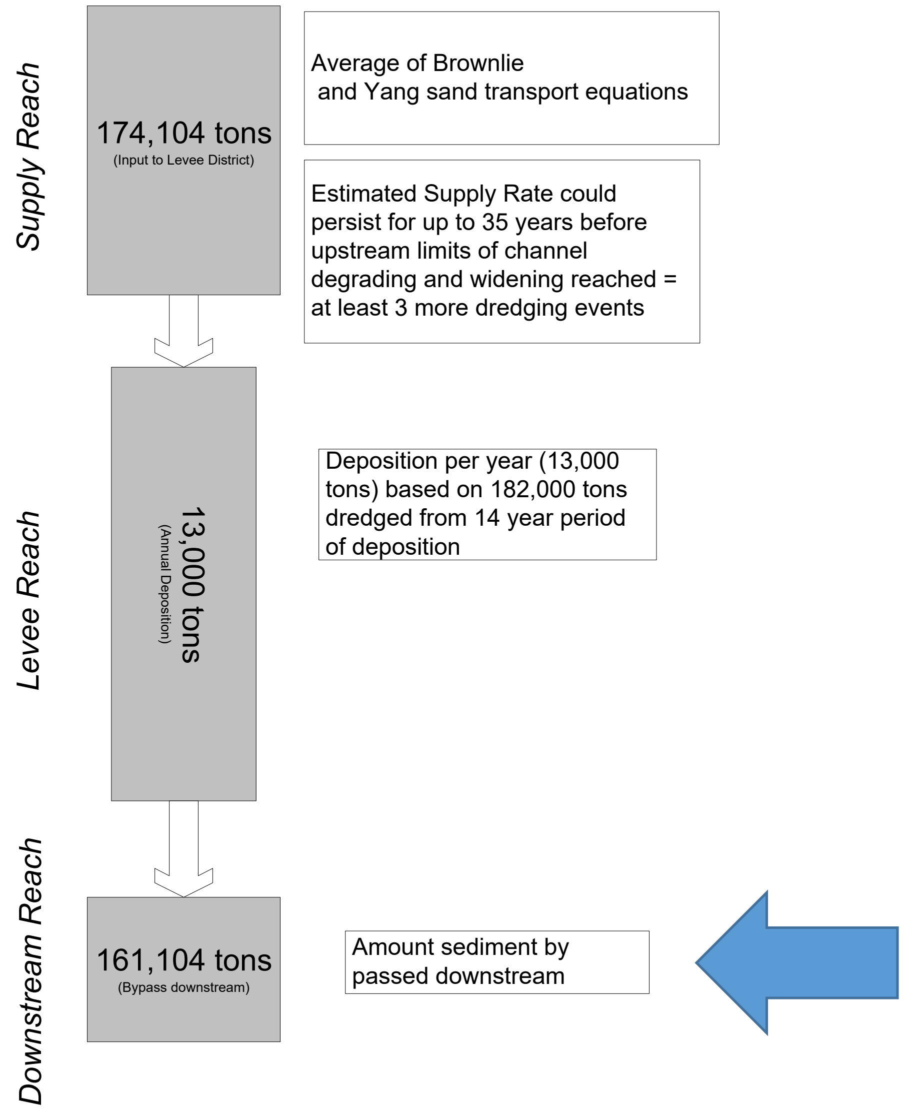


CSR: SWAT *Flow Duration and Channel Dimensions*





Annual Sediment Budget for DCLID #1



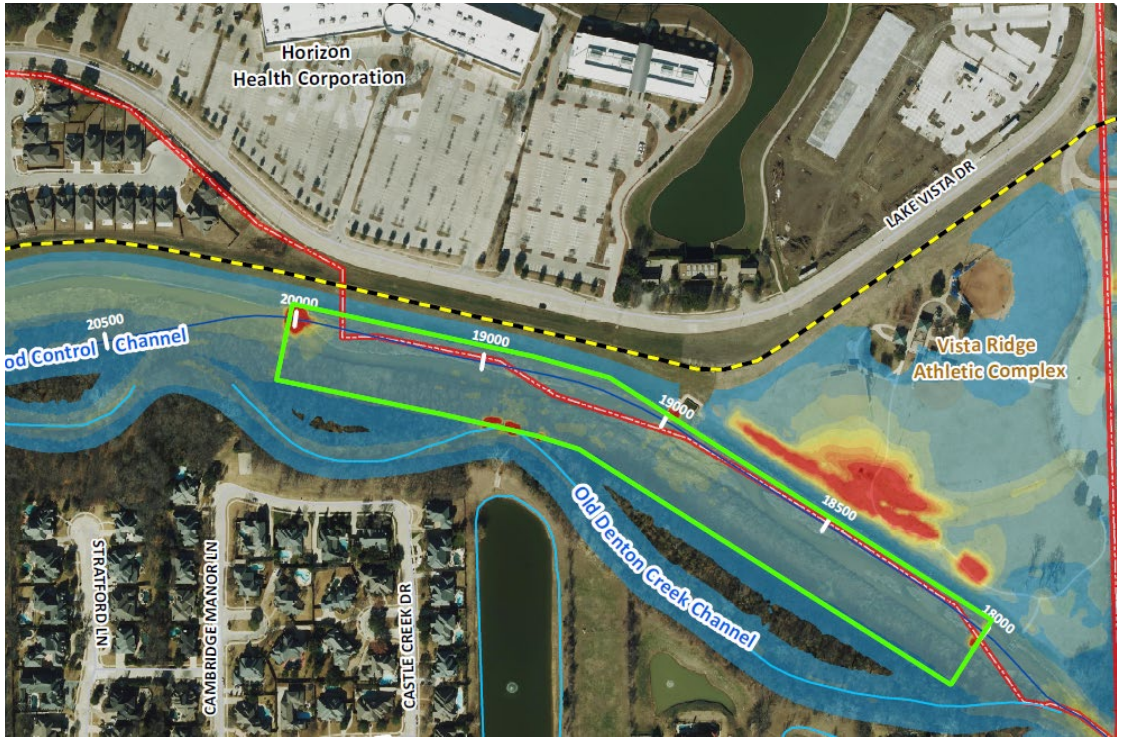
Options Being Considered

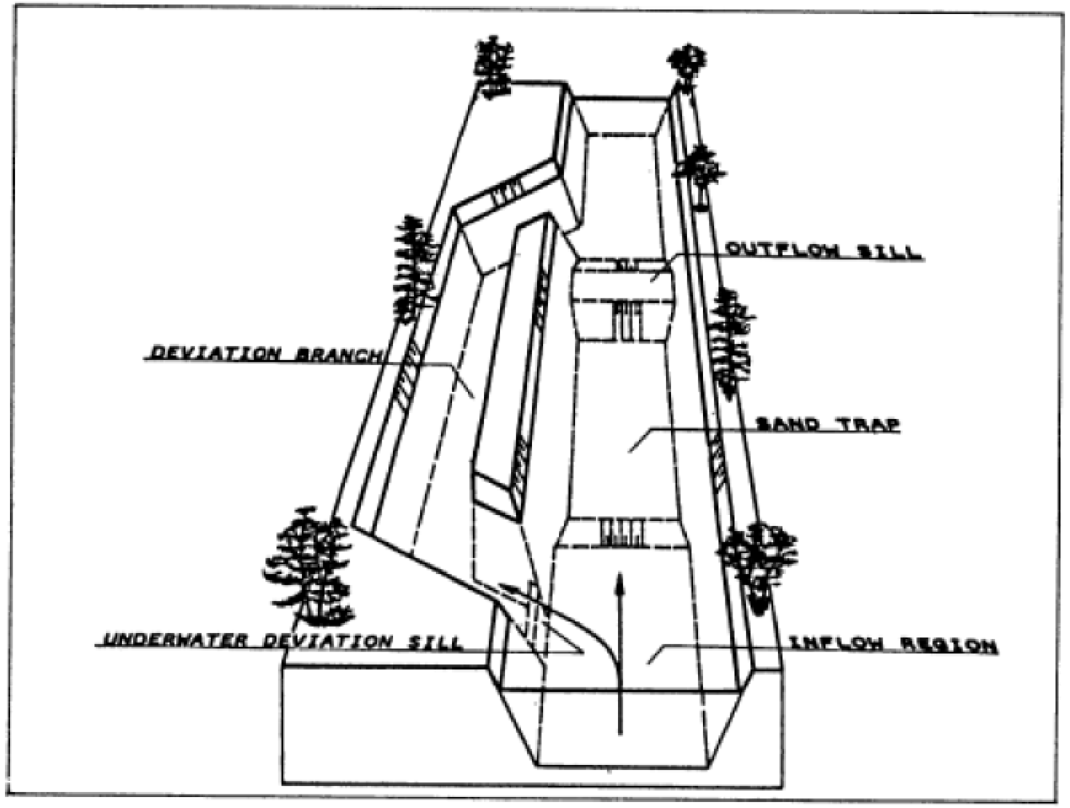
1. Sand Trap (.75)

2. Restablish old channel to route bed material (.25)

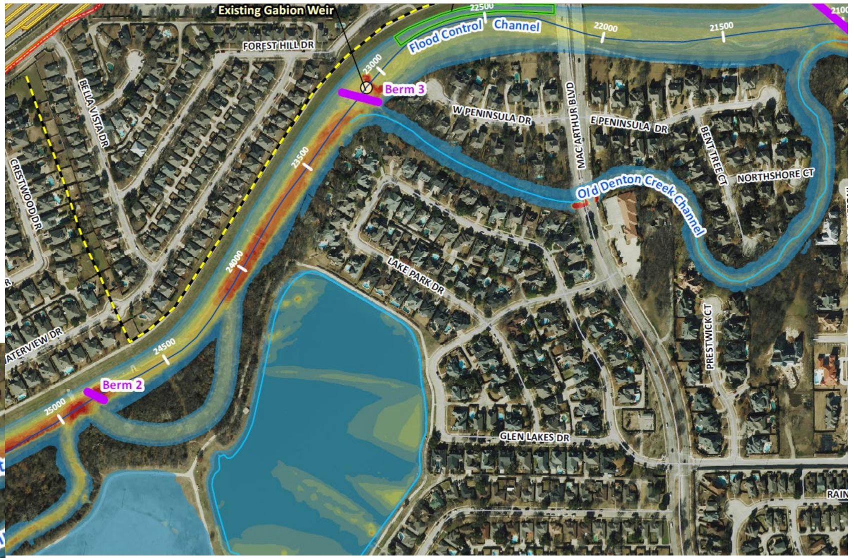
3. Dredging until upstream stabilizes (1)

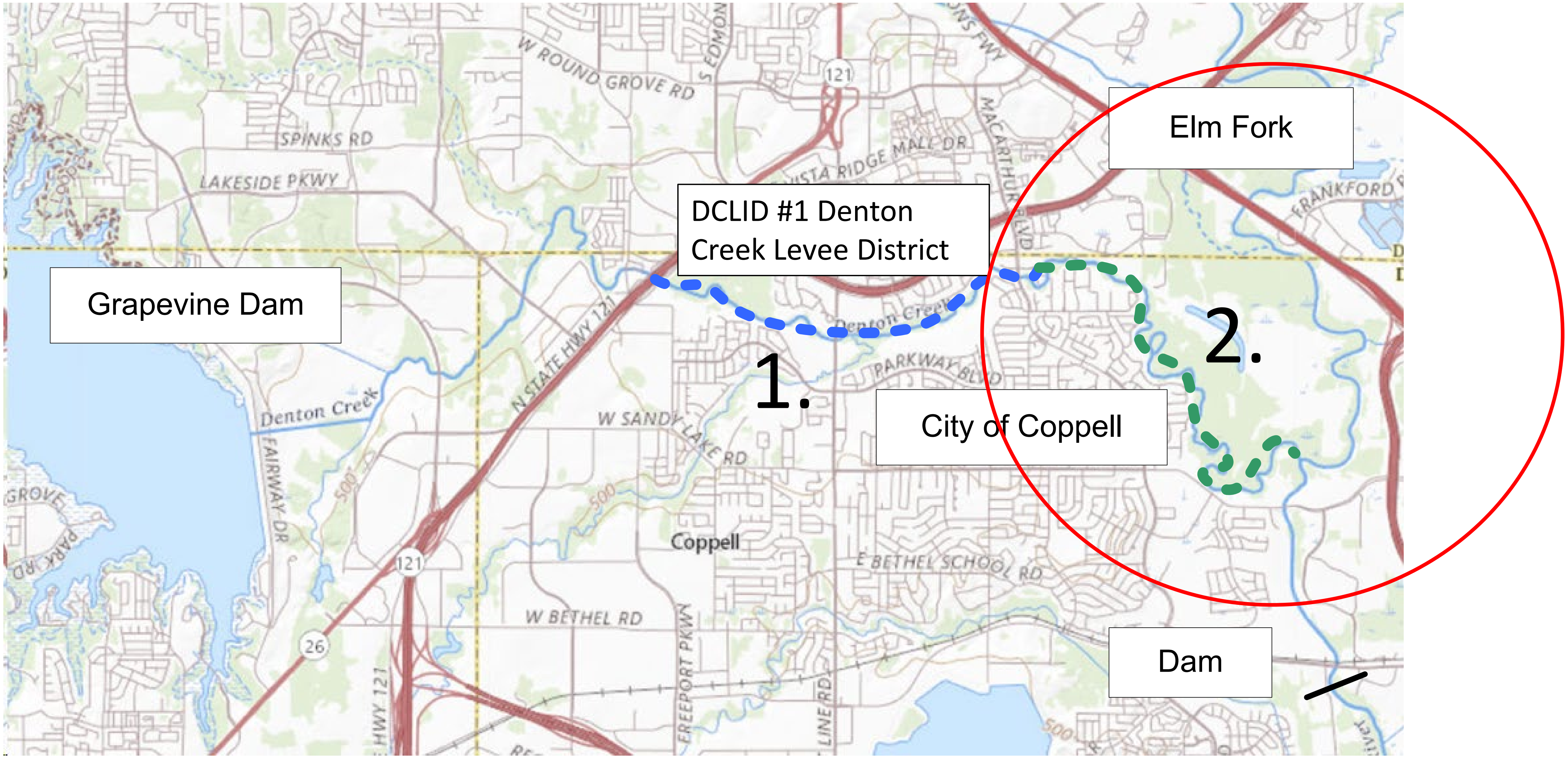
Sediment Trap



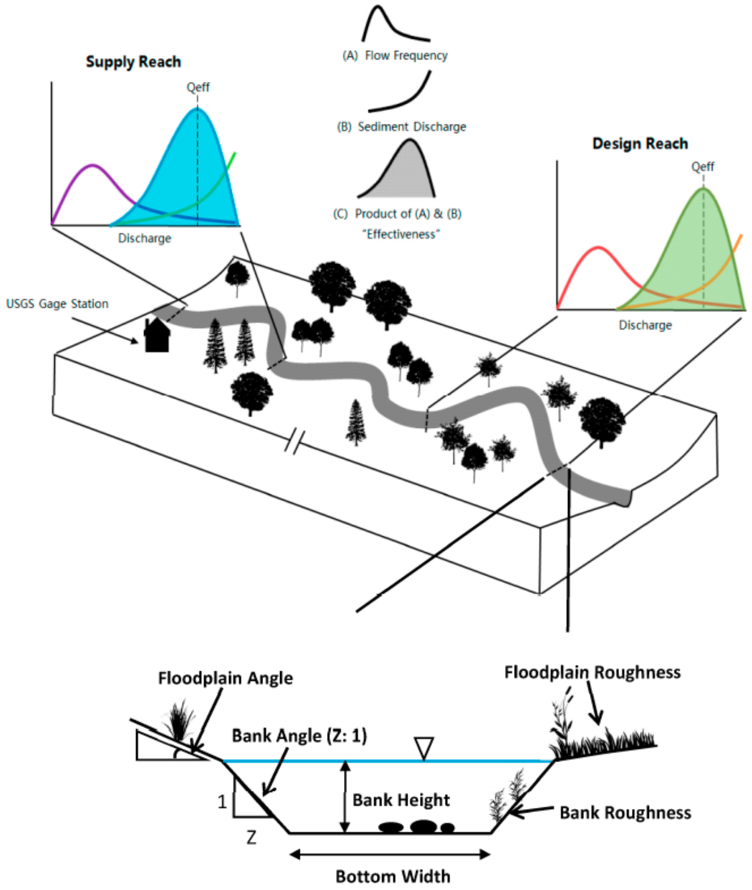


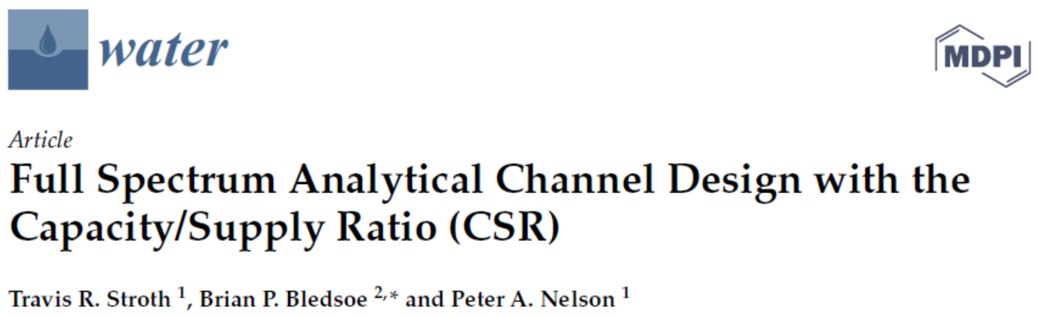
Reattach Old Channel to Route Sand Bedload



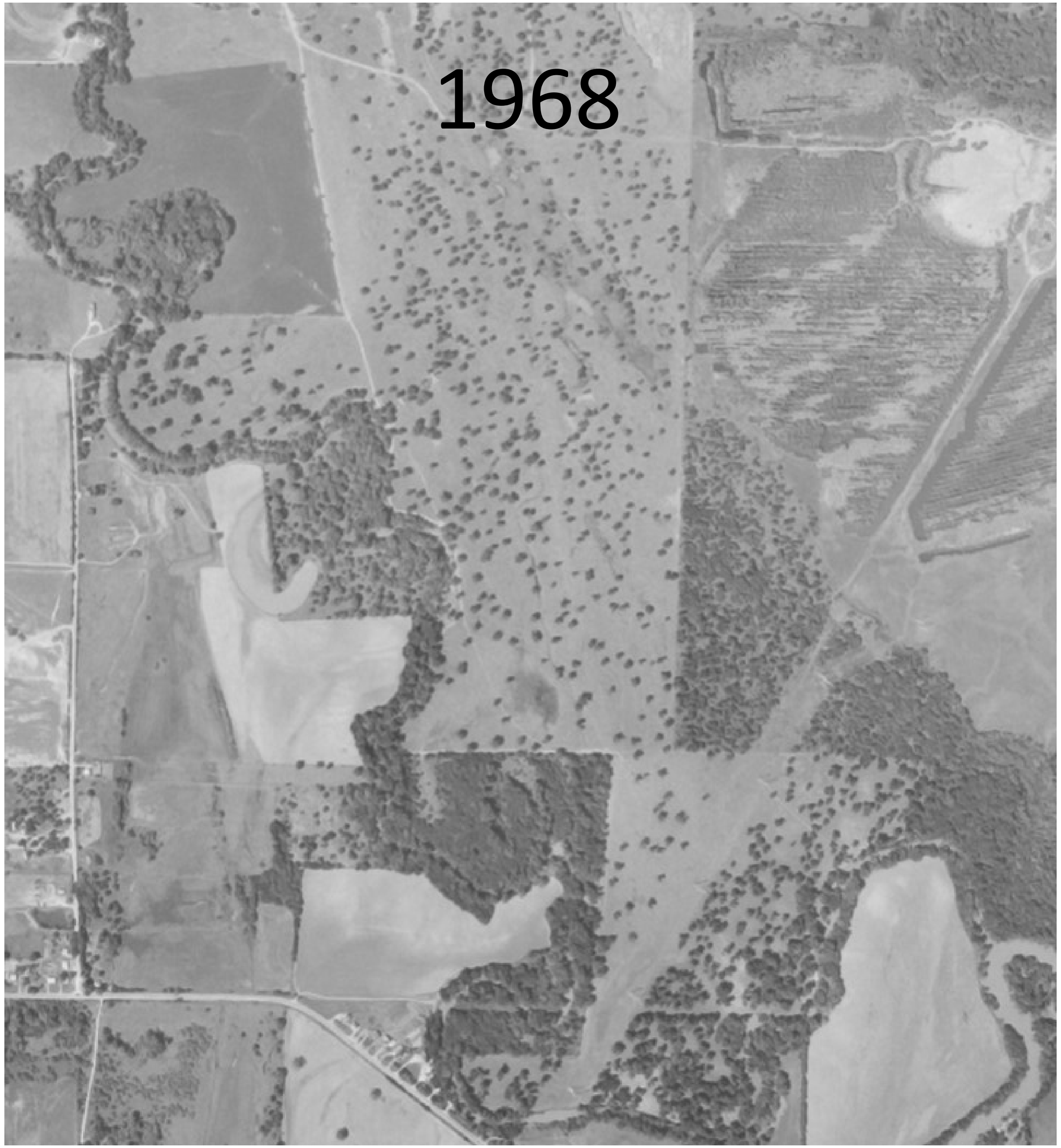


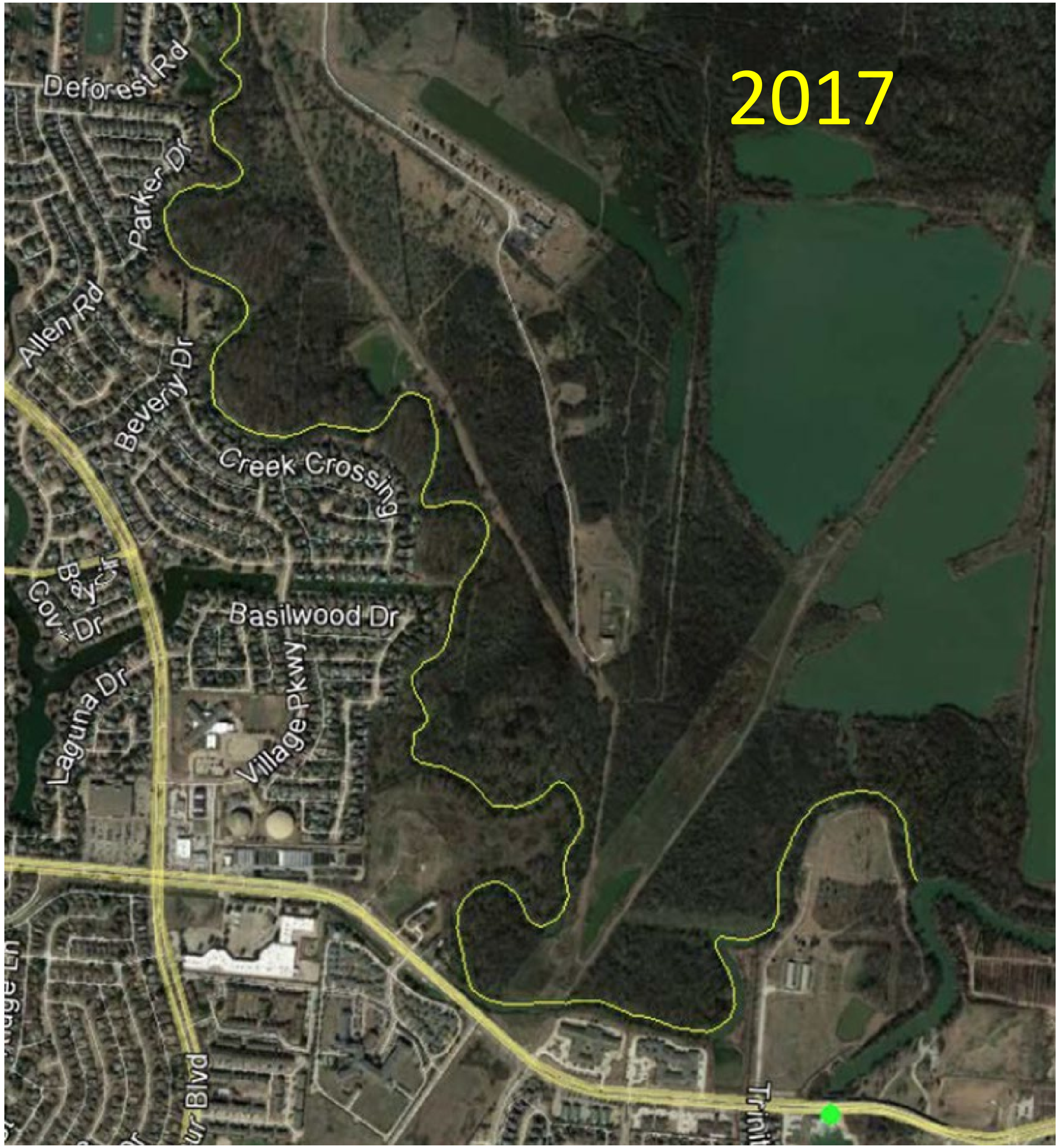
Elm Fork
DCLID #1 Denton
Creek Levee District
Grapevine Dam
2.
1.
City of Coppell
Dam
Coppell
Denton Creek
W ROUND GROVE RD
SPINKS RD
LAKESIDE PKWY
N STATE HWY 121
W SANDY LAKE RD
PARKWAY BLVD
E BETHEL SCHOOL RD
W BETHEL RD
FAIRWAY DR
FRANKFORD
121
26



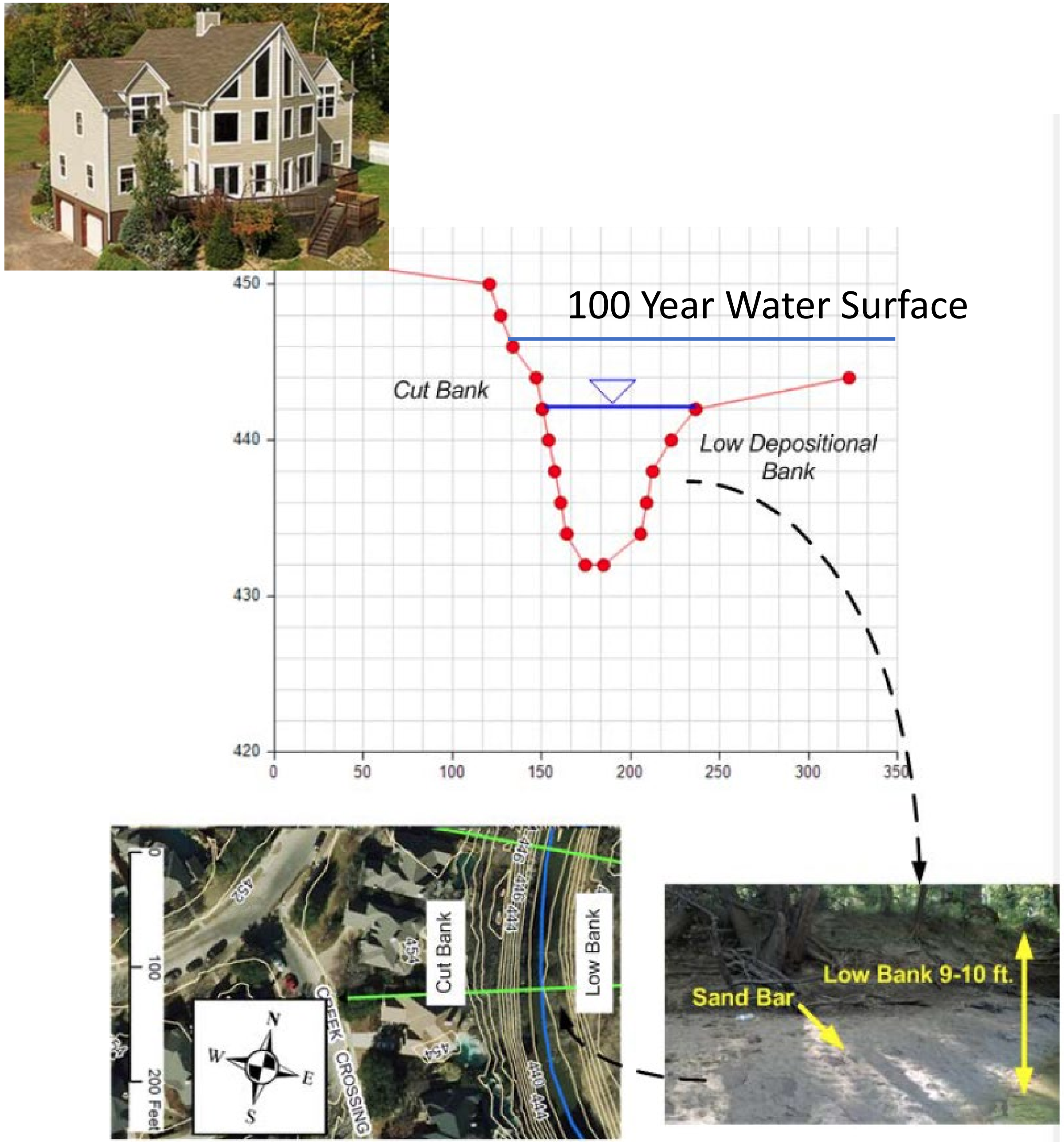


REM: Sediment Trapped Upstream:


1968


2017
Deforest Rd
Parker Dr
Allen Rd
Beverly Dr
Creek Crossing
Basilwood Dr
Village Pkwy
Laguna Dr

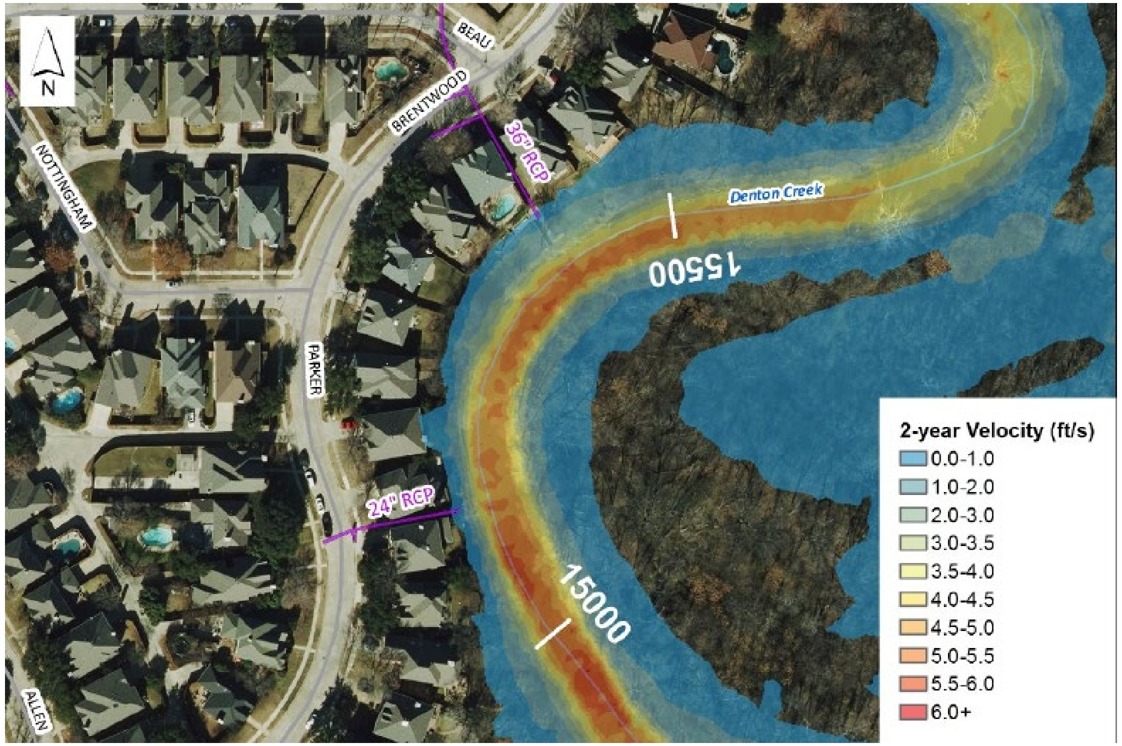
Homes Built on Cutbank

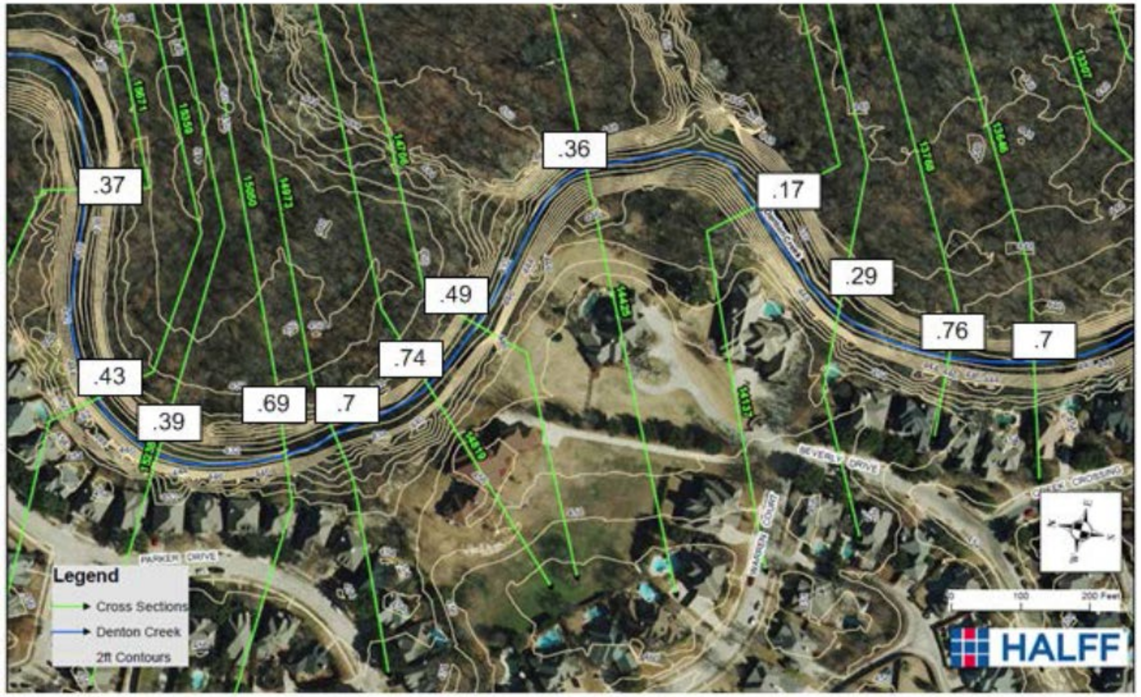


Problems

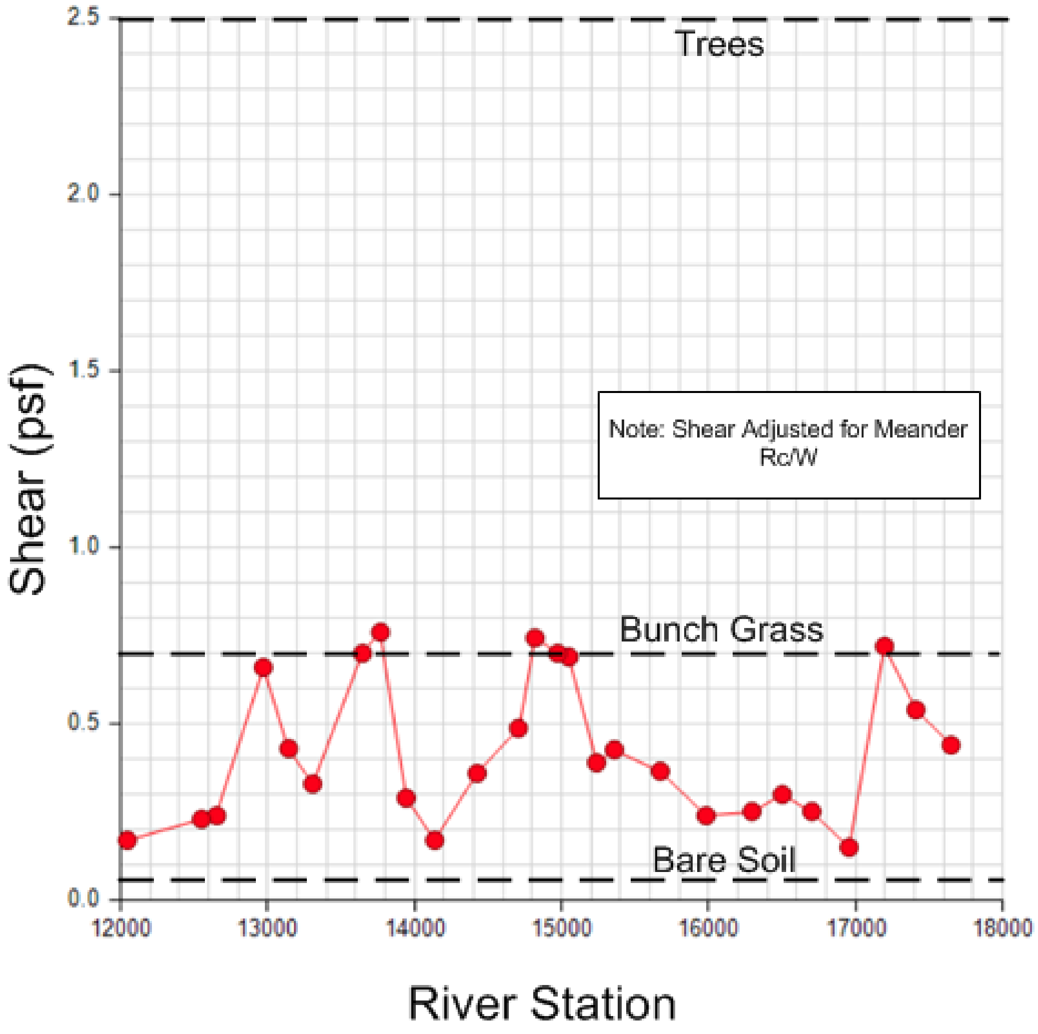
Solutions: “Castle Approach”

2-D Flow and Shear

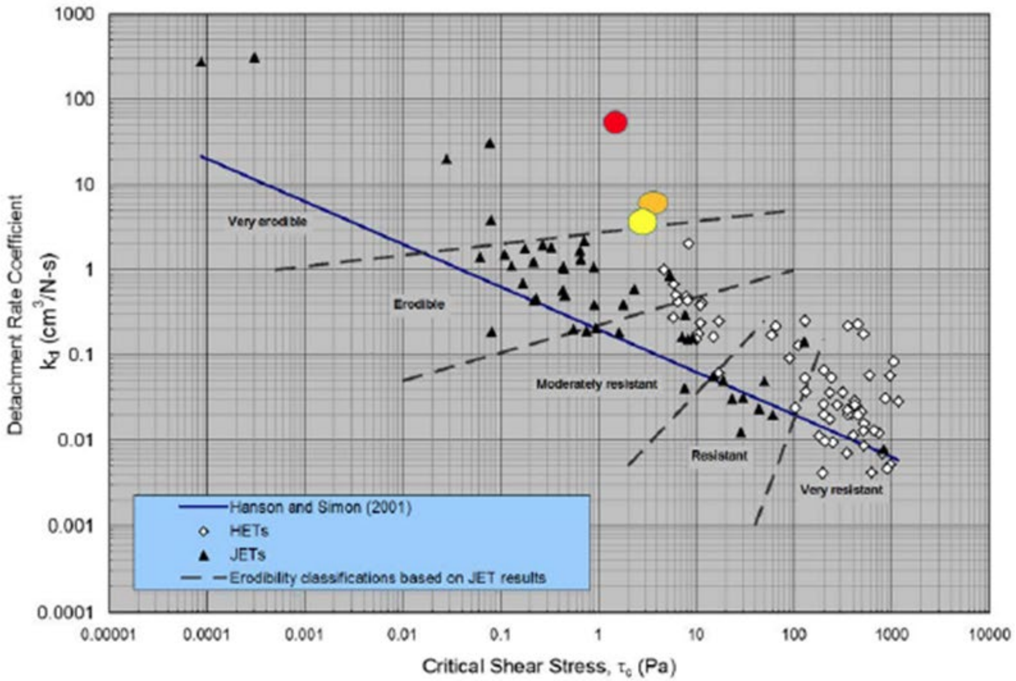




Shear

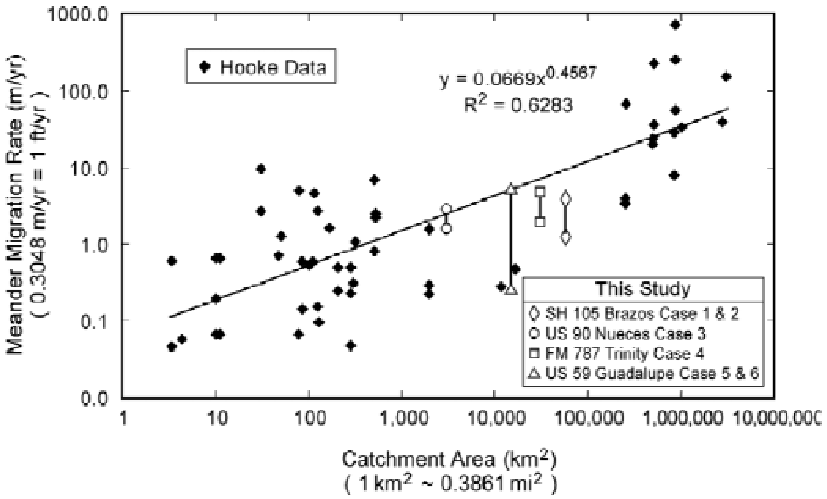


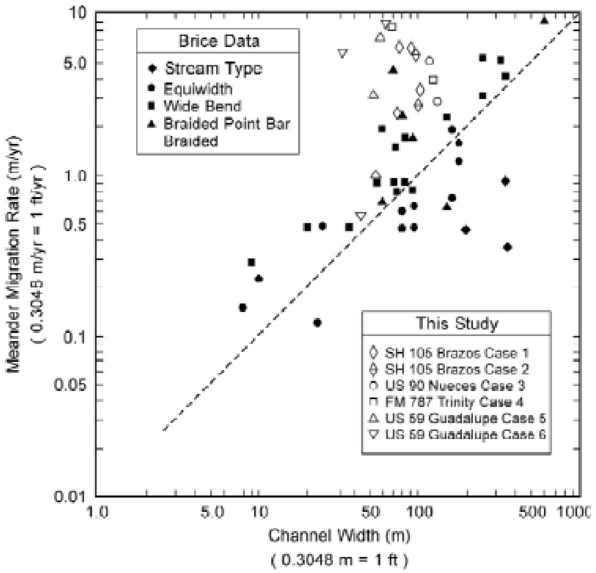
Soil

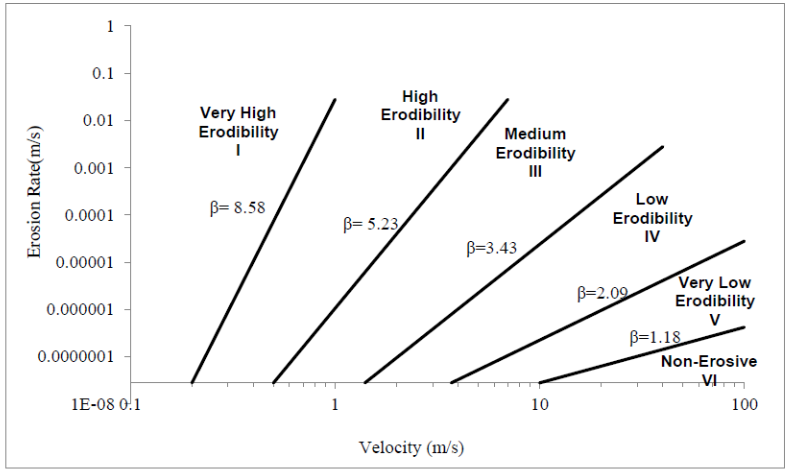


Very Erodible When Cover Removed

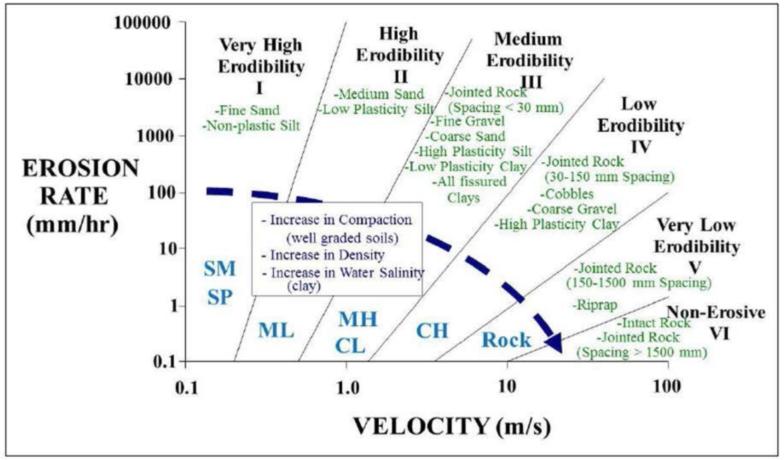
Briaud (2009) Channel Meander Rates Literature





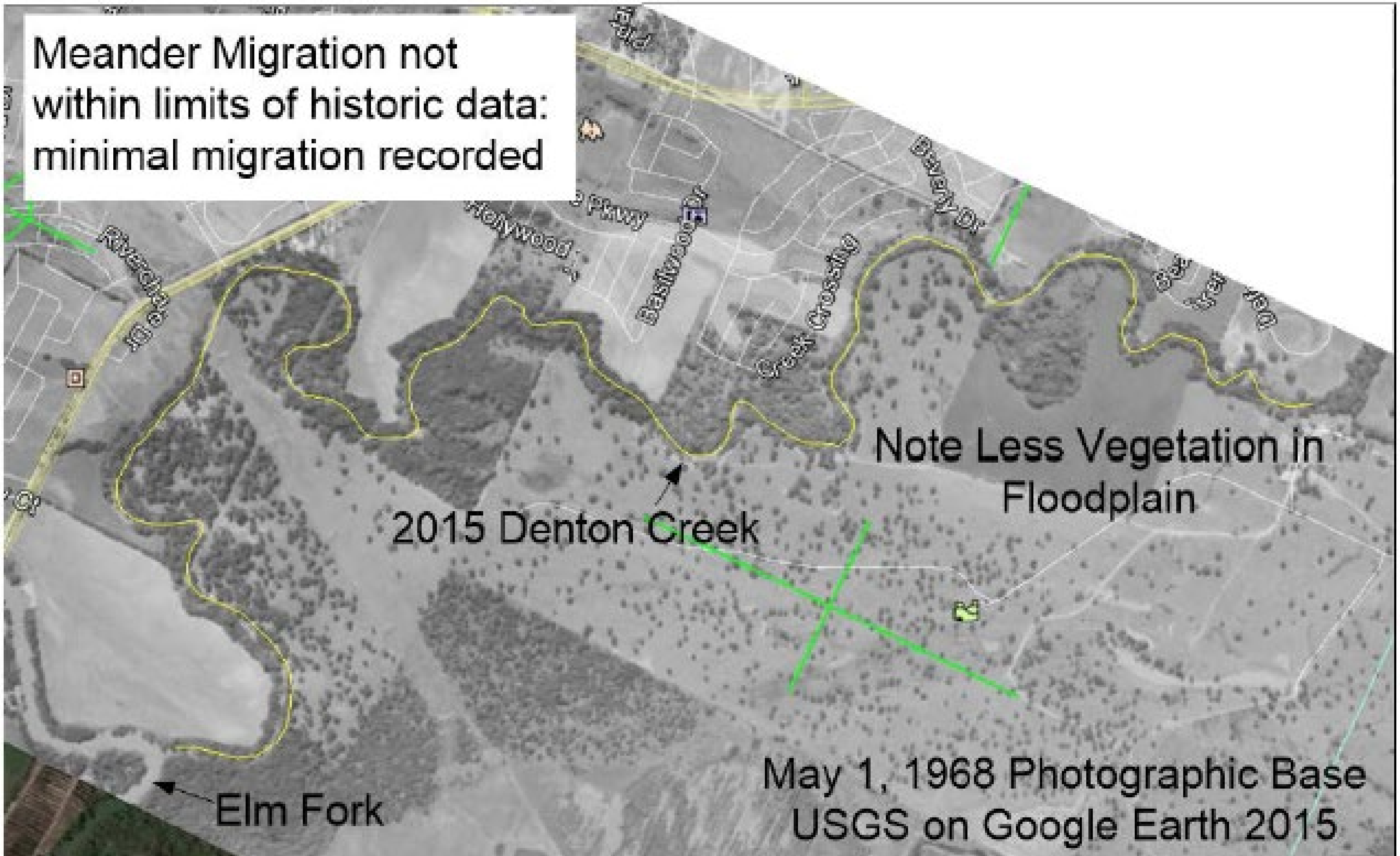


$$M = \alpha' \left(\frac{v}{v_c} \right)^{\beta} \times v_c \times \Delta t$$



<2 to 10 ft./yr. Lateral Erosion ~SWAT Flow

47 Years of River History: 1968-2015



Meyer-Peter and Mueller Limiting Slope

Note: fill in values that are underlined, calculated results are in ***bold red***

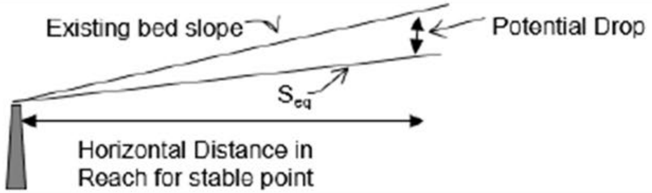
Note: The equilibrium slope of a channel is defined as the slope at which the sediment transport capacity of the reach is in balance with the sediment transported into the reach. If the sediment transport capacity were to exceed the sediment supply, channel bed degradation will occur until the channel bed slope is reduced so much that the boundary shear stress is less than what is needed to mobilize the bed material an armor layer forms. This new, lower slope may be called the equilibrium slope, S_{eq}.

conversion constant	K1=	0.19		
	D(50) =	0.18	mm	Note: sediment sample from riffle (typical)
	D(90) =	0.2	mm	
	Depth =	6	ft	
Manning's	n =	0.035		
Equilibrium slope	Seq =	**5.58E-05**		*Note: Review MPM applicability*

compare Sl to bed slope (energy slope). If less, there is a potential for degradation

Potential Drop

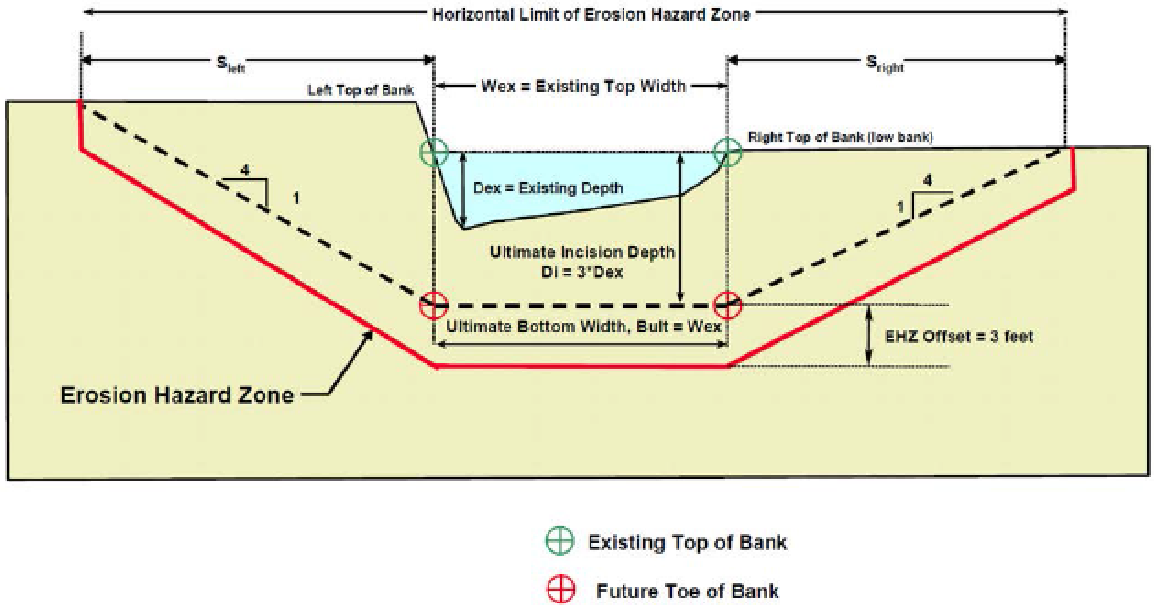
Existing Slope =	0.0006	
Horizontal Distance in Reach=	1000	ft
Amount of Drop in Reach	**0.54**	ft



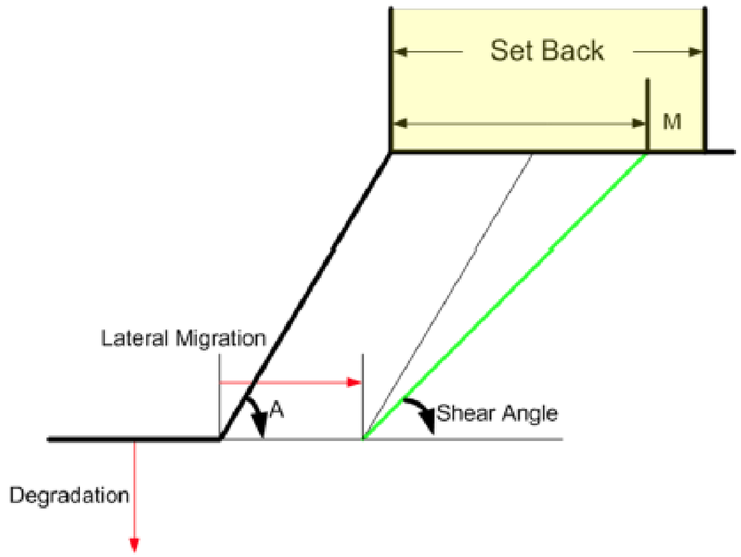
NDCSMC Nov, 2005

Potential Downcutting?

Erosion Hazard Zone: Homes Versus Erosion



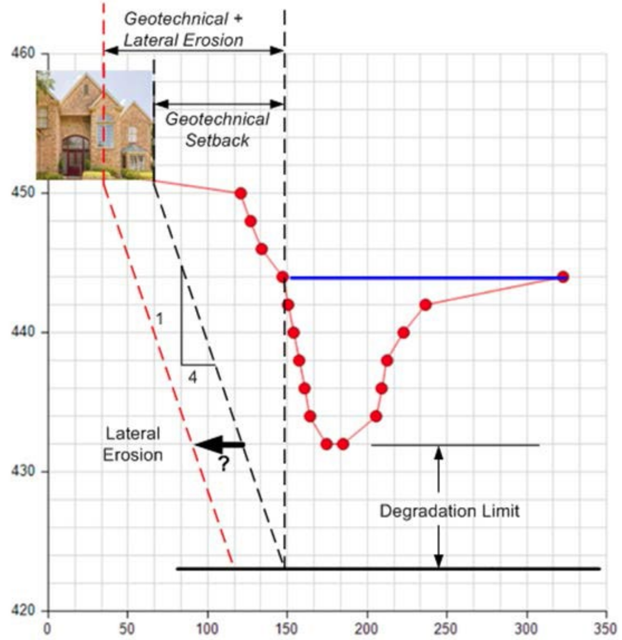
Calculation of Stream Danger Zone

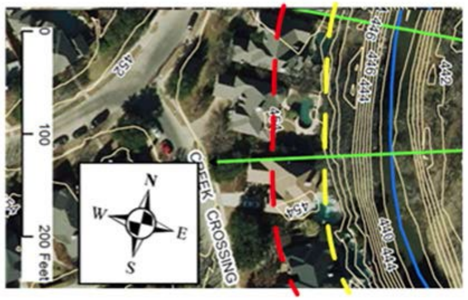


Set Back = Maintenance + Lateral Migration + ((Hs + Deg)/Tan SA)-(Hs+Deg)/Tan A))

Setbacks: EROSION HAZARD ZONE

Station	Austin	Method 2
17649	78.57834	78.84131
17410	78.41809	78.46707
17197	77.19443	77.53915
16956	76.66982	76.96215
16702	74.47691	75.45213
16501	72.43938	74.091
16294	69.70878	72.34154
15983	67.39179	70.69505
15671	65.23263	69.13416
15359	63.43347	67.77124
15238	62.57008	67.15158
15050	60.60084	65.84357
14973	60.35323	65.61522
14819	59.178	64.78457
14706	58.37202	64.20606
14425	57.00034	63.11534
14137	55.69342	62.05185
13942	54.90895	61.38701
13768	54.29018	60.83843
13646	53.70461	60.37036
13307	52.60668	59.36075
13144	52.29186	58.99249
12970	51.9931	58.6199
12654	51.34523	57.88533
12551	51.16102	57.66072
12046	49.18173	55.96771

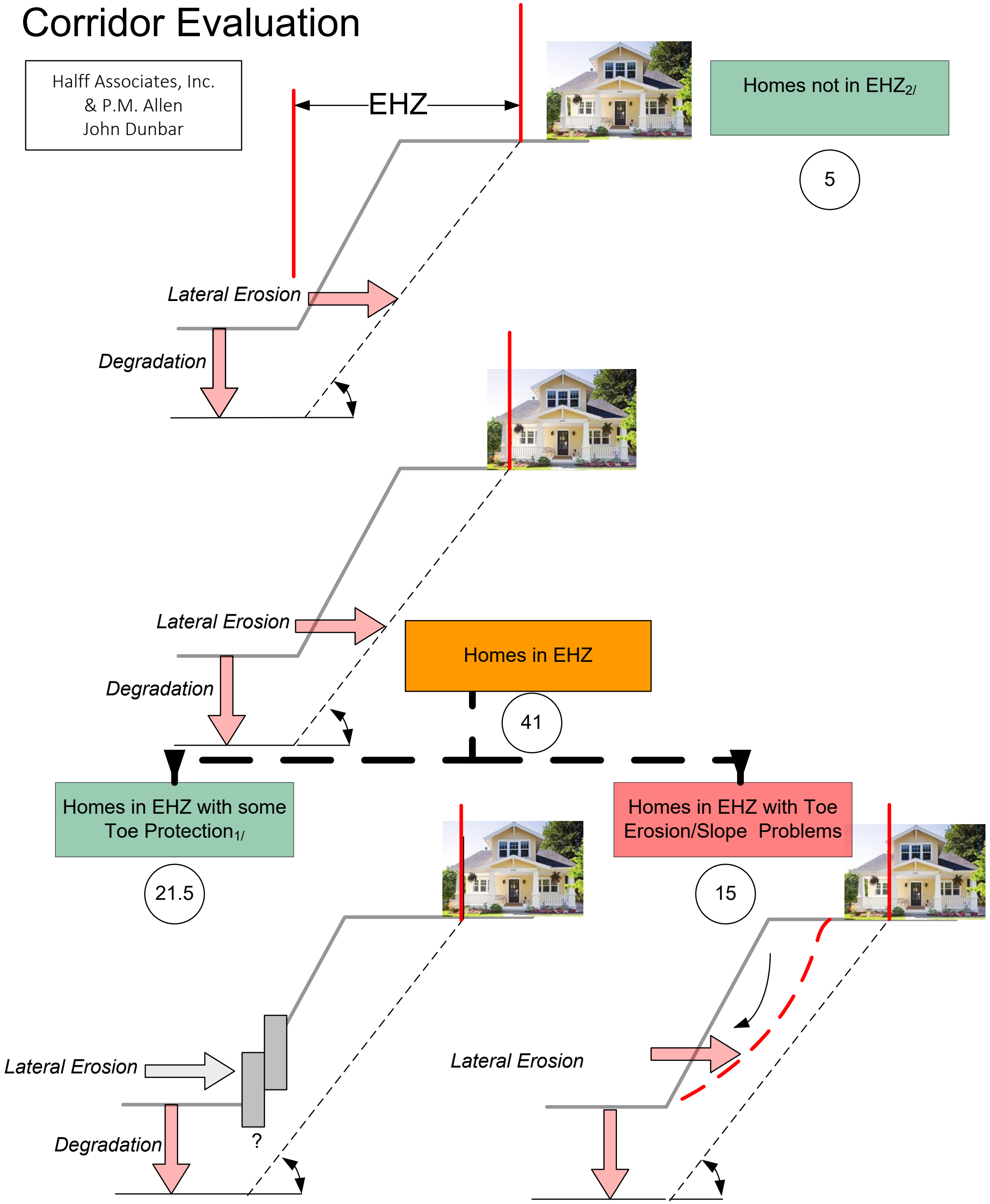




Summary of Corridor EHZ

Summary: Erosion Corridor Evaluation

Halff Associates, Inc.
& P.M. Allen
John Dunbar

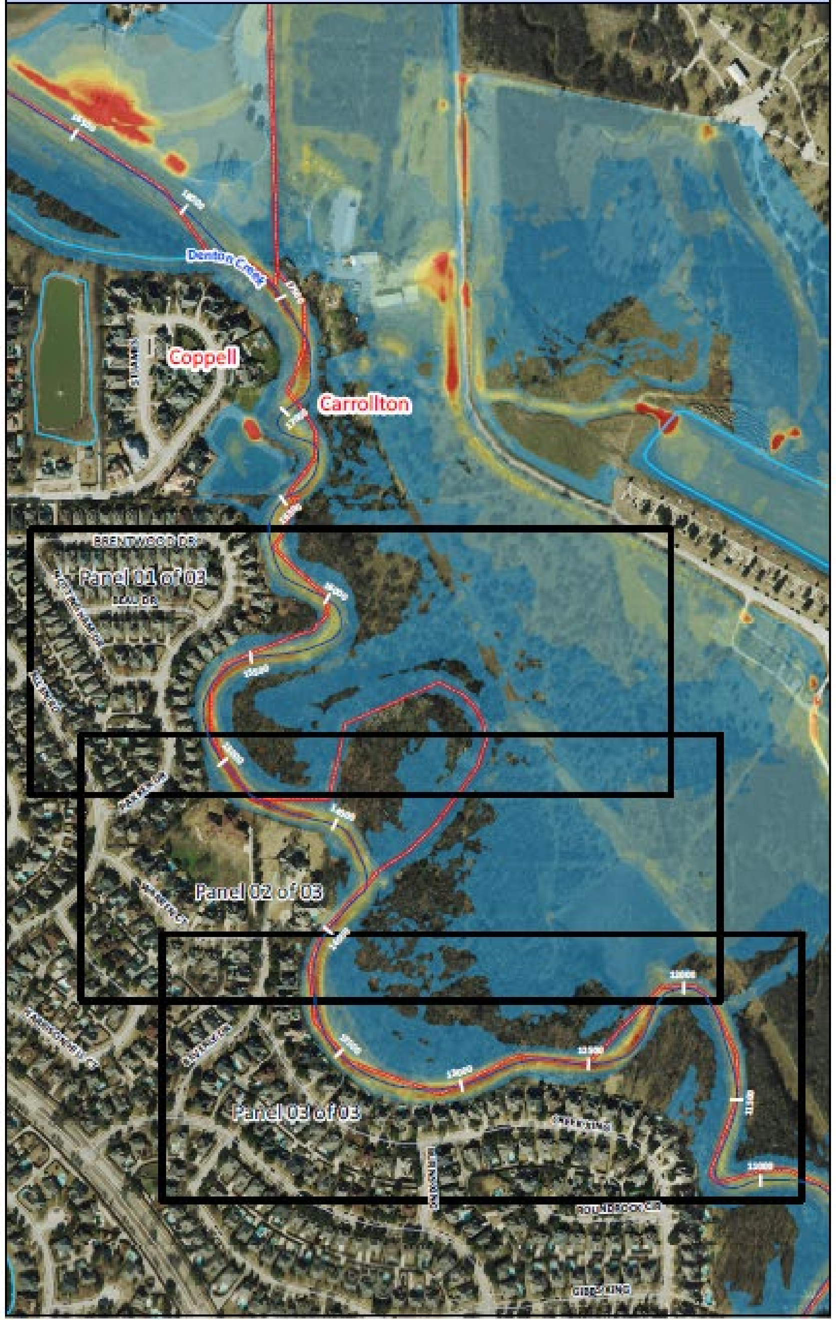


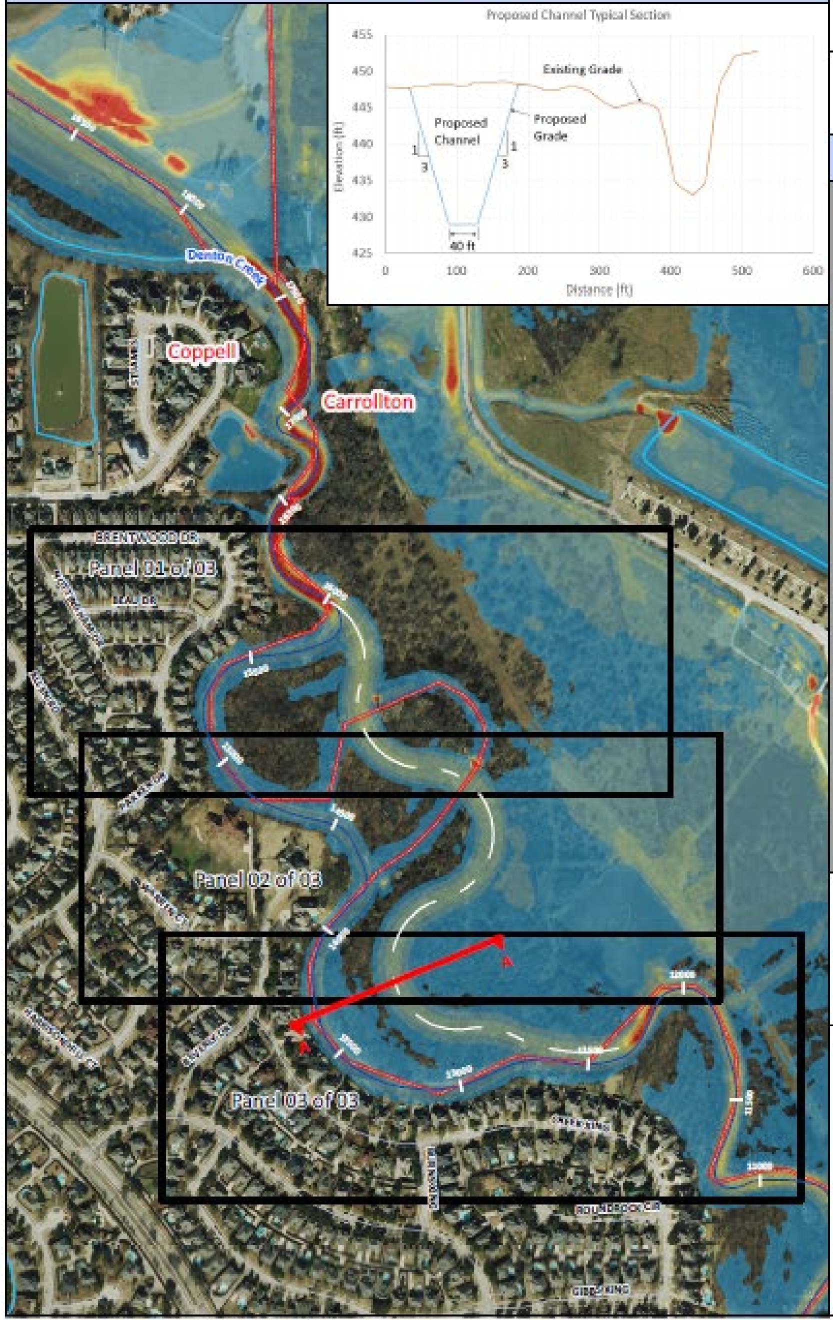
1/ Toe protection visible but not assessed as to stability 2/ Homes along river but not in Tables as out of EHZ

Options Being Considered:

1. Buyback ($1)
2. Reroute river away homes ($.2)
3. Bank Protection (bendway weirs) ($.02)

EXISTING CONDITIONS	PROPOSED CONDITONS





THE CITY OF COPPELL

HALFF

KEY TO FEATURES

- Study Stream
- Non-Study Stream
- 1000 River Station
- Local Road
- Proposed Bypass Channel
- Political Boundary

2-Year Velocity (ft/s)

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 3.5
- 3.5- 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- 5.0 - 5.5
- 5.5 - 6.0
- 6.0 +

Aerial Imagery from 2015 Woolpert

0 250 500

Scale in Feet

1 inch = 500 feet

N

Exhibit

Exhibit 8
Index Map

Project
Denton Creek Drainage Study

Title
Alternative 1
Proposed Bypass Channel

Watershed
Denton Creek

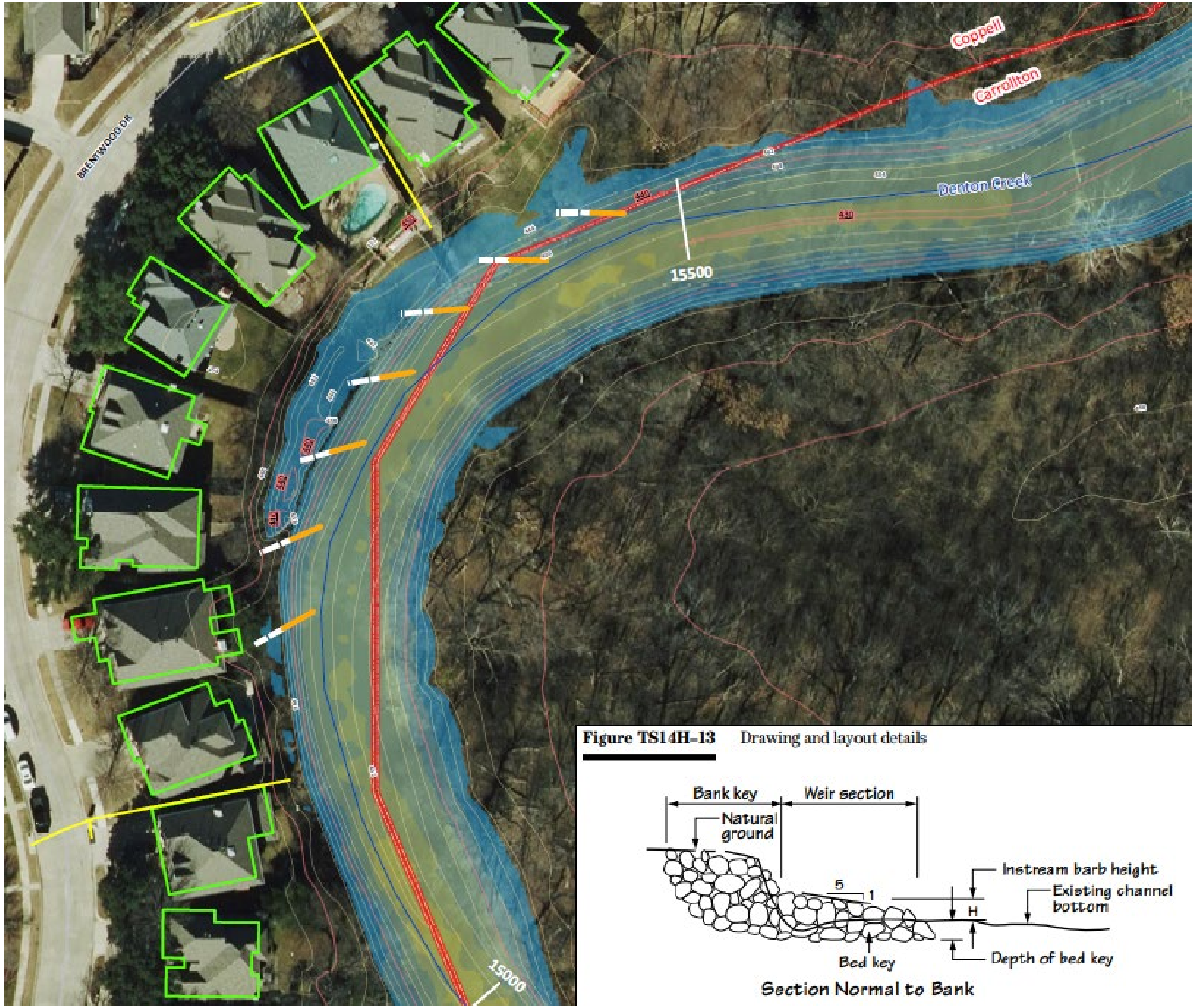
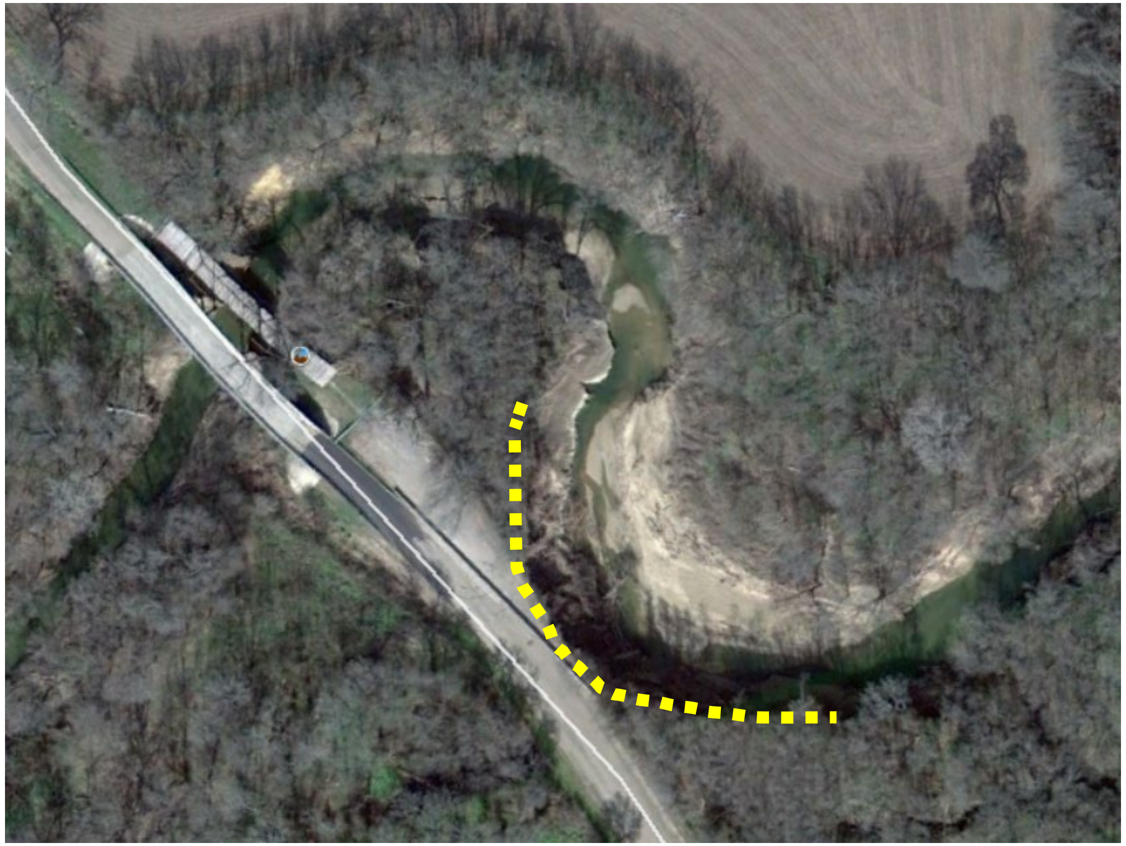


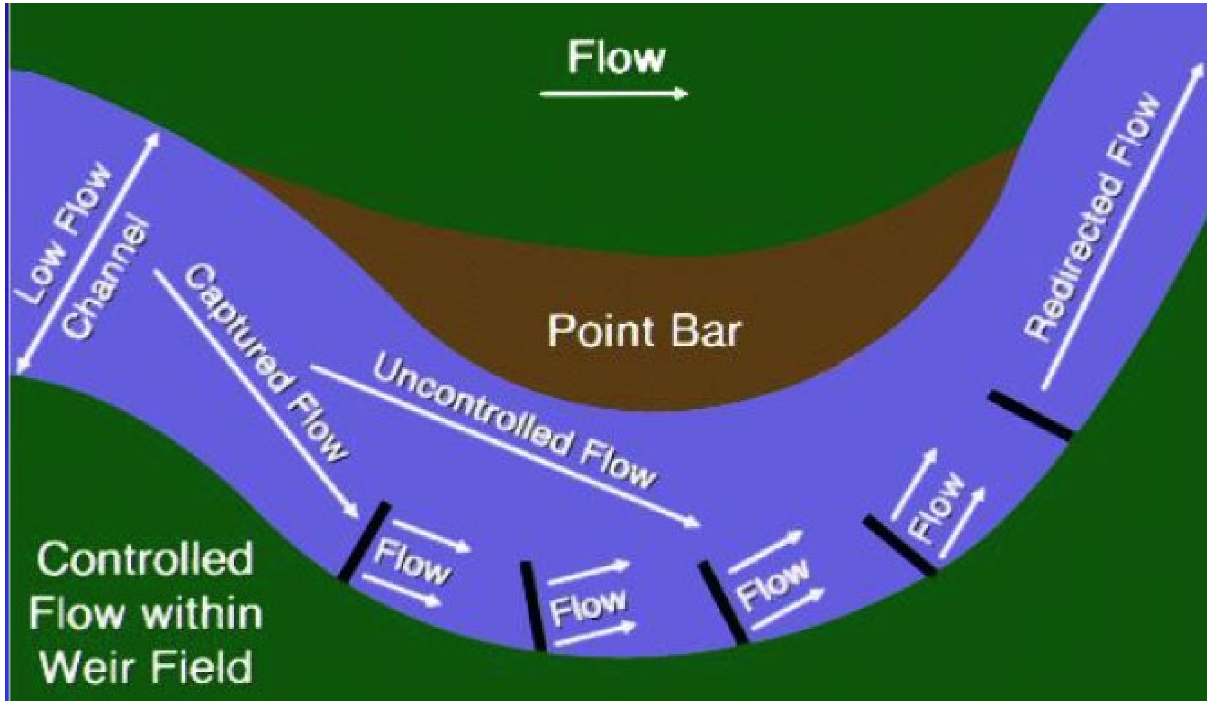
Figure TS14H-13 Drawing and layout details

Before and After Bendway Weirs




CAT

Design Engineering



NRCS

Inherent that we need to Protect Stream Riparian Corridors Prior to Urbanization

A Methodology for Delineating Planning-Level Channel Migration Zones

DEPARTMENT OF ECOLOGY State of Washington

July 2014
Publication no. 14-06-025

Fluvial Hazard Zone Delineation
A Framework for Mapping Channel Migration and Erosion Hazard Areas in Colorado

DRAFT

Prepared by:

Katie Jagt, P.E., Watershed Science and Design, PLLC.

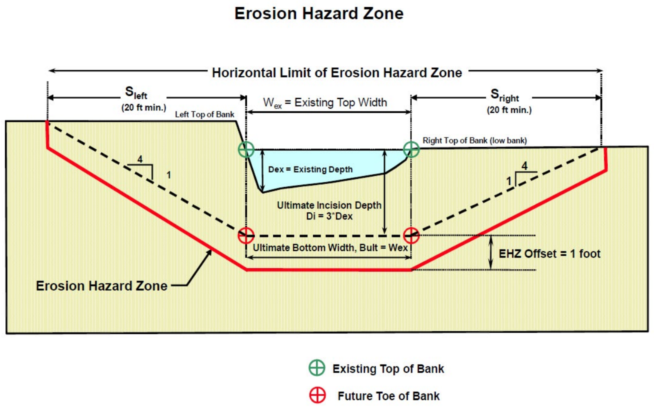
Michael Blazewicz, Round River Design, LLC.

Joel Sholtes, PhD, Colorado State University

January 14, 2016

For: Colorado Water Conservation Board, Department of Natural Resources

CO DNR



Technical Supplement 14S — Sizing Stream Setbacks to Help Maintain Stream Stability

In riverine environments, by the year 2100, the relative increase in the median estimates of the 1 percent annual chance floodplain (floodplain) depth and area (Special Flood Hazard Area or SFHA) is projected to average about 45% across the nation, with very wide regional variability. FEMA (2013)

Questions?