FLOODING IN THE GUADALUPE RIVER BASIN AT NEW BRAUNFELS, TEXAS

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Figure 1: Photos of Flooding along the Guadalupe River [1] [2]

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INTRODUCTION

While the state of Texas is well-known for flooding, the Guadalupe River Basin is "one of the three most dangerous regions in the U.S.A for flash floods" [3]. However, two floods in 1998 and 2002 stand out amongst the rest. These two floods devastated the town. Table 1 contains a compilation of facts about these two floods. The flood of 1998 was the "most significant flooding in recorded history" downstream of the dam [4], and the flood of 2002 is the only flood, thus far, to overflow the Canyon Lake emergency spillway carving out the Canyon Lake Gorge [4]. These two floods have a personal note to me, as I experienced and vividly remember them both as they effected New Braunfels (Figure 1) located about 20 miles south of the Canyon Lake Dam. New Braunfels is the largest city in Comal County, located along IH-35 between San Antonio and Austin. One of the main sources of revenue is due to tourism and recreation along the Guadalupe and Comal Rivers in New Braunfels. The mean annual precipitation for Comal County is 27.54 inches [5]. Both the 1998 and 2002 floods encompassed a total of approximately 20 inches of rain over New Braunfels.

A video of the damage caused by the 1998 flood [6] is provided by the USGS here.

Table 1: 1998 and 2002 Flood Facts

Date	October 17-18, 1998	June 30 – July 7, 2002
Frequency	500-yr	250-yr
Duration	2 days!	8 days!
Cause	Hurricane Madeline and Hurricane Lester, coupled with an atmospheric trough of low pressure	low-pressure system combined with a flow of deep tropical moisture from the Gulf of Mexico
Damage	$0.5 billion	$1 billion [48,000 homes]
Deaths	31	12
Displaced	10,000 people	
Area affected	20,000 mi^2	80 counties
Max Precipitation	31 inches	35 inches

In October of 1998, a 500-yr flash flood [7] characterized by "unusually high velocities" [3] completely destroyed homes and businesses along the Guadalupe River; 19 homes were washed downstream in New Braunfels, alone. Lifetime citizens of New Braunfels stood by astonished and unprepared; this flood was twice as bad as anything that had been seen in New Braunfels before. In Comal County alone, over $27 million [3] was granted in FEMA (Federal Emergency Management Agency) and SBA (Small Business Administration) disaster assistance. Fortunately, most citizens obeyed flood warnings and evacuated. Additionally, the flooding began mid-day as opposed to during the night when citizens were awake and alert of the dangerous conditions [3]. After the flood, businesses picked up the pieces and remodeled, and citizens rebuilt their homes. Many people proclaimed that a flood like this would never happen again in their lifetime. 1998 flood data was later used to revise the City's Flood Insurance Studies [5], to create a GBRA Interim Flood Preparedness Plan [3], and to evaluate the feasibility of additional flood control structures within the City of New Braunfels [7]. During the 1998 flood I was 10 years old, and for the first time I fully understood the power of water.

Less than four years later, in June to July of 2002 citizens of New Braunfels starting having flashbacks. On June 29th, a low pressure system met gulf moisture and stalled above the Texas Hill Country. Rain fell for the next 8 days creating a 250-yr flood [8]. By the time the rain dissipated, 34 counties were identified as Federal Disaster Areas [6]. For the City of New Braunfels, July 4th – Independence Day – was a turning point in the storm. Up until that day, Canyon Lake had withheld storm waters from upstream keeping stream discharge in New Braunfels under control. However, at 3:30 PM on July 4th, the spillway overtopped with flood waters 7 ft above the spillway. Less than 24 hours later, by 10 AM on July 5th, 850,000 yd^3 had been eroded below the spillway creating a new gorge along the water path [8]. Citizens again listened to warnings and heeded evacuation notices early on July 4th. Fortunately, the longer duration of this storm allowed for more predictability and warning than the 1998 flood. Nevertheless, it was just as, or maybe even more, tragic. Homes were again washed downstream and businesses were again flooded.

The objective of this report is to use ArcGIS as a tool to analyze and compare these two floods. Streamflow, gage height, lake storage, and precipitation data were used to illustrate the differences between these two traumatic storm events. Additionally, this hydrologic data was used to demonstrate the role of Canyon Lake as a flood control device in these two floods.

BASEMAP

To begin analysis, a baseman (Figure 2) of the Guadalupe River Watershed was created. The Guadalupe River is bounded by three watersheds: the Upper Guadalupe (HUC 12100201), the Mid Guadalupe (HUC 12100202) and the Lower Guadalupe (HUC 12100204). The Mid Guadalupe Watershed is bounded to the north by the Canyon Lake Dam. Streamlines, water bodies, and watersheds were downloaded from the National Hydrography Dataset (NHDPlus). The dissolve feature was used to create an outline of the three Guadalupe River watersheds. The select by feature tool was used to create shapefiles with the water bodies and streamlines that lie within the Guadalupe River watersheds. Figure 1 displays the Guadalupe River watershed set against a topographic basemap. Streamlines were thickened by joining the mean annual flow data provided by NHDPlus to the streamline shapefile attribute table, copying mean annual flow data into a new field with mean annual flow data, and selecting a graduated symbology.

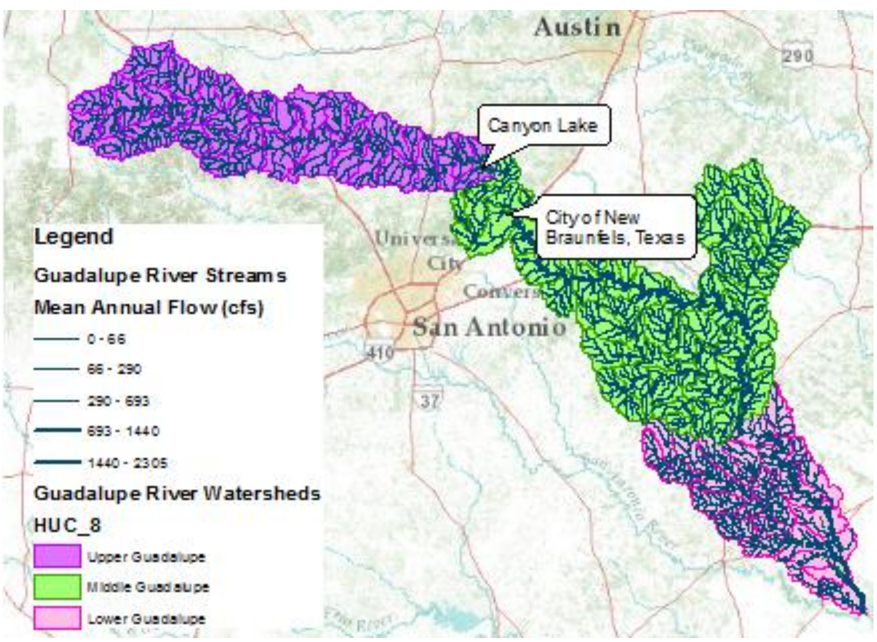

Figure 2: Guadalupe River Basin

The main area of interest for the current analysis is Comal County including the City of New Braunfels, Texas, Spring Branch (located just North of Canyon Lake) and Sattler (located immediately South of Canyon Lake). A shapefile of Texas Counties downloaded from the Texas Parks and Wildlife Department was displayed for a spatial reference. Three USGS gages along the Mid Guadalupe River were selected for analysis, and are displayed in Figure 3 (08167800: Guadalupe Rv at Sattler, TX; 08169500: Guadalupe Rv at New Braunfels, TX; 08167500: Guadalupe Rv nr Spring Branch, TX).

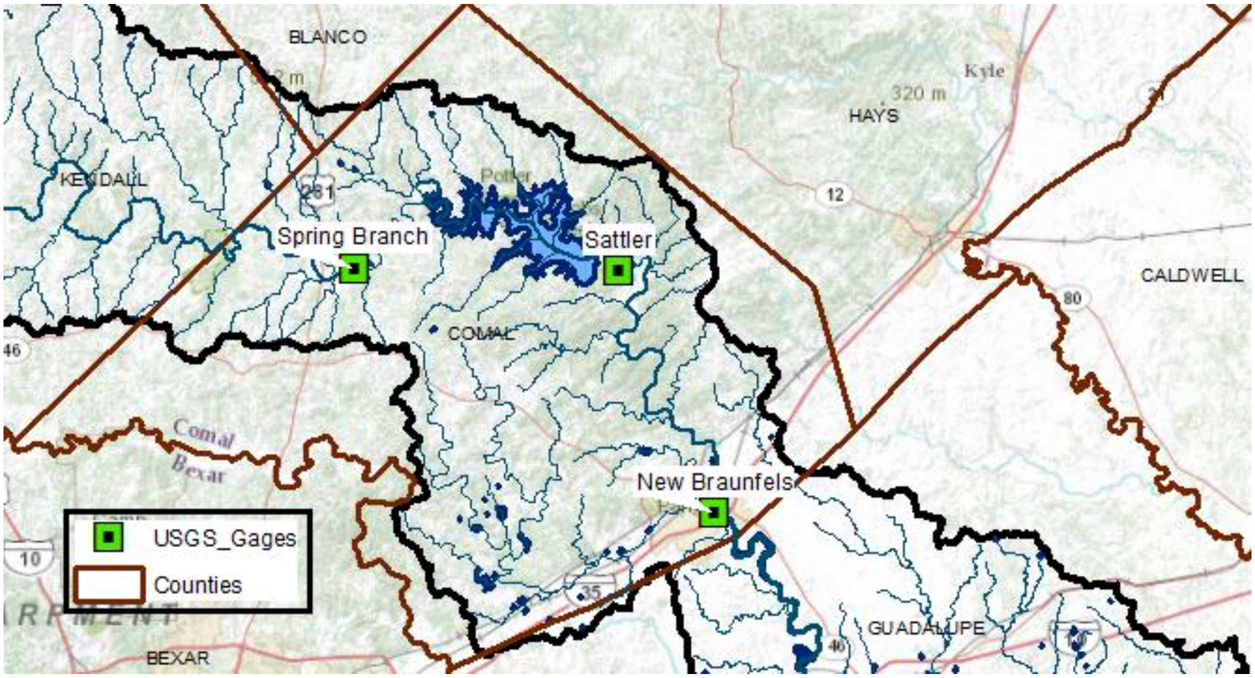

Figure 3: USGS Gages in Comal County

DIGITAL ELEVATION MODEL (DEM)

A National Elevation Dataset was downloaded for this area via the National Map Viewer. The raster data was projected into the Albers Equal Area projection. A map displaying the elevations in Comal County and the surrounding area is displayed in Figure 4. It is apparent that water from above Canyon Lake drains into Canyon Lake at the bottom of the Upper Guadalupe watershed. Below Canyon Lake, elevations decrease down toward New Braunfels. It is also interesting to note that the decrease in elevation at the City of New Braunfels coincides with the Edwards Aquifer, a major water supply source for Central Texas. The Edwards Aquifer overlaid shapefile was retrieved from the Texas Natural Resource Information System (TNRIS).

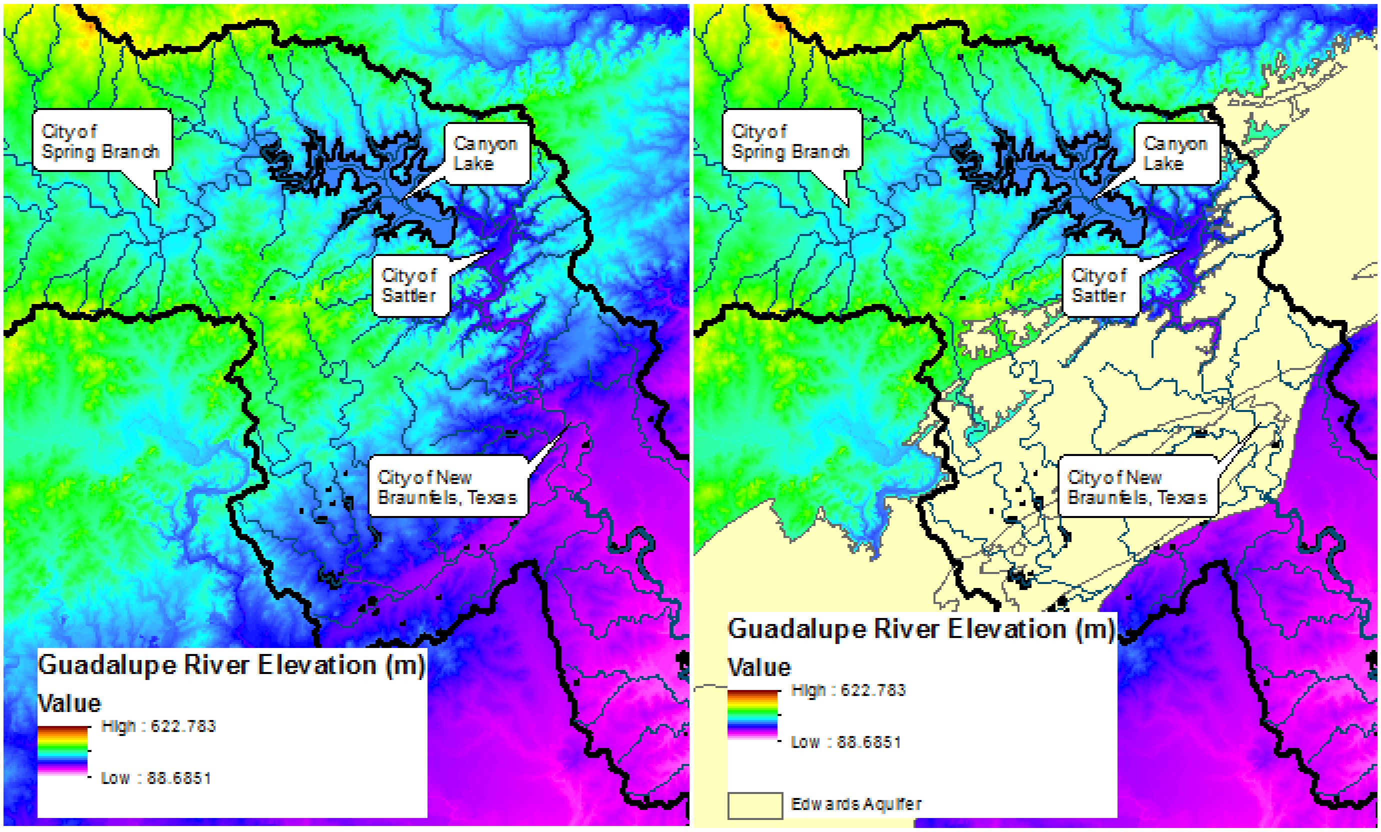

Figure 4: Digital Elevation Model (DEM)

STREAMFLOW DATA

To illuminate the magnitude of the 1998 and 2002 floods, Figure 5 shows plots of streamflow data over time since the construction of the Canyon Lake dam in 1964 [9]; Figure 6 shows mean daily stream gage height for the years data was available.

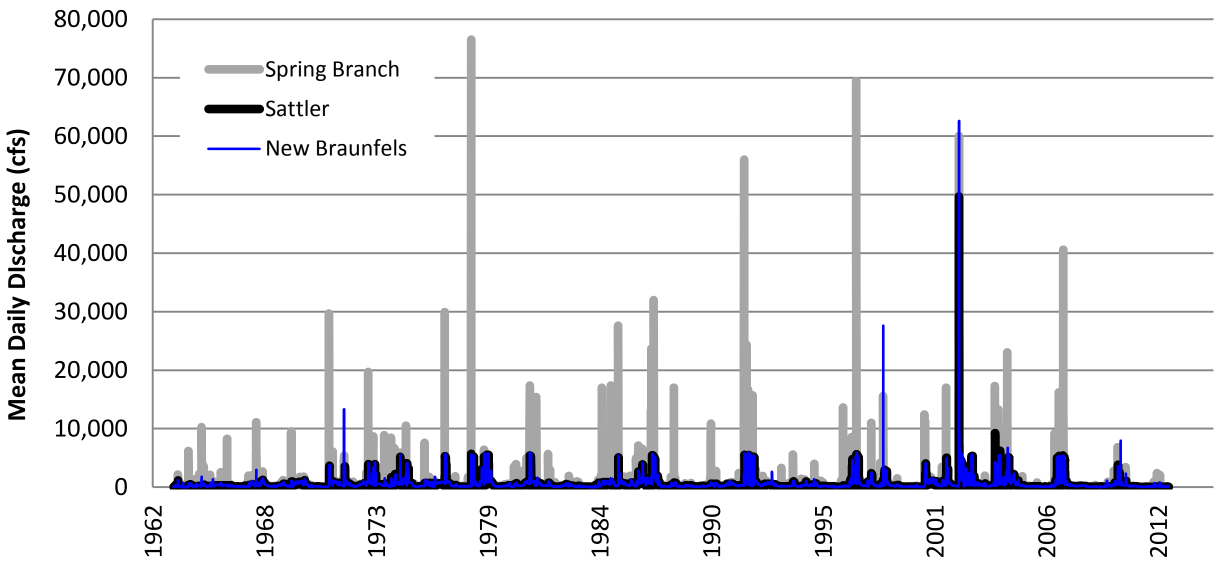

Figure 5: UGSG Streamflow Data at New Braunfels, Sattler and Spring Branch

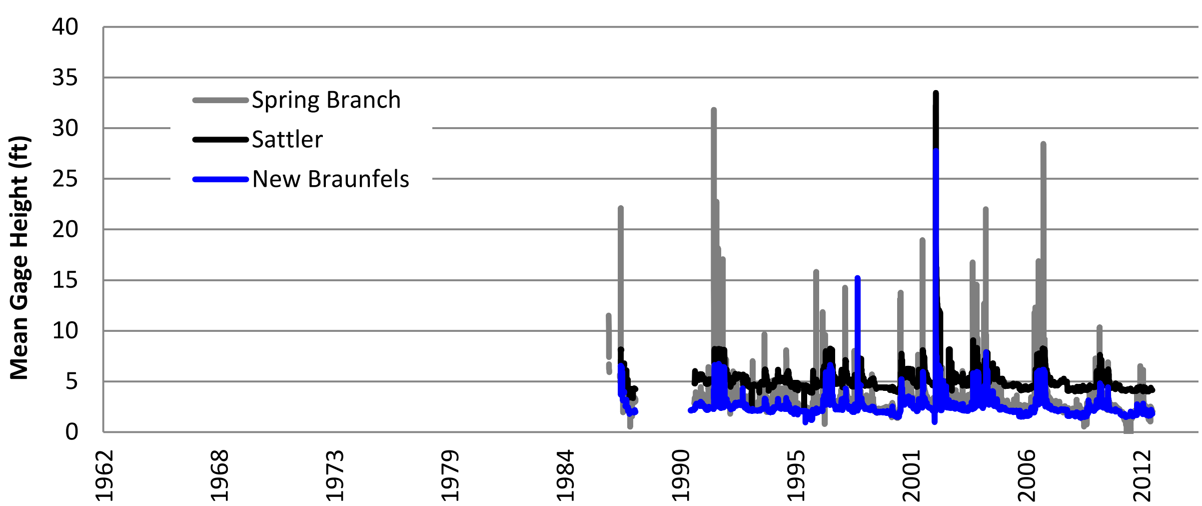

Figure 6: USGS Mean Gage Height Data at New Braunfels, Sattler, and Spring Branch

Beginning most downstream at New Braunfels, three very large floods (above 10,000 cfs) are seen in 1972, 1998 and 2002. Moving toward Sattler, one large (above 10,000 cfs) flood is seen in 2002. Finally, considering Spring Branch above Canyon Lake, over 20 floods (including the 2002, but not the 1998, flood) above 10,000 cfs are evident. This is clear evidence that Canyon Lake is dampening flooding downstream. This also suggests that the location of maximum rainfall is important, and may be a determining factor in the differences between the 1998 and 2002 floods. However, considering data from all three USGS stations (especially the plots where the vertical axis is limited) flooding is a common occurrence in Comal County.

Thus, even in the 575 square miles of Comal County, the 1998 flood is seen distinctly at New Braunfels, but not above at Sattler or Spring Branch, while the 2002 flood was evident at all three locations. Since the data shown above show that Canyon Lake does help to dampen downstream flooding, it is interesting to note (and further consider) why the 1998 and 2002 floods do not follow the typical pattern of streamflow variation through these three USGS gages.

1998 FLOOD

Daily streamflow data (Figure 7) show that the 1998 flood peak flow was reached in a single day. New Braunfels has the highest flow and Sattler, located in the middle, has the lowest flow. Lake storage data (Figure 8) shows that Canyon Lake increased in storage volume over the 17th and 18th of October. Thus, Canyon Lake retained the increased upstream streamflow. Both streamflow and lake storage data were retrieved from USGS.

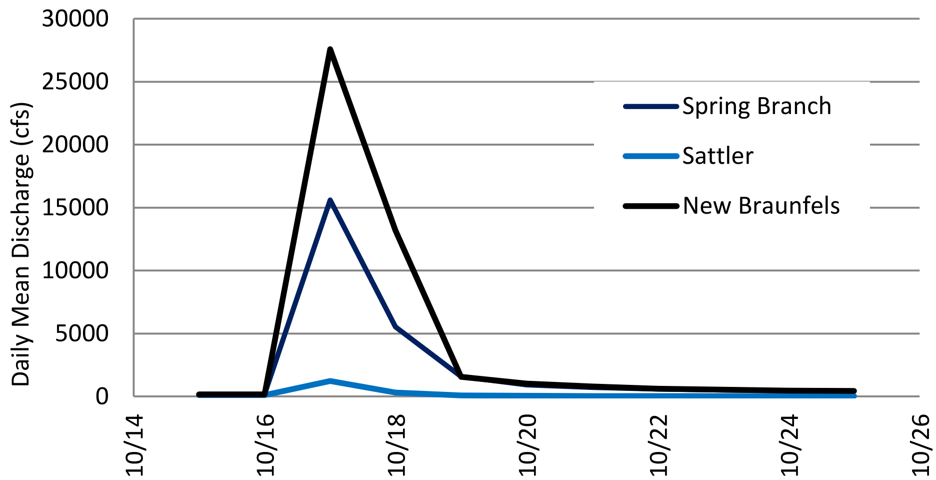

Figure 7: Streamflow Data Surrounding the 1998 Flood.

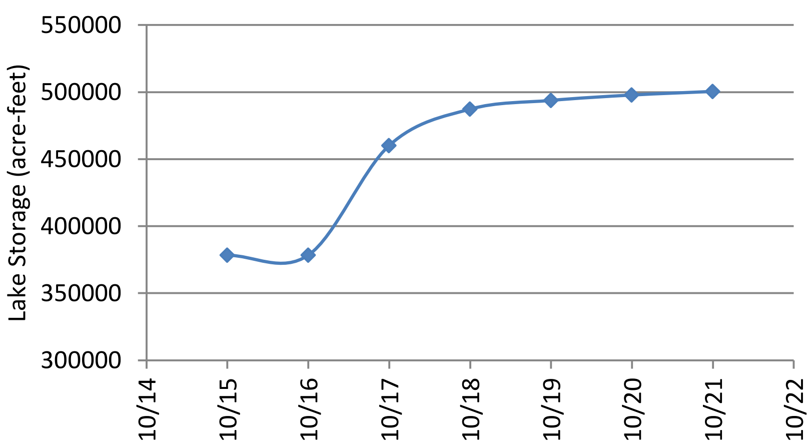

Figure 8: Lake Storage Data During the 1998 Flood

Precipitation data has been obtained using Hydrodesktop with the source as the National Weather Service West Gulf River Forecast Center (NWS – WGRFC) from October 15, 1998 to October 22, 1998; data was obtained for Comal County, Guadalupe County (downstream), and Kendall County (upstream). This data was imported into GIS, displayed as XY data (with a coordinate system matching the rest of the map data), and exported to a shapefile. The symbology of the shapefile was changed to use graduated symbols, and the time series was enabled. The time slider was used to display the rainfall over the course of the 1998 flood. Figure 10 shows a map of rainfall on October 18, 1998, and Figure 9 displays precipitation data over time at a point near the USGS gage in New Braunfels. Additionally, total precipitation over the flood was calculated in excel by summing up the daily precipitation values. This data was then imported into GIS, the XY data displayed, and a shapefile created for total rainfall values. To show the distribution of rain over the entire flood, a Kriging interpolation was used (Figure 11). The total rainfall isotopes produced by the Comal County Chief Engineer's Office (CCEO) is also displayed in Figure 11 for comparison.

The time series of precipitation was reflected in the streamflow data shown in Figure 7, and shows why the downstream USGS station received the highest flows. The main downpour of rain was received just above New Braunfels, below the Canyon Lake Dam. The time series, accompanied by a map of total rainfall, shows that over 20 inches of rain fell over New Braunfels in only two days. Streamflow increases are seen about a day sooner than the precipitation maximum due to large precipitation fall directly upstream of the USGS gage in New Braunfels the day before. The power of GIS in visualizing data over time and space is very apparent here.

Careful review of Figure 11 reveals that the rainfall totals calculated with NWIS data do not match those provided by the CCEO. Further review of flood documentation [5] revealed that many NWIS gages were overtopped during the 1998 flood. Thus, the NWIS data is incomplete! This illustrates the importance of local data collection and the availability of access to this data even today when national data collection sources are available. Nevertheless, it is apparent that the patterns of greatest rainfall are similar between the two data sources.

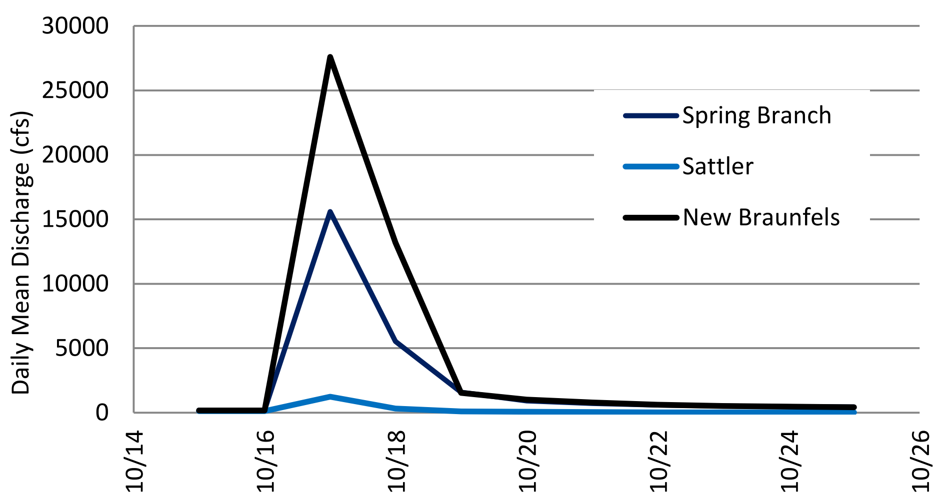

Figure 9: Precipitation over the 1998 Flood in New Braunfels

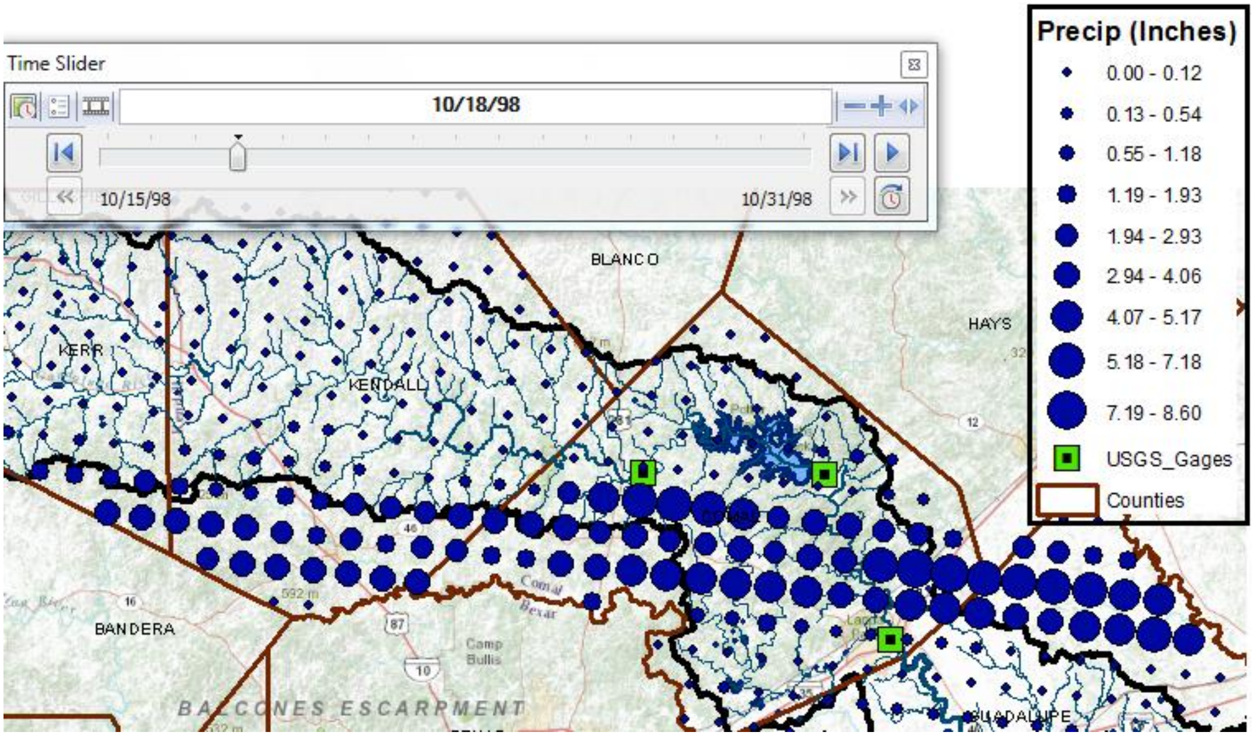

Figure 10: National Weather Service Precipitation Data for October 18, 1998

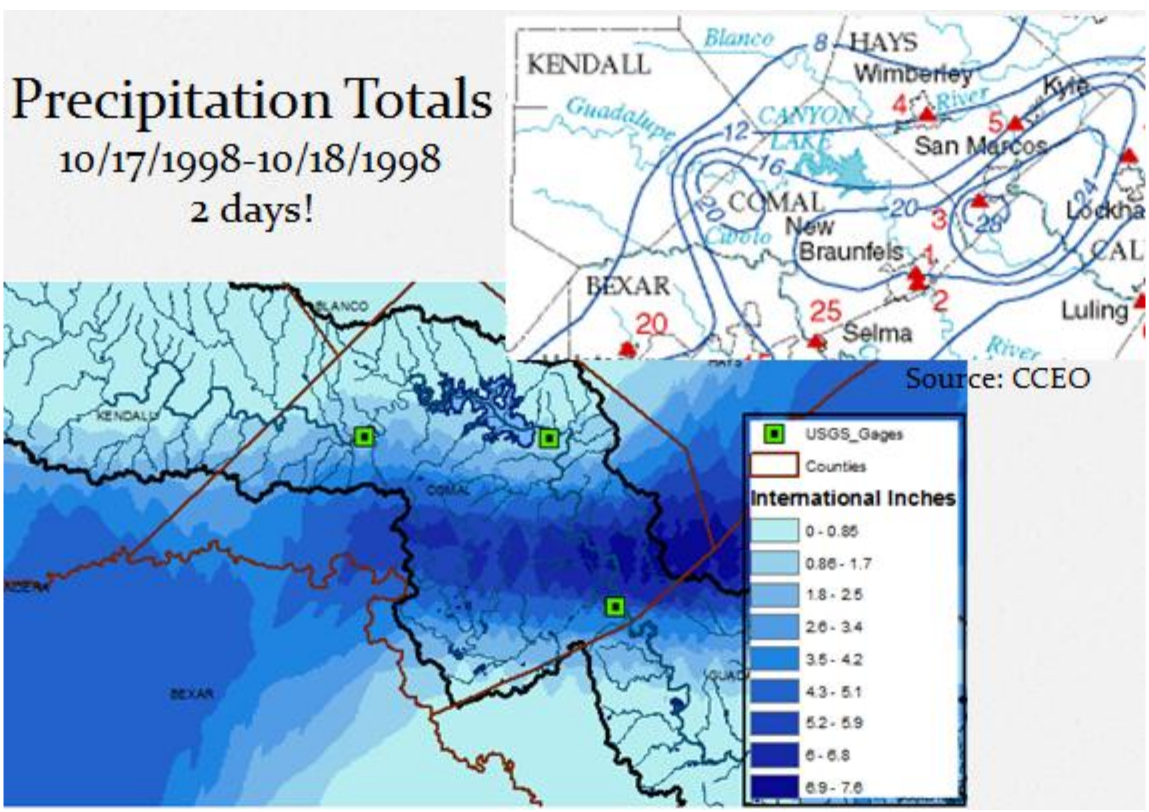

Figure 11: Total Rainfall for the 1998 Flood

A limitation with this data is that it is showing mean streamflow and total precipitation over a day. For such a short flood duration beginning the night of October 17th, it takes careful interpretation to link up why streamflow is maximum on the 17th, but precipitation is maximum on the 18th. To overcome this limitation, hourly streamflow data was downloaded from the NWIS via Hydrodesktop as described previously. The symbology was adjusted and the time slider was used to show precipitation over the duration of the flood. To gain an even better visual understanding of the flood, a time series was created for the streamflow at each USGS gage and the storage in Canyon Lake (also retrieved from USGS). However, the lake storage and streamflow values were only available per day versus per hour. Figure 12 through Figure 17 display streamflow (blue dots), lake storage (pink star), and streamflow (green diamonds) with symbology that changes size based on changes in volume.

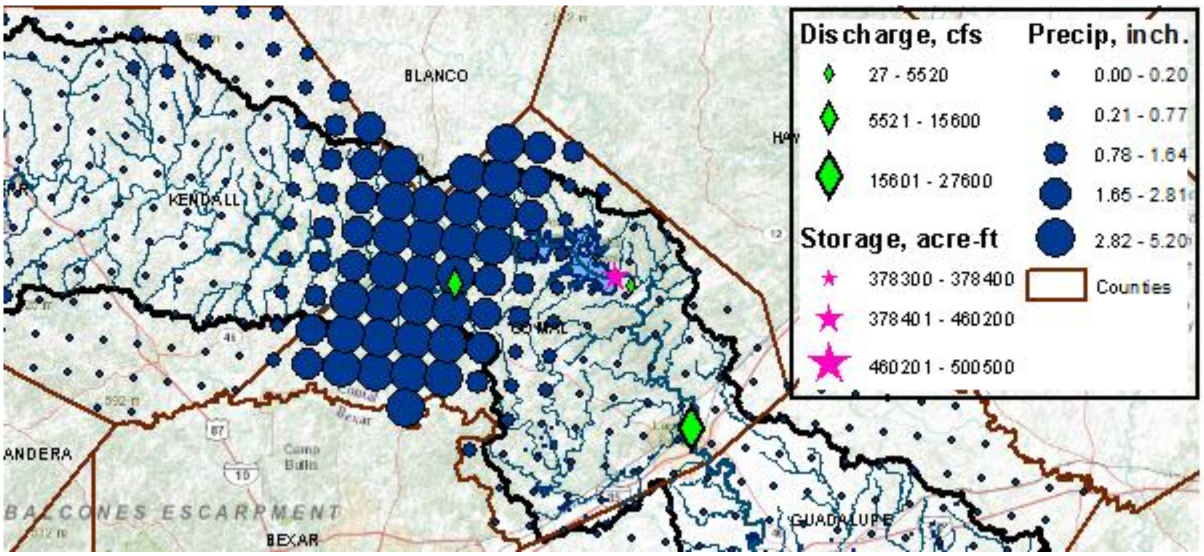

Figure 12: Hourly Precipitation at 12PM on 10/17/1998

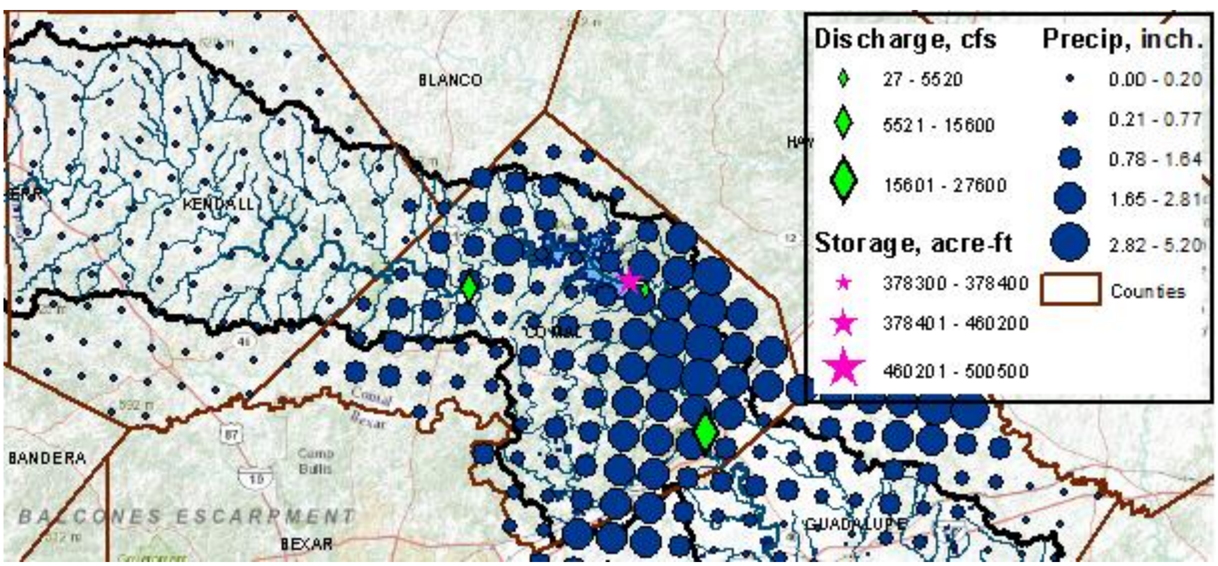

Figure 13: Hourly Precipitation at 6PM on 10/17/1998

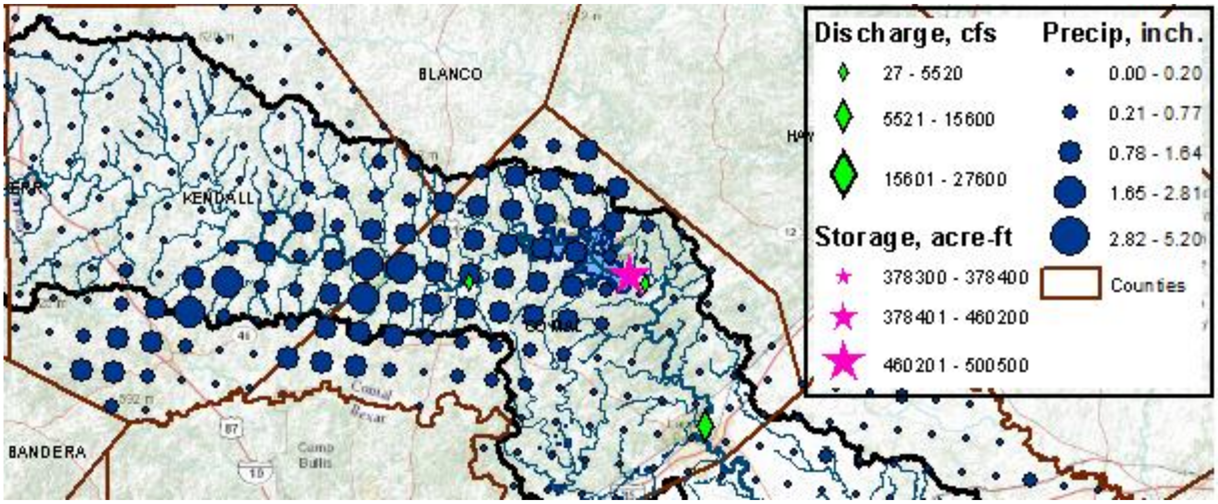

Figure 14: Hourly Precipitation at 12AM on 10/18/1998

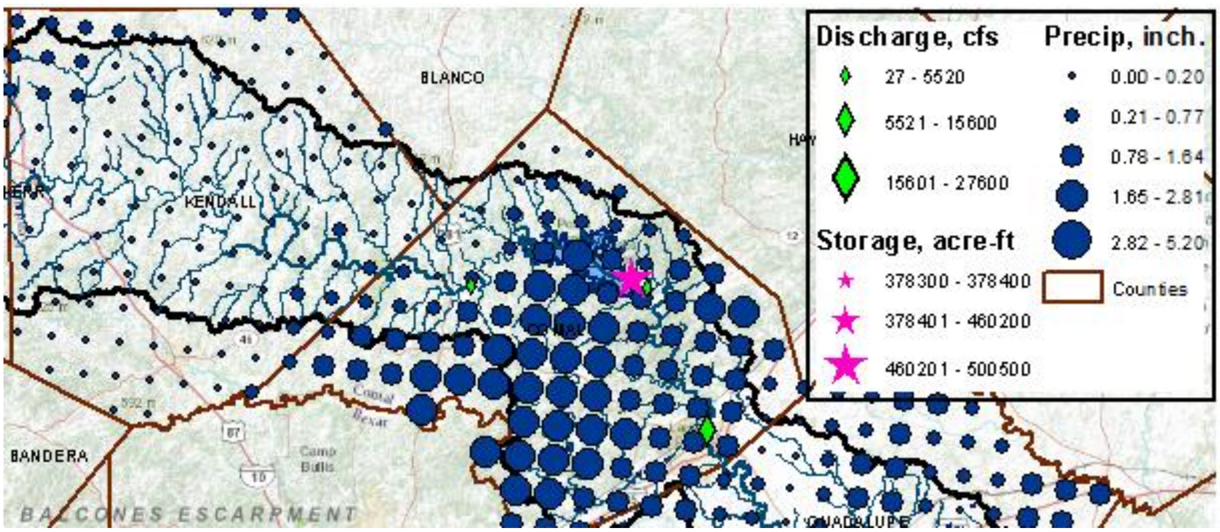

Figure 15: Hourly Precipitation at 6 AM on 10/18/1998

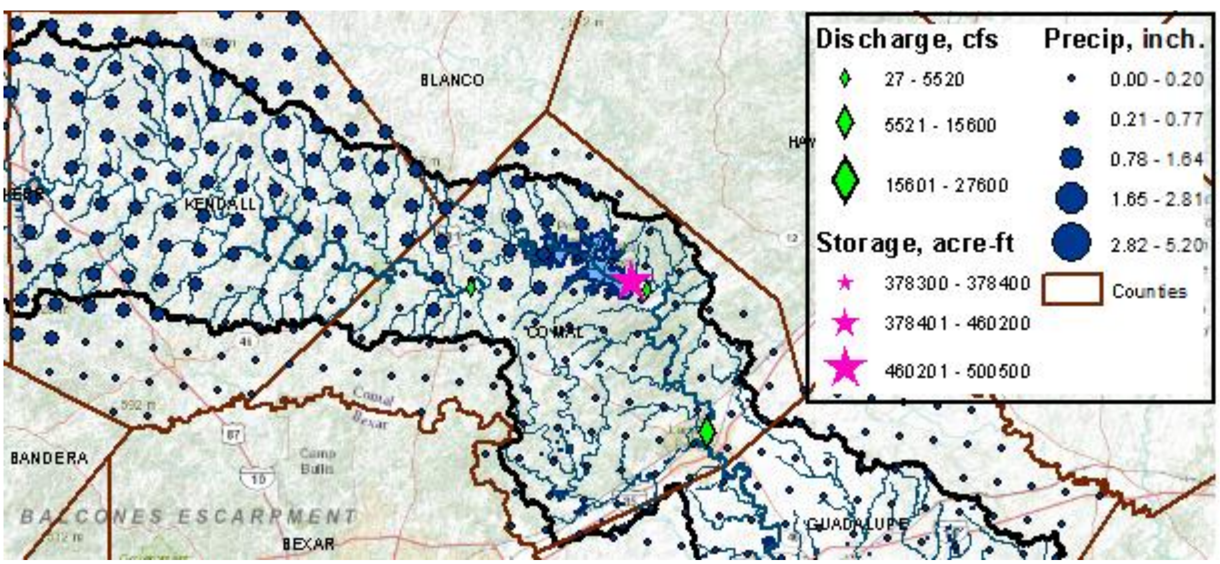

Figure 16: Hourly Precipitation at 12PM on 10/18/1998

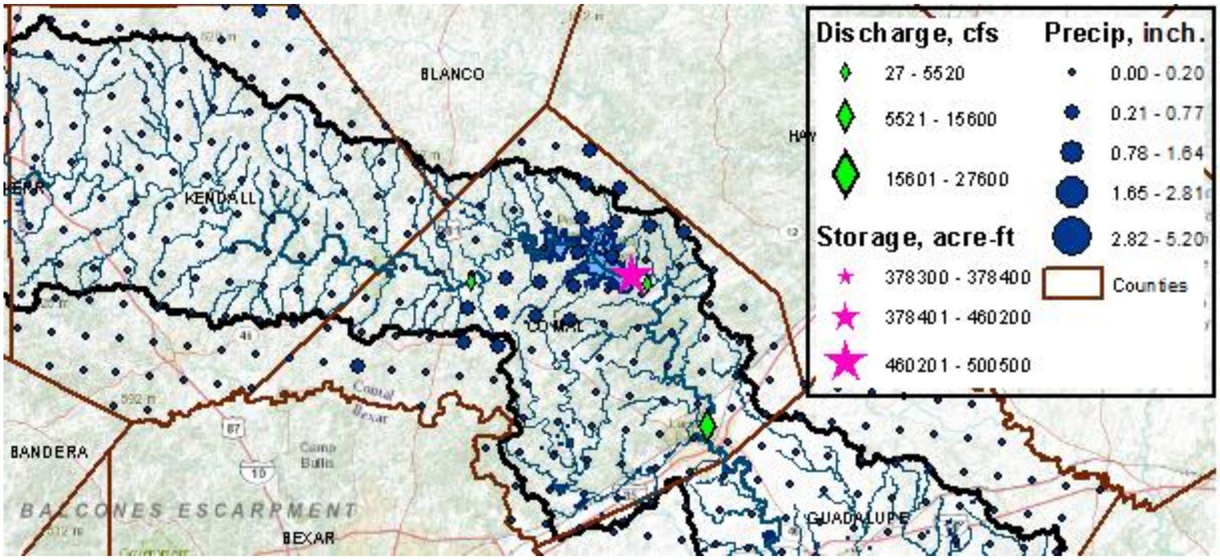

Figure 17: Hourly Precipitation at 6PM on 10/18/1998

The hourly precipitation data shows the majority of rain falling late on the 17th and early on the 18th. Displaying increases in streamflow and lake storage alongside precipitation data provides a well-rounded visual representation of the storm. Precipitation is seen moving from north the south, but focused on the region of Comal County below Canyon Lake. Above Canyon Lake, precipitation increases streamflow which increases the lake storage. Canyon Lake performed well as a flood control structure. However, these figures would be improved by the availability of hourly lake storage and streamflow data.

2002 FLOOD

Next, I investigated the same data for the 2002 flood. Daily streamflow data (Figure 18) show the effect of the dam spillway overflowing on July 4th. The downstream streamflows at New Braunfels and Sattler reflect that upstream and are near the reported 67,000 cfs that overflowed the spillway. Once the lake fell back below the spillway, the downstream flows significantly decreased, but was still higher than normal due to high controlled releases (of up to 5,100 cfs) by the Army Corps of Engineers and rainfall downstream of the dam [8].

Lake storage data (Figure 19) shows that Canyon Lake increased in storage volume until July 7th, the day the spillway overflowed. The water was reported as 7.3 feet above the spillway. After the spillway event, the water level in Canyon Lake decreased back down below the spillway and was withheld by the dam; Figure 19 shows that by about July 7th, the Lake had reached a steady state water level; water continued to flow over the spillway for approximately 6 weeks after the flood [4]. Both streamflow and lake storage data were retrieved from USGS.

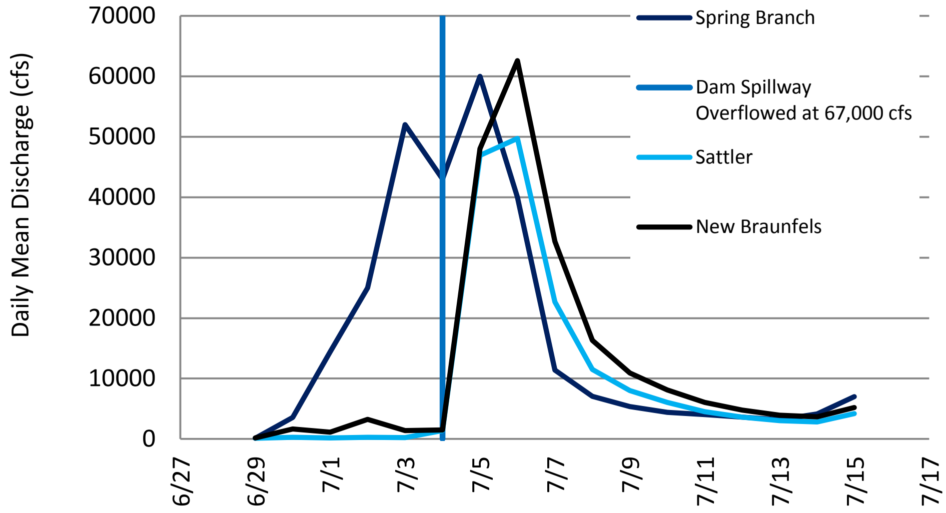

Figure 18: Streamflow Data Surrounding the 2002 Flood

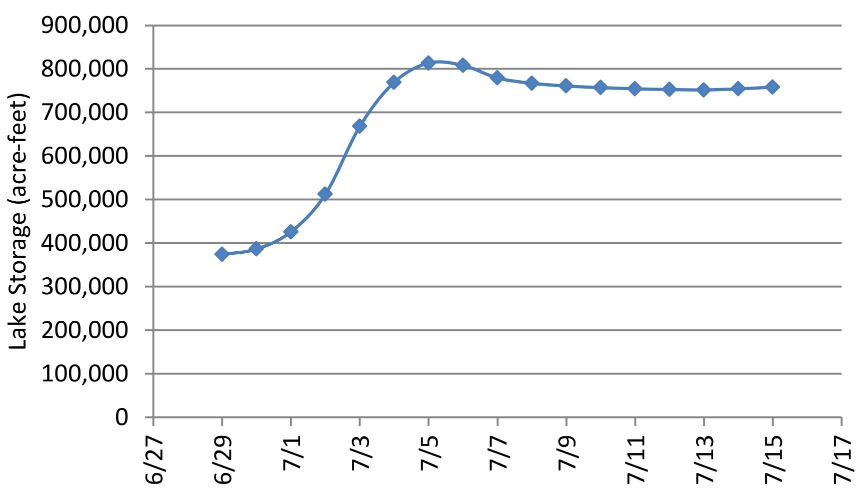

Figure 19: Lake Storage During the 2002 Flood

Precipitation data has been obtained using Hydrodesktop with the source as the National Weather Service West Gulf River Forecast Center (NWS – WGRFC) from June 29, 2002 to July 28, 2002; data was obtained for Comal County, Guadalupe County (downstream), and Kendall County (upstream). This data was imported into GIS, displayed as XY data (with coordinate system matching the rest of the map data), and exported to a shapefile. The symbology of the shapefile was changed to use graduated symbols, and the time series was enabled. The time slider was used to display the rainfall over the course of the 2002 flood.

Total precipitation displayed in Figure 21 shows that over 20 inches of rain fell over New Braunfels again; however, this time, the rain fell over a week (Figure 20) – and fell over a much larger area (Figure 21).

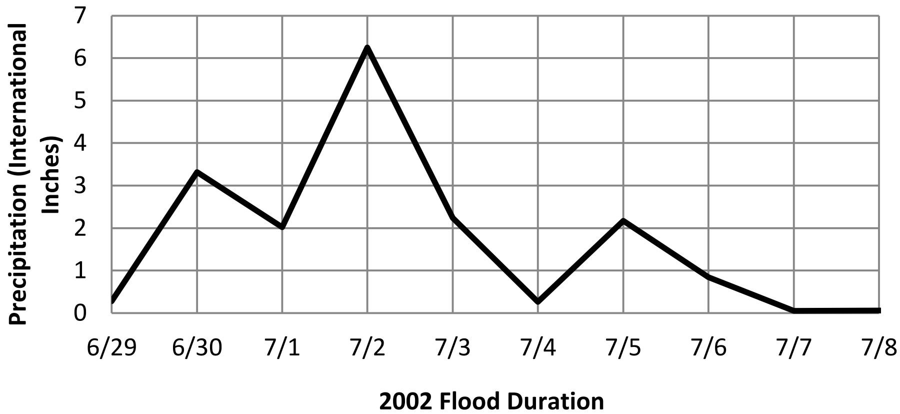

Figure 20: Precipitation over the 2002 Flood in New Braunfels

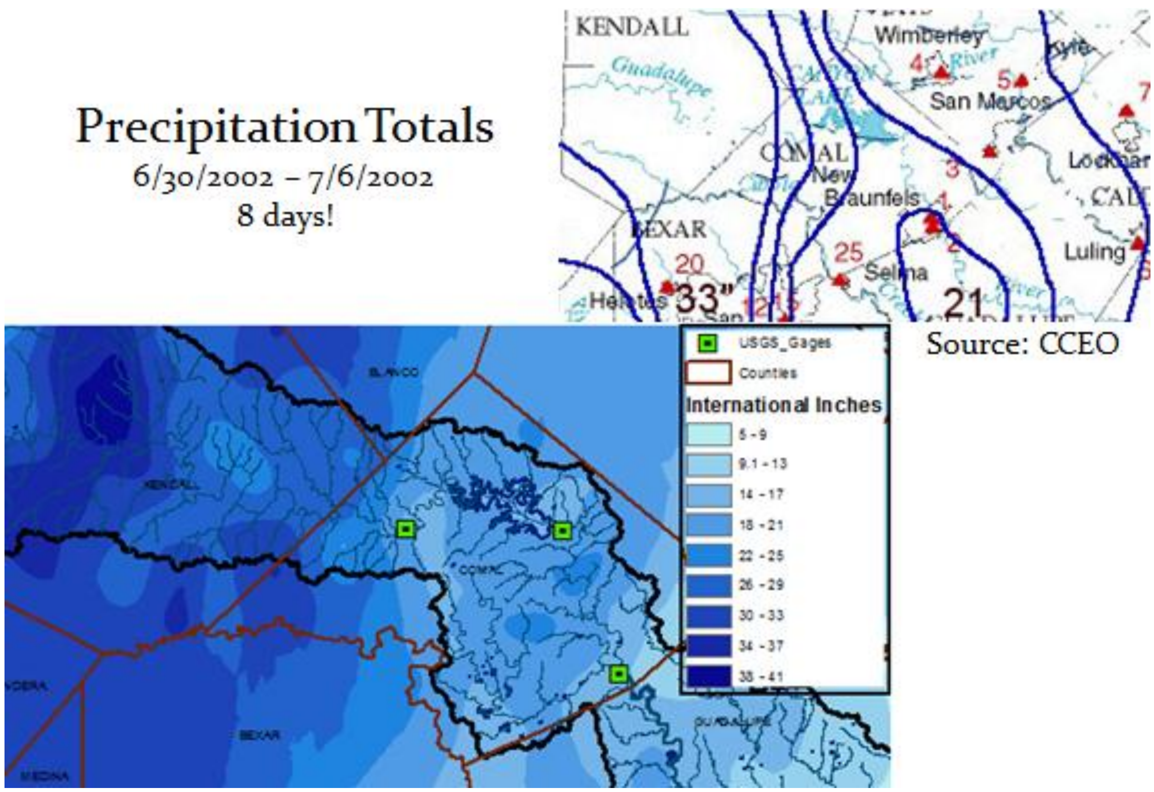

Figure 21: Total Rainfall for the 2002 Flood

Figure 22 through Figure 27 show daily precipitation data in Kendall, Comal and Guadalupe Counties over the main days of the flood. A time series was created and enabled for streamflow, precipitation and lake storage as was done for the 1998 flood. Daily precipitation data was used for the 2002 flood due to the longer duration of this flood.

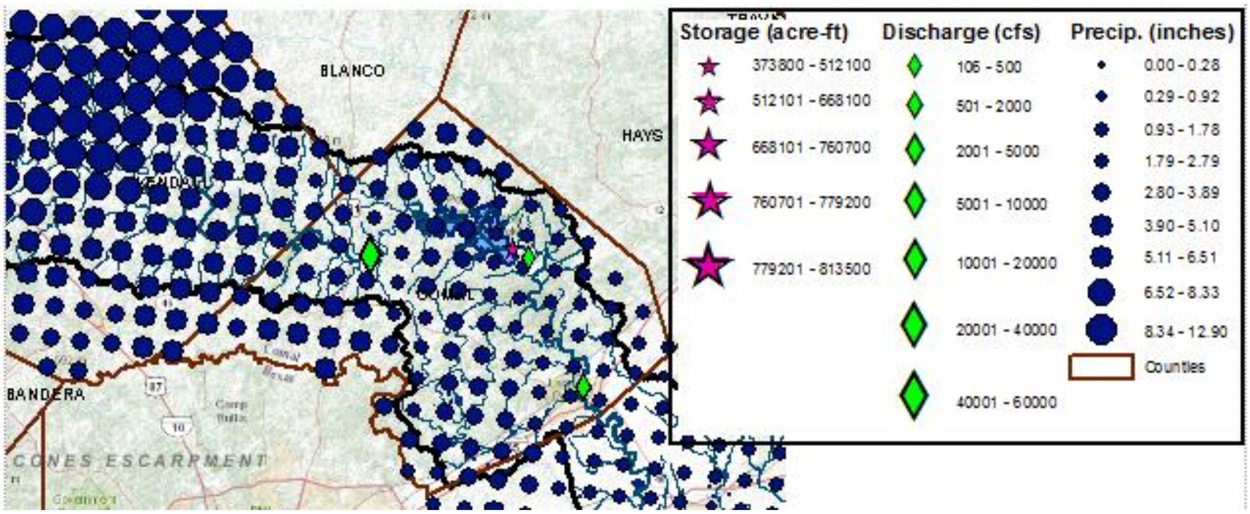

Figure 22: Daily Precipitation on July 1, 2002

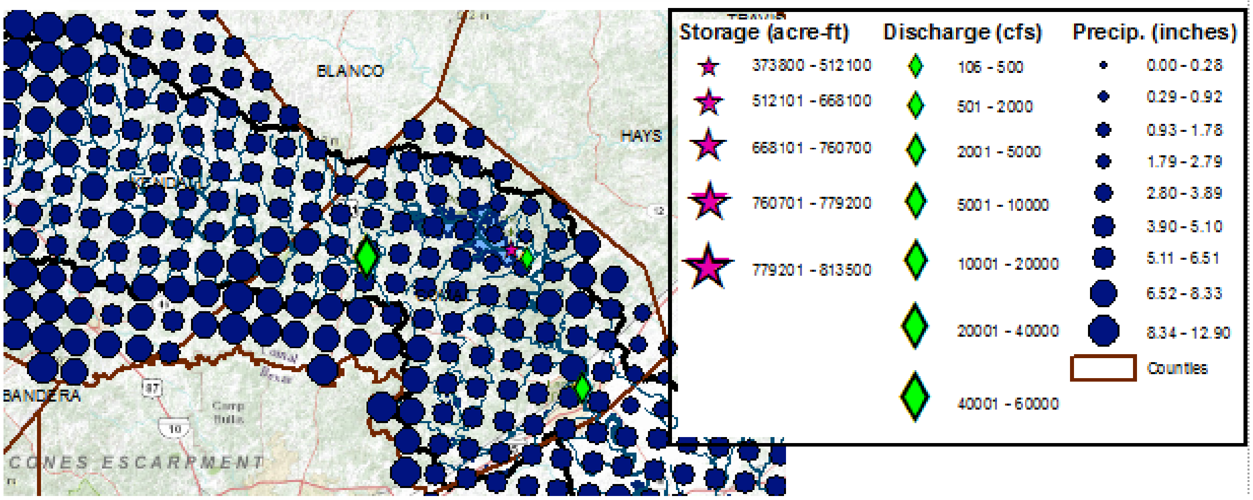

Figure 23: Daily Precipitation on July 2, 2002

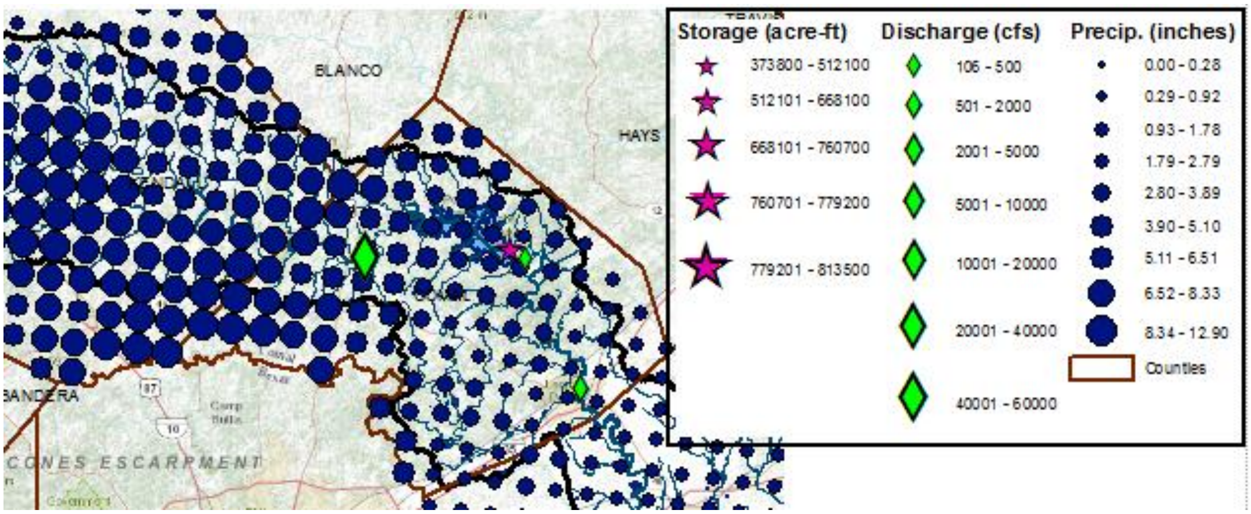

Figure 24: Daily Precipitation on July 3, 2002

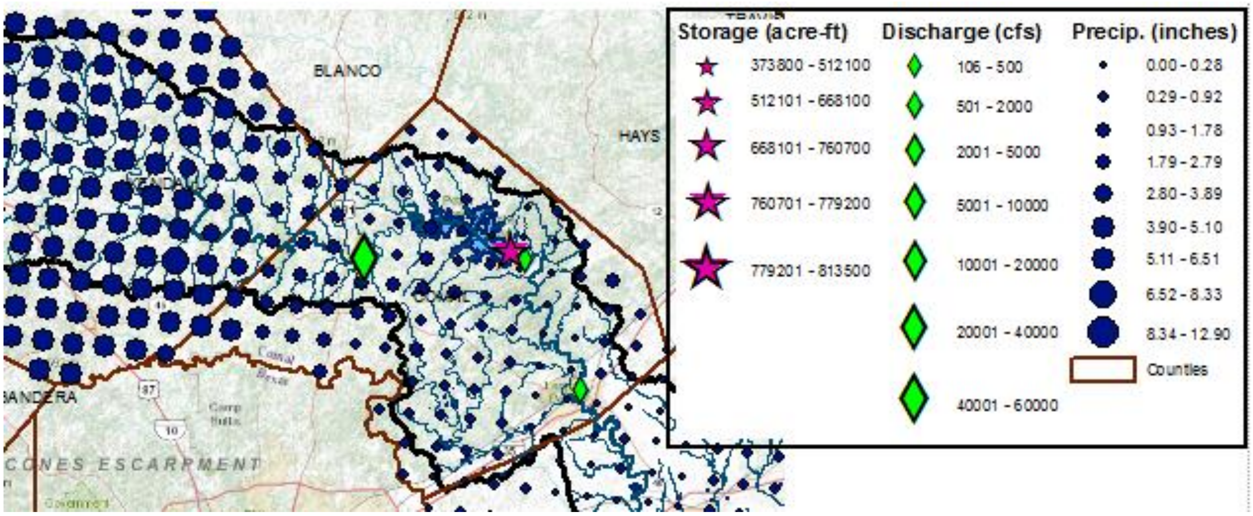

Figure 25: Daily Precipitation on July 4, 2002

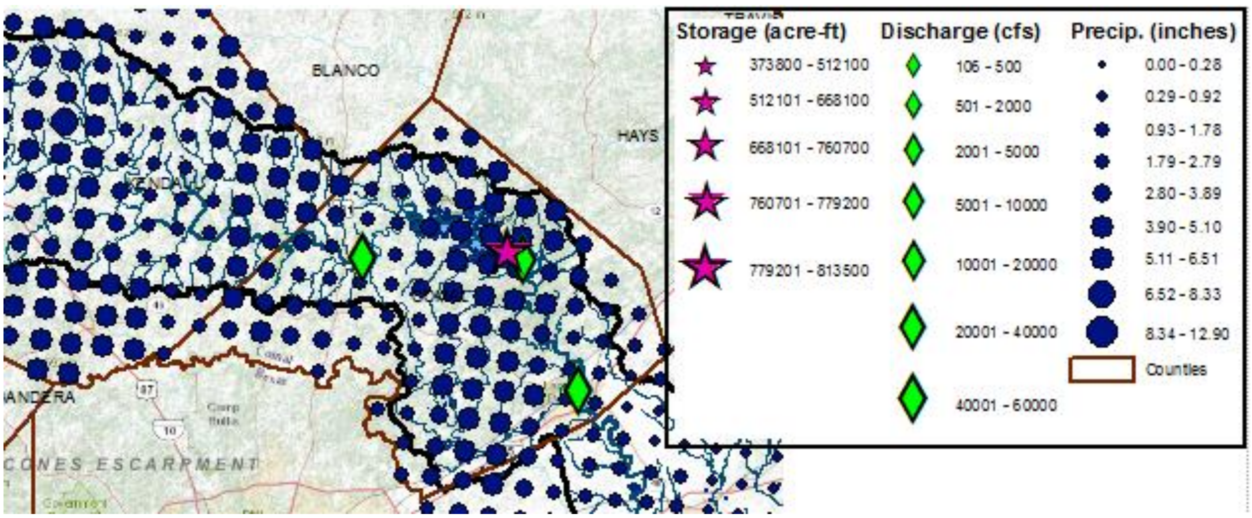

Figure 26: Daily Precipitation on July 5, 2002

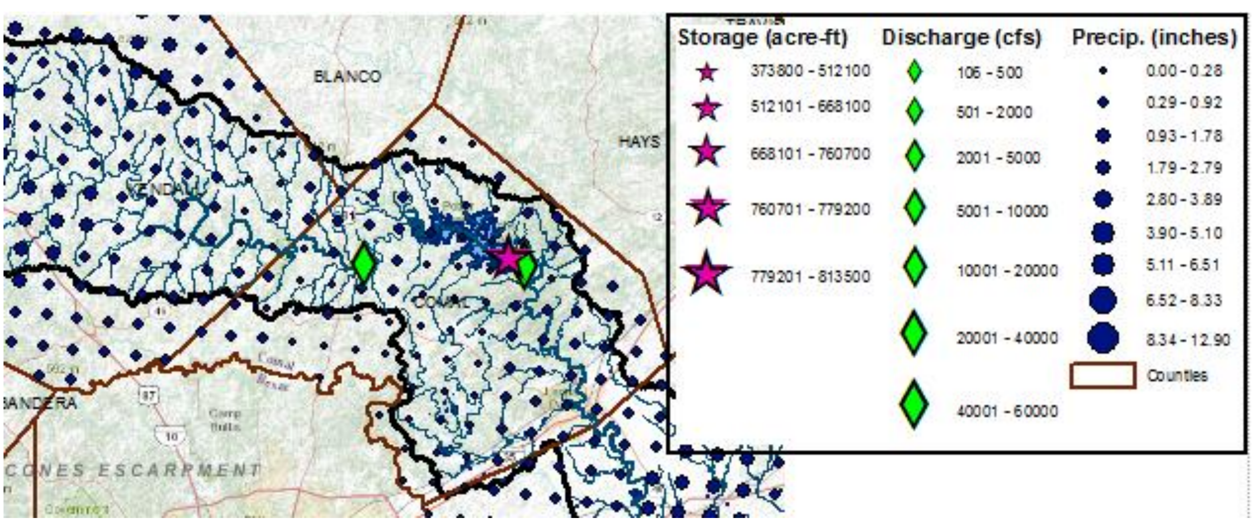

Figure 27: Daily Precipitation on July 6, 2002

The time series of precipitation, streamflow and lake storage shows again the role of Canyon Lake and the location of precipitation in the 2002 flood. Lake storage is shown as increased up until it overtopped, at which point great increases in downstream streamflow are apparent. Additionally, it is easy to see the relationship between the upstream streamflow and the increasing lake storage prior to the overtopping of the lake.

2002 FLOOD PHENOMENON – THE CANYON LAKE GORGE

On July 4th, for the first time, Canyon Lake overflowed via the emergency spillway carving out the Canyon Lake Gorge, and uncovering layers upon layers of history. While local citizens were quick to point fingers at the dam's "failure," the Army Corps of Engineers is pleased with how well the dam worked during this event. Up until July 4th, the dam withheld upstream floodwaters, maintaining the streamflow (Figure 18) downstream at approximately 5,000 cfs. The dam, even at full capacity, survived without failure. The emergency spillway designed by the Army Corps of Engineers, such that in a case as was this flood the dam would not fail, performed exactly as it was designed. The spillway allowed flood waters to flow out of the lake instead of flowing over the dam and possibly causing structural dam failures. Furthermore, the dam maintained downstream flows below 70,000 cfs, whereas the Army Corps of Engineers estimated without the dam, downstream flooding would have reached 125,000 cfs. "An estimated $38.6 Million in damages were prevented" [10].

Pictures and lidar images of the gorge before, during and after the flood are shown in Figure 28, and the DEM model focused on the Gorge accompanied by imagery of the same region are shown in Figure 29. The DEM of the Gorge was created by clipping the DEM file to a smaller square surrounding the gorge, such that a smaller elevation range would allow for greater visibility of changes in elevation via a graduated symbology. It is evident that the depth of the gorge is on average 7 meters or 23 feet [11]. This is an astonishing amount of earth carved out in less than one day!

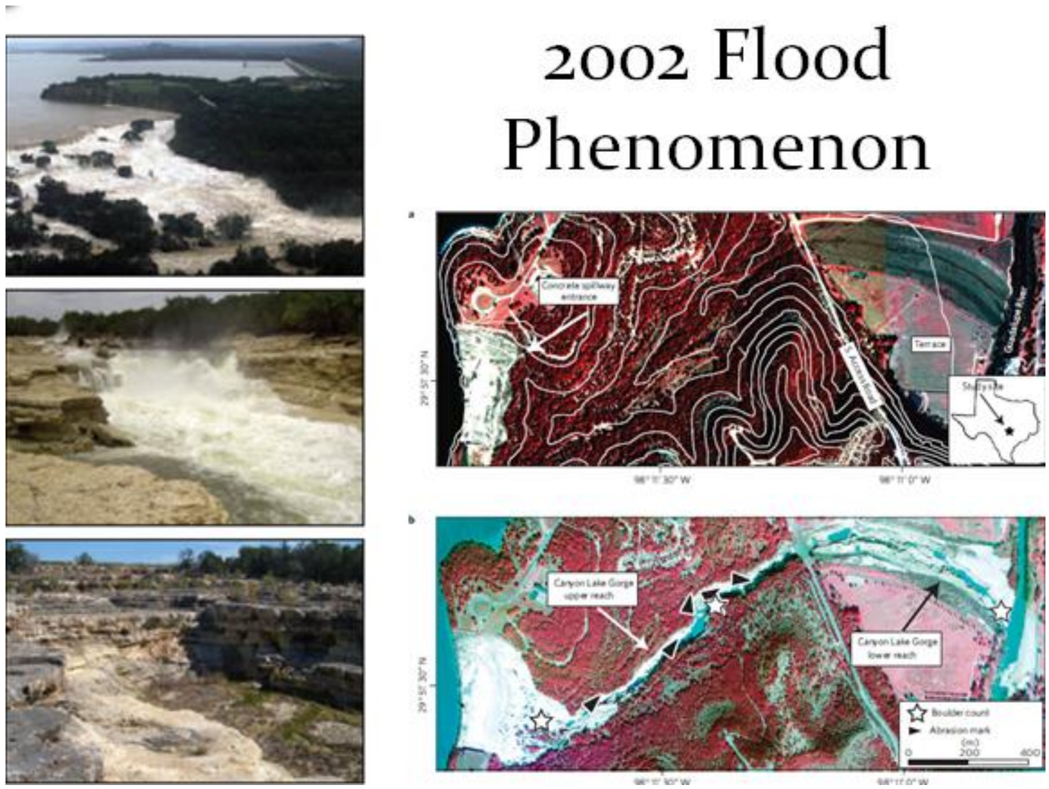

Figure 28: Canyon Lake Gorge: Before and After the 2002 Flood [11]

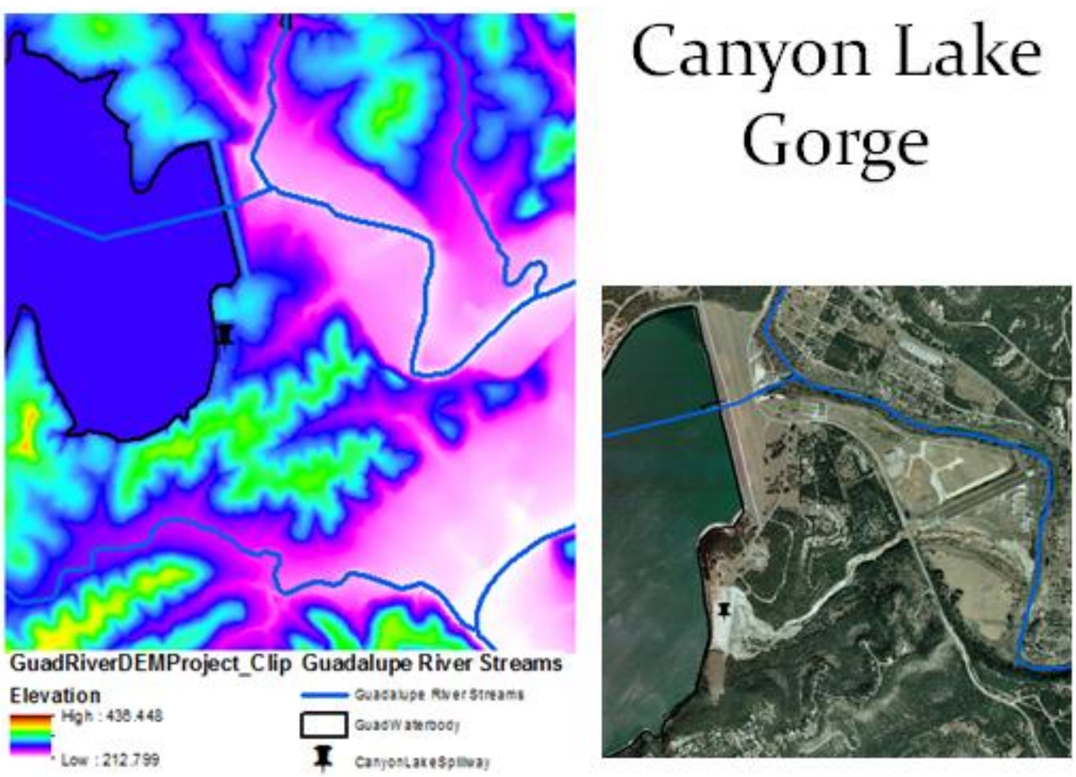

Figure 29: DEM and Imagery at the Canyon Lake Gorge

FLOODPLAINS

The DEM was then used to display the floodplain for the 1998 and 2002 floods. The 100 year FEMA FIRM (Federal Insurance Rate Map) floodplain shapefile for the U.S. was downloaded via ArcGIS online.

The maximum mean daily gage height was obtained from USGS for each stream gage location displayed in Figure 3. Additionally, the gage datums were retrieved for each site. However, the datums were provided in the National Geodetic Vertical Datum of 1929 (NGVD29) and the DEM data is in the North American Datum of 1988 (NAD88). To translate the NGVD29 to NAD88, Corpscon was downloaded from the Army Corps of Engineers and run with the input and output as shown in Figure 30.

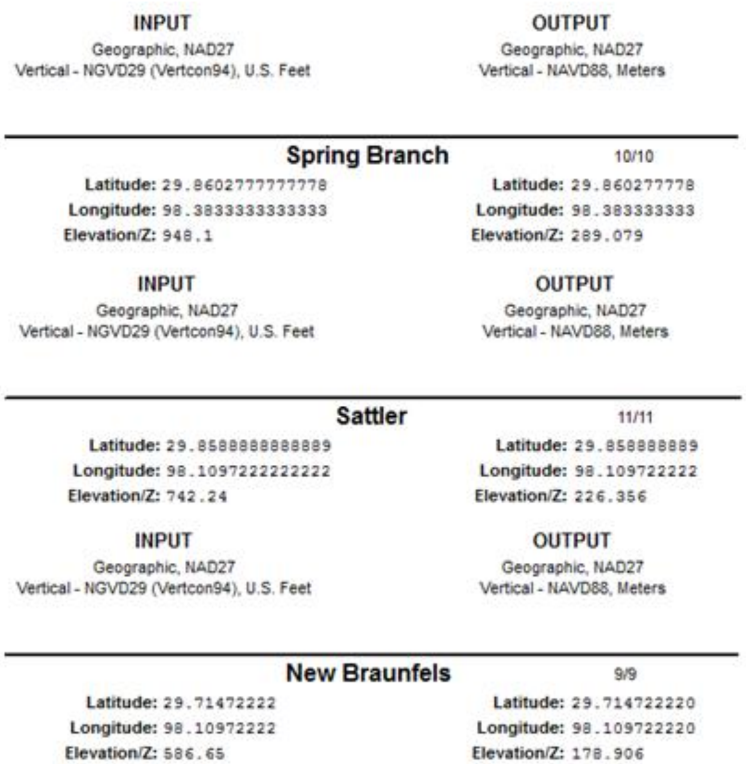

Figure 30: Corpscon Input and Output for Each Stream Gage Datum

Table 2 displays the gage elevation (and translation between vertical datums), the max gage heights for each storm (and translated into elevations), and the flood level gage heights for each USGS station. Comparing the stream gage heights with the flood levels, both of these storms were well above the “major flood” category.

Table 2: USGS Flood Gage Height Data

USGS Gage	Name	Latitude	Longitude	Datum (ft above NGVD29)	Datum (m NAVD88)
8167500	Spring Branch	29.86	-98.38	948.1	289.079
8167800	Sattler	29.86	-98.18	742.24	226.356
8168500	New Braunfels	29.71	-98.11	586.65	178.906

USGS Gage	1998 Max Gage Height (ft)	1998 Date	1998 Elevation (m)	2002 Max Gage Height (ft)	2002 Date	2002 Elevation (m)
8167500	27.43	10/17/1998	**297.44**	43.75	7/4/2002	**302.41**
8167800	5.69	10/17/1998	**228.09**	35.55	7/6/2002	**237.19**
8168500	35.57	10/17/1998	**189.75**	28.95	7/6/2002	**187.73**

USGS Gage	Major Flood Gage Height (ft)	Moderate Flood Gage Height (ft)	Flood Stage Gage Height (ft)	Action Stage Gage Height (ft)
8167500	39	36	30	25
8167800	12	10	9	8
8168500	14	10	7	6

To process the actual floodplain from each flood, the raster calculator was then used to locate all elevations below the converted gage height for both floods at each of the three gage locations. In the case of the 2002 flood, the maximum mean gage heights before and after the spillway was breached (July 4th and July 6th) were processed for comparison at the two downstream locations. The raster calculator equation set the DEM ≤ Gage Height. The output provided a raster file with values of 1 where the DEM ≤ Gage Height and 0 everywhere else. The symbology was changed so that 0 value cells were transparent and 1 value cells were filled with a blue color as depicted in the legends.

Figure 31 through Figure 36 show the floodplain for each flood and the 100 year FEMA floodplain. Both floods met or exceeded the 100 year floodplain at these three gage locations. At the Spring Branch gage, the 2002 flood had a wider floodplain than the 1998 flood. At the Sattler gage, the 1998 flood and the 2002 flood (before the Dam overflowed) approximately met the 100 year floodplain. However, after the spillway breach, the floodplain greatly increases extending beyond the 100 year floodplain. Lastly, analyzing the floodplains at the New Braunfels gage, the 1998 floodplain was actually wider than the 2002 floodplain. Prior to the spillway breach, the 2002 floodplain at New Braunfels was within the river boundaries.

Thus, the gage height data illustrates the extent of these floods as meeting or exceeding the 100 year floodplain, and the sudden increase in the floodplains downstream of the Dam after the spillway overflowed. The data also, thus, shows that before the spillway breach, the Dam was preventing downstream flooding.

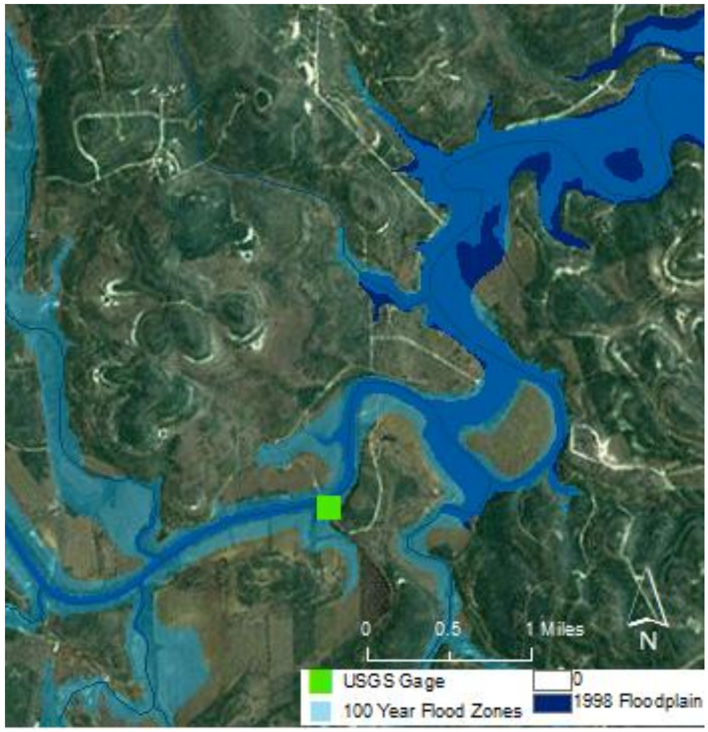

Figure 31: 1998 Floodplain at Spring Branch (Upstream of Canyon Lake)

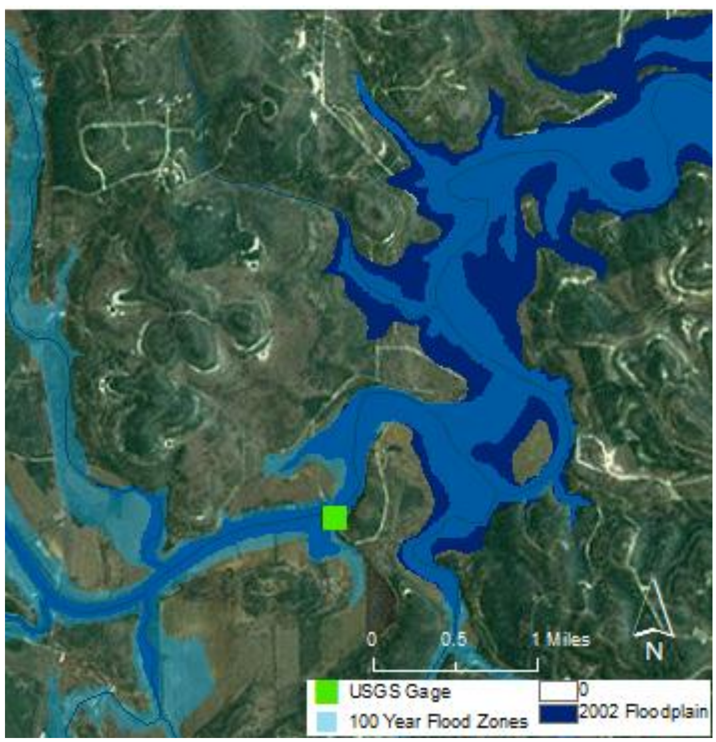

Figure 32: 2002 Floodplains at Spring Branch (Upstream of Canyon Lake)

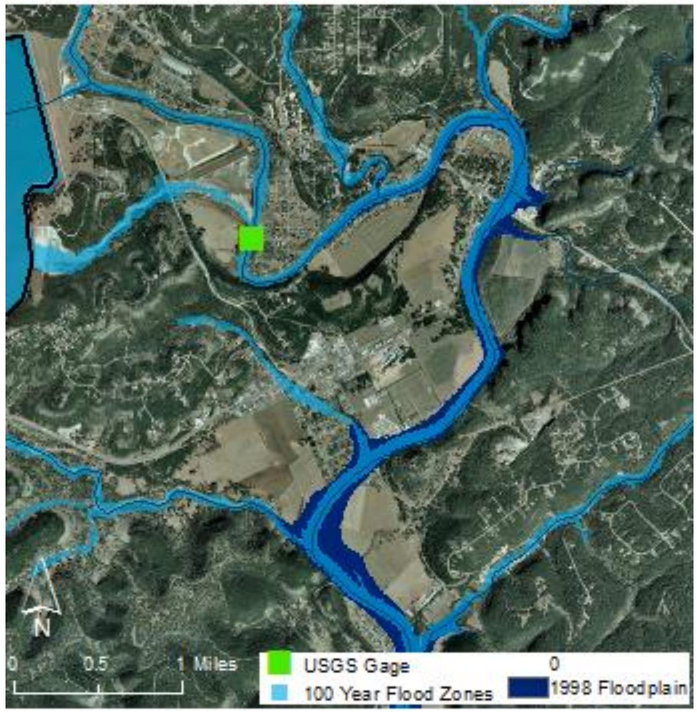

Figure 33: 1998 Floodplain at Sattler (Below the Canyon Lake Dam)

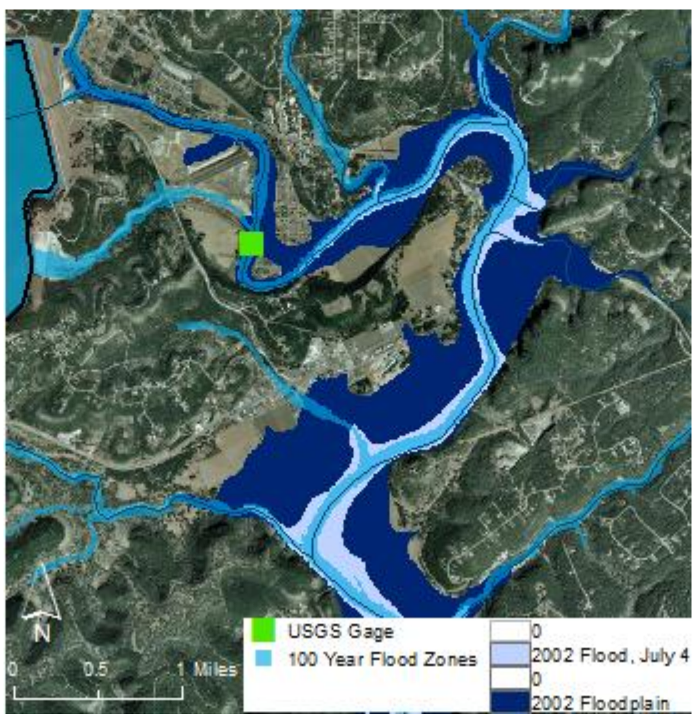

Figure 34: 2002 Floodplains at Sattler (Below the Canyon Lake Dam)

Figure 35: 1998 Floodplain at New Braunfels (20 miles Below the Dam)

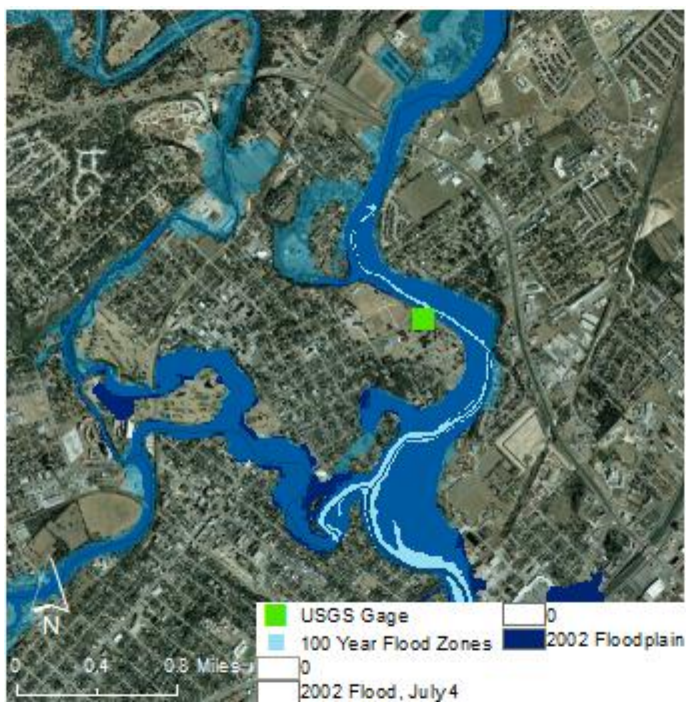

Figure 36: 2002 Floodplains at New Braunfels (20 miles Below the Dam)

TURBIDITY DATA

My original proposal had planned to obtain turbidity data from the EPA for both the 1998 and 2002 floods and plot them in GIS using graduated symbols. I expected a higher turbidity value in the 2002 flood than the 1998 flood due to the carving of the Canyon Lake Gorge. The most frequent data collection was performed by the Guadalupe-Brazos River Authority (GBRA) on a monthly basis. However, the collection dates in 1998 and 2002 were 2-3 weeks after the floods. Thus, I was unfortunately not able to locate turbidity data during or soon after the flooding.

CONCLUSIONS

GIS was used as a tool to visualize hydraulic data available over the floods of 1998 and 2002 in New Braunfels, Texas. The data show a few key differences between these two devastating floods. In 1998, there was little warning; the major rainfall was below Canyon Lake, and the precipitation fell over only 2 days! In 2002, rain fell over 2 weeks, but the rain was much more widespread, and the highest rainfall (up to 30 or 40 inches) was above Canyon Lake. Additionally, in 2002 these conditions caused the dam to overtop the emergency spillway, which resulted in downstream flooding. Yet, in both cases about 20 inches of rain fell over the City of New Braunfels. Figure 37 shows a visual of these comparisons.

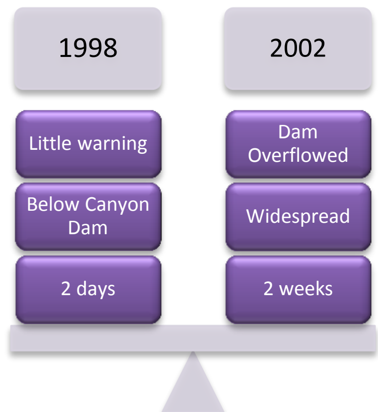

Figure 37: Comparison of the 1998 and 2002 Floods

Additionally, a few broader conclusions were apparent. The 1998 National Weather Service precipitation data is incomplete due to gages overtopping; this points out the importance of local data collection. Secondly, the main factors affecting the differences between the floods included the location of rainfall, the total rainfall over the river basin, and the duration of rainfall. Most importantly, the data show that the Canyon Lake dam performed to design during both floods; even though downstream flooding was not prevented, it was greatly mitigated.

DATA SOURCES

Data Type	Source	Link
Streamflow, Gage Height & Lake Storage	USGS	http://waterdata.usgs.gov/nwis/uv/?referred_module=sw (Gages: 08167700, 08167800, 08168500, & 08167500)
Precipitation	NWIS	http://waterdata.usgs.gov/nwis Accessed via hydrodesktop
Elevation Model	USGS	http://nationalmap.gov/viewer.html Accessed via the National Map Viewer
100-yr Floodplain	FEMA	http://www.arcgis.com/about/ Accessed via ArcGIS Online
Streamlines, Water bodies, Watersheds, & Mean Annual Flow Data	EPA/USGS	http://www.horizon-systems.com/nhdplus/ National Hydrography Dataset - Plus
Texas Counties	TPWD	http://www.tpwd.state.tx.us/landwater/land/maps/gis/data_downloads/
Edwards Aquifer	TNRIS	Projected shapefile retrieved from Dr. David Maidment, The University of Texas at Austin for CE 394K.3 GIS in Water Resources
Corpscon	Army Corps of Engineers	http://www.agc.army.mil/corpscon/ Downloaded from the Army Corps of Engineers Army Geospatial Center
Turbidity Data	GBRA	http://www.gbra.org/crp/sites/comal.aspx

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