

HURRICANE HARVEY

SAN JACINTO FLOODING, 8/2017

CAUSE, IMPACTS AND POTENTIAL SOLUTIONS

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Kingwood, TX
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Foreword and References

My home in Kingwood was not flooded. I am a registered engineer in Texas. When my friends and neighbors began to repair their homes, I began to dig deeper into the Hurricane Harvey San Jacinto watershed story. It is a story that does not need to be repeated with cooperation to implement mitigation strategies. Let me share what I found with you

REFERENCES:

The following are the primary reference materials used to prepare this document

- ◆ Hurricane Harvey Storm Event: Briefing Regarding Lake Conroe Operations, SJRA Board Meeting September 28, 2017
- ◆ USGS National Water Information System
(<https://nwis.waterdata.usgs.gov/tx>)
- ◆ Lakes Online.com
(<http://tx.uslakes.info>)
- ◆ Harris County Flood Education Mapping Tool
(<http://www.harriscountyfemt.org>)
- ◆ Harris County Flood Warning System
(<https://www.harriscountyfws.org>)

References (continued)

- ◆ FEMA Flood Map Service Center
(<https://msc.fema.gov>)
- ◆ City of Houston Disaster Recovery Information
(<https://houstonrecovers.org>)
- ◆ WeatherForYou.com
(<https://www.weatherforyou.com>)
- ◆ National Weather Service Advanced Hydrologic Prediction Service
(<http://water.weather.gov>)
- ◆ ProPublica the Texas Tribune – Boomtown, Flood Town
(<https://projects.propublica.org/houston-cypress>)
- ◆ Water Data for Texas
(<https://waterdatafortexas.org>)
- ◆ Public Meetings in Kingwood, Humble and at GRB in Houston
- ◆ Multiple public sources and You Tube for pictures

San Jacinto River Flooding

- ◆ Since 1994 serious floods have occurred in Humble and Kingwood areas and all along the West Fork (WF) of the San Jacinto River.
- ◆ Hurricane Harvey produced the worst flooding due to the extreme rainfall in excess of 30 inches in 48 hours in a 2800 sq. mi watershed.
- ◆ Impacts were to thousands of homes and a majority of the businesses in the Humble/Kingwood area.
- ◆ Flooding can not be eliminated with this amount of rain fall. There maybe ways to limit the flooded areas.
- ◆ Potential areas for mitigation investigation:
 - Lake Conroe Early Release
 - River Channel Modifications
 - Development Control
- ◆ **GOAL:**
Develop strategies and structures to limit Lake Houston levels to 100 year flood plain using Harvey rain fall rates. (nominally Elev. 52 feet above sea level (asl) at Kingwood West Lake Houston Bridge or 10 feet above normal water level (nwl) in Lake Houston.

San Jacinto River Harvey Flooding Impacts

- ◆ Many homes and apartments flooded, damaged and destroyed all along the river.
- ◆ Many businesses flooded and damaged; including schools, a college, nursing homes, medical facilities, restaurants and retail stores.
- ◆ Damaged bridges at West Fork San Jacinto; including south bound lanes of Hwy 59/I69 and Union Pacific rails.
- ◆ Damages caused by high water levels and flow rates. Secondary damages caused by fallen trees and entrained sand in the flood water.



San Jacinto River Harvey Flooding

◆ **Causes:** Most rainfall in recorded history, Lake Conroe release concurrent with peak flows, and narrow obstructed channel at the Highway 59 bridge.

◆ **Potential Solutions:**

- Goal – At West Lake Houston bridge reach level 52 ft asl which is 100 yr flood plain (necessary reduction - 8 ft.)
 1. Early Release at Lake Conroe and then no outfall until the storm is past. Predicted to reduce the level at West Lake Houston bridge to 58 ft. not enough to reach the goal.
 2. In addition to step 1, Modify River Channel under the Hwy 59 bridge is predicted to achieve the goal with unobstructed bridge at elevation 53 ft asl. Experience is that the bridge becomes 50% obstructed and results in a drop in level to only 57 ft asl. Four to five feet above the goal.
 3. Also, widening the inlet and out channels at the bridge may help the flow capacity of the channel. No predictions are made.

◆ **Next Steps:** Develop more accurate river modeling and economic considerations for potential mitigation solutions.



SAN JACINTO FLOODING POTENTIAL SOLUTIONS:

LAKE EARLY RELEASE

Lake Early Release

Water Controls for WF SanJac Watershed

- ◆ Storms drop an extraordinary amount of water over the watershed in a short amount of time creating flooding. The dams can create a way to extend the water entering the watershed in a controlled manner.
- ◆ Lake Conroe and Lake Houston have different basic characteristics:

Characteristic	Lake Conroe	Lake Houston
Watershed area, sq mi	425	2,892
Lake NWL Surface Area, acres	21,000	11,840
Total Volume, ac-ft	411,000	124,600
Normal Outfall area, ft	17	3,160
Emergency Outfall width, ft	200	40
Normal Level, ft asl	200	42
Maximum Level, ft	207	54
Minimum Level, ft (ogee crest)	173	25

Lake Early Release

Water Controls for WF SanJac Watershed



Lake Conroe
Emergency outfall



Lake Houston
Normal outfall

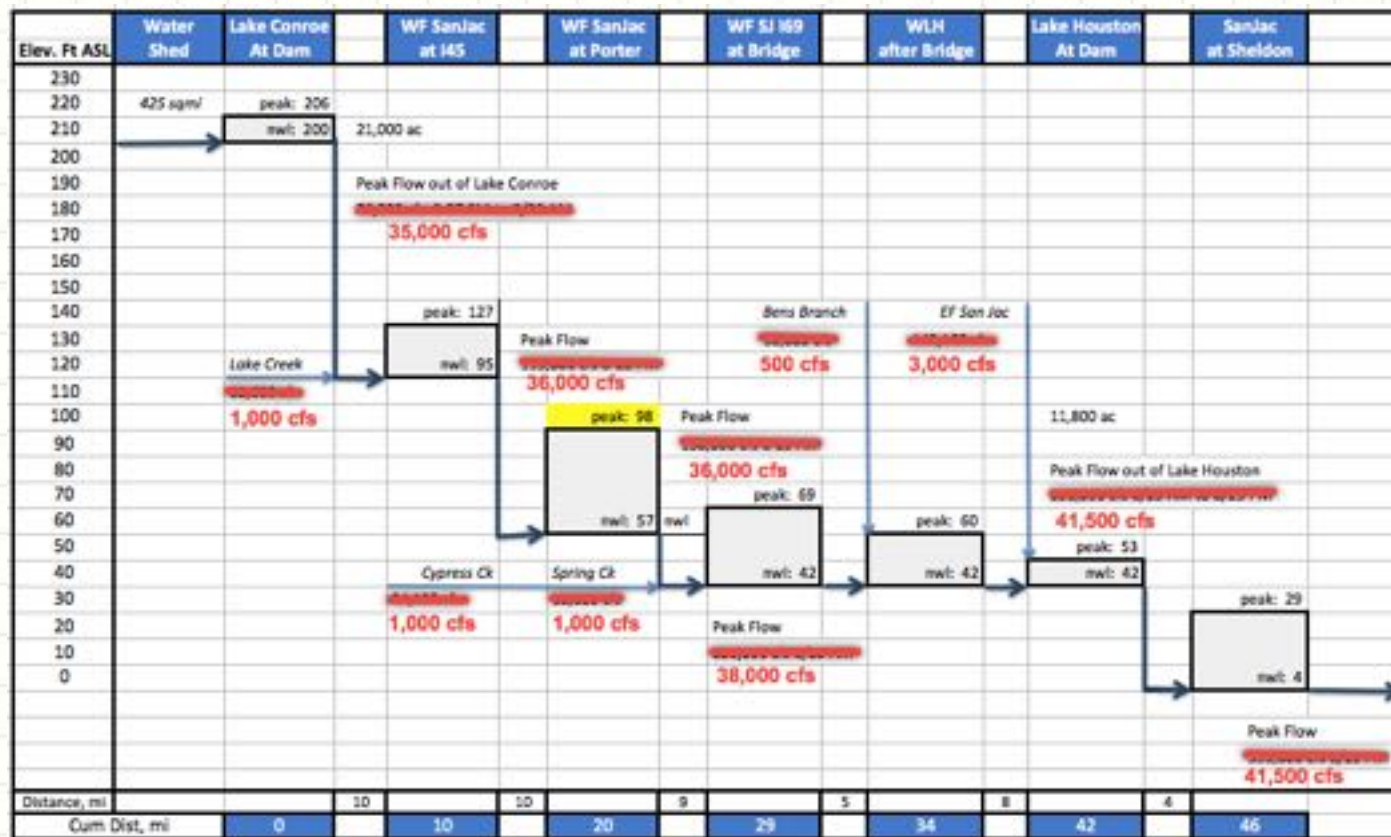


- ◆ Lake Conroe has twice the area, three times the storage volume, and one seventh the watershed area. Its normal release is very low and emergency release very high. It's focus is water storage.
- ◆ Lake Houston has an outfall 200 times larger, and a emergency outfall one fifth the Conroe size. Its focus is run of river discharge with storage.
- ◆ Lake Conroe can drop its level quickly through its emergency gates. Lake Houston cannot drop its level through the emergency gates. Its wide discharge can pass large amounts of water with small level changes.

Lake Early Release (using Harvey timing and water flows)

Step 1: Lake Conroe Early Water Release

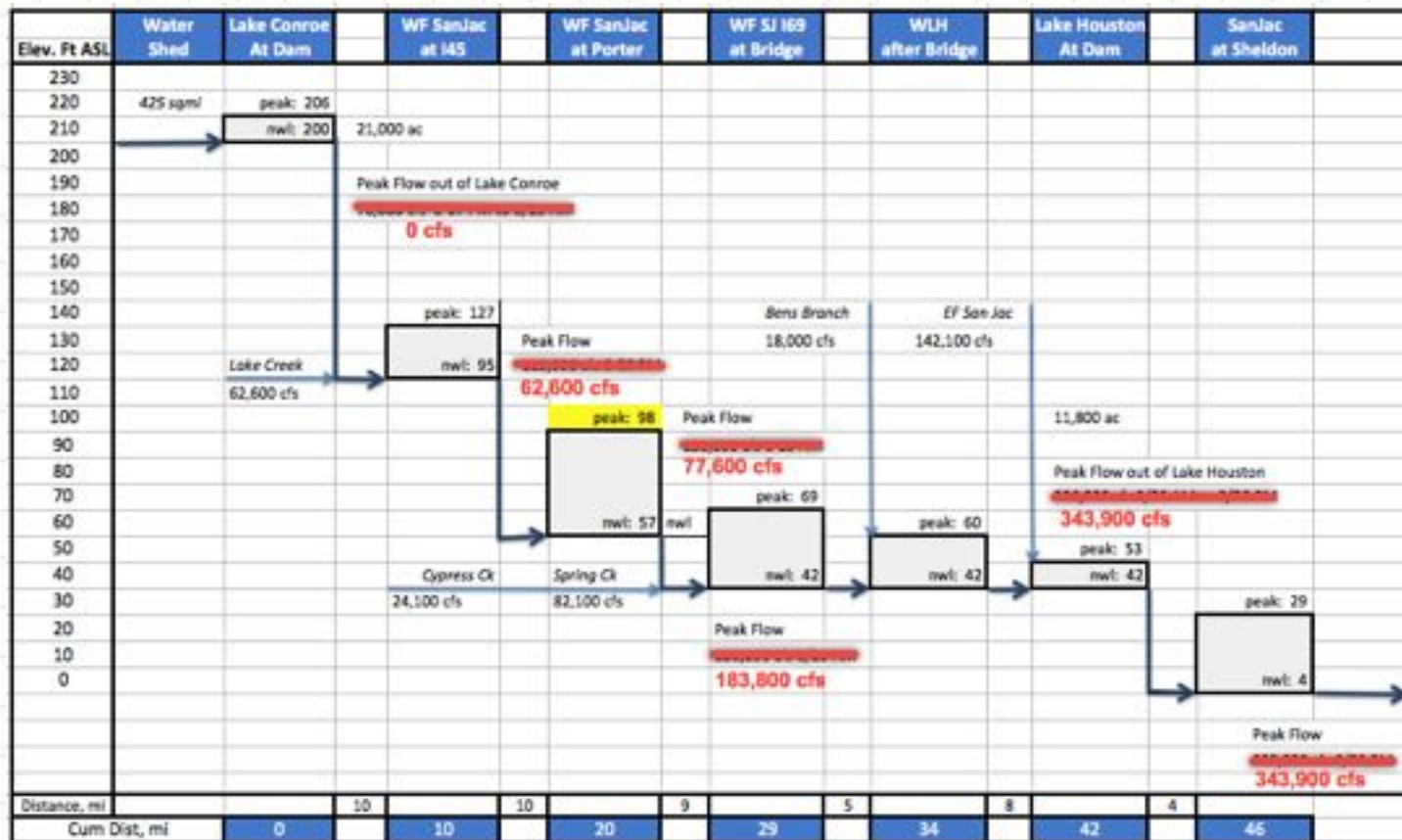
- ◆ Lake Conroe releases 35,000 cfs for three days. The period from when rain is forecast greater than 10 inches until the rain starts at Lake Conroe (3 days). The level will be 10 feet below normal. Providing 16 feet storage that is enough to absorb the total watershed flow from Harvey. Delivering 210,000 ac-ft water to Lake Houston.



Lake Early Release (using Harvey timing and water flows)

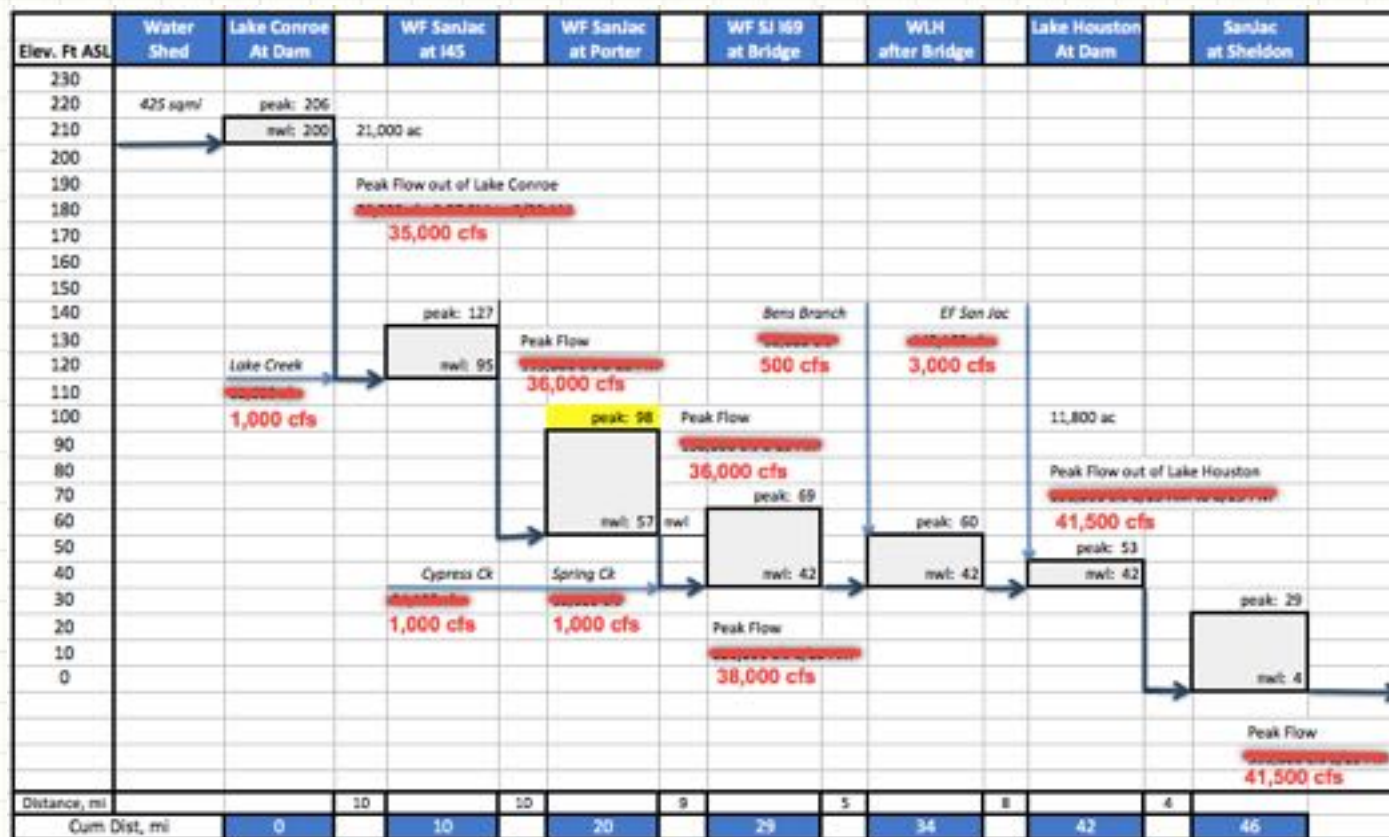
Step 2: Lake Conroe Storm Water Storage

- ◆ Lake Conroe releases zero cfs for five days. The period from when Lake Conroe rain starts until at least five days of storm event. The peak watershed flows during this period adjust as shown.



Step 3: Lake Conroe Post-flood Water Release

- ◆ Once the watershed water levels have returned to normal level, a new 35,000 cfs (max) release from Lake Conroe to bring its water level to normal will start and run for a minimum of two days. Lake Conroe releases 105,000 ac-ft to Lake Houston.



Lake Release

Potential Lake Conroe Early Release

- ◆ Reduces the WF flow at the 59 bridge to 183,800 cfs or 22% lower than Harvey actuals. This drops the water level at the Hwy 59 bridge by 2.5 ft. to 66.5 ft. asl
- ◆ Lake Houston outfall drops to 343,900 cfs and 2.4 million ac-ft storm water released by the lake. This reduces flow level at the dam by 1 foot or 51 ft. asl
- ◆ The peak at bridge is down 2.5 ft. The observed channel widening effect by the West Lake Houston bridge reduces the level by 87% or 58 ft. asl. The overall lake level is down 1 ft. at the dam.
- ◆ This predicts that the level downstream of West Lake Houston bridge is 58 ft. Unfortunately, that level is 5 to 7 feet above the 100 year flood plain target. Additional changes are required to lower the level.

Lake Release

SJRA Release Protocols Mitigation Goals

- ◆ Monitoring Tropical Storm Predictions & Pre-storm Actions
 - Initiate drawdown protocol at forecast date
 - Lower Lake Conroe to minimum levels of 190 ft asl
 - Discharge rate no greater than 35,000 cfs for 72 hours
- ◆ Storm Conditions Actions
 - Monitor Spring Creek and Cypress Creek flow conditions
 - Monitor Lake Conroe Levels to increase rate if necessary
 - Set Lake Conroe release rate to limit level increase at Humble to 55 feet
- ◆ Flooding Decisions
 - Any release from Lake Conroe will impact the WF SanJac downstream communities between the dam and I45 crossing at a minimum.
 - Make sure early notice is provided. Study and implement Houston District Notice procedures during storm events.



SAN JACINTO FLOODING POTENTIAL SOLUTIONS: RIVER CHANNEL MODIFICATION

River Channel Mods

Issues Focus at Humble/Kingwood

◆ River Channel Flow

- Spring Creek, and Cypress Creek join the WF San Jacinto
- Maximum flow rate into Lake Houston

◆ River Hwy 59 Bridge Obstructions

- Main active channel is 200 feet across. Total clear span length is 1800 ft.
- Bridge has concrete supports for each structure every 60 feet. The total width is 400 feet.
- Downstream bridge exit is constrained by trees and sand banks
- Forces water levels to max level going into the channel
- By contrast, the Grand Parkway San Jacinto bridge is six lanes and clear span length is 5,300 ft.

◆ River Channel Narrows

- Upstream natural flood plain narrowed due to development fill on south side of Cypress and Spring Creek
- Downstream channel filled by sand bars from 59 Bridge to Lake Houston past Kingwood.
- Water surge disperses lowering the water level as channel widens.

River Channel Mods

Issues Focus at Humble/Kingwood

◆ Hwy 59 Bridge in 1994

- Two lane north bound feeder was the original iron bridge.
- Two main lanes north bound separate structure.
- Two main lanes and two feeder south bound as single separate structure.
- Eight total traffic lanes and associated concrete support post into the river channel.

◆ Hwy 59/69 Bridge in 2017

- Original iron bridge is walking only
- Three feeder lanes north bound separate structure
- Five main lanes north bound separate structure
- Two HOV lanes separate structure
- Five main lanes south bound separate structure
- Three feeder lanes south bound separate structure
- Twenty total traffic lanes and associated concrete support posts into the river channel

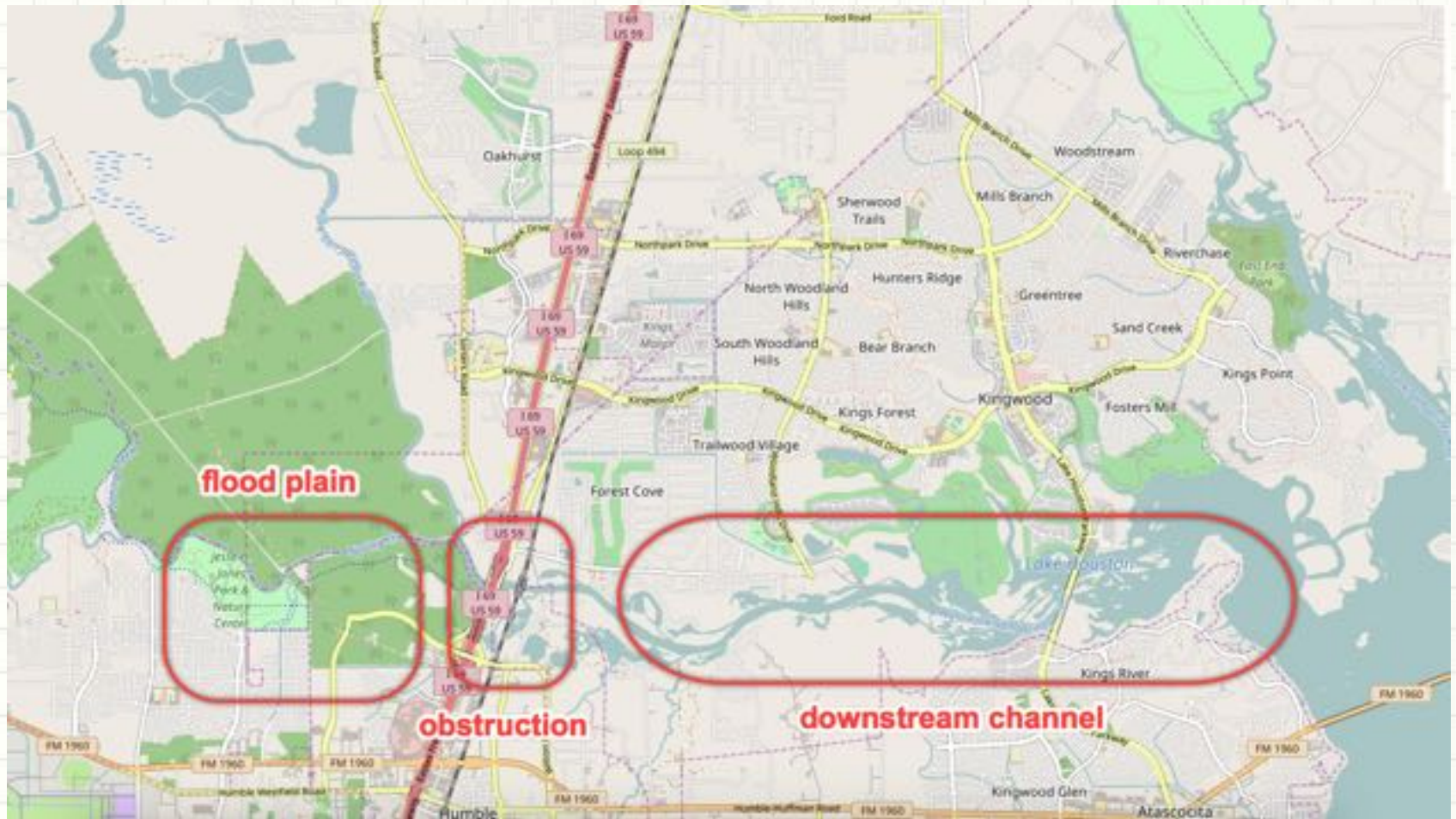
◆ River Flow Impacts

- Complexity of the current bridge structure may explain the difference in water heights between 1994 and 2017 floods with similar flow rated in the WF,



River Channel Mods

Issues Focus at Humble/Kingwood



River Channel Mods - Hwy 59 Bridge

Improve Flow Path & Obstructions

- ◆ Reducing the WF flow at the Hwy 59 bridge to 183,800 cfs or 22% lower than Harvey actuals. This drops the water level at the bridge by 2.5 ft to 66.5 ft asl. Not low enough.
- ◆ Develop changes to the bridge channel so that the water flows under the bridge at elevation 62 feet with obstructions.
- ◆ If the the peak level at bridge is down 7.0 ft. The observed channel widening effect by the West Lake Houston bridge reduces the level by 87% or 54 ft asl. The overall lake level is down 1 ft at the dam.
- ◆ This predicts with the reduced flow and widened bridge channel that the water level at downstream of the West Lake Houston bridge is 53 ft. asl This is within the target range for 100 year flood plain.

River Channel Mods - Hwy 59 Bridge

Improve Flow Path & Obstructions

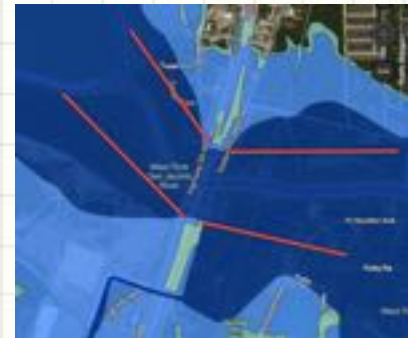
Assume Flow Area is obstructed by support posts only

7 Box Channels (A) -400ft		15 Box -1000ft Channels (B)				7 Box Channels (A) - 400ft	
Act Flow Rate, cfs						Box channels 12 x 60 x 400	
Peak	236,200					Box Model 12 x 12	
	Height, ft	Width, ft	Length, ft	Quantity	Area, sq ft		
Box Channel B	20	60	400	15	1200		
Box Channel A	13	60	400	14	780		
Cases	Size, ft.	Flow cfs	Area Adjst	Qnity Adjust	Quantity	T Flow, cfs	Wtr Level
Unobstructed	12x12	2300	0.95	5.5	38	456,665	@7 ft
50% Blocked	12x6	1200	0.95	5.5	38	238,260	@7 ft
Unobstructed	12x12	900	0.95	5.5	38	178,695	@1 ft
50% Blocked	12x6	450	0.95	5.5	38	89,348	@1 ft
max Level 69 ft nwl 42		Channel A	Channel B	Box Model			
		7 ft	10	Unobstructed	Obstructed		
		Water Level		7 or 1	7 or 1	Center Channel (B)	
		20x60ft	13x60	12x12	12x6	bottom bridge 62 ft	
		flow →				nwl 42ft asl	
Length, ft		400	400	400	400		

River Channel Mods - Hwy 59 Bridge

Improve Flow Path & Obstructions

- ◆ However, the Case with 50% obstructed drops the flow to 89,300 cfs in order to stay under the bridge at 63 ft asl. The Case at 50% blocked can handle up to 238,300 cfs at 69 ft asl.
- ◆ The 50% blocked case at 183,800 cfs results in a peak elevation of 65.5 ft asl. The observed channel widening effect by the West Lake Houston bridge reduces the level by 87% or 57 ft asl. Additional changes are required to lower the level to meet the goal with the bridge 50% blocked.
- ◆ Next modifications should consider the following:
 - Widening the downstream channel to improve water bridge exit and flow widening into the lake should be modeled.
 - Widening the upstream channel to improve the water entrance to the bridge should be modeled.
 - Creating a means to keep trees and debris out of the bridge channel .



River Channel Mods - Hwy 59 Bridge

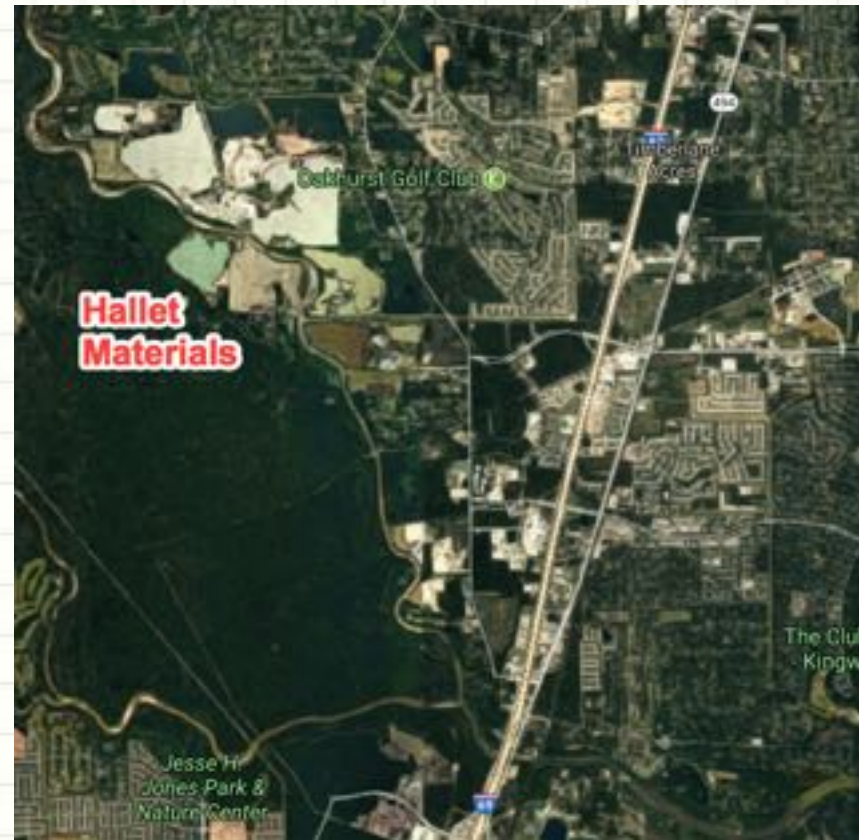
River Level Height Potential Mitigations

- ◆ Stop floodplain fill upstream of the 59 bridge.
- ◆ Widen the bridge channel under the 59 bridge.
- ◆ Replace the railroad bridge with a wider span bridge.
- ◆ Limit the railroad bridge structures in the river channel
- ◆ Widen and dredge the downstream channel.
- ◆ Dredge until the bottom of channel is two feet below the normal Lake Houston Lake level.

River Channel Mods - Hwy 59 Bridge

River Dredging Mitigation

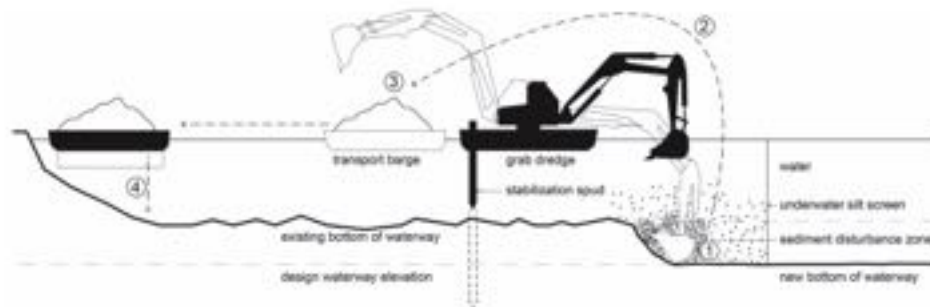
- ◆ Hallet Material's sand pit operations is upstream on WFSJ near Porter and WFSJ near New Caney.
- ◆ Sand Pit flooding likely contributes to downstream channel sandbars.
- ◆ Create a Private Public partnership to create a channel dredging, reclaiming sand operation for Hallet Materials or other interested party.



River Channel Mods - Highway 59 Bridge

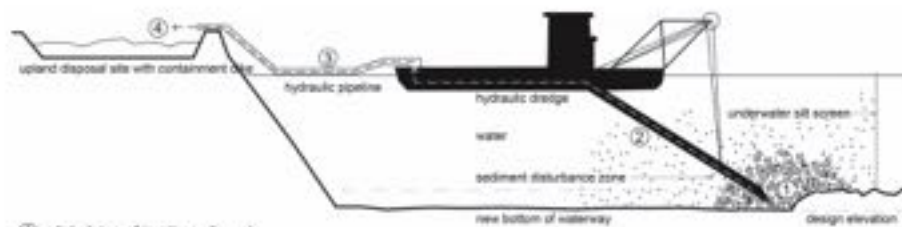
River Dredging Operation Techniques

Landscapes of Dredge



- ① - dislodging of in-situ sediment
- ② - raising of dredged material to the surface
- ③ - horizontal transport
- ④ - placement or further treatment

mechanical dredge operation landscape- each object is labeled and the four main relations between objects are represented as actions that are numbered; the primary characters or instruments work to create a dynamic landscape-in-process



- ① - dislodging of in-situ sediment
- ② - raising of dredged material to the surface
- ③ - horizontal transport
- ④ - placement or further treatment

hydraulic dredge operation landscape



SAN JACINTO FLOODING POTENTIAL SOLUTIONS: DEVELOPMENT CONTROL

Counties and Towns in the Watershed



Development Control

Counties and Entities in the Watershed

- Counties
 - Primary: Harris and Montgomery
 - Secondary: Waller, Grimes, Walker, San Jacinto, and Liberty
- Municipalities
 - Houston, Humble, Porter, Conroe, and New Caney
 - Tomball, Spring, The Woodlands, and Conroe
 - Cypress and Hockley
- Stakeholders
 - Coastal Water Authority
 - Grand Parkway Toll Road Authority
 - Sam Houston Toll Road Authority
 - San Jacinto River Authority
 - Texas Commission on Environmental Quality
 - Texas Department of Transportation
 - Texas Water Development Board
 - United States Army Corps of Engineers
 - United States Environmental Protection Agency

Development Control

Major Watershed Developments

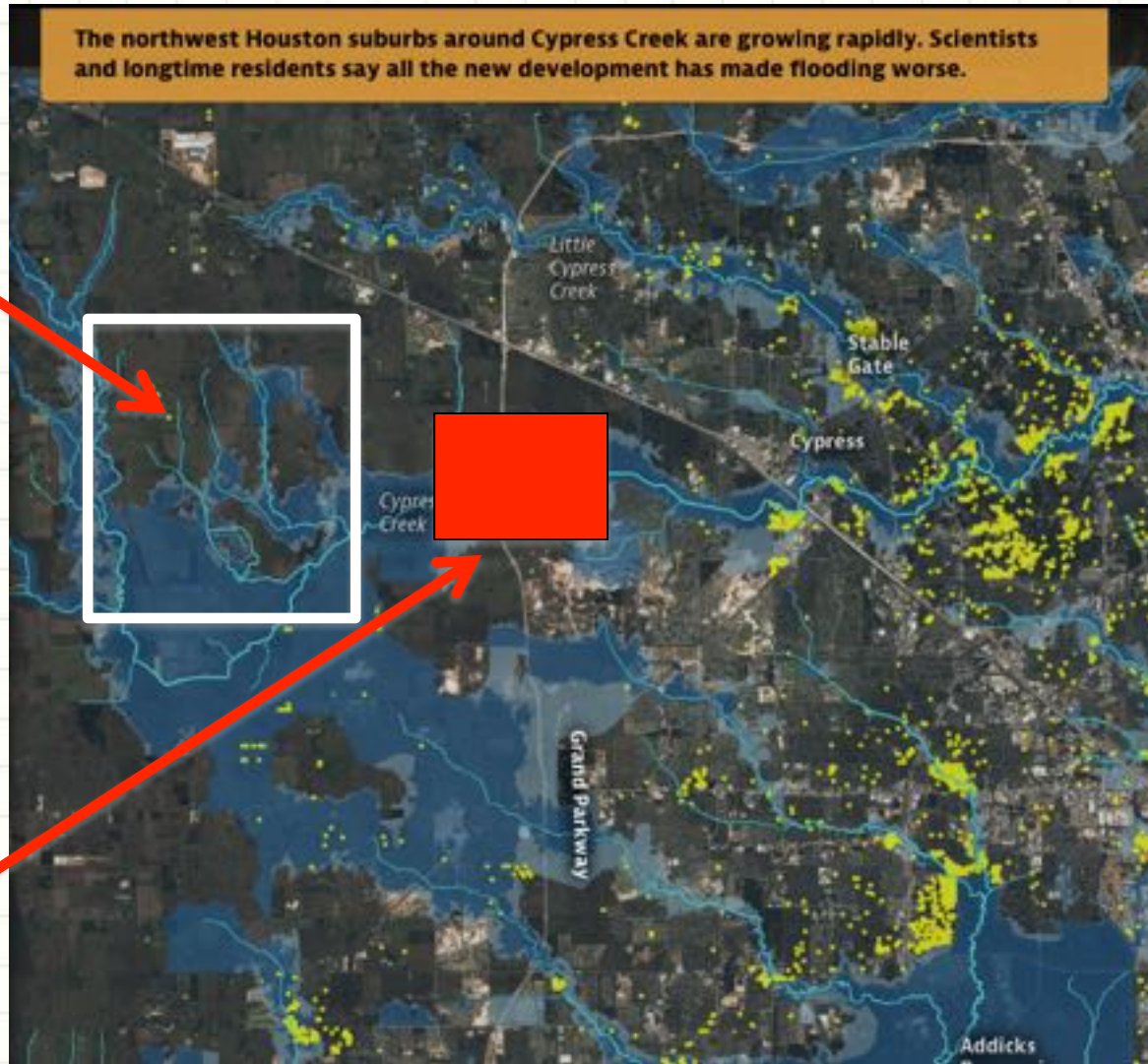
- Grand Parkway Development West
 - Creating commercial and residential (i.e. Bridgeland at 11,500 ac)
 - Focus is the junction of GP and 290
 - Cypress Creek watershed is currently Katy Prairie
- Grand Parkway Development North
 - Creating commercial and residential (i.e. Benders Landing)
 - Focus is the junction of GP and 45 north to Lake Conroe
 - Focus is the junction of GP and 45 south and east of Spring
 - Spring Creek and WF San Jacinto watershed is rural under developed
- Grand Parkway Development East
 - Creating commercial and residential (i.e. Valley Ranch)
 - Focus is the junction of GP and 59 north and south to Kingwood
 - West Fork San Jacinto watershed is rural under developed

Development Control

Major Watershed Developments

Potential location of
Cypress Creek Storm
Reservoir west of the
Grand Parkway

Bridgeland
Planned 11,500 ac
Development
spanning Cypress
Creek



Development Control

Major Watershed Possible Regulations

- ◆ Primary Focus on the WF San Jacinto Watershed.
- ◆ Land Reservation for Storm Surge
- ◆ River Channel Integrity and Capacity Reservations.
- ◆ Regional Solutions involving Developers, Communities and Agencies.
- ◆ Addition of Addicks type reservoir in the Cypress Creek watershed west of Grand Parkway.
- ◆ Apply the New Regulations to to the EF San Jancinto as it developes.




SAN JACINTO FLOODING NEXT STEPS

Next Steps

- ◆ Peer review of this information provided; including flow and level data points, calculation techniques and operations assumptions on Lake Conroe and Lake Houston
- ◆ Identify and hire river flow engineers with software to improve the calculation and analysis accuracy and speed.
- ◆ Present results to stakeholder groups to provide accurate information for decision making
- ◆ Develop long range plans based on agreed analysis and stakeholder discussions.

Summary for Investigation

- ◆ Restructure SJRA Board members to include Humble/Kingwood representatives.
- ◆ Review SJRA operations. and disaster planning teams.
- ◆ Review and update SJRA water release protocols.
- ◆ Widen the 59 bridge channel.
- ◆ Widen the bridge entrance and exit channels.
- ◆ Public/Private partnership to dredge WF San Jacinto between 59 and Lake Houston.
- ◆ Stop flood plain re-development west of Hwy 59
- ◆ Set new regulations for storm zoning and land reservation.
- ◆ Re-build the Hwy 59 and railroad bridges at WF San Jacinto to minimize flow obstructions
- ◆ Add West Harris County storm reservoir

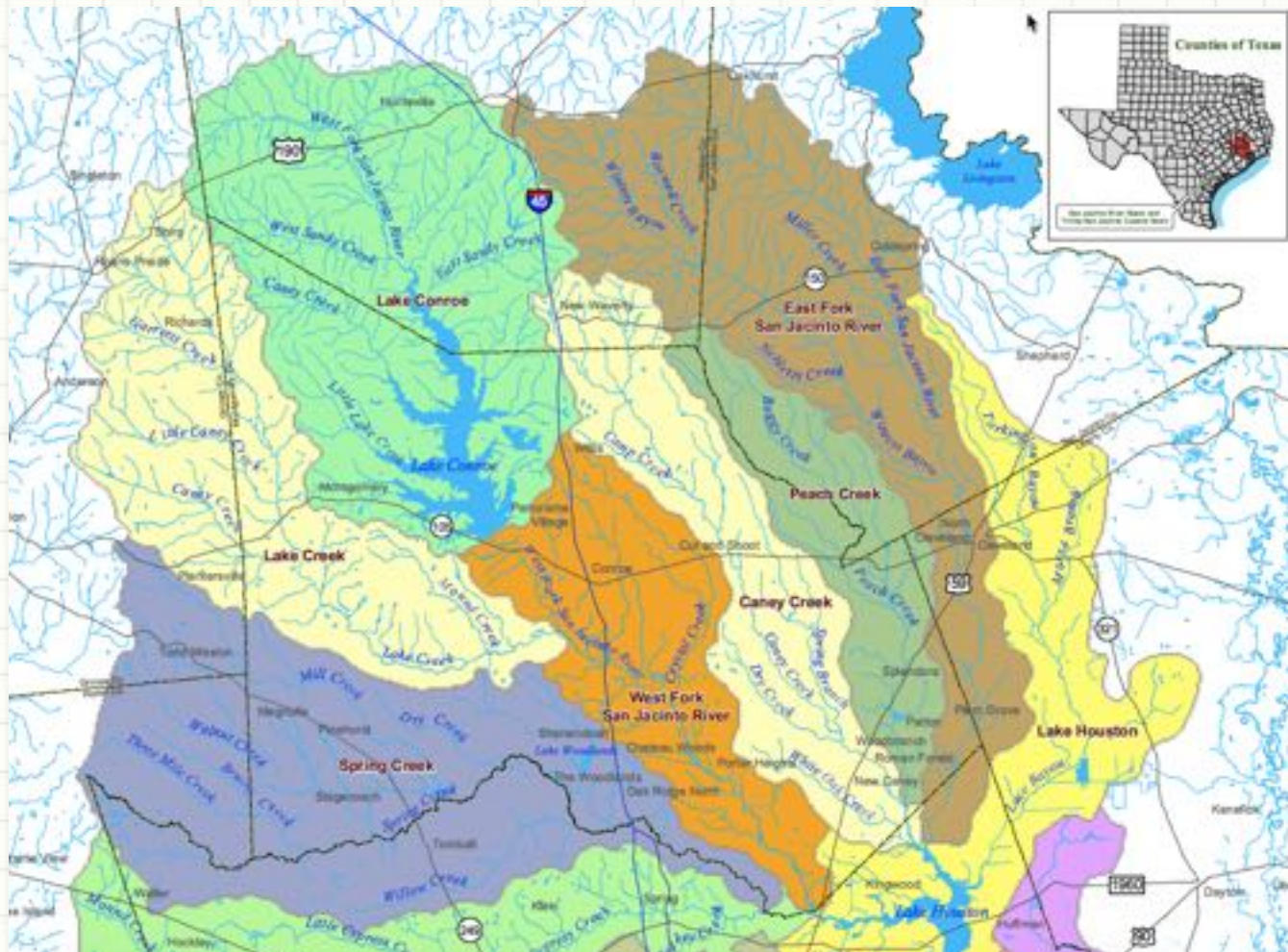


SAN JACINTO FLOODING LAKE HOUSTON WATERSHED OVERVIEW

River Flows

Montgomery County Watersheds

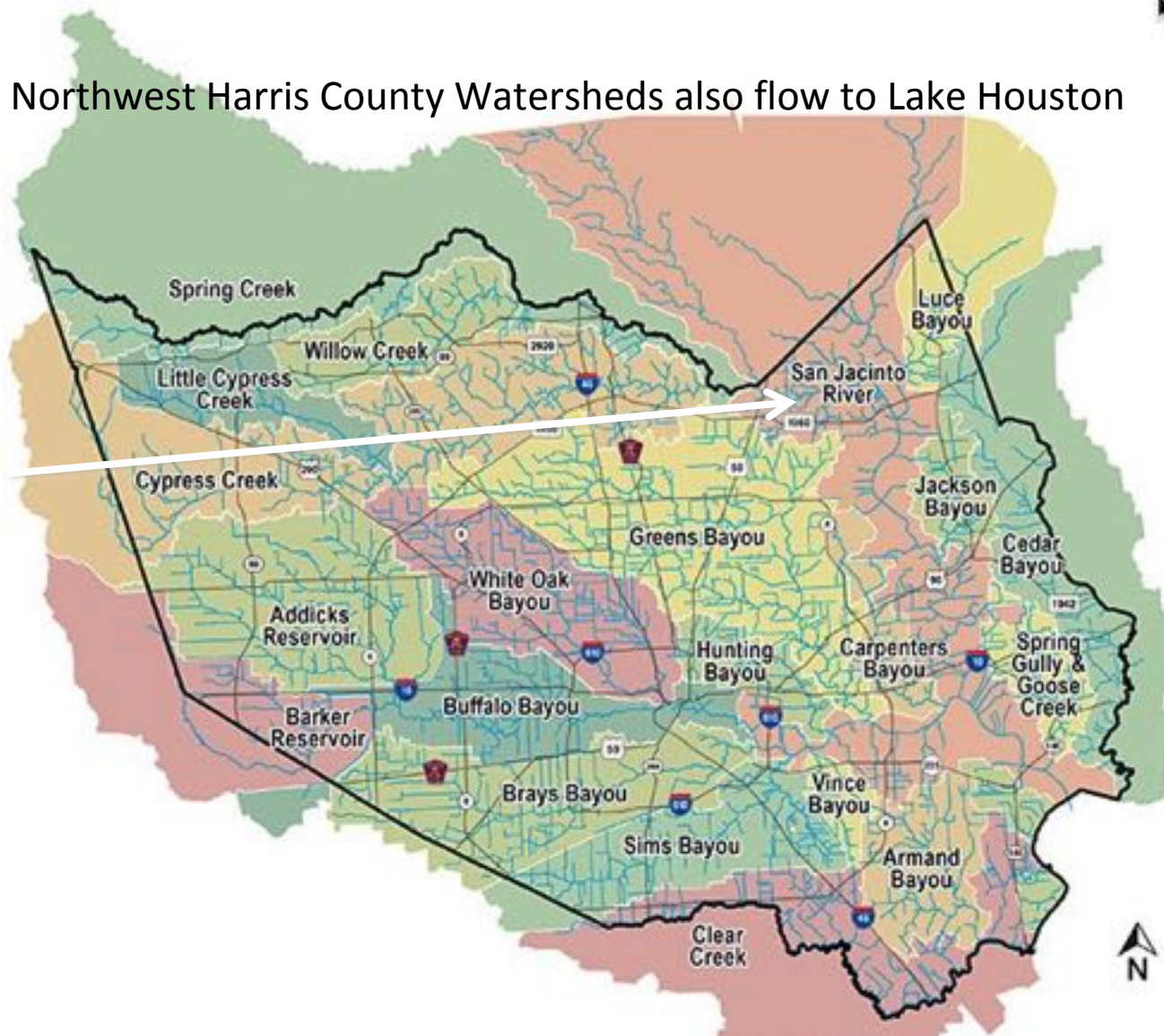
This entire watershed area ultimately flows into Lake Houston



River Flows

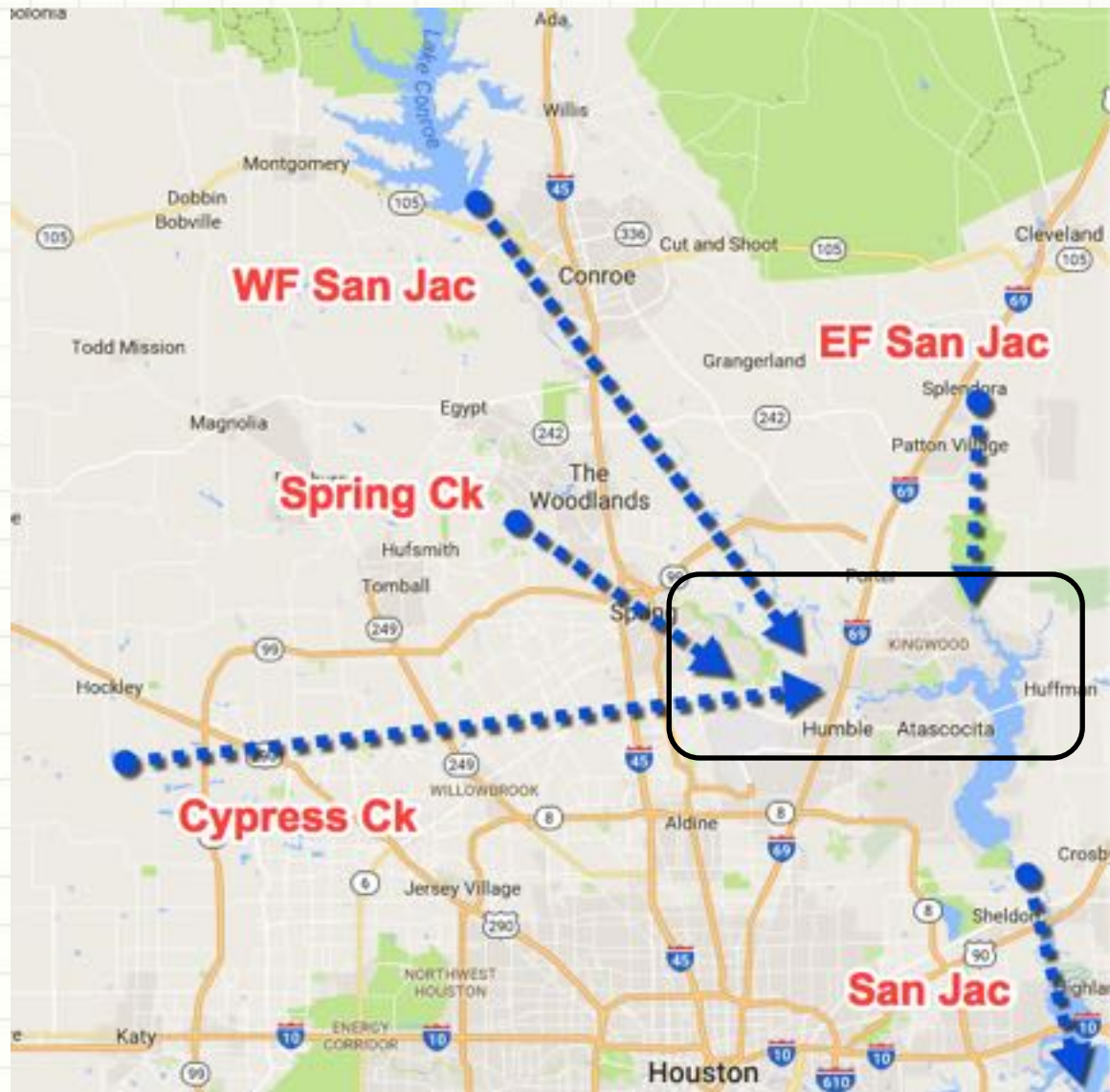
Harris County Watersheds

Northwest Harris County Watersheds also flow to Lake Houston

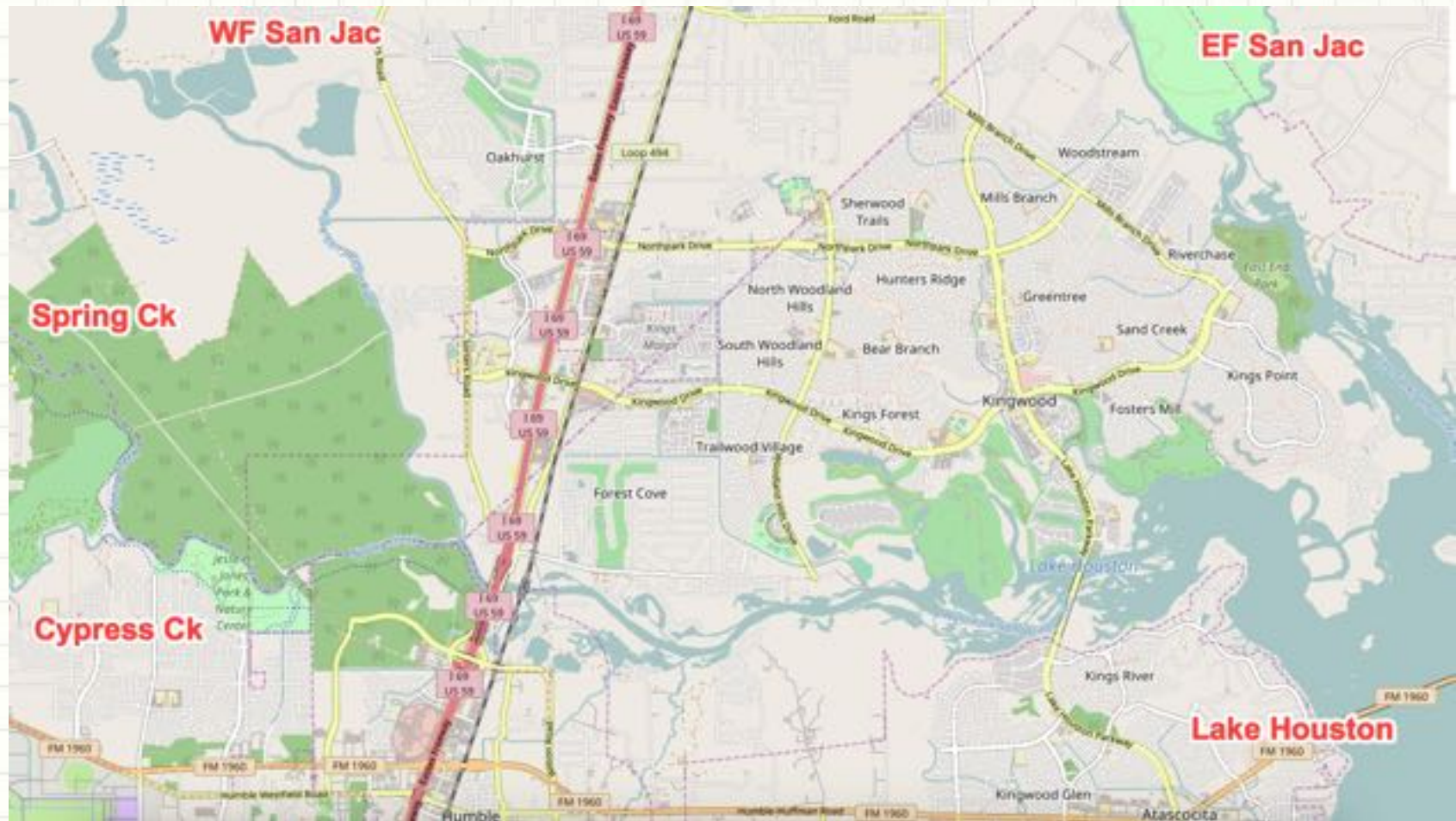


Overall Watershed Focus

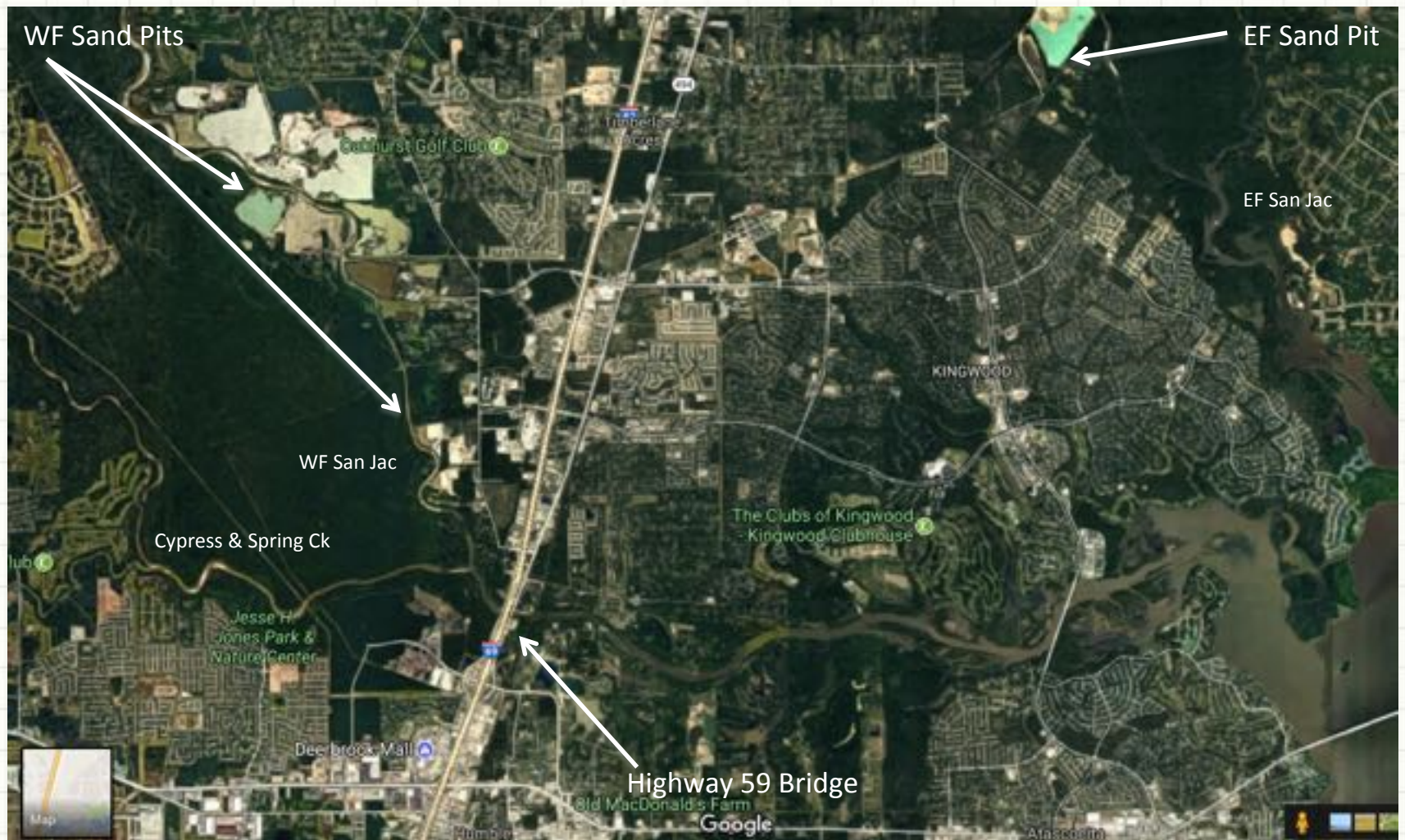
- Lake Conroe
- Spring Creek
- Cypress Creek
- WF San Jacinto
- EF San Jacinto
- Lake Houston
- San Jacinto
- Total Area is 2892 sq. miles



Humble/Kingwood (local watershed)



Humble/Kingwood Area



WF San Jacinto at Hwy 59 bridge





SAN JACINTO FLOODING

IMPACTS:

HUMBLE/KINGWOOD

Flooding

Hwy 59 and San Jacinto Looking South to Humble



Flooding

Hwy 59 and San Jacinto Looking West



Flooding

Hwy 59 and San Jacinto Looking North



Flooding

Hwy 59 and San Jacinto Looking North

Hwy concrete median barriers moved by flood water



Flooding

Hwy 59 Bridges and San Jacinto Downstream Right



Flooding

Hwy 59 With Concrete Median Over Flow



Flooding

Kingwood Business Impacts



Kingwood High School, all the golf courses/club houses, and A majority of Kingwood businesses.



Kingwood HEB, medical clinic, banks and restaurants.

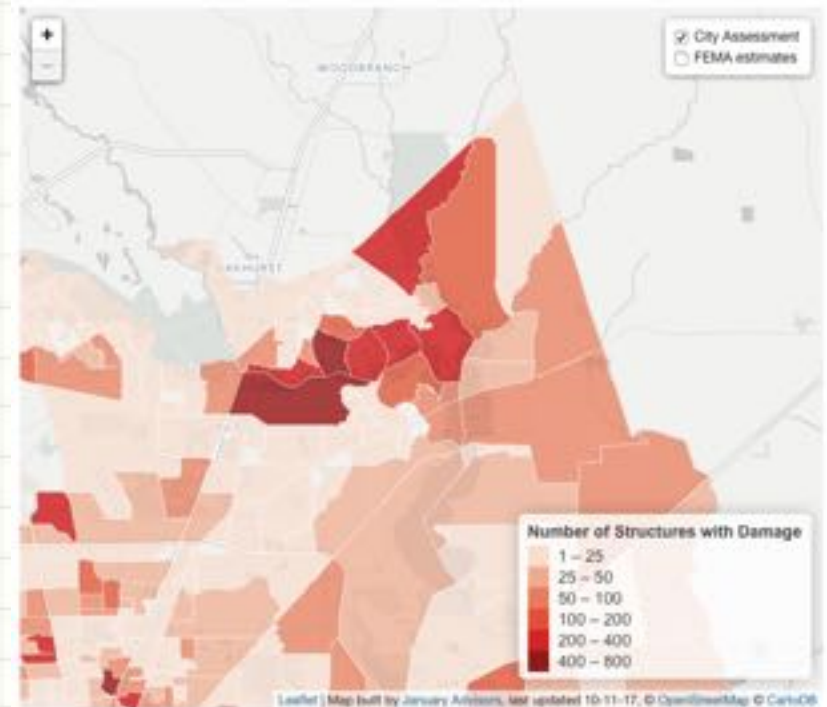


Flooding

Kingwood Home Impacts



City of Houston assessments and FEMA damage estimates of structures with damage:



Kingwood and Humble lost
3000 homes and many more
in the adjacent communities

Flooding

Hwy 59 and San Jacinto Bridges



Flooding

Hwy 59 Iron Bridge and San Jacinto



Flooding

Union Pacific Railroad Bridges and San Jacinto



One of the first trains across the repaired bridge



Flooding

Sand Collected at River Grove Park Kingwood



- ◆ Similar deposits are found through out the West and East Forks of the San Jacinto.
- ◆ East End Park has larger deposits at locations not accessible for clean up and portions of existing park trails are expected to be closed permanently.
- ◆ Large sand deposits and trees are under the Highway 59 bridges.
- ◆ Test on the sand find it to be high quality with very low levels of chemicals or hazards.



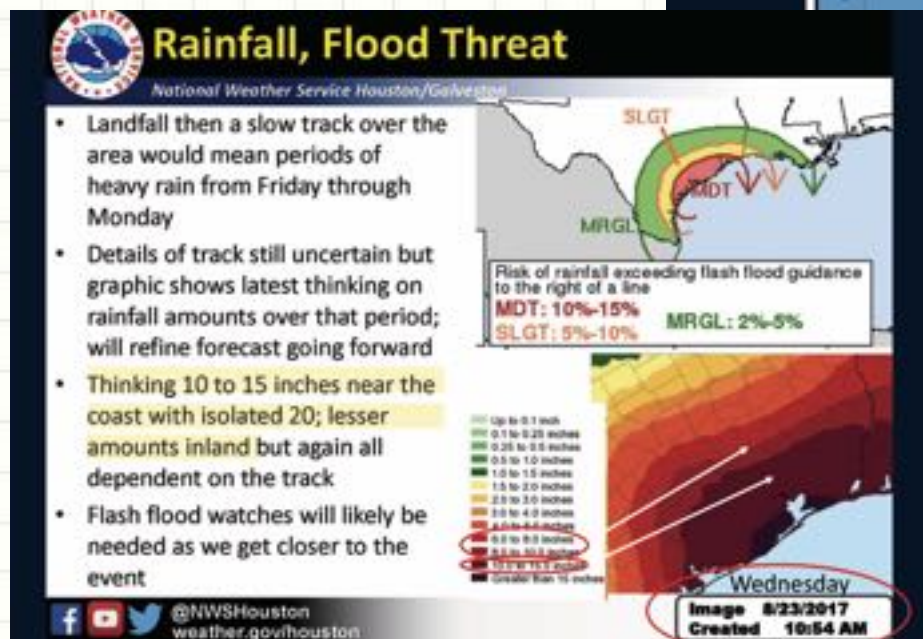
SAN JACINTO FLOODING

HURRICANE HARVEY TIMELINE

Harvey Timeline

Forecasts before the Landfall: 8/23/2017 am

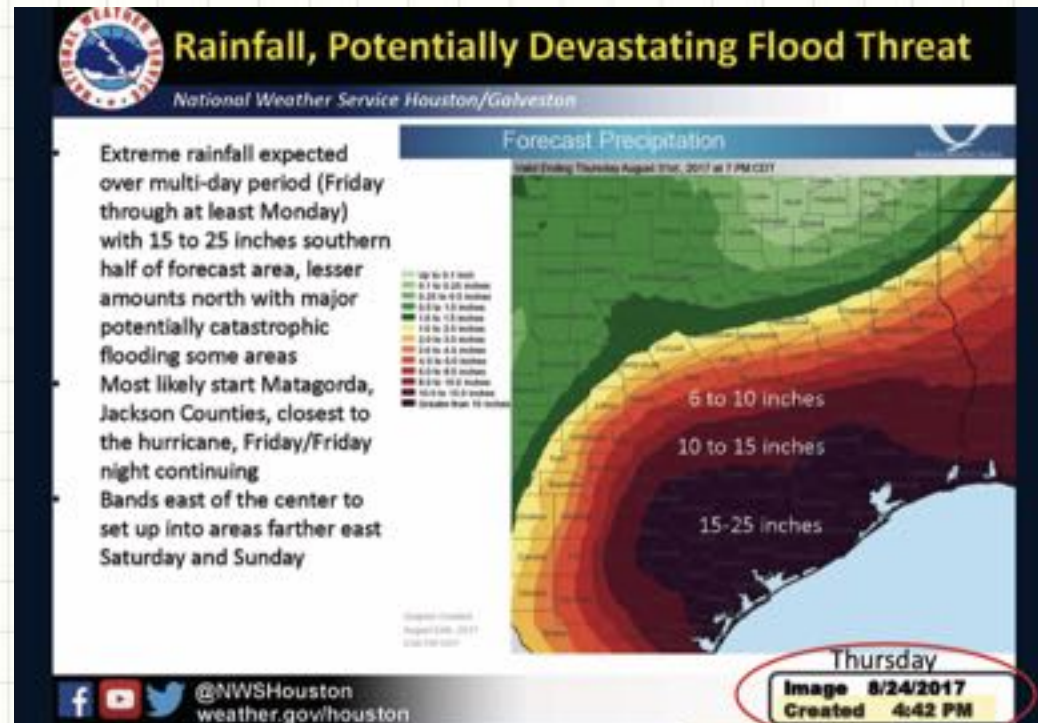
- ◆ National Weather Service (NWS) is forecasting 6-8 inches in northern watershed and 8-10 inches in southern Conroe watershed.



- ◆ Extreme rain forecast from NWS two days before landfall and three days before it started raining in the Conroe watershed.

Harvey Timeline

Forecasts before the Landfall: 8/24/2017 pm



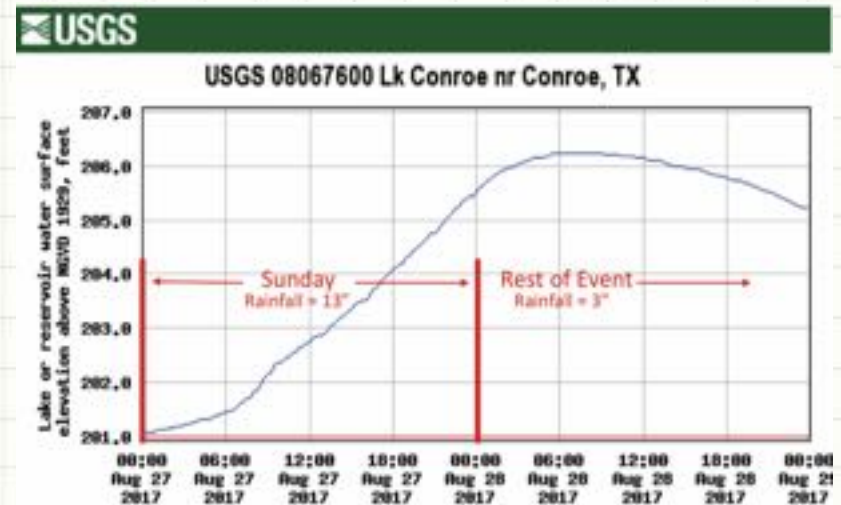
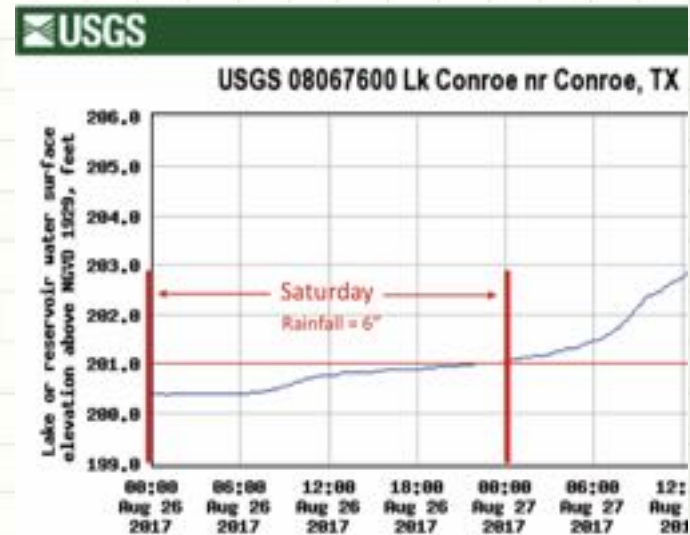
- ◆ NWS increases rainfall forecast to 10-15 inches in northern watershed and 15-25 inches in southern Conroe watershed.

- ◆ Extreme rain forecast from NWS one day before landfall and two days before it started raining in the Conroe watershed.

Harvey Timeline

Actuals after the Landfall: 8/25/2017 pm

- ◆ Hurricane Harvey makes landfall at Rockport, TX on 8/25 at 10 PM. 180 miles SSW of Lake Conroe.
- ◆ Conroe rain starts around noon on 8/26 and immediately impacts the lake level equal to the rainfall on the Lake.
- ◆ 8/27 Sunday is the big rain day with 13 in. in 24 hours. This drives the lake level up all day peaking out at 206 ft at 8/28 at 6:00 am.
- ◆ Rain tapers off after 8/27 with only 3 inches through 8/29 at Lake Conroe.



Harvey Timeline

Actuals after the Landfall: 8/28-30/2017 am

- ◆ Lake Conroe starts its release 8/28 at 1 am which slows the rise of lake level and then overcomes the water inflow at 6 am driving lake level down 3 feet.

- ◆ The start of the Lake Conroe release coincides with the downstream creeks coming out of their banks due to local watershed rain.

- ◆ The release and rainfall on 8/27 result in peak flows through the West Fork River system starting 8/28 PM through 8/29 PM.



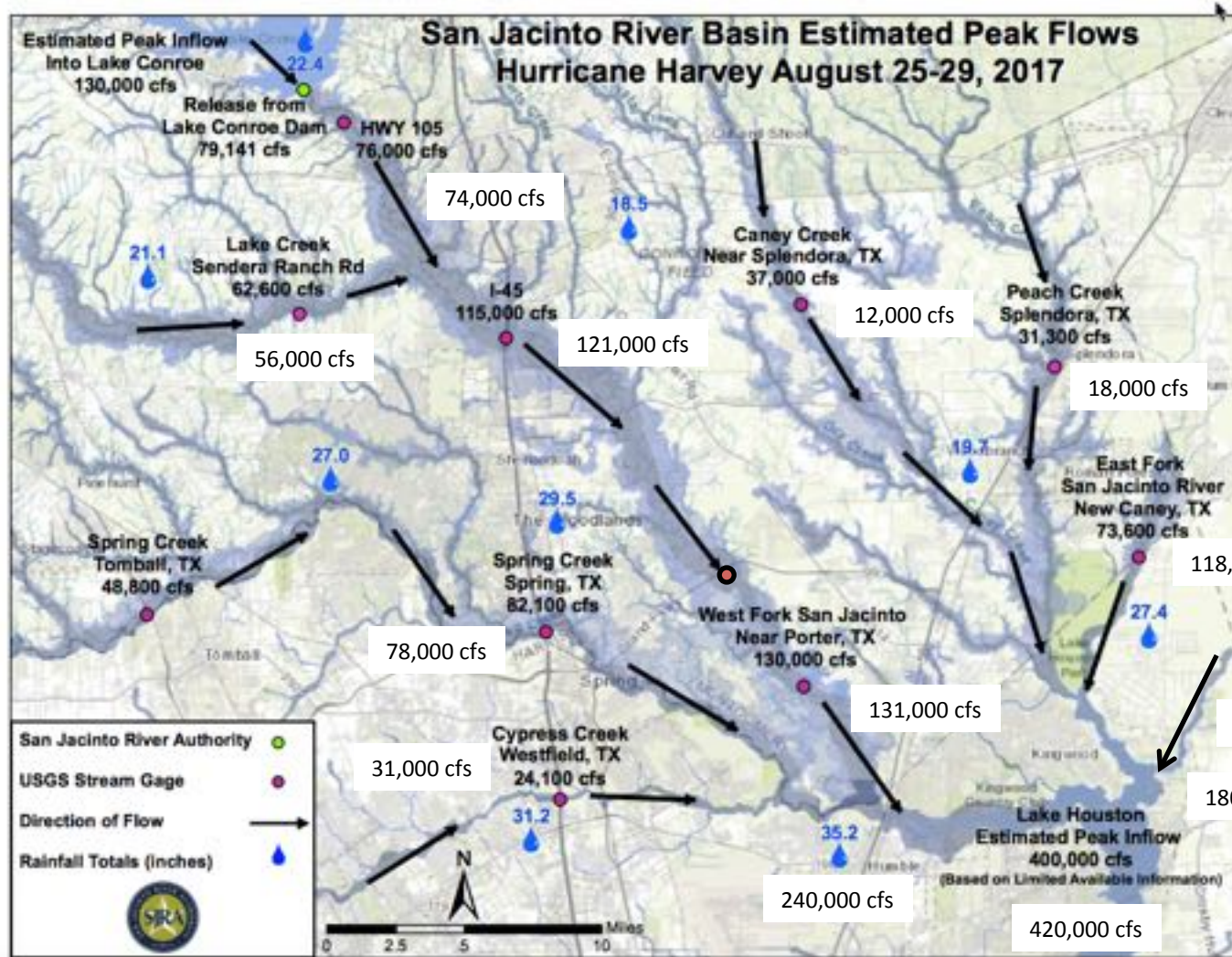
- ◆ Humble/Kingwood river Levels peaked early in the morning of Tuesday, 8/29 with little warning. The rain stopped in Conroe, but did not stop in Kingwood until 8/30. By 8/30 PM, the storm moved east to Beaumont.



SAN JACINTO FLOODING RIVER FLOWS

River Flows

Lake Houston Watershed Flows



USGS Water Flows on Tuesday August 29th at 1:00 AM

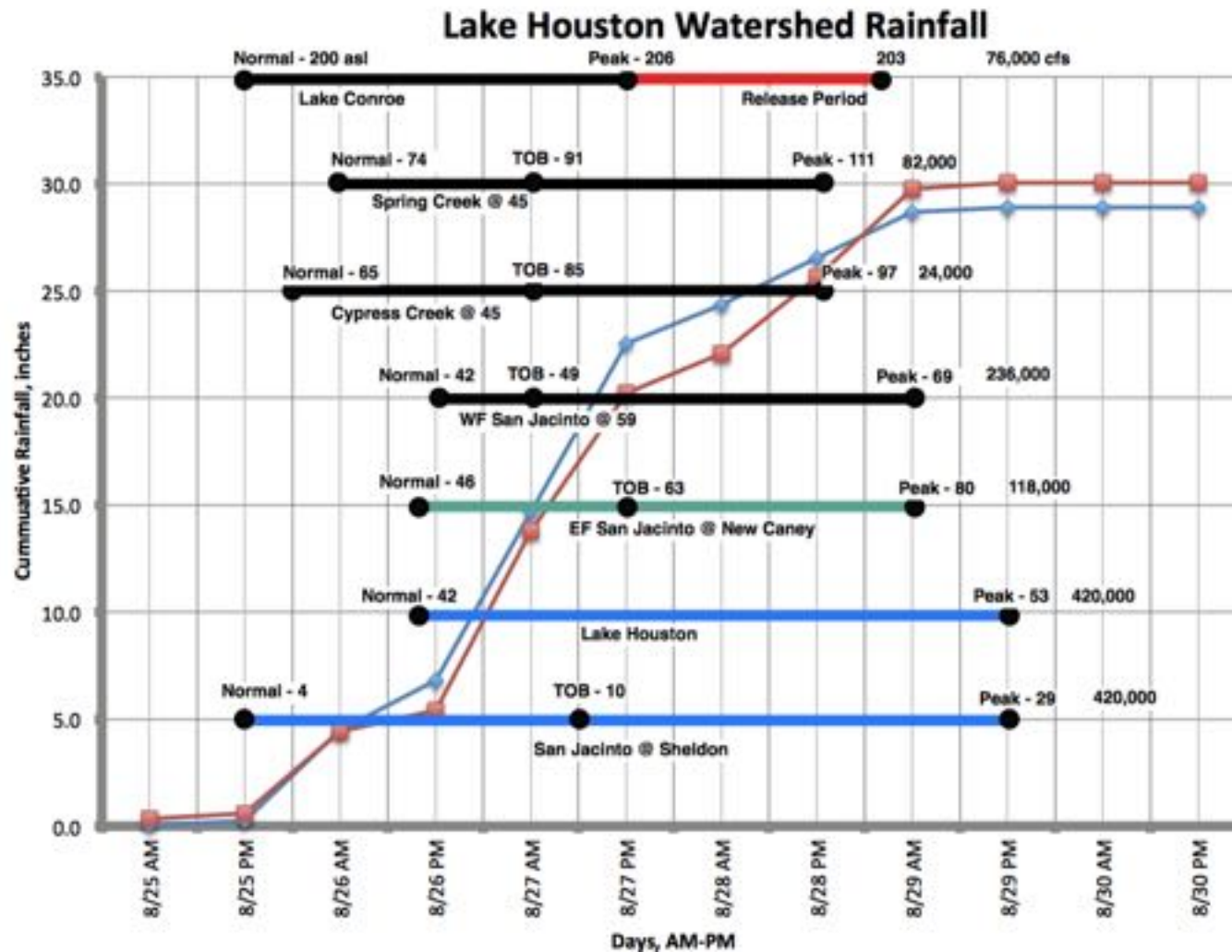
River Flows

Water Shed Rainfall and Stream levels

- ◆ Hurricane Harvey impacted the area for six days. The rainfall amounts are averaged for the West Fork and the East Fork watersheds all contributing to Lake Houston.
- ◆ The rainfall cumulative amounts over the period are shown on the following graphic. Overlaid are bar graphics representing the primary water bodies contributing to the West Fork and the East Fork.
- ◆ The bars show the timing when it was at normal water level (NWL), when it exceeded top of the banks (TOB – flooding conditions) and when it reached its highest level (PEAK).
- ◆ Key observation is that the Lake Conroe water release to protect the properties around the lake started after 85+% of the rain fell, and started after all the West Fork contributors were beyond flood stage (TOB).
- ◆ All streams were back in their banks by 09/02/2017.

River Flows

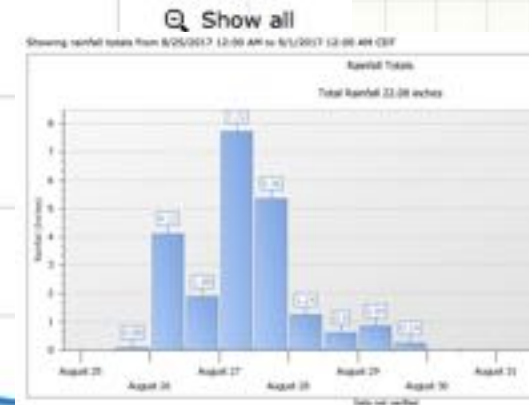
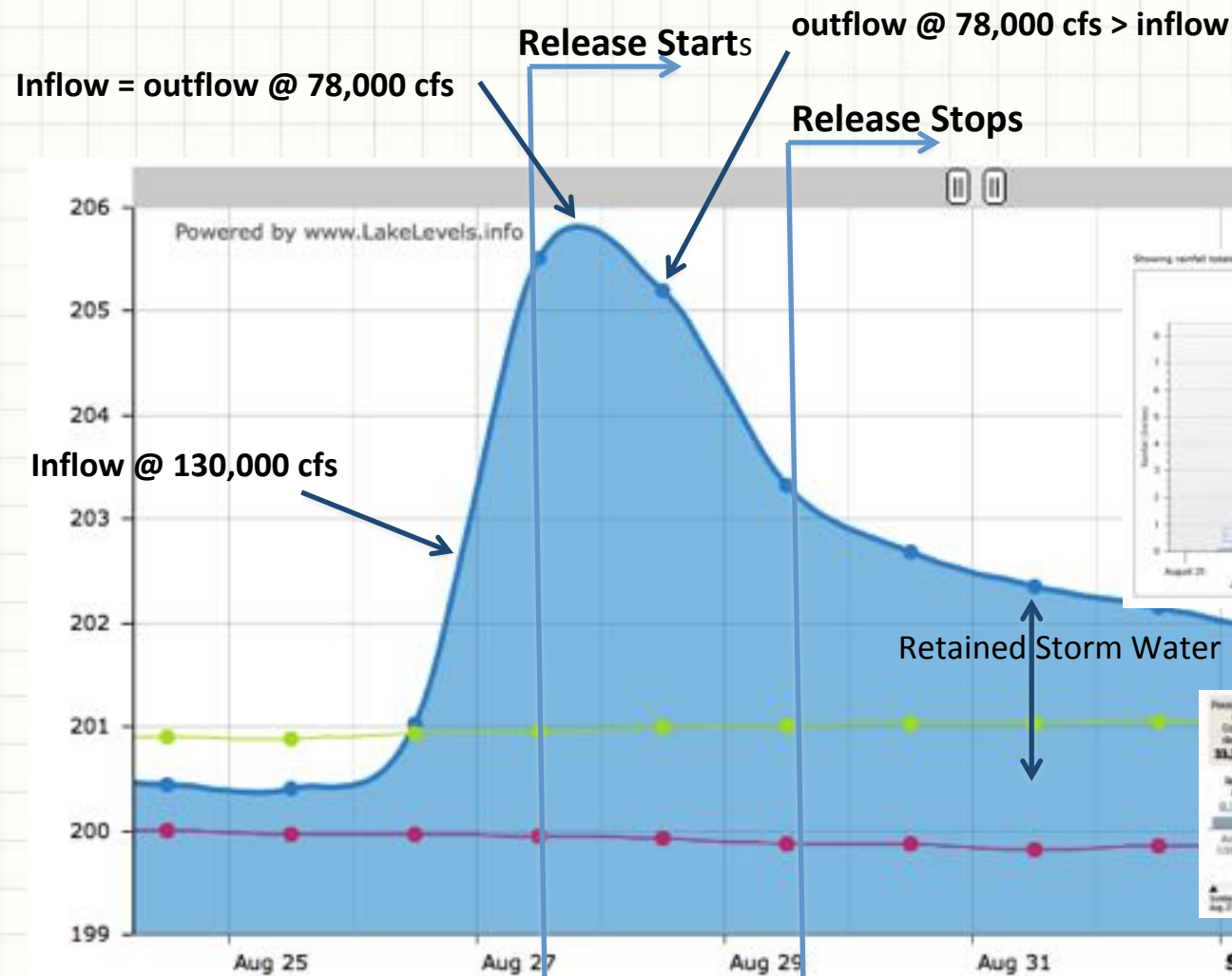
WF and EF San Jacinto Flows and Rainfall



Black bars WF
 Green bars EF
 Blue bars SanJac

WF Cum
 EF Cum

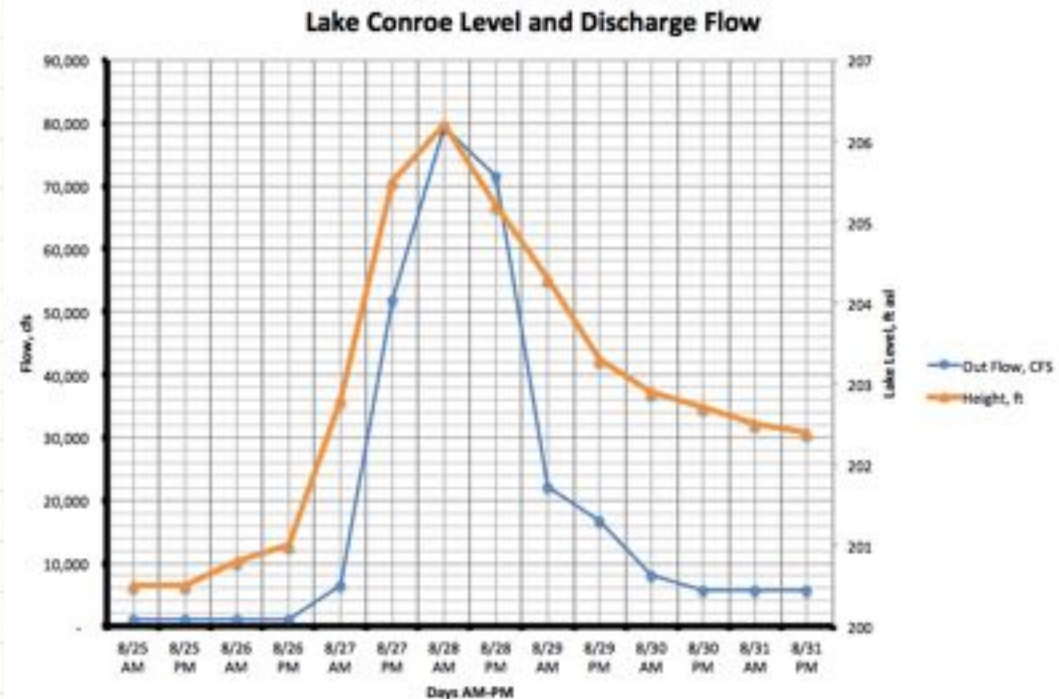
Lake Conroe Lake Levels (LCTT2)



River Flows

Lake Conroe Levels and Release Flows

- ◆ Storm put 304,700 acre-feet (ac-ft.) water into the Lake. 39,900 ac-ft. was retained in the Lake after the storm, and 264,800 ac-ft. was released into the West Fork San Jacinto.
- ◆ 12.8 in. average watershed rainfall made it into Lake Conroe. The rest was retained in the watershed soil and land features.
- ◆ If the total storm volume of water was retained in the Lake, the level would rise 15 ft.



Total Released	acres	Feet	Ac-ft Water	Hours	Ave inflow
Release High		3.5	239,801	60	48,293
Release Low		0.5	24,968	48	6,285
	Released	Sub Total	264,768	120	26,661
Total Retained	21,000	1.9	39,900		
Storm Total	21,000	15	304,668		
Watershed	445	Sq miles			
	284,800	acres			
Into the Lake	12.84	in. ave. rainfall			

River Flows

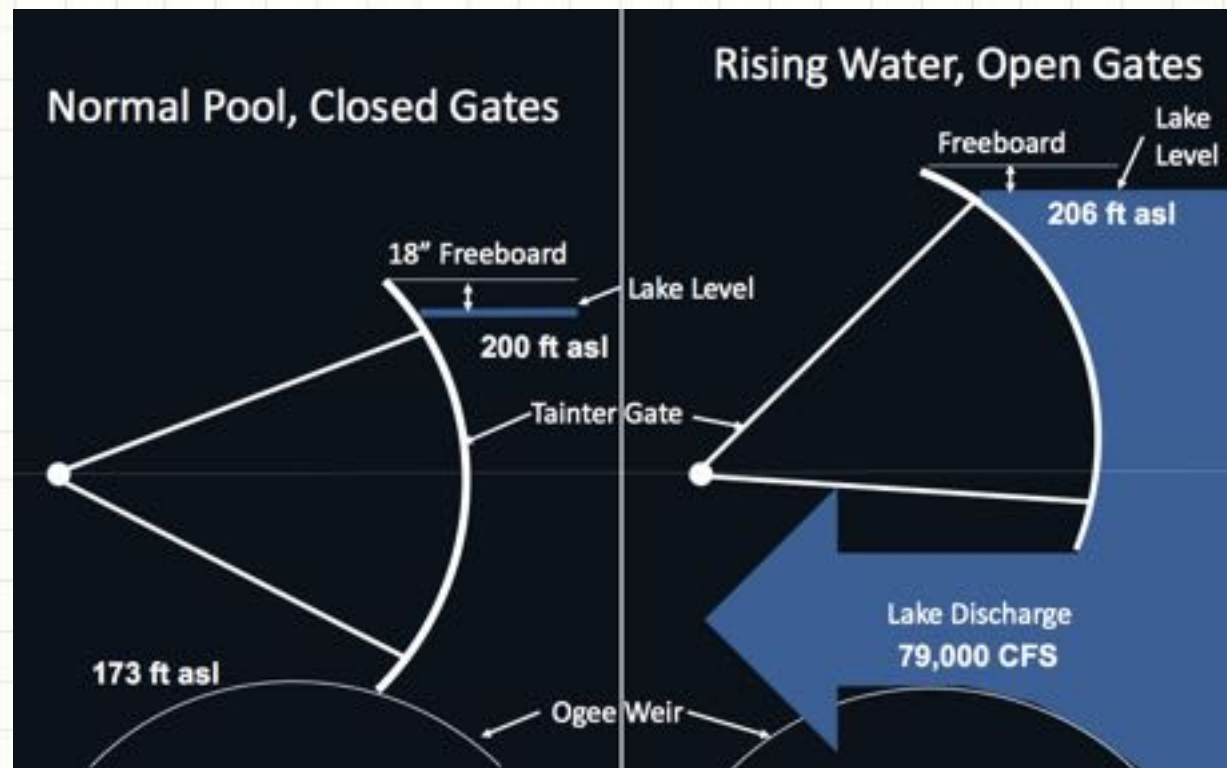
Lake Conroe Protocols and Releases

- ◆ It appears that San Jacinto River Authority (SJRA) operations held back all water releases until they reached the maximum level (206 ft) before homes flooded around Lake Conroe
- ◆ There were inflows at the 130,000 cfs levels as indicated during late August 26th.
- ◆ They began water release around 1 am on August 28th at 79,000 cfs, a rate more than double their previous maximum set in 1994 and just short of the normal flow at Niagara Falls.
- ◆ The only community notice provided was a post on their website at midnight.
- ◆ 87% of the Lake Conroe watershed rainfall occurred before the release. The 79,000 cfs release stopped the lake level rise meaning the inflow was equal to or less than the release.
- ◆ The release continued for 36 hours dropping the level almost 3 feet. This added large water volume into the lower watershed.
- ◆ Lake Conroe could have maintained it until downstream water levels dropped from the uncontrolled sources.

River Flows

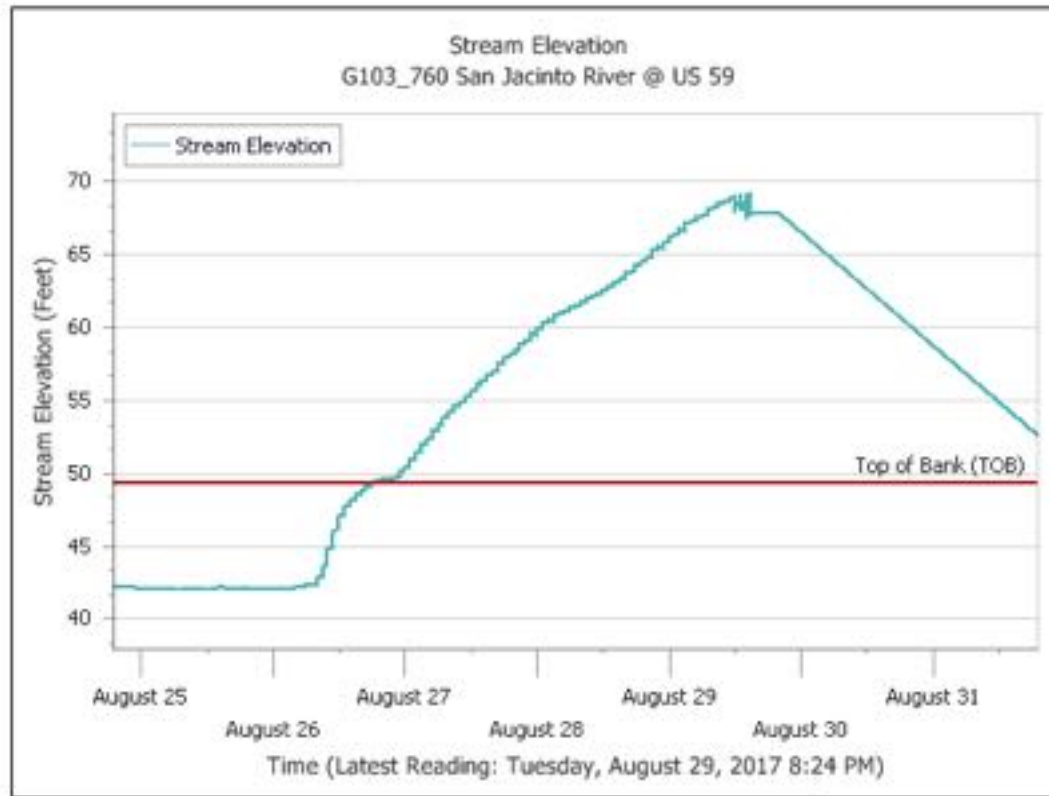
Lake Conroe Lake Level Control

- ◆ Lake Conroe has a normal pool low flow level control service outlet.
- ◆ It also has large Tainter Gates that are used to drop the level quickly. These were used in the Harvey release.
- ◆ Tainter Gates can drop the level from 206 to 173 ft-asl.



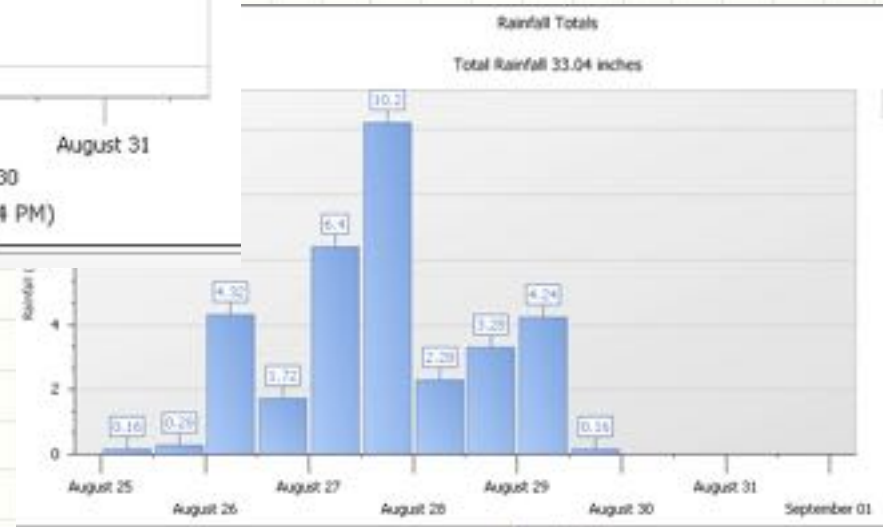
River Flows

WF San Jacinto River at Hwy 59 (HMMT2)



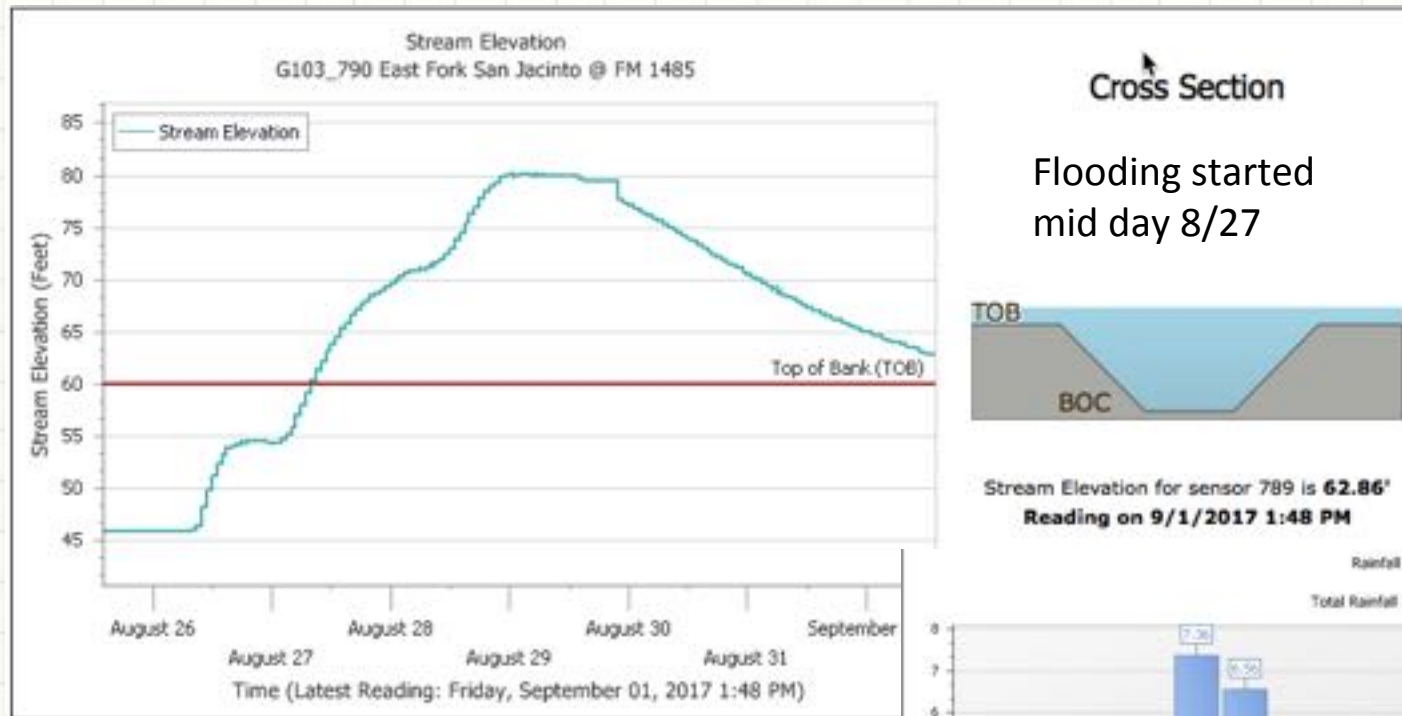
WF hit its peak, 27 ft above nwl, early in the morning on Tuesday, 8/29, when the Lake Conroe release arrived and rain continued on 8/28-29. Flooding started early morning of 8/27.

Peak was 19 feet beyond flood stage and highest level around the lake due to flow rate, size of channel and debris accumulating at the Hwy 59 bridge

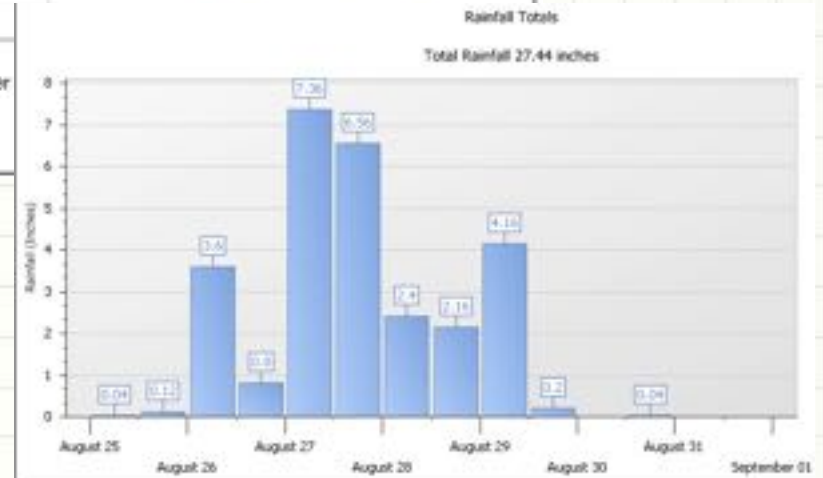


River Flows

EF San Jacinto River at FM 1485 (NCET2)



EF hit its peak, 35 ft above normal, all day on Tuesday, 8/29, when watershed flows and rain continued on 8/28-29. Peak was 20 feet beyond flood stage. The watershed size, channel size, distance to lake, and higher elevation contributed.



River Flows

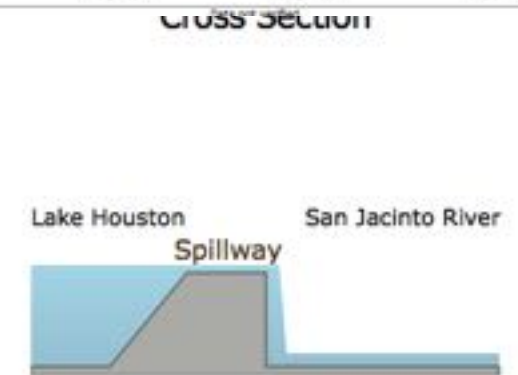
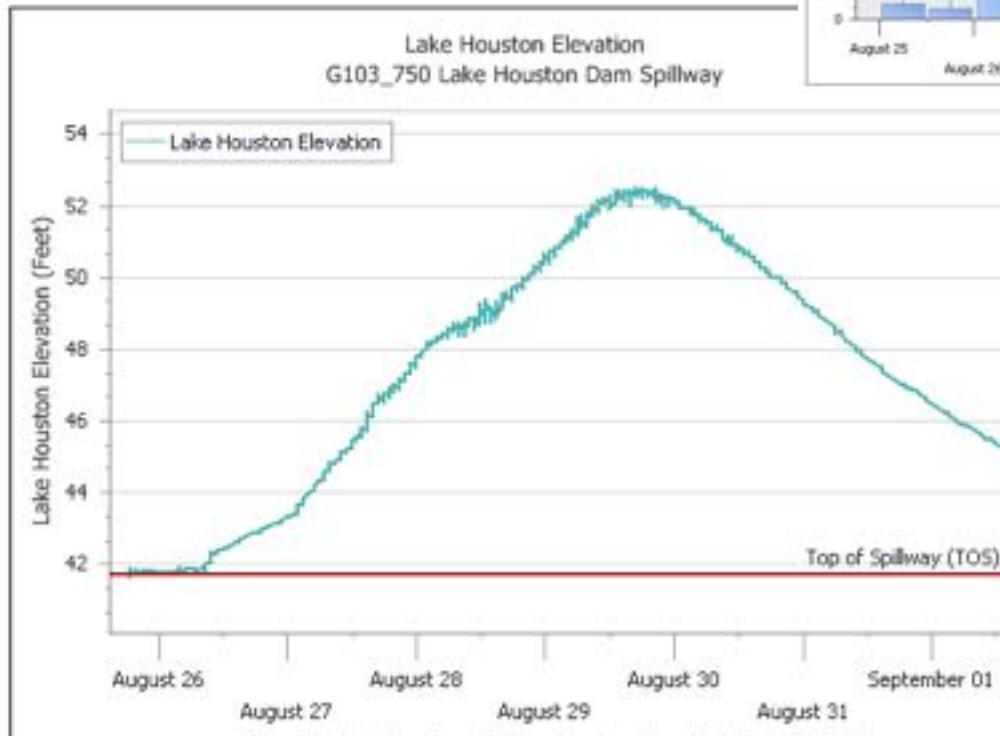
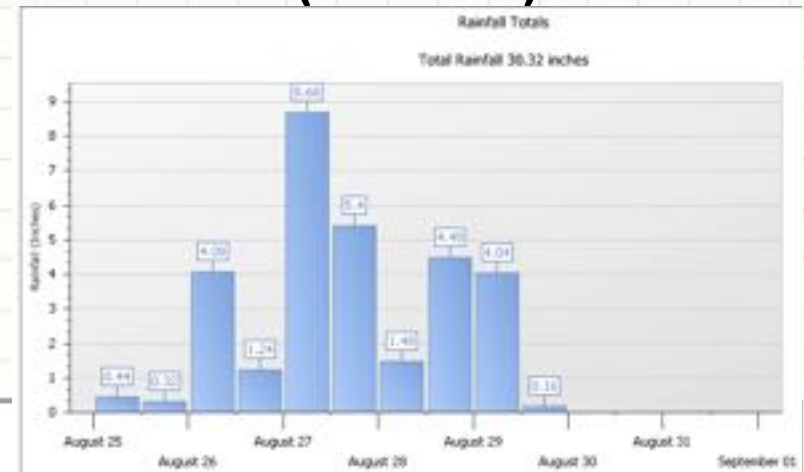
Lake Houston West and East Forks

- ◆ The West Fork started flood conditions early on the 27th and peaked late in the early morning of 29th. Peak flow is estimated at 236,200 cfs. It appears that the length of peak and decline may be inaccurate due to a gauge failure.
- ◆ The East Fork started flood conditions evening of the 27th and peaked early on the 29th and extended through the 30th. Peak flow is estimated at 142,100 cfs. East Fork went back in its banks 9/2.
- ◆ In addition to these sources, three other sources are included: Luce Creek, Caney Creek and the lake area. The following table is the total volume of water from each branch:

Watershed	Acr Ft	Share
WF SanJac	1,389,753	55%
EF San Jac	881,526	35%
Other	239,760	10%
Total	2,511,039	100%

River Flows

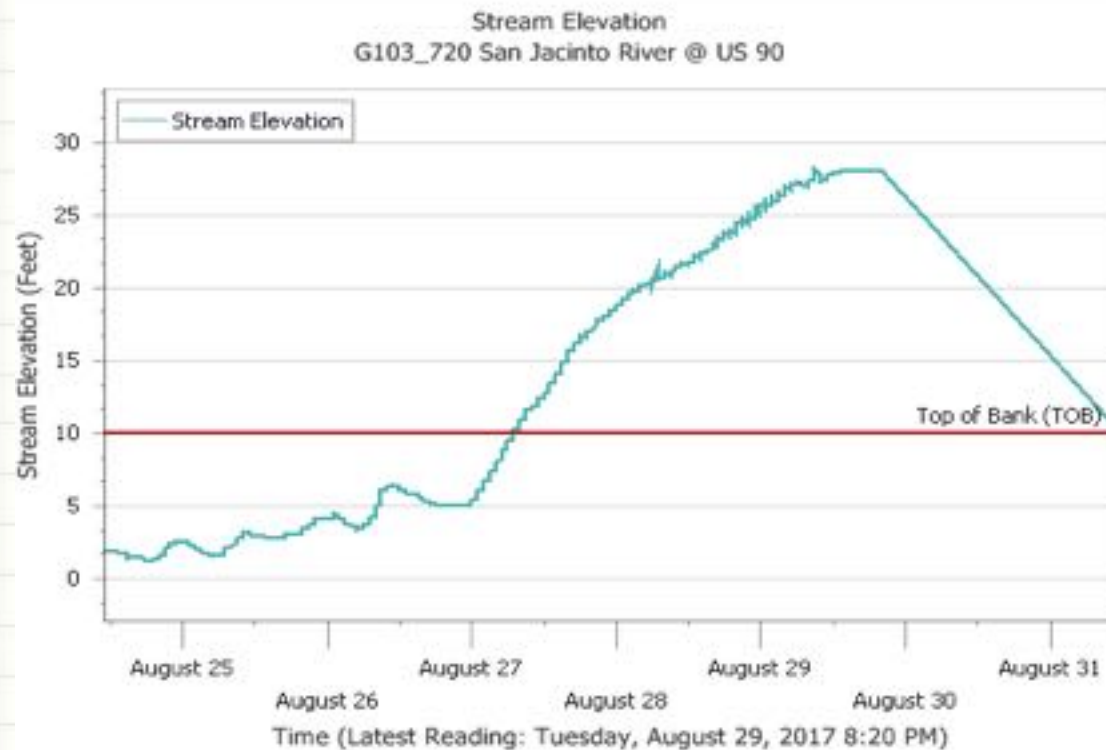
Lake Houston Lake Levels at Dam (HSJT2)



Lake Houston Elevation for sensor 749 is **45.26'**
Reading on 9/1/2017 3:02 PM

River Flows

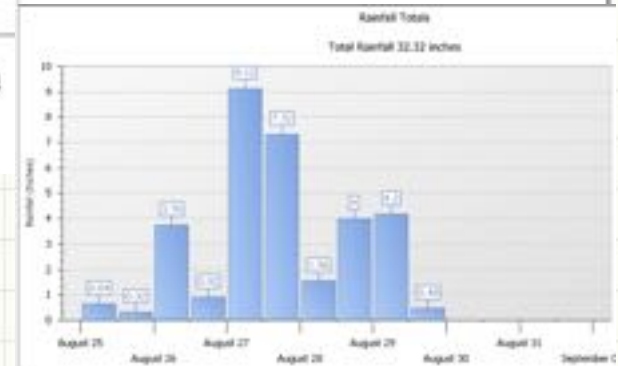
San Jacinto River at Hwy 90 (SHLT2)



Cross Section




Stream Elevation for sensor 719 is **28.00'**
Reading on 8/29/2017 8:20 PM



River Flows

Lake Houston Outfall

- ◆ Lake Houston started flood conditions early on the 27th and peaked during the day of 29th. Peak flow is estimated at 396,000 cfs with a peak level at the dam spillway of 52.2 ft. asl or 10 ft. over the spillway.
- ◆ During the storm, a surge was created across the lake. Concurrent peak levels occurred with 69 ft. asl at the bridge, down to 60 ft. asl after West Lake Houston bridge and down to 52 ft. asl at the dam. These reductions are due to continual widening of the channel from the Hwy 59 bridge, to West Lake Houston bridge, to the dam.
- ◆ During the storm, Lake Houston received 2,500,000 ac.-ft. of water and all of that water went over the spillway except for 50,000 ac.-ft. retained before 9/1.
- ◆ The flow from Lake Houston inundated the downstream San Jacinto River. The river reached flood stage mid morning on 8/27 and after midnight on 8/29 at 29 ft. asl or 25 ft. over normal. . It appears that the length of peak and decline may be inaccurate due to a gauge failure.



SAN JACINTO FLOODING

WEST FORK RIVER CHANNEL

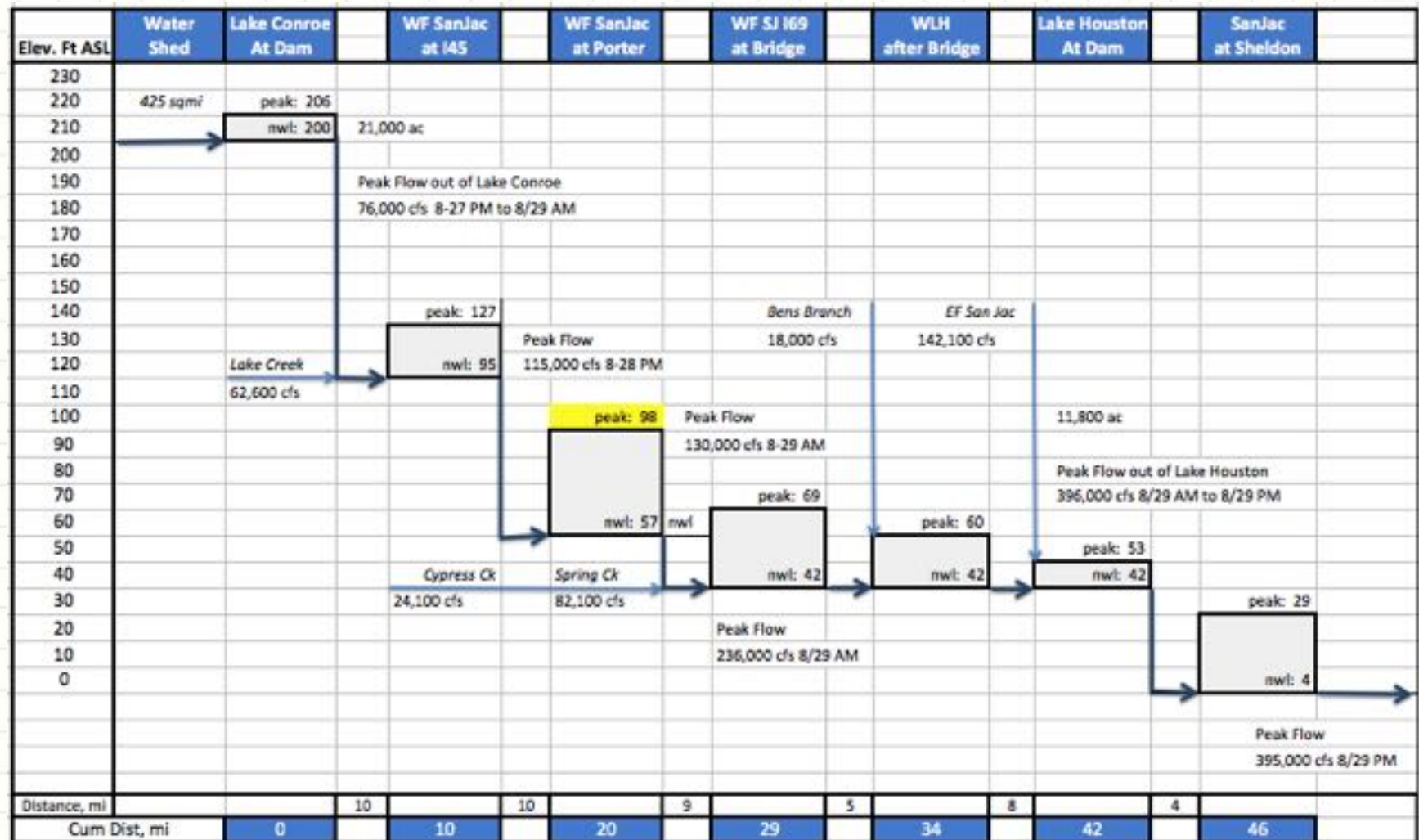
River Flows San Jacinto

River Way Issues During the Flooding

- ◆ The West Fork San Jacinto has sources of water from Lake Conroe, Lake Creek, Cypress Creek, Spring Creek and local runoff. The Lake Houston normal level is 42 ft. asl and is constant from the Hwy 59 bridge to the dam 13 miles away.
- ◆ West Fork has several sand pit operations along the river. Hallet Material's two sand pits on the West Fork and one on the East Fork are the most notable. Their mining operations were completely flooded and contributed to sand deposits downstream.
- ◆ The Hwy 59 bridges north of Humble creates a narrow channel. The bridges ultimately act as a dam when the river flow rate peaks and floating debris clog the channel under the bridge. The bridge has multiple concrete support posts every 60 ft. The peak level of 69 ft asl was forced by the dam effect at the bridge.
- ◆ Concurrent peak levels occurred with 69 ft. asl at the bridge, down to 60 ft. asl after West Lake Houston bridge. This 33% reduction is due to widening of the channel from 1.5 miles at the 59 bridge to 2.5 miles at West Lake Houston bridge during flood conditions. (5 miles).

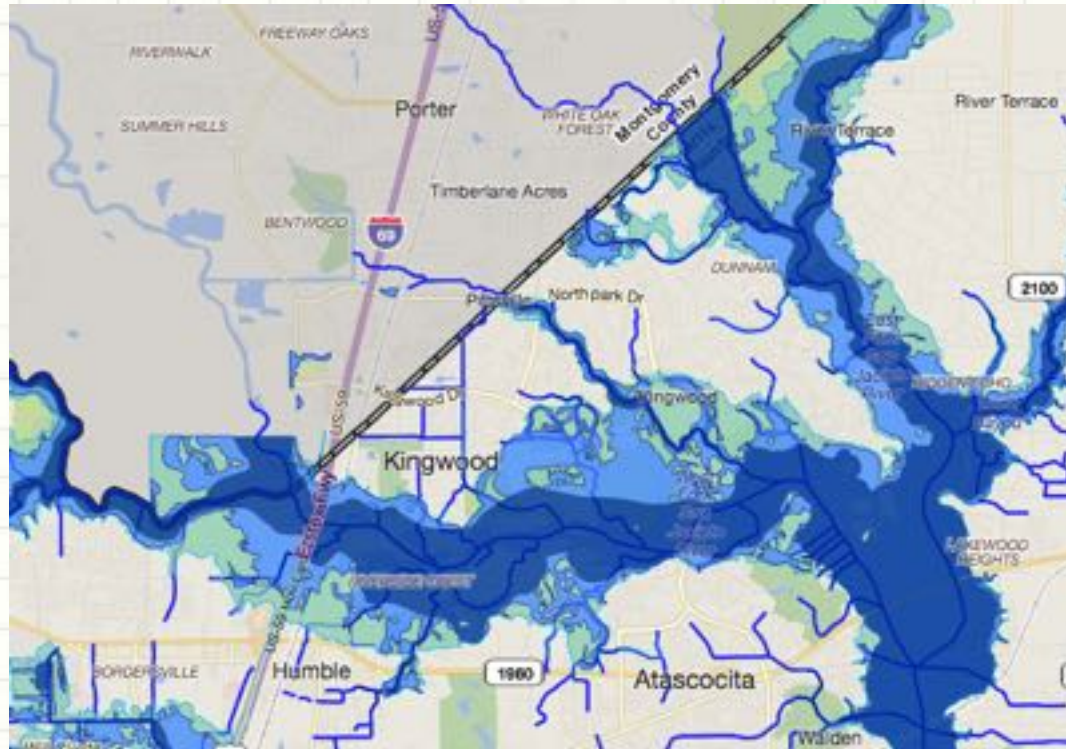
River Flows San Jacinto

Harvey Peak Flood Conditions



River Flows San Jacinto

FEMA Flood Maps: Harvey 500+ yr Levels



Location	West Lake Houston Park.	Lake Houston Dam
100 year, ft asl	52	49
500 year, ft asl	57	52
Harvey, ft,asl	60	52

River Flows San Jacinto

NWS Water Gauge at Highway 59 (HMMT2)

Flood Categories (in feet)

Major Flood Stage:	52.3
Moderate Flood Stage:	50.3
Flood Stage:	49.3
Action Stage:	45.3
Low Stage (in feet):	0

Historic Crests

- (1) 67.30 ft on 10/18/1994
- (2) 63.20 ft on 05/31/1929
- (3) 62.80 ft on 09/14/2008
- (4) 62.20 ft on 11/26/1940
- (5) 61.90 ft on 05/29/2016

[Show More Historic Crests](#)

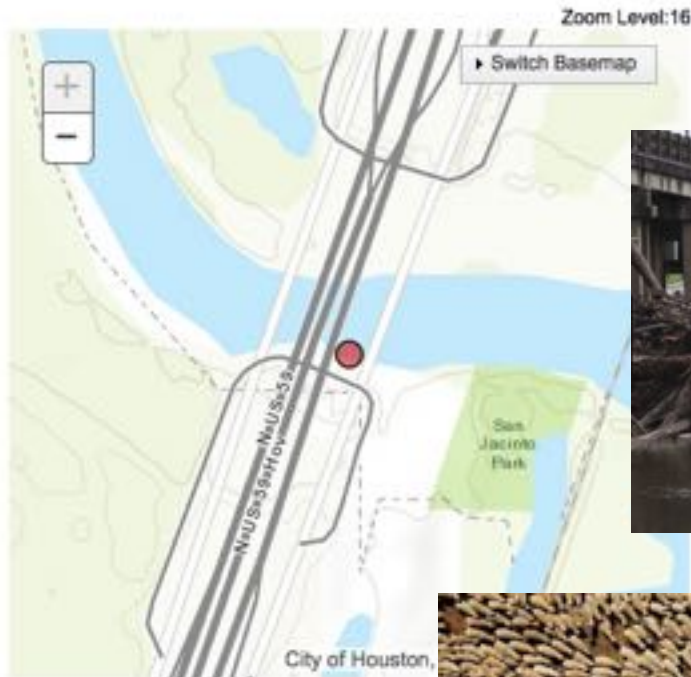
(P): Preliminary values
subject to further review.

Recent Crests

- (1) 61.90 ft on 05/29/2016
- (2) 57.29 ft on 04/20/2016
- (3) 50.11 ft on 06/21/2015
- (4) 53.65 ft on 05/28/2015
- (5) 49.56 ft on 05/18/2015

[Show More Recent Crests](#)

(P): Preliminary values
subject to further review.



These sheep show what happens to water at the bridge. Just like the bridge, the sheep will go everywhere when enough pressure causes them to jump the fence.

River Flows San Jacinto


Highway 59 Bridge Calculation Flow Model

- ◆ River overflowed the bridges reaching a level of 69 ft asl. This elevation closely matches the top of the bridge guard rails and concrete barriers. The peak flow is 236,200 cfs.
- ◆ This elevation pushed water into Humble businesses and Northshire homes. Impacting Costco, Target, Hampton Inn, and Hobby Lobby West of Hwy 59, and all retail and restaurants on the East side of 59.
- ◆ The bridge channel flow calculation model was prepared by simplifying it to a parallel grid of 12x12 ft concrete culverts 400 feet long. Cases were developed for unobstructed and 50% obstructed and cases for 7 ft head (69 ft asl) and 1 ft head (under the bridge).
- ◆ The results most duplicating the actual conditions is reasonably matched what happened at the bridge are: 200,600 cfs with the channel 50% blocked and 7 feet head.
- ◆ Once past the bridge water level of 69 ft the level of water dropped due to the widening of the channel and expansion into the flood plain.

River Flows San Jacinto

Bridge Obstruction Flow Model Results

Assume Flow Area is obstructed by support posts only

13 Box Channels (A) - 800ft				6 Box - 200ft Channels (B)		13 Box Channels (A) - 800ft	
	Act Flow Rate, cfs				Box channels 12 x 60 x 400		
	Peak	236,200			Box Model 12 x 12		
	Height, ft	Width, ft	Length, ft	Quantity	Area, sq ft		
Box Channel A	20	60	400	3	1200		
Box Channel A	13	60	400	26	780		
Cases	Size, ft.	Flow cfs	Area Adjst	Qnity Adjust	Quantity	T Flow, cfs	Wtr Level
Unobstructed	12x12	2300	0.95	5.5	32	384,560	@7 ft
50% Blocked	12x6	1200	0.95	5.5	32	200,640	@7 ft
Unobstructed	12x12	900	0.95	5.5	32	150,480	@1 ft
50% Blocked	12x6	450	0.95	5.5	32	75,240	@1 ft
		Channel A	Channel B	Box Model			
max Level 69 ft nwl 42		7 ft	7	Unobstructed	Obstructed		
		Water Level		7 or 1	7 or 1	Center Channel (B)	
		20x60ft	13x60	12x12	12x6	bottom bridge 62 ft nwl 42ft asl	
							
	Length, ft	400	400	400	400		

River Flows San Jacinto

Debris and Sand Removed at 59 Bridges





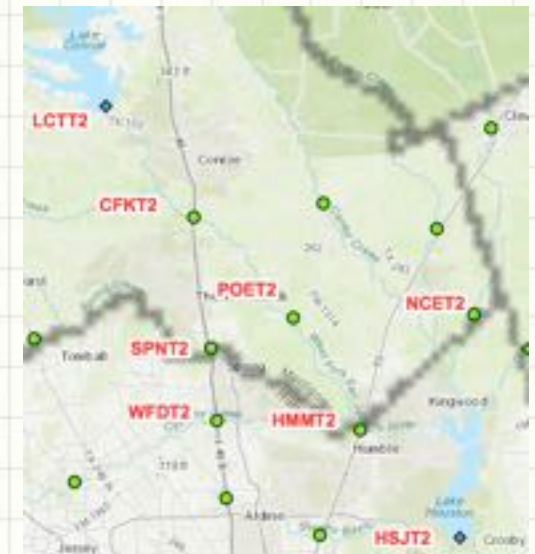
APPENDIX

River Flows

Watershed Locations: Water Levels and Peak Flows

Location	Code	Min WL 2011 feet asl	Normal WL feet asl	Flood WL feet asl	Max WL 1994 feet asl	Max WL 2017 feet asl	Delta 94-17 feet
Lake Conroe Dam	LCTT2	192	200	207	205	206	1
Spring Creek @45	SPNT2		74	92	118	111	-7
Cypress Creek @45	WFDT2		65	83	92	97	5
WF San Jacinto @Conroe	CFKT2		95	115	126	127	1
WF San Jacinto @Porter	POET2		57	81	98	98	0
WF San Jacinto @59	HMMT2		42	49	67	69	2
EF San Jacinto @1485	NCET2		46	63	79	80	1
Lake Houston Dam	HSJT2	34	42	54	53	53	0
San Jacinto @90	SHLT2		4	10	27	29	2

Location	Normal WL feet asl	Max WL 2017 feet asl	Flow 2017 cfs	^Above Nor feet	Date/Time
Lake Conroe Dam	200	206	76,000	6	8/27/17 6:00
Spring Creek @45	74	111	82,100	37	8/28/17 19:00
Cypress Creek @45	65	97	24,100	32	8/29/17 0:00
WF San Jacinto @Conroe	95	127	115,000	32	8/29/17 0:00
WF San Jacinto @Porter	57	98	130,000	41	8/29/17 12:00
WF San Jacinto @59	42	69	236,200	27	8/29/17 12:00
EF San Jacinto @1485	46	80	73,800	34	8/29/17 0:00
Lake Houston Dam	42	53	378,300	11	8/29/17 12:00
San Jacinto @90	4	29	395,000	25	8/29/17 19:00



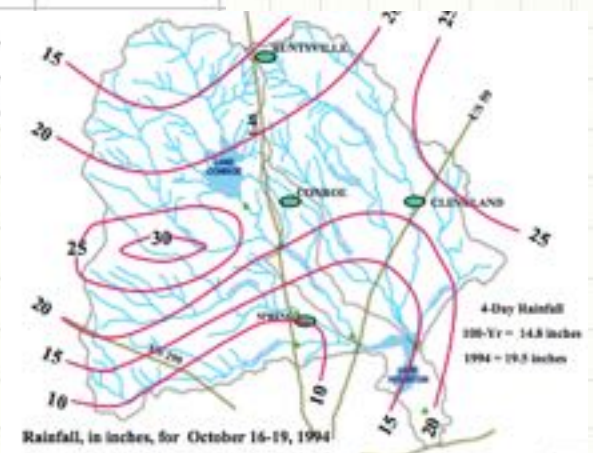
River Flows

West Fork Watershed Rainfall Statistics

Rainfall	Lake Conroe	Spring Creek	Cypress Creek	WF @ Humble	WF Ave	WF Cumm
8/25 AM	0	0	0	0.2	0.1	0.1
8/25 PM	0.1	0.2	0.2	0.3	0.2	0.3
8/26 AM	4.1	3.9	4.6	4.3	4.2	4.5
8/26 PM	1.9	2.6	3.1	1.7	2.3	6.8
8/27 AM	7.7	8.5	8.9	6.4	7.9	14.7
8/27 PM	5.4	8.4	7.5	10.2	7.9	22.6
8/28 AM	1.2	1.8	1.9	2.3	1.8	24.4
8/28 PM	0.6	2.2	2.7	3.3	2.2	26.6
8/29 AM	0.8	1.7	1.8	4.2	2.1	28.7
8/29 PM	0.3	0.2	0.2	0.2	0.2	28.9
8/30 AM	0	0	0	0.0	0.0	28.9
8/30 PM	0	0	0	0.0	0.0	28.9
Total	22.1	29.5	30.9	33.1	28.9	

Lake Conroe	inches		hours	ave rain, inph
Prior to Release	19.2	87%	48	0.40
During Release	2.9	13%	48	0.06

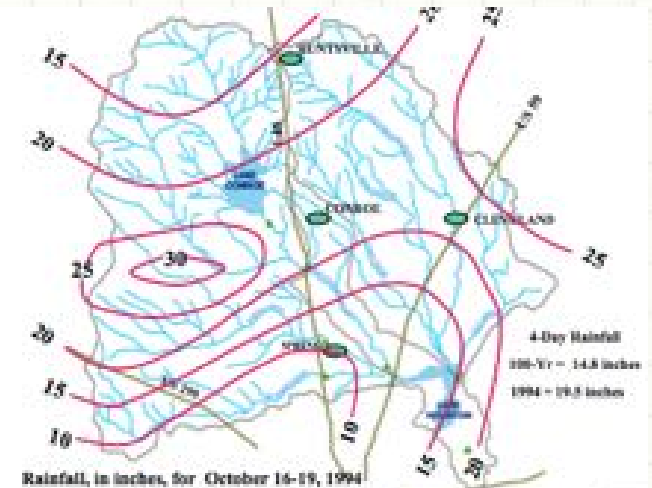
Harvey rainfall was similar to the 1994 flood in the West Fork watershed. Harvey was more widespread especially east of 45 and along the Cypress Creek watershed.



River Flows

East Fork Watershed Rainfall Statistics

Rainfall	EF @ Ncaney	Lake Houston	San Jac @ Sh	EF Ave	EF Cumm
8/25 AM	0	0.4	0.6	0.3	0.3
8/25 PM	0.2	0.3	0.3	0.3	0.6
8/26 AM	3.6	4.1	3.8	3.8	4.4
8/26 PM	0.8	1.2	0.9	1.0	5.4
8/27 AM	7.4	8.7	9.1	8.4	13.8
8/27 PM	6.6	5.4	7.3	6.4	20.2
8/28 AM	2.4	1.5	1.6	1.8	22.1
8/28 PM	2.2	4.5	4.0	3.6	25.6
8/29 AM	4.2	4.0	4.2	4.1	29.8
8/29 PM	0.2	0.2	0.5	0.3	30.1
8/30 AM	0	0	0	0.0	30.1
8/30 PM	0	0	0	0.0	30.1
Total	27.6	30.3	32.3	30.1	
Lake Houston	inches		hours	ave rain, inph	
Prior to Release	20.1	73%	48	0.42	
During Release	10.2	37%	48	0.21	



Harvey rainfall much heavier than the 1994 flood in the East Fork watershed. Harvey was more widespread especially east of Hwy 45, the entire Hwy 50 corridor, and east of Lake Houston. The East Fork water flow accounts for the difference in discharge flows at the Lake Houston dam.

Historical River Flows

Watershed Locations 1900 to 2017

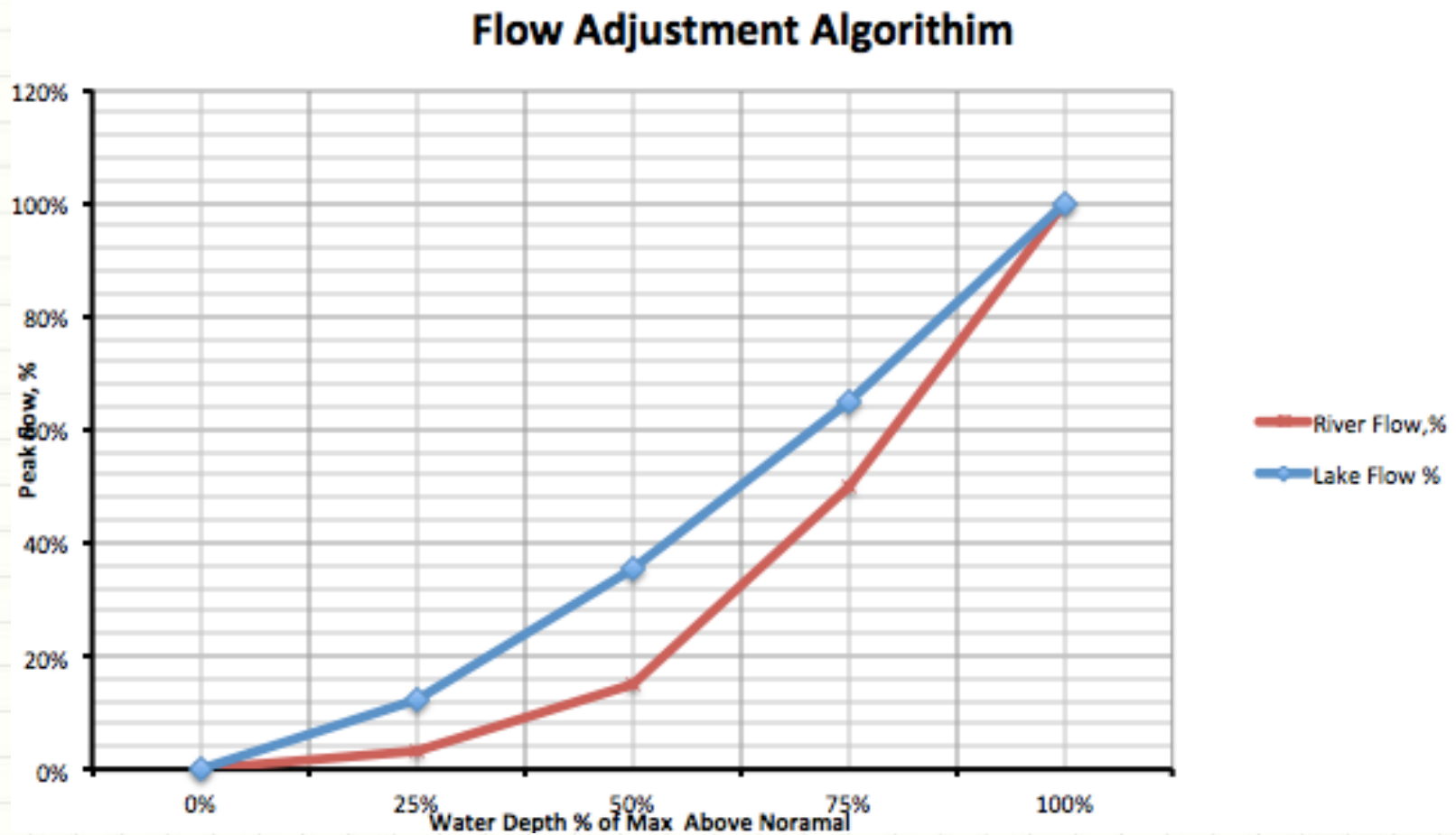
Year	Lake Conroe flow, cfs	Highway 59 flow, cfs	Highway 59 level, ft asl	Lake Houston flow, cfs	Ave Runoff Depth, in
1900	na	185,000	63	na	na
1929	na	187,000	63	237,000	na
1940	na	187,000	62	253,000	na
1994	35,000	230,000	67	356,000	12.7
2017	79,000	236,000	69	400,000	16.3

Average Runoff Depth is the average rainfall over the watershed that makes it to the river and through the lake. The Harvey statistics for lake were 16 inches for 30 inches of rain or a 54% reduction due to water remaining the soil and ponds in the watershed.

According to U. S. Weather Bureau Technical Paper No 49, the 4-day 100-year rainfall for the San Jacinto River watershed is 14.8 inches. The 4-day total rainfall for the 1994 event was about 19.5 inches, and the 2017 event was about 30 inches or approximately 100% higher than the 100-year total.

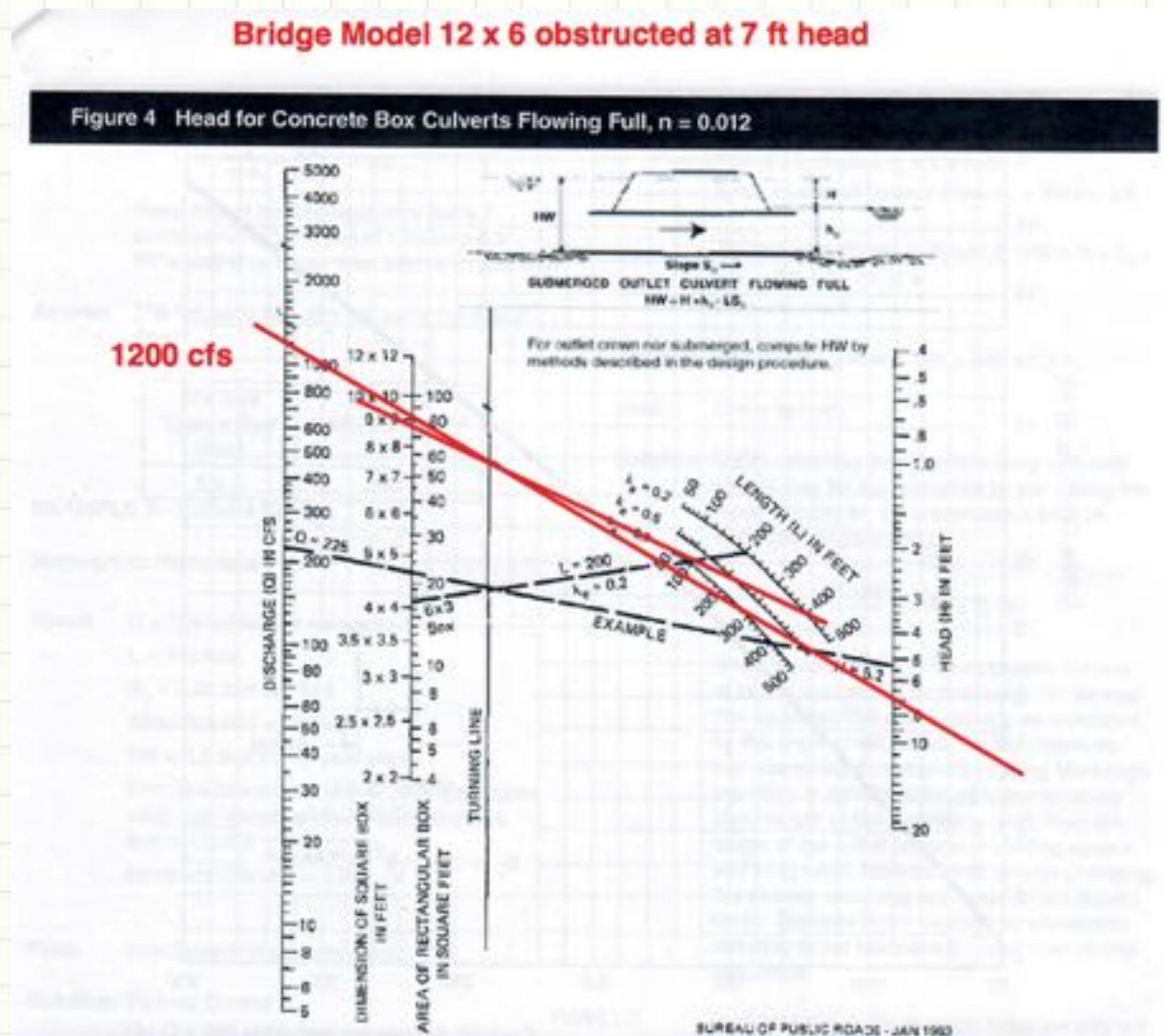
River Flows

River and Lake Weir Flow

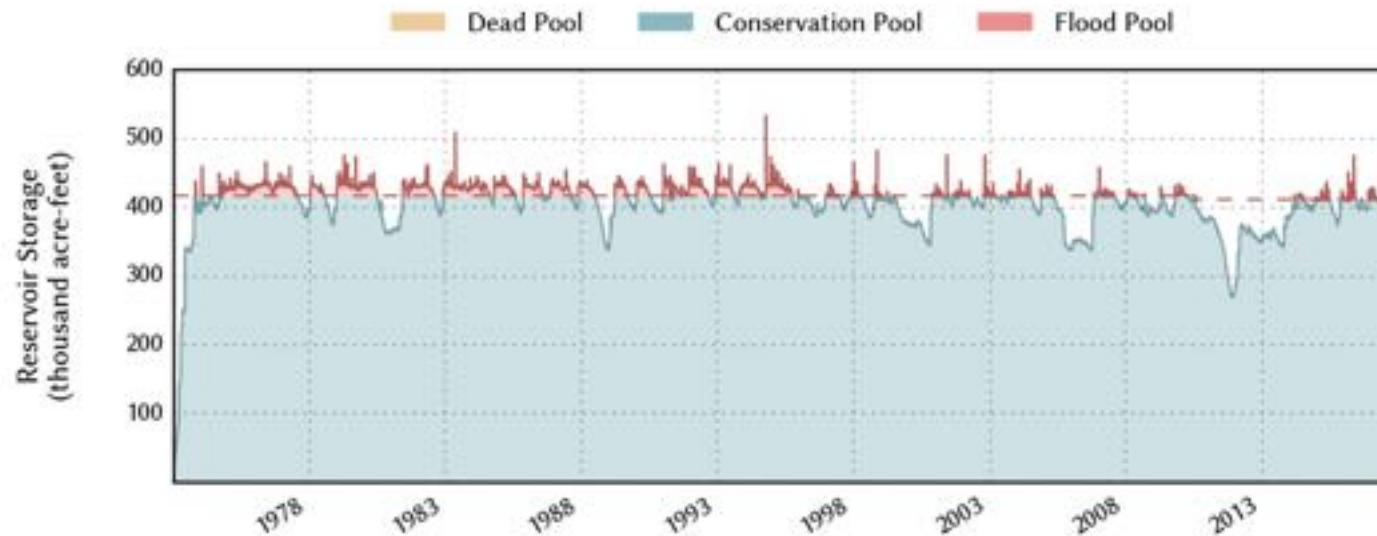


River Flows

Channel Box Culvert Nomo graph (typical)



Lake Conroe: 99.0% full as of 2017-10-03



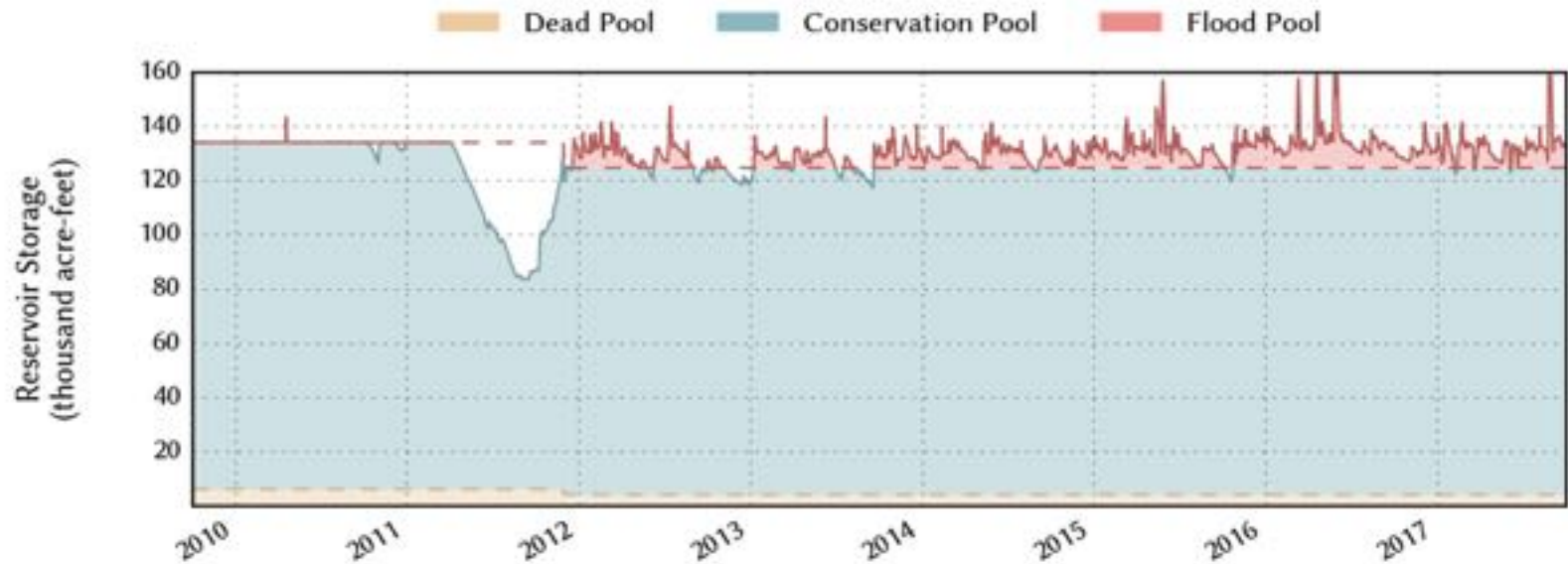
Additional Information

Impoundment date	1973-01-01
Vertical datum	NGVD29
Gauge	USGS:08067600
Dead pool elevation	145.0 ft above NGVD29
Top of flood gate elevation	202.5 ft above NGVD29
Emergency spillway crest elevation	173.0 ft above NGVD29
Maximum design elevation	207.0 ft above NGVD29
Top of dam elevation	212.0 ft above NGVD29
Conservation pool elevation	201.0 ft above NGVD29
Data download (CSV)	period of record, last one year, last 30 days

Lake Location



Lake Houston: 100.0% full as of 2017-10-03



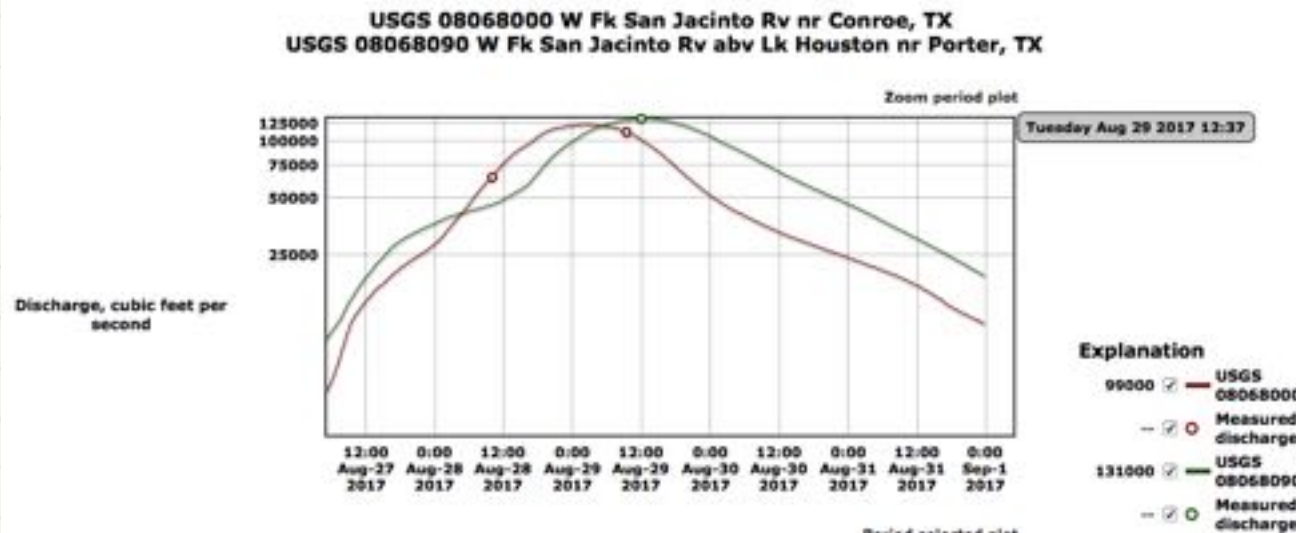
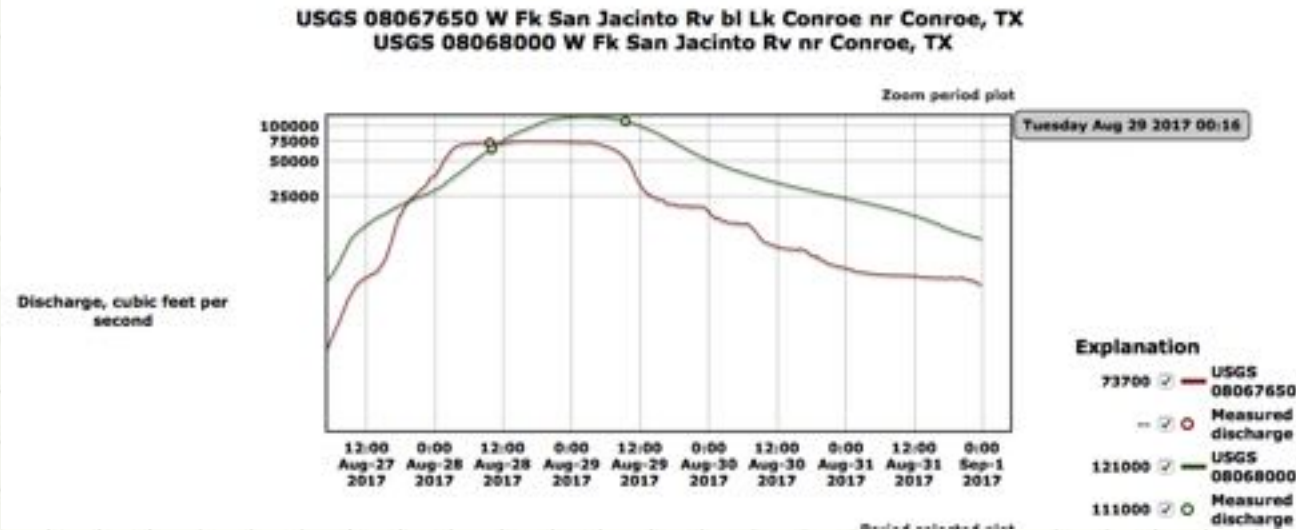
Additional Information

Impoundment date	1954-01-01
Vertical datum	NAVD88
Gauge	USGS:08072000
Dead pool elevation	19.2 ft above NAVD88
Service spillway crest elevation	41.7 ft above NAVD88
Top of flood gate elevation	45.7 ft above NAVD88
Emergency spillway crest elevation	41.7 ft above NAVD88
Maximum design elevation	54.2 ft above NAVD88
Top of dam elevation	60.2 ft above NAVD88
Conservation pool elevation	41.7 ft above NAVD88
Data download (CSV)	period of record, last one year, last 30 days

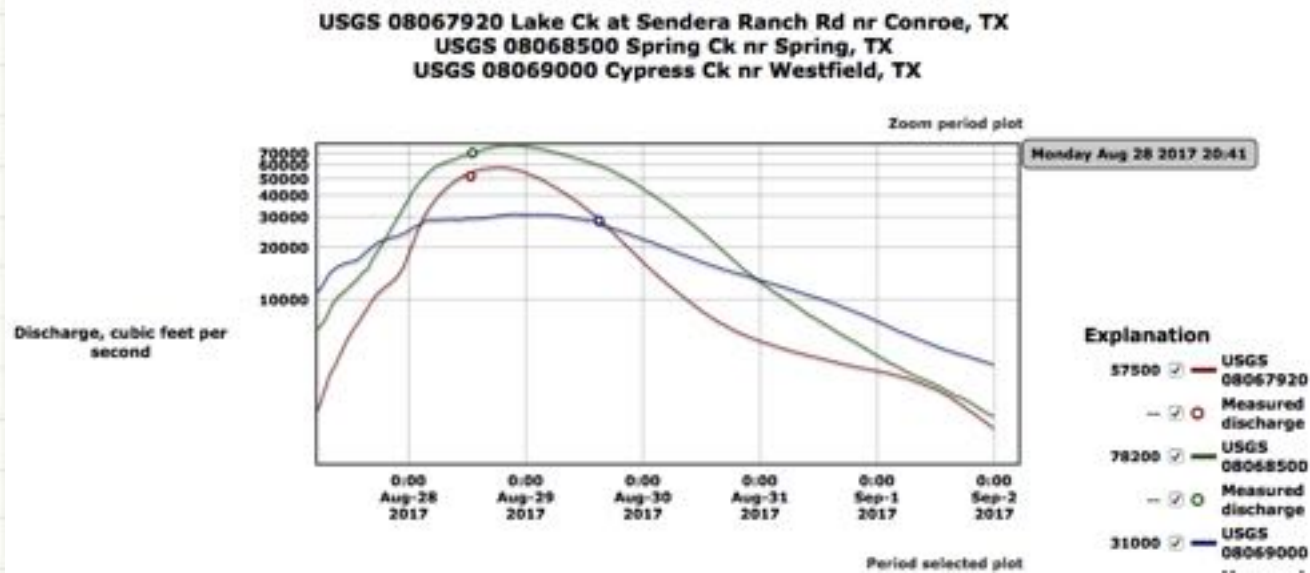
Lake Location



USGS River Flows: Main Channel of the West Fork Watershed Locations: Water Discharge and Timing



USGS River Flows: Tributaries of the West and East Forks Watershed Locations: Water Discharge and Timing



USGS River Flows: Lake Houston input from East and West Forks Watershed Locations: Water Discharge and Timing

