The “Mystery Flood” on the Upper San Marcos River, Texas, October 2015

by

Jack Ray D’Ottavio

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Committee Members:

Chair: Dr. Richard A. Earl

Member: Dr. R. Denise Blanchard

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I. Introduction

Central Texas along the Balcones Escarpment has long been recognized as one of the most flood-prone regions of the United States (Leopold, Wolman, and Miller 1964). As such, its normally hydrologically efficient drainage proves to be troublesome during large, intense precipitation events that occur frequently, resulting in high levels of flooding. Accurate data remains one of the most important aspects in risk mitigation. For this region, it is important to have precipitation and discharge data both on the spatial and temporal scales. The consequences of missing or incorrect data have proven to be costly in terms of planning, risk management, repair costs and, most importantly, human life.

The October 30th, 2015 flood in San Marcos, Texas, known as the "2015 Halloween Flood," is one of these cases in which problems with accurate data and lack of reporting occurred. Two potential issues found with this particular flood's data were due to both human error and the forces of nature. First, reported inches of rain per 24-hour precipitation event appeared to be vastly lower at the primary San Marcos National Oceanic and Atmospheric Administration (NOAA) weather station compared to all other nearby reporting weather stations. Flood experts suspected that this data was inaccurate, however, this inaccuracy has yet to be verified. Second, because the San Marcos River's U.S Geological Survey (USGS) stream gauge (08170500) was destroyed during the flood, there is no peak discharge reported for that event even though it was only the second time that the upstream dams on the river have spilled since the upstream flood control project was completed in 1991. The precipitation amounts recorded for San Marcos at the official San Marcos NOAA station were more than 30 percent less than readings from nearby reporting NOAA and CoCoRaHS stations than that reported by surrounding NOAA stations as well as community-based non-NOAA stations under the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS).

For the purposes of this research, a distinction between NOAA and the National Centers for Environmental Information (NCEI) must be clarified due to the numerous changes of agency and departmental name updates. The NCEI is essentially the data hub division of NOAA in which they describe their organization as, NOAA's National Centers for Environmental Information (NCEI) which hosting and providing public access to one of the most significant archives for environmental data on Earth. Through the Center for Weather and Climate and the Center for Coasts, Oceans, and Geophysics, the NCEI provides over 25 petabytes of comprehensive atmospheric, coastal, oceanic, and geophysical data (ncei.noaa.gov).

The goal of this study was to analyze the incongruous data values mentioned above in reference to the October 30th, 2015 flood to that of the surrounding areas. Historical precipitation records and their flood data provide insight of typical expected flood amounts and outcomes per precipitation event. The apparent errors in data for the October 30th, 2015 flood occurrence were of human and natural causes which needed to be reconciled. Gaps in data, such as with this type of event, require attention and correction in order to better understand the actual magnitude of the October 2015 flood. By means of statistical, photo, video, and historical data analyses, this research aimed to provide a quantified accurate estimation of the flood’s magnitude.

The following study questions guided this research: To what extent did the 24-hour precipitation and peak stream flow data records accurately reflect the magnitude of the October 30th, 2015 San Marcos River flood occurrence in San Marcos, Texas? Given that the data was inaccurate, what was the record of actual peak stream flow and 24-hour precipitation? To that end, through quantitative and qualitative analyses, this research aimed to identify the extent of recorded inaccurate values as well as where and how this might have occurred.

To estimate a more accurate peak stream flow this project first compared data for "stage to discharge" relationships to previous floods at stream gauge (08170500). These values for actual flow characteristics were then incorporated into the USGS's "slope-area method" to obtain the curve of peak flow discharge. Next, the 24-hour precipitation amounts for October 30th-31st, 2015 were analyzed. The October 20th-31st precipitation amounts for the official San Marcos NOAA station were considerably less than readings from nearby reporting NOAA and CoCoRaHS stations. Researching NOAA's official data standard operating procedures for precipitation reporting was the starting point. The CoCoRaHS data was then investigated to understand equipment precision and personnel reporting times.

Photograph and video evidence of the flood alluded to a much larger flood event than what was reported on the USGS discharge record. One example that indicated a larger event was observed on flood level markers for past flood events recorded on the side of Texas State University's Outdoor Center at Sewell Park. The October 30th, 2015 flood marker is positioned just 1.5 feet below the famous South Central Texas 1998 Flood event which was the largest flood occurrence since 1985 and would have been the largest flood event ever, without the upstream flood control dams. The October 1998 flood also reported the largest 24-hour precipitation amount, 15.78 inches recorded for the San Marcos station since 1896 (Earl and Wood 2002; Earl, 2007; NCEI 2019).

The overall hypothesis of this research was as follows: That flood and precipitation data published for the October 30-31st, 2015 flood occurrence in San Marcos, Texas were significantly less than the actual magnitude of the flood event. This research investigated and uncovered how these possible mistakes occurred through qualitative review of picture and video recordings as well as quantitative analysis of actual values of the flood in terms of precipitation, stream flow, basin area and downstream areas affected.

II. Background

Flooding in Texas has been severe and frequent enough that it has gained international attention on multiple occasions. When flood data is under reported, the consequences may be deadly. Accurate records are of the utmost importance in order to study, analyze and prepare for future flood events. In the absence of accurate records, researchers are then left with compiling data from unconventional or uncommon sources. The city of San Marcos, Texas, given its direct proximity to the San Marcos River, has experienced floods of all relative sizes (Figure 1), including the historic 1998 South Central Flood, the 2015 Memorial Day Flood, the October 2015 Halloween Flood as well as many other minor floods in the last decade. When data seems to be incorrect, as with the 2015 October flood, we may utilize current technology to provide gaps in data in which technology itself or human error has occurred. Some of these helpful tools include photos and videos via drone and cell phone. What has been captured by these devices, has given us a better picture of the event which has aided in assessment and correction of apparent errors. Another tool particularly useful in the aspect of weather and precipitation, are community-based reporting data hubs.

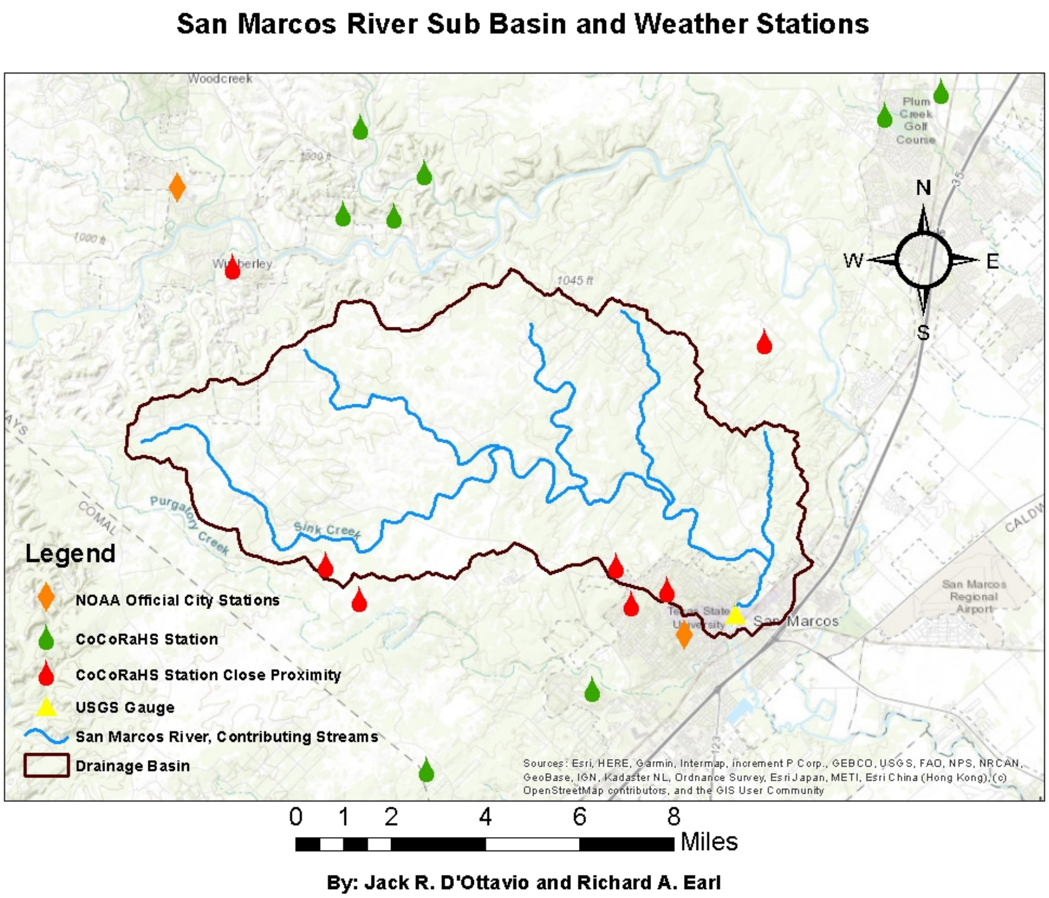

Figure 1: Location of San Marcos River Sub Basin and Weather Stations

The headwaters of the San Marcos River are fed by hundreds of springs feeding into Spring Lake in San Marcos by artesian flow from the Edwards Aquifer. In times of increased rainfall, ephemeral Sink Creek flows into Spring Lake to produce flooding on the San Marcos River. There are three flood control dams on Sink Creek that were constructed from 1981 to1991 that have significantly reduced downstream flooding in San Marcos (Table 1). Since completion of these dams, there have been only two instances when the produced runoff exceeded the design capacity of the dams, October 1998, and October 2015. Other "floods" recorded at gauge #08170500 located at the Aquarena Springs Drive bridge have been supplied by storm runoff from only the 5.2 square miles of the 48.8 square miles of the watershed downstream of the Sink Creek dams (USMWRFCD 1991).

Table 1: Major Floods of the San Marcos River at San Marcos. *Corrected to gauge location.

Year	Before Gaging Estimate ft ^{3}/sec	1956-1991* ft ^{3}/sec	Since 1991 after Flood Control Dams ft ^{3}/sec
1921	68,000		
1958		31,500	
1970		53,600	
1972		24,500	
1981		41,300	
1985		20,300	
1998			21,500
2015			Ca. 17,000

Source: USGS, USMWRFCD 1991, Earl and Wood 2002.

Table 2: NCEI Official Precipitation Records for San Marcos since 1986

24-hr, inches	Date
15.78	October 17, 1998
13.98	June 14, 1981
13.03	October 2, 1913 *
10.00	October 19, 1909
10.00	December 4, 1913 *
9.07	November 24, 1985
8.00	September 9, 1921
7.37	May 15, 1970
7.32	July 29, 1902
6.60	June 25, 1960
6.60	April 26, 1926
6.27	September 10, 1952
6.20	October 30, 2015
6.12	January 25, 2012

Source: NCEI

NOAA has recently updated their "Precipitation Frequency Estimates (PFE)" in 2018 which highlighted an interesting change. The new PFE replaces the U.S Weather Bureau's Technical Paper #40, "Rainfall Frequency Atlas of 1961" (Hershfield 1961) along with Asquith and Roussel's (2004) "Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas." The changes displayed high precipitation events occurring at smaller intervals than previously estimated by the prior reports. In all cases, each event doubled in recurrence while others even tripled (Table 3).

Table 3: Official Recurrence Intervals since 1986

24-hr, in.	Date	TP 40 (1961) A & R (2004)	NOAA PFE (2018)
15.78	1998	500	250
13.98	1981	250	100
13.03	1913	250	50
10.00	1909	100	25
10.00	1913	100	25
9.07	1985	50	10
8.00	1921	25	10
7.37	1970	10	10
7.32	1902	10	10
6.60	1960	10	5
6.60	1926	10	5
6.27	1952	10	5
6.20**	2015	10	5

Source: NOAA, Asquith and Roussel 2004

Most academic research on the analysis of precipitation events is based upon the National Oceanic and Atmospheric Administration's weather station data. These stations are widespread for most areas which increases the potential for inaccurate assessment of some floods. However, an alternative source of weather data collection is the Community Collaborative, Rain, Hail and

Snow Network, or “CoCoRaHS.” The difference of say 0.5” rainfall, may be the determining factor for an inaccurate or incomplete assessment of a particular flood study.

Using volunteer observers allows CoCoRaHS to provide more data observation points. This was not always the case, and for some areas, NOAA stations have denser coverage than CoCoRaHS stations. In turn, CoCoRaHS data has shorter observation history. In recognition of the value of CoCoRaHS data, NOAA now makes CoCoRaHS data available on their website, displayed side by side with NOAA stations in which the only discernable difference is station coding.

The brief description given on the CoCoRaHS website gives some insight into what this entity does. The CoCoRaHS network is a unique, non-profit, community-based network of volunteers of all ages and backgrounds, working together to measure and map precipitation (rain, hail, and snow). By using low-cost measurement tools, and emphasizing training and education, as well as, providing an interactive website, the aim of the organization is to provide the highest quality data for natural resource, education, and research applications (CoCoRaHS 2020).

In the academic and related research world, it is rare to see a non-NOAA data set used, referenced, and analyzed. However, it makes sense to use CoCoRHaS data as the data in question is vetted and checked by NOAA officials to ensure accuracy of the values. Despite this significant partnership, the collaborative network’s valuable data remains relatively unknown. The CoCoRaHS network has come a long way in expanding number of stations, increased credibility, more frequent public/academic use, larger amounts of data, and success in precision of data collection (Reges et al. 2016). The CoCoRHaS network is relatively new having been founded in 1998, recently celebrating its 20th anniversary. It has grown exponentially in number of stations reporting and, as time goes on, in providing historical data. Today, all 50 states in the U.S have contributors as well as a large majority in Canada and various islands located in the Caribbean region, both U.S territories and other countries alike.

III. Literature Review

Flooding in Texas

Texas has been on the international stage for deadly flooding on a regular basis. With major development along Texas rivers, reducing flood losses has proven to be a major challenge. Texas over the last decade has led the nation in fatalities and damage costs from flooding for all but a handful of years (Sharif et al. 2015). Texas, bordered by the Gulf of Mexico, has a high atmospheric moisture content and, therefore, produces high magnitude flood occurrences from a variety of storm types. For example, when hurricanes make landfall on the Gulf coast, cities even 200 to 250 miles away still experience heavy tropical storms, especially when hurricanes downgrade over land masses, which creates flood events that impact and interrupt human and environmental aspects alike (Abbott et al. 2018). Often times, hurricanes' high velocity winds are not the most deadly or damaging aspect but rather torrential rainfall and resulting floods themselves incur the greatest losses.

A number of relatively simple models have been be employed to estimate the magnitude of flooding on a particular stream. For example, the USGS office in Texas has a publication for estimating "potential extreme discharge" for streams as a function of their drainage basin size and location. The USGS also produces a publication specifically for estimating the 2, 5, 10, 25 and 100-year flood peaks for streams in Hays County (Slade et al. 1995). Another study provides values for the relationship of "daily flow to peak flow," and the relationship of 24 hour precipitation amounts to peak flow in the eastern Texas Hill Country region (Earl et al. 2018).

Stream gauge data at the San Marcos River (#08170500 and #08170000) dates back to 1956 (Earl and Wood 2002). The USGS regression models as well as their "slope-area method" have been used to estimate peak flow discharge and frequencies as a function of channel and basin characteristics (Dalrymple and Benson 1967; Cormier et al. 2018). Understanding the flood history of a stream plays a vital role in managing that stream (Perkins and Bonner 2010). Although we cannot recreate large natural events of the past, we have been able to quantify historical stream events from frequent to the extreme conditions (Moftakhari et al. 2015).

Flood Mitigation Risks

Flood mitigation has become evermore the function of local level government and policy. Organizational capacity is a key contributor to structural and non-structural flood mitigation with attention to the criticality of flood mitigation specifically at the local, rather than the state or federal level. In the text, *Identifying factors influencing flood mitigation at the local level in Texas and Florida: The role of organizational capacity* (Brody et al. 2010), due diligence of local governments and institutions were critical for flood mitigation in Gulf Coast communities. Flood management organizations or departments were found to be as, or more important, than observed and scientifically measured factors considered before, such as geographical location, previous flood experience, and the environment of the floodplain.

Brody et al. goes on to address that structural flood mitigation has six main weaknesses: 1) exceeding structure capacity, 2) levees and channels that raise water levels, 3) a false sense of security, 4) high financial and environmental costs, 5) damaging effects on aquatic wildlife of dams, and levees, and 6) water quality and hydrological functions. Failed structures can create even more damage when releasing high amounts of water. Higher water levels create velocity resulting in "flashier" floods and downstream flooding. The belief that flood control measures, particularly structural, can increase development in floodplains often leads to increased mortality rates and property damage. The study estimates that the United States Army Corps of Engineers (USACE) has spent over $100 billion ($154,117,046,818.73 in 2019 dollars) since the 1940s on structural flood mitigation efforts across the nation (Brody et al. 2010).

Different non-structural strategies may lend themselves helpful in terms of sustainability and reducing the effects of climate change. Within the work of sustainability projects, non-structural mitigation strategies tend to be more sustainable due to the reversibility and environmentally friendly nature. Flexibility is essential in mitigation strategies in order to keep up with the changing climate. Kundzewicz (2002) writes that,

> Vulnerability of societies grows as they become wealthier and more exposed - technology helps populate more "difficult" areas. Vulnerability to floods can be regarded as a function of exposure and adaptive capacity. However, since exposure grows faster than adaptive capacity, the vulnerability growth is not slowing down. The rise in exposure has largely been caused by human activity,

> e g. elimination of storage: wetlands and natural vegetation; and encroachment of infrastructure in floodplains. An efficient flood preparedness system should embrace solutions to a plethora of problems (page #3).

Forecasting, based on mathematical modelling, allows experts to convert the information on the past-to-present rainfall, status of moisture and snow cover into a river flow forecast (discharge, stage, and inundated area for a future time horizon). Watershed management in terms of flood mitigation includes modifying formation of flood water, zoning, and regulation of floodplain development. The observed data allows us to understand and see the impact that humans are inherently having on the environment and the changes in consequences from hazard events. Built environment and urbanization may be seen to increase the likelihood of flooding events in more urbanized areas, just as the same may be seen in areas that are impacted by the changing climate. This was evidenced by the 2001 Intergovernmental Panel on Climate Change (IPCC) that showed increased land precipitation in the Northern hemisphere, while the same could be assumed for extreme events in the areas that showed increased precipitation.

Extreme events are probable in the wake of climate change and include: increased frequency and magnitude of precipitation events of high intensity in many locations; more frequent wet spells in mid/high latitude winters; more intense mid-latitude storms; and more El Niño-like mean states of ENSO. Some models show increases of mean and peak intensities of precipitation as well as peak wind intensity of tropical cyclones. The climate and weather patterns will continue to change in the future, however, the need for awareness and knowledge in the public is increasingly paramount. Structural and non-structural mitigation strategies are needed for a sustainable and effective water management approach. State/regional bodies should focus their efforts on creating and helping maintain well-organized, reliable public organizations that are designed to handle flood emergencies (Zahran et al. 2008).

Alternative Data Sources

There is a literature that advocates and stresses the importance of employing underutilized sources in combination with what is already commonly used. The articles that compare, merge, and analyze the CoCoRaHS network with NOAA data are few and limited to small research projects, if used at all (Burakowski et al. 2013). Further, articles regarding missing data on a scale such as the October 2015 flood also remain scarce. The CoCoRaHS data may be combined with NOAA data to provide better analysis of major floods such as the October 2015 flood on the Upper San Marcos River (Reges et al. 2016).

The issue of scale is vital towards understanding stream flow and precipitation (Marteleira et al. 2014). We have the means to record precipitation on larger scales by generalizing to the aggregate area of a river basin; however, this system masks or overlooks actual local amounts. To rectify this, a useful tool in accurate assessment for all aspects of this process would be a spatial statistical analysis and representative map highlighting potential areas in which the coverage of data would need to be increased (Yahaya et. al 2015). Rain gauge reporting stations with more frequent cover such as CoCoRaHS provides vital data on a smaller scale analysis. Significant progress has been made with assessing macro climate regions (Sahin, Manioglu 2018); however, progress in determining precipitation amounts on a micro scale remains challenging and requires innovative applications of current technology and data sources, which will benefit from future advances (Afzali 2018).

IV. Research Methods

This research employed a mixed methods approach to answer the research questions stated in the Introduction, and are repeated here again: To what extent did the 24-hour precipitation and peak stream flow data records accurately reflect the magnitude of the October 30th, 2015 San Marcos River flood occurrence in San Marcos, Texas? Given that the data was inaccurate, what was the actual record in peak stream flow and 24-hour precipitation? Phase 1 analysis required a qualitative approach involving video and photographic analyses. In addition, the qualitative aspect served to further understand results from variables measured in the quantitative data analysis. Essentially, analyzing the existing data alone did not reveal why there were possible mistakes in the data recorded for the 2015 October flood event. The purpose of this phase was to identify, through qualitative analysis, how inaccurate data reporting might have occurred as well as correcting the data via alternative sources to rectify the quantitative characteristic of the flood.

Phase 2 employed quantitative methods utilizing formulas based on: historical data records, basin delineation, peak flow estimation, basin runoff calculation, topographic volume of stream size during the event, and comparison of precipitation values. The alternative data source CoCoRHaS supplemented the analysis process by providing data in missing "gaps" which ultimately constituted a primary data option within the various related research fields.

Phase 1: Qualitative Analysis

Phase 1 involved analyzing drone video clips which gave an almost complete view of the water level for most sections of the San Marcos River in the city center area of San Marcos which also included the gauge location. This video evidence, used in tandem with a topographic map, helped determine the volume of water flowing, by providing a water level for cross sectional measurement. Pictorial evidence was analyzed to include human-made water level signs affixed to Texas State University's Sewell Park Outdoor Center. The markers were put up by the staff to indicate the date and measurement of the largest San Marcos River flood occurrences in 1998 as well as the October 30th, 2015 flood. As mentioned earlier, the October 2015 flood level was just 1.5 feet below the 1998 flood level (Figure 2a,2b). The 1998 flood had a measurement of 21,500 ft^3 /sec. of stream flow while, as mentioned earlier, the October 2015 flood had a daily value at just 5,400 ft^3 /sec. There is no value for the peak discharge on October 30th, 2015 yet the 1998 flood's observed water level showed that the October 2015 flood was just 1.5 feet lower giving the study a starting point.

Figure 2a: Texas State University, Sewell Park Outdoor Center. Photo: Earl 2019

Figure 2b: Flood Markers on Sewell Park Outdoor Center. Photo: Earl 2019

Phase 2: Quantitative Analysis

Quantitative methods gave an estimate of the October 30th, 2015 flood resulting in confident discharge estimates while being supported and enhanced by the qualitative evidence above. While the official San Marcos NOAA station recorded a value of 6.20 inches of precipitation, one CoCoRaHS station reported 11.50 inches with a few others reflecting similar values (Table 4). NOAA stations in surrounding areas not included within Table 4 resulted in: Austin Bergstrom 12.49 inches, Canyon Dam 9.62 inches, Canyon Dam #4 8.56 inches and various others of similar values.

Table 4: Nearby CoCoRaHS and NOAA Station Precipitation Measurements. *MD= Missing Data

CoCoRaHS Station	Oct. 30	Oct. 31	2 Day Total
TX-HYS-65	0.39	9.89	10.28
TX-HYS-1 *	0.6	15.63	16.23
TX-HYS-61 *	0.64	11.45	12.09
TX-HYS-154	MD	12.32	
TX-HYS-136 *	1.74	8.45	10.19
TX-HYS-21 *	10.65	2.01	12.66
TX-HYS-19 *	11.1	1.51	22.85
TX-HYS-51	10	MD	
TX-HYS-77	1.96	9.47	11.43
TX-HYS-124 *	MD	11.5	
TX-HYS-98 *	9.89	1.7	11.59
TX-HYS-3	8.2	2.56	10.76
TX-HYS-42	MD	9.73	
TX-HYS-133	1.23	9.07	10.3
Mean	5.13	8.1	12.84
NOAA Station			
USC00417983 (Designated San Marcos Station)	6.2	3.1	9.3
USC00419815 (Designated Wimberly Station)	9.7	1	10.7
Average	7.95	2.05	10

Source: NCEI, CoCoRaHS

The second phase called for, first, producing a calculation defining the coefficient from 20 years of peak flow versus daily average at gauge 08170500. By doing so, this provided a means to estimate peak discharge based upon the daily average. Earl et al. (2018) used this method based upon Bear Creek and Onion Creek, two nearby streams with similar size and land use/ landcover characteristics and found that peak flow was 5.3 times the daily mean flow.

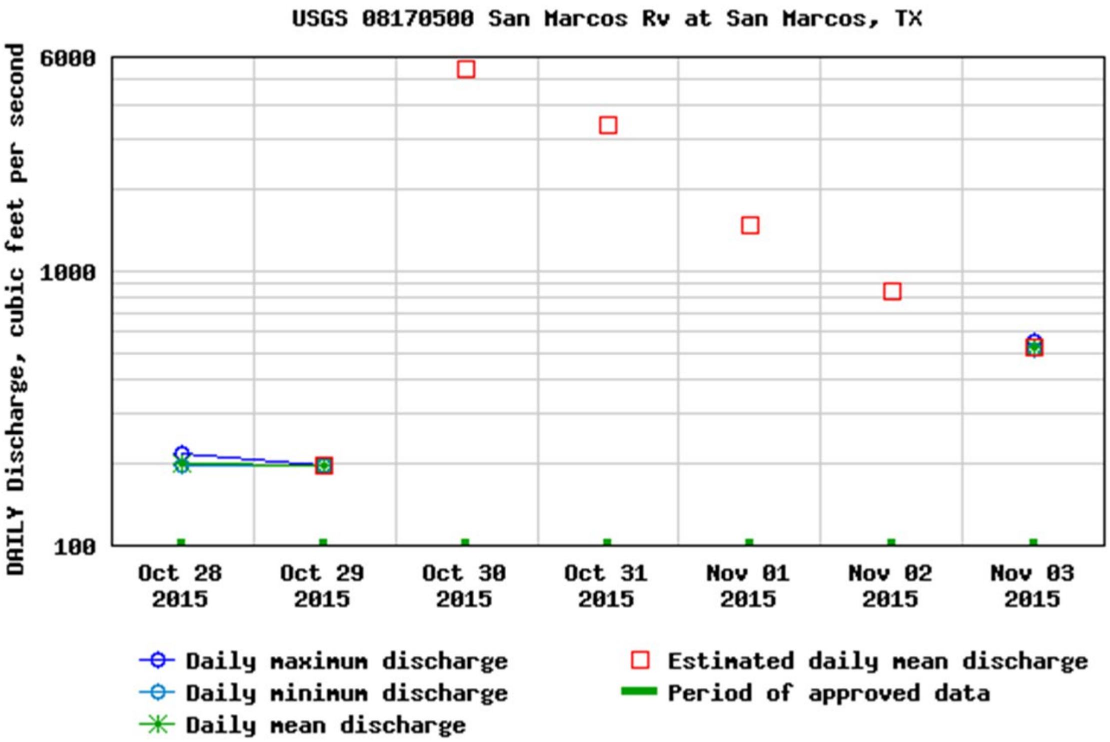

Figure 3: USGS Daily Discharge Gauge #08170500, October 28th- November 3rd, 2015. Source: USGS

Next, the utilization of the “Slope-Area Method” (Dalrymple and Benson 1967) was applied to high water marks for 1998 and 2015 floods to determine peak discharge. The equation is defined mathematically as, Q = (1.49*A*R^2/3*S^1/2)/n, where

Q = Discharge in cubic feet per second (ft^3 /sec.).

A = Cross-sectional area (calculated for stream channel at point of discharge).

R = Hydraulic radius (calculated based on stream channel characteristics).

S = Friction slope (calculated from values obtained from topographic map).

n = Manning's Roughness Coefficient (a value determined by solving for "n" with the channel characteristics and discharge from the 1998 flood).

Finally, a simple regression of flood peaks to stage was performed to identify the relationship between gauged and ungauged stream flow data at particular locations and their personal parameters.

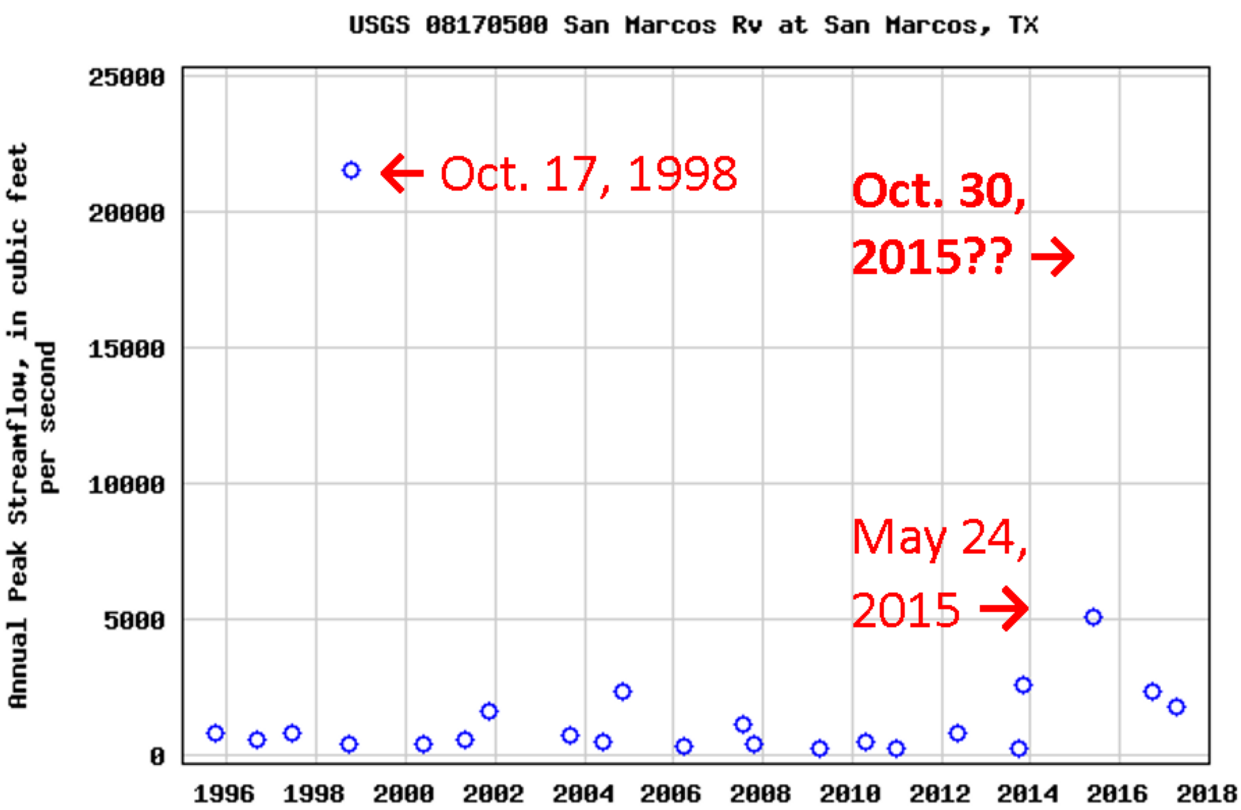

Figure 4: USGS Peak Streamflow Gauge# 08170500. Source: USGS

V. Results and Analysis

Precipitation

The official NOAA San Marcos precipitation for the date was only 6.20 inches with a two-day total of 9.30 inches, whereas nearby (<2 miles) gauges recorded one-day totals of >9 inches and 2-day totals of >12.00 inches (Table 5).

Table 5: Nearest CoCoRaHS and NOAA Station Precipitation Measurements.

CoCoRaHS Station	Oct. 30	Oct. 31	2 Day Total	Greatest 1 Day (24-hour) Total
TX-HYS-1 *	0.6	15.63	16.23	15.63
TX-HYS-61 *	0.64	11.45	12.09	11.45
TX-HYS-136 *	1.74	8.45	10.19	8.45
TX-HYS-21 *	10.65	2.01	12.66	10.65
TX-HYS-19 *	11.1	1.51	12.61	11.1
TX-HYS-124 *	MD	11.5	MD	11.5
TX-HYS-98 *	9.89	1.7	11.59	9.89
Mean	5.77	7.46	13.23	11.24
NOAA Station				
USC00417983 (Designated San Marcos Station)	6.2	3.1	9.3	6.2

Source: NCEI, CoCoRaHS ***MD= Missing Data **See Figure 1 for locations**.

Based on this analysis the highest 24-hour precipitation for the CoCoRAHS stations was 15.63 inches, which is classified as a 200-250 year storm according to the 2018 NOAA PFE values. The mean for the seven CoCoRaHS stations was 11.23 inches with a recurrence interval between 25 and 50 years.

Peak Flood Discharge

Employing the daily mean to peak relationship the peak discharge estimate was 13,800 ft^3/sec.

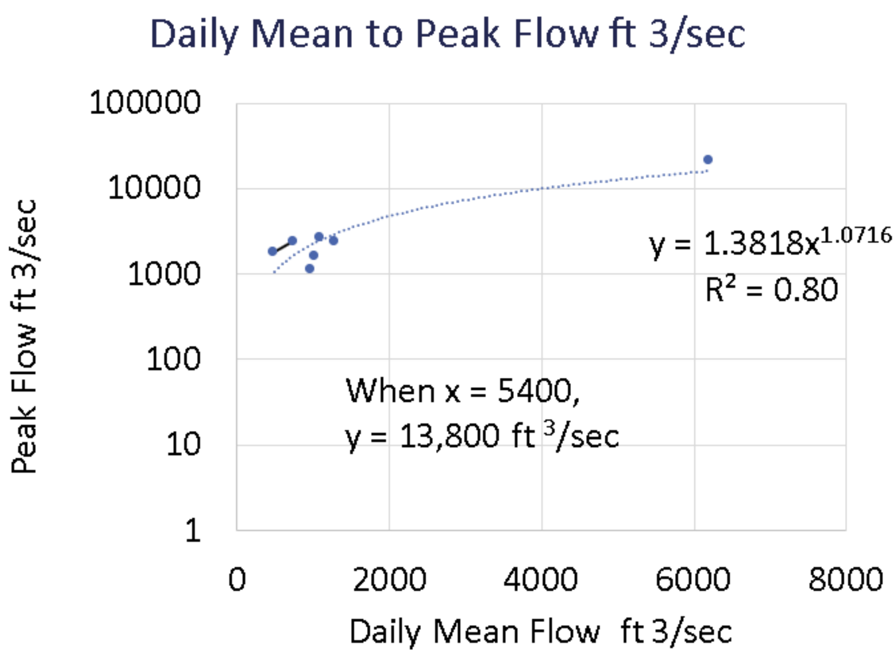

Figure 5: Simple Regression of Flood Peaks to Mean Daily Flow at Gauge 08170500. Source: USGS

Employing the slope area method to the channel characteristics for the 2015 flood and Manning's "n" calculated for 1998, the estimate was 18,300 ft^3/sec. The equation employed was as follows:

$\mathbf{Q_{peak} = A\ 1.49\ R^{0.67} S^{0.50} / n}$, where:

A = Cross Sectional Area

R = Hydraulic Radius

S = Channel Slope

n = Manning's Roughness Coefficient

Solving for Manning's n for 1998 flood, "n" = 0.12

Solving Q_{peak} for October 2015, when w = 722 ft., and d_{ave} = 9.3 ft., and S = 0.0025, n = 0.12

Q_{peak} = 18,300 ft^3/sec

Estimating the discharge for the stage to peak discharge data for the San Marcos USGS gauge gives a value of 17,000 ft^3/sec.

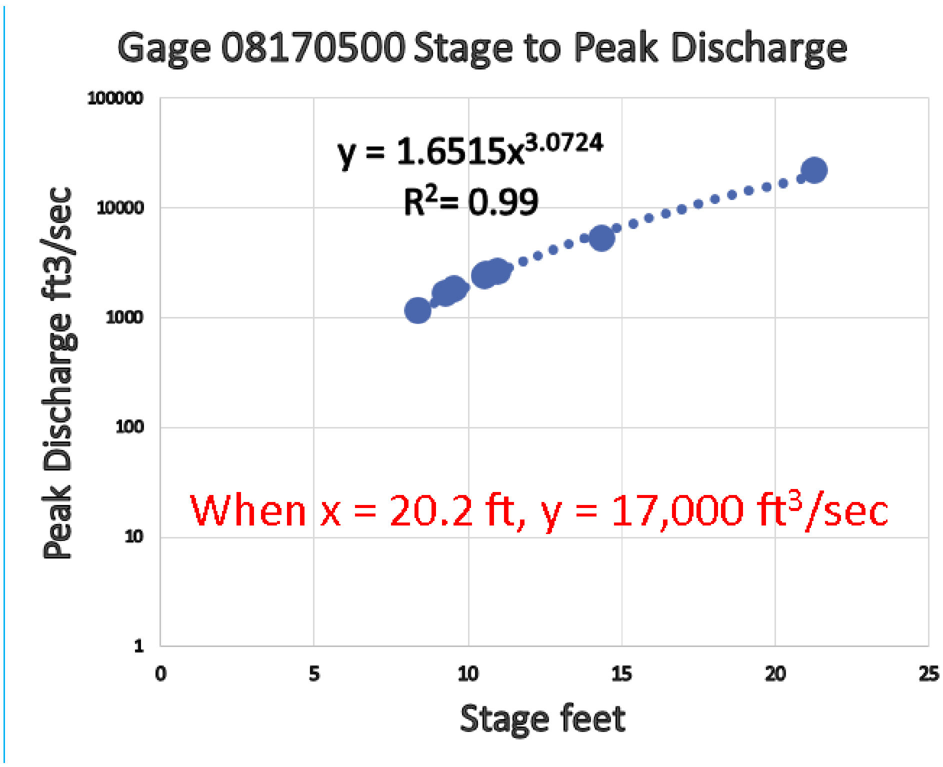

Figure 6: Simple Regression of Flood Peaks to Stage Peaks > 1,000 ft^3/sec. Source: USGS

The lowest estimated peak discharge of 13,800 ft^3/sec seemed the least likely due to the wide variety of factors that determine the relationship of mean daily to peak flow. Indeed, in their 2018 study, Earl et al. found that the Qmean to Qpeak varied from 0.05 to 0.22, for Bear Creek and from 0.06 to 0.62 for Onion Creek at Driftwood (USGS 2018).

For the smaller data set for the San Marcos River from 1995 to 2019, the Qmean to Qpeak ratios ranged from 0.27 to 0.85, in which this higher ratio may at least be partially attributed to the high baseflow from San Marcos Springs that during this period (1995 to 2019) ranged from 100 to over 250 ft^3/sec (USGS 2020). Thus the lower Qpeak for October 30, 2015, calculated by this method may be attributed to the distortion of the Qmean to Qpeak relationship by the baseflow contributions as well as the intensity of precipitation during the 24-hour period; the October 2015 was noted for the intense precipitation that fell during the three hour period of 8 to 11am and it is not surprising the other Qmean to Qpeak relationships were near, but not beyond, the Qmean to Qpeak relationships observed for Onion and Bear creeks. Indeed, if the Qpeak to Qmean ratio of 0.29 for the October 1998 flood is used to calculate the October 2015 peak discharge, the value would be 18,600, which is within 10 percent of the values obtained by the other methods.

VI. Conclusions

This study sought to provide more realistic values for the precipitation amounts and peak discharge for the October 2015 flood. The values summarized below provide realistic precipitation and discharge values that would be associated with the second largest flood on the San Marcos River in San Marcos, since 1994, and only the second flood caused by a spill from the upstream flood control dams since completion of the Upper San Marcos Watershed project in 1991. The upstream dams were designed for a 10 inches in 24 hours storm (SCS 1978) and the high spill flows for October 2015 would indicate that the basin precipitation exceeded that amount, which is in direct contrast to the one day total of 6.20 inches for the NWS/NCEI Station. That lower 24-hour value that has been recorded for San Marcos on several occasions since 1991 and did not produce spills from the flood control dams. The peak discharge for the flood would be expected to be considerably greater than the peaks since 1995 that were not associated with spills from the upstream dams. The estimated peak discharge of between 17,000 and 18,600 ft^3/sec is less than the 1998 peak but considerably greater than the largest post-1995 peak (2600 ft^3/sec) that was not produced by a spill from the dams.

- **Basin Precipitation**
  - Greatest precipitation occurred between 8-11 AM, on 10-30-2015
  - Two-day total average for the 6 closest CoCoRaHS stations = 13.23 in.

    - Average of one day greatest precipitation for CoCoRaHS stations was 11.24 inches, which has a recurrence interval of between 25 and 50 years by the 2018 NOAA Atlas. One-day total for NWS San Marcos was 6.20 in.
    - Two-day total for NWS San Marcos was 9.30 in.

- **Peak Discharge**
    - Based upon stage: 17,000 ft^3/sec
    - Based upon daily mean: 13,800 ft^3/sec, 18,600 when Oct 1998 ratio is used.
    - Employing Slope Area Method: 18,300 ft^3/sec
    - Most likely between 17,000 and 18,600 ft^3/sec

The daily mean to peak stream flow regression value of 13,800 ft^3/sec was rejected due to the variability of the San Marcos River's contributing factors both in storm events and regular flow. As mentioned in the Background section, the Sink Creek dam systems do not spill over until the occurrence of a precipitation event is more than 10 inches and holds back all but 5.2 square miles of the 48.8 square mile drainage basin. This occurrence projects extreme flood events almost like "outliers" but with less weight upon the regression input data. By consistently holding back precipitation events less than 10 inches, stream flow changes from lesser precipitation are not necessarily reflected in streamflow recordings.

The CoCoRaHS one-day average of 11.24 inches and two-day average of 13.23 inches placed precipitation amounts that produced this flood having a recurrence interval between the 25 and 50 years, according to the 2018 NOAA atlas. Thus, it is significant to recognize that flood control facilities that were designed for the "100 year event" based upon a 24-hour precipitation of 10 inches, as stated in earlier references (Hershfield 1961 and Asquith and Roussel 2004), actually will exceed their design flood by what is now recognized as a 25-year event.

It is hoped that the study will result in more reliable information about the October 2015 flood. Arguably, the precipitation amounts contributing to the flood rank as one of the highest in inches per 24-hour event since 1896. As for the San Marcos River stream flow records, evidence also suggests that the flood ranks as the 2nd highest in cubic feet per second since the installation of gauge 08170500 in 1994 and completion of the upstream flood control dams in 1991. Missing or incorrect data, especially for severe events, will hinder future research as well as prevent accurate planning and obscure the October 2015's historical record significance. Essentially, all that remained from the aftermath of this flood were high water marks, dramatic photos (Figure 7a,7b), citizen recollections and millions of dollars in damage. Mistakes in data recording such as with this occurrence cannot be afforded, whether human error or an "act of God" in record collection and correction.

Figure 7a: Sewell Park Before Flood. Photo: Earl 2019

Figure 7b: Sewell Park After Flood. Photo: Earl 2015

VII. References

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