Floods on the Llano River, Texas — Fall 2018-DRAFT

Llano River Watershed Alliance

Tyson Broad - January 4, 2019

This report was made possible by generous support from the Texas Parks and Wildlife Department.

NOTE: Where possible, hazards to navigation resulting from the flood have been noted. However, it is highly probable that not all navigation hazards were detected or new hazards developed after river surveys. The Llano River Watershed Alliance and Texas Parks and Wildlife assume no responsibility for accidents resulting from noted or unnoted river hazards.

The Llano River Watershed Alliance is a 501c(3) organization of landowners and interested stakeholders dedicated to preserving and enhancing the Llano River and adjoining watersheds by encouraging land and water stewardship through collaboration, education, and community participation.

Cover Photo: South Llano River at bankfull stage at South Llano River State Park, October 9, 2018.

Executive Summary

The Llano River in located in central Texas and flows from its headwaters above the City of Junction to its confluence with the Colorado River at Lyndon B. Johnson Reservoir near the community of Kingsland. In August 2018, the Llano River nearly ceased flowing, dropping to 0.03 cubic feet per second (13 gallons per minute) on August 8, 2018 at the U.S. Geological Survey (USGS) gage in the City of Llano. Two months later, on the morning of October 16, 2018, a series of flood waves swept down the Llano River. A peak flow of 40.17 ft with an estimated discharge of 278,000 cfs (125 million gallons per minute) was recorded at 7:05 am at the USGS gage in the City of Llano. This was the second highest flow on record; the flood of June 14, 1935 reached 41.5 feet with a estimated discharge of 380,000 cfs, while the third highest flow on record occurred on June 21, 1997, when flows peaked at 260,000 cfs (39.1 ft). [1]

The peak flood wave on October 16, 2018 was one of a series of high-flow events that occurred over a three-week period. On September 22, a flood wave of 14.32 ft swept down the North Llano River and on October 8, a flood wave of 26.63 ft swept down the South Llano River. These events were the result of record, two-month rainfall across the Edwards Plateau ecoregion, with some locations in the Llano River watershed, such as Valley Spring (14 mi WNW of the City of Llano) recording more than 22 inches during the period, and more than 10 inches of rain in a 48-hour period.

This report describes the timing and magnitude of these flood events in the Llano River watershed, characterizes changes to the aquatic and riparian habitats of the river, and profiles the effects of the flooding on recreational access and use of the river. Descriptions are based upon observations by the author.

General Description

The Llano River watershed (figure 1) encompasses 4,456 square miles of the Edwards Plateau ecoregion of central Texas. The North Llano River, originating in Sutton County, and the South Llano River, originating in Edwards County, serve as the headwaters of the basin. The mainstream Llano River emerges at the City of Junction in Kimble County, at the confluence of the North Llano and South Llano rivers. From Junction, the Llano River flows

[1] River discharge data in this report are provisional data from US Geological Survey and Lower Colorado River Authority as retrieved December 26, 2018. These data are subject to revision by these agencies.

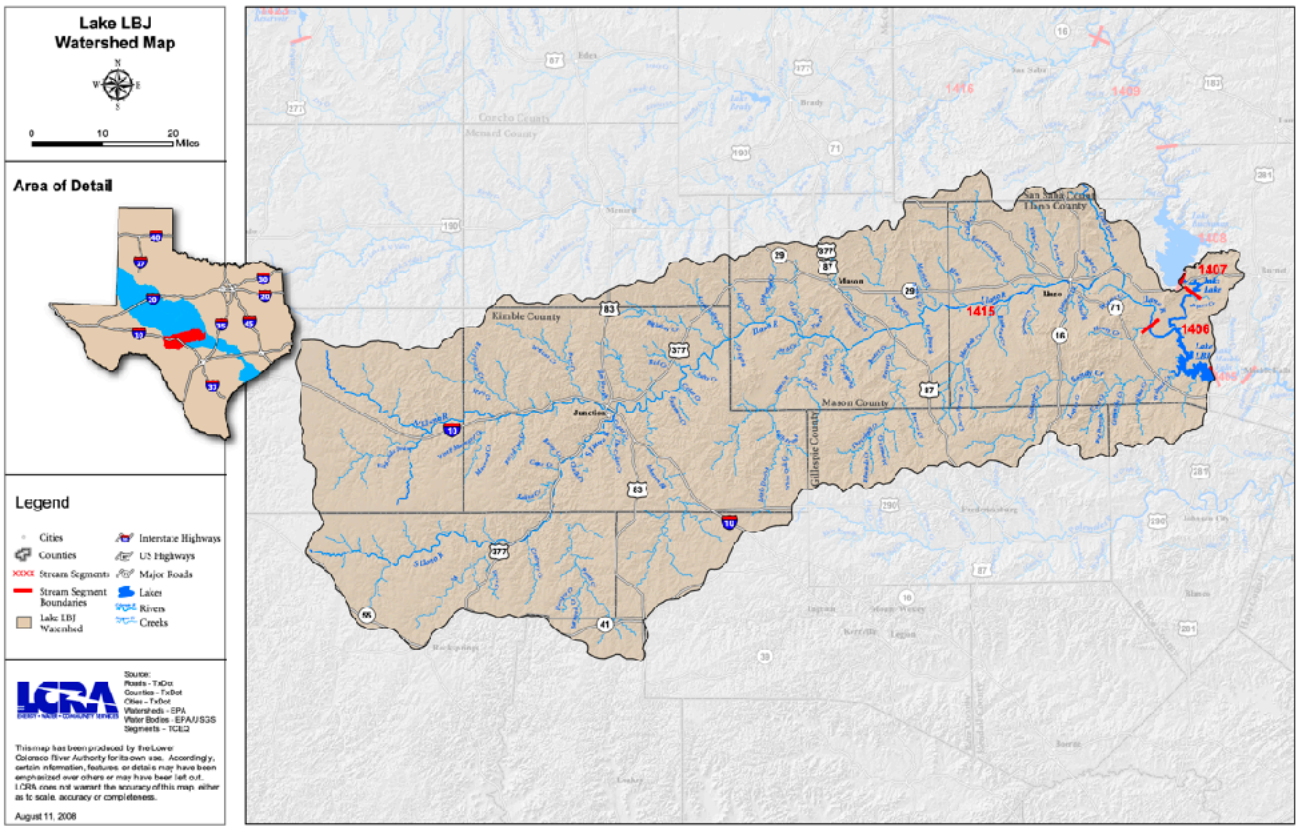

Figure 1. Llano River Watershed. From Lower Colorado River Authority
Note: Additional maps of watershed available at the end of the report.

through Mason and Llano counties to its confluence with the Colorado River at Lake Lyndon B. Johnson (LBJ) near the community of Kingsland. The USGS estimates that 81% of the flow past the river gage below the City of Junction is from baseflow (that part of streamflow that is not direct surface runoff), or spring flow that emanates from the karst, limestone landscape of the Edwards Plateau ecoregion. [2]

The Edwards Plateau ecoregion is characterized by the presence of caves, sinkholes and subsurface drainage networks or conduits. On average, approximately 22-24 inches of precipitation falls annually on the Llano River watershed. As most of the upper watershed consists of thin soil atop limestone bedrock, the majority of this precipitation runs off quickly. However, some of the precipitation finds its ways through sinkholes, caves, rock fractures and root zones to enter and recharge the Edwards-Trinity Aquifer. Where rivers such as the

[2] E.L. Kuniansky, "Precipitation, streamflow, and baseflow, in West-Central Texas, December 1974 through March 1977". U.SI Geological Survey Water-Resources Investigations Report 89-4208, 1989.

North Llano and South Llano carve valleys into the limestone plateau, these conduits are exposed, resulting in the emergence of groundwater as springs.

While the majority of flows of the Llano River consist of baseflows (near City of Junction: 81%; near City of Mason: 72%; at City of Llano: 62%), the Llano River is subject to severe flooding. The Llano River is located within an area referred to as "Flash Flood Alley", where the convergence of moisture from the Gulf of Mexico and topography can combine to deliver significant precipitation events that fall on shallow soils and steep slopes, producing significant runoff in short amounts of time.

Description of the Fall 2018 Llano River Floods

Floods in the Llano River watershed during fall 2018 consisted of a series of three events, the first occurring in September. The first event impacted mostly the North Llano River and the second event, mostly the South Llano River. The third and largest event, was a combination of floods on the South Llano River, Johnson Fork, James River, and the mainstream of the Llano River.

September 21-22, 2018

The previous month (August) ended with parts of the watershed experiencing extreme drought (Figure 2); the flow of the Llano River at the City of Llano reached 0.03 cfs (13 gallons per minute) on August 8. Conditions changed rapidly during September with the arrival of tropical disturbances from the Gulf of Mexico, setting the stage for the flood events that followed over the next three weeks. During first week of September, six to seven inches of rain fall across much of the upper watershed. The arrival of an

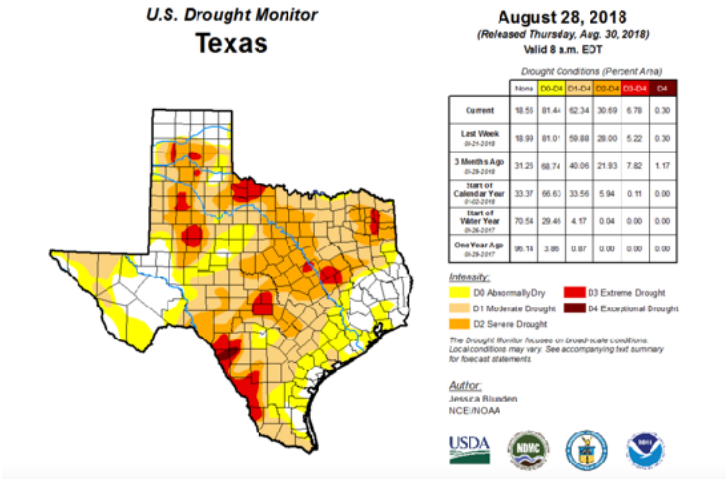

Figure 2. Drought Index August 28, 2018, from US Drought Monitor

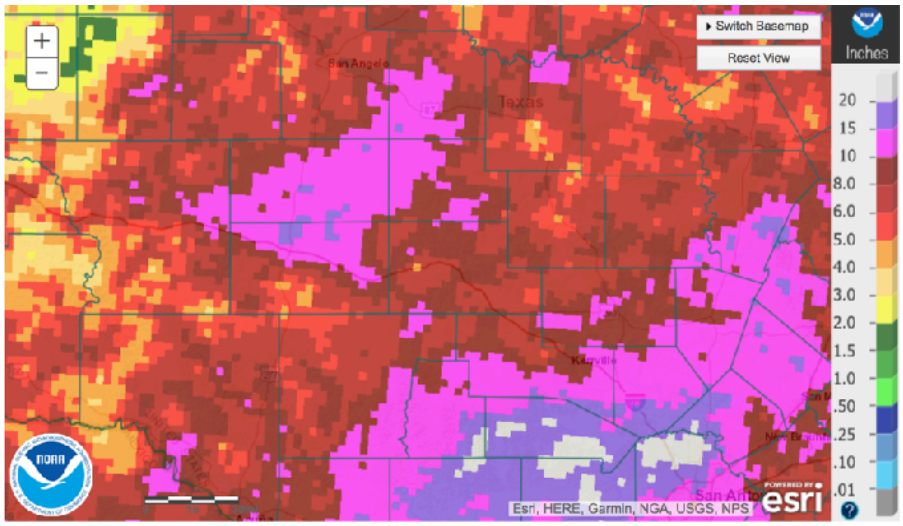

Figure 3. Total Precipitation September 2018, from National Oceanic Atmospheric Administration.

additional six inches two weeks later, on the saturated ground, resulted in immediate runoff and resulted in significant flood damage in the City Sonora to the west (figure 3).

In the Llano River watershed, late on the night of September 21, the North Llano River began to go on a small rise. The Lower Colorado River Authority (LCRA) gage near Roosevelt rose from 1.76 feet at 9:55 pm and peaked at 14.32 feet just two hours later at 12:10 am. Further downstream near the City of Junction, the USGS gage on the North Llano River recorded a rise of 13.2 ft between 12:15 am and 3:15 am, with discharge increasing from 41.5 cfs to 28,000 cfs.

This was the largest rise on the North Llano River since May 21, 2015 when the river reached 27,600 cfs. According to the USGS, a flood of 35,300 cfs is considered to have a 5-year

Gage	1 : 2	1 : 5	1 : 10	1 : 25	1 :50	1: 100	Peak Flood Event	Fall 2018
N Llano near Junction	10,300	35,300	58,700	92,300	118,000	143,000	102,000	28,000
Llano near Junction	13,700	50,100	88,200	149,000	202,000	258,000	319,000	118,000
Llano near Mason	25,700	75,300	125,000	208,000	283,000	369,000	380,000	183,000
Llano at Llano	30,500	78,400	126,000	207,000	284,000	374,000	380,000	278,000

Figure 4. Recurrence Intervals for selected gages in Llano Watershed (from Asquith, et al.)

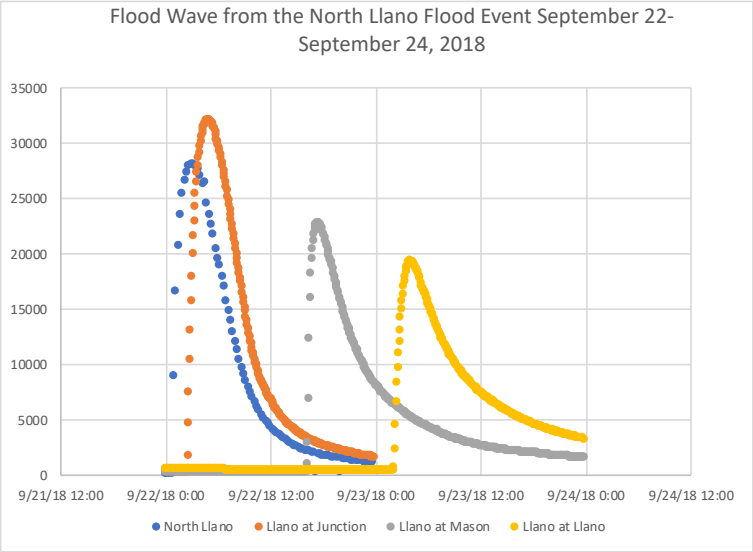

Figure 5. Flood wave crest for selected gages on Llano River, September 21-September 23, 2018

recurrence interval, which is sometimes mistakenly referred to as a 5-year flood.[3] In fact, the recurrence interval means that during any given year, there will be a 1-in-5 chance that a flood of this magnitude will occur. Prior to the 2015 event, the last time the North Llano reached this level was November 16, 2004 when the river reached 62,000 cfs or 25.3 ft, slightly above the 10-year recurrence interval of 58,700 cfs (Figure 4).

After passing the North Llano River gage, the flood wave joined the South Llano River at Junction and passed the Llano River below Junction gage, increasing slightly to 32,000 cfs or 17.25 feet (Figure 5). After traveling 12.5 more hours, the flood wave passed the USGS gage near Mason at 22,700 cfs, a decreased flow due to the attenuation of flood waters by riparian areas downstream. The flood wave continued to decrease as it traveled to the City of Llano, reaching there in 10 hours and 55 minutes at a discharge of 19,300 cfs. This flood wave traveled downstream at approximately the same rate as the May 2015 flood wave that occurred on the North Llano River.

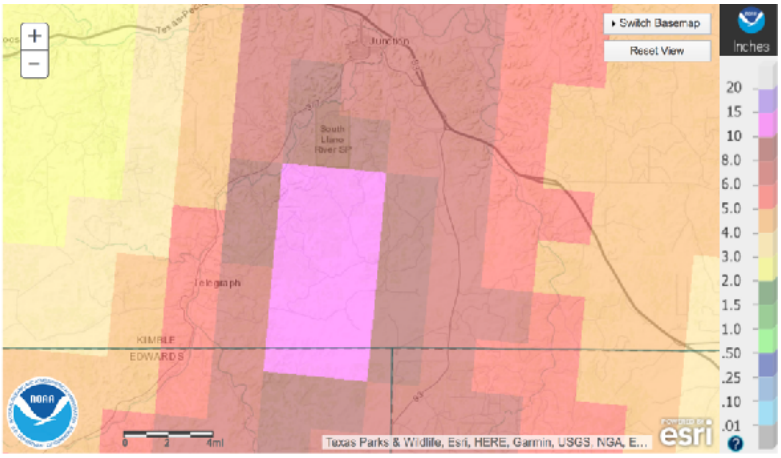

Figure 6. Estimated rainfall amounts October 7-8, 2018 for Junction area.

[3] Asquith, William H, R.M. Slade, and Jennifer Lanning-Rush, Peak-flow frequency and extreme flood potential for streams in the victim of the Highland Lakes, Central Texas, U.S. Geological Survey Water Resources Investigations Report 96-4072, 1996.

October 8, 2018 (Columbus Day Flood)

The second flood wave that occurred on the Llano River during the fall 2018, came tragically in the early morning hours of October 8 (Columbus Day). Shortly after 3:00 am, the LCRA gage at Telegraph began to rise, reaching 18 ft within 30 minutes. Flows at the gage would rise another 10 ft in the subsequent 30 minutes and eventually peak at 34.91 ft at 5:10 am, a rise of 32 ft in two hours. The LCRA Hydromet gage network did not detect significant rainfall amounts, but the National Weather Service (NWS) Doppler Radar (Figure 6) showed rainfall amounts in excess of 10 inches and NWS confirmed 11.5 inches fell in the area over Sunday night and Monday morning.

Downstream, the USGS gage on the South Llano River at the Flat Rock Crossing began to rise at 5:15am, was 3 ft higher 15 minutes later, and another 3.5 ft higher in 30 minutes, recording a peak of 26.18 ft at 10am. The South Llano River gage does not record inflows from Cedar Creek downstream, which considering the six to eight-foot gravel bar at its mouth, added significant volumes of water to the flood (Figure 7).

Figure 7. Mouth of Cedar Creek at confluence with South Llano River near Junction. Photo December 14, 2018

Campers at an RV Park (Figure 8), recently expanded onto a gravel bar next to the South Llano River, were inundated by floodwaters. Fifteen campers were rescued by boat and four by helicopter. Tragically, the bodies of four campers were recovered downstream, one as far downstream as LBJ Reservoir.

Figure 8. Destroyed RVs on South Llano River

The flood wave reached the Llano River gage near Junction at 10:10 am with a peak of 31.53 ft

or 121,000 cfs. This peak streamflow was the sixth highest recorded flow at the gage since 1915, just behind the November 2004 (31.78) flood, and has a recurrence interval between 1:10 and 1:25. The next day, following additional precipitation upstream, a peak of 19.69 ft and 41,700 cfs passed the gage.

The gage on the South Llano River at Flat Rock Crossing was installed in 2012 and does not have a long enough period of record to develop a statistical curve to calculate discharge or calculate recurrence intervals. However, a rough estimate of flow magnitudes can be calculated by subtracting discharge at the North Llano River gage from the gage on the mainstem Llano River near Junction ; both gages were installed in 1915, but have not been active over the entire period of record.

Based on this comparison, the Columbus Day flood was approximately 118,000 cfs, the third highest recorded flood on the South Llano River. The flood of 1935 was estimated to be 238,000 cfs and the 2001 flood was estimated to be 158,000. The flood was also the first rise on the South Llano River since 2004, when flows reached an estimated 58,000 cfs.[4] Figure 9 portrays the number of times the Llano River at Junction has reached bank full levels.

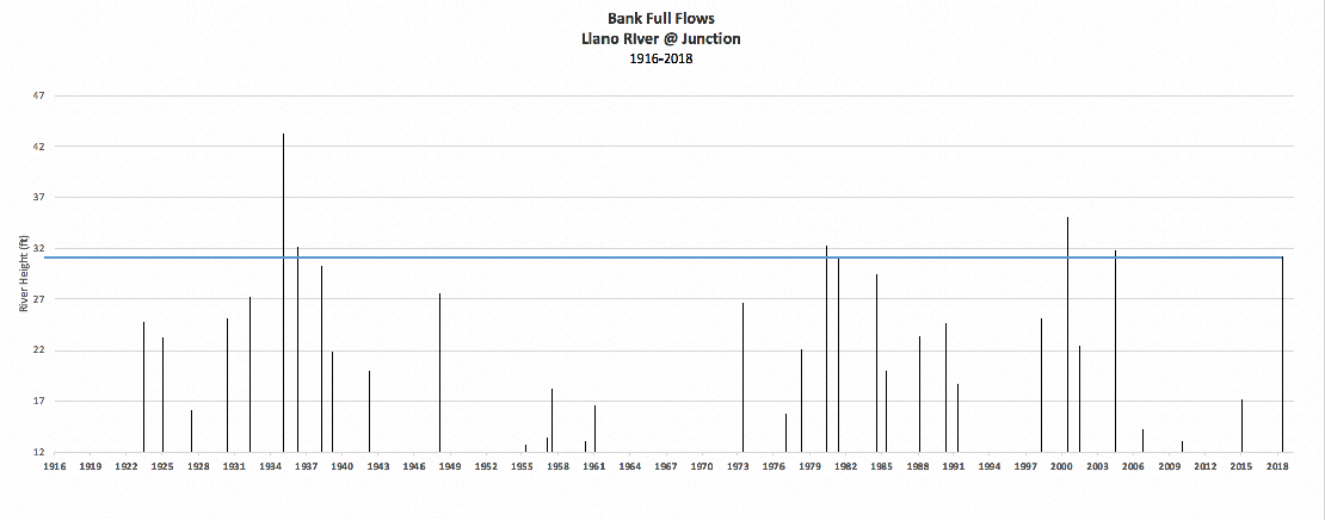

Figure 9. *The number of times the Llano River near Junction has reached 12 feet, which is considered bank full. Between 1980 and 2004, there were four events similar to the Columbus Day event.*

[4] As the North Llano gage was inactive between 1979 and 1999, it is not possible to estimate the South Llano River contribution to the floods of 1980 (139,000 cfs) and 1984 (129,000 cfs.)

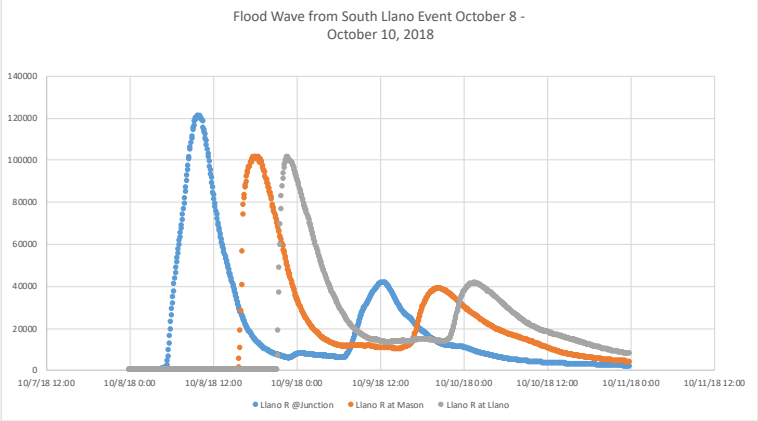

Figure 10. Flood wave crest for selected gages on Llano River, October 8 to October 10, 2018

As the flood wave moved down the Llano River, the riparian areas again mitigated the force of the flood and decreased the flood wave. A crest of 110,000 cfs arrived at the US-87 crossing bridge near the City of Mason at 6:30 pm (Figure 10). The flood wave arrived at Mason in eight hours and 35 minutes, nearly four hours faster than the September flood. It arrived in the City of Llano (99,000 cfs) in four hours and 25 minutes, over six hours faster than the September flood. The second wave, passing the Junction gage, traveled the 55 miles to Mason in seven hours and 55 minutes (40 minutes faster) and the 31 miles to the City of Llano in five hours and 10 minutes (45 minutes slower than the previous day). The faster travel times for the October event may be attributed to the fact that the debris flow had been removed by the previous event that occurred in September.

October 16, 2018 Flood

After a reprieve of a few days, heavy, widespread rain returned to the Llano River watershed on the evening of October 15. Figure 11 shows the weekly rainfall totals for October 9-16 across the watershed, the majority of which fell October 15 and 16. Residents in the Llano River watershed awoke Tuesday morning (October 16) to River

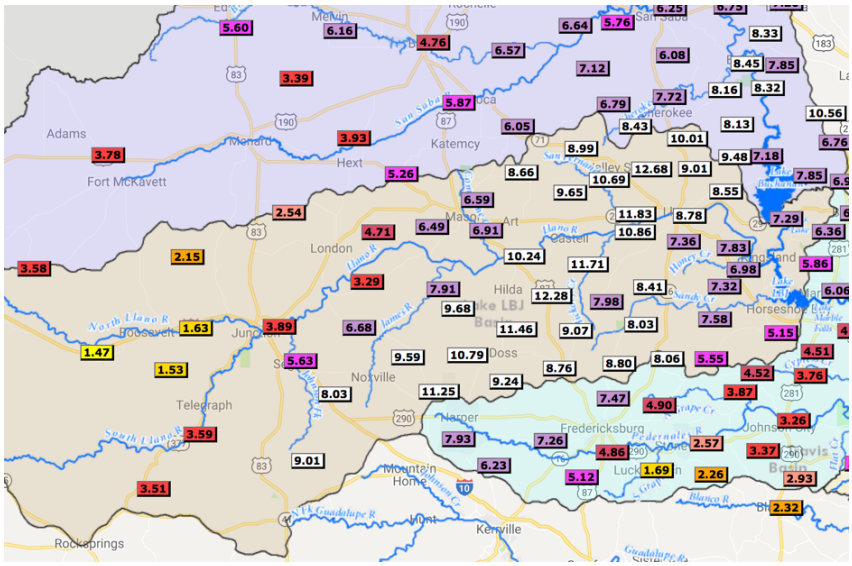

Figure 11. Rainfall totals October 9 - October 16, 2018. From LCRA Hydromet. Note: Most of this rainfall fell Monday evening and Tuesday morning, October 15-16.

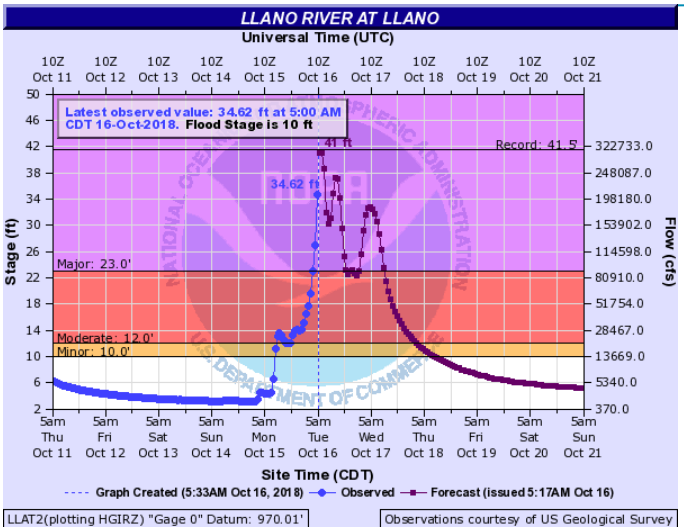

Figure 12. Flood prediction curve from National Weather Service for Llano River at Llano, first published 5:00am, October 16, 2018

Flood Warnings across the Watershed. Flood Warnings for Llano predicted near record major flooding (figure 12).

The Llano River at the City of Llano, which had been flowing the previous week at more than 1,000 cfs (3 ft), reached 30,000 cfs (13 ft) on Monday afternoon, then rapidly rose to 278,000 cfs (40.17 ft) by 7:05 am on Tuesday. This is almost equivalent to 125 million gallons per minute. This was the second highest recorded flow at the USGS gage at the City of Llano, and resulted in the destruction of the Hwy 2900 Bridge in community of Kingsland. Floodwaters approached, but did not reach the bottom of the Hwy 16 bridge in the City of Llano; no damage was sustained by the bridge (Figure 13).

In the upper watershed, rainfall amounts in excess of nine inches resulted in a flooding of the South Llano River, which that reached almost 26 ft at 8:15 am on Tuesday morning, just 0.6 ft below the Columbus Day Flood. Flood waters again overtopped Flat Rock Crossing on the South Llano River near Junction resulting in significant damage to the bridge (Figure 14). As

Figure 13. Left: Llano River at City of Llano, morning of October 16, 2018. Photo by Dana Wright. Right: Destroyed Hwy 2900 Bridge over Llano River Arm of LBJ Reservoir, November 3, 2018.

Figure 14. Left: Southern approach to Flat Rock Bridge near Junction - October 9, 2018. Right: Aerial view of Flat Rock Bridge looking west - December 14, 2018

of December 2018, Flat Rock Crossing remains closed to vehicular traffic, and debris is blocking the river passage by paddlers. Flat Rock Crossing served as an access point for the on the South Llano River Paddling Trail, but access is currently closed until repairs can be made to the bridge and paddler access facilities.

At the same time, Johnson Fork, which flows into the Llano River downstream of the City of Junction, crested at 32.6 ft (107,000 cfs) at 4:40 am, forcing closure of U.S. Interstate Hwy 10 at the community of Segovia. Due to lack of historic data, it is unclear if this was a record flood for Johnson Fork.

Meanwhile, the James River was reaching a 1 in 100 recurrence interval flood of 26.42 ft (112,000 cfs) at 3:55 am Tuesday. The 100-year event is calculated to be 101,176 cfs.[5] The James River gage does not have a long record, but previous studies have estimated the peak flow to have been in excess of 200,000 cfs in 1935. Beaver Creek, which confluences with the Llano River just downstream of the USGS gage near Mason, recorded flows of 38,900 cfs (17.6 ft) at 3:45 Tuesday morning. According to USGS, this is a 1:25 event. The record flow for Beaver Creek was 66,900 cfs (24 ft), which occurred in August 1978.

[5]Tinkler, L.J. 2001, "The case of the missing flood: The unrecorded flood of 1935 on the James River, Mason County, Texas". Geomorphology 39: 239-50.

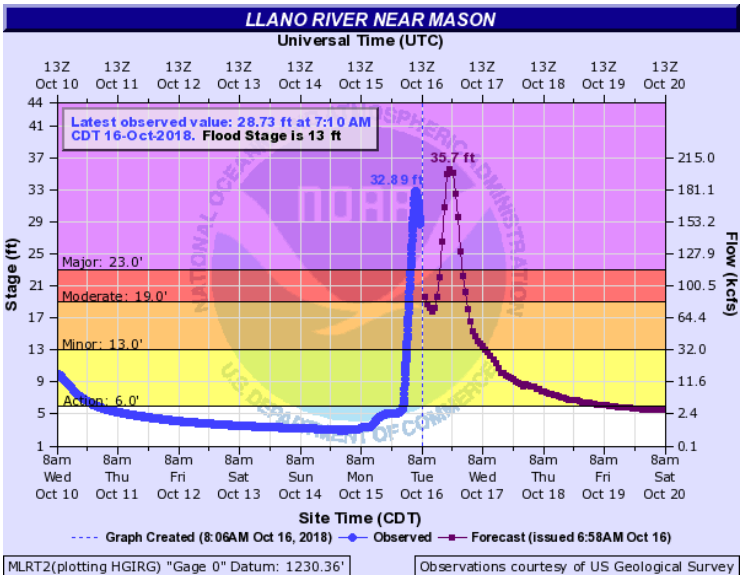

Figure 15. Flood prediction curve from National Weather Service for Llano River near Mason, published 7:10am, October 16, 2018

Other tributary streams of the Llano River also experienced significant rises, but lack sufficient historic data to determine flood recurrence intervals: in downstream order Comanche Creek (2,000 cfs/11 ft @ 8:40 am); Willow Creek (4,885 cfs/12.5 ft @ 6:25 am) Hickory Creek (37,600 cfs/22.2 ft @ 9:10 am), and San Fernando Creek (40,330 cfs/21.5 feet @ 4:56am) and Johnson Creek (15,448 cfs/15.4 ft @ 5:25am). No discharge information is available for Flag Creek in the City of Llano where a motorist drowned after driving into a low water crossing of the creek near its confluence with the Llano River; this was the fifth fatality from the fall 2018 flooding of on the Llano River.

The magnitude and timing of these flood waves likely made flood crest prediction extremely difficult. The National Weather Service originally predicted that a second flood crest, greater than the first crest, would reach both the cities of Mason and Llano on early Wednesday morning (Figure 15). The Llano River near Mason was predicted to experience a second peak of 35.7 ft. After further analysis, these predictions were later rescinded, much to the relief of residents. The Llano River near Mason originally reached 176,000 cfs (31.93 ft) at 12:30pm on Tuesday. The 1:25 recurrence interval volume is 208,000 cfs.

Changes to Aquatic and Riparian Habitats

Flooding events are natural components of a riverine ecosystems. Bankfull flood events, characterized as those events that just begin to spill out of the river into the floodplain, are important for the redistribution of sediment and reshaping of the river channel. On average, such events occur every one to three years. Periodic overbank flood events are critical for replenishing sediment, moisture and nutrients for maintaining a healthy riparian zone.

South Llano River

While the North Llano River and downstream segments experienced a bankfull event in May of 2015, the South Llano River had not experienced a significant rise since 2004 (prior to the October 8, 2018 flood). As a result, mid-channel points bars, which are usually reformed every two to five years during floods, were beginning to become larger, more permanent geomorphic features supporting mature vegetation such as sycamore and pecan trees. As a result of this point bar formation, and due to the lack of flooding, the river

Figure 16. Left: Point Bar Deposit near South Llano River State Park (photo Megan Bean) Right: Floodwater deposits, Llano River below Junction, December 14, 2018

meanders in the South Llano River were increasing, resulting in bank erosion and loss of riparian vegetation.

Based upon field observations, it appears that the fall 2018 Floods carried considerable energy. Large deposits of gravel were deposited on point bars, in some instances raising the height of the point bars by several feet (Figure 16). Many of the mid-channel point bars, or islands, were reworked or eliminated completely. In other instances, gravel was deposited out of the channel and into the floodplain. Despite the volume of energy in the floods, with one minor exception, it does not appear that avulsion (abandonment of an existing channel and formation of a new river channel) occurred across any of the meanders. In fact, it appears that the meanders along the South Llano River grew slightly larger due to the flooding.

Within the channel itself, considerable scouring occurred, removing patches of aquatic vegetation. However, it is noted that certain snags remained anchored in the river, providing cover for aquatic species in the crystal clear waters of the river following from the flood. Additional large woody debris also fell into the river from eroding streambanks. While this can create a navigation hazard and decrease bank stability and potential shade along the river, it does provide additional habitat for fish and other aquatic species (Figure 17).

Figure 17. Large woody debris along South Llano River near South Llano River State Park, November 5, 2018

Riparian habitats along the lower reaches of the South Llano River were also impacted. Large volumes of sediment and large woody debris were deposited amongst the pecan groves at the Llano River Field Station and at the South Llano River State Park. This woody debris, if left in place, will provide protection for regeneration of saplings (from herbivory by native and non-native ungulates such white tailed deer and axis). Such additional protection will help offset the more than thirty wildlife exclosures in the riparian zones that were damaged or destroyed in the flood. In one location along the South Llano River, a riparian areas that was bulldozed by an uninformed landowner earlier in the year was destroyed and a cut bank left in its place (Figure 18).

Over the last eight years, the Llano River Watershed Alliance and TPWD have worked to control Elephant Ear (*Colocasia* spp.) and Giant Cane (*Arundo donax)* along the Llano River and its tributaries. *Arundo*, being a plant originally imported for bank stability, was not impacted by the flood. At this time, it is uncertain what the impacts of the flood were on the survival and (or) dispersal of these exotic riparian plants.

Upstream of the spring systems that form the headwaters of the South Llano River, normally dry riverbeds carried significant flood waters, resulting in the flooding of riverside homes that had not previously flooded. Those flood waters carried with them great potential

Figure 18. Before and after showing flood results (right) following bulldozing of riparian area in January 2018.

for scour, in some instances removing well vegetated gravel bars completely to the bedrock (Figure 19). Some of the observed benefits of the floodwaters in the upper reaches of the South Llano River are the considerable recharge to springs that occurred from crevices in the stream bed, and the deposition of large woody debris from the uplands along stream banks.

Figure 19. Riparian habitat removed to bedrock in South Llano River watershed.

North Llano River

Changes in aquatic and riparian habitat along the North Llano River were noticeable, but less significant than those observed along the South Llano River. Large woody debris and sediment were deposited in the riparian zones and, if left undisturbed, will ultimately improve riparian health. The thick matts of water willow that previously impeded passage of canoes and kayaks in the lower stretches of the North River were removed.

Between the mid-1980s and 2004, sand and gravel was extracted from the North Llano River, at an areas located approximately one mile upstream of the confluence with the South Llano River. This extraction created more of lacustrine environment along the lower reaches

of the river. With the increase in water levels, some of these gravel pits have been reconnected with the river, temporarily offering additional species habitat. Additionally, quarrying activities originally caused the channel of the North Llano River to migrate approximately 700 feet to the south, forcing the City of Junction to undertake preventative actions to protect city infrastructure, mainly sewer lines. The floods in September of 2018 have now shifted the altered channel about 150 feet north back towards it original configuration (Figure 20). The exposed sewer line, located just upstream of the South Llano River confluence, was further eroded but not compromised.

Figure 20. Confluence of North and South Llano River. Note new mouth of North Llano in background.

Llano River

Downstream of the City of Junction, below the confluence of the North Llano and South Llano rivers, the channel geometry of the Llano River changes. The gradient of the river decreases, the channel becomes wider, and sinuosity increases. This change in channel geometry appears to have lessened the energy of the flood as channel scour appears to be less evident between Junction and Yates Crossing (Ranch Road 385). In some cases some floodwaters did temporarily cut across meanders, but the river remained in the main channel following the flood event (Figure 16).

Below Yates Crossing, the Llano River leaves the sedimentary rocks of its origin and begins to cross the pre-Cambrian Llano Uplift. At this point, near the border of Kimble and Mason County, the channel becomes more resistant to erosion, it straightens and widens, and the riparian zone becomes narrower and steeper. Mid-channel bedrock islands are more common along this reach. Along these lower reaches, the floodwaters tended to deposit more sand than gravel, except downstream of the mouth of the James River, where significant deposits of gravel occurred at the James River Crossing (Ranch Road 2389). Riparian areas

Figure 21. Left: Llano River between Castell and Llano near Schneider Slab. Right: Llano River below Yates Crossing.

along this stretch of the Llano River appear to have been less impacted than further upstream and channel scouring less common (Figure 21).

Impacts to Recreation

The floods on the Llano River during the fall 2018 resulted in short-term negative impacts on recreation, but in the long term, these floods will prove to provide long-term benefits to the river. Recreation on the Llano River, in the form of fishing and paddling, is an important economic factor to the communities in the watershed. According to a Texas Tech University study, recreational fishing for Guadalupe Bass (state fish of Texas) in the Hill Country provides $74 million annually to the region and generates over 775 jobs [6]. Guadalupe Bass rely on undisturbed pool and run habitats with adequate flow and cover, but have, along with other native fishes, adapted over millennia to periodic flooding. While some fish are displaced downstream, others seek protection from high current behind boulders and large woody debris, or move to slower moving waters in the floodplain or in tributaries. According to a TPWD, "Floods benefit Guadalupe bass habitats by clearing out excess sediment, rebuilding gravel bars and riffles, and adding boulders and woody debris to

[6] Zachary A. Thomas, T.L. Arsuffi, and S.J. Magnelia, "Fishing Warmwater Streams with Limited Public Access: Angling Behavior, Economic Impact, and the Role of Guadalupe Bass in a Twenty-Four-County Region of Texas", American Fisheries Society Symposium 82:000-000, 2014.

Figure 22. River Access and Conservation Area sign destroyed by October floods along South Llano River. Note: Kiosk was located to the left of tree.

channels, enhancing habitat quality for Guadalupe Bass and other sport fisheries." [7] Paddle sports are also a large recreational component for the region, and the South Llano River Paddling Trail provides the furthest west Paddling Trail in the state. The South Llano River State Park receives about 60,000 visitors per year.

South Llano River

There are numerous recreational sites on the South Llano River. Most all of these sites were impacted somewhat by flooding. The upper and lower Crossings of US Hwy 377 South, are the most upstream river access sites and were the least impacted. Deposition of sand and gravel at the two sites was widespread and a portion of the wing wall on the lower crossing was damaged, but recreational access to the river at these sites was not impacted. Further downstream, at KC 150 (Boone's Crossing), the bridge crossing remained intact, but the lower end of the channel on river left has had to be temporarily diverted with a gravel bar to keep it from eroding the bridge approach. The River Access Conservation Area (RACA) site at Boone's Crossing was destroyed (Figure 22). The recently installed sign regarding the RACA program was washed away and the rope fence lining the parking area knocked over. The fishing line receptacle attached to a post near the bridge was undamaged, but the signage was washed away. Although not a public access site at this time, the newly constructed

[7] Texas Parks and Wildlife News Release, "TPWD Addresses Concerns About Fish, Aquatic Habitat After Heavy Flooding in Central Texas", Nov. 1, 2018

private bridge at the Burt Crossing located approximately two miles downstream, remained intact. However, the temporary crossing just upstream of Burt Crossing was destroyed and is currently a navigation hazard. Other navigation hazards on the South Llano River between the upper Crossing of U.S. Hwy 377 South and the South Llano River State Park include woody debris in the channel 0.7 miles above Boone's Crossing and woody debris in the channel 0.4 miles above the South Llano River State Park bridge.

There was considerable damage to the South Llano River State Park. Many signs along the river, including the South Llano River Paddling Trail sign at park bridge crossing, were destroyed. Trails along the river were severely damaged and the tubing takeout was buried under a new gravel bar. One trail between the river and Buck Lake became a temporary floodway when the river topped its banks. A scour hole at least eight feet deep formed when a log temporarily jammed in the temporary floodway (Figure 23). Flood debris obviously covered much of the park. While the debris was removed from the picnic area, the park plans to leave much of the large woody debris in the river bottom, providing numerous educational opportunities for habitat restoration. Considerable damage occurred along the intermittent and ephemeral streams draining the slopes east of the park. Several trails and the primitive campground were destroyed when runoff from 10-inch rains poured down these drainages.

Figure 23. Scour hole along former Buck Lake Trail - South Llano River State Park. Photo: Megan Bean

The South Llano River Paddling Trail between South Llano River State Park and the City of Junction was severely affected. The most significant impact was the damage to the Flat Rock Crossing. A crack in the surface of the bridge forced closure of the bridge and debris continues to block the arched culverts beneath the bridge, thus making the paddling

trail unusable at the previously established access points at the state park, Flat Rock Crossing, and the Junction City Park. The South Llano River Paddling Trail signs at Flatrock Crossing and the Junction City Park were washed away. Some of the additional navigation hazards along the South Llano River Paddling Trail, primarily downed trees, are shown in Figure 24. There is also a downed tree 0.4 miles above the Flat Rock Crossing.

Figure 24. Navigation hazards on South Llano River Paddling Trail following October flooding.

The Junction City Park suffered some erosional damage. The South Llano River Paddling Trail sign was knocked down following the first flood and washed away in the second flood a week later. Given that the Junction City Park was closed between the flood events, the sign was not retrieved. The Kimble County Park, across the South Llano River from the Junction City Park, suffered extensive damage from scour at the lower end of the park and gravel deposition in the upper end, and is still closed two months following the floods.

North Llano River

As noted in Figure 4, floodwaters on the North Llano River only reached a recurrence interval of about 1 in 5. Consequently, river access points at the crossings were not significantly impacted. It is not known what new navigation hazards were created along the entire river following the flood, but no hazards were noted along the lower stretch downstream of below Kimble County Road 271. An existing navigation hazard is located at an old bridge crossing of the North Llano above the confluence with Bear Creek (Figure 25).

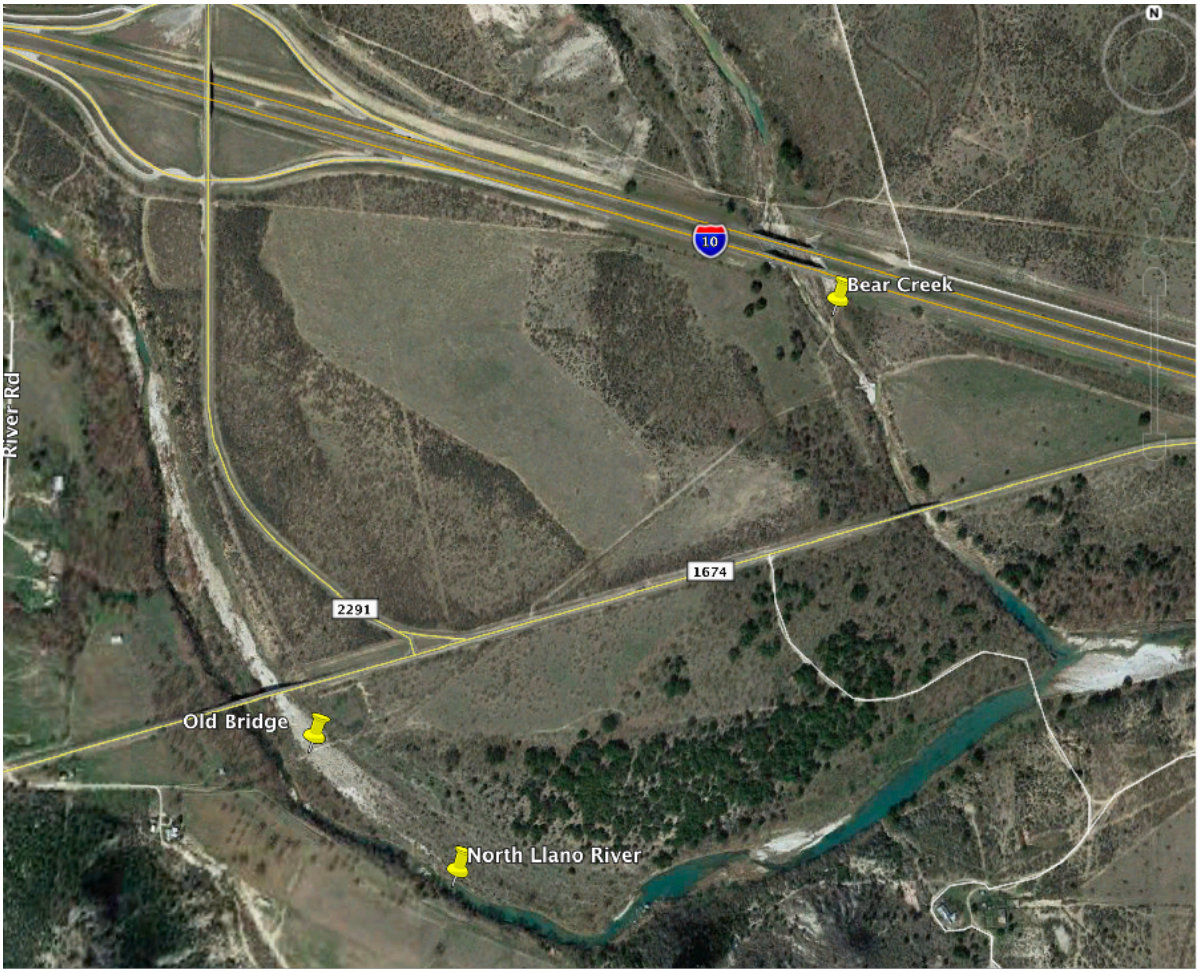

Figure 25. Navigation hazard resulting from old bridge crossing of North Llano River above its confluence with Bear Creek.

Llano River

The Llano River downstream of Junction to the mouth at LBJ Reservoir has been surveyed at river crossings and proposed RACA sites, and aerially surveyed for navigation hazards. However, the reader can not assume that all hazards have been identified.

The largest navigation hazard along the mainstem of the Llano River downstream of Junction is the Kimble County Road 310 Bridge which was destroyed by floodwaters in the 1980s. As sections of the bridge have collapsed, paddlers must line their boats under the bridge in swift water. The potential for an accident is high (Figure 26).

The gravel bar at the proposed RACA site off Kimble County Road 312, near the Johnson Fork confluence, is reported to have been stripped of vegetation and may require some vegetative restoration, However, access to the river was not affected. Grobe Crossing

Figure 26. Collapsed Bridge at Kimble County Road 310. Boaters must line unlined boats along swift current on river left (bottom)

(KC 314), Yates Crossing (RR 385) and White's Crossing (RR 1871) were temporarily closed following the flood and lost some of the banks to erosion, but are reopen and accessible for paddling and fishing.

The James River Crossing (RR 2389) is a popular access point located on an island of the Llano River just downstream of the James River confluence. As the island is considered public land, due to its location in a navigable waterway, use of the island is governed by the Mason County - James River Crossing Local River Access Plan. This plan was developed by the Mason County Commissioners in 2004 following passage of Senate Bill 155, which limited the use of motorized vehicles in state-owned waterways. As noted above, the island was inundated with gravel from the outflows of the James River, and the channels on both sides of the island were reworked and widened by the flood flows (Figure 27). Downed trees at the entrance to the north channel could cause a navigation hazard for paddlers. Riparian vegetation was destroyed or heavily damaged. The crossing has reopened but was slightly damaged with the loss of concrete slabs on the downstream side. Access to the island was impacted at first, due to the deposition of sand and gravel, but it becoming easier as the gravel is compacted by travel on re-emerging access roads.

Figure 27. Mouth of the James River, August 2017 and October 2018

The next access points down the River are Martin's Crossing and the U.S. Hwy 87 Bridge. Martin's Crossing was closed for nine days following the flood, but suffered was no significant alterations regarding access. The 1935 Flood on the Llano River destroyed the previous U.S. Hwy 87 Bridge, but the reconstructed bridge suffered no damage or alterations

in access. A downed tree on river left, 3.8 miles above Castell, is a potential navigation hazard; this hazard is located just below Twelve Mile Creek.

There are three low-water crossings in Llano County: Castell, Schneider Slab Crossing, and Scott's Slab (or Crossing) in order downstream. Scott's Slab was closed due to high water until mid-November, but has now reopened. Schneider Slab remains closed. Access does not seem to have been altered. The Castell Bridge has reopened, with no significant changes to recreational access. The proposed RACA sites at the Castell Bridge and downstream towards Schneider Slab (Figure 28) lost some vegetation during the flood and may benefit from some vegetative restoration, one of the components of the RACA program.

Figure 28. Schneider Slab, Llano River, November 10, 2018

Figure 29. Damaged playground equipment, Robinson Park, Llano, Texas.

Robinson Park, Badu Park, and Crenwelge Park in the City of Llano are all located next to the Llano River, providing popular access points and recreational opportunities. All of the parks, suffered considerable damage to infrastructure (Figure 29), but have reopened for recreational access. The rock art displays in Crenwelge Park, site of the Llano Earth Art Festival, were destroyed.

Like the Mason Bridge, the Llano Bridge (Hwy 16) was also destroyed in the 1935 flood. The current bridge was closed during flooding on the morning of October 16 as the river neared the top of the bridge pilings located along both banks of the rivers. These bank-side pilings appear to have been constructed to a height of 41.5 ft, the level of the 1935 flood. The pilings in the middle of the channel are higher.

The Kingsland Slab is located just upstream of the point where the Llano River flows into LBJ Reservoir. The Slab was not damaged, but the parking areas at the Slab will require maintenance. The Slab was closed due to high water until November 13th (Figure 30).

The Hwy 2900 bridge over the Llano River Arm of LBJ Reservoir was destroyed by the October 16 flood. This crossing did not provide recreational access.

Figure 30. Barricades at Kingsland Slab, November 4, 2018

Recommendations

The Llano River Watershed Alliance has identified several post-flood actions to be undertaken in the coming year to help preserve and restore the natural and recreational resources of the Llano River watershed. Those actions include delivery of riparian landowner workshops and establishment of related conservation demonstration areas, removal of navigational hazards, and the necessary steps to facilitate reopening of the South Llano River Paddling Trail and RACA sites.

The fall 2018 floods in the Llano River watershed provided much needed sediment redistribution and channel reshaping, and replenished sediment, moisture and nutrients to the riparian zone. As this was the first major rise on the river in 14 years, flood waters also carried and deposited considerable debris in the riparian zone. This debris can be an important component of river stability and riparian recovery following a flood. Large woody debris can serve as natural retaining walls, helping to dissipate the energy from future floods and once eventually buried, provide bank reinforcement. Debris piles can serve as a nursery for new seedlings to reestablish in the trapped sediment.[8]

[8] Steve Nelle, "The Blanco River Flood : The Healing Has Begun" in Texas Wildlife Magazine, January 2016.

Unfortunately, many landowners affected by this flooding often believe the best remedy is to remove the debris with heavy equipment and burning. Such actions often result in a degradation of riparian recovery and function, a decrease in stream stability, and an increase in sedimentation to the river.

Education of riparian landowners is a critical component for enhancing riparian recovery from flood events. It is recommended that landowner workshops and site visits be made available to inform landowners about the role properly functioning riparian areas provide to aquatic ecosystems and what Best Management Practices (BMPs) are available to restore and maintain riparian areas following disturbances such as flooding. In addition, a riparian conservation area should be established to demonstrate BMPs for managing flood debris. This conservation area, located in a publicly accessible location, should demonstrate the restoration design guidelines for riparian canopy and buffer that were assembled for the Blanco River following historic floods in 2015. [9]

The Alliance also recommends the removal of both natural and artificial navigational hazards on the river. The primary natural hazards are downed trees that create hazardous 'strainers' where boaters could potentially be pinned against the woody debris by the current. Several of these 'strainers' have been identified on the South Llano River but passage can be restored by crews cutting passages through the downed trees with a chainsaw. Other natural hazards occur at the RACA sites along the river where some debris needs to be removed and parking areas, kiosks, and signage need to be reestablished.

The primary artificial hazards are the KC 310 Bridge downstream of Junction and the Flat Rock Crossing located just upstream of Junction. Although the KC 310 Bridge has been a hazard for some years, with flood mitigation efforts likely resulting in a temporary surge in capacity for recovery efforts in the Llano River, this is likely an ideal time to revisit and address the situation.

The Flat Rock Crossing is currently closed to vehicular traffic and debris is still blocking passage under the bridge by paddlers utilizing the South Llano River Paddling Trail.

[9] John Hart Asher II, M. Bertelsen, M O'Toole, "Blanco River Design Guidelines, Ecosystem Design Group, Lady Bird Johnson Wildflower Center.

Removal of the debris will facilitate paddler passage at the bridge to continue downstream to the paddling trail takeout at Junction City Park, immediately below the South Llano River Bridge. However, due to the uncertainties regarding reconstruction of the Flat Rock Crossing and resulting access by vehicles and paddlers, there may be merit in establishing a temporary RACA site upstream of Flat Rock Crossing in order to reestablish use of the paddling trail. Kiosk and signage for the South Llano River Paddling Trail will also need to be replaced at all three paddling trail access points, located at the South Llano River State Park, Flat Rock Crossing, and Junction City Park.

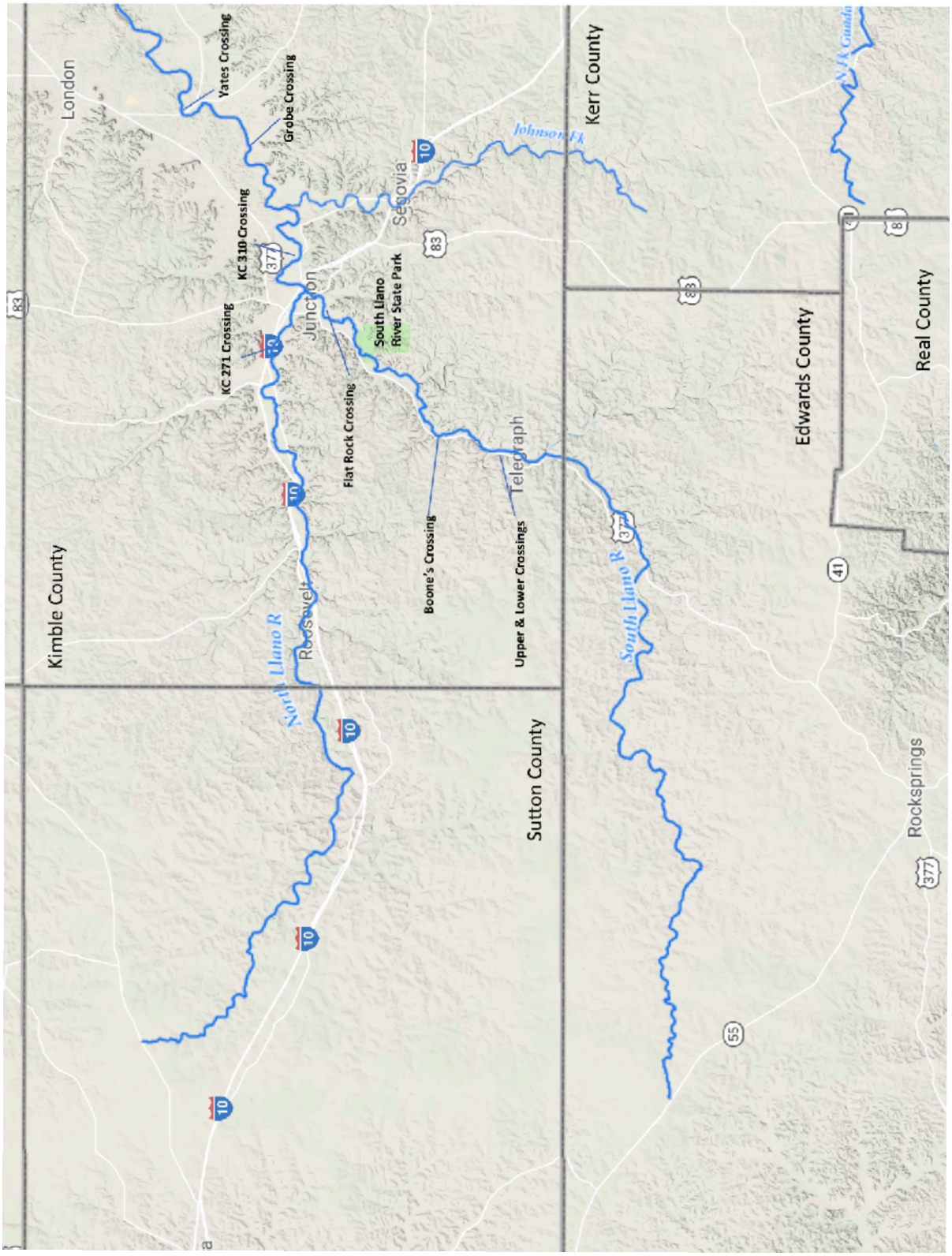

Figure 31. Map of Upper Llano Watershed
Source : Lower Colorado River Authority

Figure 32. Map of Lower Llano Watershed
Source : Lower Colorado River Authority