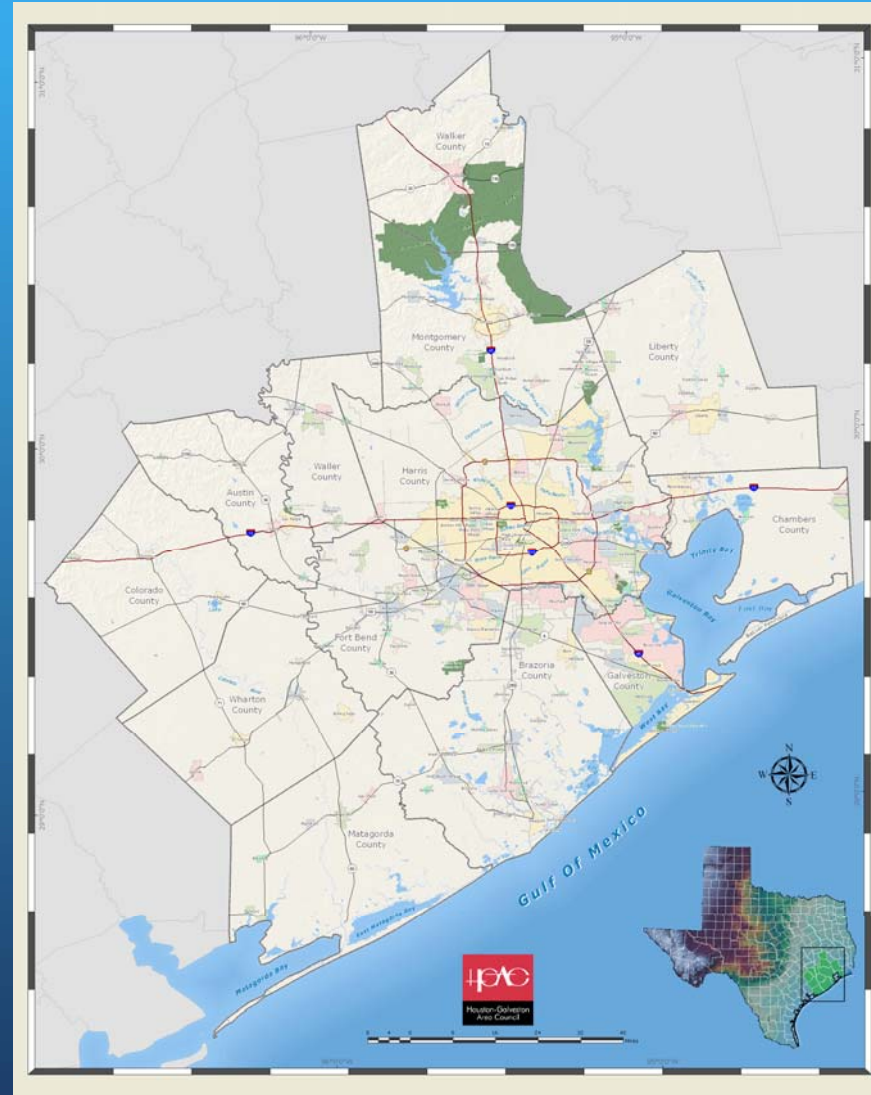




# *Hurricane Harvey - What Have We Learned?*

*Developing Resiliency In  
Harris County Streams  
and Flood Control  
Channels*

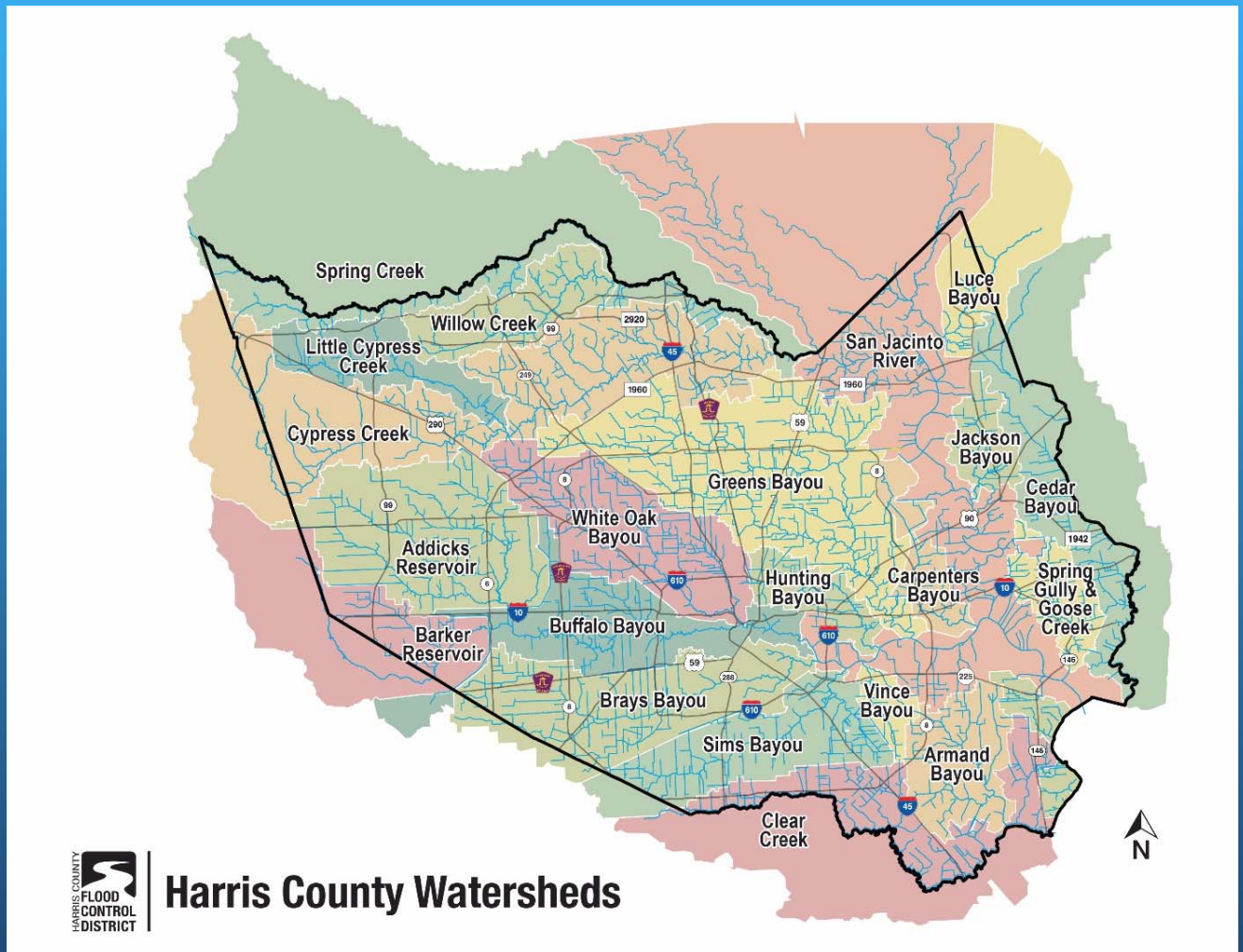
# Houston Texas & the Harris County Flood Control District



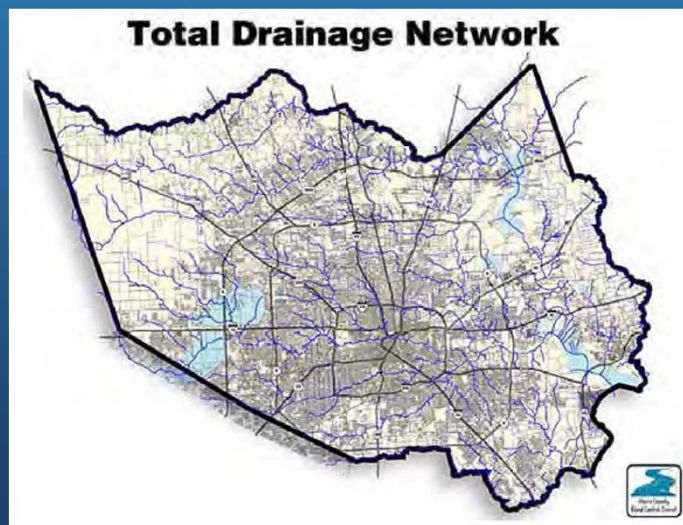
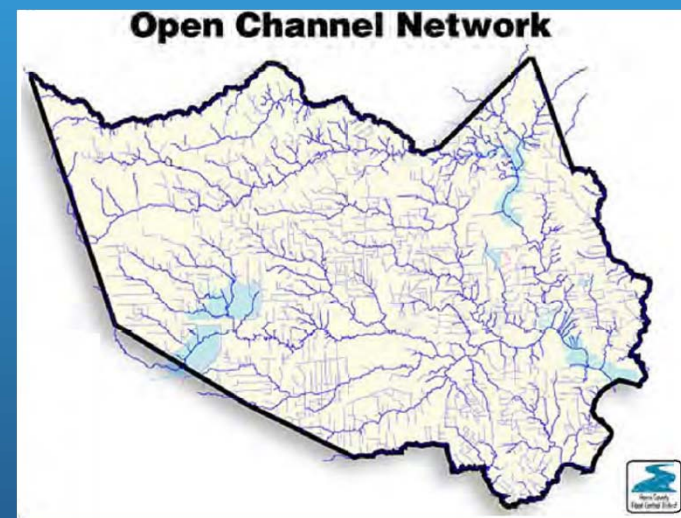
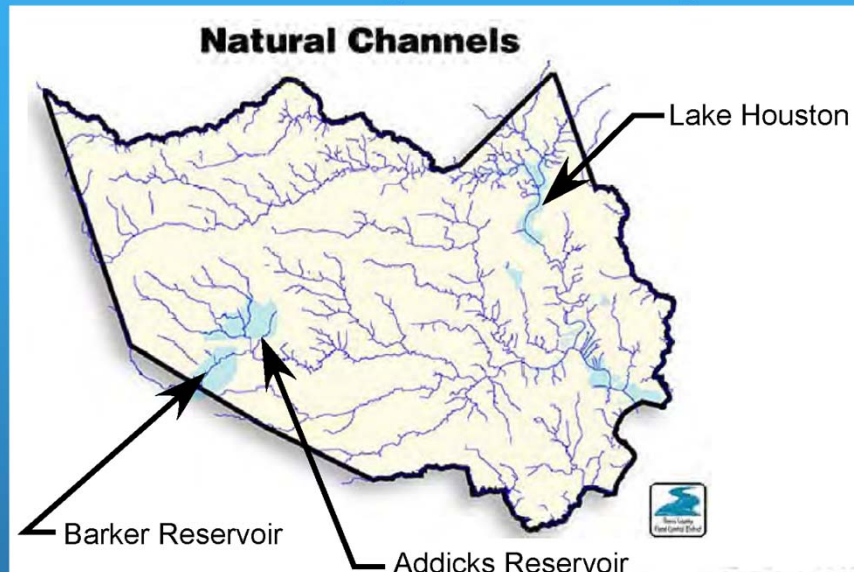


# Harris County Flood Control District

- 4.09 million people in Houston & Harris County
- HCFCF manages 22 watersheds with 2,500 miles of bayous and channels in Harris County

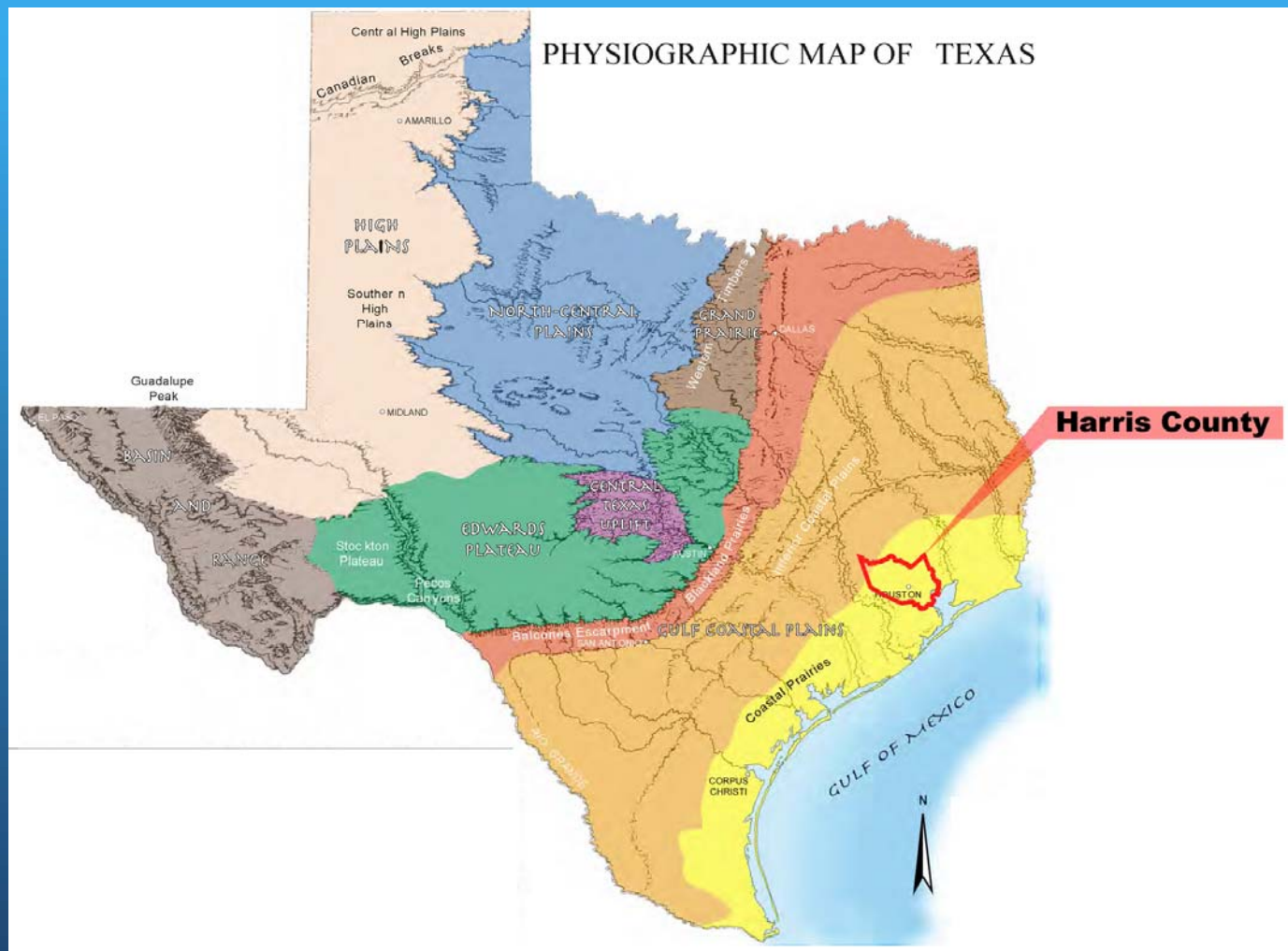


# Harris County Drainage Networks





# Coastal Prairie Physiographic Province



# Recent “Named” Flooding in Houston

- 2001 - Tropical Storm “Allison”
- 2006 - “Juneteenth” Flood
- 2008 - Hurricane “Ike”
- 2015 - “Tax Day” Flood
- 2016- “Memorial Day” Flood
- 2017 - Hurricane “Harvey”

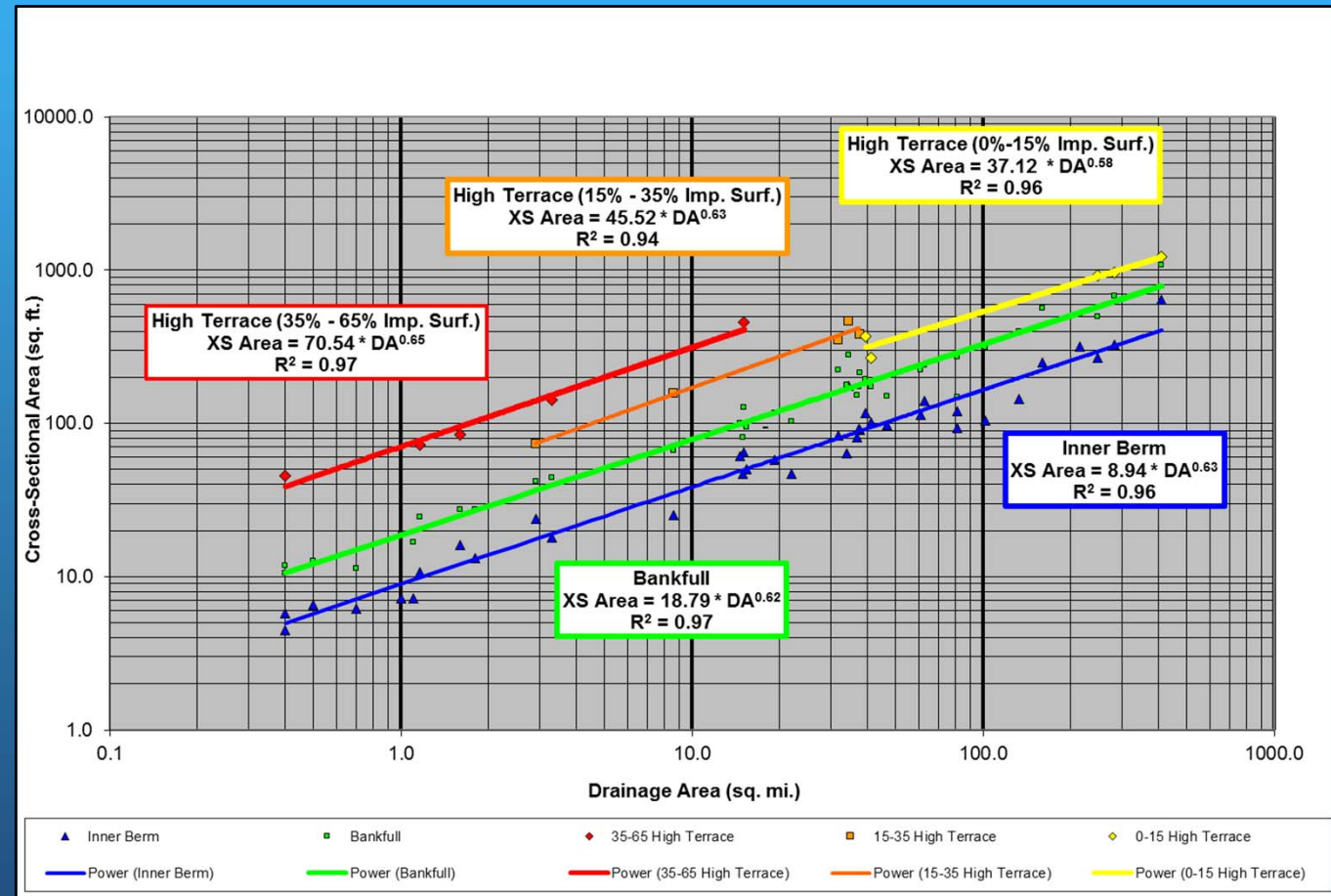


# Timeline for HCFCD Natural Stable Channel Solutions for Channel Resiliency

- 2001 – T.S. Allison Recovery Program (TSARP)
- 2006 – 1<sup>st</sup> NCD project (Cypress Crk @ Meyer Park – Reach 1)
- 2008 – Countywide Fluvial Geomorphic Study
- 2015 – Addition of NSCD prescriptions to specifications
- 2016 – Development of NSCD Guidance Manual
- 2018 – Development of Watershed Level NSCD Plan

# HCFCD Countywide Fluvial Geomorphic Study (2008)

- 45 streams surveyed



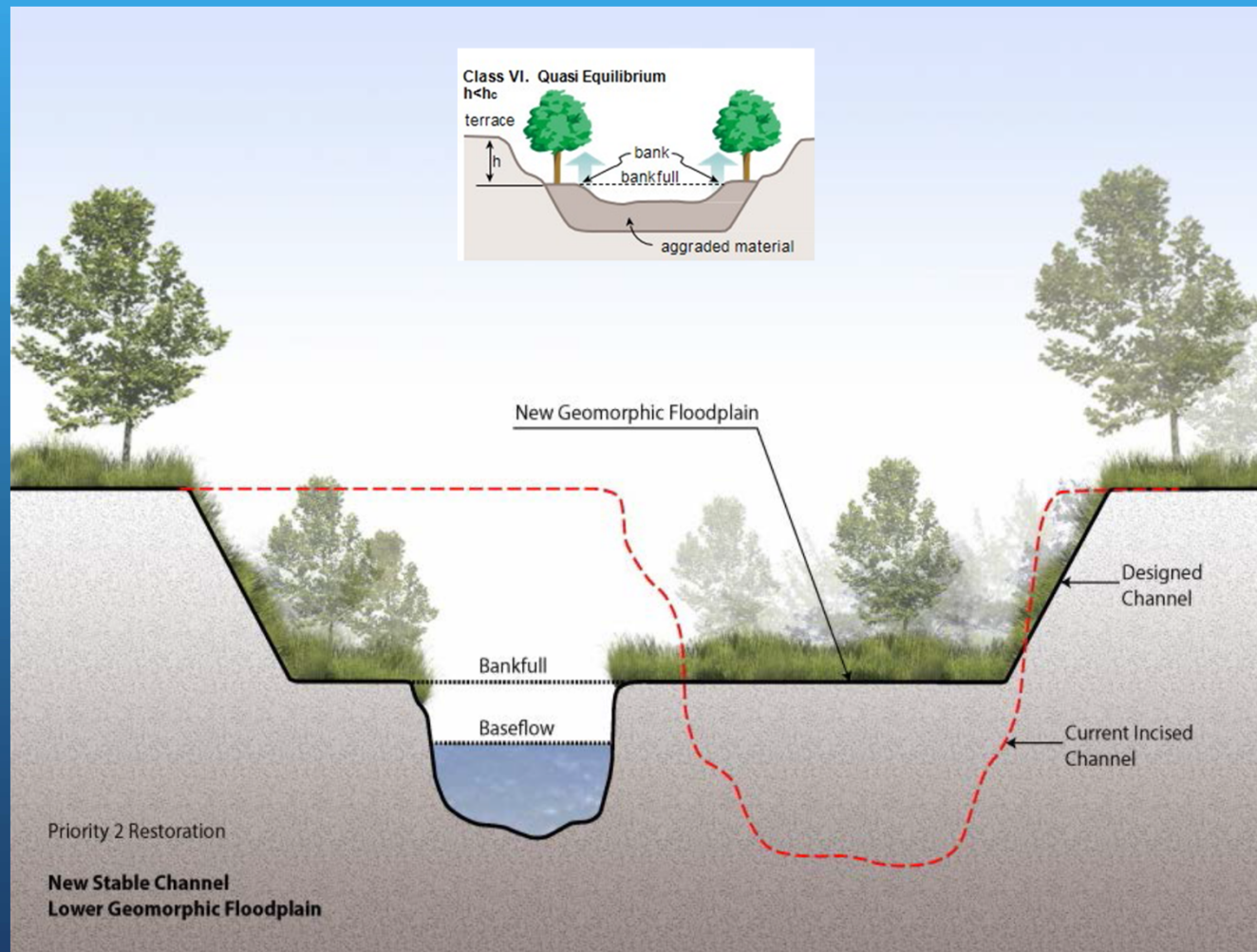


# Harris County Flood Control District Solutions

- Rosgen Priority 2 Restoration wherever possible
- Promotion of Rosgen Priority 1 Restoration in headwaters

# HCFCF Priority 2 Restoration Components

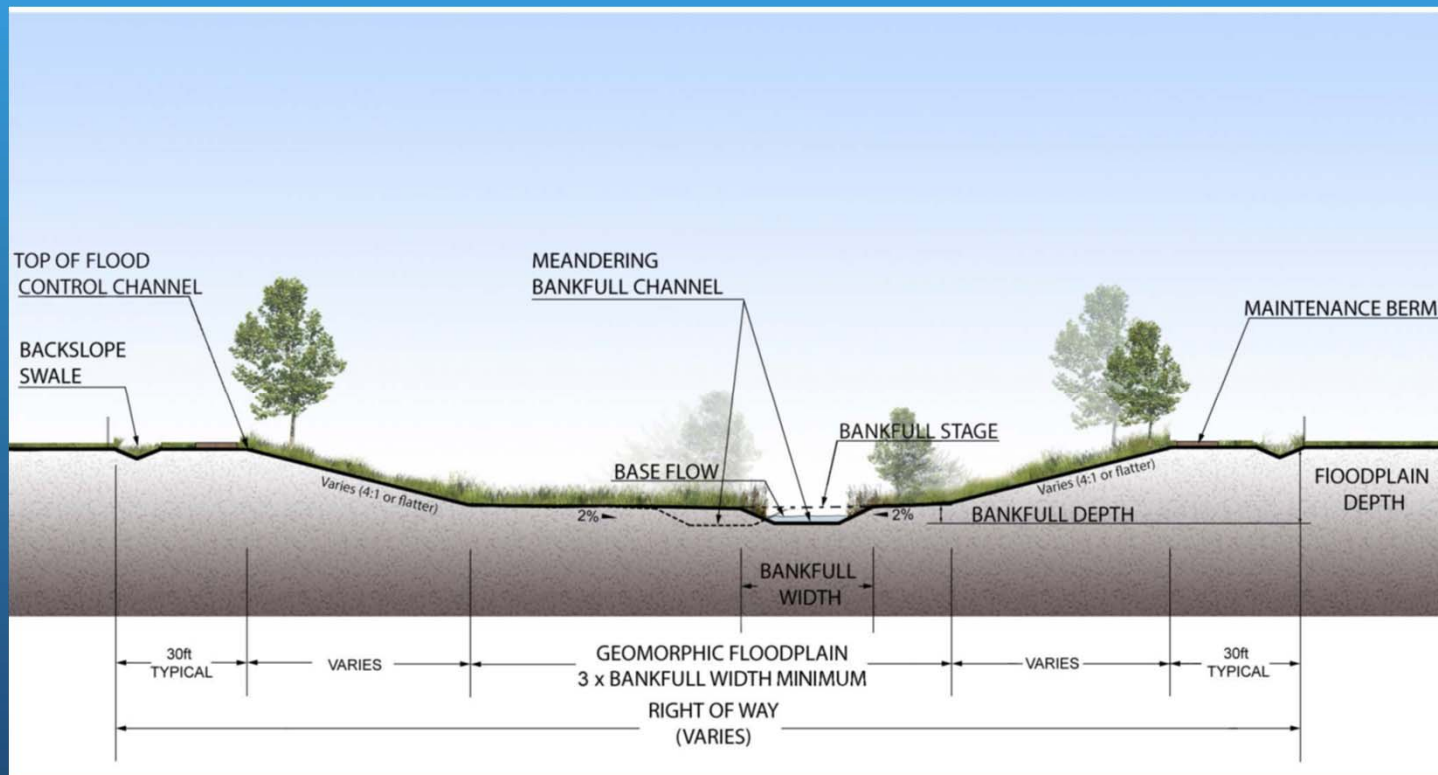
- Establish equilibrium at lower elevation





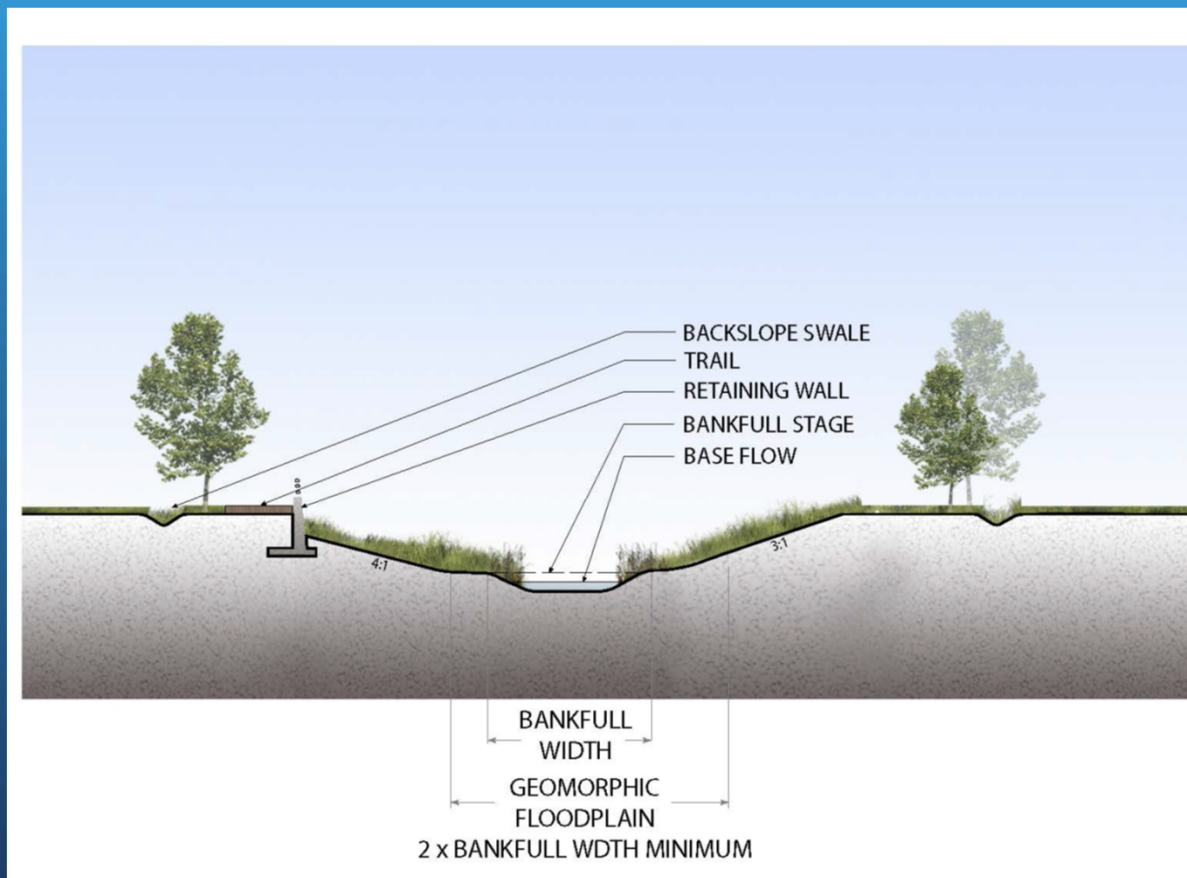
# HCFCD Priority 2 Restoration Components

- Rosgen C channels (with possible transition to E channel)
- Nominal bankfull floodplain bench (Min:  $3 \times W_{BKF}$ )



# HCFCD Priority 2 Restoration Components

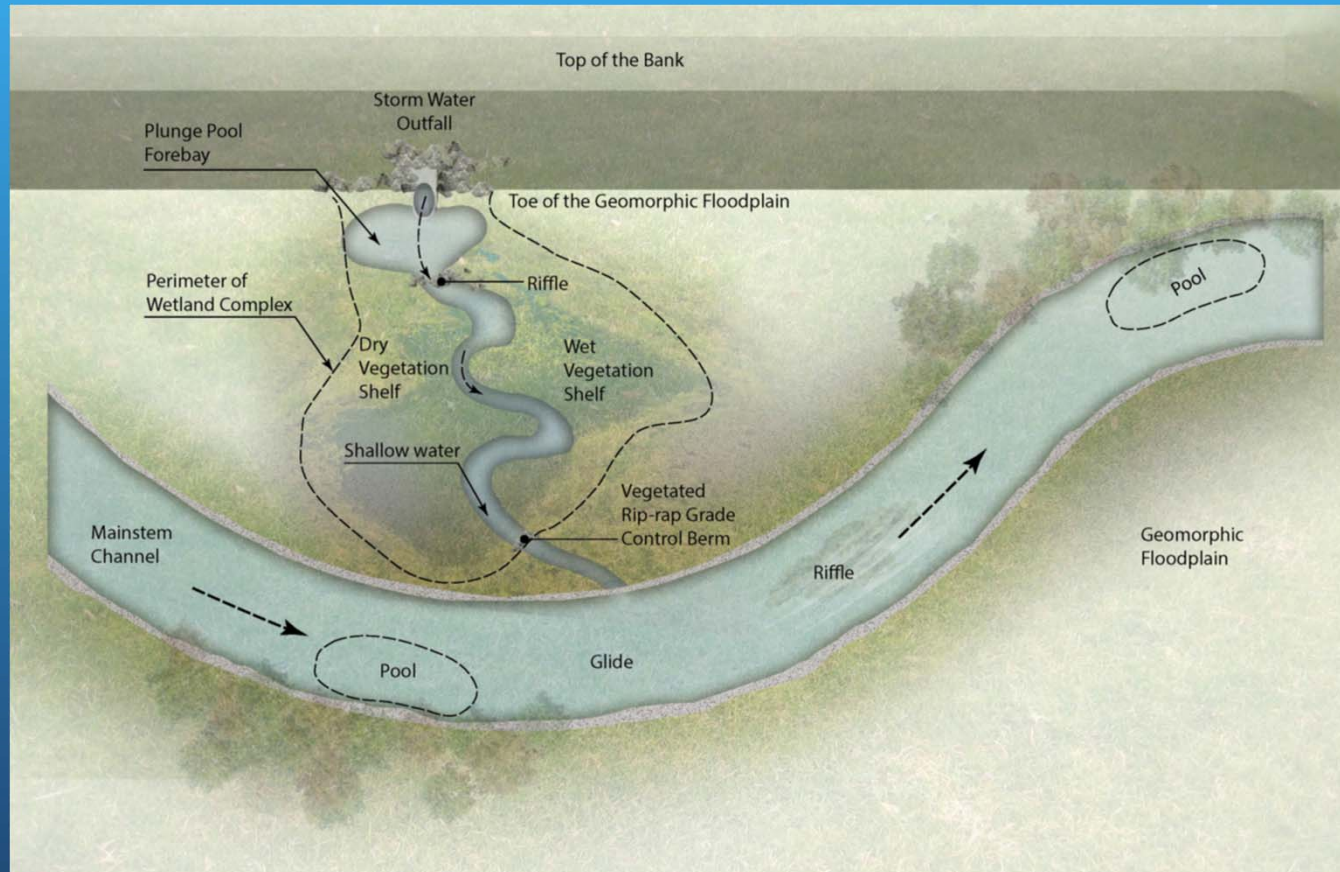
- Rosgen B (step-pool) channels where lateral constraints or slopes require
- Nominal bankfull floodplain bench (Min:  $2 \times W_{BKF}$ )





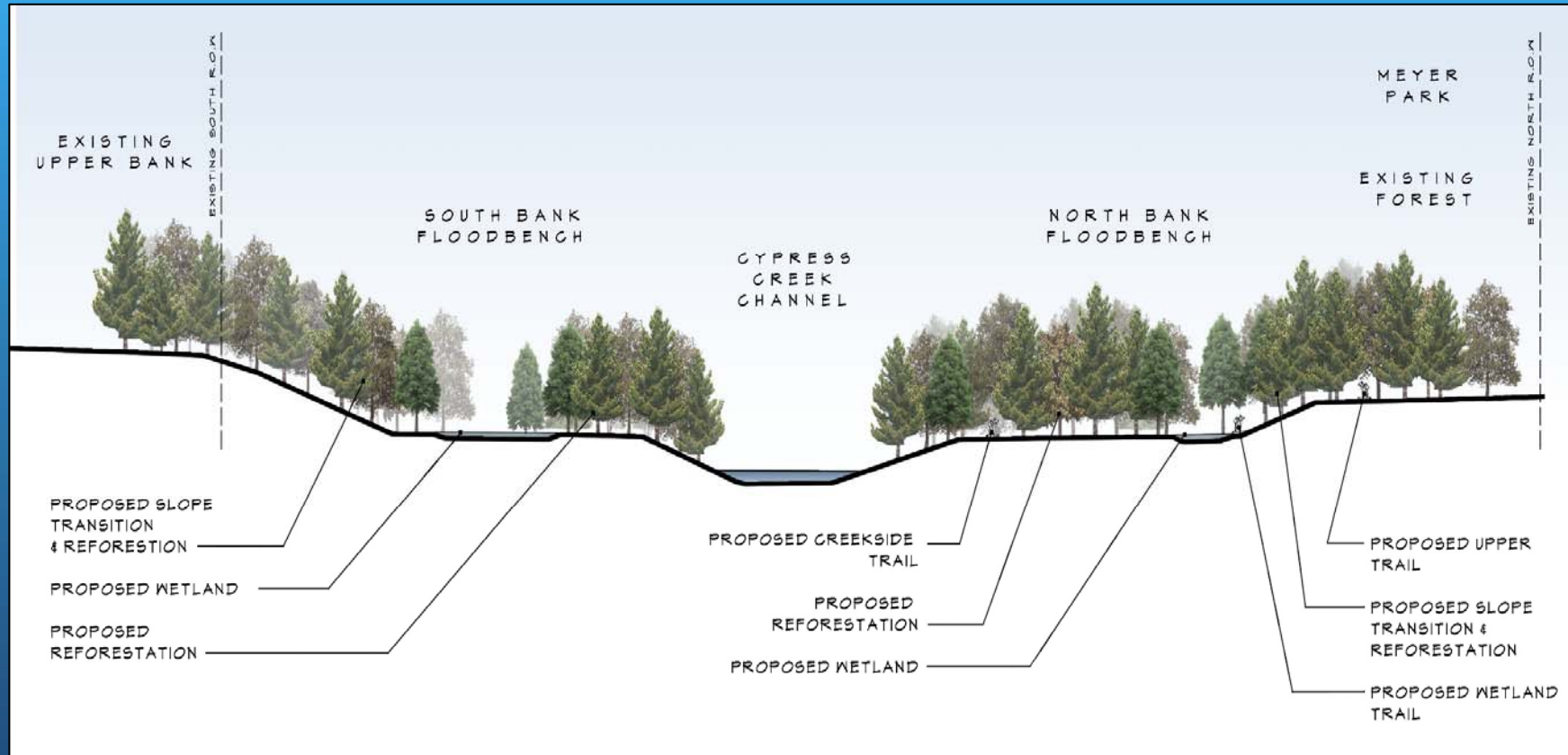
# HCFCD Priority 2 Restoration Components

- Stormwater quality wetlands on bankfull bench



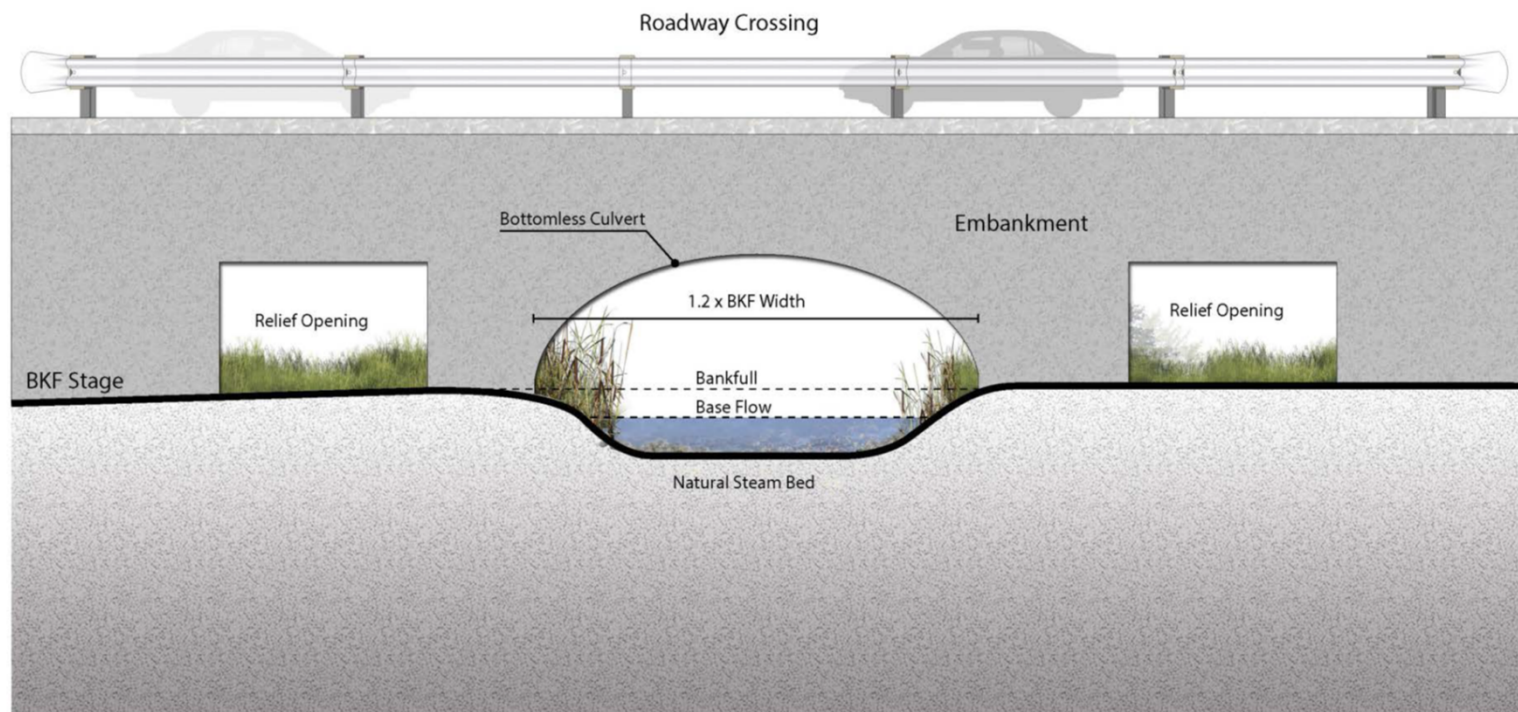
# HCFCF Priority 2 Restoration Components

- Greenway trails on bankfull bench



# HCFC Priority 2 Restoration Components

- Bankfull channel-spanning crossings & floodplain culverts





# Tributary to Big Gulch @ North Shore Family Park, Houston

- 115 acres (.18 mi<sup>2</sup>) drainage area
- Watershed is completely piped subdivision (no sediment load) with no stormwater detention (flashy)
- “Sugar” sand banks and relic refuse burn pits (melted glass and metal) uncovered by downcutting stream
- Steep system for Houston (2%)
- “Hungry” (no sediment load) and flashy flows
- Downcutting (over 10 feet) and over-widening in channel evolution
- Overwidening threatens park on one side, schools on the other side, and stormsewer outfalls





# Pre-Improvement



Photo 1



Photo 2



# Pre-Improvement



Photo 3



Photo 4



# Pre-Improvement



Photo 5



Photo 6



# Pre-Improvement



Photo 7



Photo 8



# Pre-Improvement



Photo 9



Photo 10

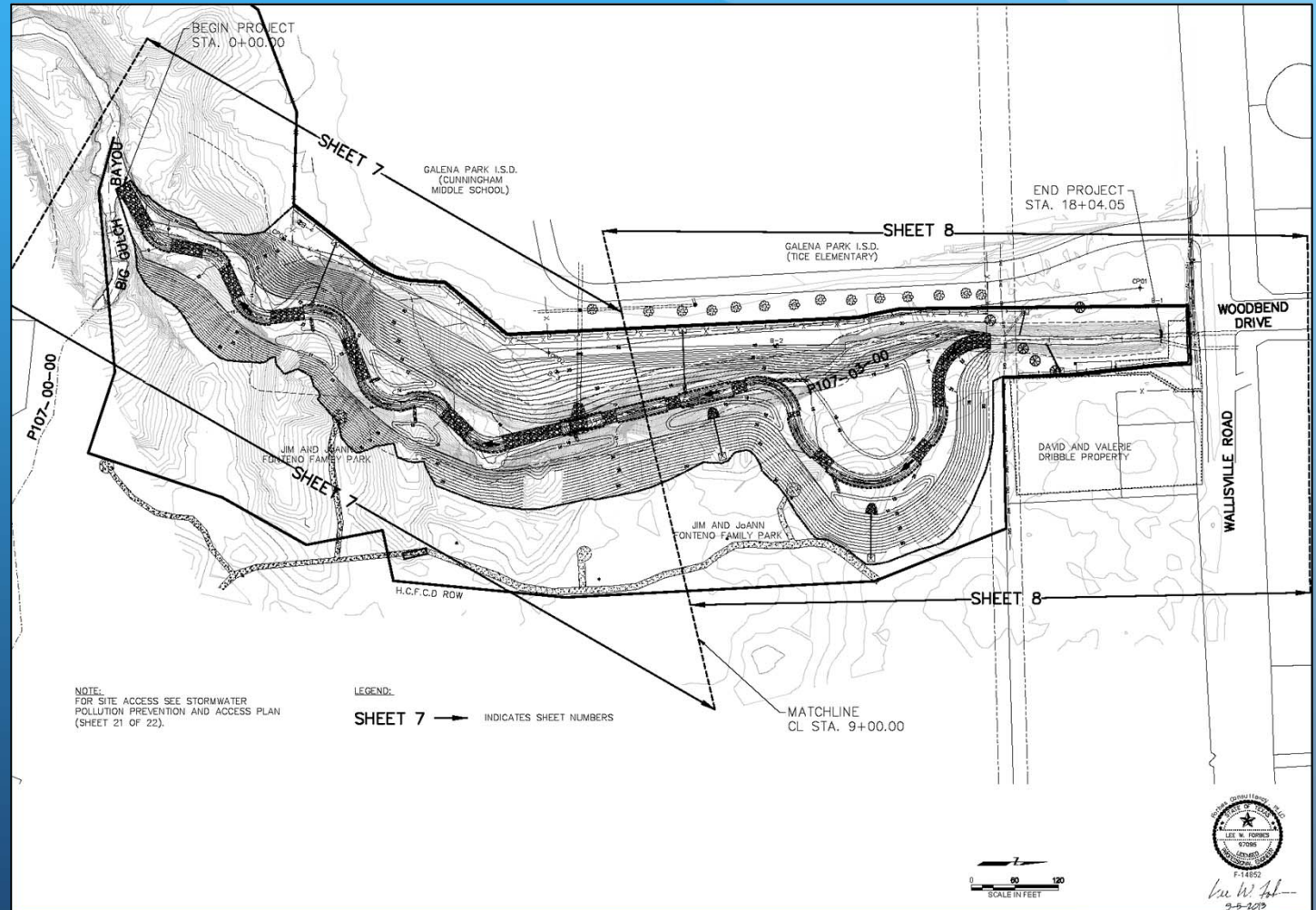


# Pre-Improvement



# Improvements

- Relocated Priority 2 NCD Channel
- Constructed Boulder Riffles
- Constructed Floodplain Bench
- Stabilized Banks & Slopes
- Floodplain SWQ Wetlands
- Grass & Tree Plantings
- Backslope Interceptors
- Armored Stormsewer Outfalls





## After (July 2015)

- Project Completed: April 2015
- Memorial Day Flood: May 2015





## After (July 2015)

- Project Completed: April 2015
- Memorial Day Flood: May 2015





# After (July 2015)

- Project Completed: April 2015
- Memorial Day Flood: May 2015





# After (July 2015)

- Project Completed: April 2015
- Memorial Day Flood: May 2015





## After (July 2015)

- Project Completed: April 2015
- Memorial Day Flood: May 2015



## After (July 2015)

- Project Completed: April 2015
- Memorial Day Flood: May 2015





# After (July 2017)

- HCFCFCD Repaired in late 2015
- Stable and self-improving after Tax Day Flood (2016), and Hurricane Harvey (2017)

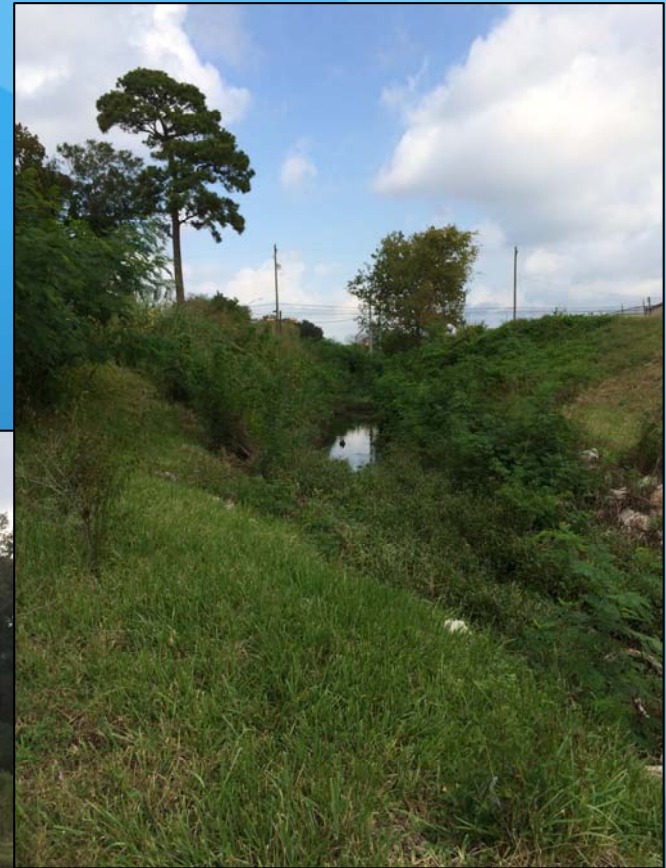


# After (July 2017)





# After (July 2017)





# After (July 2017)





After (July 2017)



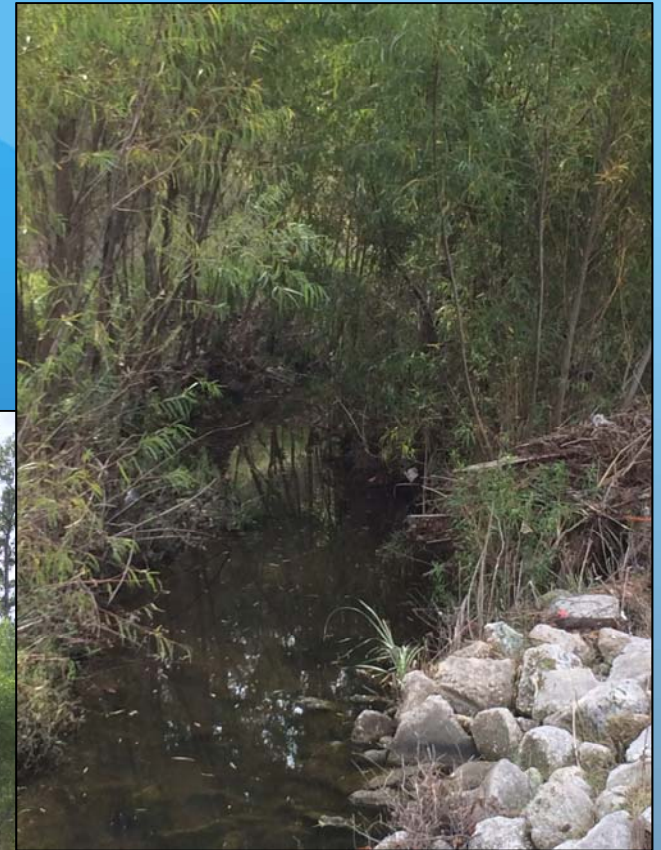
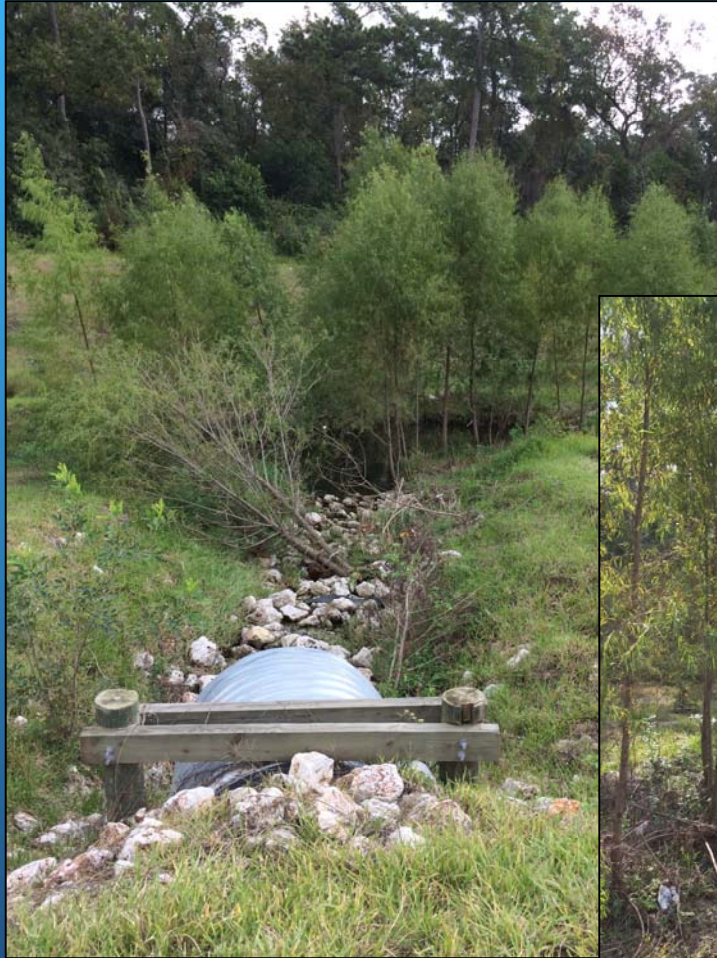


After (July 2017)





# After (July 2017)





After (July 2017)





After (July 2017)





After (July 2017)





After (July 2017)





After (July 2017)



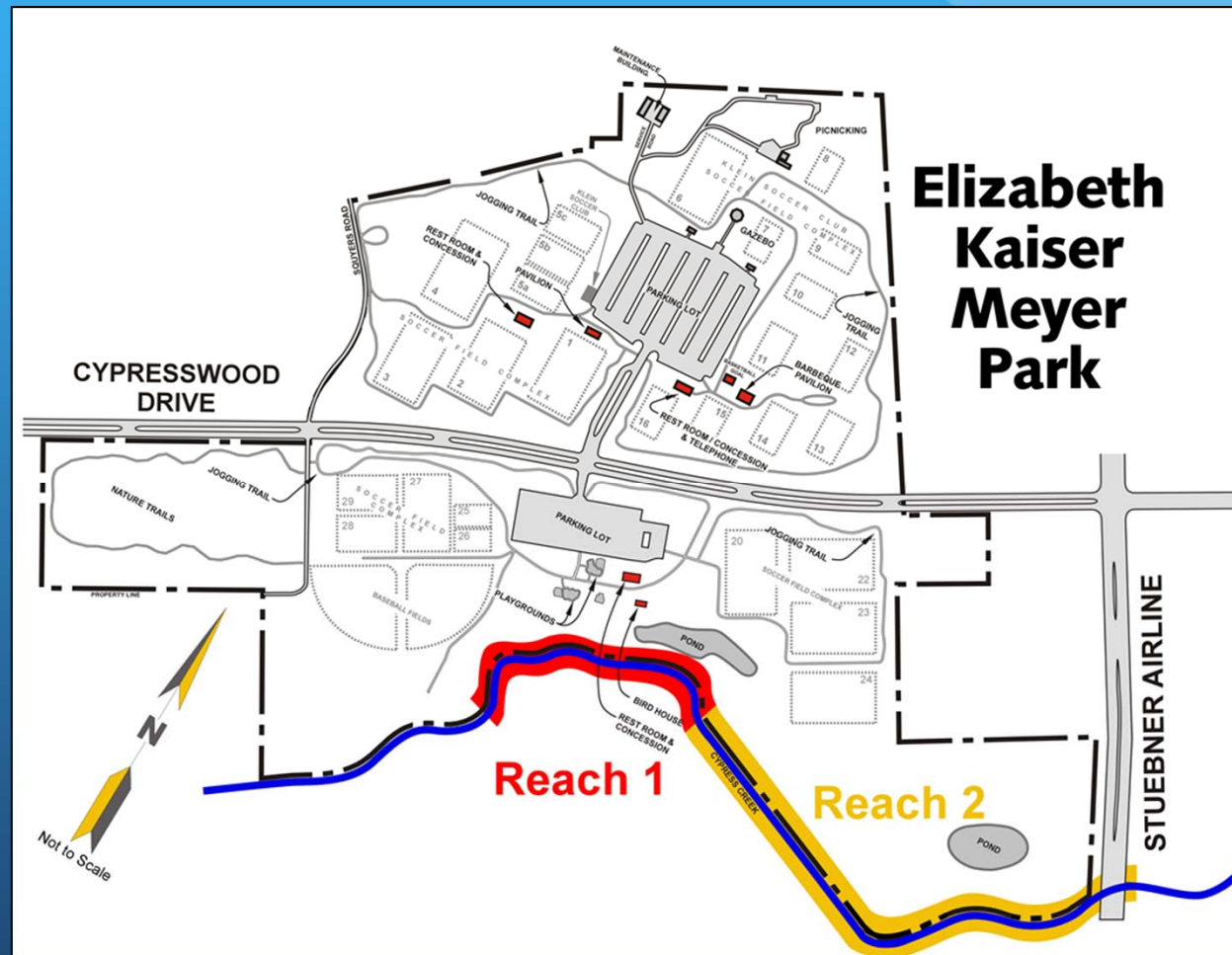


# Cypress Creek @ Mayer Park, Houston

- 189 mi<sup>2</sup> drainage area
- Sand bed & banks with stiff marine clay outcroppings acting as natural, slowly melting grade control
- Natural, but majority of reaches in area had been dredged in the past
- Unstable reaches upstream sending large sediment loads through project reach
- Overwidening threatens park infrastructure and stormsewer outfalls



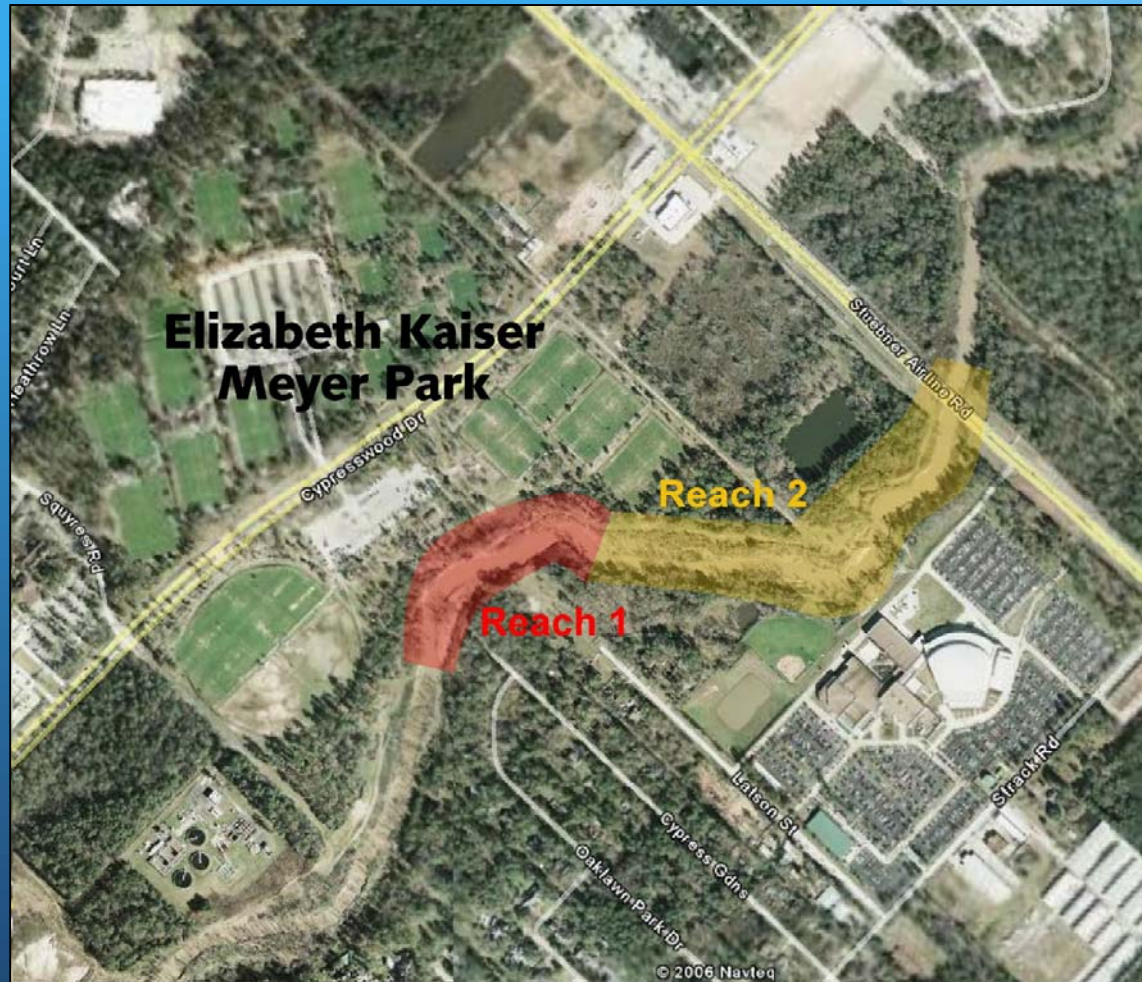
# Park Layout



## Elizabeth Kaiser Meyer Park

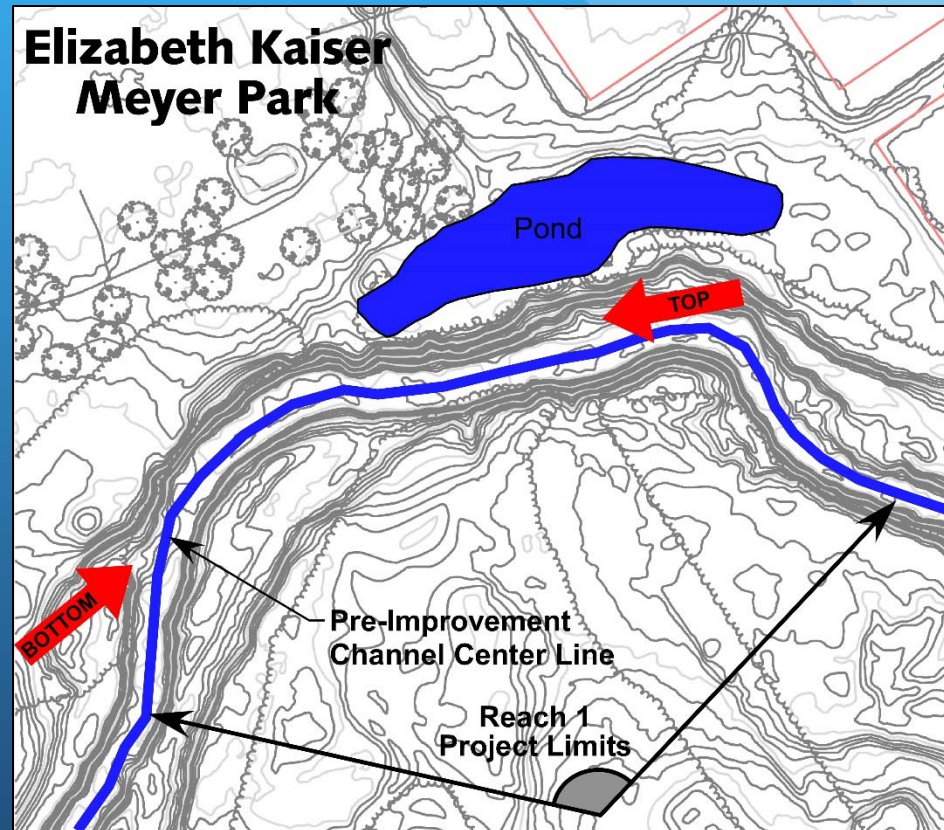


# Project Extents



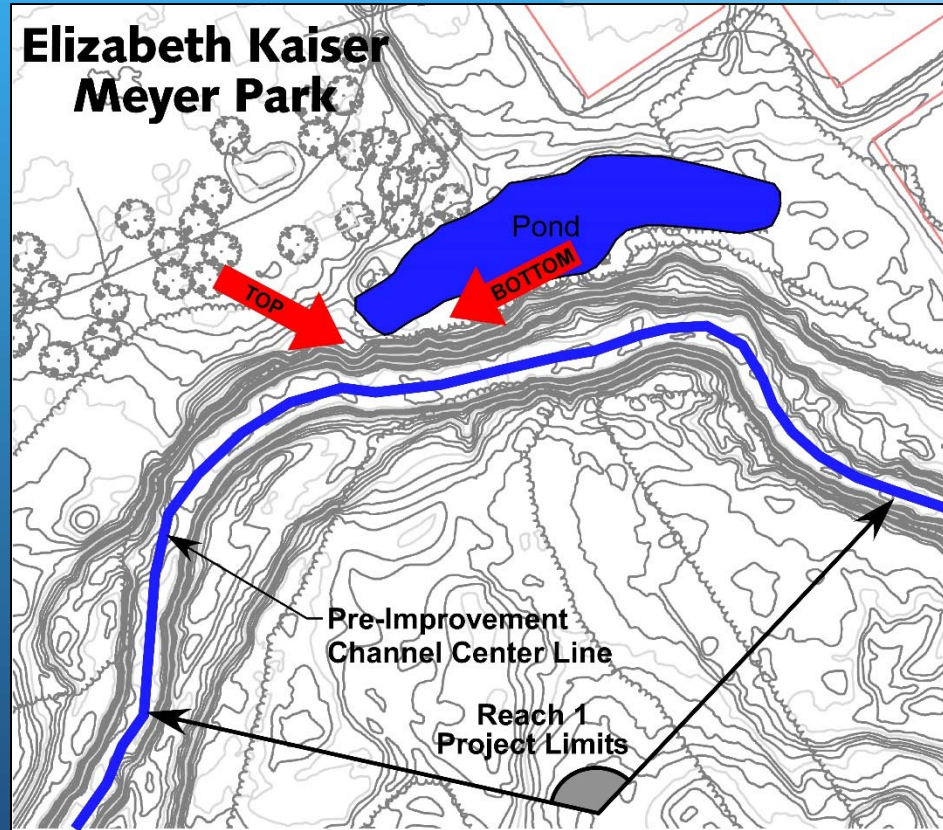


# Reach I - Pre-Improvement



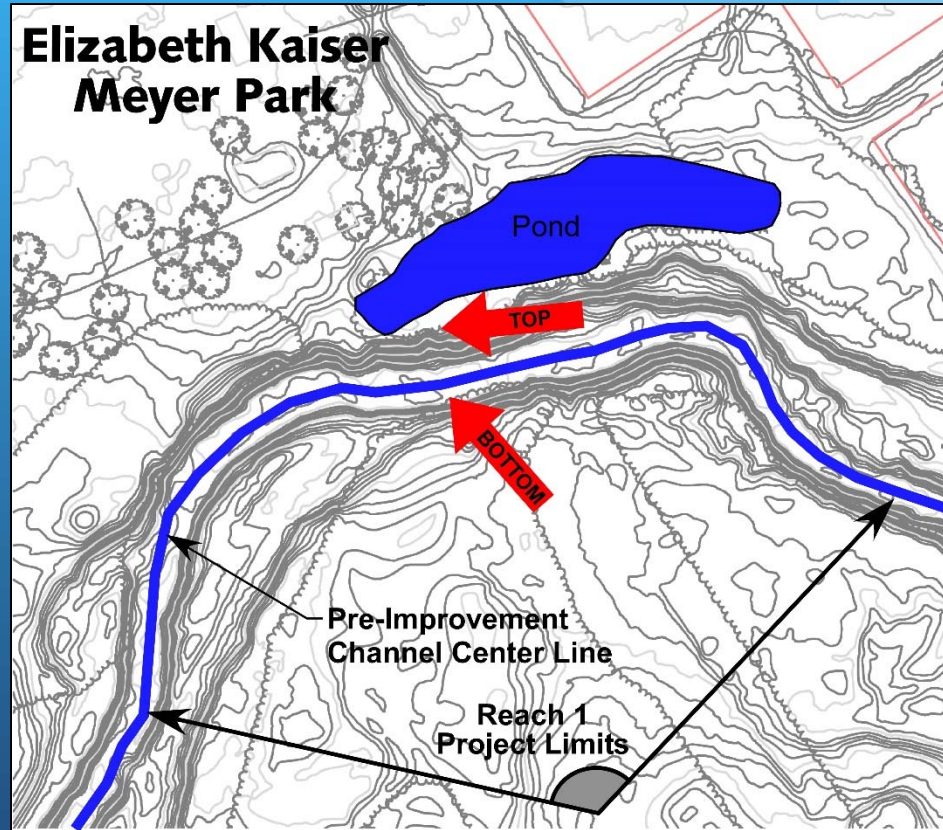


# Reach I - Pre-Improvement



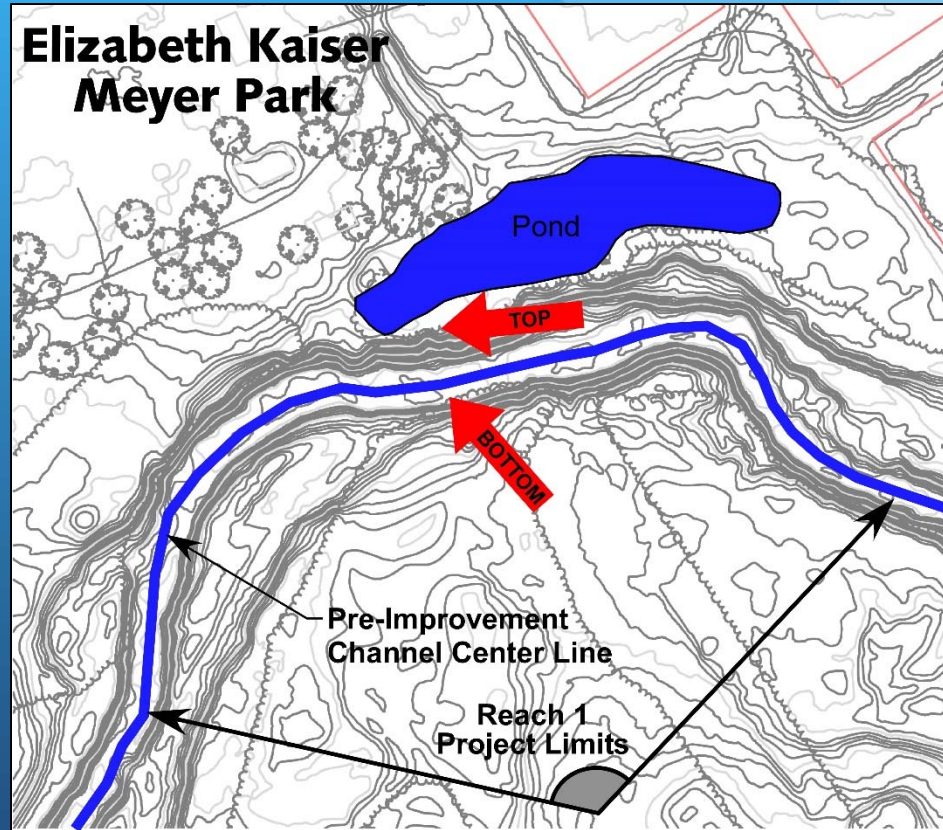


# Reach I - Pre-Improvement





# Reach I - Pre-Improvement





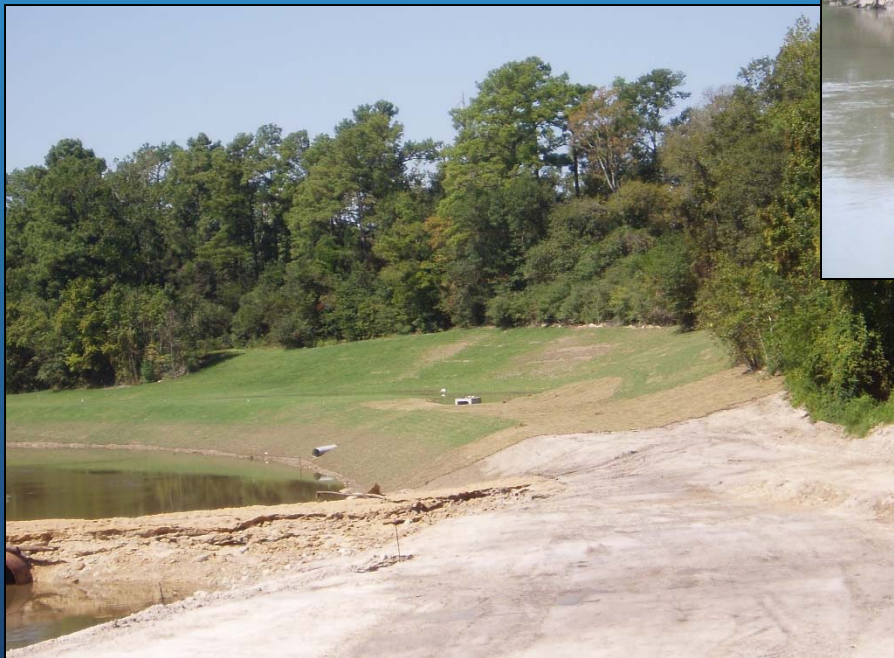
# Reach I - Improvements

- Relocated Priority 2 NCD Meander Bend
- Riprap Armored Channel Toe (Both Banks)
- Constructed Floodplain Bench
- Stabilized Banks & Slopes
- Floodplain SWQ Wetlands
- Grass & Tree Plantings
- Backslope Interceptors
- Armored Stormsewer Outfalls

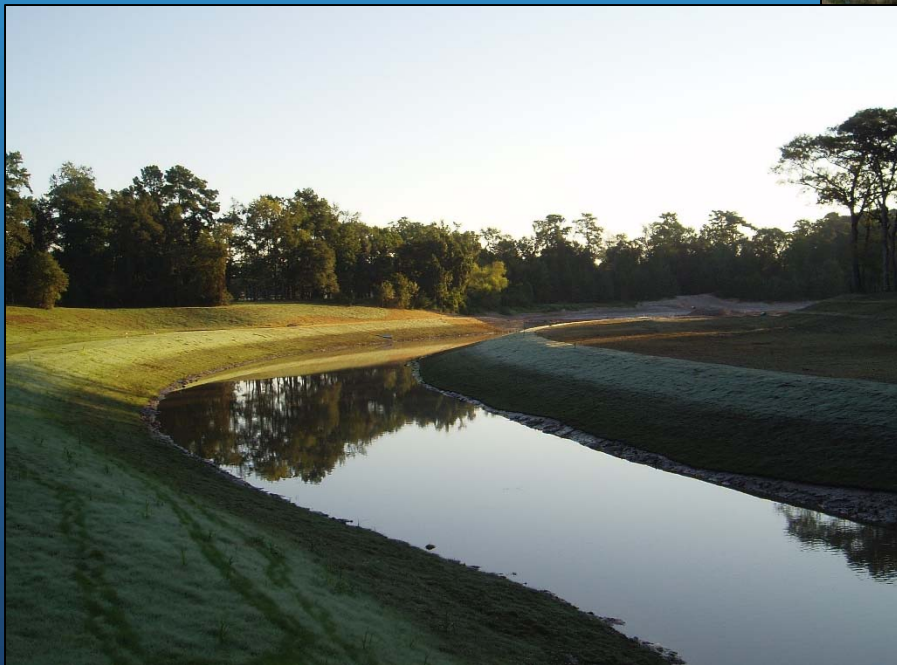




# Reach 1 Before and Post-Const. (2006)

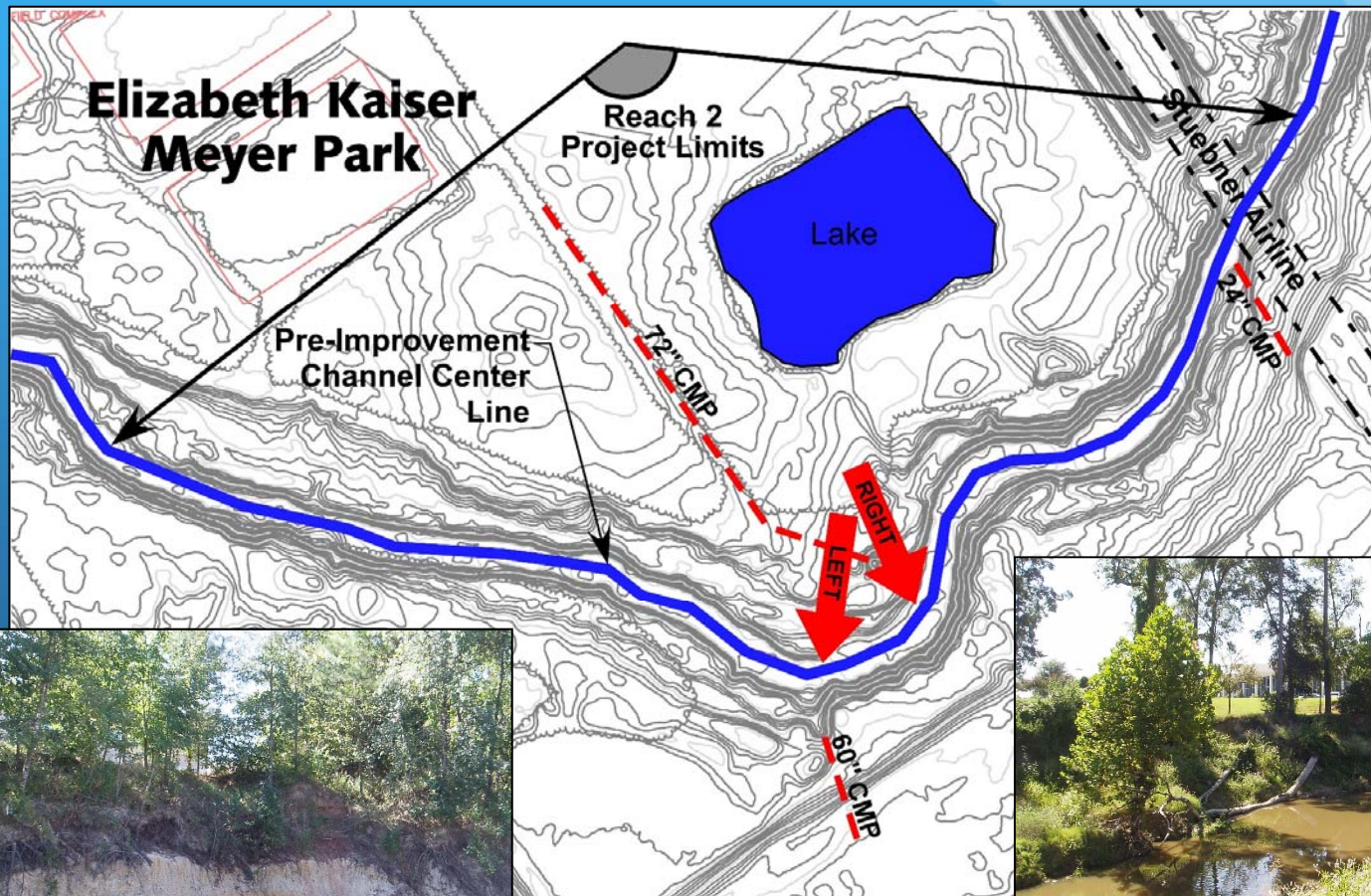


# Reach 1 Before and Post-Const. (2006)



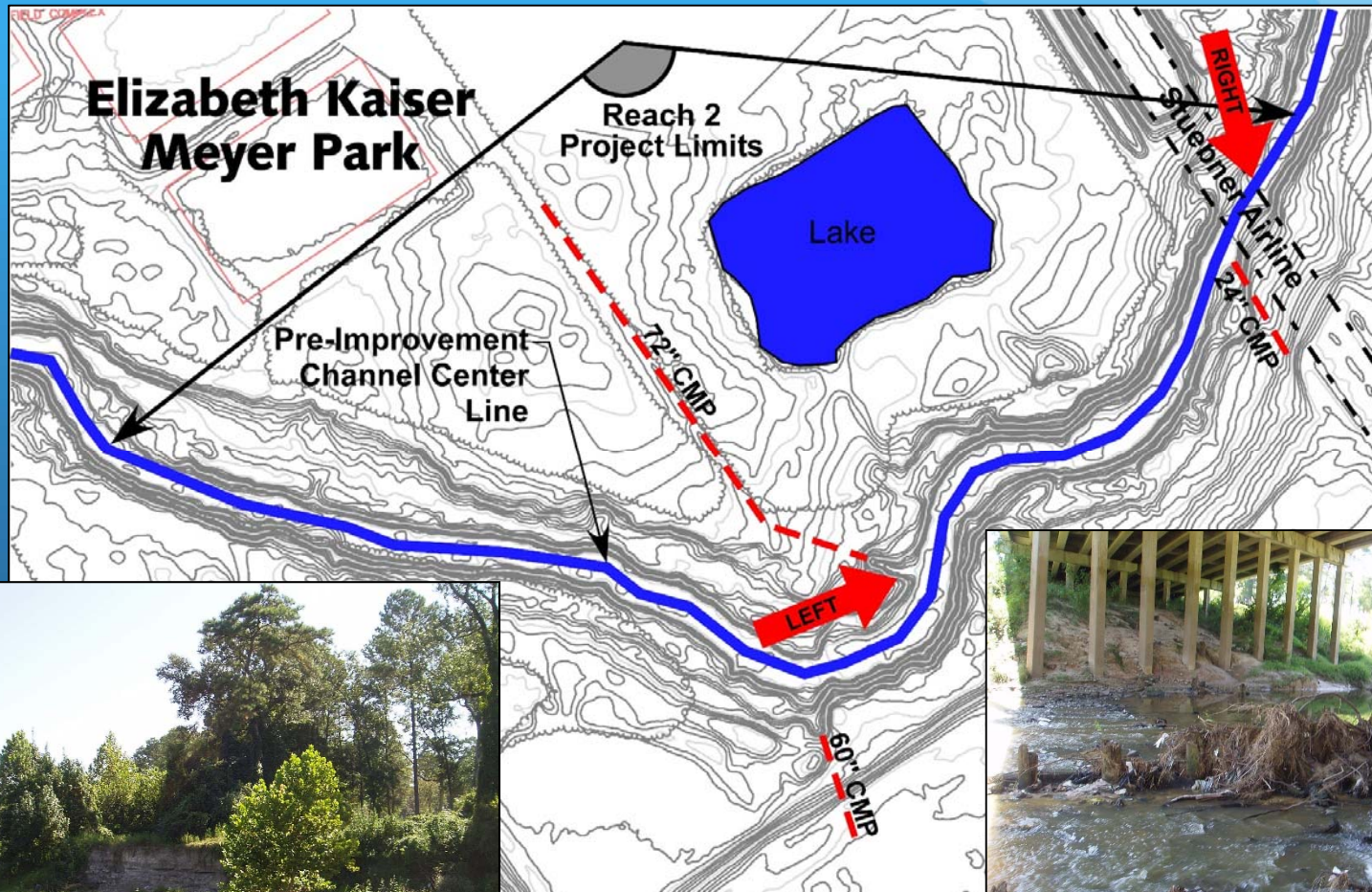


# Reach 2 - Existing





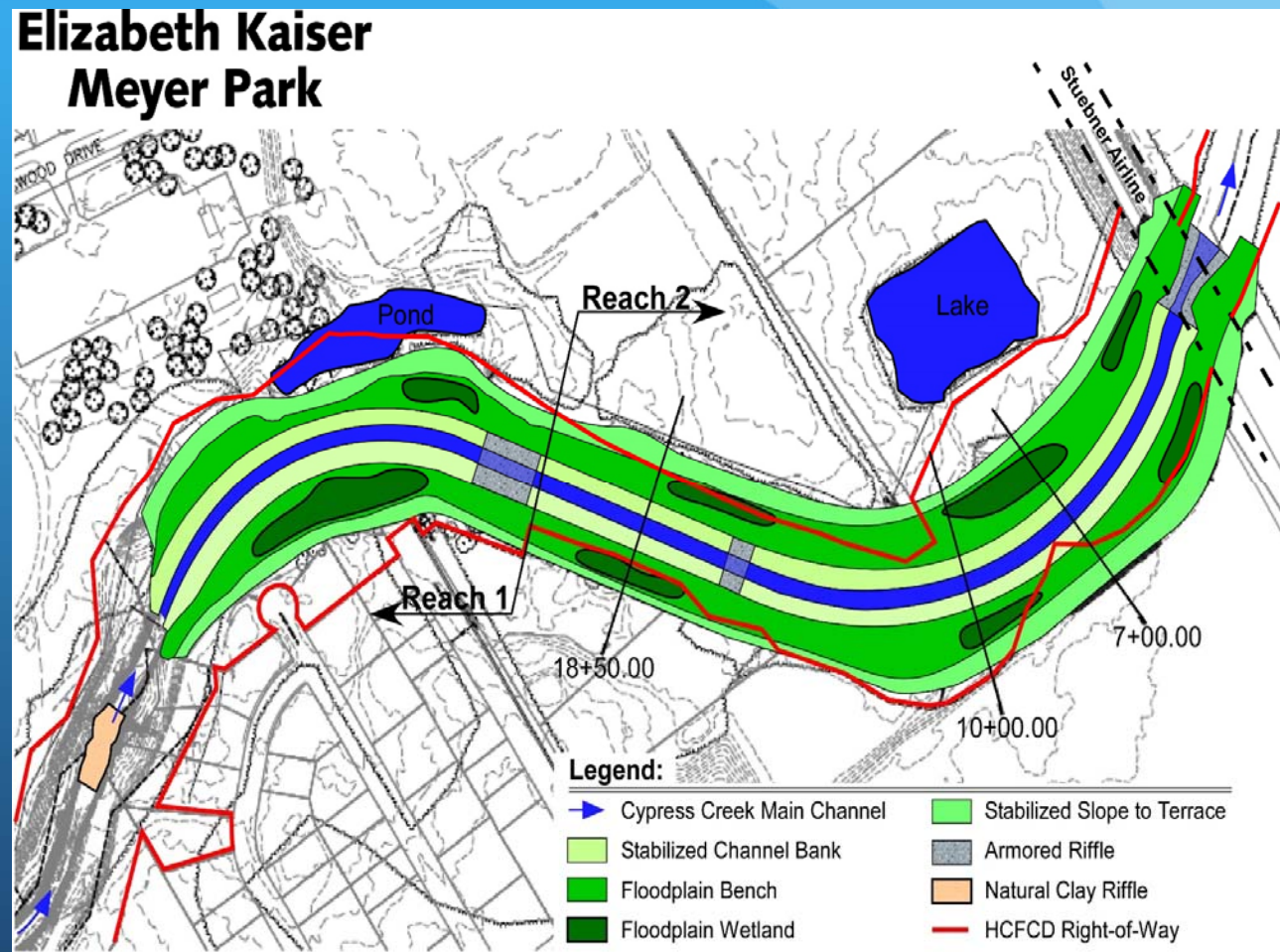
# Reach 2 - Existing



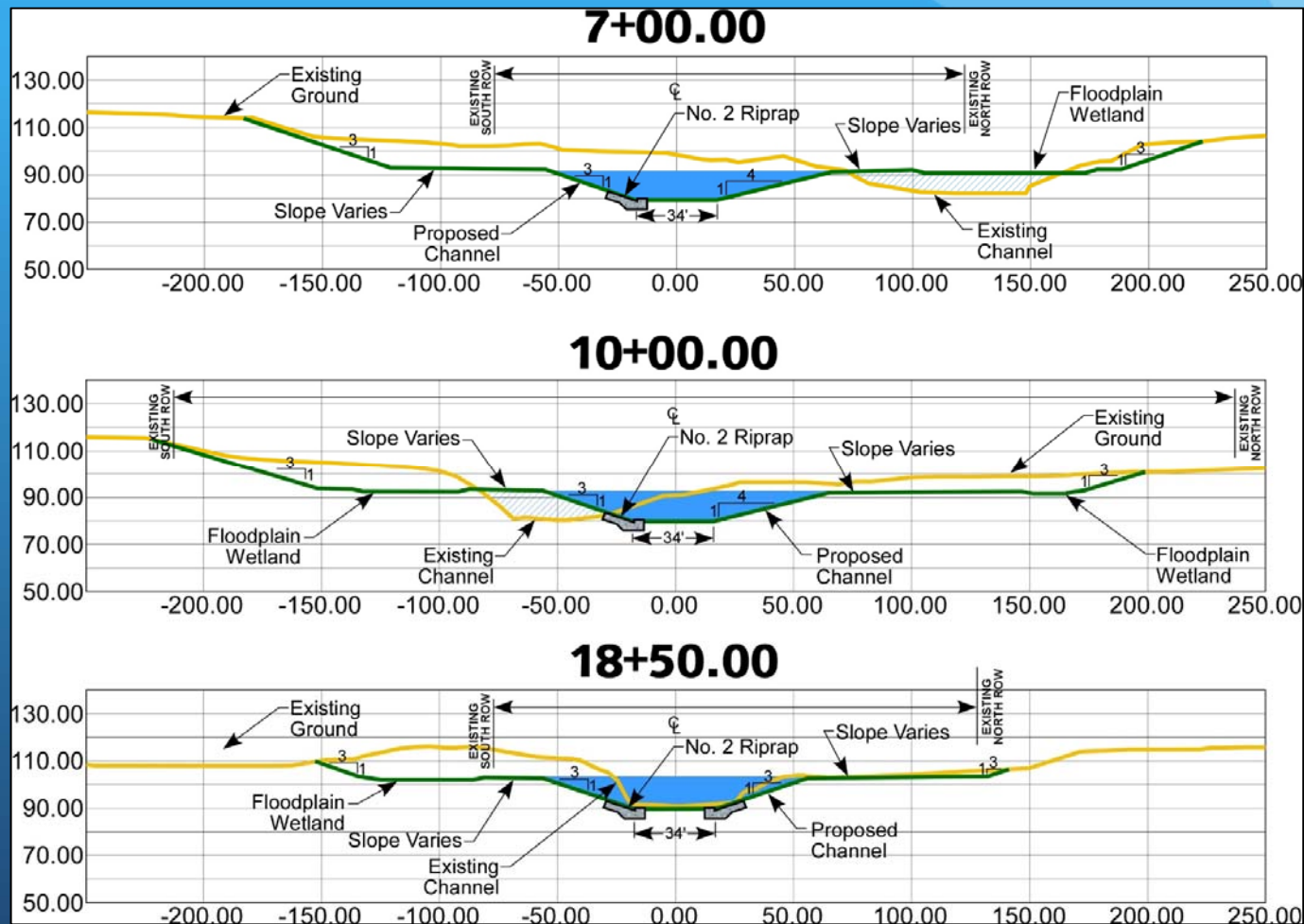


# Reach 2 - Improvements

- New, Priority 2 NCD Channel
- Constructed Boulder Riffles
- Constructed Floodplain Bench
- Stabilized Slopes
- Floodplain Wetlands
- Grass & Tree Plantings
- Armored Stormsewer Outfalls
- Greenway & Park Trail Alignments



# Reach 2 - Improvements





# Reach 2 - Construction



# Reach 2 - Construction





# Reach 2 - Construction



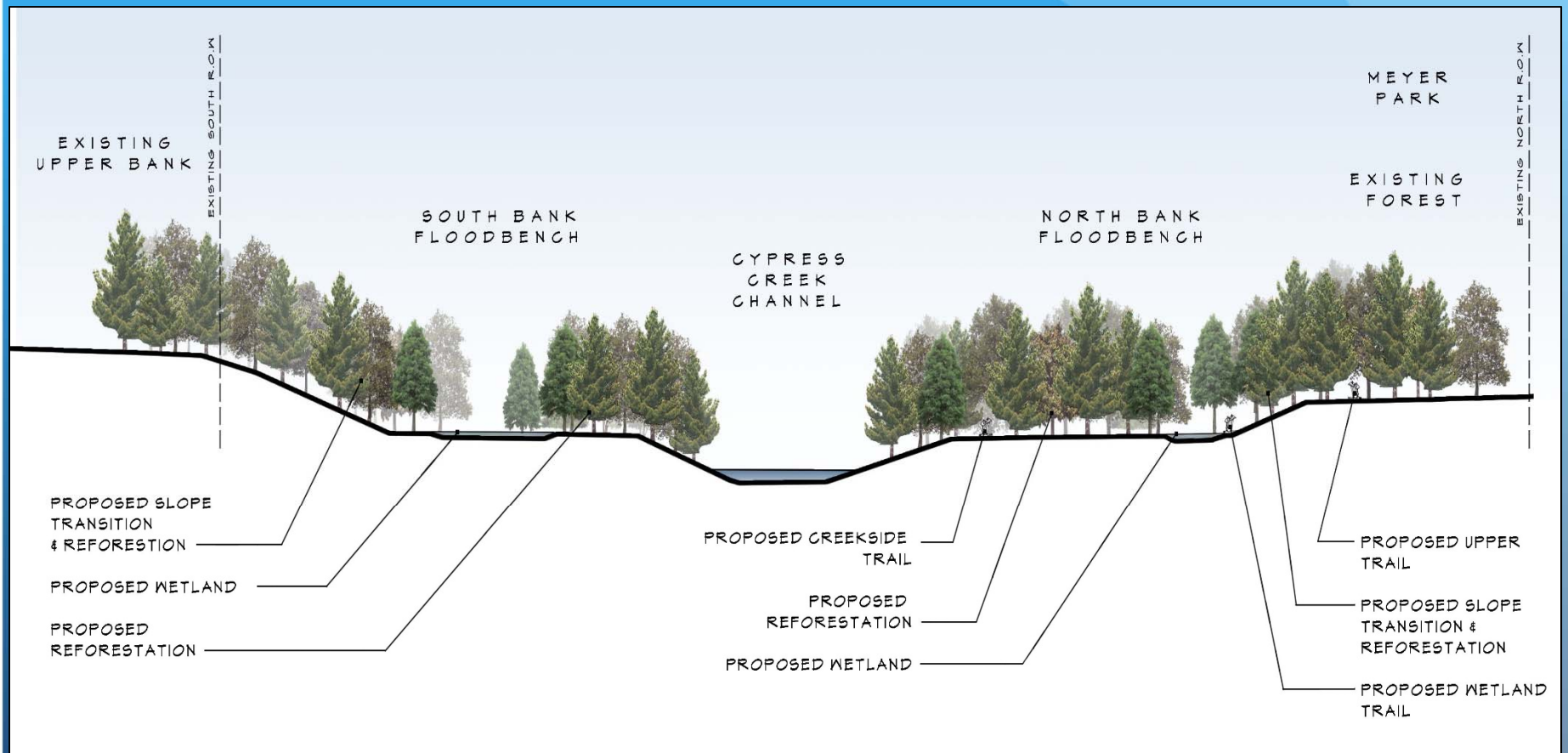


# Project Linear Park/Greenway Plan





# Project Linear Park/Greenway Plan



# Reach 1 Before & After (2009)

- Stable and self-improving after 8 bankfull events



**BEFORE**



**AFTER**





# Reaches 1 & 2 After (2017)

- Stable and self-improving after Memorial Day Flood (2015), Tax Day Flood (2016), and Hurricane Harvey (2017)



# Reaches 1 & 2 After (2017)

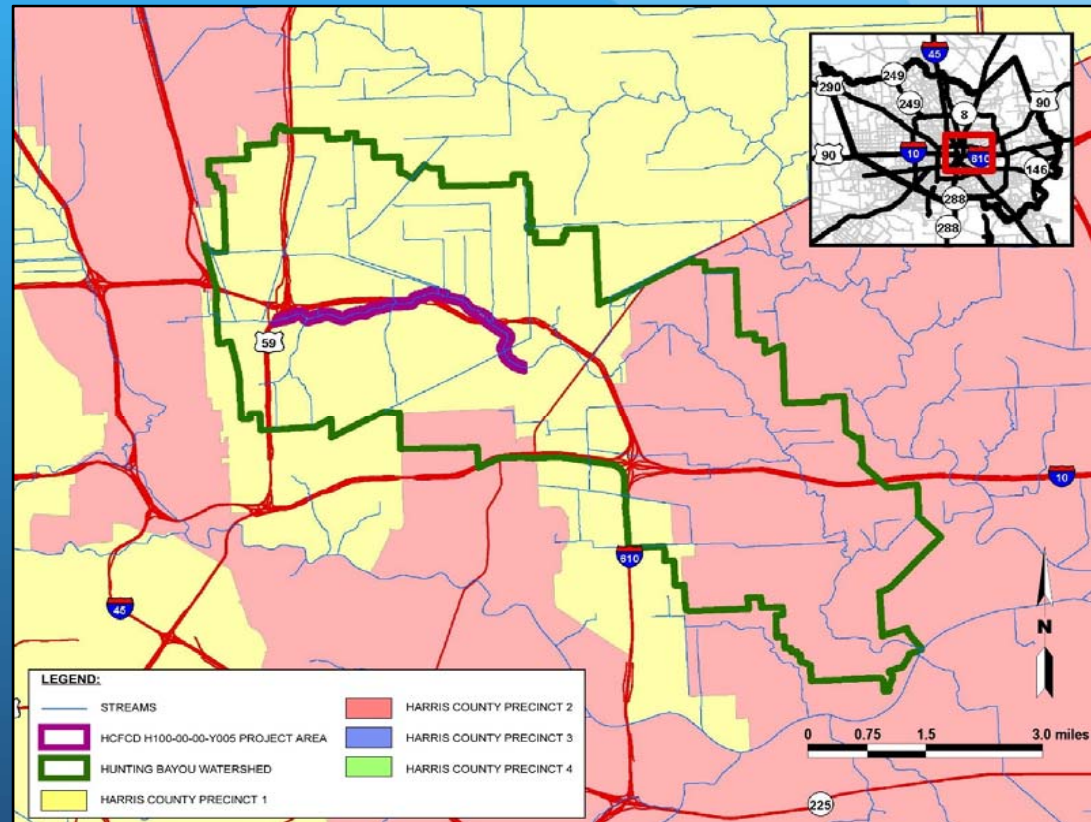
- Stable and self-improving after Memorial Day Flood (2015), Tax Day Flood (2016), and Hurricane Harvey (2017)



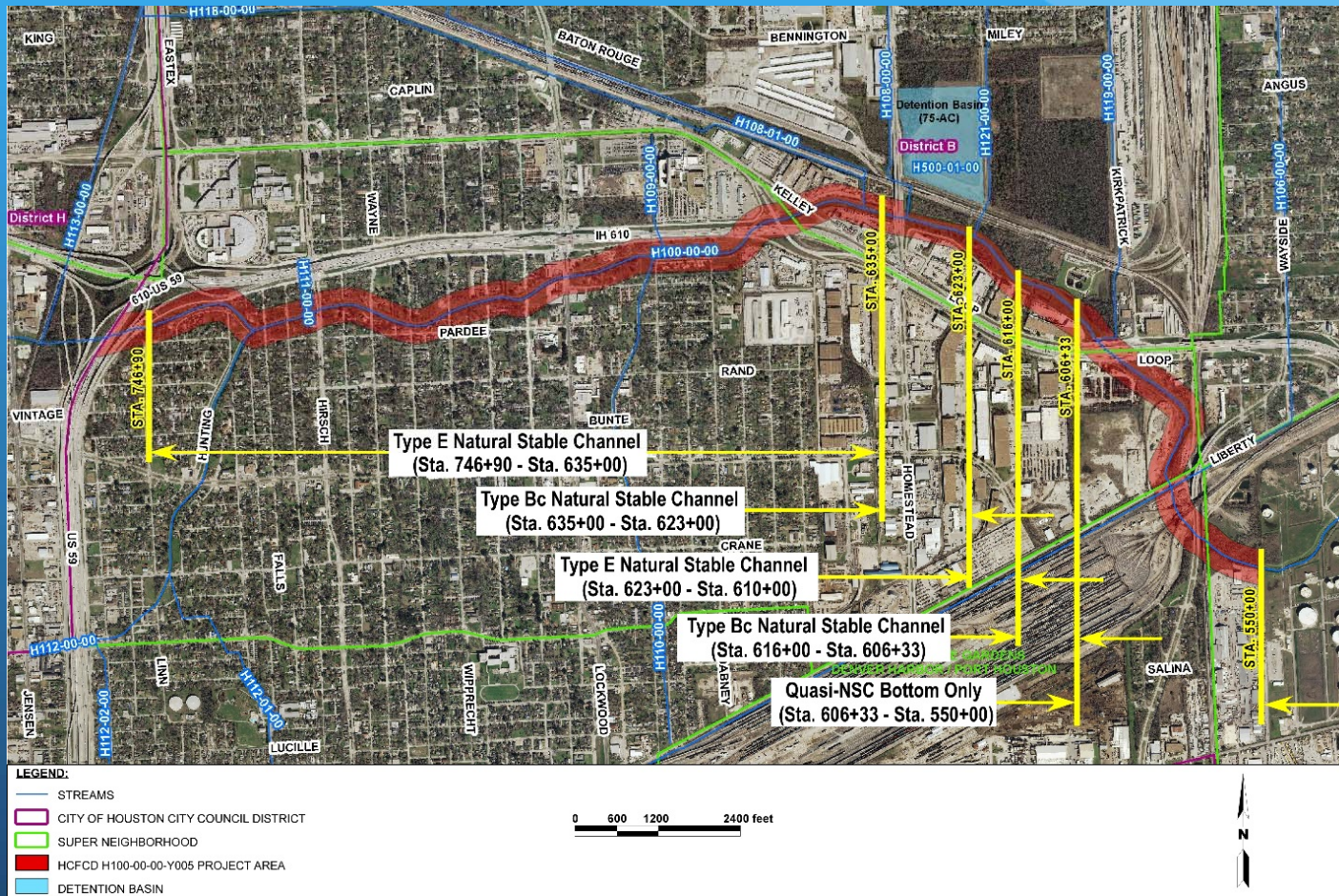


# Hunting Bayou Joint USACE Flood Risk Reduction Project

- Objectives:
  - Contain 10 or 25-year storm within FCC banks
  - Greenway trails
  - 3.8 miles of channel modifications
- Modification or replacement of:
  - 4 pedestrian bridges
  - 22 vehicular bridge structures
  - 6 rail and road bridges
- 75 acres of off-line detention



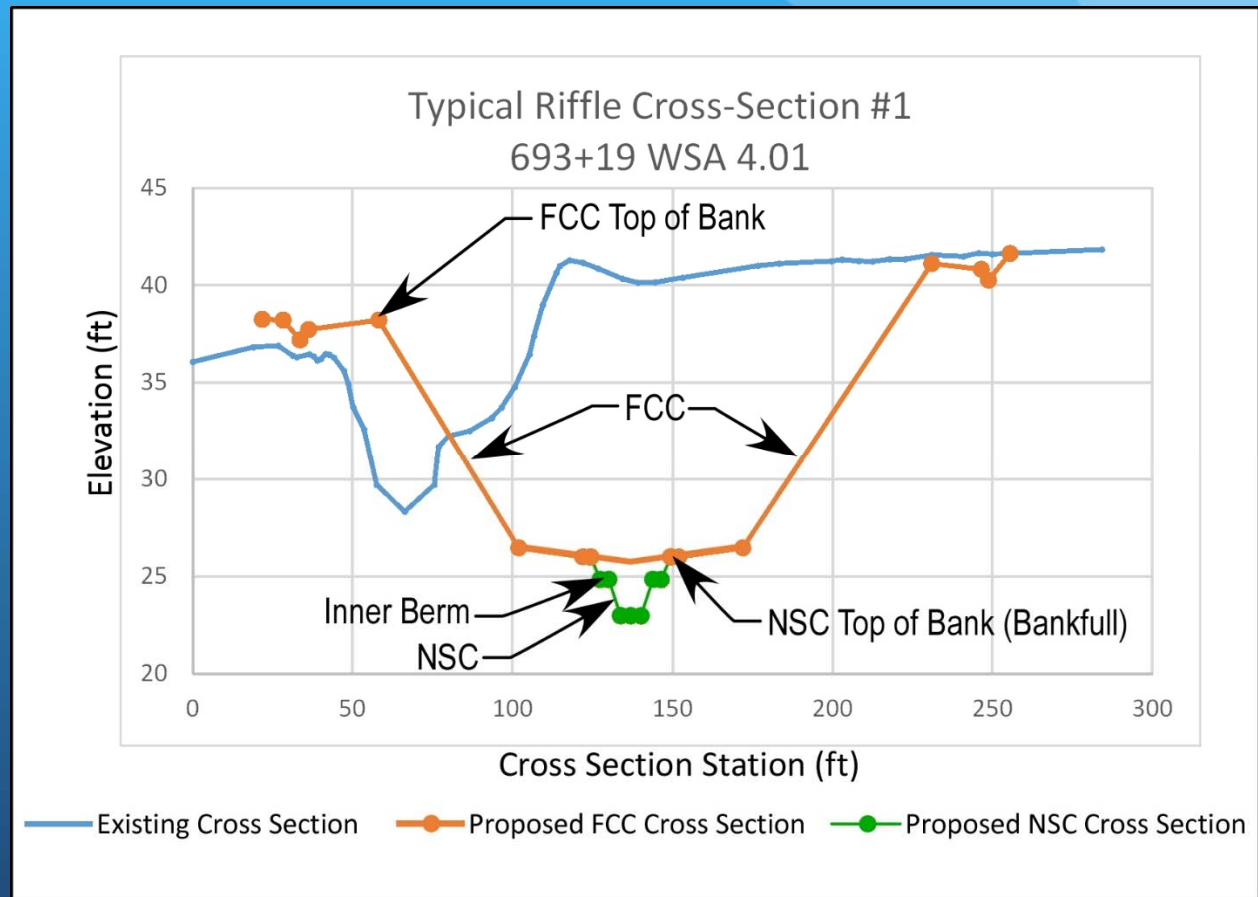
# Upper Hunting Bayou Joint USACE Flood Damage Reduction Project





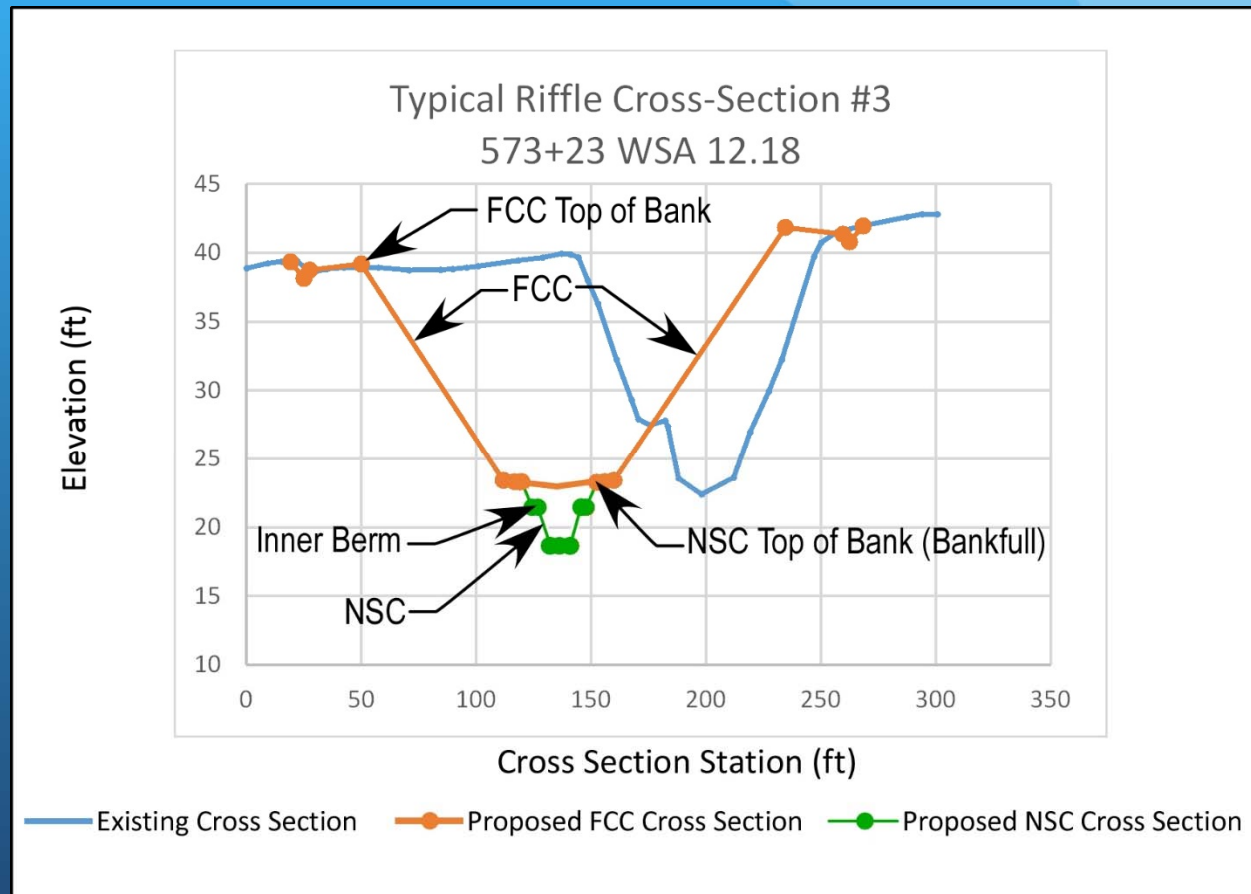
# Upper Hunting Bayou Joint USACE Flood Damage Reduction Project

- Rosgen C Channel (upstream end)



# Upper Hunting Bayou Joint USACE Flood Damage Reduction Project

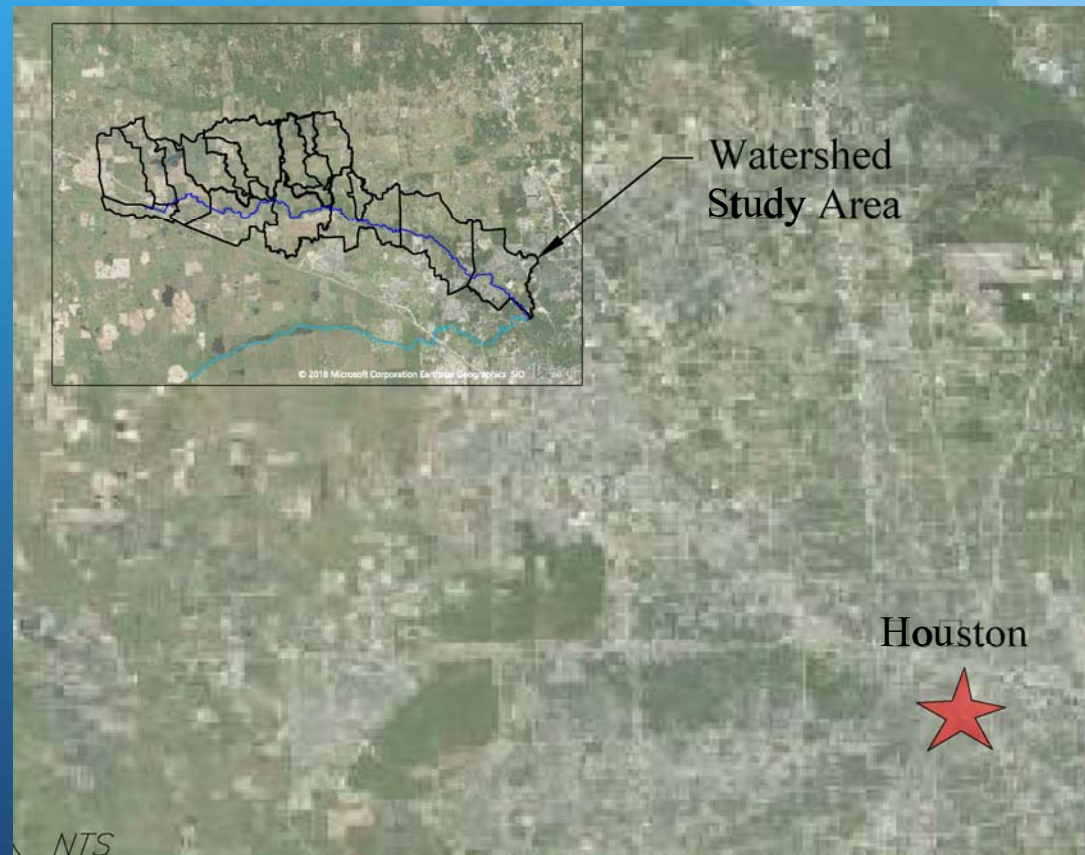
- Rosgen B Channel  
(downstream end)





# NSCD Concepts for Little Cypress Creek Master Drainage Plan

- Harris Cnty. "Frontier" is rapidly developing quasi-rural lands in NW Harris Cnty.
- Streams and channels already experiencing channel instability from hydromodification
- HCFCD will develop Priority 2 NSCD channels inside FCCs & detention basins to accommodate future growth

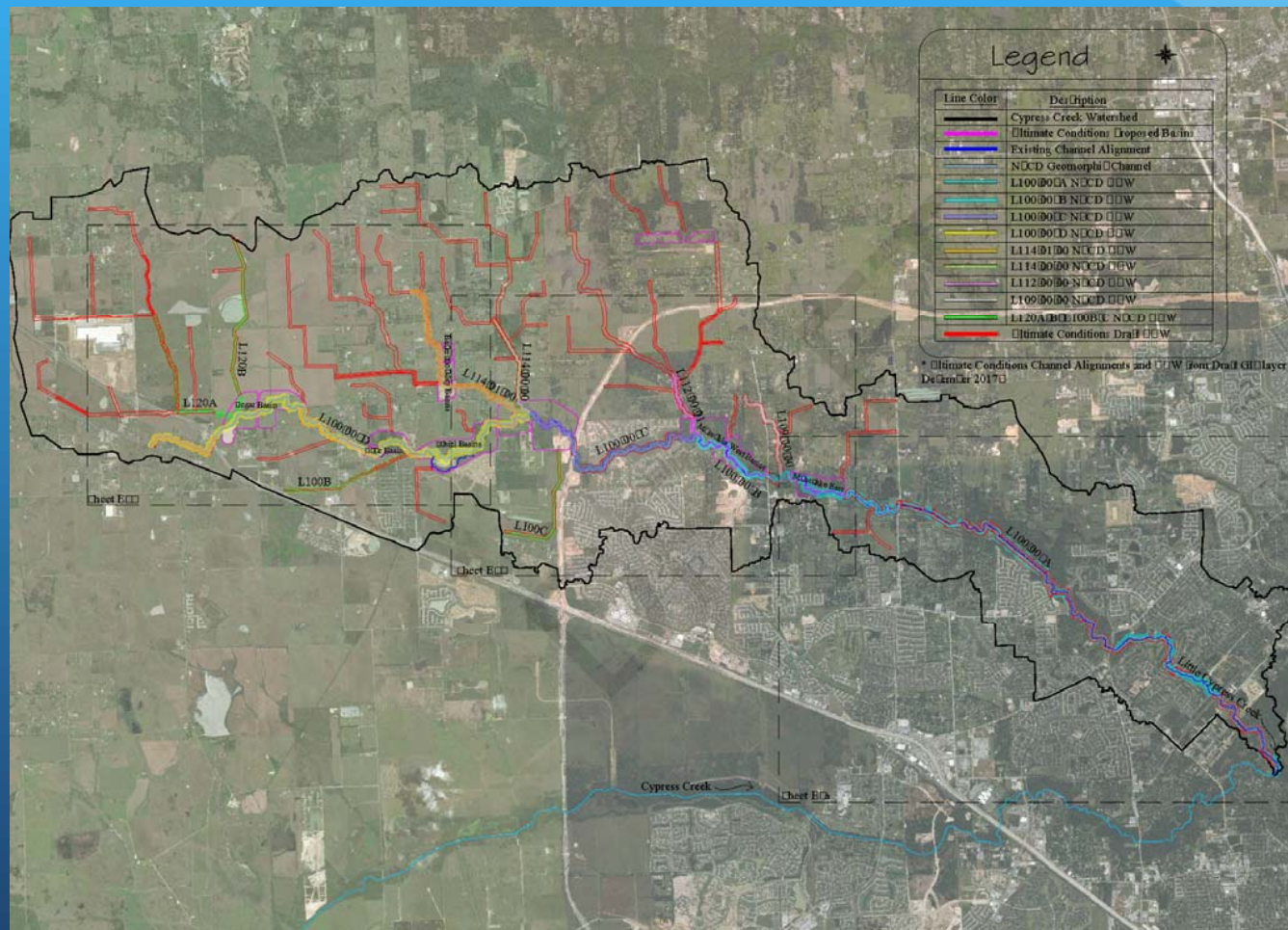


# NSCD Concepts for Little Cypress Creek Master Drainage Plan

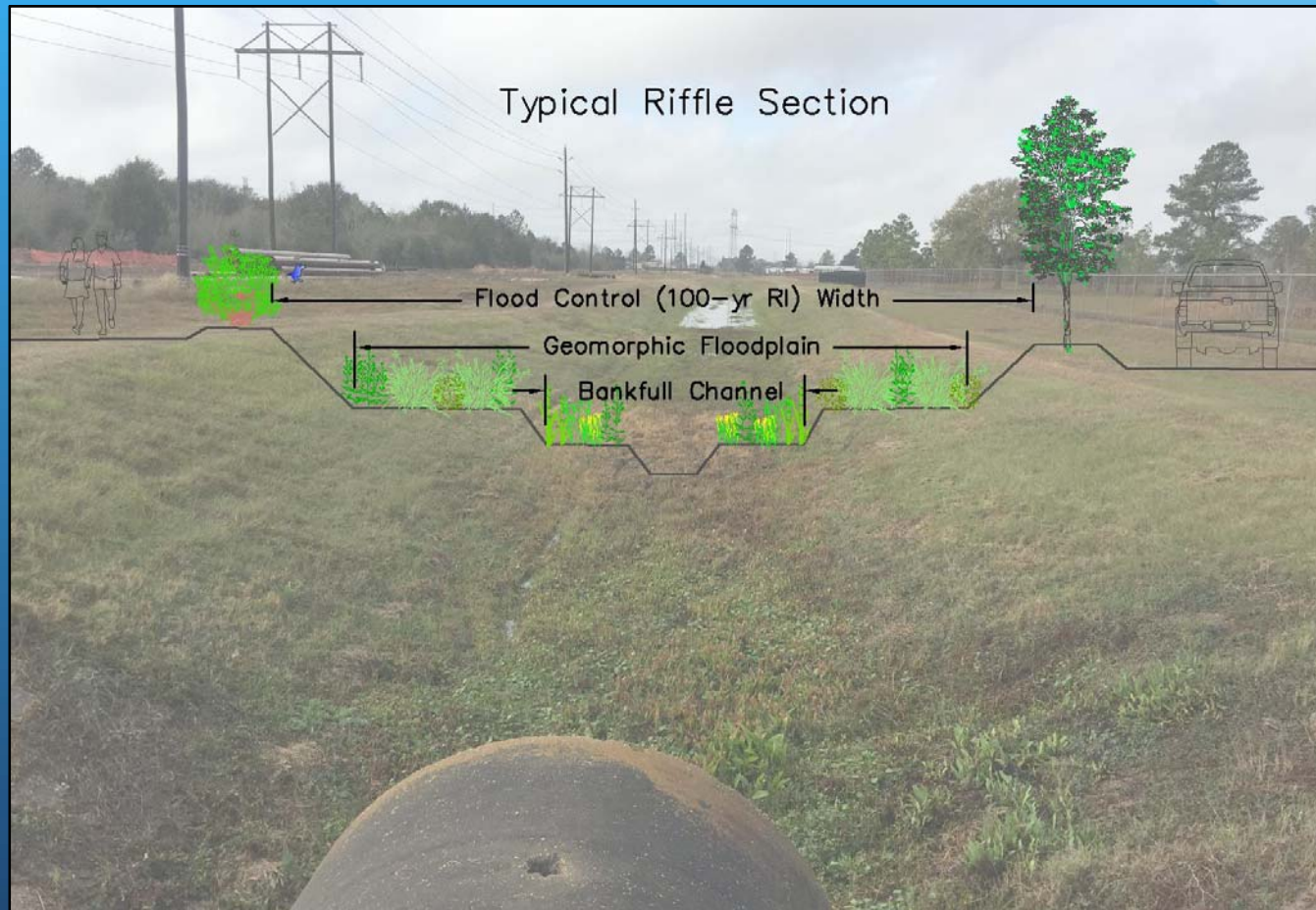




# NSCD Concepts for Little Cypress Creek Master Drainage Plan

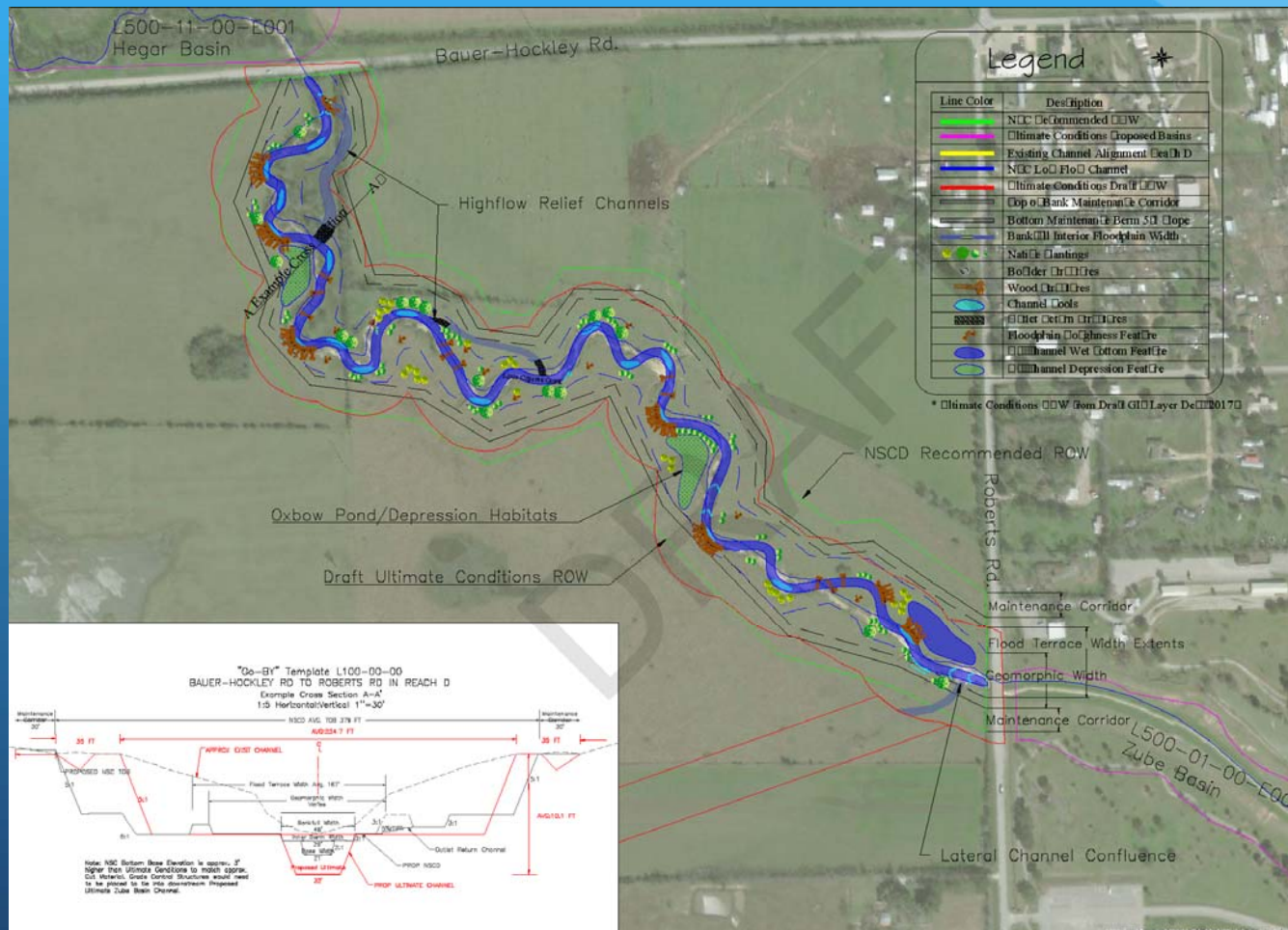


# NSCD Concepts for Little Cypress Creek Master Drainage Plan





# NSCD Concepts for Little Cypress Creek Master Drainage Plan



# NSCD Concepts for Little Cypress Creek Master Drainage Plan

Exhibit 7. Natural Stable Channel Conceptual Design Targets

Variable	Little Cypress Creek Mainstem								Tributaries (TSARP Catchments)			
Reach ID	L100-00_A	L100-00_B	L100-00_C	L100-00_D	L109-00-00	L112-00-00	L114-00-00	L114-01-00	L120A	L120B	L100B	L100C
River Station	51947.2-1315.9	60219.9-53547.5	77338.64-61906.7	115231.7-79600.74	4209.3-669.2	11804.0-500	6606.2-903.7	5494-755.7	-	-	-	-
Drainage Area (DA) sq. mi.	52.3	33.9	27.2	18.3	0.85	6.65	4.82	4.11	4.06	2.58	4.02	4.24
Ultimate 2-yr (max) Bankfull Discharge cfs	2070	1745	1462	1135	291	1027	727	79	-	-	-	-
Ultimate Avg. Channel Slope (ft/ft)	0.0008	0.0005	0.0006	0.0012	0.0026	0.0043	0.0026	0.0025	0.001	0.0005	0.001	0.001
Ultimate Q 2-yr (avg) slope (ft/ft)	0.0006	0.0002	0.0010	0.0009	0.0026	0.0041	0.0019	0.0001	-	-	-	-
Ultimate 100-yr Omax cfs	6980	4915	4610	4791	746	3179	2946	233	1369	833	1538	2057
Ultimate Avg. Q 100-yr depth (ft.)	21	14	12	12	8	10	12	14	-	-	-	-
Ultimate Reach Length (miles)	9.6	1.7	3.2	7.0	1.4	4.2	1.3	2.6	-	-	-	-
Ultimate Sinuosity (K)	1.2	1.3	1.3	1.2	1.03	1.04	1.09	1.03	-	-	-	-
Ultimate ROW	400-500	-	320	320	240	240	240	240	160	240	160	-
NSCD Stream Type	C5c	C5c	C6c	C6	B5c	B5c	B5c	B5c	B5c	B5c	B5c	B5c
HCFC Discharge by Impervious Cover (Q <sub>b</sub> ft)	1143	787	651	464	33	190	158	144	144	111	143	147
Threshold Floodplain Applied Shear Stress (lb/sqft)	2	2	2	2	2	2	2	2	2	2	2	2
Maximum Permissible Velocity Threshold (ft/s)	2	2	2	2	2	2	2	2	2	2	2	2
NSCD 100-yr Cross-sectional Area (sq.ft)	3490	2458	2305	2396	373	1590	1473	117	685	416	769	1029
Bankfull Area (A <sub>b</sub> ft) (sq.ft.)	218	167	146	114	17	61	50	45	34	34	45	46
Width/Depth Ratio (WDR)	20	20	20	20	22	22	22	22	22	22	22	22
Bankfull Riffle Width (W <sub>b</sub> ft) (ft.)	66	58	54	48	19	37	33	32	31	27	31	32
Bankfull Riffle Width Extents (ft)	178	201	187	165	64	124	112	106	106	91	106	107
Bankfull Mean Riffle Depth (D <sub>b</sub> ft) (ft.)	3.3	2.9	2.7	2.4	0.9	1.7	1.5	1.4	1.4	1.2	1.4	1.4
Bankfull Max Riffle Depth (ft.)	5.3	4.6	4.3	3.8	1.4	2.7	2.4	2.3	2.3	2.0	2.3	2.3
Low Flow Q (cfs)	480	331	274	195	14	80	66	61	60	46	60	62
Inner Berm Area (sq.ft)	102	78	68	53	8	28	23	21	21	16	21	22
Inner Berm Width (ft.)	39	34	32	28	11	22	20	19	19	16	19	19
Inner Berm Width Extents (ft.)	65	57	53	47	19	36	32	31	31	27	31	31
Base Width (ft.)	29	25	23	21	9	16	15	14	14	12	14	14
Low Flow Depth (ft.)	2.6	2.3	2.1	1.9	0.7	1.3	1.2	1.1	1.1	1.0	1.1	1.1
Entrenchment ratio (W <sub>b</sub> /W <sub>b</sub> ft)	3	3	3	3	2	2	2	2	2	2	2	2
Flood Terrace Area (sq.ft)	551	697	604	467	64	242	196	177	175	131	174	180
Flood Terrace Width (W <sub>t</sub> ft) (ft.)	182	204	190	167	65	126	114	108	108	93	107	109
Flood Terrace Width Extents (ft.)	209	235	219	192	75	145	131	124	124	107	123	125
Flood Terrace Depth (ft.)	7	6	5	5	2	3	3	3	3	2	3	3
Radius of Curvature RC Range (ft.)	111-166	90-134	84-125	68-102	29-43	60-90	84-125	47-70	50-75	44-66	48-72	48-72
Sinuosity K (ft/ft)	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Belt Width Avg. (ft.)	149	130	121	107	44	82	74	71	71	61	70	72
Meander Wave Length Avg. λ (ft)	676	591	552	488	198	374	339	322	321	279	320	326
ROW Recommendations Unconfined Reaches	518	444	432	439	217	384	372	148	273	226	285	321

\*Discharge (2yr max), Channel Slope, 2yr Q avg Slope, populated from Ultimate Conditions W/Channel Improvements HEC-RAS model (Draft LAN 2017).

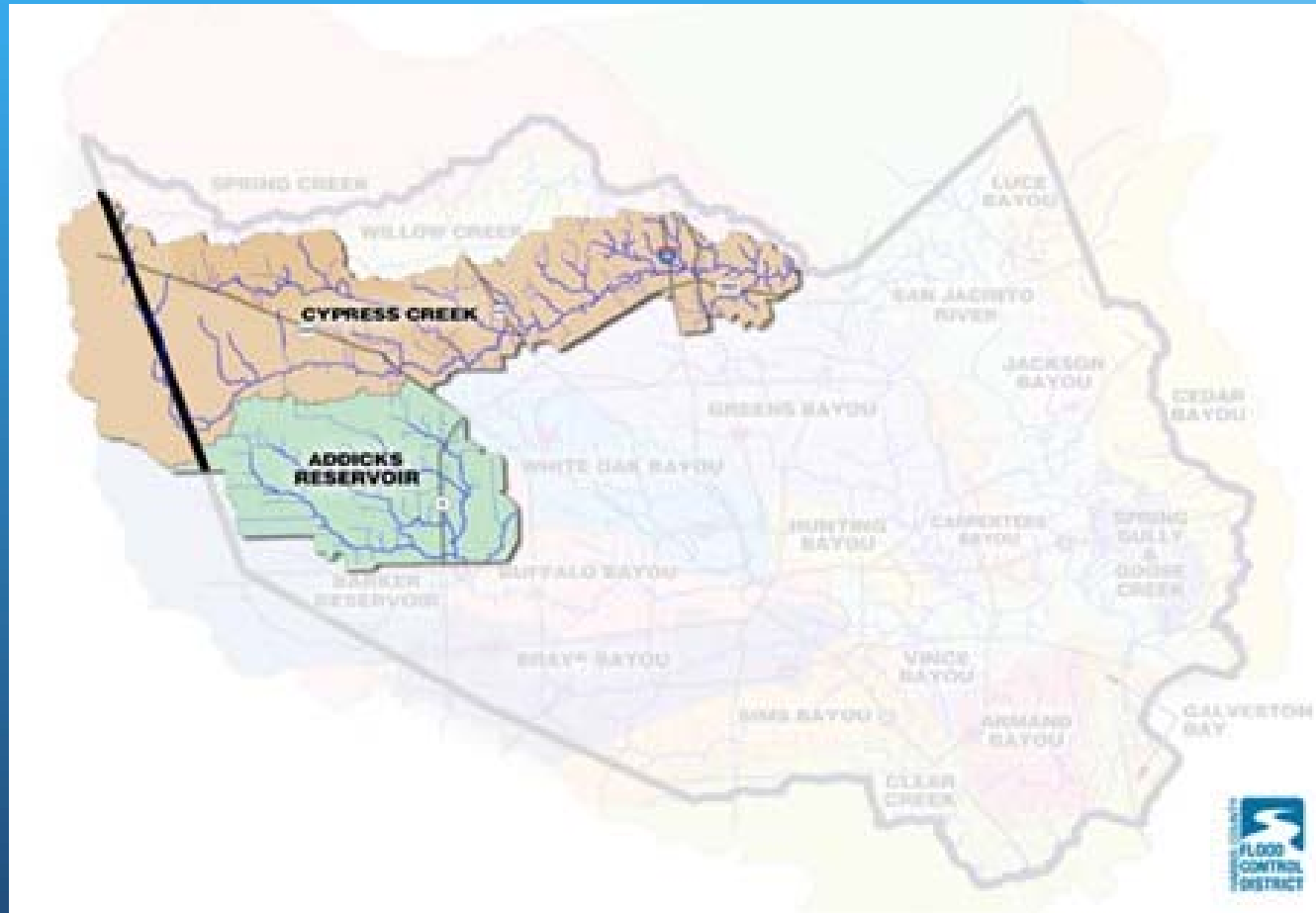
\*Drainage areas based on sub watersheds values provided in TC&R K100&L100, FEMA template, 2013. Drainage basins shown on Cover Page.

\*Reach L109-00 drainage area based from LAN shape file.

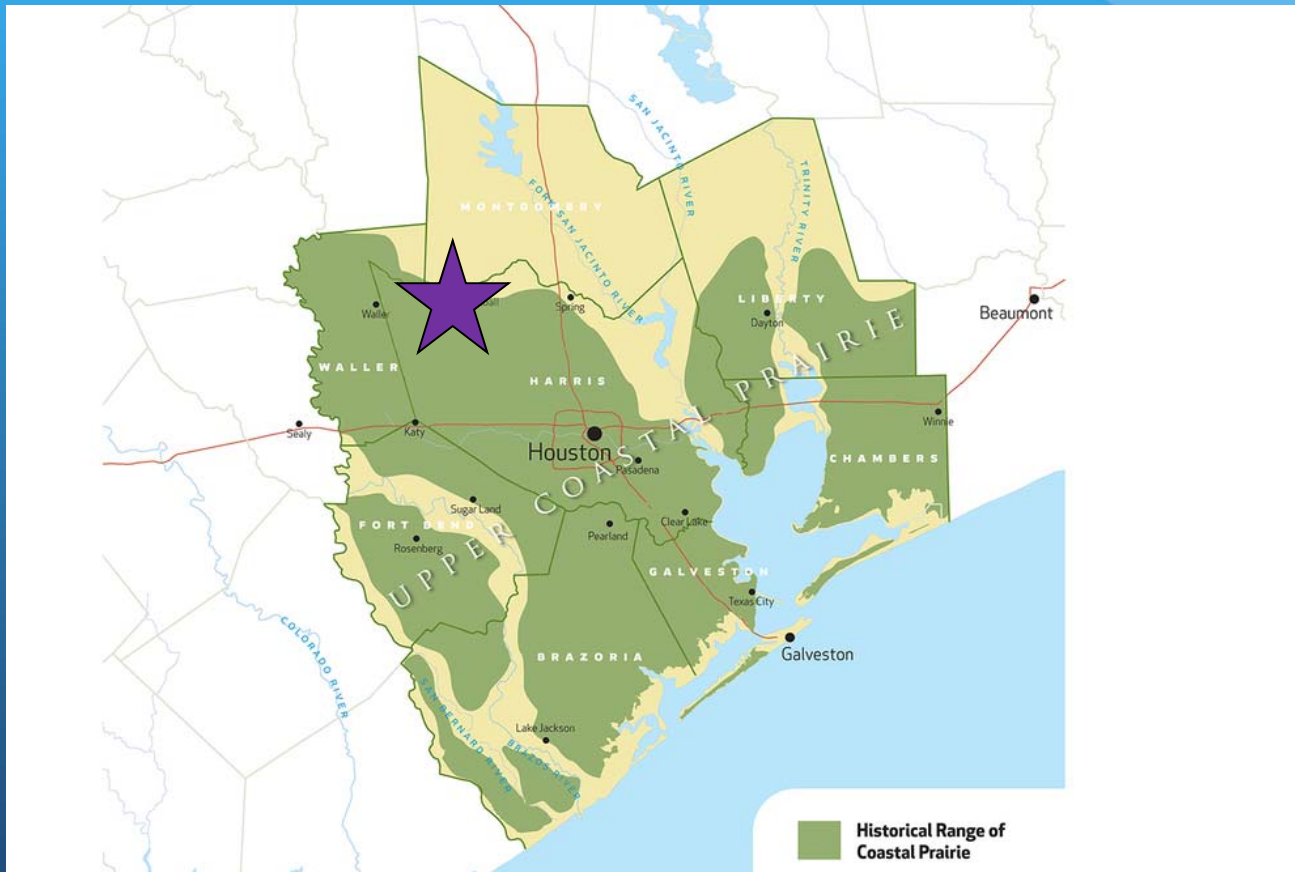
\*Values listed for L114\_00 are from the hydraulic model reach L114\_00B.



# Cypress Creek Overflow & Priority 1 Restoration of Headwater Streams



# Katy Prairie Stream Mitigation

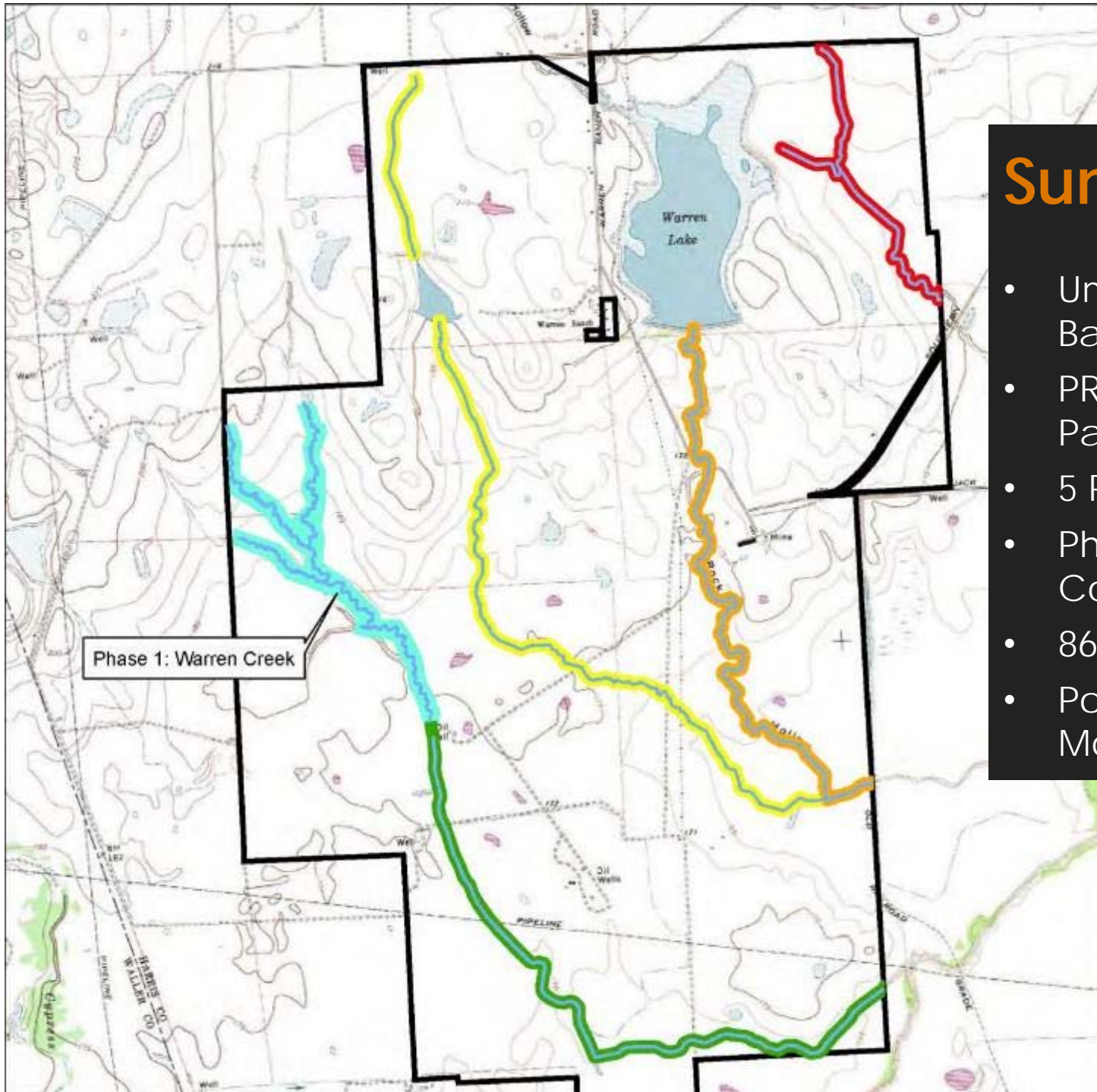




# Project Partners

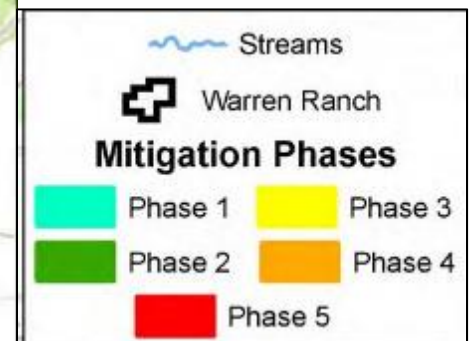
- Restoration Systems LLC
- Warren Ranch
- Katy Prairie Conservancy
- Stantec
- Forbes Consultancy
- Land Mechanics
- Wright Contracting
- Stuckey's Contract Services





## Summary

- Umbrella Mitigation Bank
- PRM for the Grand Parkway
- 5 Phases
- Phases 1 – 4 Constructed
- 86,000 Total Feet
- Post Construction Monitoring



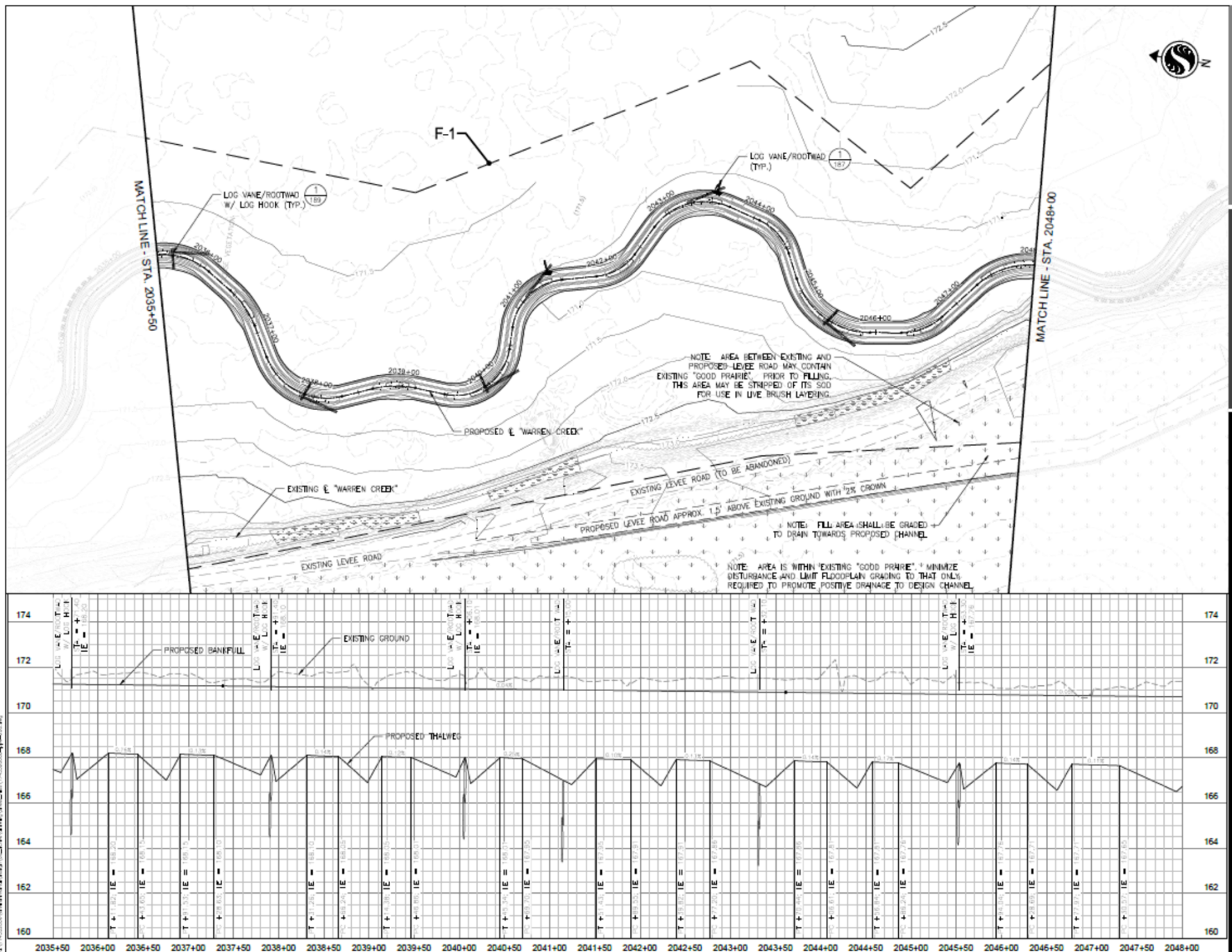


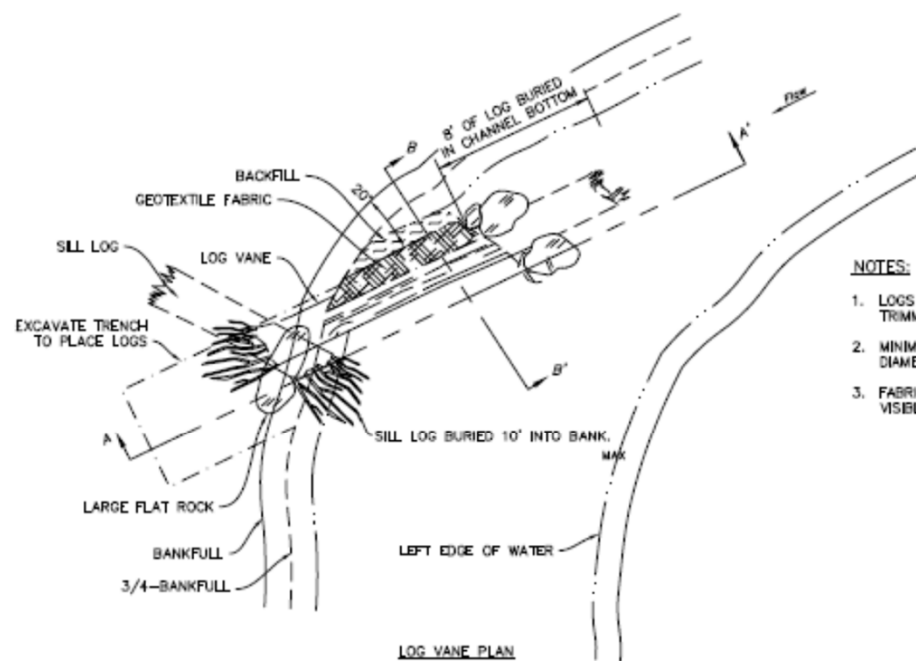
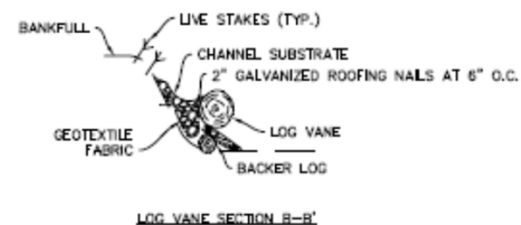
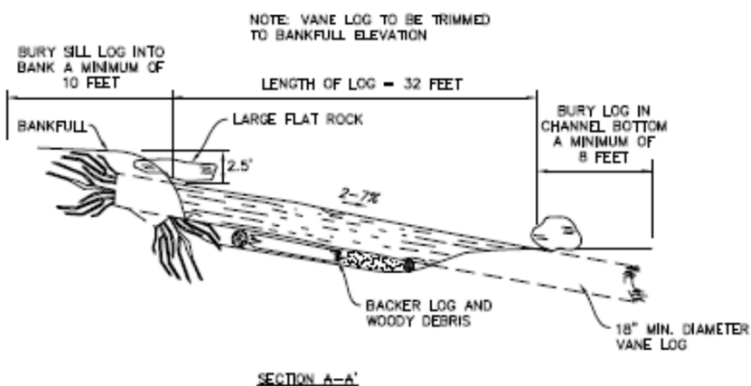












NOTES:

1. LOGS SHALL BE STRAIGHT AND LIMBS SHALL BE TRIMMED FLUSH.
2. MINIMUM LOG LENGTH IS 50 FEET AND MINIMUM DIAMETER IS 16 INCHES.
3. FABRIC SHALL BE COMPLETELY BURIED AND NOT VISIBLE.





















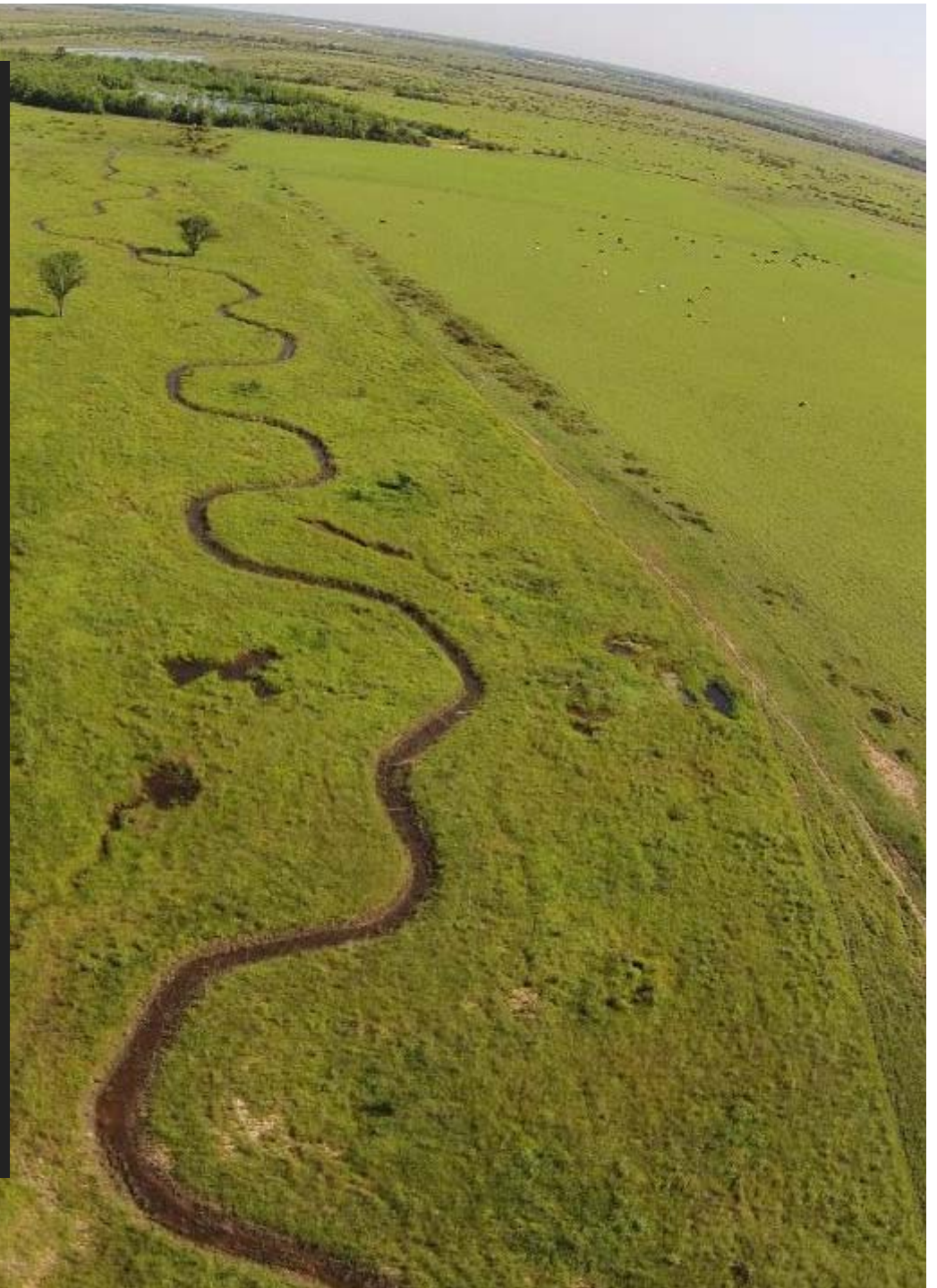


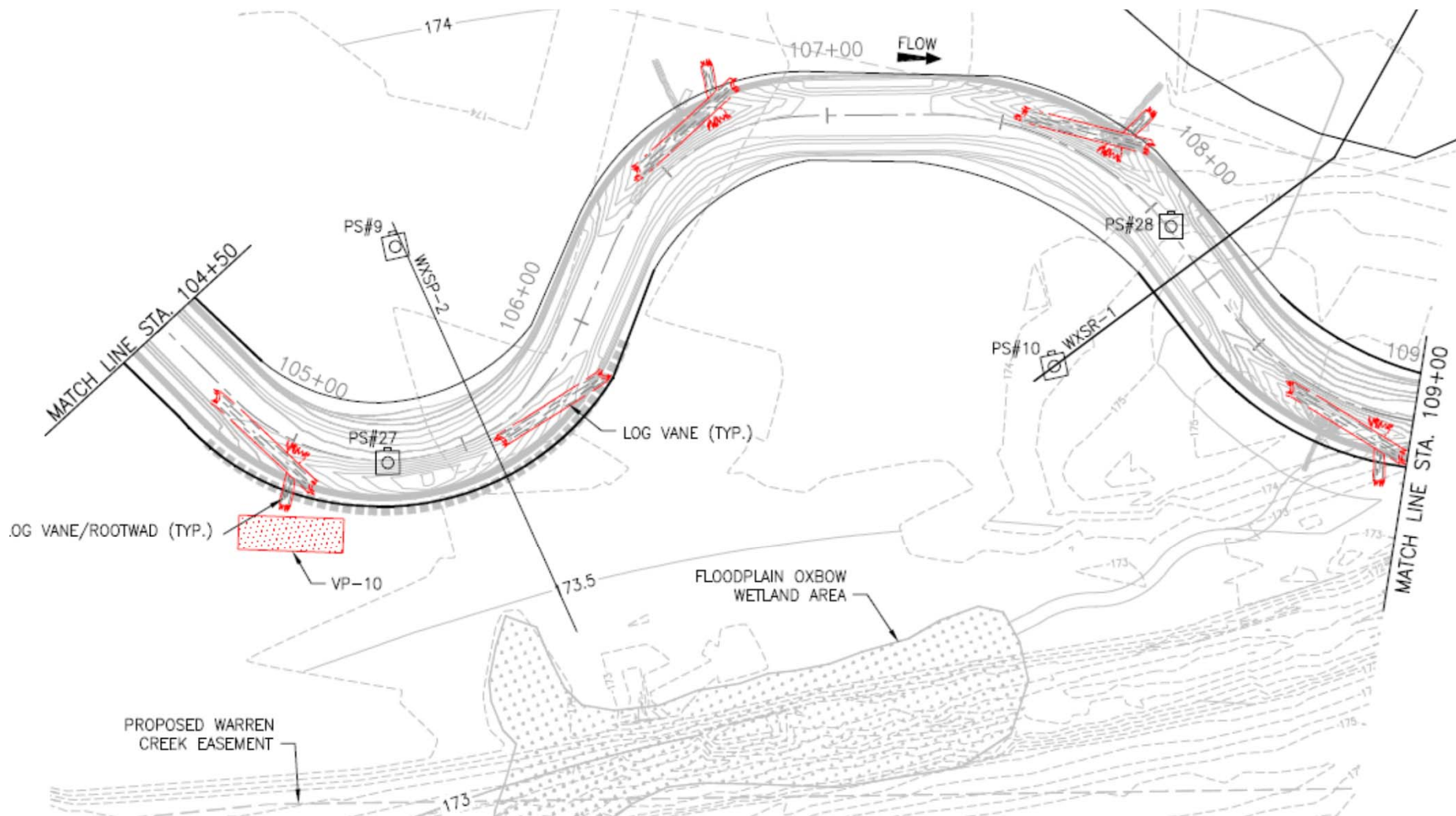




# Monitoring Summary

- As-Built Survey
- Geomorphic Survey
  - Longitudinal Profile
  - Cross Sections
- Photographic Documentation
- Vegetation Survey
  - Species Composition
  - % Cover
  - Density
- Level 1 Stream Condition Assessment
- Bankfull Event



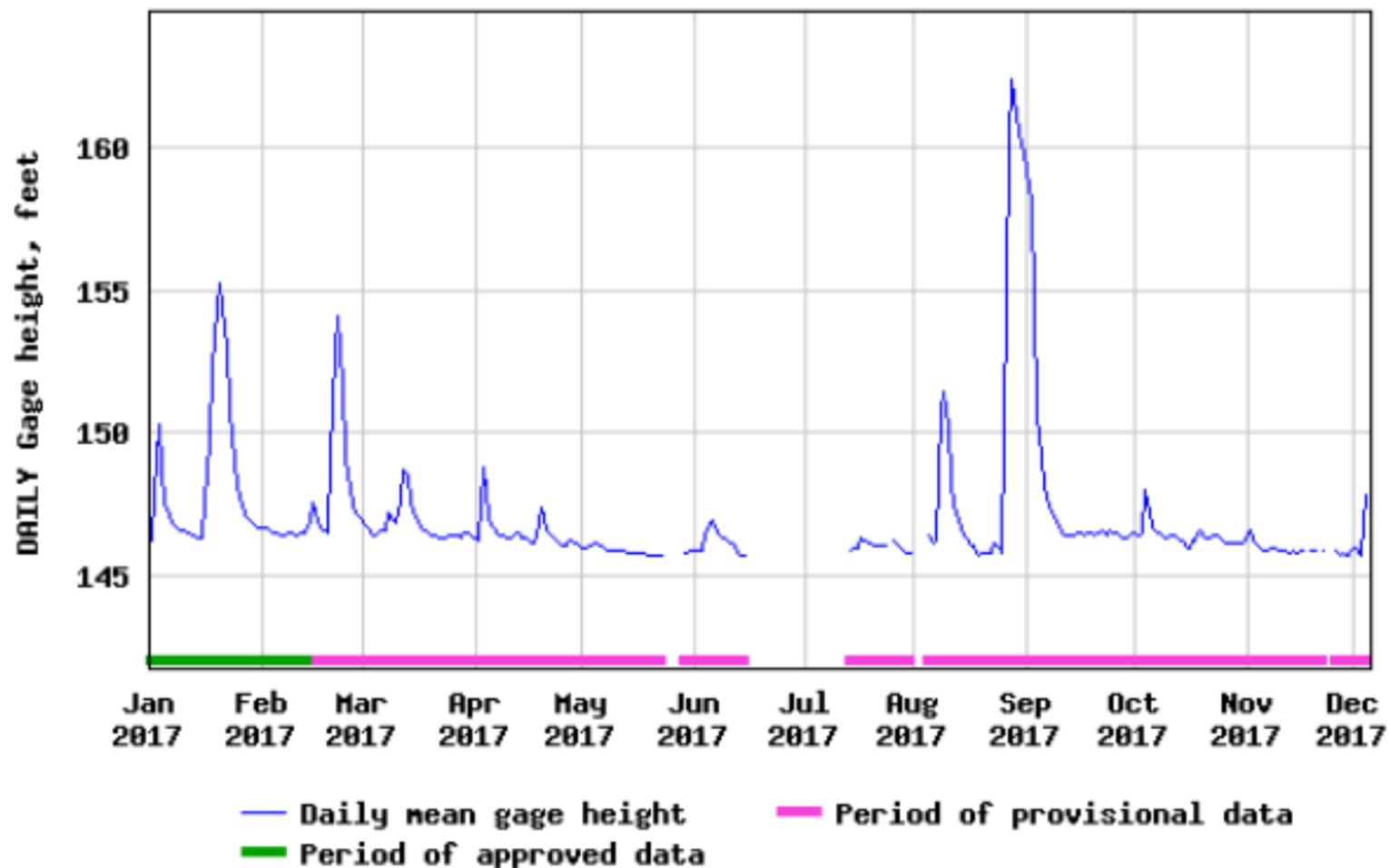




# Daily Gage Height Jan. – Dec. 2017

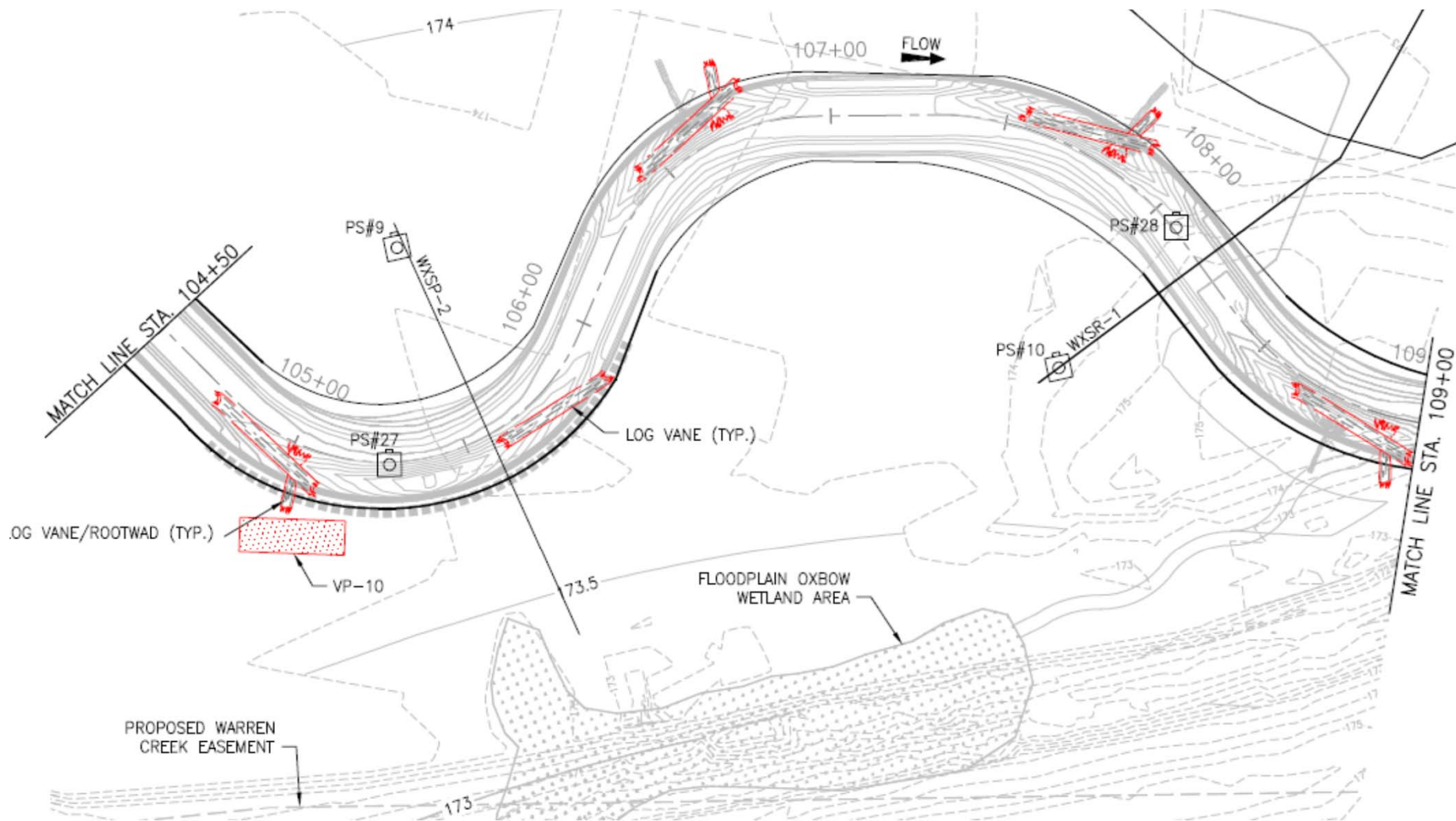


USGS 08068720 Cypress Ck at Katy-Hockley Rd nr Hockley, TX

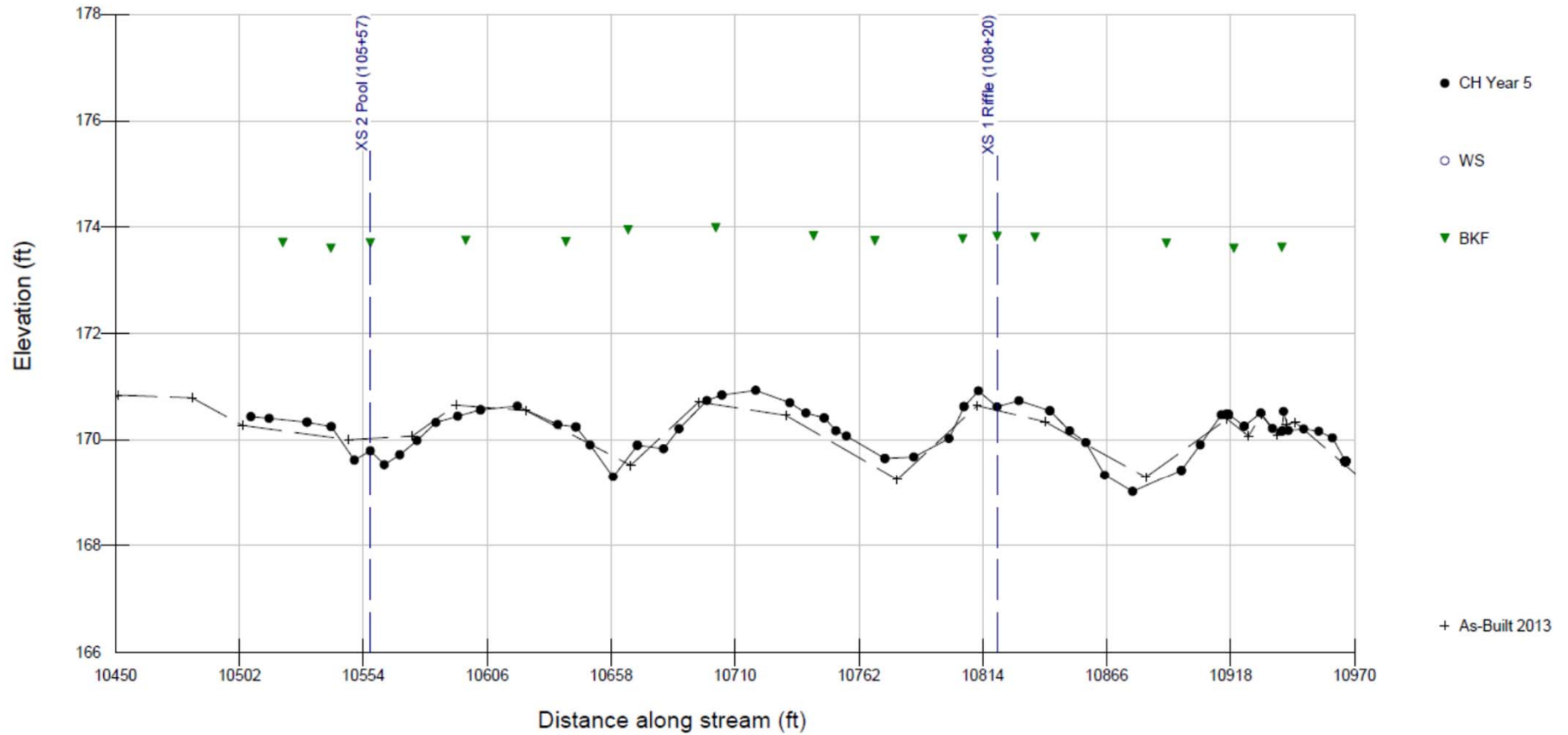






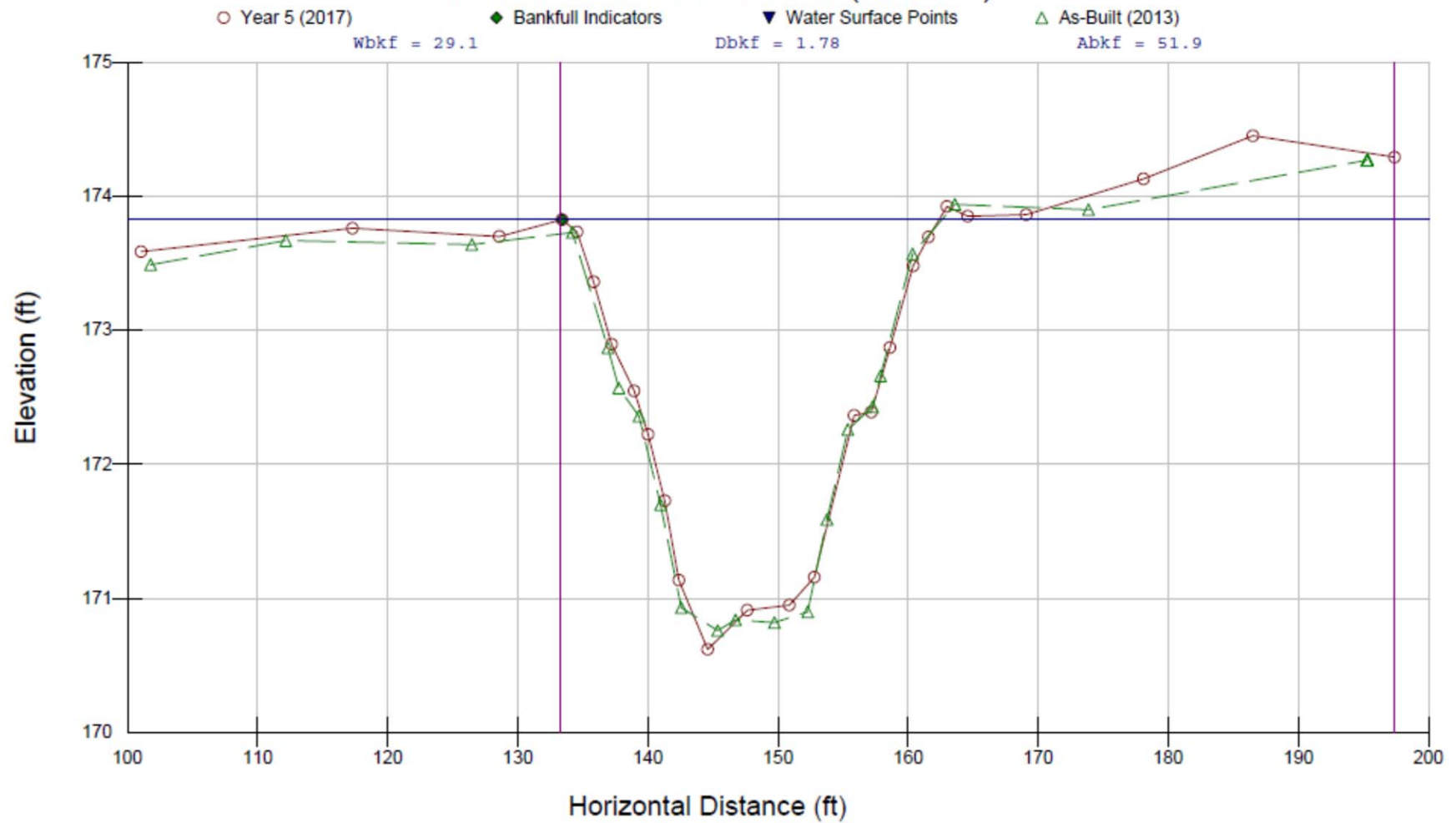


Warren Creek Reach 3 Longitudinal Profile 104+52 to 109+41 Year 5 (2017)

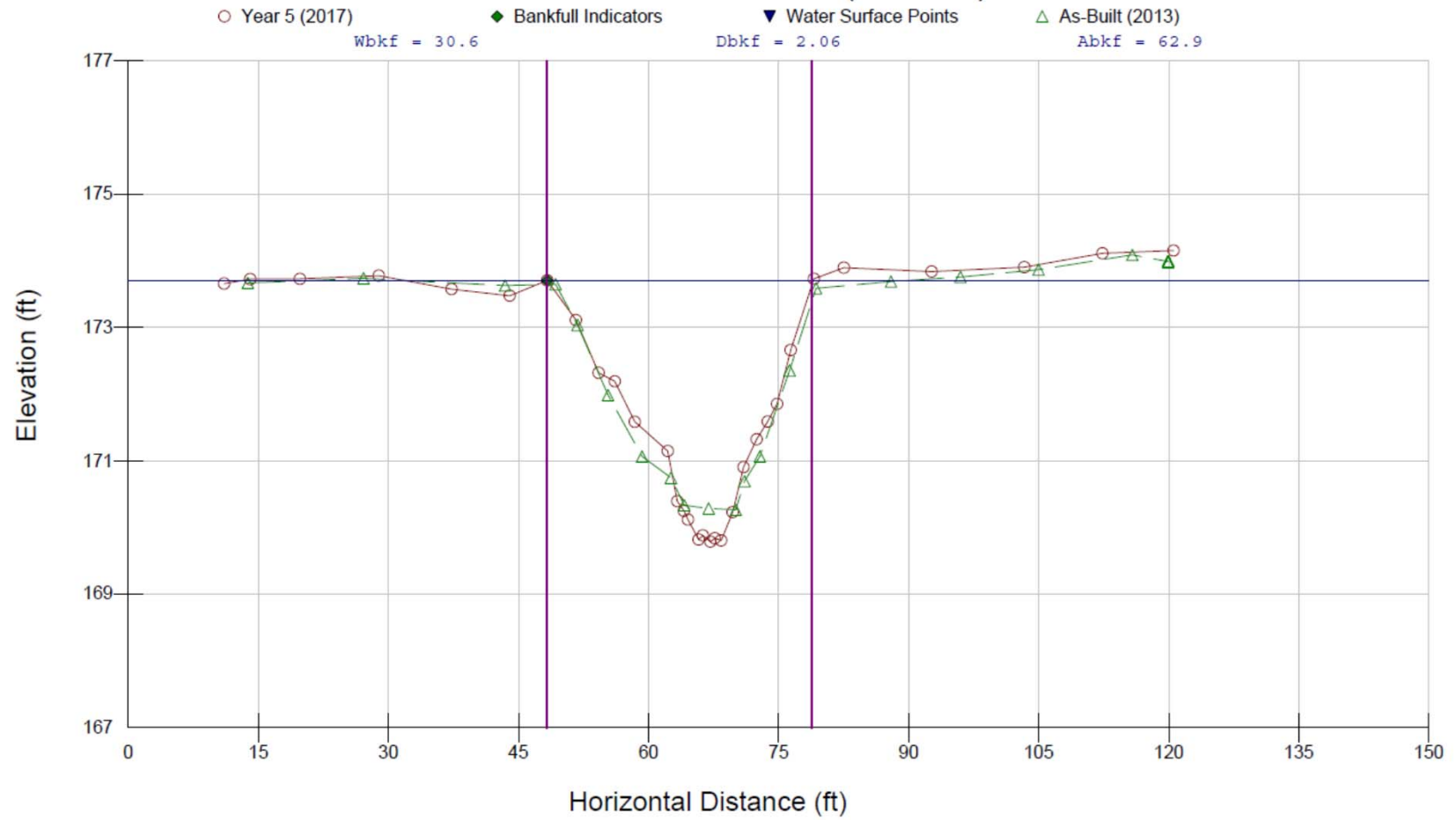




## Warren Creek XS 1 Riffle (108+20)

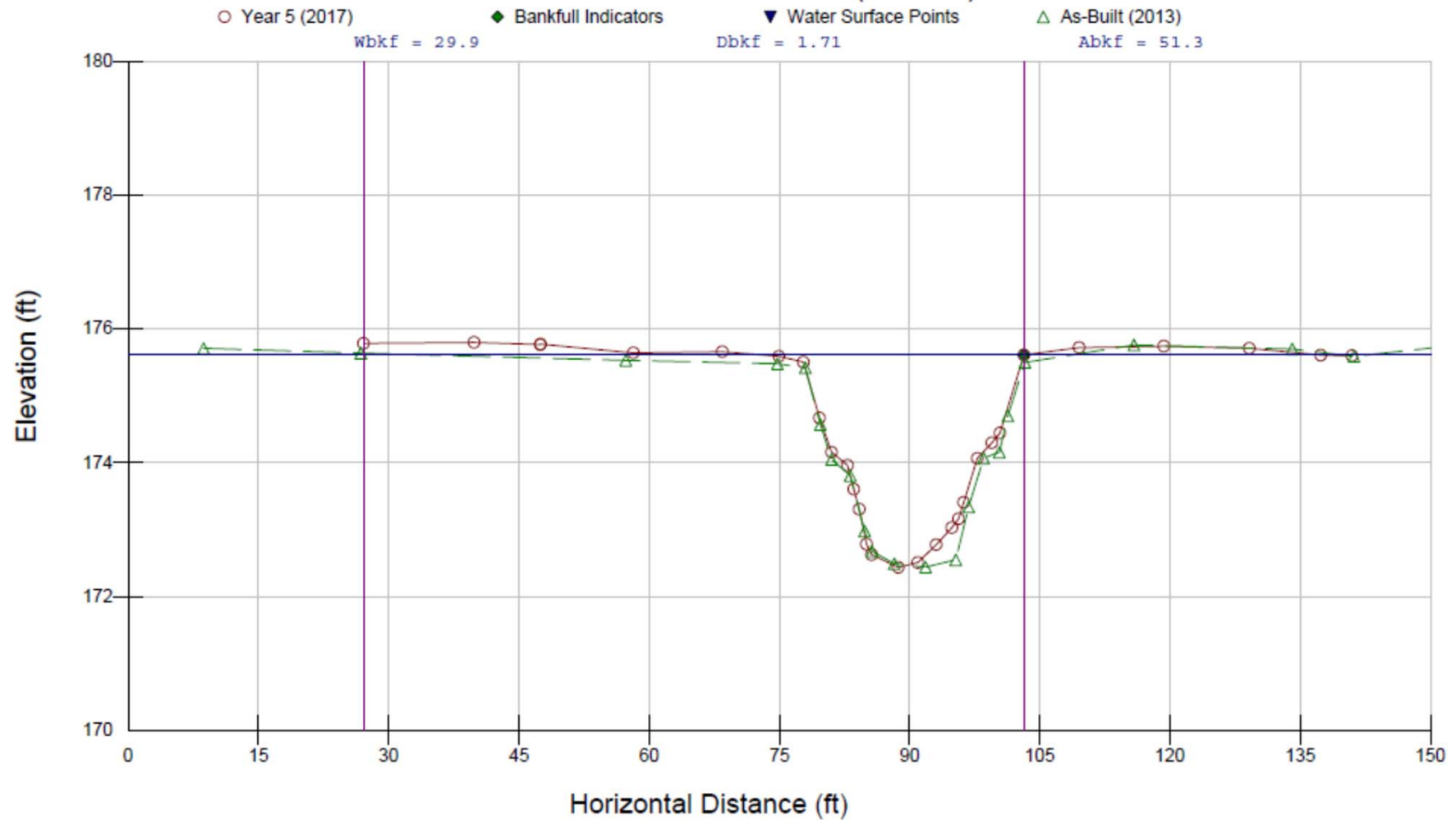


## Warren Creek XS 2 Pool (105+57)

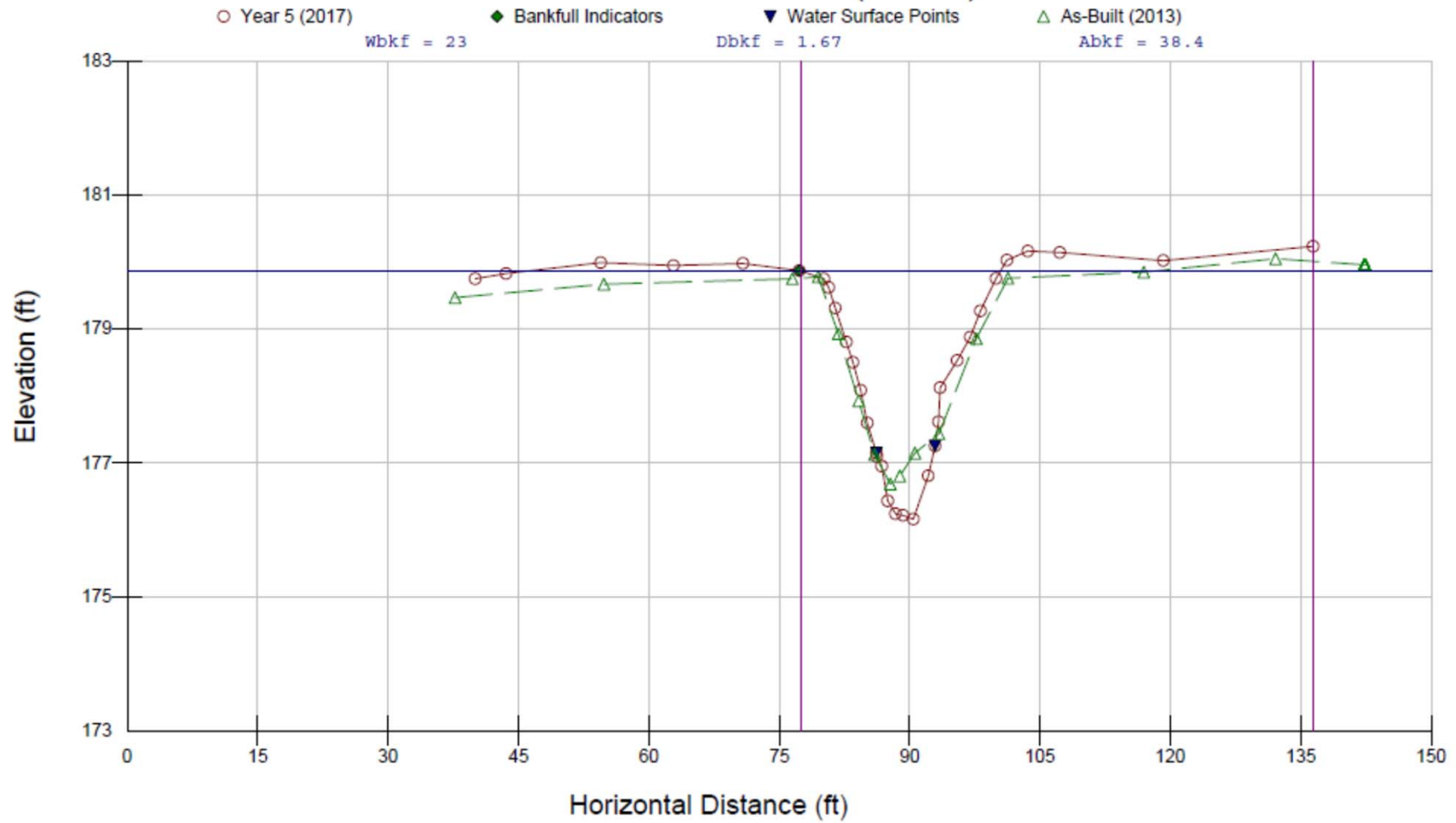




## Warren Creek XS3 Riffle (84+74)



## Warren Creek XS 6 Pool (56+07)





Cross-Section	Reach	Type	As-built Cross-Sectional Area (ft <sup>2</sup> )	Year 2 Cross-Sectional Area (ft <sup>2</sup> )	Year 3 Cross-Sectional Area (ft <sup>2</sup> )	Year 4 Cross-Sectional Area (ft <sup>2</sup> )	Year 5 Cross-Sectional Area (ft <sup>2</sup> )	Year 5 Percent Change from As-built
XS1	Warren Creek R3	Riffle	50.3	48.9	51.2	51.3	51.9	3.18%
XS2	Warren Creek R3	Pool	62.8	70.6	68.1	66.0	62.9	0.16%
XS3	Warren Creek R3	Riffle	49.6	48.7	48.4	54.5	51.3	3.43%
XS4	Warren Creek R2	Riffle	38.2	36.8	34.1	34.7	34.3	-10.2%
XS5	Warren Creek R2	Riffle	34.8	35.3	34.3	36.1	36.7	5.46%
XS6	Warren Creek R2	Pool	37.0	42.6	40.8	42.3	38.4	3.78%
XS7	Warren Creek R1	Riffle	21.1	22.2	21.4	21.8	22.3	5.69%

## Photos Station 1 – As-Built Survey





## Photos Station 1 – 2013



## Photos Station 1 – 2014





## Photos Station 1 – 2015



## Photos Station 1 – 2016





## Photos Station 1 – 2017



An aerial photograph of a vast, green, grassy field. A dark, winding path or ditch cuts through the field, starting from the bottom left and curving towards the top right. In the background, there is a small pond or wetland area with some trees and a line of houses or buildings under a clear sky.

# Summary

- Importance of Floodplain Access
- Majority of Site Performing Well
- Few Areas in Need of Repair
  - Areas with Difficulty Establishing Vegetation
  - Poor Topsoil Conditions



Thank you!