Interagency Flood Risk Management (InFRM)

Watershed Hydrology Assessment for the Guadalupe River Basin

September 2019

INTERAGENCY FLOOD RISK MANAGEMENT

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The InFRM Team

As flooding remains the leading cause of natural-disaster loss across the United States, the Interagency Flood Risk Management (InFRM) team brings together federal agencies with mission areas in water resources, hazard mitigation, and emergency management to leverage their unique skillsets, resources, and expertise to reduce long term flood risk throughout the region. The Federal Emergency Management Agency (FEMA) Region VI began sponsorship of the InFRM team in 2014 to better align Federal resources across the States of Texas, Oklahoma, New Mexico, Louisiana and Arkansas. The InFRM team is comprised of FEMA, the US Army Corps of Engineers (USACE), the US Geological Survey (USGS), and the National Weather Service (NWS), which serves under the National Oceanic and Atmospheric Administration (NOAA). One of the first initiatives undertaken by the InFRM team was performing Watershed Hydrology Assessments for large river basins in the region.

The Federal Emergency Management Agency (FEMA) funded the Watershed Hydrology Assessments to leverage the technical expertise, available data and scientific methodologies for hydrologic assessment through the InFRM team. This partnership allows FEMA to draw from the local knowledge, historic data and field staff of its partner agencies and develop forward leaning hydrologic assessments at a river basin level. These studies provide outcomes based on all available hydrologic approaches and provide suggestions for areas where the current flood hazard information may require update. FEMA will leverage these outcomes to assess the current flood hazard inventory, communicate areas of change with community technical and decision makers, and identify/prioritize future updates for Flood Insurance Rate Maps (FIRMs).

The US Army Corps of Engineers (USACE) has participated in the development of the Watershed Hydrology Assessments as a study manager and member of the InFRM team. USACE served in an advisory role in this study where USACE's expertise in the areas of hydraulics, hydrology, water management, and reservoir operations was required. USACE's primary scientific contributions to the study have been in its rainfall runoff watershed modeling and its reservoir analyses. The reservoir analyses in this study are based on USACE's first hand reservoir operations experience and the latest scientific techniques from USACE's Dam Safety program.

The U.S. Geological Survey (USGS) Texas Water Science Center has participated in the development of this study as an adviser and member of the InFRM team. USGS served in an advisory role for this study where USGS' expertise in stream gaging, modeling, and statistics was requested. USGS's primary scientific contribution to the study has been statistical support for flood flow frequency analysis. This flood flow frequency analysis included USGS first hand stream gaging expertise as well as advanced statistical science.

NOAA National Weather Service (NWS) has participated in the development of this study as an adviser and member of the InFRM team. NOAA NWS served in an advisory role of this study where expertise in NOAA NWS' area of practice in water, weather and climate was requested. NOAA's primary scientific contribution to the study has been the NOAA Atlas 14 precipitation frequency estimates study for Texas. This precipitation-frequency atlas was jointly developed by participants from the InFRM team and published by NOAA. NOAA Atlas 14 is intended as the U.S. Government source of precipitation frequency estimates and associated information for the United States and U.S. affiliated territories.

More information on the InFRM team and its current initiatives can be found on the InFRM website at www.InFRM.us.

EXECUTIVE SUMMARY

The National Flood Insurance Program (NFIP) was created in 1968 to guide new development (and construction) away from flood hazard areas and to help transfer the costs of flood damages to the property owners through the payment of flood insurance premiums. The Federal Emergency Management Agency (FEMA) administers the NFIP. The standard that is generally used by FEMA in regulating development and in publishing flood insurance rate maps is the 1% annual chance (100-yr) flood. The 100-yr flood is defined as a flood which has a 1% chance of happening in any year. The factor that has the greatest influence on the depth and width of the 100-yr flood zone is the expected 1% annual chance (100-yr) flow value.

This report summarizes new analyses that were completed as part of a study to estimate the 1% annual chance (100-yr) flow, along with other frequency flows, for various stream reaches in the Guadalupe River Basin. This study was conducted for FEMA Region VI by an Interagency Flood Risk Management (InFRM) team. The InFRM team includes subject matter experts (SME) from the U.S. Army Corps of Engineers (USACE), the U.S. Geological Survey (USGS), and the National Weather Service (NWS). The InFRM team used several different methods, including statistical hydrology, rainfall-runoff modeling, and reservoir period-of-record simulations, to calculate the 1% annual chance (100-yr) flow and then compared those results to one another. The purpose of the study is to produce 100-yr flow values that are consistent and defendable across the basin.

The 1% annual chance (100-yr) flows that are on the currently effective flood insurance rate maps for a large portion of the Guadalupe River basin (including Hays, Kerr, Kendall, Guadalupe, Gonzales, and Victoria Counties), were based on regression equations. A regression equation is a simplistic method with known drawbacks that allows for calculation of the 1% annual chance (100-yr) flow with very little information about the watershed. The Hays County regression equation, for example, requires only two variables (the slope of the river and the area of the watershed) to calculate the 1% flow.

The regression equation for the 1% annual chance (100-yr) flow was developed by drawing a “best fit” curve through 100-yr flow points that were estimated at a number of sites across the region. The accuracy of that equation depends first on the precision of the estimated 100-yr flow points. For Hays County, the 100-yr flow points were estimated based on a statistical analysis of the available stream gage records through the year 1992. However, several major floods have occurred in the basin since then, which drastically change statistical estimates of the 1% annual chance (100-yr) flow. For example, since 1998, there have been five major floods that have exceeded a flow of 70,000 cubic feet per second (cfs) in magnitude at Wimberley, Texas; whereas the 70 years prior to 1998 saw only three floods greater than 70,000 cfs, as illustrated in Figure ES.1. The limited period of record that was available during the early 1990s would have caused the 1% annual chance (100-yr) flow values from that time to be significantly underestimated.

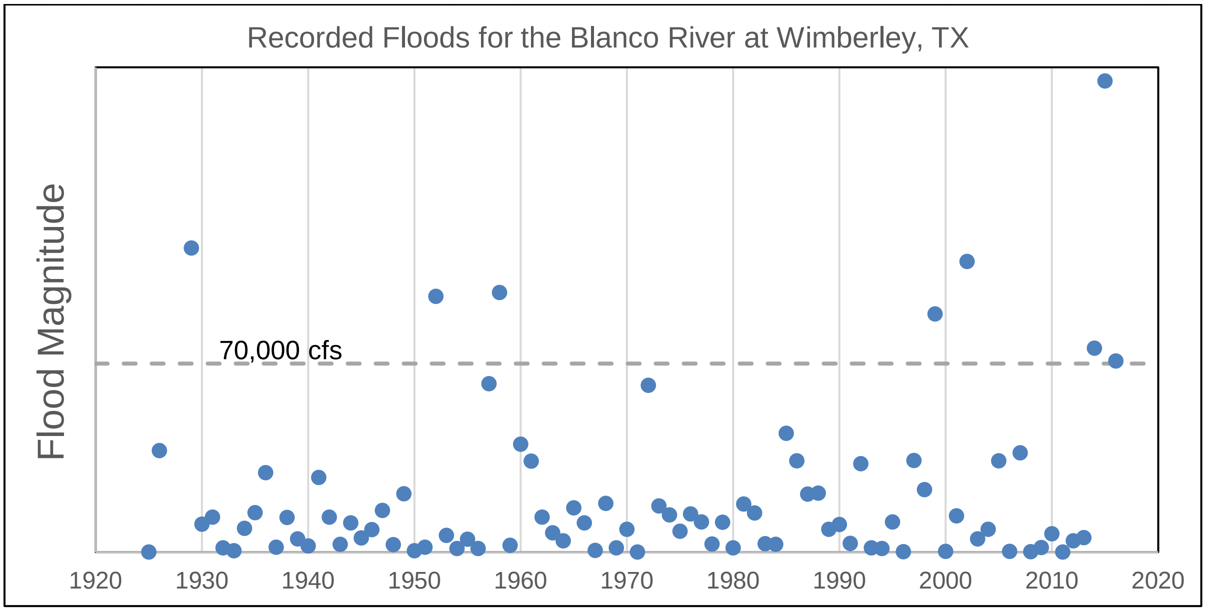

Figure ES.1: Recorded Floods from 1925-2016 for the Blanco River at Wimberley, TX

This trend is shown even more dramatically in Figure ES.2 for the San Marcos River at Luling, Texas. Prior to 1998, the largest flood on record at Luling was 57,000 cfs. Post 1998, there have been four major flood events that were much larger than all prior recorded floods, the largest being the 1998 flood with a flow of 206,000 cfs. This further illustrates that the 1% annual chance (100-yr) flows that are on the currently effective maps were likely underestimated.

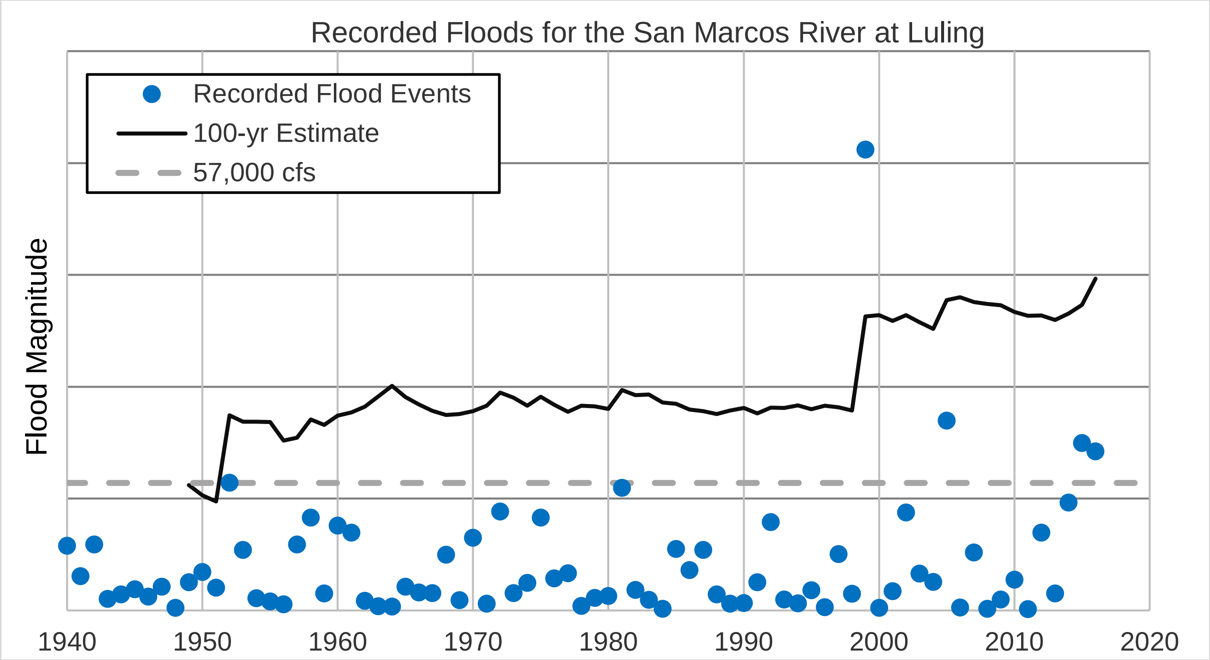

Figure ES.2: Recorded Floods from 1940-2016 for the San Marcos River at Luling, TX

By contrast, in the current study, the InFRM team used up-to-date statistical analysis along with state-of-the-art rainfall-runoff watershed modeling and reservoir modeling to estimate the 1% annual chance (100-yr) flow values throughout the Guadalupe River Basin. In the statistical analysis, the gage records were updated through the year 2016 or 2017 to include all recent major flood events. However, since statistical estimates inherently change with each additional year of data, their results were compared to the results of a detailed watershed model which is less likely to change over time.

Rainfall-runoff watershed modeling is used to simulate the physical processes that occur during storm events to simulate how water moves across the land surface and through the streams and rivers. A watershed model was built for the Guadalupe River Basin with input parameters that represented the physical characteristics of the watershed. After building the model, the InFRM team calibrated the model to verify that it was accurately simulating the response of the watershed to a range of observed flood events, including large events similar to a 1% annual chance (100-yr) flood. A total of twenty recent storm events were used to fine tune the model, as shown in Table ES.1.

Table ES.1: Flood Events Simulated in portions of the Guadalupe Watershed Model

Storm Event	Guadalupe Basin above Canyon	Blanco / San Marcos Basin	Guadalupe Basin below Canyon	Coleto Creek Basin
Oct-97				Yes
Oct-98		Yes	Yes	Yes
Sep-01			Yes	Yes
Nov-01		Yes		
Jul-02	Yes		Yes	
Nov-02			Yes	
Jun-04				
Nov-04	Yes	Yes	Yes	Yes
May-05				Yes
Mar-07		Yes		Yes
Jul-Aug-07	Yes		Yes	Yes
Apr-09			Yes	
Oct-Nov-09			Yes	
Apr-10	Yes			
Jun-10			Yes	
Jan-12		Yes	Yes	
Oct-13		Yes	Yes	
May-15	Yes	Yes	Yes	
Oct-15	Yes	Yes	Yes	
May-16			Yes	

For these storms, the availability of National Weather Service (NWS) hourly rainfall radar data allowed for more detailed fine tuning of the watershed model than would have been possible during earlier modeling efforts. The model calibration and verification process undertaken during this study substantially exceeds the standard of a typical FEMA floodplain study. The final model results accurately simulated the expected response of the watershed, as it reproduced the timing, shape, and magnitudes of the observed floods very well. An example plot of the modeled flow versus the recorded flow is shown on Figure ES.3, but many other similar figures are available in Chapter 6 of this report.

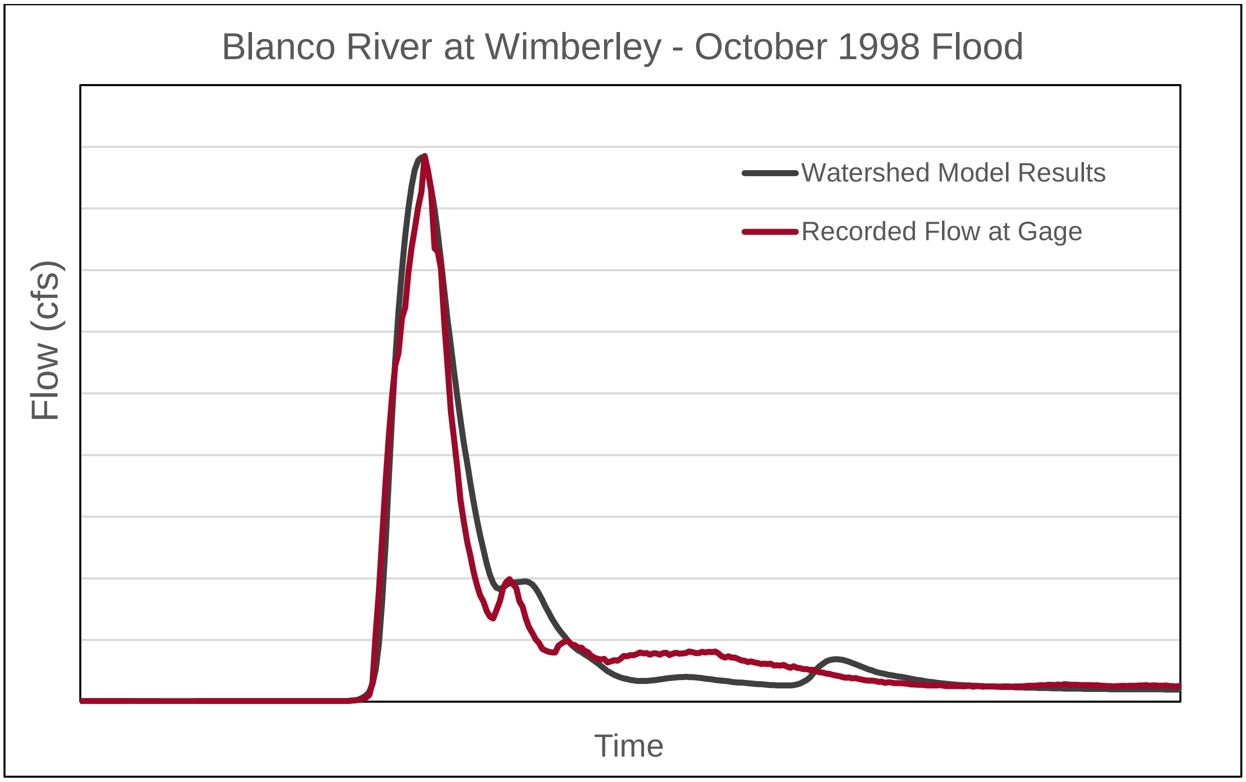

Figure ES.3: Example Watershed Model Results versus Recorded Flow

The 1% annual chance (100-yr) flow values were then calculated by applying the 100-yr storm to the watershed model. Rainfall estimates for the 100-yr storm are considered more reliable than statistical estimates for the 100-year flow due to the larger number of rainfall stations and the longer periods of time during which rainfall measurements have been made. Tha accuracy of those rainfall frequency estimates was further advanced by the release of NOAA Atlas 14 for Texas in 2018.

NOAA Atlas 14 is the U.S. Government source of precipitation frequency estimates and is the most accurate, up-to-date, and comprehensive study of rainfall depths in Texas. The regional approach used in NOAA Atlas 14 incorporated at least 1,000 cumulative years of daily data into each location's rainfall estimate, yielding better estimates of rare rainfall depths such as the 100-yr storm. In addition, the interpolation techniques used in NOAA Atlas 14 better accounted for the change in terrain in the Texas Hill Country, where moisture from the Gulf is pushed upward by the Balcones Escarpment and then falls back to the earth as rainfall. As a result, the eastern Hill Country tends to experience more rainfall than other flatter areas in Texas.

These new rainfall depths from NOAA Atlas 14 were applied to the calibrated watershed model for the Guadalupe River basin. After completing the model runs, the watershed model results were compared to all of the other results from the study. Table ES.2 and Figures ES.4 to ES.6 compare the watershed model results to the statistical analyses, the flood of record, and the effective FEMA flows.

Table ES.2: Summary of 1% Annual Chance (100-yr) Flow Results (cfs)

Location	Currently Effective FIS Flow	2016 / 2017 Statistical Analysis	Flood of Record	Recommended Model Results
Guadalupe at Kerrville	215,000	266,500	196,000	215,300
Guadalupe at Comfort	247,600	201,900	240,000	263,900
Guadalupe at Spring Branch	160,570	175,900	160,000	235,800
Blanco River at Wimberley	112,800	154,000	175,000	211,300
Blanco River near Kyle	122,600	170,000	180,000	216,500
San Marcos River at Luling	110,000	143,600	206,000	201,900
Guadalupe at New Braunfels	120,962	107,800	152,000	119,000
Guadalupe at Gonzales	287,000	238,600	340,000	338,800
Guadalupe at Cuero	-	363,000	473,000	401,500
Guadalupe at Victoria	129,000	239,100	466,000	372,100

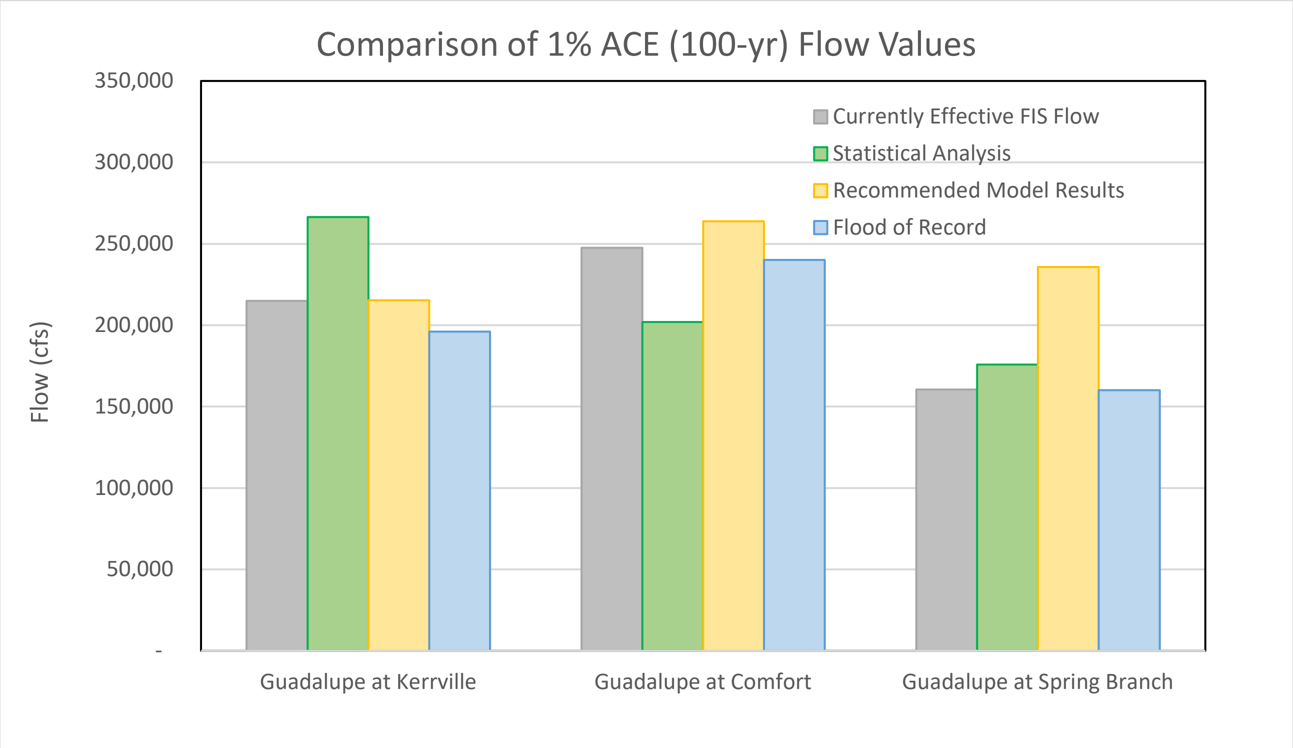

Figure ES.4: Comparison of 1% annual chance (100-yr) Flow Results in the Upper Guadalupe Basin

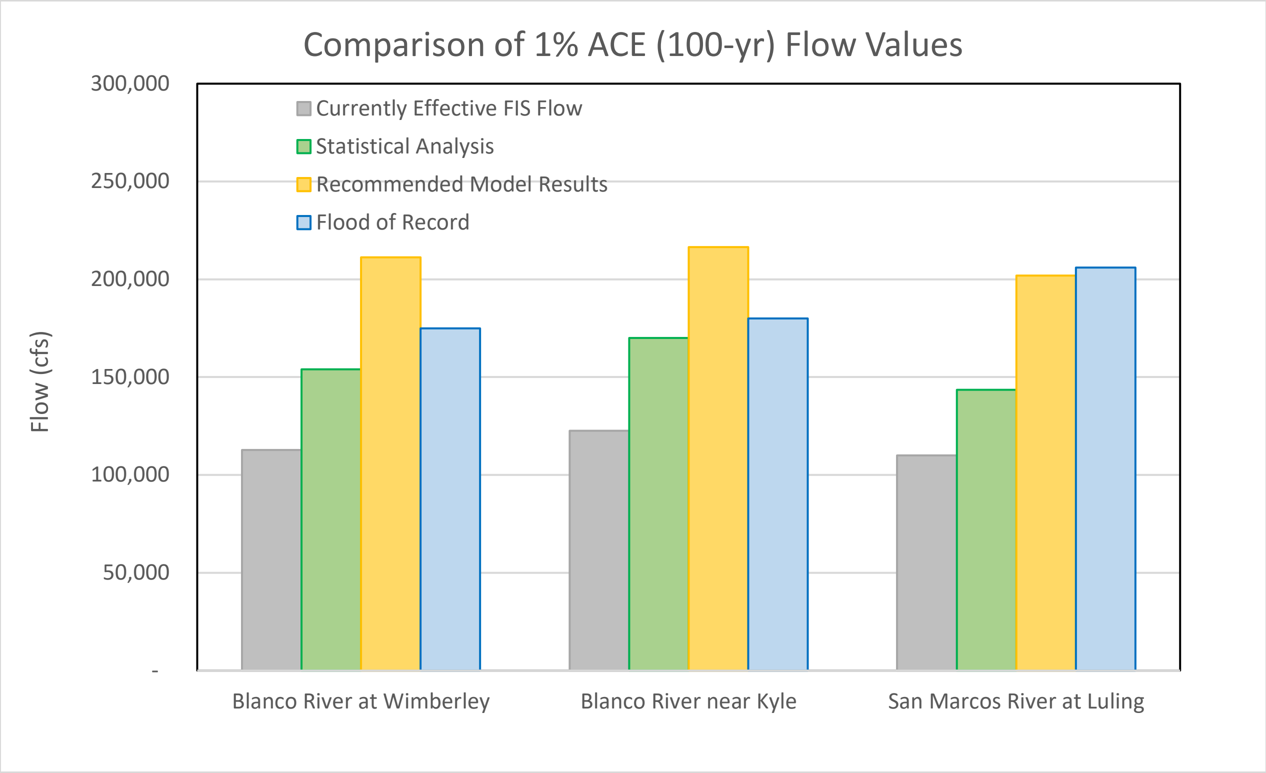

Figure ES.5: Comparison of 1% annual chance (100-yr) Flow Results in the San Marcos River Basin

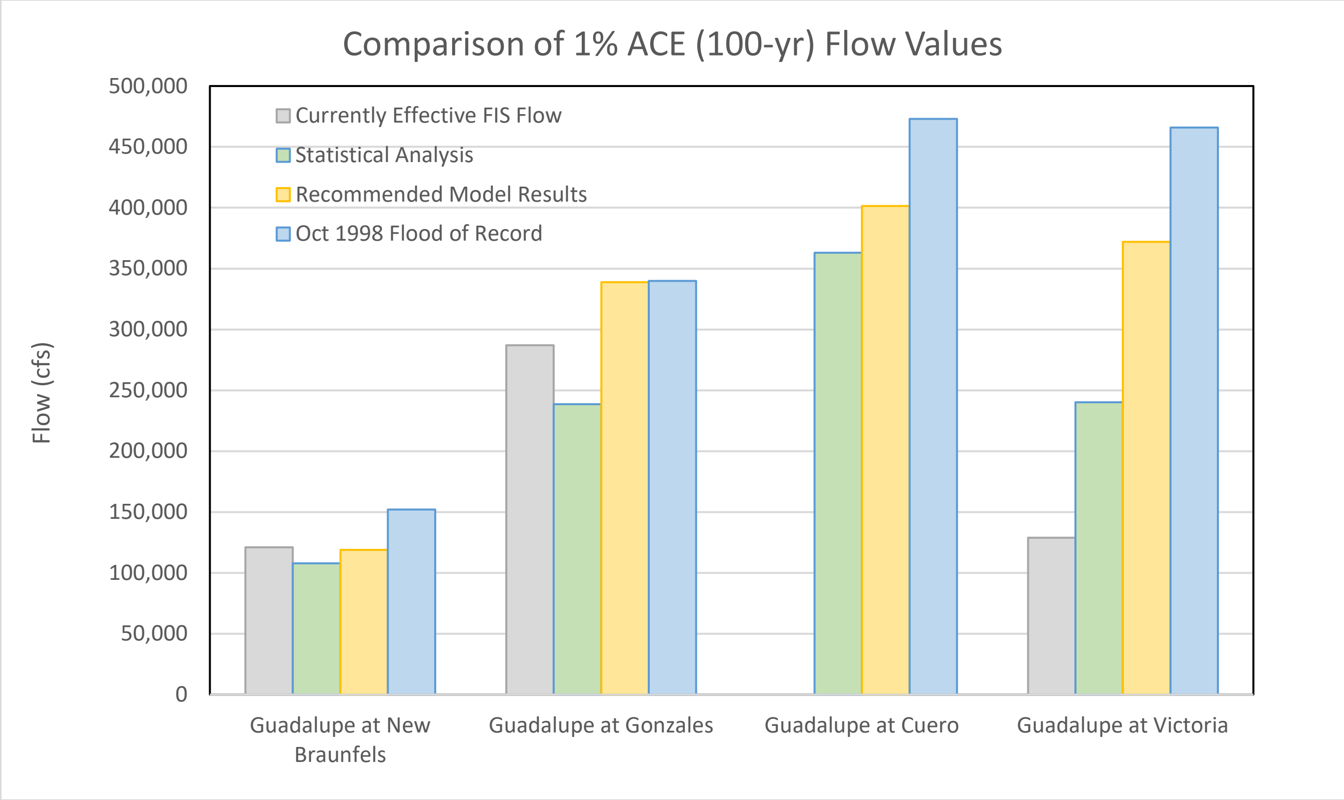

Figure ES.6: Comparison of 1% annual chance (100-yr) Flow Results in the Lower Guadalupe Basin

From these figures, one may notice that the watershed model results are higher than the statistical results in many locations. This is primarily due to the increased rainfall in the Guadalupe River basin that came from NOAA Atlas 14, as well as the fact that the statistical estimates will continue to change each year as new data is added to the record, as demonstrated in Figure ES.2. However, at several locations, such as the Lower Guadalupe Basin and the San Marcos River at Luling, the flood of record still exceeded the watershed model results. In several locations, the flows on the currently effective flood insurance rate maps are shown to be significantly lower than all three of the other datasets. This is true in all of the San Marcos basin and at the Guadalupe River at Victoria.

The final recommendations for the Guadalupe Watershed Hydrology Assessment were formulated through a rigorous process which required technical feedback and collaboration between all of the InFRM subject matter experts. This process included the following steps: (1) comparing the results of the various hydrologic methods to one another, (2) performing an investigation into the reasons for the differences in results at each location in the watershed, (3) selecting of the draft recommended methods, (4) performing interal and external technical reviews of the hydrologic analyses and the draft recommendations, and finally, (5) finalizing the study recommendations. After completing this process, the flows that were recommended for adoption by the InFRM team came from a combination of watershed model results using NOAA Atlas 14 uniform rain, elliptical storms, and a reservoir study of Canyon Dam.

These recommended flows represent the best available estimate of flood risk for the larger streams in the Guadalupe River basin based on a range of hydrologic methods performed by an expert team of engineers and scientists from multiple federal agencies. For the smaller tributaries, the new flows from the watershed model provide a good starting point which could be further refined by adding additional subbasins and using methodologies that are consistent with this study. The recommended flows presented in this report can be adopted by communities to revise their flood insurance rate maps and to help inform residents on their level of flood risk, which is important for the protection of life and property.

1 Study Background and Purpose

In 1968, Congress passed the National Flood Insurance Act to correct some of the shortcomings of the traditional flood control and flood relief programs. The NFIP was created to:

- Transfer the costs of private property flood losses to the property owners through flood insurance premiums.
- Provide property owners with financial assistance after floods that do not warrant federal disaster aid.
- Guide development away from flood hazard areas.
- Require that new construction be built in ways that would minimize or prevent damage during a flood.

The NFIP program is administered by the FEMA within the Department of Homeland Security. The NFIP is charged with determination of the 1% annual chance flood risk and with mapping that flood risk on the Flood Insurance Rate Maps (FIRMs). FEMA Region VI has an inventory of hundreds of thousands of river miles that are in need of flood risk mapping updates or validation. FEMA has historically maintained the FIRMs at a community and county level, but recently shifted (2010) to analyzing flood analysis at a watershed level. This transition to watershed based analysis requires a broader flood risk assessment than has historically been undertaken. Early in 2015, the Water Resources Branch of the USACE Fort Worth District began talking with FEMA Region VI representatives on ways that USACE's new basin-wide models could be leveraged in FEMA's flood risk mapping program.

In 2013, USACE established a program, known as Corps Water Management System (CWMS), to develop a comprehensive suite of models for every basin across the United States which contains a USACE asset. This modeling represents in excess of a $125 million dollar investment and provides the tools necessary to perform flood risk assessments at a larger watershed scale. Representatives of FEMA Region VI attended the CWMS implementation handoff meetings for the Guadalupe River and other basins. Subsequent discussions resulted in an interagency partnership between FEMA Region VI and USACE to produce basin-wide hydrology from these models for FEMA flood risk mapping. Additionally, USACE, the NWS and the USGS have conducted numerous hydrologic studies across Region VI, at the watershed and local scales, which can be leveraged for watershed scale flood risk assessments.

The objective of this interagency flood risk program is to establish consistent flood risk hydrology estimates across large river basins. These watershed assessments will examine the hydrology across the entire basin, reviewing non-stationary influences such as regulation and land use changes, to ensure all variables affecting flood risk in the watersheds are considered. The studies' scope includes a multi-layered analysis with the purpose of producing flood frequency discharges that are consistent and defendable across a given basin. The multi-layered analysis will employ a range of hydrologic methods (e.g. numerical modeling, statistical hydrology, etc.) to examine all available data affecting the hydrologic processes within the watersheds. The end product of these basin-wide hydrology studies will be a hydrology report for use as a reference to evaluate against existing studies and also to support new local studies. These watershed hydrology assessments will also provide a tool set for use on local studies to provide the additional detail necessary to develop frequency flows at a smaller scale.

The basin-wide hydrology study for the Guadalupe River Basin is being conducted for FEMA Region VI by the InFRM team which includes representatives from USACE, USGS, and NWS. The scope of this basin-wide hydrology study includes a multi-layered analysis with the purpose of producing flood frequency estimates that are consistent and defendable across the basin.

This report summarizes the hydrologic analyses that were completed to estimate frequency peak stream flows for reaches throughout the Guadalupe River Basin. The results of all hydrologic analyses and the recommended frequency discharges are summarized herein.

1.1 STUDY TEAM MEMBERS

The following table lists the primary InFRM team members who participated in the development of the Guadalupe River Basin Watershed Hydrology Assessment. Max Strickler, a hydrologist from USACE Fort Worth District, served as the team lead for this study. In addition to those listed, the InFRM team would also like to acknowledge the many others who served supervisory and support roles during this study.

Table 1.1: Study Team Members

	Name	Agency	Office
1	Dr. William Asquith	USGS	Lubbock
2	Frank Bell, P.E.	NWS	WGRFC
3	Simeon Benson, P.E.	USACE	Fort Worth
4	Kristine Blickenstaff, P.E.	USGS	Fort Worth
5	Jerry Cotter, P.E.	USACE	Fort Worth
6	Landon Erickson, P.E.	USACE	Fort Worth
7	Heitem Ghanuni, P.E.	USACE	Fort Worth
8	Diane Howe	FEMA	Region 6
9	Kris Lander, P.E.	NWS	WGRFC
10	Craig Loftin, P.E.	USACE	Fort Worth
11	Mikaela Mahoney	USACE	Fort Worth
12	Emily Matthews	USACE	Fort Worth
13	Brittany McFall	USACE	ERDC
14	Paul McKee	NWS	WGRFC
15	James Moffitt	USACE	Fort Worth
16	Helena Mosser, P.E.	USACE	Fort Worth
17	Steve Pilney	USACE	Fort Worth
18	Cassandra Ross	USACE	ERDC
19	Max Strickler, CFM	USACE	Fort Worth
20	Stephen Turnbull	USACE	ERDC
21	Larry Voice	FEMA	Region 6
22	Sam Wallace	USGS	Fort Worth
23	Josh Willis	USACE	Fort Worth
24	Shang Gao	Univ of Texas	Arlington
25	Elizabeth Savage, P.E.	FEMA Support	Region 6

1.2 TECHNICAL REVIEW PROCESS

The InFRM Hydrology Assessments undergo a rigorous review process. Numerous peer reviews are performed by InFRM team members throughout the study. Each model, analysis, and technical product is peer reviewed as it is developed by an InFRM Subject Matter Expert (SME). Any technical issues that are discovered during the review process are thoroughly discussed and resolved, often with input from multiple team members. This same review process is also applied to the process of comparing and selecting final results. The draft results are shared with the rest of the InFRM team, and input is solicited from multiple subject matter experts. The draft study recommendations are then documented in the draft report.

The InFRM Academic Council also reviewed the methods and results of the InFRM Guadaupe Hydrology Assessment. The InFRM Academic Council is comprised of a select group of professors from local universities with unique skillsets, resources, and regional expertise in water resources and hydrology. Their involvement provides an independent and unbiased review of the InFRM team's methods and results. Collaboration with the InFRM Academic Council also helps the InFRM team to stay abreast with the latest advances in hydrologic science and technology. The primary InFRM Academic Council reviewers for the Guadalupe Hydrology Assessment were Dr. Nick Fang from the University of Texas at Arlington and Dr. Phil Bedient from Rice University.

2 Guadalupe River Basin

2.1 WATERSHED AND RIVER SYSTEM DESCRIPTION

The Guadalupe River Basin stretches from Central to South Texas, , approximately 30 miles northeast of San Antonio. The basin has a drainage area of approximately 6,700 square miles. Significant tributaries to the Guadalupe River Basin include the San Marcos and Comal Rivers. The basin intersects significant portions of Kerr, Kendall, Blanco, Hays, Comal, Travis, Caldwell, Guadalupe, Gonzales, DeWitt, and Victoria counties. Figure 2.1 shows the location of the Guadalupe River Basin with its major tributaries and stream gages.

The Guadalupe River Basin is relatively long and narrow, with an over-all length of approximately 237 miles and a maximum width of about 50 miles. From its source, the Guadalupe River flows in an easterly direction for a distance of about 184 miles to the Balcones Escarpment near the city of New Braunfels. Then turning southeasterly, the river flows for about 280 miles to San Antonio Bay, an estuary of the Gulf of Mexico. The elevation of the basin increases from sea level at the mouth to an elevation of about 2,400 feet National Geodetic Vertical Datum (NGVD) in the extreme headwater area.

The city of New Braunfels, Texas is located in Comal and Guadalupe counties and approximately 15 miles Southeast of Canyon Dam. The Guadalupe River discharges through New Braunfels are driven by runoff from further upstream, which includes releases from Canyon Dam and local runoff from areas of Comal County which are downstream of the dam. The area upstream of Canyon Dam is expected to remain primarily rural, so releases from the dam are not anticipated to increase in the future.

The city of Wimberley, Texas is located in Hays County at the confluence of the Blanco River with Cypress Creek. The Blanco River, which has a drainage area of 355 square miles at Wimberley, is the primary source of flooding through Wimberley. Upstream of Wimberley, the Blanco River flows through narrow canyons that are up to 200 feet deep, following a steep stream bed over frequent outcroppings of rock. Flash flooding is a frequent problem in Wimberley, as the steep topography produces rapidly rising river stages during storm periods, leaving residents with little warning time.

The city of San Marcos, Texas is located at the confluence of the Blanco River with the San Marcos River. At San Marcos, the Blanco River has a drainage area of 436 square miles, while the drainage area of the San Marcos River is only 50 square miles. The San Marcos River above San Marcos is a spring fed stream that is largely controlled by NRCS flood detention structures. The Blanco River, on the other hand, flows through narrow canyons and steep stream beds until it approaches the San Marcos city limits. Near San Marcos, the valley widens and the stream bed flattens. Rapidly rising floodwaters from the Blanco River spread out when they reach San Marcos, inundating neighborhoods on flat floodplains and over the eastern and western drainage divides into the neighboring watersheds. The combination of the steep terrain and rapid flash flooding upstream of the city, and the flat terrain through the city itself causes substantial flood damage in San Marcos when the Blanco River exceeds its flood stage.

Below San Marcos, the San Marcos River transitions to an area of broader plains, allowing flood waters to spread out and attenuate. The downstream portions of the San Marcos River Basin, including Plum Creek, are primarily rural, with farming and ranching being the principal land uses. Luling, Texas sits on a high bluff near the confluence of the San Marcos River with Plum Creek and is less susceptible to flooding due to its elevation.

The city of Victoria, Texas is located in Victoria County and is one of the largest population centers on the Lower Guadalupe River. Victoria is approximately 30 miles from San Antonio Bay and can be significantly impacted from hurricanes that come through the Gulf of Mexico.

The climate over the Guadalupe River Basin is generally mild. In summers, the days are hot and the nights cool. Normally, the winter periods are short and comparatively mild, but occasional cold periods of short duration result from the rapid movement of cold, high pressure air masses from northwestern polar areas and the continental western highlands. Freezing temperatures occur yearly over a large portion of the headwater area of the San Marcos River, and snowfall is experienced occasionally. Wind movements during December, January, and February are usually northerly and are influenced by continental high pressure areas. During the remainder of the year, southerly or southeasterly winds from the Gulf of Mexico are dominant. The mean annual temperature over the basin is about 68 degrees Fahrenheit. January, is the coldest month with an average minimum daily temperature of 42 degrees; August is the warmest month with an average maximum daily temperature of 94 degrees. The mean annual precipitation over the Guadalupe Basin ranges from 26 to 40 inches, increasing from West to Southeast.

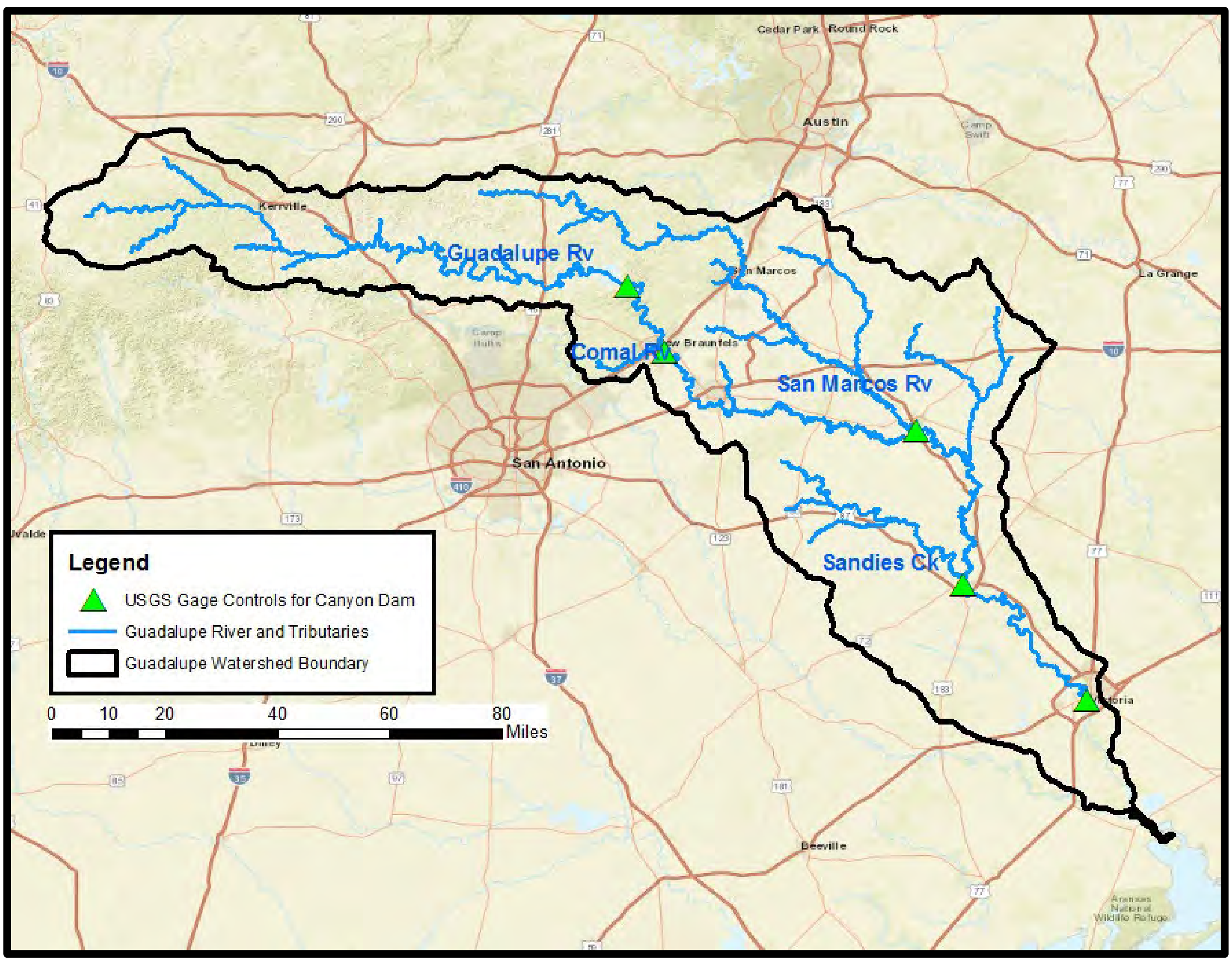

Figure 2.1: Guadalupe Basin Major Tributaries and Stream Gages

2.2 MAJOR FLOODS IN THE BASIN

The Guadalupe River basin has a history of flooding that spans back to 1869, when major flood stages were recorded at Wimberley, New Braunfels and Comfort, TX. Available streamflow records show that major floods have been experienced over nearly all sections of the Guadalupe River Basin. While there have been scattered floods throughout the basin's nearly 150 year history, the last 20 years has shown an uptick in the frequency and magnitude of devastating floods. The following sections summarize information on some of the major floods in the Guadalupe basin of the last 20 years, including the 2002 flood on the Guadalupe River above Canyon Dam, the 1998 flood on the lower Guadalupe River, and the 2015 floods on the Blanco and San Marcos Rivers.

2.2.1 Upper Guadalupe Basin – 2002 Storm

In late June 2002, a low-pressure system migrated west from Florida to Texas and eventually stalled over South Central Texas. From 29 June to 6 July, tropical moisture was pulled inland from the Gulf of Mexico and the orographic lift provided by the Balcones Escarpment caused widespread heavy rainfall. Rains moved from south to north repeatedly causing tremendous rainfall accumulations on an area from southwest of San Antonio to the northern Hill Country. The low-pressure system moved north on 5 July, only to stall again in Central Texas. The system again produced heavy rains in this area on 6 July. The low-pressure system finally moved northwest and weakened, ending the period of heavy rain in the Hill Country.

Between 8 July and 17 July, three more rounds of showers and thunderstorms occurred over the region. On 8 July, a weak tropical wave of low pressure moved inland along the Texas coast, bringing additional thunderstorms to much of South and Central Texas. On 12 July, a weak cold front moved into North Texas and stalled. Storms developed along this front and moved south, bringing additional showers to much of the Hill Country. Finally, a weak trough of low pressure moved across North Texas on 17 July, bringing another round of showers and thunderstorms over the region. Although the rains during the second period were not nearly as heavy as that of the first, runoff from these storms aggravated the ongoing flooding problems.

The main part of the storm event, between 29 June and 6 July, was concentrated in Kendall County and surrounding counties. The heaviest rainfall occurred between early morning and noon of 30 June. Rainfall intensities of 3 inches per hour were common. In the first week of July, a pattern of afternoon heating led to explosive evening and overnight thunderstorms. These evening thunderstorms also produced heavy rainfall. Rainfall amounts recorded at National Weather Service stations located in the Upper Guadalupe watershed from 29 June to 6 July are listed in Table 2.1. As one can see, several stations recorded more than 30 inches of rain during this eight day period.

Table 2.1 - Precipitation (inches) recorded in the Canyon Lake watershed

NWS Station	29-30 June	1-6 July	Storm Total
Bankersmith	7.70	24.18	31.88
Camp Verde	3.00	31.17	34.17
Canyon Dam	5.60	14.23	19.83
Comfort 2	3.85	27.74	31.59
Hunt 10W	0.00	6.22	6.22
Ingram No. 2	0.26	12.01	12.27
Kendalia	3.63	22.03	25.66
Kerrville 3NNE	1.67	17.47	19.14
Northington	4.28	17.76	22.04
Sisterdale	2.65	28.10	30.75

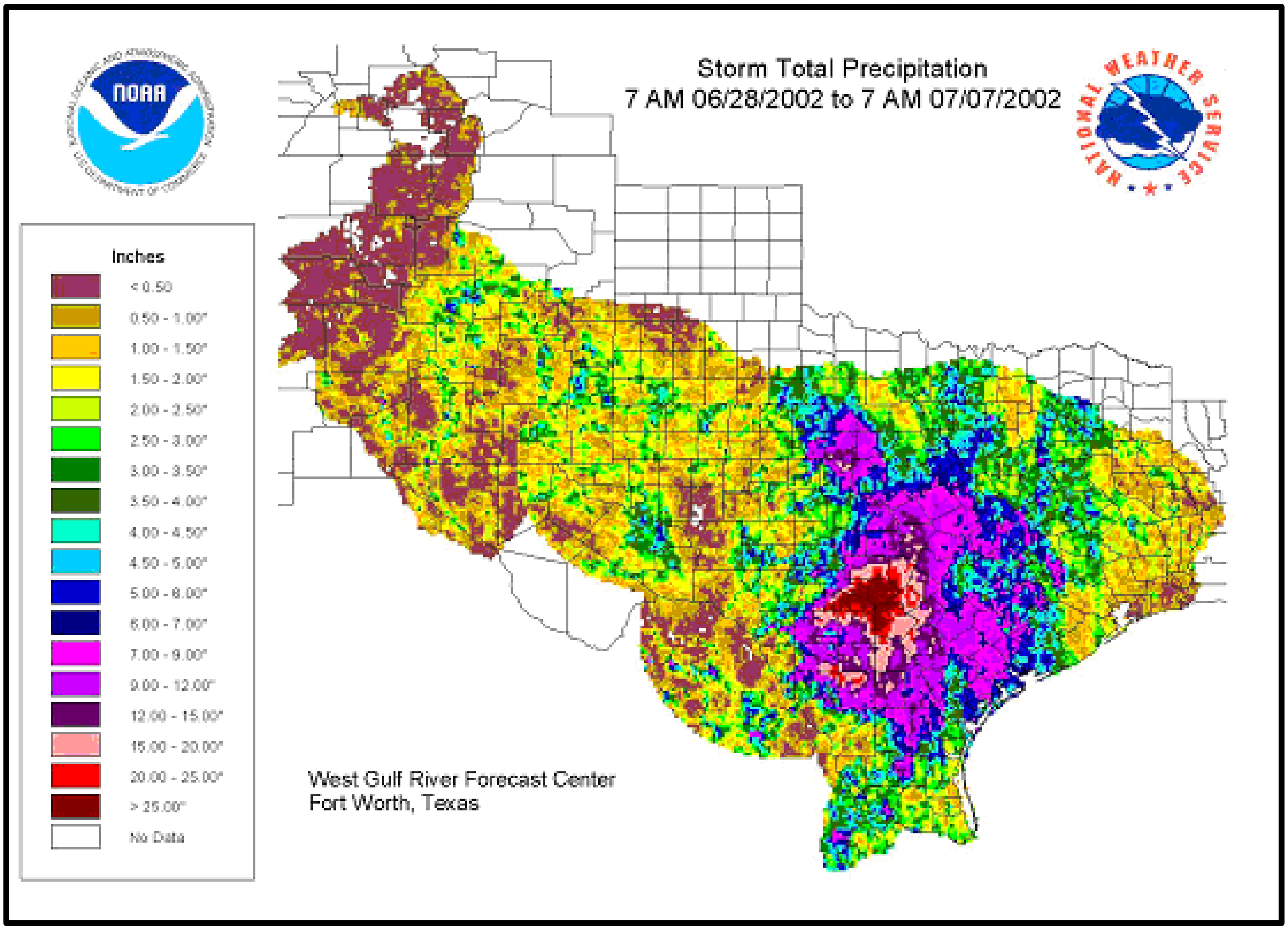

Figure 2.2: NEXRAD Rainfall Distribution Map

The torrential rains of 2002 caused flooding of historic proportions on south Texas rivers. Major to record flooding occurred along portions of all the rivers in the Hill Country. Extensive damage occurred from flash flooding and headwater flooding in Wimberley on the Blanco River and in Kerrville on the Guadalupe River. Some communities were isolated by the flood waters in the upper Guadalupe River for a day or more. Damage on the Guadalupe River below Canyon Dam was catastrophic in some locations.

Widespread rainfall across Kerr County and Kendall County sent five flood waves down the Guadalupe River into Canyon Lake in the first week of July. The highest inflow peak, of approximately 110,000 cfs, occurred on 5 July. During the first nine days in July, the total inflow into Canyon Lake was about 700,000 acre-feet of floodwater. The capacity of the flood pool is approximately 355,000 acre-feet.

Between 30 June and 31 July, the computed inflow totaled 872,000 acre-feet. This volume of water is equal to 11.5 inches of runoff over the entire basin, which is enough to have more than filled the flood control pool twice. Due to saturation of the watershed, the Guadalupe River and its tributaries continued to run at well above normal stages for several months.

On 28 June, before the flooding began, Canyon Lake was at elevation 908.38 feet NGVD or 0.62 feet below the top of the conservation pool. The heavy rains and high inflow filled the lake to the top of the flood pool, elevation 943.0 feet NGVD, at 1530 hours on 4 July. The continuing waves of flood water raised the lake level above the emergency spillway crest. The lake peaked on 6 July at elevation 950.32 feet NGVD. At this elevation, the lake level was 7.32 feet above the spillway crest, having risen nearly 42 feet in just over a week. The maximum discharge over the spillway was about 66,800 cfs, whereas the control flow in the downstream channel at New Braunfels, Texas was 12,000 cfs. The 2002 flood is the flood of record at Canyon Lake.

2.2.2 Lower Guadalupe Floods – 1998 Storm

Severe flooding in parts of south-central Texas resulted from a major storm during October 17–18, 1998. The flooding occurred in parts of the major streams and tributaries of the San Jacinto, San Benard, Colorado, Lavaca, Guadalupe, and San Antonio River Basins. Peak gage height, peak streamflow, and documentation of the significance of the peaks were compiled for the streamflow-gaging stations where the storm caused substantial flooding.

The meteorologic conditions that produced the storm rainfall were dominated by Hurricane Madeline in the Eastern Pacific near the tip of Baja California, and Hurricane Lester in the Eastern Pacific near Acapulco, Mexico. The hurricanes, coupled with an atmospheric trough of low pressure over the western United States, forced a very deep layer of air with high water-vapor content across Mexico and into Texas. Meanwhile, an atmospheric ridge of high pressure to the east, extending from the North Atlantic to the Yucatan Peninsula of Mexico, confined the surface and mid-level water-vapor plumes to south-central Texas. During the morning of October 17, 1998, a strong low-level inflow of moist air traveling 23 to 35 miles per hour flowed from the Gulf of Mexico across Texas into Bexar County. An upper-level divergent wind pattern over south-central Texas lifted the extremely moist air mass from lower levels. Early thunderstorms slowly pushed eastward throughout the day into the prevailing moisture-rich flow. In the early morning hours of October 17, extreme atmospheric instability over western Bexar County extending northward to Kendall County caused rapid uplift of low-level moisture, forming heavy thunderstorms. By 6 a.m., the area from western Comal County to eastern Medina County had received 4 to 6 inches of rain. By 8 a.m., 6 to 10 inches had fallen; and by late morning, this area had received about 15 inches. By late morning on October 17, the rains extended into Hays and Travis Counties. The NWS rain gage at Wimberley (Hays County) indicated that intense rainfall began by 8 a.m. and recorded 4.5 inches by 11 a.m., 6 inches by 1 p.m., 9 inches by 4 p.m., and 11.25 inches by 8 p.m. At 11:30 p.m., the 12-inch rain collector overflowed. Finally, by mid-day October 18, the tropical plume and intense rainfall shifted eastward to the upper Texas Coastal Plain and extended into Louisiana. During the Oct 1998 flood event, approximately 22 inches of rain fell in western Comal County, near the city of New Braunfels over a two day period. 30 inches of rain was also recorded in parts of the San Marcos River basin.

The volume of runoff for the USGS gage, Guadalupe River at Cuero, was computed for the period October 17–31, 1998, at about 1,840,000 acre-feet. The total outflow from Canyon Lake during October 18–31 was only about 2,600 acre-feet (Tommy Hill, Guadalupe-Blanco River Authority, oral commun., 1999); thus, almost all runoff at the Cuero station originated from the basin downstream of the reservoir. The rainfall volume in the drainage basin upstream of the Cuero station and downstream of Canyon Lake is about 2,580,000 acre-feet, which represents a mean depth of about 15.0 inches over almost 3,500 square miles of drainage area. (U.S. Geological Survey, *Floods in the Guadalupe and San Antonio River Basins in Texas, October 1998.)*

The October 1998 flood event resulted in record flooding along much of the lower Guadalupe River and in record flood stages at several gages on the Comal, San Marcos and Guadalupe Rivers. The recorded peak flows for the Guadalupe River at Cuero and Victoria in October 1998, which were 473,000 and 466,000 cfs respectively, have never even been approached anywhere else the basin. This one flood event resulted in 31 deaths and approximately $750 million in property damage in the Guadalupe River Basin.

2.2.3 Blanco and San Marcos Watersheds – 2015 Storms

Recently, back-to-back large flood events occurred in the Blanco River Basin in May and October of 2015. In May 2015, heavy rainfalls produced devastating floods throughout the state of Texas. The Blanco River experienced some of the most severe flooding as a result of an intense rain event that occurred during 6-hour period in the evening of May 23, 2015. During that flash flood event, the Blanco River rose more than 20 feet in one hour and peaked at a stage of almost 45 feet. The high velocity nature of the flooding uprooted thousands of large cypress trees, destroyed bridges and damaged or destroyed over 350 homes, some of which were washed completely off of their foundations and carried down river. The flood also resulted in 12 deaths, including two children. Property damage in the city of Wimberley was estimated at more than $30 million.

During that event, both the Kyle and Wimberley USGS stream gages on the Blanco River were damaged and ceased to operate. The May 2015 event was estimated to be the highest flood of record for the Blanco River gages at Wimberley and near Kyle. The May 2015 peak streamflow at Wimberley has been estimated by the USGS as 175,000 cfs with a peak stage of 44.90 feet. The peak for Blanco Kyle was also estimated by the USGS as 180,000 cfs. Many of the homes that were damaged in this flood event were outside of the existing FEMA 1% floodplain, and some of the high water marks that were collected after the flood were 5 to 10 feet higher than the existing base flood elevations (BFEs).

A second major flood occurred in October 2015. The estimated peak flows for that event were 71,000 cfs at Wimberley and 115,000 cfs near Kyle. Extensive property damage occurred once again in both Wimberley and San Marcos, with over 1,000 structures flooded in the city of San Marcos.

Other major floods that have occurred in the Guadalupe River basin, along with their peak flow estimates, are listed in Table 2.2. Several of these floods were used as calibration events for this study's rainfall-runoff model, as denoted in the table. From this table one may observe that since 1998, there have been several major flood events that have equaled or exceeded historic flooding within the basin.

Table 2.2: Major Floods in the Guadalupe River Basin

Date of Flood	Event used for Model Calibration	Observed Peak Flow (cfs)			
		Guadalupe River at Comfort	Guadalupe River abv Comal River at New Braunfels	Blanco River at Wimberley	Guadalupe River at Victoria
Jul-1869		40.30 ft	38 ft	25 ft	-
Jul-1900		182,000	-	-	-
Dec-1913		-	38 ft	-	28.3 ft
Sep-1915		114,000	-	-	-
May-Jun-1929		-	-	113,000	30.2 ft
Jul-1932		-	95,200	-	-
Jun-1935		148,000	101,000	-	38,500
Jul-1936		-	-	-	179,000
Sep-1936		107,000	52,800	-	-
May-1944		74,200	26,500	-	-
Sep-1952		-	72,900	95,000	-
Apr-1957		-	26,900	62,600	35,300
Feb-1958		-	-	-	58,300
May-1958		-	47,900	96,400	-
Oct-1959		111,000	35,700	40,100	-
Jun-1961		-	-	-	55,800
Sep-1967		-	-	-	70,000
May-1972		-	92,600	-	58,500
Aug-1978		240,000	-	-	-
Sep-1981		-	-	-	105,000
Oct-1985		73,700	-	-	-
Jun-1987		-	-	-	83,400
Jul-1987		130,000	-	-	-
Dec-1991		-	-	32,900	61,500
Jun-1997		73,700	-	-	-
Oct-1998	Yes	-	90,000	88,500	466,000
Nov-2001	Yes	-	-	108,000	-
Jul-2002	Yes	128,000	73,200	82,500 [1]	71,700
Nov-2002	Yes	-	-	-	58,500
Jun-2004	Yes	55,600	-	-	-
Nov-2004	Yes	7,550	17,000	34,000	102,000
Mar-2007	Yes	-	-	36,900	-
Aug-2007	Yes	62,800	-	-	-
Apr-2010	Yes	30,500	-	-	-
Jun-2010	No	-	69,000	-	-
Oct-2013	Yes	-	25,500	75,800	-
May-2015	Yes	72,600	-	175,000	49,100
Oct-2015	Yes	-	39,000	71,000	-
May-2016		83,800	-	-	-
Aug-2017		-	-	-	86,500

2.3 PREVIOUS HYDROLOGY STUDIES

The hydrology of the Guadalupe River and its tributaries has been analyzed many times over the years. Data and models from several existing hydrologic and hydraulic studies were available at the time of this study. Table 2.3 below summarizes all of the notable existing studies, models, and hydrologic information that were previously performed in the Guadalupe River basin.

Table 2.3: Previous Hydrologic Studies in the Guadalupe River Basin

Study Name	River Extents	Frequency Flows	Hydrologic Methods	Description
Kerr County Flood Insurance Study 2011	Guadalupe River within Kerr County and the City of Kerrville	Yes	Regional regression	Bulletin 17B at 15 nearby gauges, then regional correlation of flowrate relative to drainage area
Kendall County Flood Insurance Study 2010	Guadalupe River within Kendall County	Yes	Regional Regression	Bulletin 17B and application of Jarris-Meyer's power curve for flowrate relative to drainage area
Comal County Flood Insurance Study 2009	Guadalupe River above Canyon Dam	Yes	Regional Regression	Bulletin 17B
Comal County Flood Insurance Study 2009	Guadalupe River at Canyon Dam	Yes	SUPER	Extended Period of Record Analysis
Comal County Flood Insurance Study 2009	Guadalupe River below Canyon Dam	Yes	Rainfall-runoff modeling	HEC-HMS with NRCS Methods
Guadalupe County Flood Insurance Study 2007	Guadalupe River from the County Line down through the City Seguin	Yes	Rainfall-runoff modeling	HEC-HMS with NRCS Methods
Guadalupe County Flood Insurance Study 2007	Guadalupe River below Seguin	Yes	Regional Regression	Bulletin 17B
Gonzales County Flood Insurance Study 2010	Guadalupe River within Gonzales County and the City of Gonzales	Yes	Regional Regression	Bulletin 17B
DeWitt County Flood Insurance Study 2011	Guadalupe River within DeWitt County	Yes	N/A	N/A
Victoria County Flood Insurance Study 1998	Guadalupe River through the County and the City of Victoria	Yes	Regional Regression	Bulletin 17B
Comal County Flood Insurance Study 2006	Comal River within New Braunfels	Yes	Rainfall-runoff modeling	HEC-HMS with NRCS Methods
Hays County Draft Flood Insurance Study by USACE 1988	Blanco and San Marcos Rivers	Yes	Rainfall-runoff modeling	NUDALLAS / HEC-1 with small subbasins, detailed HEC-2 models for routing
Hays County Effective Flood Insurance Study 1996 and 2005	Blanco and San Marcos Rivers in Hays County	Yes	USGS Regression Equations	Simple method to calculate flows with little information
Guadalupe County Flood Insurance Study 1998	San Marcos River at Luling	Yes	Statistical analysis	Bulletin 17B analysis of the San Marcos at Luling gage

Study Name	River Extents	Frequency Flows	Hydrologic Methods	Description
USACE Lower Guadalupe Feasibility Study 2013	Entire San Marcos and Guadalupe Basins below Canyon Dam	Yes	Rainfall-runoff modeling & Statistical analysis	HEC-HMS with large subbasins, detailed HEC-RAS models for routing, Statistical analysis of the gages
Guadalupe CWMS Implementation 2014	Entire Guadalupe River Basin	No	Rainfall-runoff modeling & Reservoir Simulation	HEC-HMS with large subbasins, calibrated to multiple flood events.

2.4 CURRENTLY EFFECTIVE FEMA FLOWS

The frequency flows that are on the currently effective flood insurance rate maps for Kerr, Kendall, Guadalupe, Gonzales, Victoria, and Hays Counties were based on regression equations. A regression equation is a method that allows one to calculate the 1% annual chance (100-yr) flow with very little information about the watershed. In the case of the Hays County, one can simply plug two variables (the slope of the river and area of the watershed) into an equation to calculate the 1% annual chance (100-yr) flow. However, this method has its drawbacks.

The equation for the 1% annual chance (100-yr) flow was developed by drawing a "best fit" curve through the 100-yr flow points that were estimated at a number of sites across the region. The accuracy of that equation depends on many factors including the accuracy of the estimated 100-yr flow points.

For example, the 100-yr flow points for Hays County were estimated based on a statistical analysis of the stream gage records through the year 1992. However, as documented in Table 2.2, several major floods have occurred in the basin since 1998 which drastically change the statistical estimates of the 1% annual chance (100-yr) flow. For example, at Wimberley, in the twenty years since 1998, there have been five major floods that have exceeded 70,000 cfs in magnitude; whereas the seventy year period prior to 1998 saw only three floods greater than 70,000 cfs.

Another example is the 1998 Flood Insurance Study for Victoria County. That study published a 1% annual chance (100-yr) flow value for the Guadalupe River at Victoria of 129,000 cfs and a 0.2% annual chance (500-yr) flow value of 219,000 cfs, based on a Bulletin 17B statistical analysis. Later that year, the monster flood of October 1998 occurred, with a recorded peak flow at Victoria of 466,000 cfs. This flood was 3.5 times larger than the published 100-yr flood and two times larger than the published 500-yr flood. Nevertheless, 129,000 cfs is still the currently effective FEMA flow at that location.

All of the major floods that have occurred in the last 20 years indicate that 1% annual chance (100-yr) flow values that were calculated based on statistical or regional regression equations could have been significantly underestimated. Therefore, it is imperative that these values be updated and weighed against other hydrologic methods.

3 Methodology

The methodology that was used for this basin-wide hydrology study was a multi-layered analysis that calculated frequency flows in the Guadalupe River Basin through several different methods and compared their results to each other before making final flow recommendations. The purpose of this analysis is to produce a set of frequency flows that are consistent and defendable across the basin.

The current study builds upon the information that was available from the previous hydrology studies by combining detailed data from different models, updating land use data, calibrating the models to multiple recent flood events, and updating statistical analyses to include the most recent flood events.

The multi-layered analysis for the current study of the basin consists of four main components: (1) statistical analysis of the stream gages, (2) rainfall-runoff watershed modeling in the Hydraulic Engineering Center's Hydrologic Modeling System (HEC-HMS), (3) extended period-of-record modeling in RiverWare, and (4) a reservoir study of Canyon Dam. After completing all of these different types of analyses, their results were then compared to each other and to the existing published frequency flows within the basin. Frequency flow recommendations were then made after consideration of all the known hydrologic information.

4 Data Collection

This section describes the data that was collected/reviewed for the hydrologic study effort, including geospatial and climatic information, field observations and previous reports for the Guadalupe River Basin.

4.1 SPATIAL TOOLS AND REFERENCE

ArcGIS version 10.2.2 (developed by ESRI), together with HEC-GeoHMS version 10.2 were used to process and analyze the data necessary for hydrologic modeling and to generate the sub-basin boundaries.

The geographic projection parameters used for this study are listed below:

- Horizontal Datum: North American Datum 1983 (NAD83);
- Projection: USA Contiguous Albers Equal Area Conic USGS version;
- Vertical Datum: North American Vertical Datum, 1988 (NAVD 88); and
- Linear units: U.S. feet.

4.2 DIGITAL ELEVATION MODEL (DEM)

As part of the Guadalupe CWMS implementation, 10-meter and 30-meter DEMs were collected from the seamless USGS National Elevation Dataset (NED, accessed January 2013) for the study watershed from the http://seamless.usgs.gov <http://seamless.usgs.gov> website. The elevations of the NED are in meters. The vertical elevation units were converted from meters to feet, and the datasets were projected into the standard map projection.

In addition, high resolution LiDAR data was available for most of the basin, including Hays, Caldwell, Comal, Fayette, Guadalupe, and Gonzales counties. This LiDAR data was collected in the form of a basin wide terrain dataset created by Halff & Associates for USACE's Lower Guadalupe Feasibility Study in 2012 (Halff, Mar 2014). The final terrain dataset utilized the best available LiDAR data from various sources with collection dates varying from 2008 to 2012. The final terrain dataset was in State Plane Texas South Central 4204 projection, North American Datum (NAD) 1983 horizontal datum, and with elevations in North American Vertical Datum (NAVD) 1988. This terrain dataset was further processed into 3-foot by 3-foot DEMs for hydraulic modeling and hydrologic routing.

4.3 VECTOR AND RASTER GEOSPATIAL DATA

The mapping team member utilized web mapping services and downloaded the USGS hydrologic unit boundaries, USGS stream gages, USGS medium resolution National Hydrography Dataset (NHD), National Inventory of Dams (NID) data, National Levee Database (NLD) levee centerlines as well as general base map layers. Additional vector data were obtained from the ESRI database and used in figures prepared for the final report. Raster Data includes the National Land Cover Database (NLCD) 2011 land cover layer and percent imperviousness layer from the http://seamless.usgs.gov website, accessed February 2014.

4.4 AERIAL IMAGES

The CWMS team utilized current high resolution imagery from the National Aerial Imagery Program (NAIP) with a horizontal accuracy based upon National Map Accuracy Standards (NMAS), with 1"=200' scale (1-foot imagery) accuracy of +/- 5.0-feet and the 1"=100' scale (0.5-foot imagery) accuracy of +/- 2.5-feet. Digital photos were used to verify watershed boundaries as well as delineate centerlines and other geographic features. In addition, Google Earth, and Bing Maps were also used to locate important geographic features.

4.5 SOIL DATA

Gridded Soil Survey Geographic (SSURGO) datasets were obtained during the Guadalupe CWMS study. These datasets were used to estimate initial and constant loss rates for the frequency storm events in HEC-HMS and to calculate initial estimates of the Snyder's lag time. The lag times were modified during calibration.

4.6 PRECIPITATION DATA

Historic precipitation data for observed storm events were collected from the NWS gridded precipitation data files. NEXRAD Stage III grids were used for the basin. The NEXRAD Stage III grids are stored in a binary file format called XMRG. The historical XMRG data were processed into hourly precipitation grids in HEC-DSS format using HEC-METVUE. This data was acquired from the NWS West Gulf River Forecasting Center (WGRFC) and the http://dipper.nws.noaa.gov/hdsb/data/nexrad/nexrad.html website.

Frequency point rainfall depths of various durations and recurrence intervals were collected from the 2004 Atlas of Depth-Duration Frequency (DDF) of precipitation for Texas published by the USGS (Asquith, 2004). The point rainfall depths above Canyon Dam utilized estimates that were averaged between Kerr and Kendall county estimates. For the Guadalupe River below Canyon Dam to the Victoria gage, each subbasin was assigned the precipitation values from the county where the subbasin was located in. The precipitation value assigned to each county was approximately taken from the center of the county. The counties were Comal, Guadalupe, Gonzales, and DeWitt. The point rainfall depths for the Blanco River subbasins were taken from a point near Wimberley, Texas, and the point rainfall depths for the rest of the San Marcos subbasins were taken from a point near the lower basin's centroid. These also happened to be the same point rainfall depths as were used in the Lower Guadalupe feasibility study. All of the above sets of frequency precipitation depths were utilized in the final HEC-HMS rainfall-runoff model, as shown in Tables 4.1 through 4.9.

Table 4.1: Frequency Point Rainfall Depths (inches) for the Blanco River Basin

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.00	1.24	1.41	1.75	2.00	2.25	2.65	2.95
1hr	1.74	2.30	2.70	3.25	3.80	4.33	5.20	5.90
2hr	2.20	2.90	3.42	4.10	4.80	5.60	6.60	7.60
3hr	2.40	3.18	3.75	4.55	5.30	6.20	7.40	8.60
6hr	2.73	3.67	4.27	5.20	6.10	7.10	8.60	10.00
12hr	3.08	4.10	4.90	6.00	7.00	8.20	10.00	11.90
24hr	3.70	5.10	6.18	7.60	8.80	10.10	12.10	14.00

Table 4.2: Frequency Point Rainfall Depths (inches) for the San Marcos River Basin

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.07	1.41	1.66	2.02	2.33	2.69	3.23	3.71
1hr	1.83	2.41	2.82	3.41	3.9	4.45	5.29	6.01
2hr	2.3	3.07	3.61	4.39	5.06	5.8	6.94	7.93
3hr	2.41	3.29	3.94	4.87	5.68	6.59	8	9.25
6hr	2.73	3.68	4.38	5.39	6.27	7.27	8.82	10.2
12hr	3.14	4.26	5.08	6.27	7.31	8.49	10.32	11.95
24hr	3.6	5.1	6.18	7.67	8.9	10.23	12.15	13.75

Table 4.3: Frequency Point Rainfall Depths (inches) for Upper Guadalupe Above Canyon

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	0.98	1.23	1.48	1.73	2.00	2.28	2.63	2.95
30min	1.40	1.70	2.00	2.30	2.60	2.93	3.33	3.70
1hr	1.80	2.30	2.75	3.30	3.80	4.40	5.20	5.90
2hr	2.20	2.88	3.50	4.23	4.95	5.75	6.90	8.00
3hr	2.40	3.25	3.90	4.80	5.60	6.50	7.80	9.05
6hr	2.80	3.85	4.70	5.70	6.60	7.70	9.10	10.70
12hr	3.20	4.43	5.45	6.60	7.60	8.90	10.45	12.20
24hr	3.60	5.00	6.15	7.50	8.65	10.10	11.75	13.65

Table 4.4: Frequency Point Rainfall Depths (inches) for Coleto Creek

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.15	1.45	1.73	2.00	2.28	2.58	2.88	3.20
30min	1.55	1.98	2.30	2.70	3.05	3.43	3.83	4.20
1hr	1.90	2.48	2.90	3.43	3.93	4.43	5.05	5.65
2hr	2.25	3.03	3.65	4.33	4.90	5.63	6.55	7.45
3hr	2.45	3.35	4.05	4.85	5.58	6.43	7.55	8.63
6hr	2.83	3.93	4.78	5.80	6.70	7.85	9.35	10.65
12hr	3.23	4.55	5.53	6.78	7.88	9.28	11.15	12.70
24hr	3.63	5.13	6.25	7.75	9.05	10.70	13.00	14.70

Table 4.5: Frequency Point Rainfall Depths (inches) for Comal County

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.00	1.25	1.50	1.75	2.05	2.30	2.70	3.00
30min	1.35	1.70	2.00	2.35	2.65	2.95	3.45	3.85
1hr	1.75	2.30	2.65	3.25	3.70	4.20	5.00	5.70
2hr	2.15	2.85	3.35	4.10	4.80	5.50	6.50	7.50
3hr	2.40	3.20	3.75	4.60	5.40	6.30	7.40	8.60
6hr	2.80	3.80	4.50	5.50	6.50	7.50	9.00	10.40
12hr	3.20	4.45	5.30	6.50	7.60	8.80	10.50	12.20
24hr	3.60	5.05	6.10	7.40	8.70	10.20	12.20	14.00

Table 4.6: Frequency Point Rainfall Depths (inches) for Guadalupe County

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.10	1.40	1.70	2.00	2.25	2.50	3.10	3.60
30min	1.45	1.85	2.15	2.50	2.80	3.10	3.70	4.25
1hr	1.80	2.35	2.75	3.35	3.80	4.35	5.15	5.90
2hr	2.20	2.95	3.45	4.30	4.85	5.60	6.65	7.60
3hr	2.40	3.30	3.85	4.80	5.45	6.30	7.50	8.60
6hr	2.75	3.80	4.50	5.60	6.50	7.50	9.00	10.30
12hr	3.12	4.40	5.20	6.50	7.50	8.80	10.50	12.00
24hr	3.50	5.00	5.90	7.40	8.60	10.00	12.00	13.70

Table 4.7: Frequency Point Rainfall Depths (inches) for Gonzales County

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.05	1.40	1.75	2.10	2.40	2.70	3.20	3.70
30min	1.50	1.90	2.25	2.65	3.00	3.30	3.80	4.25
1hr	1.85	2.40	2.85	3.40	3.90	4.40	5.30	5.90
2hr	2.25	2.90	3.55	4.20	4.95	5.60	6.80	7.65
3hr	2.45	3.25	3.90	4.70	5.55	6.35	7.65	8.70
6hr	2.85	3.75	4.60	5.60	6.60	7.60	9.15	10.40
12hr	3.25	4.30	5.35	6.50	7.65	8.90	10.70	12.10
24hr	3.65	4.85	6.10	7.40	8.70	10.20	12.20	13.80

Table 4.8: Frequency Point Rainfall Depths (inches) for DeWitt County

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.15	1.45	1.75	2.05	2.35	2.70	3.05	3.40
30min	1.55	1.95	2.30	2.70	3.05	3.45	3.85	4.25
1hr	1.90	2.45	2.90	3.45	3.95	4.45	5.10	5.70
2hr	2.25	3.00	3.64	4.35	4.90	5.70	6.65	7.60
3hr	2.45	3.30	4.00	4.85	5.55	6.45	7.60	8.70
6hr	2.80	3.85	4.75	5.75	6.60	7.80	9.30	10.60
12hr	3.20	4.50	5.45	6.65	7.70	9.15	11.00	12.50
24hr	3.60	5.05	6.20	7.60	8.80	10.50	12.70	14.30

Table 4.9: Frequency Point Rainfall Depths (inches) for Lavaca County

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.10	1.45	1.70	2.00	2.30	2.60	3.00	3.40
30min	1.55	1.95	2.30	2.65	3.00	3.30	3.70	4.10
1hr	1.90	2.45	2.90	3.45	3.95	4.45	5.10	5.70
2hr	2.30	3.05	3.65	4.40	5.00	5.70	6.80	7.80
3hr	2.55	3.40	4.05	4.95	5.70	6.50	7.80	9.10
6hr	2.95	4.00	4.85	5.95	6.90	8.00	9.60	11.20
12hr	3.40	4.70	5.65	7.00	8.20	9.50	11.50	13.30
24hr	3.80	5.30	6.40	7.95	9.40	11.00	13.40	15.30

NOAA Atlas 14 Volume 11, which contains precipitation frequency estimates for the state of Texas, was published in September of 2018 while this hydrology study was nearing its completion (NOAA, 2018). Following its publication, the InFRM team updated the Guadalupe rainfall runoff modeling with the new rainfall depths that were published in NOAA Atlas 14 (NA14). NA14 point rainfall depths from the annual maximum time series for various durations and recurrence intervals were collected from the NA14 Precipitation Frequency Data Server (PFDS) for the centroid of each subbasin. This method resulted in 165 separate point rainfall tables being applied in the Guadalupe River basin, one for each subbasin. Figures 4.1 to 4.5 illustrate the variance of the NA14 100-yr rainfall depths across the Guadalupe River basin, while Figures 4.6 and 4.7 illustrate how the new NA14 depths vary by duration and frequency at Wimberley, TX.

From these figures, one can see that the NA14 100-yr rainfall depths in the Guadalupe River basin were significantly higher than the previous rainfall estimates from the 2004 USGS Rainfall Atlas. Additional information and discussion on the NA14 rainfall data, along with the modeling runs that included this data, are documented in Chapter 10 of this report.

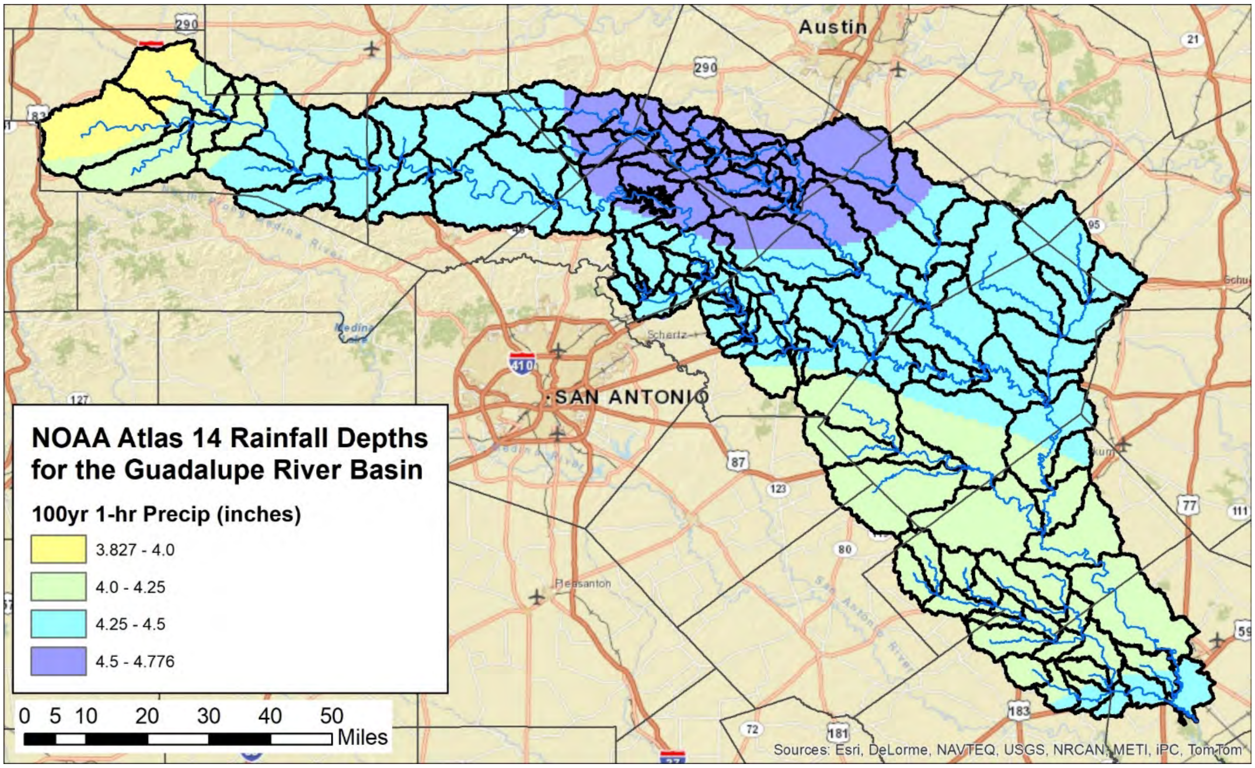

Figure 4.1: 100-yr, 1-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

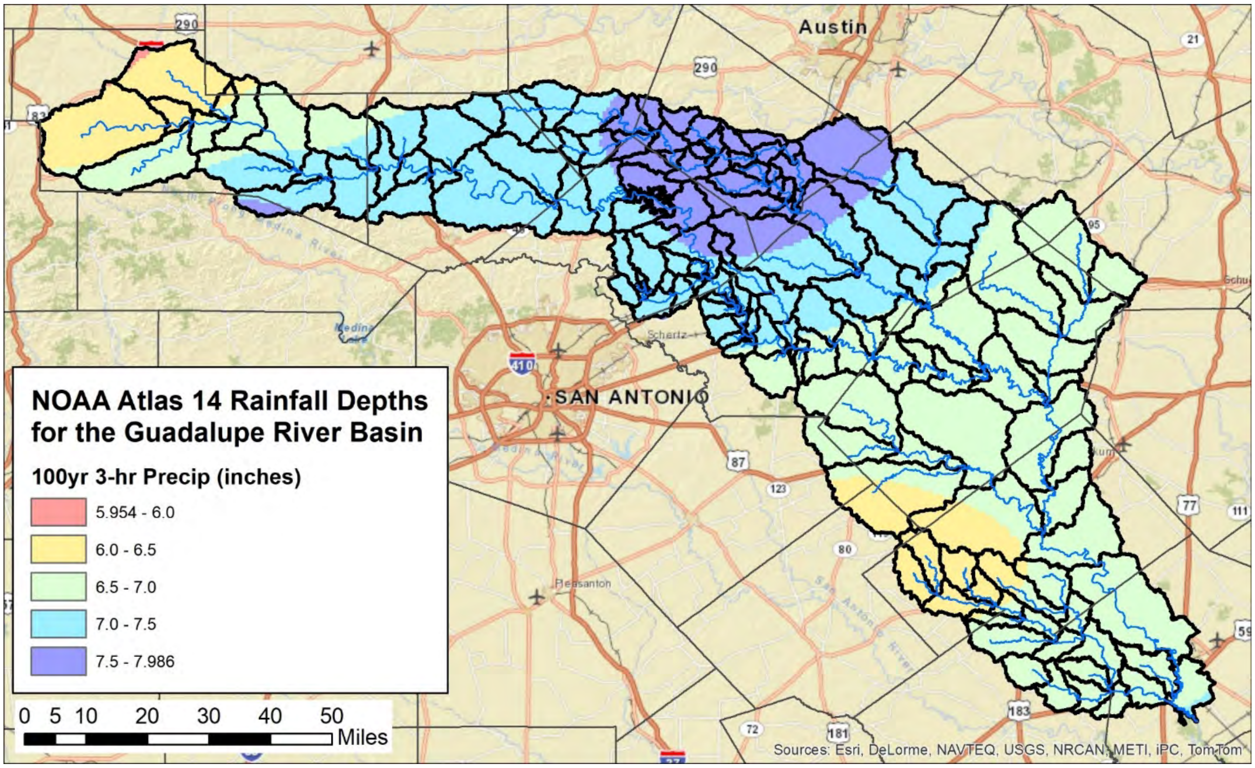

Figure 4.2: 100-yr, 3-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

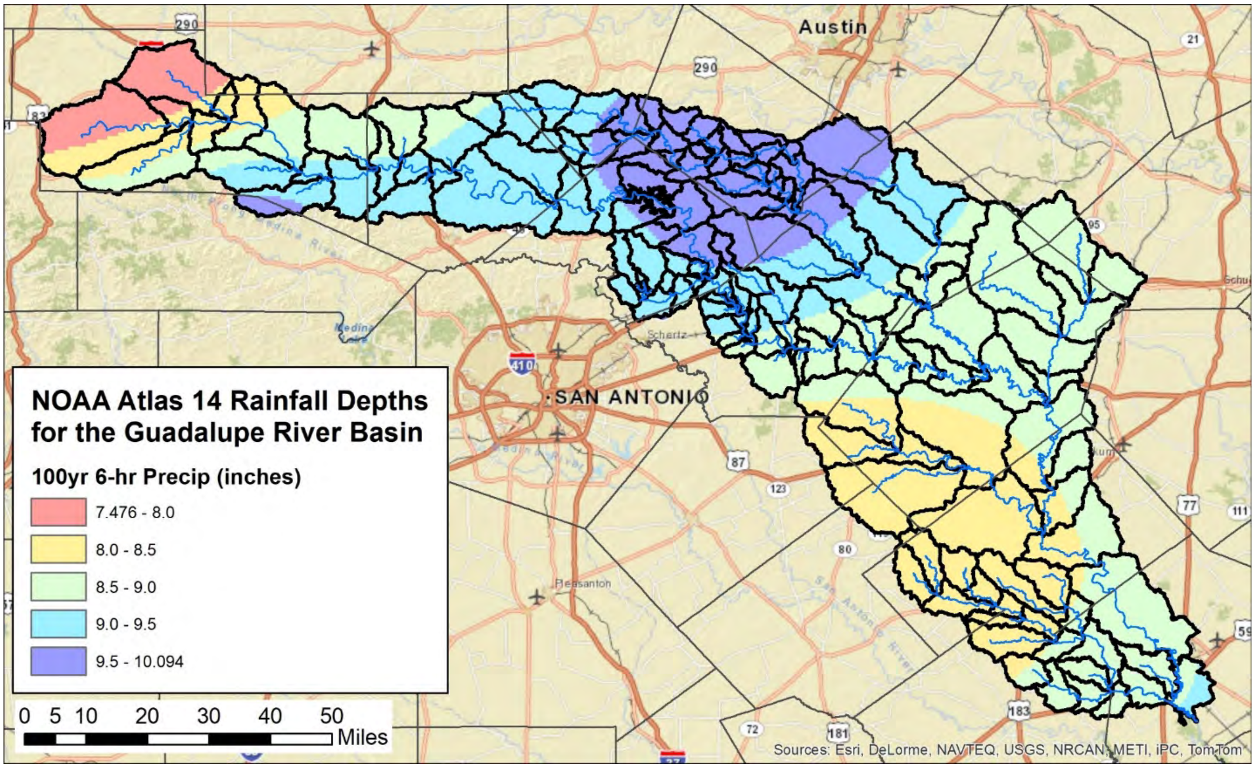

Figure 4.3: 100-yr, 6-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

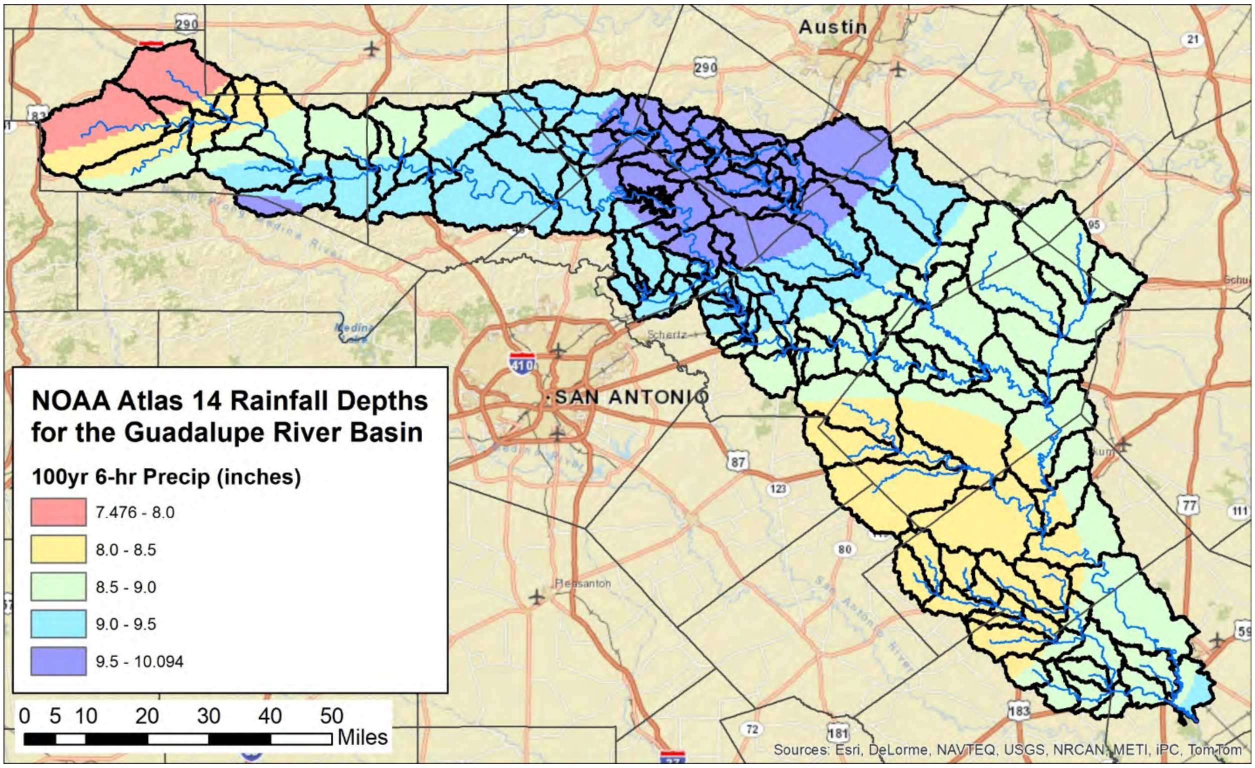

Figure 4.4: 100-yr, 12-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

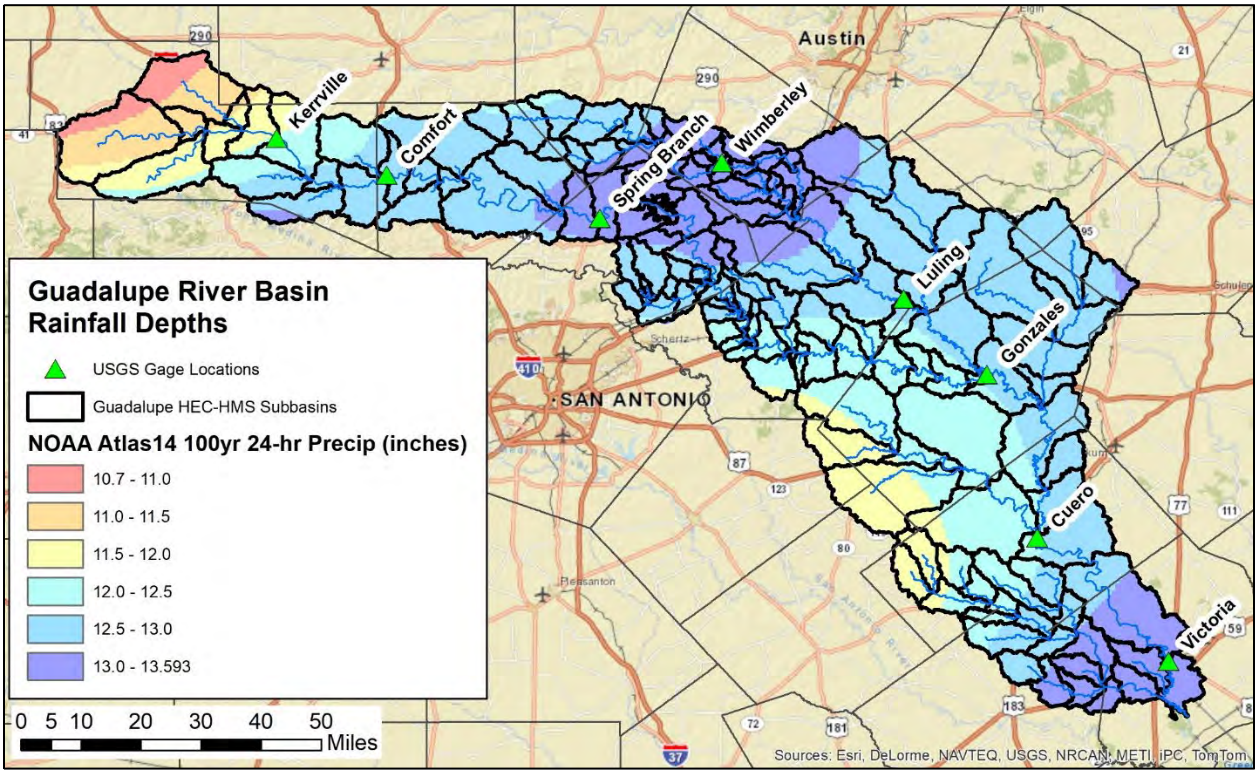

Figure 4.5: 100-yr, 24-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

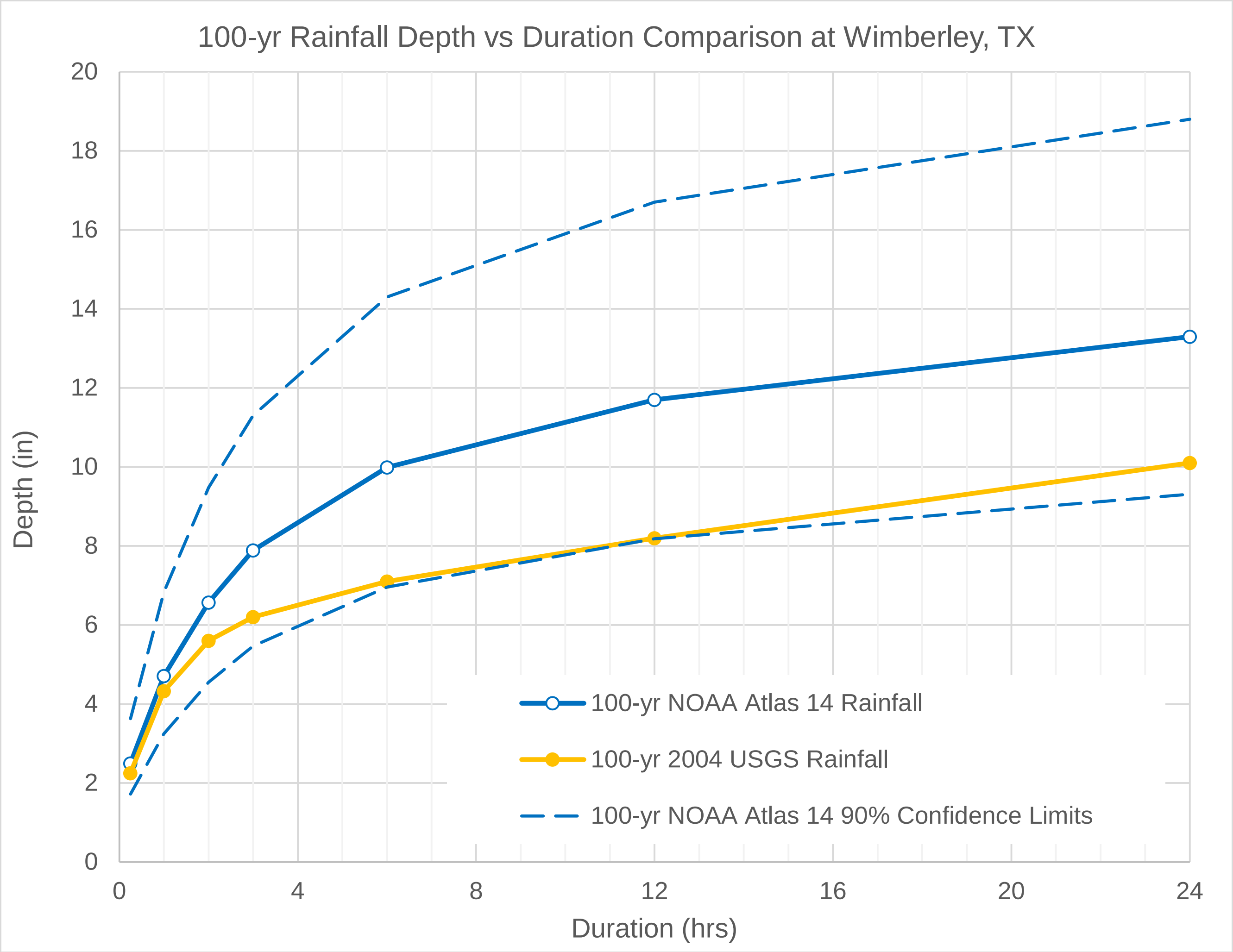

Figure 4.6: 100-yr Rainfall Depth versus Duration Comparison at Wimberley, TX

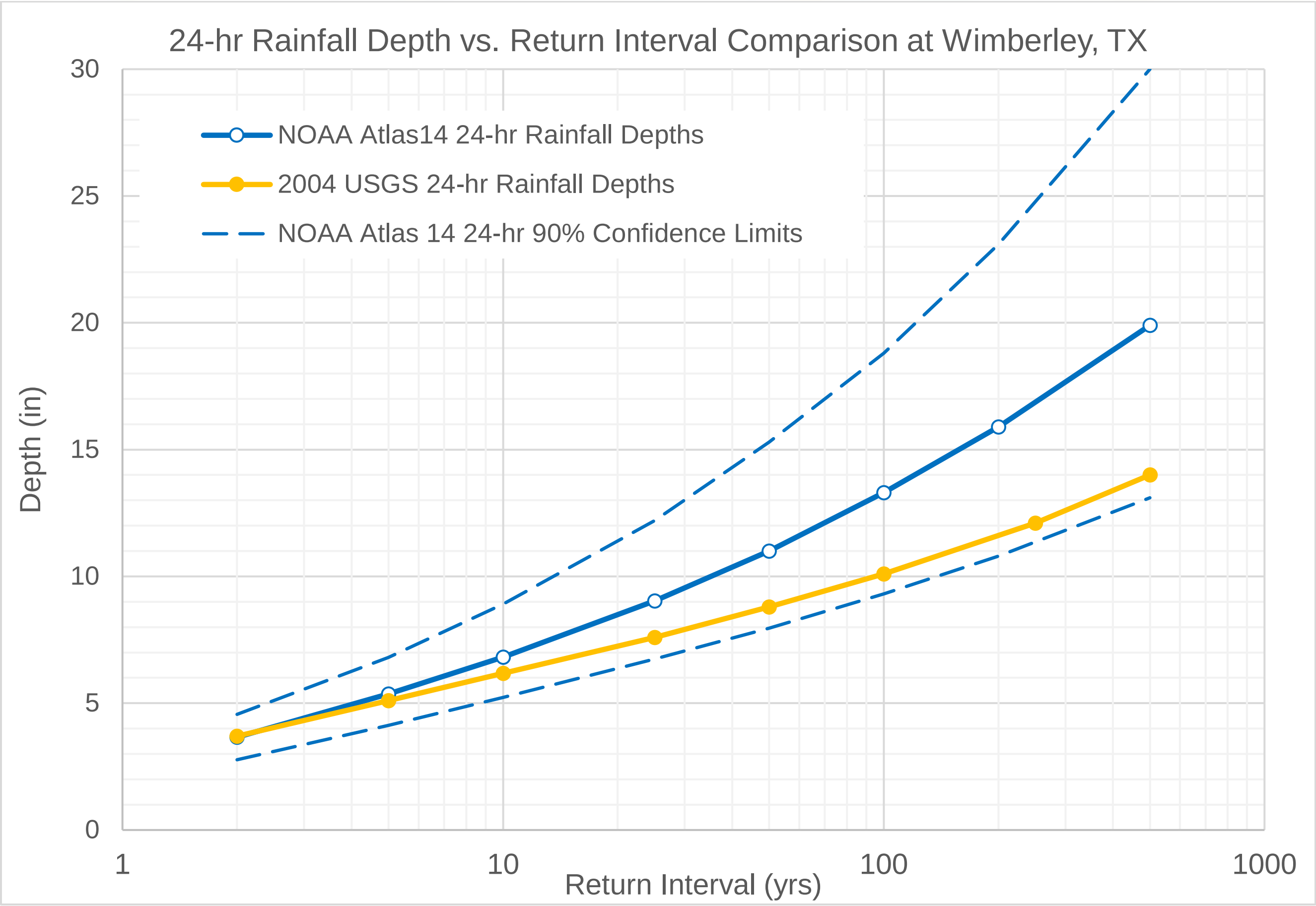

Figure 4.7: 24-hr Rainfall Depth versus Return Interval Comparison at Wimberley, TX

From these figures, one can see that the NA14 100-yr rainfall depths in the Guadalupe River basin were significantly higher than the previous rainfall estimates from the 2004 USGS Rainfall Atlas. Additional information and discussion on the NA14 rainfall data is included in Chapter 10 of this report.

4.7 STREAM FLOW DATA

The USGS stream flow gages located in the basin are listed in Table 4.10 below. Table 4.10 also indicated whether the gage record was used in this study's statistical analysis or in the calibration of the HEC-HMS model. For these gage sites, annual peak flow data and 15-minute stream flow and stage data was collected from the USGS NWIS website.

Table 4.10: USGS Stream Flow Gages in the Guadalupe Basin

SHEF ID	USGS ID	Location Description	Gage Type	Drainage Area (sq mi)	Used in HEC-HMS Calibration	Included in the Statistical Analysis
HNFT2	08165300	N FK Guadalupe River nr Hunt	Flow/Stage	169	Yes	Yes
HNTT2	08165500	Guadalupe River at Hunt	Flow/Stage	288	Yes	Yes
JCIT2	08166000	Johnson Creek nr Ingram	Flow/Stage	114	Yes	Yes
GRHT2	08166140	Guadalupe River ab Bear Creek at Kerrville	Flow/Stage	494		

SHEF ID	USGS ID	Location Description	Gage Type	Drainage Area (sq mi)	Used in HEC-HMS Calibration	Included in the Statistical Analysis
KRRT2	08166200	Guadalupe River at Kerrville	Flow/Stage	510	Yes	Yes
GCTT2	08166250	Guadalupe River nr Center Point	Flow/Stage	553		
COMT2	08167000	Guadalupe River at Comfort	Flow/Stage	839	Yes	Yes
GUBT2	08167200	Guadalupe Rv at FM 474 nr Bergheim, TX	Stage	N/A		
SRGT2	08167500	Guadalupe River nr Spring Branch	Flow/Stage	1315	Yes	Yes
STLT2	08167800	Guadalupe River at Sattler	Flow/Stage	1436		Yes
BEST2	08167870	Bear Ck at FM 2722 nr Sattler, TX	Stage	8.75		
GRTT2	08167900	Guadalupe Rv at Third Crossing nr Sattler, TX	Stage	N/A		
HOST2	08168000	Hueco Spgs nr New Braunfels, TX	Flow/Stage	N/A		
NBRT2	08168500	Guadalupe River abv Comal River at New Braunfels	Flow/Stage	1518	Yes	Yes
WCST2	08168770	WFk Dry Comal Ck at Schuetz Dam, New Braunfels, TX	Stage	N/A		
NBDT2	08168797	Dry Comal Ck at Loop 337 nr New Braunfels, TX	Stage	107	Yes	
CMOT2	08168913	Comal Rv (oc) nr Landa Lk, New Braunfels, TX	Flow/Stage	112		
CMRT2	08168932	Comal Rv (nc) nr Landa Lk, New Braunfels, TX	Flow/Stage	112		
NBCT2	08169000	Comal River at New Braunfels	Flow/Stage	130	Yes	Yes
GBCT2	08169500	Guadalupe River at New Braunfels	Stage	1652		Yes
SEGT2	08169740	Guadalupe Rv at Hwy 123-BR at Sequin, TX	Stage	N/A		
SGGT2	08169792	Guadalupe River at FM 1117 nr Seguin	Stage	1957	Yes	
GWGT2	08169845	Guadalupe Rv at CR 143 nr Gonzales, TX	Stage/Flow	N/A		
SRUT2	08170500	San Marcos at San Marcos, TX	Flow/Stage	49	Yes	Yes
BAPT2	08170800	Blanco Rv at Crabapple Rd nr Blanco, TX	Stage	53		
LBFT2	08170890	Little Blanco Rv at FM32 nr Fischer, TX	Stage	50		
BFST2	08170950	Blanco Rv at Fischer Store Rd nr Fischer, TX	Flow/Stage	N/A		
JWMT2	08170990	Jacobs Well Spg nr Wimberley, TX	Flow/Stage	N/A		
WMBT2	08171000	Blanco River at Wimberley, TX	Flow/Stage	355	Yes	Yes
HFXT2	08171290	Blanco Rv at Halifax Rch nr Kyle, TX	Flow/Stage	391		
KYET2	08171300	Blanco River nr Kyle, TX	Flow/Stage	412	Yes	Yes
BSMT2	08171350	Blanco Rv at San Marcos, TX	Flow/Stage	436		
SMRT2	08171400	San Marcos Rv nr Martindale, TX	Flow/Stage	547		

SHEF ID	USGS ID	Location Description	Gage Type	Drainage Area (sq mi)	Used in HEC-HMS Calibration	Included in the Statistical Analysis
LLGT2	08172000	San Marcos River at Luling	Flow/Stage	838	Yes	Yes
LCPT2	08172400	Plum Creek at Lockhart	Flow/Stage	112	Yes	Yes
LULT2	08173000	Plum Creek nr Luling	Flow/Stage	309	Yes	Yes
GNLT2	08173900	Guadalupe Rv at Gonzales, TX	Flow/Stage	3490	Yes	Yes
SFWT2	08174200	Sandy Fork Ck at Hwy 97 nr Waelder, TX	Flow/Stage	137		
PEWT2	08174550	Peach Creek at Hwy 90 nr Waelder, TX	Flow/Stage	N/A		
DLWT2	08174600	Peach Ck bl Dilworth, TX	Flow/Stage	460	Yes	Yes
GDHT2	08174700	Guadalupe Rv at Hwy 183 nr Hochheim, TX	Flow/Stage	4071		
SCGT2	08174970	Sandies Ck at FM 108 nr Smiley, TX	Stage	197		
WHOT2	08175000	Sandies Ck nr Westhoff, TX	Flow/Stage	549	Yes	Yes
CUET2	08175800	Guadalupe Rv at Cuero, TX	Flow/Stage	4934	Yes	Yes
VICT2	08176500	Guadalupe Rv at Victoria, TX	Flow/Stage	5198	Yes	Yes
WRST2	08176550	Fifteenmile Ck nr Weser, TX	Stage	167	Yes	Yes
SCDT2	08176900	Coleto Ck at Arnold Rd Crsg nr Schroeder, TX	Flow/Stage	357	Yes	Yes
PEDT2	08177300	Perdido Ck at FM 622 nr Fannin, TX	Flow/Stage	28	Yes	Yes
CCVT2	08177500	Coleto Ck nr Victoria, TX	Flow/Stage	500	Yes	Yes
DUPT2	08177520	Guadalupe Rv nr Bloomington, TX	Flow/Stage	5816	Yes	
TIVT2	08188800	Guadalupe Rv nr Tivoli, TX	Flow/Stage	10128		
TVLT2	08188810	Guadalupe Rv at SH 35 nr Tivoli, TX	Flow/Stage	10280		

4.8 RESERVOIR PHYSICAL DATA

For Canyon Dam, the Elevation-Storage tables, spillway rating curves, and outlet structure rating curves were all provided from the USACE Fort Worth District

Approximately 200 NRCS dams and other small dams are located within the Guadalupe River Basin above Bloomington, Texas. Of these, reservoir elements were used in the HEC-HMS rainfall-runoff model for four NRCS dams in the upper San Marcos basin and six dams within the Comal River Basin. These dams were selected to be modeled in detail due to their sizable flood storage and their proximity to developed areas. Table 4.11 summarizes the reservoir data obtained for these dams and their corresponding data sources. The remaining dams were scattered throughout the rural areas of the basin, especially on the York Creek and Plum Creek watersheds. These dams were not modeled in detail but were accounted for in the model through adjustments to the loss rates and peaking coefficients. Data for these dams was obtained from the National Inventory of Dams (USACE, 2016).

In addition, six hydropower dams are located along the Guadalupe River between New Braunfels and Gonzales. These hydropower dams were built in the 1920s and early 1930s and are operated by the Guadalupe Blanco River Authority. While these dams do not have significant flood control storage, they do have an effect on the way a flood wave attenuates as it moved downstream. Therefore, these structures were included in the model also.

Table 4.11: Reservoir Data and Sources for Dams Modeled in Detail

Reservoir / Facility	Data	Source(s)
Canyon Dam	Elevation-Storage, Spillway and Outlet Structures	USACE – Fort Worth District
Upper San Marcos NRCS Site 1	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Upper San Marcos NRCS Site 2	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Upper San Marcos NRCS Site 3	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Upper San Marcos NRCS Site 5	Elevation-Storage-Discharge	NRCS As-Built Plans
Comal River NRCS Site 1	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Comal River NRCS Site 2	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Comal River NRCS Site 3	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Comal River NRCS Site 4	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Comal River NRCS Site 5	Elevation-Storage, Spillway and Outlet Structures	NRCS As-Built Plans
Dry Comal Ck FRS (Comal Co.)	Elevation-Storage, Spillway and Outlet Structures	County As-Built Plans
Lake Dunlap	Elevation-Discharge	Guadalupe-Blanco River Authority
Lake McQueeney	Elevation-Discharge	Guadalupe-Blanco River Authority
Lake Nolte	Elevation-Discharge	Guadalupe-Blanco River Authority
Lake Placid	Elevation-Discharge	Guadalupe-Blanco River Authority
Lake Gonzales	Elevation-Discharge	Guadalupe-Blanco River Authority
Lake Wood (H-5)	Elevation-Discharge	Guadalupe-Blanco River Authority

4.9 SOFTWARE AND DOCUMENTATION

The following table provides a summary of the significant computer software programs and versions that were used in the hydrologic analysis of the basin.

Table 4.12: List of Computer Programs Used in this Hydrology Study

Program	Version	Capability	Developer
ArcGIS	10.2.2	Geographical Information System	ESRI
HEC-DSSVue	2.0.1	Plot, tabulate, edit and manipulate data in HEC-DSS format	HEC
HEC-GeoHMS	10.2	Watershed delineation and generating HEC-HMS input	HEC
HEC-METVUE	2.2.10.2 Beta	Processing and viewing precipitation data	HEC
HEC-HMS	4.2.1	Rainfall-runoff simulation	HEC
HEC-RAS	5.0.3	Steady and Unsteady Flow Analysis, ModPuls routing	HEC
HEC-SSP	2.1.1	Statistical Software Package	HEC
RMC-RFA	1.0.0	Reservoir Frequency Analysis	RMC
PeakFQ	7.1	Statistical Analysis of Gage Records for Flood Frequency	USGS

5 Statistical Hydrology

Statistical analysis of the observational record (systematic and historical) at USGS streamflow-gaging stations (stream gages) provides an informative means of estimating flood frequency flows. The annual peak streamflow data as part of systematic operation of a stream gage provide the foundation, but additional historical information or anticipated flow contexts also can be used. An annual peak streamflow is defined as the maximum instantaneous streamflow for a stream gage for a given water year, and annual peak streamflow data for USGS stream gages can be acquired through the USGS National Water Information System (NWIS) (USGS, 2016). The statistical analyses are based on water year increments. A water year is the 12-month period October 1 through September 30 designated by the calendar year in which it ends.

For the statistical hydrology portion of the multi-layered analysis, InFRM team members from the USGS analyzed annual peak streamflow gage records for the selected USGS stream gages listed in Table 5.1. These stream gages have at least 20 years of annual peak streamflow data and are important to the InFRM-study objectives. The locations of the stream gages are shown in Figure 5.1. In August of 2017, Hurricane Harvey made landfall on the Texas Gulf Coast and slowly moved northeast. As it did so, it produced 60 inches (in.) of rainfall in some areas, which is approximately 15 in. more than the average annual amount of rainfall for eastern Texas and the Texas Coast (Blake and Zelinsky, 2018). As a result of Hurricane Harvey, two of the gages included in the Guadalupe River basin analysis recorded annual peak streamflow ranking in the top five of all annual peaks for that given station. Therefore, the period of record analyzed at those gages was extended through 2017 to include this exceptional event.

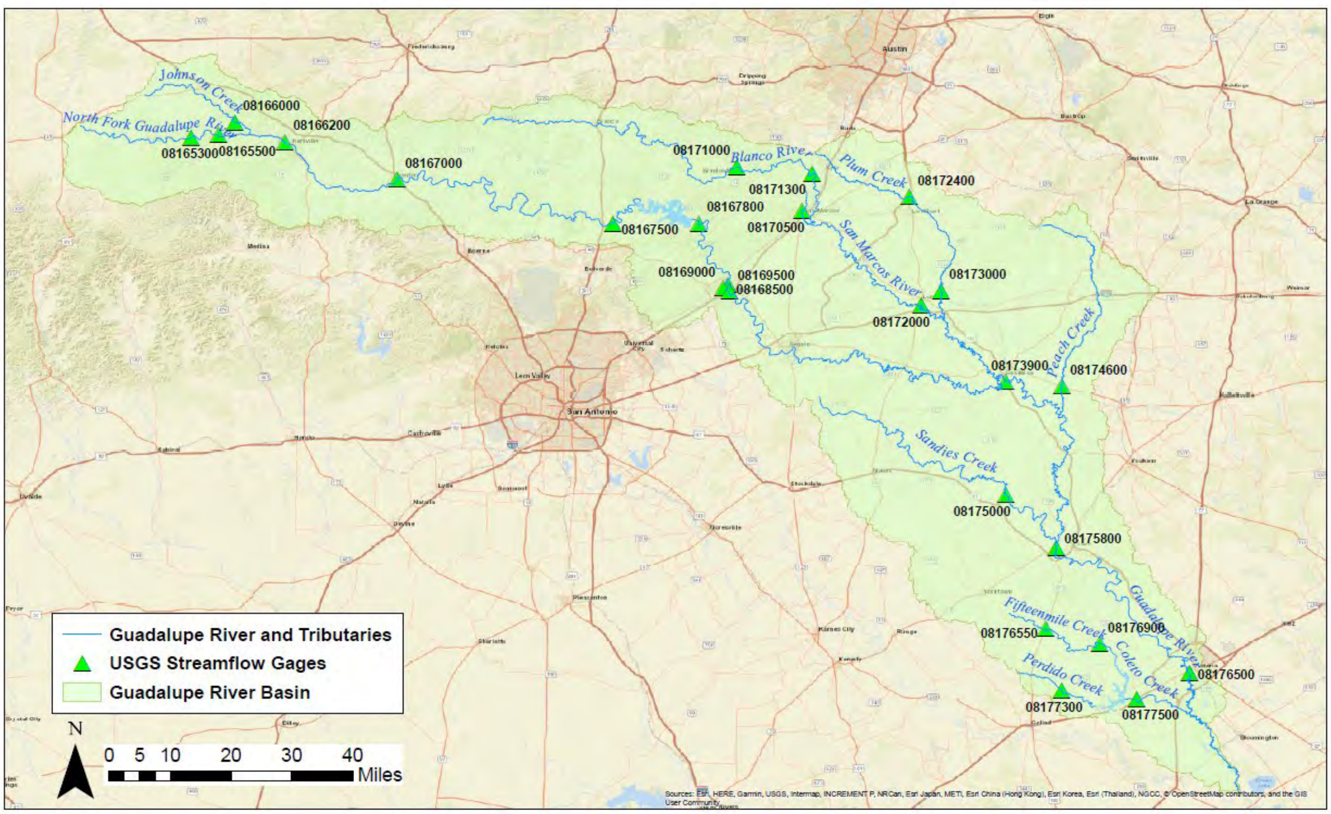

Figure 5.1: Map of USGS Streamflow-gaging stations included in the Statistical Analysis

Table 5.1. Summary of Selected U.S. Geological Survey Streamflow-Gaging Stations in the Guadalupe River Basin, South-Central, Texas with Ancillary Information Concerning Statistical Analyses

[Est., estimated; mi², square miles; –, dimensionless or not applicable; in., inches; ft ³/s, cubic feet per second; acre-ft/mi ², acre-feet per square mile; PRISM, data product of the Northwest Alliance for Computational Science and Engineering (2016, accessed on July 16, 2016 at *http://www.prism.oregonstate.edu/explorer/*); MGBT-0, indicates that the Multiple Grubbs-Beck test for low-outlier threshold did not identify low outliers, unfortunately USGS-PeakFQ software does not report the numerical value of the threshold. Note, right-justification and red text for p-value indicates a statistically significant trend at alpha=0.05, which is directly caused by completion of Canyon Reservoir about 1964 and note general lack of significant trend detection for downstream main stem Guadalupe River streamgages given suitable spanning of record across 1964.]

Station number	Station name	Latitude	Longitude	Horizontal datum as reported by NWISWeb public interface	Period of analyzed annual peak stream-flows	Contri-buting drainage area (mi^2)	Main-channel slope (Asquith and Roussel, 2009) (–)	Mean annual rainfall (PRISM 1981–2010) (in.)	Cumulative flood storage for last year of analysis (acre-ft/mi^2)	Est. effect of cumulative flood storage on mean annual peak streamflow (Asquith, 2001, fig. 11a) (ft^3/s)	Low-outlier threshold used (ft^3/s)	Kendall's Tau p-value of analyzed annual peak streamflows (–)
08165300	North Fork Guadalupe River near Hunt, Tex.	30°03'50"	99°23'12"	NAD27	1852–2015	169.0	0.00385	29.93	0.00	0	1,110	0.090
08165500	Guadalupe River at Hunt, Tex.	30°04'11"	99°19'17"	NAD27	1852–2015	288.0	0.00362	30.20	0.03	0	1,080	0.058
08166000	Johnson Creek near Ingram, Tex.	30°06'00"	99°16'58"	NAD27	1852–2015	114.0	0.00440	30.51	1.16	0	MGBT-0	0.925
08166200	Guadalupe River at Kerrville, Tex.	30°03'11"	99°09'47"	NAD27	1852–2015	510.0	0.00203	31.73	3.56	0	MGBT-0	0.046
08167000	Guadalupe River at Comfort, Tex.	29°57'55"	98°53'50"	NAD83	1848–2015	839.0	0.00189	33.49	4.42	0	3,110	0.495
08167500	Guadalupe River near Spring Branch, Tex.	29°51'37"	98°23'00"	NAD27	1900–2015	1,315.0	0.00199	33.36	3.08	0	1,000	0.607
08167800	Guadalupe River at Sattler, Tex.	29°51'32"	98°10'47"	NAD27	1964–2015	1,436.0	0.00187	35.75	520.38	-7,966	700	0.646
08168500	Guadalupe River above Comal River at New Braunfels, Tex.	29°42'53"	98°06'35"	NAD27	1928–2015	1,518.0	0.00323	34.68	492.27	-8,238	5,000	0.008
08169000	Comal River at New Braunfels, Tex.	29°42'21"	98°07'20"	NAD27	1869–2015	130.0	--	34.68	292.86	-560	1,500	0.657
08169500	Guadalupe River at New Braunfels, Tex.	29°41'52"	98°06'23"	NAD27	1915–2015	1,652.0	0.00189	34.68	475.58	-8,842	5,000	0.085

Table 5.1. Summary of Selected U.S. Geological Survey Streamflow-Gaging Stations in the Guadalupe River Basin, South-Central, Texas with Ancillary Information Concerning Statistical Analyses—Continued

Station number	Station name	Latitude	Longitude	Horizontal datum as reported by NWISWeb public interface	Period of analyzed annual peak stream-flows	Contri-buting drainage area (mi^2)	Main-channel slope (Asquith and Roussel, 2009) (–)	Mean annual rainfall (PRISM 1981–2010) (in.)	Cumulative flood storage for last year of analysis (acre-ft/mi^2)	Est. effect of cumulative flood storage on mean annual peak streamflow (Asquith, 2001, fig. 11a) (ft^3/s)	Low-outlier threshold used (ft^3/s)	Kendall's Tau p-value of analyzed annual peak streamflows (–)
08170500	San Marcos River at San Marcos, Tex.	29°53'20"	97°56'02"	NAD27	1995–2015	48.9	–	33.68	520.12	-271	MGBT-0	0.315
08171000	Blanco River at Wimberley, Tex.	29°59'39"	98°05'19"	NAD27	1869–2016	355.0	0.00342	36.63	2.50	0	1,360	0.542
08171300	Blanco River near Kyle, Tex.	29°58'45"	97°54'35"	NAD27	1929–2016	412.0	0.00315	34.79	2.16	0	4,000	0.597
08172000	San Marcos River at Luling, Tex.	29°39'58"	97°39'02"	NAD27	1869–2016	838.0	0.00172	34.16	73.95	-1,362	MGBT-0	0.738
08172400	Plum Creek at Lockhart, Tex.	29°55'22"	97°40'44"	NAD27	1959–2016	112.0	0.00327	34.56	360.38	-532	1,380	0.830
08172400.01	Plum Creek at Lockhart, Tex.	29°55'22"	97°40'44"	NAD27	1930–2016	112.0	0.00327	34.56	360.38	-532	1,380	0.830
08173000	Plum Creek near Luling, Tex.	29°41'58"	97°36'12"	NAD27	1930–2016	309.0	0.00209	34.67	221.08	-1,142	5,910	0.878
08173900	Guadalupe River at Gonzales, Tex.	29°29'03"	97°27'00"	NAD27	1977–2016	3,490.0	–	35.38	270.13	-14,411	MGBT-0	0.782
08174600	Peach Creek below Dilworth, Tex.	29°28'26"	97°18'59"	NAD27	1960–2015	460.0	0.00118	36.04	3.44	0	560	0.341
08174600.01	Peach Creek below Dilworth, Tex.	29°28'26"	97°18'59"	NAD27	1960–2015	460.0	0.00118	36.04	3.44	0	560	0.341

Table 5.1. Summary of Selected U.S. Geological Survey Streamflow-Gaging Stations in the Guadalupe River Basin, South-Central, Texas with Ancillary Information Concerning Statistical Analyses—Continued

Station number	Station name	Latitude	Longitude	Horizontal datum as reported by NWISWeb public interface	Period of analyzed annual peak stream-flows	Contri-buting drainage area (mi^2)	Main-channel slope (Asquith and Roussel, 2009) (–)	Mean annual rainfall (PRISM 1981–2010) (in.)	Cumulative flood storage for last year of analysis (acre-ft/mi^2)	Est. effect of cumulative flood storage on mean annual peak streamflow (Asquith, 2001, fig. 11a) (ft^3/s)	Low-outlier threshold used (ft^3/s)	Kendall's Tau p-value of analyzed annual peak streamflows (–)
08175000	Sandies Creek near Westhoff, Tex.	29°12'54"	97°26'57"	NAD27	1914–2015	549.0	0.00153	34.80	2.32	0	MGBT-0	0.407
08175800	Guadalupe River at Cuero, Tex.	29°05'25"	97°19'46"	NAD27	1935–2017	4,934.0	0.00048	34.31	192.04	-16,733	MGBT-0	0.026
08176500	Guadalupe River at Victoria, Tex.	28°47'34"	97°00'46"	NAD27	1935–2017	5,198.0	0.00034	39.10	182.32	-17,044	MGBT-0	-0.007
08176550	Fifteenmile Creek near Weser, Tex.	28°53'51"	97°21'17"	NAD27	1985–2015	167.0	0.00188	34.33	0.36	0	1,000	0.568
08176900	Coleto Creek at Arnold Road Crossing near Schroeder, Tex.	28°51'41"	97°13'34"	NAD27	1872–2015	357.0	0.00154	36.53	0.17	0	8,060	0.079
08176900.01	Coleto Creek at Arnold Road Crossing near Schroeder *combined with* 08177000 Coleto Creek near near Schroeder, Tex.	28°51'41"	97°13'34"	NAD27	1872–2015	357.0	0.00154	36.53	0.17	0	8,060	0.116
08177300	Perdido Creek at FM 622 near Fannin, Tex.	28°45'05"	97°19'01"	NAD27	1872–2015	28.0	0.00323	34.85	0.00	0	2,640	0.278
08177500	Coleto Creek near Victoria, Tex.	28°43'51"	97°08'18"	NAD27	1872–2015	500.0	0.00137	37.68	267.83	-2,055	8,550	0.203

There are two stream gages, though being on river main stems, are not included in this study. The USGS stream gage for the Guadalupe River at Bear Creek at Kerrville (USGS station identification number 08166140) has sporadic and select annual peak streamflow data only for 11 years between the years 1983–2015. The USGS stream gage for the San Marcos River near Martindale (USGS station identification number 08171400) was not included because a sufficient period of record (record 2011–present) is lacking to support computation of flood flow frequency. Neither of these stream gages is identified in Table 5.1.

There are three duplicated entries in Table 5.1. A duplicated entry for Plum Creek at Lockhart is shown because an alternative analysis was made; the period of time analyzed for the two entries for Plum Creek at Lockhart have a different beginning year. A duplicated entry for Peach Creek below Dilworth also is shown because an alternative analysis was made. A duplicated entry for Coleto Creek at Arnold Road Crossing is shown because an alternative analysis was made by combining the record of Coleto Creek at Arnold Road Crossing near Schroeder and a separate but older stream gage (Coleto Creek at Schroeder). For the three duplications, it is useful to show a pseudo-station identification number to keep some discussion consistent with software outputs. The period to time analyzed for the two entries for Peach Creek below Dilworth reflect alternatives to mitigate for a substantial gap in record (1980–2000). The two columns related to "flood storage" are discussed in Section 5.6. Lastly, the two columns related to "flood storage" are discussed elsewhere in this chapter.

The remainder of this chapter is organized as follows: Section 5.1 provides a brief review of statistical methods pertinent to this chapter, Section 5.2 provides a review of stream gage data and settings for computations and a review with discussion of statistical flood flow frequency results, Section 5.3 provides examples of how statistical flood flow frequency estimates change over time as the amount and nature of information changes, Section 5.4 provides perspective of the sensitivity of statistical estimates of flood flow frequency to historic climate variability in the study area, Section 5.5 provides limited discussion on landuse related to flood regulation (flood storage).

5.1 STATISTICAL METHODS

The statistical methods involved in this chapter include the fitting of a log-Pearson Type III probability distribution (LPIII) to the data. The general purpose of fitting a probability distribution is to provide an objective mechanism to extrapolate to hazard levels (as represented by annual exceedance probabilities and equivalently expressed as annual recurrence interval or recurrence interval measured in years) beyond those represented by the sample size of annual peak streamflow data for a given stream gage. A distribution, such as the LPIII, can be fit by numerous methods, and the logarithms (base-10) of the annual peak streamflow data are most commonly used in practice. The USGS-PeakFQ software version 7.1 (Veilleux and others, 2013; USGS, 2014) provide the foundation for the results of the flood frequency flows which are specified by average annual recurrence intervals computed and extracted from software output at 2, 5, 10, 25, 100, 200, and 500 years and accompanied by the 95-percent confidence limits.

Flood flow frequency analyses were conducted for the stream gages using the annual peak data from the USGS NWIS website (USGS, 2016) with historical information when available and data augmentation when required. The Interagency Advisory Committee on Water Data (IACWD, 1982) describes a so-called Bulletin 17B method (B17B) to conduct the frequency analysis (USGS, 2014), but the statistical frequency analysis performed for the Guadalupe River basin is singularly focused on updated guidelines from Bulletin 17C (England and others, 2018).

A complication to be addressed is that periods of record between stream gages are seldom identical. An effort to normalize somewhat the years of data input into statistical methods amongst the stream gages was made. The effort was based on scrutiny of available data in observational records and in particular this includes peak streamflows and (or) stages (gage heights) of notable flood events outside the systematic record. An objective is to mitigate for asymmetry in time periods between stream gages by defendable inclusion of historical and nonstandard information. It is deemed important to comment on data processing, but here it is important to remark that interpretations are required and differing analysts could produce somewhat different results. The fact that the stream gages selected for analysis generally, though not exclusively, have long systematic records tends to imply that different interpretations for analysis lead to differences in detail but not in generalities in regards to the final LPIII fits (flood flow frequency curves) that are recommended for application. Mathematically nonstandard peak streamflow information, such as discharge thresholds and discharge intervals, more often influence (usually contract) the confidence limits of the fitted LPIII and less so for the actual fitted curve.

Other statistical techniques used for data evaluation included the Kendall Test. The Kendall's tau test (Hollander and Wolfe, 1973; Helsel and Hirsch, 2002) was used through the USGS-PeakFQ software to detect for the presence of monotonic trends in the annual peak streamflow data. Kendall's tau test is a popular statistic for quantifying the presence of monotonic changes in the central tendency of streamflow data in time. The Kendall tau results are listed in Table 5.1, and only one of the stream gages show a trend in annual peak streamflow for an alpha at the 0.10 probability significance level. This is the Guadalupe River above Comal River at New Braunfels and only this location on the main stem of the Guadalupe River has record balanced prior and after reservoir construction compared to the other stream gages below Canyon Lake in the vicinity of New Braunfels, Texas. This is the formative reason that the Kendall Tau test detects a significant trend for this stream gage.

The use of the expected-moments algorithm (EMA, England and others, 2017; USGS, 2014) permits sophisticated interpretations of the historical record that are intended to enhance the estimates of peak streamflow, especially for the rare frequency events such as the 100-year streamflow. Inclusion of historical record interpretations can have the net impact of lowering (decreasing) flood flow frequency estimates for the largest of streamflows because the largest documented events are assigned lower empirical probabilities when historical information is available. EMA also permits inclusion of nonstandard information such as data censoring. For example, an annual peak might be known to be lower than a specified discharge threshold. EMA can also accommodate time varying discharge thresholds based on assigning a discharge threshold as a "highest since" (a term intrinsic to flood flow frequency analyses) within discrete blocks or intervals of time. This nonstandard information collectively can be thought of as a framework fostering record extension.

Although the drainage-area ratio method is used with limited selectivity for record augmentation (Asquith and others, 2006), because of the available overlapping years of annual peak streamflow in select circumstances, the line of organic correlation (LOC) described by Helsel and Hirsch (2002) and equivalently the method of total-least squares (TLS) is preferred for record extension when records between to stream gages are compared. The TLS regression is also preferred over conventional linear regression because of a critical need for variance maintenance; conventional regression will result in underestimation of variability and hence a flood flow frequency curve that would not be steep enough and is expected to contribute to underestimation of flood flow frequency. Application of TLS is location specific and is discussed in Section 5.2. A TLS regression equation was used to make estimates of discharge and these were converted to a discharge interval by adding and subtracting one-standard deviation of the equation from the estimate to form the interval.

Two especially important options of the USGS-PeakFQ software are the choice of a low-outlier threshold and generalized skew, which are technical elements of the statistical analysis. The skew involves the decision as to incorporate in the analyses in a weighting between the generalized skew and that computed using the site-specific data. Low outliers (potentially influential low floods, PILF) within a time series of peak streamflow, such as annual peaks that in reality were likely not storm flows or highly localized storm flow, often require removal from the analysis using a form of conditional probability adjustment. To this end, the so-called Multiple Grubbs-Beck low-outlier threshold (MGBT) was used. For location-specific reasons, the analyst can manually specify a low-outlier threshold. These are identified in Section 5.2 and listed in Table 5.1. Skew is an expression of the curvature or shape of the LPIII distribution intended to mimic that of the data (Asquith, 2011a,b). The importance of a generalized or regional skew is stressed in IACWD (1982) to mitigate for high sampling variance using typical record lengths available for stream gages. A substantial motivation for a generalized skew is to compensate for inefficient estimation of the product moment skew for highly variable and skewed data such as annual peak streamflow. The generalized skew coefficient is a built-in feature of USGS-PeakFQ but can be overridden by the user. Because of age as well as study objectives for the present (2016) study, the maps of generalized skew for Texas in IACWD (1982) or Judd and others (1996) are of uncertain applicability for this study. The former reference represents a highly generalized estimate of skew dating from about the late 1970s, the later reference represents a substantially more recent, but still dated, estimate of generalized skew for Texas. Low-outlier thresholds can greatly affect the estimate of skewness; for this study, the station-skew option in USGS-PeakFQ exclusively was used.

Confidence limits of flood flow frequency can be informative to decision makers. The lower and upper limits of 95-percent confidence intervals were computed for this study. Confidence intervals can be expected to encompass the true value 95 percent of the time (Good and Hardin, 2003, p. 100). The range in these numbers for the lower and upper 95-percent confidence limits increases with the more extreme events.

5.2 STREAM GAGE DATA AND STATISTICAL FLOOD FLOW FREQUENCY RESULTS

The stream gage data are reviewed in this section. Several of these stream gages have augmentation to their records based on historical information, gaps in record, or other circumstances. Some of these gaps are substantial enough to require a listing of information that was manually added to the USGS-PeakFQ software. The data listings are in Table 5.2 (located at the beginning of the section) that is referenced as need on a gage-by-gage basis. A brief introduction to the table is needed. The "low estimate" refers to a lower estimate of annual peak flow that is typically defined as minus one standard error of estimate from a total least squares (TLS) regression (also known as line of organic correlation) and a "high estimate" is the converse typically defined as plus one standard error of estimate from TLS. The "point estimate" represents an estimated annual peak flow from methods such as the drainage-area ratio method (Asquith and others, 2006). Values are listed to the nearest 1 cubic feet per second (ft^3/s), which functions as an analyst-needed indicator of auxiliary information added to analyses described in the text.

This section presents the results of the statistical analysis of the annual peak streamflow data at each analyzed stream gage. Statistical flow frequency estimates, along with associated uncertainty intervals, are presented in both graphical and tabular formats. Tables of flood flow frequency values with attendant confidence limits are listed in Table 5.3 (located at the end of the section). This table contains the preferred values for the statistical analysis computed using USGS-PeakFQ software with EMA-LPIII methods. Table 5.4 lists LPIII fits using B17B methods using exclusively the systematic record.

Table 5.2. Estimates of Annual Peak Streamflow by Discharge Interval by Total Least Squares (TLS) Regression or Other Methods for Selected U.S. Geological Survey Streamflow-Gaging Stations in the Guadalupe River Basin, South-Central, Texas

[ft^3/s, cubic feet per second; "<=>", a compound symbol to denote a discharge interval: low < unobserved value < high.]

Station number or water year	Either low estimate for discharge interval or point estimate (ft^3/s)		High estimate for discharge interval (ft^3/s)	Station number or water year	Either low estimate for discharge interval or point estimate (ft^3/s)		High estimate for discharge interval (ft^3/s)	Station number or water year	Either low estimate for discharge interval or point estimate (ft^3/s)		High estimate for discharge interval (ft^3/s)
08166000, TLS regression with 08165500				08172400.01, TLS regression with 08173000—Continued				08173000, TLS regression with 08172000 (scenario 1)			
1994	3,377	<=>	18,685	1936	30,131	<=>	92,324	1994	1,029	<=>	3,163
1995	238	<=>	1,319	1937	1,585	<=>	4,857	1995	3,122	<=>	9,598
1996	433	<=>	2,398	1938	4,151	<=>	12,720	1996	433	<=>	1,330
1997	5,809	<=>	32,132	1939	209	<=>	640	1997	9,371	<=>	28,808
1998	4,070	<=>	22,517	1940	3,787	<=>	11,604	1998	2,544	<=>	7,821
1999	601	<=>	3,327	1941	3,714	<=>	11,381	1999	87,644	<=>	269,424
08172000, TLS regression analysis with 08173000				1942	13,623	<=>	41,742	2000	331	<=>	1,019
1930	3,908	<=>	12,909	1943	729	<=>	2,235	08173000, TLS regression with 08172400 (scenario 2)			
1931	3,311	<=>	10,938	1944	1,199	<=>	3,674	1994	178	<=>	516
1932	3,658	<=>	12,083	1945	2,120	<=>	6,498	1995	7,750	<=>	22,395
1933	3,128	<=>	10,334	1946	6,967	<=>	21,348	1996	594	<=>	1,718
1934	2,699	<=>	8,916	1947	7,117	<=>	21,808	1997	5,402	<=>	15,610
1935	3,727	<=>	12,311	1948	423	<=>	1,297	1998	1,662	<=>	4,804
1936	60,289	<=>	199,159	1949	2,528	<=>	7,746	1999	41,569	<=>	120,106
1937	4,379	<=>	14,466	1950	6,742	<=>	20,659	2000	334	<=>	966
1938	10,320	<=>	34,090	1951	5,438	<=>	16,664	--	--	--	--
1939	721	<=>	2,382	1952	944	<=>	2,893	--	--	--	--
08172400.01, TLS regression with 08173000				1953	11,880	<=>	36,403	--	--	--	--
1930	1,395	<=>	4,274	1954	910	<=>	2,790	--	--	--	--
1931	1,158	<=>	3,549	1955	417	<=>	1,278	--	--	--	--
1932	1,295	<=>	3,969	1956	833	<=>	2,553	--	--	--	--
1933	1,086	<=>	3,329	1957	5,253	<=>	16,098	--	--	--	--
1934	920	<=>	2,821	1958	6,967	<=>	21,348	--	--	--	--
1935	1,322	<=>	4,053	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--

Table 5.2. Estimates of Annual Peak Streamflow by Discharge Interval by Total Least Squares (TLS) Regression or Other Methods for Selected U.S. Geological Survey Streamflow-Gaging Stations in the Guadalupe River Basin, South-Central, Texas—Continued

Station number or water year	Either low estimate for discharge interval or point estimate		High estimate for discharge interval	Station number or water year	Either low estimate for discharge interval or point estimate		High estimate for discharge interval	Station number or water year	Either low estimate for discharge interval or point estimate		High estimate for discharge interval
	(ft^3/s)		(ft^3/s)		(ft^3/s)		(ft^3/s)		(ft^3/s)		(ft^3/s)
08173000, TLS regression with 08172000 (scenario 1)				08174600.01, TLS regression with 08175000							
1994	178	<=>	516	1980	1,458	<=>	6,115	--	--	--	--
1995	7,750	<=>	22,395	1981	39,464	<=>	165,454	--	--	--	--
1996	594	<=>	1,718	1982	1,882	<=>	7,892	--	--	--	--
1997	5,402	<=>	15,610	1983	1,133	<=>	4,750	--	--	--	--
1998	1,662	<=>	4,804	1984	848	<=>	3,557	--	--	--	--
1999	41,569	<=>	120,106	1985	649	<=>	2,725	--	--	--	--
2000	334	<=>	966	1986	1,569	<=>	6,580	--	--	--	--
08173000, TLS regression with 08172000 (scenario 2)				1987	11,913	<=>	49,946	--	--	--	--
1994	1,029	<=>	3,163	1988	241	<=>	1,014	--	--	--	--
1995	3,122	<=>	9,598	1989	404	<=>	1,695	--	--	--	--
1996	433	<=>	1,330	1990	377	<=>	1,583	--	--	--	--
1997	9,371	<=>	28,808	1991	4,359	<=>	18,279	--	--	--	--
1998	2,544	<=>	7,821	1992	21,132	<=>	88,596	--	--	--	--
1999	87,644	<=>	269,424	1993	14,479	<=>	60,707	--	--	--	--
2000	331	<=>	1,019	1994	2,770	<=>	11,617	--	--	--	--
08173900, estimates from rating curve though no intervals provided				1995	2,175	<=>	9,120	--	--	--	--
1989	5,200	--	--	1996	2,319	<=>	9,725	--	--	--	--
1990	5,700	--	--	1997	4,389	<=>	18,404	--	--	--	--
1991	9,400	--	--	1998	1,902	<=>	7,977	--	--	--	--
1992	16,500	--	--	1999	19,973	<=>	83,739	--	--	--	--
1993	7,600	--	--	2000	761	<=>	3,193	--	--	--	--
1994	6,800	--	--	--	--	--	--	--	--	--	--

North Fork Guadalupe River near Hunt, Texas

The systematic stream gage record for the North Fork Guadalupe River near Hunt is 1968–2015. The peak streamflow in 1932 of 140,000 ft^3/s at a stage of 37.3 feet (ft), and this peak was treated as the largest for 1852–1967 where 1852 and 1967 are years that source from consensus between stream gages that are downstream along the Guadalupe River. The data as set up for statistical frequency analysis are shown in Figure 5.2, in which the rectangular region demarks the historical context of the 1932 peak.

The flood flow frequency for the North Fork Guadalupe River near Hunt is shown in Figure 5.3. The combination of substantial systematic record and extensive historical information leads to a reliable flood flow frequency curve. The MGBT low-outlier test acceptably truncates the small magnitude record, and it is obvious that peaks less than about 100 ft^3/s can be associated with a different generation process in the watershed. For example, most certainly the peaks are not-storm events in drought years. The frequency curve has considerable curvature towards the right but this seems consistent with the available data though. A striking feature of this (and other such curves throughout much of the Guadalupe River basin) is the orders of magnitude range in the observational data; approximately four orders of magnitude (four log-cycles).

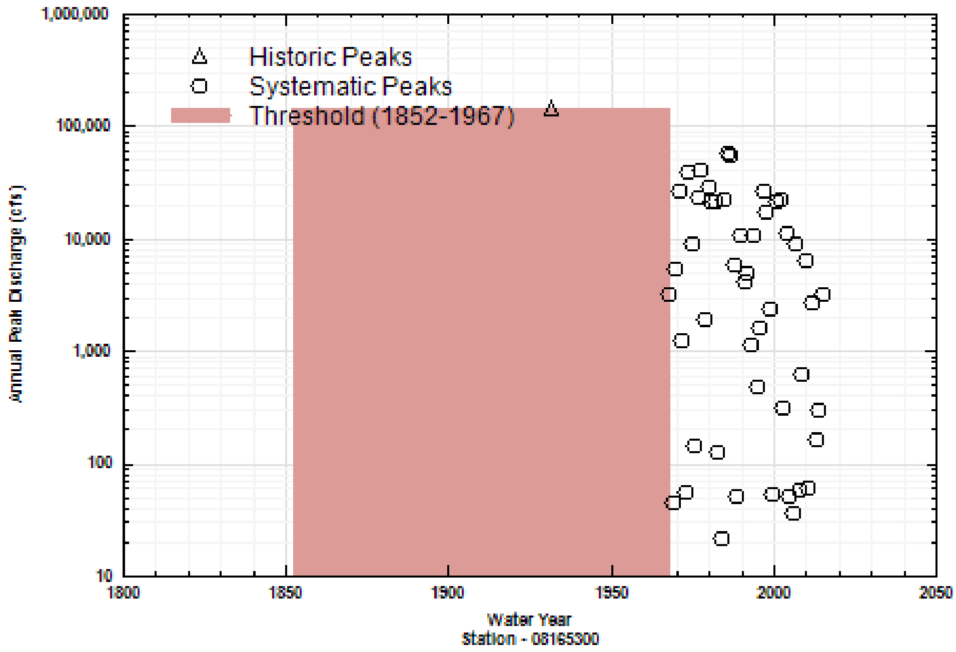

Figure 5.2: Annual Peak Streamflow Data for the North Fork Guadalupe River near Hunt, TX

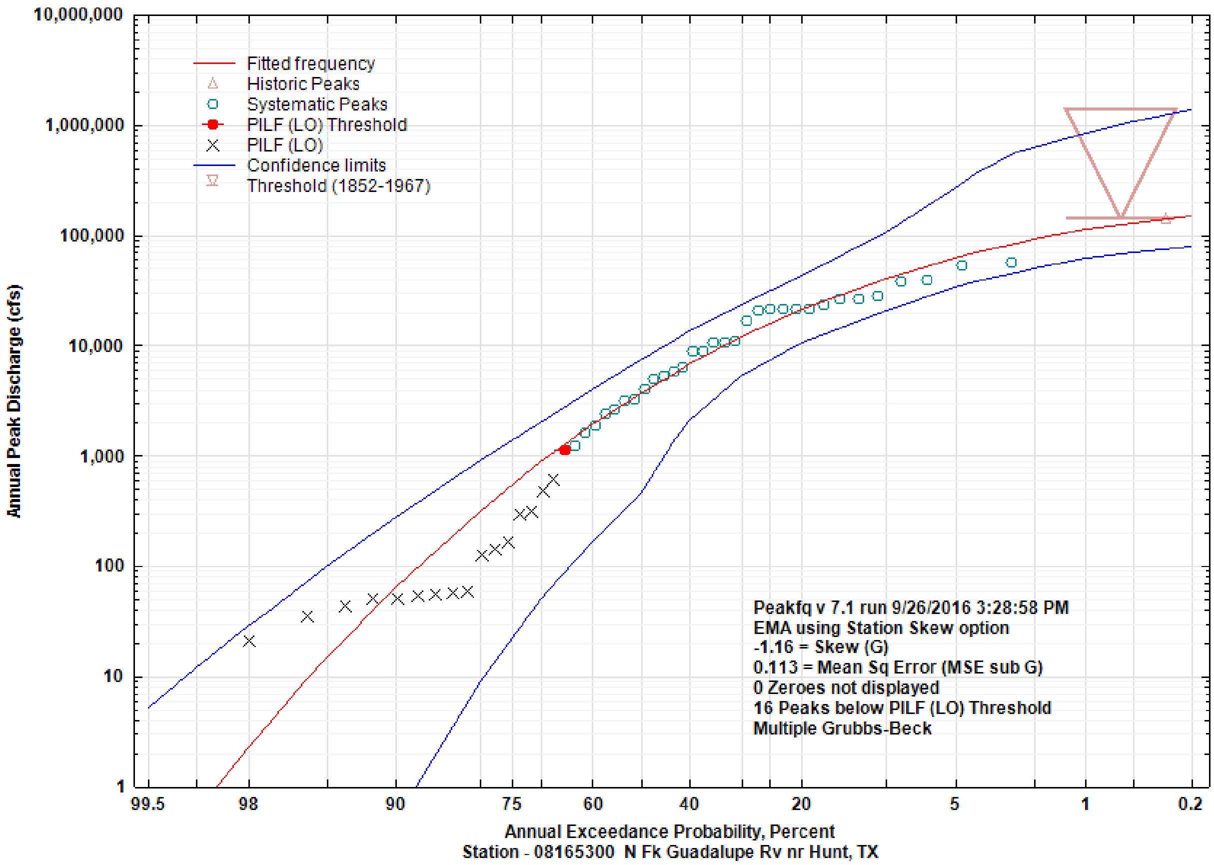

Figure 5.3: Flood Flow Frequency Curve for the North Fork Guadalupe River near Hunt, TX

Guadalupe River at Hunt, Texas

The systematic stream gage record for the Guadalupe River at Hunt is 1966–2015. The peak streamflow in 1932 of 206,000 ft^3/s at a stage of 36.6 feet was treated as the largest for 1852–1965. The 1852 and 1965 are years that source from consensus between stream gages that are downstream along the Guadalupe River. The data as set up for statistical frequency analysis are shown in Figure 5.4, in which the rectangular regions demark the historical context of the 1932 peak.

The flood flow frequency for the Guadalupe River near Hunt is shown in Figure 5.5. The combination of substantial systematic record and extensive historical information leads to a reliable flood flow frequency curve. The MGBT low-outlier test acceptably truncates the small magnitude record, and it is obvious that peaks less than about 500 ft^3/s can be associated with a different generation process in the watershed. For example, most certainly the peaks are not-storm events in drought years. The frequency curve has considerable curvature towards the right but this seems consistent with the available data.

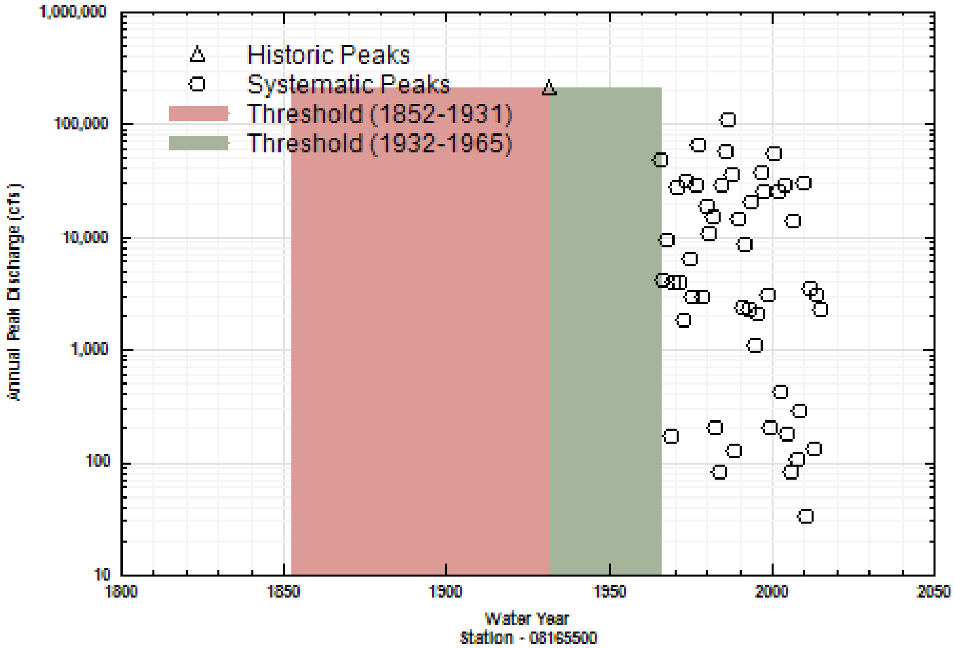

Figure 5.4: Annual Peak Streamflow Data for the Guadalupe River at Hunt, TX

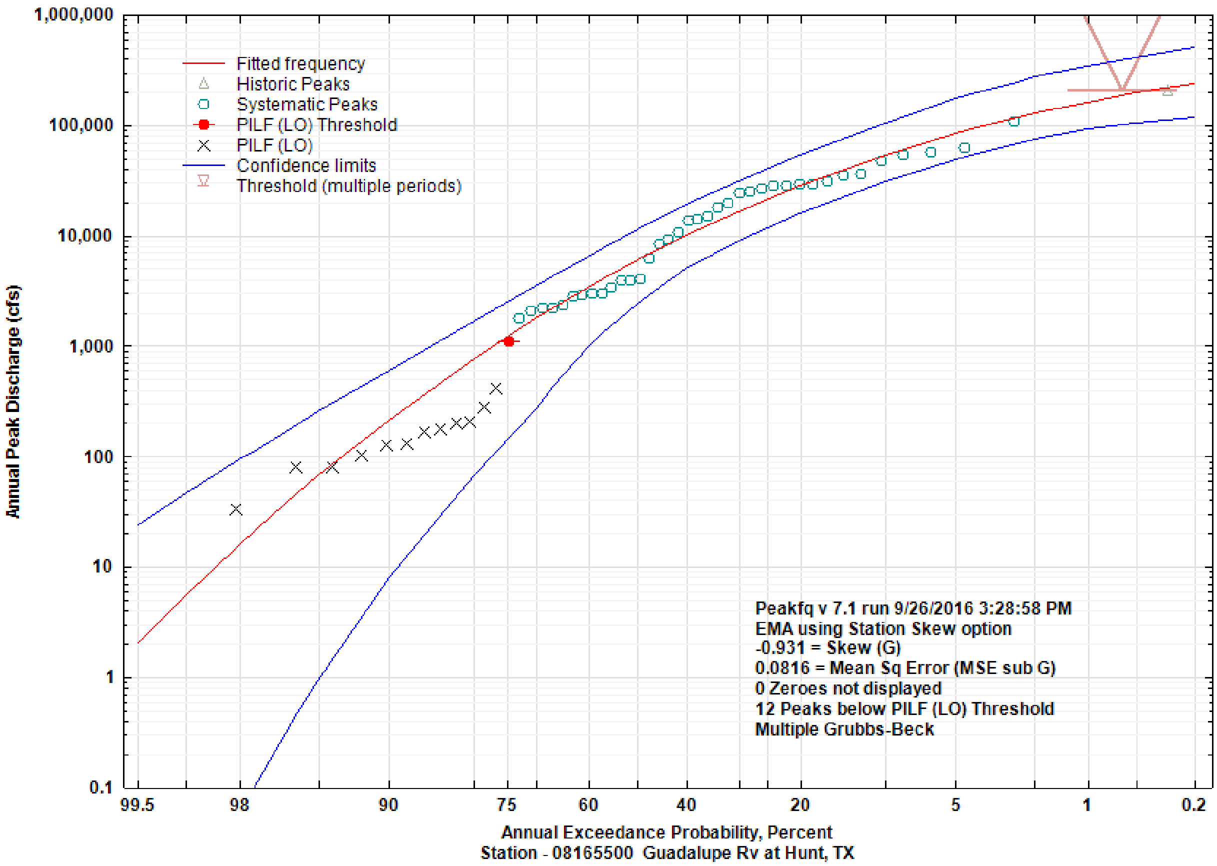

Figure 5.5: Flood Flow Frequency Curve for the Guadalupe River at Hunt, TX

Johnson Creek near Ingram, Texas

The systematic stream gage record for Johnson Creek near Ingram is 1942–1953, 1955–1960, 1962–1993, and 2000–2015. The peak streamflow in 1932 of 138,000 ft^3/s at a stage of 35 ft is identified as largest since 1852. This peak was treated as largest for 1852–1941 and for the missing year in 1961. The 1954 streamflow is missing but backwater gage height 4.80 ft, which implies a discharge less than the approximate value on the rating curve. From generalized inspection of peaks associated with gage heights of 4.70 ft and 4.78 ft and similar. The 1954 peak discharge is assigned as less than 1,500 ft^3/s. This is necessary and prudent to avoid treating 1954 as less than 138,000 ft^3/s as implied by the historical record. Lastly, six years are missing (1994–1999), and a TLS regression between Guadalupe River at Hunt and Johnson Creek near Ingram was made, and discharge intervals developed (Table 5.2). The data as set up for statistical frequency analysis are shown in Figure 5.6, in which the three rectangular regions demark the historical context of the 1932 peak, and the discharge intervals in the 1990s also are shown.

The flood flow frequency for Johnson Creek near Ingram is shown in Figure 5.7. The combination of substantial systematic record and extensive historical information leads to a reliable flood flow frequency curve. Compared to the two upstream Guadalupe River stream gages, the MGBT low-outlier test does not identify any low outliers. The frequency curve is straight, which leads to continued increase in discharge for increasing small AEP, and does not show the considerable curvature towards the right compared to the two upstream Guadalupe River stream gages. The plotting of the historical peak of 1932 far to the right and seemingly away from the trajectory of the other data points could be indicative of a historical record not as well understood as extant documentation suggests. It is difficult to see how the frequency curve could bend hard enough to the right to remain consistent with the solitary historical peak of 1932.

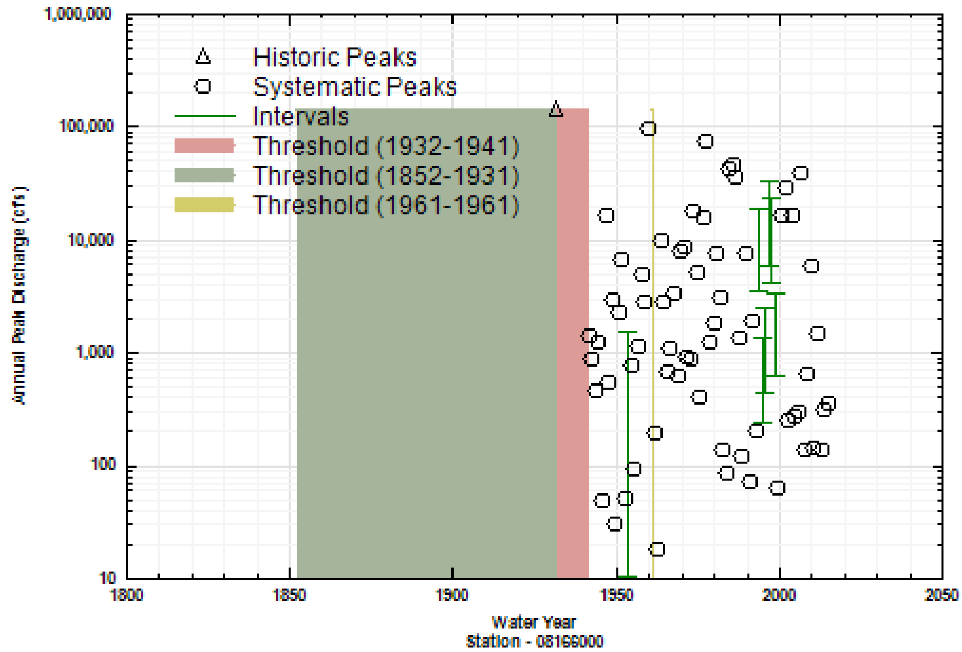

Figure 5.6: Annual Peak Streamflow Data for the Johnson Creek near Ingram, TX

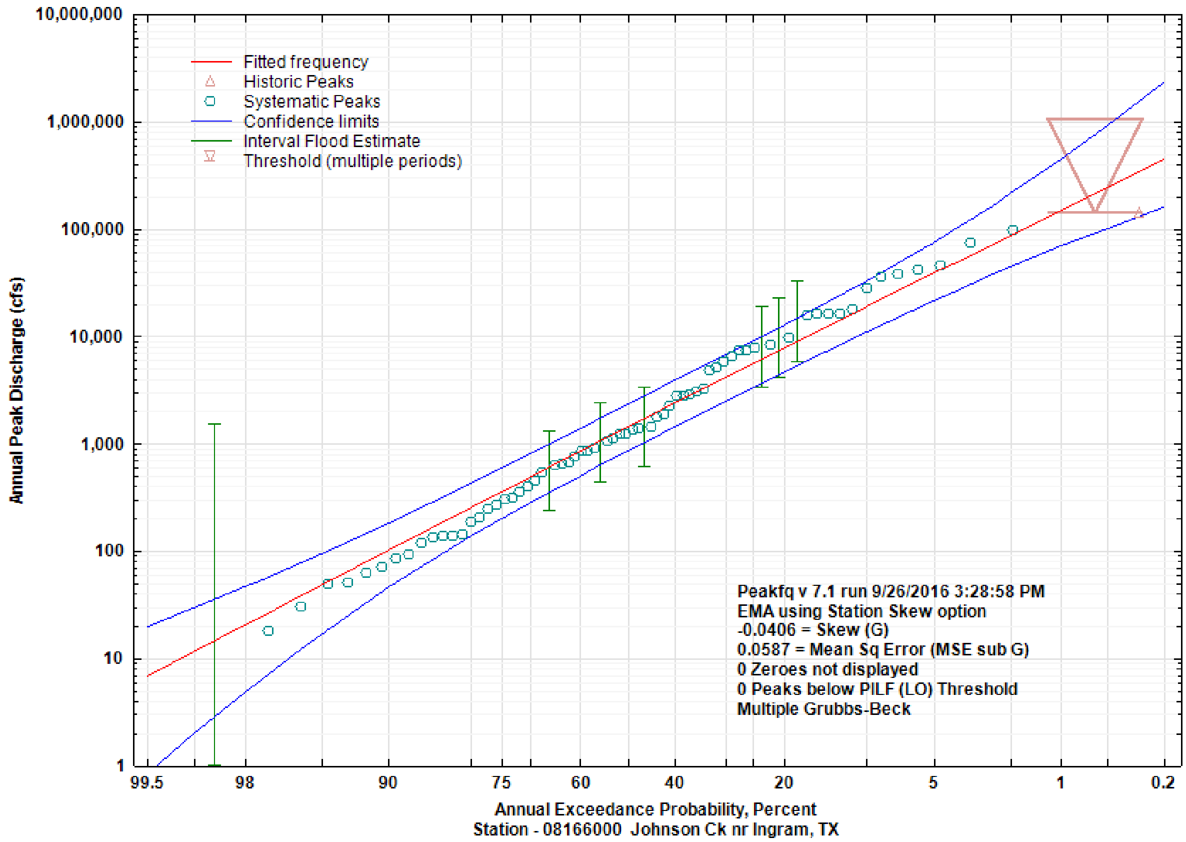

Figure 5.7: Flood Flow Frequency Curve for the Johnson Creek near Ingram, TX

Guadalupe River at Kerrville, Texas

The systematic stream gage record for the Guadalupe River at Kerrville is 1986–2015. The peak streamflow in 1932 of 196,000 ft^3/s at a stage of 39.00 ft was treated as largest for 1852–1985, but it is known that a major flood in 1978 occurred and no documentation for this stream gage appears evident. The 1978 peak was assigned the discharge interval 156,310 <=> 187,120 ft^3/s (not listed in Table 5.2), where this interval was computed by the drainage area ratio method using the 1978 discharges at stream gages Johnson Creek near Ingram and Guadalupe River at Comfort. The drainage area ratio method for this study was based on the square-root-of-area rule implied by Asquith and others (2006) and Asquith and Thompson (2008). The data as set up for statistical frequency analysis are shown in Figure 5.8, in which the three rectangular regions demark the historical context of the 1932 peak, and the discharge interval for the 1978 event also is shown.

The flood flow frequency for the Guadalupe River at Kerrville is shown in Figure 5.9. The combination of modest systematic record and extensive historical information leads to a less secure flood flow frequency curve than for many of the longer-record stream gages in the region. The frequency curve has considerable curvature towards the right but this seems consistent with the available data. The plotting of the historical peak of 1932 far to the right and seemingly away from the trajectory of the other data points could be indicative of a historical record not as well understood as extant documentation suggests. It is difficult to see how the frequency curve could bend hard enough to the right to remain consistent with the solitary historical peak of 1932. The green bar represents the discharge interval computed for the unobserved 1978 event. The MGBT low-outlier test does not identify any low outliers.

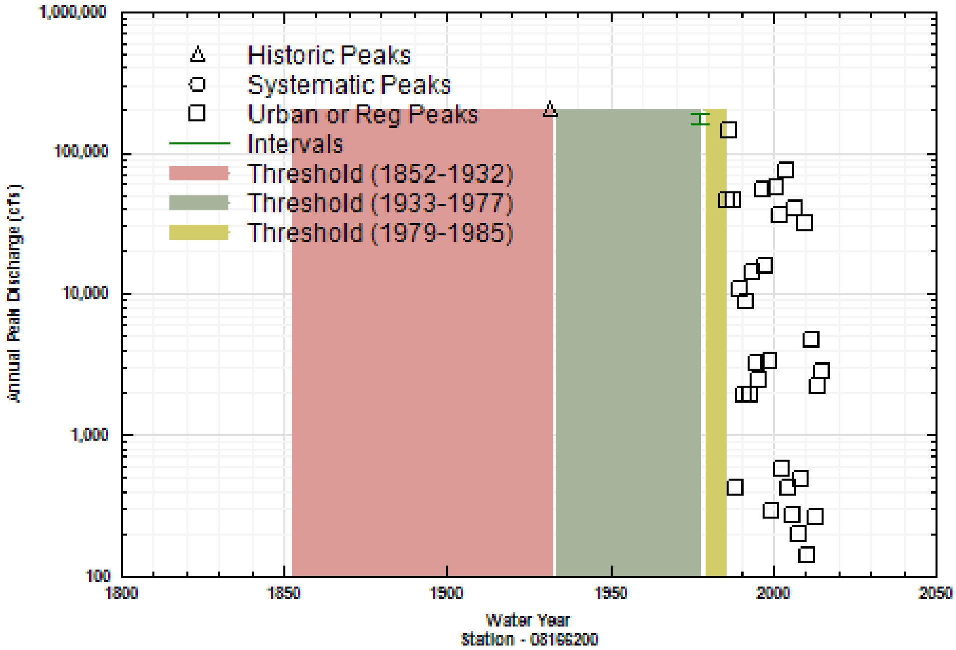

Figure 5.8: Annual Peak Streamflow Data for the Guadalupe River at Kerrville, TX

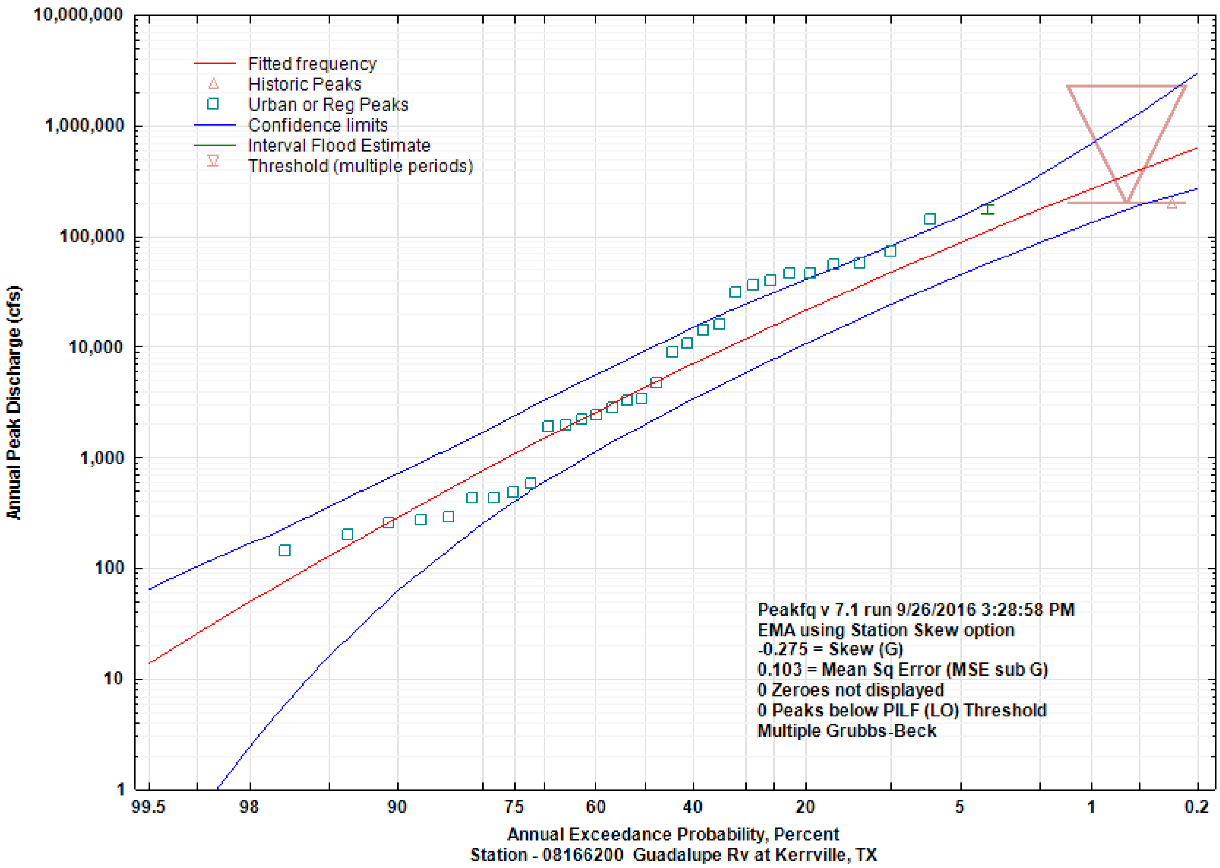

Figure 5.9: Flood Flow Frequency Curve for the Guadalupe River at Kerrville, TX

Guadalupe River at Comfort, Texas

The systematic stream gage record for the Guadalupe River at Comfort is 1935–2015. The peak streamflow in 1978 of 240,000 ft^3/s at a stage of 40.9 ft is the highest since 1848, but discharges for major events in 1900, 1915, 1935, and 1936 also are available. Thus, the 1978 peak is the highest for 1848–1899 and the other peaks for the individual years previously listed control information for the period 1901–1938. It is possible that there could be confusion on a missing 1932 peak amongst these because of the quite substantial 1932 peak at several upstream locations. It was decided to assign 1932 the discharge interval 96,650 <=> 148,000 ft^3/s (not listed in Table 5.2), where the smaller is a drainage area ratio estimate with stream gage Guadalupe River near Spring Branch and 148,000 ft^3/s is the 1935 peak. The data as set up for statistical frequency analysis are shown in Figure 5.10, in which the five rectangular regions demark the historical context, and the discharge interval for the 1932 event also is shown.

The flood flow frequency for the Guadalupe River at Comfort is shown in Figure 5.11. The combination of substantial systematic record and extensive historical information with multiple peaks leads to a reliable flood flow frequency curve. The discerning eye will see some two irregularities in the plotting of two large magnitude events (circle at about 10 percent AEP and just greater than 100,000 ft^3/s; the triangle at about 2 percent AEP and just less than 200,000 ft^3/s); these are errors in internal plotting by USGS-PeakFQ software. These errors do not reflect erroneous computation of final results. The MGBT low-outlier test identifies many low outliers. The frequency curve has considerable curvature towards the right but this seems consistent with the available data.

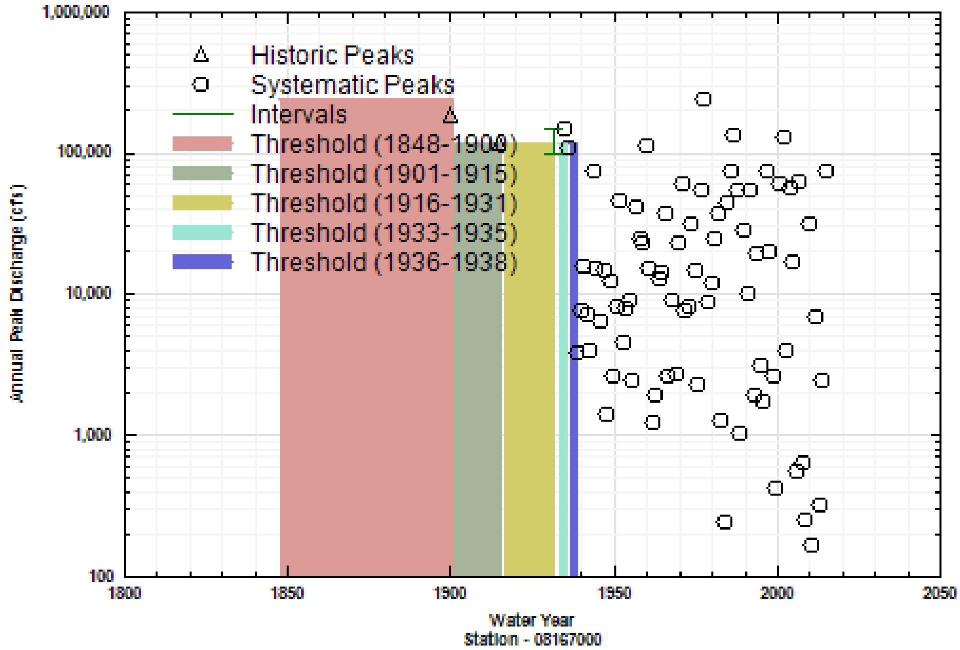

Figure 5.10: Annual Peak Streamflow Data for the Guadalupe River at Comfort, TX

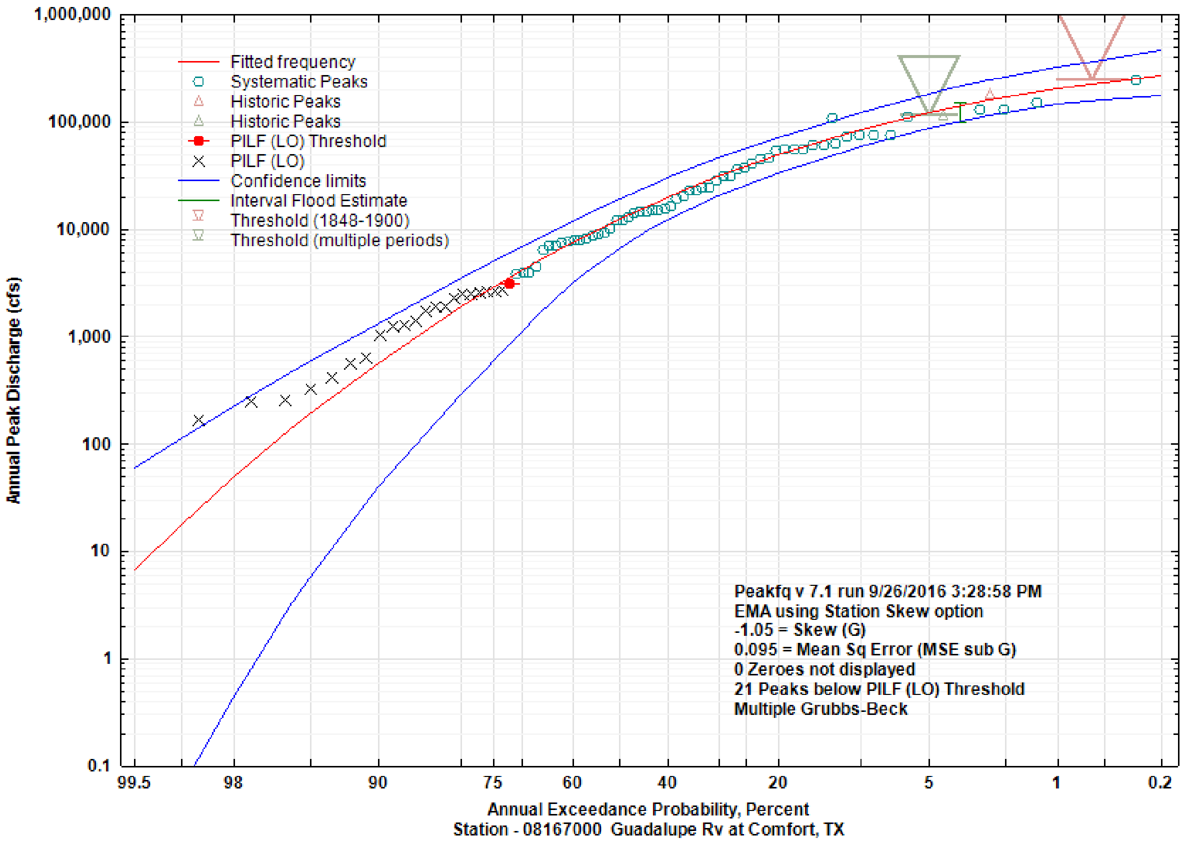

Figure 5.11: Flood Flow Frequency Curve for the Guadalupe River at Comfort, TX

Guadalupe River near Spring Branch, Texas

The systematic stream gage record for the Guadalupe River near Spring Branch is 1923–2015. The peak streamflow in 1978 of 160,000 ft^3/s at a stage of 45.25 ft was treated as highest for 1901–1923, the possibly higher gage height peaks but discharge is lacking in 1900 and 1869 (the highest since 1859 and possibly through to the present day) but were provisionally assigned discharges by rating extension for this study. Downstream stream gages do not offer further history. It was judged not feasible to accommodate the 1869 event per se but rough rating extension computes at 236,985 ft^3/s. By rough rating extension, the 1900 peak computes at 178,982 ft^3/s but was assigned a discharge interval of 140,500 <=> 228,000 ft^3/s (not listed in Table 5.2), where 228,000 ft^3/s comes from a drainage area ratio method with stream gage Guadalupe River at Comfort and 140,500 ft^3/s is the computed value:

$$140{,}500 \text{ ft}^3/\text{s} = 10\text{^}[\ \log_{10}(178982) - \{ \log_{10}(228000) - \log_{10}(178982) \}\ ],$$

where a logarithmic offset has been reflected to provide the lower bounds. Because the 1900 event might be the larger compared to 1978, it was decided to stop the historical record at 1900 and not to infer the historical period from either 1859–1899 or 1869–1899. Using the interval estimate for 1900 and if 178,982 ft^3/s for 1869–1899 is treated as a perception threshold, the 100-year discharge drops about 4.5 percent relative to stopping the historical record at 1900. This drop is not entirely reliable though, the knowledge that an extremely large event did occur 1869 for which no discharge exists, which means that the frequency curve might not drop as suggested by the 4.5 percent drop but could just as likely increase at the 100-year level. The data as set up for statistical frequency analysis are shown in Figure 5.12, in which the rectangular region demarks the historical context, and the discharge interval for the 1900 event also is shown.

The flood flow frequency for the Guadalupe River at Spring Branch is shown in Figure 5.13. The combination of long systematic record and modest historical information with multiple peaks leads to a reliable flood flow frequency curve. A low-outlier threshold of 1,000 ft^3/s was assigned by inspection as the data plot such that a separate small-magnitude, peak-generation process is anticipated. The frequency curve has considerable curvature towards the right but this seems consistent with the available data. The green bar represents the discharge interval assigned to the 1900 event.

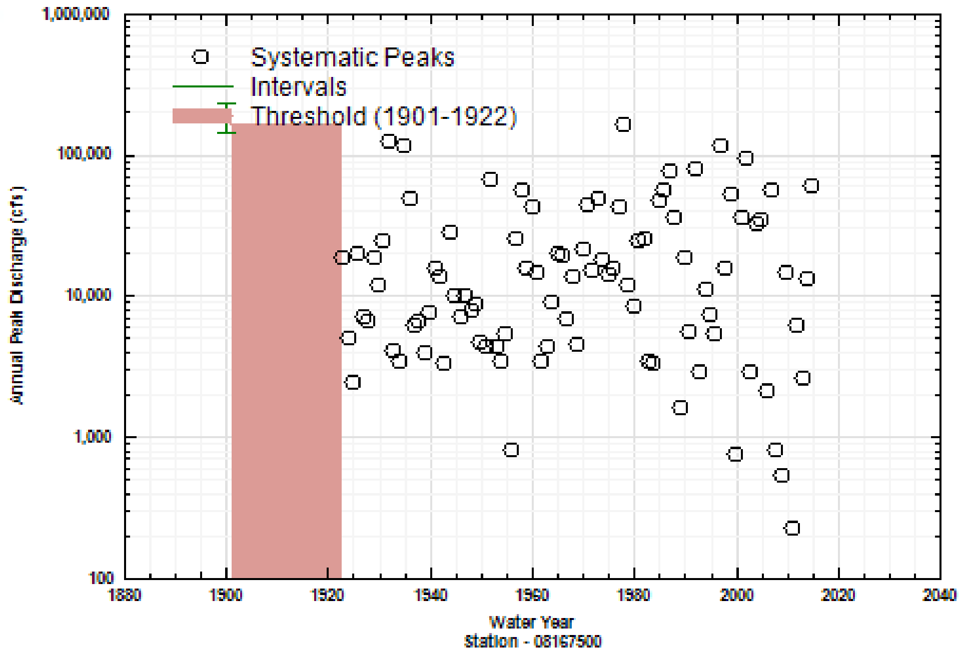

Figure 5.12: Annual Peak Streamflow Data for the Guadalupe River near Spring Branch, TX

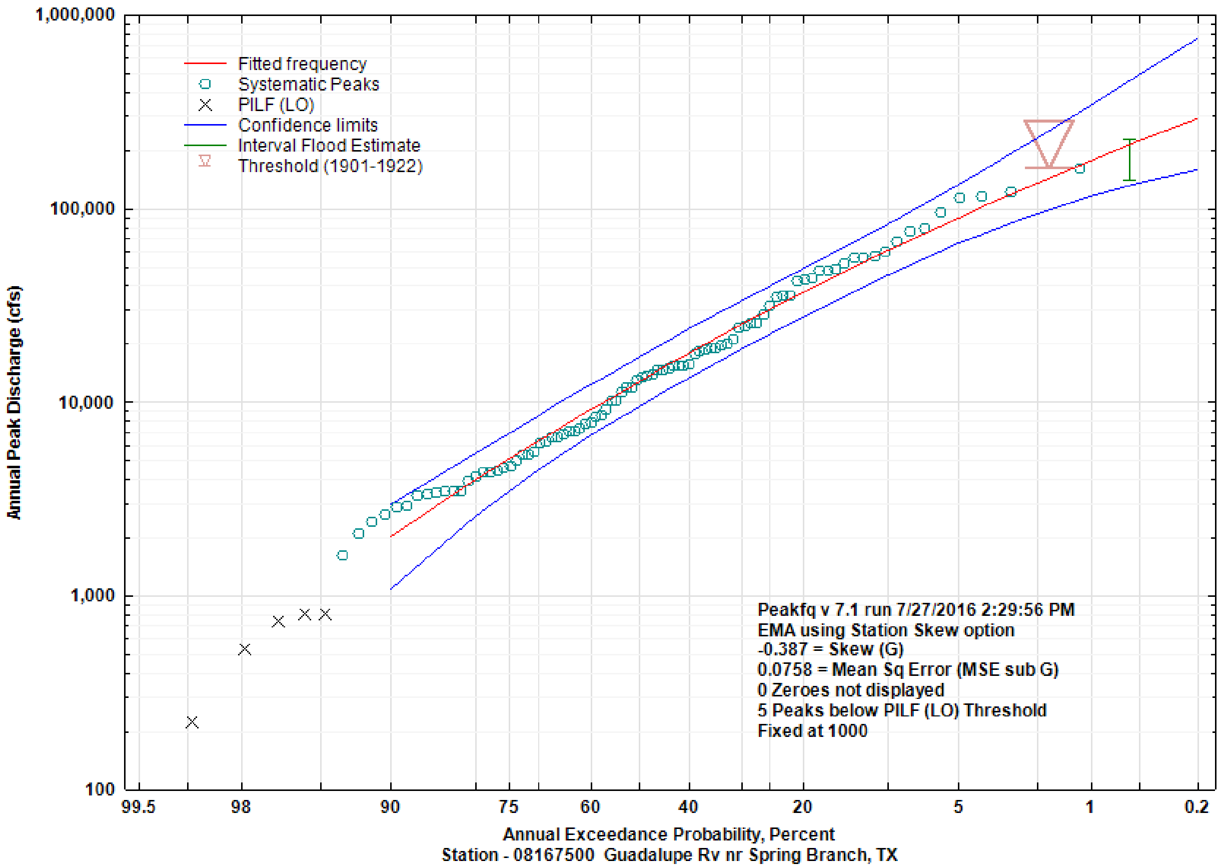

Figure 5.13: Flood Flow Frequency Curve for the Guadalupe River near Spring Branch, TX

Guadalupe River at Sattler, Texas

The systematic stream gage record for the Guadalupe River at Sattler is 1960–2015. This is a problematic site to interpret. There appears no historical information to interpret, record is mostly after completion of Canyon Lake in about 1964. It was decided to not combine the records of 1960–1963 with 1964–2015. Peak streamflows are missing for 2011 and 2014. Respectively, these were acquired from the unit-values (15-minute discharges in USGS database) of discharge as 240 ft^3/s (10/01/2011) and 2,470 ft^3/s (10/31/2013). Also, proximity to Canyon Lake clearly complicates and potentially limits the depth of interpretation available for statistical results. The peak of record is 70,000 ft^3/s at 36.36 ft in 2002. The data as set up for statistical frequency analysis are shown in Figure 5.14.

The flood flow frequency for the Guadalupe River at Sattler is shown in Figure 5.15. The combination of modest systematic record, ambiguous historical information, and uncertainty in statistical processing of peaks for a stream gage with downstream proximity to Canyon Lake leads to a flood flow frequency curve with unknown applicability. The largest value is the 2002 event and is strikingly larger than the remainder of the record. The annual peak discharges on the frequency plot clearly show undulation with decreasing AEP, which is characteristic of a regulated peak streamflow regime heavily modified by flood regulation. It is possible that statistical processing should be for peaks greater than say 6,000 ft^3/s, which would result in a far steeper frequency curve into the right tail than the analysis herein indicates. This scenario, however, cannot be processed through the USGS-PeakFQ software though because it fatally faults the software with more than 1/2 of the annual peaks conditionally removed. Other methods might be more suitable for LPIII, such as method of percentiles, for peaks greater than about 6,000 ft^3/s with empirical probability estimates remaining as if whole record is being used. Lastly, a low-outlier threshold of 700 ft^3/s was assigned to mitigate for a change in distribution pattern at about the 70th percentile of AEP.

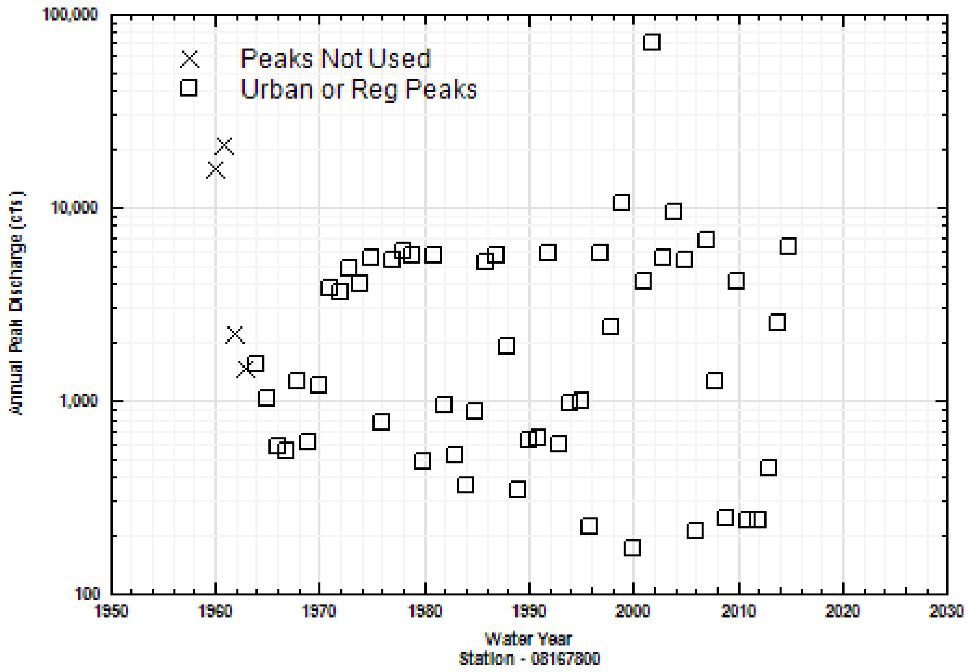

Figure 5.14: Annual Peak Streamflow Data for the Guadalupe River at Sattler, TX

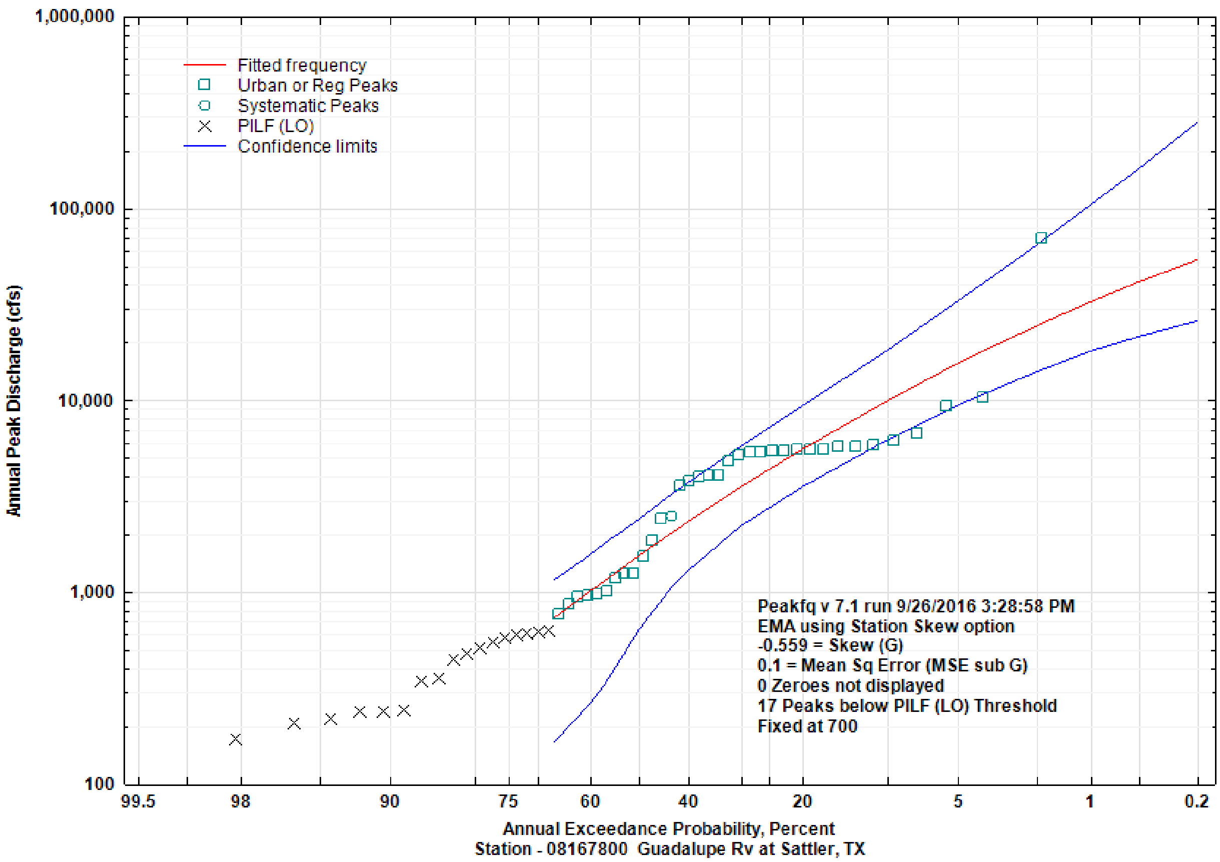

Figure 5.15: Flood Flow Frequency Curve for the Guadalupe River at Sattler, TX

Guadalupe River above Comal River at New Braunfels, Texas

The systematic stream gage record for the Guadalupe River above Comal River at New Braunfels is 1928–2015. This is a problematic site to interpret. The record 1928–1963 predates Canyon Lake and is flagged as regulated from 1964–2015 (to present) after Canyon Lake construction. For purposes of this study, it was decided to combine the records with the perspective that some of the largest record events before and after Canyon Lake have parity. The watershed seemingly is capable of producing quite substantial flood peaks at local contributing area scales. Peaks are missing in 2011 and 2013 and unit-values (15-minute discharges in USGS database) of discharge as 374 ft^3/s and 705 ft^3/s, respectively, were used. The data as set up for statistical frequency analysis are shown in Figure 5.16.

The flood flow frequency for the Guadalupe River above Comal River at New Braunfels is shown in Figure 5.17. Though there is a long systematic record, there are open questions about statistically processing in conjunction with flood regulation impacts by Canyon Lake. This is true because about 2/3 of the peaks are after creation of Canyon Lake. However, it is important to note that though the 2002 peak was large relative to record for Guadalupe River at Sattler, this peak (73,200 ft^3/s for 2002) for Guadalupe River above Comal River at New Braunfels is comparatively similar to others. In fact, the peak of record of 90,000 ft^3/s was in 1999 (October 1998 event) for which the Guadalupe River at Sattler had a peak of only 10,300 ft^3/s. Thus the data Guadalupe River above Comal River at New Braunfels are more suitable for statistical analyses than they were for the Guadalupe River at Sattler. These considerations lead to a flood flow frequency curve with some general applicability. A low-outlier threshold of 5,000 ft^3/s was assigned to mitigate for a change in distribution pattern, which does remove many of the small-magnitude peaks.

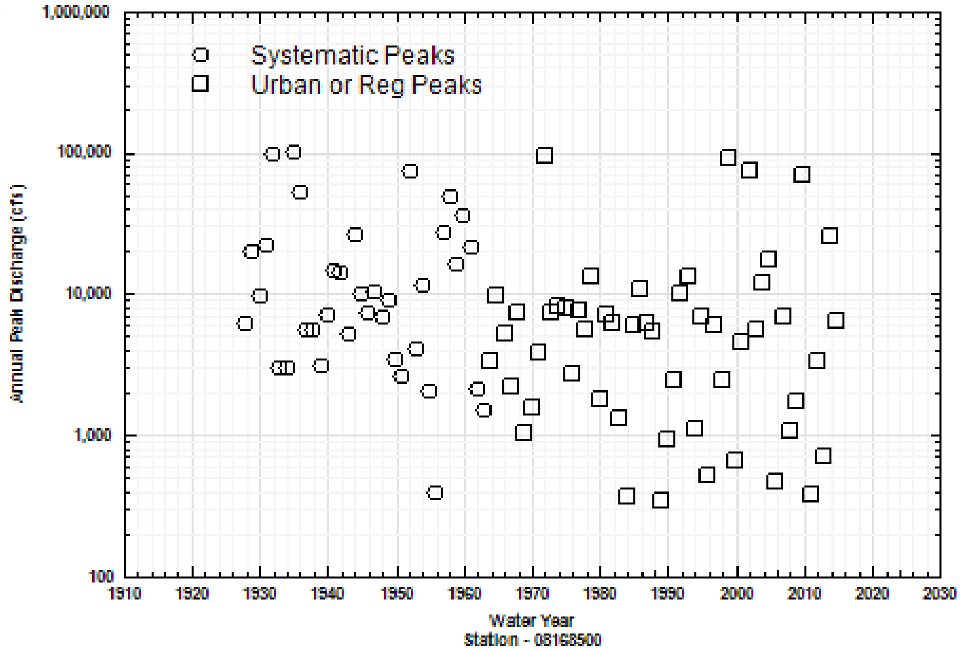

Figure 5.16: Annual Peak Streamflow Data for the Guadalupe River above Comal River at New Braunfels, TX

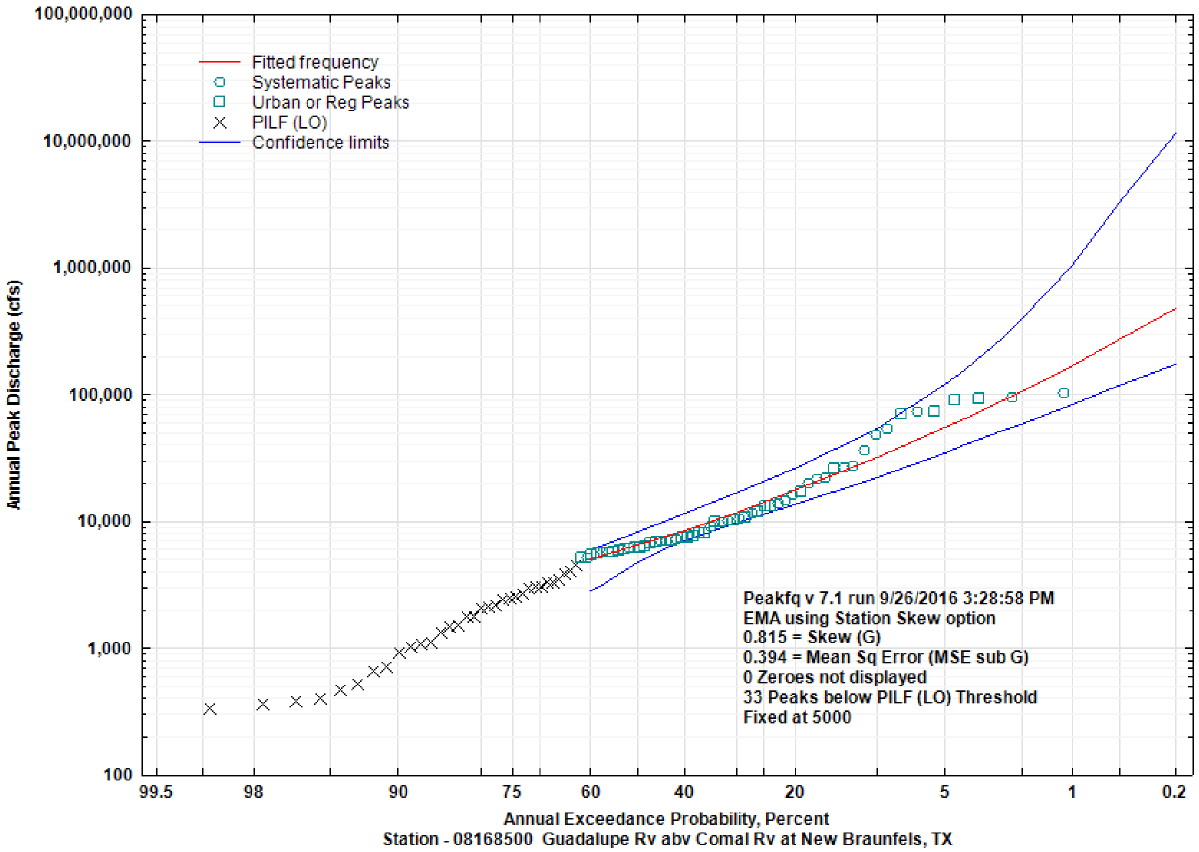

Figure 5.17: Flood Flow Frequency Curve for the Guadalupe River above Comal River at New Braunfels, TX

Comal River at New Braunfels, Texas

The systematic stream gage record for the Comal River at New Braunfels is 1928–2015 but many annual peaks themselves remained unrecorded though peak gage heights are available. Thus, this stream gage has very long record but is complicated by springflow and sporadic years of measurement and (or) general acquisition from about the period 1928–1948. During these years, the annual peak discharge was not reported during unimportant flood years (note the base flow is directly representative of springflow from Comal Springs). The largest peak is in the systematic record (fortunately for interpretation) and is 73,500 ft^3/s at a stage of 39.28 ft in 1999 and is highest since 1870 but likely 1869 based on gage height as well. The 1978 peak is the highest for the period 1869–1927 and across the unreported discharge years between the years 1928–1948. There was a substantial peak in late October 2015 but the magnitude is well within the magnitudes of about decadal scale events and thus no special consideration for the incomplete year of 2016 were made. The data as set up for statistical frequency analysis are shown in Figure 5.18, in which the rectangular regions demark the historical context of the 1999 peak.

The flood flow frequency for the Guadalupe River above Comal River at New Braunfels is shown in Figure 5.19. This is a springflow-dominated site and thus a low-outlier threshold of 1,500 ft^3/s is assigned and conditionally truncates the analysis above springflow and very localized storm flow. The long record coupled with historical information appears to produce a reliable flood flow frequency curve. It is possible that differing peak generation processes in the watershed begin to occur at about the 10 percent AEP. The flood flow frequency curve is thought to be reliable though considerable error is expressed by the confidence limits in the figure.

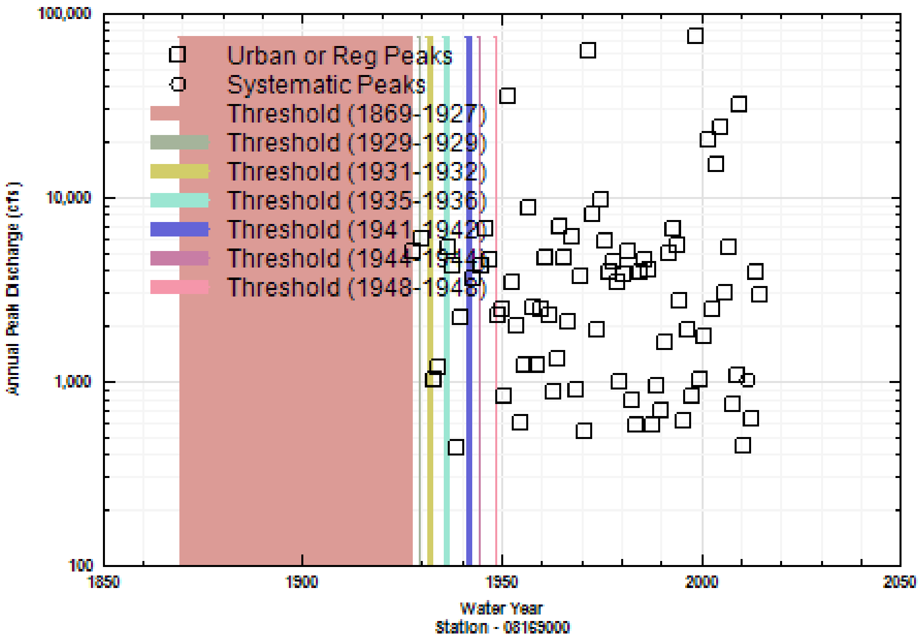

Figure 5.18: Annual Peak Streamflow Data for the Comal River at New Braunfels, TX

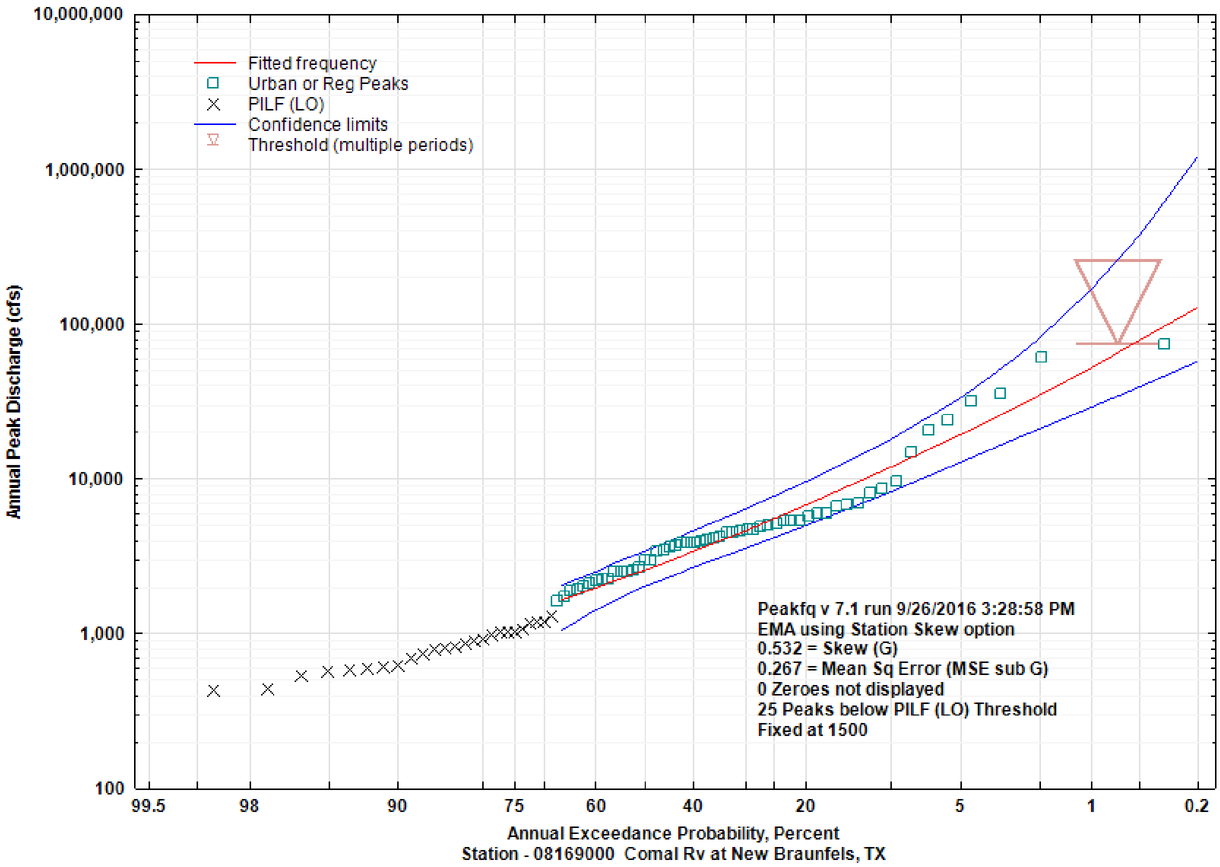

Figure 5.19: Flood Flow Frequency Curve for the Comal River at New Braunfels, TX

Guadalupe River at New Braunfels, Texas

The systematic stream gage record for the Guadalupe River at New Braunfels is 1915–1927 and 1974–2015. This is a problematic site to interpret. The largest peak is in the systematic record peak of 152,000 ft^3/s at a stage of 38.54 ft in 1999. Many years of unreported peak streamflow but peak gage heights are available. Three gaps in discharge are present and are the periods 1983–1984, 1994–1996, and 2000–2015. The 1999 peak was used as highest in period 1869–2015 for years lacking reported discharges. The data as set up for statistical frequency analysis are shown in Figure 5.20, in which the rectangular regions demark the historical context of the 1999 peak.

The flood flow frequency for the Guadalupe River at New Braunfels is shown in Figure 5.21. The systematic record length is comparatively short, which lessens the reliability of the flood flow frequency curve. The nature of the historical information and gaps in systematically reported peak discharges do make frequency analysis for this stream gage numerically more sensitive to interpretation of the 1999 peak (October 1998 event) than generally applicable for other stream gages in this study. It is possible that an LPIII by method of percentiles for the empirical probabilities for those annual exceedance probabilities less than about the 20th percentile would be preferable. A low-outlier threshold of about 5,000 ft^3/s conditionally truncates the analysis above springflow and very localized storm flow and provision for consistency with the Guadalupe River above Comal River at New Braunfels.

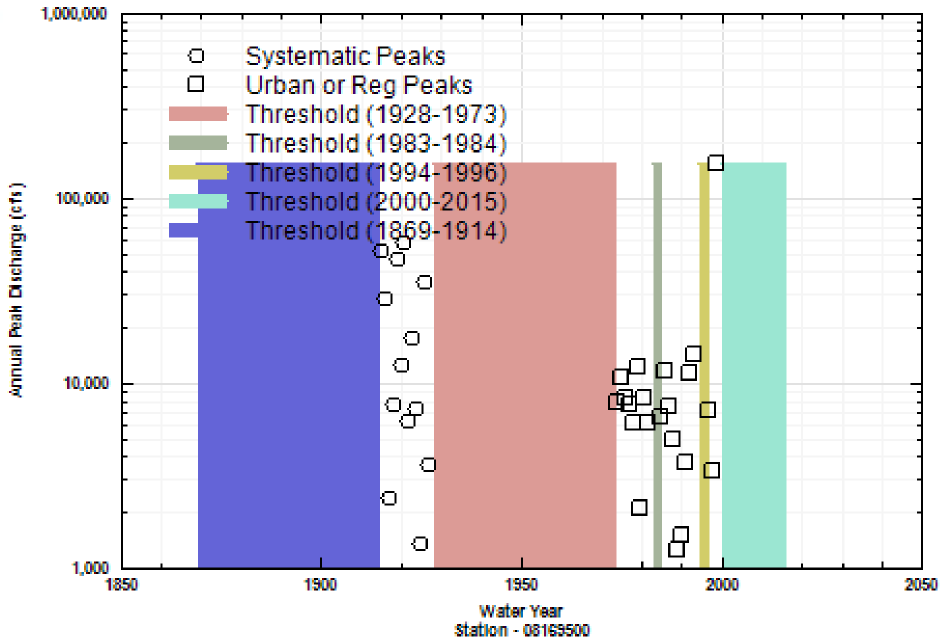

Figure 5.20: Annual Peak Streamflow Data for the Guadalupe River at New Braunfels, TX

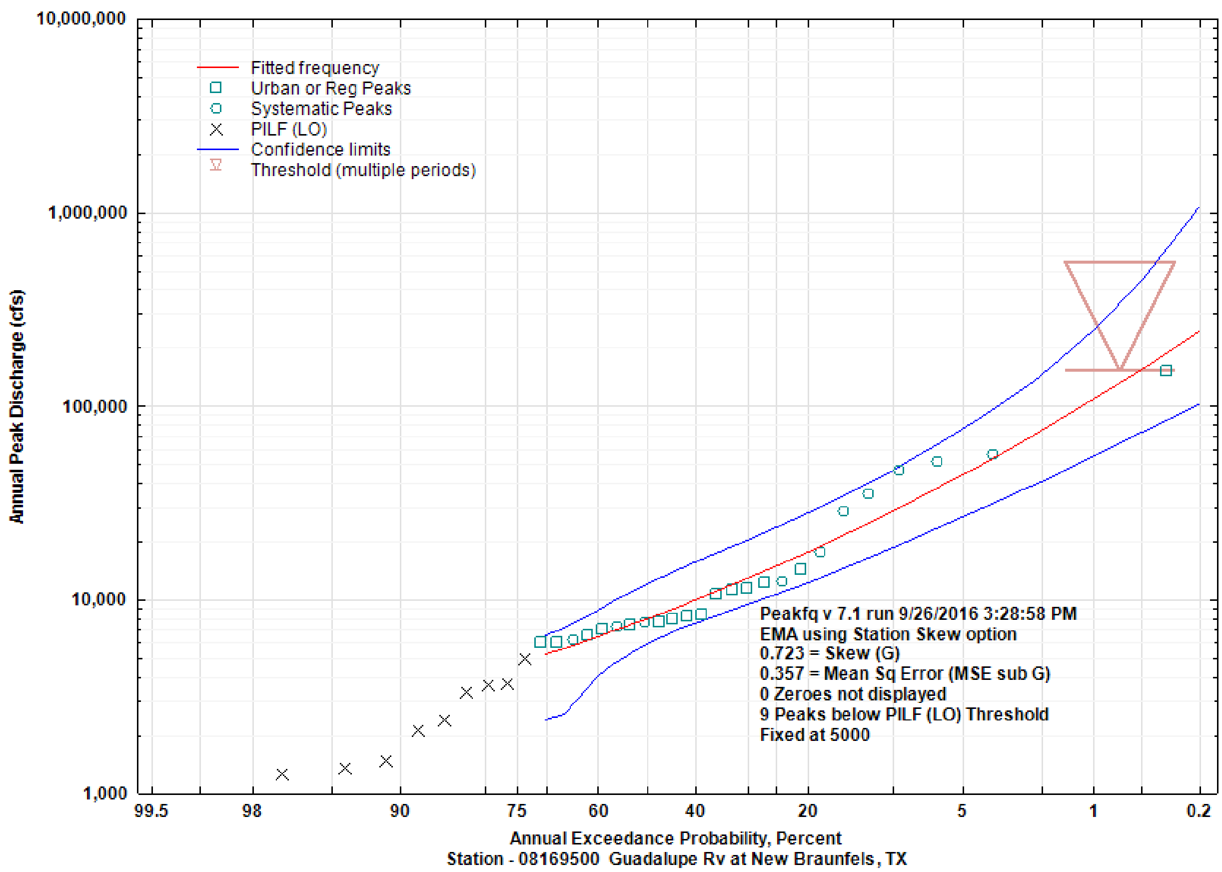

Figure 5.21: Flood Flow Frequency Curve for the Guadalupe River at New Braunfels, TX

San Marcos River at San Marcos, Texas

The systematic stream gage record for the San Marcos River at San Marcos is 1995–2015. The 1999 peak streamflow of 21,500 ft^3/s at a stage of 21.29 ft is the flood of record at that location. This is a problematic site to interpret owing to relatively short record length and spring flow dominated hydrologic processes with some local storm flow. The 2012 and 2015 peaks are unrecorded in USGS peak streamflow databases (USGS, 2016). The 2012 peak was inferred from unit-values (15-minute discharges in USGS database) as 809 ft^3/s (05/10/2012). The 2015 peak was affected by backwater from the Blanco River. A discharge interval was developed for the 2015 peak as 237 <=> 21,500 ft^3/s, where the smaller value is the daily mean streamflow for 05/24/2015 and the larger value is the 1999 peak discharge. The 1999 peak discharge quite likely is the largest of a considerable historical time span, and frequency analysis results for this stream gage are highly influenced by the absence and (or) inclusion of how the 1999 peak is interpreted. The data as set up for statistical frequency analysis are shown in Figure 5.22, in which the discharge interval for 2015 is seen.

The flood flow frequency for the San Marcos River at San Marcos is shown in Figure 5.23. The data for this stream gage are perhaps the most problematic in this study for secure inference by statistical methods. The record is short and most of the peaks are close in magnitude to daily mean streamflows. The large discharge interval estimate for 2015 also contributes to difficulties for interpretation. This discharge interval further complicate the inference of the historical importance of the October 1998 event. This event is certainly historically large outside the period of systematic record based on other stream gages in the area. The flood flow frequency curve begins its steep climb at about 1,000 ft^3/s in accordance with the four observed peaks with the fifth (October 1999) likely plotting too much to the left because of a lack in historical information. The confidence limits are prodigiously wide and usefulness is inherently questionable.

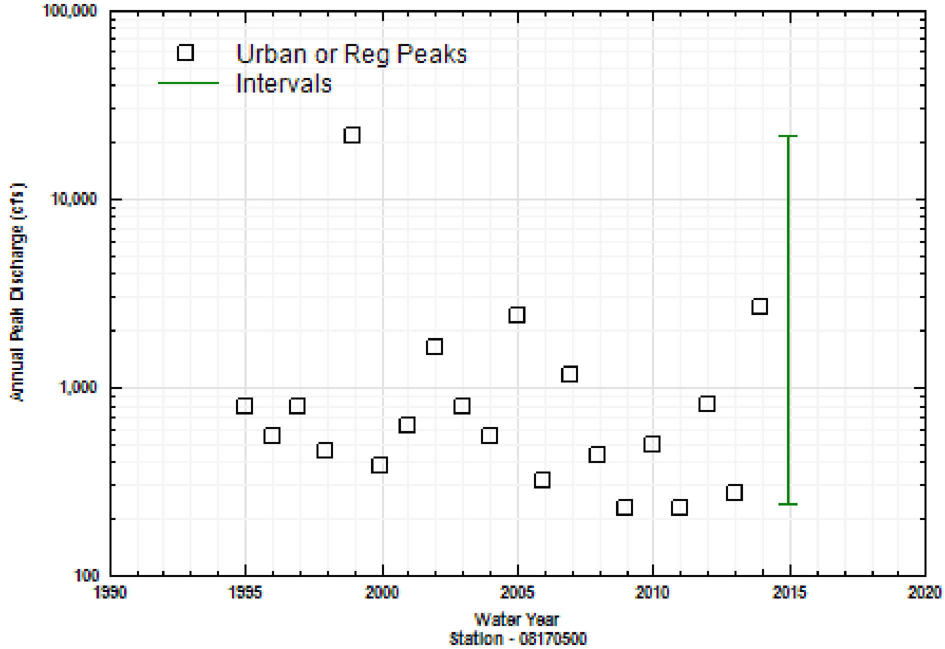

Figure 5.22: Annual Peak Streamflow Data for the San Marcos River at San Marcos, TX

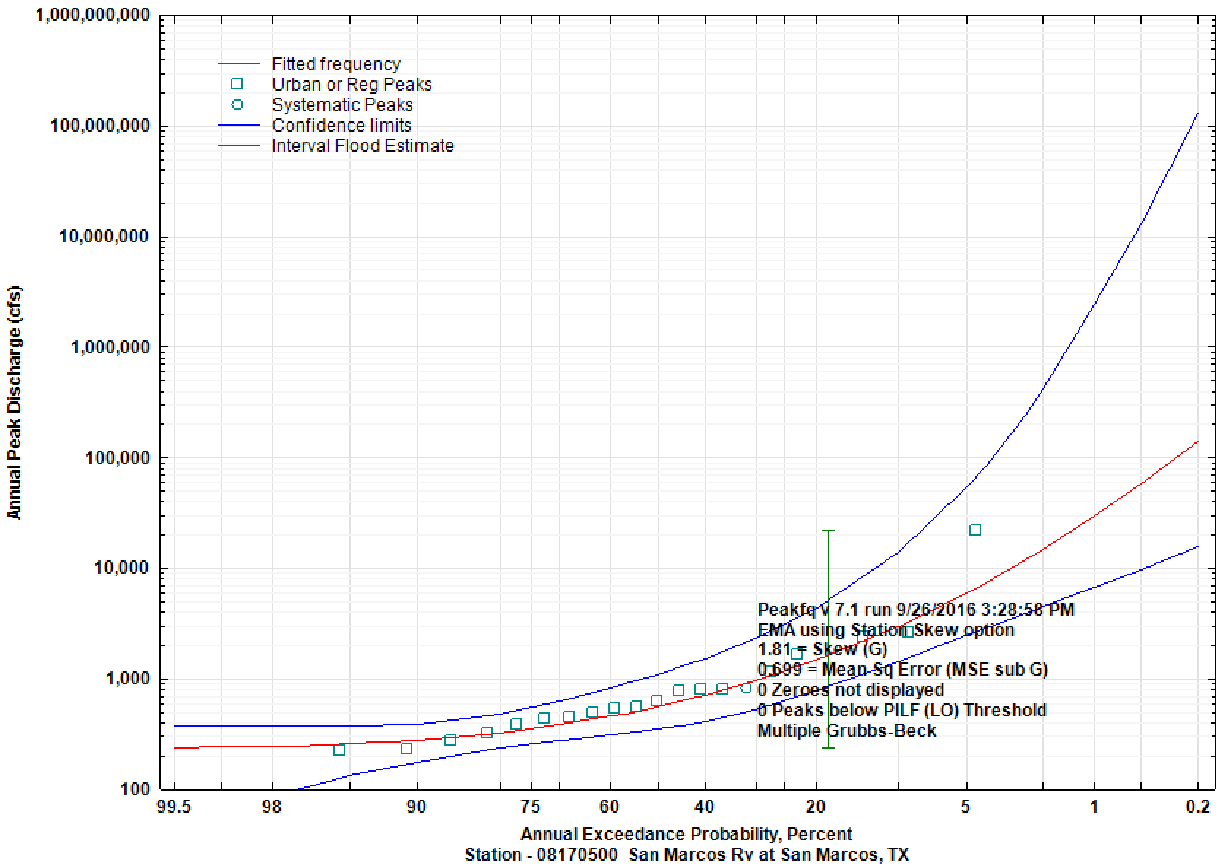

Figure 5.23: Flood Flow Frequency Curve for the San Marcos River at San Marcos, TX

Blanco River at Wimberley, Texas

The systematic record for Blanco at Wimberley is 1925–1926 and 1929–2016. The peak streamflow in 1929 of 113,000 ft^3/s at a stage of 33.30 ft is believed to be the highest since 1869 and also was the highest peak until May 2015 as documented in USGS (2016) data. The peak of record occurred in May 2015 at 175,000 ft^3/s and stage of 44.90 ft. The peak in late October 2015 indicates that water year 2016 annual peak will be at least 71,000 ft^3/s. The joint probability of timing in the water year for some 1,475 peaks was investigated. Inclusion of the incomplete 2016 water year is deemed judicious because late October 2015 was itself a substantial event and thus inclusion of 71,000 ft^3/s at this time represents at least a minimum impact on the fitted frequency curve. The data as set up for statistical frequency analysis are shown in Figure 5.24, in which the two rectangular regions demark the historical context of the 1929 peak.

The flood flow frequency for the Blanco River at Wimberley is shown in Figure 5.25. The long systematic record and extensive historical information lead to a reliable flood flow frequency curve. The largest event plots along the general trajectory of the curve. It could be that unspecified processes in the watershed tend to produce somewhat limiting rare peaks in the range 80,000–120,000 ft^3/s but the May 2015 peak substantiates the fact that considerably larger peaks, though rare, can occur. The low-outlier threshold can conditionally remove peaks below about 1,000 ft^3/s, and those data are seen to break away from the other data.

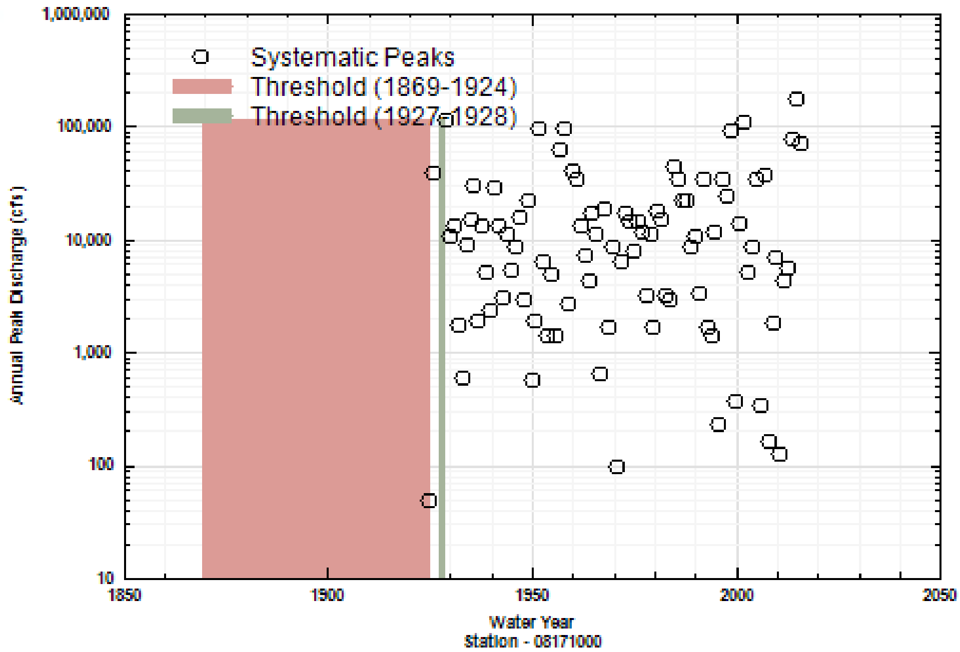

Figure 5.24: Annual Peak Streamflow Data for the Blanco River at Wimberley, TX

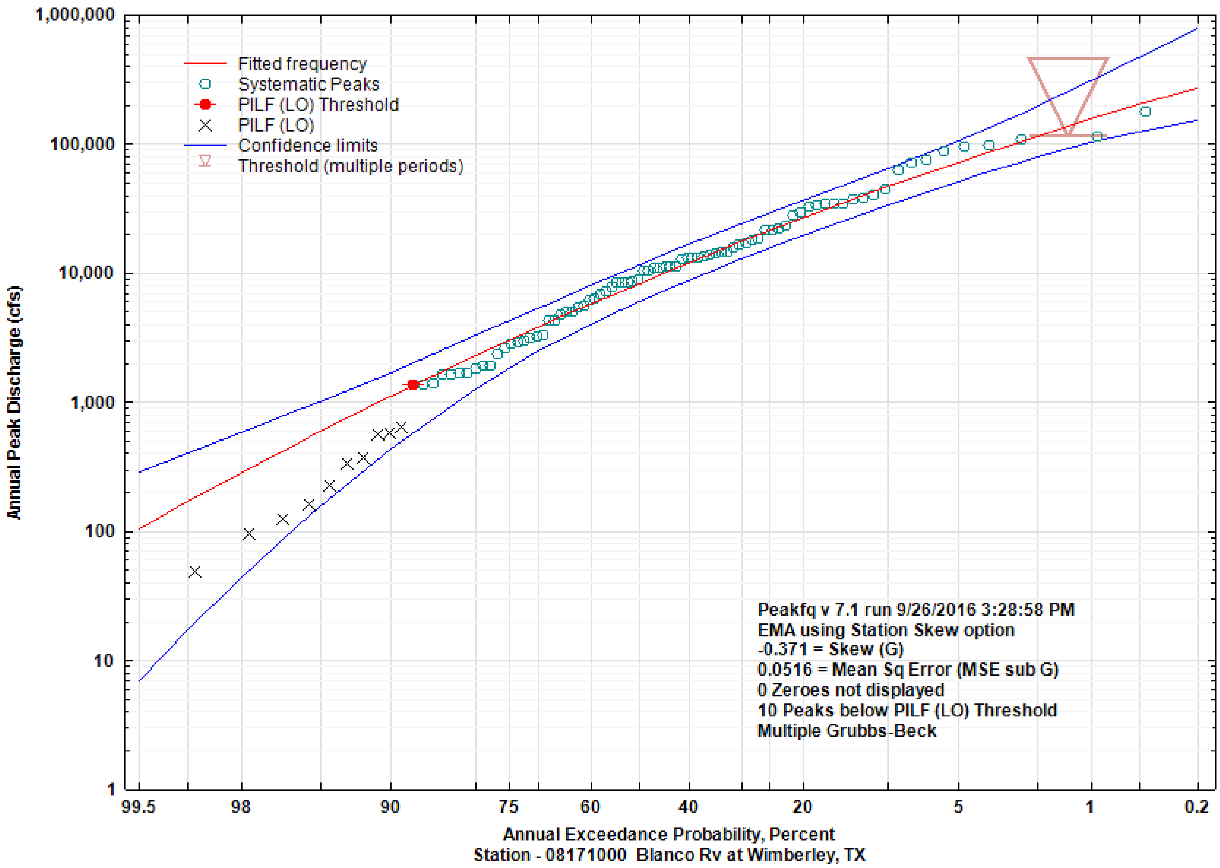

Figure 5.25: Flood Flow Frequency Curve for the Blanco River at Wimberley, TX

Blanco River near Kyle, Texas

The systematic record for the Blanco River near Kyle is 1957–2016 for which historical peak streamflows in 1929 (139,000 ft^3/s at stage of 40.00 ft) and 1952 (115,000 ft^3/s at a stage of 38.00 ft) are also available. The May 2015 peak streamflow at Kyle is estimated at 180,000 ft^3/s and is the highest flood of record at that location. The 1929 peak streamflow is considered the highest for 1882–1929 as documented in USGS (2016) data. Because of proximity to Blanco Wimberley and the high degree of correlation of large annual peaks between the two stream gages, the 1929 peak at Blanco Kyle was assumed to be the highest since 1869 in lieu of 1882. The historical record is interpreted as 139,000 ft^3/s being the highest for 1869–1928. The period of record at Kyle is not as long as Wimberley, but because physically much of the same watershed is monitored by each stream gage, additional inferences can be made through TLS regression. From TLS regression analysis between Wimberley and Kyle, a discharge threshold of 32,822 ft^3/s for 1930–1951 is used, and a discharge threshold of 6,822 ft^3/s for 1953–1956. A low-outlier threshold of 4,000 ft^3/s was chosen for statistical frequency computations. Similar to the Blanco River at Wimberley, special addition of 2016 is made. The October 2015 peak of 115,000 ft^3/s was incorporated into the analysis as the presumed annual peak for water year 2016. The data as set up for statistical frequency analysis are shown in Figure 5.26, in which the three rectangular regions demark the historical context corresponding to the three discharge thresholds identified.

The flood flow frequency for the Blanco River near Kyle is shown in Figure 5.27. The substantial systematic record and the extensive historical information lead to a reliable flood flow frequency curve. The three blocks demarked in Figure 5.26 with a discharge threshold can be seen scattered within the empirical probabilities. The largest event plots just below the general trajectory of the curve. It could be that unspecified processes in the watershed tend to produce somewhat limiting rare peaks in the range 80,000–120,000 ft^3/s but the May 2015 peak substantiates the fact that considerably larger peaks, though rare, can occur. The rapid steepening of the data near AEP of 10 percent (40,000–90,000 ft^3/s) suggests a population mixing. The low-outlier threshold can be seen conditionally removing peaks below about 4,000 ft^3/s, and those data are seen to break away from the other data.

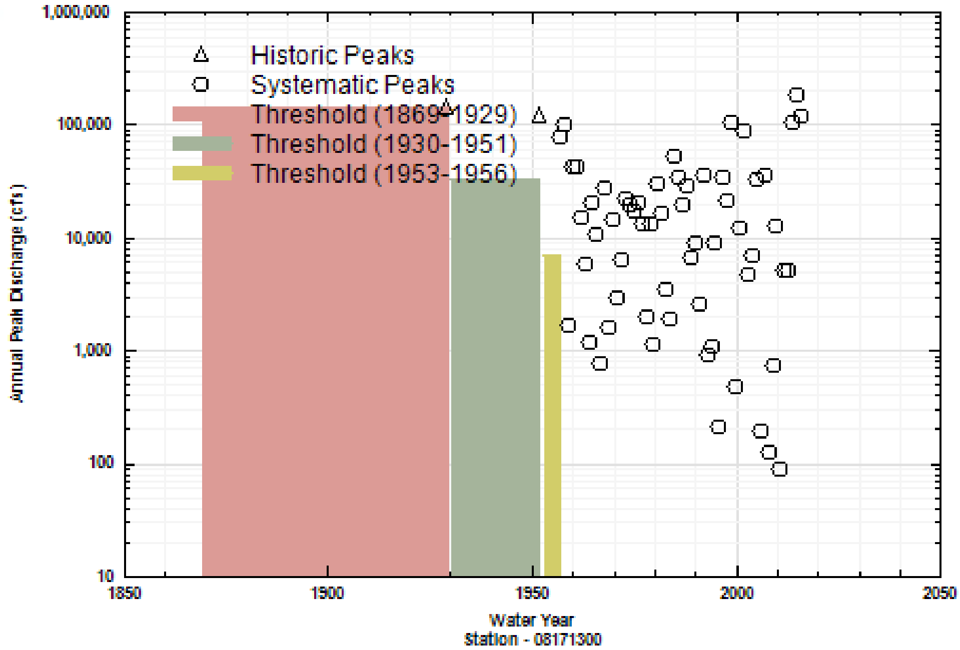

Figure 5.26: Annual Peak Streamflow Data for the Blanco River near Kyle, TX

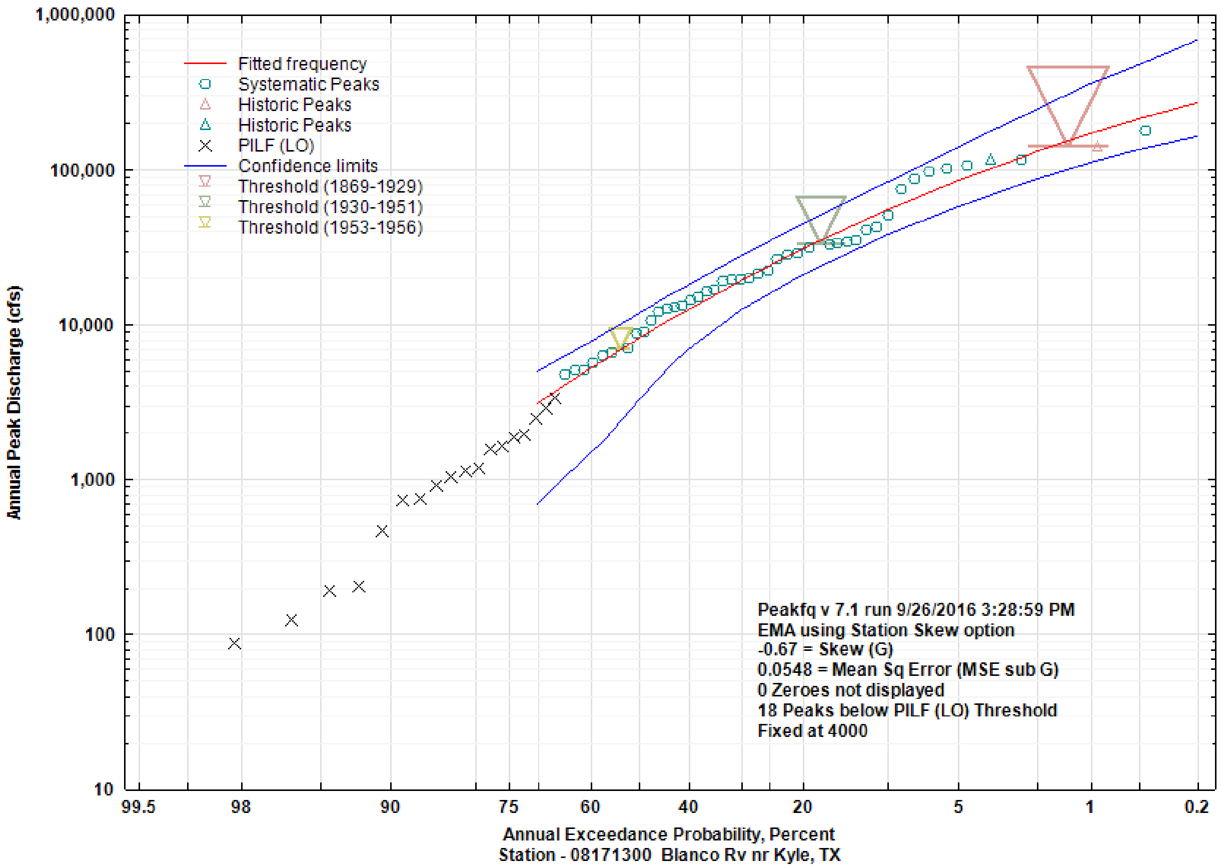

Figure 5.27: Flood Flow Frequency Curve for the Blanco River near Kyle, TX

San Marcos River at Luling, Texas

The systematic record for the San Marcos River at Luling is 1940–2016. Both regulated and unregulated records were accepted into the analysis for two primary reasons: (1) the regulation in the San Marcos-Luling watershed is considered passive through detention storage in small flood-water retarding structures, and (2) visualization of the time series of annual peaks shows a situation in which the data can be combined. Even in the presence of regulated streamflow record, it is clear that large magnitude peaks can occur. The October 1998 peak of 206,000 ft^3/s at a stage of 41.85 ft is considered the highest since 1859. From TLS regression analysis between stream gages San Marcos at Luling and Plum Creek near Luling, the period 1930–1939 can be found in Table 5.2. The substantial peak in late October 2015 indicates that water year 2016 annual peak will be at least 71,000 ft^3/s. Special addition of incomplete water year 2016 was made where 71,000 ft^3/s is the October 31, 2015 peak unit-value of discharge (15-minute discharge in USGS database). The data as set up for statistical frequency analysis are shown in Figure 5.28, in which the rectangular region demarks the historical context of the October 1998 peak. The discharge intervals are represented as green bars in the figure.

The flood flow frequency for the San Marcos River at Luling is shown in Figure 5.29. The long systematic record and the extensive historical information lead to a reliable flood flow frequency curve. The single block demarked in Figure 5.28 with a discharge threshold can be seen affecting the empirical plotting of the largest event for which the fitted frequency curve nearly passes through. The discharge intervals are scattered amongst the empirical probabilities with the fitted curve generally bisecting (not deliberately) the intervals. No low outliers are identified.

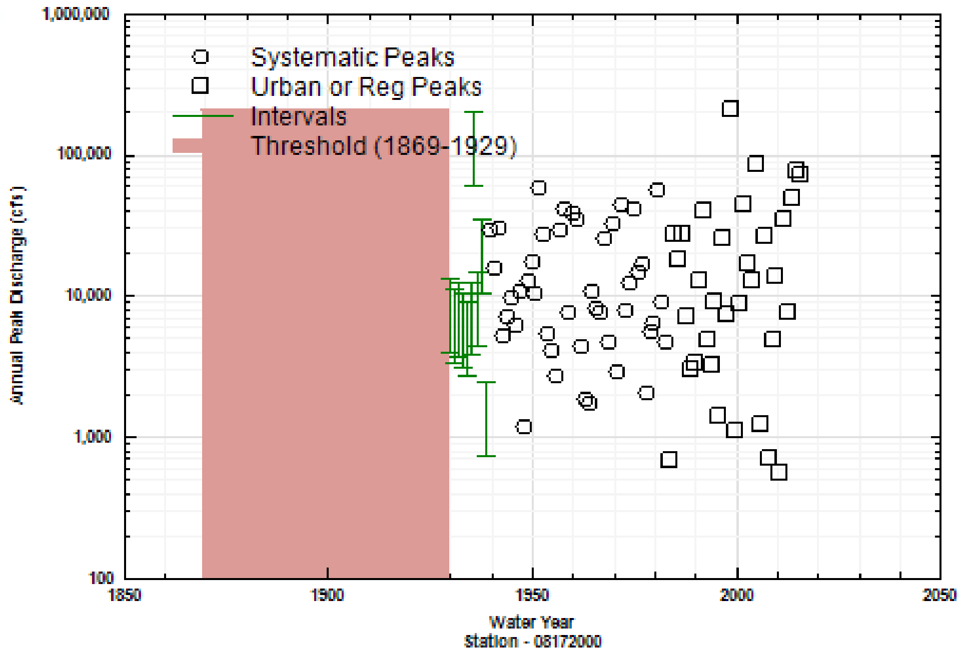

Figure 5.28: Annual Peak Streamflow Data for the San Marcos River at Luling, TX

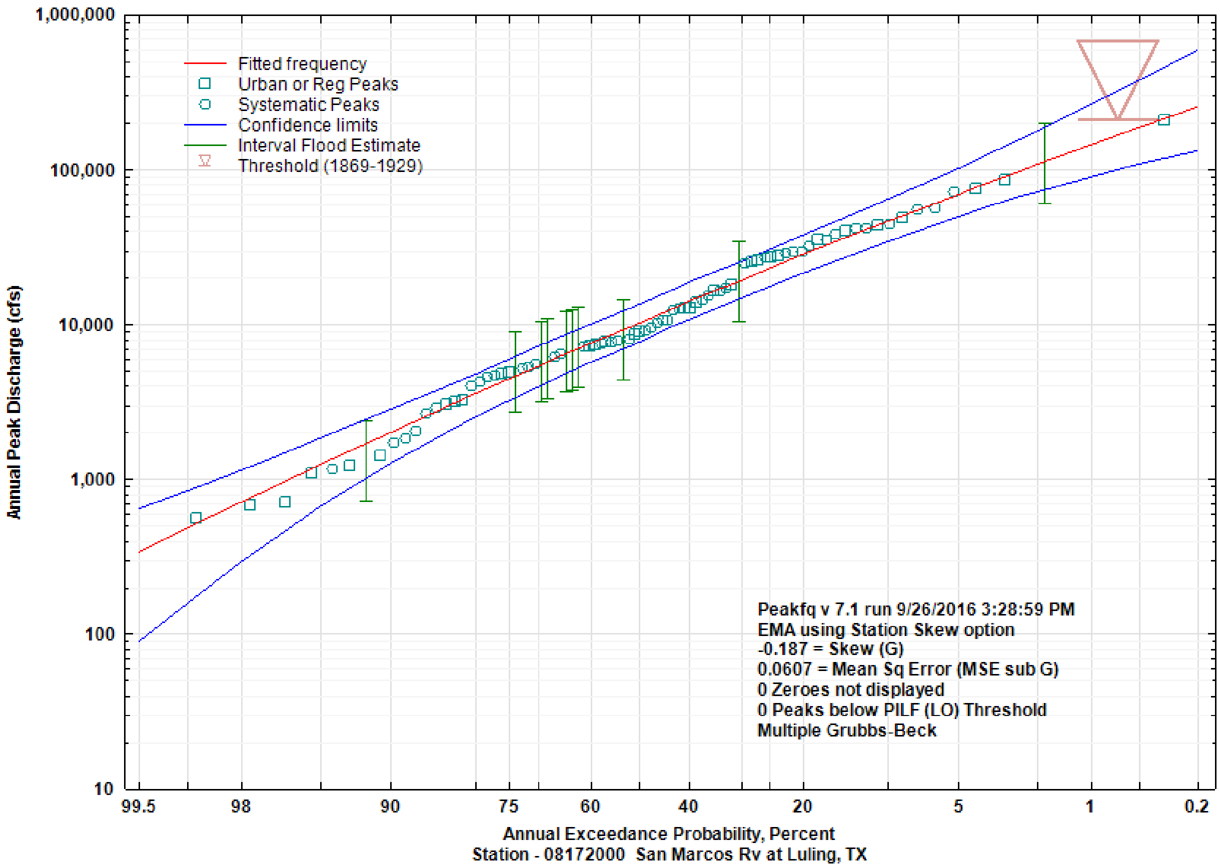

Figure 5.29: Flood Flow Frequency Curve Results for the San Marcos River at Luling, TX

Plum Creek at Lockhart, Texas

The systematic record for the Plum Creek at Lockhart is 1959–2016. Both regulated and unregulated records were accepted into the analysis. Visualization of the time series of annual peaks shows a situation in which the data can be combined. The October 1998 peak of 47,200 ft^3/s at stage of 23.09 ft is the largest for the period of record. The substantial peak in late October 2015 indicates that water year 2016 annual peak will be at least 39,100 ft^3/s from the unit values. Special addition of incomplete water year 2016 was made. The data as set up for statistical frequency analysis are shown in Figure 5.30.

The flood flow frequency for Plum Creek at Lockhart is shown in Figure 5.31. Recall that an alternative analysis also is provided in the next section. The substantial systematic record leads to a reliable flood flow frequency curve. The low-outlier threshold can be seen conditionally removing peaks below about 1,400 ft^3/s, and those data are seen to break away from the other data.

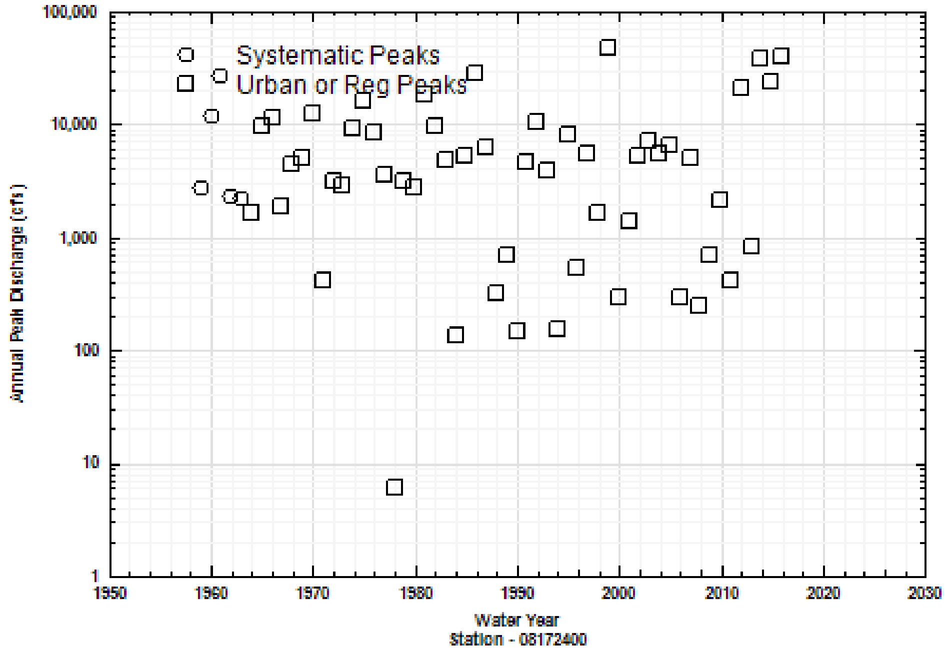

Figure 5.30: Annual Peak Streamflow Data for Plum Creek at Lockhart, TX

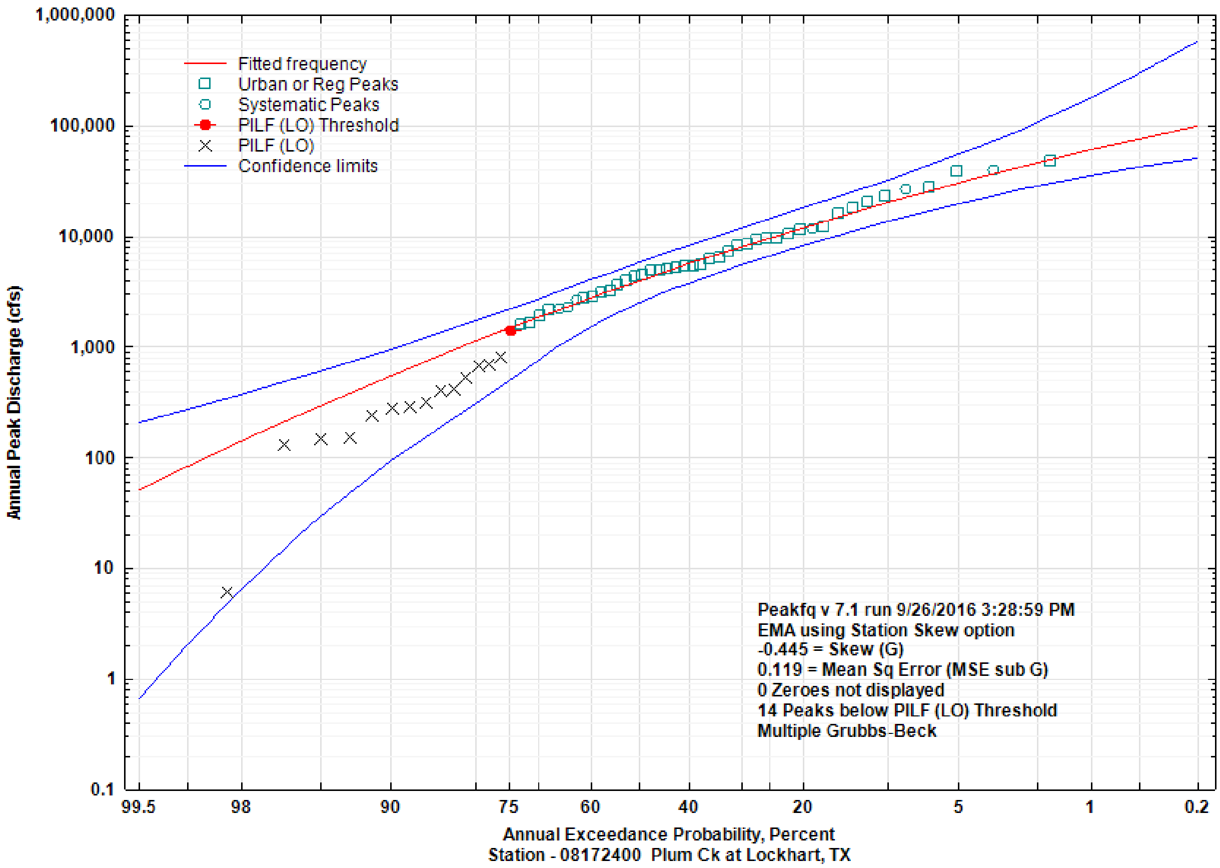

Figure 5.31: Flood Flow Frequency Curve for Plum Creek at Lockhart, TX

Plum Creek at Lockhart, Texas (alternative analysis)

An alternative analysis for Plum Creek at Lockhart was made because of a large gap in record relative to downstream the Plum Creek near Luling stream gage but sited along the same watershed main stem. This alternative analysis is preferable because the 1999 peak was so large and of considerable historical importance. The 1930–1958 information gap relative to Plum Creek near Luling was augmented by TLS regression and can be found in Table 5.2. This alternative analysis is identified by either the pseudo-station identification number 08172400.01 or 0817240001 (depending on software limitations). The data as set up for statistical frequency analysis for the alternative analysis are shown in Figure 5.32, in which the listed discharge intervals (Table 5.2) are represented as green bars in the figure.

The alternative flood flow frequency for Plum Creek at Lockhart is shown in Figure 5.33. The substantial systematic record plus the inclusion of discharge intervals also leads to a reliable flood flow frequency curve. The same low-outlier threshold was used and can be seen conditionally removing peaks below about 1,400 ft^3/s. The interval data was derived from TLS regression and the record at downstream Plum Creek near Luling. These intervals are an important addition, though numerous, to the analysis because the large 1936 event observed at Plum Creek near Luling is of great contextual interest. The alternative analysis with the discharge intervals (1930–1958) provides a common historical period of 87 years with Plum Creek near Luling. It is noteworthy for discussion with the next stream gage (Plum Creek near Luling) that the October 1998 peak is 47,200 ft^3/s at a stage of 23.09 ft.

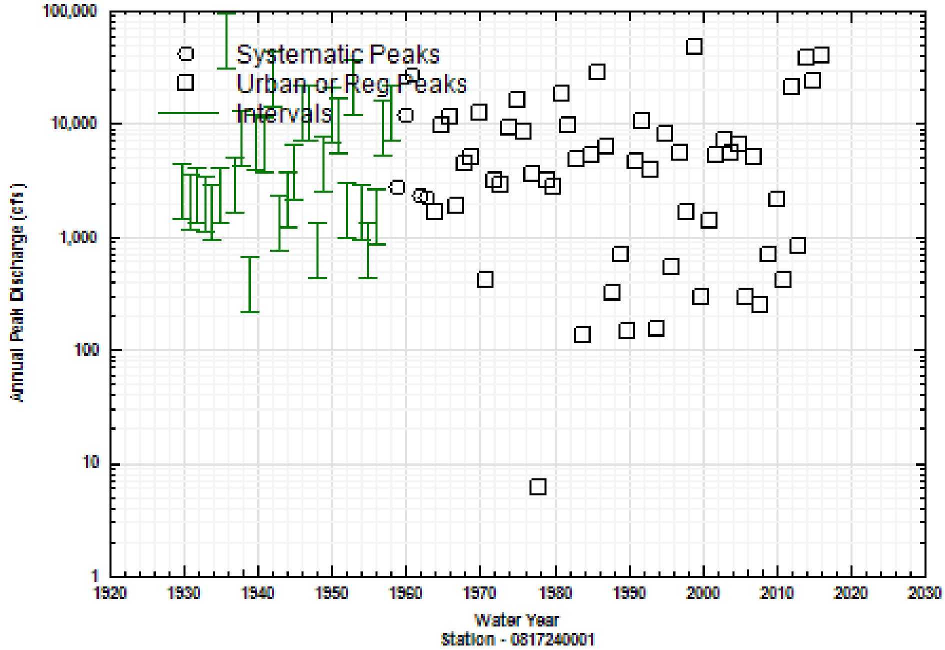

Figure 5.32: Annual Peak Streamflow Data for Plum Creek at Lockhart, TX (alternative analysis)

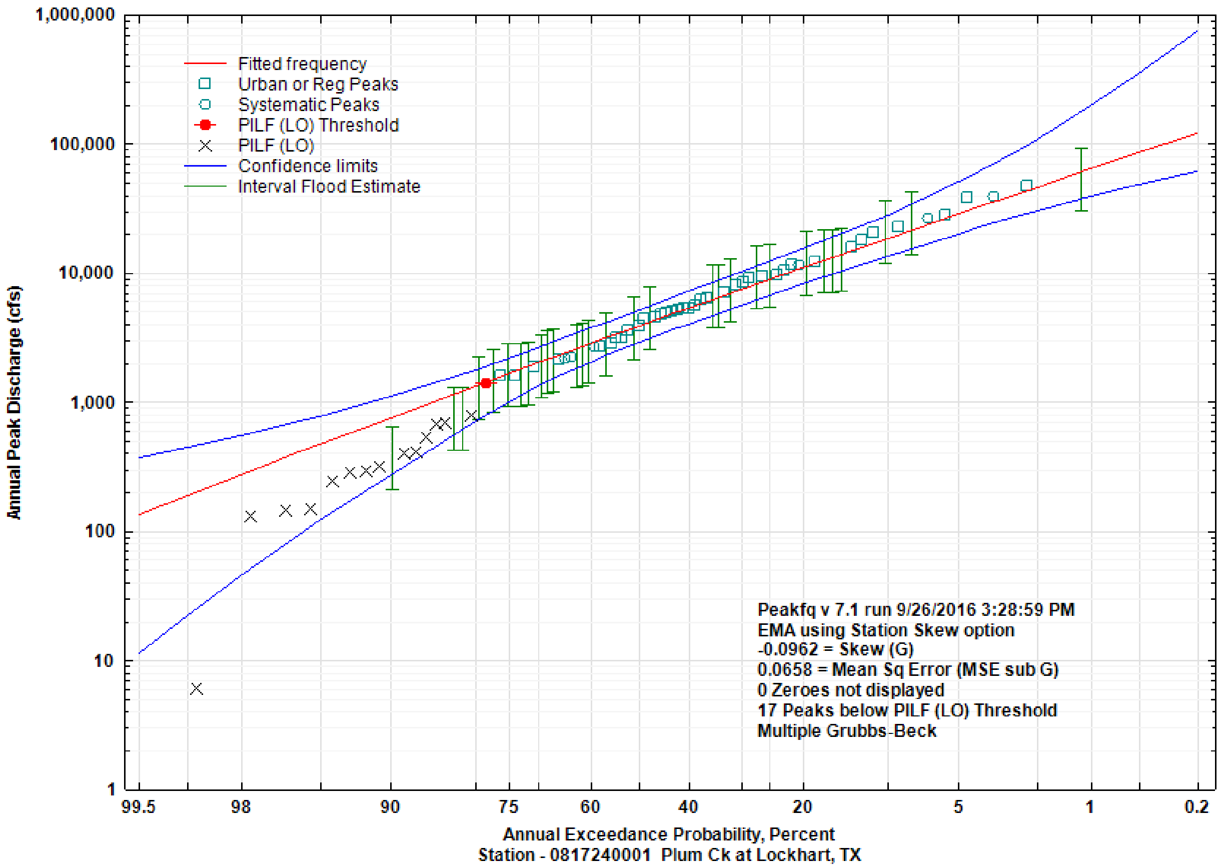

Figure 5.33. Flood Flow Frequency Curve for Plum Creek at Lockhart, TX (alternative analysis)

Plum Creek near Luling, Texas

The systematic record for Plum Creek near Luling is 1930–1993 and 2001–2016. Two scenarios were computed and subsequently combined by arithmetic averaging for reasons described as follows. Both regulated and unregulated records were accepted into the analysis because the regulation in the Plum Creek near Luling watershed is considered passive through detention storage in small flood-water retarding structures, and more importantly, visualization of the time series of annual peaks shows a situation in which the data can be combined. Even in the presence of regulated streamflow record, it is clear that large magnitude peaks can occur. A quite substantial peak associated with the October 2015 event occurred. Special addition of incomplete water year 2016 was made where 15,800 ft^3/s is the October 31, 2015 peak unit-value of discharge (15-minute discharge in USGS database).

Plum Creek near Luling was not operational (discontinued) from 1994–2000. Within this gap, it is near certain that a major event occurred in October 1998 based on regional comparisons of peak streamflow. Two scenarios of analysis were done with the only difference being how the gap from 1994 to 2000 was treated. In scenario 1 a TLS regression of observed data between Plum Creek near Luling and San Macros River at Luling was developed and the results can be found in Table 5.2. The data as set up for statistical frequency analysis for scenario 1 are shown in Figure 5.34 in which the discharge intervals are represented as green bars. In scenario 2 a TLS regression of observed data between Plum Creek near Luling and Plum Creek at Lockhart was used and the results can be found in Table 5.2. The data as set up for statistical frequency analysis for scenario 2 are shown in Figure 5.36 in which the discharge intervals (Table 5.2) are represented as green bars.

The flood flow frequency for Plum Creek near Luling is shown in Figures 5.35 and 5.37. The extensive systematic record leads to a reliable flood flow frequency curve with the caveat that it is unknown how much contrast exists related to the unregulated and regulated record as flagged in USGS data (USGS, 2016). The period 1994–2000 is a gap in stream gage operation, and the record is in-filled for this study with discharge interval data based on TLS regression with San Marcos River at Luling and separately with Plum Creek at Lockhart. The Plum Creek near Luling streamflow-gaging stream gage has recorded the large 1936 peak (78,500 ft^3/s at a stage of 30.70 ft) but the October 1998 event, which produced large peaks for other stream gages in the study area was not observed because the stream gage was discontinued for the gap. It is difficult to identify a preferred application of TLS regression for gap in-fill for this stream gage and hence the two shown in Figures 5.35 and 5.37 were both treated as plausible with the best estimate computed as the arithmetic mean of the confidence limit curves and the flood flow frequency curve being recommended for this study. These are the values listed in Table 5.3.

SCENARIO 1

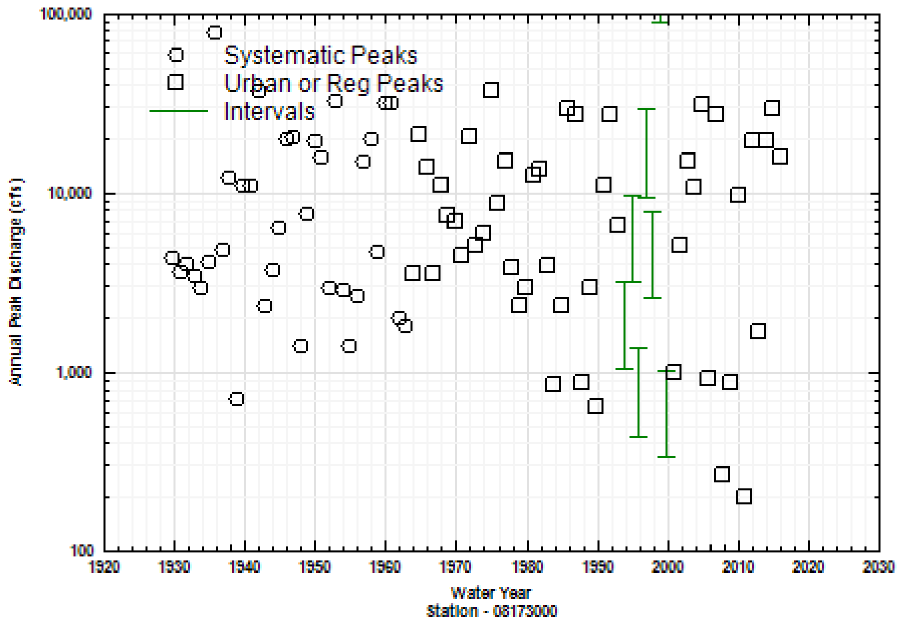

Figure 5.34: Annual Peak Streamflow Data for Plum Creek near Luling, TX with interval estimates of peak discharge based on total-least squares regression with San Marcos River at Luling, TX

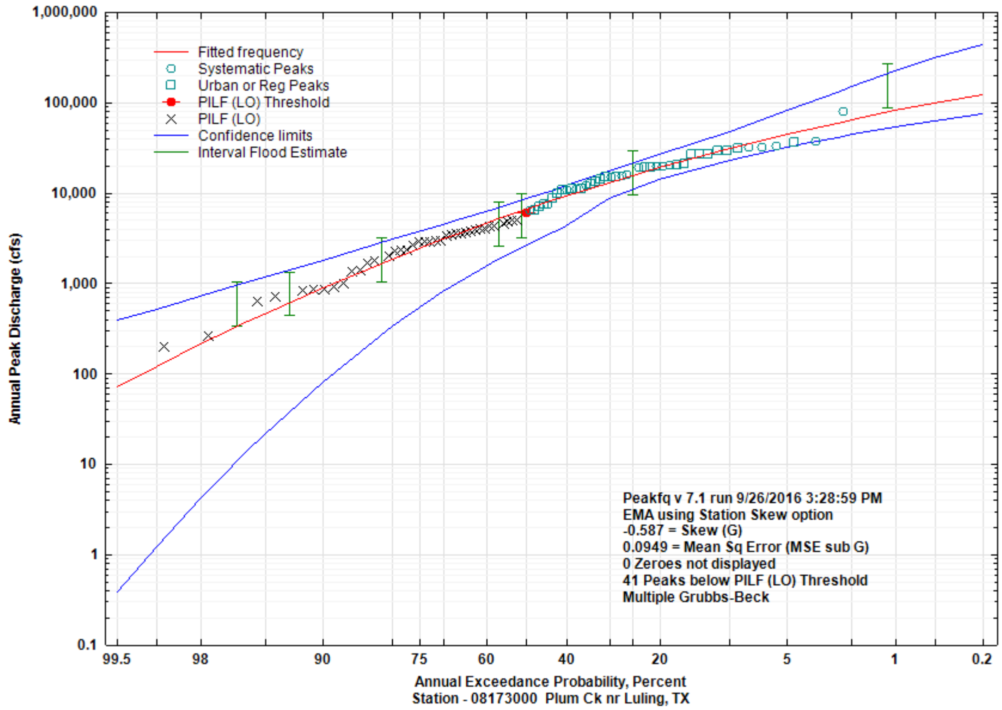

Figure 5.35: Flood Flow Frequency Curve for Plum Creek near Luling, TX with interval estimates of peak discharge based on total-least squares regression with San Marcos River at Luling, TX

SCENARIO 2

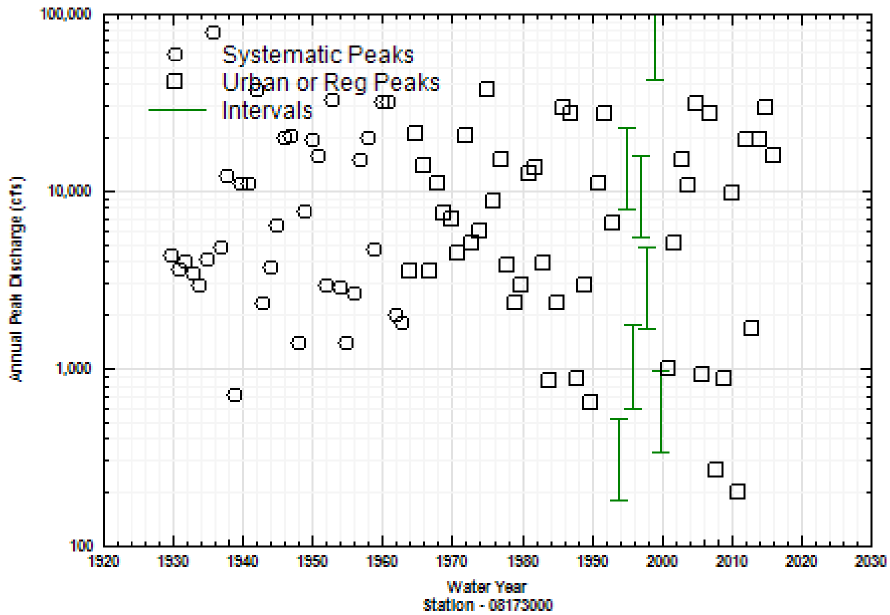

Figure 5.36: Annual Peak Streamflow Data for Plum Creek near Luling, TX with interval estimates of peak discharge based on total-least squares regression with Plum Creek at Lockhart, TX

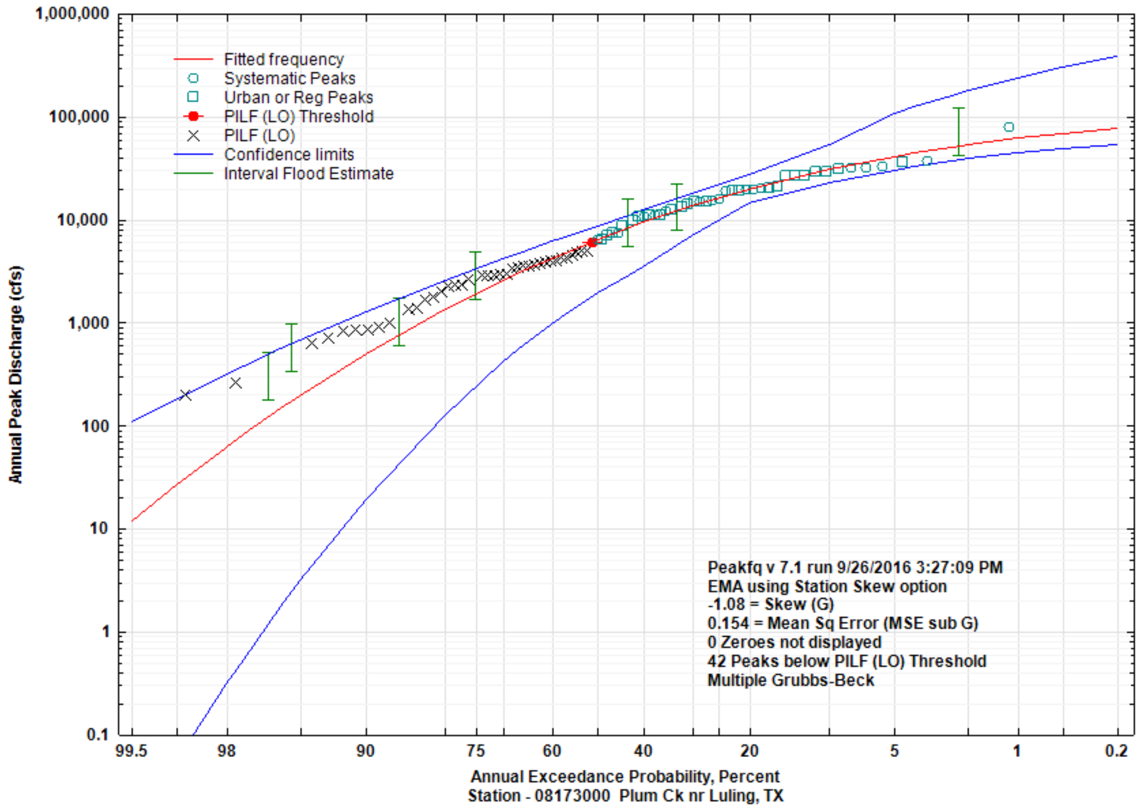

Figure 5.37: Flood Flow Frequency Curve for Plum Creek near Luling, TX with interval estimates of peak discharge based on total-least squares regression with Plum Creek at Lockhart, TX

Guadalupe River at Gonzales, Texas

The systematic record for Guadalupe River at Gonzales is 1977–1988 and 1997–2015. The largest peak is in the systematic record of 340,000 ft^3/s at a stage of 50.44 ft in 1999 (October 1998) and is treated as highest for 1976–1935 based on information for Guadalupe River at Victoria. This same value was used as the discharge threshold also for missing 1984 and 1995 as well as 1989–1994. Rating lookup for 1989–1994 could be used because gage heights are provided in the USGS peak values file and rating 3.0 (USGS databases) appears applicable to provide point estimates of discharge for purposes of this study so discharge intervals were not chosen for this analysis. The estimates are listed in Table 5.2. The quite substantial peak in early November 2015 indicates that water year 2016 annual peak will be at least 42,600 ft^3/s (11/01/2015). The data as set up for statistical frequency analysis are shown in Figure 5.38 in which the three rectangular regions demark the interpretation of the 1999 peak.

The flood flow frequency for Guadalupe River at Gonzales is shown in Figure 5.39. The systematic record is comparatively short relative to other stream gages on the Guadalupe River and other major streams in the basin. The extensive historical information for the 1999 peak (October 1998 event) adds credence to the reliability of the flood flow frequency. The MGBT identifies no low outliers and this is appropriate for the available data. The data have a substantial positive skewness, which leads to a curve that bends upward as AEP decreases. Whether this pattern continues with the addition of systematic data is unknown.

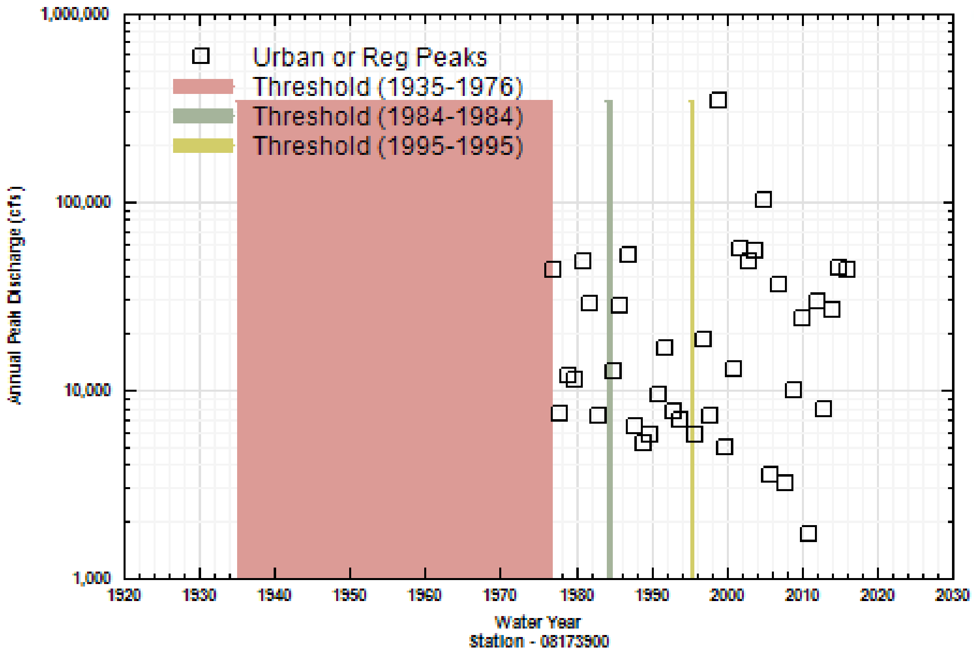

Figure 5.38: Annual Peak Streamflow Data for the Guadalupe River at Gonzales, TX

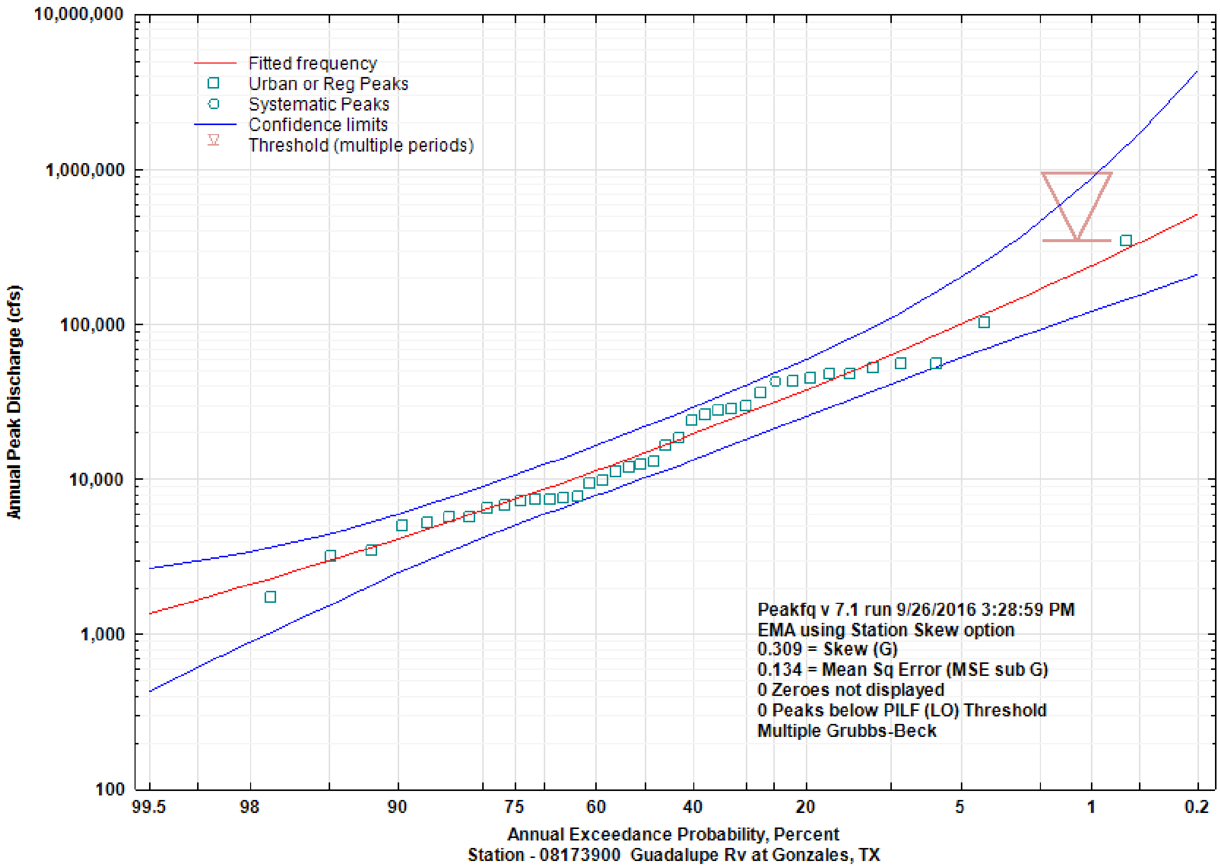

Figure 5.39: Flood Flow Frequency Curve for the Guadalupe River at Gonzales, TX

Peach Creek below Dilworth, Texas

The systematic record for Peach Creek below Dilworth is 1960–1979 and 2001–2015. There is no historical information per se to interpret. There is a gap in record from 1980–2000, which is retained for scenario 1 for this stream gage. The data as set up for statistical frequency analysis are shown in Figure 5.40.

The flood flow frequency for Peach Creek below Dilworth is shown in Figure 5.41. Recall that an alternative analysis also is provided in the next section. The systematic record leads to a reliable flood flow frequency curve. The MGBT identifies an appropriate low-outlier threshold. There is a substantial gap in record for 1980–2000 in which several large peaks likely occurred, and in particular the October 1998 event that is an important peak for other stream gages. It was decided to in-fill the gap in record as explained in the next section.

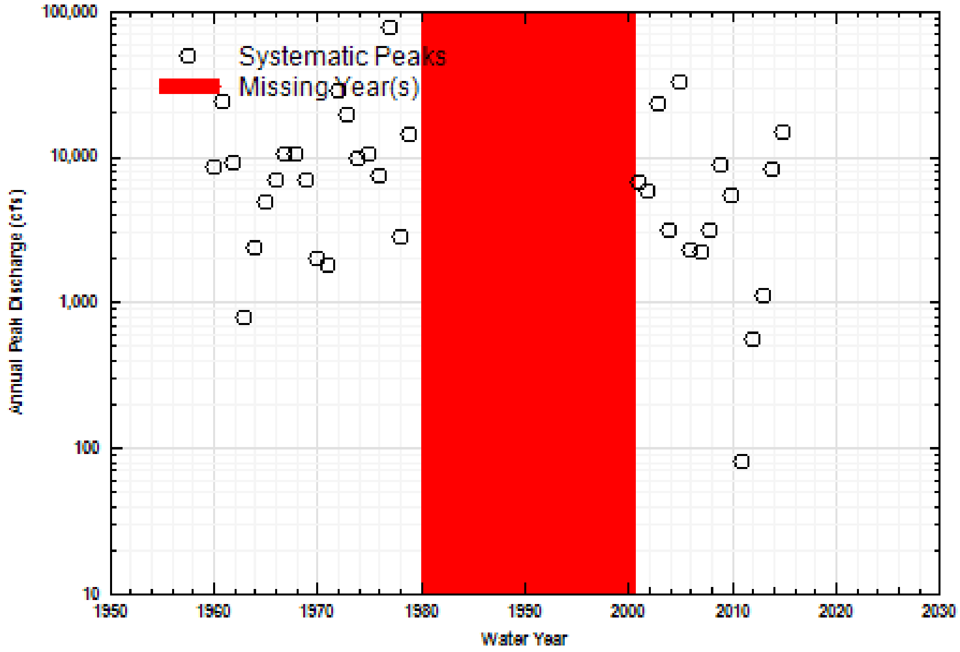

Figure 5.40: Annual Peak Streamflow Data for the Peach Creek below Dilworth, TX

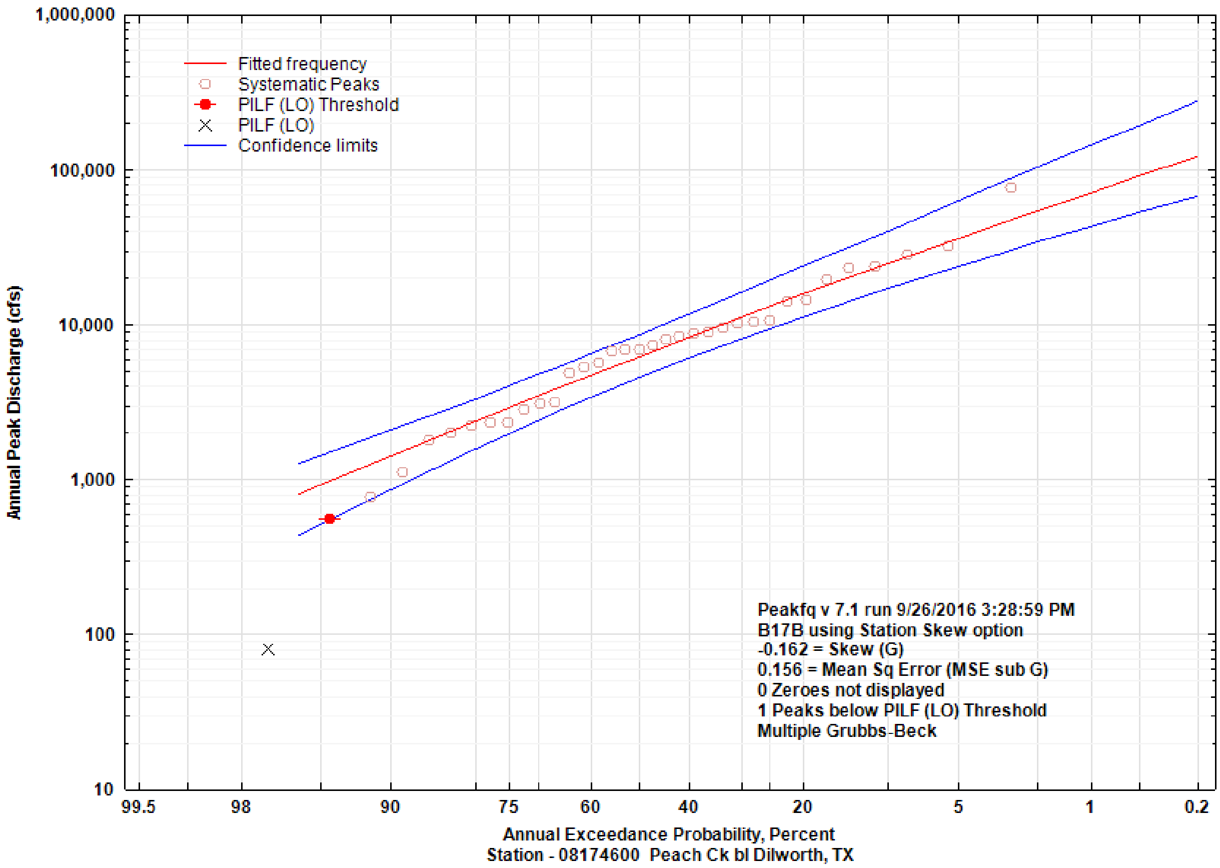

Figure 5.41: Flood Flow Frequency Curve for the Peach Creek below Dilworth, TX

Peach Creek below Dilworth, Texas (alternative analysis)

An alternative analysis was developed for Peach Creek below Dilworth in which the 1980–2000 gap is in-filled by TLS regression with Sandies Creek near Westhoff, and the discharge intervals are listed in Table 5.2. This alternative analysis is identified by either by the pseudo-station identification number 08174600.01 or 0817460001 (depending on software limitations). Including these intervals in the analysis is preferable because it is quite likely based on record inspection at nearby stream gages that water years 1981, 1992, and 1999 likely represent years for which quite substantial peak streamflow occurred for Peach Creek below Dilworth. However, 21 years of record in-fill represents a large fraction relative to the 35 years of systematic record. The data as set up for statistical frequency analysis are shown in Figure 5.42, in which the discharge intervals (Table 5.2) are represented as green bars in the figure.

The alternative flood flow frequency for Peach Creek below Dilworth is shown in Figure 5.43, in which 21 discharge intervals are shown and representative of the gap in-fill for 1980–2000. The TLS regression between the Peak Creek data and data at Sandies Creek near Westhoff provide the intervals. It is interpreted that the flood flow frequency depicted in the figure for the alternative analysis is preferable for applications because attention has been made to three unobserved by likely large events (AEP <10 percent) including the October 1998 event that does plot with its discharge interval furthest to the right in the figure.

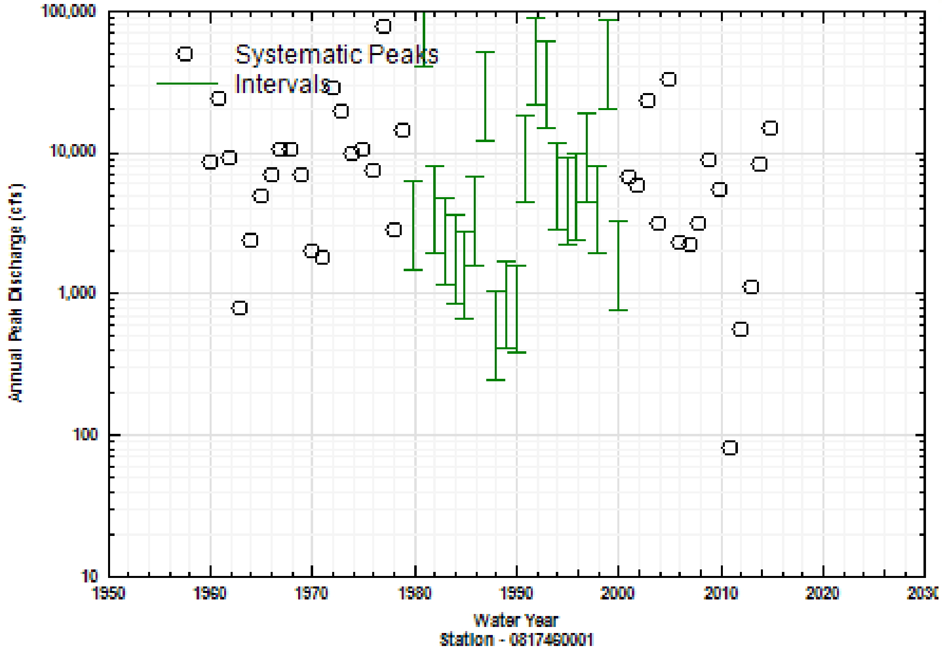

Figure 5.42: Annual Peak Streamflow Data for Peach Creek below Dilworth, TX with interval estimates of peak discharge based on total-least squares regression with Sandies Creek near Westhoff, TX

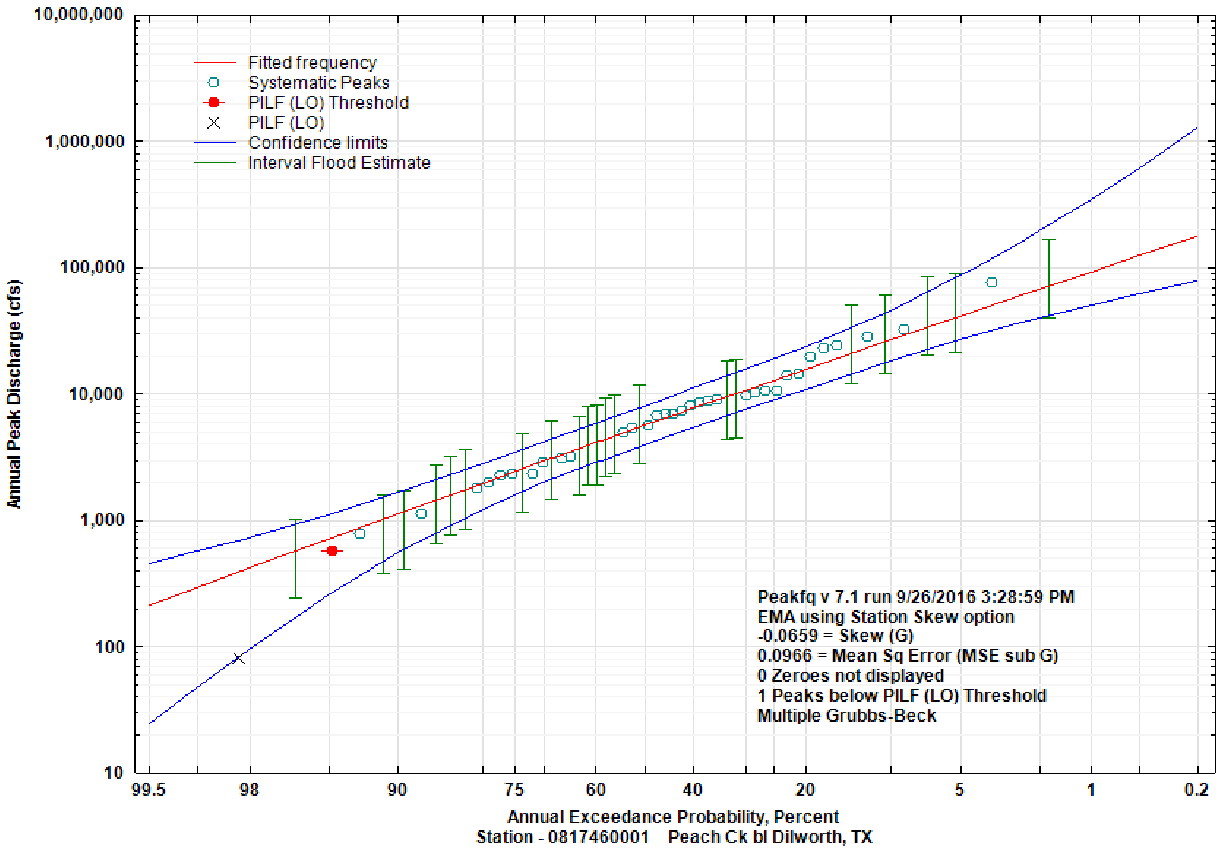

Figure 5.43: Flood Flow Frequency Curve for the Peach Creek below Dilworth, TX (alternative analysis)

Sandies Creek near Westhoff, Texas

The systematic record for Sandies Creek near Westhoff is 1931–1934 and 1960–2015. The peak streamflow in 1936 of 92,700 ft^3/s at a stage of 33.10 ft, which is treated as highest for 1864–1930, 1935, and 1937–1959. The peak gage height of 1936 of 33.10 ft exceeds that in 1913 of 26.00 ft. The data as set up for statistical frequency analysis are shown in Figure 5.44 in which the two rectangular regions demark the interpretation of the 1936 peak.

The flood flow frequency for Sandies Creek near Westoff is shown in Figure 5.45. The combination of modest systematic record and extensive historical information leads to reliable flood flow frequency. The plotting of the historical peak of 1936 (Hurricane Three of 1936 Atlantic Hurricane Season) far to the right and seemingly away from the trajectory of the other data points could be indicative of a historical record not as well understood as extant documentation suggests. The MGBT low-outlier test does not identify any low outliers. Of general interest, the next two largest peaks were in 1981 (Tropical Depression Eight of the 1981 Atlantic Hurricane Season) and 1967 (Hurricane Beulah) and are of similar magnitudes (78,600 ft^3/s in 1981; 79,700 ft^3/s in 1967).

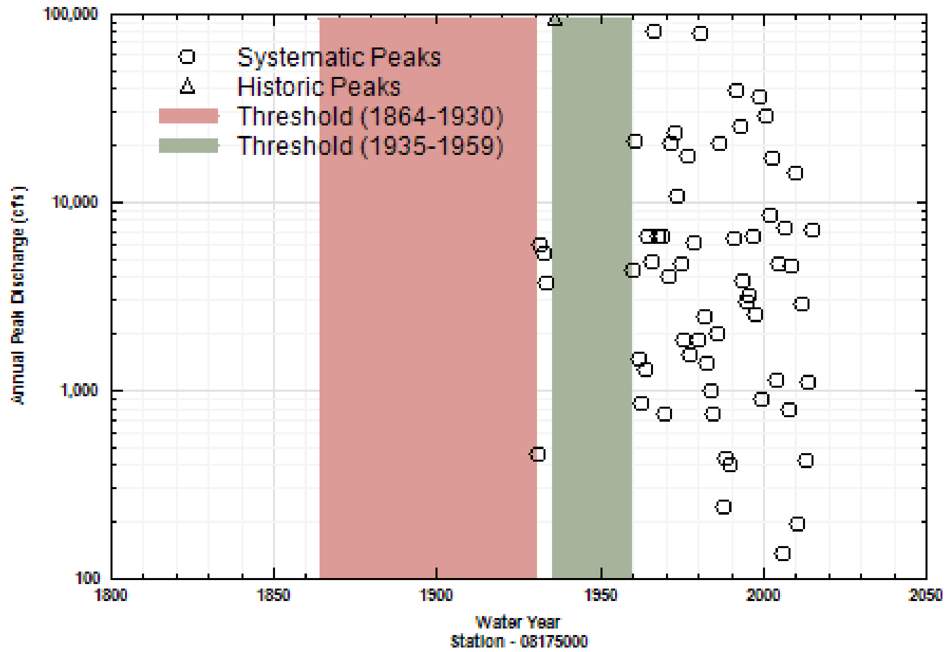

Figure 5.44: Annual Peak Streamflow Data for the Sandies Creek near Westhoff, TX

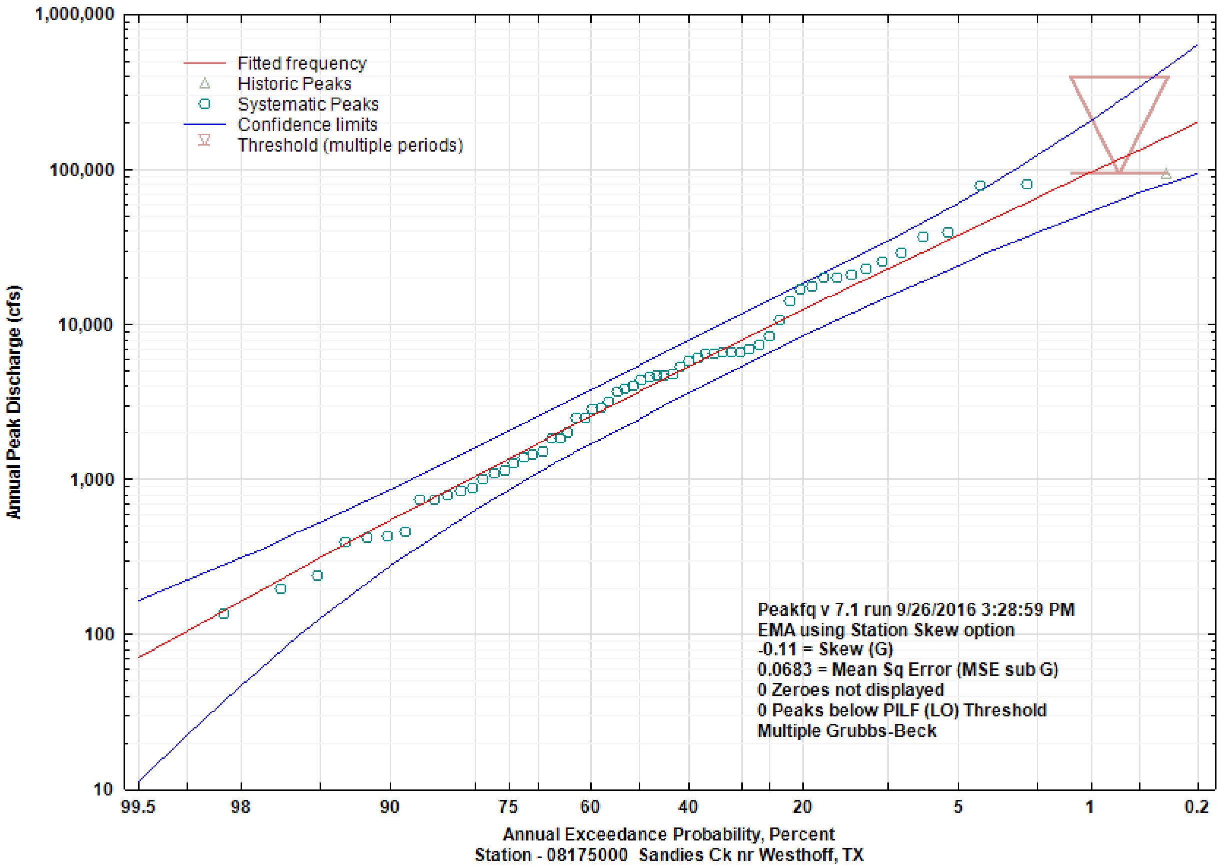

Figure 5.45: Flood Flow Frequency Curve for the Sandies Creek near Westhoff, TX

Guadalupe River at Cuero, Texas

The systematic record for Guadalupe River at Cuero is 1964–2017, extended to include the peak streamflow from Hurricane Harvey, which resulted in the second highest peak of record at the gage. The largest peak is 473,000 ft^3/s at a stage of 50.35 in 1999 (October 1998). It is important to note that the October 1998 event seems to be controlling upstream of Hurricane Beulah in 1967, which is the time and year of the largest peak for many stream gages closer to the coast. The data as set up for statistical frequency analysis are shown in Figure 5.46.

The flood flow frequency for Guadalupe River at Cuero is shown in Figure 5.47. The substantial length of systematic record leads to reliable flood flow frequency. The MGBT low-outlier test does not identify any low outliers.

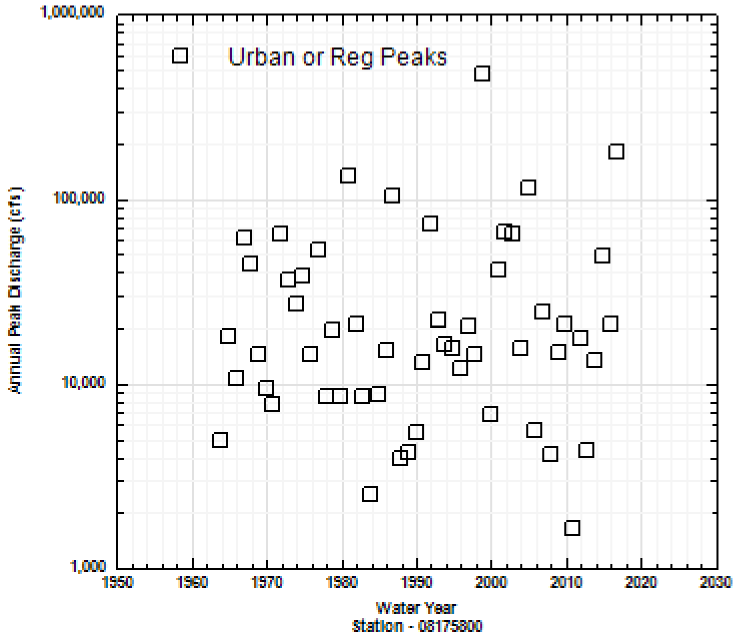

Figure 5.46: Annual Peak Streamflow Data for the Guadalupe River at Cuero, TX

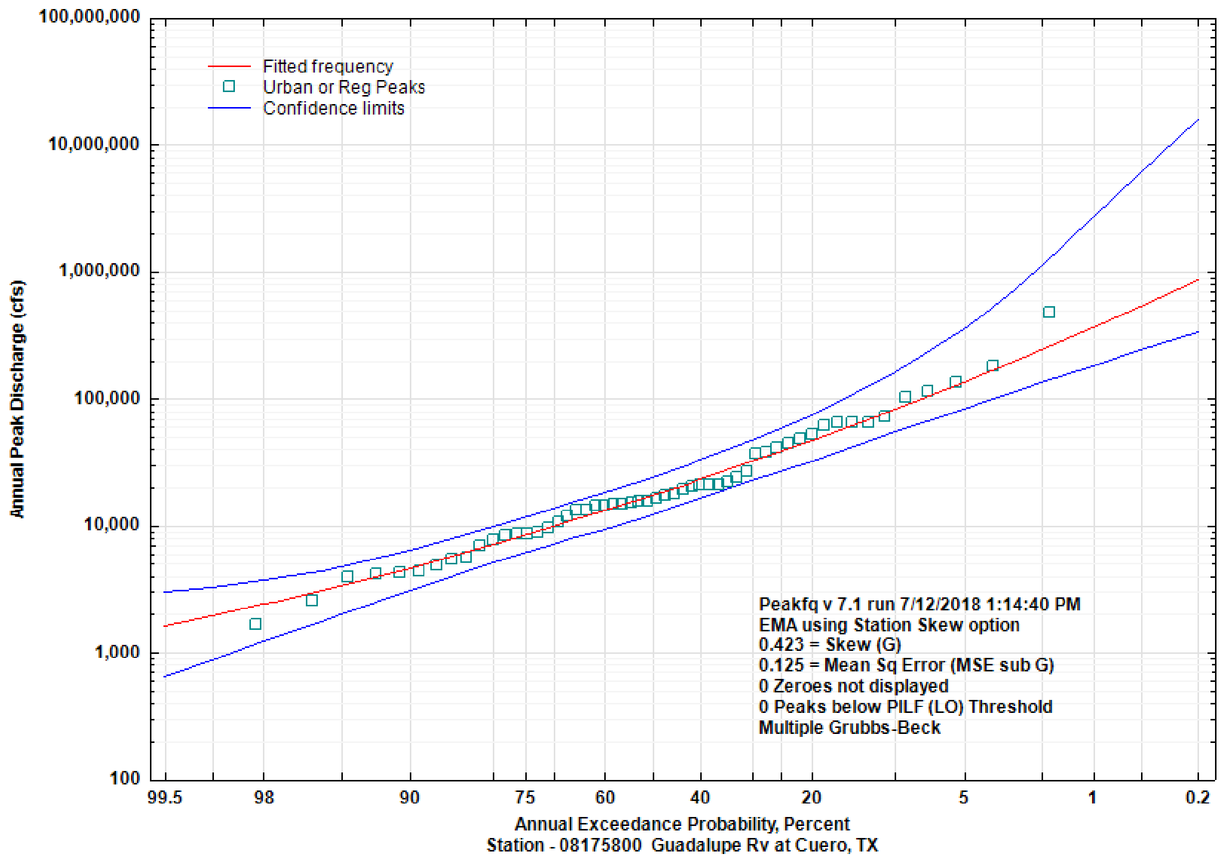

Figure 5.47: Flood Flow Frequency Curve for the Guadalupe River at Cuero, TX

Guadalupe River at Victoria, Texas

The systematic record for Guadalupe River at Victoria is 1935–2017, extended to include the peak streamflow from Hurricane Harvey, which resulted in the fifth highest peak of record at the gage. There is no historical information to interpret and there is complete systematic record of 1935–2017. The largest peak is 466,000 ft^3/s at a stage of 34.04 ft in 1999 (October 1998). This stream gage provides historic period for upstream Guadalupe River at Cuero. The data as set up for statistical frequency analysis are shown in Figure 5.48 in which is it seen that the 1999 peak stands out against eight decades of record.

The flood flow frequency for Guadalupe River at Victoria is shown in Figure 5.49. The substantial systematic record leads to generally reliable flood flow frequency. The MGBT low-outlier test does not identify any low outliers. The largest value is the 1999 event (October 1998), which is immensely large and most certainly the largest for a time period in excess of the available systematic record. The USGS database does not identify a historical period and thus one is not used. Thus the largest value on the figure plots too much too the right (not enough to the left) though no alternative plotting position is available. A curious feature of the data in the figure is that there appears to be a relatively flat portion between about 10,000 ft^3/s to 15,000 ft^3/s and another relatively flat part at about 60,000 ft^3/s; this suggests an unknown degree of bimodality of the data. Processes in the watershed seem to contribute and greater than expected occurrence of peaks at about 10,000 ft^3/s to 15,000 ft^3/s and again at about 60,000 ft^3/s. This is discussed further in Section 5.4.

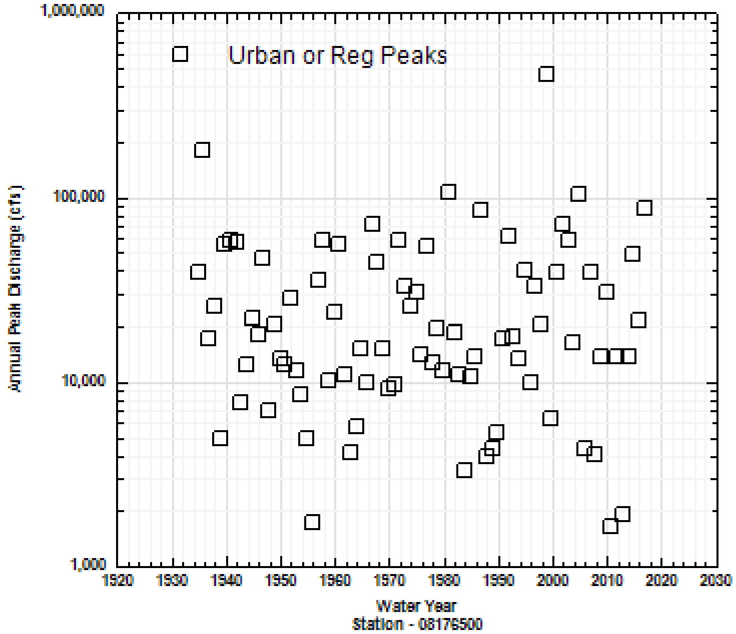

Figure 5.48: Annual Peak Streamflow Data for the Guadalupe River at Victoria, TX

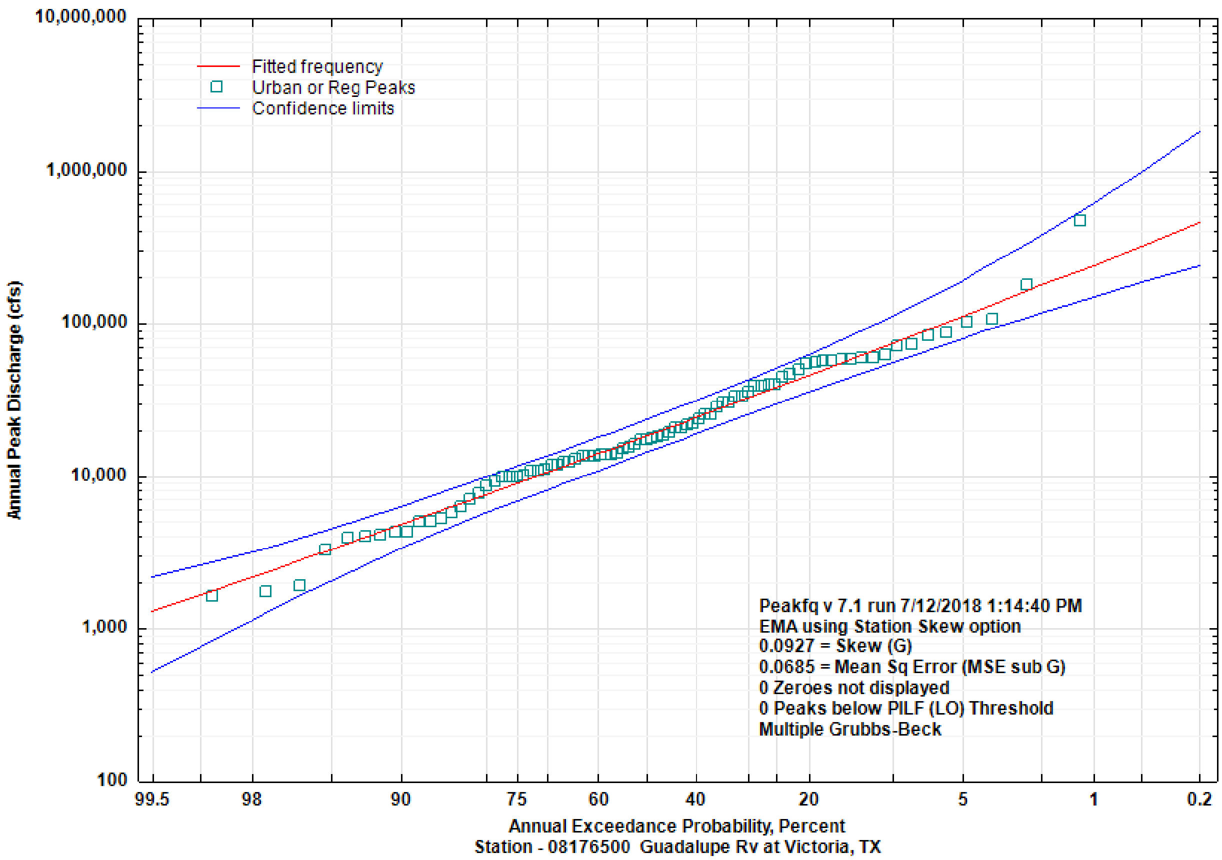

Figure 5.49: Flood Flow Frequency Curve for the Guadalupe River at Victoria, TX

Fifteenmile Creek near Weser, Texas

The systematic record for Fifteenmile Creek near Weser is 1985–2015. The stream gage has peaks above a base and thus use 1,000 ft^3/s as a low-outlier threshold but insert for the unrecorded years 1996, 2000, 2006, 2008, and 2011–2013 on the discharge interval 1 <=> 999 ft^3/s for the EMA algorithm of the USGS-PeakFQ software. The primary side effect is that a fully informative input time series is constructed in this way. The software has several ways to get to the same solution for this particular data circumstance. The data as set up for statistical frequency analysis are shown in Figure 5.50.

The flood flow frequency for Fifteenmile Creek near Weser is shown in Figure 5.51. The comparatively short systematic record inherently leads to a less reliable flood flow frequency. The confidence limits are comparatively wide as a result. The low-outlier threshold is set at 1,000 ft^3/s that accommodates conditional removal of the years for which the discharge was below a base discharge of 1,000 ft^3/s. This particular stream gage of those considered for this study is the only "peaks above base" stream gage.

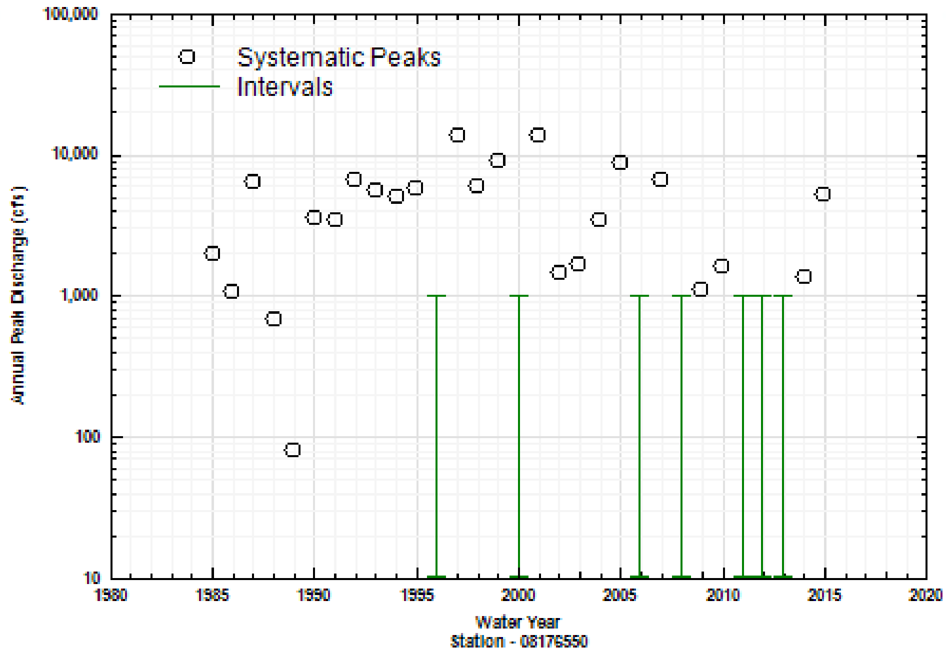

Figure 5.50: Annual Peak Streamflow Data for Fifteenmile Creek near Weser, TX

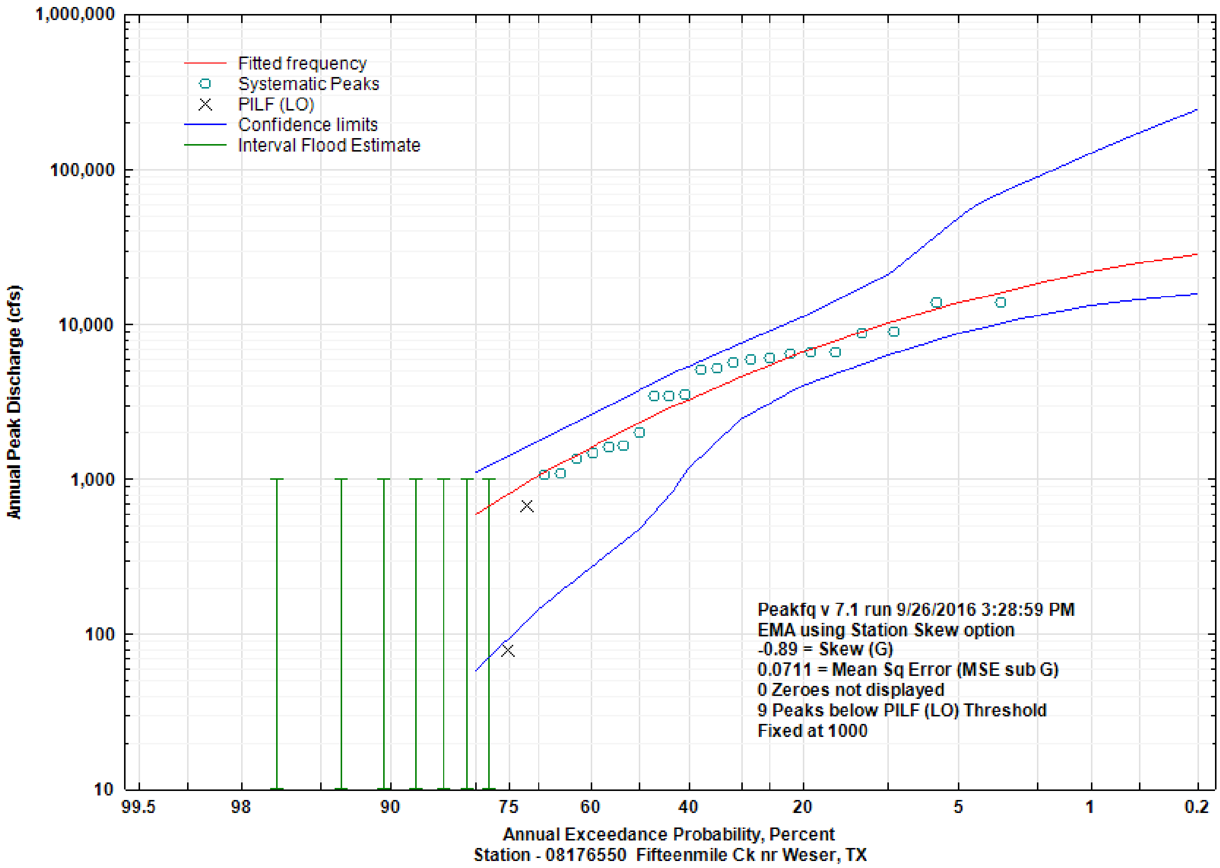

Figure 5.51: Flood Flow Frequency Curve for the Fifteenmile Creek near Weser, TX

Coleto Creek at Arnold Road Crossing near Schroeder, Texas

The systematic record for Coleto Creek at Arnold Crossing near Schroeder is 1979–2015. The peak streamflow in 1967 of 122,000 ft^3/s (no stage available) is associated with Hurricane Beulah but other historical peaks of 63,700 ft^3/s in 1947 and 46,700 ft^3/s in 1926 are available. The 1926 peak magnitude is nearly the same as the 1997 so the 1926 peak might not be too rare. With regard only to the information listed the USGS database for this stream gage, only a simple historical treatment for the 1967 peak as the highest for 1872–1925, 1927–1946, 1948–1966, and 1968–1978 and let the two other historical peaks for 1925 and 1946 stand on their own within the analysis. Such treatment might lead to conceptually to a situation of over estimation because the 1947 and 1926 certainly were controlling large peaks for a number of year near those years of occurrence. The 2013 peak is missing but the entire year has approved zeros for the unit values, yet gage height data resembling hydrographs are available. For this study, a discharge threshold for 2013 is inferred as <44 ft^3/s. The data as set up for statistical frequency analysis are shown in Figure 5.52 in which the rectangular region demarks the historical context of the 1967 peak.

The flood flow frequency for the Coleto Creek at Arnold Crossing near Schroeder is shown in Figure 5.53. The combination of modest systematic record and extensive historical information creates a reliable flood flow frequency curve though the confidence limits are wide. The MGBT low-outlier test identifies low outliers in an acceptable way. On balance the historical record length for the 1967 peak (Hurricane Beulah) plots at a position consistent with the general trajectory of the data and the fitted frequency curve.

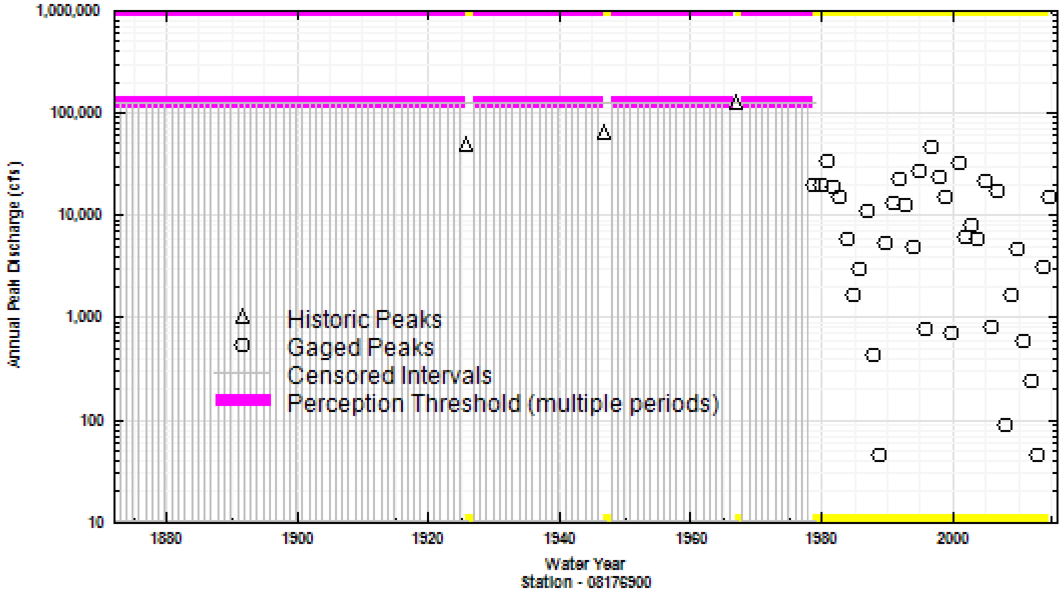

Figure 5.52: Annual Peak Streamflow Data for the Coleto Creek at Arnold Road Crossing near Schroeder, TX

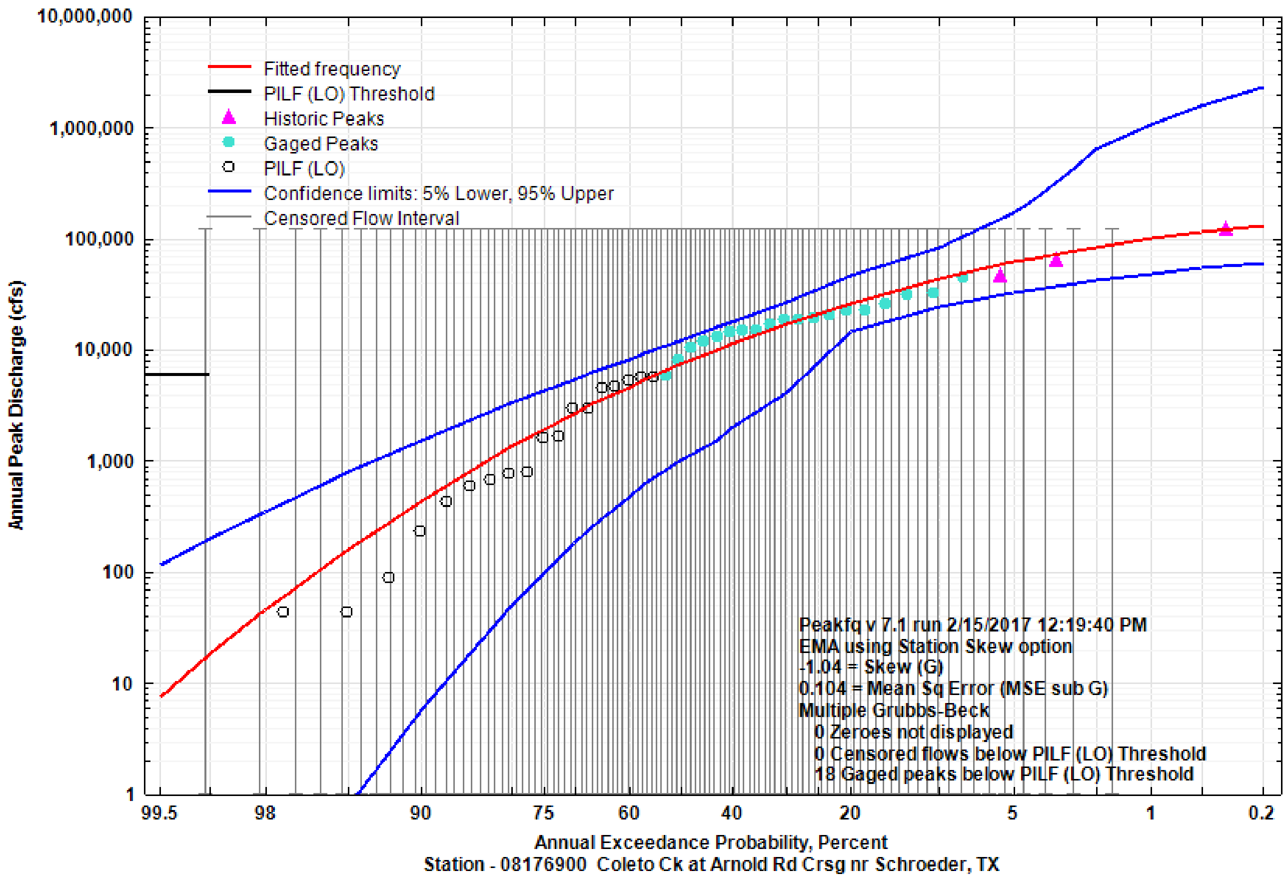

Figure 5.53: Flood Flow Frequency Curve for the Coleto Creek at Arnold Road Crossing near Schroeder, TX

Coleto Creek at Arnold Road Crossing near Schroeder, Texas (alternative analysis)

An alternative analysis for Coleto Creek at Arnold Road Crossing near Schroeder was made by combining the record of station 08176900 Coleto Creek at Arnold Road Crossing near Schroeder with the record of discontinued station 08177000 Coleto Creek near Schroeder. This alternative analysis is identified by either the pseudo-station identification number 08176900.01 or 0817690001 (depending on software limitations). The stream gage at Coleto Creek near Schroeder was discontinued after 1979 because of the filling of Coleto Creek Reservoir, which appears to have put the stream gage in backwater. Both stream gages recorded peaks in 1979. Value used for statistical analysis was 19,350 ft^3/s, which is the arithmetic mean of the peak from each station (1979 peak at Coleto Creek at Arnold Road Crossing is 19,600 ft^3/s and 1979 peak at Coleto Creek near Schroeder is 19,100 ft^3/s). The entire historic period is 1872–2015. The records have the respective records of 1926, 1947, 1967, 1979–2015 for 08176900 and 1926, 1930–1933, 1947, 1953–1979 for 08177000. In a general sense the records for both streamgages can be combined as evidenced by the combined data shown in Figure 5.54. Historic peak streamflows outside the systematic record are the 1967, 1926, and 1947 peaks. The 1967 peak streamflow is associated with Hurricane Beulah. All three are assumed historic peaks over multiple water years as shown in Figure 5.54. The 1926 peak is assumed largest for a 1927–1929 period, the 1947 peak is treated as largest for 1934–1946 and 1948–1952, and the 1967 peak is documented as the largest back to 1872. Finally, the data as set up for statistical frequency analysis for the alternative analysis are shown in Figure 5.54.

The alternative flood flow frequency for Coleto Creek at Arnold Road Crossing near Schroeder is shown in Figure 5.55. The MGBT low-outlier test identifies low outliers in an acceptable way. The combination of peak streamflow data from station 08176900 Coleto Creek at Arnold Road Crossing near Schroeder and station 08177000 Coleto Creak near Schroeder lead to a reliable flood flow frequency curve. In fact, because of the greater information content of the combined record and likely more reliable treatment of the historical record with more precise treatment of the 1926 and 1947 historic peaks, this alternative analysis potentially is more applicable for Coleto Creek at the Arnold Crossing than for the analysis focused only on the modern record (Fig. 5.52 and 5.53). There is the possibility that the lower value peaks in modern times (1995 present) are smaller than seen earlier times. The low-outlier threshold, however, mitigates for the potential that this observation is true, because so many small annual peaks are conditionally removed from the statistical computations.

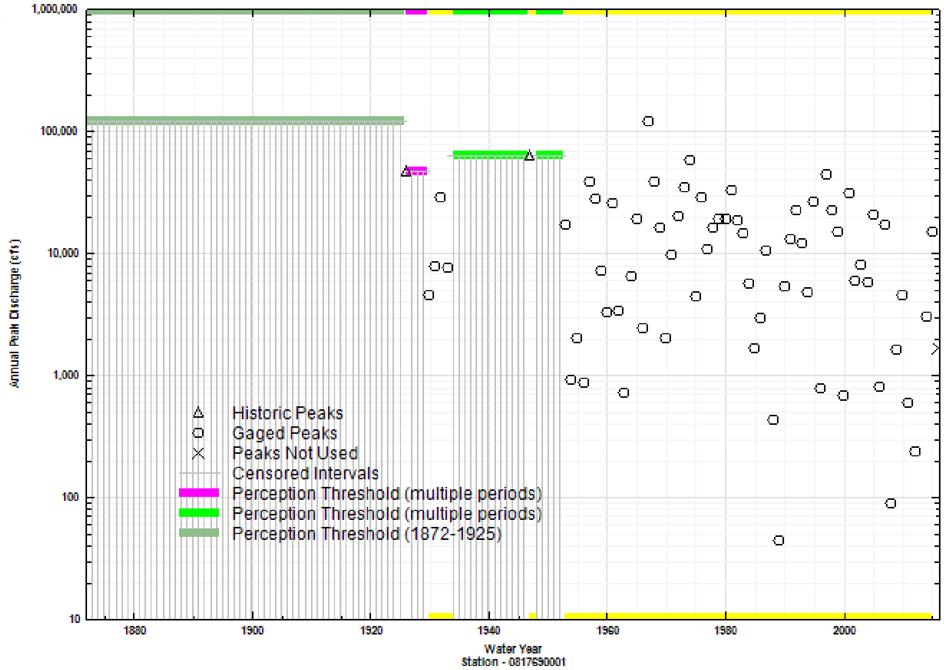

Figure 5.54: Annual Peak Streamflow Data for the Coleto Creek at Arnold Road Crossing near Schroeder, TX (alternative analysis)

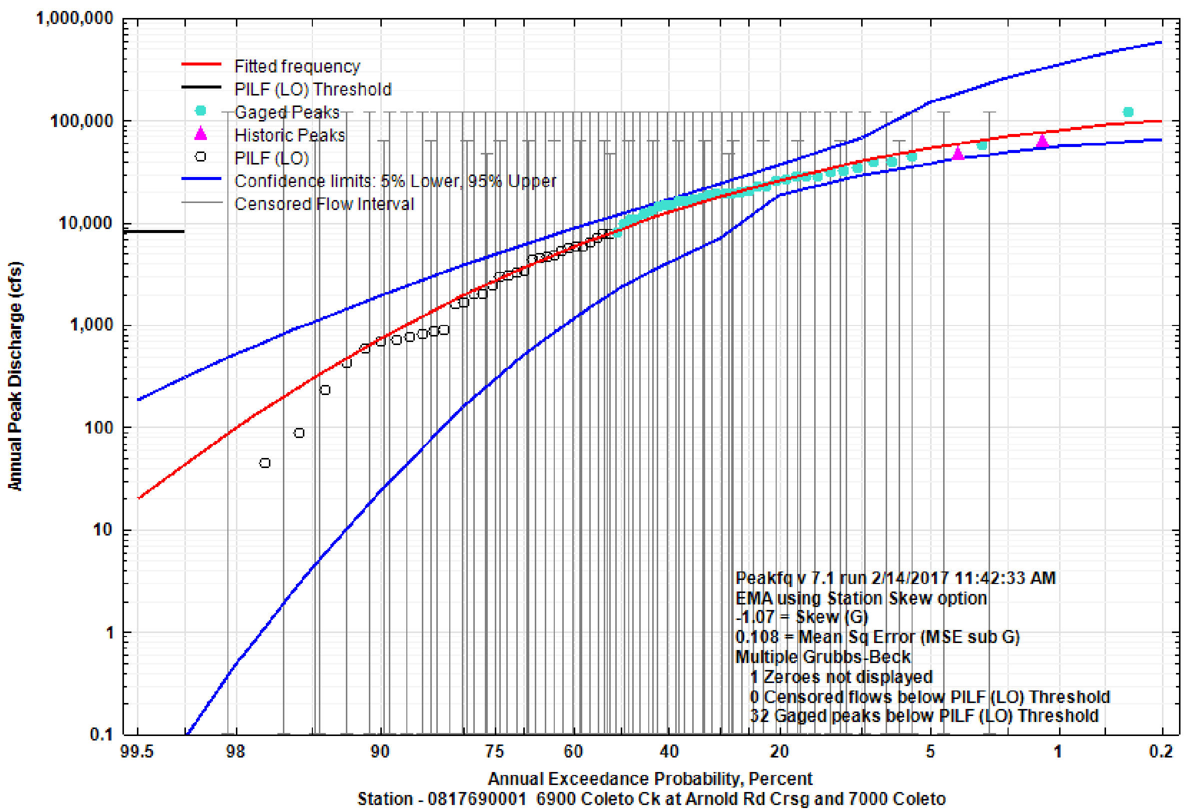

Figure 5.55: Flood Flow Frequency Curve for the Coleto Creek at Arnold Road Crossing near Schroeder, TX (alternative analysis)

Perdido Creek at FM 622 near Fannin, Texas

The systematic record for Perdido Creek at FM 622 near Fannin is 1979–2015. No historical information exists within the USGS peak discharge database for this stream gage, thus there appears to be no information regarding 1967 peak (Hurricane Beulah) unlike the information available in nearby and potentially applicable stream gages. Watershed area is 28.0 square miles. However, the year 1967 assuredly contained a large event. Consider thus estimates for 1967 using the square-root area rule (Asquith and others, 2006; Asquith and Thompson, 2008):

[Coleto Creek at Arnold Road Crossing near Schroeder] = 122,000 * (28/357)^0.5 = 34,200 ft^3/s

[Coleto Creek near Victoria] = 236,000 * (28/500)^0.5 = 55,850 ft^3/s.

The logarithmic mean between these two estimates is 10^([log10(34,200) + log10(55,850)] / 2) = 43,700 ft^3/s. It is possible that this discharge as an estimated point value of 43,700 ft^3/s could be used as a threshold for year 1872 [Coleto Creek at Arnold Road Crossing near Schroeder] or year 1875 [Coleto Creek near Victoria] through to 1978. (1978 is the year before systematic record begins). For this study, it was decided to use the period 1872–1966, and 1968–1978 set with a perception threshold of 43,700 ft^3/s. There is a concern of using a drainage area ratio method to transfer 1967 from Coleto Creek at Arnold Road Crossing near Schroeder (357 square miles) and from Coleto Creek near Victoria (500 square miles). These are substantial area differences and a watershed of 28.0 square miles is expected to generate peaks not with absolute volume but short duration intensity. Though these arguments do accommodate Hurricane Beulah in 1967. The data as set up for statistical frequency analysis are shown in Figure 5.56, in which the rectangular region demarks the historical context of 1967 event. The discharge interval for 1967 of 34,200 <=> 55,850 ft^3/s is represented as green bar in the figure.

The flood flow frequency for the Perdido Creek at FM 622 near Fannin is shown in Figure 5.57. The modest systematic record length but extensive historical information has been inferred amongst other stream gages. The 1967 unobserved event (Hurricane Beulah) is treated as a discharge interval estimate as the largest for the period 1875–2015. This is a prudent treatment for guiding the statistics of the flood flow frequency curve that is judged reliable though the confidence limits are necessarily wide.

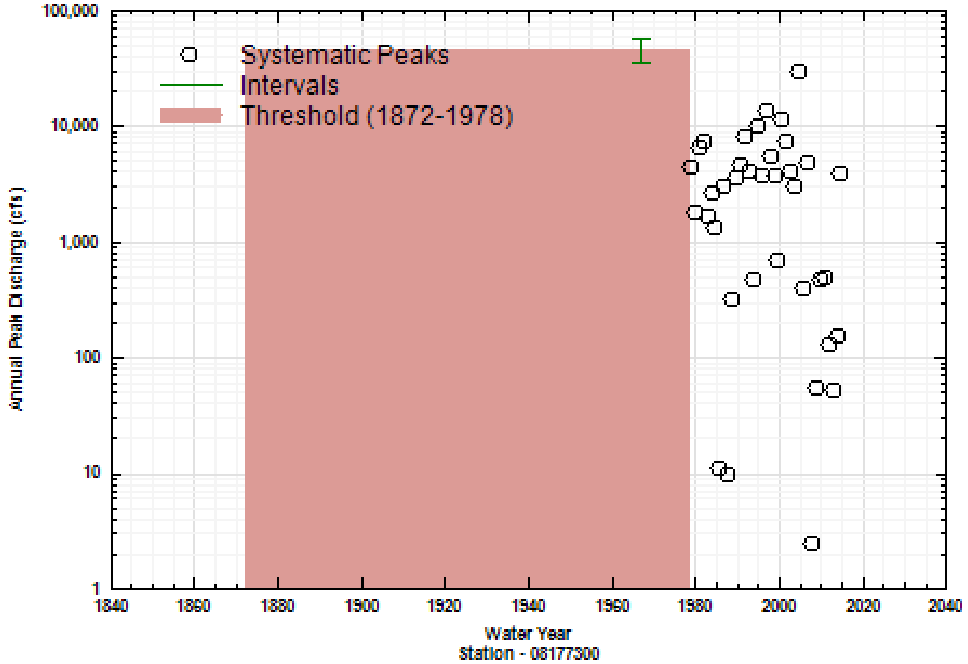

Figure 5.56: Annual Peak Streamflow Data for the Perdido Creek at FM 622 near Fannin, TX

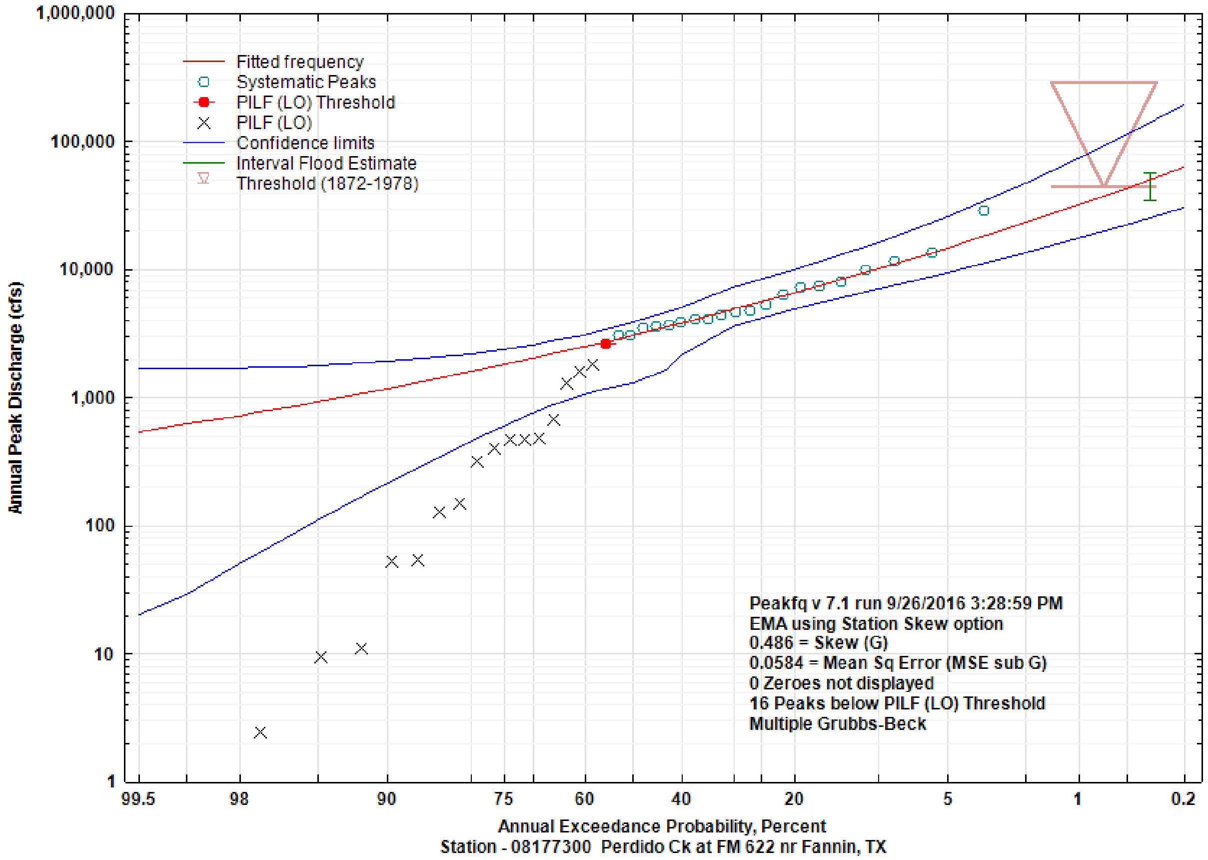

Figure 5.57: Flood Flow Frequency Curve for the Perdido Creek at FM 622 near Fannin, TX

Coleto Creek near Victoria, Texas

The systematic record for Coleto Creek near Victoria is 1939–1954, 1979–2015. The peak streamflow in 1967 of 236,000 ft^3/s at a stage of 42.00 ft is treated as highest for 1872–1938, 1955–1966, 1968–1978. USGS peak value database lists 1875 but Coleto Creek at Arnold Road Crossing near Schroeder lists the 1967 event as highest since 1872. The earlier date is deliberately used. The data as set up for statistical frequency analysis are shown in Figure 5.58, in which the two rectangular regions demark the historical context of the 1932 peak. Visually the data since 1979 seem to indicate a bimodal distribution. Many peaks are centered at about 25,000 ft^3/s and a distinct population of data resides in the range 10 ft^3/s to about 10,000 ft^3/s.

The flood flow frequency for the Coleto Creek near Victoria is shown in Figure 5.59. The combination of substantial systematic record and extensive historical information could lead to a reliable flood flow frequency curve. A complication for this stream gage is a mixture of regulated and unregulated record and peak reduction potential of a reservoir. The MGBT low-outlier test identifies many low outliers in an acceptable way. On balance the historical record length for the 1967 peak (Hurricane Beulah) plots at a position consistent with the general trajectory of the data and the fitted frequency curve. The data are for Coleto Creek downstream of the Coleto Creek Reservoir (a cooling pond for electrical generation). The time series of the data shown in Figure 5.56 visually shows change in statistical properties (more low values and a notable central tendency at about 10,000 ft^3/s to 40,000 ft^3/s). This is indicative of a circumstance for which a proximal reservoir is substantially reducing the peak in drought-like years and tending to control (reduce) peaks through reservoir routing.

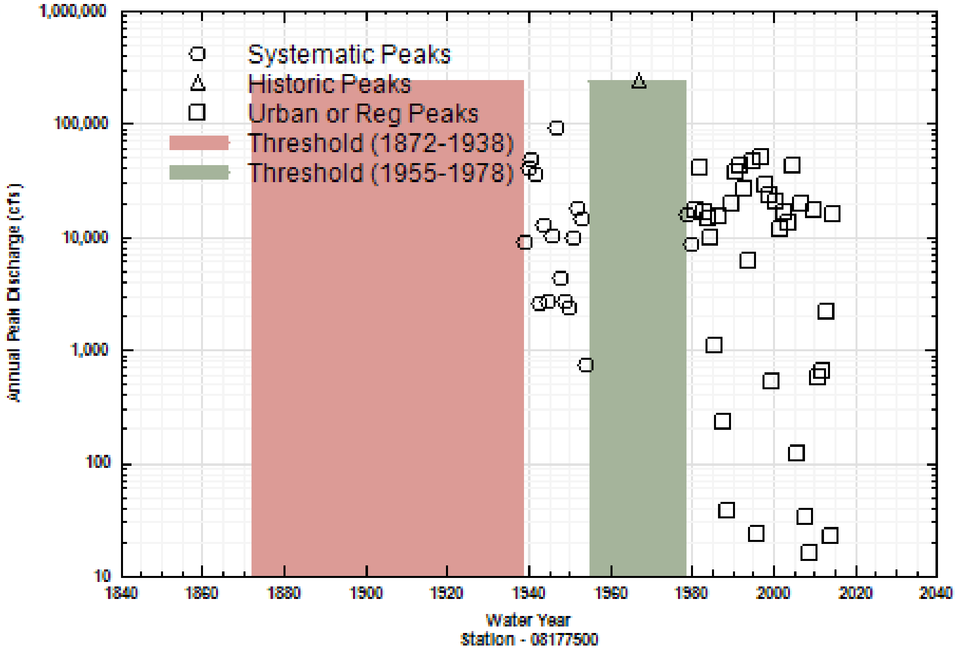

Figure 5.58: Annual Peak Streamflow Data for the Coleto Creek near Victoria, TX

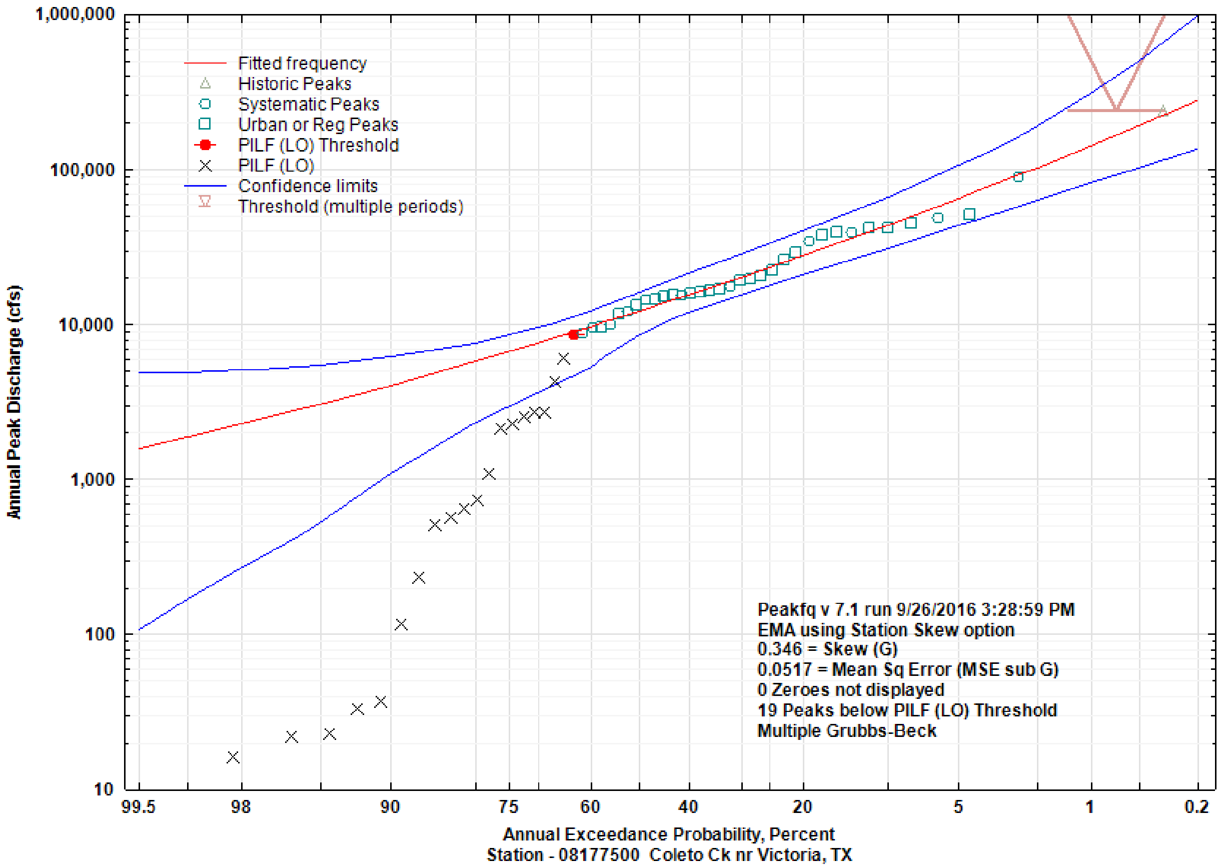

Figure 5.59: Flood Flow Frequency Curve for the Coleto Creek near Victoria, TX

Table 5.3. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging Stations in the Guadalupe River Basin, South-Central, Texas based on the USGS-PeakFQ EMA-LPIII Computations

[--, not applicable; ft^3/s, cubic feet per second; %, percent; CI, confidence limit; Note, table contents derived from so-called EXP file (file extension name) of USGS-PeakFQ software output (USGS, 2014). The estimates are of primary interest and are accentuated using a bold typeface.]

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft^3/s)	5 year (ft^3/s)	10 year (ft^3/s)	25 year (ft^3/s)	50 year (ft^3/s)	100 year (ft^3/s)	200 year (ft^3/s)	500 year (ft^3/s)
08165300 North Fork Guadalupe River near Hunt, Tex.								
Lower 95%-CI	453	10,570	20,970	37,450	49,880	60,850	69,850	78,790
Estimate	**3,692**	**21,000**	**40,610**	**69,740**	**91,480**	**111,600**	**129,400**	**149,200**
Upper 95%-CI	7,427	43,010	105,200	358,900	626,400	840,800	1,065,000	1,374,000
08165500 Guadalupe River at Hunt, Tex.								
Lower 95%-CI	2,440	15,660	30,550	55,340	74,640	91,410	104,600	117,400
Estimate	**5,916**	**28,110**	**53,310**	**93,650**	**127,000**	**160,900**	**194,300**	**236,300**
Upper 95%-CI	11,230	53,130	104,700	196,100	271,000	342,100	409,600	502,000
08166000 Johnson Creek near Ingram, Tex.								
Lower 95%-CI	847	4,665	10,910	25,890	43,960	68,990	101,800	158,200
Estimate	**1,408**	**7,733**	**18,690**	**47,630**	**86,890**	**148,900**	**243,300**	**440,200**
Upper 95%-CI	2,328	12,860	32,440	96,700	211,500	448,200	921,300	2,294,000
08166200 Guadalupe River at Kerrville, Tex.								
Lower 95%-CI	1,957	10,720	23,770	52,340	86,670	133,500	188,600	267,900
Estimate	**4,255**	**21,200**	**46,700**	**104,400**	**172,200**	**266,500**	**393,000**	**620,900**
Upper 95%-CI	9,096	40,870	82,110	183,200	346,000	671,300	1,286,000	2,884,000
08167000 Guadalupe River at Comfort, Tex.								
Lower 95%-CI	6,596	32,850	58,570	96,390	122,500	143,500	159,400	174,400
Estimate	**12,230**	**48,430**	**83,380**	**132,300**	**168,300**	**201,900**	**232,300**	**267,300**
Upper 95%-CI	18,900	70,850	122,400	201,400	260,900	317,800	376,900	465,900
08167500 Guadalupe River near Spring Branch, Tex.								
Lower 95%-CI	9,461	27,490	45,210	72,460	93,850	114,600	134,100	157,900
Estimate	**12,730**	**36,410**	**60,210**	**99,490**	**135,100**	**175,900**	**221,700**	**289,800**
Upper 95%-CI	17,070	48,500	82,920	153,100	231,500	338,400	482,400	750,100
08167800 Guadalupe River at Sattler, Tex.								
Lower 95%-CI	641	3,541	6,242	10,570	14,170	17,840	21,420	25,900
Estimate	**1,545**	**5,551**	**9,968**	**17,540**	**24,480**	**32,370**	**41,140**	**53,900**
Upper 95%-CI	2,417	9,246	18,350	39,410	65,440	103,500	159,400	277,100
08168500 Guadalupe River above Comal River at New Braunfels, Tex.								
Lower 95%-CI	4,725	13,350	22,210	39,570	58,230	82,920	114,900	171,200
Estimate	**6,458**	**17,230**	**31,420**	**63,890**	**105,100**	**168,900**	**266,700**	**477,600**
Upper 95%-CI	8,076	25,440	53,620	154,400	382,300	1,049,000	3,158,000	11,330,000

Table 5.3. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging stations in the Guadalupe River Basin, Texas based on the USGS-PeakFQ EMA-LPIII Computations — Continued

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft³/s)	5 year (ft³/s)	10 year (ft³/s)	25 year (ft³/s)	50 year (ft³/s)	100 year (ft³/s)	200 year (ft³/s)	500 year (ft³/s)
08169000 Comal River at New Braunfels, Tex.								
Lower 95%-CI	1,997	4,959	8,275	14,460	20,810	28,900	39,030	56,030
Estimate	**2,554**	**6,708**	**11,760**	**22,360**	**34,700**	**52,410**	**77,510**	**126,900**
Upper 95%-CI	3,390	9,564	17,970	40,750	80,190	168,500	376,000	1,167,000
08169500 Guadalupe River at New Braunfels, Tex.								
Lower 95%-CI	5,918	12,300	18,530	29,640	40,750	54,810	72,320	101,600
Estimate	**7,928**	**17,650**	**28,570**	**50,200**	**74,300**	**107,800**	**154,000**	**242,200**
Upper 95%-CI	12,010	28,030	46,780	88,310	144,700	247,000	445,300	1,060,000
08170500 San Marcos River at San Marcos, Tex.								
Lower 95%-CI	344	757	1,431	2,862	4,454	6,657	9,688	15,450
Estimate	**552**	**1,453**	**2,944**	**7,370**	**14,650**	**28,980**	**57,140**	**139,700**
Upper 95%-CI	1,083	4,252	13,740	83,170	409,500	2,398,000	12,750,000	126,800,000
08171000 Blanco River at Wimberley, Tex.								
Lower 95%-CI	5,931	19,310	33,540	57,500	78,710	101,200	123,800	153,000
Estimate	**8,284**	**26,530**	**46,410**	**81,240**	**114,400**	**153,700**	**199,300**	**269,400**
Upper 95%-CI	11,470	36,300	63,960	122,500	195,400	304,400	463,000	782,300
08171300 Blanco River near Kyle, Tex.								
Lower 95%-CI	3,319	20,930	37,780	64,960	87,970	111,600	134,900	163,700
Estimate	**8,110**	**30,450**	**54,810**	**95,290**	**131,100**	**170,400**	**212,500**	**271,100**
Upper 95%-CI	11,810	43,990	82,820	162,400	247,600	353,000	477,700	678,700
08172000 San Marcos River at Luling, Tex.								
Lower 95%-CI	7,736	21,140	34,270	54,850	72,020	89,930	108,200	132,500
Estimate	**10,250**	**27,890**	**46,100**	**77,540**	**107,600**	**143,600**	**186,100**	**253,500**
Upper 95%-CI	13,570	37,250	63,680	117,000	177,200	260,500	374,700	590,100
08172400 Plum Creek at Lockhart, Tex.								
Lower 95%-CI	2,481	8,107	13,410	21,680	28,440	35,220	41,840	50,090
Estimate	**3,915**	**11,850**	**19,990**	**33,480**	**45,700**	**59,600**	**75,130**	**98,020**
Upper 95%-CI	5,760	17,900	32,190	64,150	106,400	176,300	290,900	566,200
08172400.01* Plum Creek at Lockhart, Tex.								
Lower 95%-CI	2,892	8,103	13,460	22,410	30,360	39,100	48,440	61,520
Estimate	**3,863**	**10,900**	**18,540**	**32,400**	**46,240**	**63,490**	**84,650**	**119,600**
Upper 95%-CI	5,155	15,210	28,040	60,670	109,000	194,900	346,000	732,600
08173000 Plum Creek near Luling, Tex.								
Lower 95%-CI	2,220	14,230	22,760	33,600	41,520	49,010	56,000	64,300
Estimate	**6,370**	**19,190**	**30,610**	**46,850**	**59,580**	**72,480**	**85,430**	**102,600**
Upper 95%-CI	8,530	26,830	50,760	111,100	169,000	238,400	319,000	439,100

* The ".01" shown is unique to this study and does not represent an official USGS station number but denotes an alternative scenario.

Table 5.3. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging Stations in the Guadalupe River Basin, Texas based on the USGS-PeakFQ EMA-LPIII Computations—Continued

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft^3/s)	5 year (ft^3/s)	10 year (ft^3/s)	25 year (ft^3/s)	50 year (ft^3/s)	100 year (ft^3/s)	200 year (ft^3/s)	500 year (ft^3/s)
08173900 Guadalupe River at Gonzales, Tex.								
Lower 95%-CI	10,110	25,250	40,730	66,760	91,330	120,600	154,800	208,200
Estimate	**14,760**	**37,620**	**63,330**	**113,100**	**166,700**	**238,600**	**333,900**	**506,600**
Upper 95%-CI	21,540	58,850	108,600	241,100	453,000	872,000	1,711,000	4,263,000
08174600 Peach Creek below Dilworth, Tex.								
Lower 95%-CI	4,538	11,140	17,010	26,070	34,010	42,930	52,900	67,770
Estimate	**6,220**	**15,550**	**24,690**	**39,920**	**54,080**	**70,740**	**90,110**	**120,300**
Upper 95%-CI	8,547	23,470	40,280	71,480	103,100	142,900	192,100	273,500
08174600.01* Peach Creek below Dilworth, Tex.								
Lower 95%-CI	3,893	10,860	17,990	29,650	39,750	50,590	61,960	77,550
Estimate	**5,563**	**15,590**	**26,520**	**46,460**	**66,520**	**91,690**	**122,800**	**174,500**
Upper 95%-CI	7,944	23,580	45,450	104,900	192,900	346,500	610,600	1,266,000
08175000 Sandies Creek near Westhoff, Tex.								
Lower 95%-CI	2,442	8,280	15,010	27,290	39,290	53,430	69,360	92,710
Estimate	**3,657**	**12,280**	**22,770**	**43,530**	**65,750**	**94,890**	**132,300**	**197,100**
Upper 95%-CI	5,459	18,170	34,180	71,680	122,200	204,100	333,900	622,500
08175800 Guadalupe River at Cuero, Tex.								
Lower 95%-CI	11,810	30,590	50,130	83,690	115,700	154,000	199,100	270,200
Estimate	**16,520**	**43,700**	**74,970**	**136,600**	**203,900**	**295,000**	**416,900**	**640,100**
Upper 95%-CI	23,100	66,090	127,000	297,500	573,500	1,115,000	2,178,000	5,299,000
08176500 Guadalupe River at Victoria, Tex.								
Lower 95%-CI	13,820	33,990	53,730	85,770	114,400	146,600	182,500	235,600
Estimate	**17,810**	**44,380**	**72,390**	**123,100**	**174,300**	**239,100**	**320,200**	**458,000**
Upper 95%-CI	22,960	60,540	109,100	226,100	382,700	635,600	1,039,000	1,950,000
08176550 Fifteenmile Creek near Weser, Tex.								
Lower 95%-CI	473	3,981	6,366	9,411	11,410	13,050	14,340	15,610
Estimate	**2,304**	**6,532**	**10,080**	**14,830**	**18,300**	**21,610**	**24,690**	**28,390**
Upper 95%-CI	3,748	11,060	20,990	59,920	89,310	125,800	170,000	240,800
08176900 Coleto Creek at Arnold Crossing near Schroeder, Tex.								
Lower 95%-CI	1,007	14,340	24,520	34,680	42,020	48,430	53,880	59,750
Estimate	**7,394**	**26,350**	**43,580**	**66,910**	**83,720**	**99,210**	**113,100**	**129,100**
Upper 95%-CI	11,970	46,490	82,110	225,300	643,000	1,051,000	1,544,000	2,336,000
08176900.01* Coleto Creek at Arnold Rd Crossing near Schroeder combined with 08177000 Coleto Creek near Schroeder, Tex.								
Lower 95%-CI	2,325	18,470	29,420	41,070	48,610	54,970	60,230	65,720
Estimate	**8,661**	**26,070**	**40,170**	**57,890**	**69,950**	**80,650**	**89,960**	**100,300**
Upper 95%-CI	12,180	36,880	67,910	174,900	259,000	352,700	452,900	591,700

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Table 5.3. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging Stations in the Guadalupe River Basin, Texas based on the USGS-PeakFQ EMA-LPIII Computations—Continued

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft^3/s)	5 year (ft^3/s)	10 year (ft^3/s)	25 year (ft^3/s)	50 year (ft^3/s)	100 year (ft^3/s)	200 year (ft^3/s)	500 year (ft^3/s)
08177300 Perdido Ck at FM 622 near Fannin, Tex.								
Lower 95%-CI	1,306	4,912	6,987	10,280	13,450	17,350	22,110	29,920
Estimate	**3,049**	**6,491**	**10,030**	**16,470**	**23,080**	**31,650**	**42,690**	**62,140**
Upper 95%-CI	3,830	9,942	16,170	30,200	47,490	73,370	111,600	191,900
08177500 Coleto Ck near Victoria, Tex.								
Lower 95%-CI	8,534	20,660	30,810	47,490	62,890	80,950	101,900	134,300
Estimate	**12,110**	**27,440**	**43,410**	**72,530**	**102,400**	**140,900**	**190,200**	**276,300**
Upper 95%-CI	15,980	39,710	66,140	121,500	190,700	303,500	493,700	976,100

Table 5.4. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging Stations in the Guadalupe River Basin, Texas based on the USGS-PeakFQ EMA-LPIII Computations using Only Systematic Record (no Historical Information Inclusion)

[--, not applicable; ft3/s, cubic feet per second; %, percent; CI, confidence limit; Note, table contents derived from so-called EXP file (file extension name) of USGS-PeakFQ software output (USGS, 2014). The estimates are of primary interest and are accentuated using a bold typeface.]

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft^3/s)	5 year (ft^3/s)	10 year (ft^3/s)	25 year (ft^3/s)	50 year (ft^3/s)	100 year (ft^3/s)	200 year (ft^3/s)	500 year (ft^3/s)
08165300 North Fork Guadalupe River near Hunt, Tex.								
Lower 95%-CI	2,929	10,650	18,220	29,720	39,160	48,940	58,880	71,990
Estimate	**4,498**	**16,950**	**30,280**	**51,890**	**70,510**	**90,500**	**111,400**	**139,800**
Upper 95%-CI	6,998	29,580	57,070	106,100	151,400	202,500	258,300	336,900
08165500 Guadalupe River at Hunt, Tex.								
Lower 95%-CI	4,532	15,520	27,150	46,980	65,390	86,790	111,200	148,100
Estimate	**6,582**	**23,220**	**42,500**	**77,830**	**112,600**	**154,900**	**204,900**	**283,600**
Upper 95%-CI	9,612	37,530	74,370	149,200	229,300	332,500	461,700	676,500
08166000 Johnson Creek near Ingram, Tex.								
Lower 95%-CI	849	4,916	11,930	30,440	55,660	95,860	157,800	289,400
Estimate	**1,307**	**7,830**	**20,280**	**56,590**	**110,500**	**202,700**	**354,500**	**701,000**
Upper 95%-CI	2,009	13,440	38,670	123,300	264,700	530,700	1,009,000	2,216,000
08166200 Guadalupe River at Kerrville, Tex.								
Lower 95%-CI	2,217	12,540	28,780	67,550	115,700	186,700	287,900	484,400
Estimate	**4,232**	**24,620**	**61,360**	**161,600**	**301,100**	**526,000**	**874,900**	**1,617,000**
Upper 95%-CI	8,088	57,530	170,200	552,900	1,191,000	2,380,000	4,487,000	9,679,000
08167000 Guadalupe River at Comfort, Tex.								
Lower 95%-CI	10,260	31,050	52,810	90,570	126,700	170,100	221,400	302,600
Estimate	**13,280**	**41,160**	**72,550**	**130,300**	**188,400**	**260,800**	**349,100**	**493,800**
Upper 95%-CI	17,210	56,880	106,000	203,700	308,200	444,700	618,900	917,300
08167500 Guadalupe River near Spring Branch, Tex.								
Lower 95%-CI	9,954	26,200	43,340	74,490	106,200	146,500	197,500	284,800
Estimate	**12,120**	**32,460**	**55,430**	**99,640**	**146,800**	**209,200**	**290,700**	**435,900**
Upper 95%-CI	14,740	41,370	74,110	141,800	218,400	324,800	470,100	741,800
08167800 Guadalupe River at Sattler, Tex.								
Lower 95%-CI	1,318	3,707	6,255	10,890	15,580	21,540	29,030	41,760
Estimate	**1,754**	**5,026**	**8,844**	**16,340**	**24,440**	**35,250**	**49,460**	**74,890**
Upper 95%-CI	2,329	7,208	13,640	27,650	44,180	67,830	101,000	164,600
08168500 Guadalupe River above Comal River at New Braunfels, Tex.								
Lower 95%-CI	5,039	14,010	24,630	46,310	70,950	105,600	153,700	246,000
Estimate	**6,201**	**17,500**	**31,910**	**63,380**	**101,300**	**157,100**	**238,200**	**402,000**
Upper 95%-CI	7,607	22,530	43,410	93,060	157,400	258,100	413,100	747,100

Table 5.4. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging Stations in the Guadalupe River Basin, Texas based on the USGS-PeakFQ EMA-LPIII Computations using Only Systematic Record (no Historical Information Inclusion)—Continued

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft³/s)	5 year (ft³/s)	10 year (ft³/s)	25 year (ft³/s)	50 year (ft³/s)	100 year (ft³/s)	200 year (ft³/s)	500 year (ft³/s)
08169000 Comal River at New Braunfels, Tex.								
Lower 95%-CI	2,279	5,447	9,363	17,940	28,510	44,630	69,060	121,400
Estimate	**2,733**	**6,566**	**11,690**	**23,810**	**39,800**	**65,590**	**106,900**	**201,400**
Upper 95%-CI	3,255	8,110	15,270	33,900	60,670	107,100	187,200	386,200
08169500 Guadalupe River at New Braunfels, Tex.								
Lower 95%-CI	6,069	14,580	24,510	45,020	69,060	104,100	154,900	258,400
Estimate	**8,045**	**19,290**	**33,990**	**67,920**	**111,700**	**180,700**	**289,000**	**530,000**
Upper 95%-CI	10,510	27,080	52,540	121,200	222,700	403,300	721,200	1,532,000
08170500 San Marcos River at San Marcos, Tex.								
Lower 95%-CI	358	984	1,878	4,124	7,298	12,770	22,200	45,800
Estimate	**552**	**1,459**	**2,973**	**7,507**	**15,020**	**29,940**	**59,490**	**146,900**
Upper 95%-CI	813	2,400	5,821	19,480	49,030	123,700	312,100	1,060,000
08171000 Blanco River at Wimberley, Tex.								
Lower 95%-CI	6,978	20,930	36,420	65,280	94,950	132,900	180,800	262,500
Estimate	**8,796**	**26,950**	**48,600**	**91,410**	**137,700**	**199,400**	**279,900**	**422,900**
Upper 95%-CI	11,090	35,920	68,340	137,600	217,400	329,200	482,100	767,600
08171300 Blanco River near Kyle, Tex.								
Lower 95%-CI	9,455	26,340	43,390	72,560	100,400	133,800	173,600	237,000
Estimate	**12,390**	**35,260**	**60,320**	**106,100**	**152,300**	**210,100**	**281,400**	**399,900**
Upper 95%-CI	16,240	49,630	90,400	171,900	260,100	377,000	528,800	795,000
08172000 San Marcos River at Luling, Tex.								
Lower 95%-CI	8,468	22,930	36,780	59,210	79,480	102,700	129,100	169,000
Estimate	**10,730**	**29,700**	**49,200**	**82,550**	**114,000**	**151,400**	**195,000**	**263,100**
Upper 95%-CI	13,620	40,010	69,680	124,200	178,600	246,100	327,900	460,700
08172400 Plum Creek at Lockhart, Tex.								
Lower 95%-CI	3,310	8,483	13,650	22,560	31,200	41,800	54,690	75,870
Estimate	**4,234**	**11,050**	**18,440**	**32,080**	**46,080**	**64,010**	**86,700**	**125,600**
Upper 95%-CI	5,412	15,070	26,730	50,290	76,350	111,800	159,000	245,000
08172400.01* Plum Creek at Lockhart, Tex.								
Lower 95%-CI	--	--	--	--	--	--	--	--
Estimate	--	--	--	--	--	--	--	--
Upper 95%-CI	--	--	--	--	--	--	--	--
08173000 Plum Creek near Luling, Tex.								
Lower 95%-CI	5,009	13,330	19,870	28,380	34,520	40,330	45,750	52,310
Estimate	**6,480**	**17,700**	**27,080**	**39,780**	**49,230**	**58,330**	**66,980**	**77,580**
Upper 95%-CI	8,440	24,510	39,060	59,800	75,840	91,700	107,100	126,300

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Table 5.4. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging Stations in the Guadalupe River Basin, Texas based on the USGS-PeakFQ EMA-LPIII Computations using Only Systematic Record (no Historical Information Inclusion) —Continued

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft^3/s)	5 year (ft^3/s)	10 year (ft^3/s)	25 year (ft^3/s)	50 year (ft^3/s)	100 year (ft^3/s)	200 year (ft^3/s)	500 year (ft^3/s)
08173900 Guadalupe River at Gonzales, Tex.								
Lower 95%-CI	12,520	32,910	53,370	88,960	123,800	167,000	219,900	308,000
Estimate	**17,590**	**46,890**	**79,690**	**142,200**	**208,300**	**295,200**	**407,900**	**606,800**
Upper 95%-CI	24,660	72,860	136,200	274,400	438,100	673,400	1,005,000	1,647,000
08174600 Peach Creek below Dilworth, Tex.								
Lower 95%-CI	4,538	11,140	17,010	26,070	34,010	42,930	52,900	67,770
Estimate	**6,220**	**15,550**	**24,690**	**39,920**	**54,080**	**70,740**	**90,110**	**120,300**
Upper 95%-CI	8,547	23,470	40,280	71,480	103,100	142,900	192,100	273,500
08174600.01* Peach Creek below Dilworth, Tex.								
Lower 95%-CI	--	--	--	--	--	--	--	--
Estimate	--	--	--	--	--	--	--	--
Upper 95%-CI	--	--	--	--	--	--	--	--
08175000 Sandies Creek near Westhoff, Tex.								
Lower 95%-CI	2,633	8,839	16,030	29,720	43,980	62,340	85,560	125,200
Estimate	**3,616**	**12,450**	**23,620**	**46,550**	**71,990**	**106,400**	**151,900**	**233,500**
Upper 95%-CI	4,969	18,590	38,020	82,240	135,700	212,900	321,600	529,800
08175800 Guadalupe River at Cuero, Tex.								
Lower 95%-CI	12,680	33,570	56,070	98,010	141,900	199,300	273,800	405,800
Estimate	**16,490**	**44,330**	**77,150**	**143,400**	**217,300**	**319,500**	**458,700**	**719,300**
Upper 95%-CI	21,360	61,560	115,100	235,100	381,900	599,900	917,900	1,561,000
08176500 Guadalupe River at Victoria, Tex.								
Lower 95%-CI	14,620	35,820	56,660	92,300	126,700	168,600	219,400	302,500
Estimate	**17,810**	**44,380**	**72,390**	**123,100**	**174,300**	**239,100**	**320,200**	**458,000**
Upper 95%-CI	21,670	56,710	96,990	175,300	259,200	370,500	516,000	774,700
08176550 Fifteenmile Creek near Weser, Tex.								
Lower 95%-CI	2,612	5,231	7,122	9,611	11,510	13,430	15,360	17,960
Estimate	**3,522**	**7,145**	**10,050**	**14,140**	**17,430**	**20,880**	**24,490**	**29,470**
Upper 95%-CI	4,779	10,690	16,160	24,720	32,170	40,440	49,530	62,760
08176900 Coleto Creek at Arnold Crossing near Schroeder, Tex.								
Lower 95%-CI	6,341	13,830	19,180	25,920	30,770	35,400	39,820	45,310
Estimate	**8,525**	**18,990**	**27,120**	**37,930**	**46,040**	**54,010**	**61,770**	**71,660**
Upper 95%-CI	11,570	28,070	42,470	63,190	79,650	96,490	113,500	135,800
08176900.01* Coleto Creek at Arnold Rd Crossing near Schroeder combined with 08177000 Coleto Creek near Schroeder, Tex.								
Lower 95%-CI	6,739	16,390	24,380	35,730	44,830	54,300	64,060	77,340
Estimate	**8,539**	**21,230**	**32,480**	**49,280**	**63,270**	**78,200**	**93,980**	**115,900**
Upper 95%-CI	10,860	28,680	45,950	73,430	97,460	124,100	153,000	194,600

* The ".01" shown is unique to this study and does not represent an official USGS station number but denotes an alternative scenario.

Table 5.4. Statistically Estimated Annual Flood Flow Frequency Results for Selected USGS Streamflow-Gaging Stations in the Guadalupe River Basin, Texas based on the USGS-PeakFQ EMA-LPIII Computations using Only Systematic Record (no Historical Information Inclusion) —Continued

Station number and name	Peak-streamflow frequency by corresponding average return period (recurrence interval) in years							
	2 year (ft³/s)	5 year (ft³/s)	10 year (ft³/s)	25 year (ft³/s)	50 year (ft³/s)	100 year (ft³/s)	200 year (ft³/s)	500 year (ft³/s)
08177300 Perdido Ck at FM 622 near Fannin, Tex.								
Lower 95%-CI	2,425	4,833	7,056	10,780	14,390	18,840	24,340	33,630
Estimate	**3,010**	**6,031**	**9,114**	**14,720**	**20,510**	**28,060**	**37,850**	**55,300**
Upper 95%-CI	3,712	7,895	12,750	22,600	33,750	49,420	71,250	113,400
08177500 Coleto Ck near Victoria, Tex.								
Lower 95%-CI	10,680	21,340	29,850	42,150	52,390	63,510	75,580	93,080
Estimate	**13,000**	**26,350**	**37,870**	**55,450**	**70,730**	**87,890**	**107,000**	**135,600**
Upper 95%-CI	15,830	33,850	50,950	79,000	104,800	135,100	170,200	224,800

5.3 CHANGES TO FLOOD FLOW FREQUENCY ESTIMATES OVER TIME

Statistically based flow frequency estimates are dependent on observational data and historical information. Examples of changes to flood flow frequency estimates over time are provided for (1) five stream gages on the Guadalupe River at Comfort, Spring Branch, above Comal River at New Braunfels, at Gonzales, and at Victoria; (2) for the stream gage on the Comal River at New Braunfels; (3) for two stream gages on the Blanco River at Wimberley and near Kyle; and (4) for the San Marcos River at Luling. Collectively, these are shown in Figures 5.58–5.66. The annual recurrence intervals of interest here are 2, 10, 100, and 500 years.

Each of these figures is discussed in downstream order. Some general remarks are necessary. Each of these examples is intended to illustrate that there is a progression in statistical estimates over time. Peaks outside the period of record are not shown. For example, the 1952 peak at Blanco Wimberley near Kyle is 115,000 ft³/s but not shown in Figure 5.65 because systematic record begins in 1957. Because the data used to plot the values of the 2, 10, 100, and 500 year discharge estimates in a given year are dependent on all data before that year, it is anticipated to see more variation in the line for a given recurrence interval than the line shown in the extreme right of the plot. This occurs because the total sample size as a measure of information content of flood flows increases at a proportionally smaller rate. For example, one more year of data for a sample of 10 years represents a 10-percent increase information, whereas, one more year of data for a sample of 50 years is only a 2 percent increase in information. In other words, as the record length increases given other factors remaining relatively constant (landuse for example), the curves should vary year to year to a lesser degree for the simple reason that proportionally less information is included with each successive year.

The USGS-PeakFQ software when setup for data processing by EMA does not readily facilitate computations such as those required for similar graphics. The computations involved were based on fitting the LPIII to the L-moments (Asquith, 2011a,b) of the data points shown from a given year backwards in time. The computations included a minimum of 10 years. As a result, the actual starting year varies amongst the figures. The results of USGS-PeakFQ as listed in Table 5.3 provide the ordinates for 2016 (right-most side of the figures), and logarithmic-derived offsets between the L-moment-based LPIII fit in 2016 were used to adjust the curves in prior years for each of the four recurrence intervals.

Guadalupe River at Comfort, Texas

Relative impact of record length and magnitudes of substantial floods for the Guadalupe River at Comfort are shown in Figure 5.60. Two brackets of time period seem to exist based on results: (1) analysis of periods of record ending before 1978 and (2) analysis of periods of record ending after 1978. The 1978 event has a discharge of 240,000 ft^3/s at a stage of 40.90 ft. The 100-year estimate has a highly generalized value of about 150,000 ft^3/s until the 1978 event was observed. After 1978, a highly generalized value of the 100-year estimate is about 220,000 ft^3/s with the estimate through 2015 being about 201,900 ft^3/s (see Table 5.3). The higher estimates after the 1978 event are re-enforced by large events in 1987 and 2002. Though two time periods are mentioned this is an artifact of the 1978 event occurring near the middle of the available record. The 10-year event has been systematically increasing throughout all of time with the possibility of being a stable estimate since about the 2002 event. This observation can be attributable in part to a period of below typical annual peaks occurring in the 1940s and 1950s. Not shown on the plot are the peaks of 182,000 ft^3/s (1900), 114,000 ft^3/s (1915), 148,000 ft^3/s (1935), and 107,000 ft^3/s (1936).

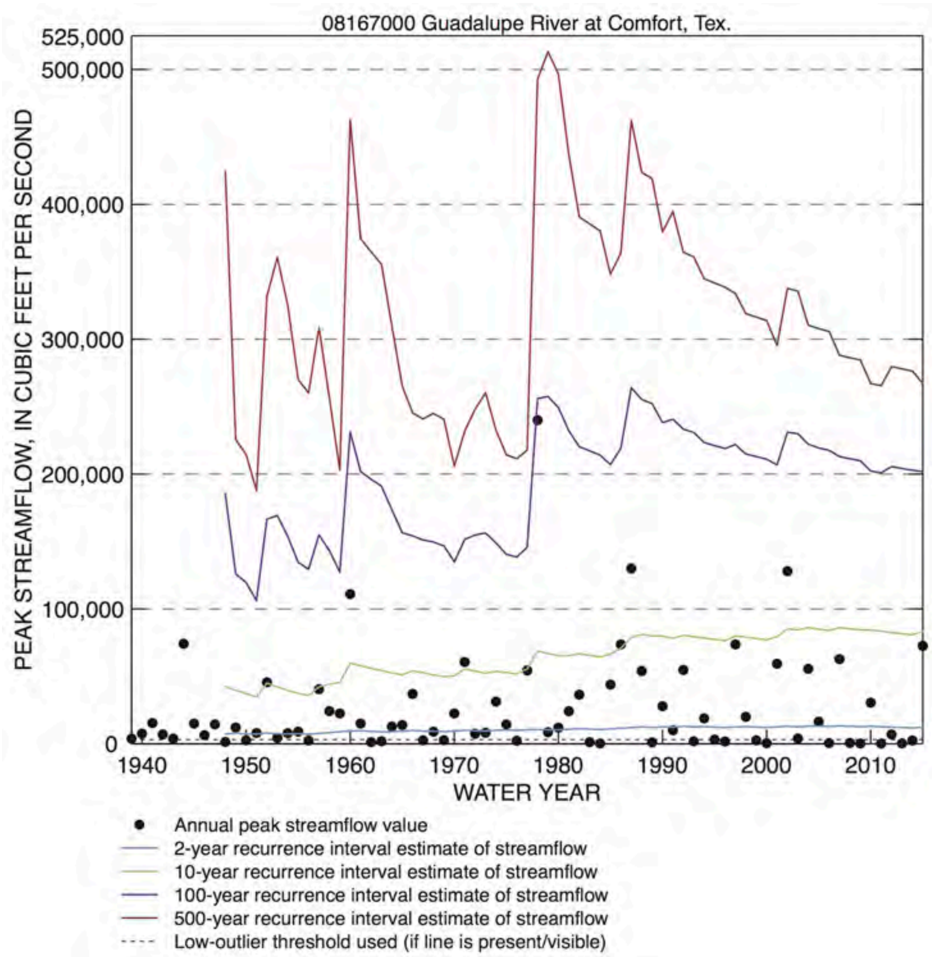


Figure 5.60: Statistical Frequency Flow Estimates versus Time for the Guadalupe River at Comfort, TX

Guadalupe River near Spring Branch, Texas

Relative impact of record length and magnitudes of substantial floods for the Guadalupe River near Spring Branch are shown in Figure 5.61. The 100-year estimate is the focus here. The initial estimates of the 100-year event are large and rapidly decline through 1951. This is attributable to the large skewness early in time with the large peaks in 1932 (121,000 ft^3/s) and 1935 (114,000 ft^3/s) being compensated by relatively small peaks for the other years. The 1952 event of 66,900 ft^3/s does cause a slight jump but the 100-year estimate continues to decline through to the 1978 event (160,000 ft^3/s). Since about that time, the 100-year estimate has remained relatively constant through the estimate in 2015 of 175,900 ft^3/s (Table 5.3).

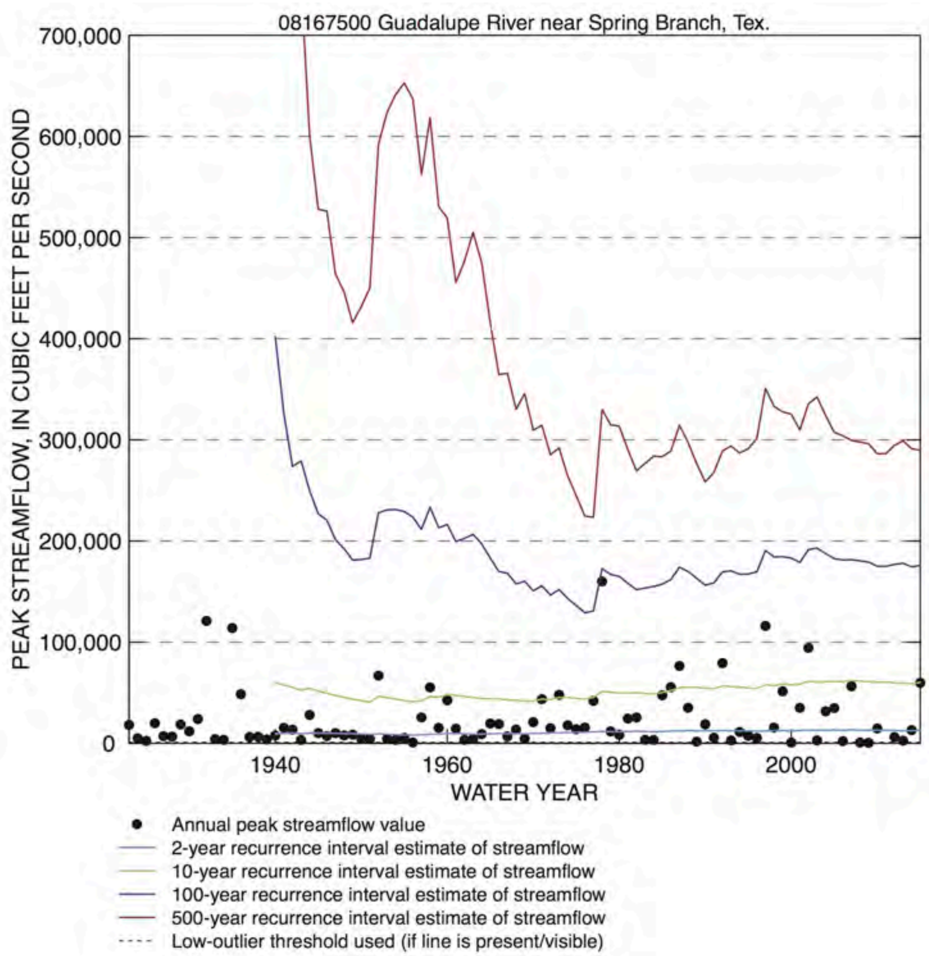


Figure 5.61: Statistical Frequency Flow Estimates versus Time for the Guadalupe River near Spring Branch, TX

Guadalupe River above Comal River at New Braunfels, Texas

Relative impact of record length and magnitudes of substantial floods for the Guadalupe River above Comal River at New Braunfels are shown in Figure 5.62. The 100-year estimate is the focus here. Like the upstream stream gage for the Guadalupe River at Spring Branch, the initial estimates of the 100-year event are large and rapidly decline through to about 1960 and have remained mostly stable since that time through the estimate in 2015 of 168,900 ft^3/s (Table 5.3). A factor contributing to the general stability of the 100-year estimate is that there are about eight events all above about 50,000 ft^3/s and less than about 100,000 ft^3/s. (The 1935 event is 101,000 ft^3/s). Exceptionally larger events (>100,000 ft^3/s) such as observed in the Guadalupe River at Comfort and Guadalupe River near Spring Branch with small drainage area over similar periods are not present in the record for the Guadalupe River above Comal River at New Braunfels. How much these observations are a direct impact of flood-control regulation of Canyon Reservoir and fundamental differences in watershed processes generating flood peaks between is unknown.

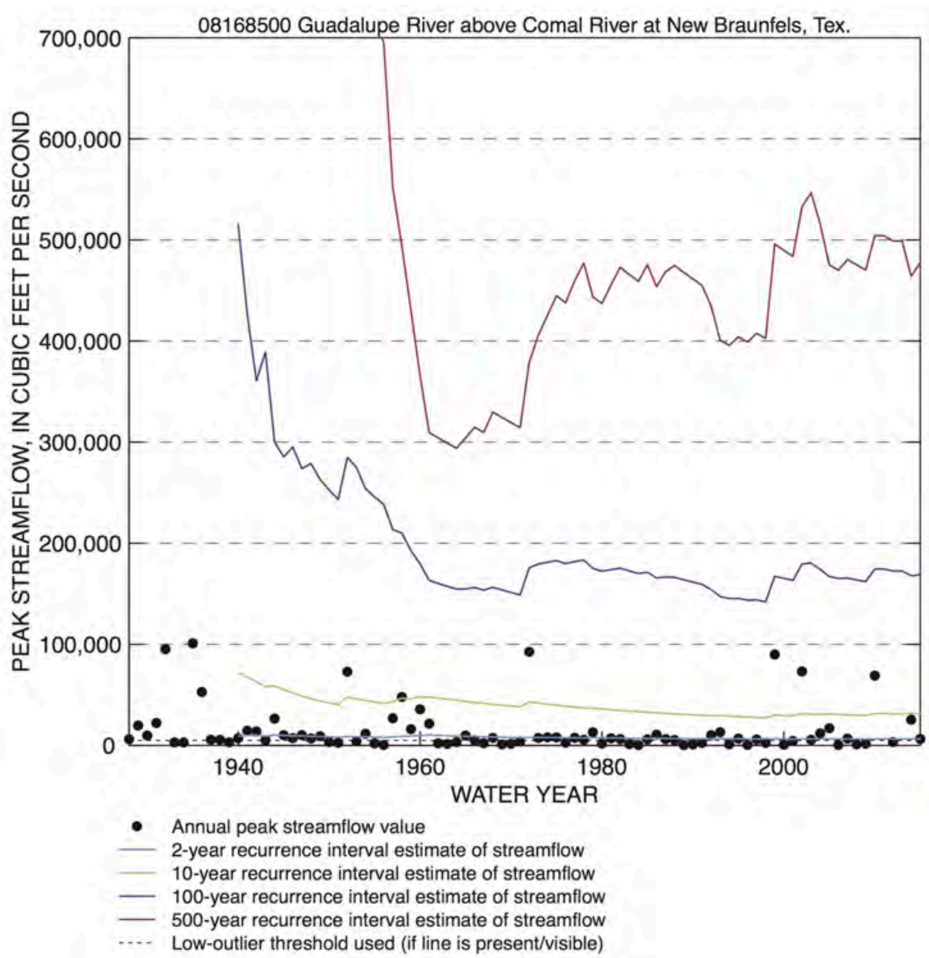


Figure 5.62: Statistical Frequency Flow Estimates versus Time for the Guadalupe River above Comal River at New Braunfels, TX

Comal River at New Braunfels, Texas

Relative impact of record length and magnitudes of substantial flood impacts for the Comal River at New Braunfels are shown in Figure 5.63. The three major events in 1952 (35,000 ft^3/s), 1972 (60,800 ft^3/s), and 1999 (73,500 ft^3/s) directly cause considerable jumps in the estimates for the 10-, 100-, and 500-year recurrence intervals with declines as years increase after 1952 and 1972. The character of how the estimates change in time though changes after the 1999 event. The 100-year estimates appear to progressively increase after 1999. This is directly attributable to a spate of four other "large" events (2002, 2004, and 2010) has formed a general increase in the 100-year estimate since about 2000. It is notable that of seven large events, five have occurred since 1999, but the 2nd and 3rd largest events were decades earlier. It is though that cluster of large peaks after about 1999 represents vagaries of random samples.

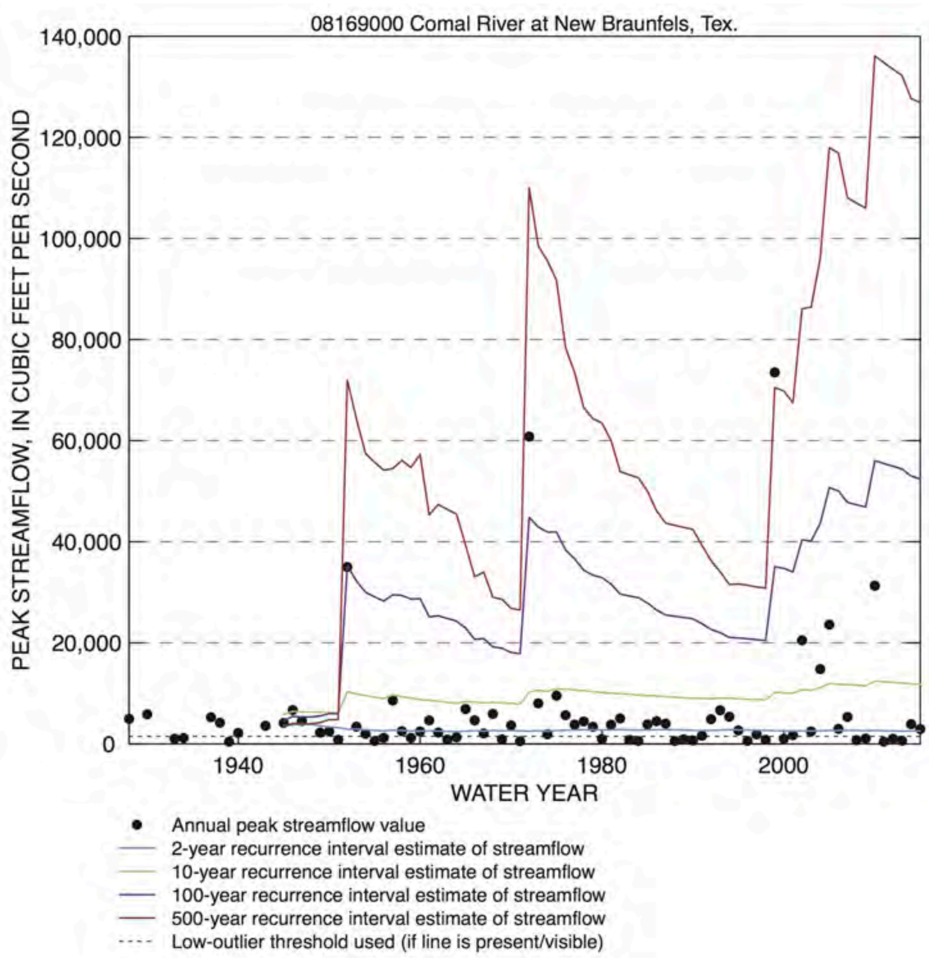


Figure 5.63: Statistical Frequency Flow Estimates versus Time for the Comal River at New Braunfels, TX

Blanco River at Wimberley, Texas

Relative impact of record length and magnitudes of substantial floods for the Blanco River at Wimberley can be seen in Figure 5.64. In Figure 5.64, flow estimates spike in response to three substantial peaks clustered in time (1952, 1957, and 1958) and the great increase centered circa 1960 is also showing sensitivity to a smaller sample size. The increase circa 2016 is relatively larger than that seen 15 years earlier because the 2015 event is also the peak of record bound by 2014 and 2016 peaks which are of the same general magnitude as seen six prior times in the record not counting 2015.

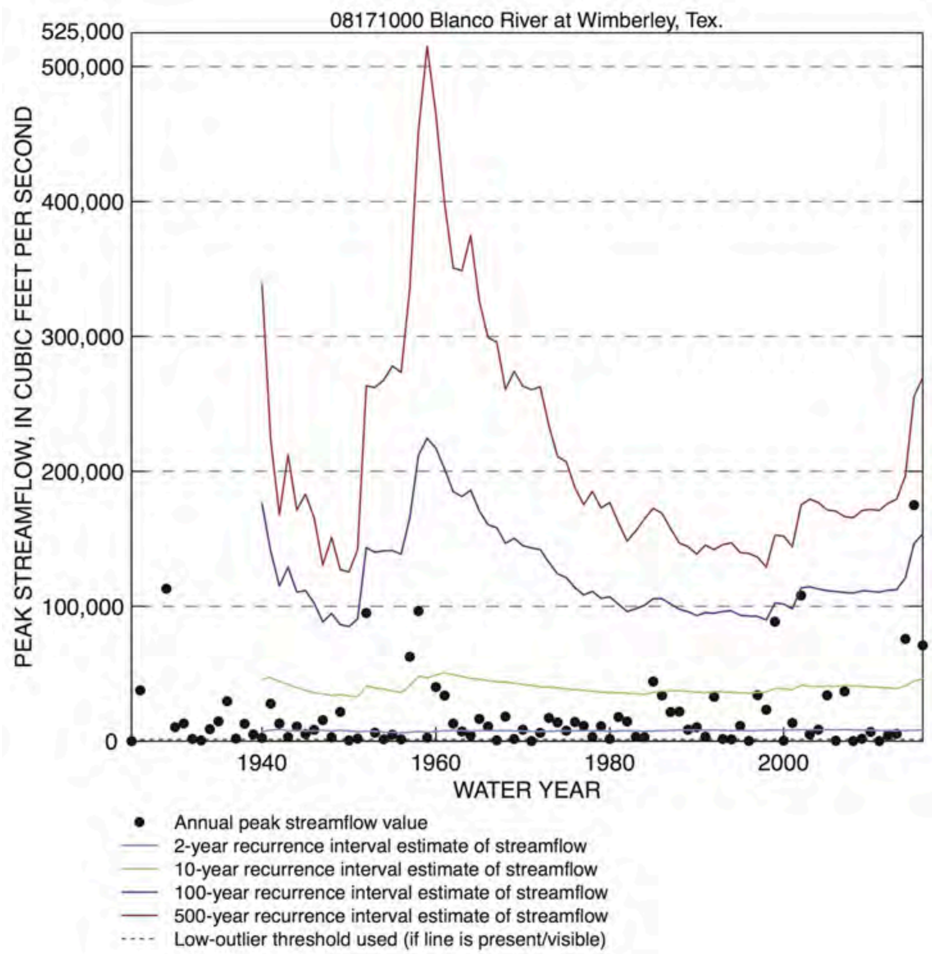


Figure 5.64: Statistical Frequency Flow Estimates versus Time for the Blanco River at Wimberley, TX

Blanco River near Kyle, Texas

Relative impact of record length and magnitudes of substantial floods for the Blanco River near Kyle can be seen in Figure 5.65. In Figure 5.65, a trough in the estimates ending circa 2000 with the October 1998 and 2002 events clustering and being substantial floods of a magnitude not seen since the late 1950s (1957 and 1958). The estimates substantially increase circa 2016 with observation of the 2014, 2015, and 2016 peaks. Collectively, the five large peaks in the past 17 years act to substantially change relative estimates when compared to Blanco River at Wimberley because Wimberley has a considerably longer systematic record. The vertical axis limits are not the same between the two Blanco River stream gages hence purely visual comparison of curve "jumps" is not possible.

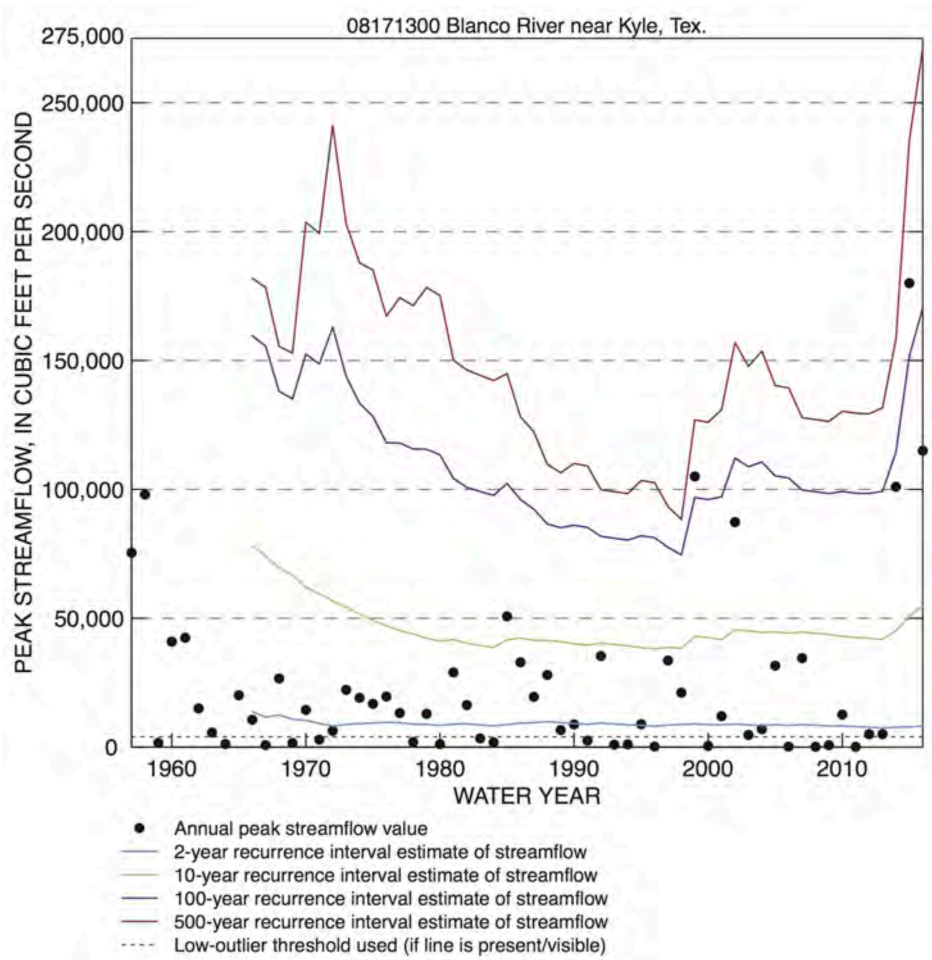


Figure 5.65: Statistical Frequency Flow Estimates versus Time for the Blanco River near Kyle, TX

San Marcos River at Luling, Texas

Relative impact of record length and magnitudes of substantial floods for the San Marcos Rivet at Luling can be seen in Figure 5.66. The focus is the 100-year estimate. A striking feature of the San Marcos River is the general growth in the 100-year estimate with a period of stabilization until the inclusion of the October 1998 event (206,000 ft^3/s with a stage of 36.55 ft; 1999 water year and plotted as such). This is a remarkable event with a discharge substantially larger than all others, though potentially exceeded by the unknown discharge for the 1929 event with a stage of about 37.1 ft and the unknown discharge for the 1869 event with a stage of about 40.4 ft. The 100-year estimate oscillated around 90,000 ft^3/s for about 35 years (circa 1962–1998) in which the largest flood on record at that time was 57,000 ft^3/s in 1952. Since 1999 there have been three years with flood peaks (2004, 2015, and 2016) that exceeded all observed flood events prior to 1998 by substantial margins. Collectively, these contribute to very recent (2015 and 2016) increases in the 100-year estimate. The October 1998 event however is by far the contributing reason for modern estimates to be on the order of about 50,000 ft^3/s more than existed prior to the October 1998 event.

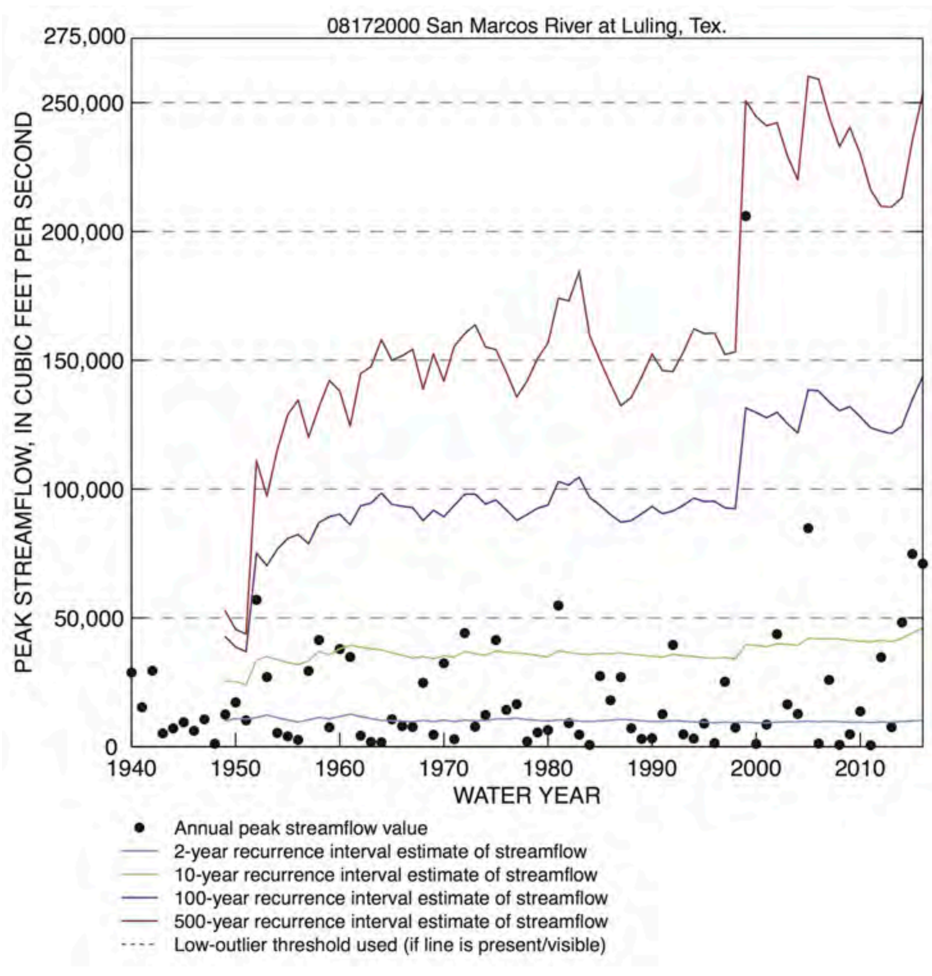


Figure 5.66: Statistical Frequency Flow Estimates versus Time for the San Marcos River at Luling, TX

Guadalupe River at Gonzales, Texas

Relative impact of record length and magnitudes of substantial floods for the Guadalupe River at Gonzales can be seen in Figure 5.67. The focus is the 100-year estimate. The dominating event of record for this part of the Guadalupe River basin is the 1999 event (October 1998). For this stream gage, the 1999 peak was 340,000 ft^3/s with a stage of 50.44 ft. This peak has been associated with a far larger historical record than the relatively short observational record for the Guadalupe River at Gonzales. The short record contributes to enormous variability in the 100-year estimate for this location. This makes interpretive comparisons to other effects of time on flood flow frequency estimates in this study problematic.

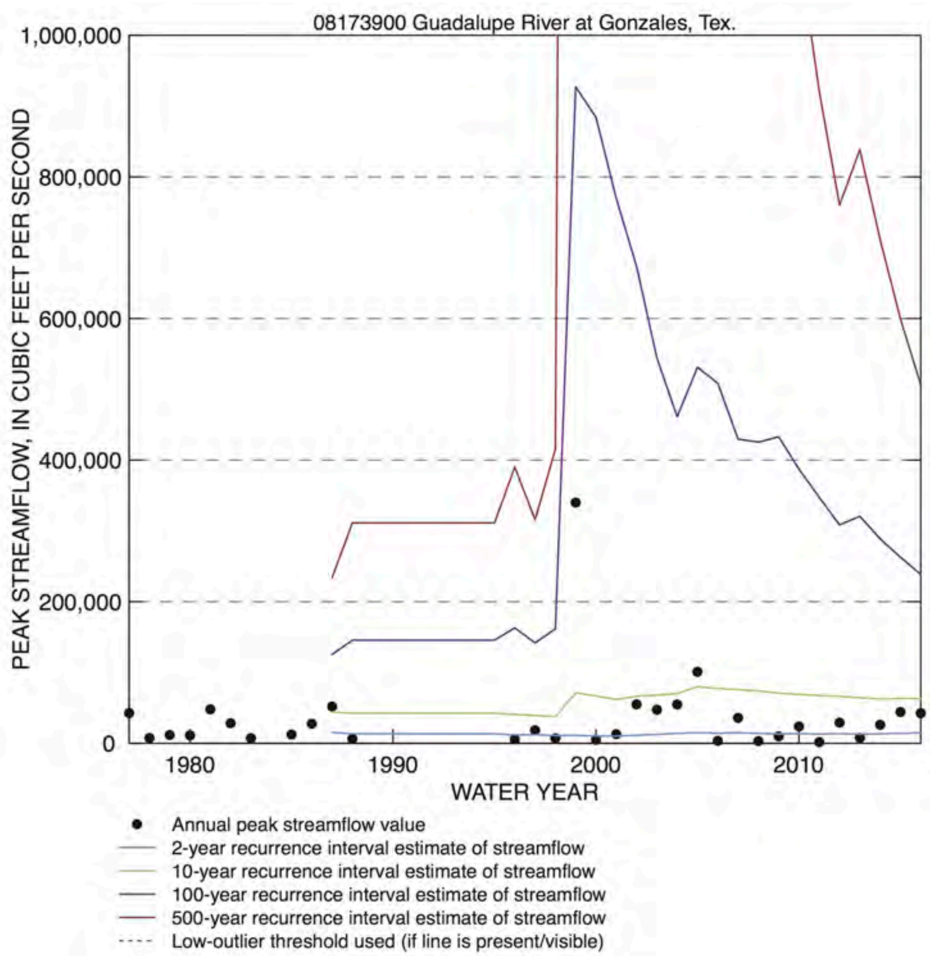


Figure 5.67: Statistical Frequency Flow Estimates versus Time for the Guadalupe River at Gonzales, TX

Guadalupe River at Victoria, Texas

Relative impact of record length and magnitudes of substantial flood impacts for the Guadalupe River at Victoria can be seen in Figure 5.68. The focus is the 100-year estimate. The data for this stream gage provide an informative example of how the placement of heavy rainfall in time and space and intensity and total volume relative to a USGS stream gage is critically important for large magnitude flood peak production. The dominating event of record for stream gage is the 1999 event (October 1998; 466,000 ft^3/s with a stage of 34.04 ft). However, for other stream gages of this study in the greater region near Victoria but not part of the analyses in this section concerning changes to flood flow frequency estimates over time, the 1967 event (Hurricane Beulah) and not the 1999 event is the peak of record or estimated to be of such. The 1967 event coincident with Hurricane Beulah for the Guadalupe River at Victoria was just 70,000 ft^3/s. The Hurricane Harvey event in 2017 resulted in the fifth highest peak of record at the gage, and only a relatively small increase in the longer return intervals is observed.

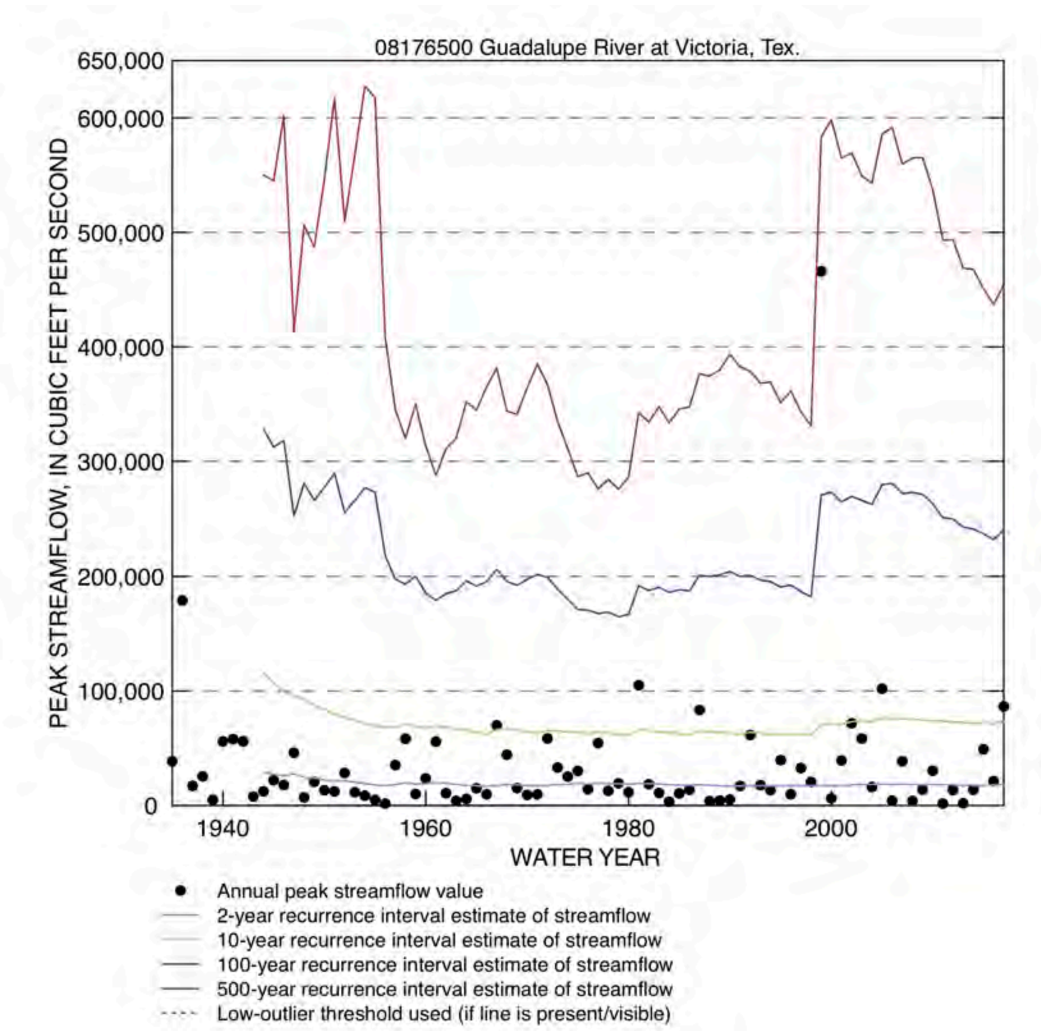


Figure 5.68: Statistical Frequency Flow Estimates versus Time for the Guadalupe River at Victoria, TX

5.4 INFLUENCE OF CLIMATIC VARIABILITY

Stochastically annual peak streamflow does not occur at the same time in each water year. Each year the annual peak streamflow for a stream gage is generated in the watershed by immensely complex interactions between weather patterns and discrete rainfall events, physical aspects of the terrain coupled with the amalgamation of the arrival time of flood waves amongst tributaries, and conditional storage conditions and infiltration capacities. Storage conditions represent both manmade structures (reservoirs and detention basins) but also nonpoint storage such as initial watershed losses and depression storage. Conversely, some water years might effectively have such limited rainfall input that residual waters draining for many months or longer periods of previous rainfall episodes would not be considered as “flood events.” The conditional status of the watershed is influenced by general climate conditions because such conditions express antecedent moisture conditions.

A sensitivity study was conducted to evaluate the effects of climate variability on the record. Runoff and soil loss rates in Texas have been observed to vary greatly from one storm to another, depending on the antecedent moisture conditions of the soil at the time of the storm. Therefore, for this sensitivity test, the Palmer Drought Severity Index (PDSI) was used at the time of each recorded annual peak to divide the streamflow-gaging stations record into a “wet” peak series and a “dry” peak series. For each of the six stream gages, a threshold of PDSI demarking dry and wet conditions for the month of each annual peak streamflow was selected as PDSI = 1.4, which approximately bifurcates the data. An annual peak occurring in a month having PDSI less than or equal to 1.4 was classified as a dry condition peak and conversely an annual peak occurring in a month having PDSI greater than 1.4 was classified as a wet condition peak. In particular, the PDSI is used to distinguish between periods of below typical and abundant moisture conditions. Details about the PDSI are described by Palmer (1965) and other information is available from National Centers for Environmental Information ([NCEI], 2016a,b,c,d).

Blanco River at Wimberley, Texas

The Blanco River at Wimberley was selected as one example. Annual peak streamflow data split between wet and dry conditions is plotted (Fig. 5.69) using empirical annual exceedance probabilities and compared to the annual exceedance probabilities of all of the data sourced from USGS-PeakFQ EMA-LPIII analysis (Table 5.3). In the figure, the blue line represents an estimated frequency curve for the wet condition data, and the red line represents an estimated frequency curve from the dry condition data. From this graph, one can see that there is significant separation between the wet and dry curves. The two largest observed flows (filled red circles) near the dry condition curve were from the 1952 and 2014 events. Both of these events occurred during extremely dry periods. Had those storm events occurred during wet climate conditions, their peak discharges likely would have been much larger. Two take away messages are (1) it appears that climate variation contributes to greater separation for small recurrence intervals (say 2 and 5 year recurrence intervals), and (2) the separation between the two curves diminishes as probability decreases. Similar results for the other stream gages were seen with another example given for the Guadalupe River at Victoria in the discussion that follows.

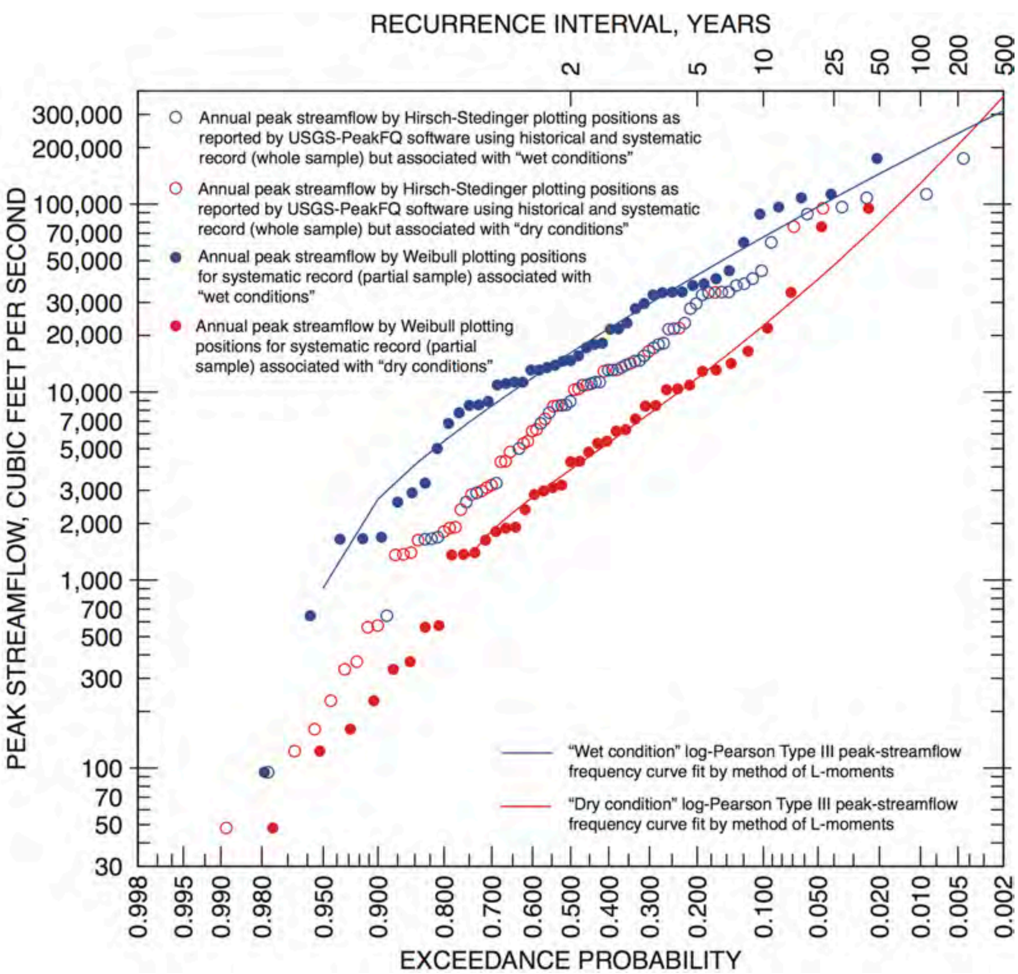


Figure 5.69: Effects of Climate Variability as Expressed by a Threshold of the Palmer Drought Severity Index of 1.4 on the Flow Frequency Curve for the Blanco River at Wimberley, TX

Guadalupe River at Victoria, Texas

The Guadalupe River at Victoria was selected as the other example. Annual peak streamflow data split between wet and dry conditions is plotted (Fig. 5.70) using empirical annual exceedance probabilities and compared to the annual exceedance probabilities of all of the data sourced from USGS-PeakFQ EMA-LPIII analysis (Table 5.3). From this graph, one can see that there is significant separation between the wet and dry curves. The curves do not converge for small AEP but appear to have an offset from each other of about 1/2 a log-cycle with the dry condition curve obviously less than the wet condition. This represents a different circumstance than for the Blanco River at Wimberley (Fig. 5.69) in which the two curves converge for low AEP or the high-magnitude tail of the distribution. The first and second largest observed flows are for years 1999 and 1936, respectively. It was noted in the discussion of Figure 5.49 that there seems to be greater than expected occurrence of peak flows at about 10,000 ft^3/s to 15,000 ft^3/s and again at about 60,000 ft^3/s for the entirely of the record. After separating the peak flows by wet and dry conditions, the flat part at about 12,000 ft^3/s to 14,000 ft^3/s in dry condition peaks is pronounced, and the wet condition peaks does not show flattening in this range. Conversely, the wet condition peaks show a flat part near 60,000 ft^3/s with only a sole dry condition peak in that range. The causative watershed processes are unknown.

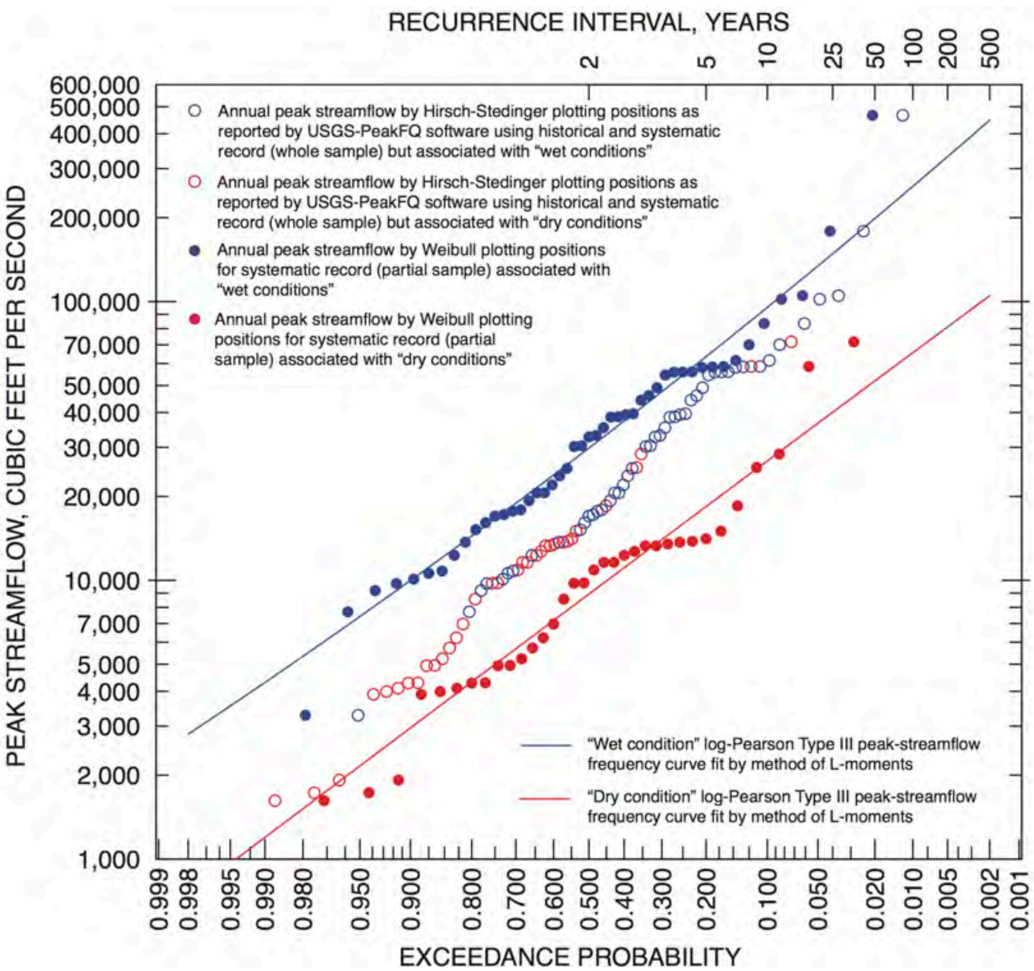


Figure 5.70: Effects of Climate Variability as Expressed by a Threshold of the Palmer Drought Severity Index of 1.4 on the Flow Frequency Curve for the Guadalupe River at Victoria, TX

5.5 EFFECTS OF REGULATION ON STATISTICAL ESTIMATES OF FLOOD FLOW FREQUENCY

The USGS database of annual peak streamflow (USGS, 2016) has only a rudimentary data qualification scheme identifying peaks as regulated ("code 6") or unregulated (non-code 6). The USGS code 6 designation is based on whether about 10 percent of the contributing drainage area is affected by reservoirs. For this study, all available peaks were analyzed regardless of code 6 designation.

Asquith (2001) provides a very general statistical overview study of the effects of flood-storage capacity per unit area on the L-moments (Asquith, 2011a,b) of annual peak streamflow data. Asquith's results suggest that effects of regulation as implicated by flood-storage capacity per unit area become detectable at about 100 acre-feet per square mile (acre-ft/mi^2) and with possible substantial impact at about 400 acre-ft/mi^2. Asquith developed regression estimates of the change in mean annual peak streamflow as a function of this flood-storage capacity which suggest that higher dimensionless L-moments remain unaffected. The impact is relative to drainage area size and in turn the mean peak streamflow at a given stream gage.

InFRM team members from the USACE computed temporal changes in normal capacity and flood-storage capacities from the National Inventory of Dams. The cumulative differences between flood-storage and normal capacity are referred to as cumulative flood storages, and the values divided by contributing drainage area are listed in Table 5.1 for the last year of analysis (2016). The estimated effect of cumulative flood storage as computed from Asquith's equations (Asquith, 2011, fig. 11a) are also listed in the Table 5.1. These can help guide interpretations of statistical flood flow frequency estimates in this chapter.

The results listed in Table 5.1 indicate that annual peak streamflows are unaffected by regulation from North Fork Guadalupe River near Hunt downstream to the Guadalupe River near Spring Branch. This is because the six stream gages have a zero estimated effect of cumulative flood storage on the mean annual peak streamflow. Conversely, the annual peak streamflows for the three main stem Guadalupe River stream gages at Sattler, above Comal River at New Braunfels, and at New Braunfels are affected to varying degrees by regulation with Canyon Lake being the predominate feature in the watershed. The effect is about –8,000 ft^3/s amongst these sites. The peak flows for the Comal River at New Braunfels are less affected by the effect of regulation on the mean being about –560 ft^3/s.

Continuing, the results listed in Table 5.1 also indicate that annual peak streamflow data for the Blanco River at Wimberley, Blanco River at Kyle, and San Marcos River at Luling are not anticipated to be substantially influenced by flood-storage capacity in their respective watersheds. The San Marcos River at San Marcos has the highest relative impact of about –271 ft^3/s, which when compared to a general magnitude of annual peak of about 750 ft^3/s is of the same order of about 36 percent (100 * 271 / 750). The two Plum Creek stream gages have relative impacts of about –532 ft^3/s (Lockhart) and –1,142 ft^3/s (Luling) compared to general magnitude of annual peak of about 3,500 ft^3/s (Lockhart) and 4,700 ft^3/s (Luling) are of about 15 percent (Lockhart) and 24 percent (Luling). So a demonstrable impact is likely. However, considering that the 100-year estimates for the two Plum Creek stream gages are about 60,000 ft^3/s, it seems that the small flood-water retarding structures in the watersheds have relatively lesser impact on high magnitude and rare peak streamflows. Large-scale flood-control regulation in the watersheds is lacking. Further evaluation of the impacts of regulation in all the watersheds of this study seems beyond statistical analysis and hydrologic rainfall-runoff modeling would be informative.

Continuing, the results listed in Table 5.1 also indicate that annual peak streamflow data for the main stem of the Guadalupe River at Gonzales, at Cuero, and at Victoria are affected to some degree by regulation. This is also true for Coleto Creek near Victoria, whereas for the remaining stream gages in the table (Peach Creek below Dilworth, Sandies Creek near Westhoff, Coleto Creek at Arnold Crossing near Schroeder, and Perdido Creek at FM 622 near Fannin) all appear to have too little cumulative flood storage capacity in their respective watersheds to influence annual peak streamflows.

6 Rainfall-Runoff Modeling in HEC-HMS

While statistical analysis of the gage record is a valuable means of estimating the magnitude of flood frequency flows at the gage, watershed rainfall-runoff modeling is often used to estimate the rare frequency events whose return periods exceed the gaged period of record as well as to account for non-stationary watershed conditions such as urban development, reservoir storage and regulation, and climate variability. Rainfall-runoff modeling also provides a means of estimating flood frequency flows at other locations throughout the watershed that do not coincide with a stream flow gage. Rainfall-runoff watershed modeling is used to simulate the physical processes that occur during storm events that move water across the land surface and through the streams and rivers.

In this phase of the multi-layered hydrologic analysis, a watershed model was built for the Guadalupe River Basin with input parameters that represented the physical characteristics of the watershed. The rainfall-runoff model for the basin was completed using the basin-wide HEC-HMS model developed for the 2014 Guadalupe Basin CWMS Implementation as a starting point. This model was further refined by adding additional detailed data, updating the land use, and calibrating the model to multiple recent flood events. Through calibration, the updated HEC-HMS model was verified to accurately reproduce the response of the watershed to multiple recent observed storm events, including those similar in magnitude to a 1% annual chance (100-yr) storm. Finally, frequency storms were built using the depth area analysis in HEC-HMS and the latest published frequency rainfall depths (Asquith, 2004). These frequency storms were run through the verified model, yielding consistent estimates of the 1% annual chance (100-yr) and other frequency peak flows at various locations throughout the basin.

6.1 HEC-HMS MODEL FROM THE GUADALUPE CWMS IMPLEMENTATION

The HEC-HMS model from the Guadalupe CWMS Implementation was used as the starting point for the current study. The CWMS model contained 72 subbasins in the Guadalupe River Basin above Victoria, Texas and totaled approximately 5,198 square miles. The subbasins were delineated using the HEC-GeoHMS program and utilized 30-meter NED terrain data. The Guadalupe CWMS HEC-HMS model used the following methods.

- **Losses** – Deficit and Constant
- **Transform** – Snyder Unit Hydrograph
- **Baseflow** – Recession
- **Routing** – Modified Puls
- **Computation Interval** – 60 minutes

A map of the Guadalupe CWMS subbasins are shown in Figure 6.1. More information on the CWMS model development is given in the final CWMS report for the Guadalupe River Basin (USACE, 2014).

6.2 UPDATES TO THE HEC-HMS MODEL

To better define the hydrology of the Guadalupe River Basin, additional subbasin breaks were added to the original CWMS delineation. The number of subbasins in the basin was increased from 72 to 143. The Coleto Creek watershed was added to the watershed model which brought the total number of subbasins in the Guadalupe River Basin model to 165. Additional subbasins were added in 4 areas: the Blanco River, Sink Creek, Comal River, and the Guadalupe River (from below Canyon Dam to the confluence with the San Marcos River). These areas were selected for additional detail due to their locations near developed areas or near Guadalupe-Blanco River Authority (GBRA) hydropower dams. The Coleto Creek watershed was delineated into 20 subbasins and was added to the Guadalupe River HEC-HMS model, thereby extending the model downstream to Bloomington, Texas.

The Blanco River is an important part of the basin as it tends to be the primary source of flooding for the cities of Wimberley and San Marcos, Texas. Additional subbasins were added to the Blanco River basin in order to give better definition to the rainfall patterns and the timing of the tributaries entering the Blanco River. In total, the number of subbasins in the Blanco River basin was increased from 6 to 29. The new subbasin break points were chosen based on several factors which include: the locations of significant tributaries, the locations of the new USGS stream flow gages that were installed after the flood events of 2015, and the locations of developed areas or major road crossings.

Sink Creek is a tributary to the San Marcos River just upstream of the city of San Marcos. Flood flows from the Sink Creek Watershed are significantly attenuated by the presence of three NRCS dams in the watershed. In order to better account for the effects of these dams, subbasin breaks were added at the locations of the dams. The physical data for these NRCS dams, including elevation-capacity curves, spillway and outlet structures, were also added to the HEC-HMS model. In total the number of subbasins on Sink Creek was increased from 1 subbasin to 6.

The Comal River and Dry Comal Creek are tributaries to the Guadalupe River just upstream of the city of New Braunfels. Dry Comal Creek provides the majority of the drainage area within the Comal River Basin. Flood flows from the Comal River watershed are significantly attenuated by the presence of 6 dams (5 of which are NRCS dams) in the watershed. In order to better account for the effects of these dams, subbasin breaks were added at the locations of the dams. The physical data for these dams, including elevation-capacity curves, spillway and outlet structures, were also added to the HEC-HMS model. In total the number of subbasins on the Comal River was increased from 1 subbasin to 17.

Subbasin breaks were also added on the Guadalupe River to provide flood frequency estimates at each of the 6 GBRA hydropower dams. The final HEC-HMS subbasin layout for the Guadalupe Basin is shown in Figure 6.2.

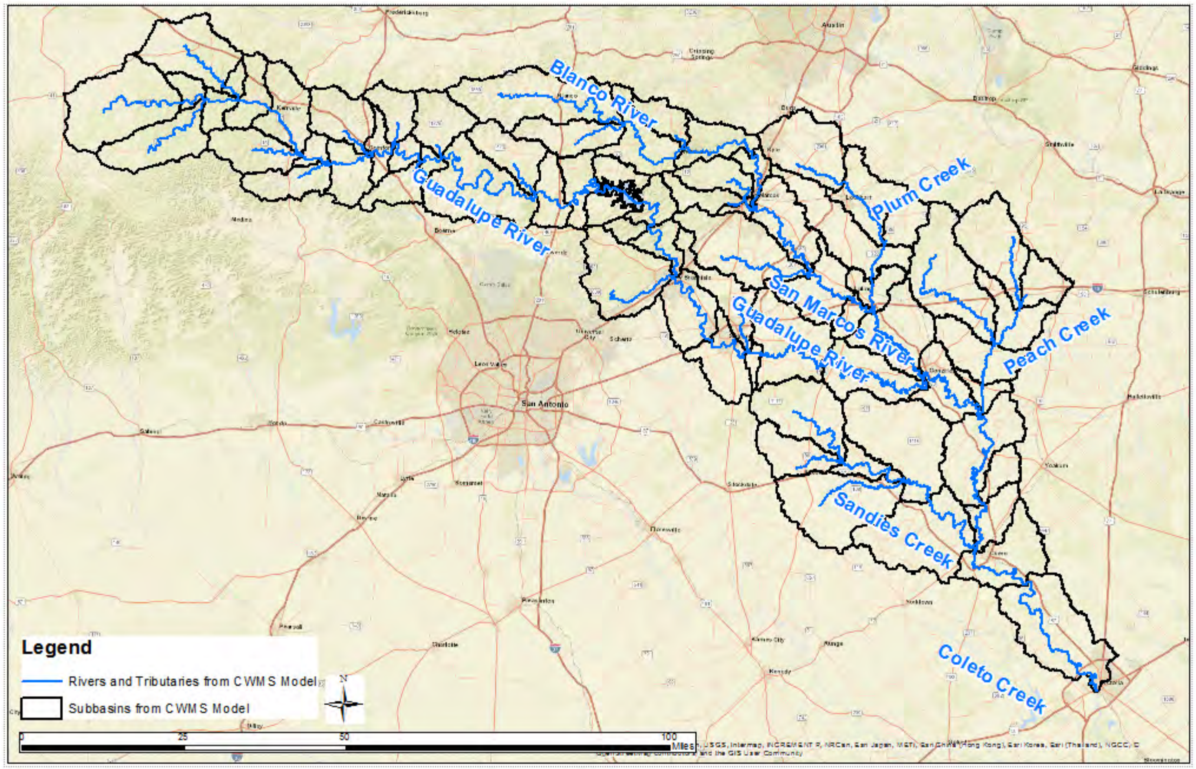


Figure 6.1: Existing CWMS subbasins for the Guadalupe River Basin

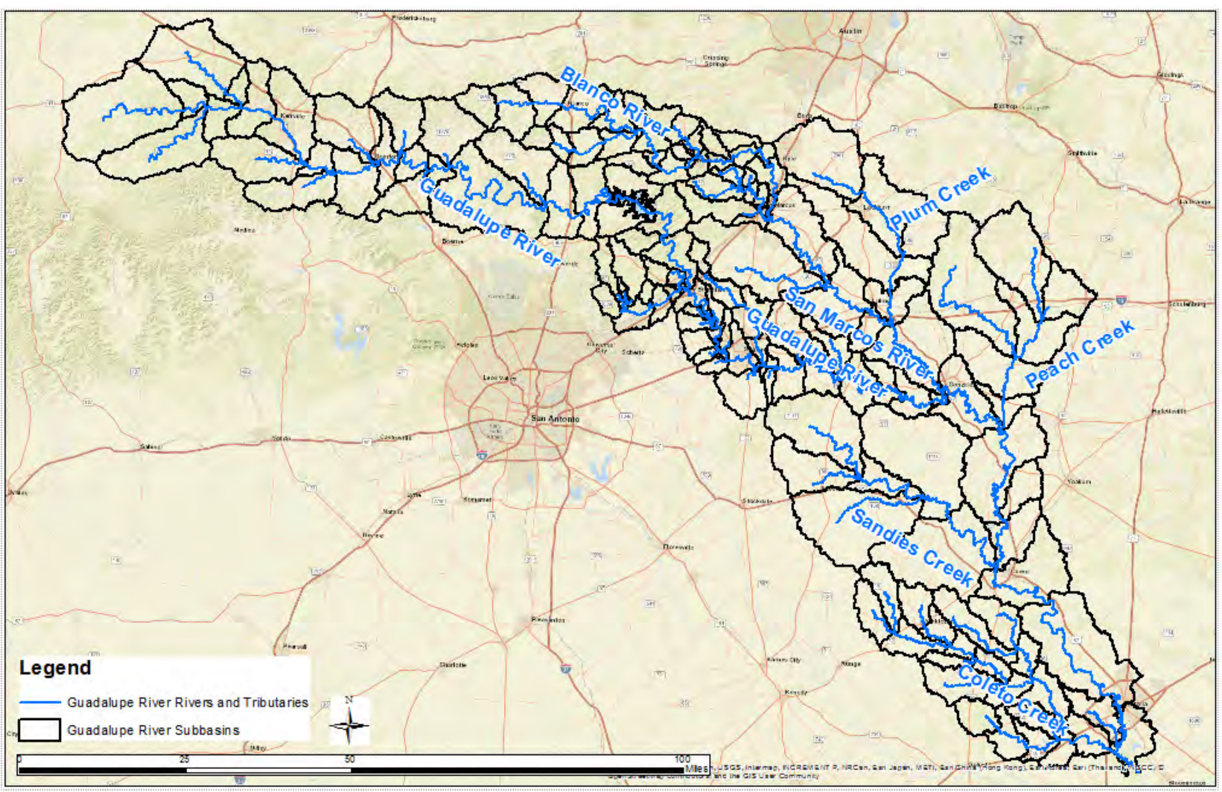


Figure 6.2: Final HEC-HMS subbasins for the Guadalupe River Basin

After breaking out the additional subbasins, detailed routing data was added to the HEC-HMS model for the associated new river reaches where detailed hydraulic modeling was available. This hydraulic routing data is used for the Modified-Puls routing method which calculates the change in flow through the reach based on the volume of floodplain storage through that reach.

For the San Marcos River Basin, the Modified Puls routing method was used for all of the reaches throughout the model. The necessary storage-discharge curves for the Modified Puls routing were extracted from the best available detailed hydraulic models, which included detailed HEC-RAS models of the Blanco River, San Marcos River, Plum Creek and Sink Creek from the Lower Guadalupe Feasibility Study. These HEC-RAS models were built off of detailed LiDAR topographic data and included other detailed information such as bridge and channel surveys. For more information on the development of those hydraulic models, please refer to the hydraulic modeling appendices from the Lower Guadalupe Feasibility Study (Halff, 2014 and 2015). Modified Puls routing data for other reaches, such as the Blanco River and Little Blanco River in Blanco County, which were not included in the Lower Guadalupe Feasibility study area, were extracted from existing detailed HEC-1 hydrologic models from the 1988 draft Hays County Flood Insurance Study.

For the Comal River Basin, the Modified Puls routing method was used for all reaches. Hydraulic models were developed using the high resolution LiDAR dataset created by Halff & Associates for USACE's Lower Guadalupe Feasibility Study in 2012 (Halff, Mar 2014).

The Guadalupe River Modified Puls routing data from New Braunfels to the confluence with the San Marcos River was updated due to additional subbasin breaks as well as modifications to the elevation-discharge relationships at the GBRA dams. During calibration of the CWMS model, the hydrographs appeared to be traveling too quickly through this reach when compared to observed data. This area was investigated at the onset of the InFRM hydrology assessment for the Guadalupe River Basin. It was discovered that there was significant room for refinement in the way the GBRA dams were being modeled in the CWMS RAS model. Some of the items that needed refining were the high weir coefficients being used (3.84), the gates were fully open for all flows and not maintaining the normal pool elevation, and the general geometry data for the dams. A 2012 PMF and Dam Break Study was performed by Freese and Nichols for the GBRA and utilized 2010 survey data of the GBRA dams. During this study, the HEC-RAS model was calibrated to large events. The elevation-discharge relationships from this model were similar to the observed elevation-discharge information for the GBRA dams. The Freese and Nichols model as well as the GBRA observed elevation-discharge data were considered and used to produce final elevation-discharge relationships. These relationships were input into the HEC-RAS model as rating curves and new Modified Puls data was developed. During calibration, the routing through this reach was improved significantly from the routing in the CWMS model, suggesting an improvement to the GBRA dam elevation-discharge relationships.

Any future refinements to the GBRA dam elevation-discharge relationships (rating curves) should be verified by simulating previous observed events such as the October 1998, July 2002, June 2010, October 2013, and October 2015 storm with the proposed relationships. For these events, the runoff on the Guadalupe River between Canyon Dam and the San Marcos River was primarily due to rainfall near Canyon Dam, and because of this these are good events to compare the simulated routing to the actual observed routing for these events. Any new elevation-discharge relationships should result in a reasonable travel time when compared to the observed GBRA and USGS data. Even if there are differences between the simulated and observed peak flows, the timing of the peaks can be compared and should be reasonably close.

The Coleto Creek basin was not included in the original CWMS model and so new routing information needed to be developed. Above Coleto Creek Reservoir, Halff Associates provided Base Level Engineering (BLE) HEC-RAS models that were developed using LiDAR data. However, models were only available for a very limited number of river miles and so Muskingum routing estimates were made where hydraulic modeling was not available. Below Coleto Creek Reservoir, routing data was developed using a Coleto Creek Dam Break model also developed by

Halff Associates. For reaches in the Coleto Creek with no hydraulic models available, the Muskingum routing method was used.

Finally, after adding all of the above detailed data, the loss method was updated from deficit constant to initial and constant. The computation interval of the model was also increased from 60 to 15 minutes.

6.3 HEC-HMS MODEL INITIAL PARAMETERS

The Guadalupe River HEC-HMS model contains 165 subbasins totaling about 5,814 square miles. The subbasins were delineated using the HEC-GeoHMS program and utilized 30-meter NED terrain data. The Guadalupe River HEC-HMS model used the same methods as the Guadalupe CWMS model, which including initial and constant losses, Snyder unit hydrograph transform parameters, recession baseflows, and Modified Puls and Muskingum routing. The sources of the initial estimates for these parameters are described below.

- **Initial Loss and Constant Loss Rate** –.Initial estimates of losses were made using NRCS soil data. The constant loss rate estimates in the model ranged from 0.03 to 0.21 depending on soil type. These losses were adjusted during calibration and varied significantly between events. The initial estimates for the constant loss rates for the calibration runs were based on NRCS soil type. These differ slightly from the Fort Worth District Loss Rates in that the Fort Worth District Loss Rates vary by frequency. The constant loss were very different for each calibration event based on the soil moisture condition. The initial loss rate estimates as well as the final frequency loss rates fell within the range of the events observed during calibration.
- **Percent Impervious** – The percent impervious values were developed based on the 2011 NLCD percent developed impervious dataset.
- **Snyder Transform Parameters** – The time to peak and peaking coefficients were developed from the USACE Fort Worth District urban curves based on length and slope watershed characteristics extracted from HEC-GeoHMS, percent urban values taken from the 2011 NLCD, and percent sand values taken from the NRCS soil data. From this data, the following regional equation, which was developed as part of the Fort Worth District urban studies (Nelson, 1979) (Rodman, 1977) (USACE, 1989), was used to calculate lag time:
  log (tp) = .383log (L*Lca/(Sst ^ .5))+(Sand*(log1.81-log.92)+log.92)-(BW*Urban./100)

  where: tp = Snyder's lag time (hours)

  L = longest flow path within the subbasin (miles)

  Lca = distance along the stream from the subbasin centroid to outlet (miles)

  Sst = stream slope over reach between 10% and 85% of L (feet per mile)

  Sand = percentage of sand factor as related to the permeability of the soils

  (0% Sand = low permeability, 100% Sand = high permeability)

  BW = log(tp) bandwidth between 0% and 100% urbanization = 0.266 (log hours)

  Urban. = percentage urbanization factor

- **Baseflow Parameters** – Initial baseflow parameters were taken from the existing USACE Guadalupe CWMS HEC-HMS model.

- **Routing Parameters (Modified Puls)** – Storage-discharge curves for the Modified Puls routing were extracted from the best available detailed hydraulic and hydrologic models. Initial subreach values were estimated based on the reach length and an average travel time through the reach.
- **Routing Parameters (Muskingum)** – The Muskingum routing method was used for reaches on the upper Guadalupe River above Canyon dam and for a portion of the Coleto Creek watershed. Muskingum k values were estimated using an estimated velocity of about 3 and 6 feet per second, respectively, for the Coleto Creek and the Upper Guadalupe Basins. The Coleto Creek watershed has very heavy brush and would be expected to have slow to medium velocities, while the Guadalupe Basin above Canyon is steeper and would have higher velocities. The total reach length divided by the velocity produces the Muskingum k estimate. Moderate Muskingum x values of 0.2 to 0.3 were estimated for the initial values. Initial subreach values were estimated based on the reach length and an average travel time through the reach. All of the Muskingum parameters were adjusted during calibration.

The initial subbasin and routing parameters that were entered into the HEC-HMS model are shown in Tables 6.1 through 6.5. Some of these parameters were adjusted during calibration.

Table 6.1: Subbasin Area, Percent Impervious and Initial Estimate of Loss Rates

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Initial Loss (in)	Constant Loss (in/hr)
NF_Guad_S010	168.18	0	0	0.12
NF_Guad_S020	21.06	0	0	0.12
SF_Guad_S010	97.40	0	0	0.12
Guad_S010	24.75	1	0	0.13
JohnsonCr_S010	113.51	0	0	0.12
JohnsonCr_S020	13.25	1	0	0.13
Guad_S020	47.53	3	0	0.13
Guad_S030	78.17	4	0	0.13
TurtleCr_S010	70.47	0	0	0.13
Guad_S040	18.13	1	0	0.14
VerdeCr_S010	56.16	0	0	0.13
Guad_S050	54.88	0	0	0.13
CypressCr_GR_S010	73.49	0	0	0.13
Guad_S060	28.10	1	0	0.13
BlockCr_S010	44.64	0	0	0.12
Guad_S070	19.96	0	0	0.13
JoshuaCr_S010	41.66	0	0	0.12
Guad_S080	12.59	0	0	0.13
SisterCr_S010	64.30	0	0	0.12
Guad_S090	149.01	0	0	0.12
CurryCr_S010	69.15	0	0	0.12
Guad_S100	47.37	1	0	0.12
Guad_S110	46.28	2	0	0.12

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Initial Loss (in)	Constant Loss (in/hr)
Guad_S120	58.52	4	0	0.12
CanyonLk_S010	12.51	100	0	0
Blanco_S010	26.44	0	0	0.1
Blanco_S020	40.84	0	0	0.1
Blanco_S030	35.90	0.3	0	0.09
Blanco_S040	43.58	1.1	0	0.09
Blanco_S050	22.38	0.2	0	0.09
LittleBlanco_S010	12.83	0.2	0	0.1
LittleBlanco_S020	13.41	0.2	0	0.1
LittleBlanco_S030	24.15	0.6	0	0.09
LittleBlanco_S040	18.32	0.2	0	0.1
Blanco_S060	1.19	0.1	0	0.1
WanslowCr_BR_S010	13.37	0.4	0	0.1
Blanco_S070	16.42	0.4	0	0.1
Blanco_S080	5.86	0.6	0	0.1
CarpersCr_BR_S010	15.35	0.9	0	0.1
Blanco_S090	19.06	1	0	0.1
Blanco_S100	1.59	2.7	0	0.1
WilsonCr_BR_S010	5.34	0.6	0	0.1
Blanco_S110	0.93	12.5	0	0.1
CypressCr_BR_S010	15.02	0.2	0	0.1
CypressCr_BR_S020	15.11	1	0	0.1
CypressCr_BR_S030	8.01	3.9	0	0.1
Blanco_S120	8.49	1.7	0	0.1
Blanco_S130	6.95	0.2	0	0.1
LoneManCr_BR_S010	12.37	0.3	0	0.1
Blanco_S140	9.85	0.1	0	0.1
HalifaxCr_BR_S010	12.92	0.1	0	0.09
Blanco_S150	6.65	0.2	0	0.09
Blanco_S160	20.39	2.2	0	0.09
Blanco_S170	3.57	16.4	0	0.1
SinkCk_S010	23.53	0	0	0.07
SinkCk_S020	9.89	0	0	0.07
SinkCk_S030	4.34	0	0	0.07
SinkCk_S040	5.61	3	0	0.07
SanMarcos_S005	5.58	6	0	0.07

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Initial Loss (in)	Constant Loss (in/hr)
SanMarcos_S008	0.98	46	0	0.07
PurgatoryCr_S010	37.13	2	0	0.07
SanMarcos_S010	7.99	16	0	0.08
SanMarcos_S020	82.34	1	0	0.08
YorkCr_S010	142.92	1	0	0.11
SanMarcos_S030	82.38	1	0	0.08
SanMarcos_S040	22.89	1	0	0.09
PlumCr_S010	111.30	2	0	0.07
PlumCr_S020	83.29	1	0	0.08
TenneyCr_S010	39.82	0	0	0.09
PlumCr_S030	117.08	0	0	0.08
PlumCr_S040	37.34	1	0	0.08
SanMarcos_S050	108.37	0	0	0.09
DryComalCk_S010	30.25	0	0	0.06
DryComalCk_S020	0.81	0	0	0.07
WFk_DryComalCk_S010	18.47	1	0	0.04
WFk_DryComalCk_S020	1.27	1	0	0.08
WF_Trib_S010	1.84	2	0	0.08
WF_Trib_S020	1.09	0	0	0.08
WFk_DryComalCk_S030	0.25	1	0	0.1
DryComalCk_S030	1.38	0	0	0.11
BearCk_S010	13.37	1	0	0.05
DryComalCk_S040	20.29	7	0	0.07
DCCk_Trib14_S010	5.72	0	0	0.07
DryComalCk_S050	12.52	8	0	0.06
DryComalCk_S060	3.98	23	0	0.09
BliedersCk_S010	11.49	4	0	0.06
Comal_S010	5.58	9	0	0.09
Comal_S020	1.23	31	0	0.16
Comal_S030	0.59	47	0	0.15
Guad_S130	36.03	2	0	0.12
BearCr_S010	16.74	1	0	0.12
Guad_S140	35.49	3	0	0.12
Guad_S142	15.00	19	0	0.1
Guad_S144	0.72	1	0	0.13
Guad_Trib22_S010	4.51	10	0	0.06

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Initial Loss (in)	Constant Loss (in/hr)
Guad_S145	1.00	3	0	0.2
LongCk_S010	11.49	1	0	0.05
Guad_S147	0.44	4	0	0.18
Guad_Trib20_S010	8.82	3	0	0.06
Guad_S149	3.59	5	0	0.15
Guad_S152	0.71	17	0	0.21
YoungsCk_S010	14.76	1	0	0.04
Guad_S154	0.26	41	0	0.14
CottonwoodCkS_S010	6.01	0	0	0.03
Guad_S156	0.60	13	0	0.18
Little_MillCk_S010	8.70	3	0	0.06
Guad_S158	1.36	5	0	0.13
DeadmanCk_S010	8.57	1	0	0.04
Guad_S160	22.24	10	0	0.09
CottonwoodCk_S010	41.19	0	0	0.18
Guad_S162	1.19	1	0	0.18
AlligatorCk_S010	10.62	3	0	0.04
GeronimoCk_S010	20.01	3	0	0.04
GeronimoCk_S020	29.06	1	0	0.04
GeronimoCk_S030	9.98	10	0	0.07
Guad_S164	4.27	0	0	0.13
CantauCk_S010	6.64	0	0	0.15
Guad_S166	31.70	0	0	0.2
MillCk_S010	39.41	0	0	0.08
Guad_S168	32.51	0	0	0.19
NashCk_S010	26.51	0	0	0.18
Guad_S170	35.71	0	0	0.14
Guad_S172	22.92	0	0	0.12
Guad_S174	28.50	0	0	0.11
Guad_S176	4.40	0	0	0.18
Guad_S200	69.52	3	0	0.13
PeachCr_S010	110.41	0	0	0.14
BigFiveMileCr_S010	44.64	1	0	0.13
PeachCr_S020	64.77	1	0	0.13
SandyFork_S010	159.64	0	0	0.14
PeachCr_S030	80.30	0	0	0.13

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Initial Loss (in)	Constant Loss (in/hr)
PeachCr_S040	22.74	1	0	0.13
Guad_S210	122.37	0	0	0.14
McCoyCr_S010	32.59	0	0	0.14
Guad_S220	48.45	0	0	0.13
SandiesCr_S010	117.29	0	0	0.15
ClearForkCr_S010	63.87	1	0	0.13
SandiesCr_S020	33.01	1	0	0.14
ElmCr_S010	158.76	1	0	0.13
SandiesCr_S030	176.42	0	0	0.13
SandiesCr_S040	161.79	0	0	0.14
Guad_S230	98.87	2	0	0.14
Guad_S240	170.88	3	0	0.13
DryCk_S010	35.55	2	0	0.08
SmithCk_S010	32.66	0	0	0.15
ThomasCk_S010	30.55	0	0	0.16
SmithCk_S020	29.85	0	0	0.14
YorktownCk_S010	27.96	1	0	0.13
YorktownCk_S020	17.43	1	0	0.13
FifteenmileCk_S010	13.13	0	0	0.13
HoosierCk_S010	12.96	0	0	0.14
FifteenmileCk_S020	17.95	0	0	0.15
EighteenmileCk_S010	47.98	0	0	0.15
FifteenmileCk_S030	19.85	0	0	0.16
TwelvemileCk_S010	47.68	0	0	0.13
FivemileCk_S010	39.00	0	0	0.17
TwelvemileCk_S020	19.19	0	0	0.19
ColetoCk_S010	38.97	4	0	0.1
ColetoCk_S020	22.57	5	0	0.09
PerdidoCk_S010	27.68	0	0	0.15
PerdidoCk_S020	27.57	0	0	0.1
PerdidoCk_S030	21.08	10	0	0.06
ColetoCk_S030	17.22	1	0	0.08
ColetoCk_S040	29.13	1	0	0.11
Guad_S250	39.40	7	0	0.12

Table 6.2: Initial Estimates of Snyder's Transform Parameters

Subbasin Name	% Urban	% Sand	Lag Time (hr)	Peaking Coefficient
NF_Guad_S010	0	4	5.74	0.8594
NF_Guad_S020	0	11	2.38	0.8594
SF_Guad_S010	0	9	5.62	0.8594
Guad_S010	0	34	2.66	0.8594
JohnsonCr_S010	0	8	4.13	0.8594
JohnsonCr_S020	0	31	2.05	0.8594
Guad_S020	0	28	2.42	0.8594
Guad_S030	0	37	4.63	0.8594
TurtleCr_S010	0	28	4.99	0.8594
Guad_S040	0	58	2.38	0.8594
VerdeCr_S010	0	42	4.65	0.8594
Guad_S050	0	47	4.07	0.8594
CypressCr_GR_S010	0	33	4.37	0.8594
Guad_S060	0	30	2.3	0.8594
BlockCr_S010	0	14	3.14	0.8594
Guad_S070	0	36	2.95	0.8594
JoshuaCr_S010	0	16	2.98	0.8594
Guad_S080	0	30	1.35	0.8594
SisterCr_S010	0	15	2.81	0.8594
Guad_S090	0	13	8.4	0.8594
CurryCr_S010	0	15	3.86	0.8594
Guad_S100	0	14	2.3	0.8594
Guad_S110	0	9	2.58	0.8594
Guad_S120	0	5	2.75	0.8594
CanyonLk_S010	0	0	0	0.8594
Blanco_S010	0	83	3.2	0.72
Blanco_S020	0	85	3.9	0.72
Blanco_S030	0	77	2.9	0.72
Blanco_S040	1	72	5.2	0.72
Blanco_S050	0	68	4.9	0.72
LittleBlanco_S010	0	86	2.2	0.72
LittleBlanco_S020	0	82	2.6	0.72
LittleBlanco_S030	1	70	2.9	0.72
LittleBlanco_S040	0	89	4.2	0.72
Blanco_S060	0	93	0.9	0.72

Subbasin Name	% Urban	% Sand	Lag Time (hr)	Peaking Coefficient
WanslowCr_BR_S010	0	93	3.2	0.72
Blanco_S070	1	90	2.9	0.72
Blanco_S080	2	87	2.7	0.72
CarpersCr_BR_S010	1	95	4.4	0.72
Blanco_S090	1	92	3.1	0.72
Blanco_S100	5	90	1.2	0.72
WilsonCr_BR_S010	1	94	2.6	0.72
Blanco_S110	15	91	1	0.72
CypressCr_BR_S010	0	94	2.7	0.72
CypressCr_BR_S020	1	95	2.5	0.72
CypressCr_BR_S030	4	92	3.2	0.72
Blanco_S120	2	94	2.1	0.72
Blanco_S130	2	95	2.9	0.72
LoneManCr_BR_S010	0	100	4.8	0.72
Blanco_S140	2	93	2.9	0.72
HalifaxCr_BR_S010	0	80	4.6	0.72
Blanco_S150	2	81	2.8	0.72
Blanco_S160	3	74	3.6	0.72
Blanco_S170	21	100	3.9	0.72
SinkCk_S010	0	85	4.4	0.78
SinkCk_S020	0	84	3.4	0.78
SinkCk_S030	0	86	1.1	0.78
SinkCk_S040	3	79	1.4	0.78
SanMarcos_S005	7	71	1.5	0.78
SanMarcos_S008	54	26	0.8	0.78
PurgatoryCr_S010	2	84	8.5	0.78
SanMarcos_S010	20	43	1.9	0.78
SanMarcos_S020	3	33	8.6	0.78
YorkCr_S010	3	18	6.5	0.78
SanMarcos_S030	1	60	6.9	0.78
SanMarcos_S040	2	78	5	0.78
PlumCr_S010	5	13	12.1	0.78
PlumCr_S020	2	33	5.3	0.78
TenneyCr_S010	1	61	4	0.78
PlumCr_S030	2	36	6.8	0.78
PlumCr_S040	2	66	4.6	0.78
SanMarcos_S050	1	76	13	0.78

Subbasin Name	% Urban	% Sand	Lag Time (hr)	Peaking Coefficient
DryComalCk_S010	0	88	7.7	0.78
DryComalCk_S020	0	62	0.8	0.78
WFk_DryComalCk_S010	1	96	6.7	0.78
WFk_DryComalCk_S020	1	67	1.4	0.78
WF_Trib_S010	3	86	1.3	0.78
WF_Trib_S020	0	61	0.9	0.78
WFk_DryComalCk_S030	0	78	0.5	0.78
DryComalCk_S030	0	91	1.4	0.78
BearCk_S010	2	79	3.2	0.78
DryComalCk_S040	11	53	3.1	0.78
DCCk_Trib14_S010	0	77	2.1	0.78
DryComalCk_S050	13	40	2.1	0.78
DryComalCk_S060	36	58	1.5	0.78
BliedersCk_S010	7	78	2.1	0.78
Comal_S010	15	88	2.8	0.78
Comal_S020	46	92	0.9	0.78
Comal_S030	65	74	0.7	0.78
Guad_S130	0	12	2.3	0.78
BearCr_S010	0	3	1.9	0.78
Guad_S140	6	91	3	0.78
Guad_S142	33	43	3.7	0.78
Guad_S144	6	80	0.8	0.78
Guad_Trib22_S010	16	21	1.8	0.78
Guad_S145	15	90	3.2	0.78
LongCk_S010	1	13	1.4	0.78
Guad_S147	23	73	0.8	0.78
Guad_Trib20_S010	7	22	2.3	0.78
Guad_S149	22	63	1.5	0.78
Guad_S152	32	92	0.7	0.78
YoungsCk_S010	2	7	2.3	0.78
Guad_S154	60	58	0.7	0.78
CottonwoodCkS_S010	2	2	2.2	0.78
Guad_S156	32	73	0.9	0.78
Little_MillCk_S010	8	28	2.7	0.78
Guad_S158	15	56	1	0.78
DeadmanCk_S010	3	14	2.1	0.78

Subbasin Name	% Urban	% Sand	Lag Time (hr)	Peaking Coefficient
Guad_S160	17	47	3.5	0.78
CottonwoodCk_S010	0	90	6.4	0.78
Guad_S162	5	85	1.3	0.78
AlligatorCk_S010	5	63	2.6	0.78
GeronimoCk_S010	7	6	3.3	0.78
GeronimoCk_S020	4	10	2.8	0.78
GeronimoCk_S030	15	41	2.2	0.78
Guad_S164	3	69	2.2	0.78
CantauCk_S010	0	81	3.2	0.78
Guad_S166	1	94	5.3	0.78
MillCk_S010	1	52	6.3	0.78
Guad_S168	2	94	8.5	0.78
NashCk_S010	0	91	6.2	0.78
Guad_S170	2	86	11.6	0.78
Guad_S172	2	67	5.6	0.78
Guad_S174	3	53	5.2	0.78
Guad_S176	4	81	5.3	0.78
Guad_S200	0	38	10.1	0.78
PeachCr_S010	0	55	15	0.75
BigFiveMileCr_S010	0	25	6.1	0.75
PeachCr_S020	0	22	9	0.75
SandyFork_S010	0	78	17.7	0.75
PeachCr_S030	0	32	8.8	0.75
PeachCr_S040	0	28	6.1	0.75
Guad_S210	0	55	10.3	0.78
McCoyCr_S010	0	56	5.3	0.78
Guad_S220	0	48	6.4	0.78
SandiesCr_S010	0	94	14.1	0.75
ClearForkCr_S010	0	46	12.1	0.75
SandiesCr_S020	0	62	11.3	0.75
ElmCr_S010	0	42	16.7	0.75
SandiesCr_S030	0	32	28.6	0.75
SandiesCr_S040	0	63	16.9	0.75
Guad_S230	0	56	4.6	0.78
Guad_S240	0	41	13	0.78
SmithCk_S010	0	76	7.2	0.78

Subbasin Name	% Urban	% Sand	Lag Time (hr)	Peaking Coefficient
ThomasCk_S010	0	85	6.3	0.78
SmithCk_S020	0	82	6.8	0.78
YorktownCk_S010	0	71	4.9	0.78
YorktownCk_S020	0	87	4.1	0.78
FifteenmileCk_S010	0	81	3.9	0.78
HoosierCk_S010	0	85	5.7	0.78
FifteenmileCk_S020	0	94	6	0.78
EighteenmileCk_S010	0	86	8.1	0.78
FifteenmileCk_S030	0	89	5.9	0.78
TwelvemileCk_S010	0	90	10.1	0.78
FivemileCk_S010	0	98	8.4	0.78
TwelvemileCk_S020	0	100	6	0.78
ColetoCk_S010	0	74	6.7	0.78
ColetoCk_S020	0	72	5.5	0.78
PerdidoCk_S010	0	86	4.4	0.78
PerdidoCk_S020	0	75	4.9	0.78
PerdidoCk_S030	0	62	4.6	0.78
ColetoCk_S030	0	52	3.5	0.78
ColetoCk_S040	0	68	6.2	0.78
DryCk_S010	0	62	6.4	0.78
Guad_S250	0	50	13.8	0.78

Table 6.3: Initial Estimates of Baseflow Parameters

Subbasin Name	Initial Discharge (cfs / sq mi)	Recession Constant	Ratio to Peak
NF_Guad_S010	0.3	0.887	0.05
NF_Guad_S020	0.3	0.887	0.05
SF_Guad_S010	0.3	0.887	0.05
Guad_S010	0.3	0.887	0.05
JohnsonCr_S010	0.3	0.887	0.05
JohnsonCr_S020	0.3	0.887	0.05
Guad_S020	0.3	0.887	0.05
Guad_S030	0.3	0.887	0.05
TurtleCr_S010	0.3	0.887	0.05
Guad_S040	0.3	0.887	0.05
VerdeCr_S010	0.3	0.887	0.05
Guad_S050	0.3	0.887	0.05
CypressCr_GR_S010	0.3	0.887	0.05
Guad_S060	0.3	0.887	0.05
BlockCr_S010	0.3	0.887	0.05
Guad_S070	0.3	0.887	0.05
JoshuaCr_S010	0.3	0.887	0.05
Guad_S080	0.3	0.887	0.05
SisterCr_S010	0.3	0.887	0.05
Guad_S090	0.3	0.887	0.05
CurryCr_S010	0.3	0.887	0.05
Guad_S100	0.3	0.887	0.05
Guad_S110	0.3	0.887	0.05
Guad_S120	0.3	0.887	0.05
CanyonLk_S010	0.3	0.887	0.05
Blanco_S010	0.2	0.92	0.03
Blanco_S020	0.2	0.92	0.03
Blanco_S030	0.2	0.92	0.03
Blanco_S040	0.2	0.92	0.03
Blanco_S050	0.2	0.92	0.03
LittleBlanco_S010	0.2	0.92	0.03
LittleBlanco_S020	0.2	0.92	0.03
LittleBlanco_S030	0.2	0.92	0.03
LittleBlanco_S040	0.2	0.92	0.03
Blanco_S060	0.2	0.92	0.03

Subbasin Name	Initial Discharge (cfs / sq mi)	Recession Constant	Ratio to Peak
WanslowCr_BR_S010	0.2	0.92	0.03
Blanco_S070	0.2	0.92	0.03
Blanco_S080	0.2	0.92	0.03
CarpersCr_BR_S010	0.2	0.92	0.03
Blanco_S090	0.2	0.92	0.03
Blanco_S100	0.2	0.92	0.03
WilsonCr_BR_S010	0.2	0.92	0.03
Blanco_S110	0.2	0.92	0.03
CypressCr_BR_S010	0.2	0.92	0.03
CypressCr_BR_S020	0.2	0.92	0.03
CypressCr_BR_S030	0.2	0.92	0.03
Blanco_S120	0.2	0.89	0.03
Blanco_S130	0.2	0.89	0.03
LoneManCr_BR_S010	0.2	0.89	0.03
Blanco_S140	0.2	0.89	0.03
HalifaxCr_BR_S010	0.2	0.89	0.03
Blanco_S150	0.2	0.89	0.02
Blanco_S160	0.2	0.89	0.02
Blanco_S170	0.2	0.89	0.02
SinkCk_S010	0.3	0.89	0.05
SinkCk_S020	0.3	0.89	0.05
SinkCk_S030	0.3	0.89	0.05
SinkCk_S040	0.3	0.89	0.05
SanMarcos_S005	0.3	0.89	0.05
SanMarcos_S008	0.3	0.89	0.05
PurgatoryCr_S010	0.3	0.89	0.05
SanMarcos_S010	0.3	0.89	0.05
SanMarcos_S020	0.3	0.89	0.05
YorkCr_S010	0.3	0.79	0.1
SanMarcos_S030	0.3	0.89	0.05
SanMarcos_S040	0.3	0.89	0.05
PlumCr_S010	0.3	0.79	0.1
PlumCr_S020	0.3	0.79	0.1
TenneyCr_S010	0.3	0.79	0.1
PlumCr_S030	0.3	0.79	0.1
PlumCr_S040	0.3	0.79	0.1

Subbasin Name	Initial Discharge (cfs / sq mi)	Recession Constant	Ratio to Peak
SanMarcos_S050	0.3	0.89	0.05
DryComalCk_S010	0.3	0.89	0.05
DryComalCk_S020	0.3	0.89	0.05
WFk_DryComalCk_S010	0.3	0.89	0.05
WFk_DryComalCk_S020	0.3	0.89	0.05
WF_Trib_S010	0.3	0.89	0.05
WF_Trib_S020	0.3	0.89	0.05
WFk_DryComalCk_S030	0.3	0.89	0.05
DryComalCk_S030	0.3	0.89	0.05
BearCk_S010	0.3	0.89	0.05
DryComalCk_S040	0.3	0.89	0.05
DCCk_Trib14_S010	0.3	0.89	0.05
DryComalCk_S050	0.3	0.89	0.05
DryComalCk_S060	0.3	0.89	0.05
BliedersCk_S010	0.3	0.89	0.05
Comal_S010	57.35	0.89	0.05
Comal_S020	0.3	0.89	0.05
Comal_S030	0.3	0.89	0.05
Guad_S130	0.3	0.89	0.01
BearCr_S010	0.3	0.89	0.01
Guad_S140	0.3	0.89	0.01
Guad_S142	0.3	0.89	0.05
Guad_S144	0.3	0.89	0.05
Guad_Trib22_S010	0.3	0.89	0.05
Guad_S145	0.3	0.89	0.05
LongCk_S010	0.3	0.89	0.05
Guad_S147	0.3	0.89	0.05
Guad_Trib20_S010	0.3	0.89	0.05
Guad_S149	0.3	0.89	0.05
Guad_S152	0.3	0.89	0.05
YoungsCk_S010	0.3	0.89	0.05
Guad_S154	0.3	0.89	0.05
CottonwoodCkS_S010	0.3	0.89	0.05
Guad_S156	0.3	0.89	0.05
Little_MillCk_S010	0.3	0.89	0.05
Guad_S158	0.3	0.89	0.05

Subbasin Name	Initial Discharge (cfs / sq mi)	Recession Constant	Ratio to Peak
DeadmanCk_S010	0.3	0.89	0.05
Guad_S160	0.3	0.89	0.05
CottonwoodCk_S010	0.3	0.89	0.05
Guad_S162	0.3	0.89	0.05
AlligatorCk_S010	0.3	0.89	0.05
GeronimoCk_S010	0.3	0.89	0.05
GeronimoCk_S020	0.3	0.89	0.05
GeronimoCk_S030	0.3	0.89	0.05
Guad_S164	0.3	0.89	0.05
CantauCk_S010	0.3	0.89	0.05
Guad_S166	0.3	0.89	0.05
MillCk_S010	0.3	0.89	0.05
Guad_S168	0.3	0.89	0.05
NashCk_S010	0.3	0.89	0.05
Guad_S170	0.3	0.89	0.05
Guad_S172	0.3	0.89	0.05
Guad_S174	0.3	0.89	0.05
Guad_S176	0.3	0.89	0.05
Guad_S200	0.3	0.89	0.05
PeachCr_S010	0.3	0.89	0.01
BigFiveMileCr_S010	0.3	0.89	0.01
PeachCr_S020	0.3	0.89	0.01
SandyFork_S010	0.3	0.89	0.01
PeachCr_S030	0.3	0.89	0.01
PeachCr_S040	0.3	0.89	0.01
Guad_S210	0.3	0.89	0.05
McCoyCr_S010	0.3	0.89	0.05
Guad_S220	0.3	0.89	0.05
SandiesCr_S010	0.3	0.45	0.05
ClearForkCr_S010	0.3	0.45	0.05
SandiesCr_S020	0.3	0.45	0.05
ElmCr_S010	0.3	0.45	0.05
SandiesCr_S030	0.3	0.45	0.05
SandiesCr_S040	0.3	0.45	0.05
Guad_S230	0.3	0.89	0.05
Guad_S240	0.3	0.89	0.05

Subbasin Name	Initial Discharge (cfs / sq mi)	Recession Constant	Ratio to Peak
SmithCk_S010	0.3	0.89	0.05
ThomasCk_S010	0.3	0.89	0.05
SmithCk_S020	0.3	0.89	0.05
YorktownCk_S010	0.3	0.89	0.05
YorktownCk_S020	0.3	0.89	0.05
FifteenmileCk_S010	0.3	0.89	0.05
HoosierCk_S010	0.3	0.89	0.05
FifteenmileCk_S020	0.3	0.89	0.05
EighteenmileCk_S010	0.3	0.89	0.05
FifteenmileCk_S030	0.3	0.89	0.05
TwelvemileCk_S010	0.3	0.89	0.05
FivemileCk_S010	0.3	0.89	0.05
TwelvemileCk_S020	0.3	0.89	0.05
ColetoCk_S010	0.3	0.89	0.05
ColetoCk_S020	0.3	0.89	0.05
PerdidoCk_S010	0.3	0.89	0.05
PerdidoCk_S020	0.3	0.89	0.05
PerdidoCk_S030	0.3	0.89	0.05
ColetoCk_S030	0.3	0.89	0.05
ColetoCk_S040	0.3	0.89	0.05
DryCk_S010	0.3	0.89	0.05
Guad_S250	0.3	0.89	0.05

Table 6.4: Modified Puls Routing Data

HEC-HMS Reach Name	Storage-Discharge Source	Initial Subreaches
Blanco_R020F	Hays Co FIS HEC-1	2
Blanco_R020H	Hays Co FIS HEC-1	3
Blanco_R030J	Hays Co FIS HEC-1	1
Blanco_R030L	Hays Co FIS HEC-1	2
Blanco_R030M	Hays Co FIS HEC-1	1
Blanco_R040O	Hays Co FIS HEC-1	2
Blanco_R040P	Hays Co FIS HEC-1	3
Blanco_R040R	Hays Co FIS HEC-1	5
Blanco_R050S	Hays Co FIS HEC-1	3
Blanco_R050T	Hays Co FIS HEC-1	5
LittleBlanco_R020V	Hays Co FIS HEC-1	2
LittleBlanco_R030W	Hays Co FIS HEC-1	3
LittleBlanco_R030X	Hays Co FIS HEC-1	3
LittleBlanco_R040Y	Hays Co FIS HEC-1	5
Blanco_R060Z	Hays Co FIS HEC-1	1
Blanco_R070	Blanco River HEC-RAS	5
Blanco_R080	Blanco River HEC-RAS	4
Blanco_R090	Blanco River HEC-RAS	4
Blanco_R100	Blanco River HEC-RAS	2
Blanco_R110	Blanco River HEC-RAS	1
CypressCr_R0204C	Hays Co FIS HEC-1	1
CypressCr_R0206C	Hays Co FIS HEC-1	1
CypressCr_R0206CL	Hays Co FIS HEC-1	1
CypressCr_R02010C	Hays Co FIS HEC-1	1
CypressCr_R03012C	Hays Co FIS HEC-1	1
CypressCr_R03014C	Hays Co FIS HEC-1	1
CypressCr_R03016C	Hays Co FIS HEC-1	1
Blanco_R120	Blanco River HEC-RAS	2
Blanco_R130	Blanco River HEC-RAS	5
Blanco_R140	Blanco River HEC-RAS	5
Blanco_R150	Blanco River HEC-RAS	4
Blanco_R160a	Blanco River HEC-RAS	2
Blanco_R160b	Blanco River HEC-RAS	3
Blanco_R170	Blanco River HEC-RAS	6
SinkCk_R010	Upper San Marcos HEC-RAS	1
SinkCk_R020	Upper San Marcos HEC-RAS	1

HEC-HMS Reach Name	Storage-Discharge Source	Initial Subreaches
SinkCk_R030	Upper San Marcos HEC-RAS	1
SinkCk_R040	Upper San Marcos HEC-RAS	1
SinkCk_R050	Upper San Marcos HEC-RAS	1
SanMarcos_R003	Upper San Marcos HEC-RAS	1
SanMarcos_R005	Upper San Marcos HEC-RAS	1
SanMarcos_R007	Upper San Marcos HEC-RAS	1
SanMarcos_R020	San Marcos River HEC-RAS	8
SanMarcos_R030	San Marcos River HEC-RAS	5
SanMarcos_R040	San Marcos River HEC-RAS	2
PlumCr_R010	Plum Creek HEC-RAS	8
PlumCr_R020	Plum Creek HEC-RAS	6
SanMarcos_R050	San Marcos River HEC-RAS	7
DryComalCk_R010	Comal River HEC-RAS	2
WFk_DryComalCk_R010	Comal River HEC-RAS	3
WF_Trib_R010	Comal River HEC-RAS	2
WFk_DryComalCk_R020	Comal River HEC-RAS	1
DryComalCk_R020	Comal River HEC-RAS	3
BearCk_R010	Comal River HEC-RAS	1
DryComalCk_R030	Comal River HEC-RAS	9
DCCk_Trib14_R010	Comal River HEC-RAS	2
DryComalCk_R040	Comal River HEC-RAS	6
DryComalCk_R050	Comal River HEC-RAS	4
Comal_R010	Comal River HEC-RAS	6
Comal_R020	Comal River HEC-RAS	1
Comal_R030	Comal River HEC-RAS	1
Comal_R040	Comal River HEC-RAS	2
Guad_R120	Guadalupe River HEC-RAS	1
Guad_R130	Guadalupe River HEC-RAS	2
Guad_R135	Guadalupe River HEC-RAS	1
Guad_R140	Guadalupe River HEC-RAS	1
Guad_R147	Guadalupe River HEC-RAS	1
Guad_R152	Guadalupe River HEC-RAS	1
Guad_R157	Guadalupe River HEC-RAS	1
Guad_R165	Guadalupe River HEC-RAS	1
Guad_R170	Guadalupe River HEC-RAS	1
Guad_R175	Guadalupe River HEC-RAS	1
Guad_R180	Guadalupe River HEC-RAS	1

HEC-HMS Reach Name	Storage-Discharge Source	Initial Subreaches
Guad_R185	Guadalupe River HEC-RAS	1
Guad_R190	Guadalupe River HEC-RAS	2
Guad_R195	Guadalupe River HEC-RAS	1
GeronimoCk_R010	Geronimo Creek HEC-RAS	3
GeronimoCk_R020	Geronimo Creek HEC-RAS	2
GeronimoCk_R030	Geronimo Creek HEC-RAS	2
Guad_R200	Guadalupe River HEC-RAS	1
Guad_R205	Guadalupe River HEC-RAS	2
Guad_R210	Guadalupe River HEC-RAS	4
Guad_R215	Guadalupe River HEC-RAS	6
Guad_R220	Guadalupe River HEC-RAS	4
Guad_R225	Guadalupe River HEC-RAS	4
Guad_R228	Guadalupe River HEC-RAS	4
Guad_R230	Guadalupe River HEC-RAS	13
PeachCr_R010	Peach Creek HEC-RAS	8
PeachCr_R020	Peach Creek HEC-RAS	8
PeachCr_R040	Peach Creek HEC-RAS	6
Guad_R240	Guadalupe River HEC-RAS	14
Guad_R250	Guadalupe River HEC-RAS	6
SandiesCr_R010	Sandies Creek HEC-RAS	6
SandiesCr_R020	Sandies Creek HEC-RAS	3
SandiesCr_R030	Sandies Creek HEC-RAS	5
Guad_R260	Guadalupe River HEC-RAS	7
Guad_R280	Guadalupe River HEC-RAS	15
ColetoCk_R010	Coleto Creek BLE HEC-RAS	2
PerdidoCk_R020	Coleto Creek BLE HEC-RAS	1
PerdidoCk_R030	Coleto Creek BLE HEC-RAS	1
ColetoCk_R030	Coleto Dam Break HEC-RAS	1
ColetoCk_R040	Coleto Dam Break HEC-RAS	5
Guad_R295	Guadalupe River HEC-RAS	5
Guad_R300	Guadalupe River HEC-RAS	1
Guad_R305	Guadalupe River HEC-RAS	2

Table 6.5: Muskingum Routing Data

HEC-HMS Reach Name	K (hrs)	X	Initial Subreaches
NF_Guad_R010	0.998	0.2	4
Guad_R010	1.1	0.2	4
JohnsonCr_R010	0.743	0.2	4
Guad_R020	1.039	0.2	4
Guad_R030	1.839	0.2	8
Guad_R040	1.055	0.2	4
Guad_R050	1.682	0.2	8
Guad_R060	1.107	0.2	4
Guad_R070	1.678	0.2	8
Guad_R080	0.889	0.2	4
Guad_R090	7.007	0.2	28
Guad_R100	1.432	0.2	4
Guad_R110	2.94	0.2	12
SmithCk_R020	6.9	0.3	1
YorktownCk_R020	4.1	0.3	1
FifteenmileCk_R010	3.6	0.3	1
FifteenmileCk_R020	5.4	0.3	1
FifteenmileCk_R030	3.9	0.3	1
TwelvemileCk_R020	4.4	0.3	1

6.4 HEC-HMS MODEL CALIBRATION

After building the more detailed HEC-HMS model with its initial parameters, the InFRM team calibrated the model to verify it was accurately simulating the response of the watershed to a range of observed flood events, including large events similar to a 1% annual chance (100-yr) flood. A total of twenty recent storm events were used throughout different parts of the watershed to fine tune the model, as shown in Table 6.6. The model calibration and verification process undertaken during this study exceeds the standards of a typical FEMA floodplain study.

For these storms, the National Weather Service (NWS) hourly rainfall radar data allowed the team to fine tune the watershed model through detailed calibration. Prior to the late 1990s, the NWS radar data was not available for use during earlier modeling efforts. The final model results accurately simulate the observed response of the watershed, as it generally reproduced the timing, shape, and magnitudes of the observed floods very well. Table 6.6 lists the storms that were used to calibrate each portion of the watershed, and Figures 6.3 through 6.22. illustrate the total depth of rain for the major calibration storms and how that rain was distributed spatially throughout the Guadalupe River watershed. These plots were extracted from the HEC-MetVue program for visualizing and processing rainfall data.

Since the rain fell on different parts of the basin from one event to another, the calibration of each storm was focused on those areas of the basin that received the greatest and most intense rainfall. Calibration was also only performed when the USGS stream gages were recording for that event. For some events, one or more of the gages were not recording, but the peak flow was estimated by the USGS. For these instances, the magnitude of the flood was calibrated to the estimated peak flow, but the timing and shape of the hydrograph could not be verified. Every gage was calibrated to at least three storms, and most of the gages were calibrated to between 5 and 7 storms. Table 6.7 shows which storms were calibrated for each USGS stream gage.

Table 6.6: Storm Events Used for Model Calibration

Storm Event	Guadalupe Basin above Canyon	Blanco / San Marcos Basin	Guadalupe Basin below Canyon	Coleto Creek Basin
Oct-97				Yes
Oct-98		Yes	Yes	Yes
Sep-01			Yes	Yes
Nov-01		Yes		
Jul-02	Yes		Yes	
Nov-02			Yes	
Jun-04				
Nov-04	Yes	Yes	Yes	Yes
May-05				Yes
Mar-07		Yes		Yes
Jul-Aug-07	Yes		Yes	Yes
Apr-09			Yes	
Oct-Nov-09			Yes	
Apr-10	Yes			
Jun-10			Yes	
Jan-12		Yes	Yes	
Oct-13		Yes	Yes	
May-15	Yes	Yes	Yes	
Oct-15	Yes	Yes	Yes	
May-16			Yes	

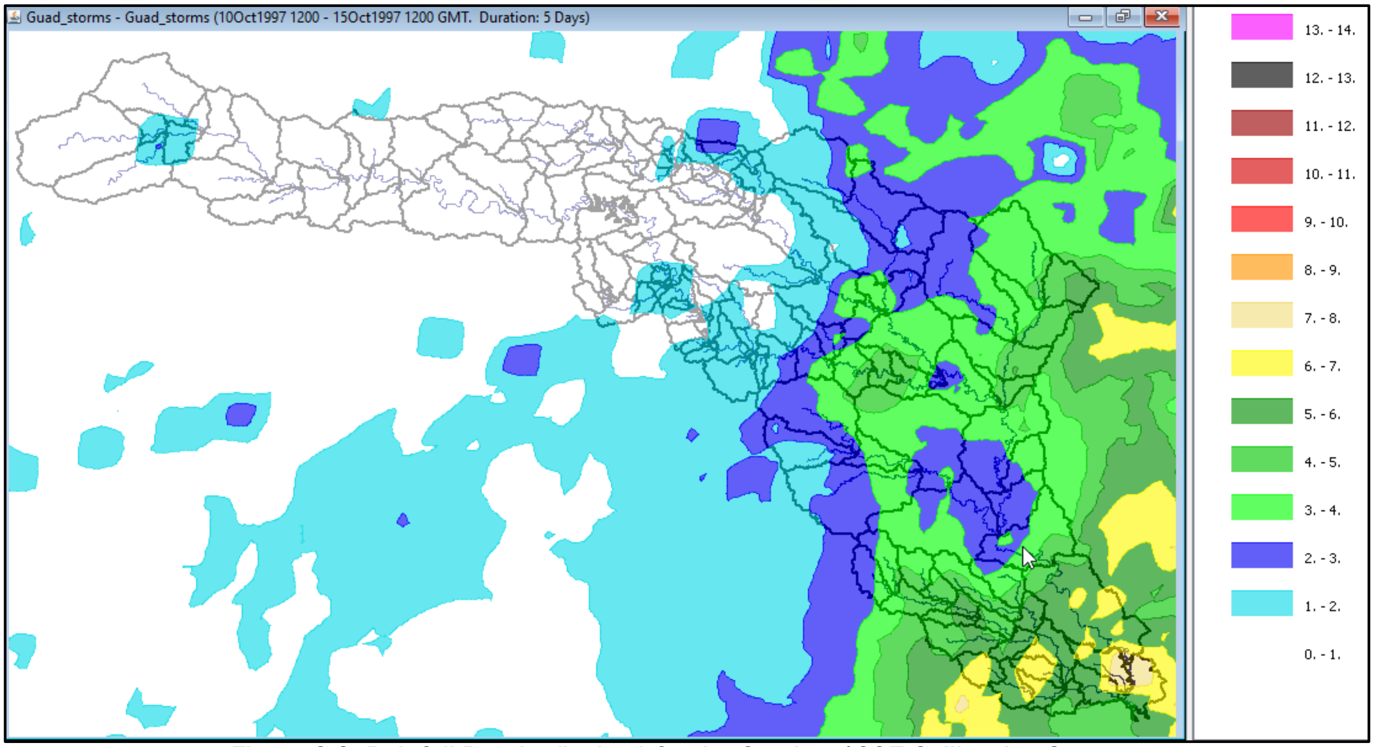


Figure 6.3: Rainfall Depths (inches) for the October 1997 Calibration Storm

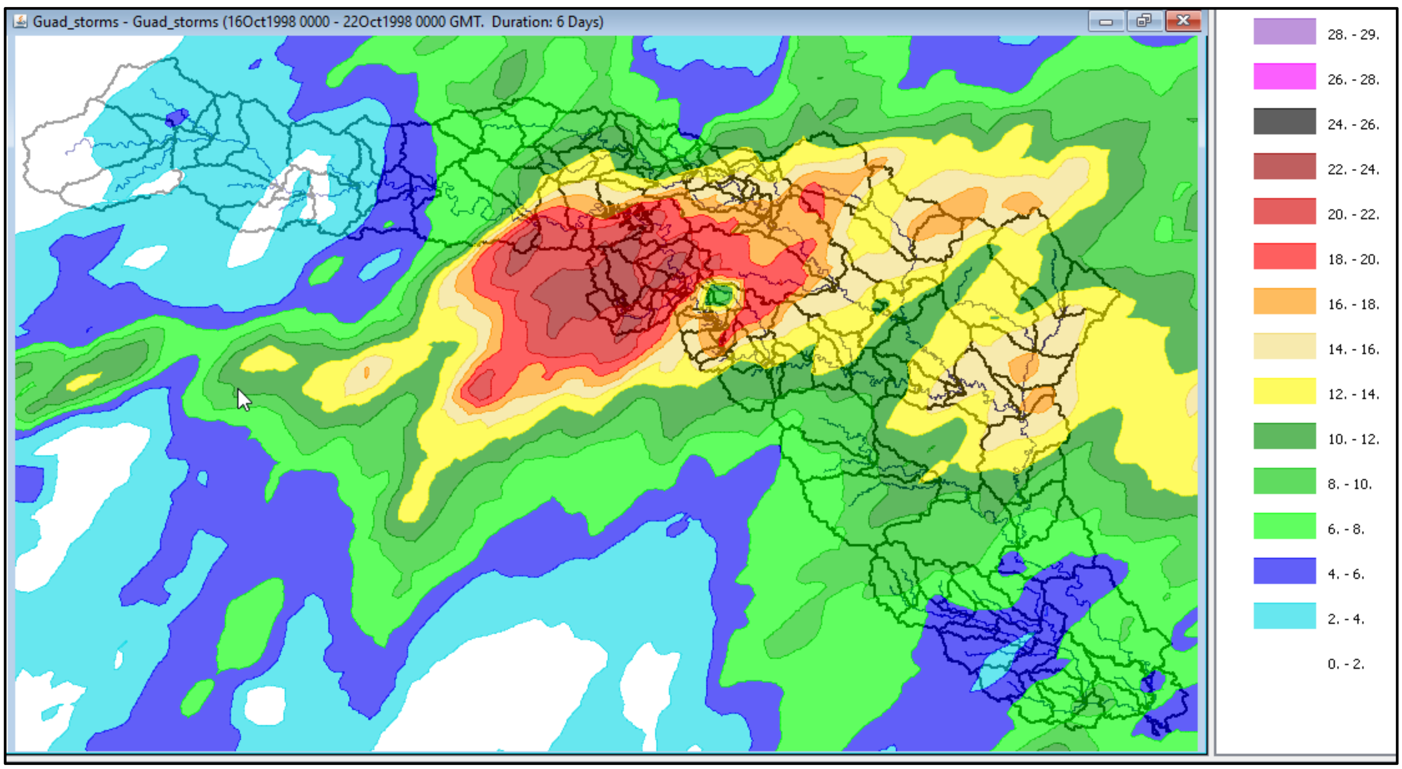


Figure 6.4: Rainfall Depths (inches) for the October 1998 Calibration Storm

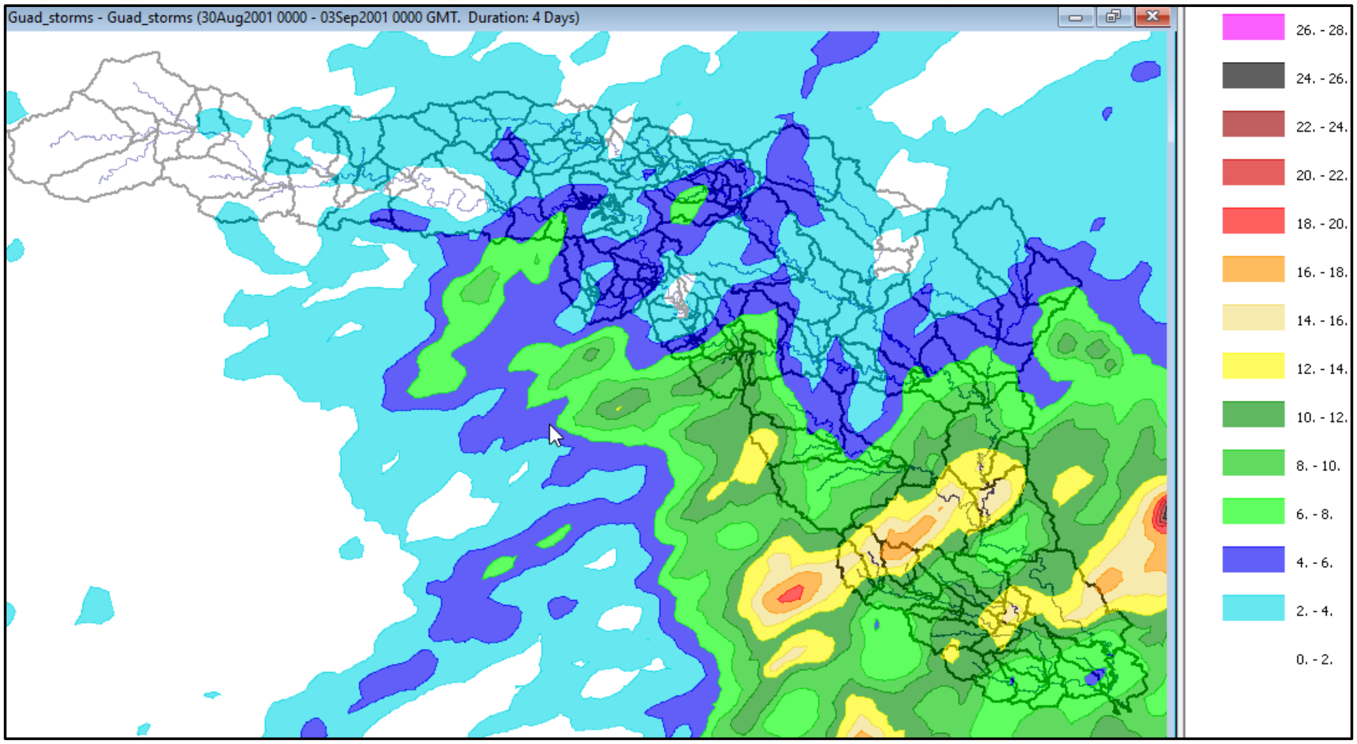


Figure 6.5: Rainfall Depths (inches) for the September 2001 Calibration Storm

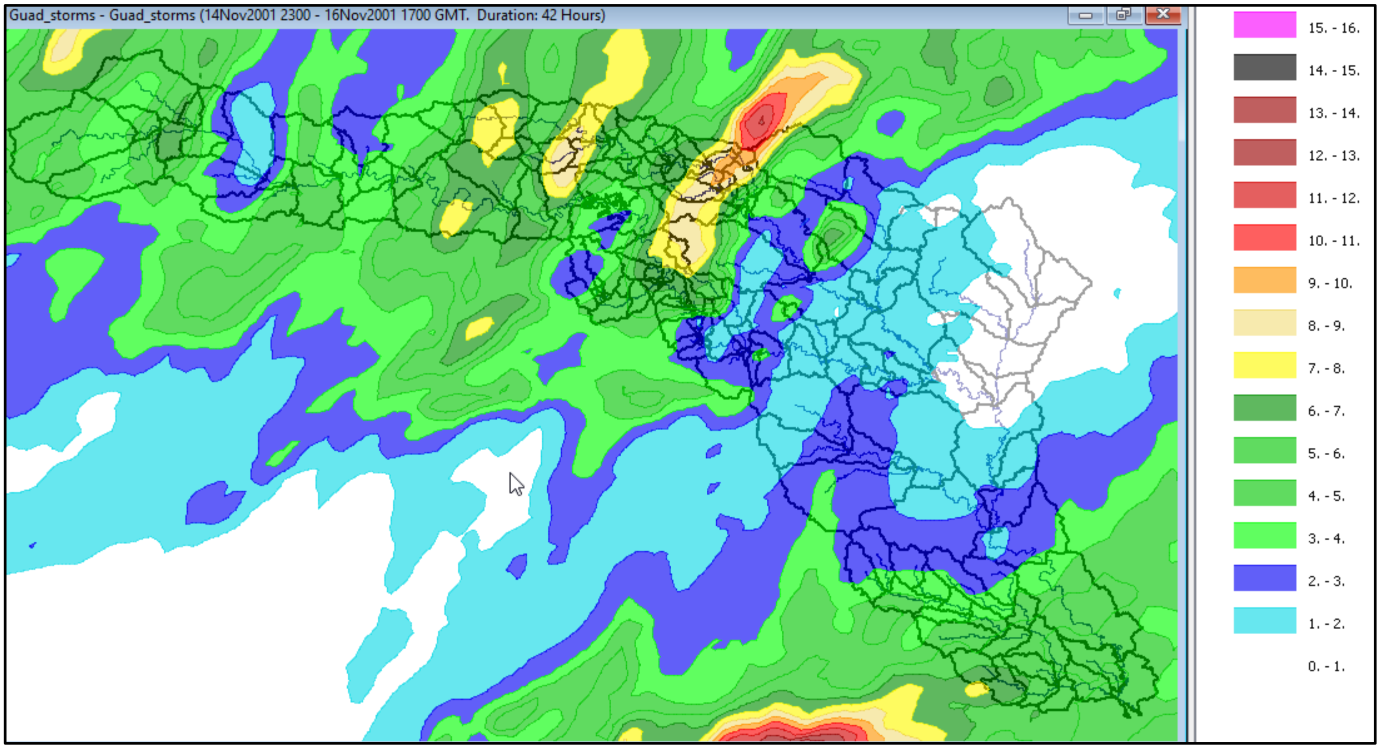


Figure 6.6: Rainfall Depths (inches) for the November 2001 Calibration Storm

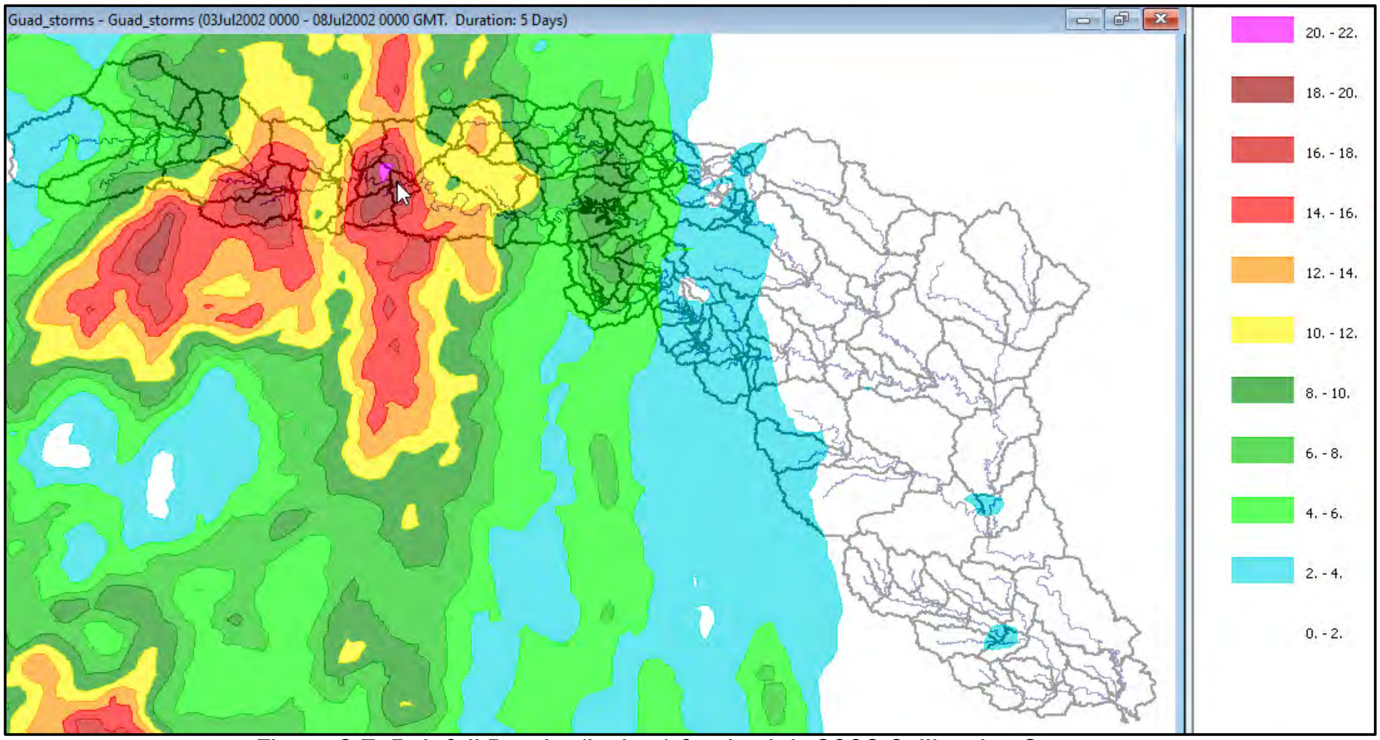


Figure 6.7: Rainfall Depths (inches) for the July 2002 Calibration Storm

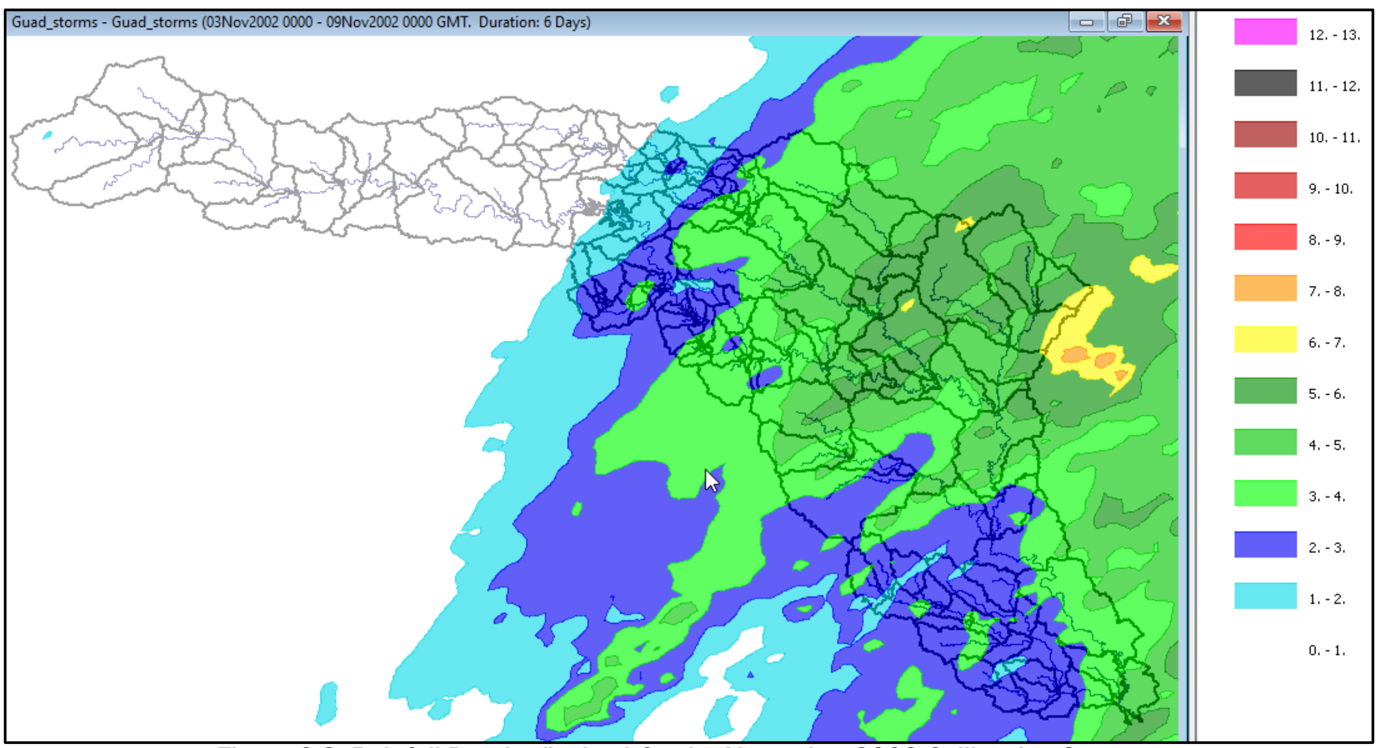


Figure 6.8: Rainfall Depths (inches) for the November 2002 Calibration Storm

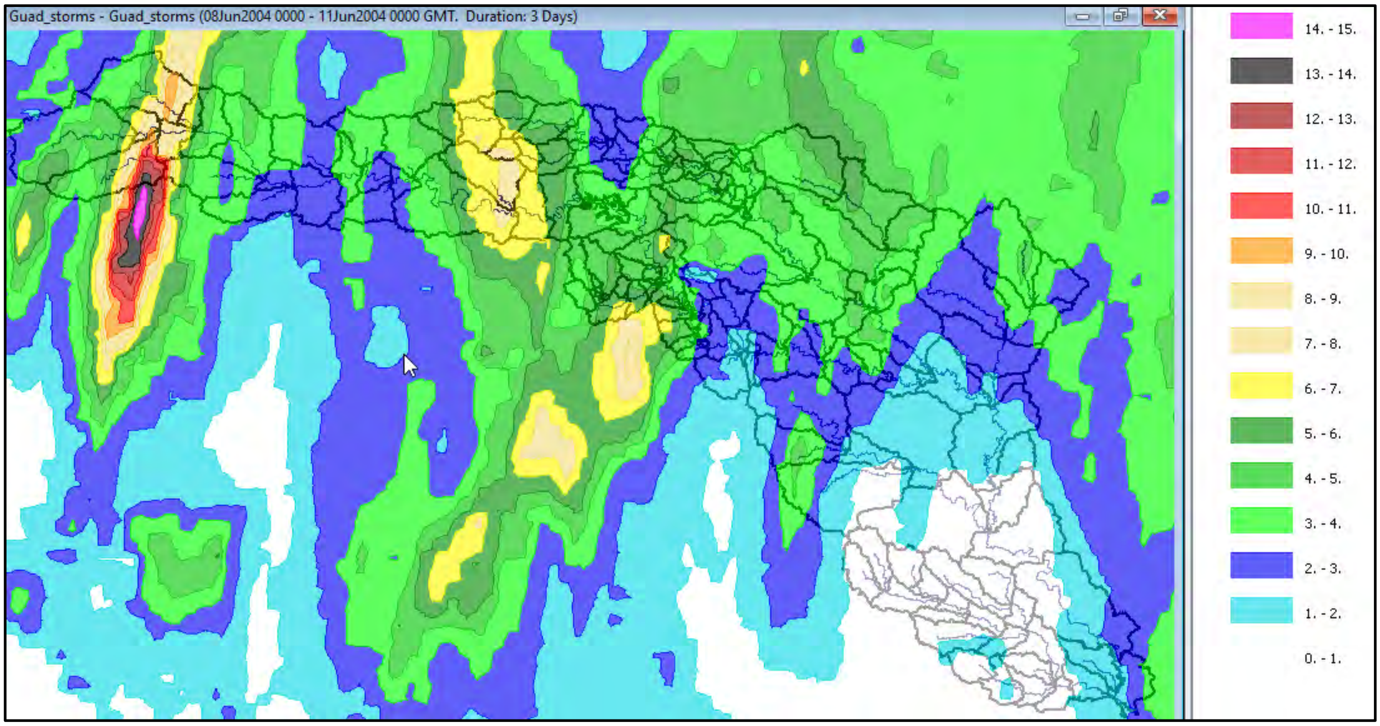


Figure 6.9: Rainfall Depths (inches) for the June 2004 Calibration Storm

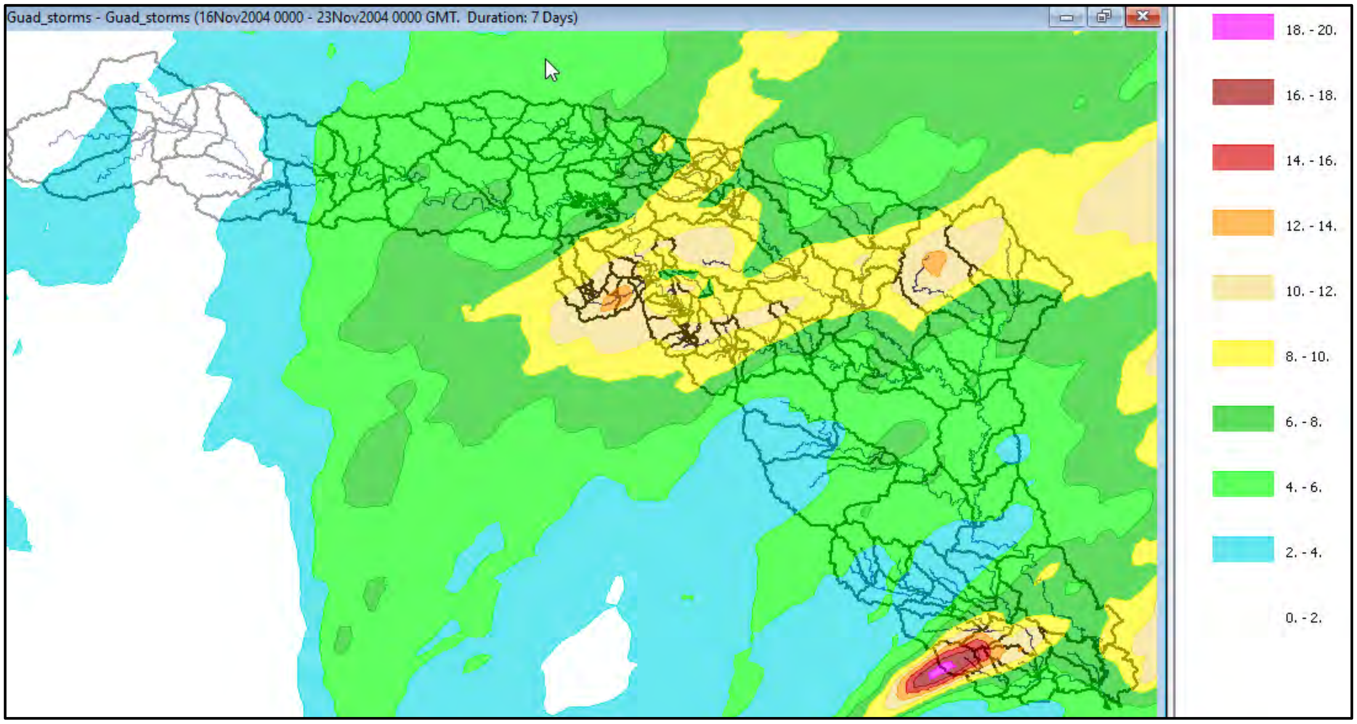


Figure 6.10: Rainfall Depths (inches) for the November 2004 Calibration Storm

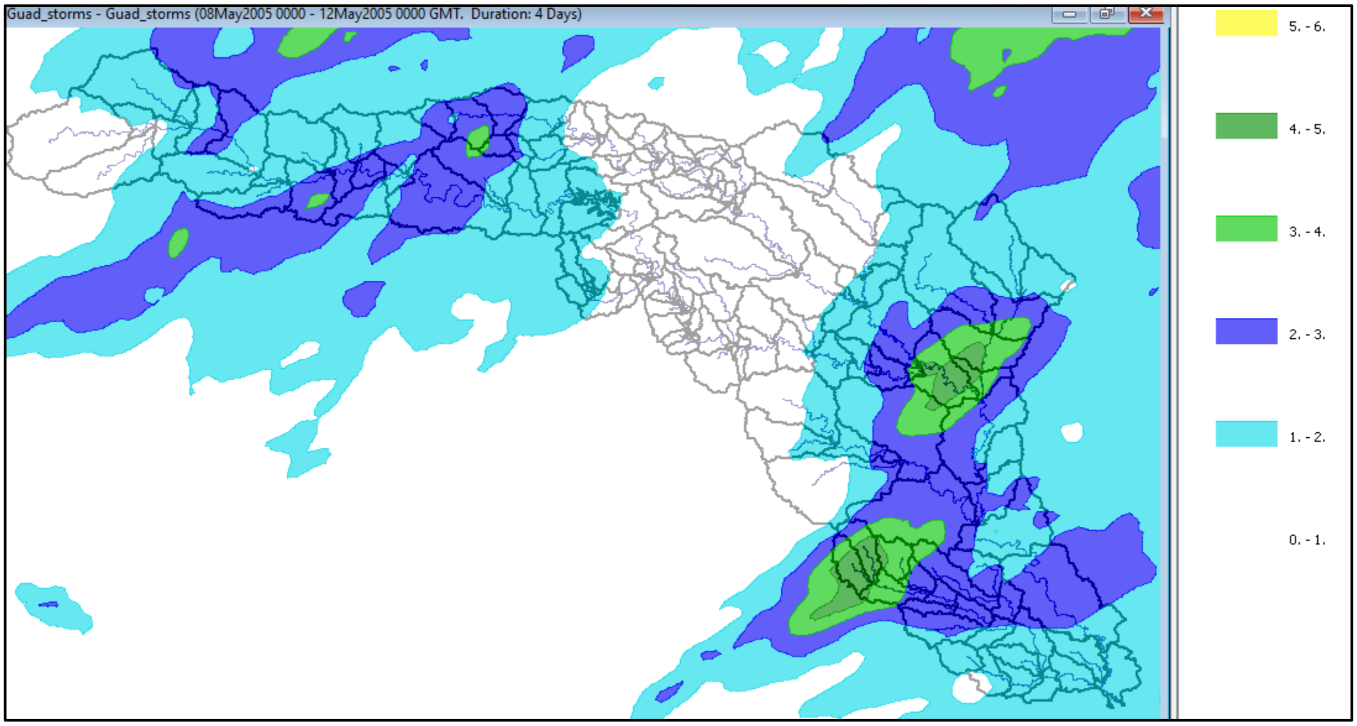


Figure 6.11: Rainfall Depths (inches) for the May 2005 Calibration Storm

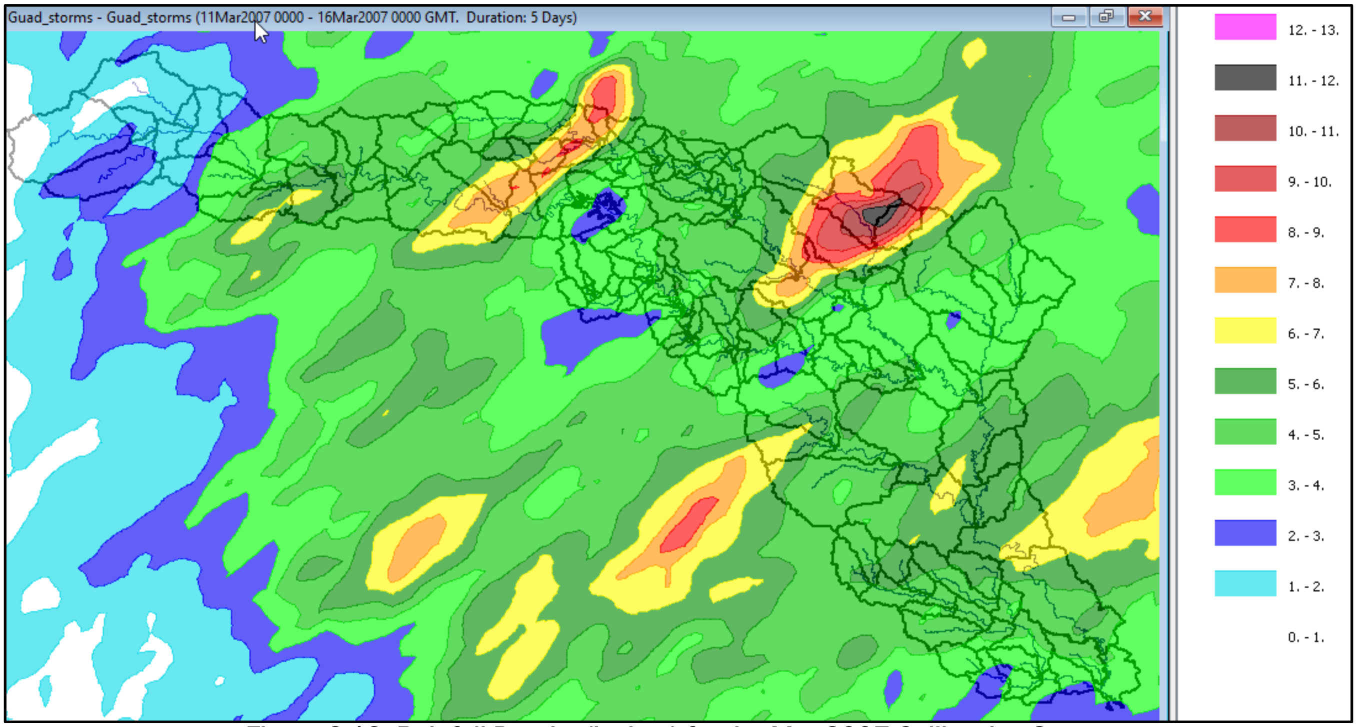


Figure 6.12: Rainfall Depths (inches) for the Mar 2007 Calibration Storm

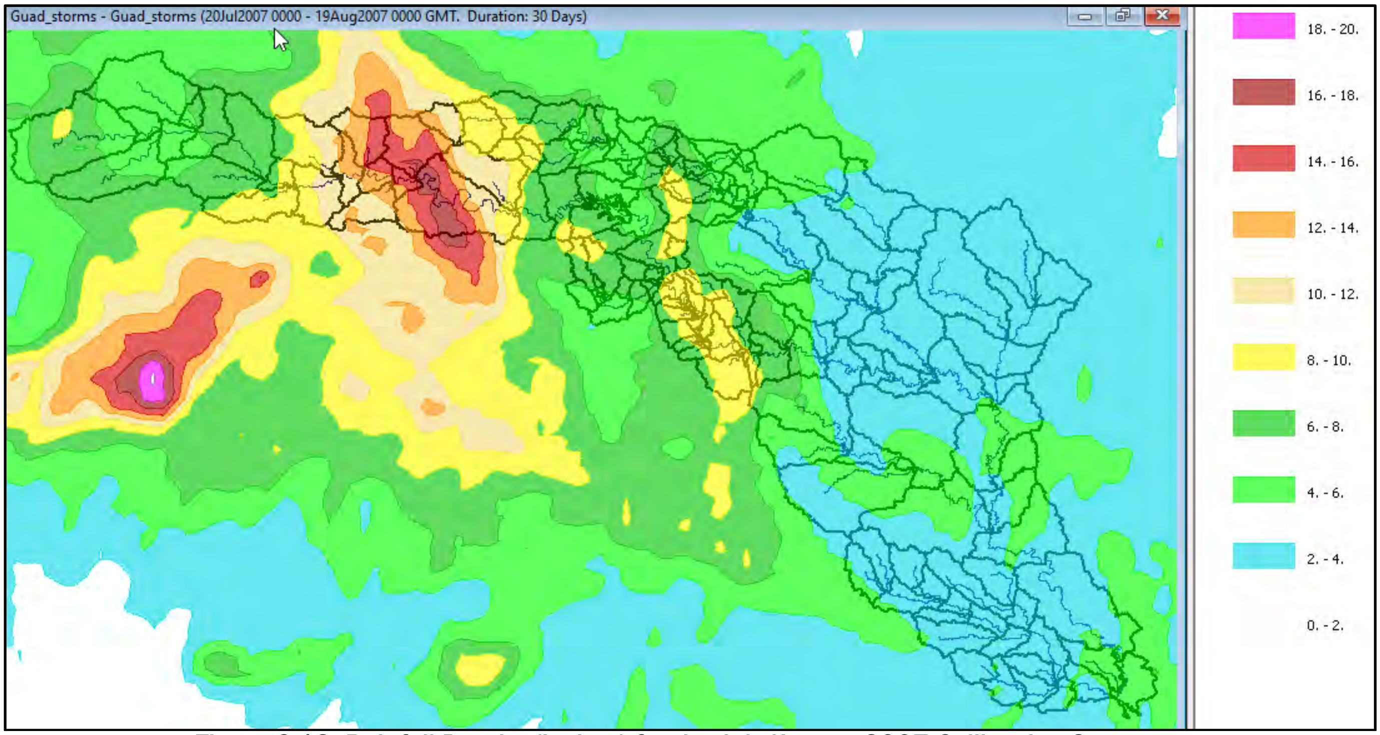


Figure 6.13: Rainfall Depths (inches) for the July/August 2007 Calibration Storms

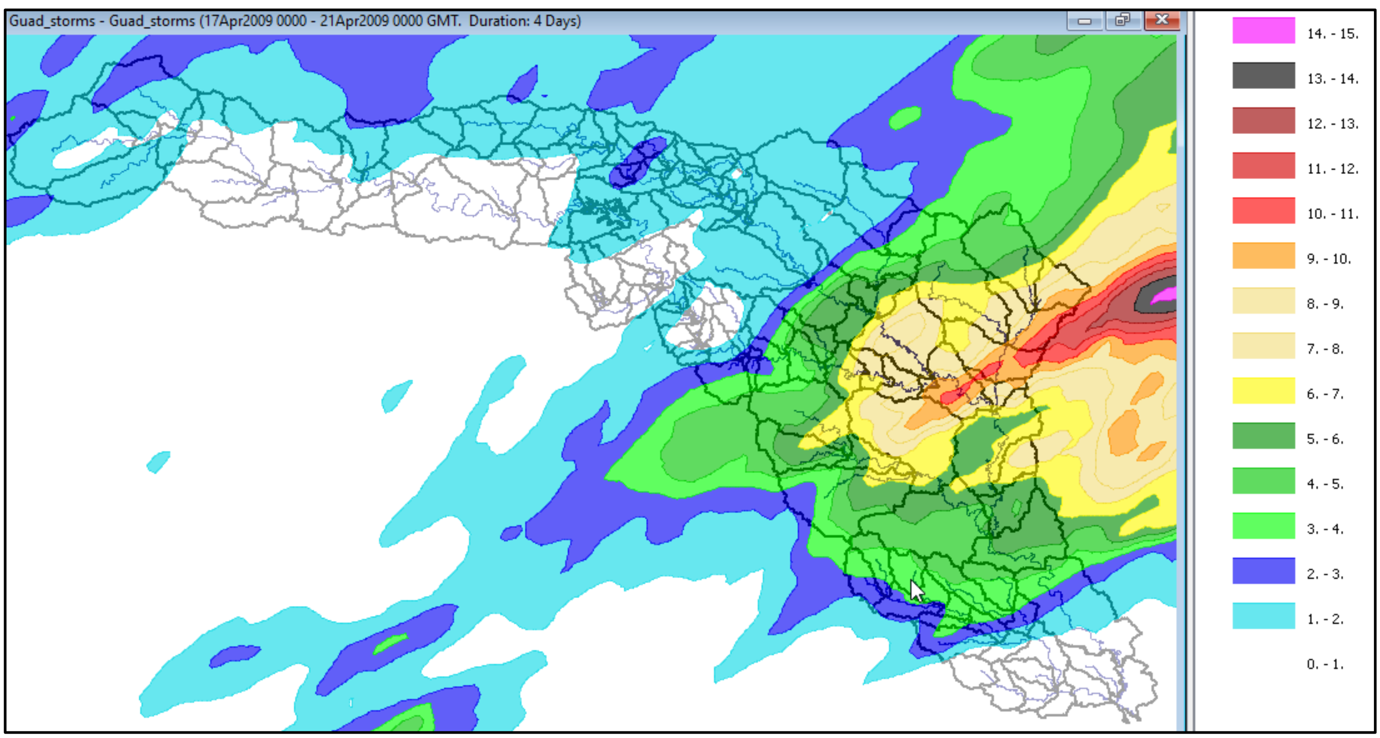


Figure 6.14: Rainfall Depths (inches) for the Apr 2009 Calibration Storm

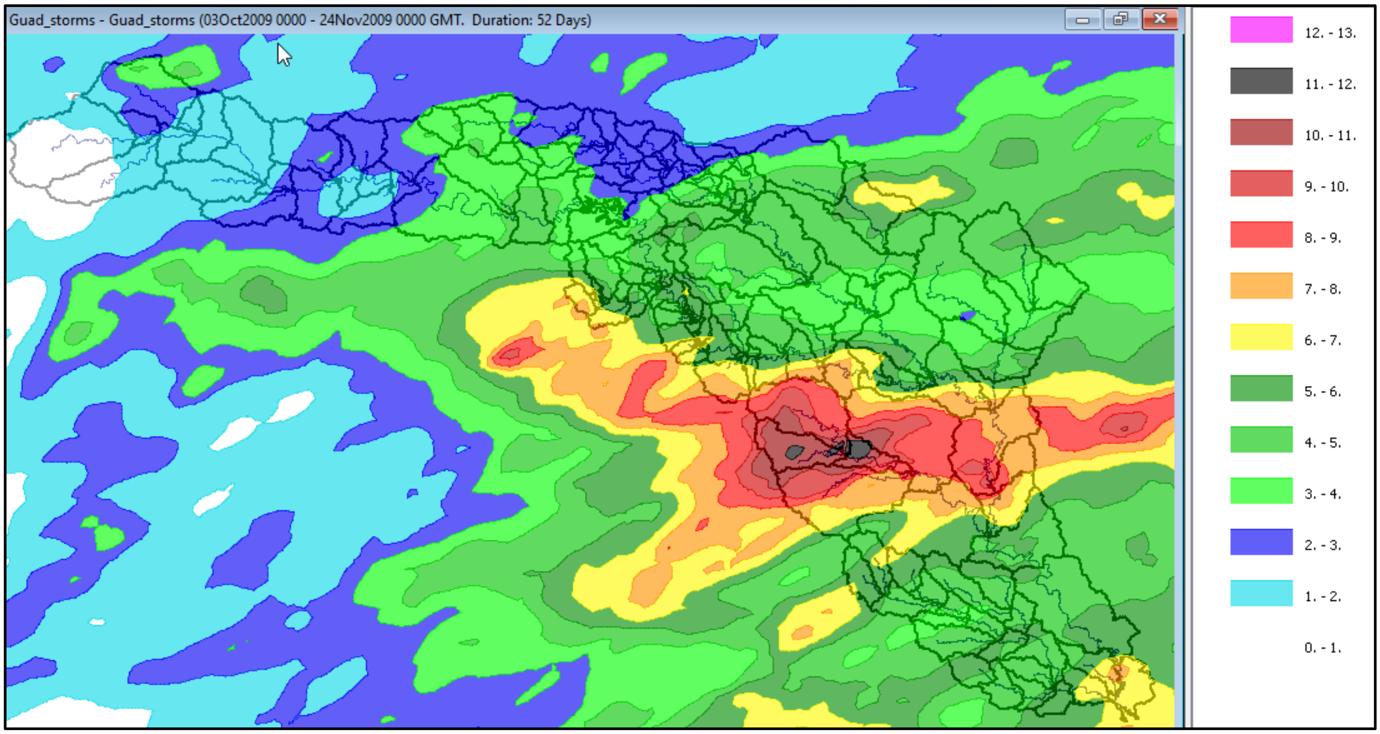


Figure 6.15: Rainfall Depths (inches) for the Oct/Nov 2009 Calibration Storm

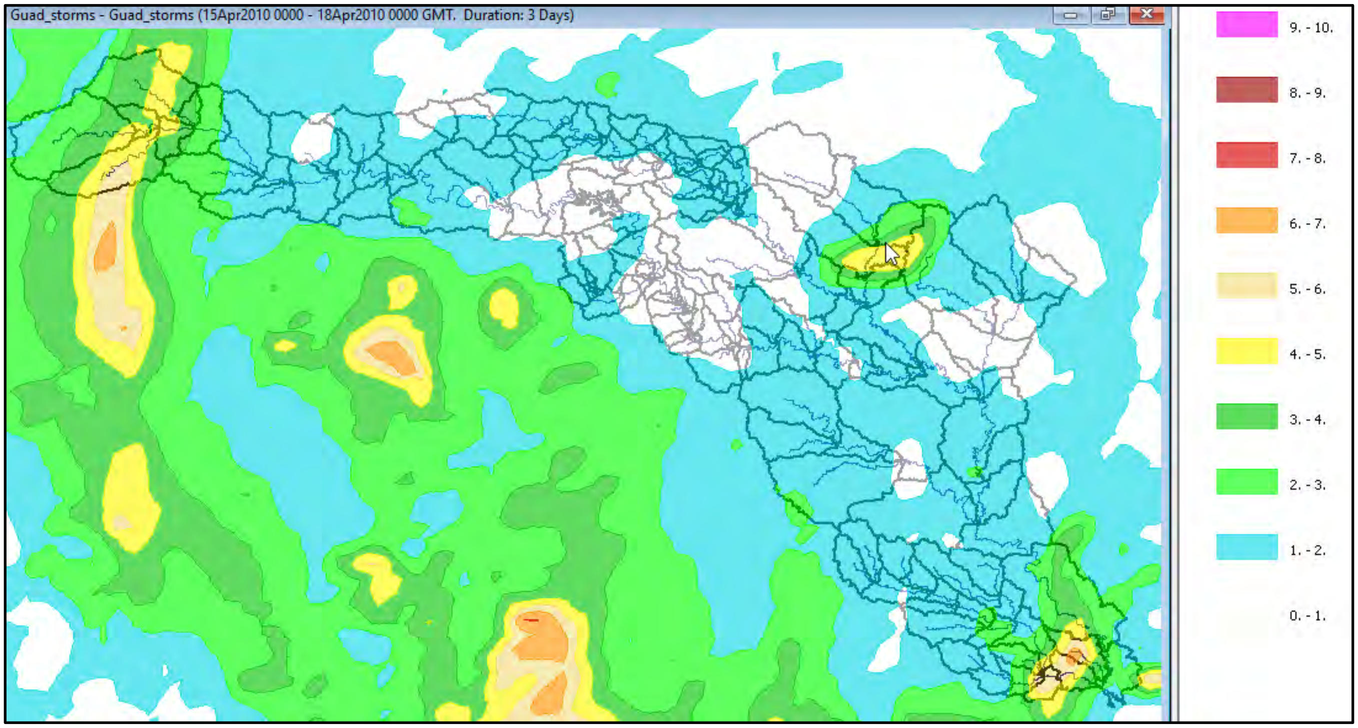


Figure 6.16: Rainfall Depths (inches) for the April 2010 Calibration Storm

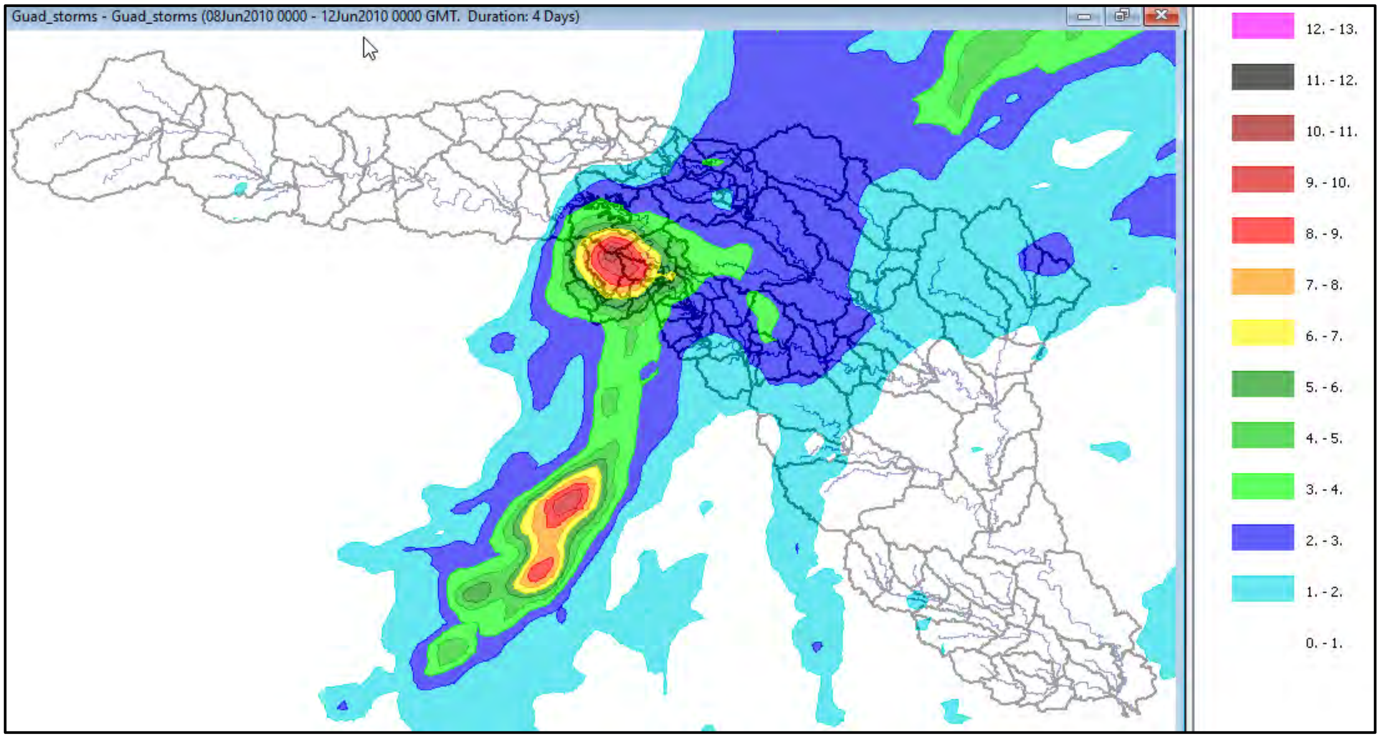


Figure 6.17: Rainfall Depths (inches) for the Jun 2010 Calibration Storm

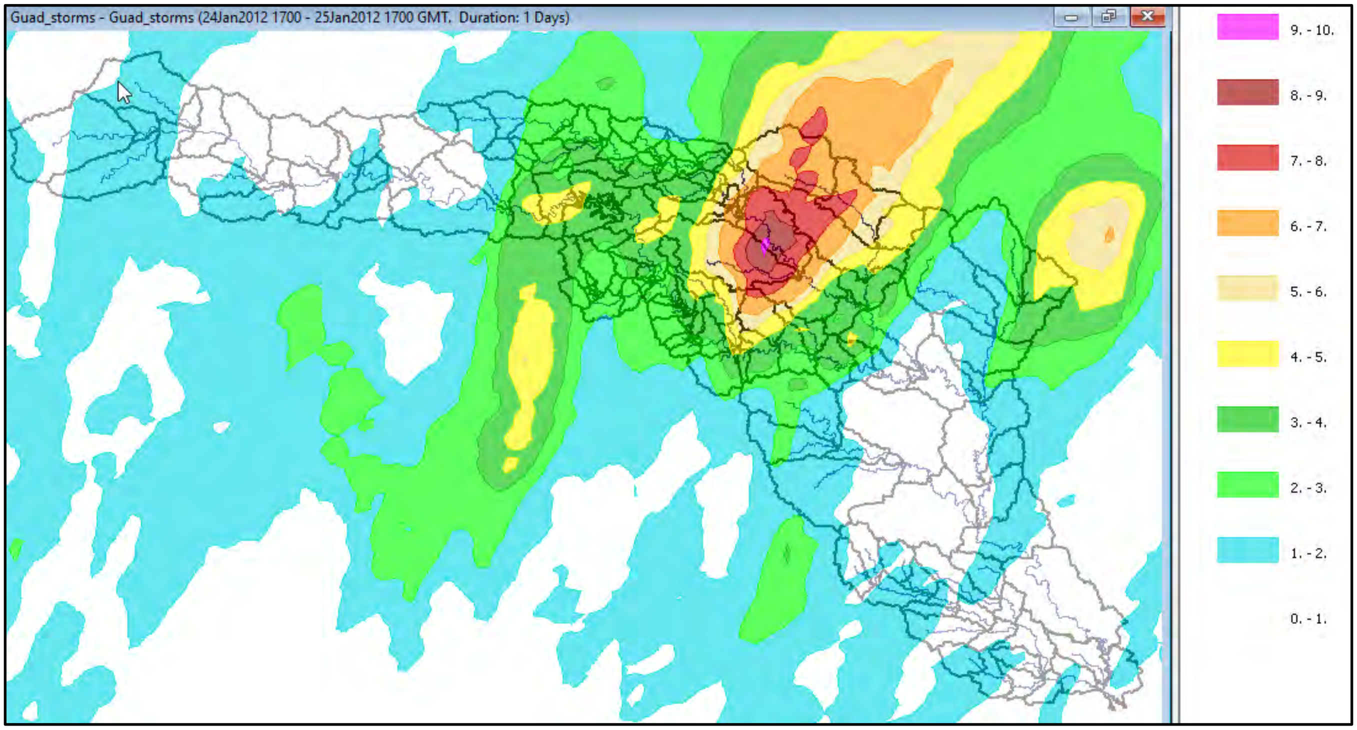


Figure 6.18: Rainfall Depths (inches) for the Jan 2012 Calibration Storm

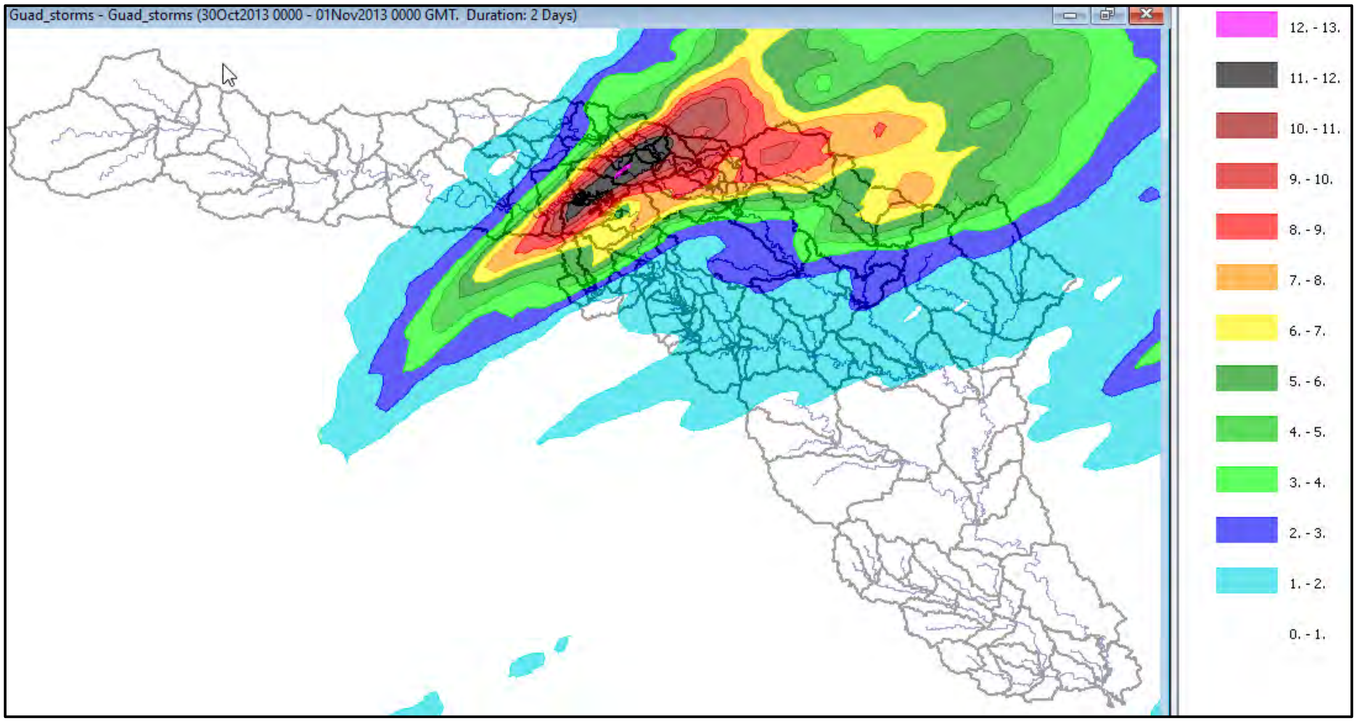


Figure 6.19: Rainfall Depths (inches) for the October 2013 Calibration Storm

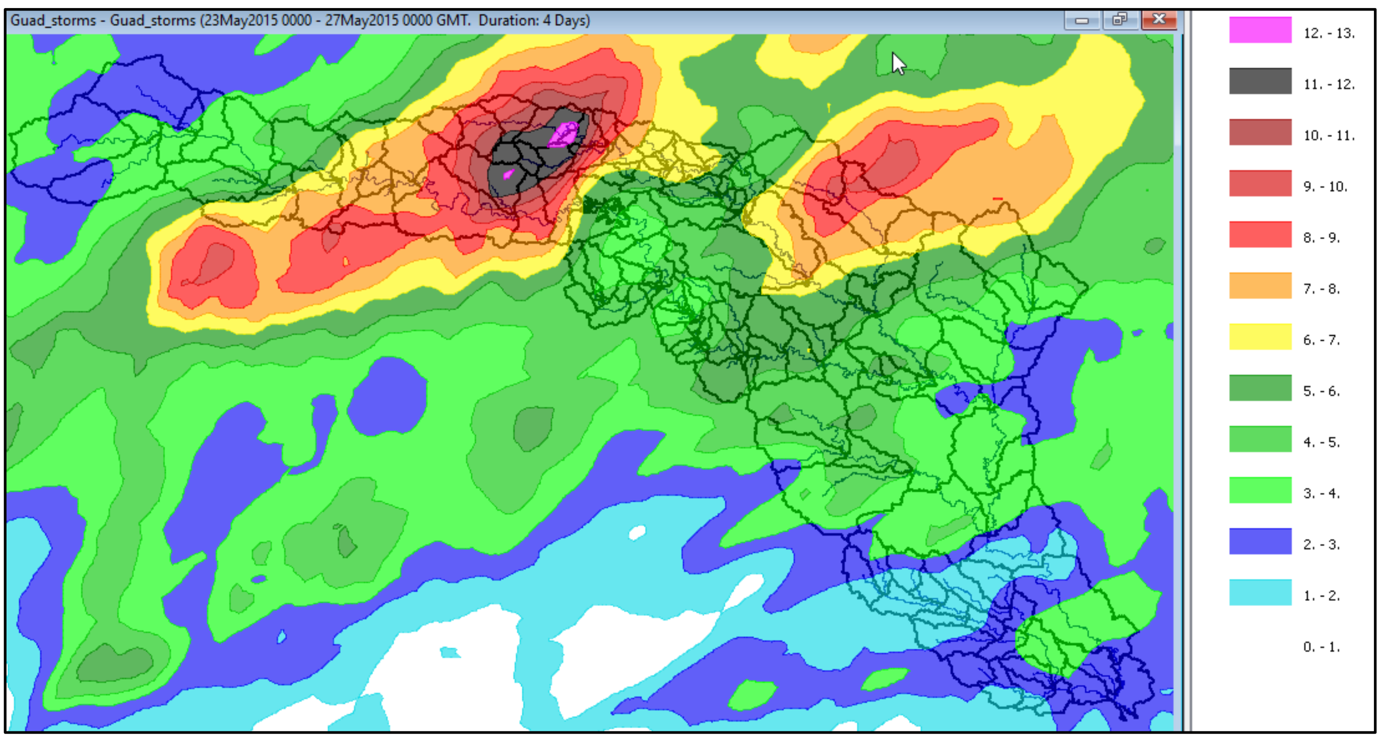


Figure 6.20: Rainfall Depths (inches) for the May 2015 Calibration Storm

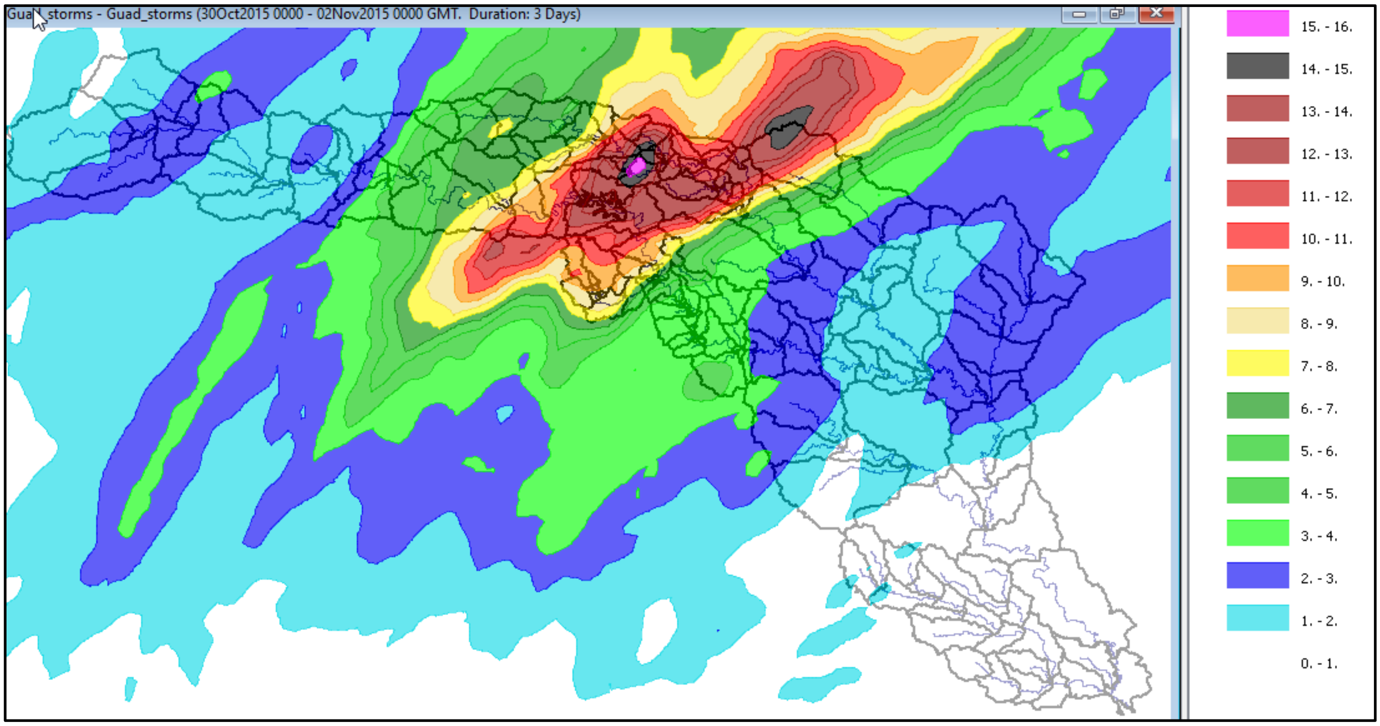


Figure 6.21: Rainfall Depths (inches) for the October 2015 Calibration Storm

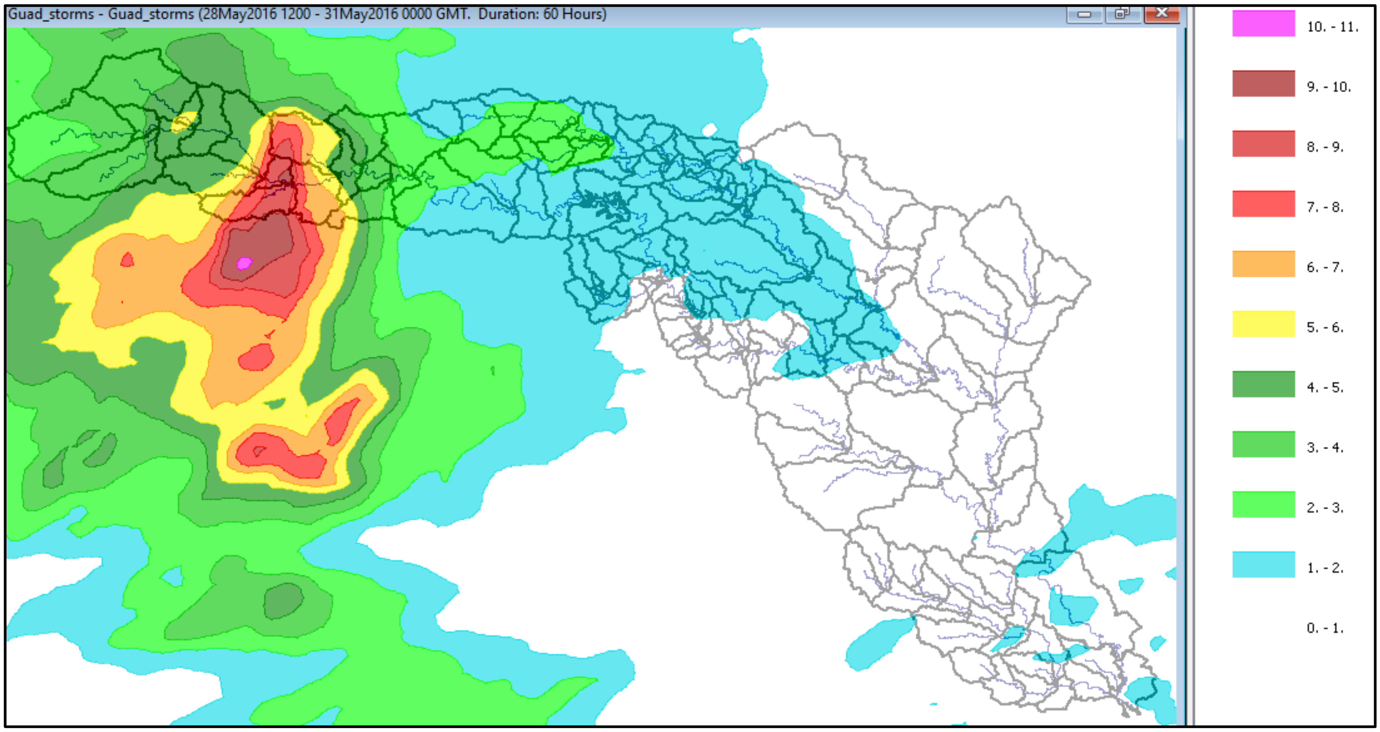


Figure 6.22: Rainfall Depths (inches) for the May 2016 Calibration Storm

Table 6.7: Calibrated Storm Events for Specific Gage Locations

USGS Gage Location	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-Aug-07	Apr-09	Oct-Nov-09	Apr-10	Jun-10	Jan-12	Oct-13	May-15	Oct-15	May-16
North Fork Guadalupe Rv near Hunt, TX					Yes									Yes				Yes		
Guadaupe River near Hunt TX					Yes		Yes				Yes			Yes				Yes		Yes
Johnson Creek near Ingram, TX					Yes		Yes				Yes			Yes						Yes
Guadalupe River at Kerrville, TX					Yes		Yes				Yes			Yes						Yes
Guadalupe River at Comfort, TX					Yes		Yes	Yes			Yes			Yes				Yes		Yes
Guadalupe River near Spring Branch, TX					Yes		Yes	Yes			Yes			Yes				Yes	Yes	Yes
Canyon Lake					Yes		Yes				Yes			Yes				Yes	Yes	
Blanco River at Wimberley		Yes		Yes				Yes		Yes						-	Yes	Yes	Yes	
Blanco River near Kyle		Yes		Yes				Peak Only		Yes						-	Peak Only	Peak Only	Yes	
San Marcos River at San Marcos		Peak Only		-				Peak Only		Yes						Yes	-	-	-	
San Marcos River at Luling		Yes		-				Yes		-						Yes	-	Yes	Yes	
Plum Creek at Lockhart		Yes		-				Yes		-						Yes	-	Yes	Yes	
Plum Creek near Luling		-		-				Peak Only		-						Yes	-	-	Yes	
Guadalupe River above the Comal River		Yes			Yes			Yes											Yes	
Dry Comal Ck at Loop 377 nr New Braunfels											Yes		Yes		Yes				Yes	Yes
Guadalupe River near Seguin											Yes				Yes	Yes	Yes	Yes	Yes	
Guadaupe River at Gonzales		Yes			Yes										Yes				Yes	
Peack Creek below Dilworth					Yes			Yes				Yes						Yes		
Sandies Creek near Westhoff		Yes	Yes			Yes							Yes							
Guadalupe River at Cuero		Yes			Yes	Yes		Yes										Yes		
Guadalupe River at Victoria		Peak Only			Yes	Yes		Yes										Yes		
Fifteenmile Creek at Weser	Yes	Yes	Yes						Yes	Yes										
Coleto Ck at Arnold Rd	Yes	Yes	Yes					Yes	Yes	Yes	Yes									
Perdido Creek near Fannin, TX	Yes	Yes	Yes					Yes		Yes	Yes									

6.4.1 Calibration Methodology

Following the initial parameter estimates, calibration simulations were made using observed hourly NEXRAD Stage III gridded precipitation data obtained from the West Gulf River Forecast Center (WGRFC). For each storm event, the model's calculated flow hydrographs were compared to the observed USGS stream flow data at the gages. The model's parameters were then adjusted to improve the match between the simulated and observed hydrographs for the observed events. Calibration was performed for the twenty storm events listed in Table 6.6. Subbasin parameters that were adjusted during calibration included the subbasins' initial and constant loss rates, lag time, peaking coefficients, and baseflow parameters. For the routing reaches, the Muskingum parameters and the Modified Puls number of subreaches were adjusted as needed.

Calibration was generally performed from upstream to downstream, with all subbasins upstream of a specific gage receiving uniform adjustments, unless specific rainfall or observed flow patterns necessitated adjusting subbasin parameters on an individual basis. Generally, subbasin parameters were adjusted in a consistent order: first baseflow parameters, then loss rates, and then lag times and peaking coefficients. Routing subreaches were the last to be adjusted. The methods of adjustment for each parameter are summarized in Table 6.8.

To the extent possible, effort was made to calibrate the model's results to the volume, timing, peak magnitude, and shape of the observed flow hydrograph. However, imperfections in the observed rainfall data and streamflow data did not always allow for a perfect match. For example, the gridded NEXRAD rainfall data from the National Weather Service was only available on an hourly basis. This meant that intense bursts of rain that occurred in 15-min or 30-min timespans might not be adequately represented in the hourly rainfall data. It also meant that even though the model was being run on a 15-min time step, the timing of the hydrographs could only be calibrated to the nearest hour. Likewise, the observed flow values at the gages are calculated indirectly from the observed stage and a limited number of flow measurements. While abundant flow measurements were usually available in the low flow range, the number and quality of USGS flow measurements were often very limited in the high flow range, leading to uncertainty in some of the observed flow hydrographs. In cases where all aspects of the observed flow hydrograph could not be calibrated simultaneously, priority was given to matching the peak flow magnitude first, followed by the peak timing, which are the aspects of model calibration that are most relevant to the 1% annual chance (100-yr) flood estimation.

Table 6.8: HEC-HMS Calibration Approach

Parameter	Calibration Approach
Baseflow Parameters	First, the baseflow parameters were adjusted to match the observed flow rates at the start and end of each calibration event. The initial discharges for the subbasins upstream of a certain gage were adjusted uniformly up or down to match the initial observed discharge at that gage. Similarly, the recession constant was adjusted to match the slope of the recession limb of the observed hydrograph, and the ratio to peak was adjusted to match the observed discharge at the end of the calibration event. All baseflow parameters were adjusted uniformly for all subbasins upstream of a given gage with the only exception being subbasins that contained a spring. Subbasins containing springs were given higher baseflow parameters than the surrounding subbasins.
Initial Loss (in)	After adjusting the baseflow parameters, the initial and constant losses were adjusted to calibrate the total volume of the flood hydrograph. The initial loss was adjusted according to the antecedent soil moisture conditions at the beginning of each observed storm event. The initial loss was increased or decreased until the timing and volume of the initial runoff generally matched the observed arrival of the flow hydrograph at the nearest downstream gage. All subbasins that were upstream of each gage were generally adjusted uniformly, unless specific rainfall and observed flow patterns necessitated adjusting the subbasin initial losses on an individual basis.
Constant Loss Rate (in/hr)	After adjusting the baseflow and initial loss parameters, the constant losses were adjusted to calibrate the total volume of the flood hydrograph. The subbasins' constant loss rates were increased or decreased until the volume and magnitude of the simulated hydrographs generally matched the observed volume of the flow hydrograph at the nearest downstream gage. The combination of the adjusted baseflow and loss rate parameters led to the total calibrated volume at the gage.
Lag Time (hours)	After adjusting the loss rates, the Snyder's lag times were the next parameters to be adjusted upstream of an individual gage. The Snyder's lag times were adjusted to match the timing of the observed peak flow at the gage. Normally, all of the subbasin lag times upstream of an individual gage were adjusted uniformly and proportionally to one another, unless the magnitude or shape of the observed hydrograph necessitated making individual adjustments. Efforts were also made to ensure that the adjusted lag times still fell within a reasonable range, using the lag times corresponding to 0% sand and 100% sand in the Fort Worth District regional lag time equation as a guide.
Peaking Coefficient	Peaking coefficients were adjusted to match the general shape of the observed flow hydrograph as higher peaking coefficients produce steeper, narrower flood hydrographs, and lower peaking coefficients produce flatter, wider flood hydrographs. An attempt was made to use the same peaking coefficient for all subbasins with similar watershed characteristics. For example, steep, hilly subbasins were given a higher peaking coefficient, whereas flatter subbasins or subbasins with many NRCS dams were given lower peaking coefficients. Efforts were also made to ensure that the adjusted peaking coefficients fell within the typical range of 0.4 to 0.8. In most cases, peaking coefficients were adjusted once and left alone between subsequent events.
Modified Puls Routing Subreaches	The number of subreaches in the Modified Puls routing reaches were the final parameters to be adjusted when necessary. Calibration of routing parameters focused on storms that fell near the upstream end of the watershed and were routed downstream with little intervening subbasin flow. Adjustments to the number of subreaches in a given routing reach were made in order to match the amount of attenuation in the peak flow that occurred from the upstream end of a reach to the downstream gage. In a very few cases, where an adjustment to the subreaches was not sufficient match the observed downstream hydrograph, a factor also applied to the reach's storage volume in the storage-discharge curve.

Parameter	Calibration Approach
Muskingum Routing Parameters	For areas of the model that included Muskingum routing (above Canyon and Coleto Creek), the Muskingum k, X and subreach values were adjusted as needed. Calibration of the routing parameters focused on storms that fell near the upstream end of the watershed and were routed downstream with little intervening local flow. The Muskingum k values were adjusted to match the timing of the observed peak flow at the gage, while the Muskingum X values were adjusted to match the relative flatness or steepness of the hydrograph. Finally, adjustments to the number of subreaches were made in order to match the amount of attenuation in the peak flow that occurred from the upstream end of a reach to the downstream gage.

6.4.2 Calibrated Parameters

The resulting calibrated subbasin and routing reach parameters that were adjusted for each storm event are shown in Tables 6.9 through 6.17.

Table 6.9: Calibrated Initial Losses (inches)

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
NF_Guad_S010					0.1		3.2	3			4.07			1.9					1.9	2.9	1.5
NF_Guad_S020					0.8		1.8	2.7			3.1			2					1.8	4.1	1.4
SF_Guad_S010					0.8		4	1.5			3.35			2					1.1	3.6	2
Guad_S010					4		2	3.32			3			2.5					1.7	4.4	1.1
JohnsonCr_S010					3.1		2.2	2			2.7			2.9					1.72	3.63	1.84
JohnsonCr_S020					4		2	3			3			2.5					1.7	4.4	1.1
Guad_S020					4		1.8	3			3			1.5					1.6	4.7	0.5
Guad_S030					0.4		1.6	2.8			2.6			1.2					0.5	5	1
TurtleCr_S010					0.4		1.6	1.7			2.6			1.2					1	4.1	1
Guad_S040					0.4		1.6	1.7			2.6			1.2					0.5	4.5	1
VerdeCr_S010					0.4		1.6	1.7			2.6			1.8					0.5	4.1	1
Guad_S050					0.4		1.6	2.2			2.6			0.8					0.4	4.1	1
CypressCr_GR_S010					0.4		1.6	2.2			2.6			0.5					0.5	4.9	1
Guad_S060					0.4		2.5	1.6			4			1					3.6	1	4.5
BlockCr_S010					0.4		2.5	1.6			4			1					3.6	1	4
Guad_S070					0.4		2	1.6			4			1.5					3.6	3	4
JoshuaCr_S010					0.4		2.2	1.6			4			1					3.6	3	4.5
Guad_S080					0.4		2	1.6			4			1					3.6	3	3
SisterCr_S010					0.4		2.5	1.6			4			1					3.6	3	3
Guad_S090					4		4	1.6			2.5			1					3.6	3	3
CurryCr_S010					4		2.5	1.6			2.5			1					1.7	2	3
Guad_S100					2.7		4.9	1			2.5			1					1.7	0.5	2.5
Guad_S110					0.4		3	0.2			2.2			0.5					1.7	5	2
Guad_S120					0.4		3	0.2			2.2			0.5					1.7	5	2
CanyonLk_S010					0		0	0			0			0					0	0	0
Blanco_S010		1		2				1.5		2						-	0.1		0.45	3	
Blanco_S020		1		2				1.5		2.2						-	0.1		0.45	3	
Blanco_S030		1		2				1.5		2						-	0.5		0.45	3	
Blanco_S040		1.5		2				1		3						-	1		0.45	3	
Blanco_S050		1.5		2				1		3						-	1.5		0.45	3	
LittleBlanco_S010		1.5		2				0.5		3						-	1		0.45	4	
LittleBlanco_S020		1.5		2				0.5		3						-	1		0.45	4	
LittleBlanco_S030		1.5		2				0.5		3						-	1.5		0.45	4	
LittleBlanco_S040		1.5		2				0.5		3						-	1.5		0.45	4	
Blanco_S060		2		2				0.5		3						-	1.5		0.45	4	
WanslowCr_BR_S010		2		2				1		3						-	1.5		0.45	4	

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Blanco_S070		2		2				1		3						-	4		0.6	5	
Blanco_S080		2		2				1		2.5						-	3.5		0.6	5	
CarpersCr_BR_S010		2		2				1		2.5						-	3.5		0.6	5	
Blanco_S090		2		2				0.5		2.5						-	3.5		0.6	5	
Blanco_S100		2		2				0.5		2.5						-	4		0.6	5	
WilsonCr_BR_S010		2		2				0.5		2.5						-	4		0.6	5	
Blanco_S110		2		2				0.5		2.5						-	4		0.6	5	
CypressCr_BR_S010		2		2				2		2.8						-	2.5		0.8	5	
CypressCr_BR_S020		2		2				2		2.8						-	3.5		0.8	5	
CypressCr_BR_S030		2		2				2		2.8						-	3.5		0.8	5	
Blanco_S120		2.5		2.5				2.5		2.5						-	4		0.4	0.8	
Blanco_S130		2.5		2.5				2.5		2.5						-	4		0.4	0.8	
LoneManCr_BR_S010		2.5		2.5				2.5		2.5						-	4		0.4	0.8	
Blanco_S140		2.5		2.5				2.5		2.5						-	4		0.4	0.8	
HalifaxCr_BR_S010		2		2.5				2.5		2.5						-	4		0.4	0.8	
Blanco_S150		2		2.5				2.5		2.5						-	4		0.4	0.8	
Blanco_S160		2		2.5				2.5		2.5						-	4		0.4	0.8	
Blanco_S170		2.5		2.5				2.5		2.5						-	4		0.4	0.8	
SinkCk_S010		1		-				1.4		0.8						-	-		0.1	4.5	
SinkCk_S020		1		-				1.4		0.8						-	-		0.1	4.5	
SinkCk_S030		1		-				1.4		0.8						-	-		0.1	4.5	
SinkCk_S040		1		-				1.4		0.8						-	-		0.1	4.5	
SanMarcos_S005		1		-				1.4		0.8						-	-		0.1	4.5	
SanMarcos_S008		1		-				1.4		0.8						-	-		0.1	4.5	
PurgatoryCr_S010		1.5		-				0.4		-						3.8	-		0.1	4.5	
SanMarcos_S010		2		-				0.4		-						3.8	-		0.1	4.5	
SanMarcos_S020		2		-				0.4		-						3.8	-		0.1	3.5	
YorkCr_S010		3		-				0.6		-						4.7	-		0.4	4	
SanMarcos_S030		2.5		-				1		-						3.8	-		0.1	1.5	
SanMarcos_S040		2		-				1		-						3.8	-		0.1	1	
PlumCr_S010		4		-				0.6		-						3	-		0.1	5	
PlumCr_S020		1.5		-				0.2		-						3	-		0.1	4	
TenneyCr_S010		1.5		-				0.2		-						3	-		0.1	4	
PlumCr_S030		1.5		-				0.2		-						3	-		0.1	4	
PlumCr_S040		1.5		-				0.2		-						4	-		0.1	4	
SanMarcos_S050		3		-				0.2		-						4.5	-		0.1	4.5	
DryComalCk_S010											0.4		1.4		1.8					3.5	0
DryComalCk_S020											0.4		1.4		1.8					3.5	0
WFk_DryComalCk_S010											0.4		1.4		1.8					3.5	0
WFk_DryComalCk_S020											0.4		1.4		1.8					3.5	0
WF_Trib_S010											0.4		1.4		1.8					3.5	0

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
WF_Trib_S020											0.4		1.4		1.8					3.5	0
WFk_DryComalCk_S030											0.4		1.4		1.8					3.5	0
DryComalCk_S030											0.4		1.4		1.8					3.5	0
BearCk_S010											0.4		1.4		1.8					3.5	0
DryComalCk_S040											0.4		1.4		1.8					3.5	0
DCCk_Trib14_S010											0.4		1.4		1.8					4.2	0
DryComalCk_S050											0.4		1.4		1.8					3.5	0
DryComalCk_S060											0.4		1.4		1.8					3.5	0
BliedersCk_S010											0.4		1.4		1.8					3.5	0
Comal_S010											0.4		1.4		1.8					3.5	0
Comal_S020											0.4		1.4		1.8					3.5	0
Comal_S030																					
Guad_S130		2.8			0.1			1							1.6		1.6		1.6	3.1	
BearCr_S010		2.8			0.1			1							1.6		1.6		1.6	3.1	
Guad_S140		2.8			0.1			1							1.6		1.6		1.6	3.1	
Guad_S142		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S144		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_Trib22_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S145		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
LongCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S147		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_Trib20_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S149		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S152		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
YoungsCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S154		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
CottonwoodCkS_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S156		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Little_MillCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S158		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
DeadmanCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S160		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
CottonwoodCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S162		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
AlligatorCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
GeronimoCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
GeronimoCk_S020		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
GeronimoCk_S030		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S164		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
CantauCk_S010		0.1			3			2.5			2				1.6	1	1.6		1.6	2	
Guad_S166		0.1			3			2.5							1.6					2.5	

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
MillCk_S010		0.1			3			2.5							1.6					2.5	
Guad_S168		0.1			3			2.5							1.6					2	
NashCk_S010		0.1			3			2.5							1.6					2	
Guad_S170		0.1			3			2.5							1.6					2	
Guad_S172		0.1			3			2.5							1.6					2	
Guad_S174		0.1			3			2.5							1.6					2	
Guad_S176		0.1			3			2.5							1.6					2	
Guad_S200		0.1			3			0											1.5	0	
PeachCr_S010						2		2.8				4.1						3.4	0.9		
BigFiveMileCr_S010						2		2.8				4.1						3.4	0.9		
PeachCr_S020						2		2.8				4.1						3.4	0.9		
SandyFork_S010						2		2.8				4.1						3.4	0.9		
PeachCr_S030						2		2.8				5.1						3.4	0.9		
PeachCr_S040		0.1			3	0		0											1.5		
Guad_S210		0.1			3	0		0											1.5		
McCoyCr_S010		0.1			3	0		0											1.5		
Guad_S220		0.1			3	0		0											1.5		
SandiesCr_S010		3.3	3.1			1.6							1.6								
ClearForkCr_S010		3.3	3.1			1.6							1.6								
SandiesCr_S020		3.3	3.1			1.6							1.6								
ElmCr_S010		3.3	3.1			1.6							1.6								
SandiesCr_S030		5.3	5.1			1.6							1.6								
SandiesCr_S040		1.5			3	0		0											1.5		
Guad_S230		1.5			3	2		0.1											3		
Guad_S240		1.5			3	2		0.1											3		
SmithCk_S010	2	3.4	3.5					3	2	1.5	4.5										
ThomasCk_S010	2	3.4	3					3	2	1.5	4.8										
SmithCk_S020	2.9	2.6	3					3	2	1.5	6										
YorktownCk_S010	2.4	2.8	2.5					3	2	1.5	4.5										
YorktownCk_S020	2.9	2.6	3					3	2	1.5	6										
FifteenmileCk_S010	3.5	2.6	3					3	2	2	2.8										
HoosierCk_S010	2.9	2.6	3					3	2	2	2.7										
FifteenmileCk_S020	2	2.4	4					0.8	2	2.2	2										
EighteenmileCk_S010	2.9	2.4	4					0.8	2	2.5	2										
FifteenmileCk_S030	2.2	2.2	4					1	1.5	2.8	2										
TwelvemileCk_S010	2.9	3	3					0	2.4	1.4	1										
FivemileCk_S010	2	3	3					0	2	1.5	1										
TwelvemileCk_S020	2.2	2.2	4					0	1.9	2.5	2										
ColetoCk_S010	1.5	2	3					1	3	2	1										
ColetoCk_S020	1.5	2	3					1	3	1.7	1										
PerdidoCk_S010	2.8	2.3	4					0	1.2	1.75	3.6										

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
PerdidoCk_S020	1.5	2	3					1	3	1.7	1										
PerdidoCk_S030	1.5	2	3					1	3	1.7	1										
ColetoCk_S030	2	2	3					1	1	2	1										
ColetoCk_S040	2	2	3					1	2	2	1										
DryCk_S010	2	2	3					1	2	2	1										
Guad_S250	2	2	3					1	2	2	1										

Table 6.10: Calibrated Constant Losses (inches per hour)

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
NF_Guad_S010					0.11		0.4	0.15			0.15			0.18					0.32	0.39	0.41
NF_Guad_S020					0.48		0.06	0.26			0.15			0.1					0.5	0.4	0.58
SF_Guad_S010					0.48		0.5	0.26			0.15			0.1					0.5	0.4	0.42
Guad_S010					0.24		0.04	0.05			0.15			0.12					0.4	0.4	0.58
JohnsonCr_S010					0.18		0.5	0.37			0.5			0.3					0.32	0.3	0.58
JohnsonCr_S020					0.24		0.04	0.26			0.21			0.12					0.4	0.4	0.58
Guad_S020					0.22		0.04	0.26			0.21			0.08					0.42	0.45	0.58
Guad_S030					0.08		0.22	0.17			0.12			0.04					0.16	0.63	0.5
TurtleCr_S010					0.08		0.22	0.17			0.12			0.04					0.07	0.4	0.5
Guad_S040					0.08		0.22	0.17			0.12			0.12					0.04	0.43	0.4
VerdeCr_S010					0.08		0.22	0.17			0.12			0.12					0.04	0.4	0.4
Guad_S050					0.08		0.22	0.21			0.12			0.1					0.04	0.4	0.4
CypressCr_GR_S010					0.08		0.22	0.23			0.12			0.12					0.04	0.4	0.4
Guad_S060					0.2		0.2	0.17			0.4			0.15					0.32	0.4	0.4
BlockCr_S010					0.2		0.2	0.17			0.4			0.1					0.32	0.4	0.4
Guad_S070					0.2		0.2	0.17			0.4			0.15					0.32	0.4	0.4
JoshuaCr_S010					0.2		0.2	0.17			0.4			0.1					0.32	0.4	0.4
Guad_S080					0.2		0.2	0.17			0.4			0.1					0.32	0.4	0.4
SisterCr_S010					0.2		0.2	0.17			0.4			0.1					0.32	0.4	0.4
Guad_S090					0.24		0.3	0.17			0.4			0.1					0.24	0.4	0.4
CurryCr_S010					0.04		0.4	0.17			0.12			0.1					0.24	0.32	0.4
Guad_S100					0.04		0.4	0.17			0.12			0.1					0.24	0.32	0.4
Guad_S110					0.12		0.2	0.09			0.05			0.1					0.24	0.56	0.4
Guad_S120					0.12		0.2	0.09			0.05			0.1					0.24	0.56	0.4
CanyonLk_S010					0		0	0			0			0					0	0	0
Blanco_S010		0.6		0.06				0.2		0.2						-	0.03		0.04	0.5	
Blanco_S020		0.6		0.06				0.2		0.2						-	0.03		0.04	0.5	
Blanco_S030		0.5		0.06				0.2		0.25						-	0.03		0.04	0.5	
Blanco_S040		0.5		0.06				0.14		0.25						-	0.03		0.04	0.5	
Blanco_S050		0.5		0.06				0.14		0.25						-	0.03		0.04	0.5	
LittleBlanco_S010		0.4		0.06				0.14		0.25						-	0.03		0.04	0.5	

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
LittleBlanco_S020		0.4		0.06				0.14		0.25						-	0.03		0.04	0.5	
LittleBlanco_S030		0.4		0.06				0.14		0.25						-	0.03		0.04	0.5	
LittleBlanco_S040		0.4		0.06				0.14		0.25						-	0.03		0.04	0.5	
Blanco_S060		0.4		0.06				0.14		0.25						-	0.03		0.04	0.5	
WanslowCr_BR_S010		0.4		0.06				0.1		0.25						-	0.03		0.04	0.5	
Blanco_S070		0.4		0.08				0.1		0.25						-	0.03		0.04	0.5	
Blanco_S080		0.5		0.08				0.1		0.25						-	0.03		0.04	0.5	
CarpersCr_BR_S010		0.5		0.08				0.1		0.25						-	0.03		0.04	0.5	
Blanco_S090		0.5		0.08				0.1		0.25						-	0.02		0.04	0.5	
Blanco_S100		0.5		0.08				0.1		0.25						-	0.02		0.04	0.5	
WilsonCr_BR_S010		0.5		0.08				0.1		0.25						-	0.02		0.04	0.5	
Blanco_S110		0.5		0.08				0.1		0.25						-	0.02		0.04	0.5	
CypressCr_BR_S010		0.5		0.08				0.1		0.25						-	0.02		0.04	0.5	
CypressCr_BR_S020		0.5		0.08				0.1		0.25						-	0.02		0.04	0.5	
CypressCr_BR_S030		0.5		0.08				0.1		0.25						-	0.02		0.04	0.5	
Blanco_S120		0.5		0.15				0.2		0.17						-	0.15		0.01	0.12	
Blanco_S130		0.5		0.15				0.2		0.17						-	0.15		0.01	0.12	
LoneManCr_BR_S010		0.5		0.15				0.2		0.17						-	0.15		0.01	0.12	
Blanco_S140		0.5		0.15				0.2		0.17						-	0.15		0.01	0.12	
HalifaxCr_BR_S010		0.4		0.15				0.2		0.17						-	0.15		0.01	0.12	
Blanco_S150		0.4		0.15				0.2		0.17						-	0.15		0.01	0.12	
Blanco_S160		0.4		0.15				0.2		0.17						-	0.15		0.01	0.12	
Blanco_S170		0.5		0.15				0.2		0.17						-	0.15		0.01	0.12	
SinkCk_S010		0.1		-				0.14		0.33						-	-		0.38	0.31	
SinkCk_S020		0.1		-				0.14		0.33						-	-		0.38	0.31	
SinkCk_S030		0.1		-				0.14		0.33						-	-		0.38	0.31	
SinkCk_S040		0.1		-				0.14		0.33						-	-		0.38	0.31	
SanMarcos_S005		0.1		-				0.14		0.33						-	-		0.38	0.31	
SanMarcos_S008		0.1		-				0.14		0.33						-	-		0.38	0.31	
PurgatoryCr_S010		0.1		-				0.01		-						0.14	-		0.38	0.31	
SanMarcos_S010		0.1		-				0.01		-						0.14	-		0.38	0.31	
SanMarcos_S020		0.1		-				0.01		-						0.14	-		0.38	0.1	
YorkCr_S010		0.2		-				0.04		-						0.2	-		0.45	0.15	
SanMarcos_S030		0.1		-				0.01		-						0.14	-		0.4	0.1	
SanMarcos_S040		0.1		-				0.01		-						0.14	-		0.4	0.1	
PlumCr_S010		0		-				0.13		-						0.4	-		0.37	0.04	
PlumCr_S020		0.1		-				0.06		-						0.42	-		0.38	0.04	
TenneyCr_S010		0.1		-				0.07		-						0.45	-		0.41	0.04	
PlumCr_S030		0.1		-				0.06		-						0.42	-		0.38	0.04	
PlumCr_S040		0.1		-				0.01		-						0.04	-		0.4	0.04	
SanMarcos_S050		0.3		-				0.01		-						0.35	-		0.43	0.35	

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
DryComalCk_S010											0.02		0.08		0.26					0.48	0.03
DryComalCk_S020											0.02		0.09		0.30					0.48	0.04
WFk_DryComalCk_S010											0.01		0.05		0.17					0.32	0.02
WFk_DryComalCk_S020											0.03		0.10		0.34					0.48	0.04
WF_Trib_S010											0.03		0.10		0.34					0.48	0.04
WF_Trib_S020											0.03		0.10		0.34					0.48	0.04
WFk_DryComalCk_S030											0.04		0.13		0.43					0.48	0.05
DryComalCk_S030											0.04		0.14		0.47					0.48	0.06
BearCk_S010											0.02		0.07		0.22					0.40	0.03
DryComalCk_S040											0.02		0.09		0.30					0.48	0.04
DCCk_Trib14_S010											0.02		0.09		0.30					0.48	0.04
DryComalCk_S050											0.02		0.08		0.26					0.48	0.03
DryComalCk_S060											0.03		0.12		0.39					0.48	0.05
BliedersCk_S010											0.02		0.08		0.26					0.48	0.03
Comal_S010											0.03		0.12		0.39					0.48	0.05
Comal_S020											0.06		0.21		0.69					0.48	0.08
Comal_S030																					
Guad_S130		0.28			0.36			0.25							0.06		0.40		0.18	0.74	
BearCr_S010		0.28			0.36			0.25							0.06		0.40		0.18	0.74	
Guad_S140		0.28			0.36			0.25							0.06		0.40		0.18	0.74	
Guad_S142		0.01			0.30			0.22			0.60				0.05	0.60	0.33		0.15	0.60	
Guad_S144		0.01			0.39			0.29			0.65				0.07	0.78	0.43		0.20	0.65	
Guad_Trib22_S010		0.01			0.18			0.13			0.60				0.03	0.36	0.20		0.09	0.60	
Guad_S145		0.01			0.50			0.44			1.00				0.10	1.20	0.66		0.30	1.00	
LongCk_S010		0.01			0.15			0.11			0.60				0.03	0.30	0.17		0.08	0.60	
Guad_S147		0.01			0.50			0.40			0.90				0.09	1.08	0.59		0.27	0.90	
Guad_Trib20_S010		0.01			0.18			0.13			0.60				0.03	0.36	0.20		0.09	0.60	
Guad_S149		0.01			0.45			0.33			0.75				0.08	0.90	0.50		0.23	0.75	
Guad_S152		0.01			0.50			0.46			1.05				0.11	1.26	0.69		0.32	1.05	
YoungsCk_S010		0.01			0.12			0.09			0.60				0.02	0.24	0.13		0.06	0.60	
Guad_S154		0.01			0.42			0.31			0.70				0.07	0.84	0.46		0.21	0.70	
CottonwoodCkS_S010		0.01			0.09			0.07			0.60				0.02	0.18	0.10		0.05	0.60	
Guad_S156		0.01			0.50			0.40			0.90				0.09	1.08	0.59		0.27	0.90	
Little_MillCk_S010		0.01			0.18			0.13			0.60				0.03	0.36	0.20		0.09	0.60	
Guad_S158		0.01			0.39			0.29			0.65				0.07	0.78	0.43		0.20	0.65	
DeadmanCk_S010		0.01			0.12			0.09			0.60				0.02	0.24	0.13		0.06	0.60	
Guad_S160		0.01			0.27			0.20			0.60				0.05	0.54	0.30		0.14	0.60	
CottonwoodCk_S010		0.01			0.50			0.40			0.90				0.09	1.08	0.59		0.27	0.90	
Guad_S162		0.01			0.50			0.40			0.90				0.09	1.08	0.59		0.27	0.90	
AlligatorCk_S010		0.01			0.12			0.09			0.60				0.02	0.24	0.13		0.06	0.60	
GeronimoCk_S010		0.01			0.12			0.09			0.60				0.02	0.24	0.13		0.06	0.60	

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
GeronimoCk_S020		0.01			0.12			0.09			0.60				0.02	0.24	0.13		0.06	0.60	
GeronimoCk_S030		0.01			0.21			0.15			0.60				0.04	0.42	0.23		0.11	0.60	
Guad_S164		0.01			0.39			0.29			0.65				0.07	0.78	0.43		0.20	0.65	
CantauCk_S010		0.01			0.45			0.33			0.75				0.08	0.90	0.50		0.23	0.75	
Guad_S166		0.01			0.50			0.44							0.10					0.20	
MillCk_S010		0.01			0.24			0.18							0.04					0.08	
Guad_S168		0.01			0.50			0.42							0.10					0.19	
NashCk_S010		0.01			0.50			0.40							0.09					0.18	
Guad_S170		0.01			0.42			0.31							0.07					0.14	
Guad_S172		0.01			0.36			0.26							0.06					0.12	
Guad_S174		0.01			0.33			0.24							0.06					0.11	
Guad_S176		0.01			0.50			0.40							0.09					0.18	
Guad_S200		0.01			0.30	0.13		0.13											0.26		
PeachCr_S010						0.03		0.10				0.24						0.14	0.24		
BigFiveMileCr_S010						0.03		0.09				0.22						0.13	0.22		
PeachCr_S020						0.03		0.09				0.22						0.13	0.22		
SandyFork_S010						0.03		0.10				0.24						0.14	0.24		
PeachCr_S030						0.03		0.09				0.22						0.13	0.22		
PeachCr_S040		0.01			0.30	0.13		0.13											0.26		
Guad_S210		0.01			0.30	0.14		0.14											0.28		
McCoyCr_S010		0.01			0.30	0.14		0.14											0.28		
Guad_S220		0.01			0.30	0.13		0.13											0.26		
SandiesCr_S010		0.04	0.16			0.02							0.04								
ClearForkCr_S010		0.04	0.14			0.01							0.04								
SandiesCr_S020		0.04	0.15			0.01							0.04								
ElmCr_S010		0.04	0.14			0.01							0.04								
SandiesCr_S030		0.04	0.14			0.01							0.04								
SandiesCr_S040		0.06	0.15		0.30	0.14		0.14					0.04								
Guad_S230		0.21			0.30	0.28		0.24											0.28		
Guad_S240		0.20			0.30	0.26		0.22											0.26		
SmithCk_S010	0.04	0.16	0.35					0.15	0.1	0.12	0.28										
ThomasCk_S010	0.04	0.16	0.35					0.16	0.1	0.12	0.28										
SmithCk_S020	0.04	0.16	0.35					0.14	0.1	0.13	0.24										
YorktownCk_S010	0.04	0.16	0.35					0.13	0.1	0.12	0.28										
YorktownCk_S020	0.04	0.16	0.35					0.13	0.1	0.13	0.24										
FifteenmileCk_S010	0.12	0.16	0.35					0.13	0.1	0.13	0.24										
HoosierCk_S010	0.12	0.16	0.35					0.14	0.1	0.13	0.24										
FifteenmileCk_S020	0.04	0.15	0.15					0.025	0.1	0.1	0.1										
EighteenmileCk_S010	0.04	0.15	0.15					0.025	0.1	0.1	0.1										
FifteenmileCk_S030	0.04	0.15	0.2					0.025	0.1	0.1	0.24										
TwelvemileCk_S010	0	0.15	0.15					0.025	0.1	0.1	0.2										

Subbasin Name	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
FivemileCk_S010	0	0.15	0.15					0.025	0.1	0.1	0.2										
TwelvemileCk_S020	0.04	0.15	0.2					0.025	0.1	0.1	0.24										
ColetoCk_S010	0.25	0.1	0.5					0.4	0.4	0.13	0.36										
ColetoCk_S020	0.25	0.1	0.5					0.39	0.39	0.13	0.36										
PerdidoCk_S010	0	0.21	0.01					0.3	0.15	0.13	0.32										
PerdidoCk_S020	0.25	0.1	0.5					0.4	0.4	0.13	0.36										
PerdidoCk_S030	0.25	0.1	0.5					0.36	0.36	0.13	0.36										
ColetoCk_S030	0.1	0.1	0.3					0.2	0.08	0.08	0.24										
ColetoCk_S040	0.1	0.15	0.3					0.15	0.1	0.13	0.24										
DryCk_S010	0.1	0.15	0.3					0.15	0.1	0.13	0.24										
Guad_S250	0.1	0.15	0.3					0.15	0.1	0.13	0.24										

Table 6.11: Calibrated Snyder's Lag Time (hours)

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
NF_Guad_S010	5.74					4.5		4.5	4.5			5.9			4.5					5.9	5.9	4.5
NF_Guad_S020	2.38					2.2		2.2	2.2			3.5			2.2					2.2	2.69	2.2
SF_Guad_S010	5.62					5.5		5	5.5			8.7			4					3.3	8.51	5.5
Guad_S010	2.66					3.1		3.1	3.1			3.1			3.1					3.1	3.14	3.1
JohnsonCr_S010	4.13					2.5		2.5	6			2.5			2.5					2.5	2.1	2.5
JohnsonCr_S020	2.05					2		2	2			2			2					2	1.1	2
Guad_S020	2.42					2.5		2.7	2.7			2.7			3					2	2.97	2.7
Guad_S030	4.63					3.6		3.6	3.6			3.6			3.6					3.6	3.44	3.6
TurtleCr_S010	4.99					4.2		4.2	4.5			4.2			4.2					4.2	3.6	4.2
Guad_S040	2.38					1.6		1.6	1.6			1.6			1.6					1.6	1.07	1.6
VerdeCr_S010	4.65					3.5		3.5	3.5			3.5			3.5					3.5	3.44	3.5
Guad_S050	4.07					3		3	3			3			3					3	2.73	3
CypressCr_GR_S010	4.37					4		4	4			4			4					4	3.32	4
Guad_S060	2.3					2		2	2			2			2					2	2	2
BlockCr_S010	3.14					3.1		3.1	3.1			3.1			3.1					3.1	3.1	3.1
Guad_S070	2.95					2.5		2.4	2.5			2.3			2.3					2.3	2.3	2.4
JoshuaCr_S010	2.98					3		3	3			3			3					3	3	3
Guad_S080	1.35					1.3		1.3	1.3			1.3			1.3					1.3	1.3	1.3
SisterCr_S010	2.81					3		3	3			3			3					3	3	3
Guad_S090	8.4					8		8	8			8			8					8	8	8
CurryCr_S010	3.86					4.5		4.1	4.1			4.1			4.1					4.1	4.1	4.1
Guad_S100	2.3					2.5		2.5	2.5			2.5			2.5					2.5	2.5	2.5
Guad_S110	2.58					4.6		4.5	4.6			4			4.6					4.6	4.6	4.5
Guad_S120	2.75					5		5	5			5			5					5	5	5

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
CanyonLk_S010	0					1		1	1			1			1					1	1	1
Blanco_S010	3.2		2		2				2.7		2.2						-	2		2	2	
Blanco_S020	3.9		2.4		2.4				3.3		2.8						-	2.4		2.4	2.4	
Blanco_S030	2.9		1.9		1.9				2.6		2.1						-	1.9		1.9	1.9	
Blanco_S040	5.2		3.5		3.5				4.8		3.7						-	3.5		3.5	3.5	
Blanco_S050	4.9		3.4		3.4				4.6		3.1						-	3.4		3.4	3.4	
LittleBlanco_S010	2.2		2.2		2.2				2.2		1.2						-	2.2		2.2	1.7	
LittleBlanco_S020	2.6		2.4		2.4				2.6		1.5						-	2.6		2.4	2.1	
LittleBlanco_S030	2.9		2.8		2.8				2.9		1.8						-	2.9		2.8	2.5	
LittleBlanco_S040	4.2		3.7		3.7				4.2		2.3						-	3.7		3.7	3.2	
Blanco_S060	0.9		0.8		0.6				0.8		0.6						-	0.8		0.6	0.6	
WanslowCr_BR_S010	3.2		3		2.6				3		1.9						-	1.9		3	3.2	
Blanco_S070	2.9		2.8		2.3				2.8		1.7						-	1.7		2.8	1.7	
Blanco_S080	2.7		2.6		2.2				2.6		1.6						-	1.6		2.6	1.6	
CarpersCr_BR_S010	4.4		4.1		3.5				4.1		3.1						-	2.4		4.1	2.4	
Blanco_S090	3.1		3		2.5				3		2.2						-	1.8		3	1.8	
Blanco_S100	1.2		1.1		0.9				1.1		0.8						-	0.7		1.1	0.7	
WilsonCr_BR_S010	2.6		2.4		2				2.4		1.8						-	1.5		2.4	1.5	
Blanco_S110	1		1		0.8				1		0.7						-	0.6		1	0.6	
CypressCr_BR_S010	2.7		2.7		2.2				2.7		2.2						-	1.7		2.2	1.7	
CypressCr_BR_S020	2.5		2.5		1.9				2.5		1.9						-	1.6		1.9	1.6	
CypressCr_BR_S030	3.2		2.7		2.2				2.7		2.2						-	1.7		2.2	1.7	
Blanco_S120	2.1		1.7		1.7				2.1		1.7						-	2.1		2.2	1.7	
Blanco_S130	2.9		2.3		2.3				2.9		2.3						-	2.9		3	2.3	
LoneManCr_BR_S010	4.8		3		3				4.8		3						-	4.8		4.8	3	
Blanco_S140	2.9		2.3		2.3				2.9		2.3						-	2.9		3	2.3	
HalifaxCr_BR_S010	4.6		3.3		3.3				4.6		3.3						-	4.6		5.2	3.3	
Blanco_S150	2.8		2.4		2.4				2.8		2.4						-	2.8		3.2	2.4	
Blanco_S160	3.6		3.3		3.3				3.3		3.3						-	3.6		3.6	3.3	
Blanco_S170	3.9		2.5		2.5				2.5		2.5						-	2.5		2.5	2.5	
SinkCk_S010	4.4		4.4		-				4.4		4.4						-	-		-	4.4	
SinkCk_S020	3.4		3.4		-				3.4		3.4						-	-		-	3.4	
SinkCk_S030	1.1		1.9		-				1.6		1.6						-	-		-	1.9	
SinkCk_S040	1.4		2.3		-				2		2						-	-		-	2.3	
SanMarcos_S005	1.5		2.6		-				2.2		2.2						-	-		-	2.6	
SanMarcos_S008	0.8		1.4		-				1.2		1.2						-	-		-	1.4	
PurgatoryCr_S010	8.5		5.5		-				5.5		-						8.5	-		8.5	5.5	
SanMarcos_S010	1.9		1.9		-				1.9		-						1.9	-		1.9	1.9	
SanMarcos_S020	8.6		6.8		-				7.5		-						6.75	-		6.75	6.75	
YorkCr_S010	6.5		8.5		-				8.5		-						8.5	-		8.5	8.5	
SanMarcos_S030	6.9		7.5		-				9		-						7.5	-		7.5	7.5	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
SanMarcos_S040	5		5		-				5		-						5	-		5	5	
PlumCr_S010	12.1		6.1		-				12.1		-						3.6	-		3.6	6.1	
PlumCr_S020	5.3		5.3		-				5.3		-						6.9	-		8	5.3	
TenneyCr_S010	4		4		-				4		-						5.2	-		6	4	
PlumCr_S030	6.8		17		-				17		-						8.8	-		10.2	6.8	
PlumCr_S040	4.6		4.6		-				4.6		-						4.6	-		4.6	4.6	
SanMarcos_S050	13		13		-				13		-						13	-		13	13	
DryComalCk_S010	7.7											7.7		7.7		7.7					7.7	7.7
DryComalCk_S020	0.8											1.1		0.9		0.7					1.1	1.1
WFk_DryComalCk_S010	6.7											6.7		6.7		6.7					6.7	6.7
WFk_DryComalCk_S020	1.4											1.9		1.5		1.3					1.8	1.8
WF_Trib_S010	1.3											1.3		1.3		1.3					1.3	1.3
WF_Trib_S020	0.9											1.2		1.0		0.8					1.1	1.1
WFk_DryComalCk_S030	0.5											0.7		0.6		0.5					0.6	0.6
DryComalCk_S030	1.4											1.9		1.5		1.3					1.5	1.5
BearCk_S010	3.2											3.2		3.2		3.2					3.2	3.2
DryComalCk_S040	3.1											4.2		3.4		2.8					4.6	4.6
DCCk_Trib14_S010	2.1											2.8		2.3		1.9					2.1	2.1
DryComalCk_S050	2.1											2.8		3.0		1.9					3.2	3.2
DryComalCk_S060	1.5											2.0		1.7		1.4					2.3	2.3
BliedersCk_S010	2.1											2.1		2.1		2.1					2.1	2.1
Comal_S010	2.8											3.8		3.1		2.5					3.3	3.3
Comal_S020	0.9											1.2		1.0		0.8					1.2	1.2
Comal_S030	0.7																					
Guad_S130	2.3		2.8			2.1			2.5							1.3		2.7			1.9	
BearCr_S010	1.9		2.6			1.9			2.3							1.1		2.5			1.7	
Guad_S140	3		3.8			2.8			3.4							1.7		3.6			3.1	
Guad_S142	3.7		3.7			3.7			3.7			4.9				3.7	5.4	3.7		4.9	3.7	
Guad_S144	0.8		0.8			0.8			0.8			0.8				0.8	0.9	0.8		0.8	0.8	
Guad_Trib22_S010	1.8		1.8			1.8			1.8			2.7				1.8	3.0	1.8		2.7	1.8	
Guad_S145	3.2		1.4			1.4			1.4			1.4				1.4	1.5	1.4		1.4	1.4	
LongCk_S010	1.4		3.2			3.2			3.2			5.2				3.2	5.8	3.2		5.2	3.2	
Guad_S147	0.8		0.8			0.8			0.8			0.8				0.8	0.9	0.8		0.8	0.8	
Guad_Trib20_S010	2.3		2.3			2.3			2.3			3.5				2.3	3.9	2.3		3.5	2.3	
Guad_S149	1.5		1.5			1.5			1.5			1.7				1.5	1.9	1.5		1.7	1.5	
Guad_S152	0.7		0.7			0.7			0.7			0.7				0.7	0.8	0.7		0.7	0.7	
YoungsCk_S010	2.3		2.3			2.3			2.3			4.0				2.3	4.4	2.3		4.0	2.3	
Guad_S154	0.7		0.7			0.7			0.7			0.8				0.7	0.9	0.7		0.8	0.7	
CottonwoodCkS_S010	2.2		2.2			2.2			2.2			3.8				2.2	4.2	2.2		3.8	2.2	
Guad_S156	0.9		0.9			0.9			0.9			0.9				0.9	1.0	0.9		0.9	0.9	
Little_MillCk_S010	2.7		2.7			2.7			2.7			4.0				2.7	4.5	2.7		4.0	2.7	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Guad_S158	1		1.0			1.0			1.0			1.3				1.0	1.4	1.0		1.3	1.0	
DeadmanCk_S010	2.1		2.1			2.1			2.1			3.4				2.1	3.8	2.1		3.4	2.1	
Guad_S160	3.5		3.5			3.5			3.5			4.5				3.5	5.0	3.5		4.5	3.5	
CottonwoodCk_S010	6.4		6.4			6.4			6.4			6.1				6.4	6.8	6.4		6.1	6.4	
Guad_S162	1.3		1.3			1.3			1.3			1.3				1.3	1.5	1.3		1.3	1.3	
AlligatorCk_S010	2.6		2.6			2.6			2.6			2.3				2.6	2.6	2.6		2.6	2.6	
GeronimoCk_S010	3.3		3.3			3.3			3.3			3.0				3.3	3.3	3.3		3.3	3.3	
GeronimoCk_S020	2.8		2.8			2.8			2.8			2.5				2.8	2.8	2.8		2.8	2.8	
GeronimoCk_S030	2.2		2.2			2.2			2.2			2.0				2.2	2.2	2.2		2.2	2.2	
Guad_S164	2.2		2.2			2.2			2.2			2.4				2.2	2.7	2.2		2.4	2.2	
CantauCk_S010	3.2		3.2			3.2			3.2			3.3				3.2	3.6	3.2		3.3	3.2	
Guad_S166	5.3		5.3			5.3			5.3							5.3					5.3	
MillCk_S010	6.3		6.3			6.3			6.3							6.3					6.3	
Guad_S168	8.5		8.5			8.5			8.5							8.5					8.5	
NashCk_S010	6.2		6.2			6.2			6.2							6.2					6.2	
Guad_S170	11.6		11.6			11.6			11.6							11.6					11.6	
Guad_S172	5.6		5.6			5.6			5.6							5.6					5.6	
Guad_S174	5.2		5.2			5.2			5.2							5.2					5.2	
Guad_S176	5.3		5.3			5.3			5.3							5.3					5.3	
Guad_S200	10.1		10.1			10.1	10.1		10.1											10.1		
PeachCr_S010	15						17.0		16.3				16.3						17.7	15.0		
BigFiveMileCr_S010	6.1						6.8		6.5				6.5						7.0	5.9		
PeachCr_S020	9						9.9		9.5				9.5						10.3	8.7		
SandyFork_S010	17.7						19.9		19.1				19.1						20.7	17.5		
PeachCr_S030	8.8						9.8		9.4				9.4						10.1	12.0		
PeachCr_S040	6.1																					
Guad_S210	10.3		10.3			10.3	10.3		10.3											10.3		
McCoyCr_S010	5.3		5.3			5.3	5.3		5.3											5.3		
Guad_S220	6.4		6.4			6.4	6.4		6.4											6.4		
SandiesCr_S010	14.1		17.9	17.9			12.8							16.0								
ClearForkCr_S010	12.1		15.7	15.7			11.2							14.0								
SandiesCr_S020	11.3		14.6	14.6			10.4							13.0								
ElmCr_S010	16.7		21.0	21.0			15.0							18.8								
SandiesCr_S030	28.6		21.9	21.9			31.8							31.8								
SandiesCr_S040	16.9																					
Guad_S230	4.6		4.6			6.4	6.4		6.4											6.4		
Guad_S240	13		13			18.2	18.2		18.2											18.2		
SmithCk_S010	7.2	8.5	8.5	8.3					4.3	7.2	8.5	8										
ThomasCk_S010	6.3	6.3	6.9	6.5					3.5	6.3	6.9	6										
SmithCk_S020	6.8	7.7	7.7	7.7					3.9	7.7	7.7	7.7										
YorktownCk_S010	4.9	6	6	6					3	6	6	6										

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
YorktownCk_S020	4.1	4.5	4.5	4.5					2.3	4.5	4.5	4.5										
FifteenmileCk_S010	3.9	4.4	4.4	4.4					2.2	4.4	4.4	4.4										
HoosierCk_S010	5.7	6.3	6.3	6.3					3.2	6.3	6.3	6.3										
FifteenmileCk_S020	6	6.3	6.3	6.3					5.6	6.3	3.2	7.3										
EighteenmileCk_S010	8.1	7.5	8.1	8.8					7.7	8.1	4.5	8.8										
FifteenmileCk_S030	5.9	5	6	6.4					6	6	3.3	6.4										
TwelvemileCk_S010	10.1	6	10.1	10.5					9.5	10	10	10.7										
FivemileCk_S010	8.4	5	8	8.5					9.5	8	8	8.5										
TwelvemileCk_S020	6	5.5	5.8	6					5.6	5.8	6	6										
ColetoCk_S010	6.7	6.7	8	8					4	8	8	8										
ColetoCk_S020	5.5	5.5	6.7	6.7					3.4	6.7	6.7	6.7										
PerdidoCk_S010	4.4	3.5	4.9	2.9					2.5	4.4	4.4	3.6										
PerdidoCk_S020	4.9	4.9	5.8	5.8					2.9	5.8	5.8	5.8										
PerdidoCk_S030	4.6	4.6	5.9	5.9					3	5.9	5.9	5.9										
ColetoCk_S030	3.5	3.5	3.5	3.5					3.5	3.5	3.5	3.5										
ColetoCk_S040	6.2	6.2	6.2	6.2					6.2	6.2	6.2	6.2										
DryCk_S010	6.4	6.4	6.4	6.4					6.4	6.4	6.4	6.4										
Guad_S250	13.8	13.8	13.8	13.8					13.8	13.8	13.8	13.8										

Table 6.12: Calibrated Snyder's Peaking Coefficient

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
NF_Guad_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
NF_Guad_S020	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
SF_Guad_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
JohnsonCr_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
JohnsonCr_S020	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S020	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S030	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
TurtleCr_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S040	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
VerdeCr_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S050	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
CypressCr_GR_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S060	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
BlockCr_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S070	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
JoshuaCr_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Guad_S080	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
SisterCr_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S090	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
CurryCr_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S100	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S110	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Guad_S120	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
CanyonLk_S010	0.8594					0.77		0.77	0.77			0.77			0.77					0.77	0.77	0.77
Blanco_S010	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S020	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S030	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S040	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S050	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
LittleBlanco_S010	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
LittleBlanco_S020	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
LittleBlanco_S030	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
LittleBlanco_S040	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S060	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
WanslowCr_BR_S010	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S070	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S080	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
CarpersCr_BR_S010	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S090	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S100	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
WilsonCr_BR_S010	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S110	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
CypressCr_BR_S010	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
CypressCr_BR_S020	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
CypressCr_BR_S030	0.72		0.78		0.78				0.78		0.78						-	0.78		0.78	0.78	
Blanco_S120	0.72		0.7		0.72				0.72		0.72						-	0.7		0.72	0.72	
Blanco_S130	0.72		0.7		0.72				0.72		0.72						-	0.7		0.72	0.72	
LoneManCr_BR_S010	0.72		0.7		0.72				0.72		0.72						-	0.7		0.72	0.72	
Blanco_S140	0.72		0.7		0.72				0.72		0.72						-	0.7		0.72	0.72	
HalifaxCr_BR_S010	0.72		0.7		0.72				0.72		0.72						-	0.7		0.72	0.72	
Blanco_S150	0.72		0.7		0.72				0.72		0.72						-	0.7		0.72	0.72	
Blanco_S160	0.72		0.7		0.72				0.72		0.72						-	0.7		0.72	0.72	
Blanco_S170	0.72		0.7		0.75				0.75		0.75						-	0.7		0.75	0.75	
SinkCk_S010	0.78		0.8		-				0.7813		0.7813						0.7813	-		-	-	
SinkCk_S020	0.78		0.8		-				0.7813		0.7813						0.7813	-		-	-	
SinkCk_S030	0.78		0.8		-				0.7813		0.7813						0.7813	-		-	-	
SinkCk_S040	0.78		0.8		-				0.7813		0.7813						0.7	-		-	-	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
SanMarcos_S005	0.78		0.8		-				0.7813		0.7813						0.7813	-		-	-	
SanMarcos_S008	0.78		0.8		-				0.7813		0.7813						0.7813	-		-	-	
PurgatoryCr_S010	0.78		0.8		-				0.7813		-						0.4688	-		0.7813	0.7813	
SanMarcos_S010	0.78		0.8		-				0.75		-						0.7813	-		0.75	0.75	
SanMarcos_S020	0.78		0.8		-				0.75		-						0.7813	-		0.75	0.75	
YorkCr_S010	0.78		0.7		-				0.7		-						0.7813	-		0.65	0.65	
SanMarcos_S030	0.78		0.8		-				0.75		-						0.7813	-		0.75	0.75	
SanMarcos_S040	0.78		0.8		-				0.75		-						0.7813	-		0.75	0.75	
PlumCr_S010	0.78		0.6		-				0.7813		-						-	-		0.4688	0.6485	
PlumCr_S020	0.78		0.8		-				0.7813		-						-	-		0.7813	0.7813	
TenneyCr_S010	0.78		0.8		-				0.7813		-						-	-		0.7813	0.7813	
PlumCr_S030	0.78		0.8		-				0.7813		-						-	-		0.7813	0.7813	
PlumCr_S040	0.78		0.8		-				0.7813		-						-	-		0.7813	0.7813	
SanMarcos_S050	0.78		0.8		-				0.7813		-						-	-		0.7813	0.7813	
DryComalCk_S010	0.78											0.78		0.7		0.78					0.78	0.78
DryComalCk_S020	0.78											0.78		0.7		0.78					0.78	0.78
WFk_DryComalCk_S010	0.78											0.78		0.7		0.78					0.78	0.78
WFk_DryComalCk_S020	0.78											0.78		0.7		0.78					0.78	0.78
WF_Trib_S010	0.78											0.78		0.7		0.78					0.78	0.78
WF_Trib_S020	0.78											0.78		0.7		0.78					0.78	0.78
WFk_DryComalCk_S030	0.78											0.78		0.7		0.78					0.78	0.78
DryComalCk_S030	0.78											0.78		0.7		0.78					0.78	0.78
BearCk_S010	0.78											0.78		0.7		0.78					0.78	0.78
DryComalCk_S040	0.78											0.78		0.7		0.78					0.78	0.78
DCCk_Trib14_S010	0.78											0.78		0.7		0.78					0.78	0.78
DryComalCk_S050	0.78											0.78		0.7		0.78					0.78	0.78
DryComalCk_S060	0.78											0.78		0.7		0.78					0.78	0.78
BliedersCk_S010	0.78											0.78		0.7		0.78					0.78	0.78
Comal_S010	0.78											0.78		0.7		0.78					0.78	0.78
Comal_S020	0.78											0.78		0.7		0.78					0.78	0.78
Comal_S030	0.78																					
Guad_S130	0.78		0.82			0.78			0.78							0.85		0.78			0.82	
BearCr_S010	0.78		0.82			0.78			0.78							0.85		0.78			0.82	
Guad_S140	0.78		0.82			0.78			0.78							0.85		0.78			0.82	
Guad_S142	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S144	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_Trib22_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S145	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
LongCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S147	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_Trib20_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Guad_S149	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S152	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
YoungsCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S154	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
CottonwoodCkS_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S156	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Little_MillCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S158	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
DeadmanCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S160	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
CottonwoodCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S162	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
AlligatorCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
GeronimoCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
GeronimoCk_S020	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
GeronimoCk_S030	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S164	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
CantauCk_S010	0.78		0.75			0.78			0.78			0.75				0.78	0.75	0.78		0.75	0.78	
Guad_S166	0.78		0.75			0.78			0.78							0.78					0.78	
MillCk_S010	0.78		0.75			0.78			0.78							0.78					0.78	
Guad_S168	0.78		0.75			0.78			0.78							0.78					0.78	
NashCk_S010	0.78		0.75			0.78			0.78							0.78					0.78	
Guad_S170	0.78		0.75			0.78			0.78							0.78					0.78	
Guad_S172	0.78		0.75			0.78			0.78							0.78					0.78	
Guad_S174	0.78		0.75			0.78			0.78							0.78					0.78	
Guad_S176	0.78		0.75			0.78			0.78							0.78					0.78	
Guad_S200	0.78		0.75			0.78	0.78		0.78											0.78		
PeachCr_S010	0.75						0.75		0.75				0.75						0.75	0.75		
BigFiveMileCr_S010	0.75						0.75		0.75				0.75						0.75	0.75		
PeachCr_S020	0.75						0.75		0.75				0.75						0.75	0.75		
SandyFork_S010	0.75						0.75		0.75				0.75						0.75	0.75		
PeachCr_S030	0.75						0.75		0.75				0.75						0.75	0.75		
PeachCr_S040	0.75																					
Guad_S210	0.78		0.75			0.78	0.78		0.78											0.78		
McCoyCr_S010	0.78		0.75			0.78	0.78		0.78											0.78		
Guad_S220	0.78		0.75			0.78	0.78		0.78											0.78		
SandiesCr_S010	0.75		0.70	0.75			0.75							0.75								
ClearForkCr_S010	0.75		0.70	0.75			0.75							0.75								
SandiesCr_S020	0.75		0.70	0.75			0.75							0.75								
ElmCr_S010	0.75		0.70	0.75			0.75							0.75								
SandiesCr_S030	0.75		0.70	0.75			0.75							0.75								

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
SandiesCr_S040	0.75																					
Guad_S230	0.78		0.75			0.78	0.78		0.78											0.78		
Guad_S240	0.78		0.75			0.78	0.78		0.78											0.78		
SmithCk_S010	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
ThomasCk_S010	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
SmithCk_S020	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
YorktownCk_S010	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
YorktownCk_S020	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
FifteenmileCk_S010	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
HoosierCk_S010	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
FifteenmileCk_S020	0.78	0.78	0.78	0.80					0.77	0.78	0.78	0.78										
EighteenmileCk_S010	0.78	0.78	0.78	0.80					0.77	0.78	0.78	0.78										
FifteenmileCk_S030	0.78	0.78	0.78	0.80					0.77	0.78	0.78	0.78										
TwelvemileCk_S010	0.78	0.78	0.78	0.80					0.77	0.78	0.78	0.78										
FivemileCk_S010	0.78	0.78	0.78	0.80					0.77	0.78	0.78	0.78										
TwelvemileCk_S020	0.78	0.78	0.78	0.80					0.77	0.78	0.78	0.78										
ColetoCk_S010	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
ColetoCk_S020	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
PerdidoCk_S010	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
PerdidoCk_S020	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
PerdidoCk_S030	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
ColetoCk_S030	0.78	0.78	0.78	0.78					0.78	0.78	0.78	0.78										
ColetoCk_S040	0.78	0.70	0.70	0.70					0.70	0.70	0.70	0.70										
DryCk_S010	0.78	0.70	0.70	0.70					0.70	0.70	0.70	0.70										
Guad_S250	0.78	0.70	0.70	0.70					0.70	0.70	0.70	0.70										

Table 6.13: Calibrated Initial Baseflow (cfs per sq mi)

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
NF_Guad_S010	0.3					1.2		0.25	0.2			0.3			0.09					0.1	0.09	0.12
NF_Guad_S020	0.3					1.2		0.1	0.3			0.3			0.15					0.3	0.1	0.7
SF_Guad_S010	0.3					1.2		0.1	0.3			0.3			0.15					0.3	0.1	0.7
Guad_S010	0.3					2.4		0.4	0.3			0.6			0.05					0.7	0.05	0.6
JohnsonCr_S010	0.3					0.15		0.26	0.3			0.45			0.24					0.6	0.25	0.47
JohnsonCr_S020	0.3					2.4		0.4	0.3			0.6			0.05					0.7	0.05	0.6
Guad_S020	0.3					2.4		0.4	0.3			0.6			0.05					0.7	0.05	0.6
Guad_S030	0.3					10		0.6	0.5			0.6			0.3					0.7	0.01	0.7
TurtleCr_S010	0.3					10		0.6	0.5			0.6			0.3					0.7	0.03	0.7
Guad_S040	0.3					10		0.6	0.5			0.6			0.3					0.7	0.03	0.7

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
VerdeCr_S010	0.3					10		0.6	0.5			0.6			0.3					0.7	0.03	0.7
Guad_S050	0.3					10		0.6	0.5			0.6			0.3					0.7	0.03	0.7
CypressCr_GR_S010	0.3					10		0.6	0.5			0.6			0.3					0.7	0.03	0.7
Guad_S060	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
BlockCr_S010	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
Guad_S070	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
JoshuaCr_S010	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
Guad_S080	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
SisterCr_S010	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
Guad_S090	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
CurryCr_S010	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
Guad_S100	0.3					25		0.6	1.8			1.4			0.23					2.4	0.05	1.5
Guad_S110	0.3					25		0.6	1.8			1.4			0.01					0.5	0.05	1.5
Guad_S120	0.3					25		0.6	1.8			1.4			0.01					0.5	0.05	1.5
CanyonLk_S010	0.3					0		0	0.3			0.01			0.3					0	0	0.1
Blanco_S010	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
Blanco_S020	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
Blanco_S030	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
Blanco_S040	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
Blanco_S050	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
LittleBlanco_S010	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
LittleBlanco_S020	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
LittleBlanco_S030	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
LittleBlanco_S040	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.13	
Blanco_S060	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
WanslowCr_BR_S010	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
Blanco_S070	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
Blanco_S080	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
CarpersCr_BR_S010	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
Blanco_S090	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
Blanco_S100	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
WilsonCr_BR_S010	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
Blanco_S110	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
CypressCr_BR_S010	0.2		0.17		0.2				0.65		0.04						-	0.06		1.25	0.15	
CypressCr_BR_S020	0.2		0.75		0.8				0.9		0.6						-	0.7		2.5	0.8	
CypressCr_BR_S030	0.2		0.17		0.1				0.65		0.04						-	0.06		1.5	0.15	
Blanco_S120	0.2		0.1		0.1				0.05		0.04						-	0.1		1.5	0.1	
Blanco_S130	0.2		0.1		0.1				0.05		0.04						-	0.1		1.5	0.1	
LoneManCr_BR_S010	0.2		0.1		0.1				0.05		0.04						-	0.1		1.5	0.1	
Blanco_S140	0.2		0.1		0.1				0.05		0.04						-	0.1		1.5	0.1	
HalifaxCr_BR_S010	0.2		0.1		0.1				0.05		0.04						-	0.1		1.5	0.1	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Blanco_S150	0.2		0.1		0.1				0.05		0.04						-	0.1		1.5	0.1	
Blanco_S160	0.2		0.1		0.1				0.05		0.04						-	0.1		1	0.1	
Blanco_S170	0.2		0.1		0.1				0.05		0.04						-	0.1		1	0.1	
SinkCk_S010	0.3		0.3		-				0.3		0.3						0.3	-		0.3	0.3	
SinkCk_S020	0.3		0.3		-				0.3		0.3						0.3	-		0.3	0.3	
SinkCk_S030	0.3		0.3		-				0.3		0.3						0.3	-		0.3	0.3	
SinkCk_S040	0.3		0.3		-				0.3		0.3						0.3	-		0.3	0.3	
SanMarcos_S005	0.3		0.3		-				0.3		0.3						0.3	-		0.3	0.3	
SanMarcos_S008	0.3		4		-				4.8		-						2	-		4	4	
PurgatoryCr_S010	0.3		0.3		-				4		-						0.2	-		0.6	0.3	
SanMarcos_S010	0.3		0.3		-				4		-						0.2	-		0.6	0.2	
SanMarcos_S020	0.3		0.3		-				4		-						0.2	-		0.6	0.2	
YorkCr_S010	0.3		0.3		-				4		-						0.2	-		0.6	0.3	
SanMarcos_S030	0.3		0.3		-				4		-						0.2	-		0.6	0.2	
SanMarcos_S040	0.3		0.3		-				4		-						0.2	-		0.3	0.2	
PlumCr_S010	0.3		0		-				4		-						0.01	-		3	0.01	
PlumCr_S020	0.3		0		-				0.01		-						0.01	-		0.01	0.01	
TenneyCr_S010	0.3		0		-				0.01		-						0.01	-		0.01	0.01	
PlumCr_S030	0.3		0		-				0.01		-						0.01	-		0.01	0.01	
PlumCr_S040	0.3		0.3		-				0.3		-						0.3	-		0.3	0.3	
SanMarcos_S050	0.3		0.3		-				0.3		-						0.3	-		0.3	0.3	
DryComalCk_S010	0.3											0.4		0		0					0	0.3
DryComalCk_S020	0.3											0		0		0					0	0.3
WFk_DryComalCk_S010	0.3											0		0		0					0	0.3
WFk_DryComalCk_S020	0.3											0		0		0					0	0.3
WF_Trib_S010	0.3											0		0		0					0	0.3
WF_Trib_S020	0.3											0		0		0					0	0.3
WFk_DryComalCk_S030	0.3											0		0		0					0	0.3
DryComalCk_S030	0.3											0		0		0					0	0.3
BearCk_S010	0.3											0		0		0					0	0.3
DryComalCk_S040	0.3											0		0		0					0	0.3
DCCk_Trib14_S010	0.3											0		0		0					0	0.3
DryComalCk_S050	0.3											0		0		0					0	0.3
DryComalCk_S060	0.3											0		0		0					0	0.3
BliedersCk_S010	0.3											0		0		0					0	0.3
Comal_S010	57.35											57.35		57.35		57.35					57.35	57.35
Comal_S020	0.3											0		0		0					0	0.3
Comal_S030	0.3																					
Guad_S130	0.3		0.3			0.3			0.3							0.3		0			0.3	
BearCr_S010	0.3		0.3			0.3			0.3							0.3		0			0.3	
Guad_S140	0.3		0.3			0.3			0.3							0.3		0			0.3	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Guad_S142	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S144	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_Trib22_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S145	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
LongCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S147	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_Trib20_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S149	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S152	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
YoungsCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S154	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
CottonwoodCkS_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S156	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Little_MillCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S158	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
DeadmanCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S160	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
CottonwoodCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S162	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
AlligatorCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
GeronimoCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
GeronimoCk_S020	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
GeronimoCk_S030	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S164	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
CantauCk_S010	0.3		0.3			0			5.0			4.0				0	0	0		0	0	
Guad_S166	0.3		0.3			0			5.0							0.3					0.3	
MillCk_S010	0.3		0.3			0			5.0							0.3					0.3	
Guad_S168	0.3		0.3			0			5.0							0.3					0.3	
NashCk_S010	0.3		0.3			0			5.0							0.3					0.3	
Guad_S170	0.3		0.3			0			5.0							0.3					0.3	
Guad_S172	0.3		0.3			0			5.0							0.3					0.3	
Guad_S174	0.3		0.3			0			5.0							0.3					0.3	
Guad_S176	0.3		0.3			0			5.0							0.3					0.3	
Guad_S200	0.3		0.3			0	0.3		0.3											0.3	0	
PeachCr_S010	0.3						0.10		1.56				0.01						0.01	0.66		
BigFiveMileCr_S010	0.3						0.10		1.56				0.01						0.01	0.66		
PeachCr_S020	0.3						0.10		1.56				0.01						0.01	0.66		
SandyFork_S010	0.3						0.10		1.56				0.01						0.01	0.66		
PeachCr_S030	0.3						0.10		1.56				0.01						0.01	0.66		
PeachCr_S040	0.3																					
Guad_S210	0.3		0.3			0	0.3		0.3											0.3		

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
McCoyCr_S010	0.3		0.3			0	0.3		0.3											0.3		
Guad_S220	0.3		0.3			0	0.3		0.3											0.3		
SandiesCr_S010	0.3		0.03	0			0.09							0.01								
ClearForkCr_S010	0.3		0.03	0			0.09							0.01								
SandiesCr_S020	0.3		0.03	0			0.09							0.01								
ElmCr_S010	0.3		0.03	0			0.09							0.01								
SandiesCr_S030	0.3		0.03	0			0.09							0.01								
SandiesCr_S040	0.3																					
Guad_S230	0.3		0.3			0.3	0.3		0.3											0.3		
Guad_S240	0.3		0.3			0.3	0.3		0.3											0.3		
SmithCk_S010	0.3	0.3	0.1	0					0.3	0.1	0.3	0.05										
ThomasCk_S010	0.3	0.3	0.1	0					0.3	0.1	0.3	0.05										
SmithCk_S020	0.3	0.2	0.1	0					0.3	0.1	0.3	0.05										
YorktownCk_S010	0.3	0.3	0.1	0					0.3	0.1	0.3	0.05										
YorktownCk_S020	0.3	0.2	0.1	0					0.3	0.1	0.3	0.05										
FifteenmileCk_S010	0.3	0.2	0.1	0					0.3	0.1	0.3	0.05										
HoosierCk_S010	0.3	0.2	0.1	0					0.3	0.1	0.3	0.05										
FifteenmileCk_S020	0.3	0.2	0.1	0					0.3	0.1	0.3	0.02										
EighteenmileCk_S010	0.3	0.2	0.1	0					0.3	0.1	0.3	0.02										
FifteenmileCk_S030	0.3	0.2	0.1	0					0.3	0.1	0.3	0.02										
TwelvemileCk_S010	0.3	0.2	0.1	0					0.3	0.1	0.3	0.02										
FivemileCk_S010	0.3	0.2	0.1	0					0.3	0.1	0.3	0.02										
TwelvemileCk_S020	0.3	0.2	0.1	0					0.3	0.1	0.3	0.02										
ColetoCk_S010	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										
ColetoCk_S020	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										
PerdidoCk_S010	0.3	0.3	0.3	0.3					0.3	0.01	0.01	0.02										
PerdidoCk_S020	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										
PerdidoCk_S030	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										
ColetoCk_S030	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										
ColetoCk_S040	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										
DryCk_S010	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										
Guad_S250	0.3	0.3	0.3	0.3					0.3	0.3	0.3	0.02										

Table 6.14: Calibrated Baseflow Recession Constant

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
NF_Guad_S010	0.887					0.85		0.9	1			0.8			0.9					0.8	1	0.89
NF_Guad_S020	0.887					0.7		0.8	1			0.75			0.8					0.85	0.89	0.7
SF_Guad_S010	0.887					0.7		0.8	1			0.75			0.8					0.85	0.89	0.7
Guad_S010	0.887					0.7		0.8	0.89			0.7			0.9					0.8	0.98	0.8
JohnsonCr_S010	0.887					0.7		0.8	1			0.2			0.8					0.9	0.95	0.7
JohnsonCr_S020	0.887					0.75		0.8	0.89			0.7			0.9					0.8	0.98	0.8
Guad_S020	0.887					0.75		0.8	0.85			0.7			0.9					0.8	0.98	0.8
Guad_S030	0.887					0.85		0.8	0.98			0.7			0.9					0.8	0.89	0.84
TurtleCr_S010	0.887					0.85		0.8	0.98			0.7			0.9					0.8	0.89	0.84
Guad_S040	0.887					0.85		0.8	0.98			0.7			0.9					0.8	0.89	0.84
VerdeCr_S010	0.887					0.85		0.8	0.98			0.7			0.9					0.8	0.89	0.84
Guad_S050	0.887					0.85		0.8	0.98			0.7			0.9					0.8	0.89	0.84
CypressCr_GR_S010	0.887					0.85		0.8	0.98			0.89			0.9					0.8	0.89	0.84
Guad_S060	0.887					0.85		0.8	0.9			0.8			0.95					0.8	0.8	0.84
BlockCr_S010	0.887					0.85		0.8	0.9			0.8			0.95					0.8	0.8	0.84
Guad_S070	0.887					0.85		0.8	0.9			0.8			0.95					0.8	0.8	0.84
JoshuaCr_S010	0.887					0.85		0.8	0.9			0.8			0.95					0.8	0.8	0.84
Guad_S080	0.887					0.85		0.8	0.9			0.8			0.95					0.8	0.8	0.84
SisterCr_S010	0.887					0.85		0.8	0.9			0.8			0.95					0.8	0.8	0.84
Guad_S090	0.887					0.8		0.8	0.9			0.8			0.95					0.8	0.8	0.84
CurryCr_S010	0.887					0.8		0.8	0.9			0.8			0.95					0.8	0.8	0.84
Guad_S100	0.887					0.8		0.8	0.9			0.8			0.95					0.8	0.8	0.84
Guad_S110	0.887					0.8		0.8	0.9			0.8			0.8					0.8	0.8	0.8
Guad_S120	0.887					0.8		0.8	0.9			0.8			0.8					0.8	0.8	0.8
CanyonLk_S010	0.887					0.8		0.8	0.85			0.89			0.89					0.8	0.8	0.8
Blanco_S010	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S020	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S030	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S040	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S050	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
LittleBlanco_S010	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
LittleBlanco_S020	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
LittleBlanco_S030	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
LittleBlanco_S040	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S060	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
WanslowCr_BR_S010	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S070	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S080	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
CarpersCr_BR_S010	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Blanco_S090	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S100	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
WilsonCr_BR_S010	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S110	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
CypressCr_BR_S010	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
CypressCr_BR_S020	0.92		0.95		0.95				0.95		0.95						-	0.95		0.95	0.95	
CypressCr_BR_S030	0.92		0.89		0.8				0.8		0.8						-	0.7		0.8	0.7	
Blanco_S120	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
Blanco_S130	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
LoneManCr_BR_S010	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
Blanco_S140	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
HalifaxCr_BR_S010	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
Blanco_S150	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
Blanco_S160	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
Blanco_S170	0.89		0.89		0.8				0.8		0.8						-	0.89		0.8	0.89	
SinkCk_S010	0.89		0.89		-				0.89		0.89						0.89	-		0.89	0.89	
SinkCk_S020	0.89		0.89		-				0.89		0.89						0.89	-		0.89	0.89	
SinkCk_S030	0.89		0.89		-				0.89		0.89						0.89	-		0.89	0.89	
SinkCk_S040	0.89		0.89		-				0.89		0.89						0.89	-		0.89	0.89	
SanMarcos_S005	0.89		0.89		-				0.89		0.89						0.89	-		0.89	0.89	
SanMarcos_S008	0.89		0.99		-				0.99		-						0.99	-		0.99	0.99	
PurgatoryCr_S010	0.89		0.75		-				0.8		-						0.8	-		0.8	0.8	
SanMarcos_S010	0.89		0.75		-				0.8		-						0.8	-		0.8	0.8	
SanMarcos_S020	0.89		0.75		-				0.8		-						0.8	-		0.8	0.8	
YorkCr_S010	0.79		0.85		-				0.85		-						0.85	-		0.85	0.85	
SanMarcos_S030	0.89		0.75		-				0.8		-						0.8	-		0.8	0.8	
SanMarcos_S040	0.89		0.75		-				0.8		-						0.8	-		0.8	0.8	
PlumCr_S010	0.79		0.8		-				0.8		-						0.8	-		0.8	0.8	
PlumCr_S020	0.79		0.5		-				0.5		-						0.5	-		0.5	0.5	
TenneyCr_S010	0.79		0.5		-				0.5		-						0.5	-		0.5	0.5	
PlumCr_S030	0.79		0.5		-				0.5		-						0.5	-		0.5	0.5	
PlumCr_S040	0.79		0.79		-				0.79		-						0.79	-		0.79	0.79	
SanMarcos_S050	0.89		0.89		-				0.89		-						0.89	-		0.89	0.89	
DryComalCk_S010	0.89											0.89		0.89		0.89					0.89	0.45
DryComalCk_S020	0.89											0.89		0.89		0.89					0.89	0.45
WFk_DryComalCk_S010	0.89											0.89		0.89		0.89					0.89	0.45
WFk_DryComalCk_S020	0.89											0.89		0.89		0.89					0.89	0.45
WF_Trib_S010	0.89											0.89		0.89		0.89					0.89	0.45
WF_Trib_S020	0.89											0.89		0.89		0.89					0.89	0.45
WFk_DryComalCk_S030	0.89											0.89		0.89		0.89					0.89	0.45
DryComalCk_S030	0.89											0.89		0.89		0.89					0.89	0.45

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
BearCk_S010	0.89											0.89		0.89		0.89					0.89	0.45
DryComalCk_S040	0.89											0.89		0.89		0.89					0.89	0.45
DCCk_Trib14_S010	0.89											0.89		0.89		0.89					0.89	0.45
DryComalCk_S050	0.89											0.89		0.89		0.89					0.89	0.45
DryComalCk_S060	0.89											0.89		0.89		0.89					0.89	0.45
BliedersCk_S010	0.89											0.89		0.89		0.89					0.89	0.45
Comal_S010	0.89											0.89		0.89		0.89					0.89	0.45
Comal_S020	0.89											0.89		0.89		0.89					0.89	0.45
Comal_S030	0.89																					
Guad_S130	0.89		0.89			0.89			0.89							0.89		0.89			0.89	
BearCr_S010	0.89		0.89			0.89			0.89							0.89		0.89			0.89	
Guad_S140	0.89		0.89			0.89			0.89							0.89		0.89			0.89	
Guad_S142	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S144	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_Trib22_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S145	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
LongCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S147	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_Trib20_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S149	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S152	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
YoungsCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S154	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
CottonwoodCkS_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S156	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Little_MillCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S158	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
DeadmanCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S160	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
CottonwoodCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S162	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
AlligatorCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
GeronimoCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
GeronimoCk_S020	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
GeronimoCk_S030	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S164	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
CantauCk_S010	0.89		0.89			0.89			0.89			0.89				0.89	0.89	0.89		0.89	0.89	
Guad_S166	0.89		0.89			0.89			0.89							0.89					0.89	
MillCk_S010	0.89		0.89			0.89			0.89							0.89					0.89	
Guad_S168	0.89		0.89			0.89			0.89							0.89					0.89	
NashCk_S010	0.89		0.89			0.89			0.89							0.89					0.89	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Guad_S170	0.89		0.89			0.89			0.89							0.89					0.89	
Guad_S172	0.89		0.89			0.89			0.89							0.89					0.89	
Guad_S174	0.89		0.89			0.89			0.89							0.89					0.89	
Guad_S176	0.89		0.89			0.89			0.89							0.89					0.89	
Guad_S200	0.89		0.89			0.89	0.89		0.89											0.89		
PeachCr_S010	0.89						0.89		0.89				0.89						0.89	0.89		
BigFiveMileCr_S010	0.89						0.89		0.89				0.89						0.89	0.89		
PeachCr_S020	0.89						0.89		0.89				0.89						0.89	0.89		
SandyFork_S010	0.89						0.89		0.89				0.89						0.89	0.89		
PeachCr_S030	0.89						0.89		0.89				0.89						0.89	0.89		
PeachCr_S040	0.89																					
Guad_S210	0.89		0.89			0.89	0.89		0.89											0.89		
McCoyCr_S010	0.89		0.89			0.89	0.89		0.89											0.89		
Guad_S220	0.89		0.89			0.89	0.89		0.89											0.89		
SandiesCr_S010	0.45		0.45	0.45			0.45							0.45								
ClearForkCr_S010	0.45		0.45	0.45			0.45							0.45								
SandiesCr_S020	0.45		0.45	0.45			0.45							0.45								
ElmCr_S010	0.45		0.45	0.45			0.45							0.45								
SandiesCr_S030	0.45		0.45	0.45			0.45							0.45								
SandiesCr_S040	0.45					0.45	0.45		0.45											0.89		
Guad_S230	0.89		0.89			0.89	0.89		0.89											0.89		
Guad_S240	0.89		0.89			0.89	0.89		0.89													
SmithCk_S010	0.89	0.89	0.85	0.85					0.85	0.85	0.85	0.85										
ThomasCk_S010	0.89	0.89	0.85	0.85					0.85	0.85	0.85	0.85										
SmithCk_S020	0.89	0.89	0.85	0.85					0.85	0.85	0.85	0.85										
YorktownCk_S010	0.89	0.89	0.85	0.85					0.85	0.85	0.85	0.85										
YorktownCk_S020	0.89	0.89	0.85	0.85					0.85	0.85	0.85	0.85										
FifteenmileCk_S010	0.89	0.89	0.85	0.85					0.85	0.85	0.85	0.85										
HoosierCk_S010	0.89	0.89	0.85	0.85					0.85	0.85	0.85	0.85										
FifteenmileCk_S020	0.89	0.89	0.85	0.60					0.65	0.30	0.30	0.80										
EighteenmileCk_S010	0.89	0.89	0.85	0.60					0.65	0.30	0.30	0.80										
FifteenmileCk_S030	0.89	0.89	0.85	0.60					0.65	0.30	0.30	0.80										
TwelvemileCk_S010	0.89	0.89	0.85	0.60					0.65	0.30	0.30	0.80										
FivemileCk_S010	0.89	0.89	0.85	0.60					0.65	0.30	0.30	0.80										
TwelvemileCk_S020	0.89	0.89	0.85	0.60					0.65	0.30	0.30	0.80										
ColetoCk_S010	0.89	0.89	0.70	0.30					0.60	0.89	0.50	0.60										
ColetoCk_S020	0.89	0.89	0.70	0.30					0.60	0.89	0.50	0.60										
PerdidoCk_S010	0.89	0.89	0.70	0.89					0.55	0.46	0.40	0.60										
PerdidoCk_S020	0.89	0.89	0.70	0.30					0.60	0.89	0.50	0.60										
PerdidoCk_S030	0.89	0.89	0.70	0.30					0.60	0.89	0.50	0.60										
ColetoCk_S030	0.89	0.30	0.70	0.30					0.30	0.30	0.30	0.50										

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
ColetoCk_S040	0.89	0.89	0.70	0.60					0.60	0.89	0.50	0.60										
DryCk_S010	0.89	0.89	0.70	0.60					0.60	0.89	0.50	0.60										
Guad_S250	0.89	0.89	0.70	0.60					0.60	0.89	0.50	0.60										

Table 6.15: Calibrated Baseflow Ratio to Peak

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
NF_Guad_S010	0.05					0.018		0.2	0.01			0.25			0.03					0.05	0.02	0.2
NF_Guad_S020	0.05					0.01		0.01	0.01			0.2			0.01					0.05	0.08	0.2
SF_Guad_S010	0.05					0.01		0.01	0.01			0.2			0.01					0.05	0.07	0.2
Guad_S010	0.05					0.04		0.01	0.4			0.05			0.07					0.15	0.04	0.03
JohnsonCr_S010	0.05					0.01		0.01	0.01			0.33			0.04					0.2	0.08	0.18
JohnsonCr_S020	0.05					0.04		0.01	0.6			0.05			0.07					0.15	0.04	0.03
Guad_S020	0.05					0.04		0.01	0.25			0.05			0.07					0.15	0.04	0.03
Guad_S030	0.05					0.02		0.03	0.05			0.02			0.1					0.02	0.01	0.03
TurtleCr_S010	0.05					0.02		0.03	0.05			0.02			0.1					0.02	0.01	0.03
Guad_S040	0.05					0.02		0.03	0.05			0.02			0.1					0.02	0.01	0.03
VerdeCr_S010	0.05					0.02		0.03	0.05			0.02			0.1					0.02	0.01	0.03
Guad_S050	0.05					0.02		0.03	0.05			0.02			0.1					0.02	0.01	0.03
CypressCr_GR_S010	0.05					0.02		0.03	0.05			0.02			0.1					0.02	0.01	0.03
Guad_S060	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
BlockCr_S010	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
Guad_S070	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
JoshuaCr_S010	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
Guad_S080	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
SisterCr_S010	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
Guad_S090	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
CurryCr_S010	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
Guad_S100	0.05					0.05		0.03	0.05			0.04			0.1					0.02	0.01	0.02
Guad_S110	0.05					0.05		0.03	0.05			0.05			0.05					0.02	0.01	0.02
Guad_S120	0.05					0.05		0.03	0.05			0.05			0.05					0.02	0.01	0.02
CanyonLk_S010	0.05					0		0.02	0.02			0.02			0.02					0.02	0.01	0.02
Blanco_S010	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S020	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S030	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S040	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S050	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
LittleBlanco_S010	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
LittleBlanco_S020	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
LittleBlanco_S030	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
LittleBlanco_S040	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S060	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
WanslowCr_BR_S010	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S070	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S080	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
CarpersCr_BR_S010	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S090	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S100	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
WilsonCr_BR_S010	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
Blanco_S110	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
CypressCr_BR_S010	0.03		0.015		0.015				0.05		0.008						-	0.002		0.01	0.001	
CypressCr_BR_S020	0.03		0.03		0.03				0.07		0.03						-	0.03		0.03	0.005	
CypressCr_BR_S030	0.03		0.015		0.015				0.05		0.007						-	0.002		0.01	0.001	
Blanco_S120	0.03		0.015		0.015				0.002		0.007						-	0.002		0.02	0.002	
Blanco_S130	0.03		0.015		0.015				0.002		0.007						-	0.002		0.02	0.002	
LoneManCr_BR_S010	0.03		0.015		0.015				0.002		0.007						-	0.002		0.02	0.002	
Blanco_S140	0.03		0.015		0.015				0.002		0.007						-	0.002		0.02	0.002	
HalifaxCr_BR_S010	0.03		0.015		0.015				0.002		0.007						-	0.002		0.02	0.002	
Blanco_S150	0.02		0.015		0.015				0.002		0.007						-	0.002		0.02	0.002	
Blanco_S160	0.02		0.015		0.015				0.002		0.007						-	0.002		0.01	0.002	
Blanco_S170	0.02		0.015		0.015				0.002		0.007						-	0.002		0.01	0.002	
SinkCk_S010	0.05		0.03		-				0.03		0.03						0.03	-		0.03	0.03	
SinkCk_S020	0.05		0.03		-				0.03		0.03						0.03	-		0.03	0.03	
SinkCk_S030	0.05		0.03		-				0.03		0.03						0.03	-		0.03	0.03	
SinkCk_S040	0.05		0.03		-				0.03		0.03						0.03	-		0.03	0.03	
SanMarcos_S005	0.05		0.03		-				0.03		0.03						0.03	-		0.03	0.03	
SanMarcos_S008	0.05		0.03		-				0.14		-						0.2	-		0.07	0.03	
PurgatoryCr_S010	0.05		0.01		-				0.02		-						0.01	-		0.02	0.02	
SanMarcos_S010	0.05		0.01		-				0.02		-						0.01	-		0.02	0.02	
SanMarcos_S020	0.05		0.01		-				0.02		-						0.01	-		0.02	0.02	
YorkCr_S010	0.1		0.03		-				0.03		-						0.03	-		0.03	0.03	
SanMarcos_S030	0.05		0.01		-				0.02		-						0.01	-		0.02	0.02	
SanMarcos_S040	0.05		0.01		-				0.02		-						0.01	-		0.02	0.02	
PlumCr_S010	0.1		0.05		-				0.15		-						0.05	-		0.05	0.05	
PlumCr_S020	0.1		0.1		-				0.1		-						0.1	-		0.1	0.1	
TenneyCr_S010	0.1		0.1		-				0.1		-						0.1	-		0.1	0.1	
PlumCr_S030	0.1		0.1		-				0.1		-						0.1	-		0.1	0.1	
PlumCr_S040	0.1		0.1		-				0.1		-						0.1	-		0.1	0.1	
SanMarcos_S050	0.05		0.05		-				0.05		-						0.05	-		0.05	0.05	
DryComalCk_S010	0.05											0.001		0.001		0.001					0.001	0.05
DryComalCk_S020	0.05											0.001		0.001		0.001					0.001	0.05
WFk_DryComalCk_S010	0.05											0.001		0.001		0.001					0.001	0.05
WFk_DryComalCk_S020	0.05											0.001		0.001		0.001					0.001	0.05

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
WF_Trib_S010	0.05											0.001		0.001		0.001					0.001	0.05
WF_Trib_S020	0.05											0.001		0.001		0.001					0.001	0.05
WFk_DryComalCk_S030	0.05											0.001		0.001		0.001					0.001	0.05
DryComalCk_S030	0.05											0.001		0.001		0.001					0.001	0.05
BearCk_S010	0.05											0.001		0.001		0.001					0.001	0.05
DryComalCk_S040	0.05											0.001		0.001		0.001					0.001	0.05
DCCk_Trib14_S010	0.05											0.001		0.001		0.001					0.001	0.05
DryComalCk_S050	0.05											0.001		0.001		0.001					0.001	0.05
DryComalCk_S060	0.05											0.001		0.001		0.001					0.001	0.05
BliedersCk_S010	0.05											0.001		0.001		0.001					0.001	0.05
Comal_S010	0.05											0.001		0.001		0.001					0.001	0.05
Comal_S020	0.05											0.001		0.001		0.001					0.001	0.05
Comal_S030	0.05																					
Guad_S130	0.01		0.001			0.01			0.07							0.001		0.001			0.001	
BearCr_S010	0.01		0.001			0.01			0.07							0.001		0.001			0.001	
Guad_S140	0.01		0.001			0.01			0.07							0.001		0.001			0.001	
Guad_S142	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S144	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_Trib22_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S145	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
LongCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S147	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_Trib20_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S149	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S152	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
YoungsCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S154	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
CottonwoodCkS_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S156	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Little_MillCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S158	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
DeadmanCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S160	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
CottonwoodCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S162	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
AlligatorCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
GeronimoCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
GeronimoCk_S020	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
GeronimoCk_S030	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S164	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
CantauCk_S010	0.05		0.001			0.001			0.001			0.032				0.001	0.001	0.001		0.001	0.001	
Guad_S166	0.05		0.001			0.001			0.001							0.05					0.05	
MillCk_S010	0.05		0.001			0.001			0.001							0.05					0.05	

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Guad_S168	0.05		0.001			0.001			0.001							0.05					0.05	
NashCk_S010	0.05		0.001			0.001			0.001							0.05					0.05	
Guad_S170	0.05		0.001			0.001			0.001							0.05					0.05	
Guad_S172	0.05		0.001			0.001			0.001							0.05					0.05	
Guad_S174	0.05		0.001			0.001			0.001							0.05					0.05	
Guad_S176	0.05		0.001			0.001			0.001							0.05					0.05	
Guad_S200	0.05		0.05			0.001	0.05		0.05											0.05		
PeachCr_S010	0.01						0.01		0.01				0.01						0.01	0.01		
BigFiveMileCr_S010	0.01						0.01		0.01				0.01						0.01	0.01		
PeachCr_S020	0.01						0.01		0.01				0.01						0.01	0.01		
SandyFork_S010	0.01						0.01		0.01				0.01						0.01	0.01		
PeachCr_S030	0.01						0.01		0.01				0.01						0.01	0.01		
PeachCr_S040	0.01																					
Guad_S210	0.05		0.05			0.001	0.05		0.05											0.05		
McCoyCr_S010	0.05		0.05			0.001	0.05		0.05											0.05		
Guad_S220	0.05		0.05			0.001	0.05		0.05											0.05		
SandiesCr_S010	0.05		0.12	0.05			0.1							0.01								
ClearForkCr_S010	0.05		0.12	0.05			0.1							0.01								
SandiesCr_S020	0.05		0.12	0.05			0.1							0.01								
ElmCr_S010	0.05		0.12	0.05			0.1							0.01								
SandiesCr_S030	0.05		0.12	0.05			0.1							0.01								
SandiesCr_S040	0.05																					
Guad_S230	0.05		0.05			0.05	0.05		0.05											0.05		
Guad_S240	0.05		0.05			0.05	0.05		0.05											0.05		
SmithCk_S010	0.05	0.01	0.02	0.01					0.05	0.02	0.03	0.03										
ThomasCk_S010	0.05	0.01	0.02	0.01					0.05	0.02	0.03	0.03										
SmithCk_S020	0.05	0.01	0.02	0.01					0.05	0.02	0.03	0.03										
YorktownCk_S010	0.05	0.01	0.02	0.01					0.05	0.02	0.03	0.03										
YorktownCk_S020	0.05	0.01	0.02	0.01					0.05	0.02	0.03	0.03										
FifteenmileCk_S010	0.05	0.01	0.02	0.01					0.05	0.02	0.03	0.03										
HoosierCk_S010	0.05	0.01	0.02	0.01					0.05	0.02	0.03	0.03										
FifteenmileCk_S020	0.05	0.02	0.04	0.01					0.02	0.05	0	0.03										
EighteenmileCk_S010	0.05	0.02	0.04	0.01					0.02	0.05	0	0.03										
FifteenmileCk_S030	0.05	0.02	0.04	0.01					0.02	0.05	0	0.03										
TwelvemileCk_S010	0.05	0.01	0.04	0.01					0.02	0.05	0	0.03										
FivemileCk_S010	0.05	0.01	0.04	0.01					0.02	0.05	0	0.03										
TwelvemileCk_S020	0.05	0.01	0.04	0.01					0.02	0.05	0	0.03										
ColetoCk_S010	0.05	0.01	0.02	0.01					0.01	0.05	0.001	0.002										
ColetoCk_S020	0.05	0.01	0.02	0.01					0.01	0.05	0.001	0.002										
PerdidoCk_S010	0.05	0.05	0.03	0.05					0.02	0.05	0.05	0.01										
PerdidoCk_S020	0.05	0.01	0.02	0.01					0.01	0.05	0.001	0.002										
PerdidoCk_S030	0.05	0.01	0.02	0.01					0.01	0.05	0.001	0.002										
ColetoCk_S030	0.05	0.01	0.02	0.01					0.05	0.05	0.05	0.03										

Subbasin Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
ColetoCk_S040	0.05	0.01	0.02	0.01					0.01	0.05	0.01	0.01										
DryCk_S010	0.05	0.01	0.02	0.01					0.01	0.05	0.01	0.01										
Guad_S250	0.05	0.01	0.02	0.01					0.01	0.05	0.01	0.01										

Table 6.16: Calibrated Routing Reach Modified Puls Subreaches

HEC-HMS Reach Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Blanco_R020F	2		2		1				2		2						-	2		2	2	
Blanco_R020H	3		3		2				3		3						-	3		3	3	
Blanco_R030J	1		1		1				1		1						-	1		1	1	
Blanco_R030L	2		2		2				2		2						-	2		2	2	
Blanco_R030M	1		1		1				1		1						-	1		1	1	
Blanco_R040O	2		2		3				2		2						-	2		2	2	
Blanco_R040P	3		3		4				3		3						-	3		3	3	
Blanco_R040R	5		5		6				5		5						-	5		5	5	
Blanco_R050S	3		3		4				3		3						-	3		3	3	
Blanco_R050T	5		5		6				5		5						-	5		5	5	
LittleBlanco_R020V	2		2		2				2		2						-	2		2	2	
LittleBlanco_R030W	3		3		3				3		3						-	3		3	3	
LittleBlanco_R030X	3		3		3				3		3						-	3		3	3	
LittleBlanco_R040Y	5		5		4				5		5						-	5		5	5	
Blanco_R060Z	1		1		1				1		1						-	1		1	1	
Blanco_R070	5		4		8				5		4						-	7		5	7	
Blanco_R080	4		3		6				4		3						-	6		4	6	
Blanco_R090	4		3		7				4		4						-	7		4	7	
Blanco_R100	2		2		3				2		2						-	3		2	3	
Blanco_R110	1		1		1				1		1						-	1		1	1	
CypressCr_R0204C	1		1		1				1		1						-	1		1	1	
CypressCr_R0206C	1		1		1				1		1						-	1		1	1	
CypressCr_R0206CL	1		1		1				1		1						-	1		1	1	
CypressCr_R02010C	1		1		2				1		1						-	1		1	2	
CypressCr_R03012C	1		1		2				1		1						-	1		1	2	
CypressCr_R03014C	1		1		4				1		1						-	1		1	4	
CypressCr_R03016C	1		1		4				1		1						-	1		1	4	
Blanco_R120	2		2		1				1		3						-	2		3	2	
Blanco_R130	5		5		1				1		6						-	5		8	5	
Blanco_R140	5		5		1				1		6						-	6		8	5	
Blanco_R150	4		4		1				1		5						-	4		6	4	
Blanco_R160a	2		2		2				2		2						-	2		2	2	
Blanco_R160b	3		3		3				3		3						-	3		3	3	

HEC-HMS Reach Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Blanco_R170	6		6		4				4		6						-	6		6	6	
SinkCk_R010	1		1		-				1		1						1	-		1	1	
SinkCk_R020	1		1		-				1		1						1	-		1	1	
SinkCk_R030	1		1		-				1		1						1	-		1	1	
SinkCk_R040	1		1		-				1		1						1	-		1	1	
SinkCk_R050	1		1		-				1		1						1	-		1	1	
SanMarcos_R003	1		1		-				1		1						1	-		1	1	
SanMarcos_R005	1		1		-				1		1						1	-		1	1	
SanMarcos_R007	1		1		-				1		1						1	-		1	1	
SanMarcos_R020	8		8		-				8		8						8	-		8	8	
SanMarcos_R030	5		5		-				5		5						5	-		5	5	
SanMarcos_R040	2		1		-				1		1						1	-		1	1	
PlumCr_R010	8		6		-				6		6						6	-		6	6	
PlumCr_R020	6		3		-				3		3						3	-		3	3	
SanMarcos_R050	7		3		-				3		3						3	-		3	3	
DryComalCk_R010	2											1		2		1					1	1
WFk_DryComalCk_R010	3											1		3		1					1	1
WF_Trib_R010	2											1		2		1					1	1
WFk_DryComalCk_R020	1											1		1		1					1	1
DryComalCk_R020	3											1		3		1					1	1
BearCk_R010	1											1		1		1					1	1
DryComalCk_R030	9											1		9		1					1	1
DCCk_Trib14_R010	2											1		2		1					1	1
DryComalCk_R040	6											1		6		1					1	1
DryComalCk_R050	4																					
Comal_R010	6																					
Comal_R020	1																					
Comal_R030	1																					
Comal_R040	2																					
Guad_R120	1		2			1			2							2		2			2	
Guad_R130	2		4			3			4							4		4			4	
Guad_R135	1		1			1			1			1				1	1	1		1	1	
Guad_R140	1		1			1			1			1				1	1	1		1	1	
Guad_R147	1		1			1			1			1				1	1	1		1	1	
Guad_R152	1		1			1			1			1				1	1	1		1	1	
Guad_R157	1		1			1			1			1				1	1	1		1	1	
Guad_R165	1		1			1			1			1				1	1	1		1	1	
Guad_R170	1		1			1			1			1				1	1	1		1	1	
Guad_R175	1		1			1			1			1				1	1	1		1	1	
Guad_R180	1		1			1			1			1				1	1	1		1	1	
Guad_R185	1		1			1			1			1				1	1	1		1	1	
Guad_R190	2		2			2			2			2				2	2	2		2	2	

HEC-HMS Reach Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-14	May-15	Oct-15	May-16
Guad_R195	1		1			1			1			1				1	1	1		1	1	
GeronimoCk_R010	3		3			3			3			3				3	3	3		3	3	
GeronimoCk_R020	2		2			2			2			2				2	2	2		2	2	
GeronimoCk_R030	2		2			2			2			2				2	2	2		2	2	
Guad_R200	1		1			1			1			1				1	1	1		1	1	
Guad_R205	2		2			1			1							2					1	
Guad_R210	4		4			2			2							4					2	
Guad_R215	6		6			3			3							6					3	
Guad_R220	4		4			2			2							4					2	
Guad_R225	4		4			2			2							4					2	
Guad_R228	4		4			1			1							1					1	
Guad_R230	13		13			3	5		6											2		
PeachCr_R010	8						8		8				8						8	8		
PeachCr_R020	8						8		8				8						8	8		
PeachCr_R040	6						8		8				8						8	8		
Guad_R240	14		14			3	6		6											2		
Guad_R250	6		6			1	2		3											1		
SandiesCr_R010	6		4	4			6							6								
SandiesCr_R020	3		3	3			3							3								
SandiesCr_R030	5																					
Guad_R260	7		7			4	4		4											4		
Guad_R280	15		15			8	8		8											8		
ColetoCk_R010	2	2	5	5					2	2	1	5										
PerdidoCk_R020	1	1	4	4					1	1	4	4										
PerdidoCk_R030	1	1	4	4					1	1	4	4										
ColetoCk_R030	1	5	5	5					2	3	7	7										
ColetoCk_R040	5	5	5	5					5	5	5	5										
Guad_R295	5	5	5	5					5	5	5	5										
Guad_R300	1	1	1	1					1	1	1	1										
Guad_R305	2	2	2	2					2	2	2	2										

Table 6.17: Calibrated Routing Reach Muskingum Parameters

Muskingum Parameter	HEC-HMS Reach Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-15	Oct-15	May-16
K (hrs)	NF_Guad_R010	1.0					0.75		1	1			1.2				0.75			3.5	1.2	1
K (hrs)	Guad_R010	1.1					1.75		1.75	1.75			1.3				1.75			1.5	1.3	1.75
K (hrs)	JohnsonCr_R010	0.7					0.75		0.75	0.75			1.2				0.75			1.5	1.2	0.75
K (hrs)	Guad_R020	1.0					1.5		1.5	1.5			1.5				1.25			2	1.2	1.5
K (hrs)	Guad_R030	1.8					3		2.5	3			2.6				2.25			2.5	2.2	2.5
K (hrs)	Guad_R040	1.1					1.5		1.5	1.5			1.6				1.5			1.5	1.3	1.5
K (hrs)	Guad_R050	1.7					2.5		2	2.5			2.3				2			2	2	2.2
K (hrs)	Guad_R060	1.1					2		1.5	2			1.5				1.7			1.5	2	2
K (hrs)	Guad_R070	1.7					3		2.5	3			2				2.2			2.5	3	2.5
K (hrs)	Guad_R080	0.9					1.3		1.3	1.3			1.2				1.3			1.3	1.3	1.3
K (hrs)	Guad_R090	7.0					12		11	12			10				12			11	12	11
K (hrs)	Guad_R100	1.4					2.3		2.3	2.3			2.5				2.5			2.3	2.3	2.3
K (hrs)	Guad_R110	2.9					2.5		2.5	2.5			2.5				2.5			2.5	2.5	2.5
K (hrs)	SmithCk_R020	6.9	8	8.5	8.5					8.5	8.5	8.5	8.5									
K (hrs)	YorktownCk_R020	4.1	6	6.6	6.6					6.6	6.5	6.5	6.5									
K (hrs)	FifteenmileCk_R010	3.6	6	6.1	6.1					6.1	6	5.9	6									
K (hrs)	FifteenmileCk_R020	5.4	5.4	4.5	3.5					6.4	7.5	3.5	8.5									
K (hrs)	FifteenmileCk_R030	3.9	3.9	3.9	3.9					3.9	7	3	7									
K (hrs)	TwelvemileCk_R020	4.4	1.7	5.4	9					5.4	5.4	6	6									
X	NF_Guad_R010	0.2					0.2		0.2	0.2			0.2			0.2				0.01	0.2	0.2
X	Guad_R010	0.2					0.2		0.3	0.2			0.2			0.2				0.4	0.2	0.2
X	JohnsonCr_R010	0.2					0.2		0.2	0.2			0.2			0.2				0.4	0.2	0.2
X	Guad_R020	0.2					0.2		0.3	0.2			0.2			0.2				0.4	0.2	0.2
X	Guad_R030	0.2					0.2		0.25	0.2			0.3			0.2				0.2	0.3	0.2
X	Guad_R040	0.2					0.2		0.25	0.2			0.3			0.25				0.2	0.3	0.2
X	Guad_R050	0.2					0.25		0.25	0.2			0.3			0.25				0.25	0.3	0.2
X	Guad_R060	0.2					0.2		0.2	0.2			0.2			0.2				0.2	0.2	0.2
X	Guad_R070	0.2					0.2		0.2	0.2			0.2			0.2				0.2	0.2	0.2
X	Guad_R080	0.2					0.2		0.2	0.2			0.2			0.2				0.2	0.2	0.2
X	Guad_R090	0.2					0.2		0.22	0.2			0.1			0.2				0.2	0.2	0.2
X	Guad_R100	0.2					0.2		0.2	0.2			0.1			0.2				0.2	0.2	0.2
X	Guad_R110	0.2					0.2		0.2	0.4			0.2			0.2				0.2	0.2	0.2
X	SmithCk_R020	0.3	0.2	0.3	0.3					0.3	0.3	0.3	0.3									
X	YorktownCk_R020	0.3	0.2	0.2	0.3					0.3	0.3	0.3	0.3									
X	FifteenmileCk_R010	0.3	0.2	0.2	0.3					0.3	0.3	0.3	0.3									
X	FifteenmileCk_R020	0.3	0.2	0.3	0.3					0.2	0.3	0.3	0.2									
X	FifteenmileCk_R030	0.3	0.2	0.3	0.3					0.3	0.1	0.3	0.3									
X	TwelvemileCk_R020	0.3	0.4	0.4	0.4					0.2	0.3	0.3	0.3									
Subreaches	NF_Guad_R010	4					1		1	1			4			1				1	4	1

Muskingum Parameter	HEC-HMS Reach Name	Initial	Oct-97	Oct-98	Sep-01	Nov-01	Jul-02	Nov-02	Jun-04	Nov-04	May-05	Mar-07	Jul-07	Apr-09	Oct-09	Apr-10	Jun-10	Jan-12	Oct-13	May-15	Oct-15	May-16
Subreaches	Guad_R010	4					1		2	1			4			1				4	4	1
Subreaches	JohnsonCr_R010	4					1		1	1			2			1				4	4	1
Subreaches	Guad_R020	4					1		2	1			2			1				8	4	1
Subreaches	Guad_R030	8					2		4	2			8			4				2	8	2
Subreaches	Guad_R040	4					1		2	1			4			2				1	4	1
Subreaches	Guad_R050	8					1		3	1			4			4				1	8	1
Subreaches	Guad_R060	4					1		1	1			1			1				1	1	1
Subreaches	Guad_R070	8					1		1	1			1			1				1	1	1
Subreaches	Guad_R080	4					1		1	1			1			1				1	1	1
Subreaches	Guad_R090	28					4		3	3			2			3				2	3	2
Subreaches	Guad_R100	4					1		1	1			1			1				1	1	1
Subreaches	Guad_R110	12					2		2	2			6			1				2	2	2
Subreaches	SmithCk_R020	1	3	2	3					3	4	3	3									
Subreaches	YorktownCk_R020	1	3	2	3					3	4	3	3									
Subreaches	FifteenmileCk_R010	1	3	2	2					3	3	4	3									
Subreaches	FifteenmileCk_R020	1	3	3	5					2	1	3	2									
Subreaches	FifteenmileCk_R030	1	2	3	4					2	1	3	3									
Subreaches	TwelvemileCk_R020	1	4	4	6					2	4	3	3									

6.4.3 Calibration Results

The final calibration results showed that the HEC-HMS model was able to accurately simulate the response of the watershed, as it reproduced the volume, timing, shape, and peak magnitudes of most observed floods very well. The resulting hydrograph comparisons can be seen in the following figures of this section. The figures show the HEC-HMS computed versus the USGS observed flow hydrographs at each gage location. Figures are only shown for the locations where the USGS stream gages were recording for that event and where the magnitude of the flow was significant enough to warrant calibration. In some cases, only a single black dot appears for the observed flow. These are cases where the gage was not recording, but the USGS did estimate the peak flow of that flood event.

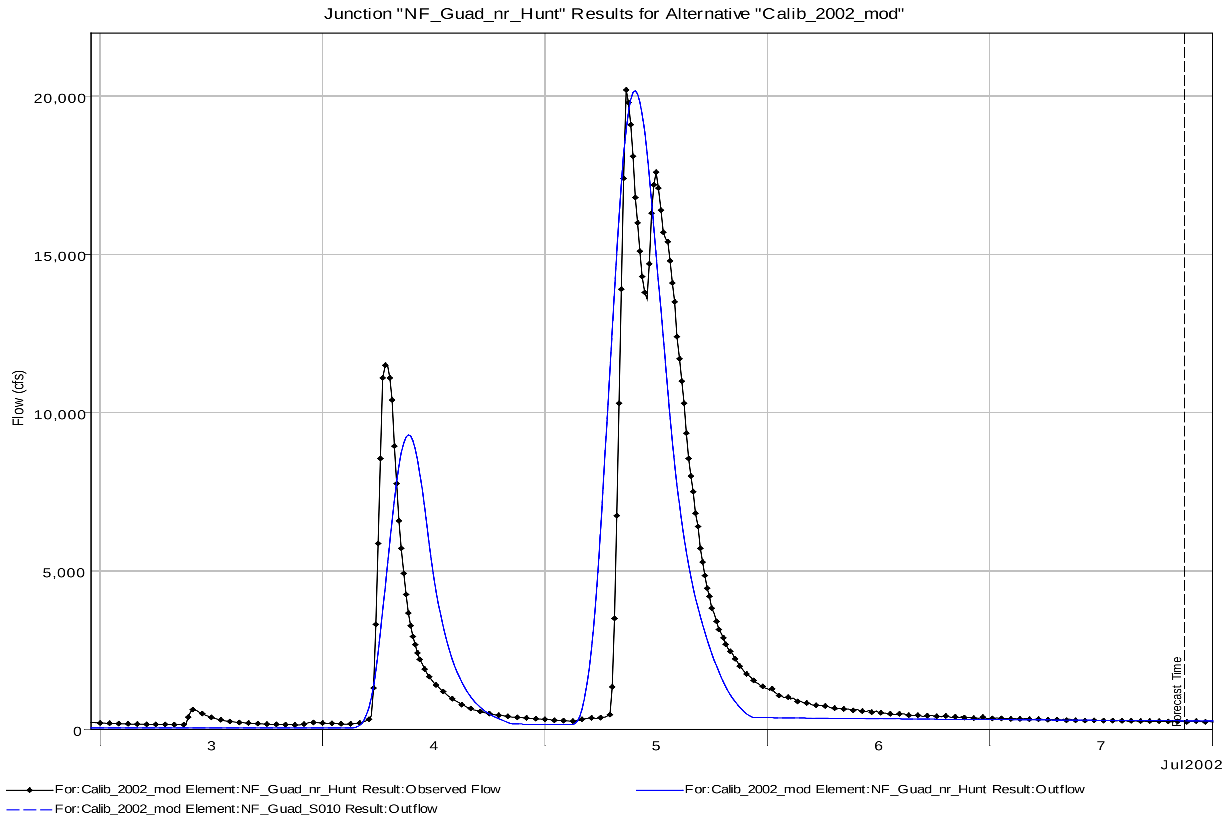


Figure 6.23: Jul 2002 Calibration Results for the North Fork Guadalupe Rv nr Hunt, TX

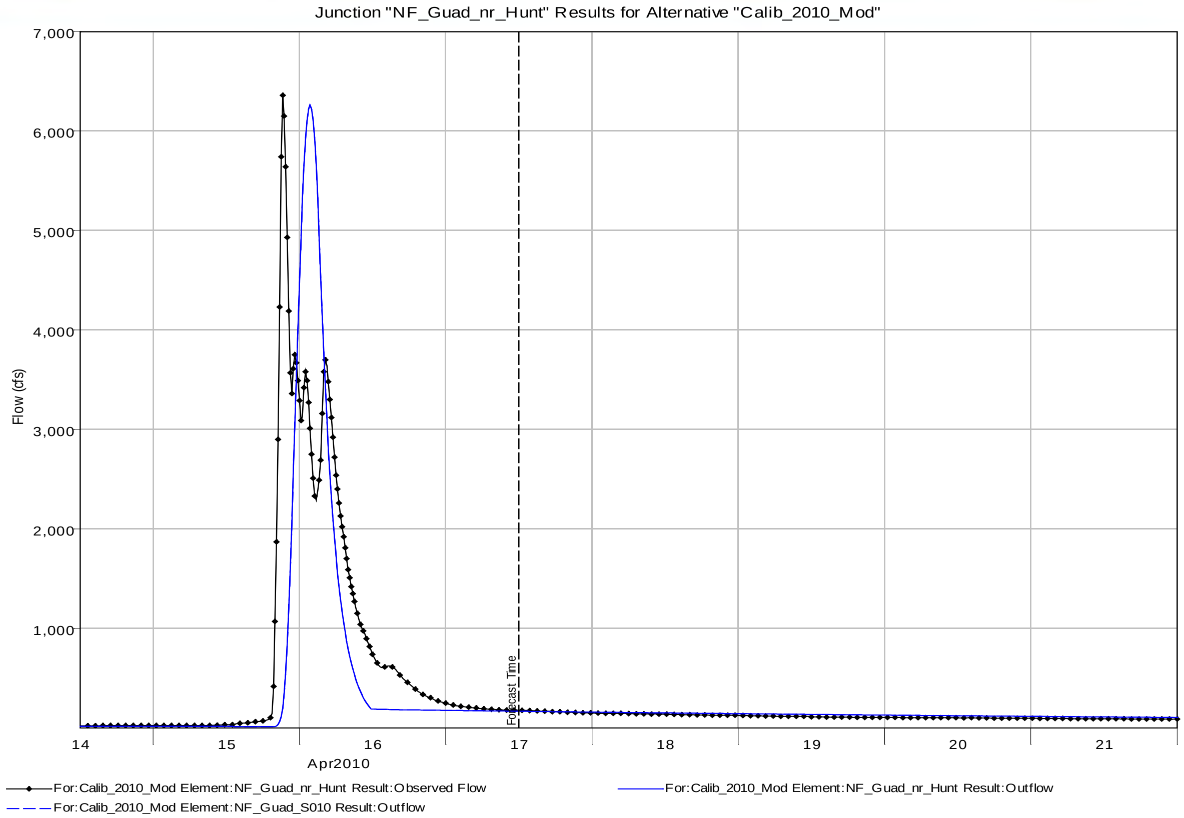


Figure 6.24: Apr 2010 Calibration Results for the North Fork Guadalupe Rv nr Hunt, TX

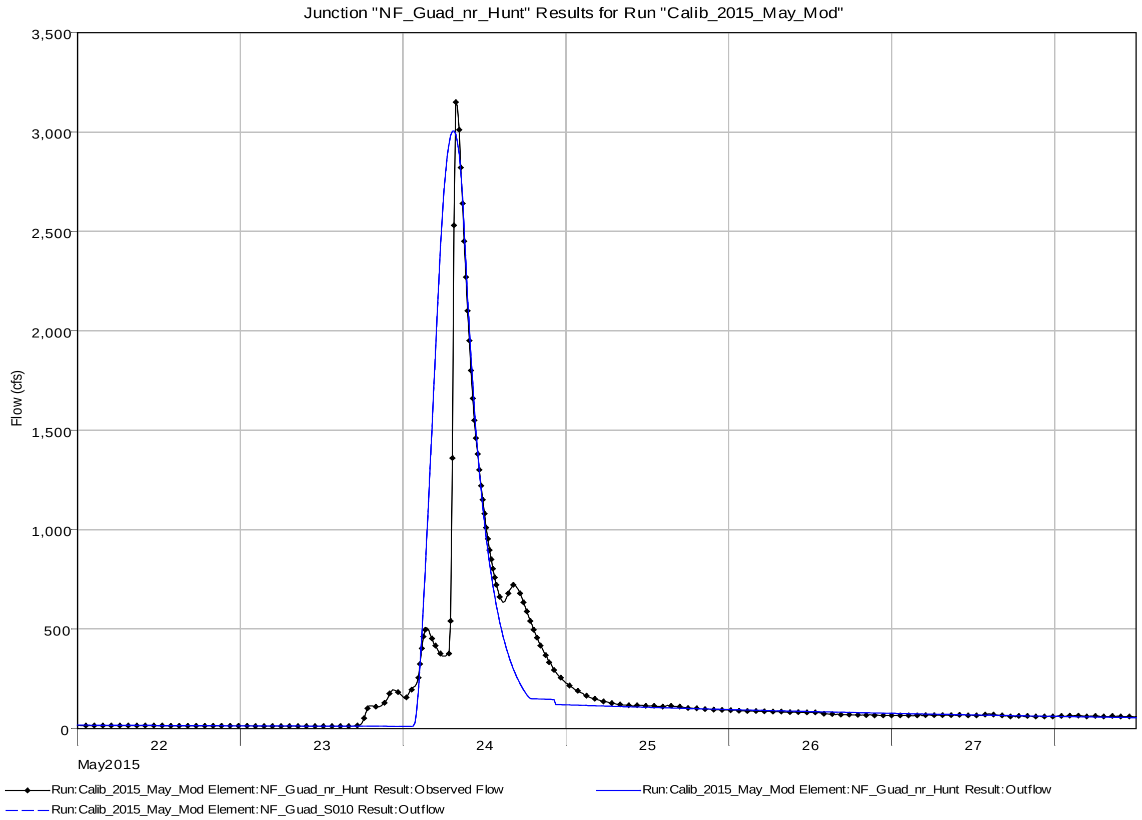


Figure 6.25: May 2015 Calibration Results for the North Fork Guadalupe Rv nr Hunt, TX

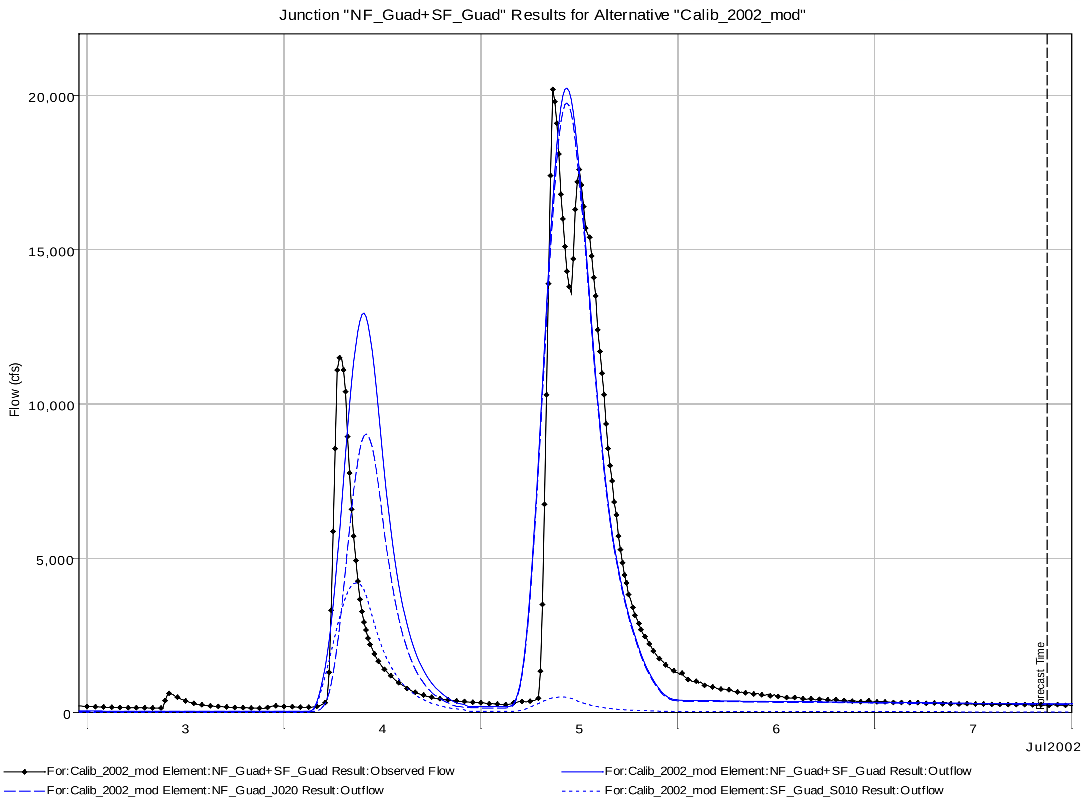


Figure 6.26: Jul 2002 Calibration Results for the Guadalupe Rv nr Hunt, TX

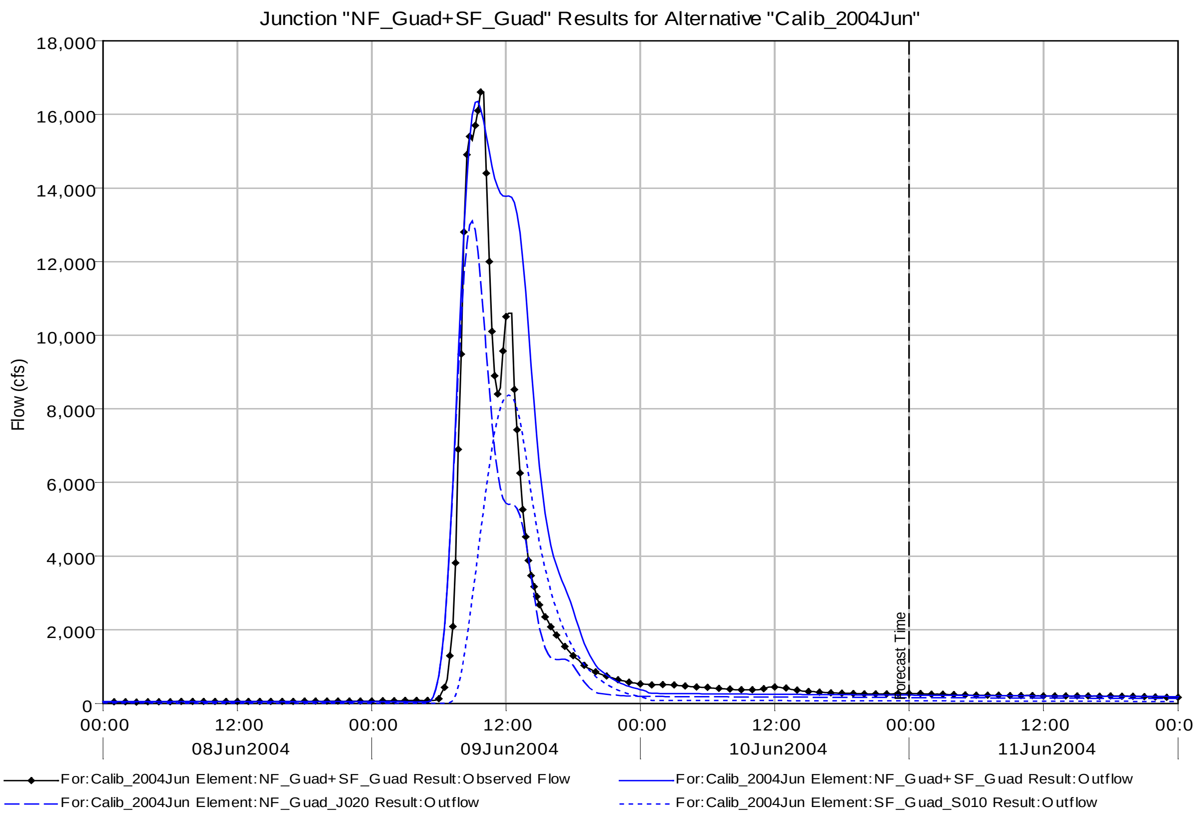


Figure 6.27: Jun 2004 Calibration Results for the Guadalupe Rv nr Hunt, TX

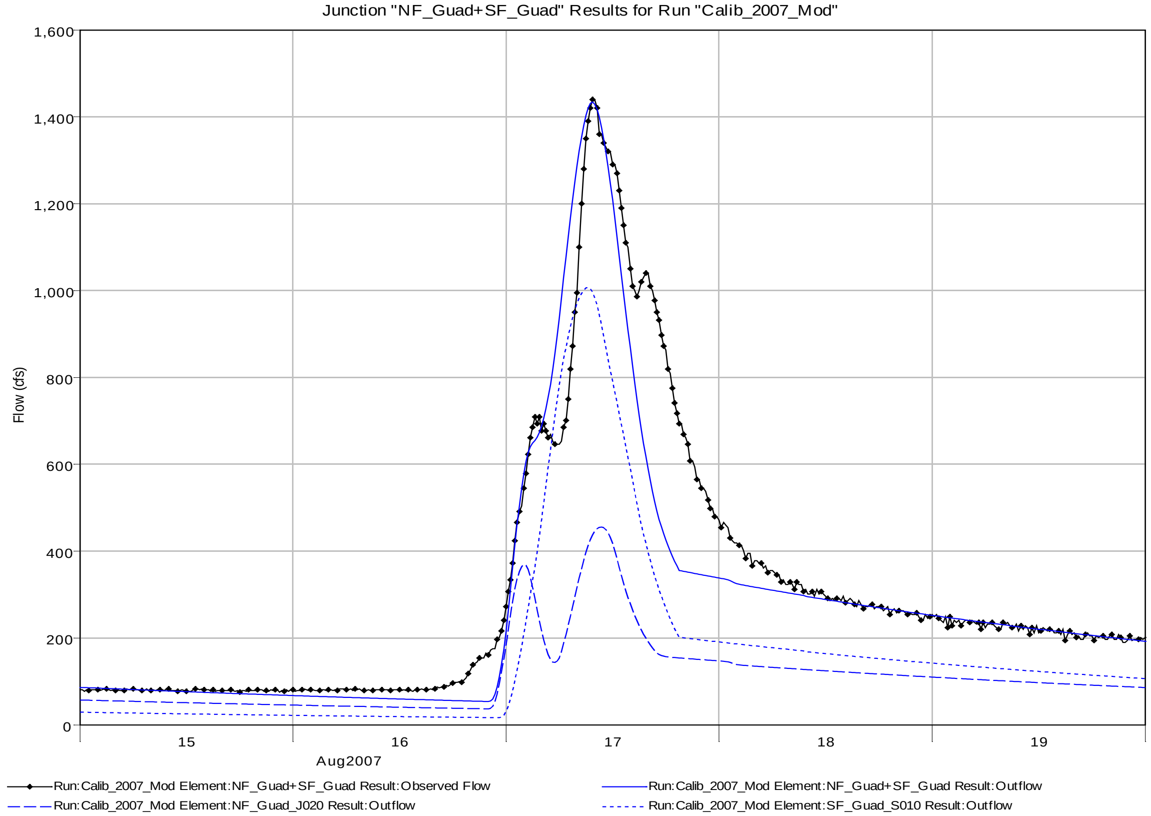


Figure 6.28: Aug 2007 Calibration Results for the Guadalupe Rv nr Hunt, TX

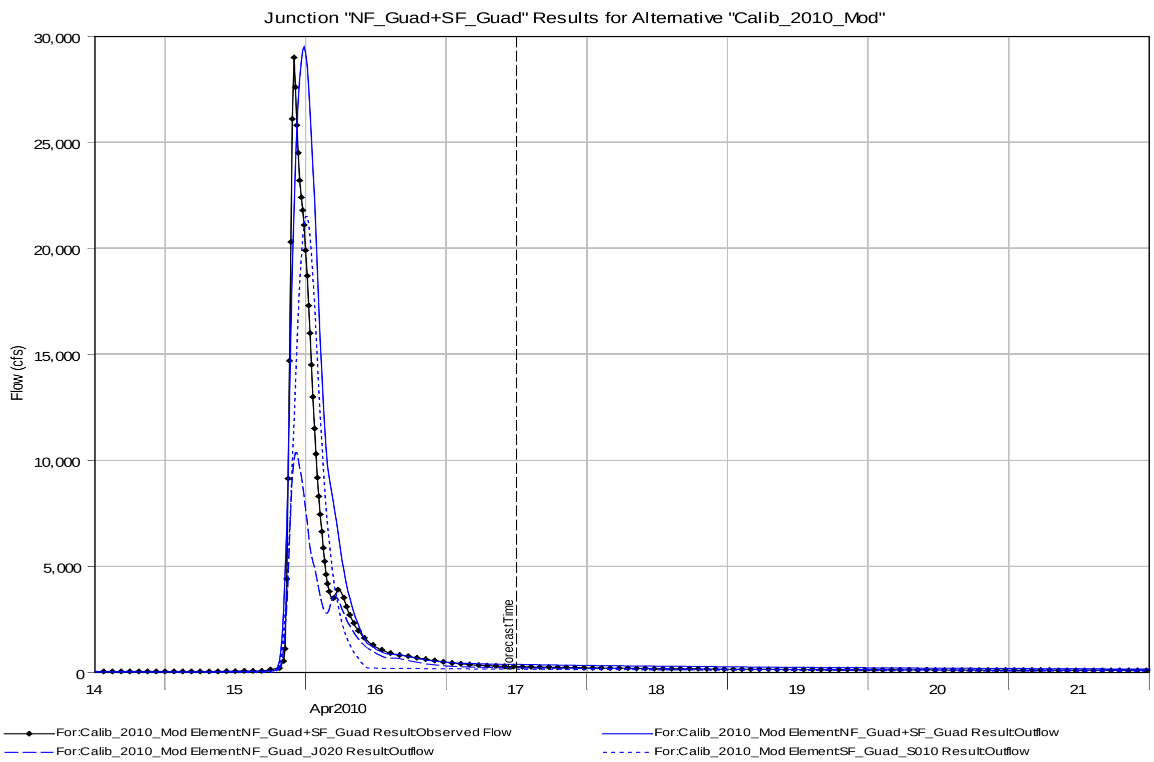


Figure 6.29: Apr 2010 Calibration Results for the Guadalupe Rv nr Hunt, TX

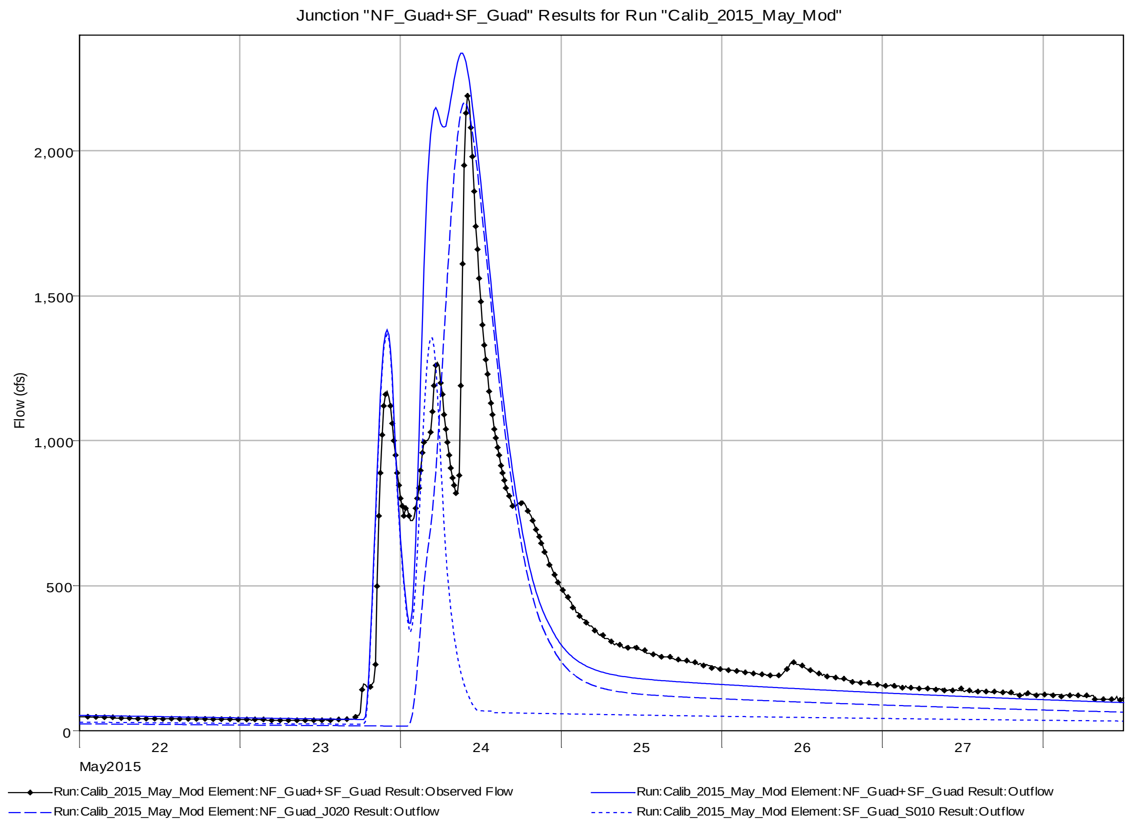


Figure 6.30: May 2015 Calibration Results for the Guadalupe Rv nr Hunt, TX

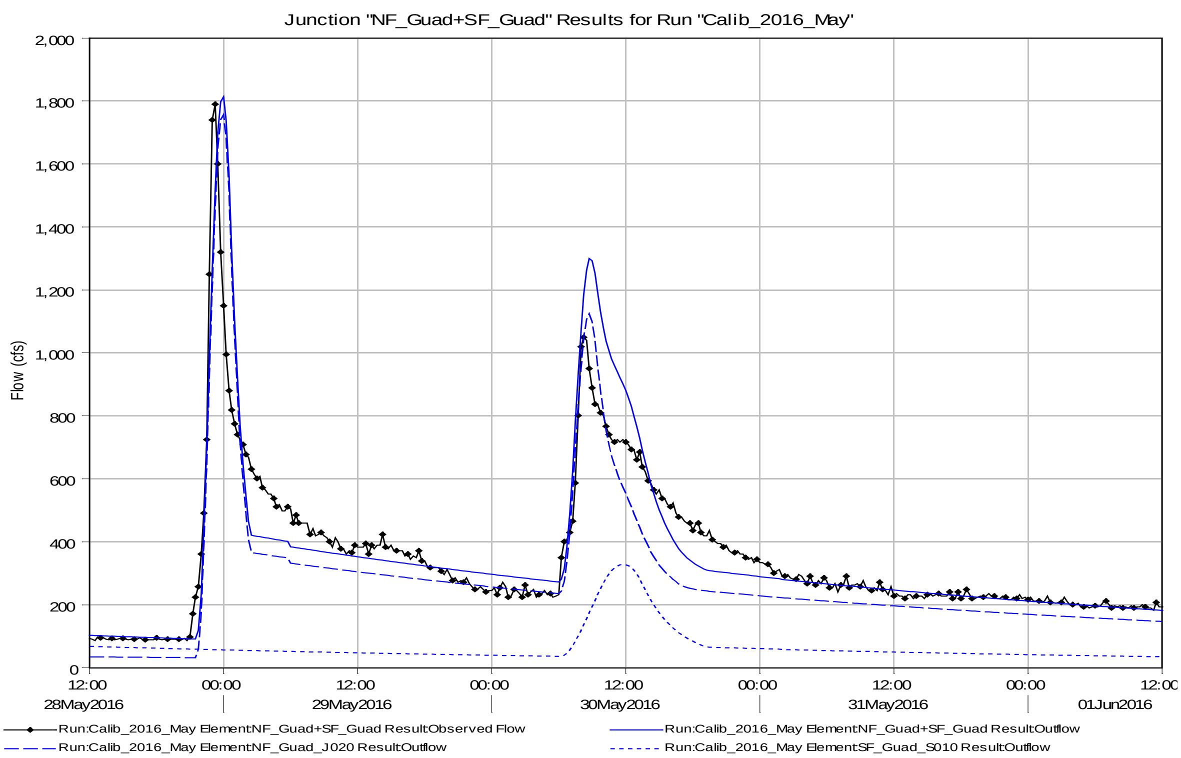


Figure 6.31: May 2016 Calibration Results for the Guadalupe Rv nr Hunt, TX

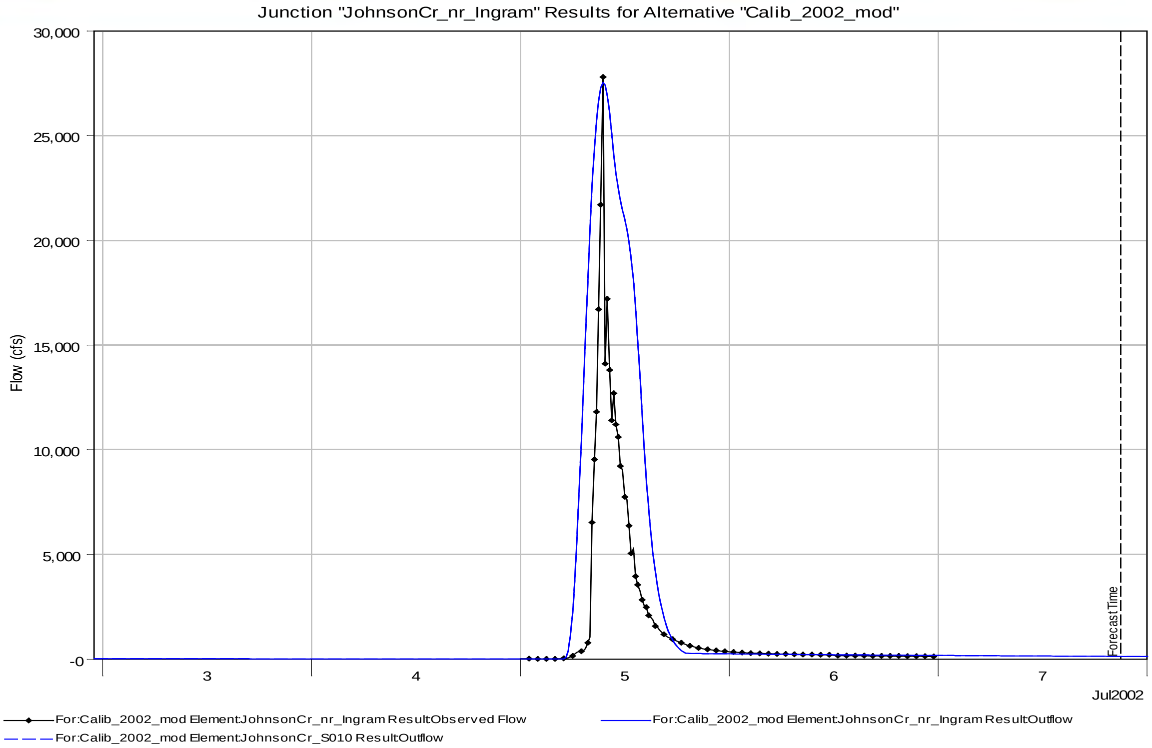


Figure 6.32: Jul 2002 Calibration Results for Johnson Ck nr Ingram, TX

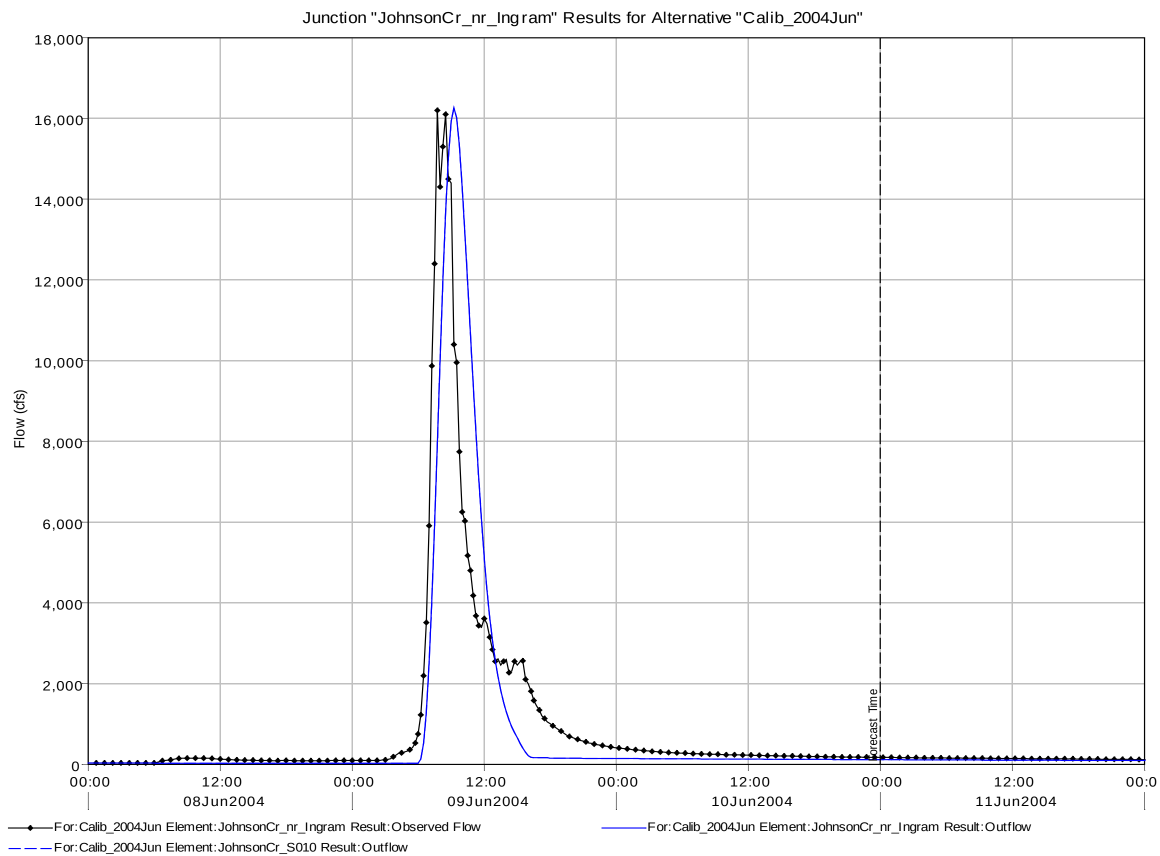


Figure 6.33: Jun 2004 Calibration Results for Johnson Ck nr Ingram, TX

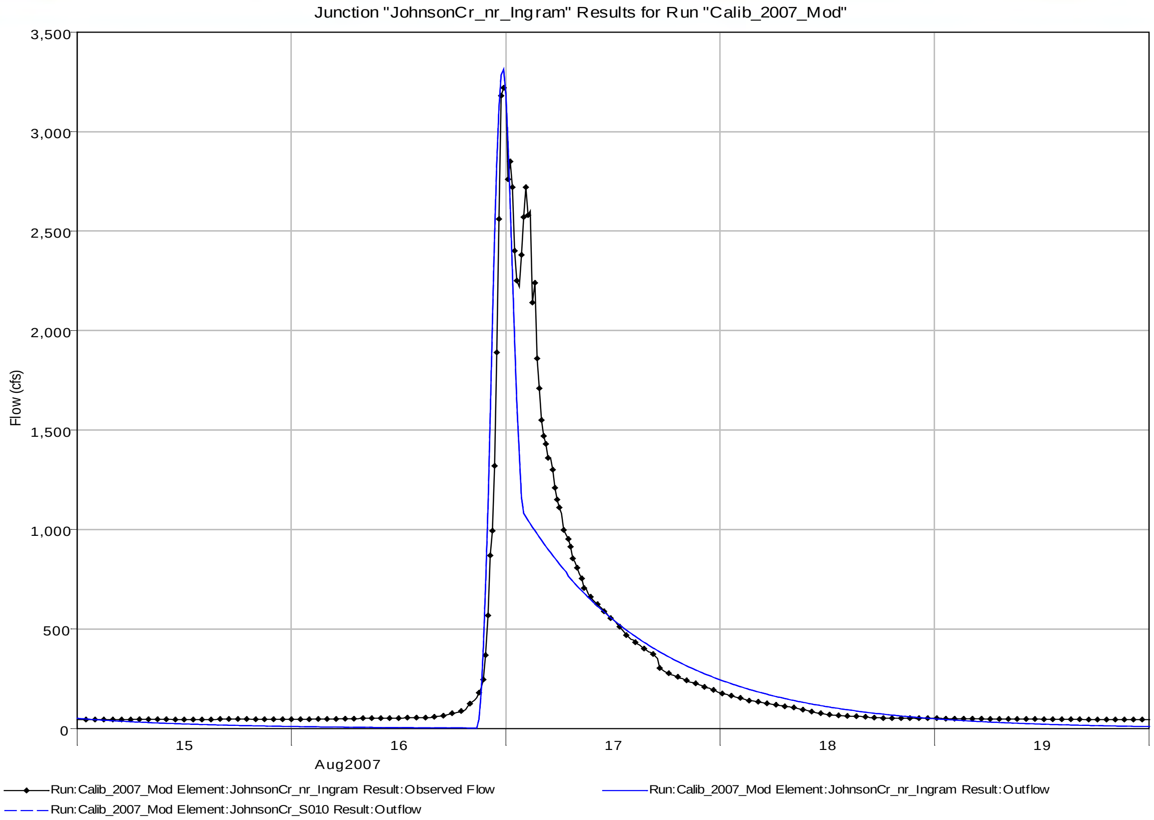


Figure 6.34: Aug 2007 Calibration Results for Johnson Ck nr Ingram, TX

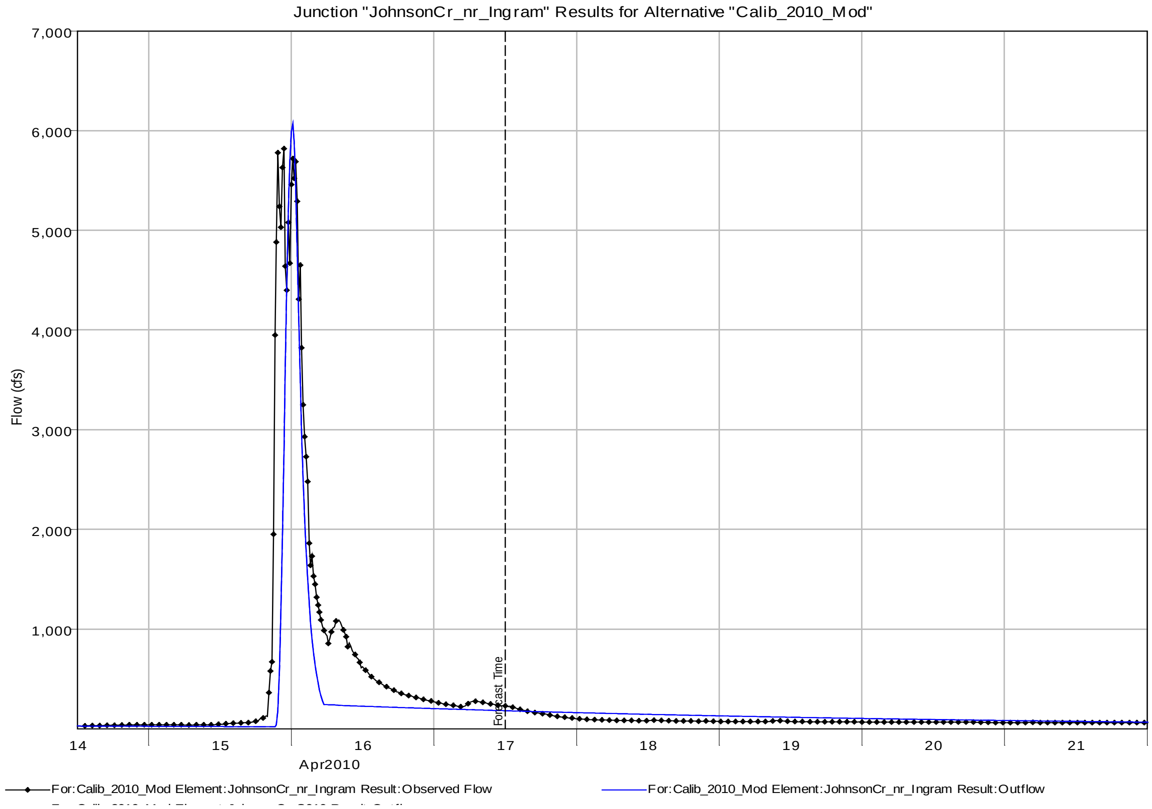


Figure 6.35: Apr 2010 Calibration Results for Johnson Ck nr Ingram, TX

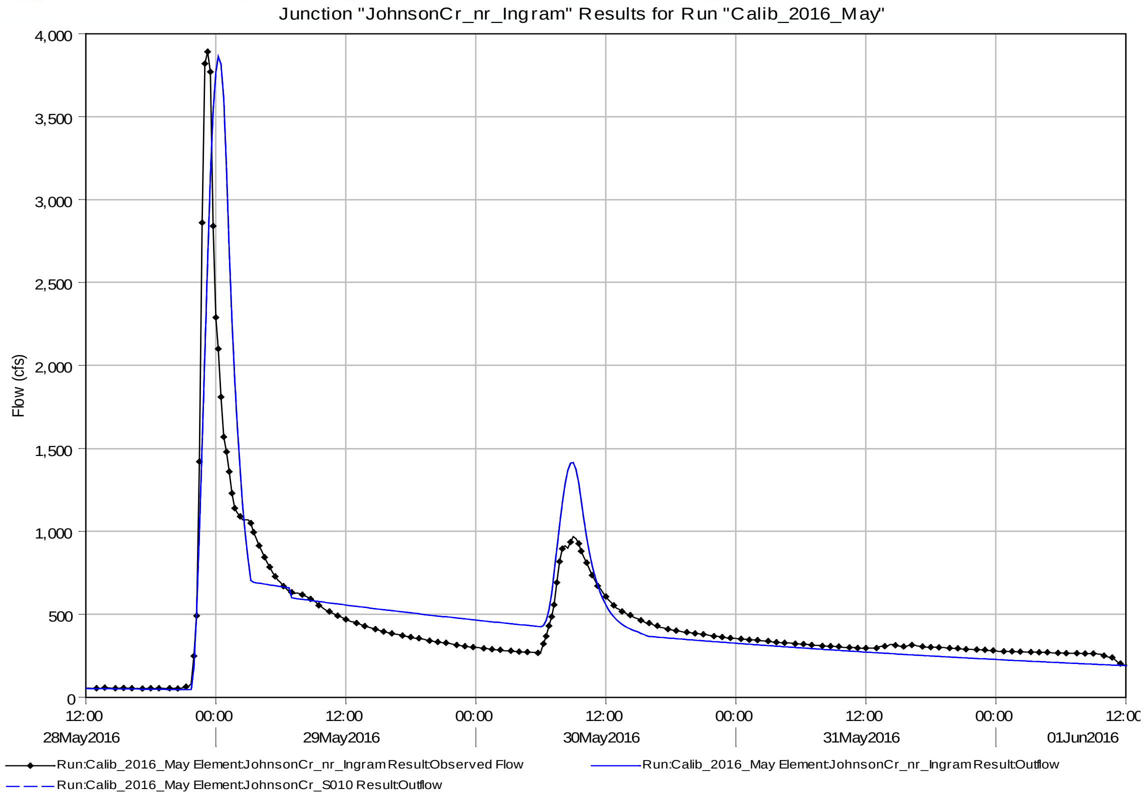


Figure 6.36: May 2016 Calibration Results for Johnson Ck nr Ingram, TX

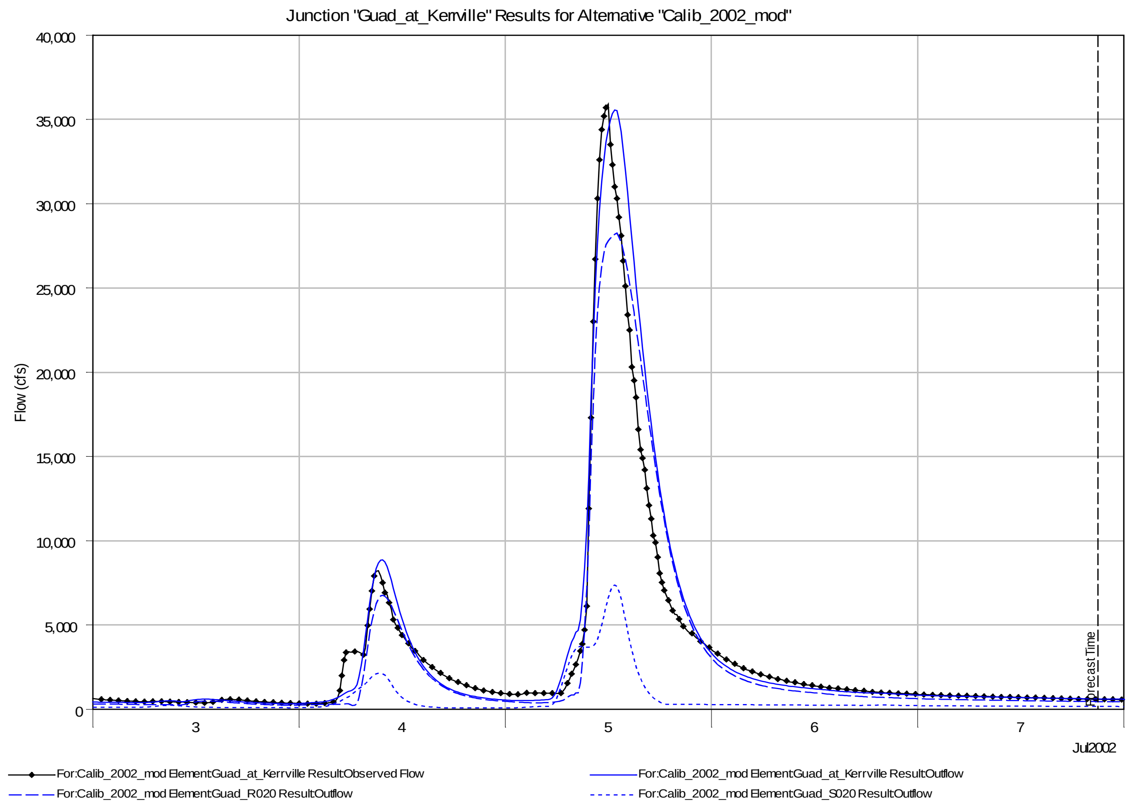


Figure 6.37: Jul 2002 Calibration Results for Guadalupe River at Kerrville, TX

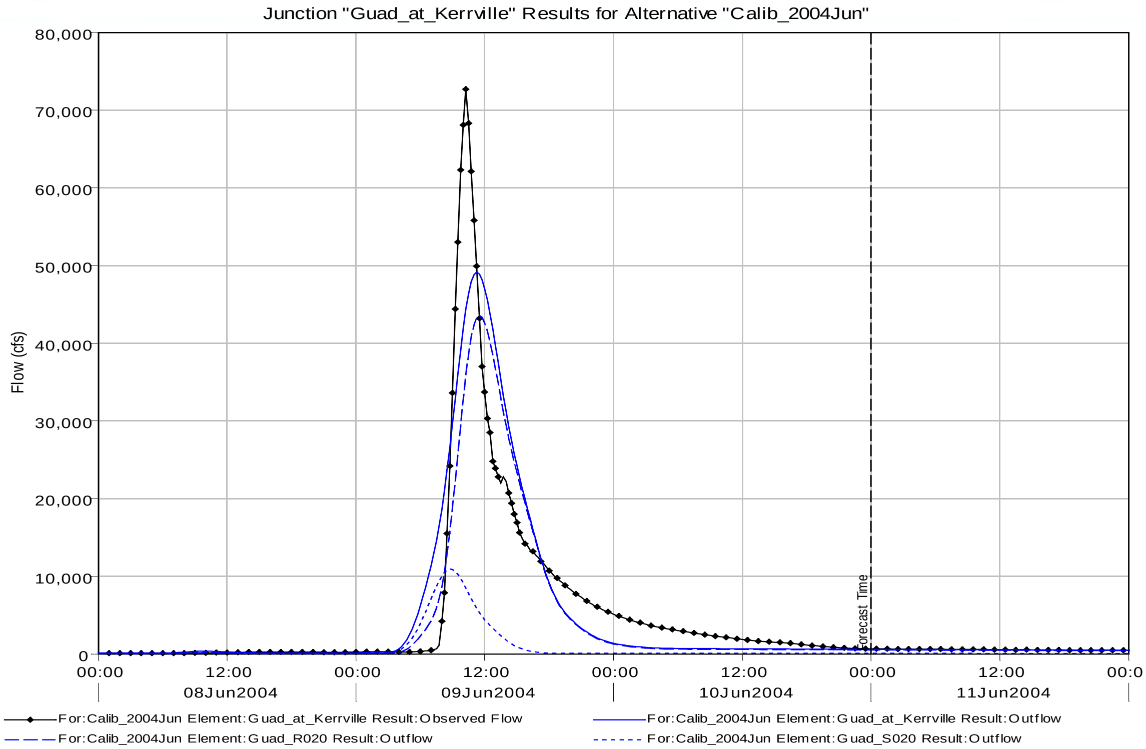


Figure 6.38: Jun 2004 Calibration Results for Guadalupe River at Kerrville, TX

NOTE – Insufficient Rainfall Data

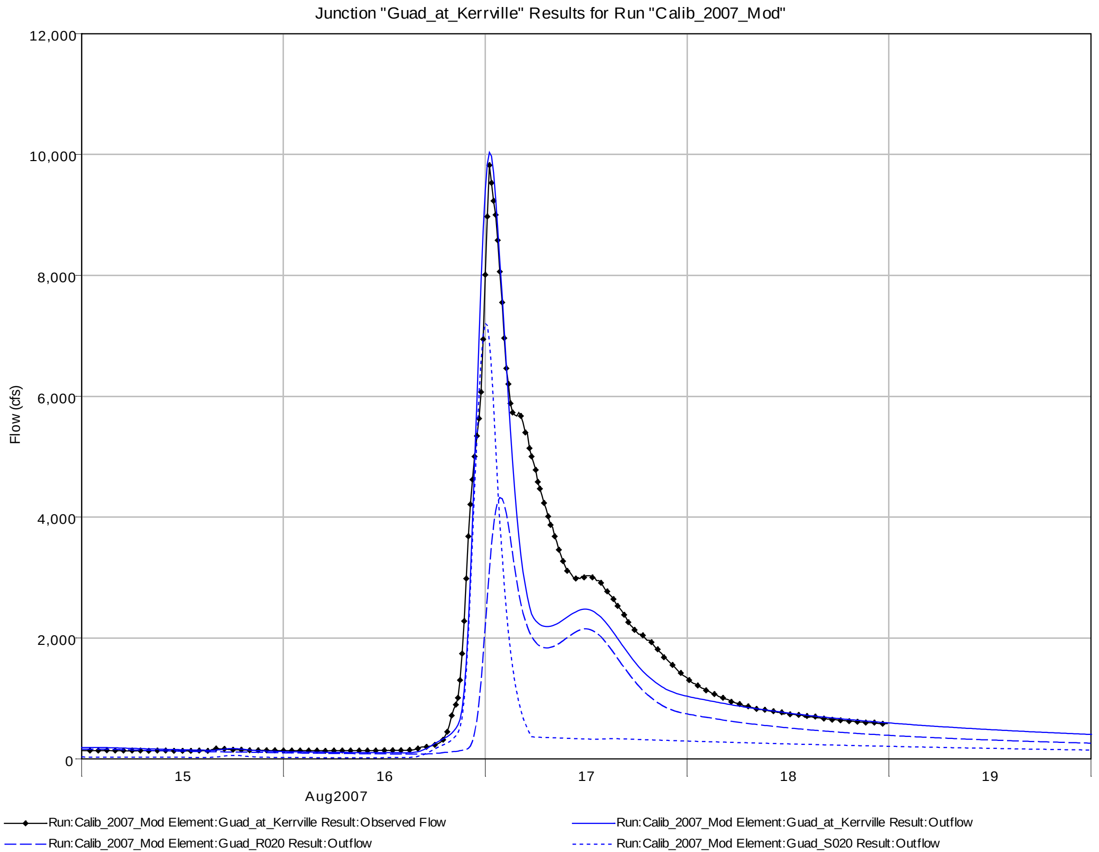


Figure 6.39: Aug 2007 Calibration Results for Guadalupe River at Kerrville, TX

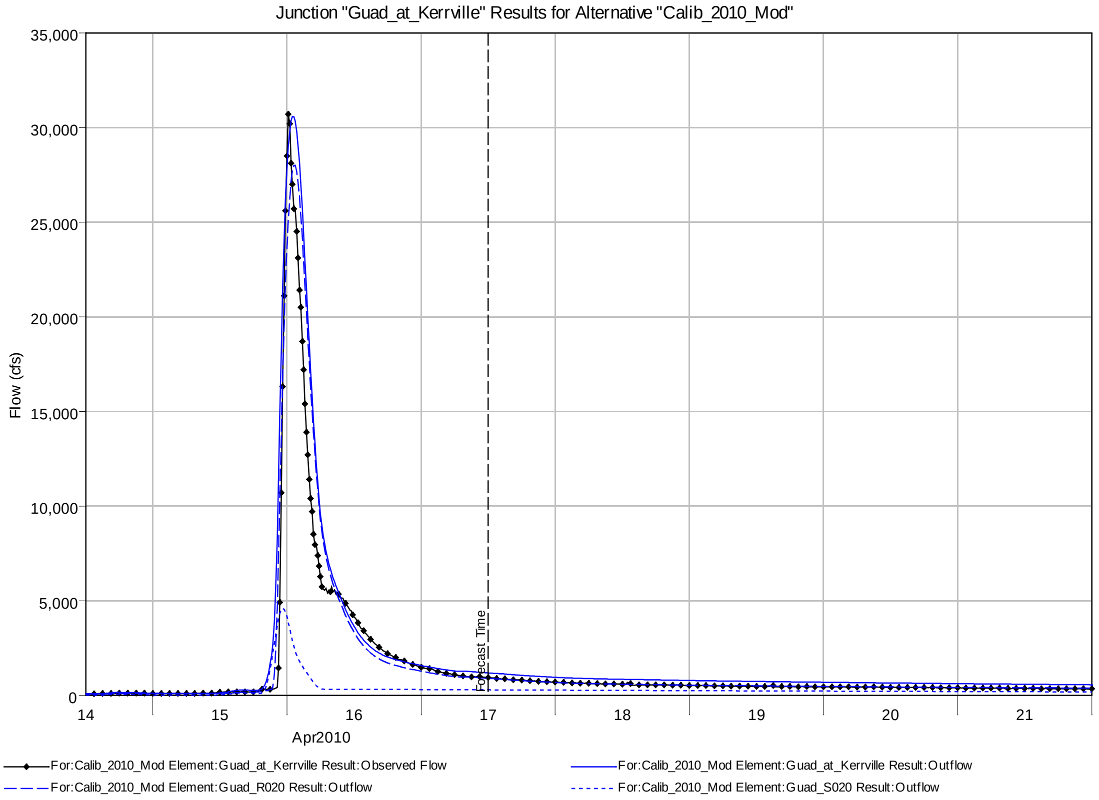


Figure 6.40: Apr 2010 Calibration Results for Guadalupe River at Kerrville, TX

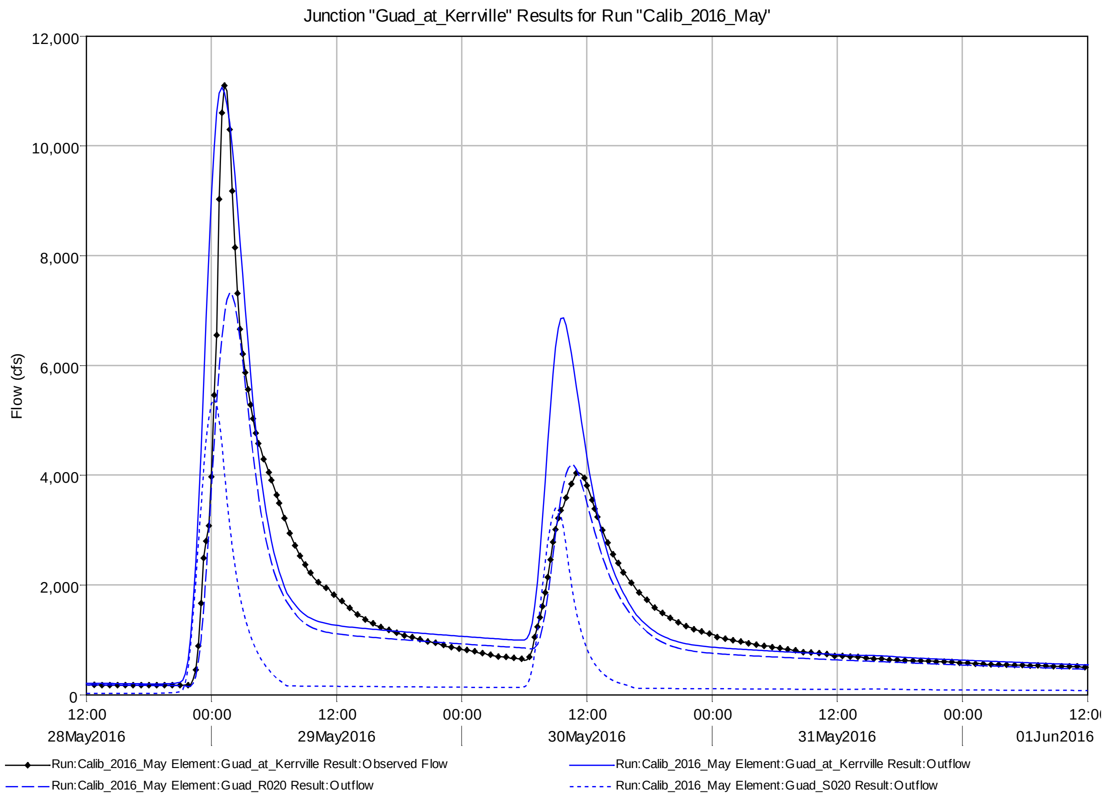


Figure 6.41: May 2016 Calibration Results for Guadalupe River at Kerrville, TX

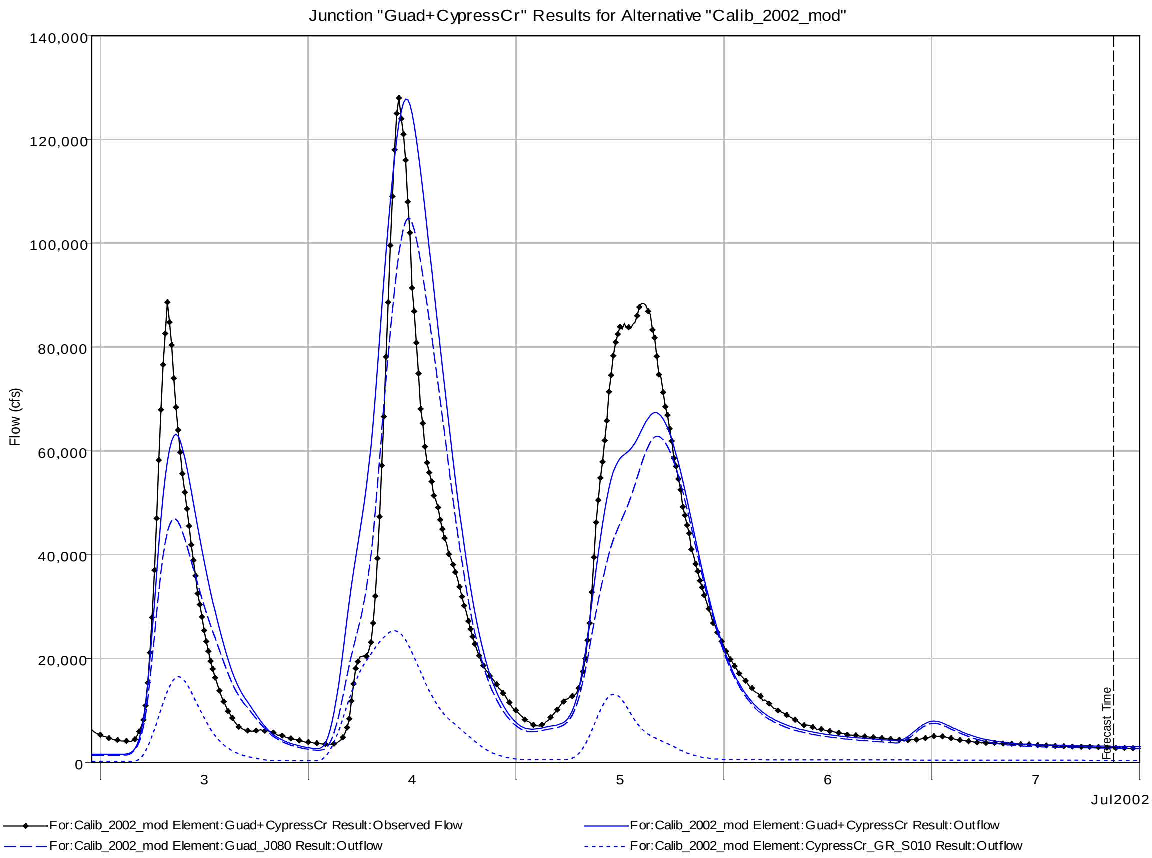


Figure 6.42: Jul 2002 Calibration Results for Guadalupe River at Comfort, TX

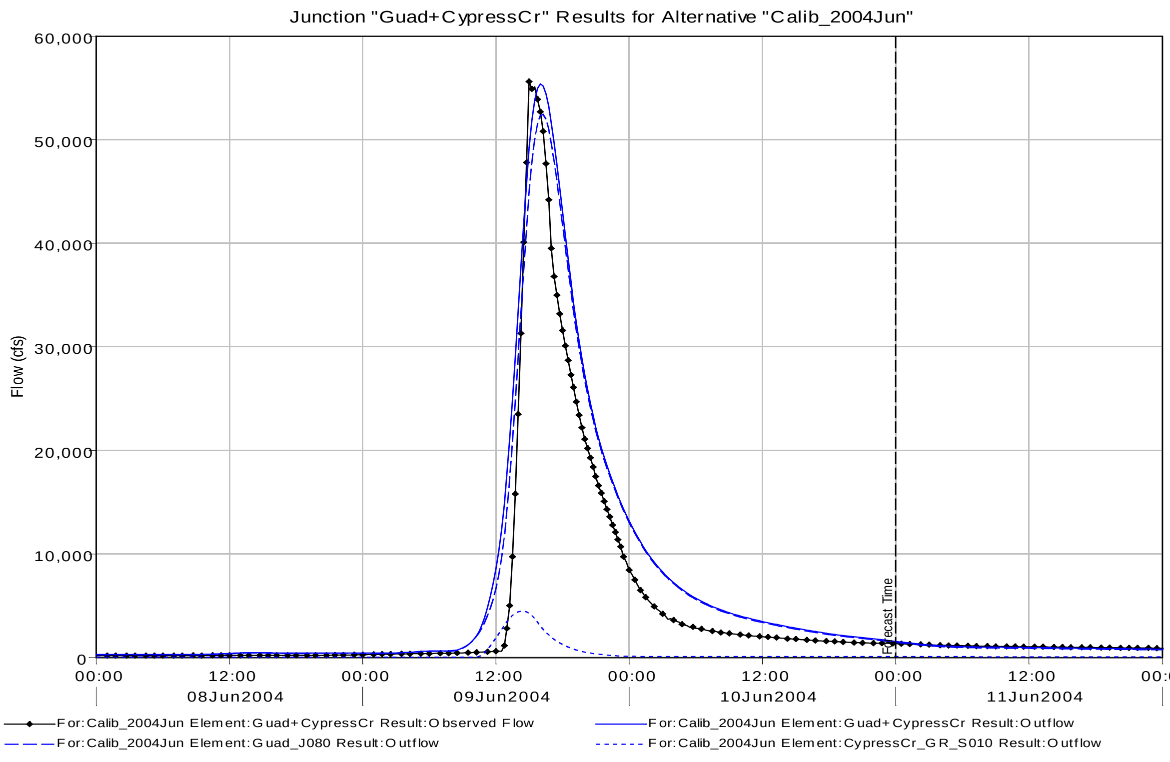


Figure 6.43: Jun 2004 Calibration Results for Guadalupe River at Comfort, TX

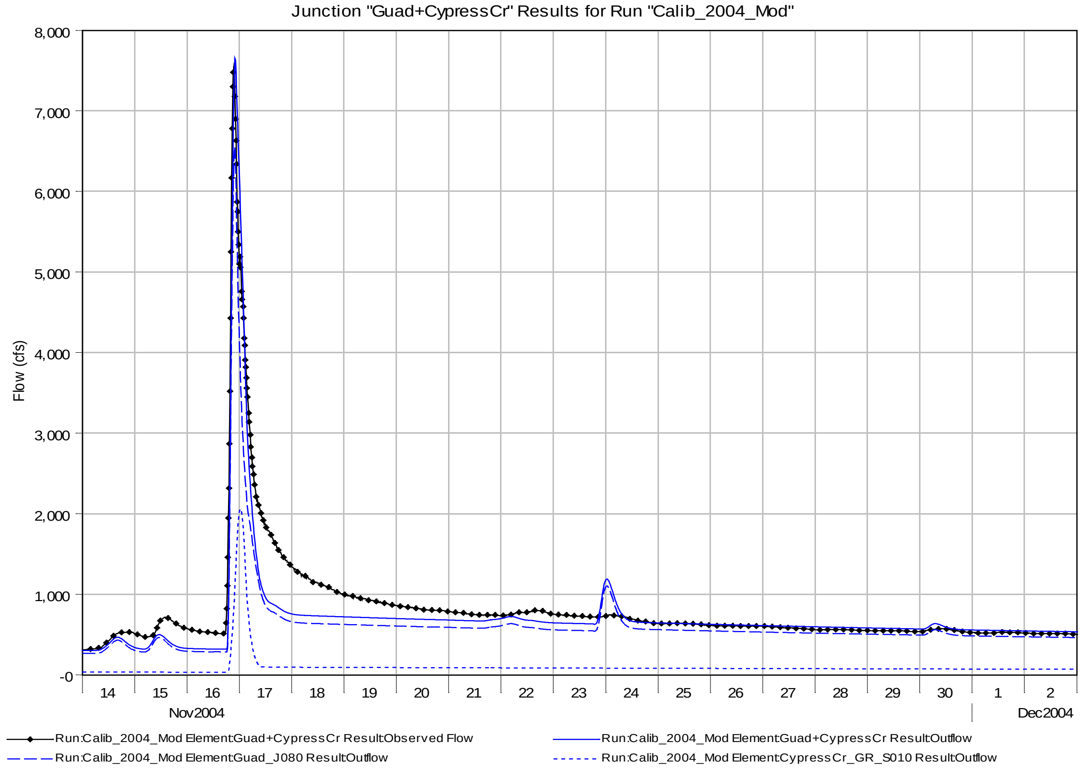


Figure 6.44: Nov 2004 Calibration Results for Guadalupe River at Comfort, TX

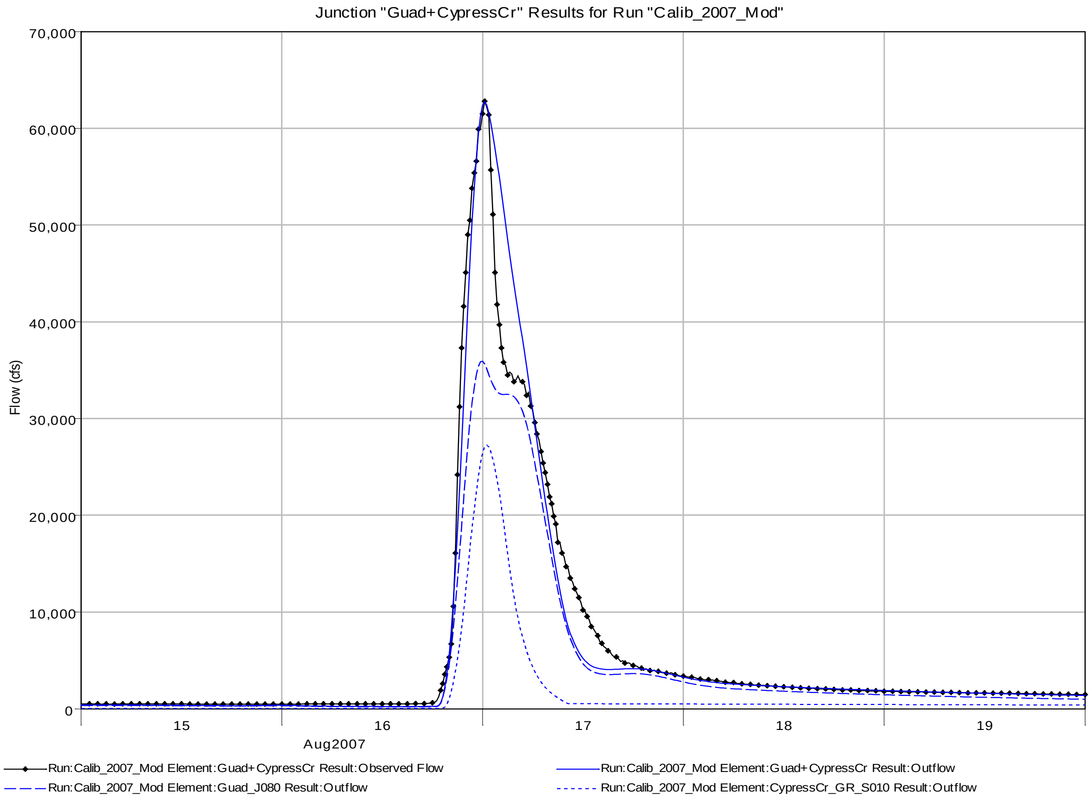


Figure 6.45: Aug 2007 Calibration Results for Guadalupe River at Comfort, TX

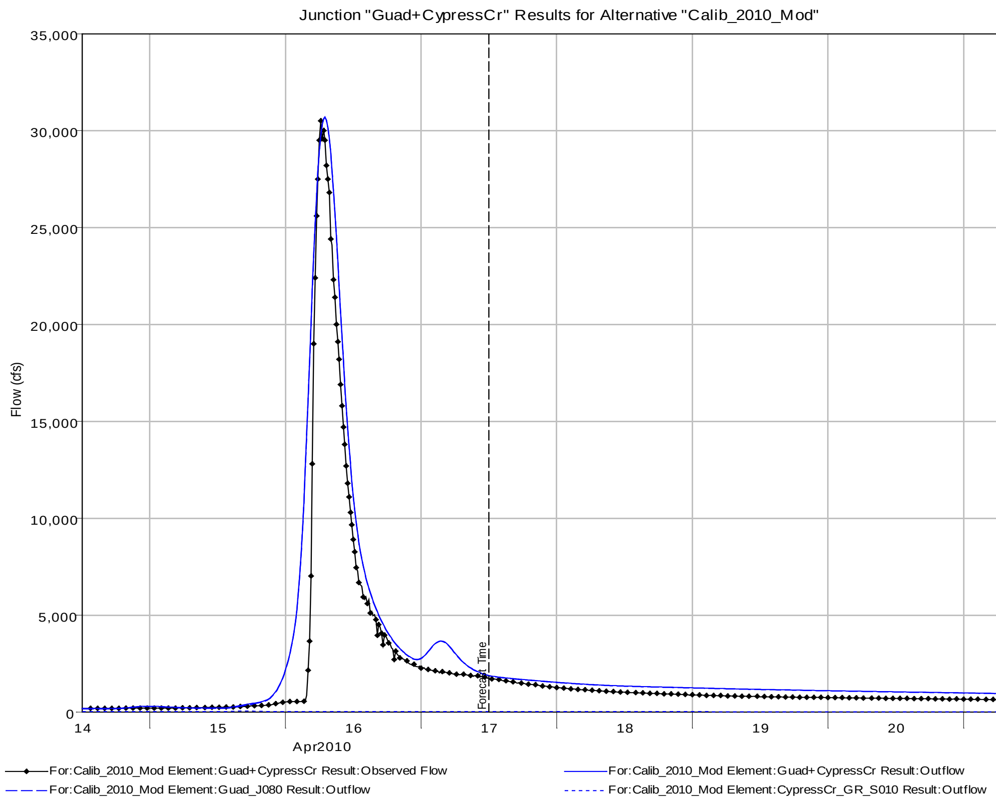


Figure 6.46: Apr 2010 Calibration Results for Guadalupe River at Comfort, TX

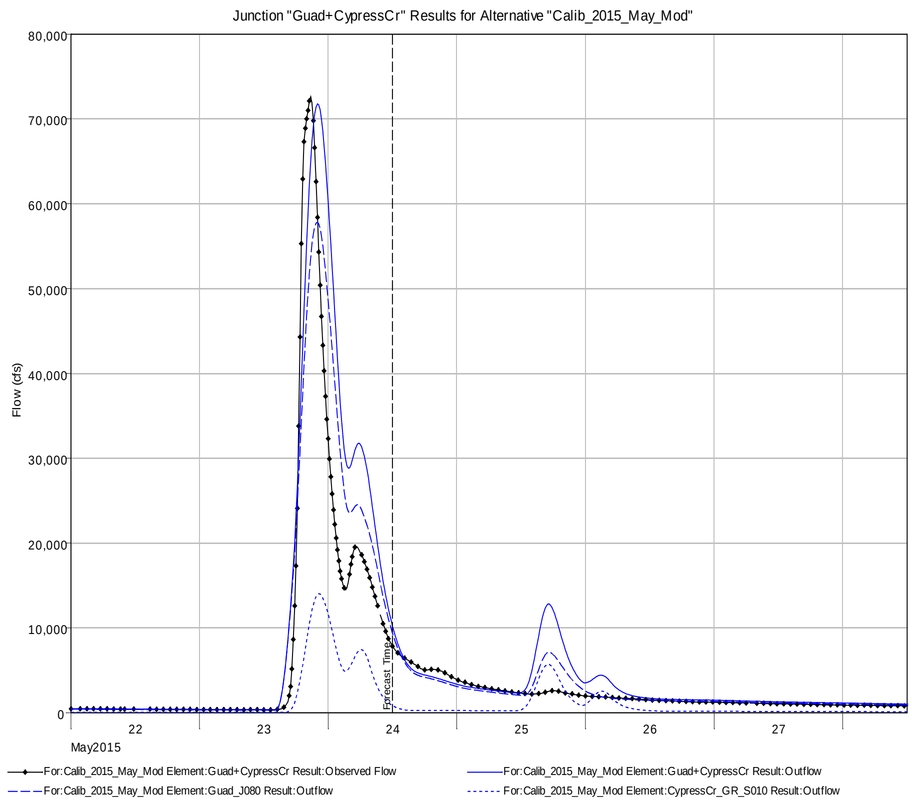


Figure 6.47: May 2015 Calibration Results for Guadalupe River at Comfort, TX

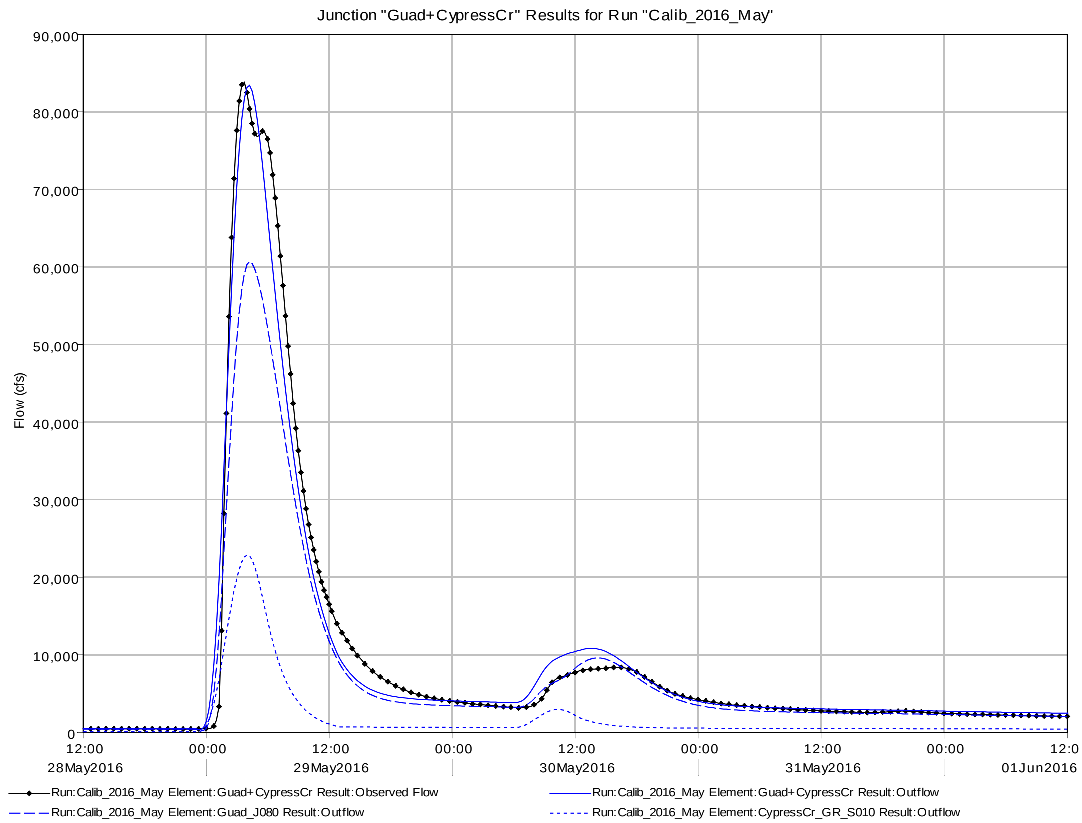


Figure 6.48: May 2016 Calibration Results for Guadalupe River at Comfort, TX

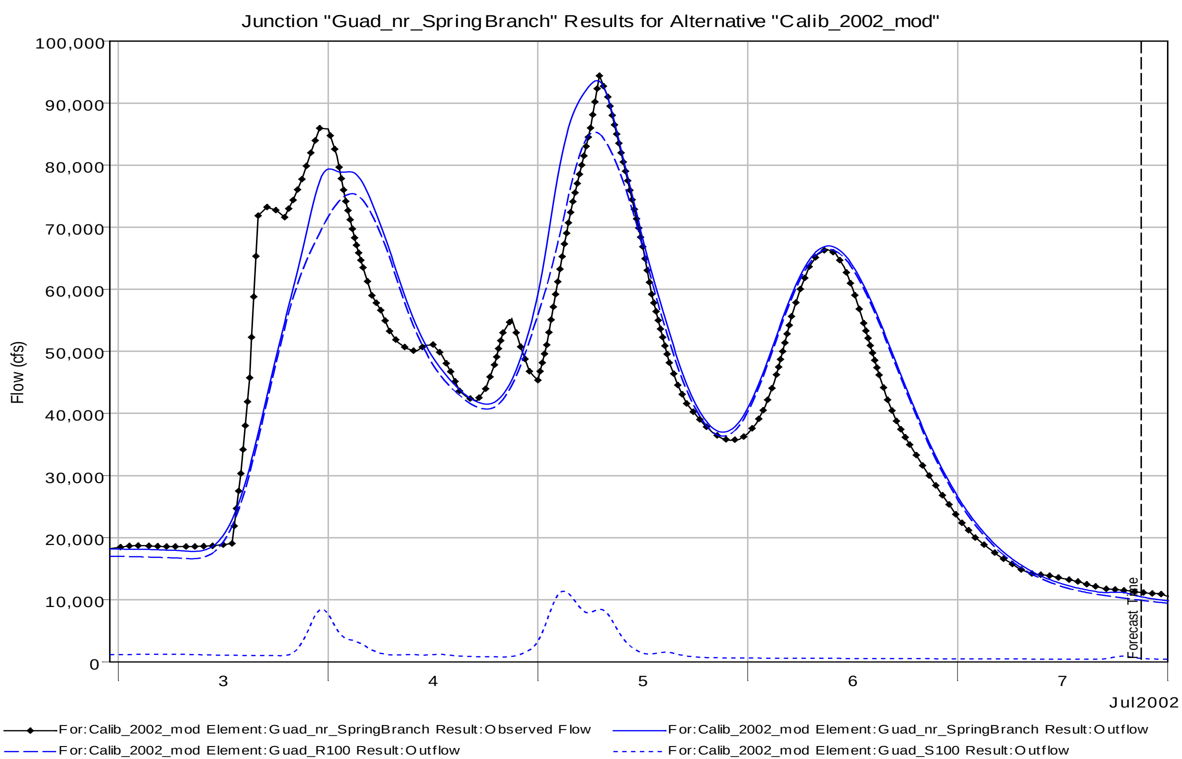


Figure 6.49: Jul 2002 Calibration Results for Guadalupe River nr Spring Branch, TX

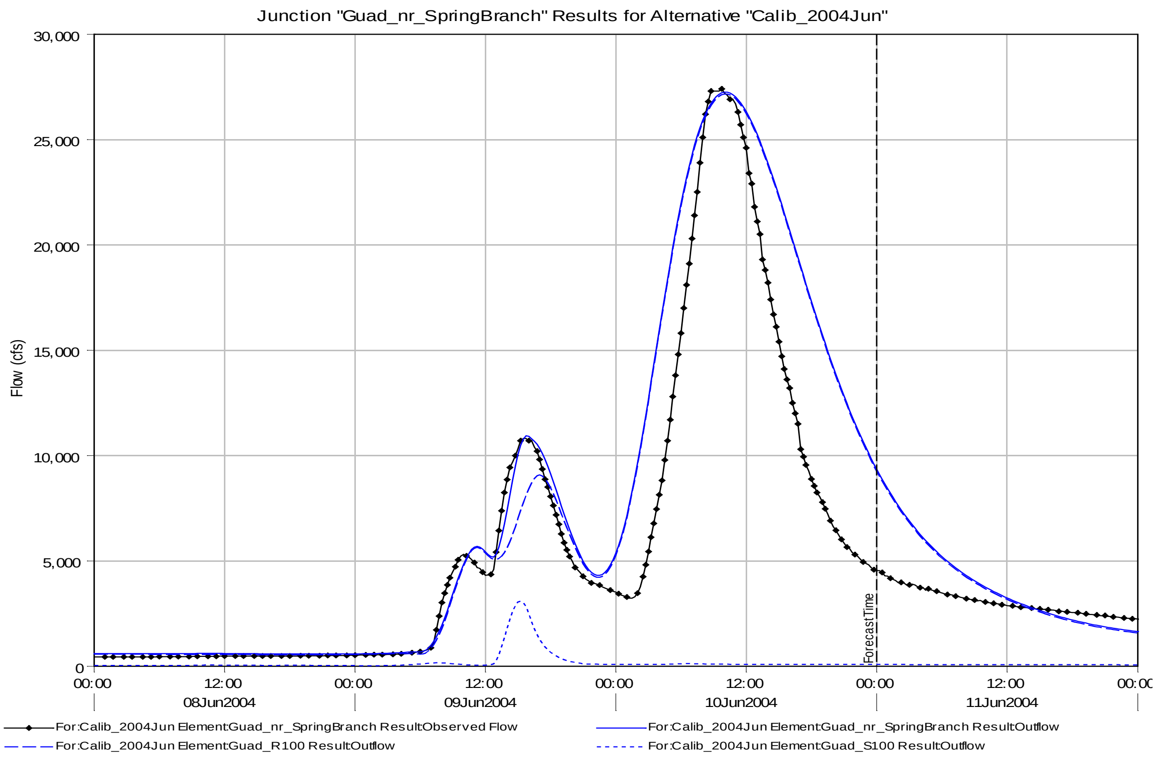


Figure 6.50: Jun 2004 Calibration Results for Guadalupe River nr Spring Branch, TX

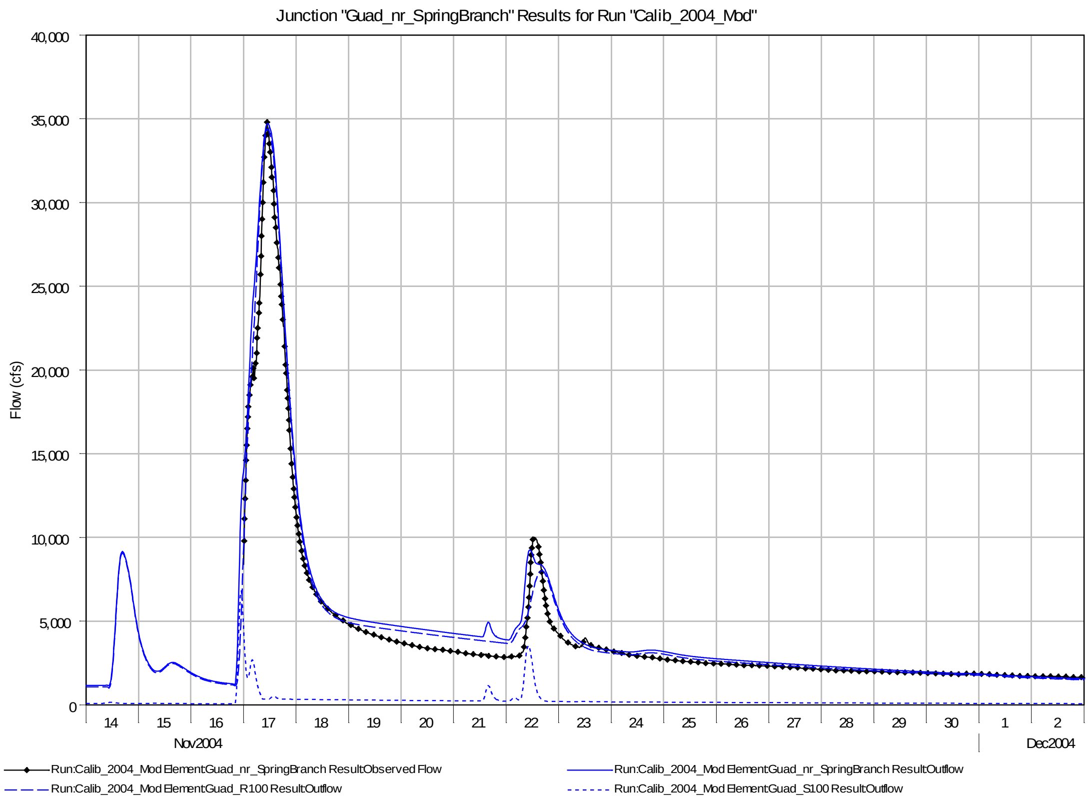


Figure 6.51: Nov 2004 Calibration Results for Guadalupe River nr Spring Branch, TX

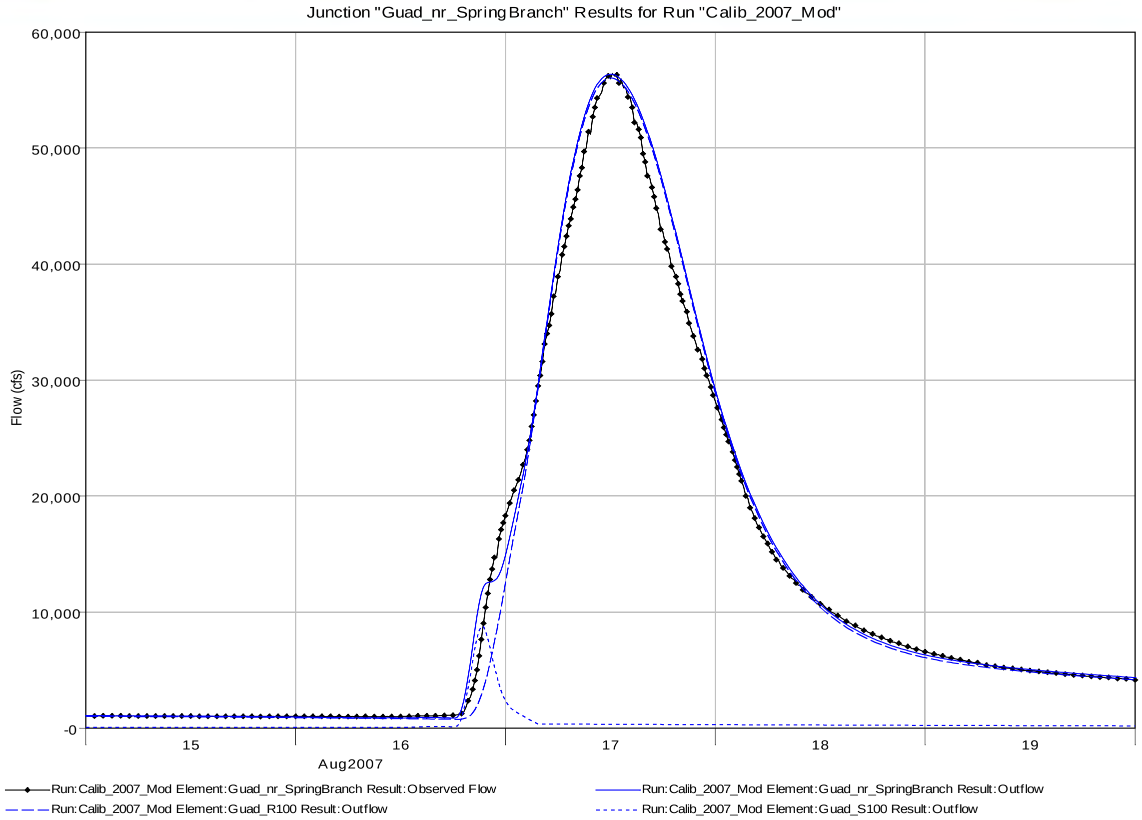


Figure 6.52: Aug 2007 Calibration Results for Guadalupe River nr Spring Branch, TX

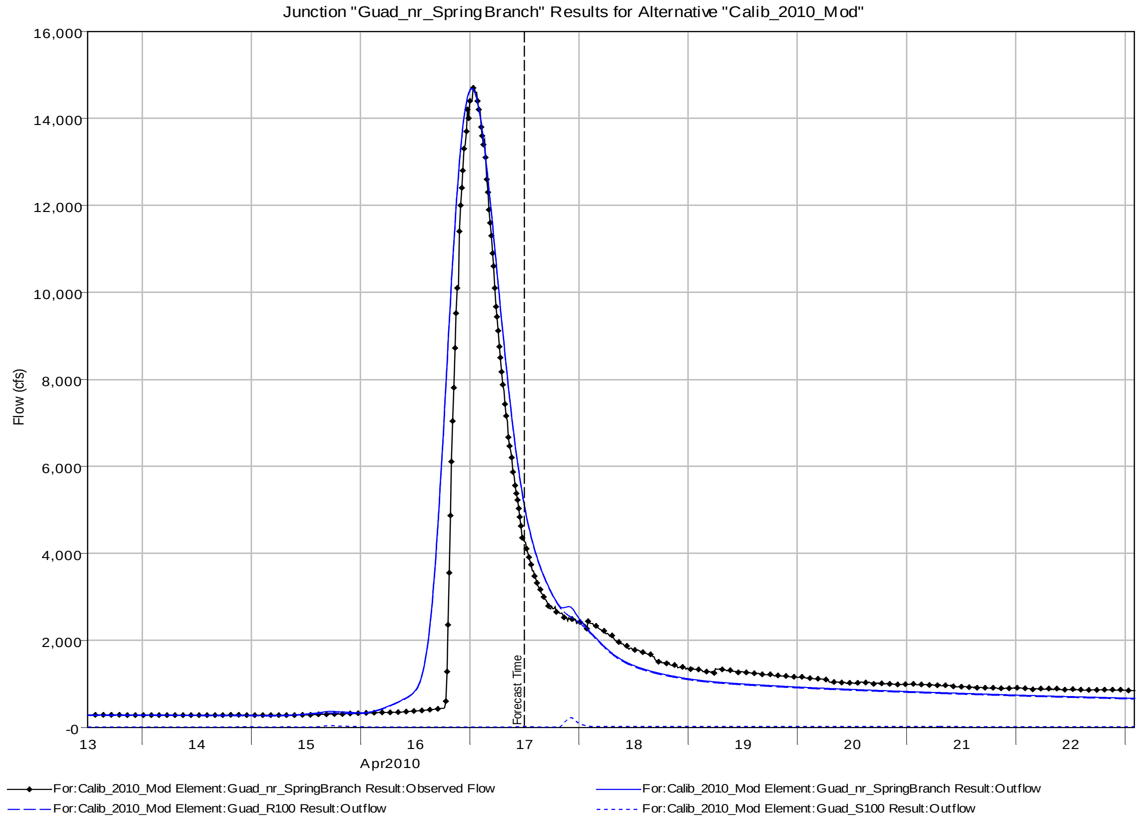


Figure 6.53: Apr 2010 Calibration Results for Guadalupe River nr Spring Branch, TX

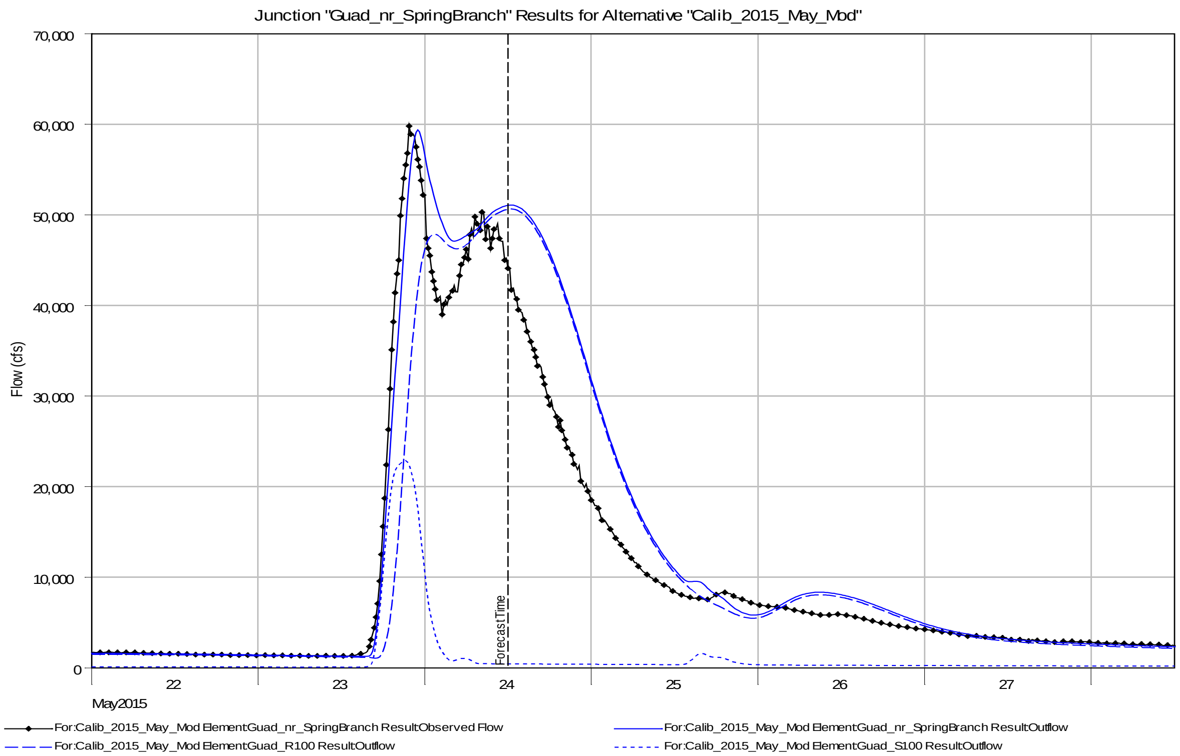


Figure 6.54: May 2015 Calibration Results for Guadalupe River nr Spring Branch, TX

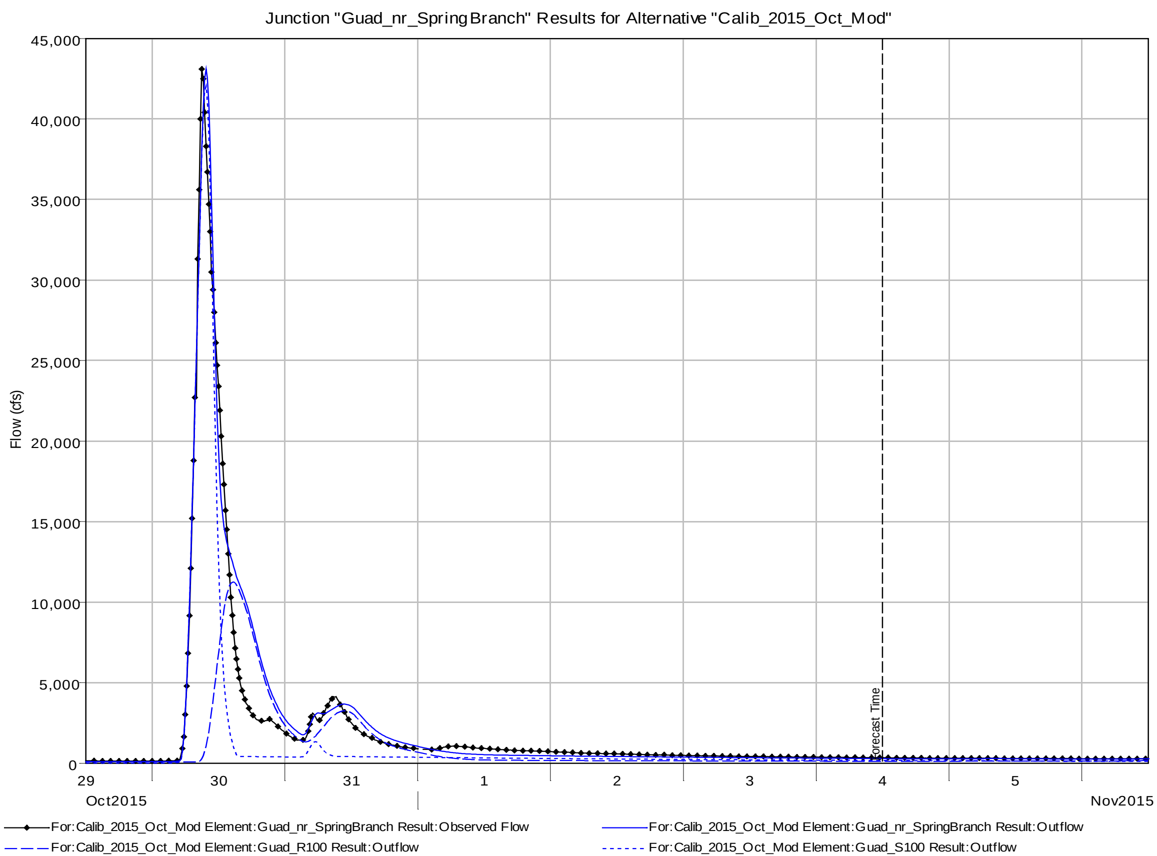


Figure 6.55: Oct 2015 Calibration Results for Guadalupe River nr Spring Branch, TX

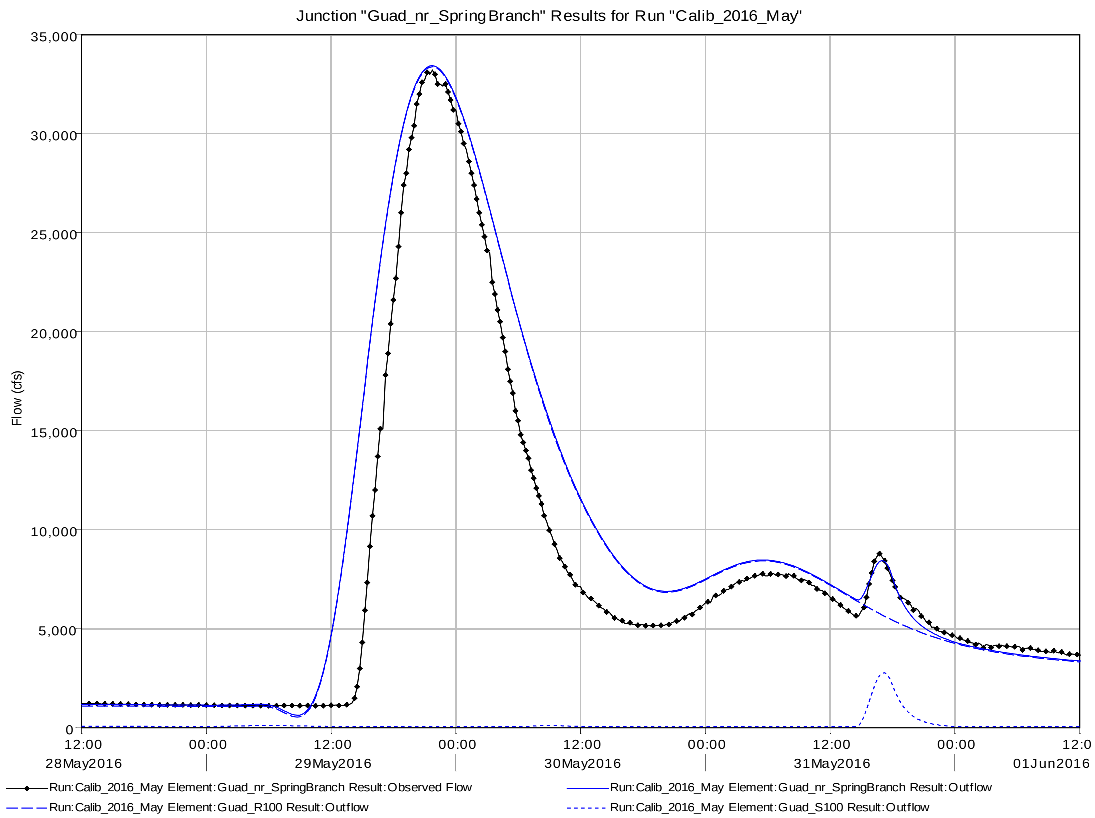


Figure 6.56: May 2016 Calibration Results for Guadalupe River nr Spring Branch, TX

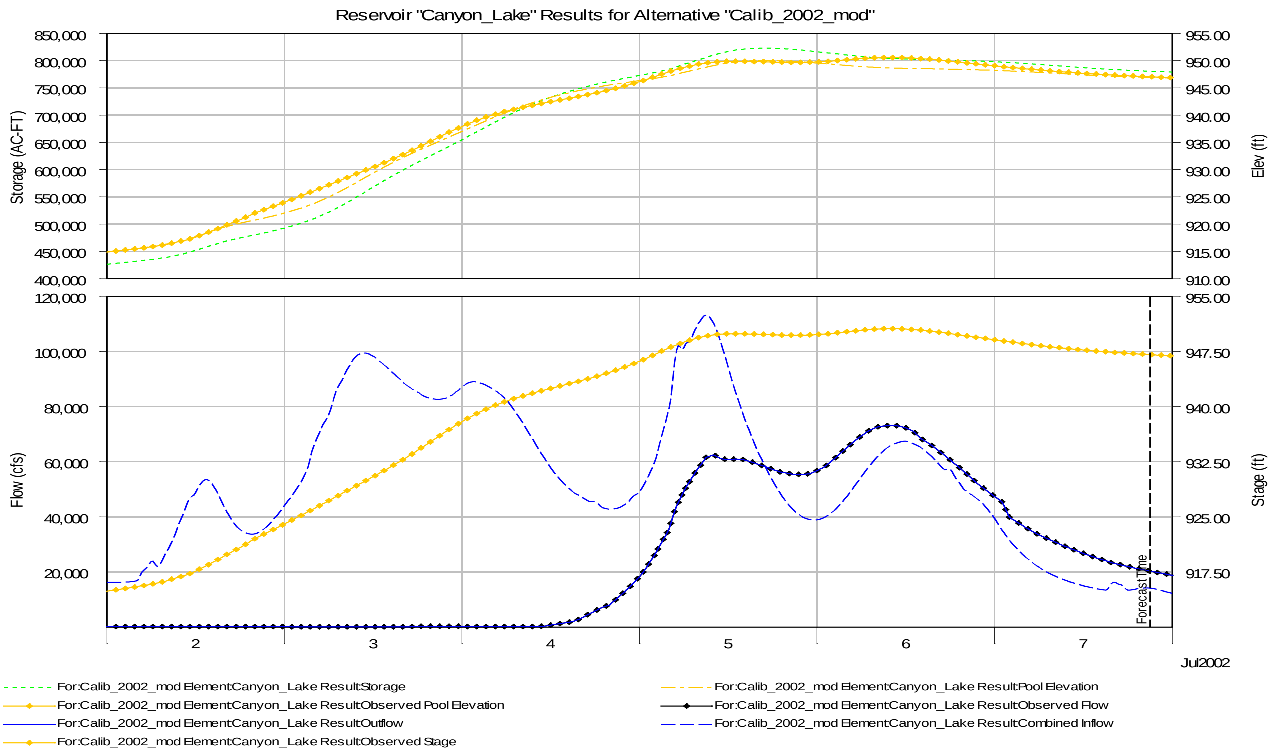


Figure 6.57: Jul 2002 Calibration Results for Canyon Lake

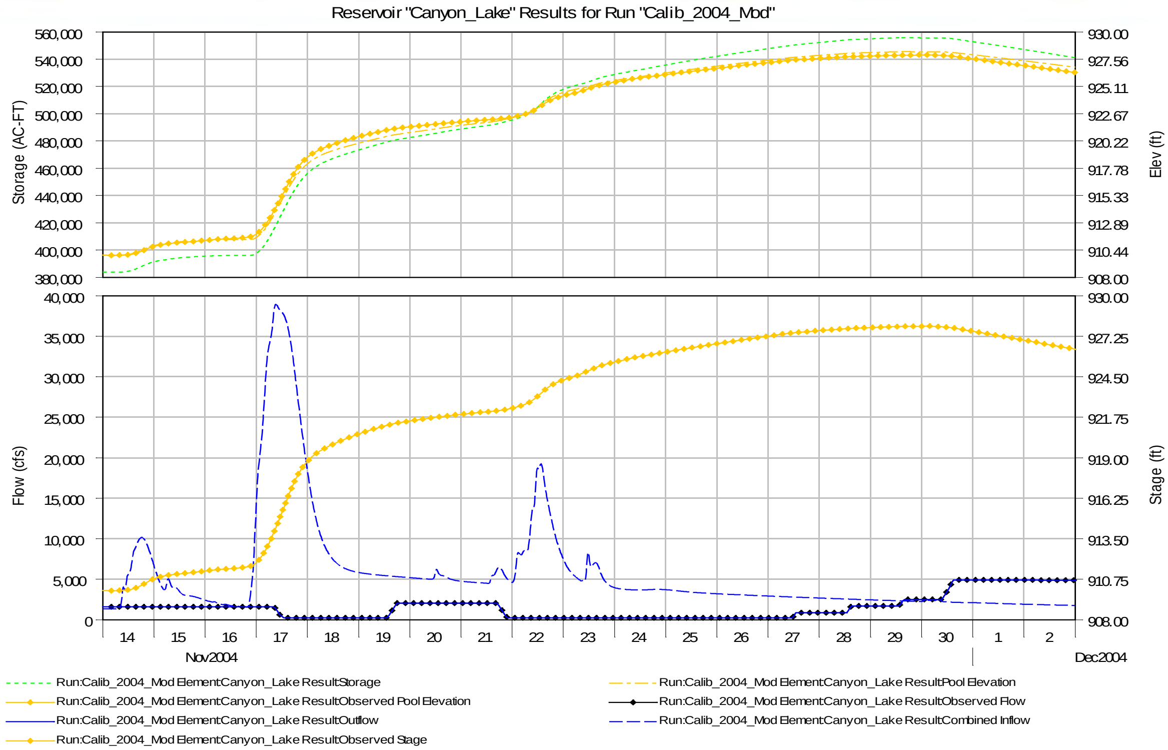


Figure 6.58: Jun 2004 Calibration Results for Canyon Lake

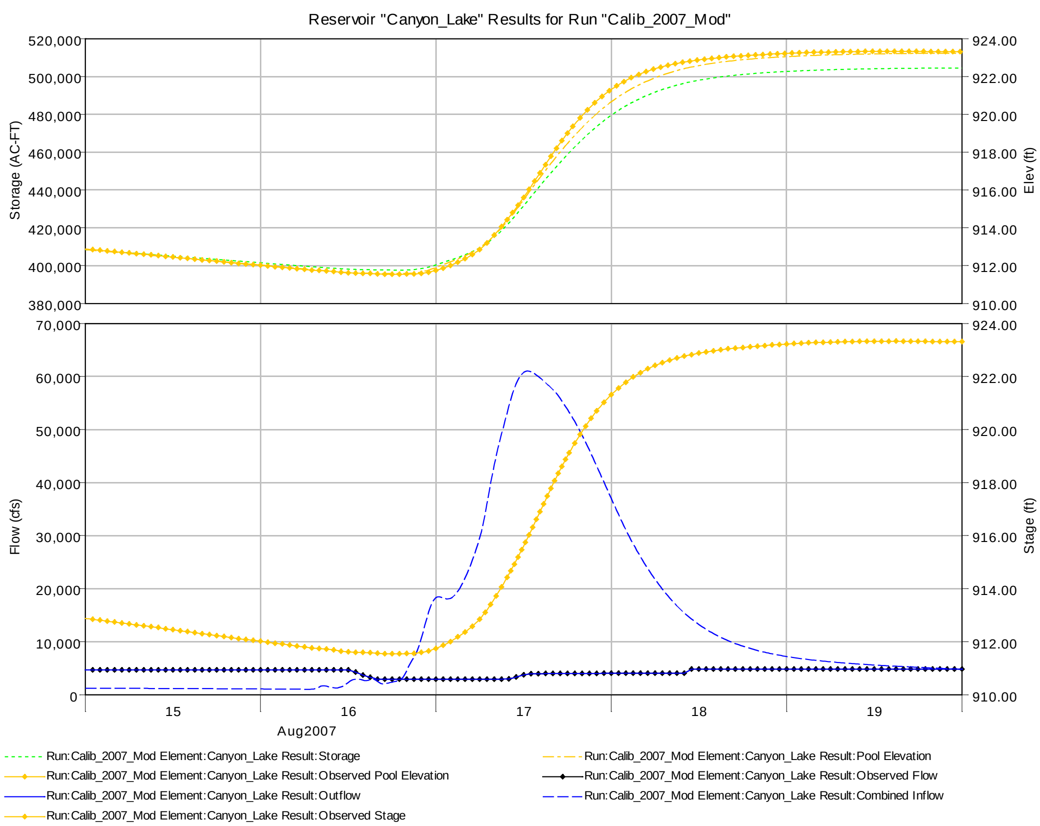


Figure 6.59: Aug 2007 Calibration Results for Canyon Lake

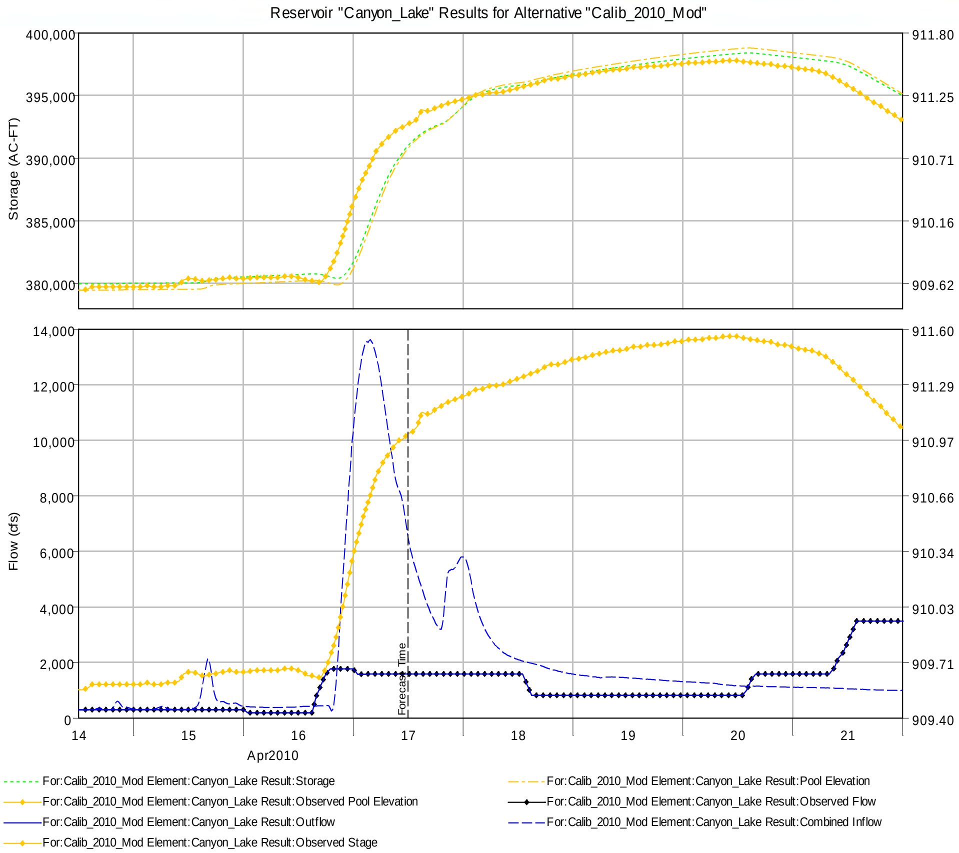


Figure 6.60: Apr 2010 Calibration Results for Canyon Lake

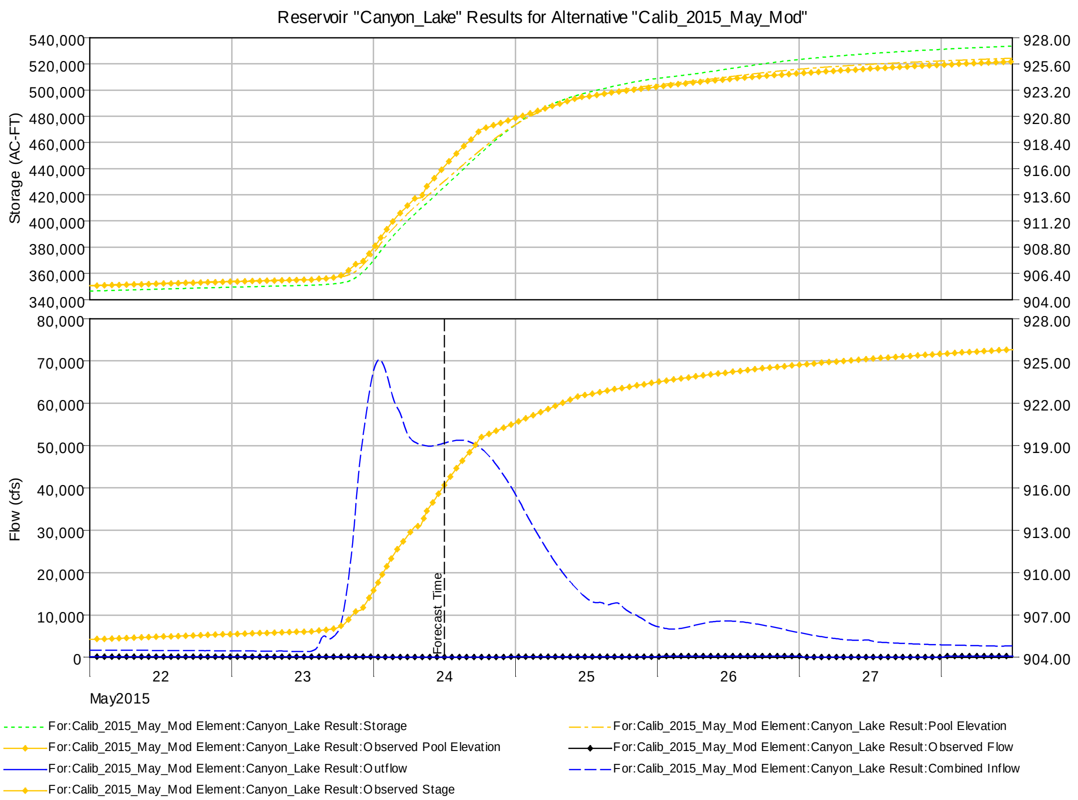


Figure 6.61: May 2015 Calibration Results for Canyon Lake

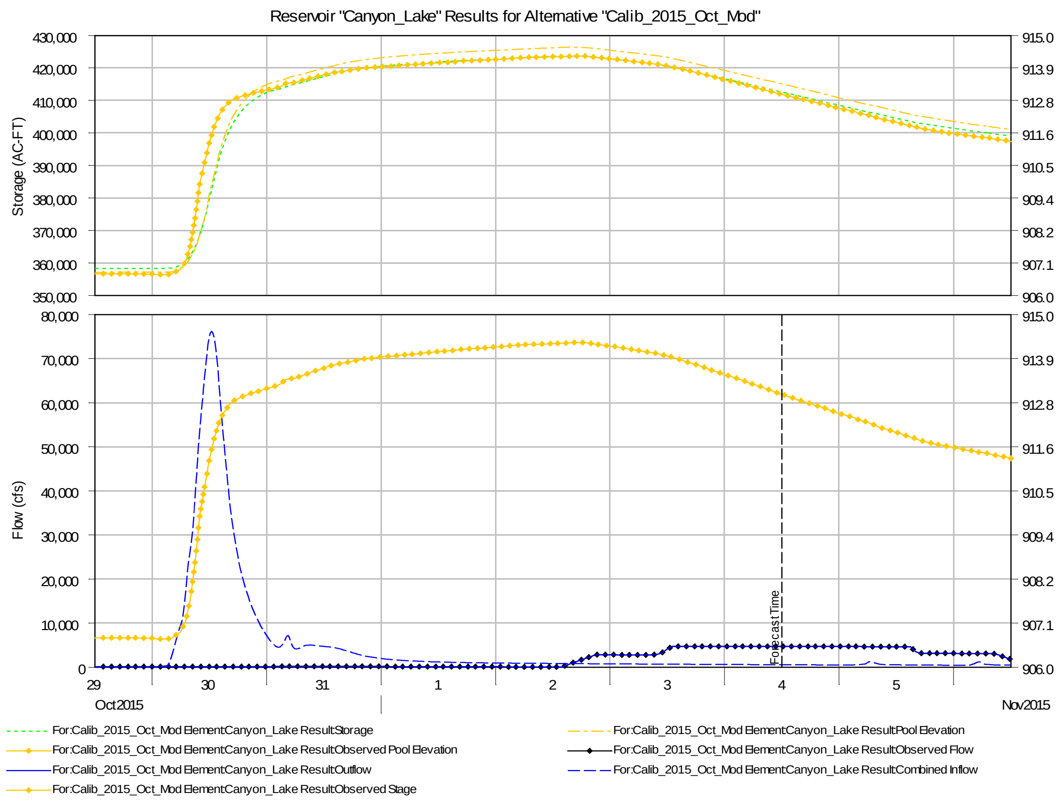


Figure 6.62: Oct 2015 Calibration Results for Canyon Lake

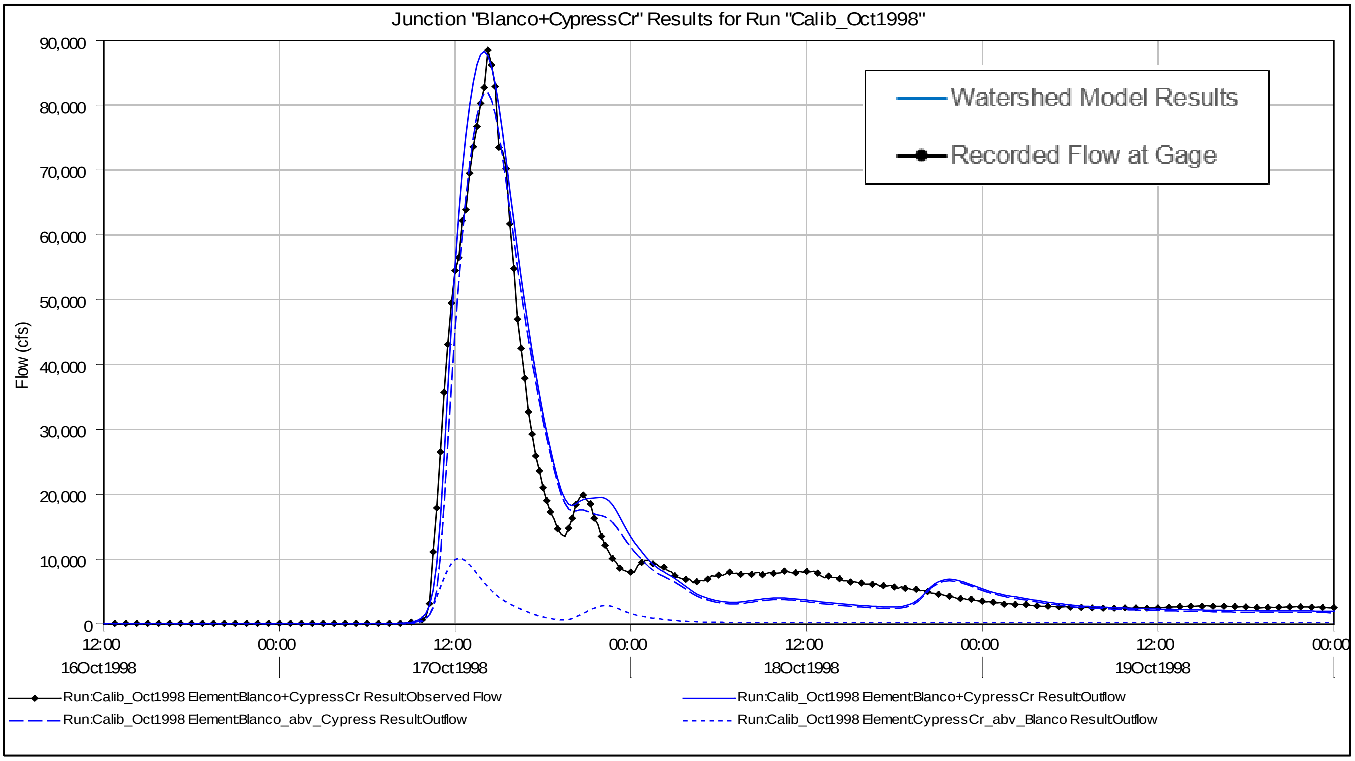


Figure 6.63: Oct 1998 Calibration Results for the Blanco River at Wimberley, TX

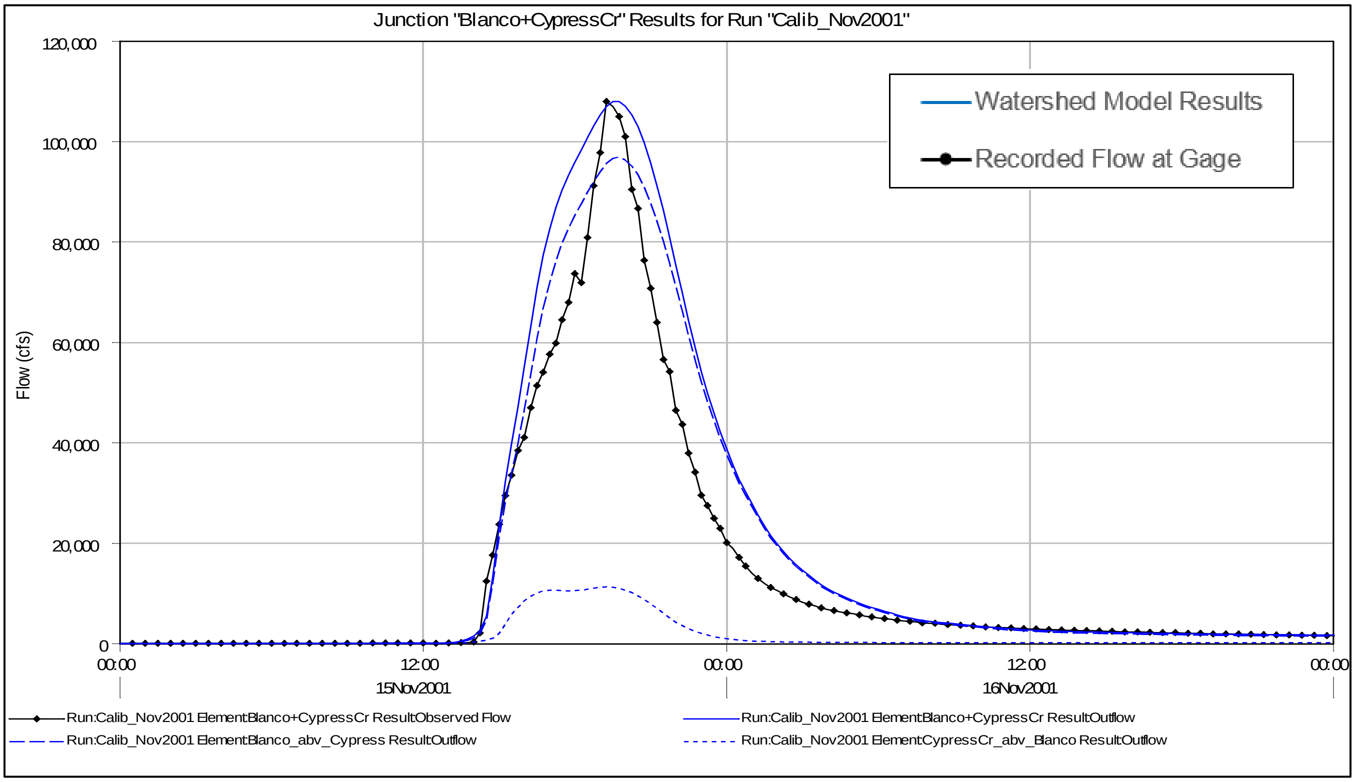


Figure 6.64: Nov 2001 Calibration Results for the Blanco River at Wimberley, TX

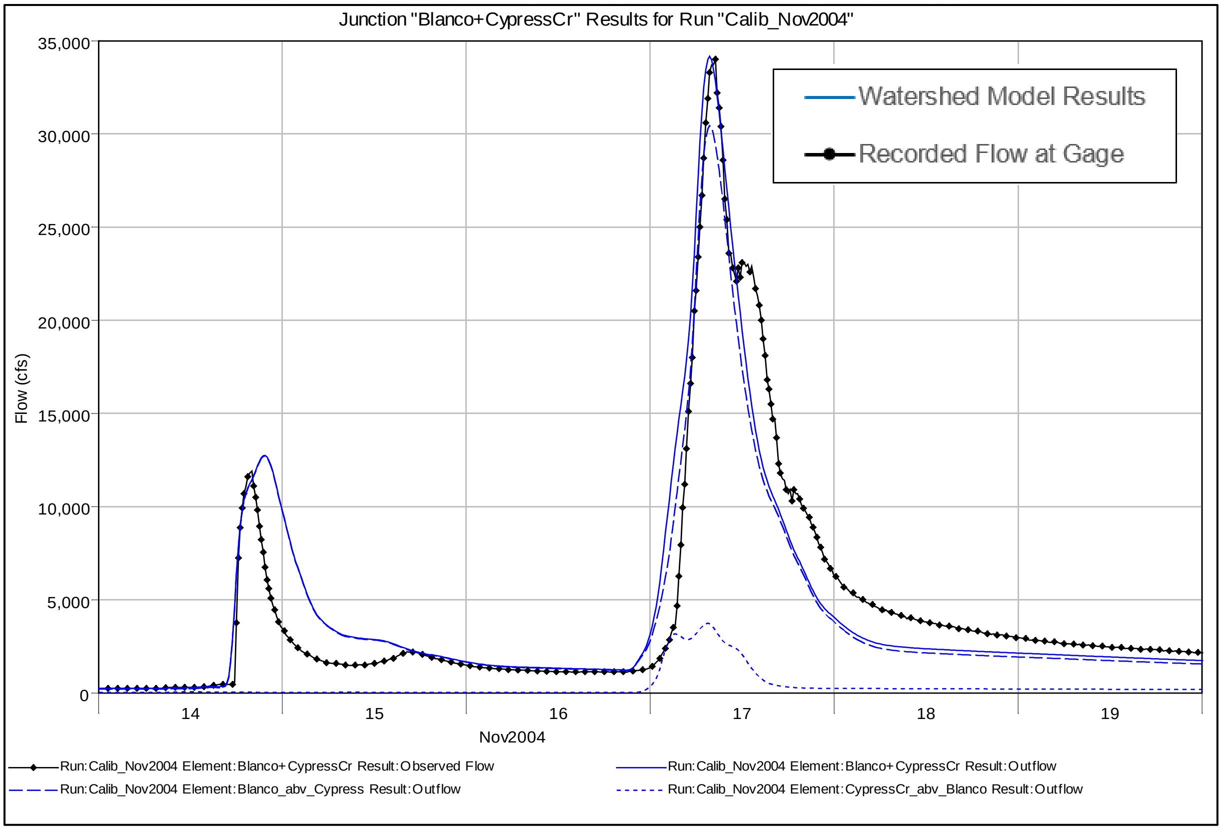


Figure 6.65: Nov 2004 Calibration Results for the Blanco River at Wimberley, TX

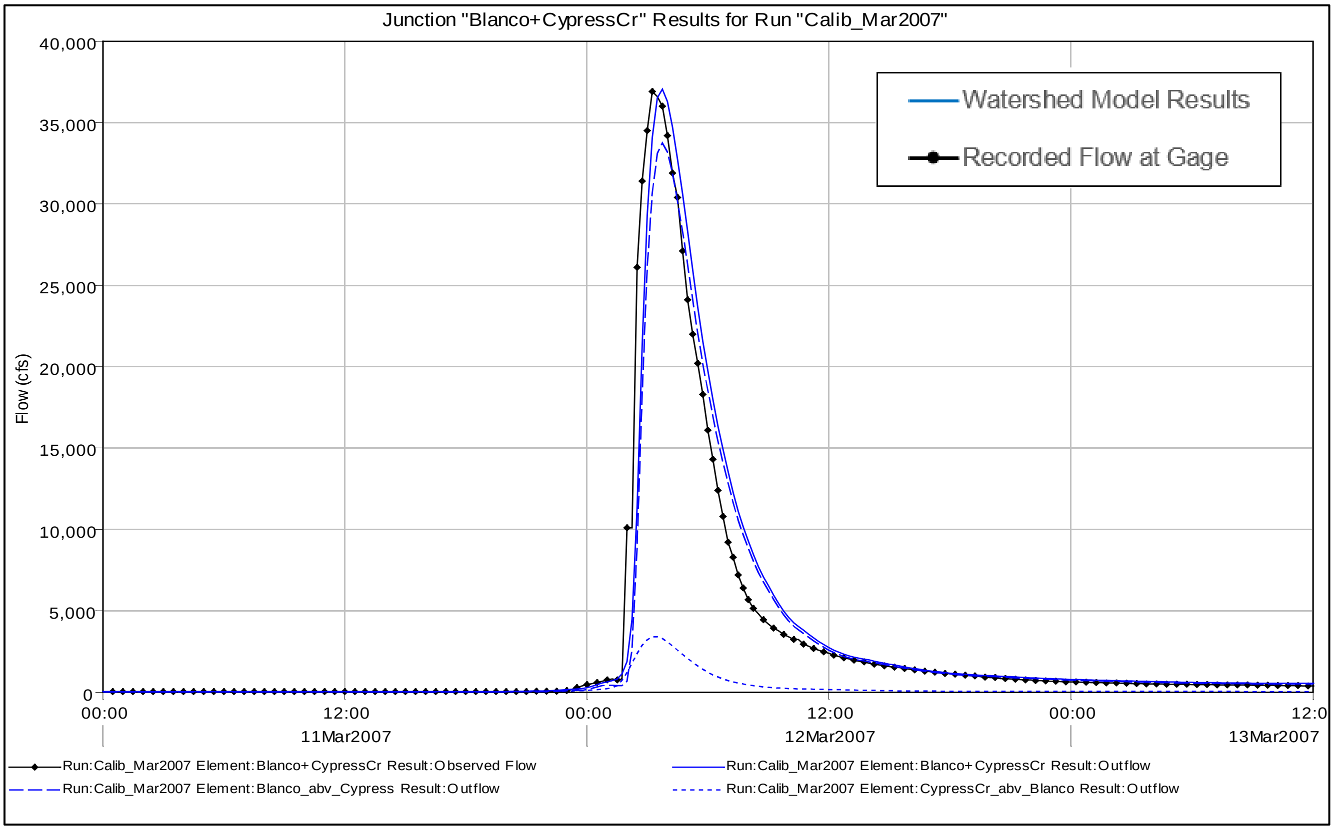


Figure 6.66: Mar 2007 Calibration Results for the Blanco River at Wimberley, TX

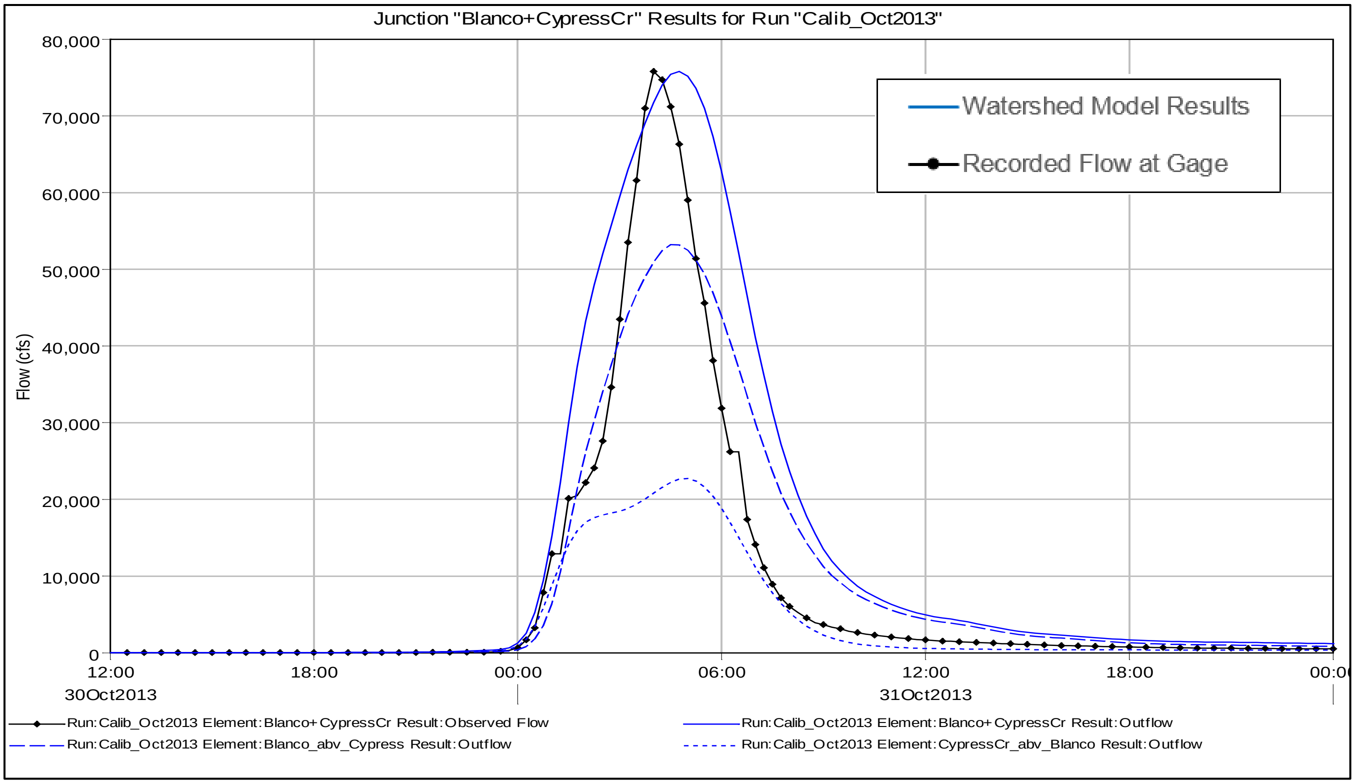


Figure 6.67: Oct 2013 Calibration Results for the Blanco River at Wimberley, TX

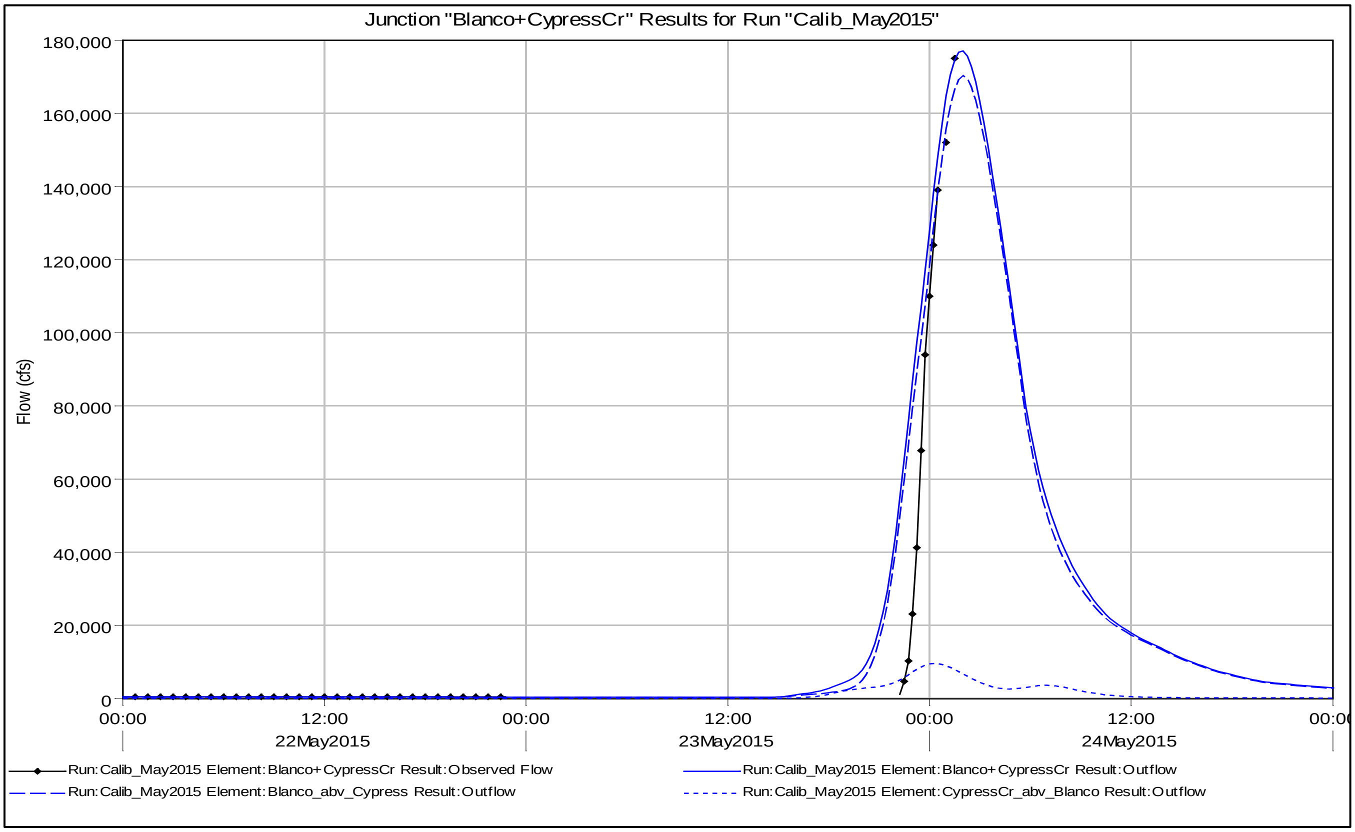


Figure 6.68: May 2015 Calibration Results for the Blanco River at Wimberley, TX

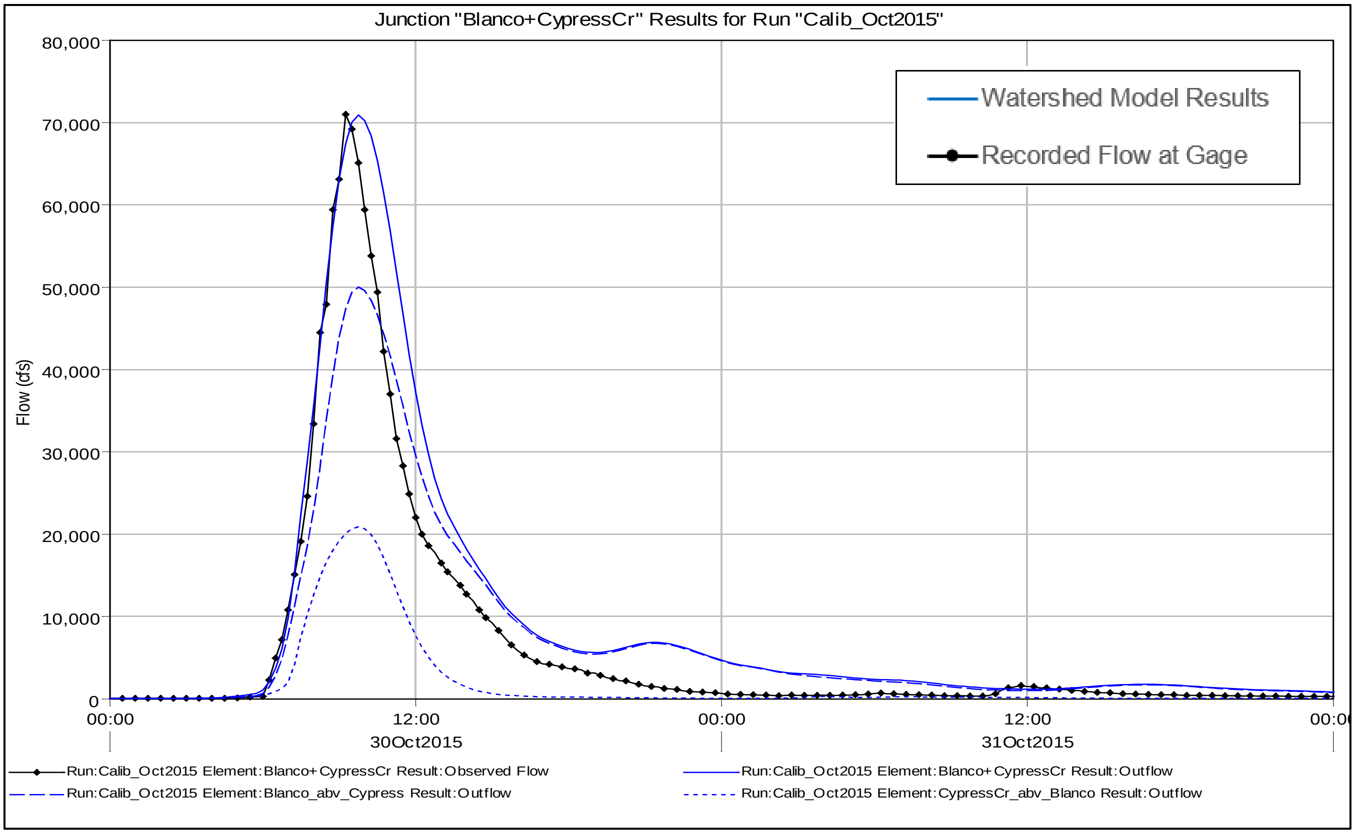


Figure 6.69: Oct 2015 Calibration Results for the Blanco River at Wimberley, TX

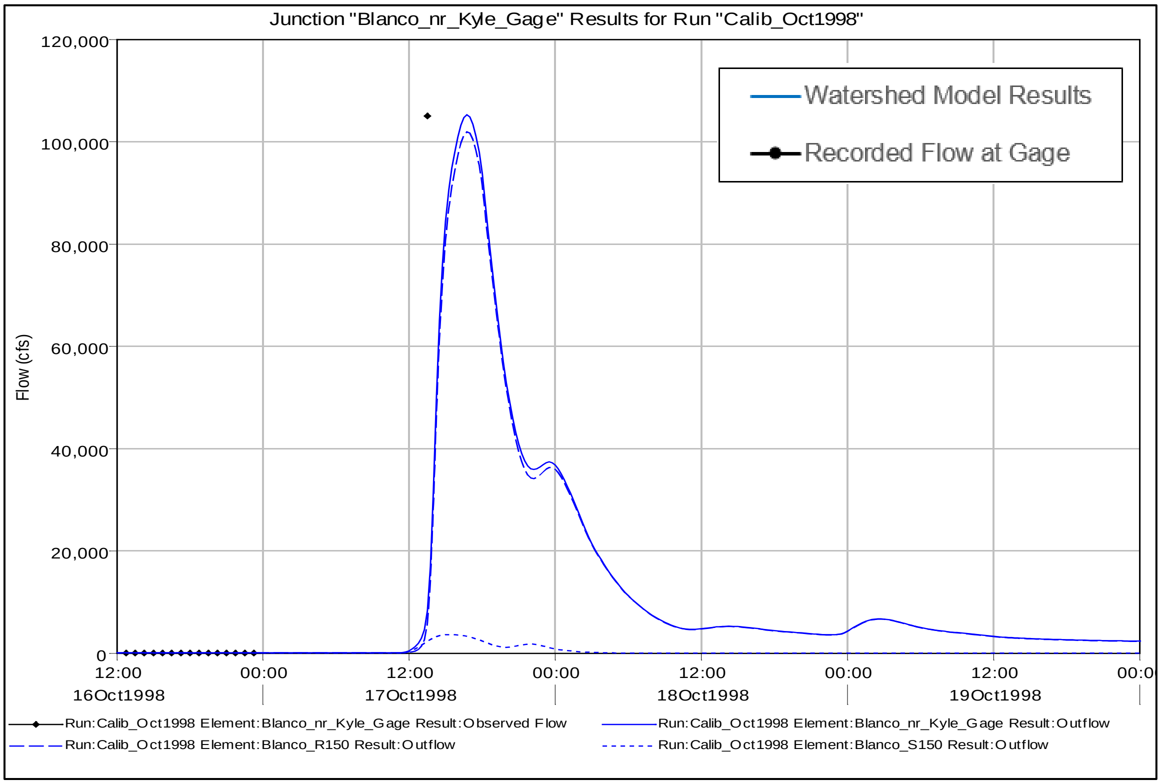


Figure 6.70: Oct 1998 Calibration Results for the Blanco River near Kyle, TX

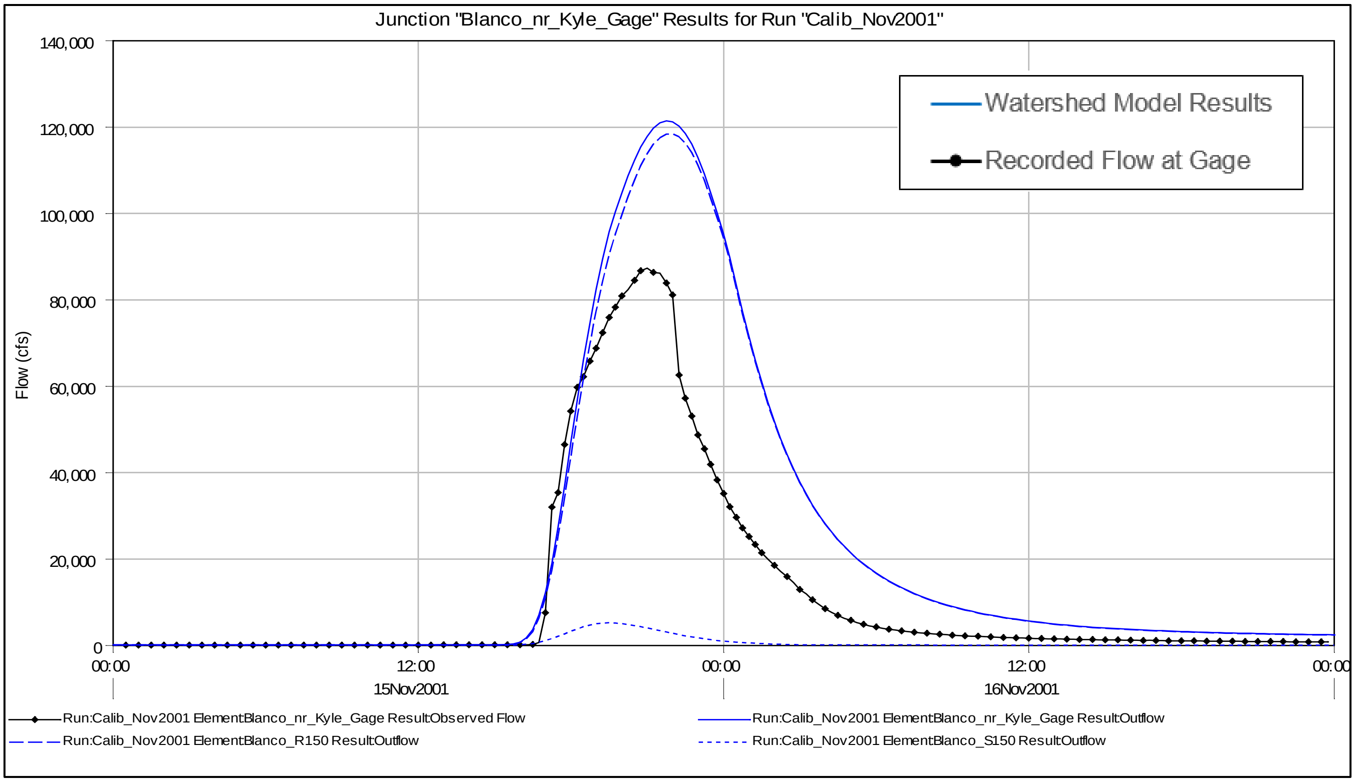


Figure 6.71: Nov 2001 Calibration Results for the Blanco River near Kyle, TX

NOTE – Gage Data has Volume Discrepancy between Wimberley & Kyle

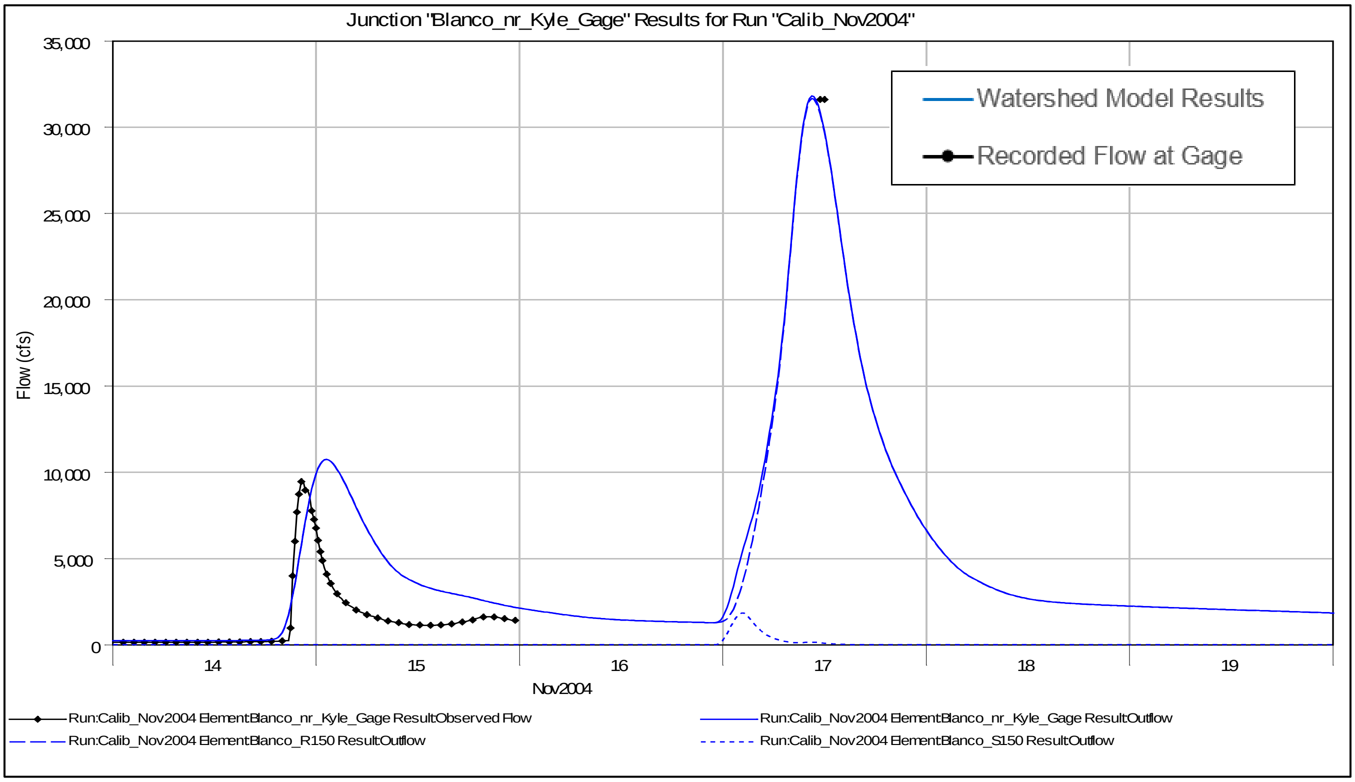


Figure 6.72: Nov 2004 Calibration Results for the Blanco River near Kyle, TX

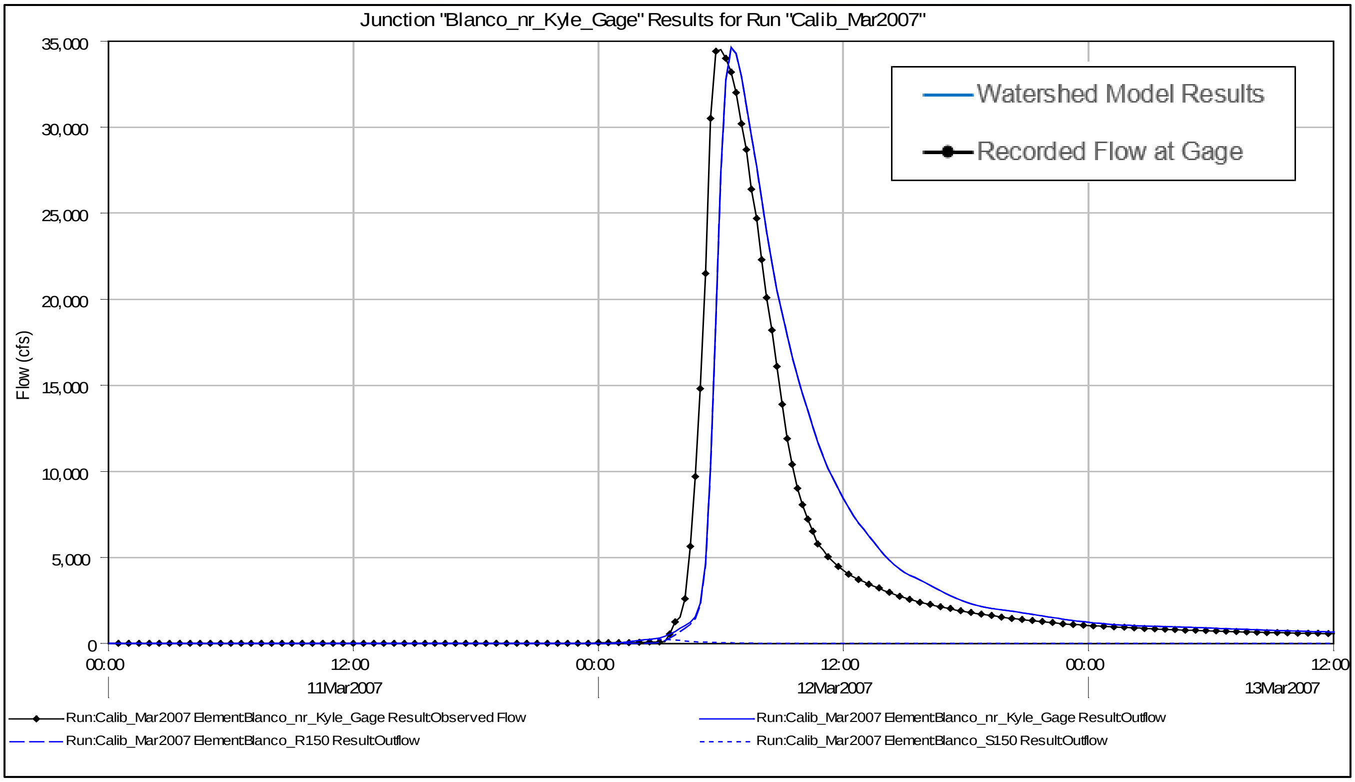


Figure 6.73: Mar 2007 Calibration Results for the Blanco River near Kyle, TX

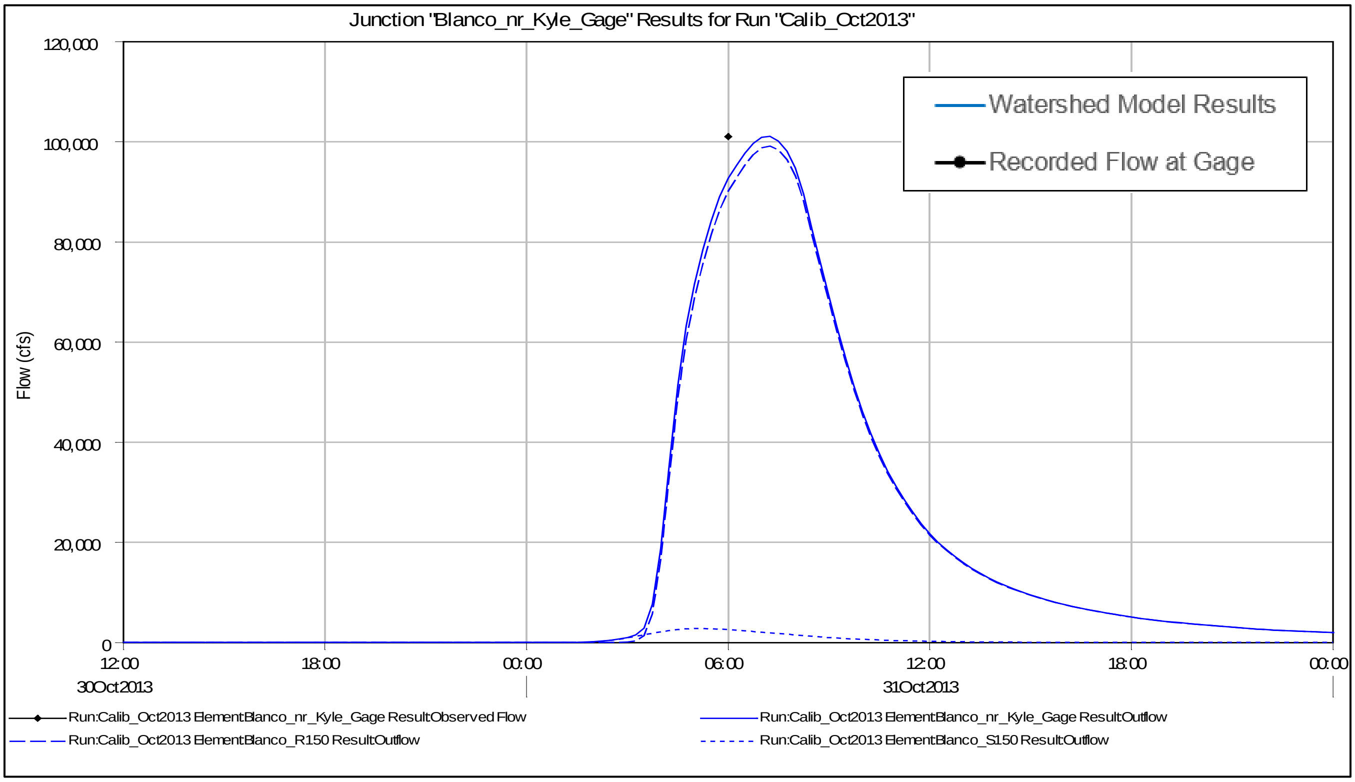


Figure 6.74: Oct 2013 Calibration Results for the Blanco River near Kyle, TX

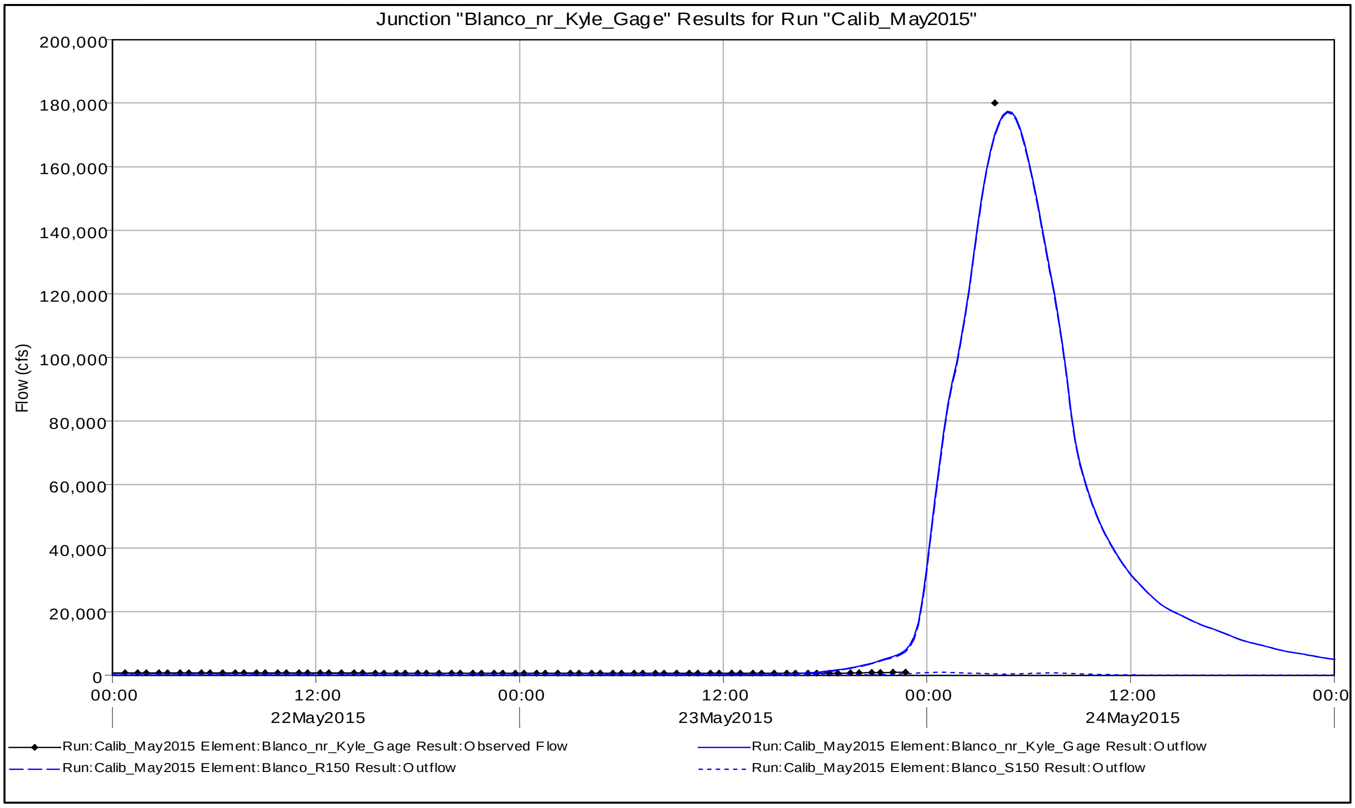


Figure 6.75: May 2015 Calibration Results for the Blanco River near Kyle, TX

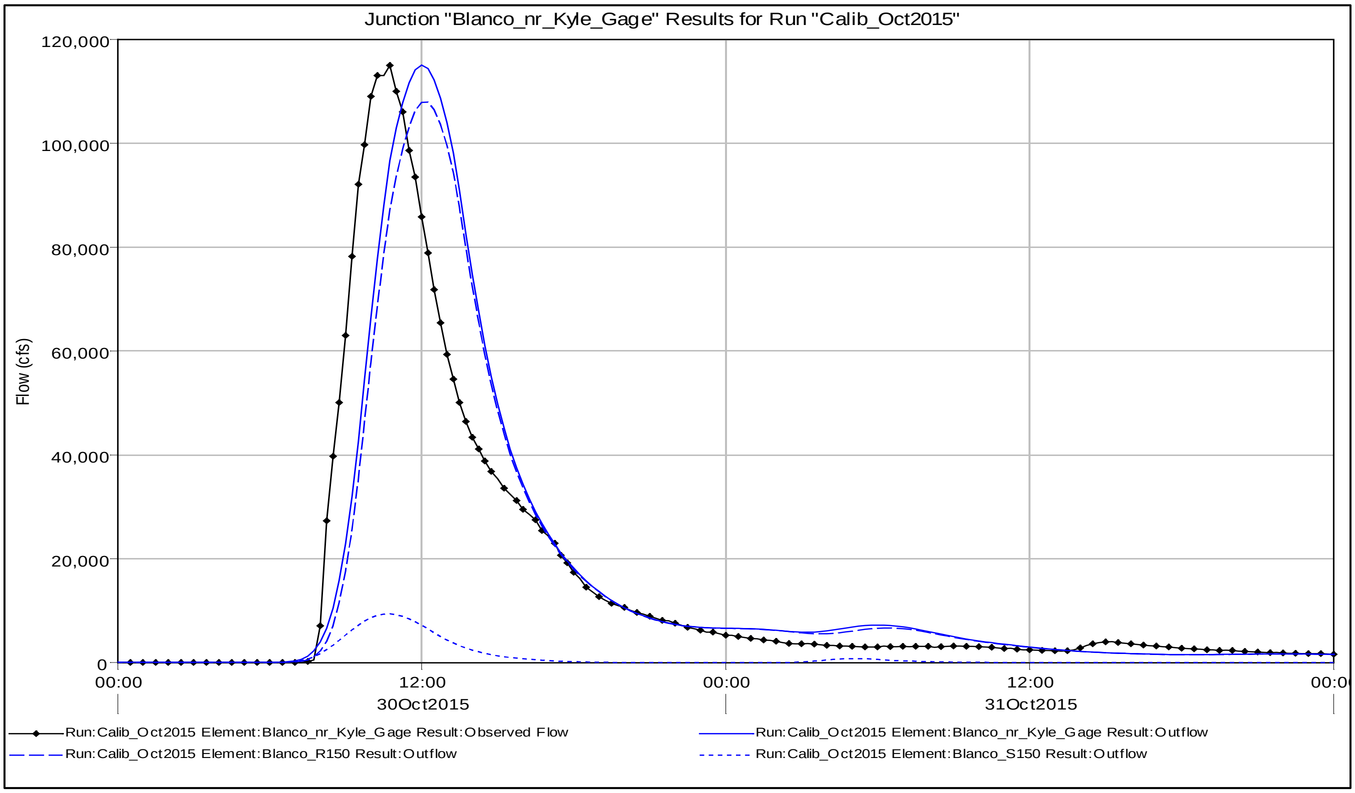


Figure 6.76: Oct 2015 Calibration Results for the Blanco River near Kyle, TX

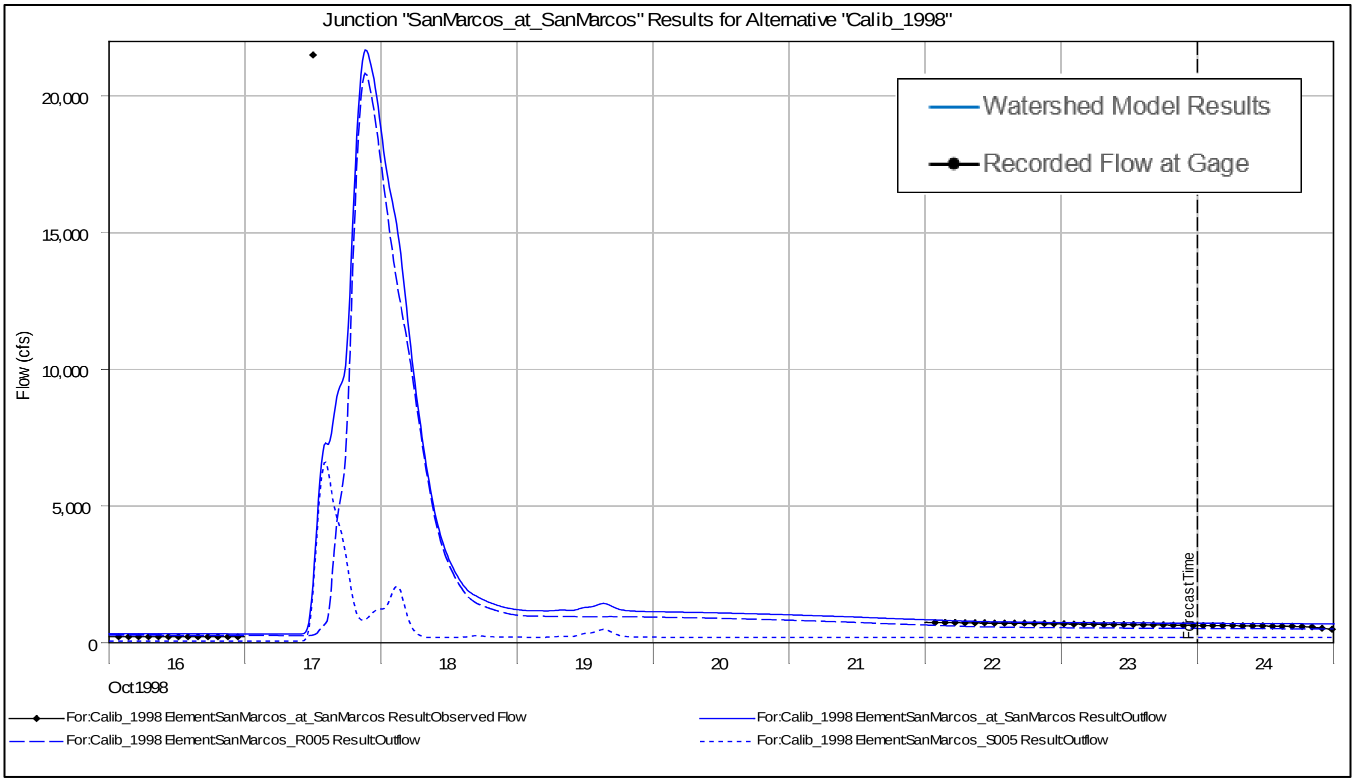


Figure 6.77: Oct 1998 Calibration Results for the San Marcos River at San Marcos, TX

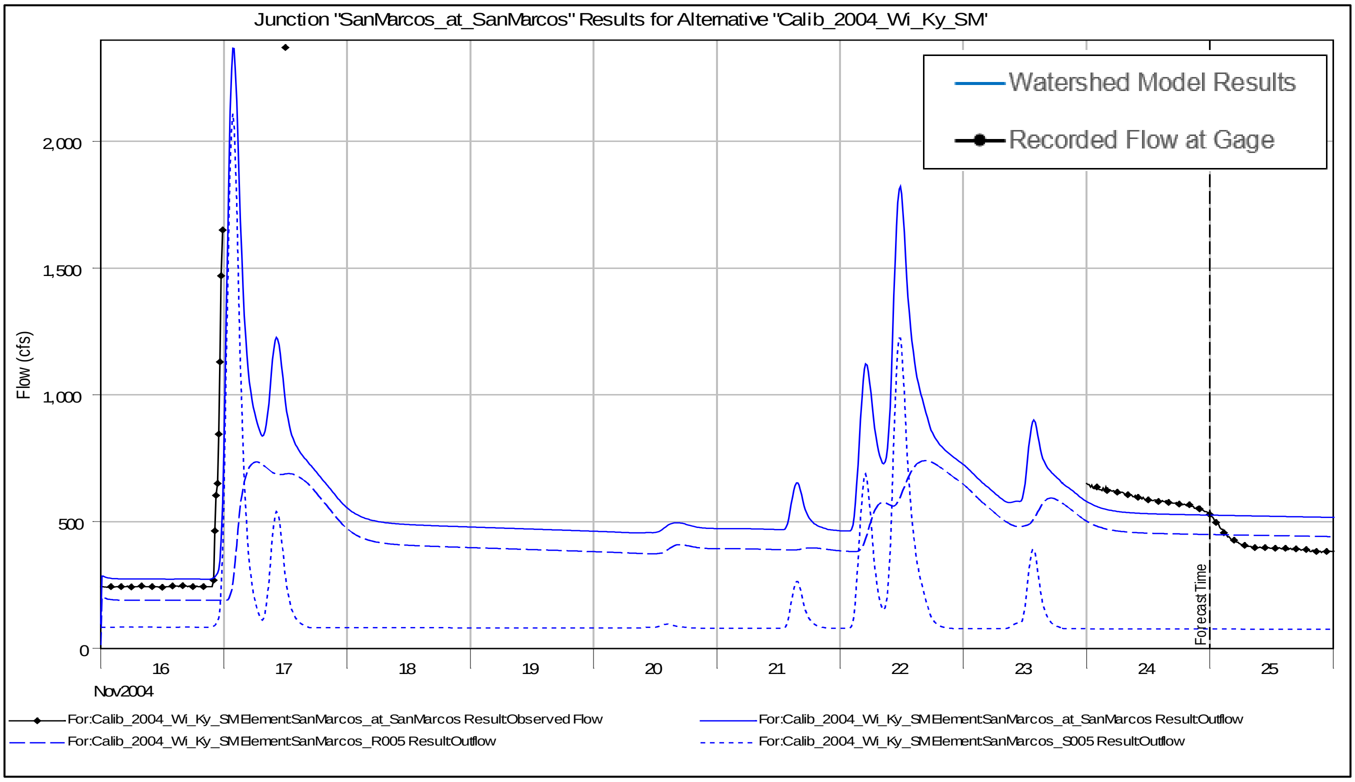


Figure 6.78: Nov 2004 Calibration Results for the San Marcos River at San Marcos, TX

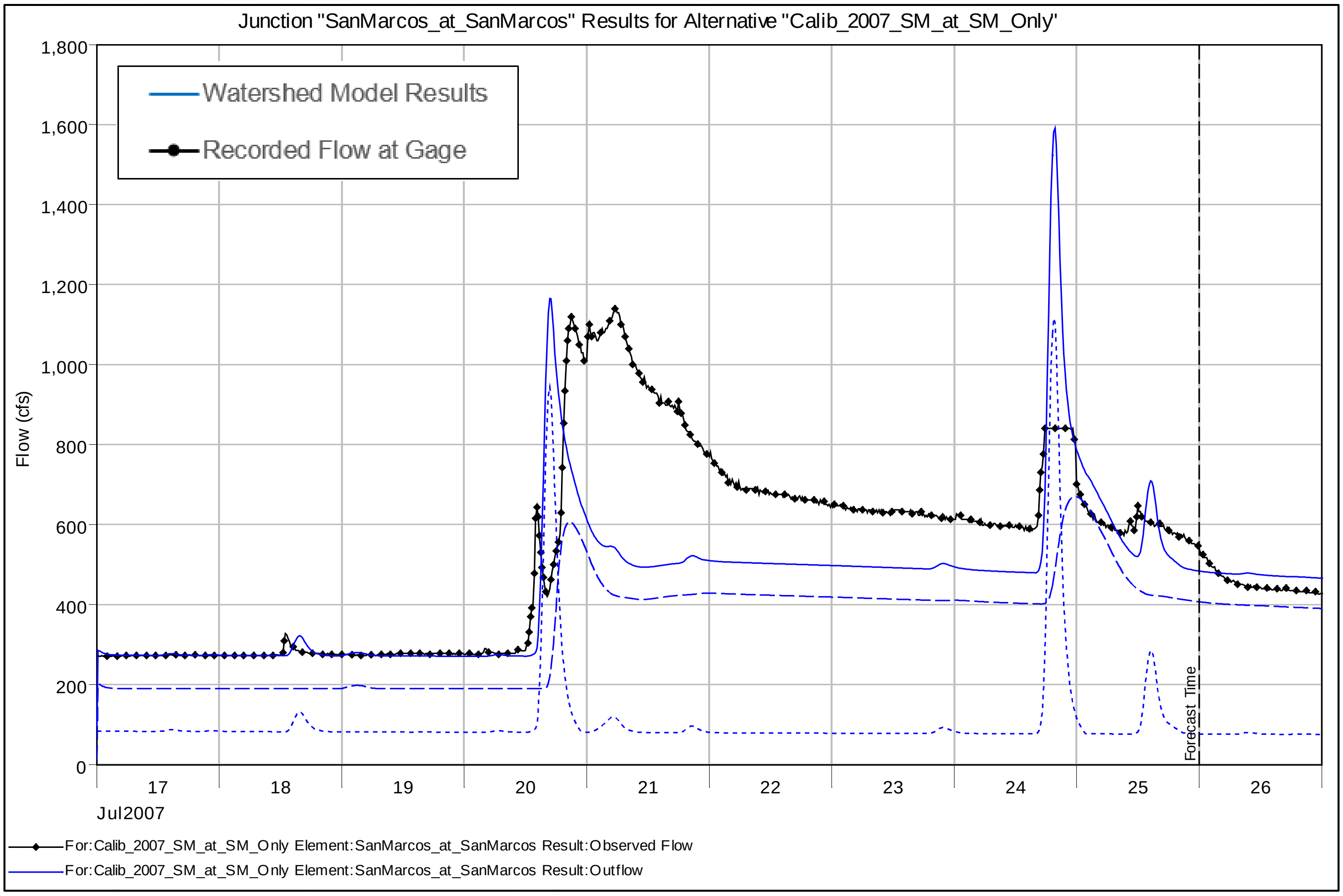


Figure 6.79: Mar 2007 Calibration Results for the San Marcos River at San Marcos, TX

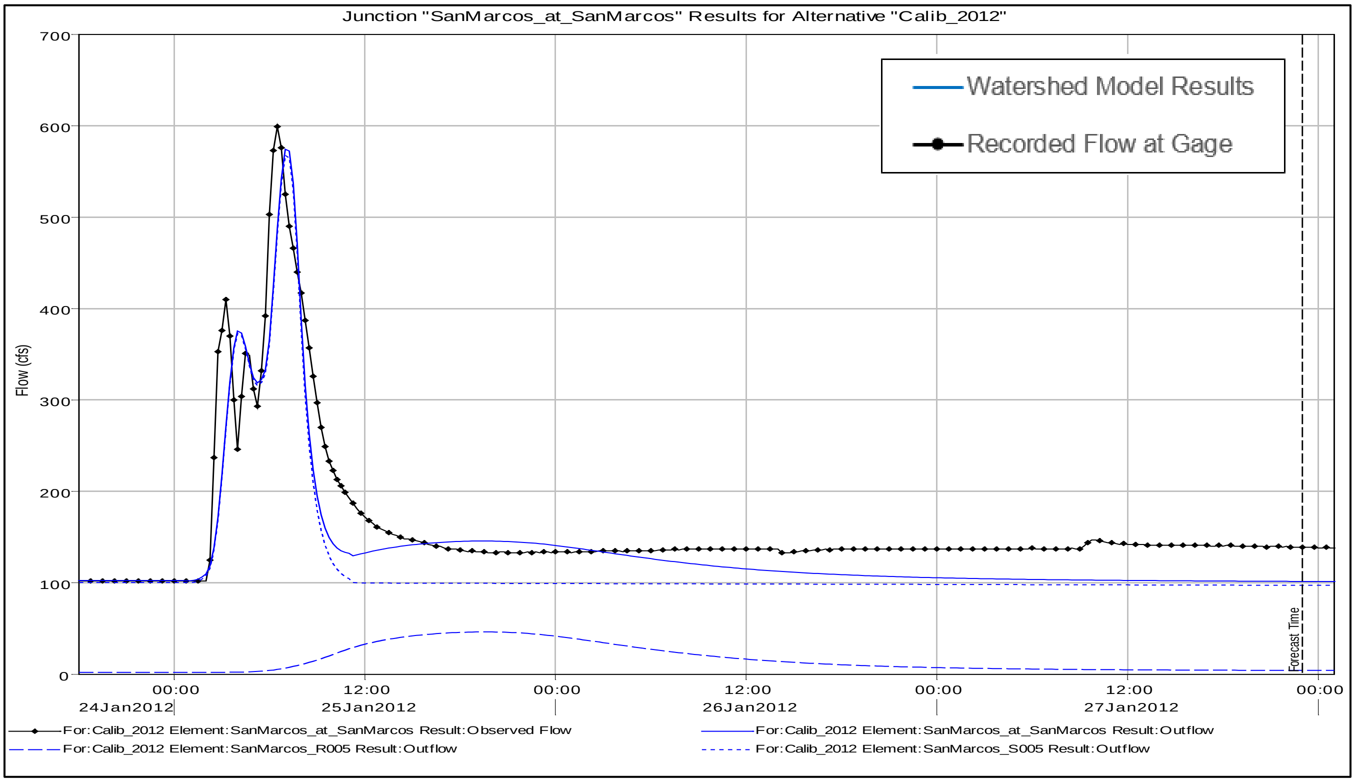


Figure 6.80: Jan 2012 Calibration Results for the San Marcos River at San Marcos, TX

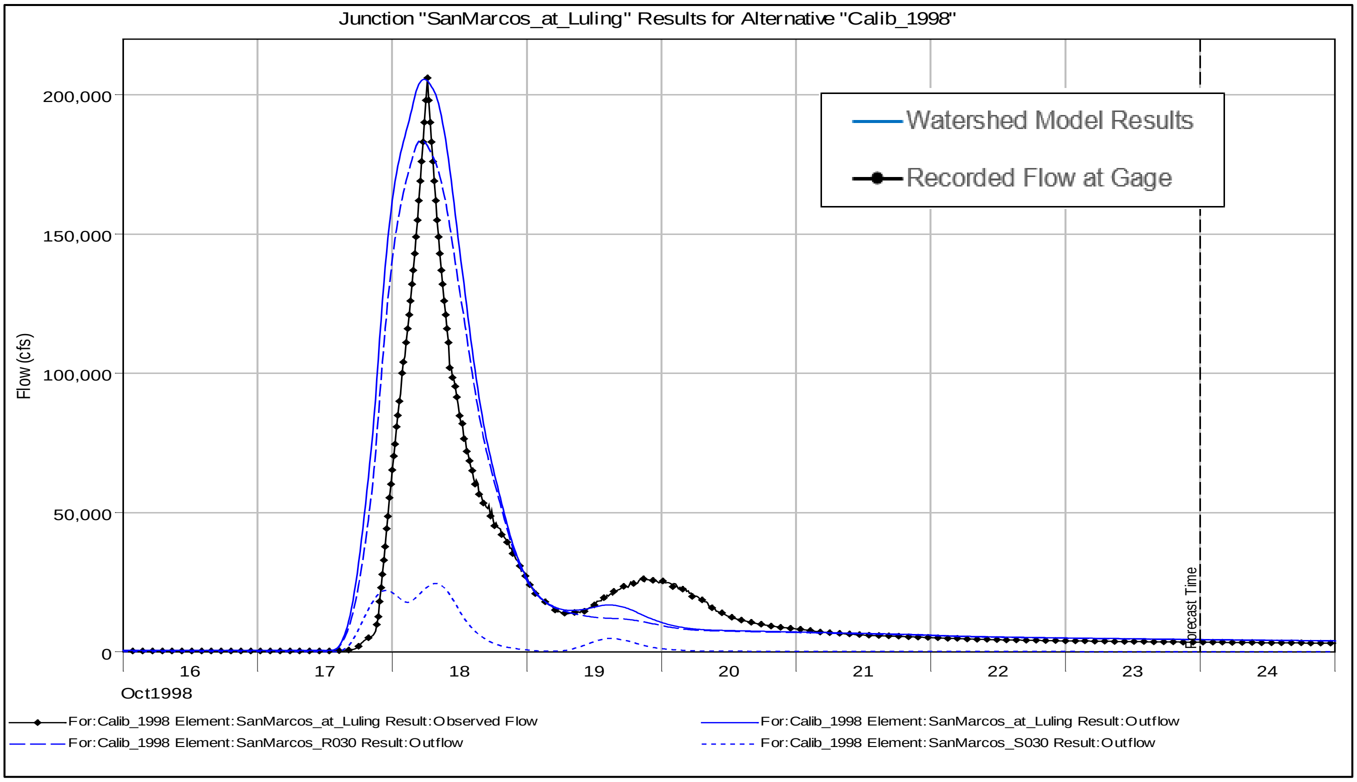


Figure 6.81: Oct 1998 Calibration Results for the San Marcos River at Luling, TX

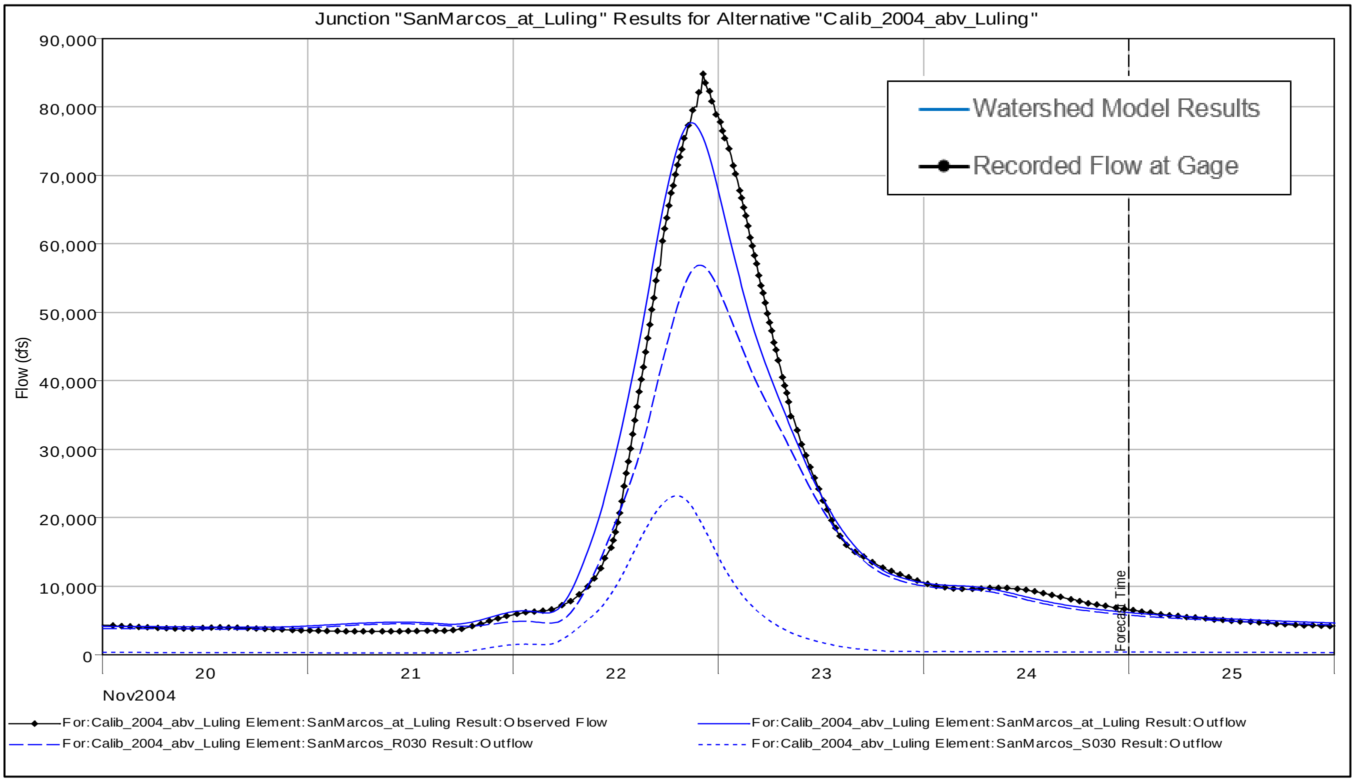


Figure 6.82: Nov 2004 Calibration Results for the San Marcos River at Luling, TX

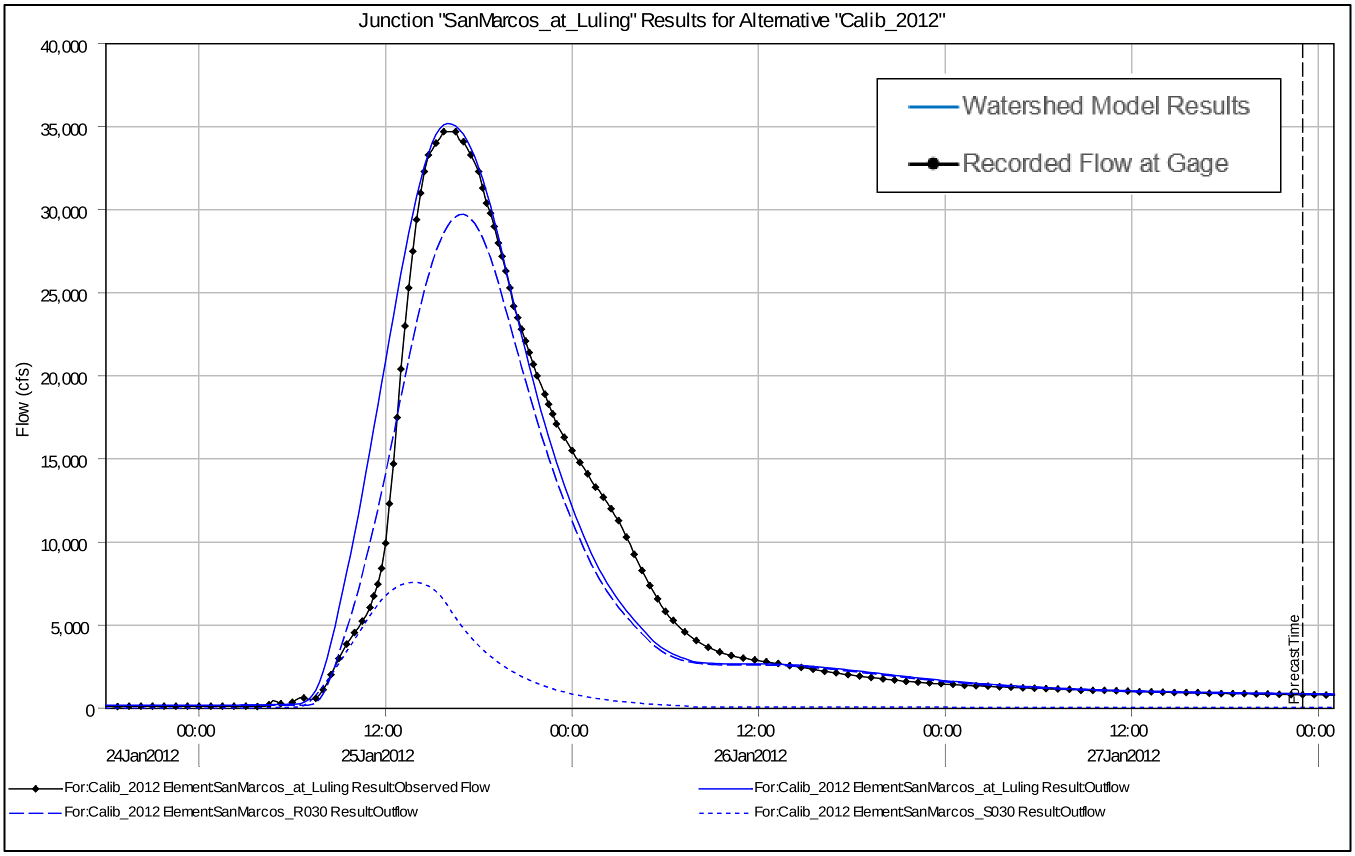


Figure 6.83: Jan 2012 Calibration Results for the San Marcos River at Luling, TX

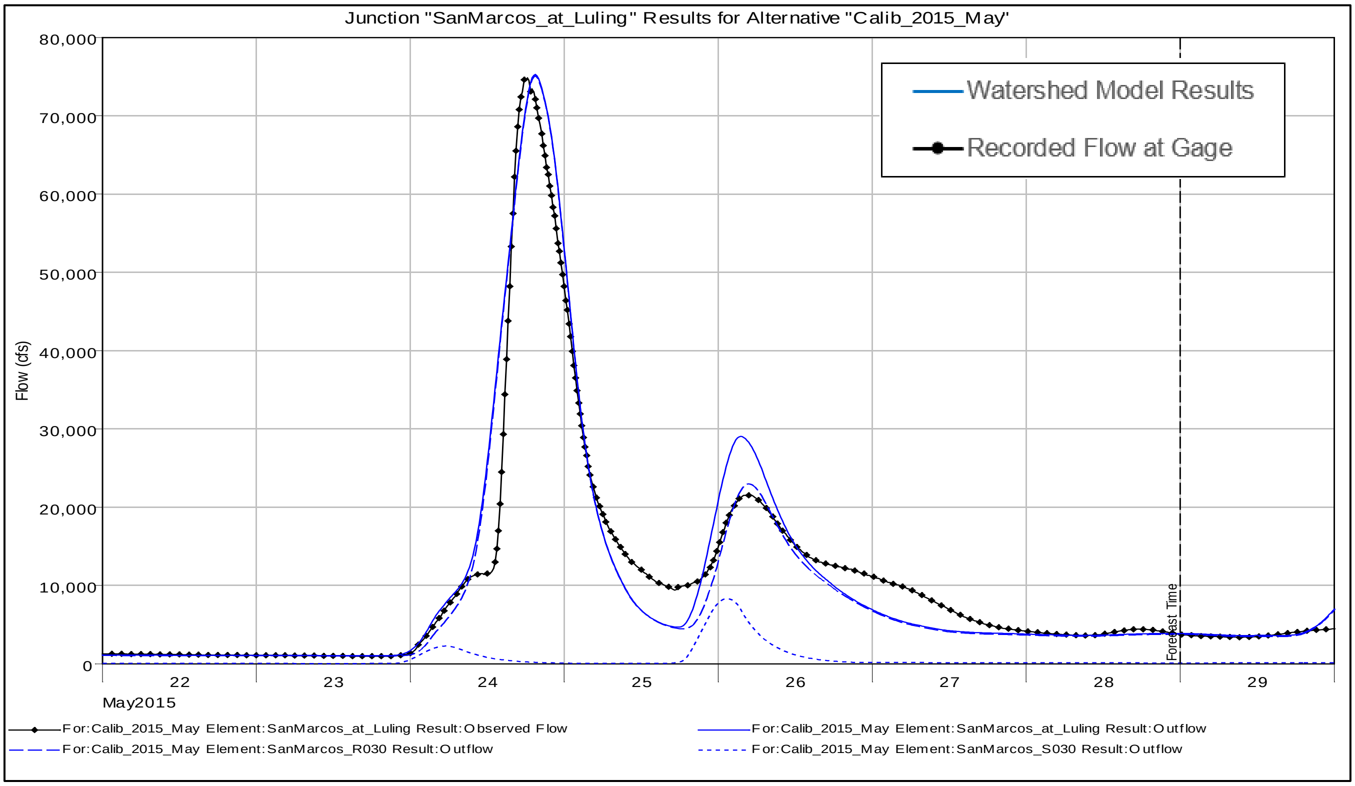


Figure 6.84: May 2015 Calibration Results for the San Marcos River at Luling, TX

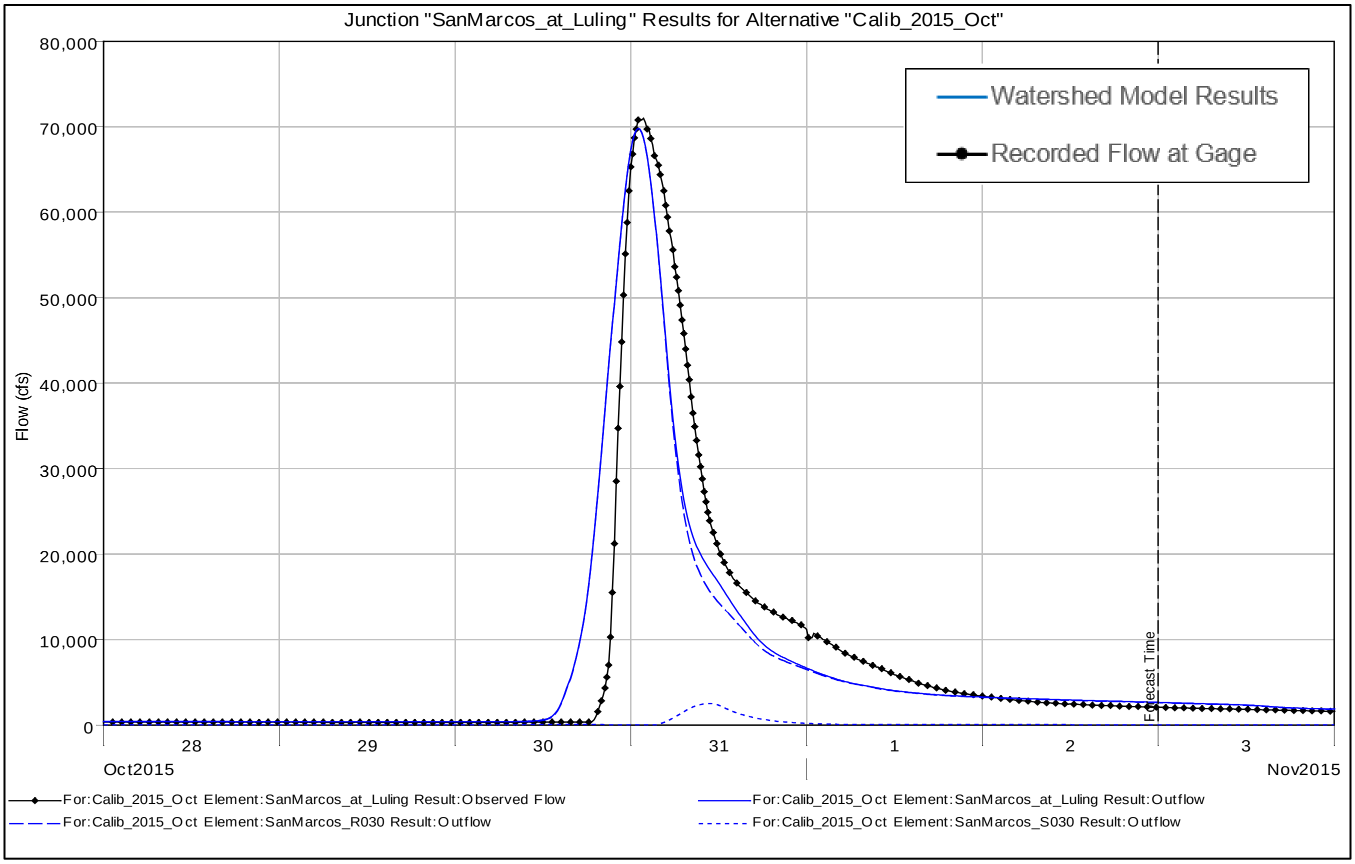


Figure 6.85: Oct 2015 Calibration Results for the San Marcos River at Luling, TX

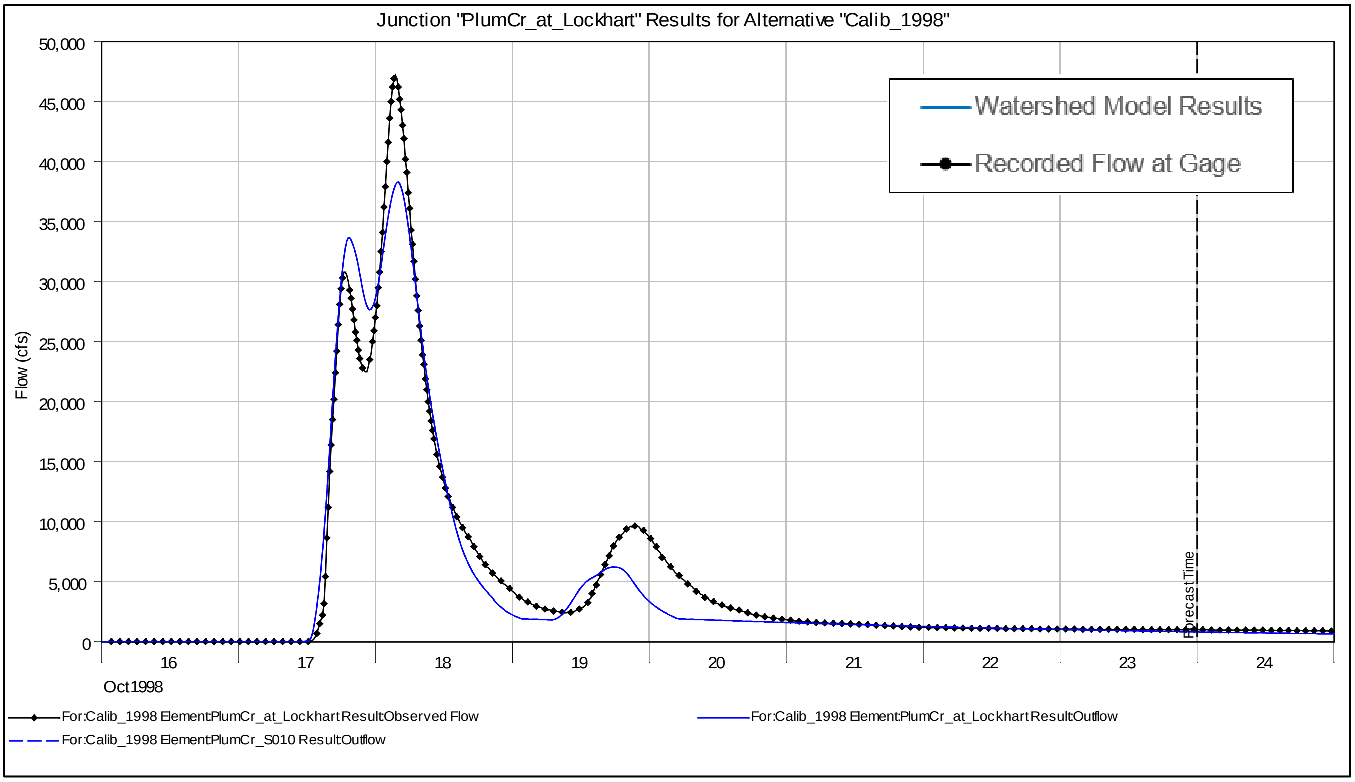


Figure 6.86: Oct 1998 Calibration Results for Plum Creek at Lockhart, TX

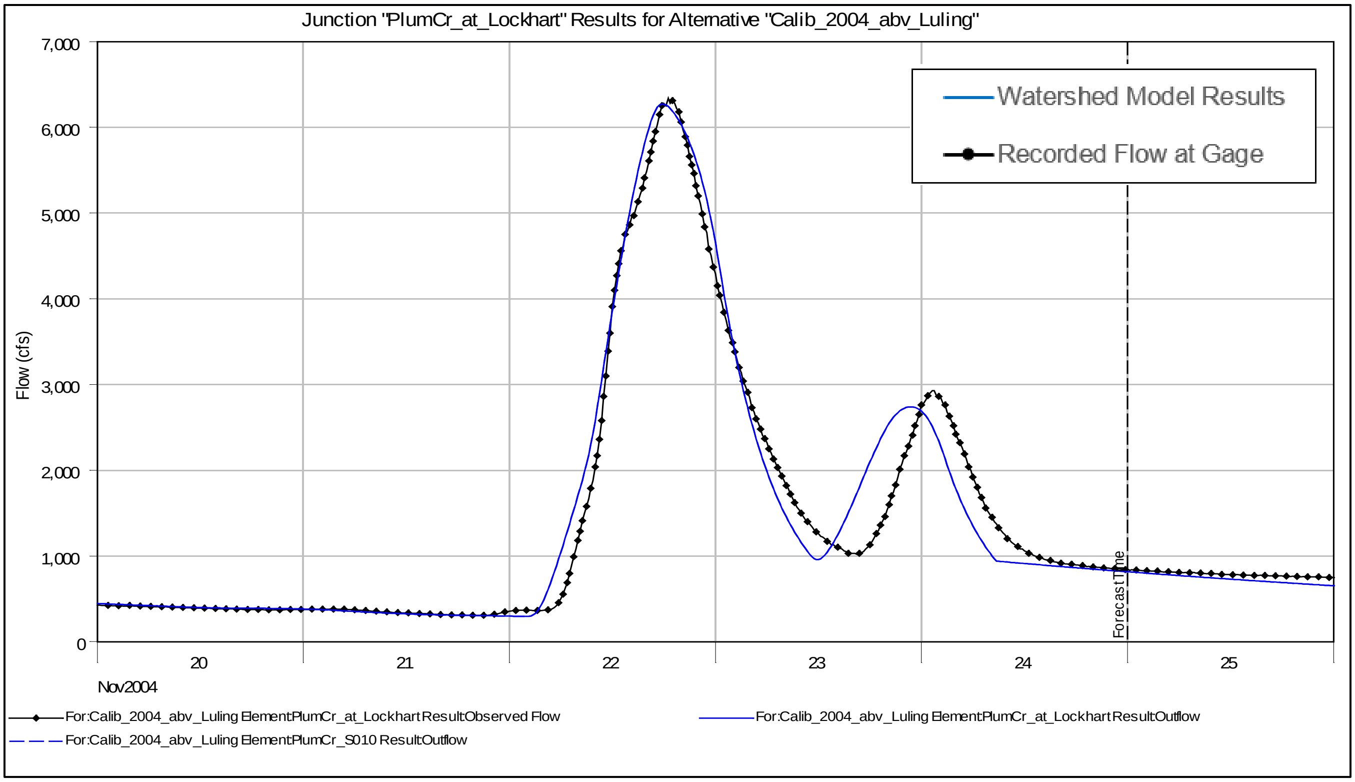


Figure 6.87: Nov 2004 Calibration Results for Plum Creek at Lockhart, TX

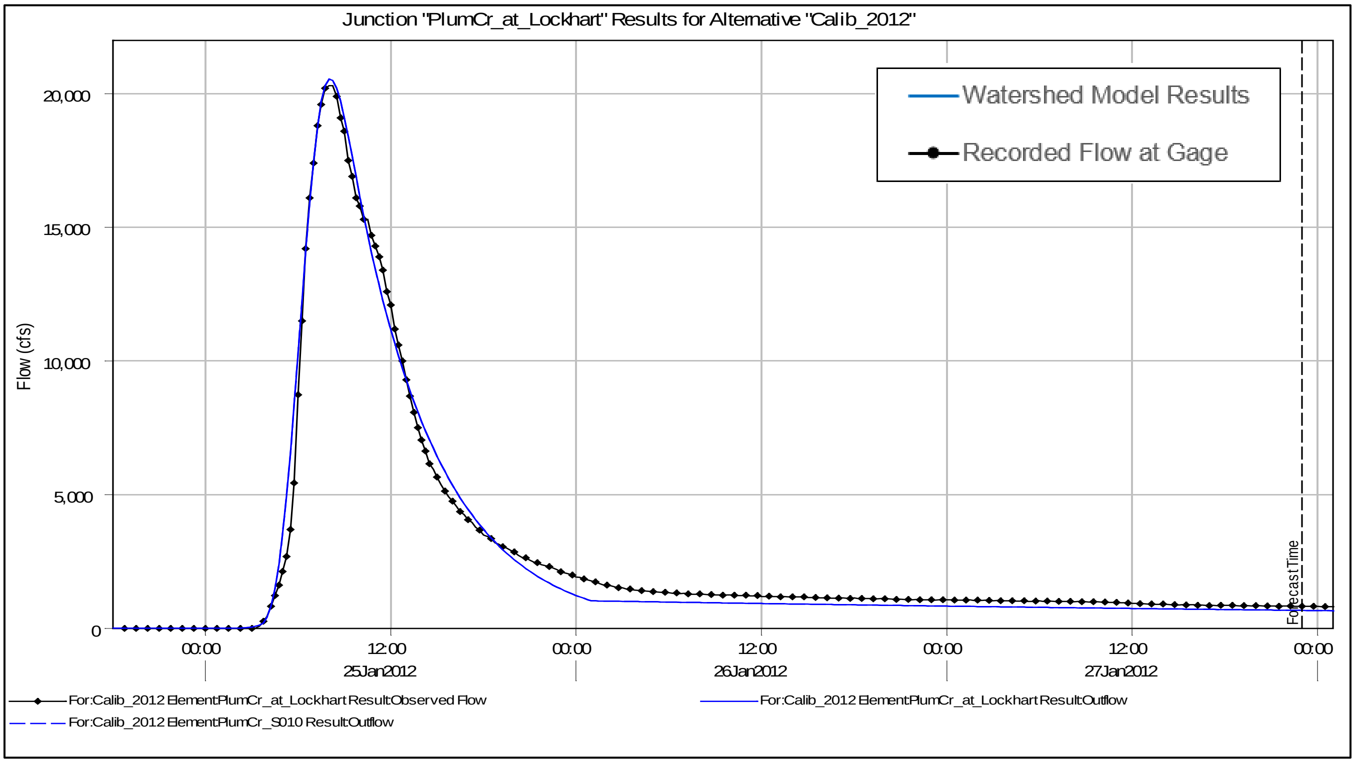


Figure 6.88: Jan 2012 Calibration Results for Plum Creek at Lockhart, TX

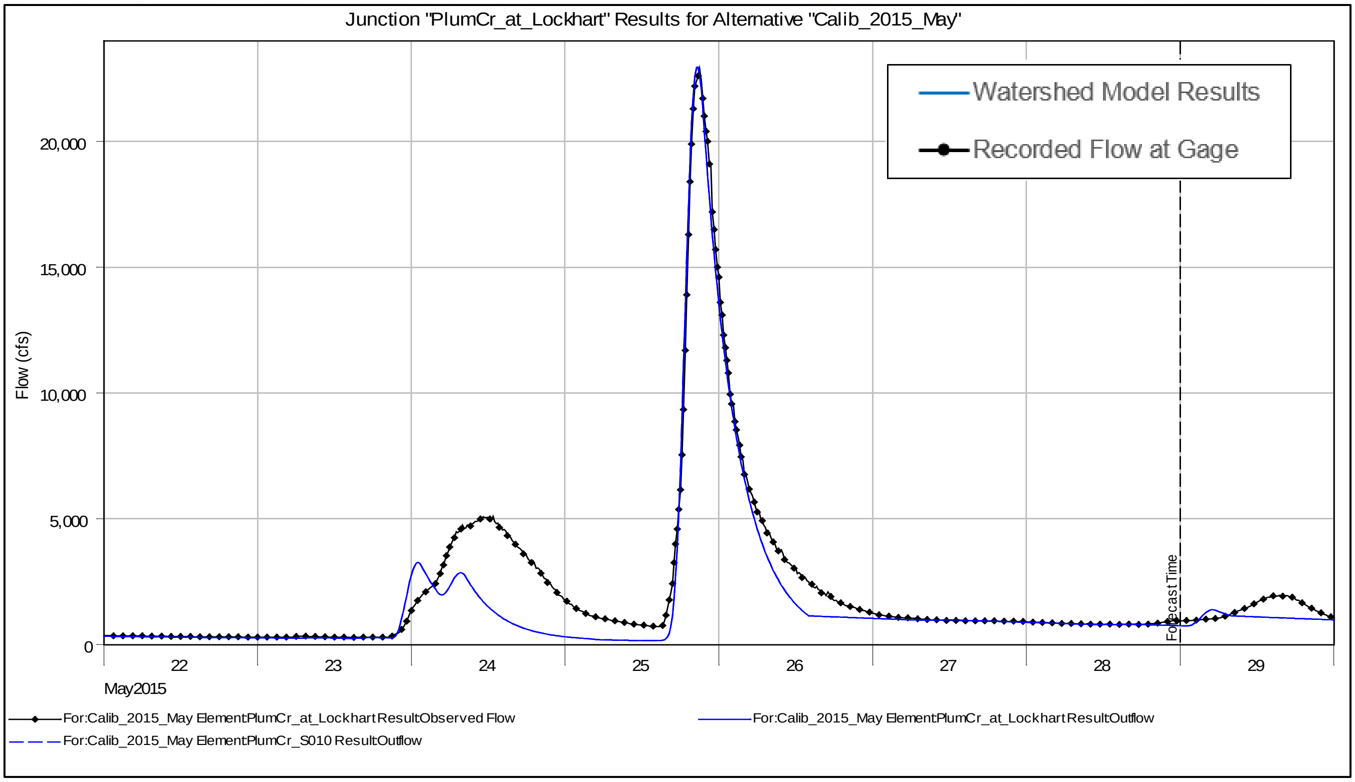


Figure 6.89: May 2015 Calibration Results for Plum Creek at Lockhart, TX

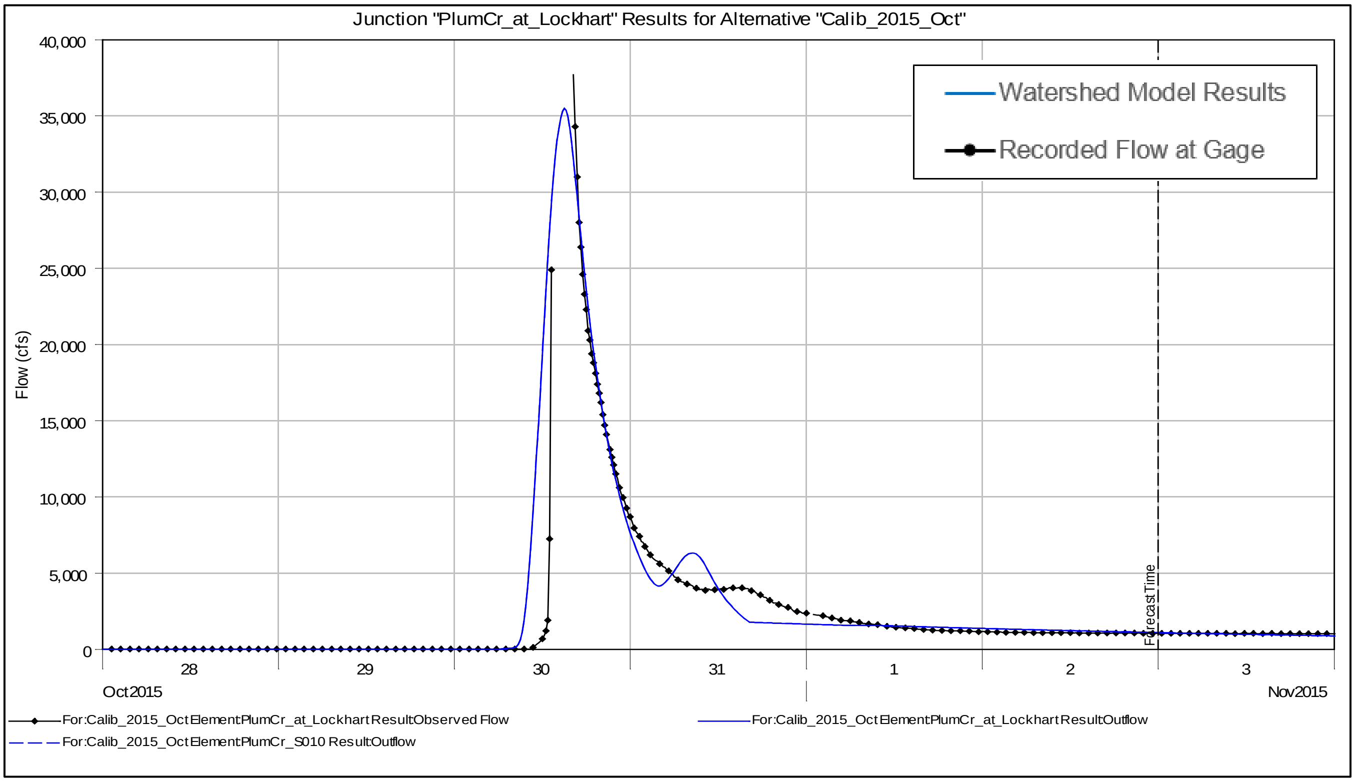


Figure 6.90: Oct 2015 Calibration Results for Plum Creek at Lockhart, TX

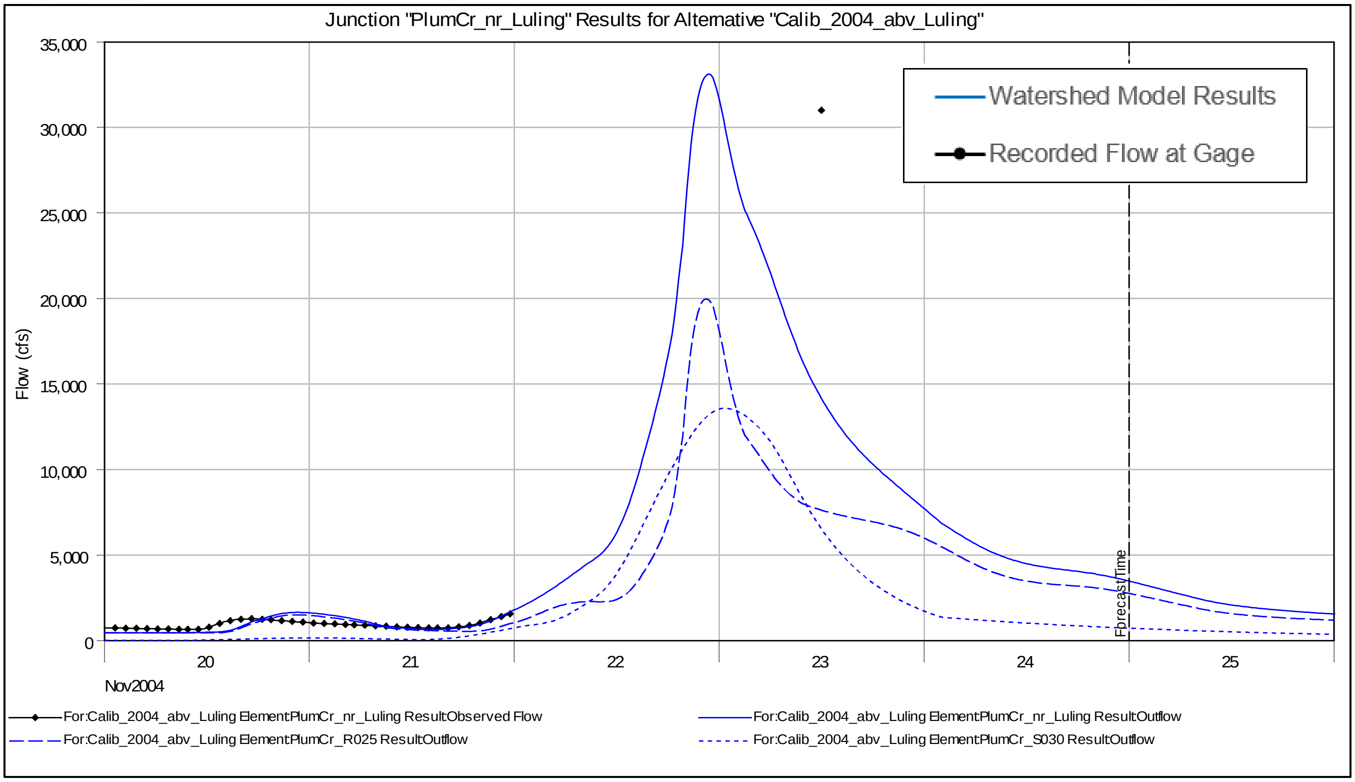


Figure 6.91: Nov 2004 Calibration Results for Plum Creek near Luling, TX

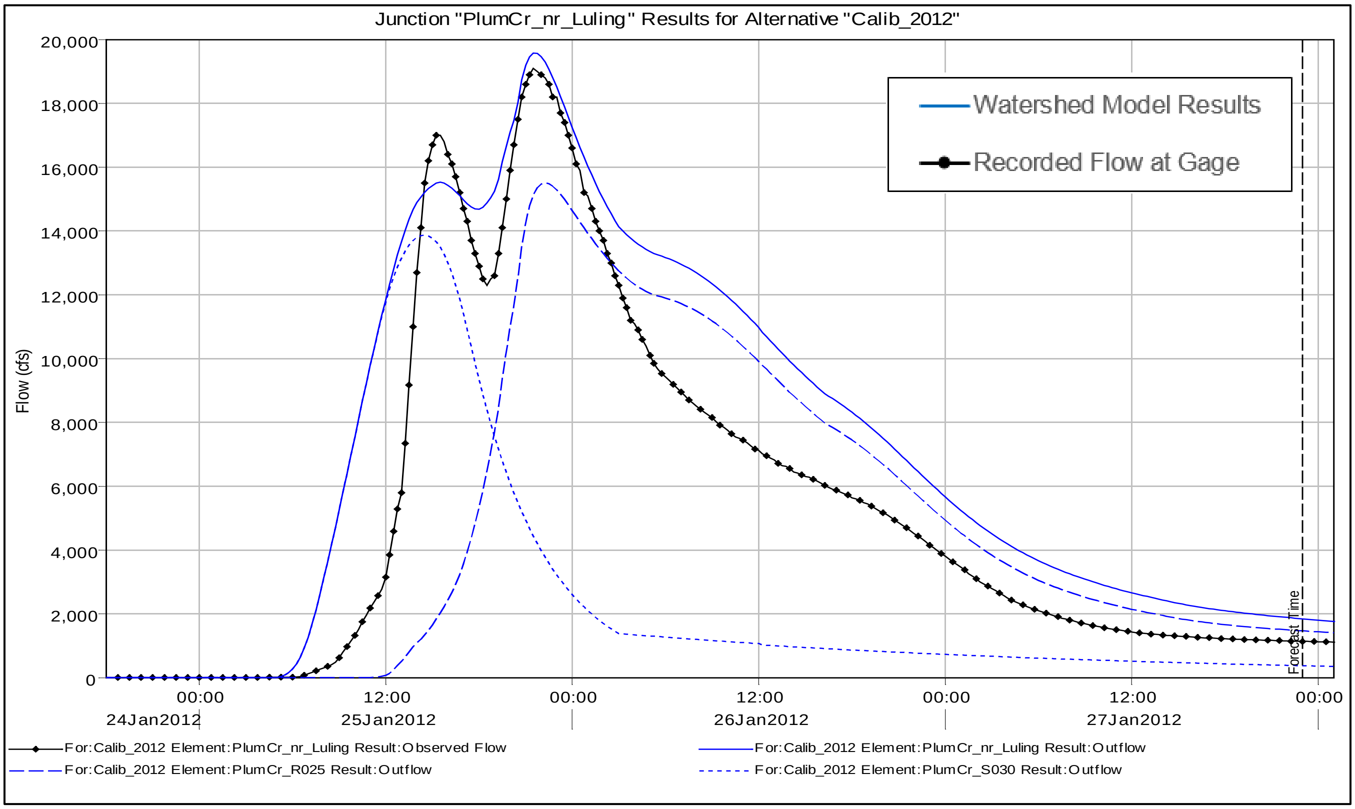


Figure 6.92: Jan 2012 Calibration Results for Plum Creek near Luling, TX

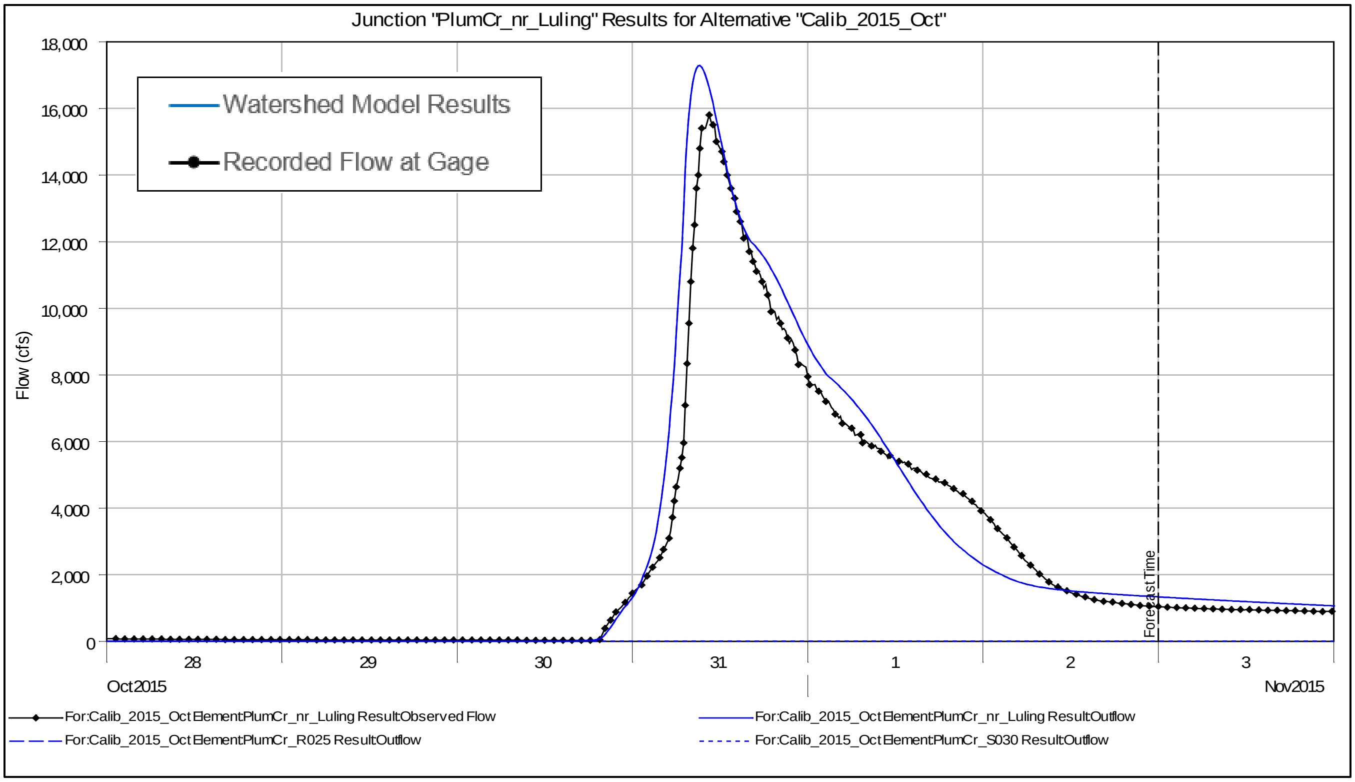


Figure 6.93: Oct 2015 Calibration Results for Plum Creek near Luling, TX

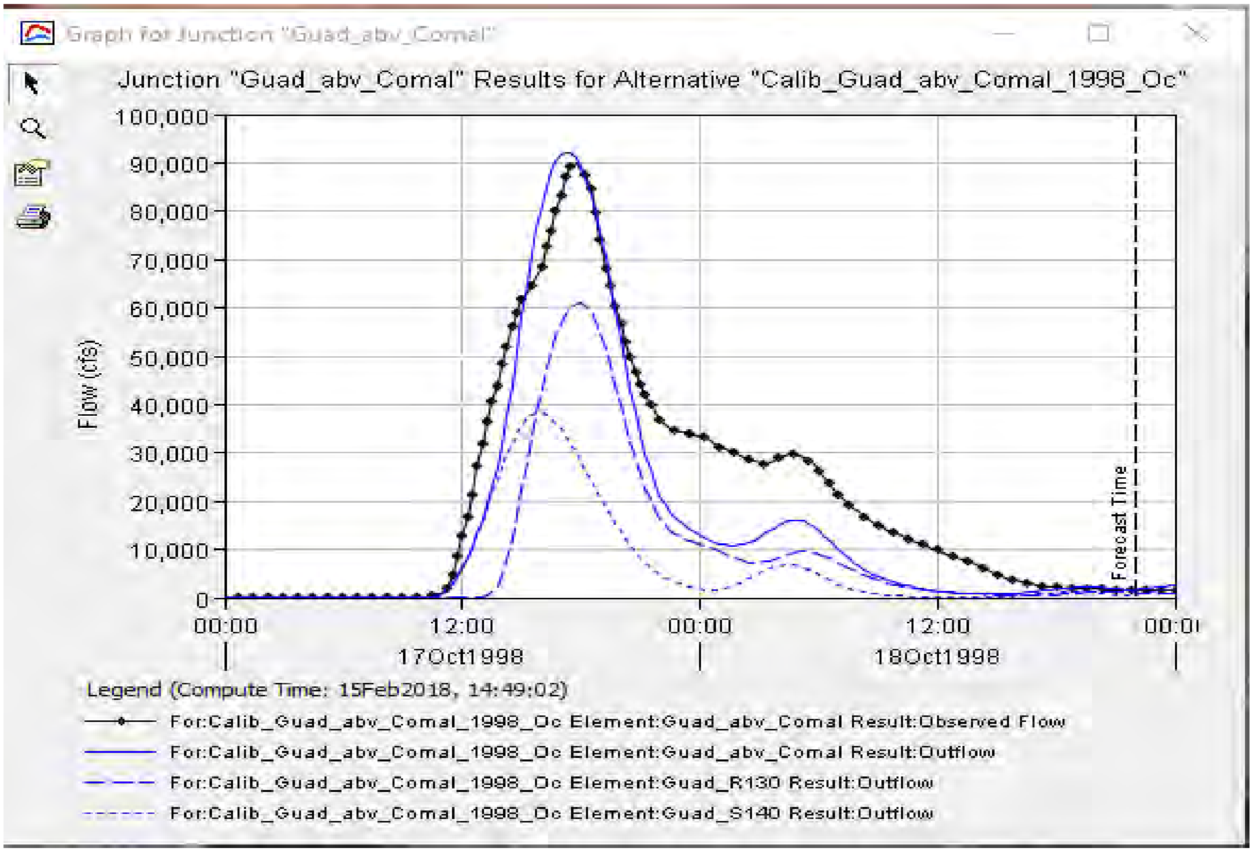


Figure 6.94: Oct 1998 Calibration Results for Guadalupe River above Comal River

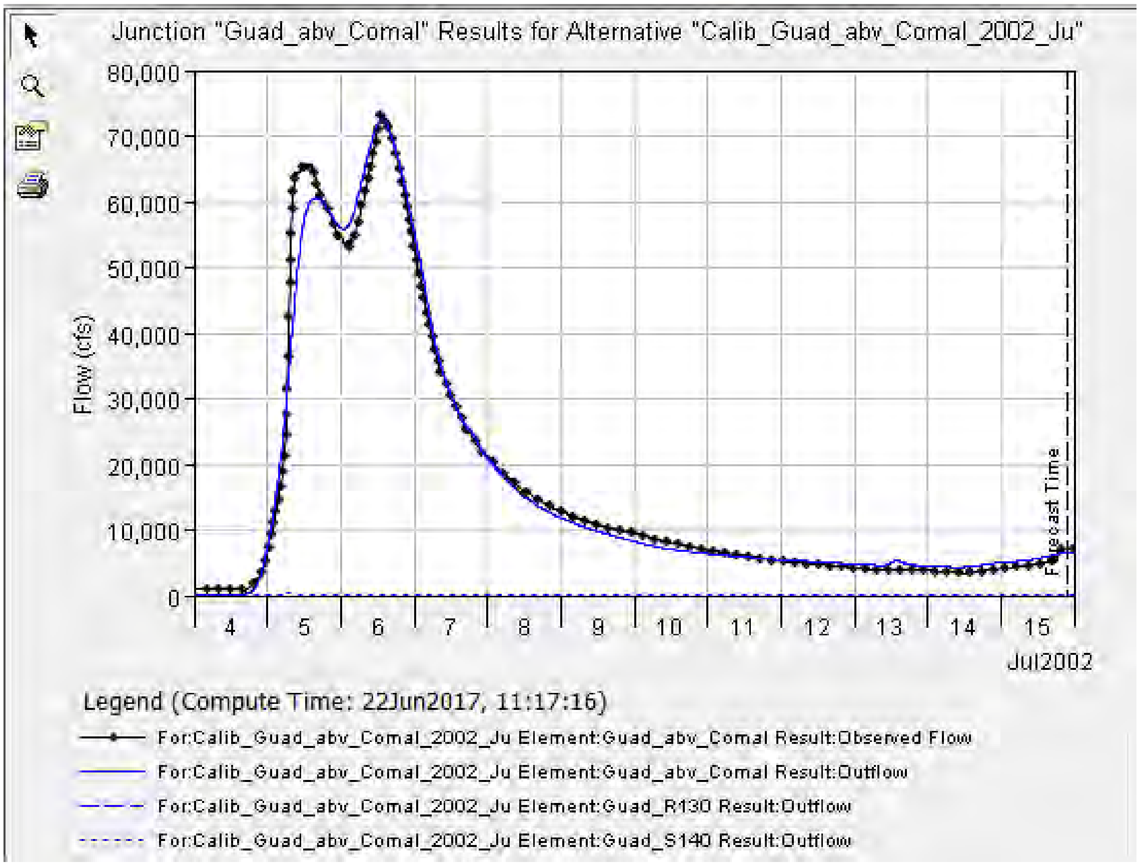


Figure 6.95: Jul 2002 Calibration Results for Guadalupe River above Comal River

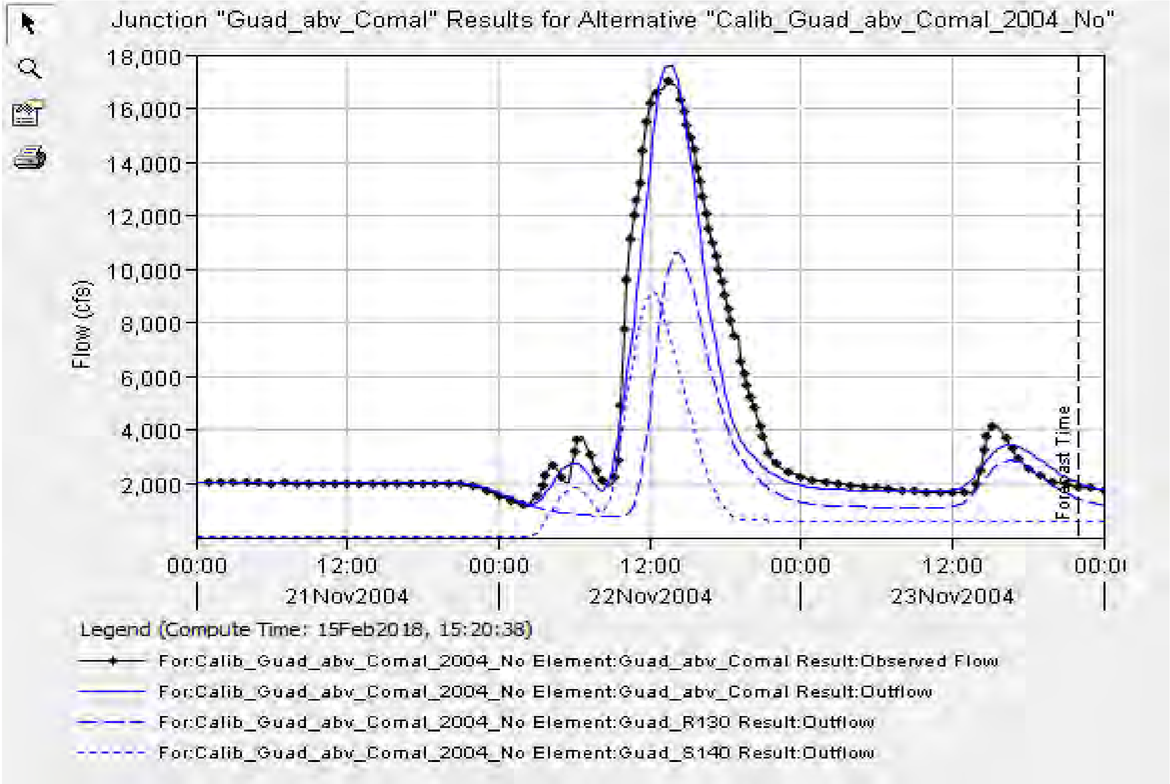


Figure 6.96: Nov 2004 Calibration Results for Guadalupe River above Comal River

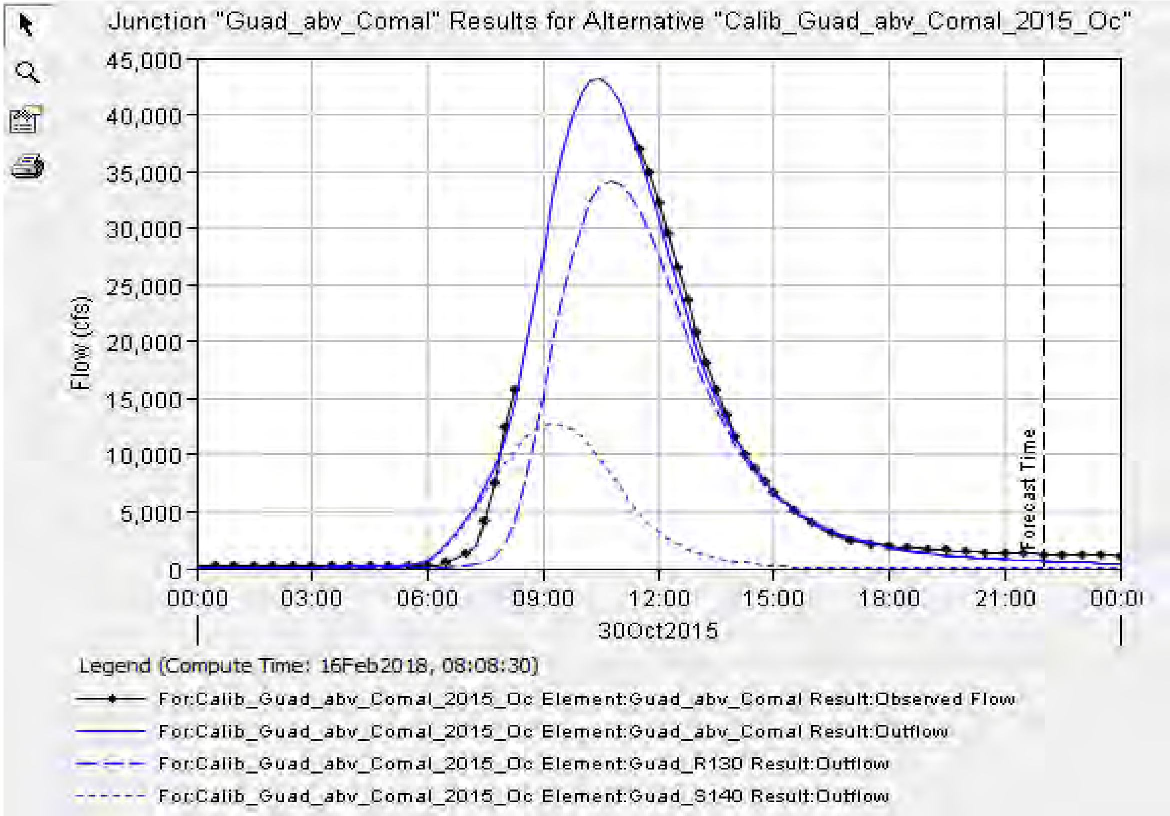


Figure 6.97: Oct 2015 Calibration Results for Guadalupe River above Comal River

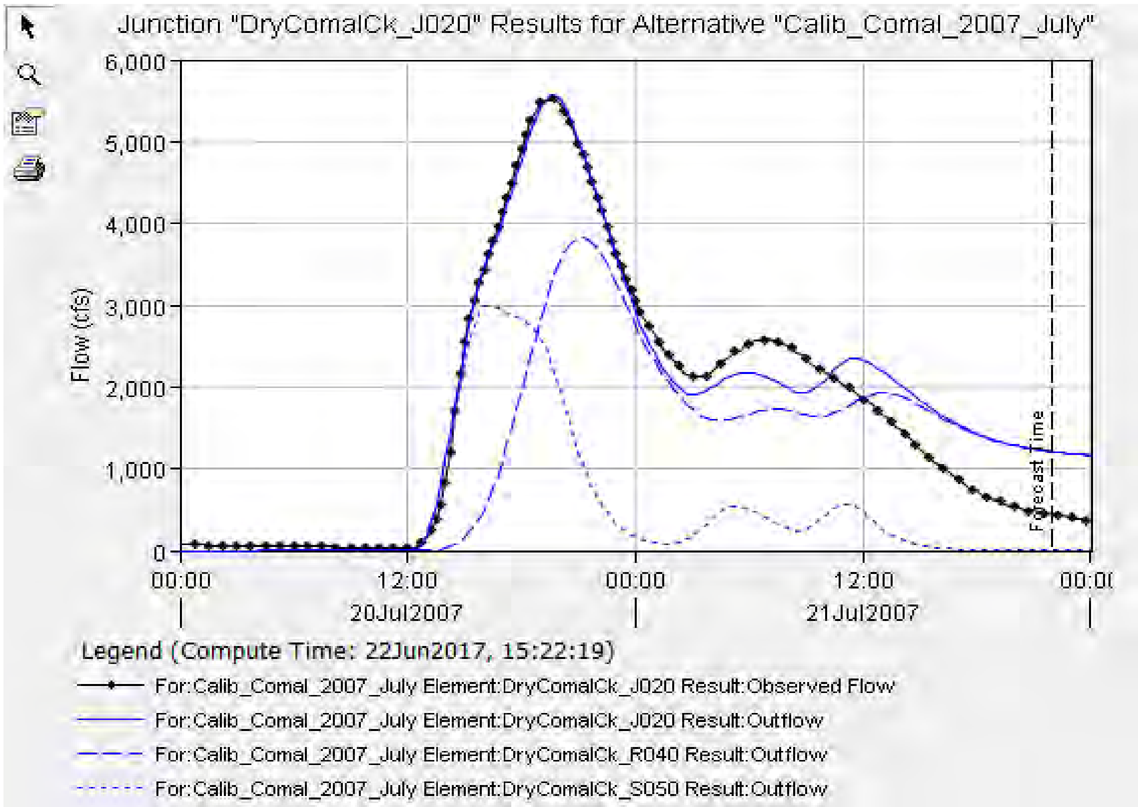


Figure 6.98: Jul 2007 Calibration Results for Dry Comal Ck at Loop 377 nr New Braunfels

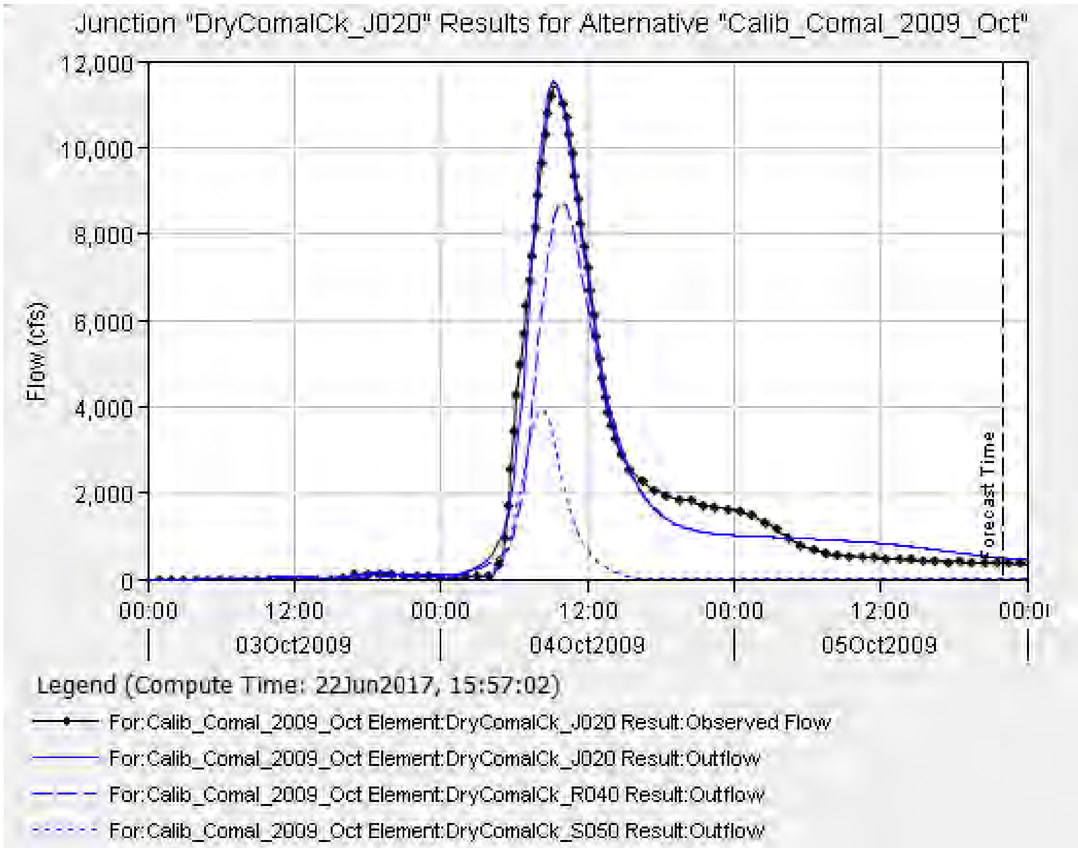


Figure 6.99: Oct 2009 Calibration Results for Dry Comal Ck at Loop 377 nr New Braunfels

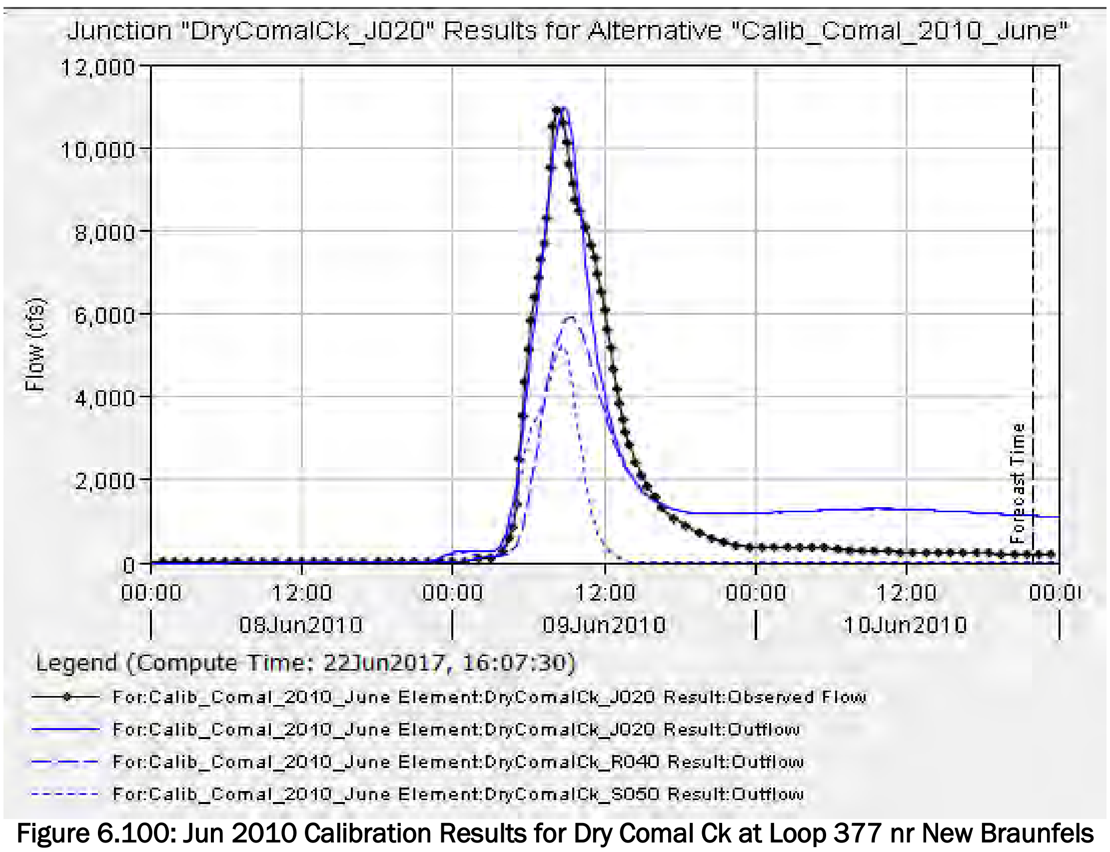


Figure 6.100: Jun 2010 Calibration Results for Dry Comal Ck at Loop 377 nr New Braunfels

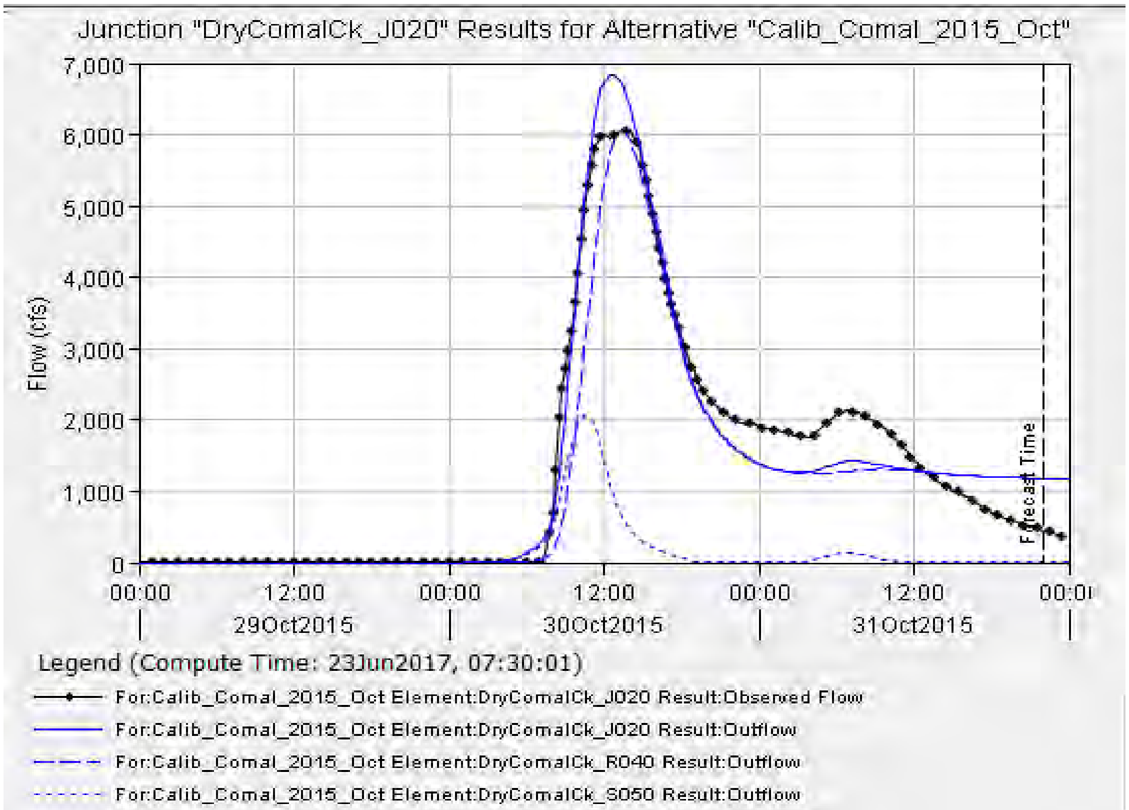


Figure 6.101: Oct 2015 Calibration Results for Dry Comal Ck at Loop 377 nr New Braunfels

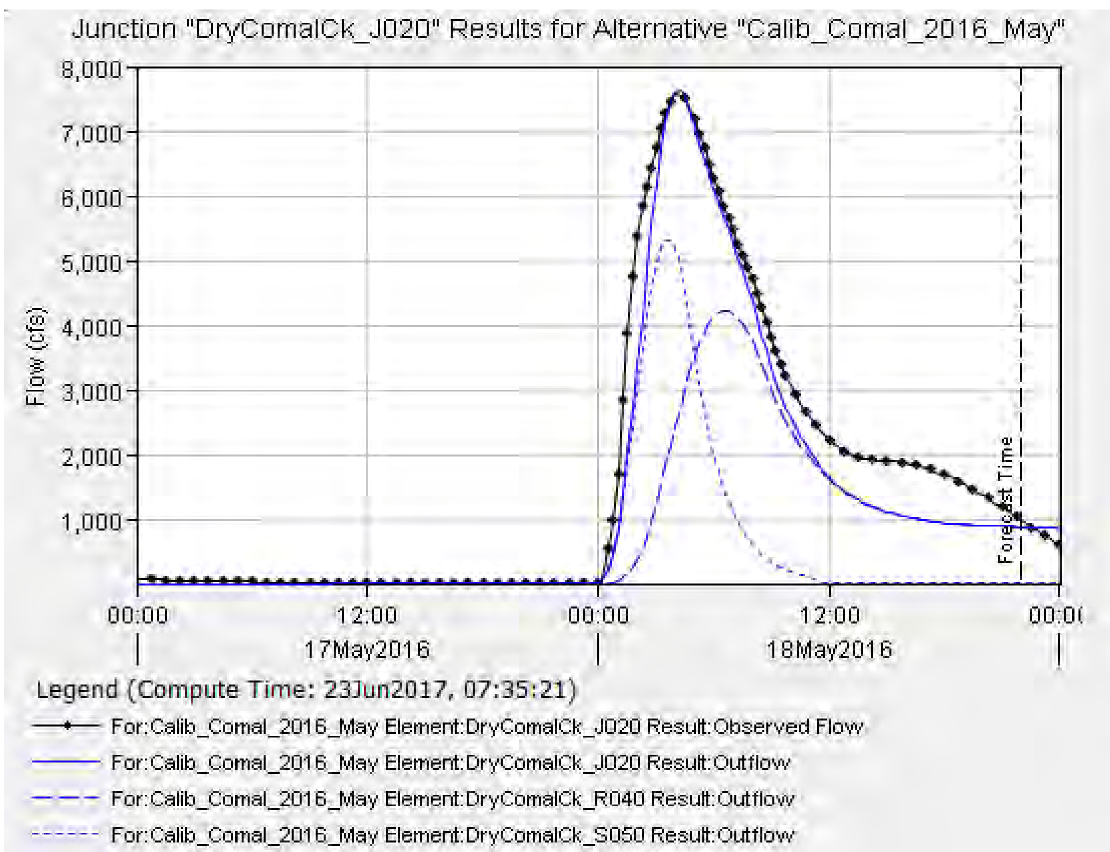


Figure 6.102: May 2016 Calibration Results for Dry Comal Ck at Loop 377 nr New Braunfels

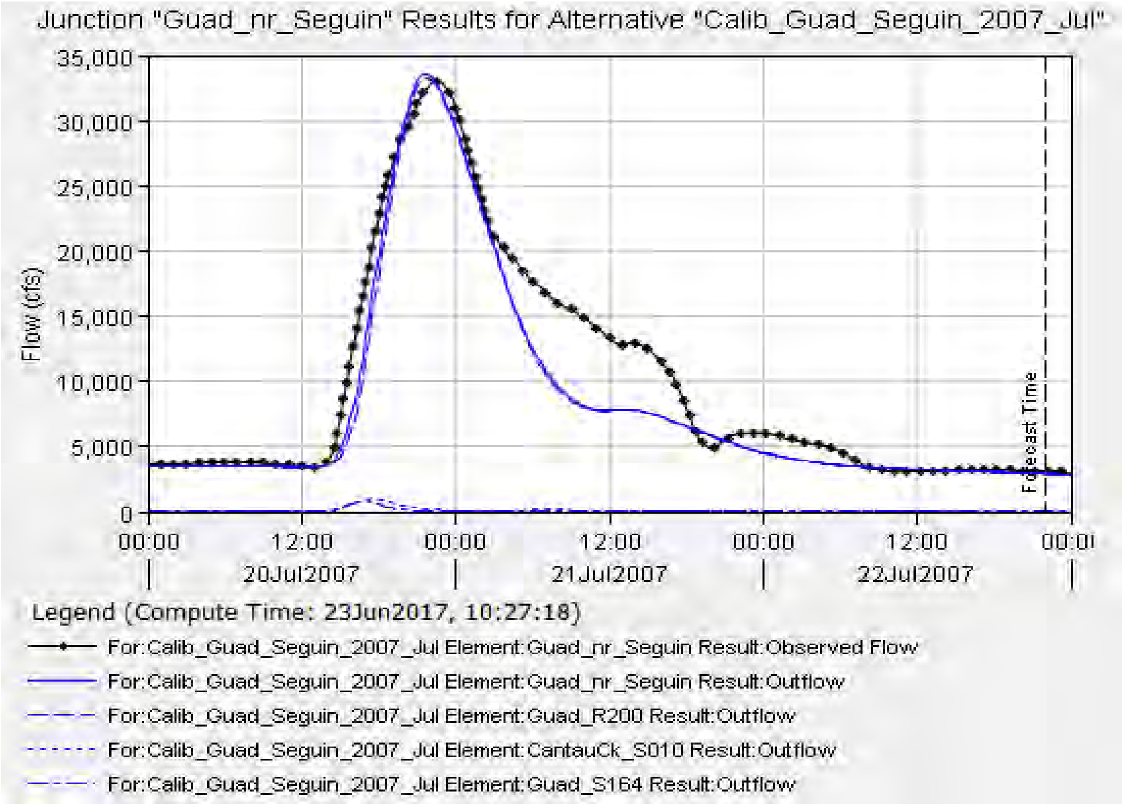


Figure 6.103: Jul 2007 Calibration Results for Guadalupe River nr Seguin

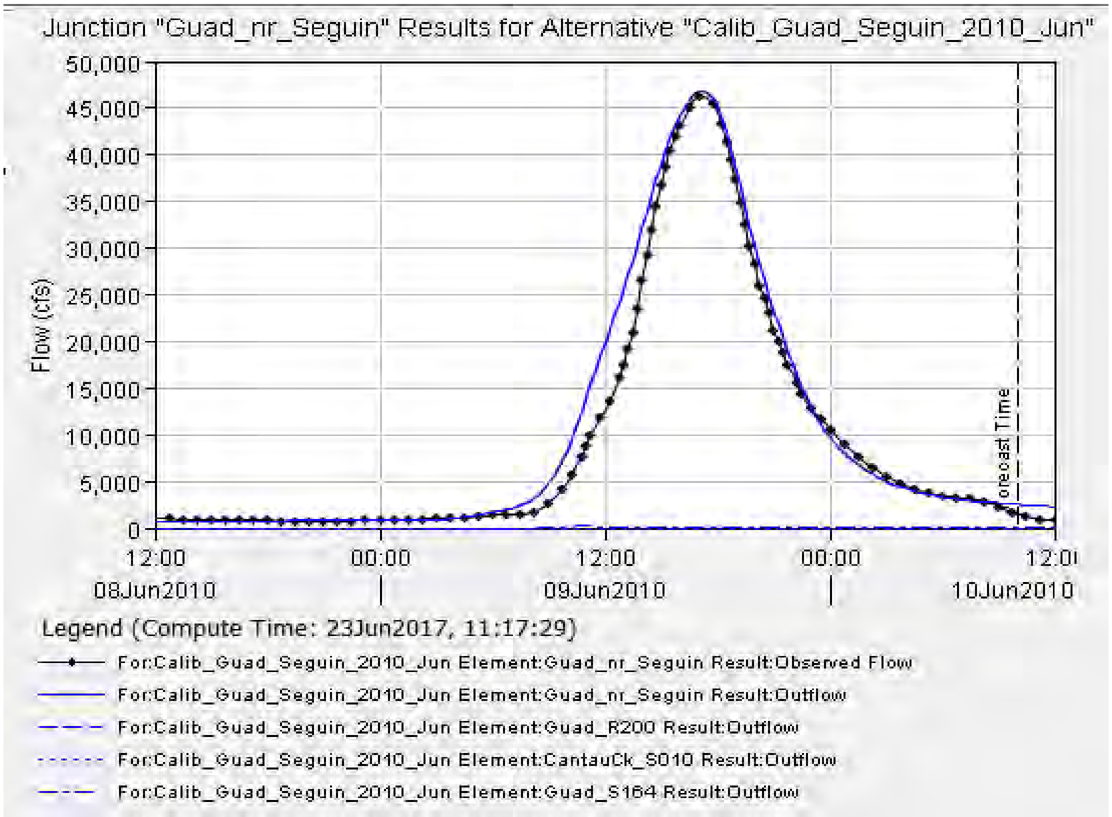


Figure 6.104: Jun 2010 Calibration Results for Guadalupe River nr Seguin

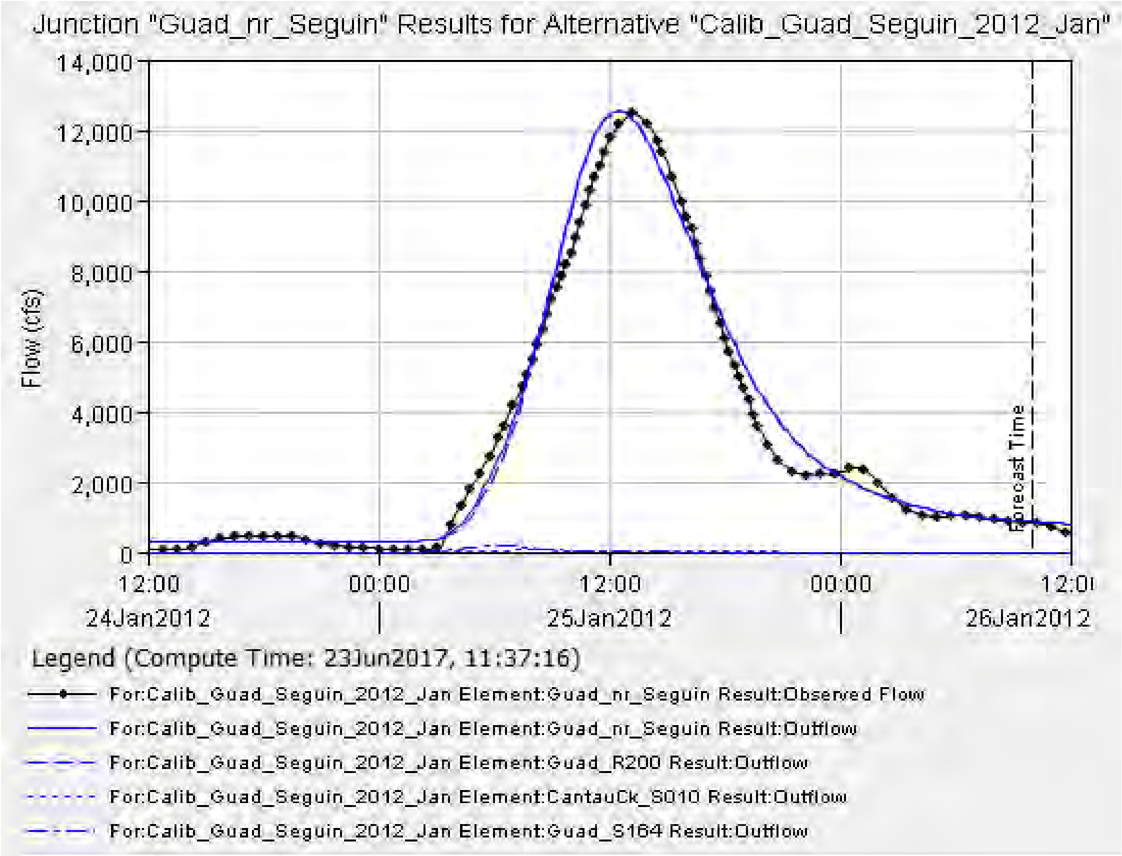


Figure 6.105: Jan 2012 Calibration Results for Guadalupe River nr Seguin

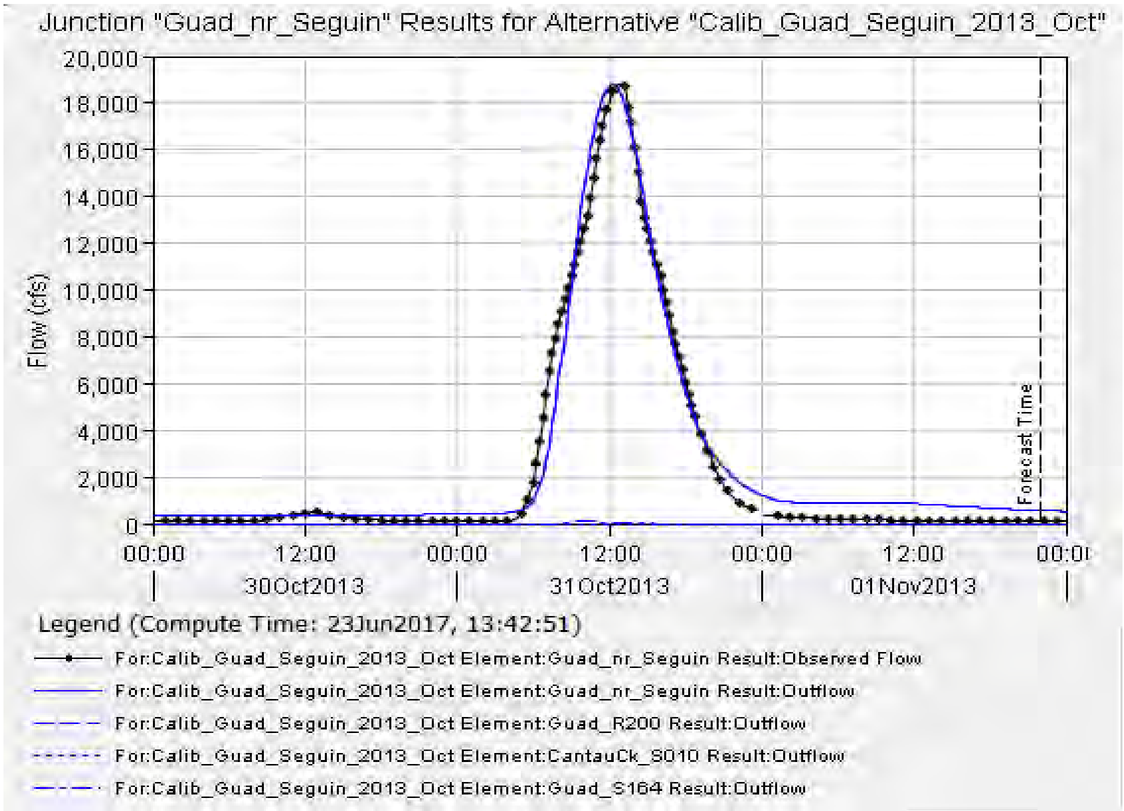


Figure 6.106: Oct 2013 Calibration Results for Guadalupe River nr Seguin

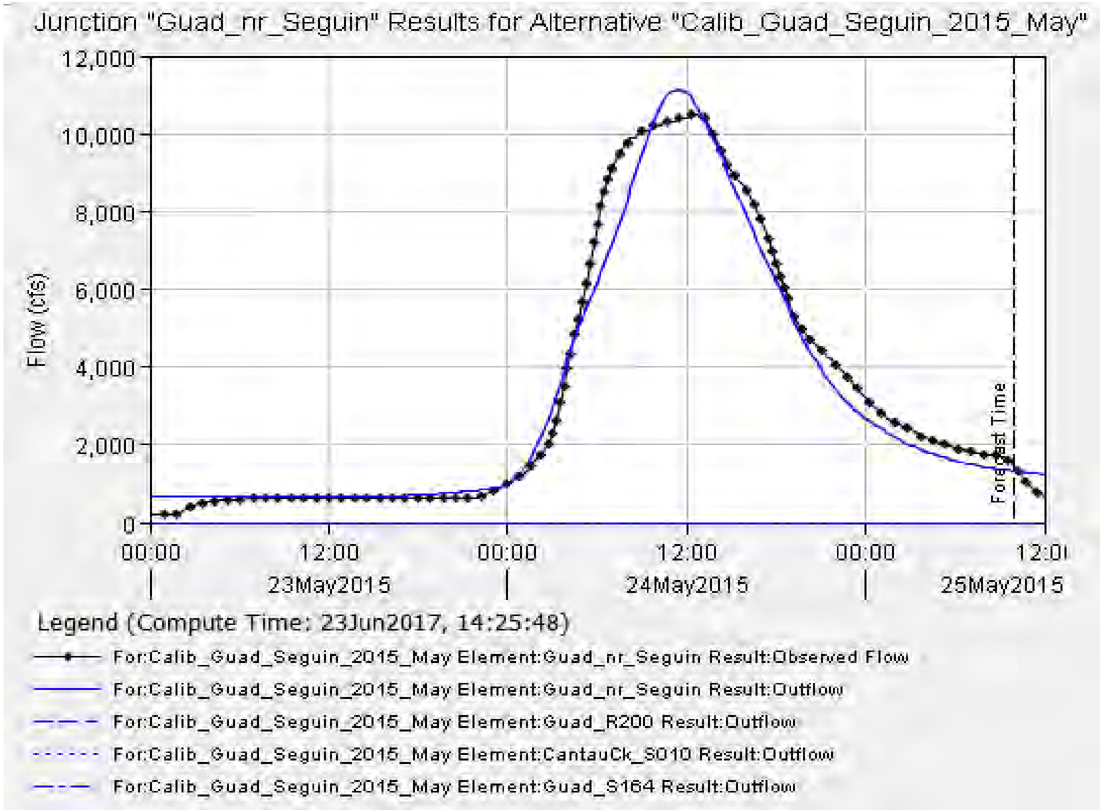


Figure 6.107: May 2015 Calibration Results for Guadalupe River nr Seguin

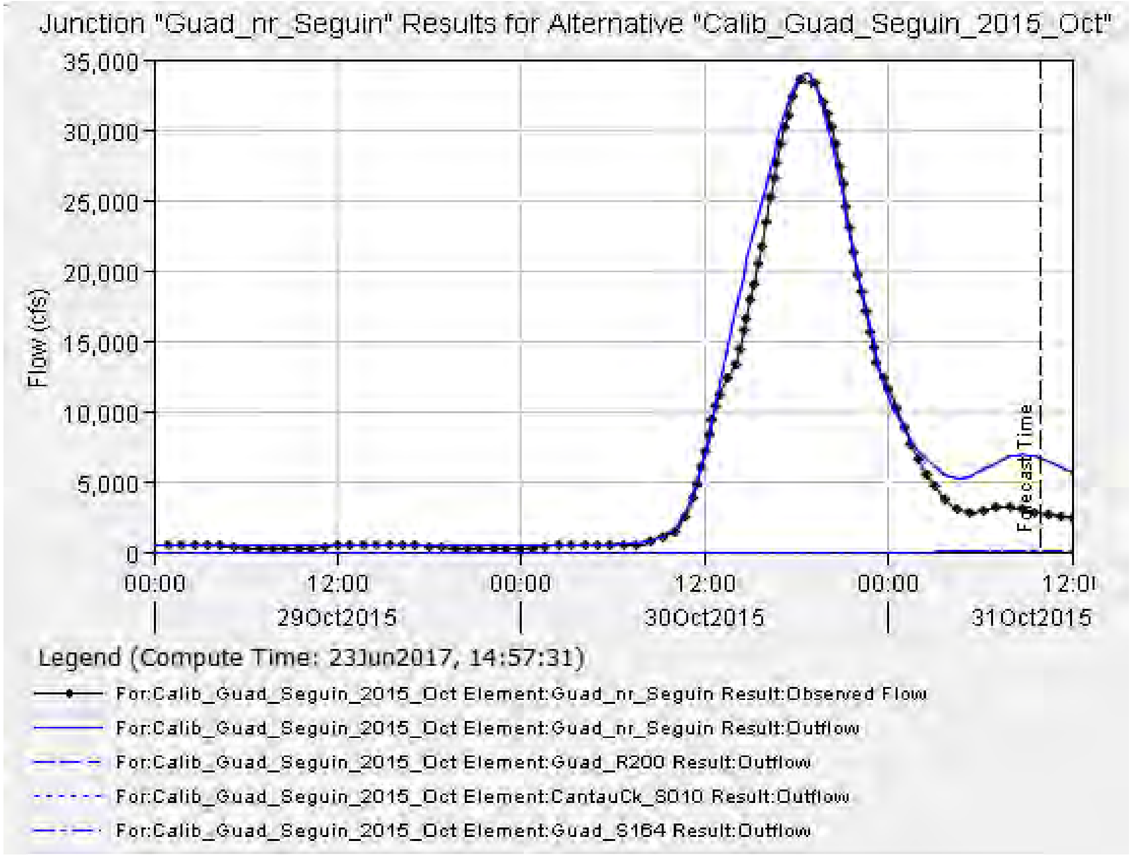


Figure 6.108: Oct 2015 Calibration Results for Guadalupe River nr Seguin

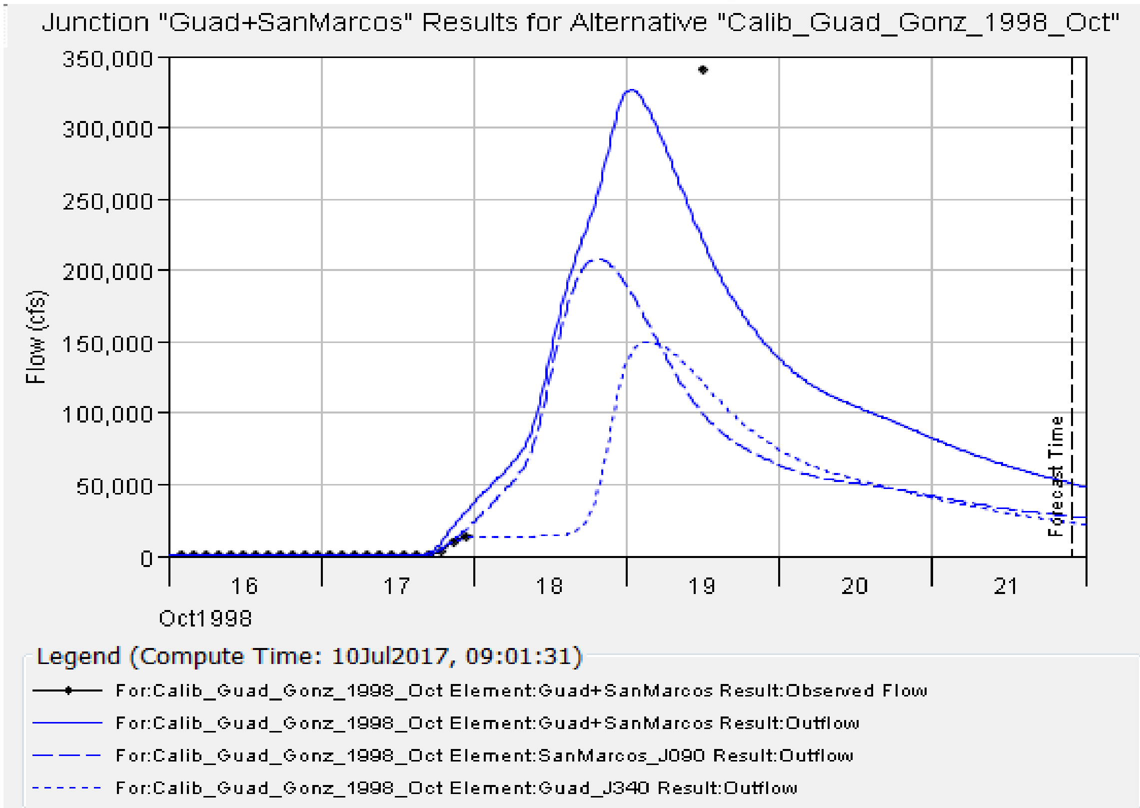


Figure 6.109: Oct 1998 Calibration Results for Guadalupe River at Gonzales

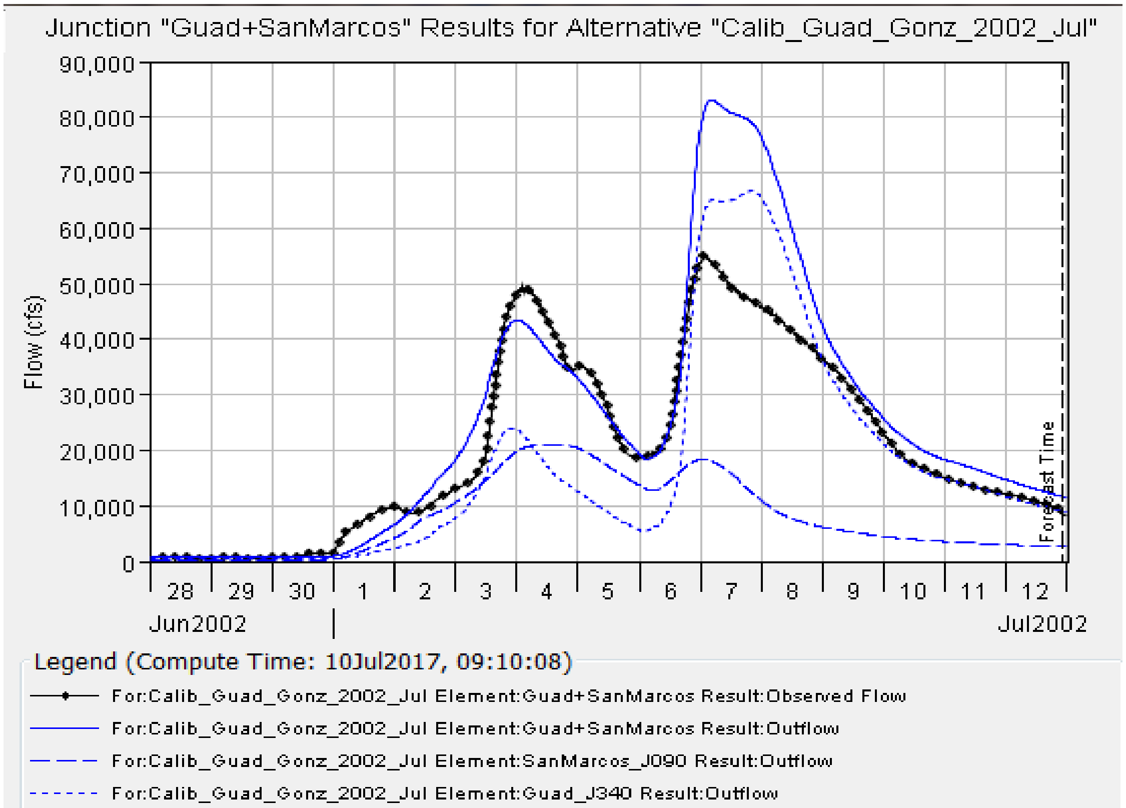


Figure 6.110: Jul 2002 Calibration Results for Guadalupe River at Gonzales

NOTE – Volume Discrepancy between Gonzales and Upstream Gages

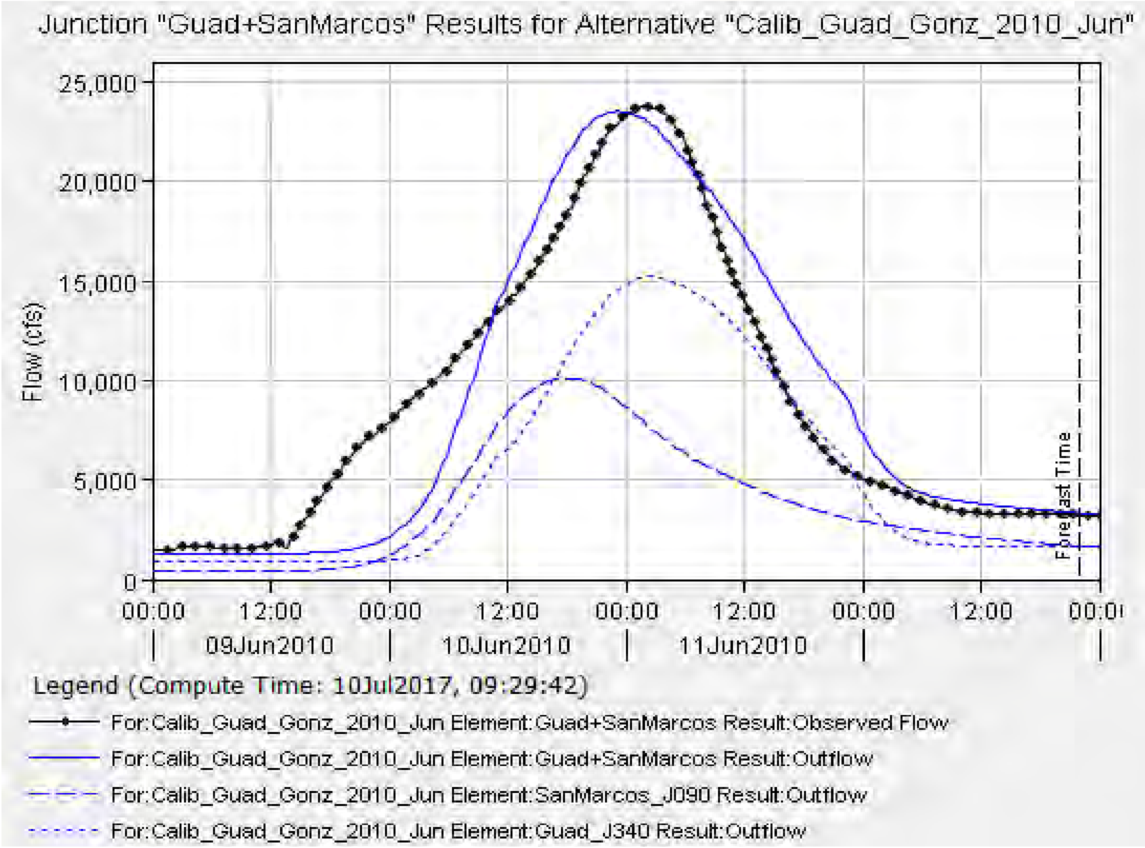


Figure 6.111: Jun 2010 Calibration Results for Guadalupe River at Gonzales

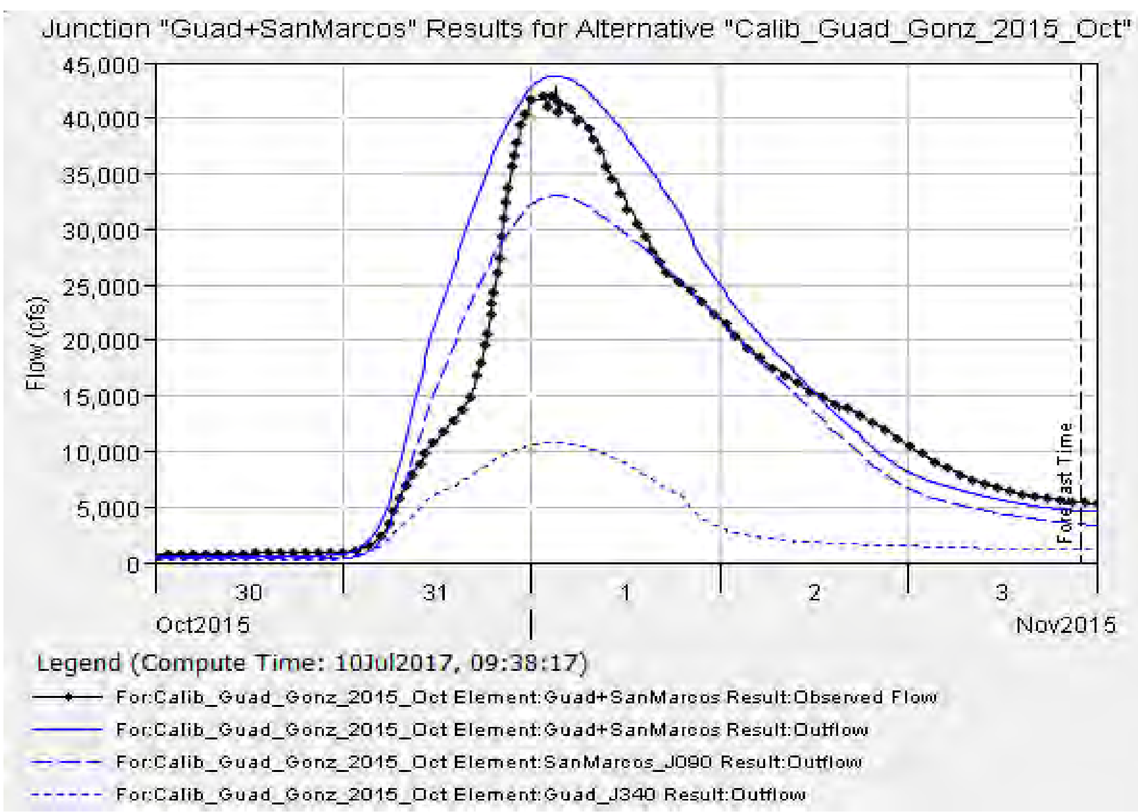


Figure 6.112: Oct 2015 Calibration Results for Guadalupe River at Gonzales

NOTE – Volume Discrepancy between Gonzales and Upstream Gages

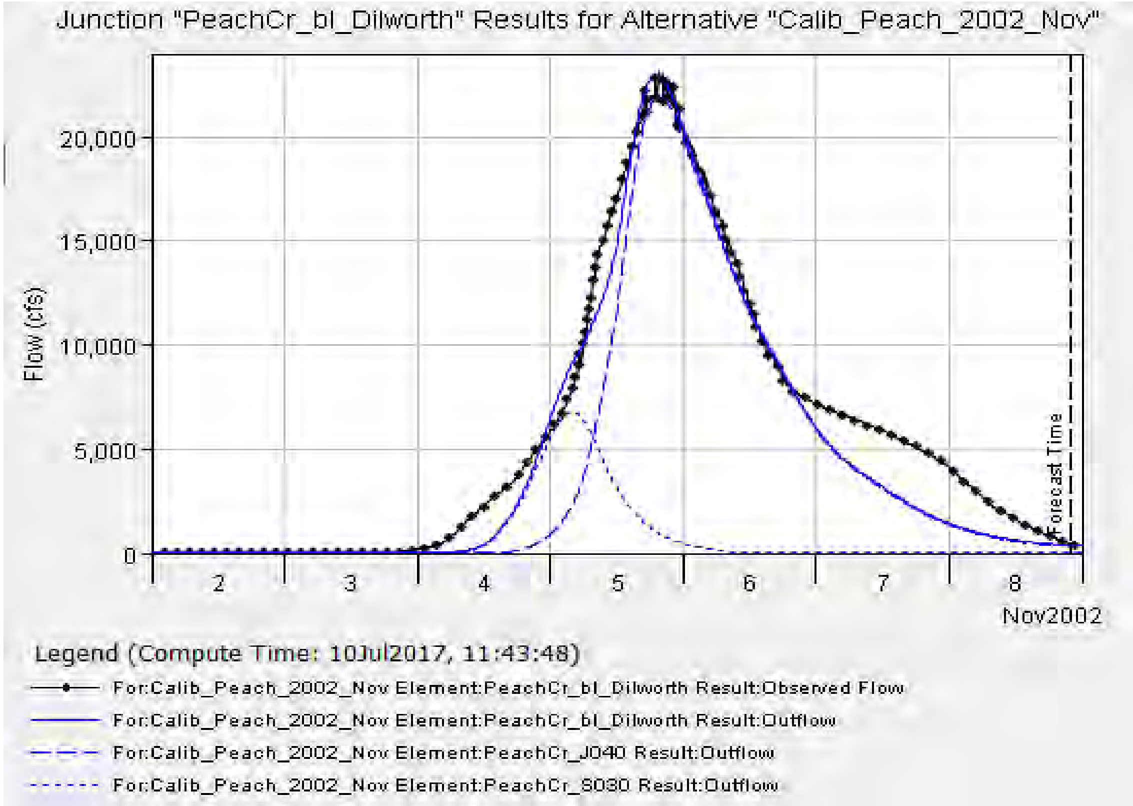


Figure 6.113: Jul 2002 Calibration Results for Peach Creek below Dilworth

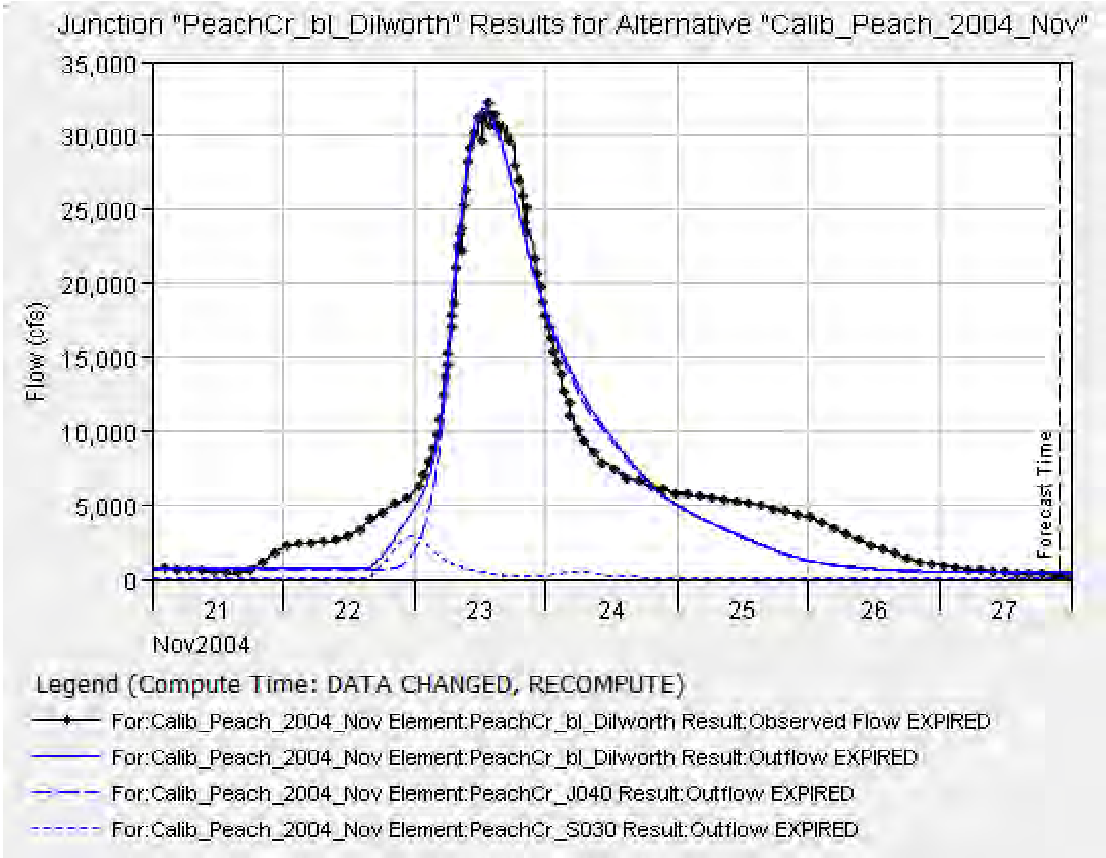


Figure 6.114: Nov 2004 Calibration Results for Peach Creek below Dilworth

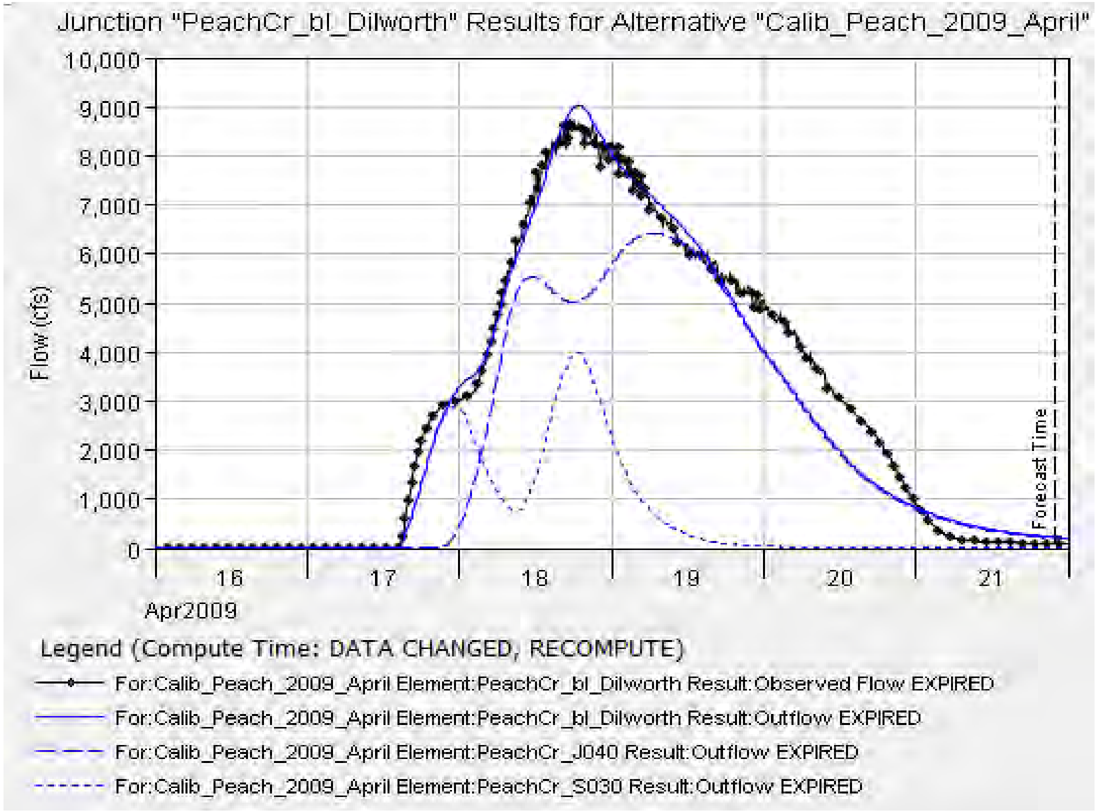


Figure 6.115: Apr 2009 Calibration Results for Peach Creek below Dilworth

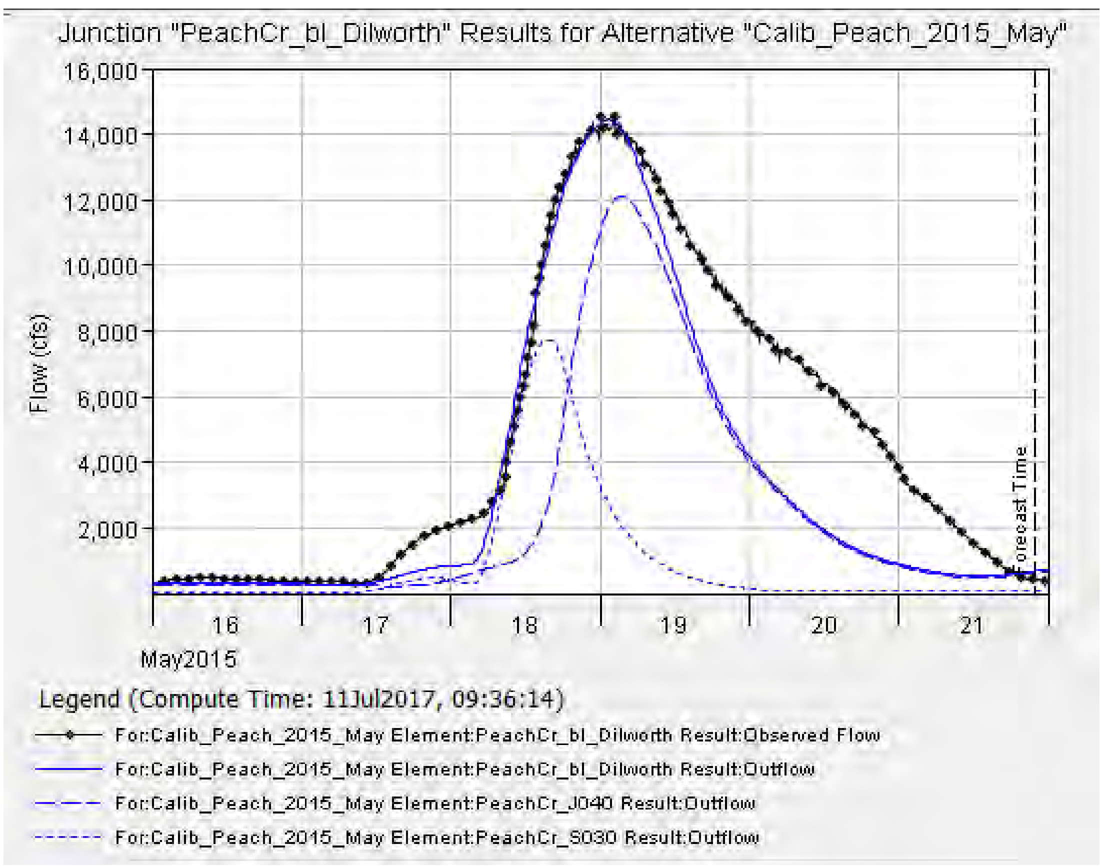


Figure 6.116: May 2015 Calibration Results for Peach Creek below Dilworth

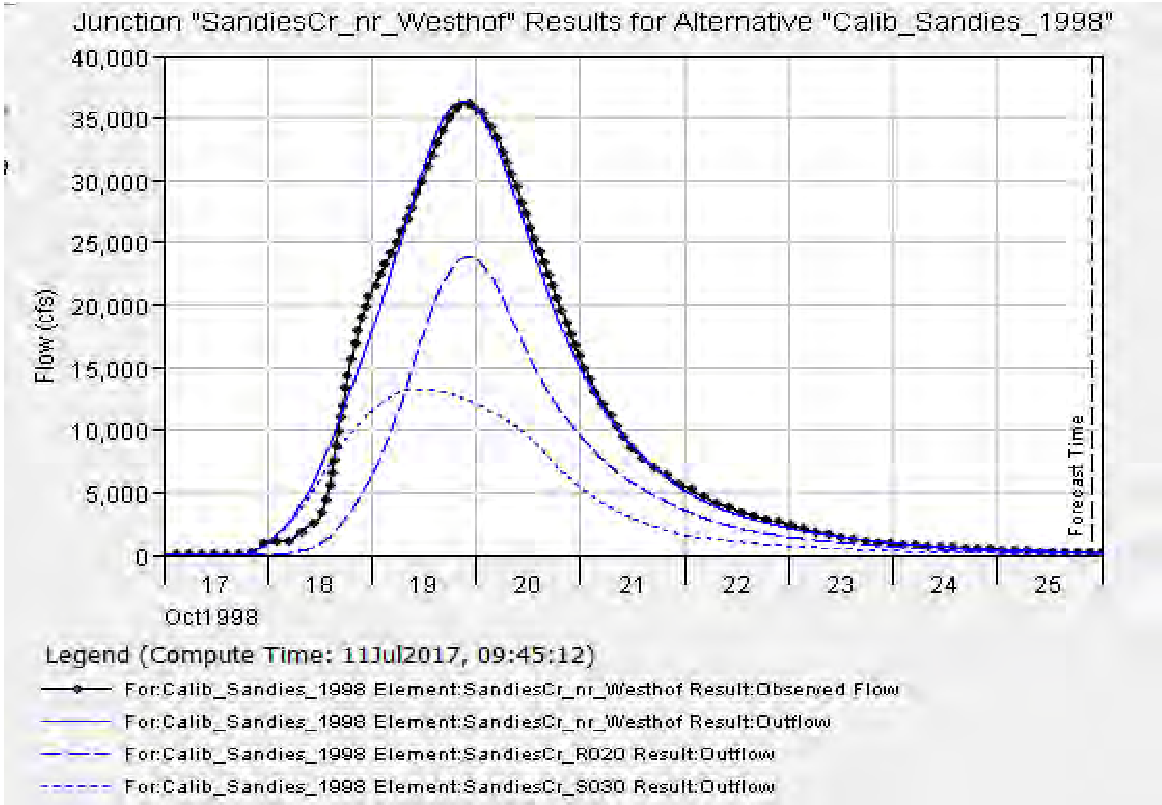


Figure 6.117: Oct 1998 Calibration Results for Sandies Creek near Westhoff

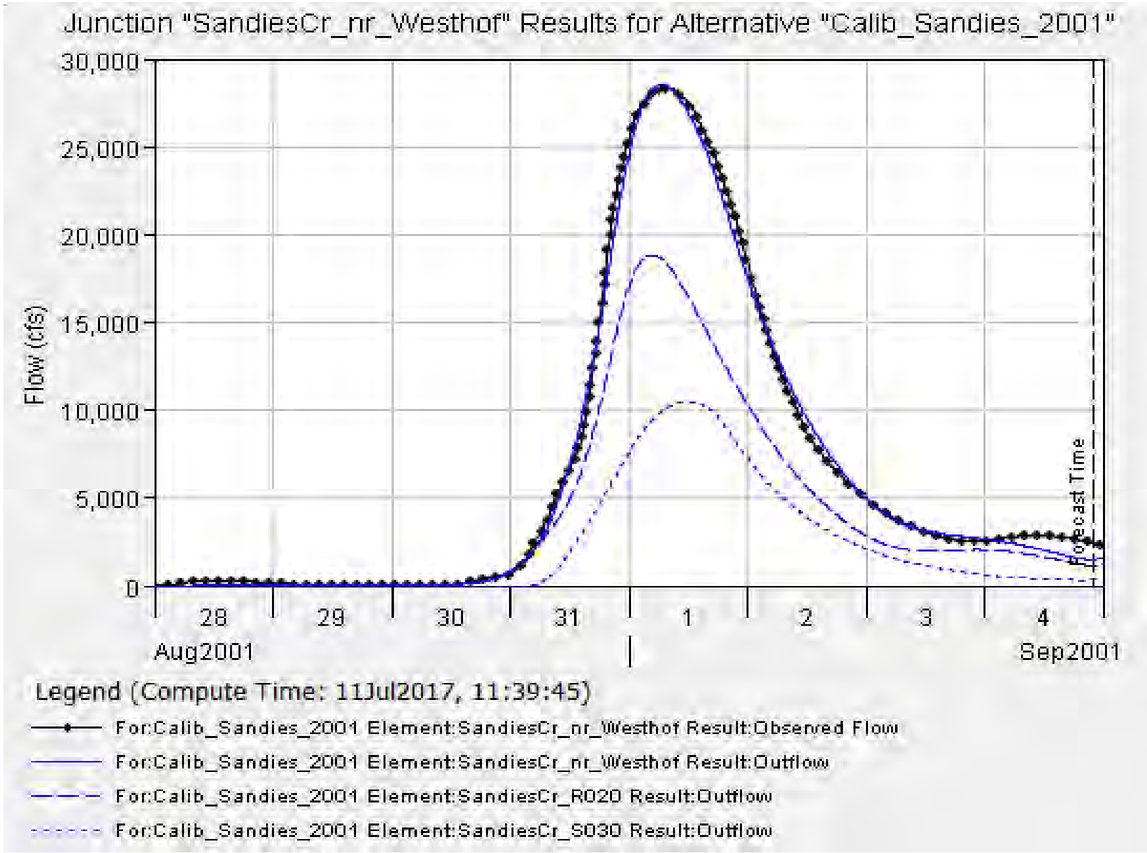


Figure 6.118: Sep 2001 Calibration Results for Sandies Creek near Westhoff

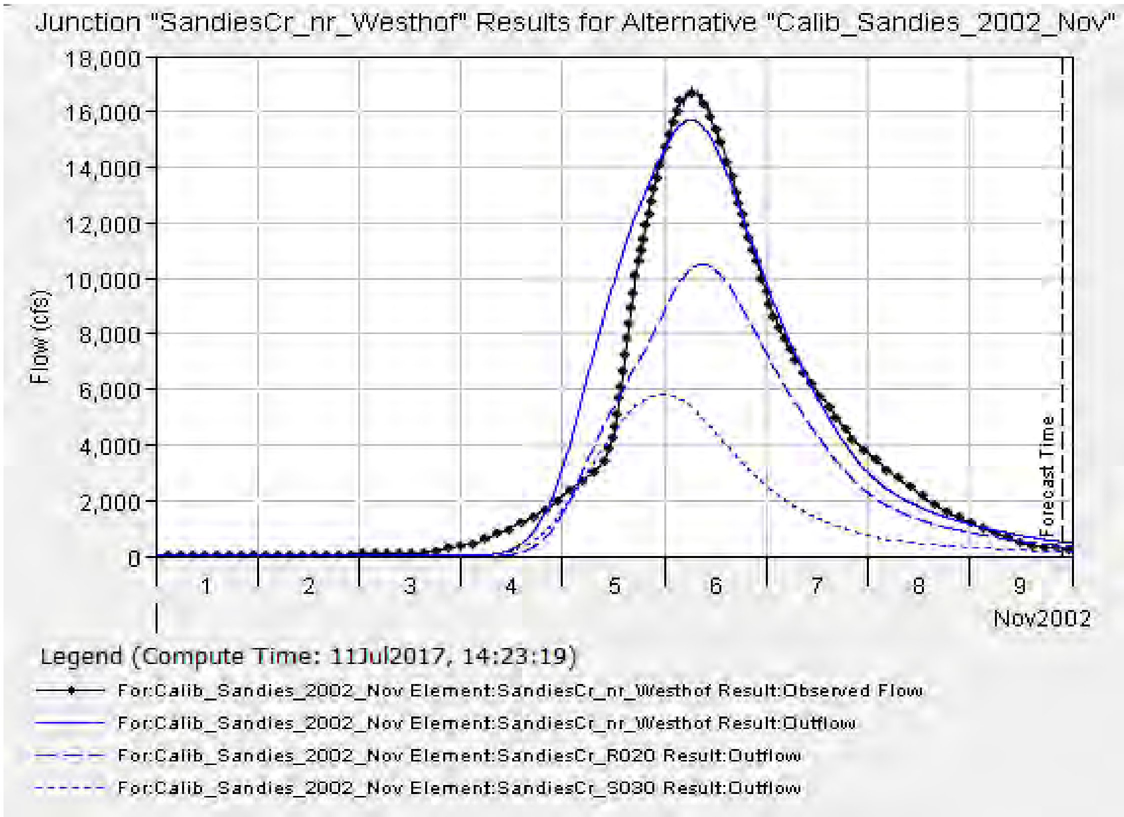


Figure 6.119: Nov 2002 Calibration Results for Sandies Creek near Westhoff

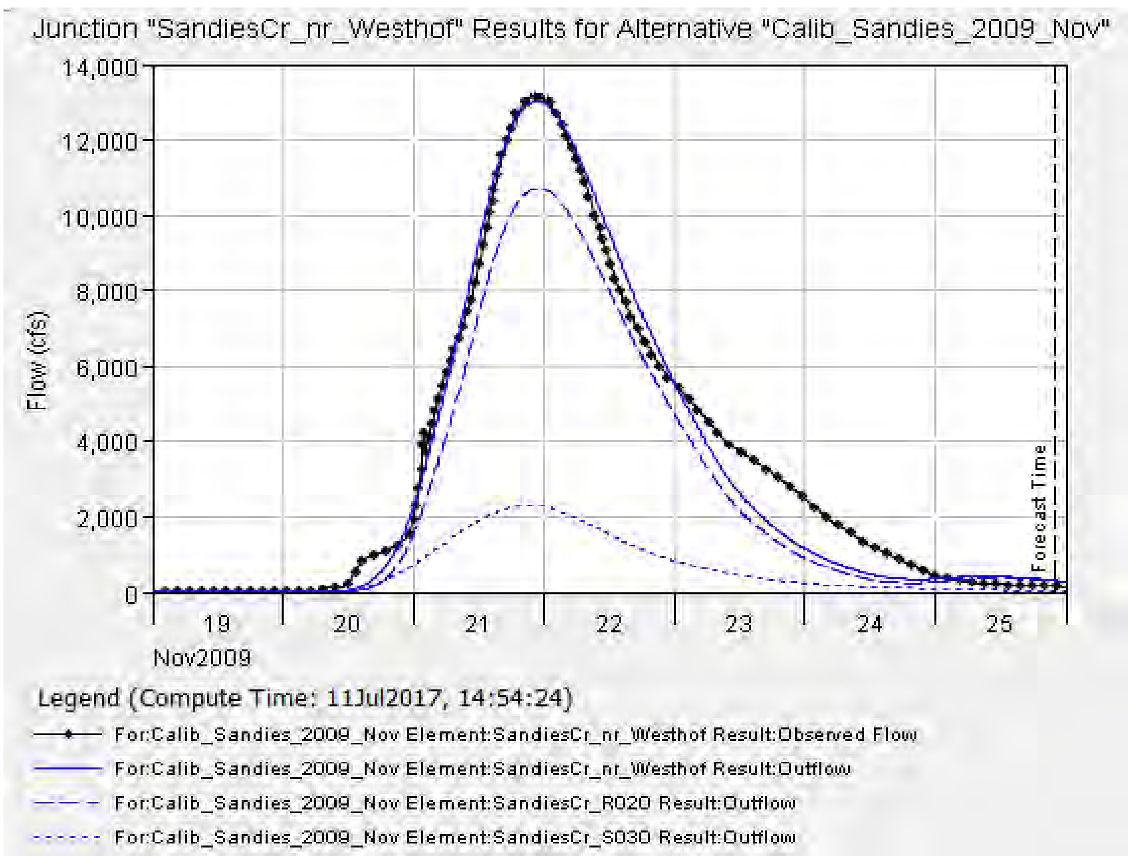


Figure 6.120: Nov 2009 Calibration Results for Sandies Creek near Westhoff

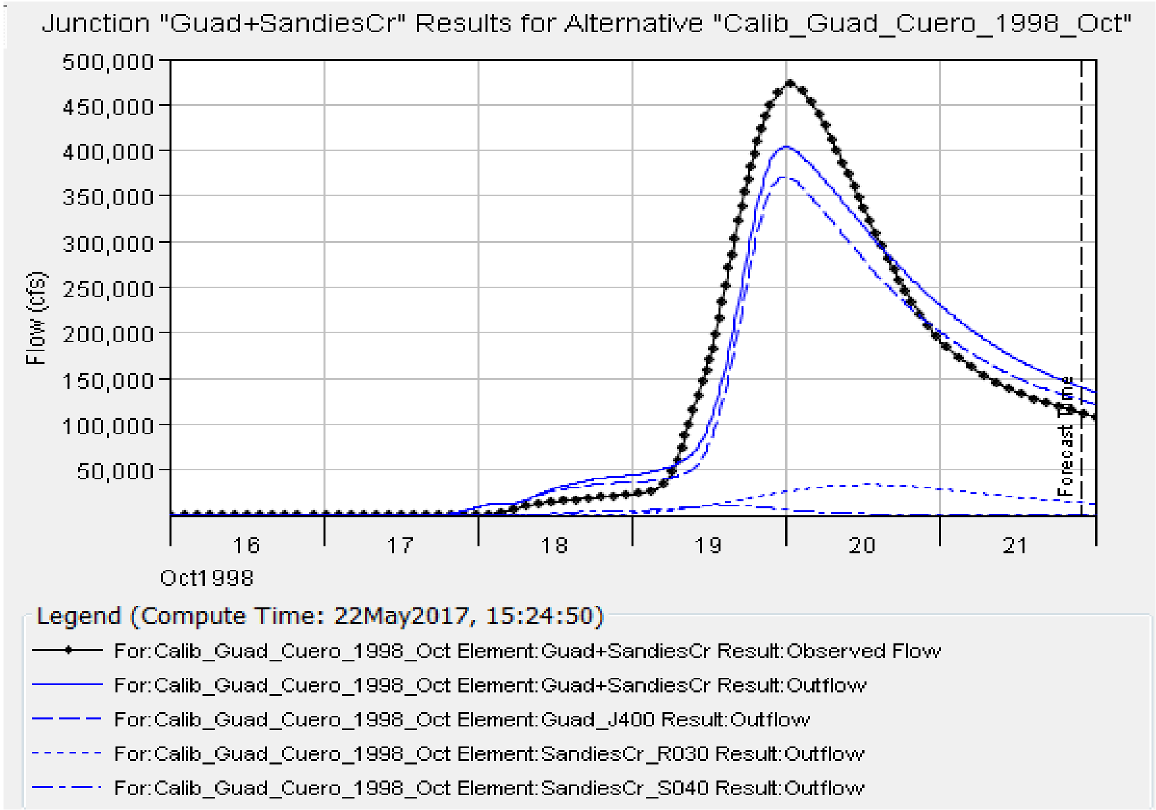


Figure 6.121: Oct 1998 Calibration Results for Guadalupe River at Cuero

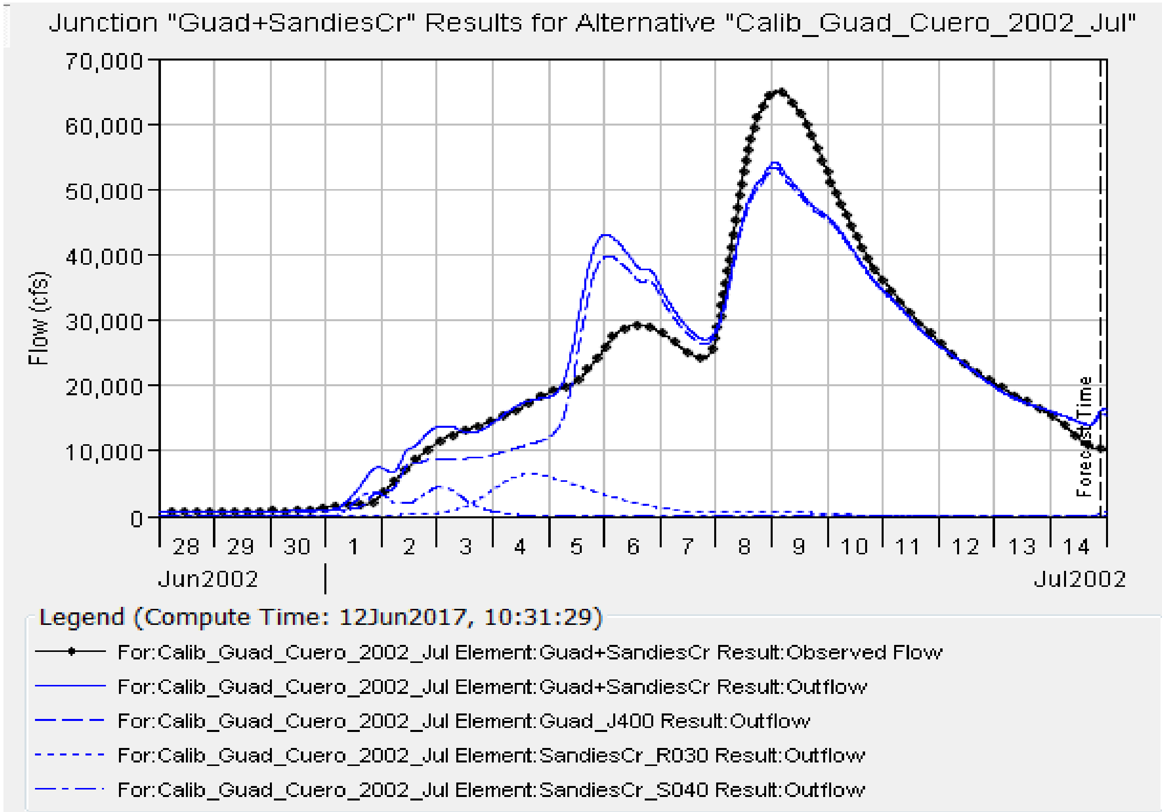


Figure 6.122: Jul 2002 Calibration Results for Guadalupe River at Cuero

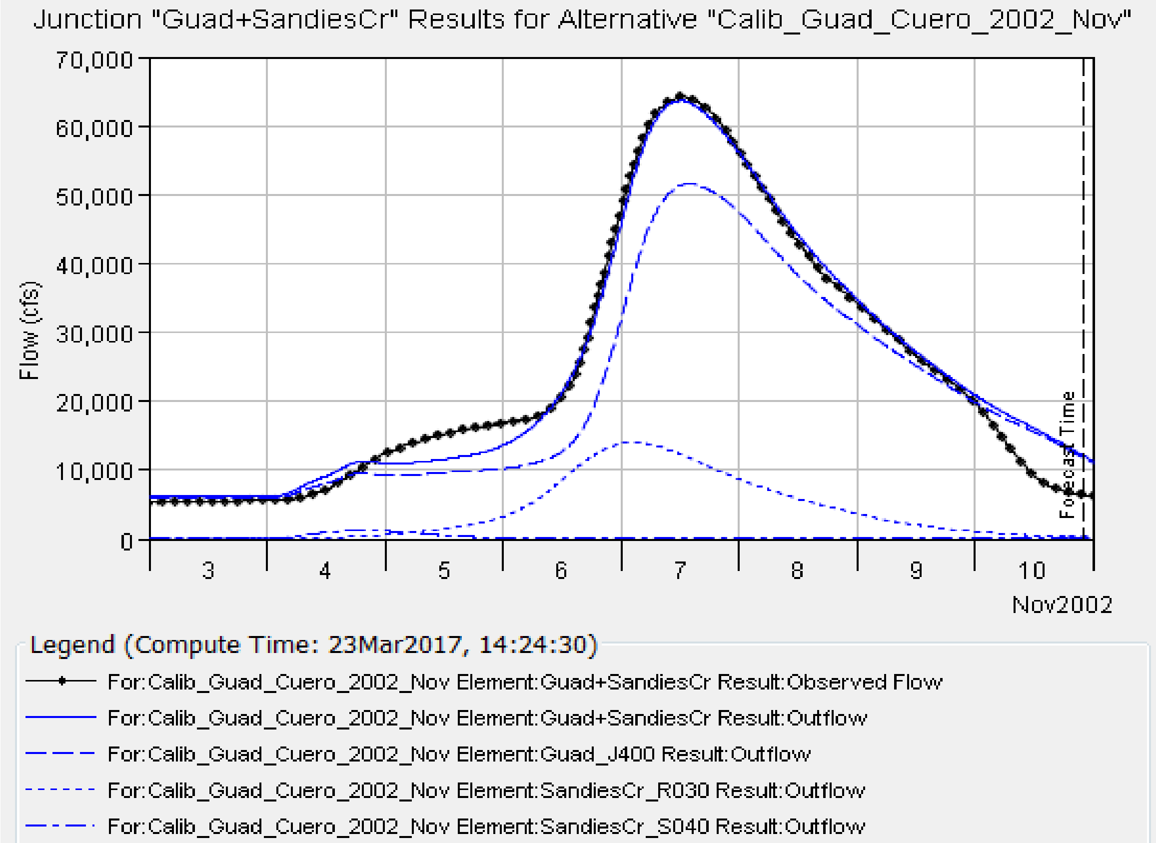


Figure 6.123: Nov 2002 Calibration Results for Guadalupe River at Cuero

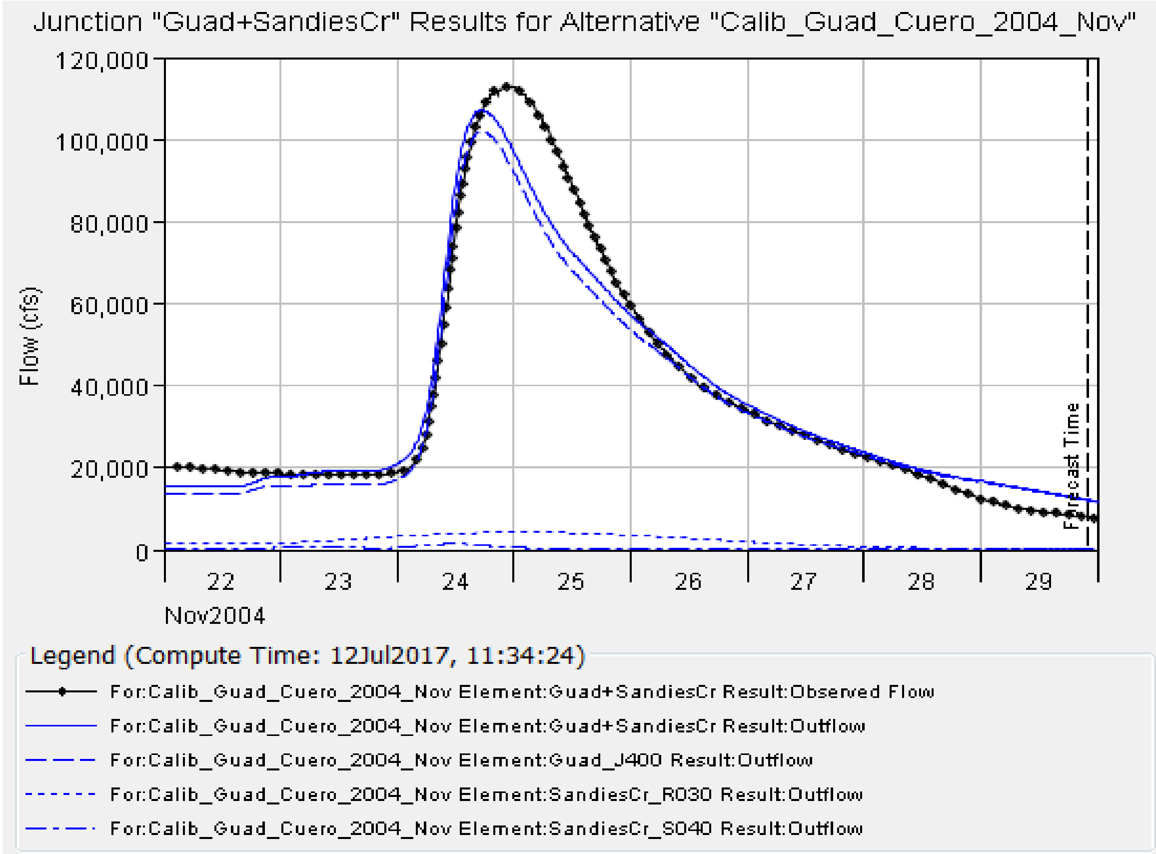


Figure 6.124: Nov 2004 Calibration Results for Guadalupe River at Cuero

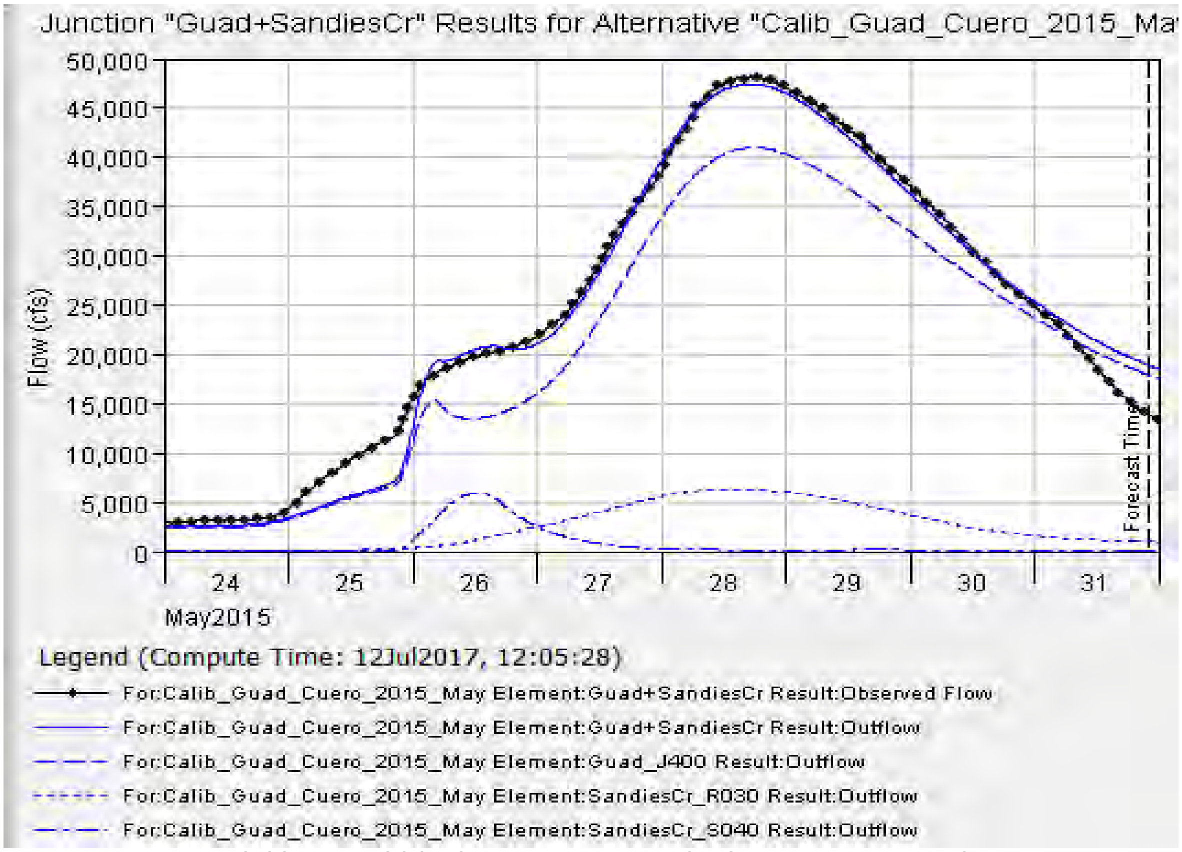


Figure 6.125: May 2015 Calibration Results for Guadalupe River at Cuero

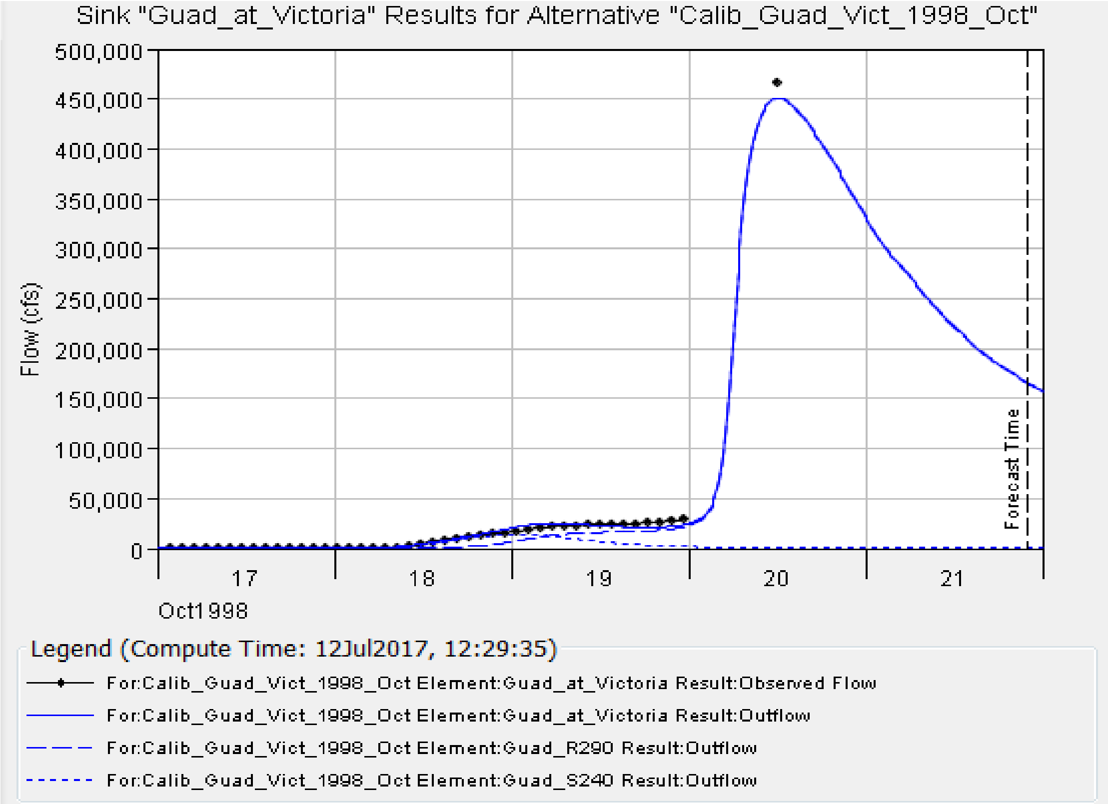


Figure 6.126: Oct 1998 Calibration Results for Guadalupe River at Victoria

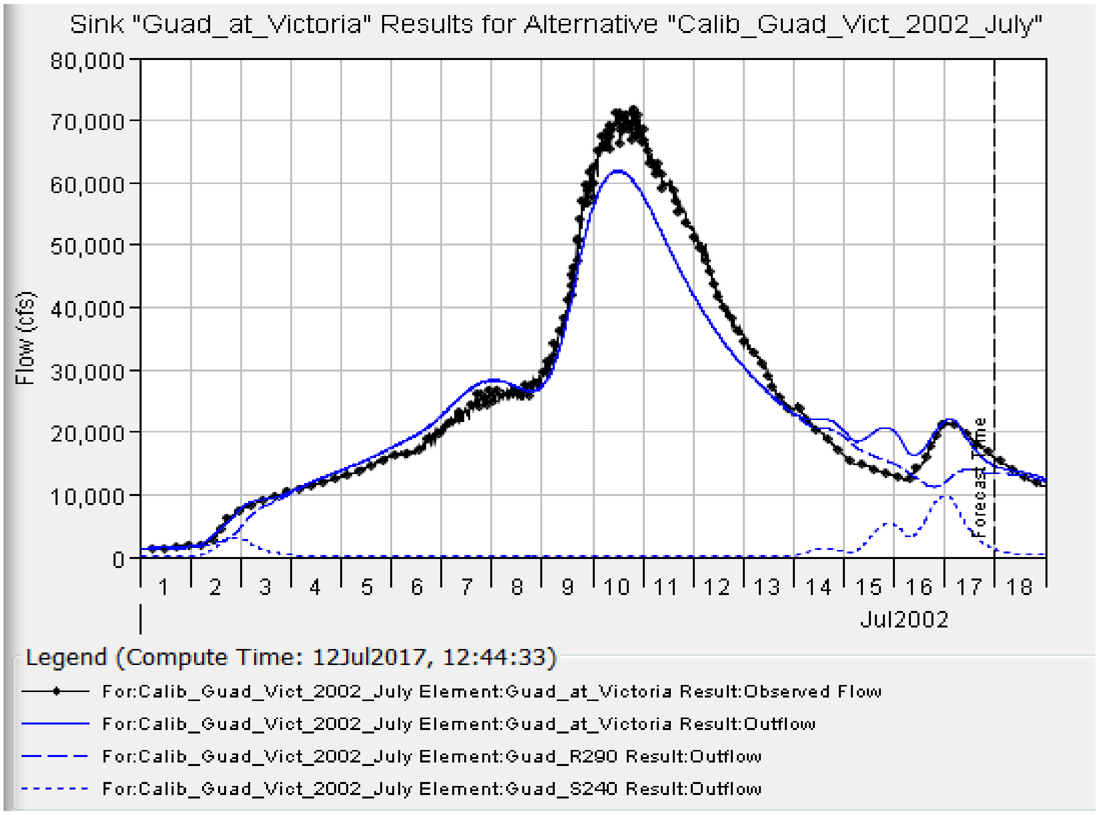


Figure 6.127: Jul 2002 Calibration Results for Guadalupe River at Victoria

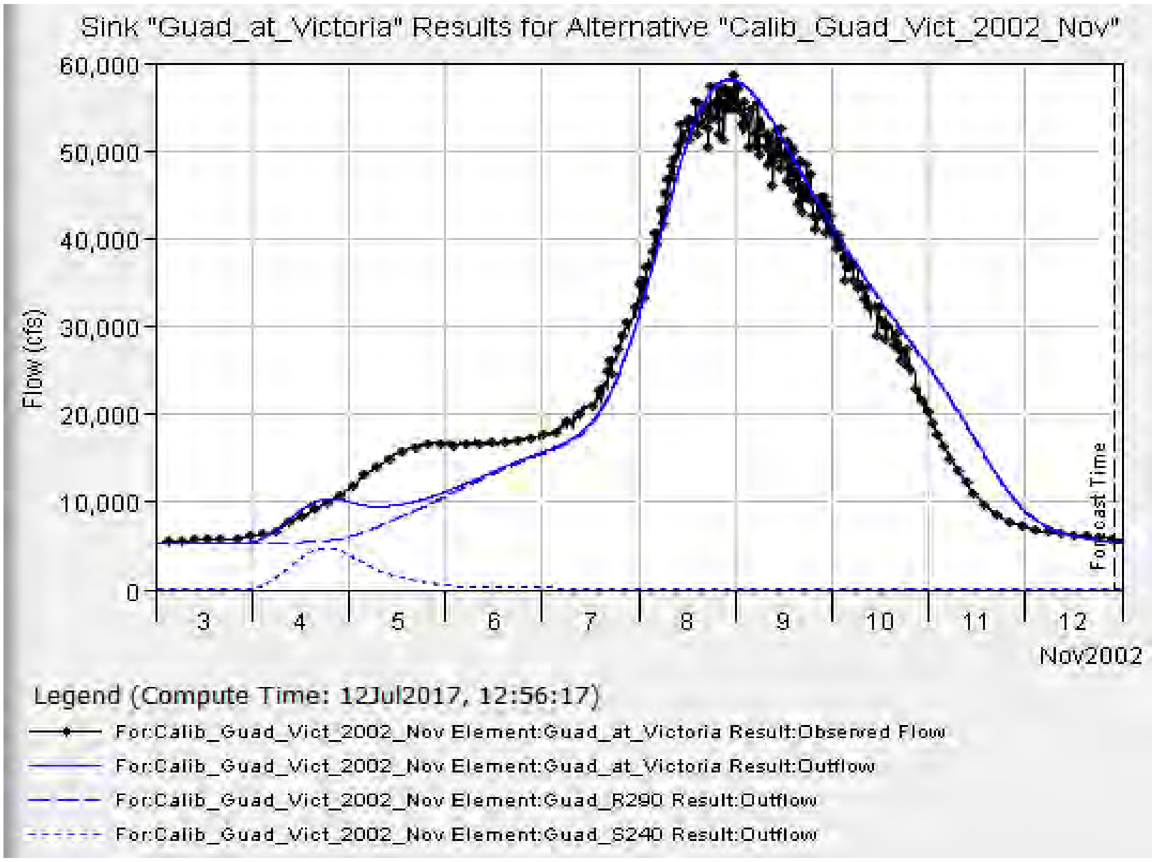


Figure 6.128: Nov 2002 Calibration Results for Guadalupe River at Victoria

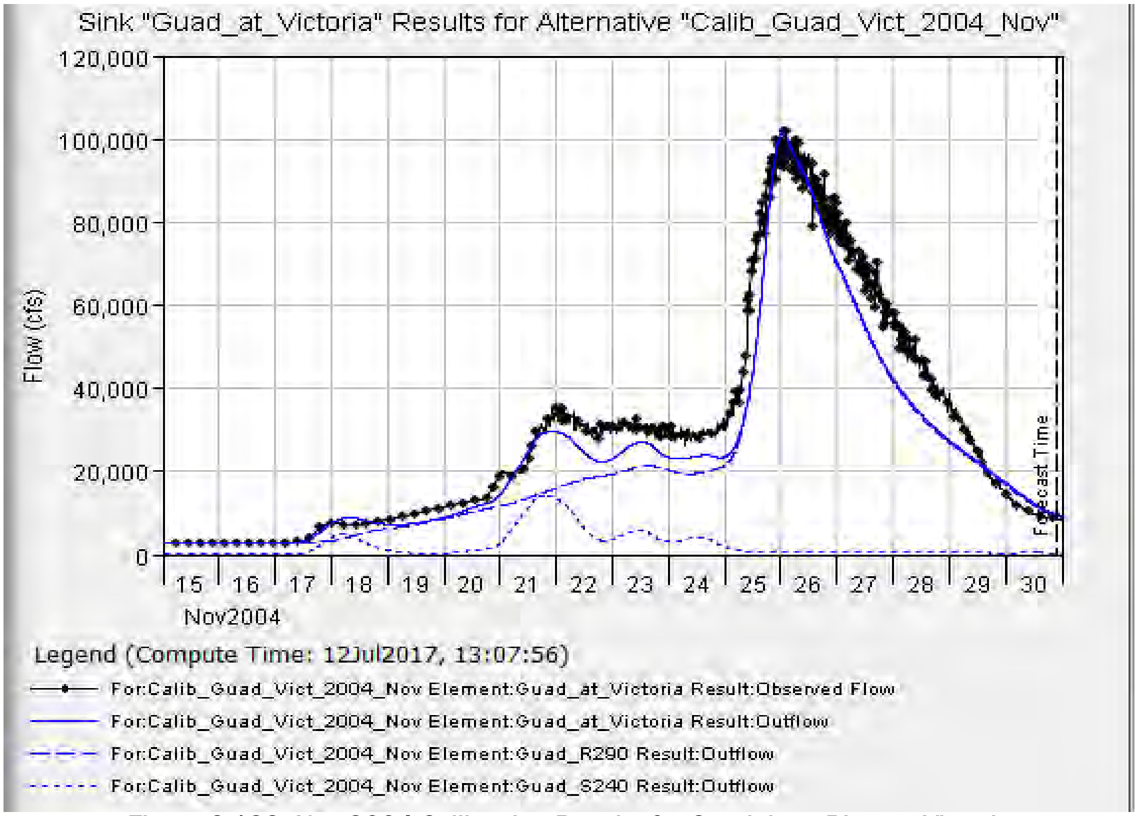


Figure 6.129: Nov 2004 Calibration Results for Guadalupe River at Victoria

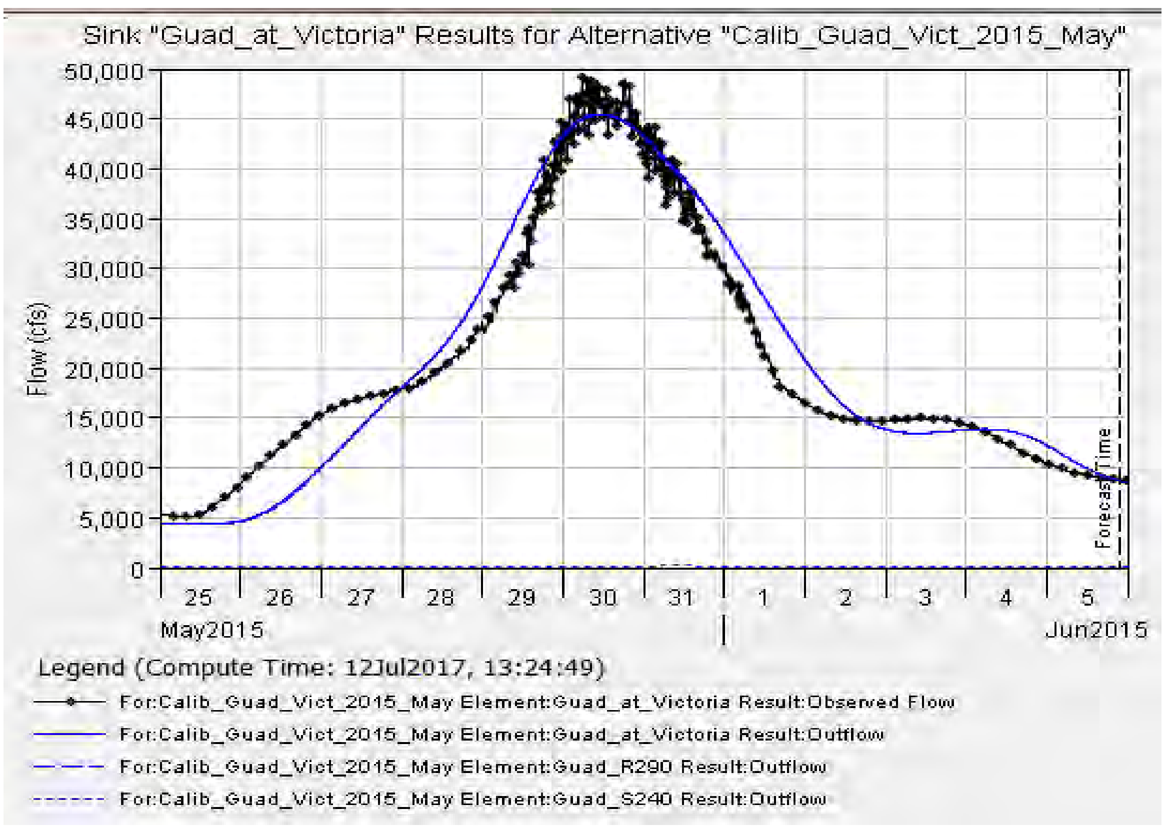


Figure 6.130: May 2015 Calibration Results for Guadalupe River at Victoria

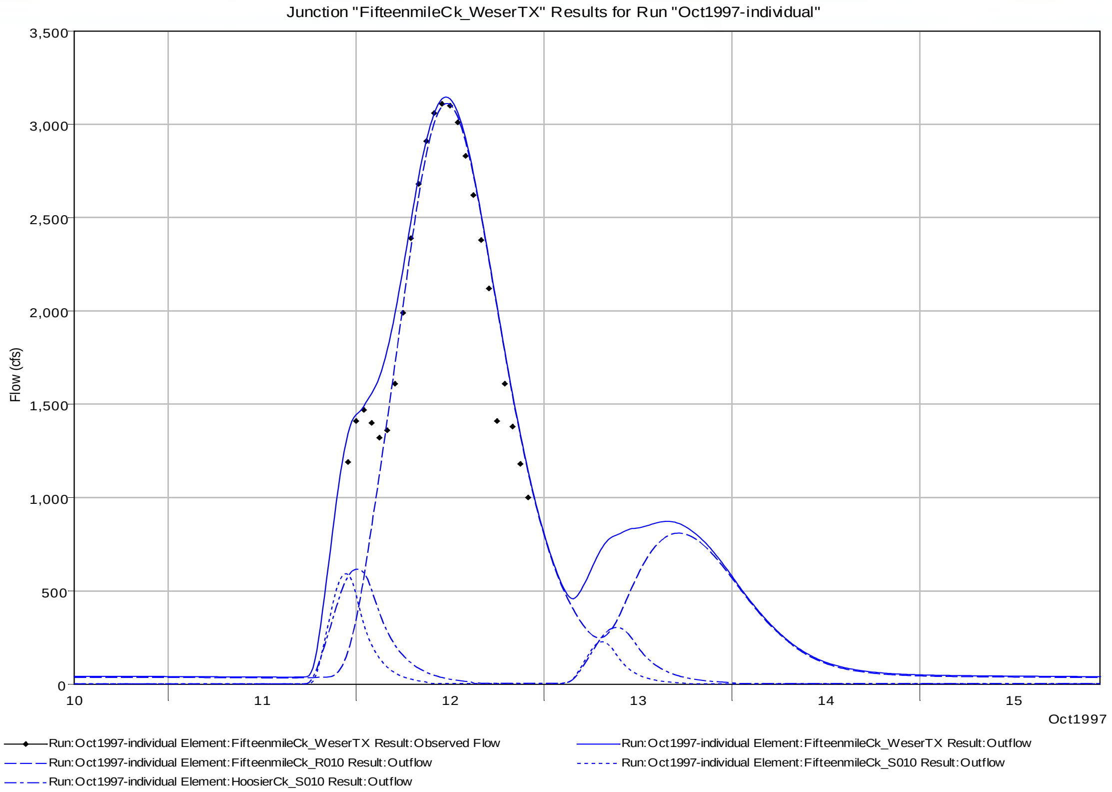


Figure 6.131: Oct 1997 Calibration Results for Fifteenmile Creek at Weser

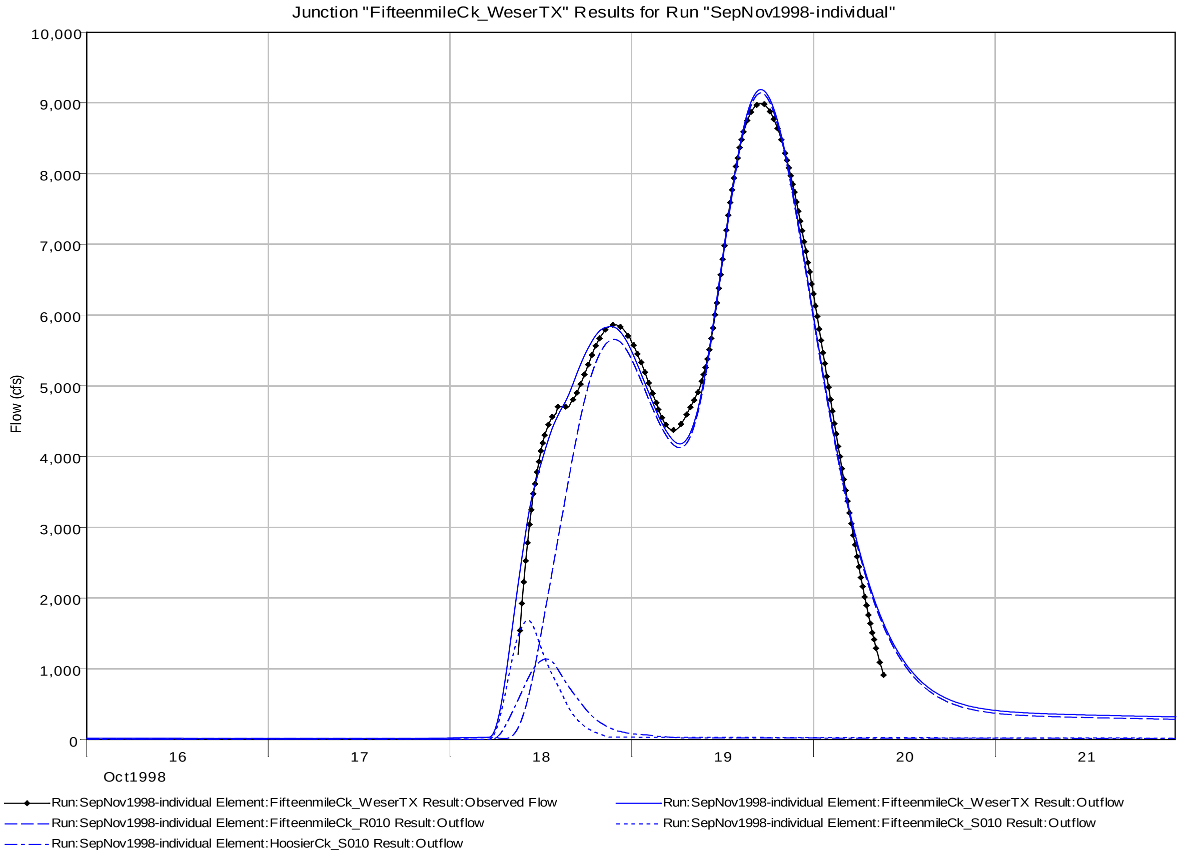


Figure 6.132: Oct 1998 Calibration Results for Fifteenmile Creek at Weser

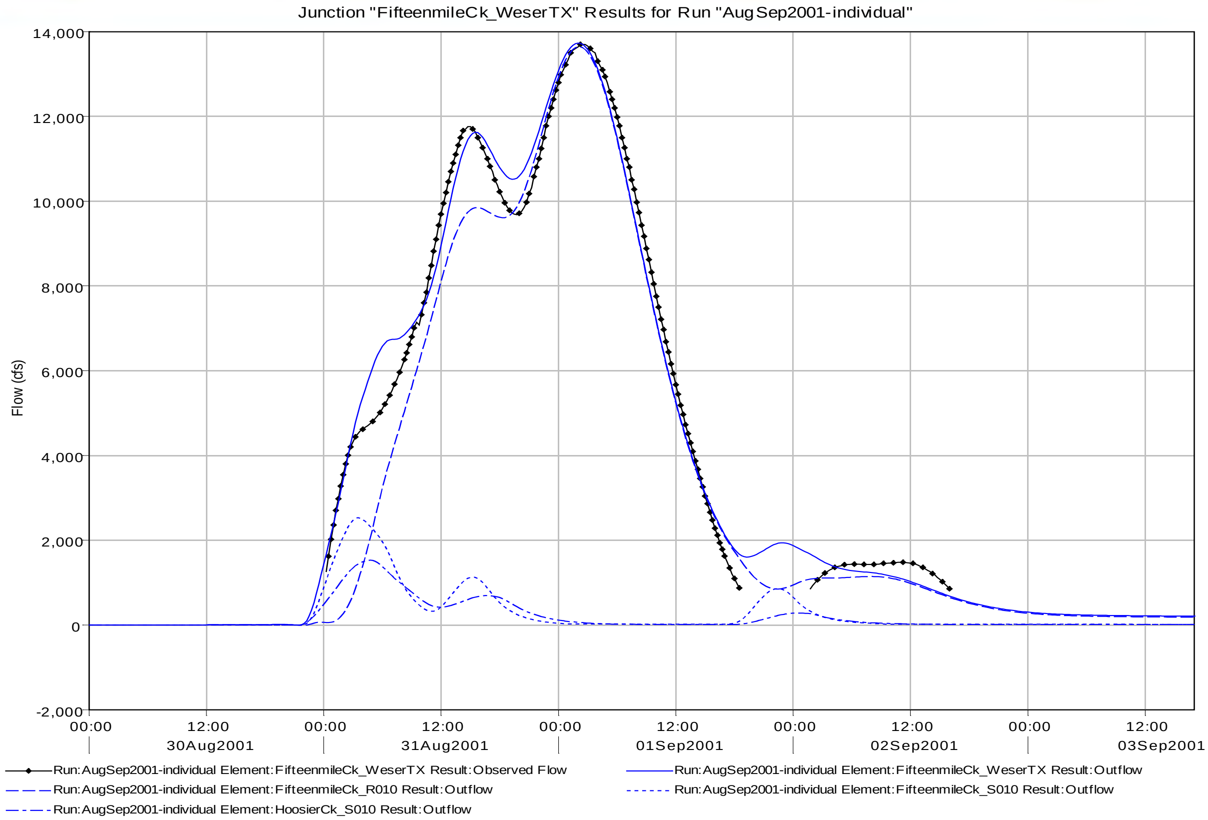


Figure 6.133: Sep 2001 Calibration Results for Fifteenmile Creek at Weser

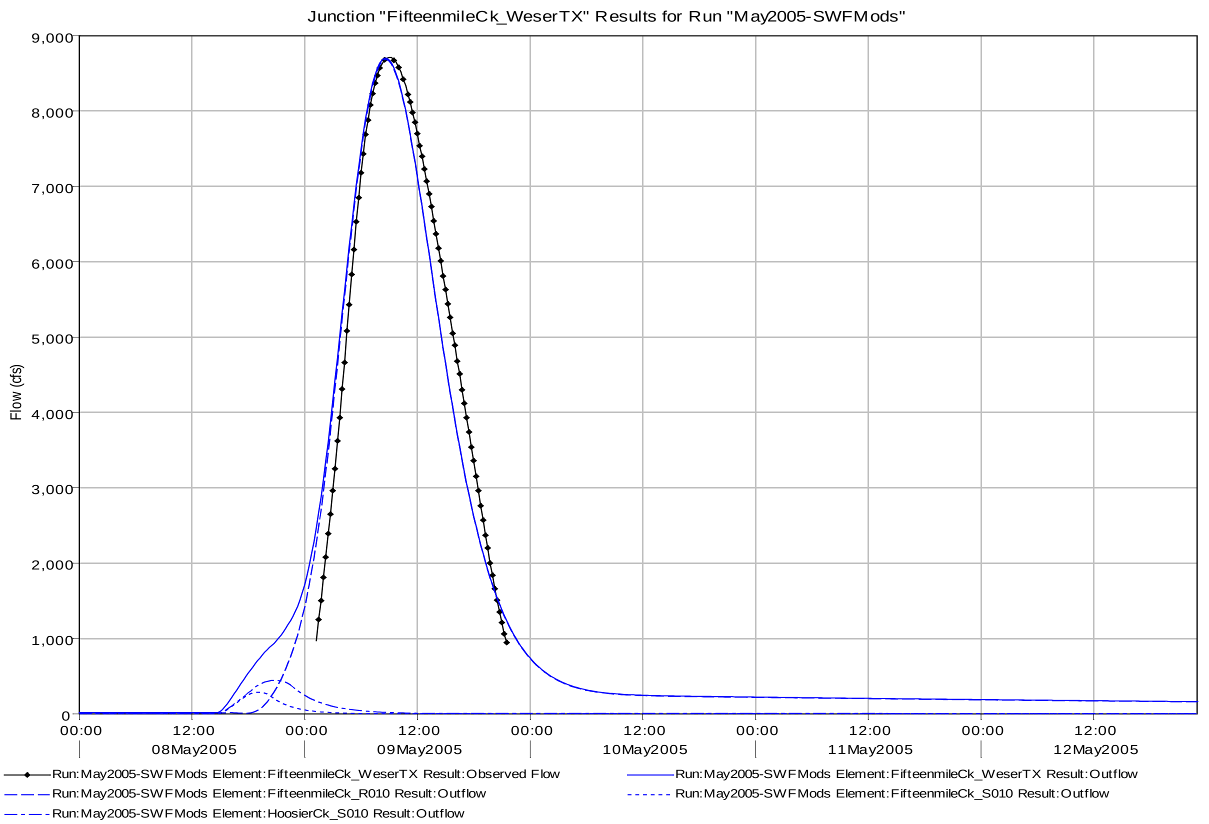


Figure 6.134: May 2005 Calibration Results for Fifteenmile Creek at Weser

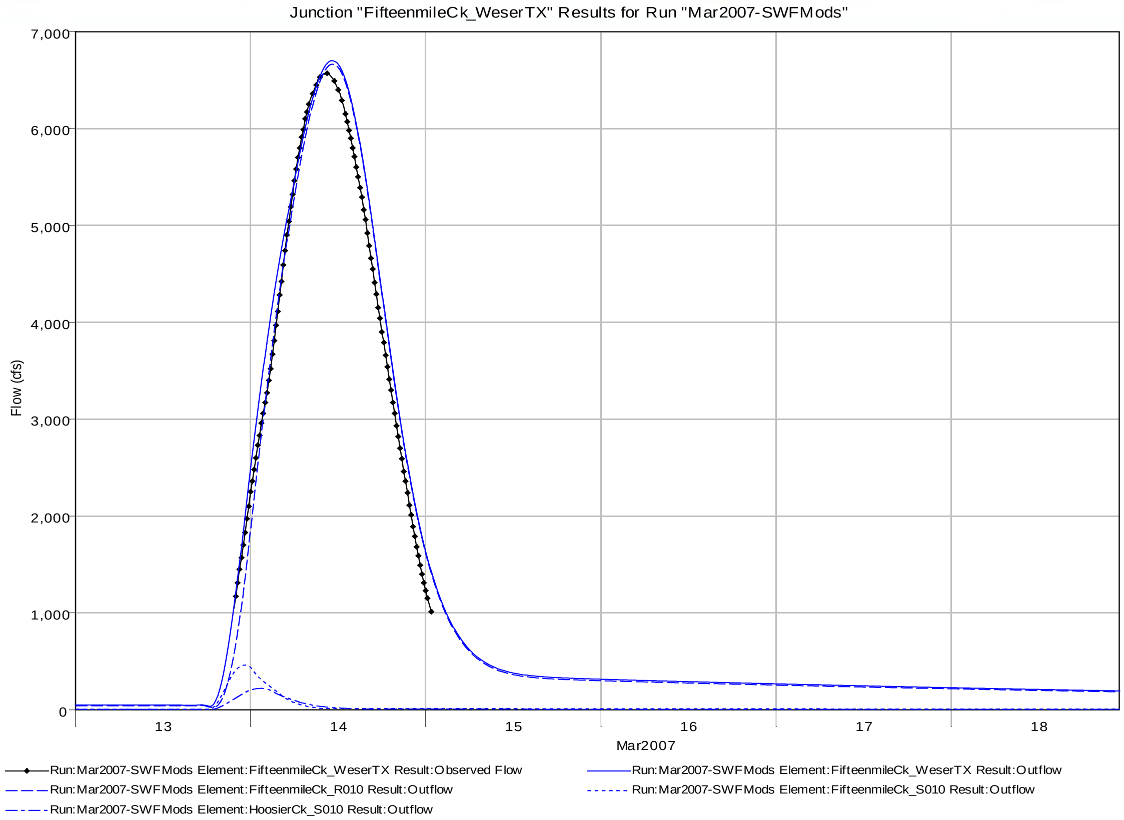


Figure 6.135: Mar 2007 Calibration Results for Fifteenmile Creek at Weser

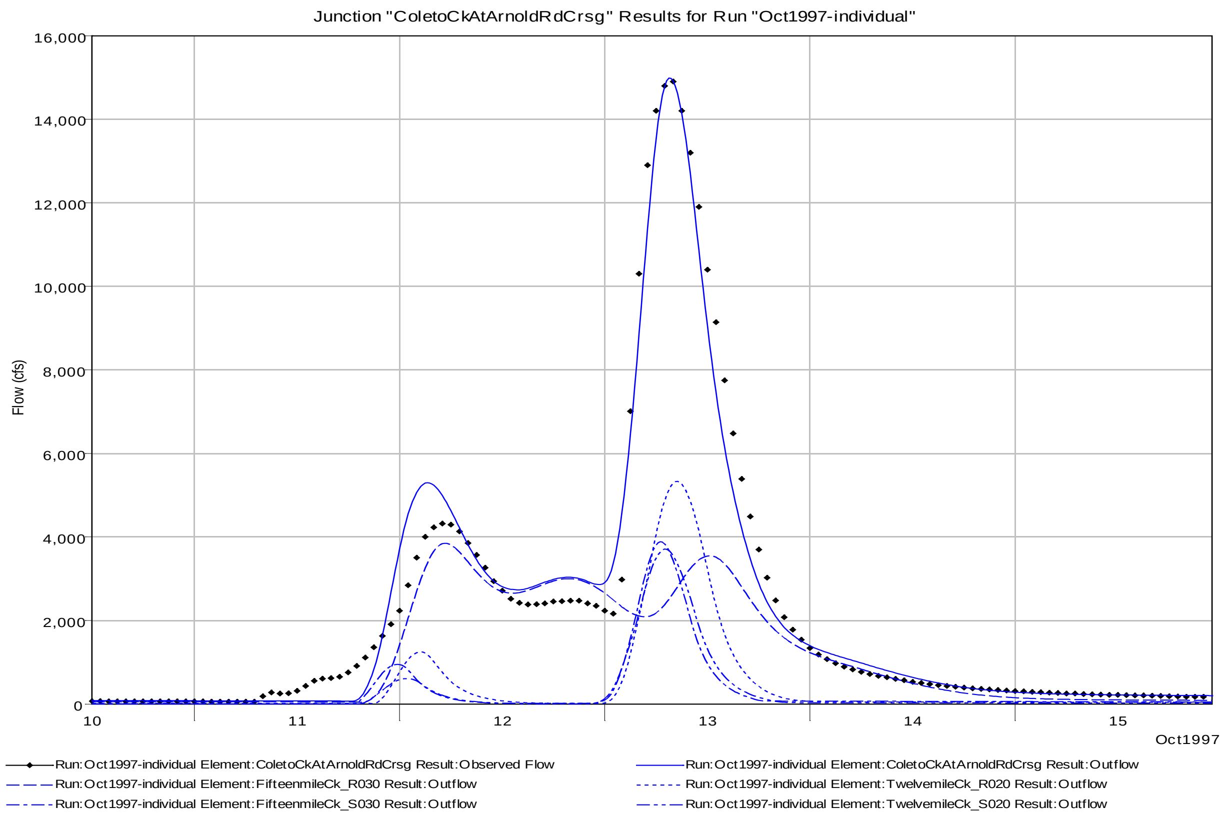


Figure 6.136: Oct 1997 Calibration Results for Coleto Creek at Arnold Rd

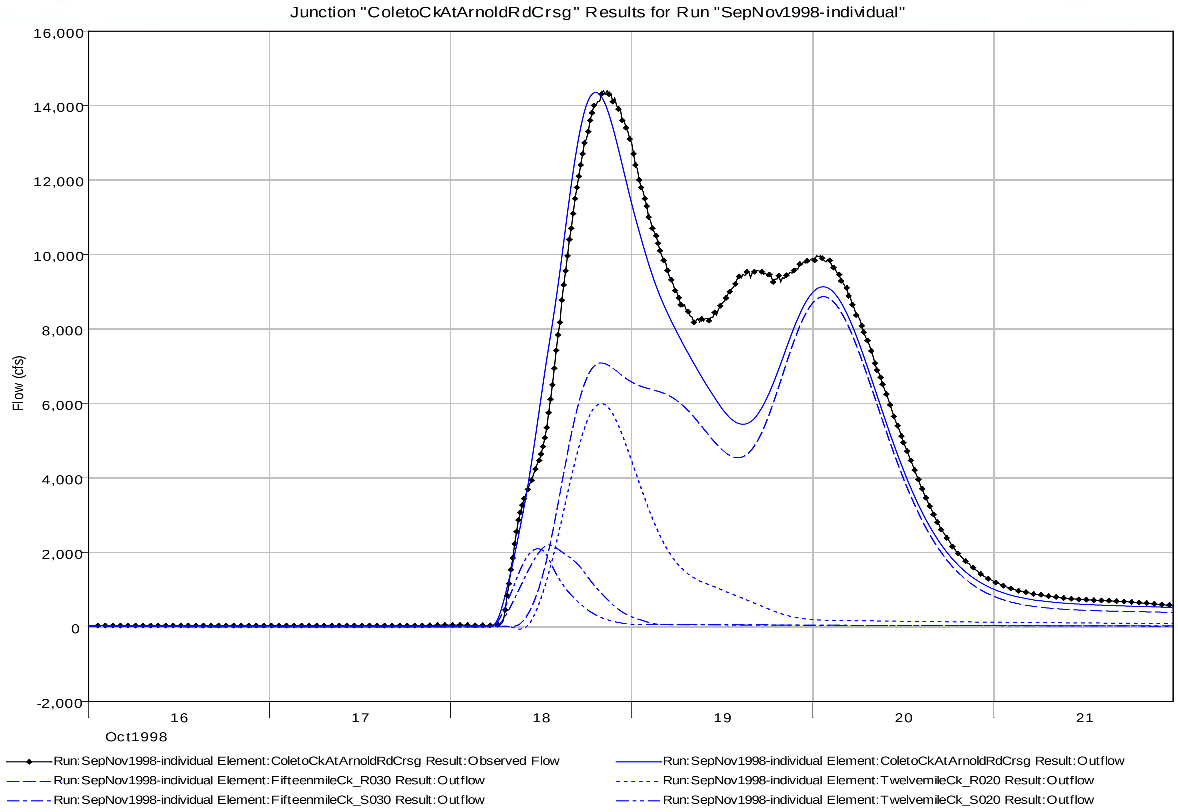


Figure 6.137: Oct 1998 Calibration Results for Coleto Creek at Arnold Rd

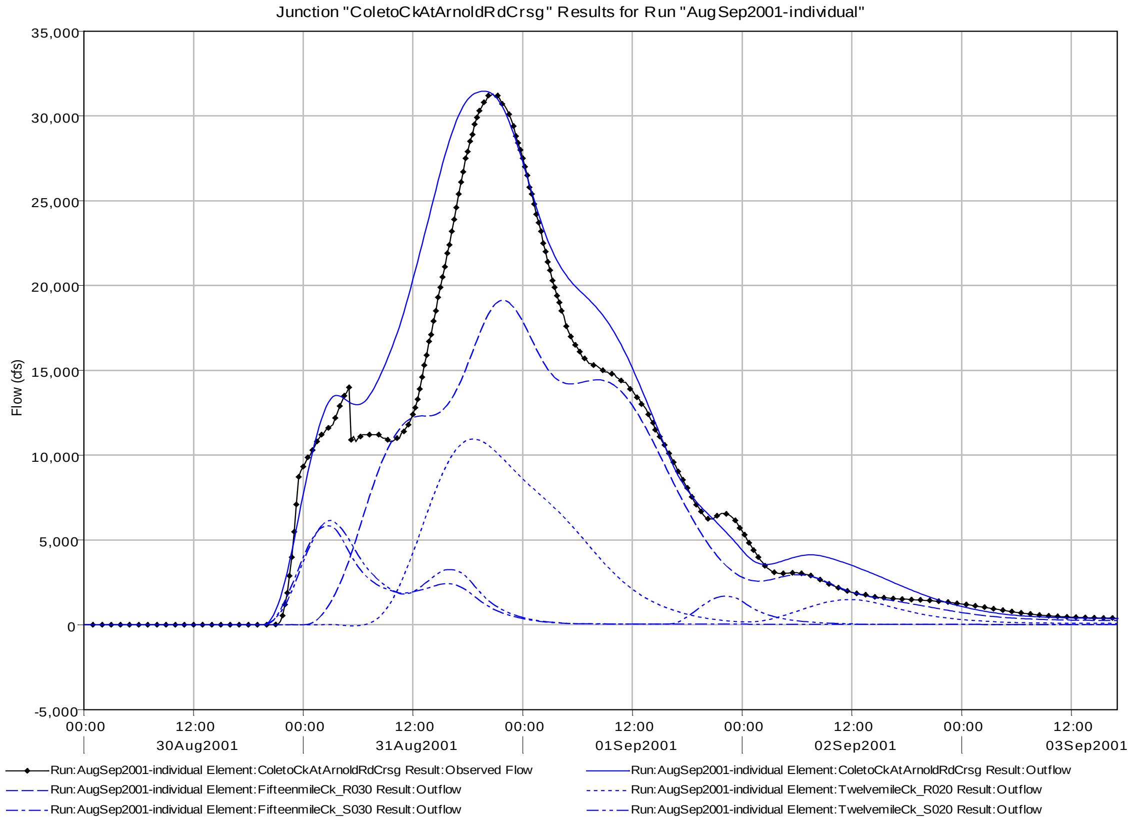


Figure 6.138: Sep 2001 Calibration Results for Coleto Creek at Arnold Rd

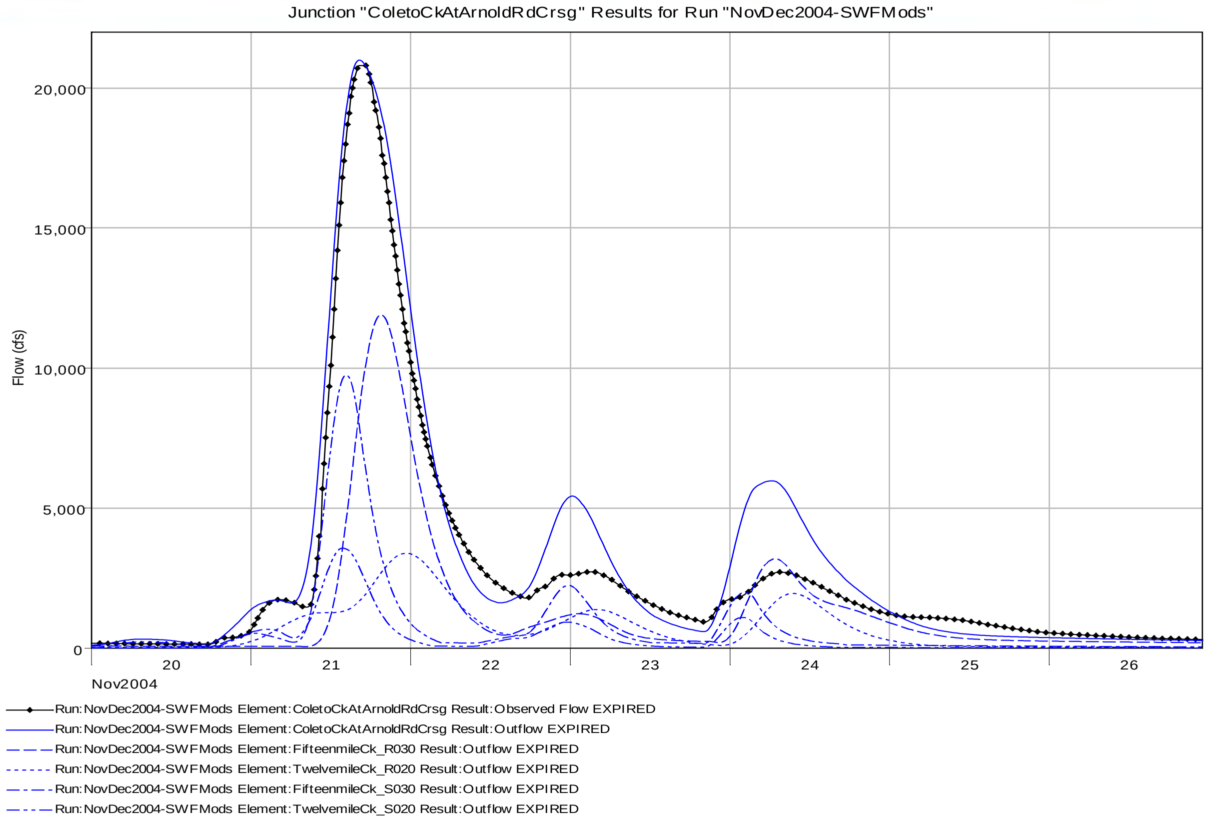


Figure 6.139: Nov 2004 Calibration Results for Coleto Creek at Arnold Rd

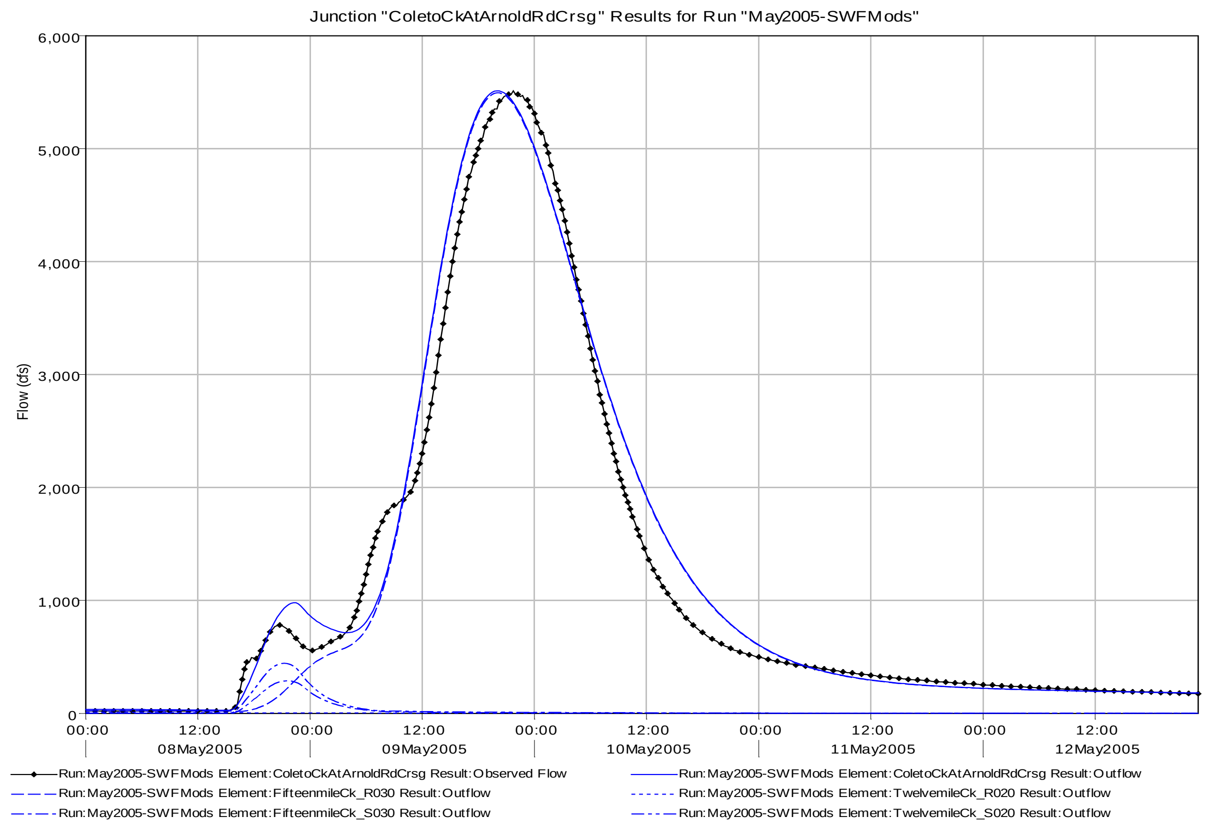


Figure 6.140: May 2005 Calibration Results for Coleto Creek at Arnold Rd

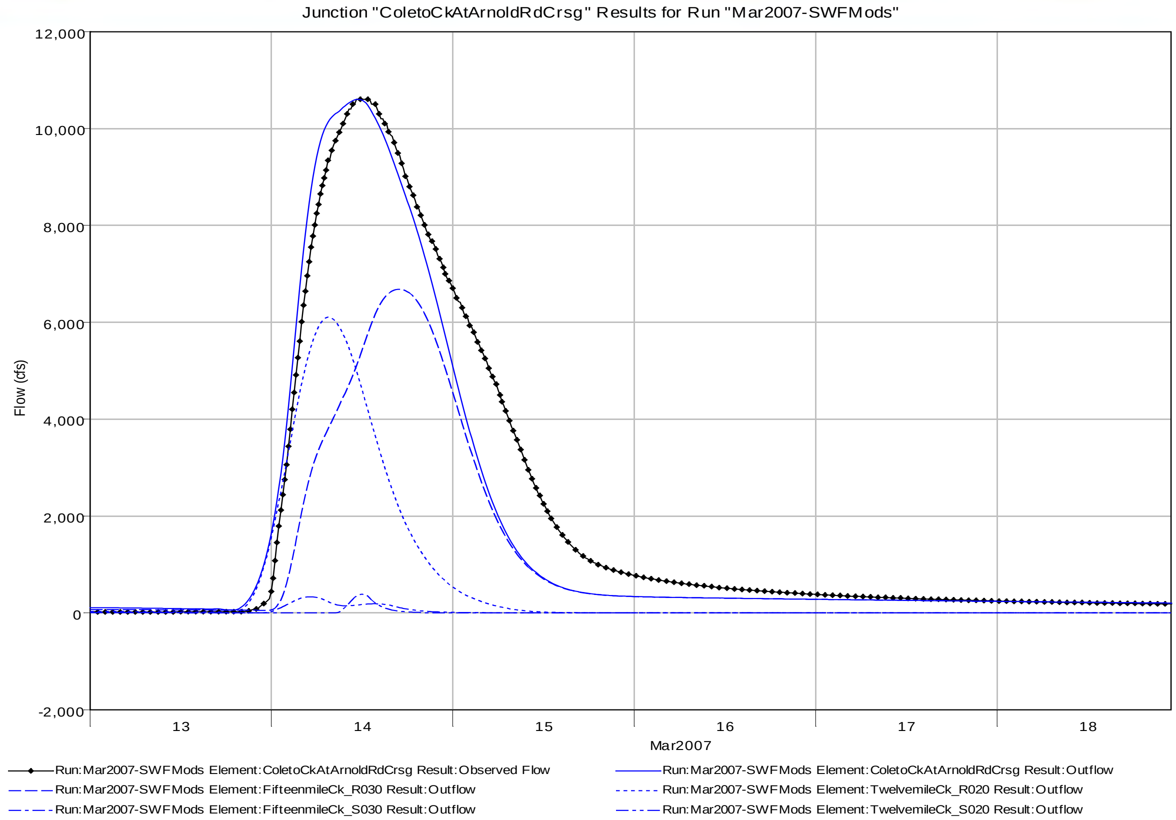


Figure 6.141: Mar 2007 Calibration Results for Coleto Creek at Arnold Rd

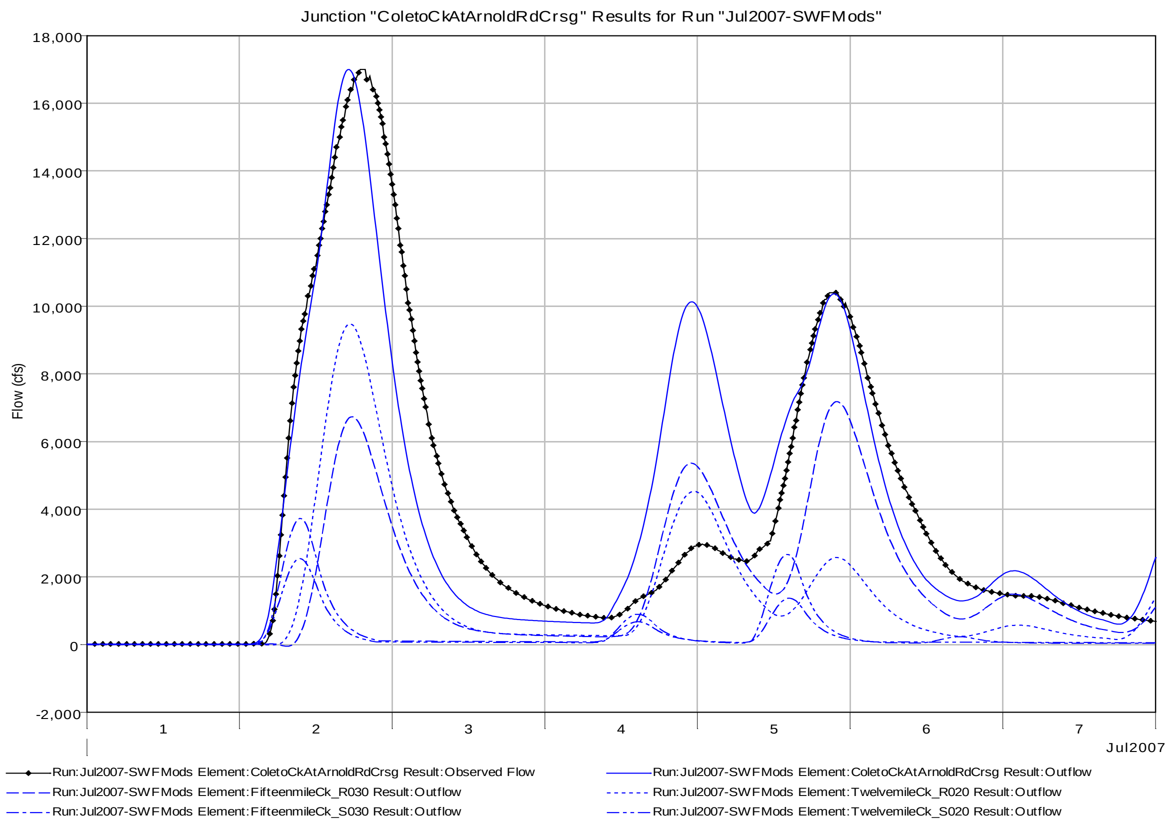


Figure 6.142: Jul 2007 Calibration Results for Coleto Creek at Arnold Rd

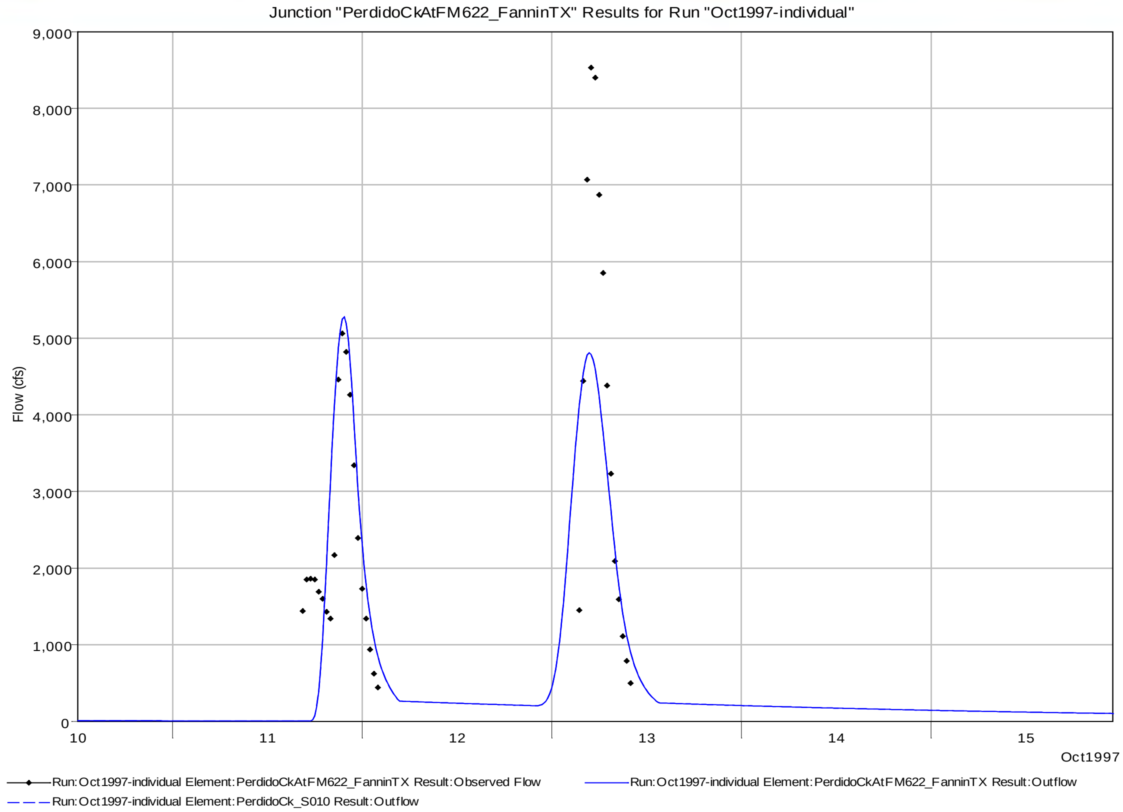


Figure 6.143: Oct 1997 Calibration Results for Perdido Creek nr Fannin, TX
NOTE – Timing calibrated, but rainfall volume was too low.

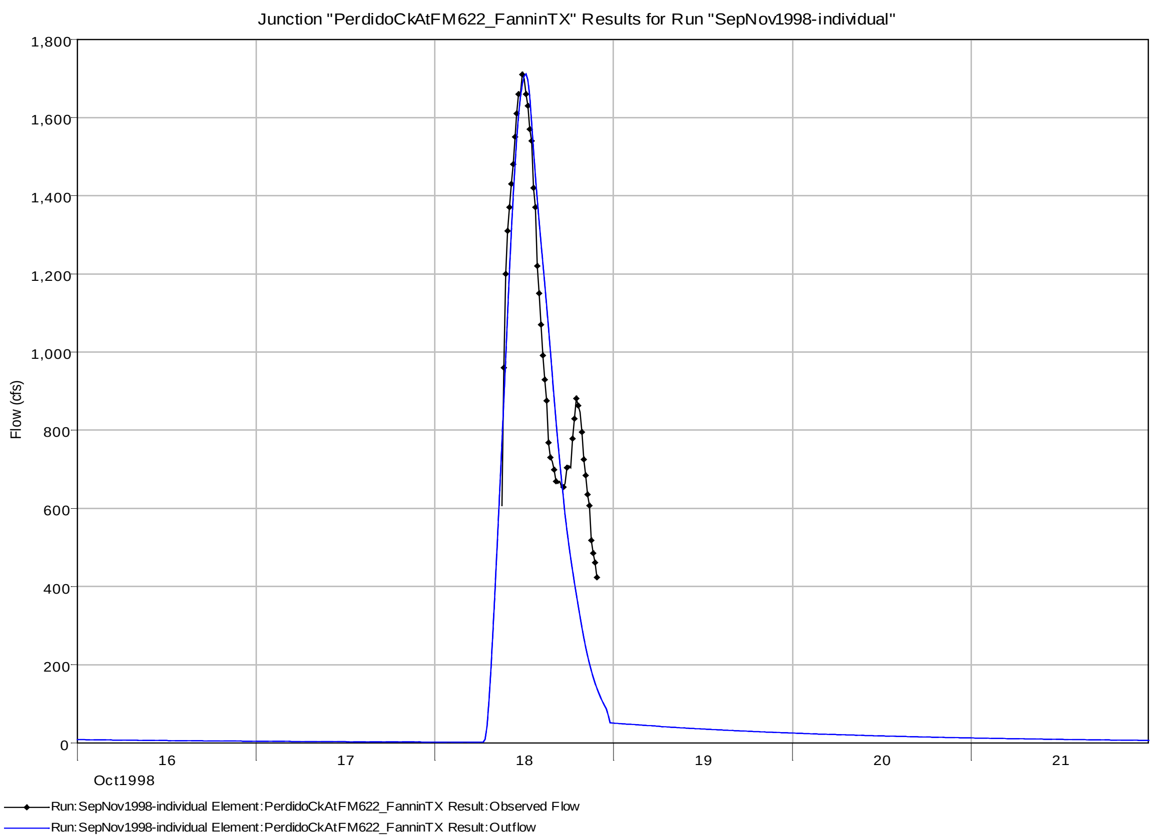


Figure 6.144: Oct 1998 Calibration Results for Perdido Creek nr Fannin, TX

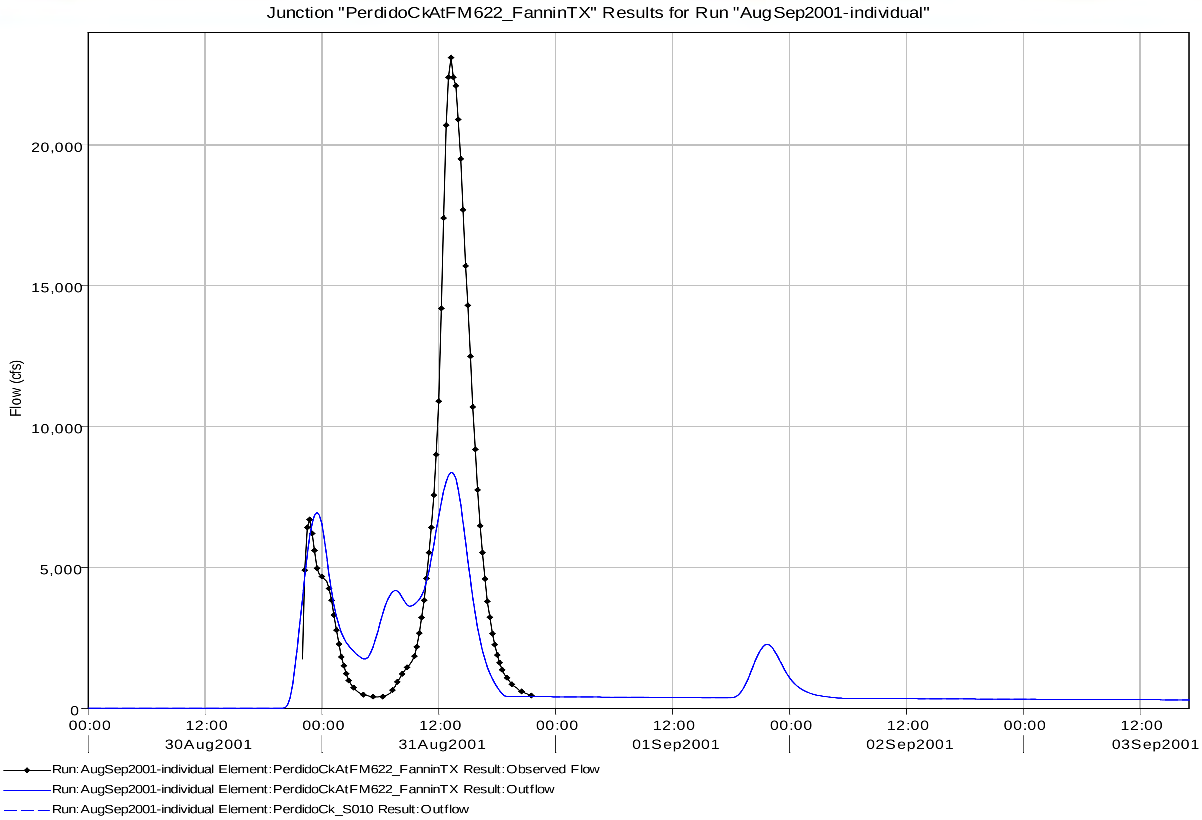


Figure 6.145: Sep 2001 Calibration Results for Perdido Creek nr Fannin, TX
NOTE – Timing calibrated, but rainfall volume was too low.

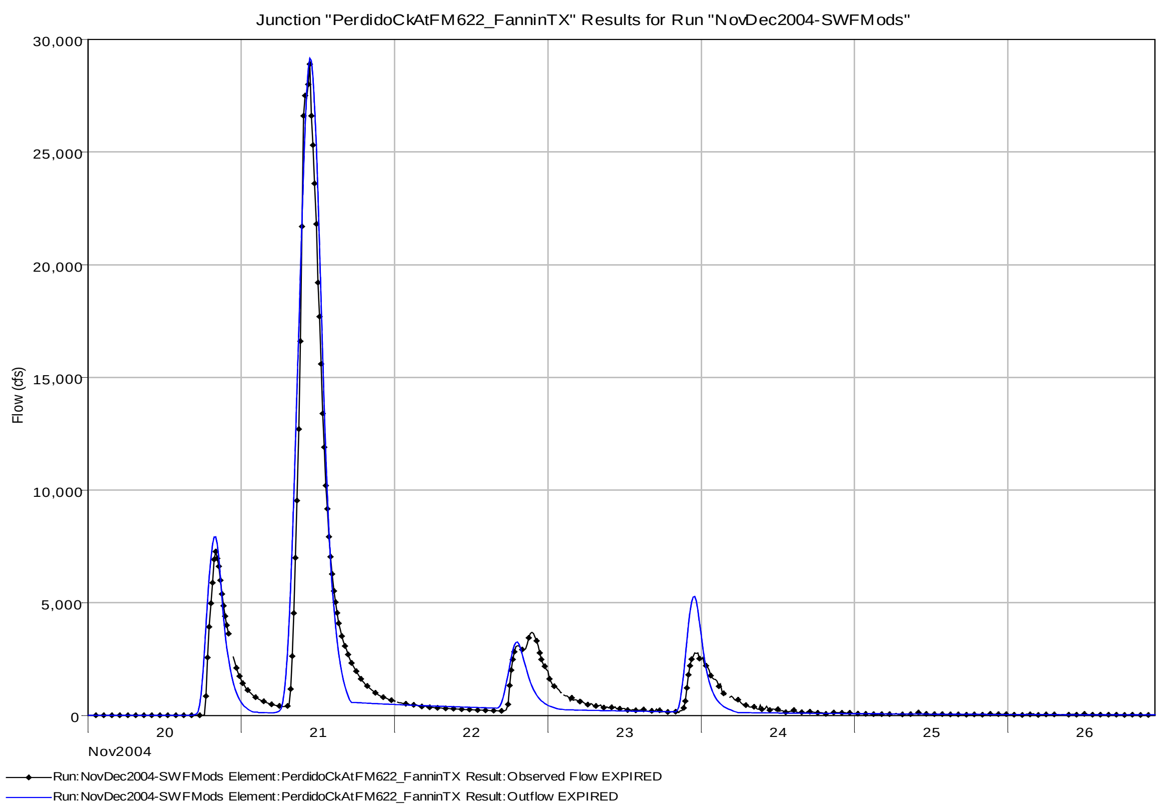


Figure 6.146: Nov 2004 Calibration Results for Perdido Creek nr Fannin, TX

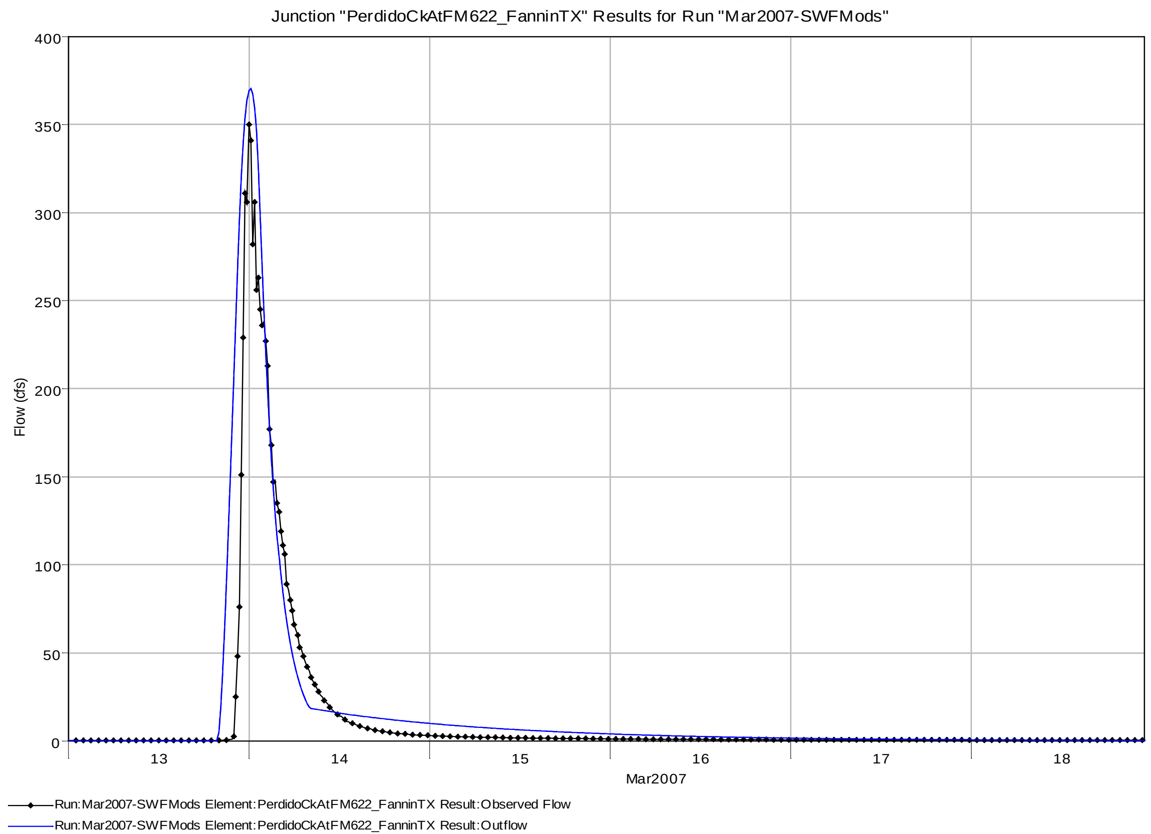


Figure 6.147: Mar 2007 Calibration Results for Perdido Creek nr Fannin, TX

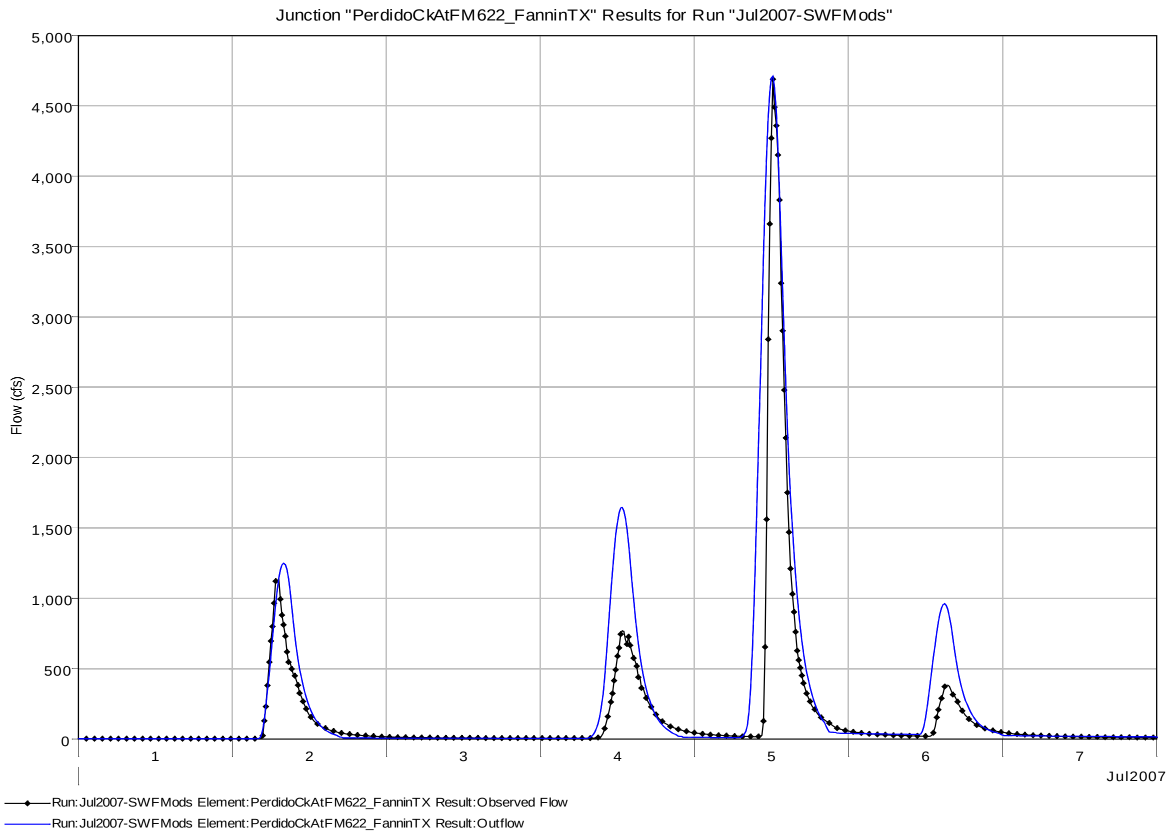


Figure 6.148: Jul 2007 Calibration Results for Perdido Creek nr Fannin, TX

The upper Guadalupe River watershed above Canyon Dam was calibrated at seven different gage locations, and each location was calibrated to multiple storm events. The number of calibrations for each location was limited by the available stream gage data and observed rainfall patterns. For example, the North Fork Guadalupe River near Hunt gage, at the upstream end of the watershed, was calibrated to only 3 storm events as those were the only events that had significant rainfall above that gage. All the other gages in that portion of the watershed were calibrated to between 5 and 8 storm events. The calibration of the Guadalupe River reaches between the Comfort and Spring Branch gages presented an interesting issue as the observed gage records show significant flood hydrograph attenuation between these gages. Five out of eight calibration events showed a significant decrease in peak flow between Comfort and Spring Branch, which ranged anywhere from 10% to 60%. The attenuation was stronger for those storm events where the rain fell primarily upstream of Comfort. The 1978 flood was the flood of record for these locations, and it also showed a decrease in peak flow of 33% between these two locations (from 240,000 cfs at Comfort to 160,000 cfs at Spring Branch). All of this observed data was used to adjust the Muskingum routing parameters between these two gages to better match the observed timing and attenuation of the hydrographs. The resulting model results at Spring Branch matched the observed timing, shape and peak flow of the observed hygrographs very well.

In the San Marcos watershed, the area above the San Marcos gage received the least amount of calibration, which was primarily due to the lack of observed hydrograph data for flood events at that gage. The 2007 and 2012 events were the only events where the full observed hydrograph was available. These were not very large events over this watershed, and the computed shape for 2012 differed from the observed. The timing of the peaks matched well for both events suggesting a reasonable lag time estimate. Estimated peaks were available for the 1998 and 2004 calibration events. The gage did not record during either of the 2015 events flood events. This watershed has a drainage area of approximately 49 square miles and is about 90% controlled by NRCS detention structures upstream of the gage. NRCS Dams No. 1, 2 and 3 are modeled as reservoir elements inside of HEC-HMS.

In the San Marcos watershed, the area above the Blanco River at Wimberley received the most calibration, as full or partial observed hydrographs were available for seven calibration storms, including the two large events in 2015. Calibration of this area revealed faster lag times than were initially estimated using the default equations. This is likely due to the steep terrain and narrow valleys upstream of Wimberley. The calibrations also indicated that during most observed events, the upper Blanco and the Little Blanco Rivers peak within one to two hours of each other. The combination of the hydrographs from those two rivers lead to rapidly rising hydrographs and large peak flows downstream of the confluence of the Blanco River with the Little Blanco River, as demonstrated by the May 2015 flood event. As seen in the preceding figures, the model was able to reproduce the peak flows, timing and shape of the observed hydrographs at Wimberely very well. This includes being able to reproduce the obseved flood of record at Wimberely, which occurred in May of 2015.

The calibration of the Blanco River near Kyle was more limited than that at Wimberley due to missing gage data. The stream gage at Kyle was washed out during three different flood events, and only peak flow estimates were available for those events. When observed hydrographs were available, the model did well at reproducing the shape and peak of the observed hydrograph. The exact timing of the peak at Kyle was sometimes difficult to match, particularly for the October 2015 event, due to the effects of the modified puls routing downstream of Wimberely. The volume of the November 2001 flow hydrograph at Kyle could not be calibrated. The USGS flow data for that event indicate that the volume of water that passed by the Wimberley gage was 8,000 acre-feet greater than the volume of water that passed by the Kyle gage. This is also in spite of the fact that over 7 inches of rain fell in between Wimberely and Kyle. The problem with the flow data for that event is likely due to inaccuracies in the USGS rating curves, but more flow measurements are needed in order to verify that. Therefore, the shape of the November 2001 observed flow hydograph at Kyle was calibrated, but the peak flow and volume were ignored.

The areas above the San Marcos at Luling and Plum Creek at Lockhart gages were well calibrated. Observed hydrographs for five significant events were available at those gages and were matched very well by the HEC-HMS model. For Plum Creek near Luling, full hydrographs were only available for two events, and an estimated peak flow was available for a third event. However, the model calibrated well to the observed flow data that was available. The October 2015 event in particular allowed for detailed calibration of the routing on Plum Creek in between Lockhart and Luling. This is because the rain for the October 2015 event fell almost entirely above Lockhart. The observed flow hydrographs at the gages indicate that the October 2015 peak flow was reduced from over 35,000 cfs at Lockhart to just over 17,000 cfs at Luling. Adjustments to the number of subreaches in the modified puls routing reaches upstream of Luling allowed the model to reproduce this level of attenuation very well.

The lower Guadalupe River watershed below Canyon Dam was calibrated at USGS streamflow gages and was calibrated to multiple storm events. This watershed experienced a significant number of large events from 1998-2015, which were very useful for model calibration. The number of calibrations for each location was limited by the available stream gage data and observed rainfall patterns. All of the gages were calibrated to between 5 and 6 storm events. The streamflow gages within this area included: Guadalupe River above Comal River, Dry Comal Ck at Loop 337 nr New Braunfels, Guadalupe River at FM 1117 near Seguin, Guadalupe River at Gonzales, Peach Creek below Dilworth, Sandies Creek near Westhoff, Guadalupe River at Cuero, and Guadalupe River at Victoria. The Guadalupe River below Canyon Dam to the confluence with the San Marcos River has 6 GBRA hydropower dams, which received special consideration to accurately simulate the travel time and amount of attenuation that would occur through the Guadalupe River during a flood. Details of how storage-discharge relationships were developed through these GBRA dams is discussed in more detail in the “Updates to the HEC-HMS Model” section. The model did a very good job simulating the routing through the GBRA dams, indicating reasonable storage-discharge relationships, particularly to Guadalupe River near Seguin gage where observed hydrograph information was available. There were also a couple special observations that were made during model calibration.

The first issue was identified during calibration of the Comal River Basin. The Comal River basin includes approximately 131 square miles of drainage area, of which approximately 62% is controlled by flood retention structures (5 NRCS, 1 Comal County). USGS remarks that the Comal River at New Braunfels gage is affected by backwater from the Guadalupe River at times. These affects appeared to be present during the Jun 9, 2010 storm, which had an estimated peak of 31k cfs. The model was calibrated to the Dry Comal Creek at Loop 377 nr New Braunfels gage and using similar losses for the remainder of the watershed resulted in a peak discharge of about 15k cfs. It is highly unlikely the relatively small drainage area (7 square miles) below the Dry Comal Creek gage and SCS Dam 3 could produce enough runoff to reach 31k cfs at the Comal gage.

A steady flow model was developed for the Dry Comal Creek and Comal River reach to quantify the potential backwater effects from the Guadalupe River. The Guadalupe River above Comal gage had an estimated peak of 69k cfs on June 9, 2010. This would produce significant backwater on the Comal River and would produce a stage that would correlate to a discharge of almost 30k cfs with about 350 cfs of actual flow from the Comal River. The below figure illustrates the potential relationship between the two rivers. A flow on the Guadalupe River of 100k cfs, which has either occurred or been very close to occurring would produce a backwater stage on the Comal River that would correlate to a discharge of almost 70k cfs, even if the actual flow on the Comal River was only about 350 cfs. The Guadalupe River above Comal gage is also similarly affected by high discharges coming from the Comal River. Because of this relationship, at least some of the peak discharges may be overestimated, unless some adjustment is made for the changing tailwater conditions.

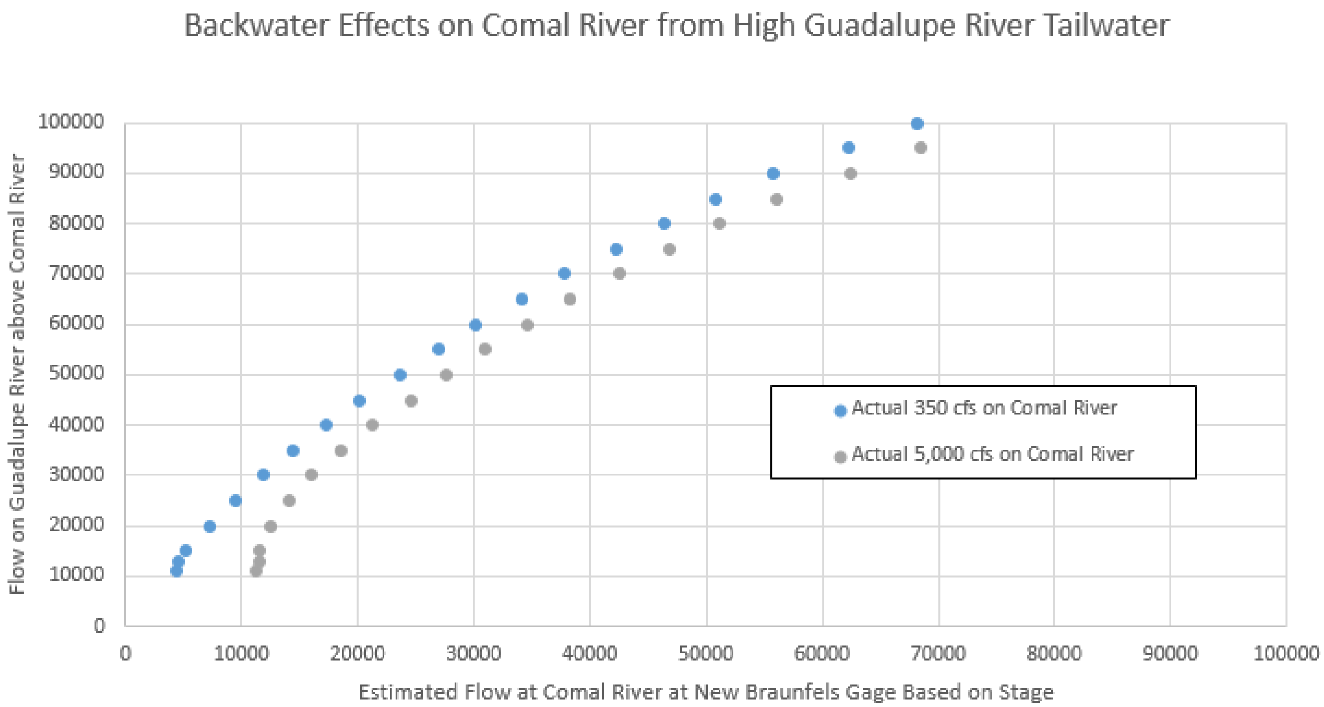


Figure 6.149: Guadalupe River Backwater Effects on the Comal River at New Braunfels Gage

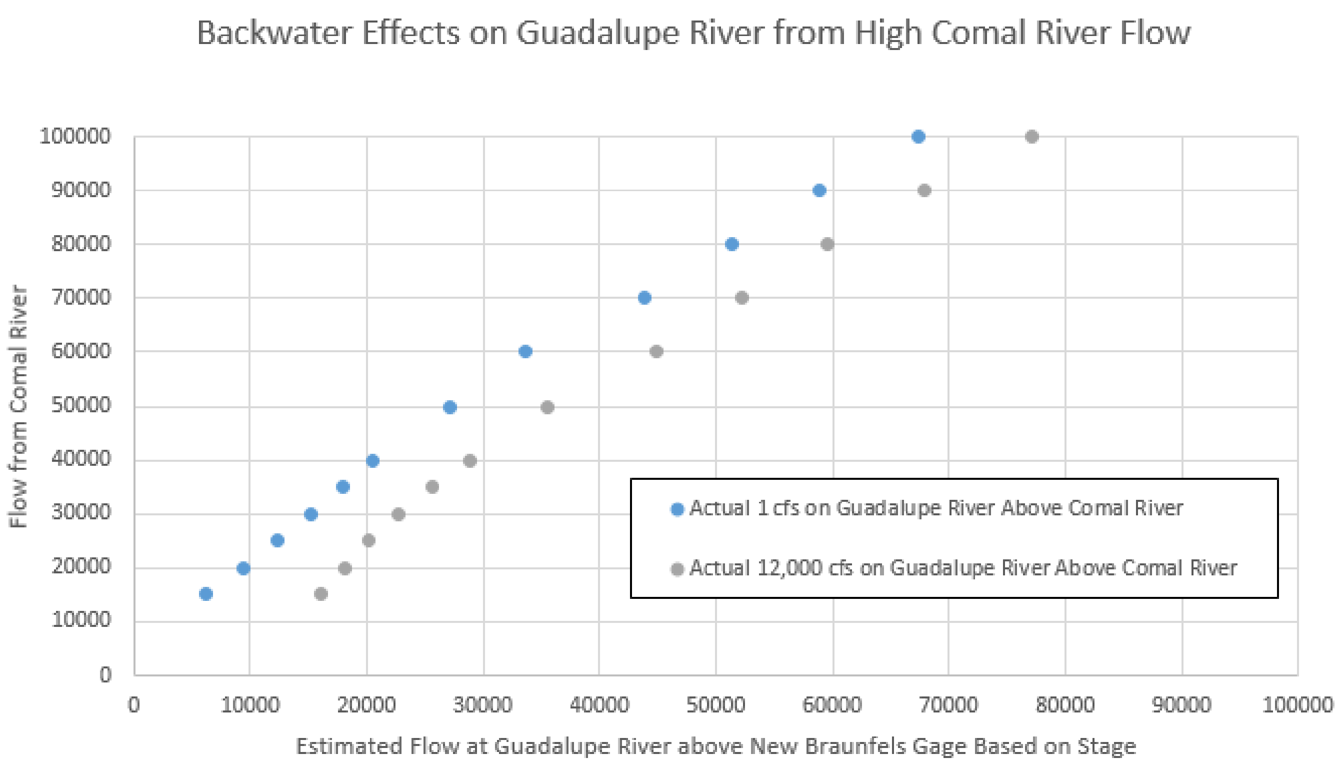


Figure 6.150: Comal River Backwater Effects on the Guadalupe River above the Comal River Gage

The USGS also indicates that discharge estimates above 1,000 cfs are poor. Given the potentially strong backwater effects from the Guadalupe River in addition to the poor discharge rating above 1,000 cfs, the Dry Comal Creek at Loop 377 nr New Braunfels gage was used for model calibration in place of the Comal River at New Braunfels gage.

The areas above the Dry Comal Creek at Loop 377 nr New Braunfels gage were well calibrated for the available storms (5). Observed hydrograph data was limited for this location ince gage was installed in 2007. Observed hydrographs for five significant events were available at those gages and were matched very well by the HEC-HMS model. Further calibration could be performed on this watershed at a future date when larger peak discharges become available.

The second issue was identified during calibration of the Guadalupe River between Gonzalez and Cuero. The Gonzales gage appeared to be underestimating the flow/volume for a couple storm events. The main example is the July 2002 event that overtopped Canyon Dam. Simply routing the observed hydrograph from the upstream gage, Guadalupe River above Comal, results in significantly more volume than is showing up at the Gonzales gage even with no additional rainfall being added. This figure is shown below.

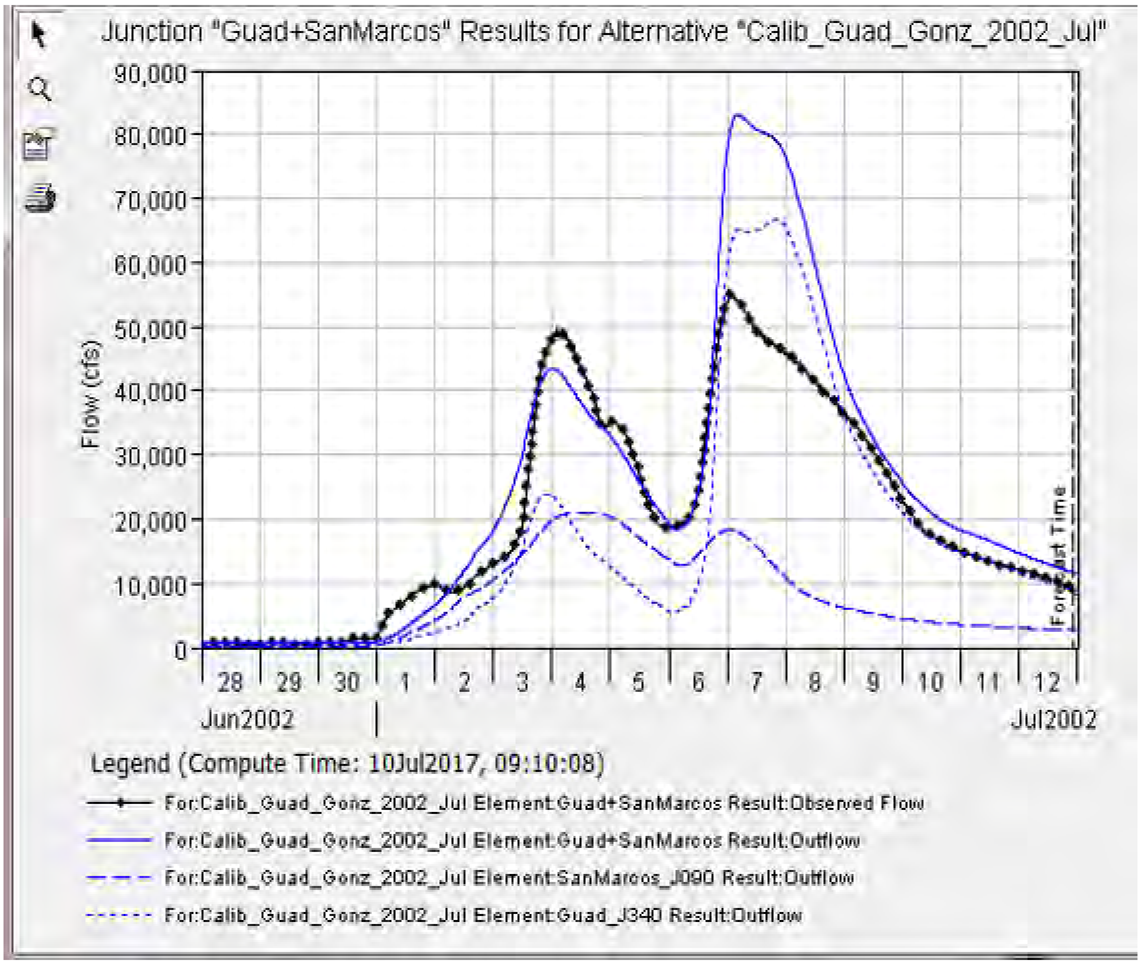


Figure 6.151: Volume Discrepancy at the Guadalupe River at Gonzales Gage from July 2002

This issue alone does not prove, that the flows are too low at Gonzales, as there could be an issue with the upstream gage overestimating flow, however the results for the November 2004 event also improved when not blending the observed hydrograph from the Gonzales gage into the HMS simulation as well. This should be an issue given further consideration on additional analyses of the watershed. Overall, the model calibrated well to the observed volume, shape, timing, and peak of the observed hydrographs of the lower Guadalupe River watershed.

The Coleto Creek portion of the watershed received most of its significant storm events during the early days of radar rainfall data (late 1990s to early 2000s). As a result, more discrepancies were observed between the rainfall data and the observed runoff volumes at the gages, especially for flashy watersheds like Perdido Creek. Calibration of the gages at Fifteenmile Creek at Weser and Coleto Creek at Arnold Rd required significant effort in order to accurately reproduce the timing of the flow from each of the multiple tributaries that join the main stem upstream of these gages. However, the final calibration of these locations matched the observed hydrographs very well.

6.5 FINAL MODEL PARAMETERS

After the initial parameter estimates were made and the calibration process was completed, the final parameters were established. The final lag times and peaking coefficients were developed by taking a weighted average of the lag times and peaking coefficients from the calibration events. The volume of runoff from the subbasin for that event was used to weight the calibrated lag times. This method has the effect of granting a higher weight to the lag times that were calibrated from larger, more intense storms, and it ignores the storms that generated no runoff from a particular subbasin. During the calibration process, the use of lower peaking coefficients, which would lead to wider and flatter hydrographs, was tested against the observed downstream hydrographs at the gages. However, in most cases, especially in in the upper parts of the basin, the lower peaking coefficients had a strongly negative impact on the model's ability to match the shape and peak value of the observed hydrographs. Lower peaking coefficients were used for Plum Creek above Lockhart and for other subbasins containing a dense network of NRCS structures which provide a dampening effect on the peak flows. The final Snyder's lag times and peaking coefficients used a weighted average and are shown in Table 6.18.

The final baseflow parameters were selected based on the results of the calibration runs. Specifically, an initial flow per square mile was selected based on typical flow rates observed on each reach of the river, and the recession constant and ratio to peak were selected based on the slope and shape of the receding limb of the hydrograph at the downstream gages. One will also notice that significantly higher baseflow parameters were used for the SanMarcos_S005 and the CypressCr_BR_S020 subbasins. Those parameters were selected in order to mimic the observed flow from the springs in the upper San Marcos and Cypress Creek watersheds. The final baseflow parameters are also shown in Table 6.18.

The final Mod Puls storage discharge relationships were calculated from detailed steady flow HEC-RAS models, and the final number of subreaches were selected based on calibration to the observed attenuation of the flood hydrograph in between stream gages. The final routing subreach values are shown in Table 6.19.

In observed storm events, the initial and constant losses vary from storm to storm according to the antecedent moisture conditions of the soil. The losses for the frequency storms were developed using the USACE Fort Worth District Method for determining losses based on percent sand (Rodman, 1977). This method produces a different set of loss rates for each storm frequency. These losses also fall well within the band of observed losses from the calibration storms. The default initial and constant losses for the 2-yr through 10-yr storms were then adjusted for each given frequency in order to have a better correlation with the statistical frequency curves estimated from the USGS gage records. This was done because of the increased confidence level in the statistical frequency curve for the 2 through 10-yr recurrence intervals. The 25-yr losses were adjusted when needed to create a smooth transition between the 50-yr to the 10-yr values. The final loss rates used for each frequency storm event are given in Tables 6.20 and 6.21.

Table 6.18: Final Subbasin Parameters

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Snyder's Lag Time (hr)	Snyder's Peaking Coefficient	Initial Baseflow (cfs / sq mi)	Baseflow Recession Constant	Baseflow Ratio to Peak
NF_Guad_S010	168.18	0	4.5	0.77	0.2	0.89	0.03
NF_Guad_S020	21.06	0	2.2	0.77	0.3	0.80	0.06
SF_Guad_S010	97.4	0	5.5	0.77	0.3	0.80	0.06
Guad_S010	24.75	1	3.1	0.77	0.4	0.80	0.04
JohnsonCr_S010	113.51	0	2.5	0.77	0.4	0.70	0.10
JohnsonCr_S020	13.25	1	2.0	0.77	0.4	0.80	0.04
Guad_S020	47.53	3	2.7	0.77	0.4	0.80	0.04
Guad_S030	78.17	4	3.6	0.77	0.5	0.84	0.04
TurtleCr_S010	70.47	0	4.2	0.77	0.5	0.84	0.04
Guad_S040	18.13	1	1.6	0.77	0.5	0.84	0.04
VerdeCr_S010	56.16	0	3.5	0.77	0.5	0.84	0.04
Guad_S050	54.88	0	3.0	0.77	0.5	0.84	0.04
CypressCr_GR_S010	73.49	0	4.0	0.77	0.5	0.84	0.04
Guad_S060	28.1	1	2.0	0.77	1.0	0.84	0.04
BlockCr_S010	44.64	0	3.1	0.77	1.0	0.84	0.04
Guad_S070	19.96	0	2.4	0.77	1.0	0.84	0.04
JoshuaCr_S010	41.66	0	3.0	0.77	1.0	0.84	0.04
Guad_S080	12.59	0	1.3	0.77	1.0	0.84	0.04
SisterCr_S010	64.3	0	3.0	0.77	1.0	0.84	0.04
Guad_S090	149.01	0	8.0	0.77	1.0	0.84	0.04
CurryCr_S010	69.15	0	4.2	0.77	1.0	0.84	0.04
Guad_S100	47.37	1	2.5	0.77	1.0	0.84	0.04
Guad_S110	46.28	2	4.5	0.77	1.0	0.80	0.04
Guad_S120	58.52	4	5.0	0.77	1.0	0.80	0.04
CanyonLk_S010	12.51	100	1.0	0.77	0.1	0.80	0.02
Blanco_S010	26.44	0	2.2	0.78	0.3	0.8	0.015
Blanco_S020	40.84	0	2.6	0.78	0.3	0.8	0.015
Blanco_S030	35.9	0.3	2	0.78	0.3	0.8	0.015
Blanco_S040	43.58	1.1	3.7	0.78	0.3	0.8	0.015
Blanco_S050	22.38	0.2	3.5	0.78	0.3	0.8	0.015
LittleBlanco_S010	12.83	0.2	2.2	0.78	0.3	0.8	0.015
LittleBlanco_S020	13.41	0.2	2.4	0.78	0.3	0.8	0.015
LittleBlanco_S030	24.15	0.6	2.7	0.78	0.3	0.8	0.015
LittleBlanco_S040	18.32	0.2	3.6	0.78	0.3	0.8	0.015
Blanco_S060	1.19	0.1	0.7	0.78	0.3	0.8	0.015
WanslowCr_BR_S010	13.37	0.4	2.7	0.78	0.3	0.8	0.015
Blanco_S070	16.42	0.4	2.3	0.78	0.3	0.8	0.015
Blanco_S080	5.86	0.6	2	0.78	0.3	0.8	0.015

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Snyder's Lag Time (hr)	Snyder's Peaking Coefficient	Initial Baseflow (cfs / sq mi)	Baseflow Recession Constant	Baseflow Ratio to Peak
CarpersCr_BR_S010	15.35	0.9	3.3	0.78	0.3	0.8	0.015
Blanco_S090	19.06	1	2.4	0.78	0.3	0.8	0.015
Blanco_S100	1.59	2.7	0.9	0.78	0.3	0.8	0.015
WilsonCr_BR_S010	5.34	0.6	1.9	0.78	0.3	0.8	0.015
Blanco_S110	0.93	12.5	0.8	0.78	0.3	0.8	0.015
CypressCr_BR_S010	15.02	0.2	2.2	0.78	0.3	0.8	0.015
CypressCr_BR_S020	15.11	1	1.9	0.78	0.8	0.95	0.03
CypressCr_BR_S030	8.01	3.9	2.2	0.78	0.3	0.8	0.015
Blanco_S120	8.49	1.7	1.8	0.72	0.2	0.8	0.007
Blanco_S130	6.95	0.2	2.5	0.72	0.2	0.8	0.007
LoneManCr_BR_S010	12.37	0.3	3.6	0.72	0.2	0.8	0.007
Blanco_S140	9.85	0.1	2.4	0.72	0.2	0.8	0.007
HalifaxCr_BR_S010	12.92	0.1	3.7	0.72	0.2	0.8	0.007
Blanco_S150	6.65	0.2	2.5	0.72	0.2	0.8	0.007
Blanco_S160	20.39	2.2	3.3	0.72	0.2	0.8	0.007
Blanco_S170	3.57	16.4	2.5	0.75	0.2	0.8	0.007
SinkCk_S010	23.53	0	4.4	0.78	0.3	0.89	0.03
SinkCk_S020	9.89	0	3.4	0.78	0.3	0.89	0.03
SinkCk_S030	4.34	0	1.9	0.78	0.3	0.89	0.03
SinkCk_S040	5.61	3	2.3	0.78	0.3	0.89	0.03
SanMarcos_S005	5.58	6	2.6	0.78	15	0.99	0.03
SanMarcos_S008	0.98	46	1.4	0.78	0.3	0.89	0.03
PurgatoryCr_S010	37.13	2	5.5	0.78	0.3	0.8	0.02
SanMarcos_S010	7.99	16	1.9	0.75	0.25	0.8	0.02
SanMarcos_S020	82.34	1	6.8	0.75	0.25	0.8	0.02
YorkCr_S010	142.92	1	8.5	0.70	0.3	0.85	0.03
SanMarcos_S030	82.38	1	7.5	0.75	0.25	0.8	0.02
SanMarcos_S040	22.89	1	5	0.75	0.25	0.8	0.02
PlumCr_S010	111.3	2	4.9	0.56	0.01	0.8	0.1
PlumCr_S020	83.29	1	7.4	0.78	0.01	0.5	0.1
TenneyCr_S010	39.82	0	5.6	0.78	0.01	0.5	0.1
PlumCr_S030	117.08	0	9.5	0.78	0.01	0.5	0.1
PlumCr_S040	37.34	1	4.6	0.78	0.3	0.79	0.1
SanMarcos_S050	108.37	0	13	0.78	0.3	0.89	0.05
DryComalCk_S010	30.25	0	7.7	0.78	0.1	0.89	0.05
DryComalCk_S020	0.81	0	1.0	0.78	0.1	0.89	0.05
WFk_DryComalCk_S010	18.47	1	6.7	0.78	0.1	0.89	0.05
WFk_DryComalCk_S020	1.27	1	1.6	0.78	0.1	0.89	0.05
WF_Trib_S010	1.84	2	1.3	0.78	0.1	0.89	0.05
WF_Trib_S020	1.09	0	1.0	0.78	0.1	0.89	0.05

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Snyder's Lag Time (hr)	Snyder's Peaking Coefficient	Initial Baseflow (cfs / sq mi)	Baseflow Recession Constant	Baseflow Ratio to Peak
WFk_DryComalCk_S030	0.25	1	0.6	0.78	0.1	0.89	0.05
DryComalCk_S030	1.38	0	1.5	0.78	0.1	0.89	0.05
BearCk_S010	13.37	1	3.2	0.78	0.1	0.89	0.05
DryComalCk_S040	20.29	7	3.8	0.78	0.1	0.89	0.05
DCCk_Trib14_S010	5.72	0	2.1	0.78	0.1	0.89	0.05
DryComalCk_S050	12.52	8	2.8	0.78	0.1	0.89	0.05
DryComalCk_S060	3.98	23	1.9	0.78	0.1	0.89	0.05
BliedersCk_S010	11.49	4	2.1	0.78	0.1	0.89	0.05
Comal_S010	5.58	9	3.1	0.78	57.4	0.89	0.05
Comal_S020	1.23	31	1.1	0.78	0.1	0.89	0.05
Comal_S030	0.59	47	1.0	0.78	0.1	0.89	0.05
Guad_S130	36.03	2	3.1	0.82	0.3	0.89	0.05
BearCr_S010	16.74	1	2.7	0.82	0.3	0.89	0.05
Guad_S140	35.49	3	4.1	0.82	0.3	0.89	0.05
Guad_S142	15	19	4.0	0.75	0.3	0.89	0.05
Guad_S144	0.72	1	0.8	0.75	0.3	0.89	0.05
Guad_Trib22_S010	4.51	10	2.0	0.75	0.3	0.89	0.05
Guad_S145	1	3	1.4	0.75	0.3	0.89	0.05
LongCk_S010	11.49	1	3.5	0.75	0.3	0.89	0.05
Guad_S147	0.44	4	0.8	0.75	0.3	0.89	0.05
Guad_Trib20_S010	8.82	3	2.6	0.75	0.3	0.89	0.05
Guad_S149	3.59	5	1.6	0.75	0.3	0.89	0.05
Guad_S152	0.71	17	0.7	0.75	0.3	0.89	0.05
YoungsCk_S010	14.76	1	2.5	0.75	0.3	0.89	0.05
Guad_S154	0.26	41	0.8	0.75	0.3	0.89	0.05
CottonwoodCkS_S010	6.01	0	2.4	0.75	0.3	0.89	0.05
Guad_S156	0.6	13	0.9	0.75	0.3	0.89	0.05
Little_MillCk_S010	8.7	3	3.0	0.75	0.3	0.89	0.05
Guad_S158	1.36	5	1.1	0.75	0.3	0.89	0.05
DeadmanCk_S010	8.57	1	2.3	0.75	0.3	0.89	0.05
Guad_S160	22.24	10	3.8	0.75	0.3	0.89	0.05
CottonwoodCk_S010	41.19	0	6.3	0.75	0.3	0.89	0.05
Guad_S162	1.19	1	1.3	0.75	0.3	0.89	0.05
AlligatorCk_S010	10.62	3	2.6	0.75	0.3	0.89	0.05
GeronimoCk_S010	20.01	3	3.3	0.75	0.3	0.89	0.05
GeronimoCk_S020	29.06	1	2.8	0.75	0.3	0.89	0.05
GeronimoCk_S030	9.98	10	2.2	0.75	0.3	0.89	0.05
Guad_S164	4.27	0	2.2	0.75	0.3	0.89	0.05
CantauCk_S010	6.64	0	3.2	0.75	0.3	0.89	0.05
Guad_S166	31.7	0	5.3	0.75	0.3	0.89	0.05

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Snyder's Lag Time (hr)	Snyder's Peaking Coefficient	Initial Baseflow (cfs / sq mi)	Baseflow Recession Constant	Baseflow Ratio to Peak
MillCk_S010	39.41	0	6.3	0.75	0.3	0.89	0.05
Guad_S168	32.51	0	8.5	0.75	0.3	0.89	0.05
NashCk_S010	26.51	0	6.2	0.75	0.3	0.89	0.05
Guad_S170	35.71	0	11.6	0.75	0.3	0.89	0.05
Guad_S172	22.92	0	5.6	0.75	0.3	0.89	0.05
Guad_S174	28.5	0	5.2	0.75	0.3	0.89	0.05
Guad_S176	4.4	0	5.3	0.75	0.3	0.89	0.05
Guad_S200	69.52	3	10.1	0.75	0.3	0.89	0.05
PeachCr_S010	110.41	0	16.5	0.75	0.1	0.89	0.01
BigFiveMileCr_S010	44.64	1	6.6	0.75	0.1	0.89	0.01
PeachCr_S020	64.77	1	9.6	0.75	0.1	0.89	0.01
SandyFork_S010	159.64	0	19.4	0.75	0.1	0.89	0.01
PeachCr_S030	80.3	0	9.6	0.75	0.1	0.89	0.01
PeachCr_S040	22.74	1	6.5	0.75	0.1	0.89	0.01
Guad_S210	122.37	0	10.3	0.75	0.3	0.89	0.05
McCoyCr_S010	32.59	0	5.3	0.75	0.3	0.89	0.05
Guad_S220	48.45	0	6.4	0.75	0.3	0.89	0.05
SandiesCr_S010	117.29	0	15.7	0.75	0.1	0.45	0.05
ClearForkCr_S010	63.87	1	13.6	0.75	0.1	0.45	0.05
SandiesCr_S020	33.01	1	12.9	0.75	0.1	0.45	0.05
ElmCr_S010	158.76	1	19.4	0.75	0.1	0.45	0.05
SandiesCr_S030	176.42	0	23.3	0.75	0.1	0.45	0.05
SandiesCr_S040	161.79	0	19.4	0.75	0.1	0.45	0.05
Guad_S230	98.87	2	5.3	0.75	0.3	0.89	0.05
Guad_S240	170.88	3	15.6	0.75	0.3	0.89	0.05
SmithCk_S010	32.66	0	8.2	0.78	0.09	0.85	0.02
ThomasCk_S010	30.55	0	6.6	0.78	0.09	0.85	0.02
SmithCk_S020	29.85	0	7.7	0.78	0.13	0.85	0.02
YorktownCk_S010	27.96	1	6.0	0.78	0.09	0.85	0.02
YorktownCk_S020	17.43	1	4.5	0.78	0.12	0.85	0.02
FifteenmileCk_S010	13.13	0	4.4	0.78	0.05	0.85	0.02
HoosierCk_S010	12.96	0	6.3	0.78	0.07	0.86	0.02
FifteenmileCk_S020	17.95	0	6.3	0.78	0.10	0.72	0.02
EighteenmileCk_S010	47.98	0	8.1	0.78	0.12	0.72	0.02
FifteenmileCk_S030	19.85	0	6.0	0.78	0.16	0.71	0.02
TwelvemileCk_S010	47.68	0	10.1	0.78	0.10	0.68	0.02
FivemileCk_S010	39	0	8.1	0.78	0.11	0.69	0.02
TwelvemileCk_S020	19.19	0	5.8	0.78	0.12	0.69	0.02
ColetoCk_S010	38.97	4	8.0	0.78	0.15	0.60	0.01
ColetoCk_S020	22.57	5	6.7	0.78	0.11	0.60	0.01

Subbasin Name	Drainage Area (sq mi)	Percent Impervious (%)	Snyder's Lag Time (hr)	Snyder's Peaking Coefficient	Initial Baseflow (cfs / sq mi)	Baseflow Recession Constant	Baseflow Ratio to Peak
PerdidoCk_S010	27.68	0	2.8	0.78	0.26	0.66	0.03
PerdidoCk_S020	27.57	0	5.8	0.78	0.10	0.60	0.01
PerdidoCk_S030	21.08	10	5.9	0.78	0.10	0.60	0.01
ColetoCk_S030	17.22	1	3.5	0.78	0.26	0.60	0.02
ColetoCk_S040	29.13	1	6.2	0.70	0.26	0.60	0.01
DryCk_S010	35.55	2	6.4	0.70	0.26	0.60	0.01
Guad_S250	39.4	7	16.6	0.75	0.30	0.89	0.05

Table 6.18: Final Modified Puls Routing Parameters

HEC-HMS Reach Name	Storage-Discharge Source	Subreaches	Storage Volume Adjustment Factor
Blanco_R020F	Hays Co FIS HEC-1	2	
Blanco_R020H	Hays Co FIS HEC-1	3	
Blanco_R030J	Hays Co FIS HEC-1	1	
Blanco_R030L	Hays Co FIS HEC-1	2	
Blanco_R030M	Hays Co FIS HEC-1	1	
Blanco_R040O	Hays Co FIS HEC-1	2	
Blanco_R040P	Hays Co FIS HEC-1	3	
Blanco_R040R	Hays Co FIS HEC-1	5	
Blanco_R050S	Hays Co FIS HEC-1	3	
Blanco_R050T	Hays Co FIS HEC-1	5	
LittleBlanco_R020V	Hays Co FIS HEC-1	2	
LittleBlanco_R030W	Hays Co FIS HEC-1	3	
LittleBlanco_R030X	Hays Co FIS HEC-1	3	
LittleBlanco_R040Y	Hays Co FIS HEC-1	5	
Blanco_R060Z	Hays Co FIS HEC-1	1	
Blanco_R070	Blanco River HEC-RAS	5	
Blanco_R080	Blanco River HEC-RAS	4	
Blanco_R090	Blanco River HEC-RAS	4	
Blanco_R100	Blanco River HEC-RAS	2	
Blanco_R110	Blanco River HEC-RAS	1	
CypressCr_R0204C	Hays Co FIS HEC-1	1	
CypressCr_R0206C	Hays Co FIS HEC-1	1	
CypressCr_R0206CL	Hays Co FIS HEC-1	1	
CypressCr_R02010C	Hays Co FIS HEC-1	1	
CypressCr_R03012C	Hays Co FIS HEC-1	1	
CypressCr_R03014C	Hays Co FIS HEC-1	1	
CypressCr_R03016C	Hays Co FIS HEC-1	1	

HEC-HMS Reach Name	Storage-Discharge Source	Subreaches	Storage Volume Adjustment Factor
Blanco_R120	Blanco River HEC-RAS	2	
Blanco_R130	Blanco River HEC-RAS	5	
Blanco_R140	Blanco River HEC-RAS	5	
Blanco_R150	Blanco River HEC-RAS	4	
Blanco_R160a	Blanco River HEC-RAS	1	
Blanco_R160b	Blanco River HEC-RAS	2	
Blanco_R170	Blanco River HEC-RAS	3	
SinkCk_R010	Upper San Marcos HEC-RAS	1	
SinkCk_R020	Upper San Marcos HEC-RAS	1	
SinkCk_R030	Upper San Marcos HEC-RAS	1	
SinkCk_R040	Upper San Marcos HEC-RAS	1	
SinkCk_R050	Upper San Marcos HEC-RAS	1	
SanMarcos_R003	Upper San Marcos HEC-RAS	1	
SanMarcos_R005	Upper San Marcos HEC-RAS	1	
SanMarcos_R007	Upper San Marcos HEC-RAS	1	
SanMarcos_R020	San Marcos River HEC-RAS	8	0.8
SanMarcos_R030	San Marcos River HEC-RAS	5	0.85
SanMarcos_R040	San Marcos River HEC-RAS	1	1.2
PlumCr_R010	Plum Creek HEC-RAS	6	
PlumCr_R020	Plum Creek HEC-RAS	3	
SanMarcos_R050	San Marcos River HEC-RAS	3	1.2
DryComalCk_R010	Comal River HEC-RAS	1	
WFk_DryComalCk_R010	Comal River HEC-RAS	1	
WF_Trib_R010	Comal River HEC-RAS	1	
WFk_DryComalCk_R020	Comal River HEC-RAS	1	
DryComalCk_R020	Comal River HEC-RAS	1	
BearCk_R010	Comal River HEC-RAS	1	
DryComalCk_R030	Comal River HEC-RAS	1	
DCCk_Trib14_R010	Comal River HEC-RAS	1	
DryComalCk_R040	Comal River HEC-RAS	1	
DryComalCk_R050	Comal River HEC-RAS	1	
Comal_R010	Comal River HEC-RAS	1	
Comal_R020	Comal River HEC-RAS	1	
Comal_R030	Comal River HEC-RAS	1	
Comal_R040	Comal River HEC-RAS	1	
Guad_R120	Guadalupe River HEC-RAS	1	
Guad_R130	Guadalupe River HEC-RAS	2	
Guad_R135	Guadalupe River HEC-RAS	1	
Guad_R140	Guadalupe River HEC-RAS	1	
Guad_R147	Guadalupe River HEC-RAS	1	

HEC-HMS Reach Name	Storage-Discharge Source	Subreaches	Storage Volume Adjustment Factor
Guad_R152	Guadalupe River HEC-RAS	1	
Guad_R157	Guadalupe River HEC-RAS	1	
Guad_R165	Guadalupe River HEC-RAS	1	
Guad_R170	Guadalupe River HEC-RAS	1	
Guad_R175	Guadalupe River HEC-RAS	1	
Guad_R180	Guadalupe River HEC-RAS	1	
Guad_R185	Guadalupe River HEC-RAS	1	
Guad_R190	Guadalupe River HEC-RAS	2	
Guad_R195	Guadalupe River HEC-RAS	1	
GeronimoCk_R010	Geronimo Creek HEC-RAS	3	
GeronimoCk_R020	Geronimo Creek HEC-RAS	2	
GeronimoCk_R030	Geronimo Creek HEC-RAS	2	
Guad_R200	Guadalupe River HEC-RAS	1	
Guad_R205	Guadalupe River HEC-RAS	1	0.9
Guad_R210	Guadalupe River HEC-RAS	3	0.9
Guad_R215	Guadalupe River HEC-RAS	4	0.9
Guad_R220	Guadalupe River HEC-RAS	3	0.9
Guad_R225	Guadalupe River HEC-RAS	3	0.9
Guad_R228	Guadalupe River HEC-RAS	2	0.9
Guad_R230	Guadalupe River HEC-RAS	8	0.9
PeachCr_R010	Peach Creek HEC-RAS	8	
PeachCr_R020	Peach Creek HEC-RAS	8	
PeachCr_R040	Peach Creek HEC-RAS	8	
Guad_R240	Guadalupe River HEC-RAS	9	0.9
Guad_R250	Guadalupe River HEC-RAS	4	0.9
SandiesCr_R010	Sandies Creek HEC-RAS	4	
SandiesCr_R020	Sandies Creek HEC-RAS	3	
SandiesCr_R030	Sandies Creek HEC-RAS	5	
Guad_R260	Guadalupe River HEC-RAS	5	0.8
Guad_R280	Guadalupe River HEC-RAS	11	0.8
ColetoCk_R010	Coleto Creek BLE HEC-RAS	5	
PerdidoCk_R020	Coleto Creek BLE HEC-RAS	4	
PerdidoCk_R030	Coleto Creek BLE HEC-RAS	4	
ColetoCk_R030	Coleto Dam Break HEC-RAS	5	
ColetoCk_R040	Coleto Dam Break HEC-RAS	5	
Guad_R295	Guadalupe River HEC-RAS	3	0.8
Guad_R300	Guadalupe River HEC-RAS	1	0.8
Guad_R305	Guadalupe River HEC-RAS	5	0.8

Table 6.19: Final Muskingum Routing Parameters

HEC-HMS Reach Name	K (hrs)	X	Subreaches
NF_Guad_R010	1.0	0.2	1
Guad_R010	1.75	0.2	1
JohnsonCr_R010	0.75	0.2	1
Guad_R020	1.5	0.2	1
Guad_R030	2.6	0.2	2
Guad_R040	1.5	0.2	1
Guad_R050	2.3	0.25	1
Guad_R060	1.7	0.2	1
Guad_R070	2.6	0.2	1
Guad_R080	1.3	0.2	1
Guad_R090	11	0.2	3
Guad_R100	2.3	0.2	1
Guad_R110	2.5	0.2	2
SmithCk_R020	8.5	0.3	3
YorktownCk_R020	6.5	0.3	3
FifteenmileCk_R010	6.0	0.3	3
FifteenmileCk_R020	4.8	0.3	3
FifteenmileCk_R030	4.4	0.3	3
TwelvemileCk_R020	6.1	0.35	4

Table 6.20: Final Initial and Constant Losses for the 2-yr through 25-yr Frequency Storms

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
NF_Guad_S010	2.13	0.21	2.12	0.21	1.84	0.20	0.97	0.12
NF_Guad_S020	2.07	0.27	2.35	0.27	2.16	0.25	1.69	0.22
SF_Guad_S010	2.06	0.27	2.35	0.26	2.16	0.25	1.68	0.22
Guad_S010	2.51	0.28	2.47	0.28	1.45	0.15	1.27	0.13
JohnsonCr_S010	2.35	0.31	2.94	0.31	2.94	0.31	1.98	0.28
JohnsonCr_S020	2.49	0.28	2.46	0.28	1.44	0.15	1.26	0.13
Guad_S020	2.47	0.28	2.45	0.27	1.44	0.15	1.27	0.13
Guad_S030	1.90	0.22	1.89	0.20	1.84	0.17	1.75	0.14
TurtleCr_S010	1.77	0.22	1.59	0.19	1.43	0.17	1.25	0.14
Guad_S040	1.95	0.23	1.74	0.21	1.54	0.18	1.35	0.15
VerdeCr_S010	1.94	0.22	1.97	0.20	1.94	0.18	1.87	0.14
Guad_S050	1.89	0.23	1.71	0.20	1.54	0.18	1.37	0.14
CypressCr_GR_S010	1.80	0.22	1.62	0.20	1.45	0.17	1.27	0.14
Guad_S060	1.74	0.22	1.72	0.22	1.70	0.21	1.70	0.21
BlockCr_S010	1.64	0.21	1.64	0.21	1.64	0.21	1.64	0.20
Guad_S070	1.78	0.22	1.75	0.22	1.73	0.21	1.72	0.21
JoshuaCr_S010	1.66	0.21	1.65	0.21	1.65	0.21	1.65	0.20
Guad_S080	1.74	0.22	1.72	0.22	1.71	0.21	1.70	0.21
SisterCr_S010	1.65	0.21	1.65	0.21	1.65	0.21	1.64	0.20
Guad_S090	1.64	0.21	1.64	0.21	1.64	0.21	1.64	0.20
CurryCr_S010	1.65	0.21	1.65	0.21	1.65	0.21	1.64	0.20
Guad_S100	1.64	0.21	1.64	0.21	1.64	0.21	1.64	0.20
Guad_S110	1.56	0.21	1.38	0.16	1.21	0.14	1.05	0.12
Guad_S120	1.53	0.20	1.32	0.16	1.14	0.14	0.97	0.12
CanyonLk_S010	1.50	0.20	1.30	0.16	1.12	0.14	0.95	0.12
Blanco_S010	1.8	0.208	1.78	0.207	1.68	0.203	1.24	0.145
Blanco_S020	1.81	0.209	1.79	0.208	1.68	0.204	1.25	0.146
Blanco_S030	1.76	0.204	1.74	0.203	1.65	0.201	1.22	0.143
Blanco_S040	1.73	0.201	1.72	0.201	1.63	0.199	1.2	0.141
Blanco_S050	1.71	0.199	1.7	0.199	1.62	0.197	1.19	0.14
LittleBlanco_S010	1.82	0.21	1.79	0.208	1.69	0.204	1.25	0.146
LittleBlanco_S020	1.79	0.207	1.77	0.206	1.67	0.203	1.24	0.145
LittleBlanco_S030	1.72	0.2	1.71	0.2	1.63	0.198	1.2	0.141
LittleBlanco_S040	1.83	0.211	1.8	0.209	1.7	0.206	1.26	0.147
Blanco_S060	1.86	0.214	1.83	0.212	1.71	0.207	1.28	0.148
WanslowCr_BR_S010	1.86	0.214	1.82	0.211	1.71	0.207	1.27	0.148
Blanco_S070	1.84	0.212	1.81	0.21	1.7	0.206	1.27	0.147
Blanco_S080	1.82	0.21	1.8	0.209	1.69	0.205	1.26	0.146
CarpersCr_BR_S010	1.87	0.215	1.84	0.213	1.72	0.208	1.28	0.149

Subbasin Name	2-yr	2-yr	5-yr	5-yr	10-yr	10-yr	25-yr	25-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
Blanco_S090	1.85	0.213	1.82	0.211	1.71	0.207	1.27	0.147
Blanco_S100	1.84	0.212	1.81	0.21	1.7	0.206	1.27	0.147
WilsonCr_BR_S010	1.87	0.215	1.83	0.212	1.72	0.208	1.28	0.148
Blanco_S110	1.85	0.213	1.82	0.211	1.71	0.206	1.27	0.147
CypressCr_BR_S010	1.86	0.214	1.83	0.212	1.72	0.207	1.28	0.148
CypressCr_BR_S020	1.87	0.215	1.83	0.212	1.72	0.208	1.28	0.148
CypressCr_BR_S030	1.85	0.213	1.82	0.211	1.71	0.207	1.27	0.148
Blanco_S120	1.86	0.214	1.83	0.212	1.72	0.208	1.28	0.148
Blanco_S130	1.87	0.215	1.84	0.213	1.72	0.208	1.28	0.149
LoneManCr_BR_S010	1.9	0.218	1.86	0.215	1.74	0.21	1.3	0.15
Blanco_S140	1.86	0.214	1.83	0.212	1.71	0.207	1.28	0.148
HalifaxCr_BR_S010	1.78	0.206	1.76	0.205	1.66	0.202	1.23	0.144
Blanco_S150	1.79	0.207	1.77	0.206	1.67	0.203	1.23	0.144
Blanco_S160	1.75	0.203	1.73	0.202	1.64	0.2	1.21	0.142
Blanco_S170	1.9	0.218	1.86	0.215	1.74	0.21	1.3	0.15
SinkCk_S010	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SinkCk_S020	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SinkCk_S030	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SinkCk_S040	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SanMarcos_S005	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SanMarcos_S008	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
PurgatoryCr_S010	1.4	0.19	1.22	0.15	1.16	0.14	0.99	0.12
SanMarcos_S010	1.47	0.19	1.27	0.15	1.2	0.15	1.03	0.13
SanMarcos_S020	1.52	0.2	1.31	0.16	1.24	0.15	1.06	0.13
YorkCr_S010	1.88	0.27	1.78	0.22	1.7	0.21	1.44	0.18
SanMarcos_S030	1.58	0.2	1.36	0.16	1.28	0.16	1.1	0.13
SanMarcos_S040	1.68	0.21	1.45	0.17	1.36	0.16	1.17	0.14
PlumCr_S010	2	0.19	2	0.19	1.8	0.14	0.98	0.12
PlumCr_S020	1.46	0.19	1.19	0.14	1.08	0.13	0.92	0.11
TenneyCr_S010	1.63	0.21	1.32	0.16	1.18	0.14	1.02	0.12
PlumCr_S030	1.49	0.19	1.21	0.15	1.09	0.14	0.93	0.11
PlumCr_S040	1.61	0.21	1.31	0.16	1.17	0.14	1.01	0.12
SanMarcos_S050	1.71	0.22	1.47	0.17	1.37	0.17	1.18	0.14
DryComalCk_S010	2.03	0.25	1.74	0.20	1.45	0.18	1.26	0.15
DryComalCk_S020	1.87	0.24	1.61	0.19	1.36	0.16	1.17	0.14
WFk_DryComalCk_S010	2.07	0.26	1.78	0.21	1.48	0.18	1.28	0.15
WFk_DryComalCk_S020	1.91	0.24	1.64	0.19	1.38	0.17	1.19	0.14
WF_Trib_S010	2.01	0.25	1.73	0.20	1.45	0.17	1.25	0.15
WF_Trib_S020	1.86	0.24	1.60	0.19	1.35	0.16	1.16	0.14
WFk_DryComalCk_S030	1.97	0.25	1.69	0.20	1.42	0.17	1.22	0.14

Subbasin Name	2-yr	2-yr	5-yr	5-yr	10-yr	10-yr	25-yr	25-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
DryComalCk_S030	2.05	0.25	1.76	0.21	1.47	0.18	1.27	0.15
BearCk_S010	1.98	0.25	1.70	0.20	1.42	0.17	1.23	0.14
DryComalCk_S040	1.82	0.23	1.57	0.19	1.32	0.16	1.14	0.14
DCCk_Trib14_S010	1.96	0.25	1.69	0.20	1.41	0.17	1.22	0.14
DryComalCk_S050	1.74	0.22	1.50	0.18	1.27	0.16	1.09	0.13
DryComalCk_S060	1.85	0.23	1.59	0.19	1.34	0.16	1.15	0.14
BliedersCk_S010	1.97	0.25	1.69	0.20	1.42	0.17	1.22	0.14
Comal_S010	2.03	0.25	1.74	0.20	1.46	0.18	1.26	0.15
Comal_S020	2.05	0.26	1.76	0.21	1.47	0.18	1.27	0.15
Comal_S030	1.94	0.24	1.67	0.20	1.40	0.17	1.21	0.14
Guad_S130	1.50	0.20	1.30	0.16	1.12	0.14	0.95	0.12
BearCr_S010	1.50	0.20	1.30	0.16	1.12	0.14	0.95	0.12
Guad_S140	1.50	0.20	1.30	0.16	1.12	0.14	0.95	0.12
Guad_S142	1.76	0.23	1.51	0.18	1.28	0.16	1.10	0.13
Guad_S144	1.98	0.25	1.70	0.20	1.42	0.17	1.23	0.14
Guad_Trib22_S010	1.63	0.21	1.41	0.17	1.20	0.15	1.02	0.13
Guad_S145	2.04	0.25	1.75	0.20	1.46	0.18	1.26	0.15
LongCk_S010	1.58	0.21	1.36	0.17	1.17	0.15	0.99	0.12
Guad_S147	1.94	0.24	1.67	0.20	1.40	0.17	1.21	0.14
Guad_Trib20_S010	1.63	0.21	1.41	0.17	1.20	0.15	1.03	0.13
Guad_S149	1.88	0.24	1.62	0.19	1.36	0.17	1.17	0.14
Guad_S152	2.05	0.26	1.76	0.21	1.47	0.18	1.27	0.15
YoungsCk_S010	1.54	0.20	1.33	0.16	1.15	0.14	0.97	0.12
Guad_S154	1.85	0.24	1.59	0.19	1.34	0.16	1.15	0.14
CottonwoodCkS_S010	1.51	0.20	1.31	0.16	1.13	0.14	0.96	0.12
Guad_S156	1.94	0.24	1.67	0.20	1.40	0.17	1.21	0.14
Little_MillCk_S010	1.67	0.22	1.44	0.17	1.22	0.15	1.05	0.13
Guad_S158	1.83	0.23	1.58	0.19	1.33	0.16	1.14	0.14
DeadmanCk_S010	1.58	0.21	1.37	0.17	1.17	0.15	1.00	0.12
Guad_S160	1.78	0.23	1.53	0.18	1.30	0.16	1.11	0.13
CottonwoodCk_S010	2.04	0.25	1.75	0.21	1.46	0.18	1.27	0.15
Guad_S162	2.01	0.25	1.72	0.20	1.44	0.17	1.25	0.15
AlligatorCk_S010	1.88	0.24	1.61	0.19	1.36	0.17	1.17	0.14
GeronimoCk_S010	1.54	0.20	1.33	0.16	1.14	0.14	0.97	0.12
GeronimoCk_S020	1.56	0.21	1.35	0.16	1.16	0.14	0.98	0.12
GeronimoCk_S030	1.74	0.22	1.50	0.18	1.27	0.16	1.09	0.13
Guad_S164	1.91	0.24	1.64	0.19	1.38	0.17	1.19	0.14
CantauCk_S010	1.98	0.25	1.70	0.20	1.43	0.17	1.23	0.14
Guad_S166	2.06	0.26	1.77	0.21	1.48	0.18	1.28	0.15
MillCk_S010	1.82	0.23	1.58	0.19	1.34	0.16	1.16	0.14

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
Guad_S168	2.09	0.26	1.87	0.21	1.63	0.18	1.46	0.15
NashCk_S010	2.05	0.25	1.76	0.21	1.47	0.18	1.27	0.15
Guad_S170	2.02	0.25	1.73	0.20	1.45	0.17	1.25	0.15
Guad_S172	1.90	0.24	1.64	0.19	1.38	0.17	1.19	0.14
Guad_S174	1.82	0.23	1.57	0.19	1.32	0.16	1.14	0.14
Guad_S176	1.98	0.25	1.70	0.20	1.43	0.17	1.23	0.14
Guad_S200	1.82	0.23	1.64	0.18	1.45	0.16	1.30	0.13
PeachCr_S010	1.94	0.24	1.70	0.20	1.46	0.17	1.28	0.14
BigFiveMileCr_S010	1.80	0.23	1.58	0.18	1.36	0.16	1.18	0.13
PeachCr_S020	1.75	0.22	1.52	0.18	1.29	0.16	1.12	0.13
SandyFork_S010	2.02	0.25	1.74	0.20	1.46	0.17	1.27	0.15
PeachCr_S030	1.80	0.23	1.57	0.18	1.34	0.16	1.16	0.13
PeachCr_S040	1.76	0.23	1.52	0.18	1.29	0.16	1.10	0.13
Guad_S210	1.91	0.24	1.64	0.19	1.38	0.17	1.19	0.14
McCoyCr_S010	1.93	0.24	1.66	0.20	1.39	0.17	1.20	0.14
Guad_S220	2.06	0.25	2.00	0.20	1.89	0.17	1.80	0.14
SandiesCr_S010	2.10	0.26	1.80	0.21	1.50	0.18	1.30	0.15
ClearForkCr_S010	1.92	0.24	1.67	0.19	1.43	0.17	1.25	0.14
SandiesCr_S020	1.91	0.24	1.65	0.19	1.39	0.17	1.21	0.14
ElmCr_S010	1.81	0.23	1.59	0.18	1.37	0.16	1.20	0.13
SandiesCr_S030	1.79	0.23	1.54	0.18	1.30	0.16	1.12	0.13
SandiesCr_S040	1.99	0.25	1.73	0.20	1.46	0.17	1.28	0.14
Guad_S230	2.11	0.26	1.84	0.21	1.55	0.18	1.37	0.15
Guad_S240	1.98	0.25	1.70	0.20	1.42	0.17	1.23	0.14
SmithCk_S010	1.86	0.25	2.02	0.25	1.97	0.20	1.22	0.14
ThomasCk_S010	1.91	0.25	2.08	0.25	2.02	0.20	1.25	0.15
SmithCk_S020	1.89	0.25	2.05	0.25	2.00	0.20	1.24	0.14
YorktownCk_S010	1.83	0.24	1.98	0.25	1.95	0.20	1.20	0.14
YorktownCk_S020	1.92	0.25	2.08	0.25	2.03	0.20	1.25	0.15
FifteenmileCk_S010	1.89	0.25	2.05	0.25	2.00	0.20	1.24	0.14
HoosierCk_S010	1.91	0.25	2.08	0.25	2.02	0.20	1.25	0.15
FifteenmileCk_S020	1.34	0.26	0.89	0.15	1.04	0.12	1.28	0.15
EighteenmileCk_S010	1.31	0.25	0.87	0.15	1.02	0.12	1.25	0.15
FifteenmileCk_S030	1.32	0.25	0.87	0.15	1.02	0.12	1.26	0.15
TwelvemileCk_S010	1.33	0.25	0.88	0.15	1.02	0.12	1.27	0.15
FivemileCk_S010	1.36	0.26	0.90	0.15	1.04	0.12	1.29	0.15
TwelvemileCk_S020	1.37	0.26	0.90	0.15	1.05	0.12	1.30	0.15
ColetoCk_S010	1.26	0.24	1.67	0.20	1.40	0.17	1.21	0.14
ColetoCk_S020	1.25	0.24	1.66	0.20	1.39	0.17	1.20	0.14
PerdidoCk_S010	1.82	0.25	2.25	0.20	2.18	0.19	1.25	0.15

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
PerdidoCk_S020	1.27	0.24	2.34	0.25	1.40	0.17	1.21	0.14
PerdidoCk_S030	1.22	0.24	2.25	0.25	1.35	0.16	1.17	0.14
ColetoCk_S030	1.18	0.23	2.18	0.24	1.32	0.16	1.13	0.14
ColetoCk_S040	1.24	0.24	2.30	0.24	1.38	0.17	1.19	0.14
DryCk_S010	1.22	0.24	2.25	0.24	1.36	0.16	1.17	0.14
Guad_S250	1.17	0.23	2.17	0.24	1.31	0.16	1.13	0.14

Table 6.21: Final Initial and Constant Losses for the 50-yr through 500-yr Frequency Storms

Subbasin Name	50-yr Initial (in)	50-yr Constant (in/hr)	100-yr Initial (in)	100-yr Constant (in/hr)	250-yr Initial (in)	250-yr Constant (in/hr)	500-yr Initial (in)	500-yr Constant (in/hr)
NF_Guad_S010	0.85	0.10	0.76	0.07	0.61	0.06	0.50	0.05
NF_Guad_S020	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
SF_Guad_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
Guad_S010	0.93	0.11	0.80	0.08	0.65	0.07	0.53	0.06
JohnsonCr_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
JohnsonCr_S020	0.92	0.11	0.80	0.08	0.65	0.07	0.53	0.06
Guad_S020	0.93	0.11	0.81	0.08	0.66	0.07	0.55	0.06
Guad_S030	1.44	0.11	1.31	0.08	1.16	0.07	1.04	0.06
TurtleCr_S010	0.91	0.11	0.79	0.08	0.64	0.07	0.53	0.06
Guad_S040	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
VerdeCr_S010	1.57	0.11	1.43	0.08	1.28	0.07	1.16	0.06
Guad_S050	1.02	0.11	0.88	0.08	0.72	0.07	0.60	0.06
CypressCr_GR_S010	0.93	0.11	0.80	0.08	0.65	0.07	0.53	0.06
Guad_S060	0.92	0.11	0.80	0.08	0.64	0.07	0.53	0.06
BlockCr_S010	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S070	0.93	0.11	0.80	0.08	0.65	0.07	0.54	0.06
JoshuaCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S080	0.92	0.11	0.80	0.08	0.64	0.07	0.53	0.06
SisterCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S090	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
CurryCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S100	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S110	0.94	0.10	0.84	0.07	0.70	0.06	0.59	0.05
Guad_S120	0.85	0.10	0.76	0.07	0.61	0.06	0.50	0.05
CanyonLk_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Blanco_S010	1.06	0.125	0.87	0.095	0.71	0.084	0.58	0.075
Blanco_S020	1.06	0.126	0.88	0.096	0.71	0.084	0.59	0.076
Blanco_S030	1.04	0.123	0.86	0.093	0.7	0.082	0.58	0.073
Blanco_S040	1.03	0.121	0.86	0.091	0.69	0.08	0.57	0.071

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
Blanco_S050	1.02	0.12	0.85	0.09	0.69	0.079	0.57	0.07
LittleBlanco_S010	1.06	0.126	0.88	0.096	0.71	0.084	0.59	0.076
LittleBlanco_S020	1.05	0.125	0.87	0.095	0.71	0.083	0.58	0.075
LittleBlanco_S030	1.02	0.121	0.86	0.091	0.69	0.08	0.57	0.071
LittleBlanco_S040	1.07	0.127	0.88	0.097	0.72	0.085	0.59	0.077
Blanco_S060	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
WanslowCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.086	0.59	0.078
Blanco_S070	1.07	0.127	0.89	0.097	0.72	0.086	0.59	0.077
Blanco_S080	1.07	0.126	0.88	0.096	0.71	0.085	0.59	0.076
CarpersCr_BR_S010	1.09	0.129	0.89	0.099	0.72	0.087	0.6	0.079
Blanco_S090	1.08	0.127	0.89	0.097	0.72	0.086	0.59	0.077
Blanco_S100	1.07	0.127	0.89	0.097	0.72	0.086	0.59	0.077
WilsonCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
Blanco_S110	1.08	0.127	0.89	0.097	0.72	0.086	0.59	0.077
CypressCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
CypressCr_BR_S020	1.09	0.128	0.89	0.098	0.72	0.087	0.59	0.078
CypressCr_BR_S030	1.08	0.128	0.89	0.098	0.72	0.086	0.59	0.078
Blanco_S120	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
Blanco_S130	1.09	0.129	0.89	0.099	0.72	0.087	0.6	0.079
LoneManCr_BR_S010	1.1	0.13	0.9	0.1	0.73	0.088	0.6	0.08
Blanco_S140	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
HalifaxCr_BR_S010	1.05	0.124	0.87	0.094	0.7	0.083	0.58	0.074
Blanco_S150	1.05	0.124	0.87	0.094	0.71	0.083	0.58	0.074
Blanco_S160	1.03	0.122	0.86	0.092	0.7	0.081	0.57	0.072
Blanco_S170	1.1	0.13	0.9	0.1	0.73	0.089	0.6	0.08
SinkCk_S010	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S020	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S030	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S040	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SanMarcos_S005	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SanMarcos_S008	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
PurgatoryCr_S010	0.87	0.1	0.77	0.07	0.61	0.06	0.51	0.05
SanMarcos_S010	0.9	0.11	0.78	0.08	0.63	0.06	0.52	0.06
SanMarcos_S020	0.92	0.11	0.8	0.08	0.64	0.07	0.53	0.06
YorkCr_S010	1.27	0.15	1.14	0.11	0.92	0.09	0.75	0.08
SanMarcos_S030	0.95	0.11	0.81	0.08	0.65	0.07	0.54	0.06
SanMarcos_S040	1	0.12	0.84	0.09	0.68	0.08	0.56	0.07
PlumCr_S010	0.82	0.1	0.76	0.07	0.61	0.06	0.51	0.05
PlumCr_S020	0.85	0.1	0.78	0.08	0.63	0.06	0.52	0.06
TenneyCr_S010	0.92	0.11	0.83	0.09	0.66	0.07	0.55	0.07

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
PlumCr_S030	0.86	0.1	0.79	0.08	0.63	0.07	0.53	0.06
PlumCr_S040	0.92	0.11	0.82	0.08	0.66	0.07	0.55	0.06
SanMarcos_S050	1.01	0.12	0.85	0.09	0.68	0.08	0.57	0.07
DryComalCk_S010	1.07	0.13	0.88	0.10	0.71	0.08	0.59	0.08
DryComalCk_S020	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
WFk_DryComalCk_S010	1.09	0.13	0.89	0.10	0.72	0.09	0.60	0.08
WFk_DryComalCk_S020	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
WF_Trib_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
WF_Trib_S020	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
WFk_DryComalCk_S030	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S030	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
BearCk_S010	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S040	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
DCCk_Trib14_S010	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S050	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
DryComalCk_S060	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
BliedersCk_S010	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
Comal_S010	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
Comal_S020	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Comal_S030	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Guad_S130	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
BearCr_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S140	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S142	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
Guad_S144	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
Guad_Trib22_S010	0.89	0.11	0.78	0.08	0.63	0.06	0.52	0.06
Guad_S145	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
LongCk_S010	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S147	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Guad_Trib20_S010	0.90	0.11	0.78	0.08	0.63	0.07	0.52	0.06
Guad_S149	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
Guad_S152	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
YoungsCk_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
Guad_S154	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
CottonwoodCkS_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S156	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Little_MillCk_S010	0.91	0.11	0.79	0.08	0.64	0.07	0.53	0.06
Guad_S158	0.98	0.12	0.83	0.09	0.68	0.08	0.56	0.07
DeadmanCk_S010	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S160	0.96	0.11	0.82	0.08	0.66	0.07	0.55	0.06

Subbasin Name	50-yr Initial (in)	50-yr Constant (in/hr)	100-yr Initial (in)	100-yr Constant (in/hr)	250-yr Initial (in)	250-yr Constant (in/hr)	500-yr Initial (in)	500-yr Constant (in/hr)
CottonwoodCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Guad_S162	1.06	0.13	0.88	0.10	0.71	0.08	0.58	0.08
AlligatorCk_S010	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
GeronimoCk_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
GeronimoCk_S020	0.87	0.10	0.76	0.07	0.62	0.06	0.51	0.05
GeronimoCk_S030	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
Guad_S164	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
CantauCk_S010	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
Guad_S166	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
MillCk_S010	1.01	0.12	0.86	0.09	0.70	0.07	0.58	0.07
Guad_S168	1.28	0.13	1.09	0.10	0.92	0.09	0.79	0.08
NashCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Guad_S170	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
Guad_S172	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
Guad_S174	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
Guad_S176	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
Guad_S200	1.16	0.11	1.02	0.08	0.86	0.07	0.74	0.06
PeachCr_S010	1.11	0.12	0.94	0.09	0.78	0.08	0.66	0.07
BigFiveMileCr_S010	1.03	0.11	0.89	0.08	0.73	0.07	0.62	0.06
PeachCr_S020	0.97	0.11	0.84	0.08	0.68	0.07	0.57	0.06
SandyFork_S010	1.08	0.13	0.89	0.10	0.73	0.08	0.60	0.08
PeachCr_S030	1.01	0.11	0.87	0.08	0.71	0.07	0.59	0.06
PeachCr_S040	0.95	0.11	0.82	0.08	0.66	0.07	0.54	0.06
Guad_S210	1.02	0.12	0.86	0.09	0.70	0.08	0.57	0.07
McCoyCr_S010	1.03	0.12	0.86	0.09	0.69	0.08	0.57	0.07
Guad_S220	1.67	0.12	1.49	0.09	1.33	0.08	1.21	0.07
SandiesCr_S010	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
ClearForkCr_S010	1.08	0.12	0.91	0.09	0.75	0.08	0.63	0.07
SandiesCr_S020	1.04	0.12	0.87	0.09	0.71	0.08	0.59	0.07
ElmCr_S010	1.05	0.11	0.90	0.08	0.75	0.07	0.63	0.06
SandiesCr_S030	0.97	0.11	0.82	0.08	0.67	0.07	0.55	0.06
SandiesCr_S040	1.10	0.12	0.92	0.09	0.76	0.08	0.63	0.07
Guad_S230	1.17	0.13	0.97	0.10	0.80	0.09	0.67	0.08
Guad_S240	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
SmithCk_S010	1.04	0.12	0.86	0.09	0.70	0.08	0.58	0.07
ThomasCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
SmithCk_S020	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
YorktownCk_S010	1.02	0.12	0.86	0.09	0.69	0.08	0.57	0.07
YorktownCk_S020	1.07	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S010	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
HoosierCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S020	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
EighteenmileCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S030	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
TwelvemileCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
FivemileCk_S010	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
TwelvemileCk_S020	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
ColetoCk_S010	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
ColetoCk_S020	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
PerdidoCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
PerdidoCk_S020	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
PerdidoCk_S030	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
ColetoCk_S030	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
ColetoCk_S040	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
DryCk_S010	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
Guad_S250	0.97	0.12	0.83	0.09	0.67	0.07	0.55	0.07

6.6 POINT RAINFALL DEPTHS FOR THE FREQUENCY STORMS

As discussed in chapter 4, frequency point rainfall depths of various durations and recurrence intervals were collected for the Guadalupe River basin from the 2004 Atlas of Depth Duration Frequency of precipitation for Texas published by the USGS (Asquith, 2004). Different point rainfall tables were used for different portions of the basin. The point rainfall depths above Canyon Dam utilized estimates that were averaged between Kerr and Kendall county estimates. The point rainfall depths for the Blanco River subbasins were taken from a point near Wimberley, Texas. The point rainfall depths for the rest of the San Marcos watershed subbasins were taken from a point near the lower basin's centroid. These also happened to be the same point rainfall depths as were used in the Lower Guadalupe Feasibility Study. For the Guadalupe River below Canyon Dam to the Victoria gage, each subbasin was assigned the precipitation values from the county where the subbasin was located in. The precipitation value assigned to each county was approximately taken from the center of the county. The counties were Comal, Guadalupe, Gonzales, and DeWitt. The point rainfall depths for the Coleto Creek watershed were taken from a point near the centroid of that watershed.

Table 6.22: Frequency Point Rainfall Depths (inches) for the Guadalupe River Basin Above Canyon Dam

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	0.98	1.23	1.48	1.73	2.00	2.28	2.63	2.95
30min	1.40	1.70	2.00	2.30	2.60	2.93	3.33	3.70
1hr	1.80	2.30	2.75	3.30	3.80	4.40	5.20	5.90
2hr	2.20	2.88	3.50	4.23	4.95	5.75	6.90	8.00
3hr	2.40	3.25	3.90	4.80	5.60	6.50	7.80	9.05
6hr	2.80	3.85	4.70	5.70	6.60	7.70	9.10	10.70
12hr	3.20	4.43	5.45	6.60	7.60	8.90	10.45	12.20
24hr	3.60	5.00	6.15	7.50	8.65	10.10	11.75	13.65

Table 6.23: Frequency Point Rainfall Depths (inches) for the Blanco River Basin

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.00	1.24	1.41	1.75	2.00	2.25	2.65	2.95
1hr	1.74	2.30	2.70	3.25	3.80	4.33	5.20	5.90
2hr	2.20	2.90	3.42	4.10	4.80	5.60	6.60	7.60
3hr	2.40	3.18	3.75	4.55	5.30	6.20	7.40	8.60
6hr	2.73	3.67	4.27	5.20	6.10	7.10	8.60	10.00
12hr	3.08	4.10	4.90	6.00	7.00	8.20	10.00	11.90
24 hr	3.70	5.10	6.18	7.60	8.80	10.10	12.10	14.00

Table 6.24: Frequency Point Rainfall Depths (inches) for the San Marcos River Basin

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.07	1.41	1.66	2.02	2.33	2.69	3.23	3.71
1hr	1.83	2.41	2.82	3.41	3.9	4.45	5.29	6.01
2hr	2.3	3.07	3.61	4.39	5.06	5.8	6.94	7.93
3hr	2.41	3.29	3.94	4.87	5.68	6.59	8	9.25
6hr	2.73	3.68	4.38	5.39	6.27	7.27	8.82	10.2
12hr	3.14	4.26	5.08	6.27	7.31	8.49	10.32	11.95
24 hr	3.6	5.1	6.18	7.67	8.9	10.23	12.15	13.75

Table 6.25: Frequency Point Rainfall Depths (inches) for the Comal County Subbasins

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.00	1.25	1.50	1.75	2.05	2.30	2.70	3.00
30min	1.35	1.70	2.00	2.35	2.65	2.95	3.45	3.85
1hr	1.75	2.30	2.65	3.25	3.70	4.20	5.00	5.70
2hr	2.15	2.85	3.35	4.10	4.80	5.50	6.50	7.50
3hr	2.40	3.20	3.75	4.60	5.40	6.30	7.40	8.60
6hr	2.80	3.80	4.50	5.50	6.50	7.50	9.00	10.40
12hr	3.20	4.45	5.30	6.50	7.60	8.80	10.50	12.20
24hr	3.60	5.05	6.10	7.40	8.70	10.20	12.20	14.00

Table 6.26: Frequency Point Rainfall Depths (inches) for Guadalupe County Subbasins

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.10	1.40	1.70	2.00	2.25	2.50	3.10	3.60
30min	1.45	1.85	2.15	2.50	2.80	3.10	3.70	4.25
1hr	1.80	2.35	2.75	3.35	3.80	4.35	5.15	5.90
2hr	2.20	2.95	3.45	4.30	4.85	5.60	6.65	7.60
3hr	2.40	3.30	3.85	4.80	5.45	6.30	7.50	8.60
6hr	2.75	3.80	4.50	5.60	6.50	7.50	9.00	10.30
12hr	3.12	4.40	5.20	6.50	7.50	8.80	10.50	12.00
24hr	3.50	5.00	5.90	7.40	8.60	10.00	12.00	13.70

Table 6.27: Frequency Point Rainfall Depths (inches) for Gonzales County Subbasins

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.05	1.40	1.75	2.10	2.40	2.70	3.20	3.70
30min	1.50	1.90	2.25	2.65	3.00	3.30	3.80	4.25
1hr	1.85	2.40	2.85	3.40	3.90	4.40	5.30	5.90
2hr	2.25	2.90	3.55	4.20	4.95	5.60	6.80	7.65
3hr	2.45	3.25	3.90	4.70	5.55	6.35	7.65	8.70
6hr	2.85	3.75	4.60	5.60	6.60	7.60	9.15	10.40
12hr	3.25	4.30	5.35	6.50	7.65	8.90	10.70	12.10
24hr	3.65	4.85	6.10	7.40	8.70	10.20	12.20	13.80

Table 6.28: Frequency Point Rainfall Depths (inches) for DeWitt County Subbasins

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.15	1.45	1.75	2.05	2.35	2.70	3.05	3.40
30min	1.55	1.95	2.30	2.70	3.05	3.45	3.85	4.25
1hr	1.90	2.45	2.90	3.45	3.95	4.45	5.10	5.70
2hr	2.25	3.00	3.64	4.35	4.90	5.70	6.65	7.60
3hr	2.45	3.30	4.00	4.85	5.55	6.45	7.60	8.70
6hr	2.80	3.85	4.75	5.75	6.60	7.80	9.30	10.60
12hr	3.20	4.50	5.45	6.65	7.70	9.15	11.00	12.50
24hr	3.60	5.05	6.20	7.60	8.80	10.50	12.70	14.30

Table 6.29: Frequency Point Rainfall Depths (inches) for Lavaca County Subbasins

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.10	1.45	1.70	2.00	2.30	2.60	3.00	3.40
30min	1.55	1.95	2.30	2.65	3.00	3.30	3.70	4.10
1hr	1.90	2.45	2.90	3.45	3.95	4.45	5.10	5.70
2hr	2.30	3.05	3.65	4.40	5.00	5.70	6.80	7.80
3hr	2.55	3.40	4.05	4.95	5.70	6.50	7.80	9.10
6hr	2.95	4.00	4.85	5.95	6.90	8.00	9.60	11.20
12hr	3.40	4.70	5.65	7.00	8.20	9.50	11.50	13.30
24hr	3.80	5.30	6.40	7.95	9.40	11.00	13.40	15.30

Table 6.30: Frequency Point Rainfall Depths (inches) for the Coleto Creek watershed

Duration	Recurrence Interval							
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
15min	1.15	1.45	1.73	2.00	2.28	2.58	2.88	3.20
30min	1.55	1.98	2.30	2.70	3.05	3.43	3.83	4.20
1hr	1.90	2.48	2.90	3.43	3.93	4.43	5.05	5.65
2hr	2.25	3.03	3.65	4.33	4.90	5.63	6.55	7.45
3hr	2.45	3.35	4.05	4.85	5.58	6.43	7.55	8.63
6hr	2.83	3.93	4.78	5.80	6.70	7.85	9.35	10.65
12hr	3.23	4.55	5.53	6.78	7.88	9.28	11.15	12.70
24hr	3.63	5.13	6.25	7.75	9.05	10.70	13.00	14.70

All of the above sets of frequency precipitation depths were utilized as point rainfall depths in the frequency storms for the final HEC-HMS rainfall-runoff model. The appropriate point rainfall depth table was assigned to each subbasin within the HEC-HMS frequency storm editor. The final frequency results were then computed in HEC-HMS through the depth-area analysis of the applied frequency storms.

6.7 FREQUENCY STORM RESULTS – UNIFORM RAINFALL METHOD

The frequency flow values were then calculated in HEC-HMS by applying the frequency rainfall depths to the final watershed model through a depth-area analysis. This rainfall pattern is known as the uniform rainfall method because the same rainfall depths are applied uniformly over the entire watershed. The final HEC-HMS frequency flows for significant locations throughout the watershed model can be seen in Table 6.31. These results will later be compared to elliptical shaped storm results from HEC-HMS along with other methods from this study.

In some cases, one may observe that the simulated discharge decreases in the downstream direction. It is not an uncommon phenomenon to see decreasing frequency peak discharges for some river reaches as flood waters spread out into the floodplain and the hydrograph becomes dampened as it moves downstream. This can be due to a combination of peak attenuation due to river routing as well as the difference in timing between the peak of the main stem river versus the runoff from the local tributaries and subbasins.

Table 6.31: Summary of Discharges (cfs) from the HEC-HMS Uniform Rainfall Method with 2004 USGS Rainfall Depths

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
North Fork Guadalupe River near Hunt TX (USGS Gage)	NF_Guad_nr_Hunt	168.2	4500	22200	41700	71400	87100	106600	129100	153100
North Fork Guadalupe River above South Fork Guad River	NF_Guad_abv_SFGuad	189.2	4300	21400	40500	70200	87700	108100	130900	155500
Guadalupe River below South Fork Guad River near Hunt (USGS Gage)	NF_Guad+SF_Guad	286.6	5900	28400	55800	97400	129400	159500	193400	229900
Guadalupe River above Johnson Creek	Guad_abv_JohnsonCr	311.4	5400	26100	52500	92300	123500	153600	186400	222200
Johnson Creek near Ingram TX (USGS Gage)	JohnsonCr_nr_Ingram	113.5	1300	7800	23800	60800	91900	110300	133200	156100
Johnson Creek above Guadalupe River	JohnsonCr_abv_Guad	126.8	1100	8100	25900	62000	93800	113000	136600	160500
Guadalupe River below Johnson Creek	Guad+JohnsonCr	438.1	5400	27300	57600	115100	167900	208800	254300	303500
Guadalupe River at Kerrville (USGS Gage)	Guad_at_Kerrville	485.7	5200	26500	59000	115700	168700	211200	257400	308000
Guadalupe River above Turtle Creek	Guad_abv_TurtleCr	563.8	5600	26100	60800	116200	170200	215300	262800	315200
Guadalupe River below Turtle Creek	Guad+TurtleCr	634.3	9800	35400	73800	129700	187700	237600	290400	348600
Guadalupe River above Verde Creek	Guad_abv_VerdeCr	652.4	8800	32400	70500	126400	183100	232300	284000	341200
Guadalupe River below Verde Creek	Guad+VerdeCr	708.6	10800	37800	75800	131400	190100	242100	296500	356600
Guadalupe River above Cypress Creek	Guad_abv_CypressCr	763.5	10100	35700	72300	126900	183700	236000	289700	349000
Guadalupe River below Cypress Creek at Comfort (USGS Gage)	Guad+CypressCr	837.0	13200	44400	78000	131100	189900	245400	301700	364100
Guadalupe River above Block Creek	Guad_abv_BlockCr	865.1	12300	42100	77100	129900	187600	242400	298100	359800
Guadalupe River below Block Creek	Guad+BlockCr	909.7	13400	44100	78000	130800	188800	244600	301100	363800
Guadalupe River above Joshua Creek	Guad_abv_JoshuaCr	929.7	12500	41300	75800	127500	183800	237900	293100	354400
Guadalupe River below Joshua Creek	Guad+JoshuaCr	971.3	12800	41800	76400	128300	184900	239300	294700	356600
Guadalupe River above Sister Creek	Guad_abv_SisterCr	983.9	12700	41500	76200	127700	183900	238100	293300	354900
Guadalupe River below Sister Creek	Guad+SisterCr	1048.2	14700	42200	77100	128900	185600	240100	295800	357800
Guadalupe River above Curry Creek	Guad_abv_CurryCr	1197.2	12300	37900	69800	114600	165200	214800	265400	321900
Guadalupe River below Curry Creek	Guad+CurryCr	1266.4	12500	38400	70500	115600	166600	216500	267500	324400

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Guadalupe River near Spring Branch TX (USGS Gage)	Guad_nr_Springbranch	1313.7	12600	38400	70300	114900	165600	215000	265600	322100
Guadalupe River above Canyon Lake	Guad_abv_CanyonLk	1360.0	12600	38500	70300	114500	165100	214300	264800	321100
Peak Inflow into Canyon Lake	Canyon_Inflow	1431.1	16200	39100	71100	115600	166300	215900	266700	323300
	NOTE: The below Drainage Areas for the Guadalupe River do not include the area above Canyon Dam.									
Guadalupe River above Bear Creek	Guad_abv_BearCr	36.0	7,100	14,600	20,500	28,100	34,800	40,100	48,000	56,000
Bear Creek above Guadalupe River	BearCr_S010	16.7	3,900	7,900	10,900	14,800	18,100	20,900	25,000	29,100
Guadalupe River below Bear Creek	Guad+BearCr	52.8	10,000	21,000	29,500	40,400	50,000	57,800	69,100	80,600
Guadalupe River above the Comal River (USGS Gage)	Guad_abv_Comal	88.3	7,400	20,100	31,500	47,000	61,200	71,000	85,800	100,100
Dry Comal Creek below the Wests Fork	DryComalCk+WFk	54.0	700	1,900	2,700	3,800	4,800	10,400	17,600	23,700
Dry Comal Creek above Bear Creek	DryComalCk_abv_BearCk	55.4	600	1,800	2,900	4,300	5,500	10,300	17,400	23,400
Dry Comal Creek below Bear Creek	DryComalCk+BearCk	68.7	700	1,900	2,900	4,300	5,500	10,800	18,500	25,200
Dry Comal Creek above Tributary 14	DryComalCk_abv_Trib14	89.0	2,000	5,200	8,200	12,300	15,500	19,100	25,200	31,600
Dry Comal Creek below Tributary 14	DryComalCk+DCCk_Trib14	94.7	2,400	6,300	9,400	13,700	16,900	20,600	26,700	34,800
Dry Comal Creek at Loop 337 near New Braunfels (USGS Gage)	DryComalCk_J020	107.3	2,500	6,500	10,300	15,500	19,500	24,000	30,000	37,000
Dry Comal Creek above Comal Rivr	DryComalCk_abv_Comal	111.2	2,200	6,200	9,900	15,200	19,200	23,700	29,600	36,100
Comal River below Dry Comal Creek	Comal+DryComalCk	128.3	2,900	7,500	11,900	18,100	23,400	29,800	38,400	47,100
Comal River at New Braunfels (USGS Gage)	Comal_at_New_Braunfels	129.5	2,900	7,500	11,900	18,100	23,400	29,900	38,500	47,200
Comal River above Guadalupe River	Comal_abv_Guad	130.1	2,900	7,500	11,900	18,100	23,500	29,900	38,600	47,300
Guadalupe River below the Comal River	Guad+Comal	218.4	9,000	25,300	40,500	61,500	79,600	94,600	116,100	136,700
Guadalupe River at Lake Dunlap	Lake_Dunlap	233.4	9,500	25,600	39,200	56,800	73,100	86,400	105,900	126,800
Guadaulupe River above Tributary 22	Guad_abv_Trib22	234.1	9,400	25,500	39,100	56,700	73,000	86,400	105,800	126,800
Guadaulupe River below Tributary 22	Guad+Trib22	238.6	9,500	25,700	39,400	57,300	73,700	87,300	107,100	128,200
Guadalupe River above Long Creek	Guad_abv_LongCk	239.6	9,300	24,800	38,400	56,000	72,200	85,700	105,300	126,200
Guadaupe River below Long Creek	Guad+LongCk	251.1	9,700	26,000	40,300	58,700	75,500	90,000	110,600	132,300

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Guadalupe River above Tributary 20	Guad_abv_Trib20	251.5	9,700	25,900	40,100	58,400	75,100	89,300	109,600	131,100
Guadaupe River below Tributary 20	Guad+Trib20	260.4	9,800	26,300	40,800	59,600	76,500	91,300	112,000	133,900
Guadalupe River at Lake McQueeney	Lake_McQueeney	264.0	9,800	26,100	39,700	56,400	71,700	84,500	105,300	126,100
Guadalupe River above Youngs Creek	Guad_abv_YoungsCk	264.7	9,800	26,000	39,600	56,400	71,600	84,500	105,300	126,000
Guadalupe River below Youngs Creek	Guad+YoungsCk	279.4	10,000	26,500	40,300	57,400	73,000	86,400	107,700	129,000
Guadalupe River above the smaller Cottonwood Ck	Guad_abv_CottonwoodCkS	279.7	10,000	26,500	40,300	57,400	72,900	86,400	107,700	129,000
Guadalupe River below the smaller Cottonwood Ck	Guad+CottonwoodCkS	285.7	10,100	26,700	40,500	57,800	73,400	87,200	108,700	130,100
Guadalupe River above Little Mill Ck	Guad_abv_LittleMillCk	286.3	10,100	26,500	40,100	57,500	73,100	86,800	107,900	129,200
Guadalupe River below Little Mill Ck	Guad+LittleMillCk	295.0	10,200	26,900	40,600	58,200	74,000	88,100	109,500	131,100
Guadalupe Rivere above Deadman Ck	Guad_abv_DeadmanCk	296.4	10,200	26,800	40,200	57,700	73,300	87,500	108,900	130,300
Guadalupe River below Deadman Ck	Guad+DeadmanCk	304.9	10,700	27,000	40,400	58,000	73,600	88,100	109,900	131,500
Guadalupe River at Lake Placid	Lake_Placid	304.9	10,700	26,900	40,200	57,700	73,400	88,000	109,800	131,400
Guadalupe River at Meadow Lake	Meadow_Lake	327.2	11,700	28,100	39,700	55,500	70,100	84,500	106,500	127,900
Guadalupe River above Cottonwood Ck	Guad_abv_CottonwoodCk	327.2	11,700	28,100	39,700	55,500	70,100	84,500	106,500	127,900
Guadalupe River below Cottonwood Ck	Guad+CottonwoodCk	368.3	12,300	32,500	45,200	62,100	76,400	93,100	118,200	142,100
Guadalupe River above Geronimo Ck	Guad_abv_GeronimoCk	369.5	11,900	31,800	44,800	61,600	76,200	92,600	117,200	140,900
Geronimo Ck at I-10 near Seguin	GeronimoCk_J020	59.7	4,500	11,200	15,200	21,000	25,500	31,400	39,000	45,800
Geronimo Ck above Guadalupe River	GeronimoCk_abv_Guad	69.7	2,900	8,200	11,900	17,700	22,800	30,200	37,900	44,700
Guadalupe River below Geronimo Ck	Guad+GeronimoCk	439.2	14,200	38,500	54,200	74,700	90,900	109,100	136,200	164,000
Guadalupe River above Cantau Ck	Guad_abv_CantauCk	443.5	13,300	36,600	52,900	73,600	90,000	108,700	135,700	163,100
Guadalupe River at FM 1117 near Seguin	Guad_nr_Seguin	450.1	13,300	36,800	53,100	74,000	90,500	109,200	136,300	163,900
Guadalupe River above Mill Ck	Guad_abv_MillCk	481.8	10,600	31,200	48,600	70,800	88,900	109,500	137,400	165,300
Guadalupe River below Mill Ck	Guad+MillCk	521.2	11,000	32,800	51,100	75,000	94,500	117,500	147,400	176,700
Guadalupe River above Nash Creek	Guad_abv_NashCk	553.7	8,300	29,100	47,500	72,100	92,100	116,400	147,800	178,800
Guadalupe River below Nash Creek	Guad+NashCk	580.2	8,300	29,300	48,000	72,900	93,200	118,400	150,900	183,000

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Guadalupe River at Lake Gonzales	Lake_Gonzales	615.9	7,500	25,300	42,500	69,100	91,600	119,300	154,200	188,800
Guadalupe River at Wood Lake	Wood_Lake	667.4	7,000	21,100	34,400	58,700	83,400	110,700	147,300	184,100
Guadalupe River above the San Marcos River	Guad_J340	671.8	6,600	18,700	31,900	56,000	80,000	108,100	145,300	180,200
Blanco River below Little Blanco	Blanco+LittleBlanco	237.8	9,100	31,800	51,900	86,500	111,800	141,300	178,700	213,300
Blanco River at Wimberley (USGS Gage)	Blanco+CypressCr	355.1	8,900	31,000	51,600	88,600	116,600	152,600	196,800	238,500
Blanco River near Kyle (USGS Gage)	Blanco_nr_Kyle_Gage	412.3	8,600	30,300	50,700	88,100	116,300	153,900	199,300	244,900
Blanco River above San Marcos River	Blanco_abv_SanMarcos	436.2	7,900	28,300	46,000	79,000	106,300	142,900	188,300	232,800
Below SCS Dam No. 5	SCS Dam No. 5	37.1	800	2,900	6,700	11,800	15,800	20,300	26,000	30,700
San Marcos River at San Marcos (USGS Gage)	SanMarcos_at_SanMarcos	49.0	310	1,380	2,530	4,100	5,160	7,860	14,800	21,100
San Marcos River below Purgatory Cr	SanMarcos+Purgatory	87.1	950	2,720	6,640	12,000	17,200	23,100	31,400	40,300
San Marcos River above Blanco River	SanMarcos_J020	95.1	2,640	5,210	7,000	11,800	17,200	23,500	32,300	40,900
San Marcos River below Blanco River	SanMarcos+Blanco	531.3	8,800	29,900	48,500	82,400	110,500	153,600	205,500	255,900
San Marcos River above York Creek	SanMarcos_J040	613.6	8,400	27,600	45,800	75,900	100,200	136,500	182,200	237,900
York Creek above San Marcos River	YorkCr_S010	142.9	3,600	12,000	18,000	27,400	35,400	45,500	58,900	70,000
San Marcos River below York Creek	SanMarcos+YorkCr	756.6	8,800	29,400	49,000	80,100	105,500	144,100	194,000	257,100
San Marcos River at Luling (USGS Gage)	SanMarcos_at_Luling	838.9	10,400	28,300	47,400	78,400	103,900	142,400	193,100	253,100
San Marcos River above Plum Creek	SanMarcos_J070	861.8	10,100	27,300	44,800	74,200	100,600	138,300	185,400	241,300
Plum Creek at Lockhart (USGS Gage)	PlumCr_at_Lockhart	111.3	3,830	12,200	20,600	32,200	39,800	48,900	60,900	71,600
Plum Creek above Tenney Creek	PlumCr_J020	194.6	5,700	13,900	18,800	26,200	39,200	53,900	74,400	91,400
Plum Creek below Tenney Creek	PlumCr+TenneyCr	234.4	7,500	19,700	27,100	37,600	46,200	61,000	85,400	105,600
Plum Creek near Luling (USGS Gage)	PlumCr_nr_Luling	351.5	6,600	17,700	29,600	45,900	60,600	78,600	106,300	132,100
Plum Creek above San Marcos River	PlumCr_J050	388.8	6,800	18,300	30,600	47,200	62,300	80,700	108,900	135,100
San Marcos River below Plum Creek	SanMarcos+PlumCr	1250.6	16,700	42,600	65,900	101,700	139,100	189,200	252,300	331,700

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
San Marcos River above the Guadalupe River	SanMarcos_J090	1359.0	13,900	38,000	56,700	91,000	128,000	178,200	239,700	304,600
Guadalupe River below the San Marcos River at Gonzales (USGS Gage)	Guad+SanMarcos	2030.8	18,700	49,900	83,100	149,300	210,200	285,700	385,000	471,300
Guadalupe River above Peach Creek	Guad_J360	2100.3	16,800	48,100	80,200	143,500	203,400	280,500	380,000	467,900
Peach Creek below Dilworth	PeachCr_bl_Dilworth	459.8	5,500	14,000	23,800	37,300	52,100	72,000	96,000	113,100
Peach Creek above the Guadalupe River	PeachCr_J060	482.5	5,400	13,500	22,300	36,100	50,700	70,500	94,200	112,300
Guadalupe River below Peach Creek	Guad+PeachCr	2582.8	17,800	53,100	91,700	167,000	234,200	326,900	447,600	554,700
Guadalupe River above McCoy Ck	Guad_J380	2705.2	16,700	51,200	88,200	159,900	227,300	318,400	438,800	543,400
Guadalupe River below McCoy Ck	Guad+McCoyCr	2737.8	16,700	51,400	88,500	160,400	227,900	319,200	439,800	544,500
Guadalupe River above Sandies Ck	Guad_J400	2786.2	16,500	49,000	83,200	149,700	215,800	306,800	429,600	536,400
Sandies Ck near Westhof (USGS Gage)	SandiesCr_nr_Westhof	549.4	6,600	13,800	22,500	35,800	50,800	71,700	96,600	116,600
Sandies Ck above the Guadalupe River	SandiesCk_abv_Guad	711.1	5,800	12,400	20,900	33,700	47,900	68,500	94,000	120,400
Guadalupe River below Sandies Ck at Cuero (USGS Gage)	Guad+SandiesCr	3497.4	17,000	54,200	96,200	174,100	253,900	367,000	518,500	642,500
Guadalupe River at Victoria (USGS Gage)	Guad_at_Victoria	3767.1	17,000	50,400	86,100	157,900	234,900	346,400	495,600	623,800
Guadalupe River above Coleto Creek	Guad_abv_ColetoCk	3802.7	16,500	50,300	85,400	154,100	232,700	337,900	483,300	618,200
Fifteenmile Ck near Weser (USGS Gage)	FifteenmileCk_WeserTX	164.5	2,400	7,800	12,900	22,200	28,600	37,800	48,700	57,000
Fifteenmile Ck above Eighteenmile Ck	FifteenmlCk_abv_EighteenmlCk	182.5	2,300	7,600	12,500	21,500	27,800	36,800	47,600	55,800
Eighteenmile Ck above Fifteenmile Ck	EighteenmileCk_S010	48.0	3,800	7,400	10,000	13,300	16,700	21,200	26,600	30,700
Fifteenmile Ck below Eighteenmile Ck	FifteenmileCk+EighteenmileCk	230.5	5,200	11,500	16,600	24,100	30,900	40,100	51,400	60,000
Fifteenmile Ck above Twelvemile Ck	FifteenmlCk_abv_TwelvemlCk	250.3	6,700	14,600	20,700	29,400	37,600	48,400	61,500	71,800
Twelvemile Ck above Fifteenmile Ck	TwelvemlCk_abv_FifteenmlCk	105.9	5,000	10,100	13,900	19,000	24,400	31,800	40,400	47,400
Coleto Creek at Arnold Rd nr Schroeder (USGS Gage)	ColetoCkAtArnoldRdCrsg	356.2	8,800	19,200	27,400	39,300	51,000	67,500	87,200	102,600
Coleto Creek above Perdido Ck	ColetoCk+ColetoCk	417.7	10,400	24,400	35,800	51,000	65,600	85,000	108,100	126,900

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Perdido Ck at FM 622 nr Fannin (USGS Gage)	PerdidoCkAtFM622_FanninTX	27.7	3,200	8,600	12,700	19,800	23,700	28,300	34,000	38,900
Perdido Ck below Road Ck	PerdidoCk_J020	55.2	3,600	9,600	14,900	23,200	28,600	35,500	43,900	51,000
Perdido Ck above Coleto Ck	PerdidoCk_abv_ColetoCk	76.3	4,900	12,400	19,600	29,800	36,900	45,900	56,800	65,900
Coleto Creek Reservoir near Victoria	ColetoCkRes_VictoriaTX	494.1	10,800	27,400	41,400	59,400	76,100	99,000	126,000	147,600
Coleto Creek near Victoria (USGS Gage)	ColetoCk_VictoriaTX	511.3	10,800	27,300	41,400	59,400	76,100	99,300	126,900	148,700
Coleto Creek above Guadalupe River	ColetoCk_abv_Guadalupe	540.4	8,000	22,600	36,700	55,500	72,400	97,500	125,000	148,900
Guadalupe River near Bloomington (USGS Gage)	GuadalupeRv_BloomingtonTX	4382.5	16,200	50,700	86,200	154,800	234,100	342,200	491,200	630,200

7 Elliptical Frequency Storms in HEC-HMS

7.1 INTRODUCTION TO ELLIPTICAL STORMS

Observations of actual storm events show that average precipitation intensity decreases as the area of a storm increases. The uniform rainfall method results in Chapter 6 use the depth-area analysis in HEC-HMS to produce frequency peak flow estimates. The depth-area analysis in HEC-HMS applies the appropriate depth-area reduction factor to the given point rainfall depths based on the drainage area at a given evaluation point, which are derived from the published depth-area reduction factors from Figure 15 of the National Weather Service TP-40 publication (Herschfield, 1961), as shown in the figure below.

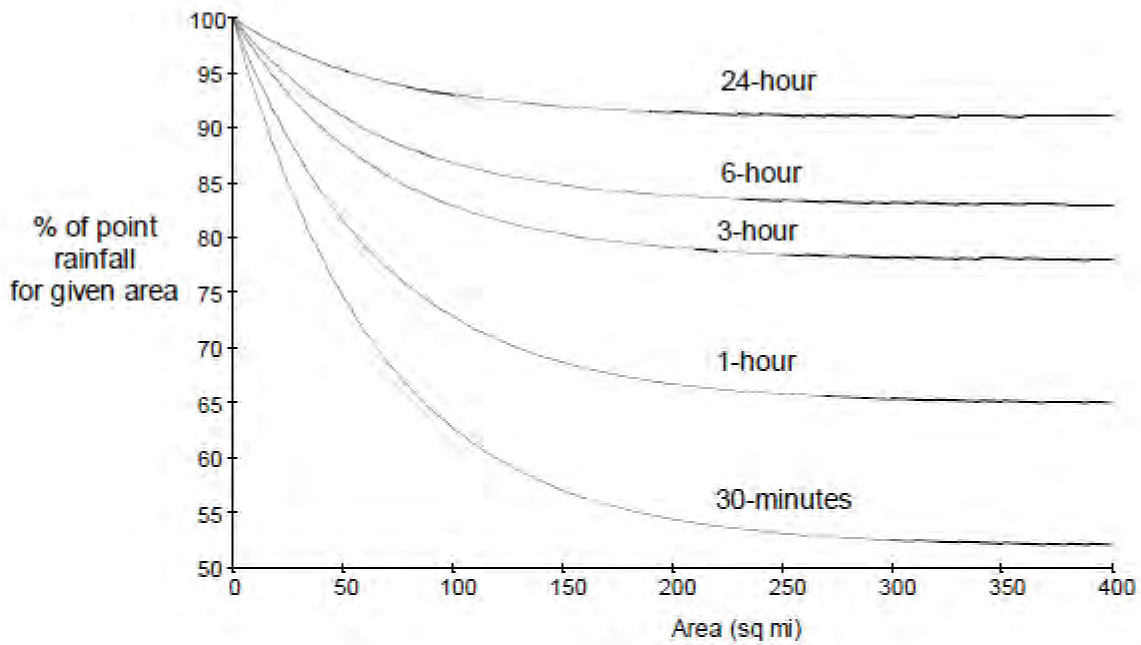


Figure 7.1: Published Depth-Area Reduction Curves from TP-40

When evaluating a point with a drainage area greater than 400 square miles, the HEC-HMS software issues a warning that the NWS depth-area reduction factors do not support storms beyond 400 square miles, as shown in the figure above. The program will still calculate the peak discharge, but the warning implies that the calculated volume of the storm may not be appropriate for larger drainage areas.

Since the Guadalupe hydrology study involves calculating frequency discharges for points with up to several thousand square miles of drainage area, the InFRM team performed a sensitivity analysis of the uniform rainfall volume using elliptical frequency storms for points with drainage areas greater than 400 square miles. In these elliptical frequency storms, the same point rainfall depths and durations were applied as in the uniform rainfall method of Chapter 6, but the spatial distribution of the rainfall varied in an elliptical shaped pattern.

Elliptical shaped storms have been used in a variety of hypothetical design applications, including the Probable Maximum Precipitation (PMP) storms from Hydrometeorlogical Report No 52 (HMR 52) (Hansen, 1982). The elliptical frequency storms constructed for this study are similar to those of HMR 52 in that concentric ellipses are used to construct the storm's spatial pattern, and the storm's location is optimized over the watershed by specifying the location of its center and the angle of its major axis. Figure 7.2 shows an example of an elliptical 1% annual chance (100-yr) storm that was centered over the watershed above the Guadalupe River at Victoria.

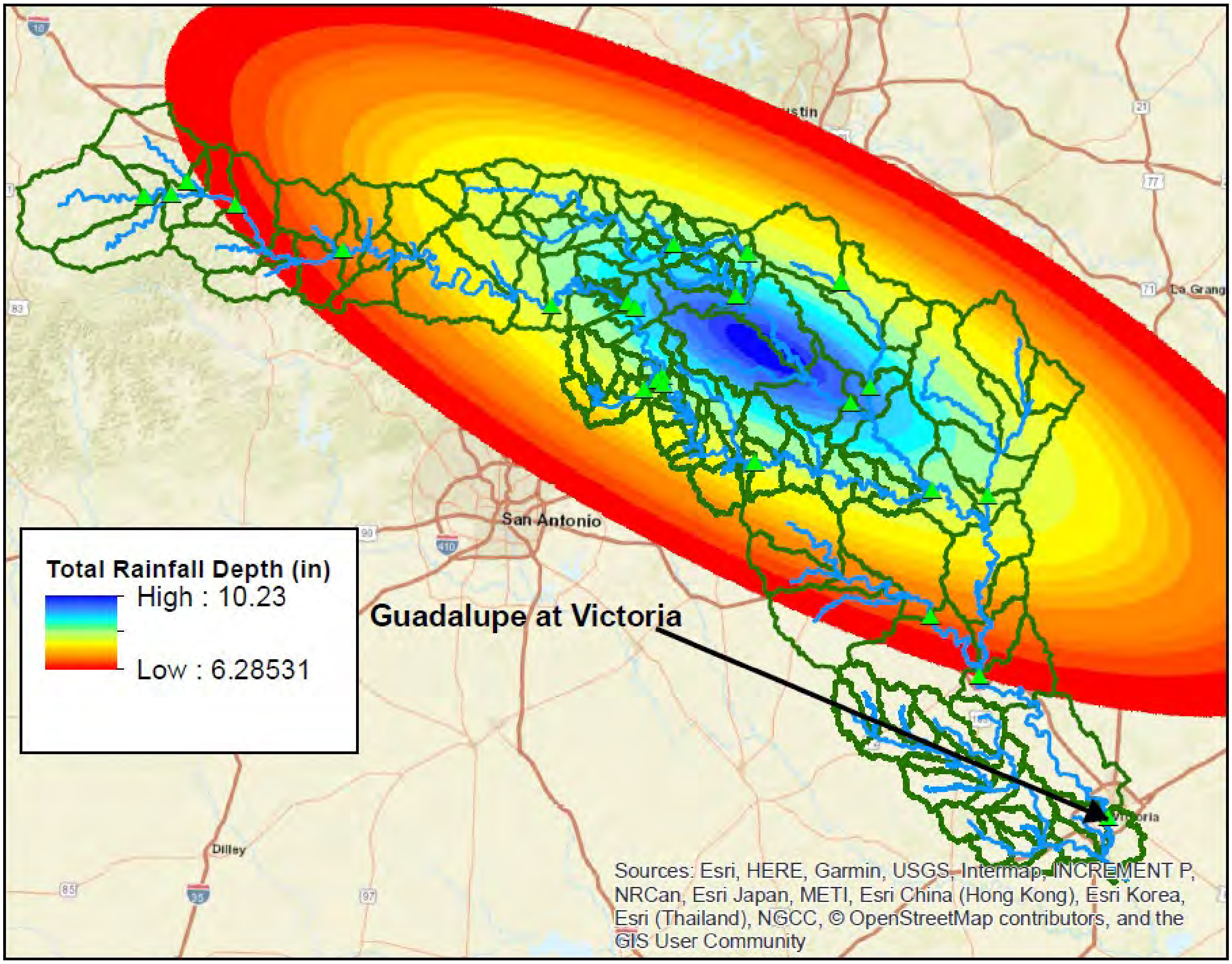


Figure 7.2: Example 1% ACE (100-yr) Elliptical Frequency Storm

7.2 ELLIPTICAL STORM PARAMETERS

7.2.1 Elliptical Storm Area

This study uses a storm extent of 10,000 square miles. This is due to the historical rainfall studies rarely including data beyond 10,000 square miles (War Dept. Storm Catalog 1967). While this extent is somewhat arbitrary, testing was done to limit the storm extent to 3,000 square miles and the resulting peak discharges were slightly reduced. However the reduction in peak discharge was not significant because some of the rainfall beyond 3,000 square miles was falling outside the watershed and therefore not contributing to the runoff. Since there is no guidance or research on the subject, the storm extent of 10,000 square miles was used in this study.

7.2.2 Elliptical Storm Rainfall Depths
Elliptical storms were designed for each of the following annual chance exceedance (ACE): 1 in 2 years, 1 in 5 years, 1 in 10 years, 1 in 25 years, 1 in 50 years, 1 in 100 years, 1 in 250 years and 1 in 500 years. Point rainfall depths and durations were applied from the 2004 Atlas of Depth Duration Frequency of precipitation for Texas (Asquith, 2004). The elliptical storms used the same point rainfall tables as were applied in the uniform rainfall method. A full listing of the applied point rainfall depth tables for the Guadalupe River Basin is shown in Section 6.6. The point precipitation values were that applied to each elliptical storm were based on the storm center's location, not the location of the outlet of interest. For example, in Figure 7.2, since the storm center for the Guadalupe River at Victoria was located in the San Marcos River basin, then the point rainfall values for the San Marcos watershed would be applied, rather than the point rainfall tables for Victoria, Texas.

7.2.3 Storm Ellipse Ratio
The HMR-52 study presents the option to design a storm with an ellipse ratio ranging from 2:1 to 3:1. For the Guadalupe basin, the 3:1 ellipse was used, as it better matched the long and thin basin shape. Testing 2:1 ratio ellipses yielded smaller peak discharges due to more precipitation falling outside the watershed boundary and therefore not contributing to runoff in the Guadalupe River.

7.2.4 Storm Temporal Pattern / Hyetograph
Historically, storms have varying intensities and temporal distributions and many studies have been done to document storm patterns. The six storm temporal distributions that were tested for this study are shown in Figure 7.3. The Soil Conservation Service (1986) documented different distributions for the United States, and Type II is the distribution applicable to Texas and was tested for this study. Other distributions were also tested, including the Frequency Rainfall Distributions from HEC-HMS with the storm centroid occurring at the 25%, 33%, 50%, 67% and 75% of the total distribution. The HEC-HMS Frequency Rainfall Distributions maintain the appropriate storm intensity throughout the storm. In other words, the 100 year, 1 hour rainfall is maintained with the 100 year, 3 hour rainfall and so on all the way through the 100 year, 24 hour rainfall.

While the varying the temporal pattern of the storm did have a small effect on the peak discharge, the difference was generally less than 5%. The 50% storm distribution was selected for this study due to its simplicity and maintaining the proper intensity throughout the storm period. This is also consistent with the temporal distribution used for the uniform rain method.

Testing was done for shorter and longer storm durations. However, it was found that shorter storm durations produced lower peak discharges due to not all the watershed contributing and longer storm durations did not add much additional flow to the peak as compared with the 24 hour. It is expected that the optimum storm duration would change depending on the watershed size being studied. For this study, the 24 hour storm duration was used throughout the watershed.

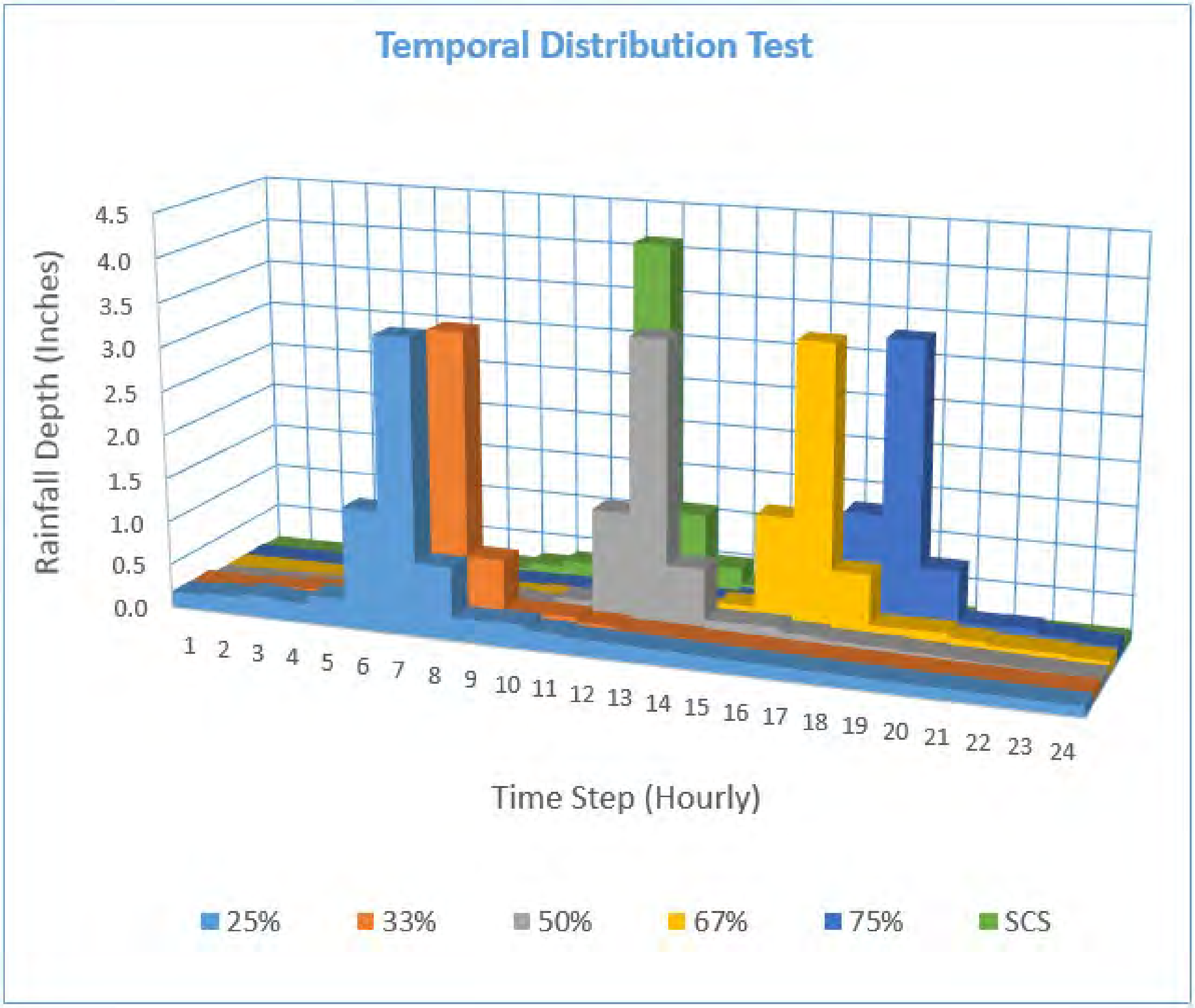


Figure 7.3: Tested Storm Temporal Distributions

7.2.5 Storm Depth Area Reduction Factors

The term depth area reduction factor refers to storm that has been spatially normalized to a unit depth at the storm center. Thus the remainder of the storm is a percentage of the storm center. A depth area duration table is a way to track the volume of the storm. All storms have varying spatial and temporal patterns and this affects the depth area duration table of the storm.

For the elliptical frequency storms, the storm duration, shape, temporal pattern and rainfall depth at the center have all been determined. All that is left is to apply is a depth area reduction curve (set of factors) to the storm to find the depths at each ellipse. An example of a depth area reduction curve applied to an elliptical storm is shown in Figure 7.4.

A large amount of research and analysis went into the determination of the appropriate depth area reduction curve for this study. A previous study of elliptical storms had been done by USACE in 2012 for the Dallas Floodway Extension project. This effort analyzed over 100 storms across Texas, Oklahoma, Arkansas and Louisiana. This curve is shown in red in Figure 7.5. For this study several other storms more local to the Guadalupe watershed were analyzed, and 3 examples of these events are shown in yellow, grey and green. To update the 2012 Corps study, this effort added the more recent and local events to the database and obtained a new depth area reduction curve shown in blue. The blue curve was adopted for this study and is tabulated in Table 7.1.

Rainfall Depth	Area of Ellipse	Depth Area Reduction Factor
10.0"	0 Sq. Mi.	100%
9.6"	10 Sq. Mi.	96%
9.2"	50 Sq. Mi.	92%
8.4"	100 Sq. Mi.	84%
7.5"	400 Sq. Mi.	75%
6.3"	800 Sq. Mi.	63%
5.0"	1,200 Sq. Mi.	50%

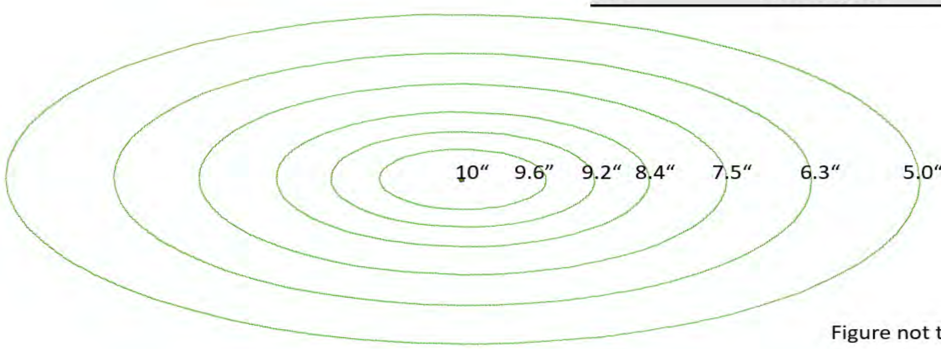


Figure not to scale. Only for demonstration.

Figure 7.4: Example of a Depth Area Reduction Curve Applied to an Elliptical Storm

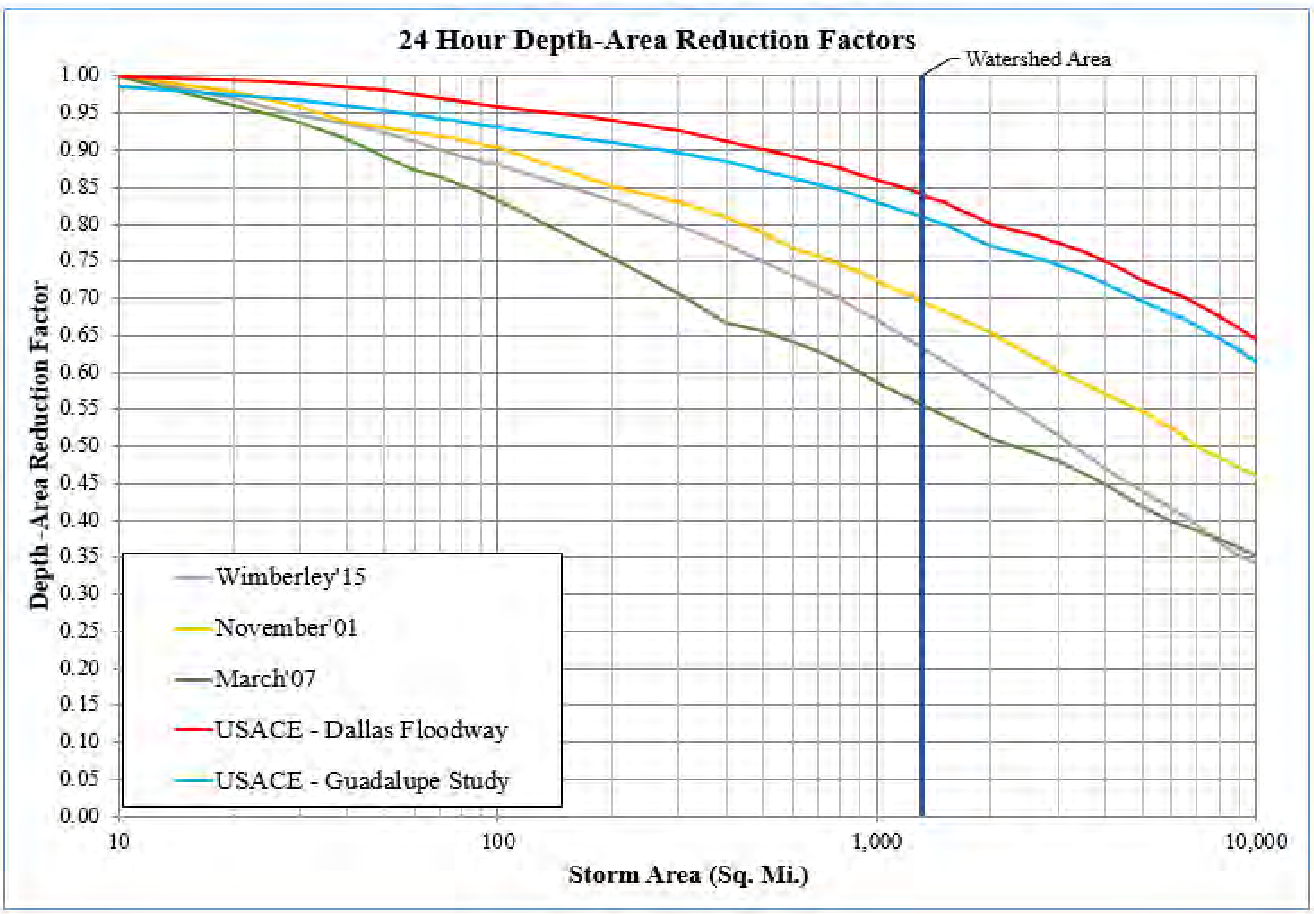


Figure 7.5: Storm Depth Area Reduction Curves

Table 7.1: Adopted Depth Area Reduction Factors

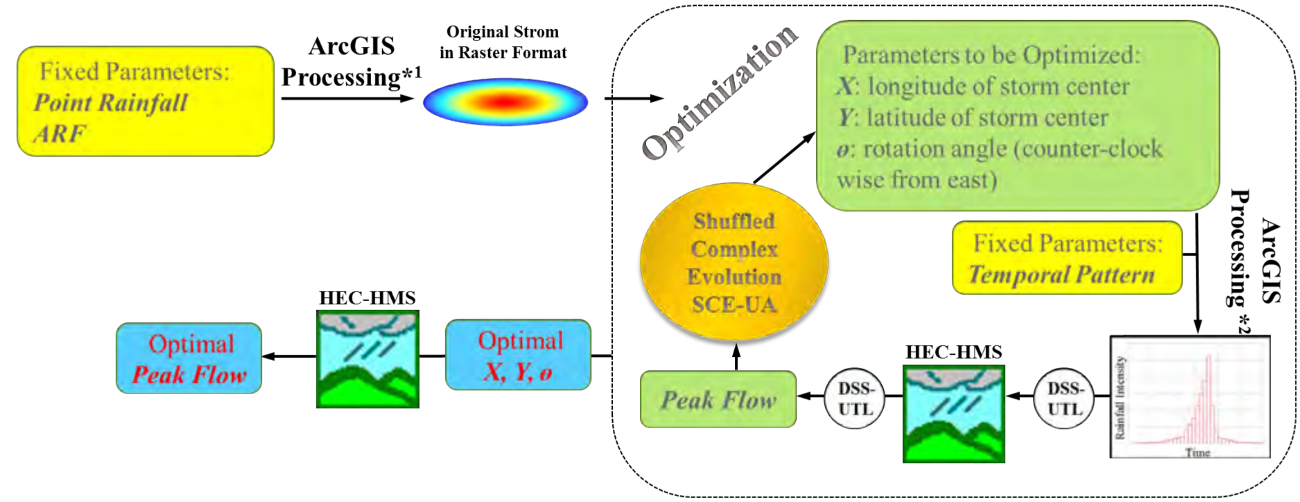
Storm Area in Square Miles	Depth Area Reduction Factor
1	1
10	0.987
30	0.967
50	0.953
100	0.93
200	0.9111
300	0.8976
400	0.884
600	0.8624
800	0.8462
1000	0.83
1500	0.8
2000	0.7701
2667	0.7535
3500	0.7328
4000	0.7204
4500	0.7079
5000	0.6955
6000	0.6793
6500	0.6712
7000	0.6631
8000	0.6468
9000	0.6306
10000	0.6144

7.3 OPTIMIZATION OF THE STORM CENTER LOCATION

For this study, a script was developed for the InFRM team that automatically locates optimal centering locations (x and y) and rotations (ɵ) of (spatially varied) elliptical frequency storms for a list of receiving junctions in a watershed. The script was expected to obtain the combination of the three parameters (x, y, and ɵ) that maximized peak flow at desired junctions while achieving the following objectives:

- To complete the task efficiently.
- To allow users to customize the scripts easily based on their needs.
- To generate reasonable results that can be validated manually.
- To outperform manual gird search method in terms of precision, accuracy and efficiency.
- To function normally on any machine at USCAE with the available software and hardware.

Figure 7.6 illustrates the schematic flow of the storm optimization. The scheme begins with creating a spatially varied design storm in raster format using ArcGIS. Given the point rainfall (total rainfall at the storm centroid) and the areal reduction factor (ARF), a storm raster is digitized by creating a series of concentric ellipses and then converting them to raster format. An optimization stage is followed including two major components: 1) automatic simulation of HEC-HMS model and 2) parameter update/optimization. In each iteration of the optimization process, the storm raster is first shifted and rotated due to updated parameters (x, y, and ɵ); and then allocated into each subbasin as mean areal precipitation (MAP); the time series MAP values, i.e. the hyetographs, are stored in the DSS format and transmitted to the HMS model for simulations; after each simulation, and the corresponding peak flow values at desired junctions are extracted from DSS files. Based on the extracted peak flow values, an optimization algorithm will update the parameters (x, y and ɵ) and then optimization proceeds into the next iteration.



*1. involves creating ellipse polygons and converting polygon to raster.
*2. involves shifting raster, rotating raster and calculating zonal statistics (for MAP).

Figure 7.6: Schematic Flowchart for the Storm Opimization Script

Originally, the scripts were designed to automate a grid search, where all possible combinations of parameters (i.e. the 'grids') are exhaustively tested and the optimal combination of the three parameters (x, y, and ɵ) can then be obtained. Although the approach of grid search seems straightforward, it does suffer from high computational cost because the computational run time depends on the number of grids, which is further constrained by the range and the interval of each parameter. Given the need of maintaining a certain level of precision or keeping constant intervals of the parameters, the UTA team found the grid search might not be appropriate for this project since the computational run time was excessively lengthy – it increases exponentially with greater drainage area (more possible x and y values).

In order to overcome this issue, the UTA team selected a global optimization (GO) algorithm entitled shuffled complex evolution (SCE) (Duan et al., 1993) - a random sampling approach. Instead of exhausting all possible grids, the random sampling approach tests the objective function around some sampled grids in an iteration while learning about the structure of the objective function for improving the sampling of grids in the next iteration. More details about global optimization (GO) and SCE are included in the following sections.

7.3.1 Global Optimization

The objective of global optimization (GO) is to find the best solution of (possibly nonlinear) models globally, in the (possible or known) presence of multiple local optima. As an example, Figure 7.7 shows a 3-D plot of a continuous objective function of two bounded parameters x and y. Suppose the goal is to locate the minimal value globally instead of just locally (Note there are many local minimal values but with only one global minimum value in the chart), a global search in the two-dimensional box region is needed. The theory of GO has been applied to many engineering problems like model calibrations and optimal operations of “black-box” system. The storm optimization here is essentially a constrained GO problem, where the objective is to seek the combination of storm centering locations and rotations yielding the maximal peak flow within the constraints of the possible parameter values.

The level of difficulty in solving a GO problem depends on several major characteristics of the objective function. First, there may be multiple local minima in the parameter space. As illustrated in Figure 7.7, the search of global minimum can be easily “trapped” in the “valleys” of the objective function, depending on the starting point of the search. Second, the objective function in the parameter space may not be smooth or even continuous. In addition, the parameters may exhibit varying degrees of highly nonlinear interaction. In order to deal with these difficulties, the UTA team employed the shuffled complex evolution (SCE) algorithm (see the following section), which promises to be effective and efficient for the storm optimization task.

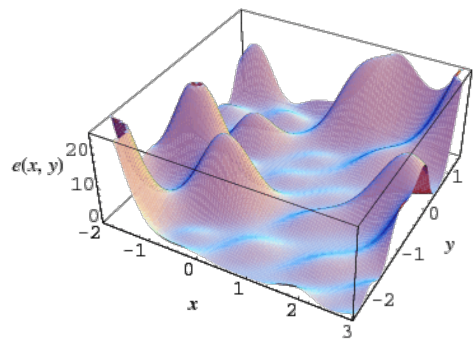


Figure 7.7: Example of a Global Optimization Problem

7.3.2 Shuffled Complex Evolution

The shuffled complex evolution (SCE) works on the basis of four concepts: (1) combination of deterministic and probabilistic approaches; (2) systematic evolution of a complex of grids; (3) competitive evolution; and (4) complex shuffling. The algorithm begins with a randomly selected population of grids from the parameter space. The grids are sorted ascendingly so that the first point represents the smallest value of the objective function and the last point represents the largest. The initial population generated randomly is first partitioned into several complexes. Each complex is allowed to evolve independently to search the parameter space in different dimensions; and each individual grid in a complex has the potential to participate in the process of reproducing new grids. From each complex, some grids are selected to form a sub-complex, where the modified Nelder and Mead Simplex Method (NMSM) (Nelder and Mead, 1965) is applied for global improvement. The grids of higher fitness values have higher chance of getting selected to generate offspring. The NMSM performs reflection and inside contraction step to get a better fit grid. This new offspring then replaces the grid with the worst performance in the simplex. The grids in the evolved complexes are then pooled together and sorted again, shuffled, and finally reassigned to new complexes to enable information sharing. This process is repeated until some convergence criteria are satisfied.

7.4 ELLIPTICAL FREQUENCY STORM LOCATIONS

The final optimized storm center locations (x, y) and rotations (ɵ) for every node of interest in the Guadalupe watershed are listed in Table 7.2. Once the optimum storm center location and rotation was determined for each location of interest, the elliptical frequency storms for the standard eight frequency events were constructed using the appropriate point rainfall depths for the storm center location from Section 6.6 of this report. The final 1% annual chance (100-yr) elliptical frequency storms for selected gage locations in the Guadalupe watershed are illustrated in Figures 7.8 to 7.16.

Table 7.2: Optimized Elliptical Storm Center Locations and Rotations for Each Model Junction

Location Description	HEC-HMS Element Name	Drainage Area (sq mi)	Longitude (X)	Latitude (Y)	Rotation of Major Axis (Theta)
Guadalupe River below Johnson Creek	GUAD+JOHNSONCR	438.14	-99.39210	30.08146	50.03
Guadalupe River at Kerrville (USGS Gage)	GUAD_AT_KERRVILLE	485.67	-99.39575	30.09904	29.99
Guadalupe River above Turtle Ck	GUAD_ABV_TURTLECR	563.83	-99.36501	30.07867	177.21
Guadalupe River below Turtle Ck	GUAD+TURTLECR	634.31	-99.27117	30.09108	169.35
Guadalupe River above Verde Creek	GUAD_ABV_VERDECR	652.44	-99.24461	30.03311	163.38
Guadalupe River below Verde Creek	GUAD+VERDECR	708.60	-99.28893	30.06722	160.13
Guadalupe River above Cypress Creek	GUAD_ABV_CYPRESSCR	763.48	-99.30530	30.06005	165.79
Guadalupe River below Cypress Creek at Comfort (USGS Gage)	GUAD+CYPRESSCR	836.97	-99.26087	30.05506	163.82
Guadalupe River above Block Ck	GUAD_ABV_BLOCKCR	865.07	-99.15227	29.99417	164.53
Guadalupe River below Block Ck	GUAD+BLOCKCR	909.72	-99.26651	30.05548	168.75
Guadalupe River above Joshua Ck	GUAD_ABV_JOSHUACR	929.67	-99.19474	30.06659	172.29
Guadalupe River below Joshua Ck	GUAD+JOSHUACR	971.33	-99.24268	30.04648	167.34
Guadalupe River above Sister Ck	GUAD_ABV_SISTERCR	983.91	-99.22753	30.04181	166.77
Guadalupe River below Sister Ck	GUAD+SISTERCR	1048.21	-99.22906	30.04543	167.75
Guadalupe River above Curry Ck	GUAD_ABV_CURRYCR	1197.22	-99.22290	30.05193	168.83
Guadalupe River below Curry Ck	GUAD+CURRYCR	1266.37	-99.19326	30.03151	170.40
Guadalupe River near Springbranch	GUAD_NR_SPRINGBRANCH	1313.74	-99.18278	30.03032	170.36
Guadalupe River above Canyon Lake	GUAD_ABV_CANYONLK	1360.02	-99.19289	30.03093	170.89
Inflow to Canyon Lake	CANYON_INFLOW	1431.05	-99.16362	30.02664	170.26
Blanco River at Wimberley (USGS Gage)	BLANCO+CYPRESSCR	355.07	-98.44777	30.08025	167.82
Blanco River below Spoke Pile Creek	BLANCO_J120	363.56	-98.44259	30.07799	167.11
Blanco River above Lone Man Creek	BLANCO_ABV_LONEMANCR	370.50	-98.43234	30.07612	166.97
Blanco River below Lone Man Creek	BLANCO+LONEMANCR	382.87	-98.42934	30.07614	167.48
Blanco River above Halifax Creek	BLANCO_ABV_HALIFAXCR	392.72	-98.43716	30.07854	167.90
Blanco River below Halifax Creek	BLANCO+HALIFAXCR	405.64	-98.43554	30.07671	167.82
Blanco River near Kyle (USGS Gage)	BLANCO_NR_KYLE_GAGE	412.28	-98.40432	30.07108	167.34
Blanco River at I-35 Bridge near San Marcos	BLANCO_AT_I-35	432.67	-98.40310	30.07199	167.80
Blanco River above San Marcos River	BLANCO_ABV_SANMARCOS	436.24	-98.37136	30.06669	167.61
San Marcos River below Blanco River	SANMARCOS+BLANCO	531.30	-98.29226	30.04248	164.84

Location Description	HEC-HMS Element Name	Drainage Area (sq mi)	Longitude (X)	Latitude (Y)	Rotation of Major Axis (Theta)
San Marcos River above York Creek	SANMARCOS_J040	613.63	-98.25209	30.02894	164.13
San Marcos River below York Creek	SANMARCOS+YORKCR	756.55	-98.20539	30.00899	160.86
San Marcos River at Luling (USGS Gage)	SANMARCOS_AT_LULING	838.93	-98.18180	29.99968	159.92
San Marcos Rivere above Plum Creek	SANMARCOS_J070	861.82	-98.21048	30.00440	160.17
Plum Creek near Luling (USGS Gage)	PLUMCR_NR_LULING	351.49	-97.62166	29.86297	150.20
Plum Creek above San Marcos River	PLUMCR_J050	388.83	-97.61488	29.85682	152.09
San Marcos River below Plum Creek	SANMARCOS+PLUMCR	1250.65	-97.91466	29.93187	166.25
San Marcos River above Guadalupe River	SANMARCOS_J090	1359.02	-97.97832	29.93258	162.38
	Drainage Areas below do NOT include the area above Canyon Dam				
Guadalupe River below Geronimo Ck	Guad+GeronimoCk	439.21	-98.05285	29.63836	127.21
Guadalupe River above Cantau Ck	Guad_abv_CantauCk	443.48	-98.06469	29.65347	126.86
Guadalupe River near Seguin (USGS Gage)	Guad_nr_Seguin	450.12	-98.06357	29.65002	127.07
Guadalupe River above Mill Ck	Guad_abv_MillCk	481.81	-98.07806	29.67239	128.31
Guadalupe River below Mill Ck	Guad+MillCk	521.23	-98.05227	29.65162	133.02
Guadalupe River above Nash Ck	Guad_abv_NashCk	553.73	-98.04775	29.65279	136.86
Guadalupe River below Nash Ck	Guad+NashCk	580.24	-98.04743	29.65520	137.51
Guadalupe River at Lake Gonzales	Lake_Gonzales	615.95	-98.02587	29.64086	141.47
Guadalupe River at Wood Lake	Wood_Lake	667.37	-98.01883	29.64050	145.82
Guadalupe River above San Marcos River	Guad_J340	671.78	-98.01394	29.64106	147.48
Guadalupe River at Gonzales (USGS Gage)	Guad+SanMarcos	2030.79	-98.03880	29.85944	152.45
Guadalupe River above Peach Creek	Guad_J360	2100.31	-97.97429	29.84366	154.36
Guadalupe River below Peach Creek	Guad+PeachCr	2582.81	-97.94085	29.84650	157.36
Guadalupe River above McCoy Creek	Guad_J380	2705.18	-97.89187	29.82787	158.79
Guadalupe River below McCoy Creek	Guad+McCoyCr	2737.77	-97.89256	29.82650	158.35
Guadalupe River above Sandies Creek	Guad_J400	2786.21	-97.86989	29.81650	159.35
Guadalupe River at Cuero (USGS Gage)	Guad+SandiesCr	3497.36	-97.86404	29.80254	156.91
Guadalupe River at Victoria (USGS Gage)	Guad_at_Victoria	3767.11	-97.85787	29.77496	152.56
Guadalupe River above Coleto Creek	Guad_abv_ColetoCk	3802.65	-97.87029	29.77752	151.52
Guadalupe River near Bloomington TX	GuadalupeRv_BloomingtonTX	4382.46	-97.84218	29.76441	152.58
Peach Creek below Dilworth (USGS Gage)	PeachCr_bl_Dilworth	459.76	-97.24981	29.71767	177.18
Peach Creek above Guadalupe River	PeachCr_J060	482.50	-97.30055	29.71531	163.96
Sandies Creek near Westhoff (USGS Gage)	SandiesCr_nr_Westhof	549.35	-97.58048	29.29259	179.67
Sandies Creek above Guadalupe River	SANDIESCK_ABV_GUAD	711.14	-97.60504	29.28571	19.42
Coleto Creek Reservoir near Victoria TX	ColetoCkRes_VictoriaTX	494.06	-97.31571	28.83403	152.94
Coleto Creek near Victoria TX (USGS Gage)	COLETOCK_VICTORIATX	511.28	-97.31090	28.83626	150.67
Coleto Creek above Guadalupe River	COLETOCK_ABV_GUADALUPE	540.41	-97.33410	28.85972	141.08

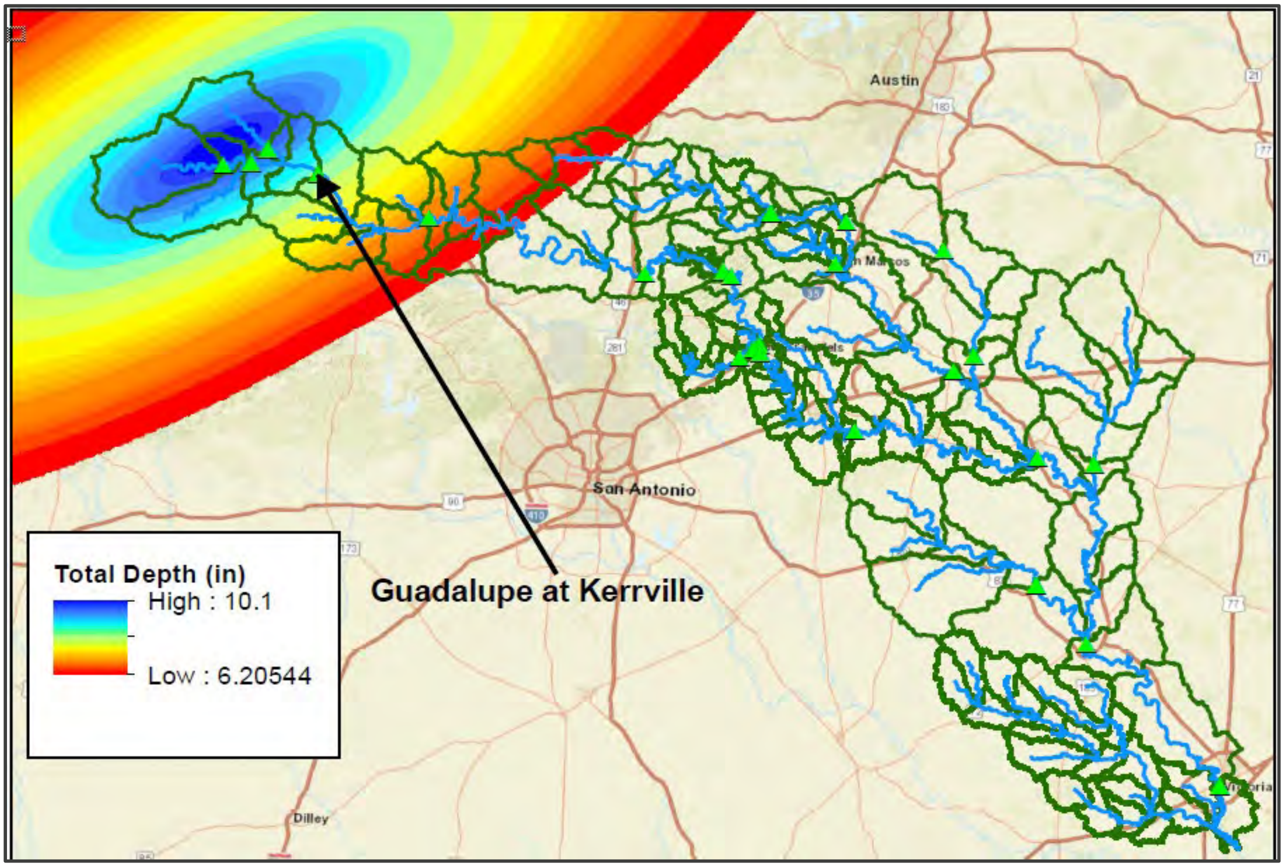


Figure 7.8: Final 1% Annual Chance Elliptical Storm for the Guadalupe River at Kerrville

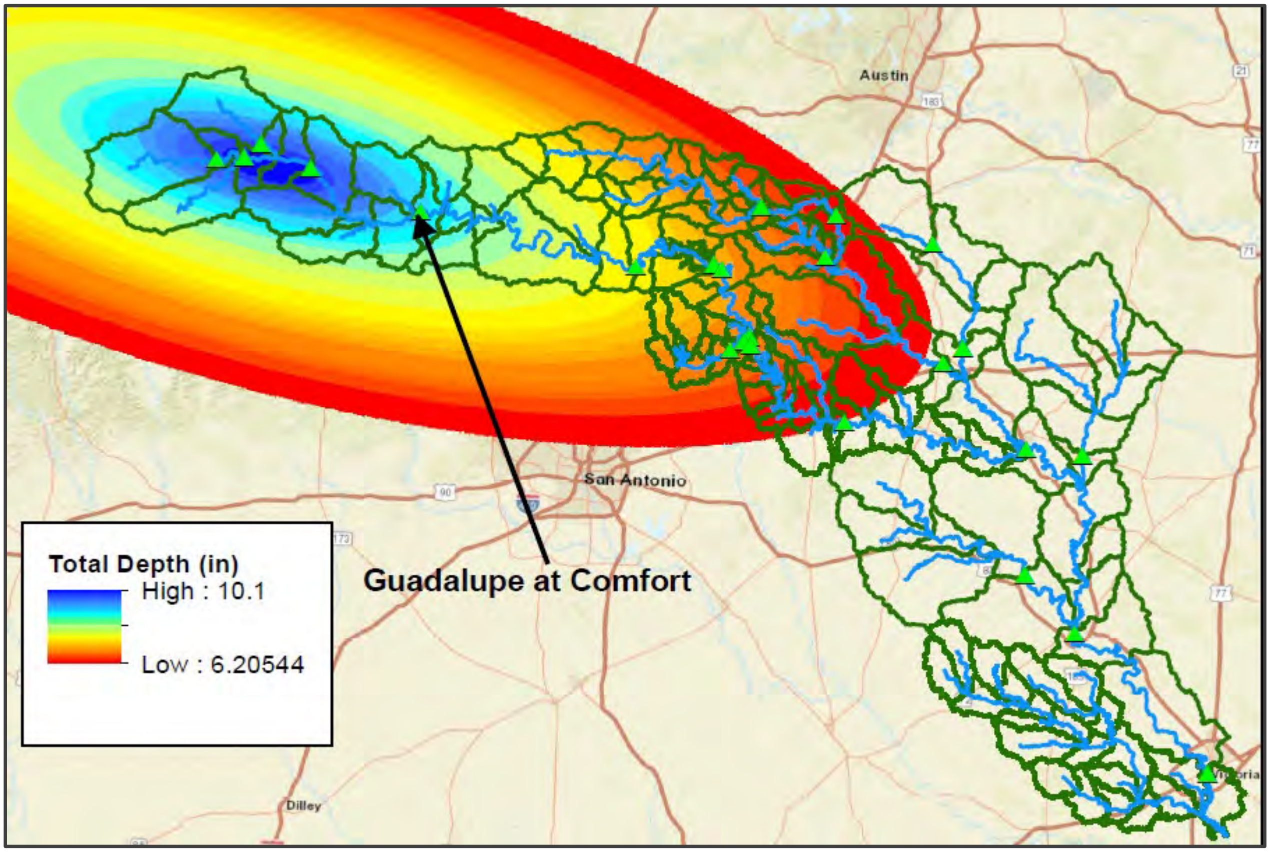


Figure 7.9: Final 1% Annual Chance Elliptical Storm for the Guadalupe River at Comfort

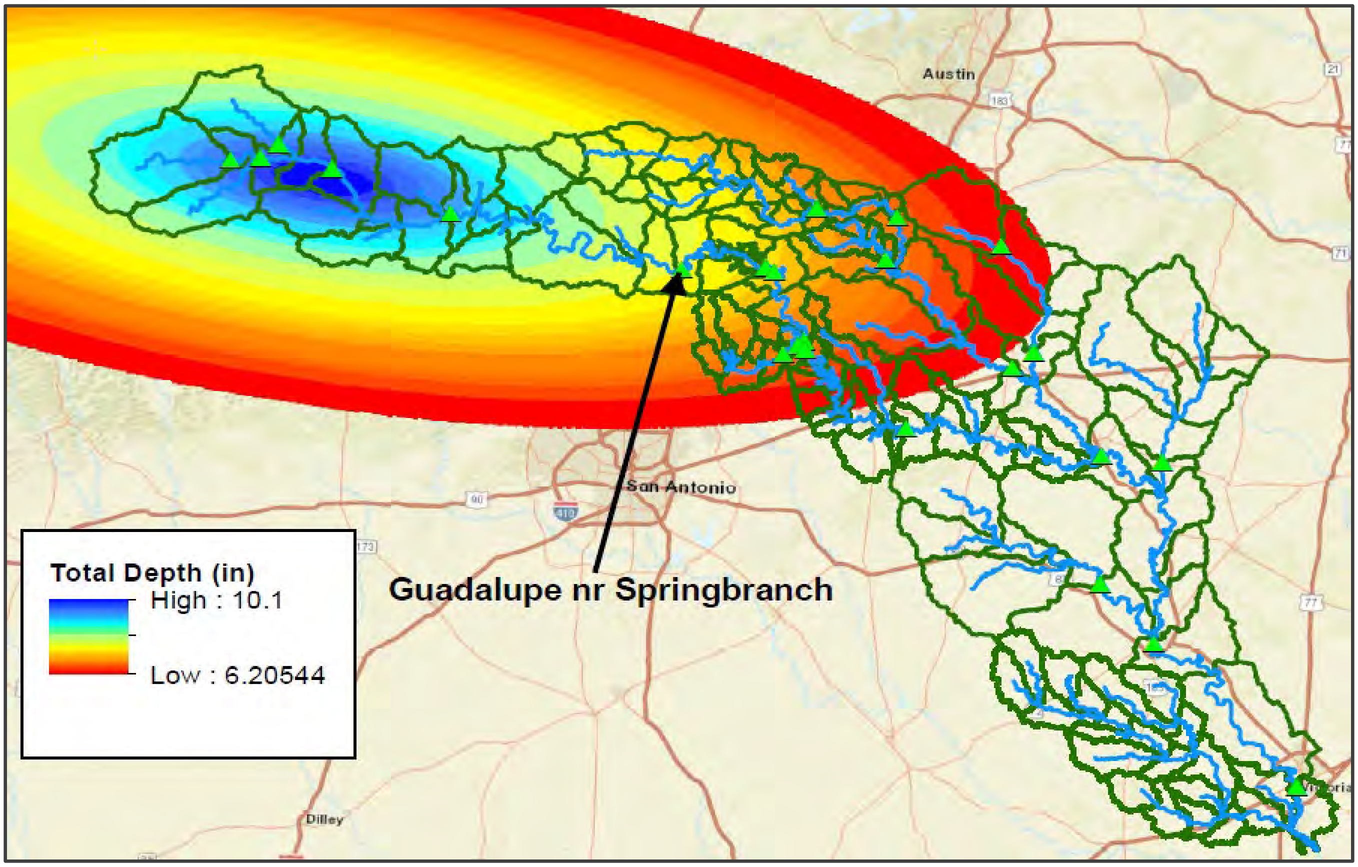


Figure 7.10: Final 1% Annual Chance Elliptical Storm for the Guadalupe River at Spring Branch

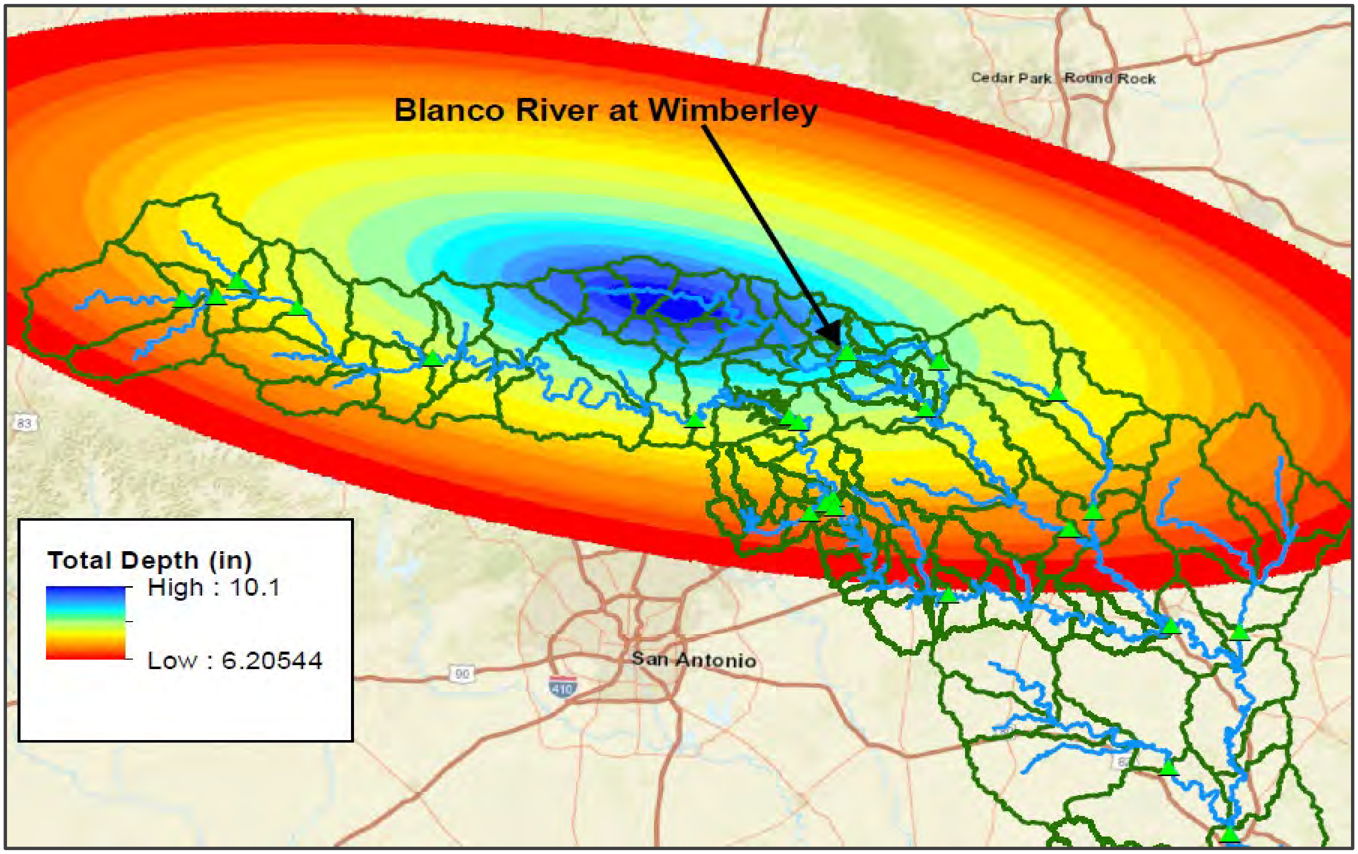


Figure 7.11: Final 1% Annual Chance Elliptical Storm for the Blanco River at Wimberley

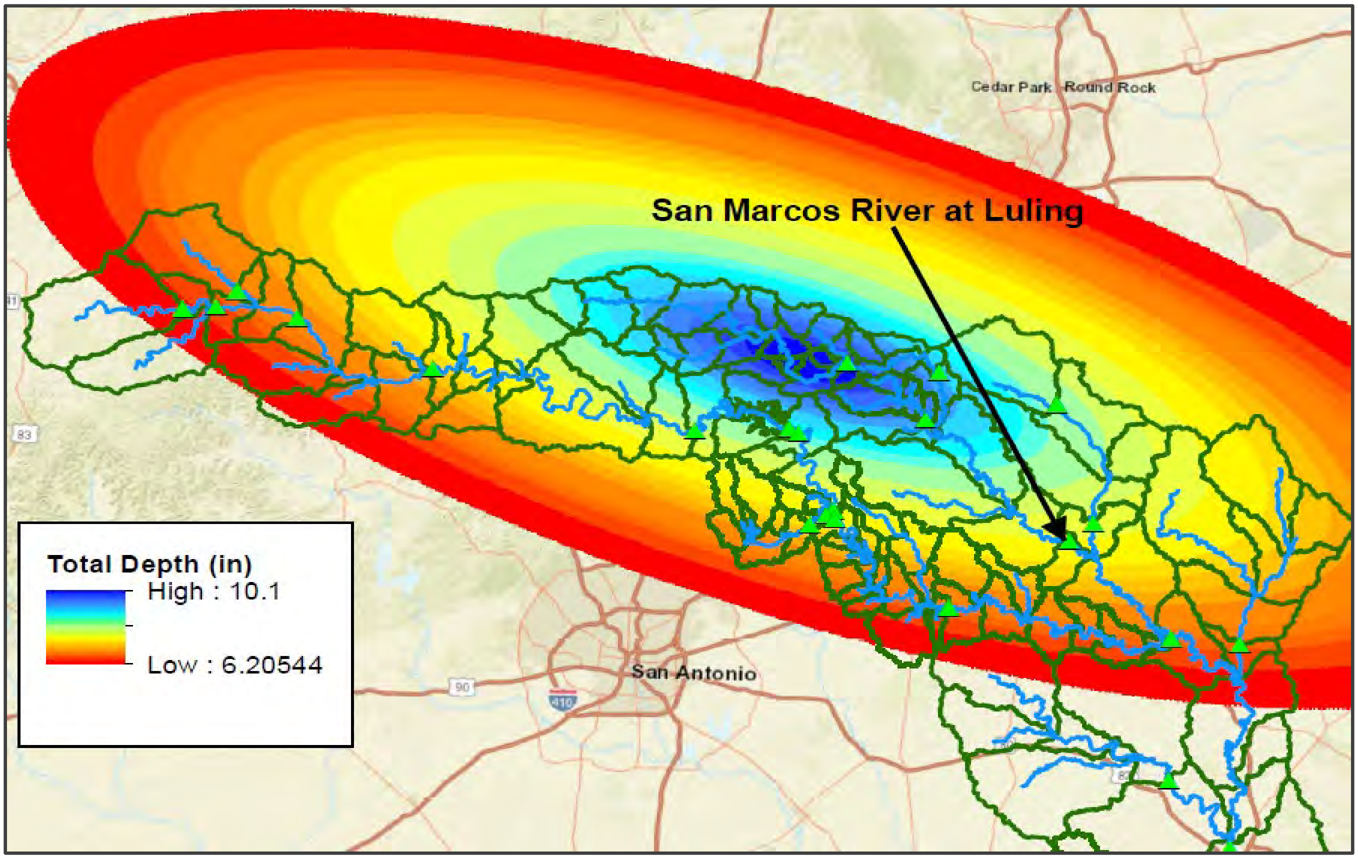


Figure 7.12: Final 1% Annual Chance Elliptical Storm for the San Marcos River at Luling

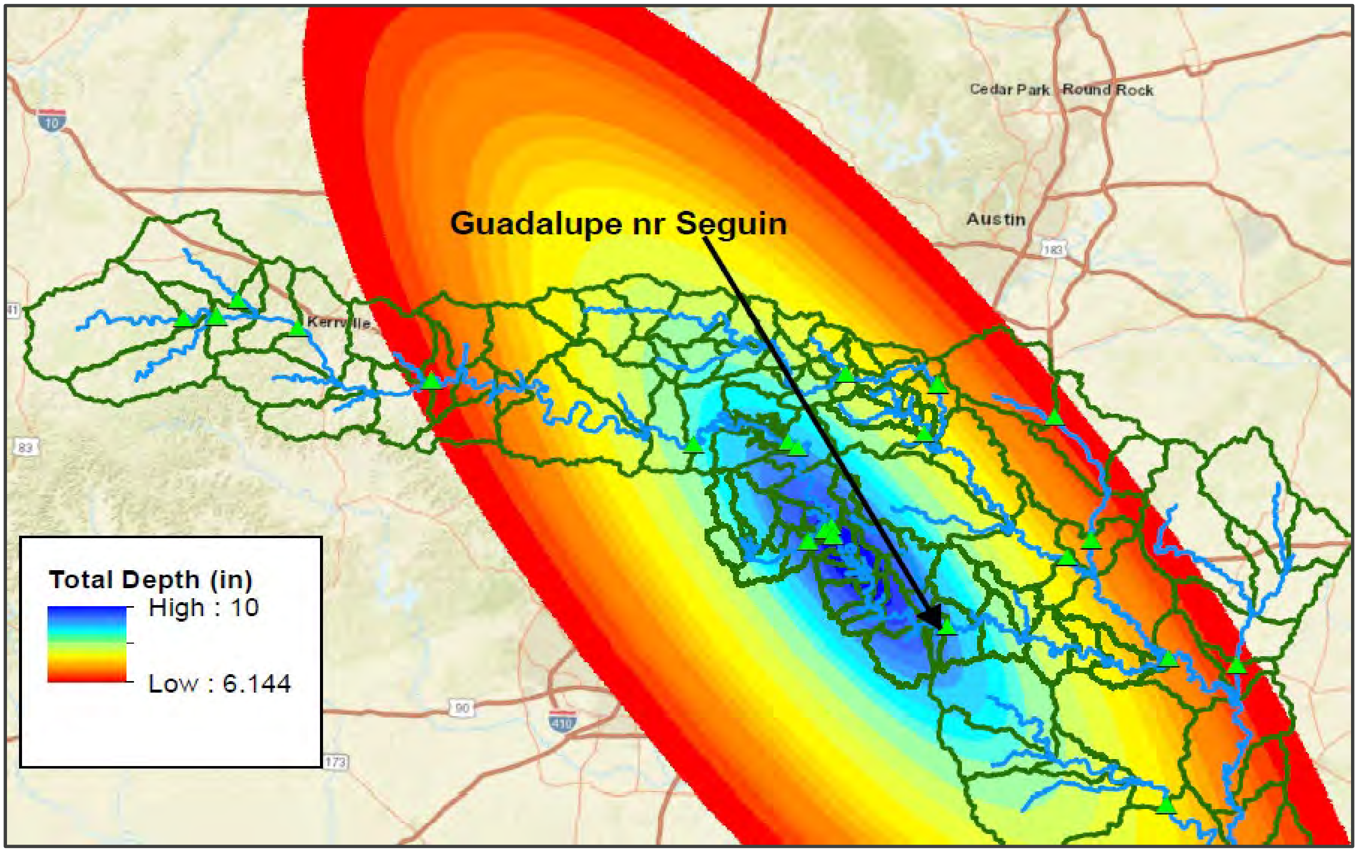


Figure 7.13: Final 1% Annual Chance Elliptical Storm for the Guadalupe River near Seguin

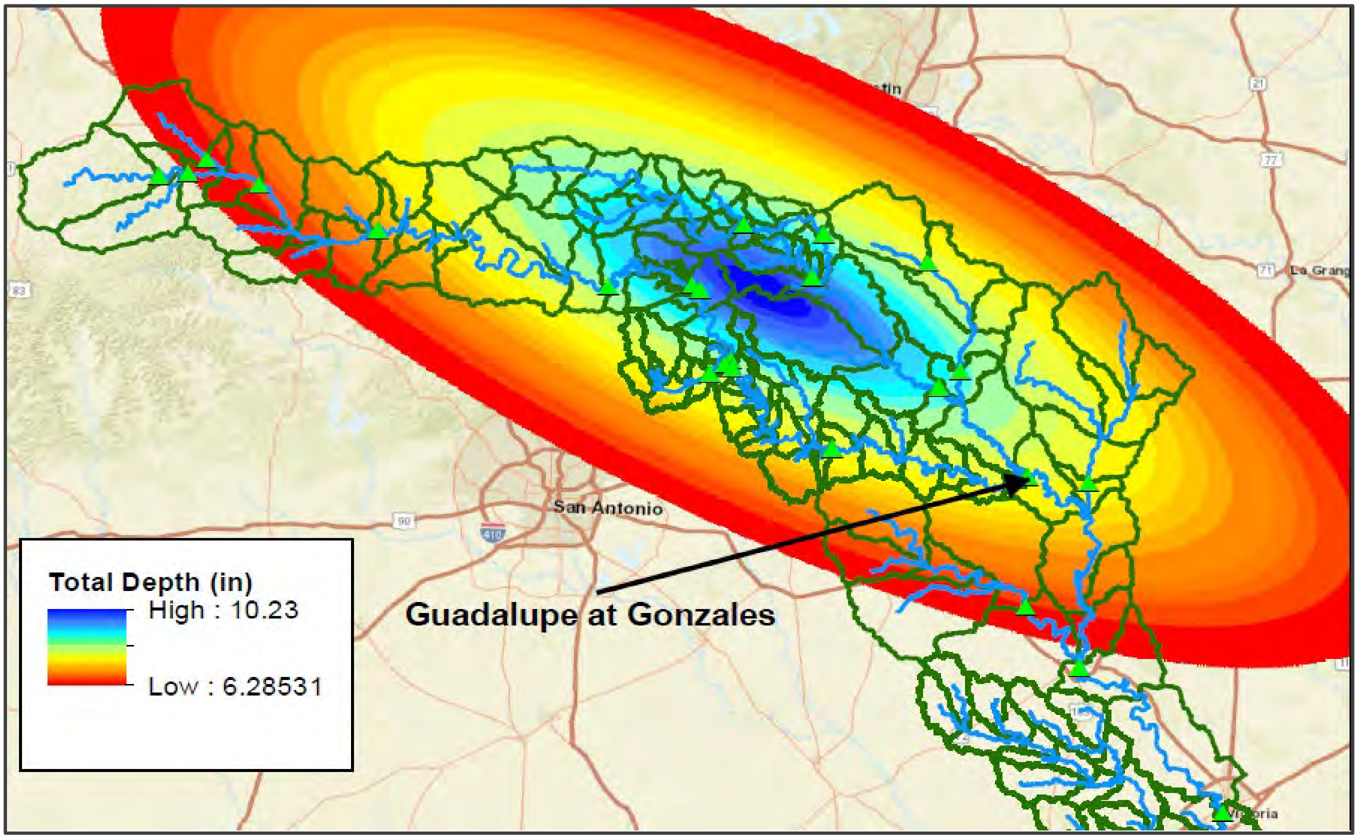


Figure 7.14: Final 1% Annual Chance Elliptical Storm for the Guadalupe River at Gonzales

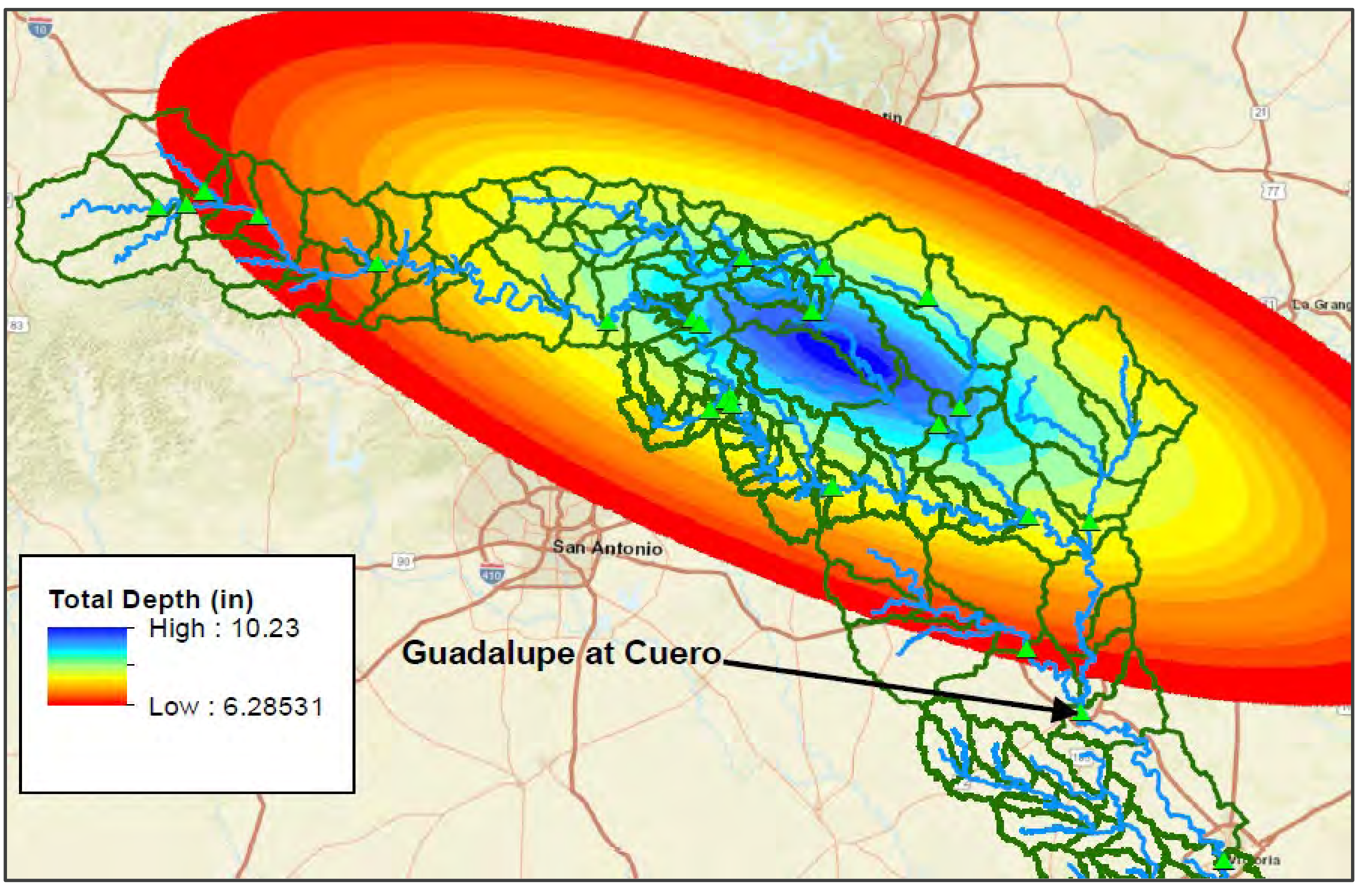


Figure 7.15: Final 1% Annual Chance Elliptical Storm for the Guadalupe River at Cuero

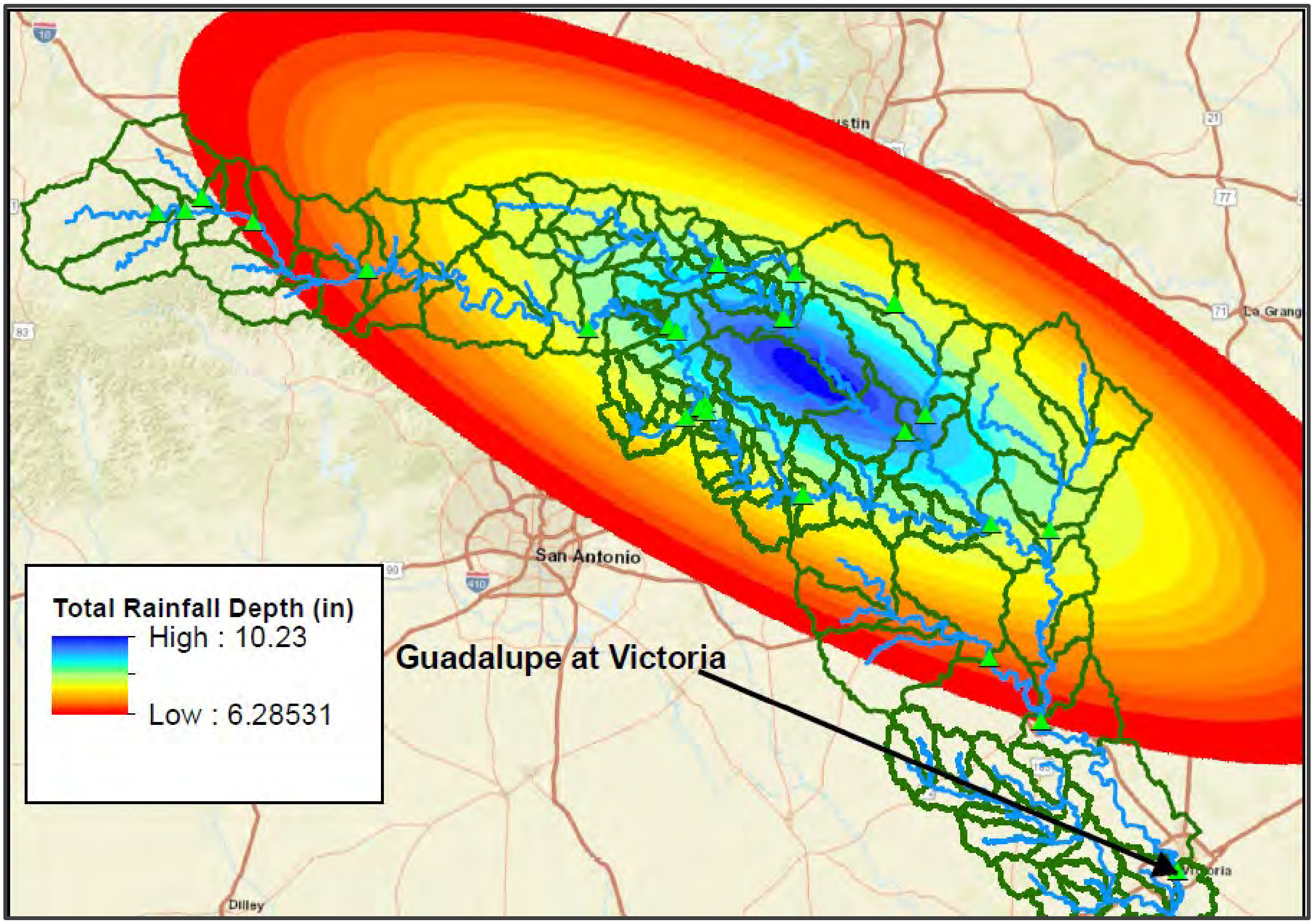


Figure 7.16: Final 1% Annual Chance Elliptical Storm for the Guadalupe River at Victoria

7.5 ELLIPTICAL FREQUENCY STORM LOSS RATES

The elliptical frequency storms were then applied to the final HEC-HMS basin model with the same frequency loss rates that were used for the uniform rainfall method in Chapter 6. In some cases, the 2-yr through 10-yr losses had to be re-adjusted to account for the elliptical storms' lower total volume and in order to maintain consistency with the frequent end of the statistical frequency curves at the USGS gages. This final adjustment was performed because of the increased level of confidence in the statistical frequency curve for the 2 through 10-yr recurrence intervals. The final 2-yr through 25-yr loss rates used for the elliptical frequency storm events are given in Table 7.3. The final 50-yr through 500-yr loss rates are the same as those used for the uniform rainfall method and are shown again in Table 7.4.

Table 7.3: Final Initial and Constant Losses for the 2-yr through 25-yr Elliptical Frequency Storms

Subbasin Name	2-yr	2-yr	5-yr	5-yr	10-yr	10-yr	25-yr	25-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
NF_Guad_S010	2.03	0.21	2.12	0.21	1.99	0.20	0.97	0.12
NF_Guad_S020	2.47	0.27	2.35	0.27	2.35	0.25	1.69	0.22
SF_Guad_S010	2.46	0.27	2.35	0.26	2.35	0.25	1.68	0.22
Guad_S010	1.91	0.28	2.47	0.28	1.90	0.24	1.27	0.13
JohnsonCr_S010	2.54	0.31	2.94	0.31	2.45	0.31	1.98	0.28
JohnsonCr_S020	1.79	0.28	2.46	0.28	1.74	0.24	1.26	0.13
Guad_S020	1.77	0.28	2.45	0.27	1.74	0.24	1.27	0.13
Guad_S030	1.80	0.22	1.74	0.20	1.64	0.17	1.55	0.14
TurtleCr_S010	1.67	0.22	1.44	0.19	1.23	0.17	1.05	0.14
Guad_S040	1.85	0.23	1.59	0.21	1.34	0.18	1.15	0.15
VerdeCr_S010	1.84	0.22	1.82	0.20	1.74	0.18	1.67	0.14
Guad_S050	1.79	0.23	1.56	0.20	1.34	0.18	1.17	0.14
CypressCr_GR_S010	1.70	0.22	1.47	0.20	1.25	0.17	1.07	0.14
Guad_S060	1.35	0.22	1.35	0.22	1.23	0.21	1.06	0.16
BlockCr_S010	1.27	0.21	1.27	0.21	1.17	0.21	1.00	0.15
Guad_S070	1.38	0.22	1.38	0.22	1.26	0.21	1.08	0.16
JoshuaCr_S010	1.28	0.21	1.28	0.21	1.18	0.21	1.01	0.15
Guad_S080	1.35	0.22	1.35	0.22	1.24	0.21	1.06	0.16
SisterCr_S010	1.28	0.21	1.28	0.21	1.18	0.21	1.00	0.15
Guad_S090	1.27	0.21	1.27	0.21	1.17	0.21	1.00	0.15
CurryCr_S010	1.28	0.21	1.28	0.21	1.18	0.21	1.00	0.15
Guad_S100	1.27	0.21	1.27	0.21	1.17	0.21	1.00	0.15
Guad_S110	1.56	0.21	1.38	0.16	1.21	0.14	1.05	0.12
Guad_S120	1.53	0.20	1.32	0.16	1.14	0.14	0.97	0.12
CanyonLk_S010	1.50	0.20	1.30	0.16	1.12	0.14	0.95	0.12
Canyon Dam								
Blanco_S010	1.86	0.208	1.86	0.207	1.86	0.203	1.24	0.145
Blanco_S020	1.87	0.209	1.87	0.208	1.87	0.204	1.25	0.146
Blanco_S030	1.82	0.204	1.82	0.203	1.82	0.201	1.22	0.143
Blanco_S040	1.79	0.201	1.79	0.201	1.79	0.199	1.2	0.141
Blanco_S050	1.77	0.199	1.77	0.199	1.77	0.197	1.19	0.14
LittleBlanco_S010	1.88	0.21	1.88	0.208	1.88	0.204	1.25	0.146
LittleBlanco_S020	1.85	0.207	1.85	0.206	1.85	0.203	1.24	0.145
LittleBlanco_S030	1.78	0.2	1.78	0.2	1.78	0.198	1.2	0.141
LittleBlanco_S040	1.89	0.211	1.89	0.209	1.89	0.206	1.26	0.147
Blanco_S060	1.92	0.214	1.92	0.212	1.92	0.207	1.28	0.148

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
WanslowCr_BR_S010	1.92	0.214	1.92	0.211	1.92	0.207	1.27	0.148
Blanco_S070	1.9	0.212	1.9	0.21	1.9	0.206	1.27	0.147
Blanco_S080	1.88	0.21	1.88	0.209	1.88	0.205	1.26	0.146
CarpersCr_BR_S010	1.93	0.215	1.93	0.213	1.93	0.208	1.28	0.149
Blanco_S090	1.91	0.213	1.91	0.211	1.91	0.207	1.27	0.147
Blanco_S100	1.9	0.212	1.9	0.21	1.9	0.206	1.27	0.147
WilsonCr_BR_S010	1.93	0.215	1.93	0.212	1.93	0.208	1.28	0.148
Blanco_S110	1.91	0.213	1.91	0.211	1.91	0.206	1.27	0.147
CypressCr_BR_S010	1.92	0.214	1.92	0.212	1.92	0.207	1.28	0.148
CypressCr_BR_S020	1.93	0.215	1.93	0.212	1.93	0.208	1.28	0.148
CypressCr_BR_S030	1.91	0.213	1.91	0.211	1.91	0.207	1.27	0.148
Blanco_S120	1.86	0.214	1.83	0.212	1.32	0.208	1.28	0.148
Blanco_S130	1.87	0.215	1.84	0.213	1.32	0.208	1.28	0.149
LoneManCr_BR_S010	1.9	0.218	1.86	0.215	1.34	0.21	1.3	0.15
Blanco_S140	1.86	0.214	1.83	0.212	1.31	0.207	1.28	0.148
HalifaxCr_BR_S010	1.78	0.206	1.76	0.205	1.26	0.202	1.23	0.144
Blanco_S150	1.79	0.207	1.77	0.206	1.27	0.203	1.23	0.144
Blanco_S160	1.26	0.203	1.24	0.202	1.21	0.142	1.21	0.142
Blanco_S170	1.4	0.218	1.34	0.215	1.3	0.15	1.3	0.15
SinkCk_S010	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SinkCk_S020	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SinkCk_S030	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SinkCk_S040	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SanMarcos_S005	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SanMarcos_S008	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
PurgatoryCr_S010	1	0.19	0.99	0.14	0.99	0.12	0.99	0.12
SanMarcos_S010	1.07	0.19	1.06	0.14	1.03	0.13	1.03	0.13
SanMarcos_S020	1.12	0.2	1.08	0.14	1.06	0.13	1.06	0.13
YorkCr_S010	1.48	0.27	1.47	0.19	1.44	0.18	1.44	0.18
SanMarcos_S030	1.18	0.2	1.12	0.14	1.1	0.13	1.1	0.13
SanMarcos_S040	1.58	0.21	1.45	0.17	1.36	0.16	1.17	0.14
PlumCr_S010	1.3	0.18	1.14	0.14	1.04	0.13	0.88	0.11
PlumCr_S020	1.36	0.19	1.19	0.14	1.08	0.13	0.92	0.11
TenneyCr_S010	1.53	0.21	1.32	0.16	1.18	0.14	1.02	0.12
PlumCr_S030	1.39	0.19	1.21	0.15	1.09	0.14	0.93	0.11
PlumCr_S040	1.61	0.21	1.31	0.16	1.17	0.14	1.01	0.12
SanMarcos_S050	1.71	0.22	1.47	0.17	1.37	0.17	1.18	0.14
DryComalCk_S010	1.03	0.10	1.03	0.10	1.03	0.10	1.26	0.15

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
DryComalCk_S020	0.99	0.09	0.99	0.09	0.99	0.09	1.17	0.14
WFk_DryComalCk_S010	1.04	0.10	1.04	0.10	1.04	0.10	1.28	0.15
WFk_DryComalCk_S020	1.00	0.10	1.00	0.10	1.00	0.10	1.19	0.14
WF_Trib_S010	1.03	0.10	1.03	0.10	1.03	0.10	1.25	0.15
WF_Trib_S020	0.99	0.09	0.99	0.09	0.99	0.09	1.16	0.14
WFk_DryComalCk_S030	1.02	0.10	1.02	0.10	1.02	0.10	1.22	0.14
DryComalCk_S030	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
BearCk_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
DryComalCk_S040	0.98	0.09	0.98	0.09	0.98	0.09	1.14	0.14
DCCk_Trib14_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.22	0.14
DryComalCk_S050	0.96	0.09	0.96	0.09	0.96	0.09	1.09	0.13
DryComalCk_S060	0.99	0.09	0.99	0.09	0.99	0.09	1.15	0.14
BliedersCk_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.22	0.14
Comal_S010	1.03	0.10	1.03	0.10	1.03	0.10	1.26	0.15
Comal_S020	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
Comal_S030	1.01	0.10	1.01	0.10	1.01	0.10	1.21	0.14
Guad_S130	0.90	0.08	0.90	0.08	0.90	0.08	0.95	0.12
BearCr_S010	0.90	0.08	0.90	0.08	0.90	0.08	0.95	0.12
Guad_S140	0.90	0.08	0.90	0.08	0.90	0.08	0.95	0.12
Guad_S142	0.96	0.09	0.96	0.09	0.96	0.09	1.10	0.13
Guad_S144	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
Guad_Trib22_S010	0.93	0.08	0.93	0.08	0.93	0.08	1.02	0.13
Guad_S145	1.04	0.10	1.04	0.10	1.04	0.10	1.26	0.15
LongCk_S010	0.92	0.08	0.92	0.08	0.92	0.08	0.99	0.12
Guad_S147	1.01	0.10	1.01	0.10	1.01	0.10	1.21	0.14
Guad_Trib20_S010	0.93	0.08	0.93	0.08	0.93	0.08	1.03	0.13
Guad_S149	1.00	0.09	1.00	0.09	1.00	0.09	1.17	0.14
Guad_S152	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
YoungsCk_S010	0.91	0.08	0.91	0.08	0.91	0.08	0.97	0.12
Guad_S154	0.99	0.09	0.99	0.09	0.99	0.09	1.15	0.14
CottonwoodCkS_S010	0.90	0.08	0.90	0.08	0.90	0.08	0.96	0.12
Guad_S156	1.01	0.10	1.01	0.10	1.01	0.10	1.21	0.14
Little_MillCk_S010	0.94	0.08	0.94	0.08	0.94	0.08	1.05	0.13
Guad_S158	0.98	0.09	0.98	0.09	0.98	0.09	1.14	0.14
DeadmanCk_S010	0.92	0.08	0.92	0.08	0.92	0.08	1.00	0.12
Guad_S160	0.97	0.09	0.97	0.09	0.97	0.09	1.11	0.13
CottonwoodCk_S010	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
Guad_S162	1.03	0.10	1.03	0.10	1.03	0.10	1.25	0.15

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
AlligatorCk_S010	0.99	0.09	0.99	0.09	0.99	0.09	1.17	0.14
GeronimoCk_S010	0.91	0.08	0.91	0.08	0.91	0.08	0.97	0.12
GeronimoCk_S020	0.92	0.08	0.92	0.08	0.92	0.08	0.98	0.12
GeronimoCk_S030	0.96	0.09	0.96	0.09	0.96	0.09	1.09	0.13
Guad_S164	1.00	0.10	1.00	0.10	1.00	0.10	1.19	0.14
CantauCk_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
Guad_S166	1.04	0.10	1.04	0.10	1.04	0.10	1.28	0.15
MillCk_S010	1.01	0.09	1.01	0.09	1.01	0.09	1.16	0.14
Guad_S168	1.24	0.10	1.24	0.10	1.24	0.10	1.46	0.15
NashCk_S010	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
Guad_S170	1.03	0.10	1.03	0.10	1.03	0.10	1.25	0.15
Guad_S172	1.00	0.10	1.00	0.10	1.00	0.10	1.19	0.14
Guad_S174	0.98	0.09	0.98	0.09	0.98	0.09	1.14	0.14
Guad_S176	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
Guad_S200	1.17	0.09	1.17	0.18	1.17	0.18	1.30	0.13
PeachCr_S010	1.44	0.20	1.28	0.19	1.28	0.17	1.13	0.12
BigFiveMileCr_S010	1.30	0.19	1.18	0.17	1.18	0.16	1.03	0.11
PeachCr_S020	1.25	0.18	1.12	0.17	1.12	0.16	0.97	0.11
SandyFork_S010	1.52	0.21	1.27	0.19	1.27	0.17	1.12	0.13
PeachCr_S030	1.30	0.19	1.16	0.17	1.16	0.16	1.01	0.11
PeachCr_S040	0.97	0.09	0.97	0.18	0.97	0.14	1.10	0.13
Guad_S210	1.01	0.10	1.01	0.19	1.01	0.15	1.19	0.14
McCoyCr_S010	1.01	0.10	1.01	0.20	1.01	0.15	1.20	0.14
Guad_S220	1.44	0.10	1.44	0.20	1.44	0.15	1.80	0.14
SandiesCr_S010	2.00	0.26	1.60	0.21	1.40	0.16	1.10	0.13
ClearForkCr_S010	1.82	0.24	1.50	0.19	1.35	0.15	1.08	0.12
SandiesCr_S020	1.81	0.24	1.48	0.19	1.31	0.15	1.04	0.12
ElmCr_S010	1.71	0.23	1.45	0.18	1.30	0.14	1.05	0.11
SandiesCr_S030	1.69	0.23	1.40	0.18	1.22	0.14	0.97	0.11
SandiesCr_S040	1.07	0.10	1.07	0.20	1.07	0.15	1.28	0.14
Guad_S230	1.12	0.11	1.12	0.21	1.12	0.16	1.37	0.15
Guad_S240	1.02	0.10	1.02	0.20	1.02	0.15	1.23	0.14
DryCk_S010	1.22	0.20	1.22	0.19	1.36	0.16	1.17	0.14
SmithCk_S010	1.86	0.25	1.86	0.24	1.76	0.21	1.22	0.14
ThomasCk_S010	1.91	0.25	1.91	0.24	1.79	0.21	1.25	0.15
SmithCk_S020	1.89	0.25	1.89	0.24	1.78	0.21	1.24	0.14
YorktownCk_S010	1.83	0.24	1.83	0.24	1.74	0.21	1.20	0.14
YorktownCk_S020	1.92	0.25	1.91	0.24	1.80	0.21	1.25	0.15

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
FifteenmileCk_S010	1.89	0.25	1.89	0.24	1.78	0.21	1.24	0.14
HoosierCk_S010	1.91	0.25	1.91	0.24	1.79	0.21	1.25	0.15
FifteenmileCk_S020	1.34	0.26	1.33	0.25	1.32	0.16	1.28	0.15
EighteenmileCk_S010	1.31	0.25	1.29	0.24	1.29	0.15	1.25	0.15
FifteenmileCk_S030	1.32	0.25	1.30	0.24	1.30	0.15	1.26	0.15
TwelvemileCk_S010	1.33	0.25	1.31	0.24	1.30	0.16	1.27	0.15
FivemileCk_S010	1.36	0.26	1.35	0.25	1.33	0.16	1.29	0.15
TwelvemileCk_S020	1.37	0.26	1.36	0.25	1.34	0.16	1.30	0.15
ColetoCk_S010	1.26	0.21	1.26	0.20	1.25	0.17	1.21	0.14
ColetoCk_S020	1.25	0.21	1.25	0.20	1.24	0.17	1.20	0.14
PerdidoCk_S010	1.82	0.25	1.82	0.25	1.81	0.19	1.25	0.15
PerdidoCk_S020	1.27	0.20	1.27	0.20	1.26	0.17	1.21	0.14
PerdidoCk_S030	1.22	0.20	1.22	0.19	1.21	0.16	1.17	0.14
ColetoCk_S030	1.18	0.19	1.18	0.19	1.17	0.16	1.13	0.14
ColetoCk_S040	1.24	0.20	1.24	0.19	1.23	0.17	1.19	0.14
Guad_S250	1.17	0.19	1.17	0.19	1.16	0.16	1.13	0.14

Table 7.4: Final Initial and Constant Losses for the 50-yr through 500-yr Elliptical Frequency Storms

Subbasin Name	50-yr Initial (in)	50-yr Constant (in/hr)	100-yr Initial (in)	100-yr Constant (in/hr)	250-yr Initial (in)	250-yr Constant (in/hr)	500-yr Initial (in)	500-yr Constant (in/hr)
NF_Guad_S010	0.85	0.10	0.76	0.07	0.61	0.06	0.50	0.05
NF_Guad_S020	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
SF_Guad_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
Guad_S010	0.93	0.11	0.80	0.08	0.65	0.07	0.53	0.06
JohnsonCr_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
JohnsonCr_S020	0.92	0.11	0.80	0.08	0.65	0.07	0.53	0.06
Guad_S020	0.93	0.11	0.81	0.08	0.66	0.07	0.55	0.06
Guad_S030	1.44	0.11	1.31	0.08	1.16	0.07	1.04	0.06
TurtleCr_S010	0.91	0.11	0.79	0.08	0.64	0.07	0.53	0.06
Guad_S040	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
VerdeCr_S010	1.57	0.11	1.43	0.08	1.28	0.07	1.16	0.06
Guad_S050	1.02	0.11	0.88	0.08	0.72	0.07	0.60	0.06
CypressCr_GR_S010	0.93	0.11	0.80	0.08	0.65	0.07	0.53	0.06
Guad_S060	0.92	0.11	0.80	0.08	0.64	0.07	0.53	0.06
BlockCr_S010	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S070	0.93	0.11	0.80	0.08	0.65	0.07	0.54	0.06
JoshuaCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S080	0.92	0.11	0.80	0.08	0.64	0.07	0.53	0.06
SisterCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S090	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
CurryCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S100	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S110	0.94	0.10	0.84	0.07	0.70	0.06	0.59	0.05
Guad_S120	0.85	0.10	0.76	0.07	0.61	0.06	0.50	0.05
CanyonLk_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Canyon Dam								
Blanco_S010	1.06	0.125	0.87	0.095	0.71	0.084	0.58	0.075
Blanco_S020	1.06	0.126	0.88	0.096	0.71	0.084	0.59	0.076
Blanco_S030	1.04	0.123	0.86	0.093	0.7	0.082	0.58	0.073
Blanco_S040	1.03	0.121	0.86	0.091	0.69	0.08	0.57	0.071
Blanco_S050	1.02	0.12	0.85	0.09	0.69	0.079	0.57	0.07
LittleBlanco_S010	1.06	0.126	0.88	0.096	0.71	0.084	0.59	0.076
LittleBlanco_S020	1.05	0.125	0.87	0.095	0.71	0.083	0.58	0.075
LittleBlanco_S030	1.02	0.121	0.86	0.091	0.69	0.08	0.57	0.071
LittleBlanco_S040	1.07	0.127	0.88	0.097	0.72	0.085	0.59	0.077
Blanco_S060	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
WanslowCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.086	0.59	0.078
Blanco_S070	1.07	0.127	0.89	0.097	0.72	0.086	0.59	0.077
Blanco_S080	1.07	0.126	0.88	0.096	0.71	0.085	0.59	0.076

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
CarpersCr_BR_S010	1.09	0.129	0.89	0.099	0.72	0.087	0.6	0.079
Blanco_S090	1.08	0.127	0.89	0.097	0.72	0.086	0.59	0.077
Blanco_S100	1.07	0.127	0.89	0.097	0.72	0.086	0.59	0.077
WilsonCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
Blanco_S110	1.08	0.127	0.89	0.097	0.72	0.086	0.59	0.077
CypressCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
CypressCr_BR_S020	1.09	0.128	0.89	0.098	0.72	0.087	0.59	0.078
CypressCr_BR_S030	1.08	0.128	0.89	0.098	0.72	0.086	0.59	0.078
Blanco_S120	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
Blanco_S130	1.09	0.129	0.89	0.099	0.72	0.087	0.6	0.079
LoneManCr_BR_S010	1.1	0.13	0.9	0.1	0.73	0.088	0.6	0.08
Blanco_S140	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
HalifaxCr_BR_S010	1.05	0.124	0.87	0.094	0.7	0.083	0.58	0.074
Blanco_S150	1.05	0.124	0.87	0.094	0.71	0.083	0.58	0.074
Blanco_S160	1.03	0.122	0.86	0.092	0.7	0.081	0.57	0.072
Blanco_S170	1.1	0.13	0.9	0.1	0.73	0.089	0.6	0.08
SinkCk_S010	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S020	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S030	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S040	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SanMarcos_S005	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SanMarcos_S008	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
PurgatoryCr_S010	0.87	0.1	0.77	0.07	0.61	0.06	0.51	0.05
SanMarcos_S010	0.9	0.11	0.78	0.08	0.63	0.06	0.52	0.06
SanMarcos_S020	0.92	0.11	0.8	0.08	0.64	0.07	0.53	0.06
YorkCr_S010	1.27	0.15	1.14	0.11	0.92	0.09	0.75	0.08
SanMarcos_S030	0.95	0.11	0.81	0.08	0.65	0.07	0.54	0.06
SanMarcos_S040	1	0.12	0.84	0.09	0.68	0.08	0.56	0.07
PlumCr_S010	0.82	0.1	0.76	0.07	0.61	0.06	0.51	0.05
PlumCr_S020	0.85	0.1	0.78	0.08	0.63	0.06	0.52	0.06
TenneyCr_S010	0.92	0.11	0.83	0.09	0.66	0.07	0.55	0.07
PlumCr_S030	0.86	0.1	0.79	0.08	0.63	0.07	0.53	0.06
PlumCr_S040	0.92	0.11	0.82	0.08	0.66	0.07	0.55	0.06
SanMarcos_S050	1.01	0.12	0.85	0.09	0.68	0.08	0.57	0.07
DryComalCk_S010	1.07	0.13	0.88	0.10	0.71	0.08	0.59	0.08
DryComalCk_S020	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
WFk_DryComalCk_S010	1.09	0.13	0.89	0.10	0.72	0.09	0.60	0.08
WFk_DryComalCk_S020	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
WF_Trib_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
WF_Trib_S020	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
WFk_DryComalCk_S030	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S030	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
BearCk_S010	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S040	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
DCCk_Trib14_S010	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S050	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
DryComalCk_S060	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
BliedersCk_S010	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
Comal_S010	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
Comal_S020	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Comal_S030	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Guad_S130	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
BearCr_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S140	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S142	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
Guad_S144	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
Guad_Trib22_S010	0.89	0.11	0.78	0.08	0.63	0.06	0.52	0.06
Guad_S145	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
LongCk_S010	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S147	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Guad_Trib20_S010	0.90	0.11	0.78	0.08	0.63	0.07	0.52	0.06
Guad_S149	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
Guad_S152	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
YoungsCk_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
Guad_S154	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
CottonwoodCkS_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S156	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Little_MillCk_S010	0.91	0.11	0.79	0.08	0.64	0.07	0.53	0.06
Guad_S158	0.98	0.12	0.83	0.09	0.68	0.08	0.56	0.07
DeadmanCk_S010	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S160	0.96	0.11	0.82	0.08	0.66	0.07	0.55	0.06
CottonwoodCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Guad_S162	1.06	0.13	0.88	0.10	0.71	0.08	0.58	0.08
AlligatorCk_S010	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
GeronimoCk_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
GeronimoCk_S020	0.87	0.10	0.76	0.07	0.62	0.06	0.51	0.05
GeronimoCk_S030	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
Guad_S164	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
CantauCk_S010	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
Guad_S166	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08

Subbasin Name	50-yr Initial (in)	50-yr Constant (in/hr)	100-yr Initial (in)	100-yr Constant (in/hr)	250-yr Initial (in)	250-yr Constant (in/hr)	500-yr Initial (in)	500-yr Constant (in/hr)
MillCk_S010	1.01	0.12	0.86	0.09	0.70	0.07	0.58	0.07
Guad_S168	1.28	0.13	1.09	0.10	0.92	0.09	0.79	0.08
NashCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Guad_S170	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
Guad_S172	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
Guad_S174	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
Guad_S176	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
Guad_S200	1.16	0.11	1.02	0.08	0.86	0.07	0.74	0.06
PeachCr_S010	1.11	0.12	0.94	0.09	0.78	0.08	0.66	0.07
BigFiveMileCr_S010	1.03	0.11	0.89	0.08	0.73	0.07	0.62	0.06
PeachCr_S020	0.97	0.11	0.84	0.08	0.68	0.07	0.57	0.06
SandyFork_S010	1.08	0.13	0.89	0.10	0.73	0.08	0.60	0.08
PeachCr_S030	1.01	0.11	0.87	0.08	0.71	0.07	0.59	0.06
PeachCr_S040	0.95	0.11	0.82	0.08	0.66	0.07	0.54	0.06
Guad_S210	1.02	0.12	0.86	0.09	0.70	0.08	0.57	0.07
McCoyCr_S010	1.03	0.12	0.86	0.09	0.69	0.08	0.57	0.07
Guad_S220	1.67	0.12	1.49	0.09	1.33	0.08	1.21	0.07
SandiesCr_S010	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
ClearForkCr_S010	1.08	0.12	0.91	0.09	0.75	0.08	0.63	0.07
SandiesCr_S020	1.04	0.12	0.87	0.09	0.71	0.08	0.59	0.07
ElmCr_S010	1.05	0.11	0.90	0.08	0.75	0.07	0.63	0.06
SandiesCr_S030	0.97	0.11	0.82	0.08	0.67	0.07	0.55	0.06
SandiesCr_S040	1.10	0.12	0.92	0.09	0.76	0.08	0.63	0.07
Guad_S230	1.17	0.13	0.97	0.10	0.80	0.09	0.67	0.08
Guad_S240	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryCk_S010	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
SmithCk_S010	1.04	0.12	0.86	0.09	0.70	0.08	0.58	0.07
ThomasCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
SmithCk_S020	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
YorktownCk_S010	1.02	0.12	0.86	0.09	0.69	0.08	0.57	0.07
YorktownCk_S020	1.07	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S010	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
HoosierCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S020	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
EighteenmileCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S030	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
TwelvemileCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
FivemileCk_S010	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
TwelvemileCk_S020	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
ColetoCk_S010	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
ColetoCk_S020	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
PerdidoCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
PerdidoCk_S020	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
PerdidoCk_S030	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
ColetoCk_S030	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
ColetoCk_S040	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
Guad_S250	0.97	0.12	0.83	0.09	0.67	0.07	0.55	0.07

7.6 ELLIPTICAL FREQUENCY STORM RESULTS FROM HEC-HMS

The frequency peak flow values were then calculated in HEC-HMS by applying the appropriate elliptical frequency storm to the final HEC-HMS basin model. The final HEC-HMS frequency flows for the calculated locations throughout the watershed model using the 2004 USGS rainfall depths can be seen in Table 7.5. These results will later be compared to the uniform rain results from HEC-HMS along with other methods from this study.

In some cases, one may observe that the simulated peak discharge decreases in the downstream direction. It is not an uncommon phenomenon to see decreasing frequency peak discharges for some river reaches as flood waters spread out into the floodplain and the hydrograph becomes dampened as it moves downstream. This can be due to a combination of peak attenuation due to river routing as well as the difference in timing between the peak of the main stem river versus the runoff from the local tributaries and subbasins.

Table 7.5: Summary of Discharges (cfs) from the HEC-HMS Elliptical Frequency Storm Method with the 2004 USGS Rainfall Depths

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Guadalupe River below Johnson Creek	GUAD+JOHNSONCR	438.14	4,600	24,300	56,300	108,900	156,500	195,600	234,700	278,800
Guadalupe River at Kerrville (USGS Gage)	GUAD_AT_KERRVILLE	485.67	4,500	24,600	55,600	108,500	156,300	196,800	236,700	281,800
Guadalupe River above Turtle Ck	GUAD_ABV_TURTLECR	563.83	8,300	23,300	55,100	107,200	155,900	198,500	239,900	286,600
Guadalupe River below Turtle Ck	GUAD+TURTLECR	634.31	12,600	34,200	66,200	118,900	170,600	217,400	263,300	314,900
Guadalupe River above Verde Creek	GUAD_ABV_VERDECR	652.44	11,900	31,700	63,700	114,500	165,200	211,400	256,600	307,300
Guadalupe River below Verde Creek	GUAD+VERDECR	708.60	12,700	36,400	69,300	120,200	172,600	221,800	269,600	323,300
Guadalupe River above Cypress Creek	GUAD_ABV_CYPRESSCR	763.48	11,200	33,600	65,200	115,400	166,800	216,600	264,300	317,900
Guadalupe River below Cypress Creek at Comfort (USGS Gage)	GUAD+CYPRESSCR	836.97	13,300	41,900	71,100	119,400	172,900	225,700	276,100	332,800
Guadalupe River above Block Ck	GUAD_ABV_BLOCKCR	865.07	14,000	41,900	70,700	116,300	168,100	219,900	269,900	326,000
Guadalupe River below Block Ck	GUAD+BLOCKCR	909.72	13,100	41,300	70,800	118,800	171,400	225,200	276,700	334,500
Guadalupe River above Joshua Ck	GUAD_ABV_JOSHUACR	929.67	12,600	38,900	68,700	115,100	165,600	217,600	267,600	324,100
Guadalupe River below Joshua Ck	GUAD+JOSHUACR	971.33	13,100	39,800	69,600	116,600	167,600	220,200	271,200	328,700
Guadalupe River above Sister Ck	GUAD_ABV_SISTERCR	983.91	13,300	39,800	69,600	116,100	166,600	219,000	269,700	326,900
Guadalupe River below Sister Ck	GUAD+SISTERCR	1048.21	15,500	40,400	70,300	117,200	168,000	220,800	271,800	329,900
Guadalupe River above Curry Ck	GUAD_ABV_CURRYCR	1197.22	12,700	35,300	63,000	104,200	148,200	196,300	242,900	295,600
Guadalupe River below Curry Ck	GUAD+CURRYCR	1266.37	13,300	36,300	63,800	105,200	149,500	198,000	244,900	298,000
Guadalupe River near Springbranch (USGS Gage)	GUAD_NR_SPRINGBRANCH	1313.74	13,500	36,300	63,600	104,600	148,300	196,300	242,900	295,700
Guadalupe River above Canyon Lake	GUAD_ABV_CANYONLK	1360.02	13,300	36,100	63,500	104,200	147,600	195,400	241,800	294,300
Canyon Lake Peak Inflow (cfs)	CANYON_INFLOW	1431.05	13,800	36,800	64,100	104,900	148,500	196,600	243,200	296,000
Canyon Lake Peak Outflow (cfs)	CANYON_LAKE	1431.05	2,800	10,500	12,000	12,000	12,500	55,600	112,100	176,800
Blanco River at Wimberley (USGS Gage)	BLANCO+CYPRESSCR	355.07	8,700	31,800	51,600	94,700	123,300	157,500	199,800	238,100
Blanco River below Spoke Pile Creek	BLANCO_J120	363.56	8,600	31,600	51,300	94,300	122,700	157,500	200,000	238,600
Blanco River above Lone Man Creek	BLANCO_ABV_LONEMANCR	370.50	8,400	31,300	50,800	93,600	121,900	155,900	197,800	236,800
Blanco River below Lone Man Creek	BLANCO+LONEMANCR	382.87	8,400	31,400	51,100	94,300	122,900	157,600	200,100	239,800
Blanco River above Halifax Creek	BLANCO_ABV_HALIFAXCR	392.72	8,400	31,200	50,800	93,800	122,400	157,200	199,900	239,800
Blanco River below Halifax Creek	BLANCO+HALIFAXCR	405.64	8,400	31,300	51,200	94,400	123,400	158,700	202,200	242,700

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Blanco River near Kyle (USGS Gage)	BLANCO_NR_KYLE_GAGE	412.28	8,100	30,700	50,400	93,300	121,900	157,800	201,700	242,900
Blanco River at I-35 Bridge near San Marcos	BLANCO_AT_I-35	432.67	7,900	29,700	48,900	90,300	116,100	152,200	198,700	240,100
Blanco River above San Marcos River	BLANCO_ABV_SANMARCOS	436.24	7,300	28,300	45,400	83,500	110,200	145,700	189,100	230,600
San Marcos River below Blanco River	SANMARCOS+BLANCO	531.30	8,000	29,000	47,000	86,200	113,600	154,000	203,600	252,100
San Marcos River above York Creek	SANMARCOS_J040	613.63	7,600	26,600	44,700	78,400	101,900	135,600	179,000	231,400
San Marcos River below York Creek	SANMARCOS+YORKCR	756.55	9,500	27,700	47,600	81,300	105,500	141,100	187,800	247,200
San Marcos River at Luling (USGS Gage)	SANMARCOS_AT_LULING	838.93	10,900	26,700	43,300	78,800	103,000	138,400	185,800	242,700
San Marcos Rivere above Plum Creek	SANMARCOS_J070	861.82	10,200	26,200	43,400	73,700	98,800	133,800	178,400	230,700
Plum Creek near Luling (USGS Gage)	PLUMCR_NR_LULING	351.49	6,600	19,100	30,600	47,300	61,700	79,200	104,100	127,500
Plum Creek above San Marcos River	PLUMCR_J050	388.83	6,800	19,600	31,500	48,500	63,200	81,000	106,200	129,600
San Marcos River below Plum Creek	SANMARCOS+PLUMCR	1250.65	17,500	40,100	62,900	94,700	128,000	174,200	233,100	301,200
San Marcos River above Guadalupe River	SANMARCOS_J090	1359.02	14,400	34,400	52,300	83,300	115,500	161,400	216,800	278,500
	NOTE: Drainage Areas below do NOT include the area above Canyon Dam									
Guadalupe River below Geronimo Ck	Guad+GeronimoCk	439.21	30,900	51,100	61,300	71,600	86,200	104,800	130,200	155,100
Guadalupe River above Cantau Ck	Guad_abv_CantauCk	443.48	29,300	50,000	60,200	70,500	85,100	104,300	130,000	154,800
Guadalupe River near Seguin (USGS Gage)	Guad_nr_Seguin	450.12	29,400	50,100	60,500	70,800	85,600	104,800	130,600	155,700
Guadalupe River above Mill Ck	Guad_abv_MillCk	481.81	24,500	45,800	57,000	67,400	83,500	105,000	131,800	157,100
Guadalupe River below Mill Ck	Guad+MillCk	521.23	25,500	47,800	59,700	70,700	88,500	111,700	140,400	167,100
Guadalupe River above Nash Ck	Guad_abv_NashCk	553.73	21,800	43,800	56,300	67,600	85,800	110,700	140,900	169,100
Guadalupe River below Nash Ck	Guad+NashCk	580.24	21,900	44,200	56,900	68,300	86,700	112,400	143,600	172,800
Guadalupe River at Lake Gonzales	Lake_Gonzales	615.95	19,000	38,500	51,300	63,300	84,200	112,600	146,300	177,800
Guadalupe River at Wood Lake	Wood_Lake	667.37	16,100	31,000	41,800	52,800	74,300	103,500	139,300	172,300
Guadalupe River above San Marcos River	Guad_J340	671.78	13,800	28,700	39,000	50,100	70,700	100,600	137,000	168,200
Guadalupe River at Gonzales (USGS Gage)	Guad+SanMarcos	2030.79	18,200	51,100	78,600	121,400	173,100	245,900	329,700	405,200
Guadalupe River above Peach Creek	Guad_J360	2100.31	17,400	47,900	74,800	116,300	166,300	238,700	324,200	398,900
Guadalupe River below Peach Creek	Guad+PeachCr	2582.81	17,900	51,500	83,300	132,800	189,800	271,800	373,800	462,000
Guadalupe River above McCoy Creek	Guad_J380	2705.18	16,900	49,100	79,200	127,600	183,600	263,200	365,000	452,500
Guadalupe River below McCoy Creek	Guad+McCoyCr	2737.77	17,000	49,300	79,400	128,000	184,200	263,800	365,700	453,300
Guadalupe River above Sandies Creek	Guad_J400	2786.21	16,700	46,300	73,400	119,500	172,700	250,700	353,500	442,000

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.40%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Guadalupe River at Cuero (USGS Gage)	Guad+SandiesCr	3497.36	16,700	48,100	79,100	130,700	188,000	274,100	388,000	486,200
Guadalupe River at Victoria (USGS Gage)	Guad_at_Victoria	3767.11	16,400	44,000	69,500	118,000	171,700	257,700	369,900	469,100
Guadalupe River above Coleto Creek	Guad_abv_ColetoCk	3802.65	15,900	44,000	69,400	116,200	167,600	255,000	361,400	460,700
Guadalupe River near Bloomington TX	GuadalupeRv_BloomingtonTX	4382.46	15,900	43,800	69,100	115,100	165,500	251,100	359,200	457,500
Peach Creek below Dilworth (USGS Gage)	PeachCr_bl_Dilworth	459.76	5,700	14,200	23,200	36,600	48,000	67,300	90,600	107,400
Peach Creek above Guadalupe River	PeachCr_J060	482.50	5,600	13,800	21,800	35,500	46,800	66,200	89,000	107,000
Sandies Creek near Westhoff (USGS Gage)	SandiesCr_nr_Westhof	549.35	3,900	12,300	21,700	34,600	45,500	65,800	89,900	109,300
Sandies Creek above Guadalupe River	SANDIESCK_ABV_GUAD	711.14	4,400	10,800	19,800	31,900	42,300	61,600	85,900	106,500
Coleto Creek Reservoir near Victoria TX	ColetoCkRes_VictoriaTX	494.06	10,700	26,000	40,300	56,800	73,200	96,000	123,800	144,500
Coleto Creek near Victoria TX (USGS Gage)	COLETOCK_VICTORIATX	511.28	10,700	26,000	40,200	56,800	73,300	96,600	125,000	146,000
Coleto Creek above Guadalupe River	COLETOCK_ABV_GUADALUPE	540.41	7,700	20,600	35,200	52,700	69,300	94,800	123,100	146,100

7.7 ELLIPTICAL STORM VERSUS UNIFORM RAIN FREQUENCY RESULTS

As mentioned at the beginning of this chapter, because the published depth-area reduction curves from TP-40 do not extend beyond 400 square miles, the uniform rainfall method may not always be appropriate for larger drainage areas. Therefore, elliptical frequency storms were computed in HEC-HMS as an alternate method to test against uniform rain results for larger drainage areas.

Figure 7.17 below gives a comparison of the percent difference in the 1% annual chance (100-yr) peak flow estimate from the elliptical storms versus the uniform rainfall method. This percent difference is then plotted versus the drainage area of the point of interest. From this figure, one may observe that the results of the two methods stay within 10% of one another up to approximately 1,500 square miles. From this example, one may conclude that the uniform rainfall method continues to give a reasonable estimate of frequency peak discharges up to at least 1,000 squre miles.

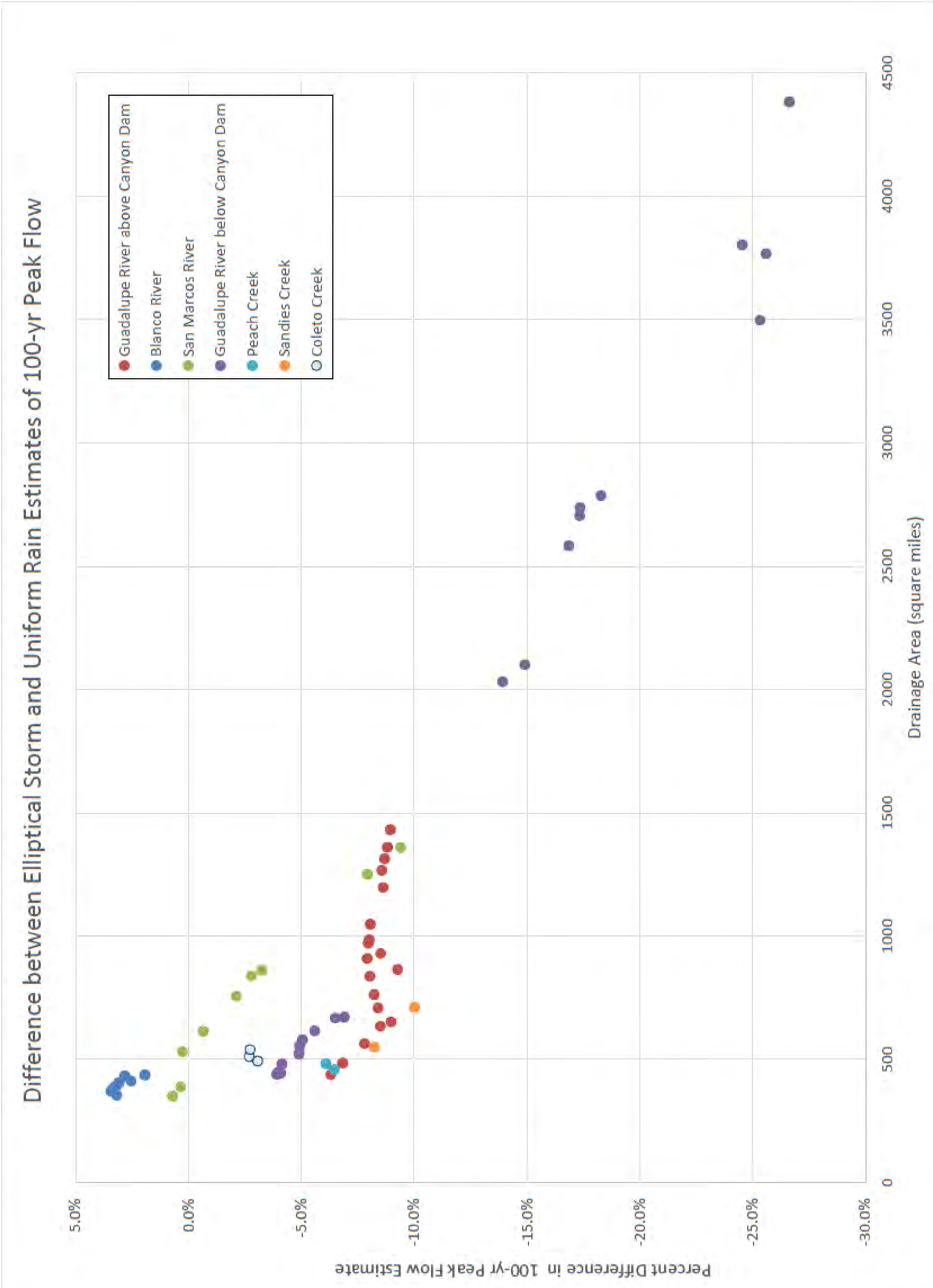


Figure 7.17: Percent Difference between Elliptical and Uniform Rain Estimates of the 1% ACE (100-yr) Peak Flow

8 Riverware Analysis

8.1 INTRODUCTION TO RIVERWARE MODELING

RiverWare is a river system modeling tool developed by CADSWES (Center for Advanced Decision Support for Water and Environmental Systems) that allows the user to simulate complex reservoir operations and perform period-of-record analyses for different scenarios. For the InFRM hydrology studies, Riverware is used to generate a regulated period-of-record by simulating the basin as if the reservoirs and their current rule sets had been present in the basin for the entire time period. Statistical analyses can then be performed on the extended records at the gages.

This report summarizes the Riverware portion of the hydrologic analysis being completed for the InFRM Hydrology study of the Guadalupe Basin. The following discussion will focus predominately on the calibration, data selection, and operational rule policies, in the simulation-run Riverware model of the Guadalupe watershed. A detailed explanation of the Guadalupe watershed period-of-record (POR) hydrology will be in this report. Ultimately, the results of the Riverware analysis hinge on the best available datasets being selected, and that the datasets are not overly susceptible to numerical error. These topics will be discussed in greater detail in the following sections.

8.1.1 Existing USACE Models

Prior to RiverWare, a legacy program called SUPER was used to establish POR hydrology or naturalized local flow datasets. The transition to RiverWare began in 2009. The existing USACE Riverware hydrology model had USGS flow data through 2011. The POR hydrology for the particular stream gages and reservoirs included: Canyon Reservoir, New Braunfels gage (USGS 8168500), Gonzales Gage (8173900), Cuero Gage (8175800), and Victoria Gage (8176500). A screenshot of the Riverware model is below.

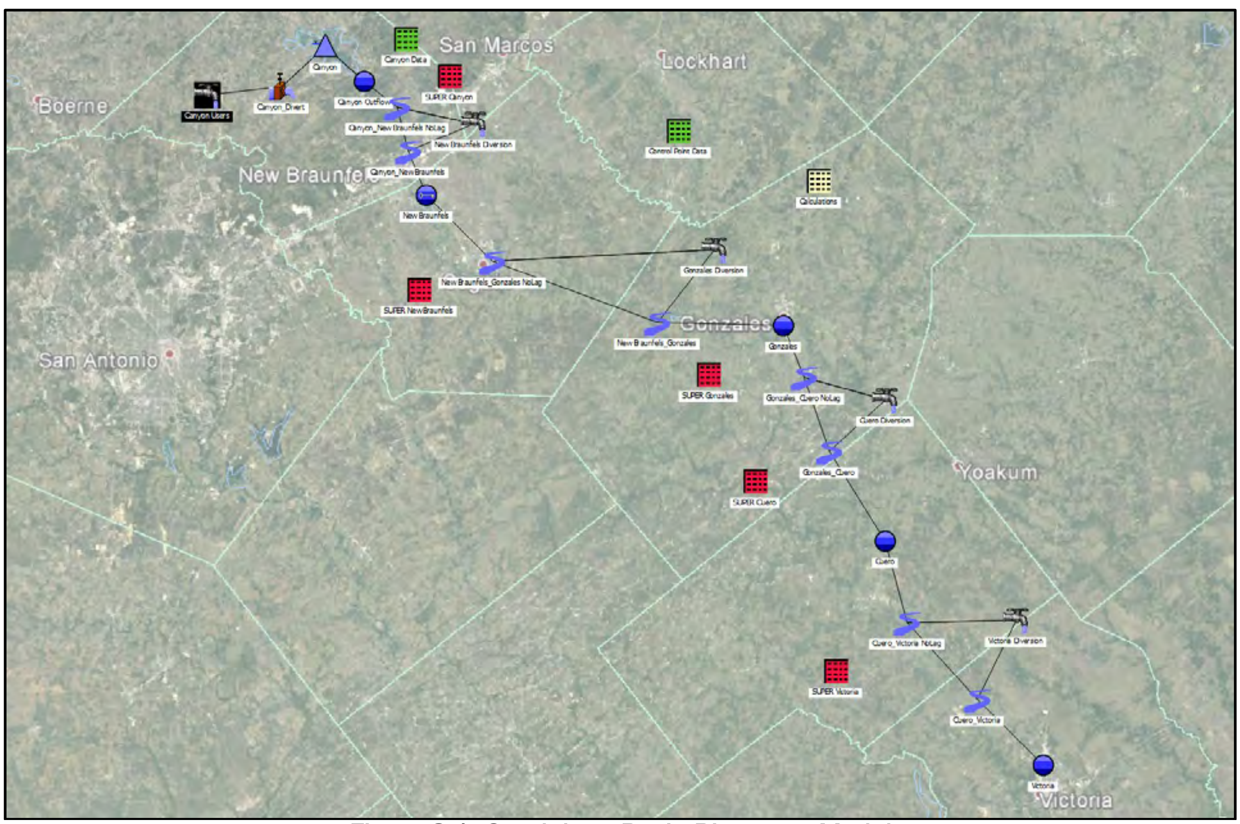


Figure 8.1: Guadalupe Basin Riverware Model

8.2 UPDATES TO THE RIVERWARE MODEL

For this study, flow data was updated through December 31st, 2015. Both the hydrology and operational models begin on January 1st, 1935. Rulesets were written for the operational model to mimic conservation releases. As conservation releases have changed throughout the years due to differing demands, the ruleset attempted to recreate recent demands and to match approximately the last 10 years of record, from 2005-2015.

8.3 DATA SOURCES USED IN THE RIVERWARE MODEL

The primary data used in the hydrology model is daily USGS flows from the gages mentioned in section 8.1. USGS elevation gage data for Canyon Reservoir and USACE data for Canyon Reservoir releases and pool evaporation was also used.

Table 8.1: USGS Gages Included in the Riverware Model

USGS Gage Data used	
Name of Gage	Gage Number
Guadalupe Rv abv Comal Rv at New Braunfels, TX	08168500
Guadalupe Rv at Gonzales, TX	08173900
Guadalupe Rv at Cuero, TX	08175800
Guadalupe Rv at Victoria, TX	08176500

8.4 METHODOLOGY USED TO DEVELOP THE POR HYDROLOGY

The important methods used to develop the POR hydrology for the Guadalupe Watershed in this report are the drainage-area-ratio method, reservoir inflow calculation, and reservoir inflow smoothing algorithm. The methods will be explained in greater detail in the following paragraphs.

Rarely is there a POR watershed study where sufficient and consistent gage datasets exist. Incomplete gage datasets for both stream gages and reservoirs gages can be attributed to budget limitations and anthropogenic changes, i.e. installation of reservoirs. To reconcile the inconsistent datasets, drainage area ratios are used to extrapolate and interpolate gage datasets. The drainage-area-ratio method (Gupta, 2008) provides a numerical approximation of the missing gage data, using gage datasets upstream or downstream on the same river (Equation 1).

$$Q_y = \frac{Q_x}{A_x} A_y$$

Equation 1: Drainage-Area-Ratio Method

$Q_y = Flow\ at\ gaged\ site\ Y\ of\ drainage\ area\ A_y\ [L^3/\,T]$

$Q_x = Flow\ at\ gaged\ site\ X\ of\ drainage\ area\ A_x\ [L^3/\,T]$

$A_y = Drainage\ area\ of\ unavailable\ gaging\ station\ record\ Y\ [L^2]$

$A_x = Drainage\ area\ of\ available\ gaging\ station\ record\ X\ \ [L^2]$

The numerous array of reservoir inflow calculations tolerate for thoroughness, as well as discontinuity. All reservoir inflow calculations share the a priori mass balance approach. The method selection for the calculation of reservoir inflow is subjective and ultimately should be selected on a case by case basis. There is one methods used to calculate reservoir inflows in this study. It is the "evaporation reservoir inflow method" (method applied to USACE datasets).

$$I = \Delta S + E + R + Q_{total}$$

Equation 2: Evaporation Reservoir Inflow Method

$I = Inflow\ into\ the\ reservoir\ [L^3/\ T]$

$\Delta S = Change\ in\ reservoir\ storage\ [L^3/\ T]$

$E = Evaporation\ from\ the\ reservoir\ [L^3/\ T]$

$R = \ Total\ release\ from\ the\ reservoir\ [L^3/\ T]$

$Q_{total} = Total\ net\ pumpage\ out\ of\ the\ reservoir\ [L^3/\ T]$

The calculated reservoir inflow is subject to measurement error and numerical error. The evaporation parameter is arguably the most difficult parameter to estimate when calculating reservoir inflow. The uncertainty in measurement often leads to negative reservoir inflow values, which violates the conservation of mass theory. Reservoir release rates can also be inaccurate due to the imperfect nature of setting the gate height at the project. To resolve these inconsistencies the reservoir inflow values are numerically smoothed by scaling positive inflows and rectifying negative inflows. The smoothed inflow algorithm is applied over a monthly time period with a daily time step and preserves the volume of the monthly total (Equation 3, Equation 4, Equation 5, and Equation 6). There are additional inflow smoothing methods available, but this method is sufficient to resolve negative reservoir inflows in this case.

$$Montly\ Total\ Inflow = \sum_i^{i_f} I_i$$

Equation 3: Monthly Total Inflow Method

$$\text{Nonnegative Inflow} = \begin{Bmatrix} if\ I_i < 0 \\ 0 \\ else \\ I_i \end{Bmatrix}$$

Equation 4: Nonnegative Inflow Method

$$Montly\ Total\ Nonnegative\ Inflow = \sum_{i}^{i_f} Nonnegative\ Local$$

Equation 5: Monthly Total Nonnegative Inflow Method

$$Smoothed\ Inflow = \left\{ \begin{matrix} if\ Monthly\ Total\ Inflow < 0\ OR\ Montly\ Total\ Nonnegative\ Inflow = 0 \\ Nonnegative\ Inflow * \ 0 \\ else \\ Nonnegative\ Inflow * \dfrac{Monthly\ Total\ Inflow}{Montly\ Total\ Nonnegative\ Inflow} \end{matrix} \right\}$$

Equation 6: Smoothed Inflow Method

$I = Inflow\ into\ the\ reservoir\ on\ the\ i^{th}\ day\ [L^3/\ T]$

$i = i^{th}\ day\ of\ the\ month\ []$

$i_f = last\ day\ of\ the\ month\ []$

$Montly\ Total\ Nonnegative\ Inflow = Summation\ of\ the\ monthly\ nonnegative\ inflows\ [L^3/\ T]$

$Montly\ Total\ Inflow = Summation\ of\ the\ monthly\ reservoir\ inflows\ [L^3/\ T]$

$Nonnegative\ Inflow = A\ nonnegative\ dataset\ of\ the\ reservoir\ inflows\ [[L^3/\ T]: [L^3/\ T]]$

$Smoothed\ Inflow = A\ smoothed\ dataset\ of\ the\ reservoir\ inflows\ [[L^3/\ T]: [L^3/\ T]]$

The methods presented above along with the RiverWare modeling software have permitted for the development of POR hydrology for the Guadalupe Watershed. The following Application section will describe how these methods were implemented within the framework of the RiverWare modeling software and the precursor to the RiverWare modeling software.

8.5 RIVERWARE HYDROLOGY MODEL APPLICATION

The POR hydrology needed to evaluate the Guadalupe watershed requires the use of numerical models. RiverWare is a river system modeling tool developed by CADSWES (Center for Advanced Decision Support for Water and Environmental Systems). RiverWare 6.9.1 was used to analyze the hydrology and hydraulic processes of Canyon Lake and the river reaches within the Guadalupe Watershed. The hydrology and hydraulic analysis includes the use of a multiple-run and simulation-run RiverWare model. The multiple-run RiverWare model produced the POR hydrology from January 1935 to December 2015 for all stream and reservoir gage sites. The POR hydrology is the naturalized local flows, where major anthropogenic impacts have been removed, including effects of reservoir regulation. The simulation-run RiverWare model used the POR hydrology datasets to simulate Canyon Reservoir's pool elevation with reservoir regulation policies incorporated for the entire POR, which will be used in the statistical frequency analysis portion of the study.

The process for developing POR hydrology, for the reservoirs and control points or stream gages of interest, is to assimilate historical reservoir inflow and stream flow datasets, then implement drainage-area-ratio methods and reservoir inflow smoothing algorithms in a multiple-run RiverWare model to numerically solve for the POR hydrology. Analyzing pool elevations and operational release over the POR requires the POR hydrology and reservoir operational policies and rule sets incorporated into a simulation-run RiverWare model. The reservoir operational policies and rule sets applied to reservoirs can be compared to historical pool elevations, releases, and local inflows to verify consistency with historical datasets. Ultimately the policies and rule sets can be applied to the POR hydrology to establish synthetic pool elevation and reservoir operation before the reservoirs existed.

The POR hydrology developed by SUPER was compared with the re-developed POR hydrology developed by RiverWare to show consistency. The comparison between POR hydrology developed in SUPER and RiverWare yielded similar historical inflows for all datasets. The small hydrologic differences can be attributed to the numerical method differences in SUPER and RiverWare, and the fact that for this Riverware update, the Gonzales gage was included into the hydrologic computations. The Gonzales gage was added to the USGS network in 1996 and SUPER did not use the available data at the time. Usually the POR hydrology cannot be verified, but the POR hydrology developed by SUPER existed and was used to verify the POR hydrology developed by the simulation-run RiverWare model.

8.6 RIVERWARE OPERATIONAL MODEL APPLICATION

The POR operational model was used to simulate Canyon Reservoir's releases and general operations. Construction began on Canyon Reservoir in June 1958 and deliberate impoundment began in June 1964. The simulation is run as if Canyon is built and operational for the entire POR.

The simulated releases from Canyon Reservoir are primarily controlled by downstream control point flows at USGS gages that are on the mainstem Guadalupe River. A table below shows the allowable flows at the control points.

Table 8.2: Key Downstream Control Points for Canyon Dam

Key Downstream Control Points (USGS Gaging Stations)					
a. Release Schedule		Control Point Discharge (cfs)			
Canyon Dam Pool Elevations (feet)	Recommended Max Allowable Release from Canyon Dam (cfs)	Guadalupe River above Comal River at New Braunfels, TX NBRT2 (08168500)	Guadalupe River at Gonzales, TX GNLT2 (08173900)	Guadalupe River at Cuero, TX CUET2 (08175800)	Guadalupe River at Victoria, TX VICT2 (08176500)
909.0 - 911.0	1,500	d. 1,500	12,000	12,000	12,000
911.0 - 943.0	5,000	. 12,000	12,000	12,000	12,000

The Riverware simulation model executes all flood control releases so as to maximize flood release within the period of perfect knowledge. This period is defined as: the number of timesteps for which the forecast will equal the Deterministic Incremental Local Inflow, i.e., the forecast is known with complete certainty. In real time historical operations, there are numerous and event-specific reasons as to why the reservoir was operated the way it was. Meteorological forecasts from the National Weather Service, as well as river stage forecasts issued by the West Gulf River Forecast Center could both potentially influence the rate of release from the project.

For example, in Figure 8.2, it is apparent that the Riverware simulated pool elevation drops at a much quicker rate than the historical record shows. When looking at the releases in Figure 8.3 that correlate to the pool elevations in Figure 8.2, the releases rise and fall at a much greater rate than the historical releases. The historical releases were more conservative, as apparent at the end of October, when the historical releases were just beginning to release a few hundred CFS, Riverware was at a 4800 CFS release. This difference is likely due to the fact that Riverware has the period of perfect knowledge, and the fact that meteorological forecasts were uncertain at the time, so the Water Management Section

The simulation ruleset for conservation releases was based primarily on FERC (Federal Energy Regulatory Commission) minimum Flows, TCEQ (Texas Commission for Environmental Quality) permits, contract releases, and Trout Unlimited releases. For most months, the FERC minimums were the controlling minimum flow. For Canyon Reservoir, FERC defined drought as: "45 consecutive days of inflow below 90 cfs". For the first attempt at a conservation ruleset, a moving 45 day period was set and drought was triggered in the model when total inflows over the period totaled less than 4,050 DSF (day-second-feet). Through calibration of the period of record, that period total was changed to 3,050 DSF to better match historical operations. Calibration was focused on the period from 2005-2015. This period of calibration is shown in Figure 8.19.

The calibration of the simulation-run RiverWare model used the POR hydrology to perform reservoir operations to mimic historical operations and historical pool elevations. The process of calibration for Canyon Reservoir was iterative. The path taken for calibration was an attempt to mimic as close as possible, the flood and conservation release schedule for the last 10 years, from 2005-2015. While flood operations have remained fairly consistent over the years, conservations releases have changed due to a variety of issues, including environmental and recreational releases. The historical pool elevation when compared to the simulated pool elevation shows agreement starting in the mid-1990's. (Figure 8.19). The pool elevation comparison does not have the same level of agreement in the 1970's and 1980's and can be attributed to the changes in conservation operations that have been made throughout the years at the reservoir.

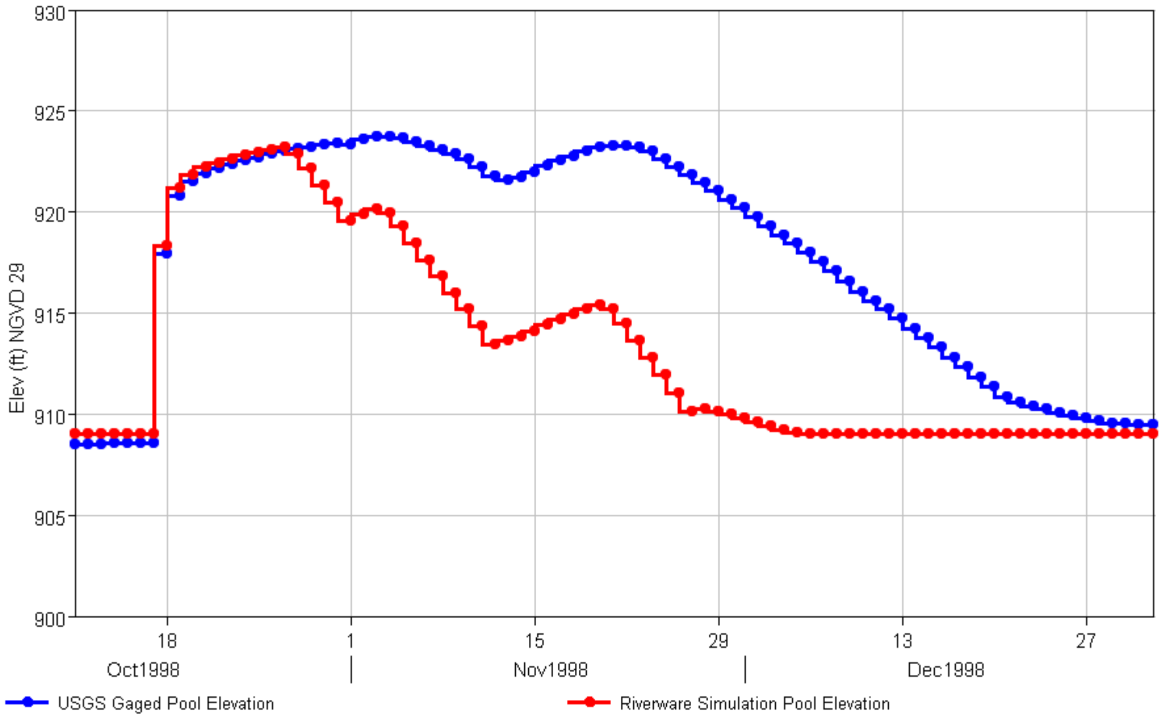


Figure 8.2: Simulated Pool Elevation Compared to Canyon Lake's Historical Pool Elevation for Fall 1998 event

In Figure 8.2 and Figure 8.3, it is apparent that the Riverware simulated release was more aggressive in making large releases from Canyon Reservoir than the historical record shows happen in reality. The Fall 1998 event saw the majority of rainfall volume fall below Canyon Dam. There were deaths and massive property damage to multiple homes downstream. The Water Management section allowed recovery efforts for bodies to finish and allow all other emergency operations to finish before slowly initiating releases from the dam.

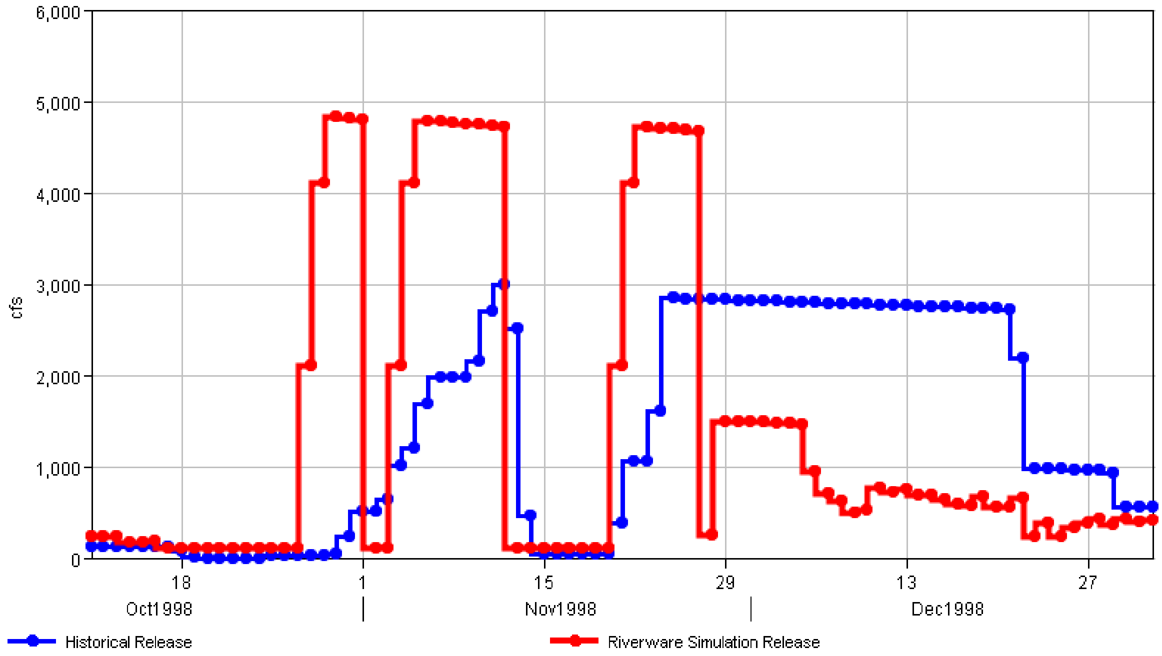


Figure 8.3: Simulated Reservoir Release Compared to Canyon Lake's Historical Release for Fall 1998 event

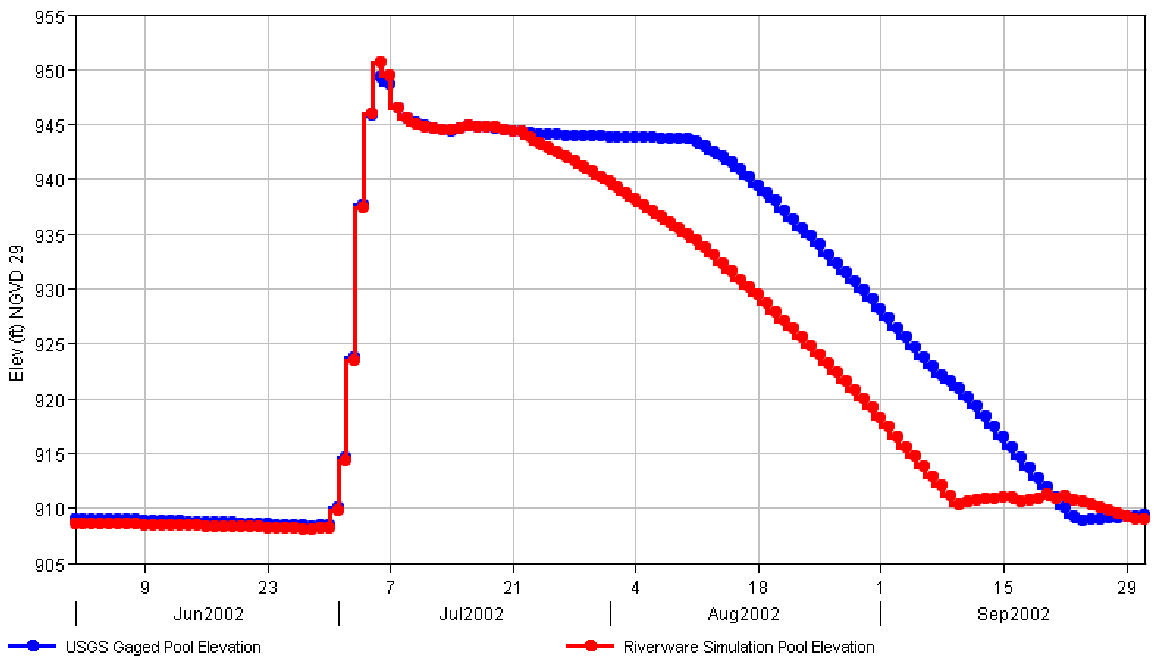


Figure 8.4: Simulated Pool Elevation Compared to Canyon Lake's Historical Pool Elevation for Summer 2002 event

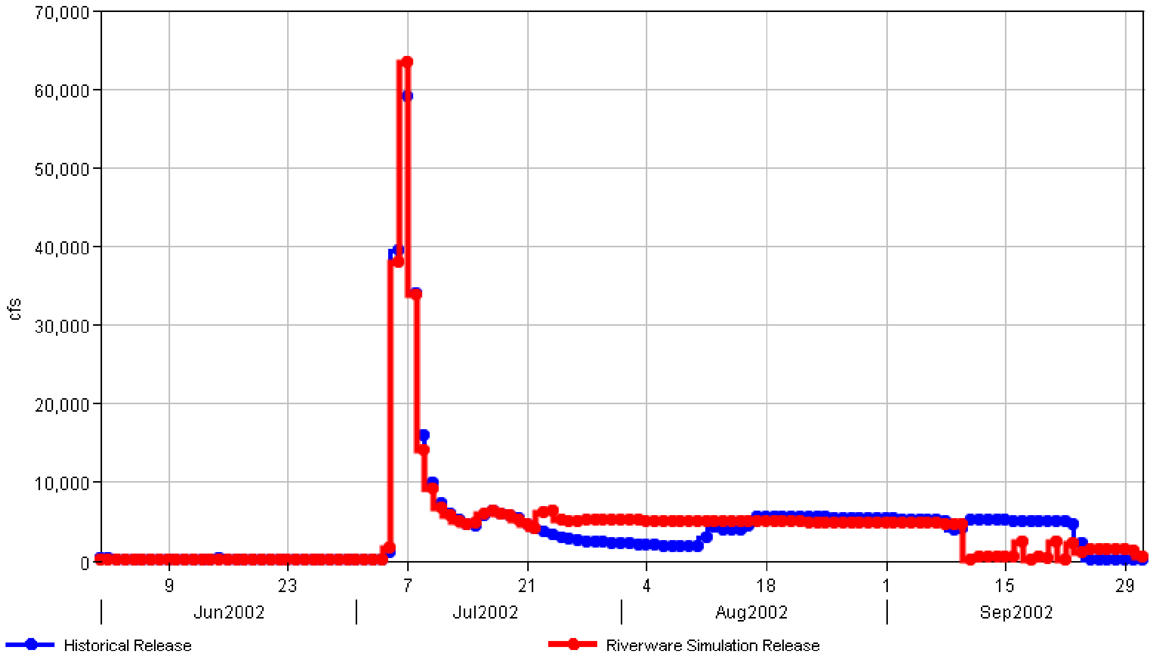


Figure 8.5: Simulated Reservoir Release Compared to Canyon Lake's Historical Release for Summer 2002 event

Similarly to the previous figures, Figures 8.4 and 8.5 show the Riverware simulation being more aggressive in filling downstream control space than the historical record. For the Summer 2002 event, due to large emergency spillway flows from Canyon Dam there were large areas downstream that suffered property damage. The Water Management section allowed debris cleanup and all other emergency operations to finish before slowly initiating releases from the dam.

The reasoning behind the differences shown in Figures 8.2 through 8.5 will be similarly applicable to the rest of the storm events covered in the plots below.

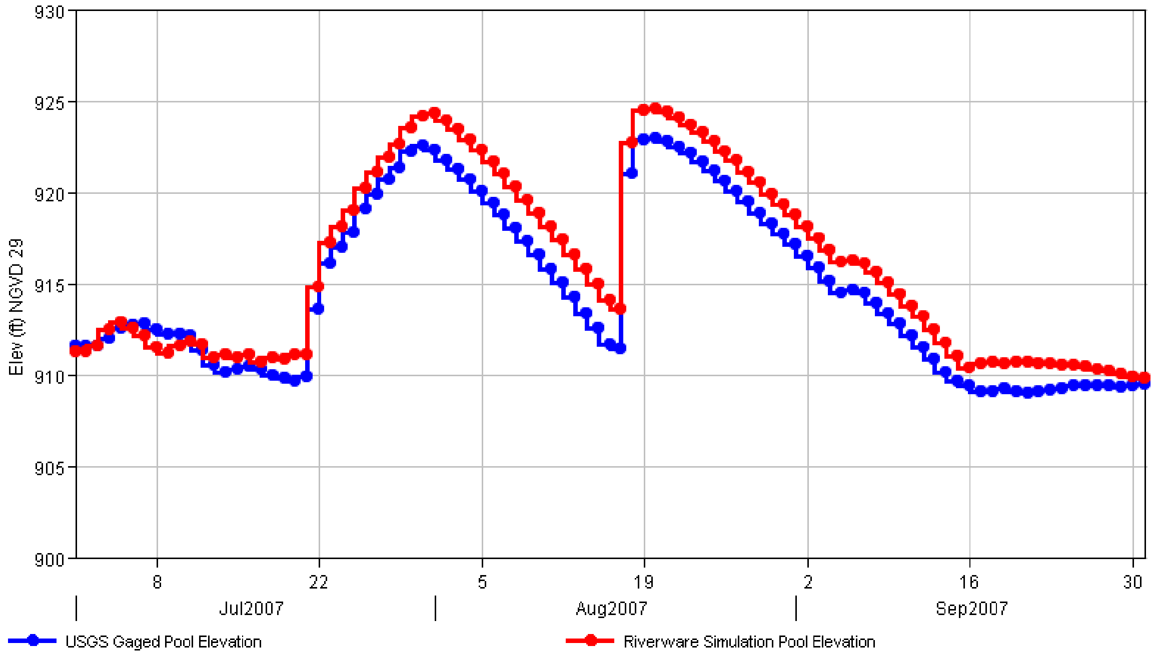


Figure 8.6: Simulated Pool Elevation Compared to Canyon Lake's Historical Pool Elevation for Summer 2007 event

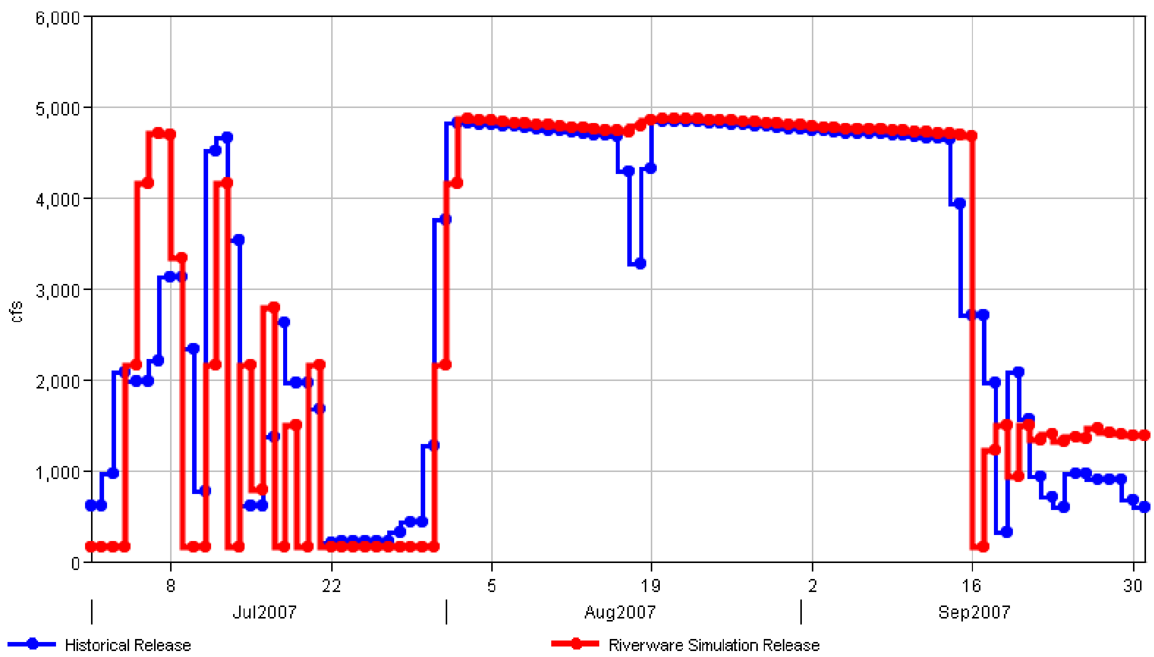


Figure 8.7: Simulated Reservoir Release Compared to Canyon Lake's Historical Release for Summer 2007 event

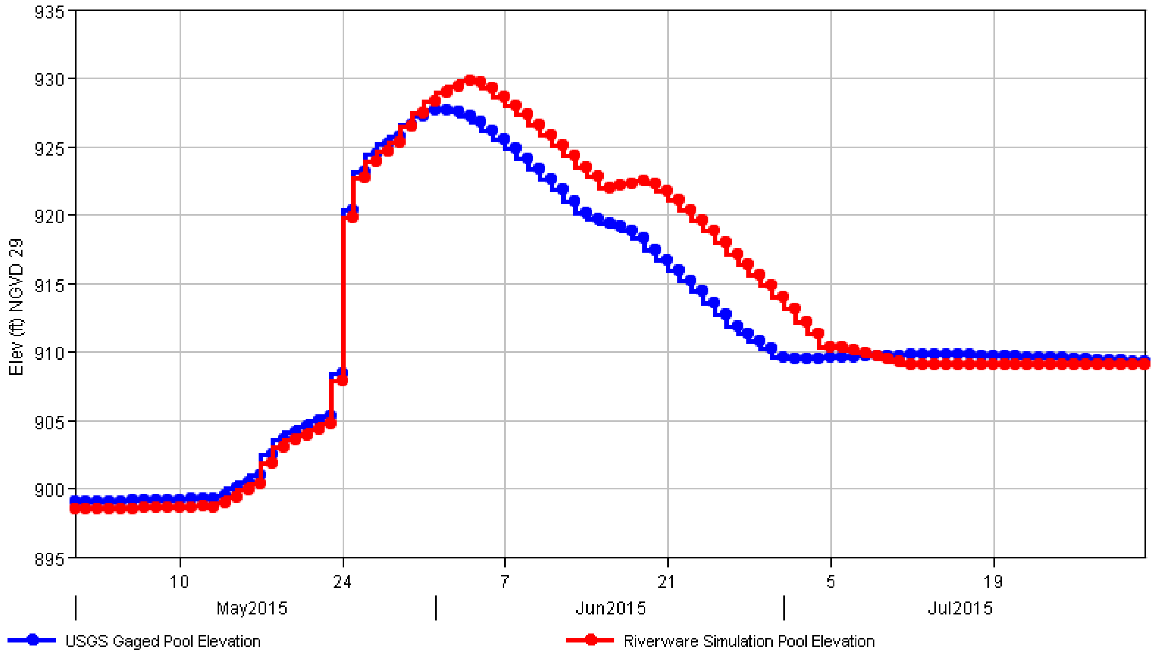


Figure 8.8: Simulated Pool Elevation Compared to Canyon Lake's Historical Pool Elevation for Spring 2015 event

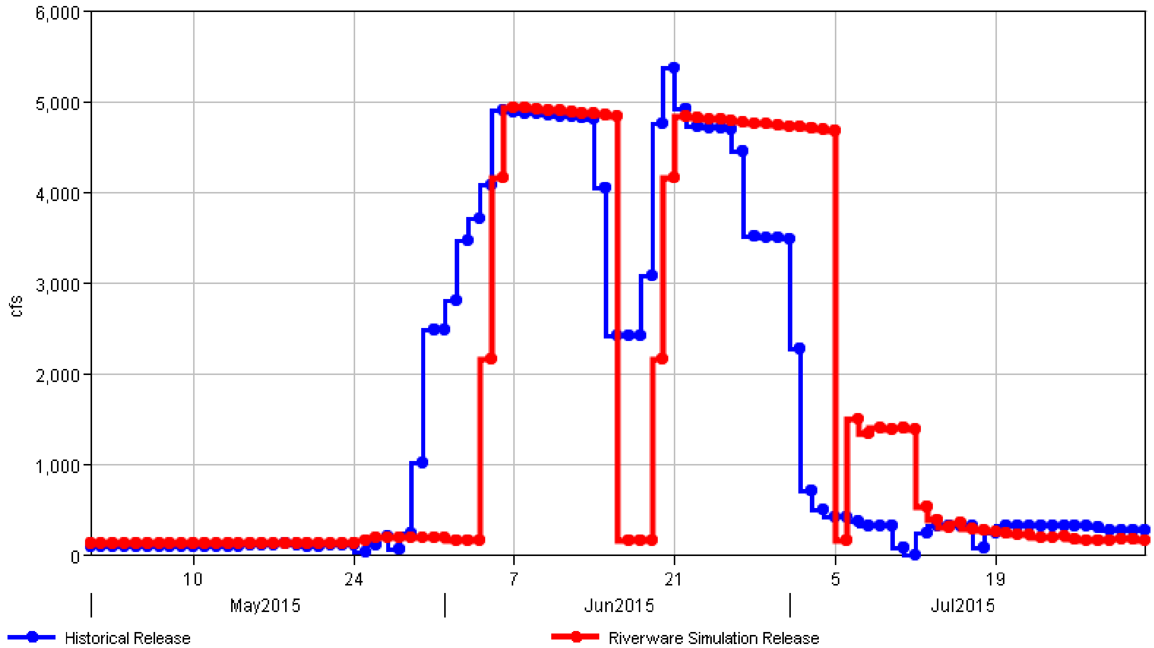


Figure 8.9: Simulated Reservoir Release Compared to Canyon Lake's Historical Release for Spring 2015 event

In Figures 8.8 and 8.9, the plots show that the actual historical release was more aggressive than the Riverware simulation. In real-time reservoir regulation, the Fort Worth District Water Management section coordinates and relies heavily on the West Gulf River Forecast Center's forecasts on downstream control points. For this event, the recession of the downstream control points Cuero and Victoria was forecasted to recede faster than the Riverware model. Depending on watershed characteristics at the time of the precipitation events, rainfall runoff and routing parameters are calibrated by the West Gulf forecasters.

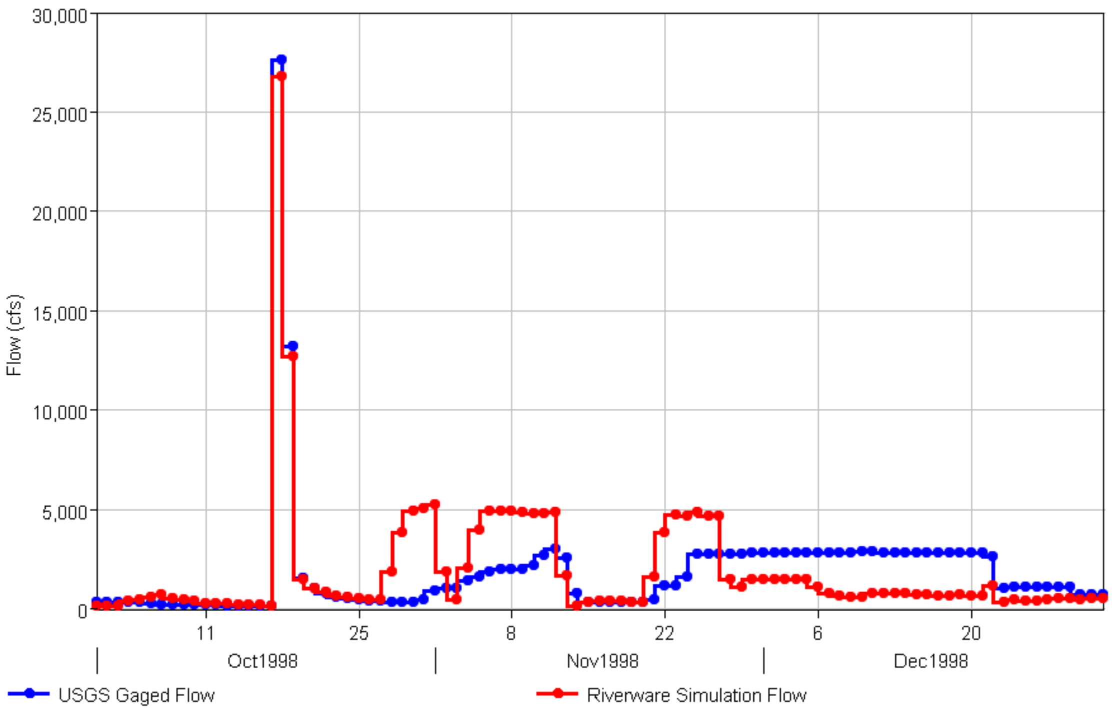


Figure 8.10: Simulated flow compared to historical gaged flow at USGS Gage 08168500 Guadalupe Rv abv Comal Rv at New Braunfels, TX for Fall 1998 event

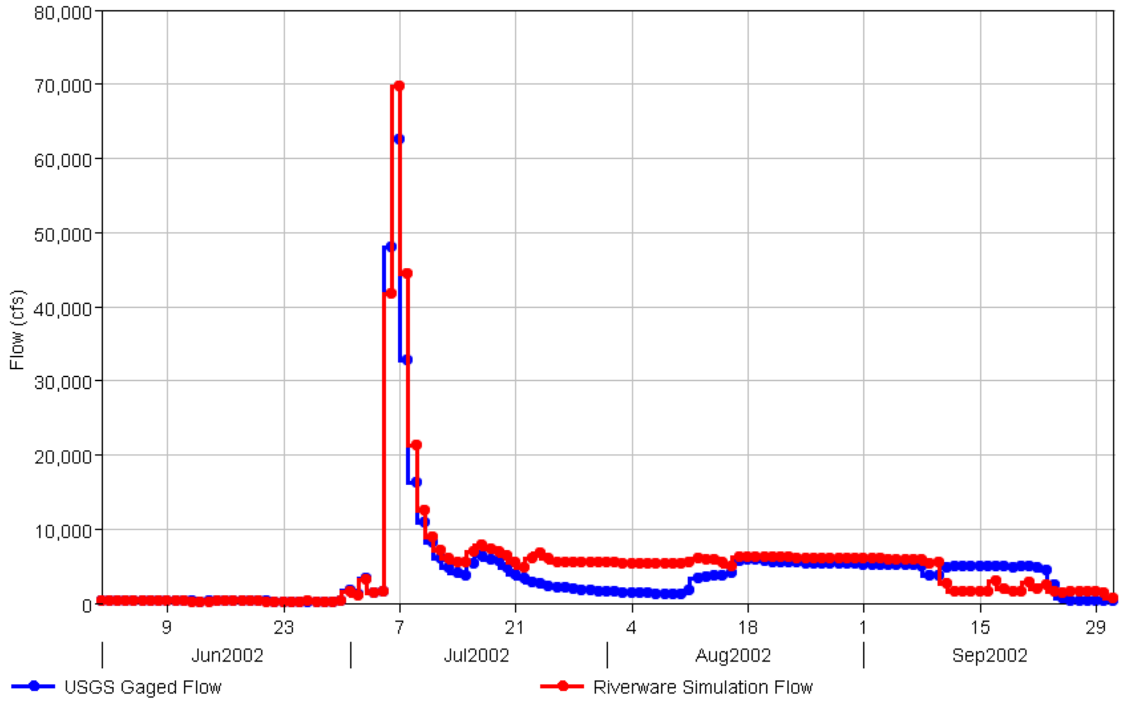


Figure 8.11: Simulated flow compared to historical gaged flow at USGS Gage 08168500 Guadalupe Rv abv Comal Rv at New Braunfels, TX for Summer 2002 event

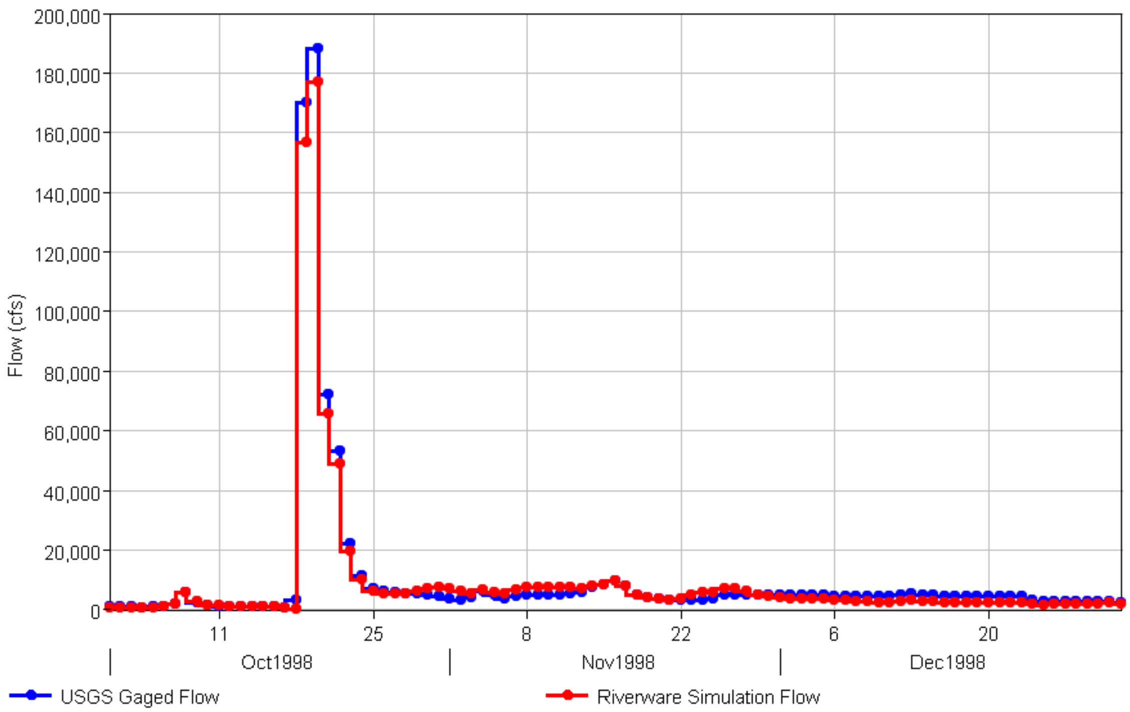


Figure 8.12: Simulated flow compared to historical gaged flow at USGS Gage 08173900 Guadalupe Rv at Gonzales, TX for Fall 1998 event

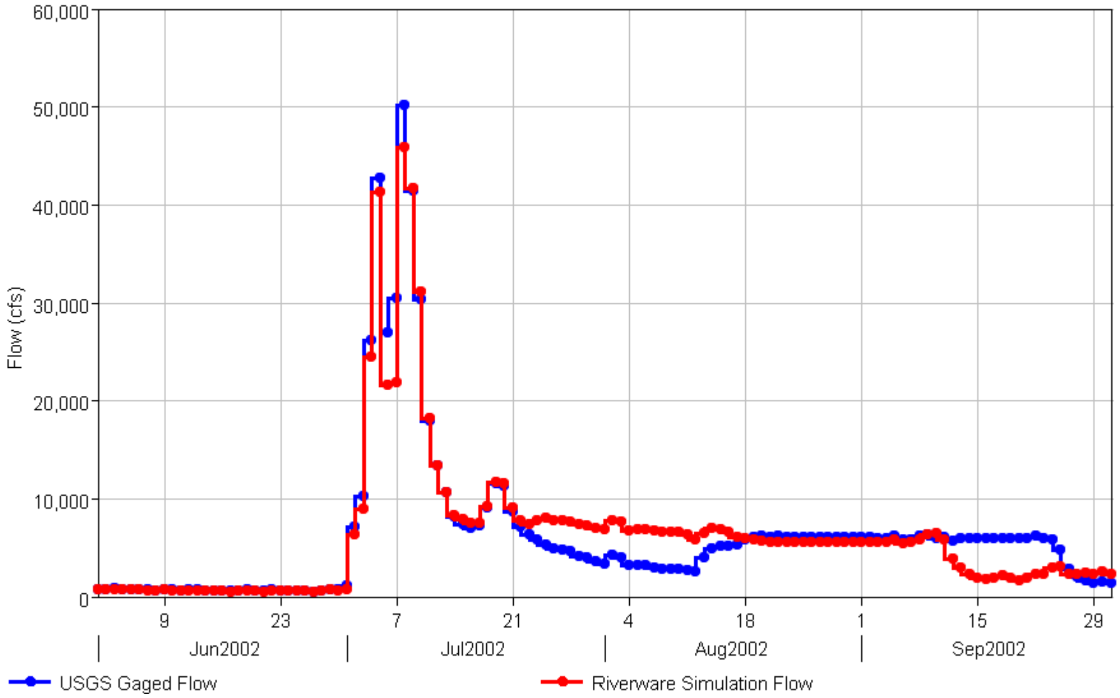


Figure 8.13: Simulated flow compared to historical gaged flow at USGS Gage 08173900 Guadalupe Rv at Gonzales, TX for Summer 2002 event

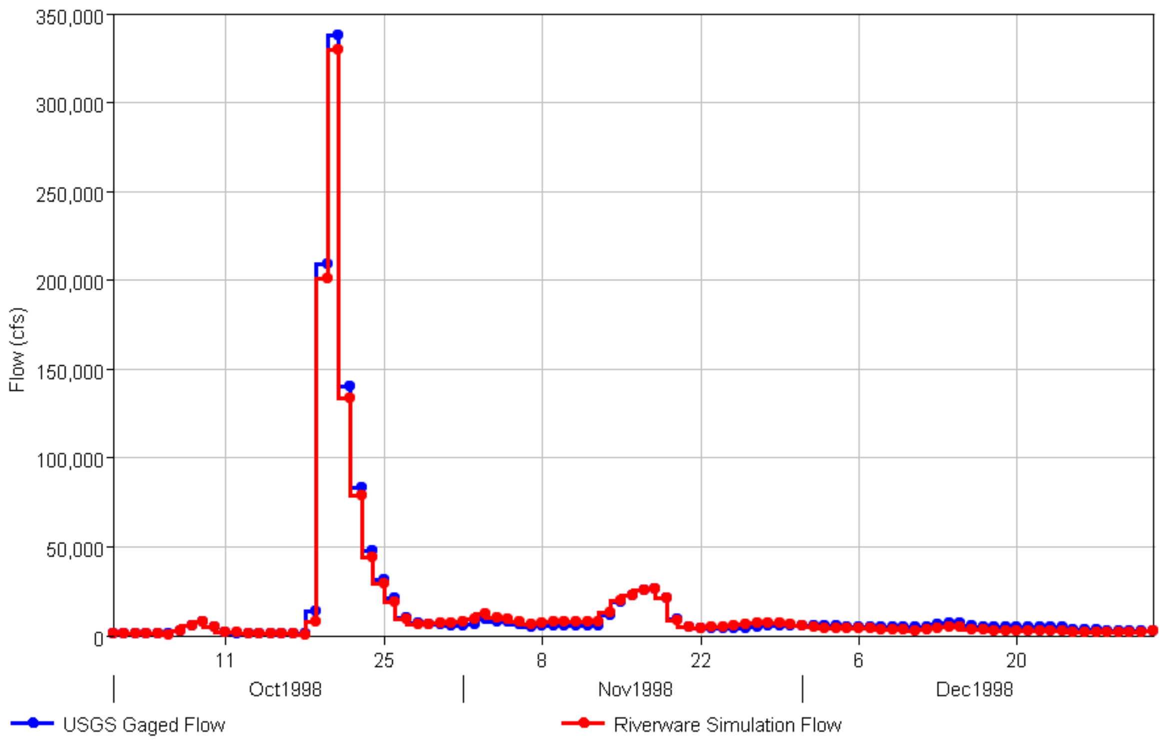


Figure 8.14: Simulated flow compared to historical gaged flow at USGS Gage 08175800 Guadalupe Rv at Cuero, TX for Fall 1998 event

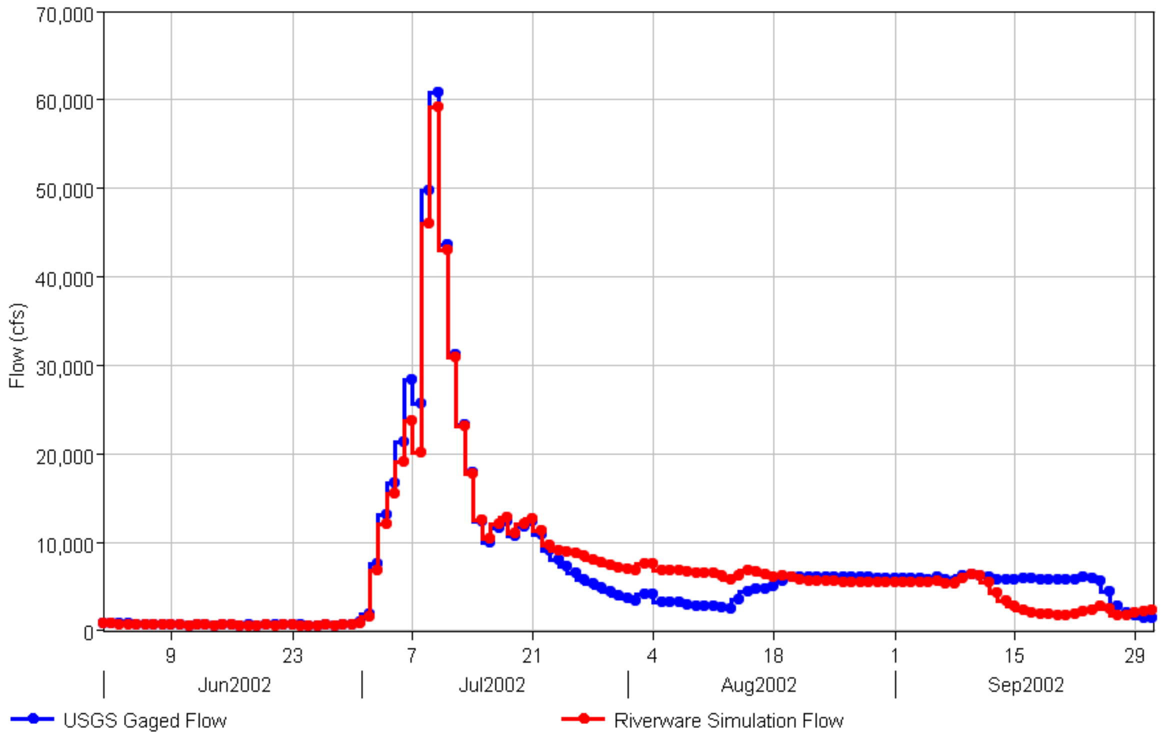


Figure 8.15: Simulated flow compared to historical gaged flow at USGS Gage 08175800 Guadalupe Rv at Cuero, TX for Summer 2002 event

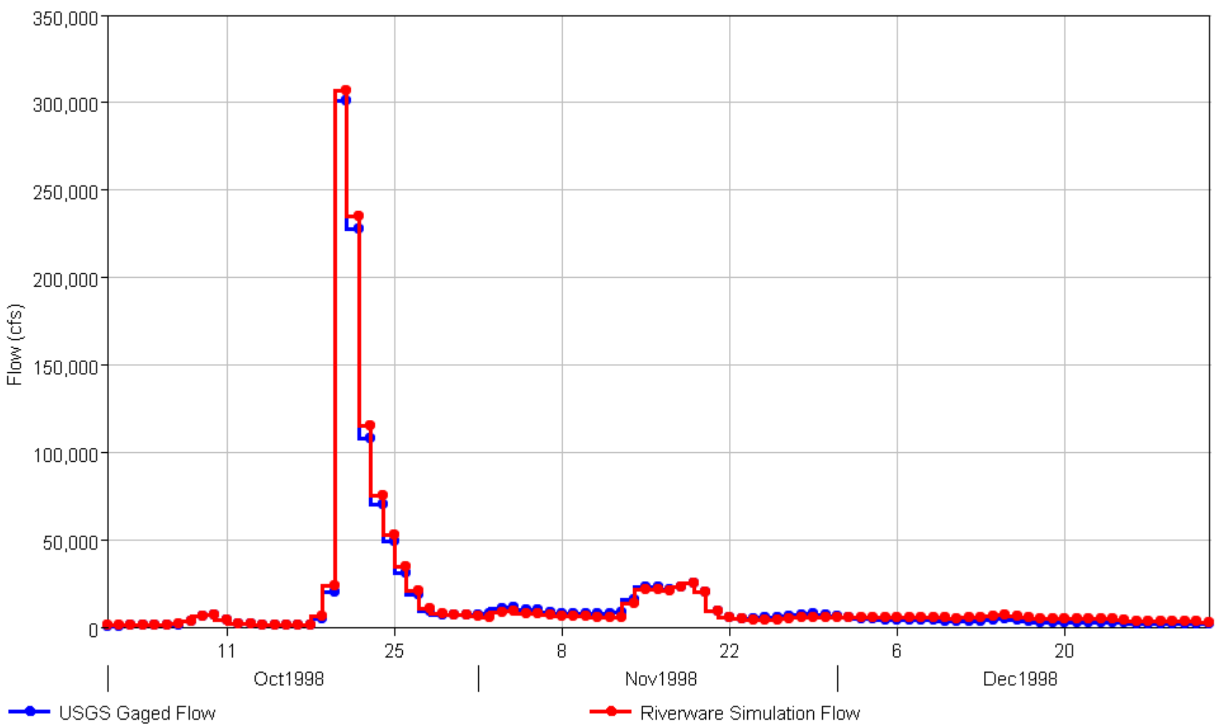


Figure 8.16: Simulated flow compared to historical gaged flow at USGS Gage 08176500 Guadalupe Rv at Victoria, TX for Fall 1998 event

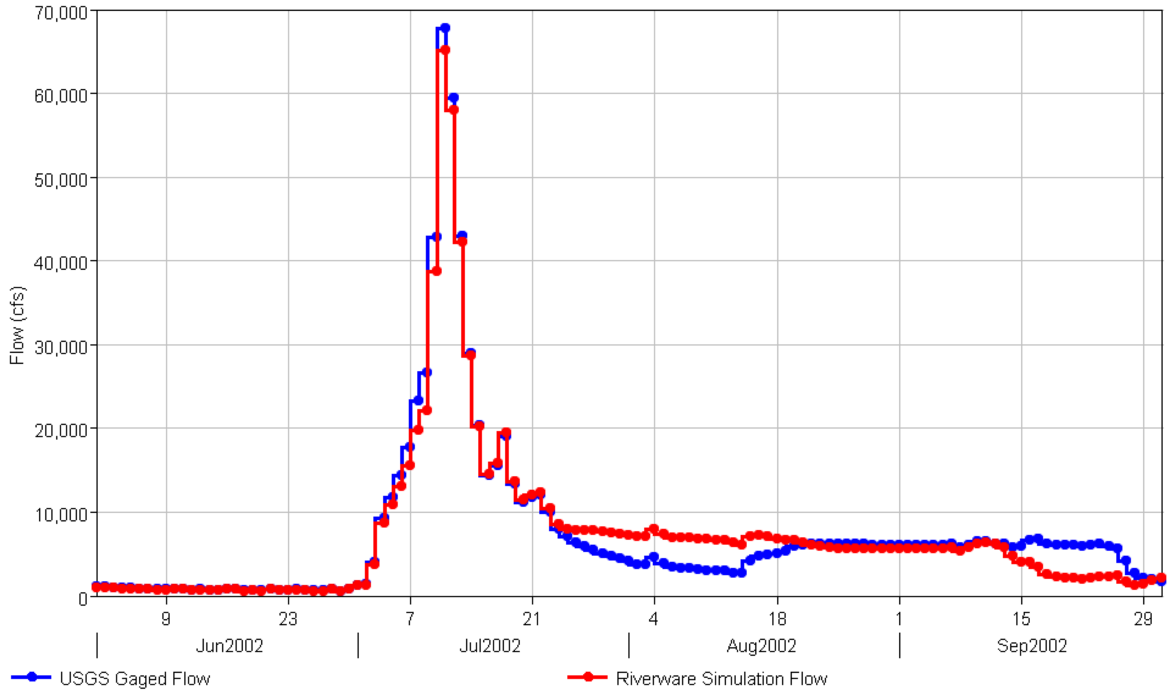


Figure 8.17: Simulated flow compared to historical gaged flow at USGS Gage 08176500 Guadalupe Rv at Victoria, TX for Summer 2002 event

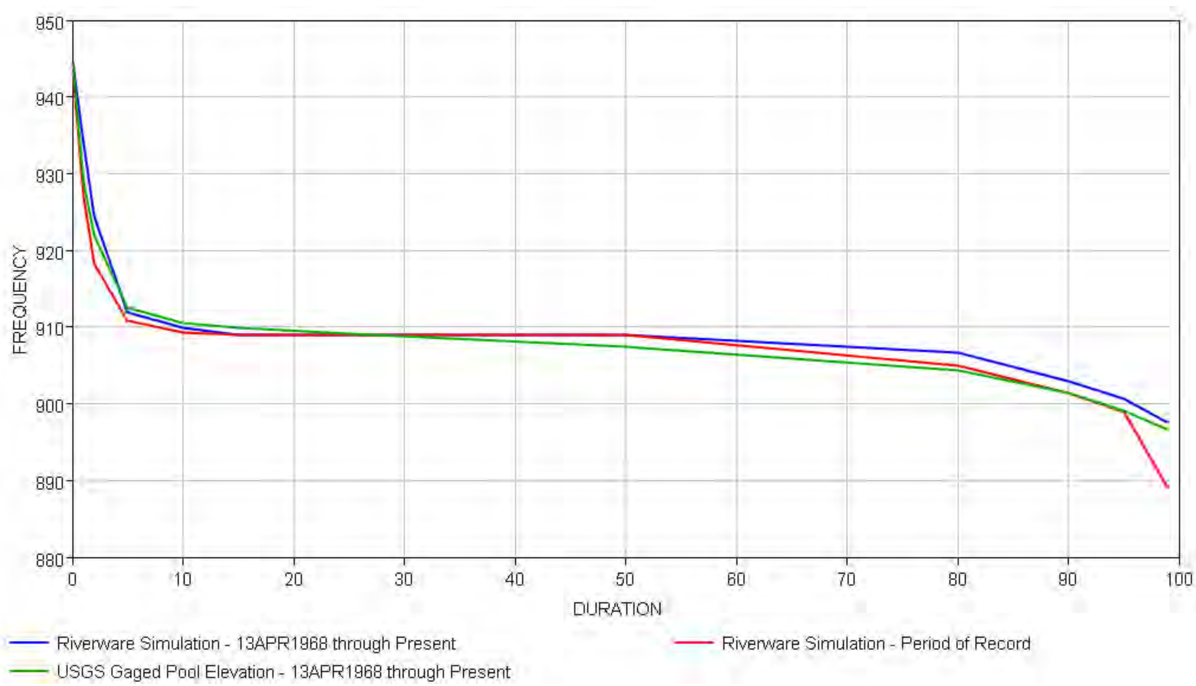


Figure 8.18: Pool Elevation Duration Frequency curve comparing gaged pool elevation to two different Riverware simulation periods. The red Period of Record curve in the above figure includes the Texas drought of the 1950's.

In Figure 8.18, an elevation duration curve is shown for three different scenarios. A historical data curve is shown using USGS pool elevation data. The historical dataset begins on 13APR1968, which is the date that the reservoir reached the conservation pool of elevation 909.00 FT. There is also a curve on the plot that is for that same period of time, but using the simulated Riverware pool elevations. Lastly, there is a curve on the plots that has the entire (1935-2015) simulated period of record included in it's dataset. It is important to note that this POR data set, as seen in Figure 8.19, includes the drought of the 1950's. This drought is the drought of record in this simulation run and draws Canyon reservoir to its lowest point in the POR.

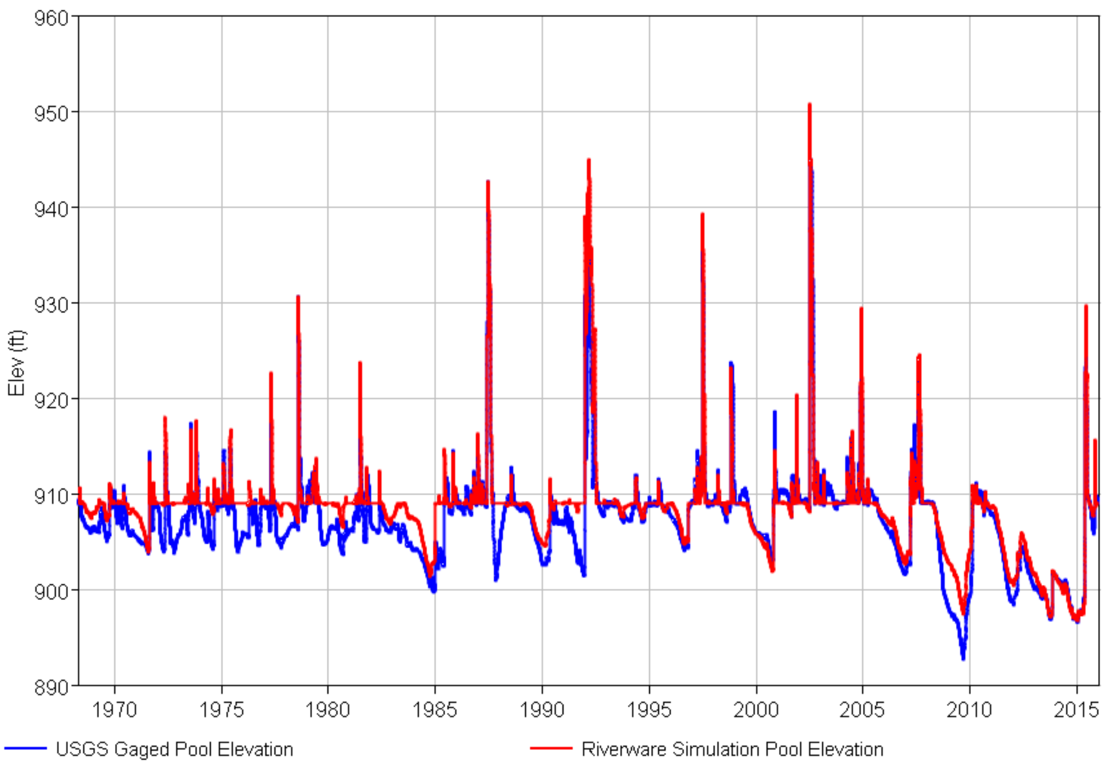


Figure 8.19: Pool Elevation for Canyon Dam. Starting date was April 13, 1968, the date at which Canyon Reservoir reached Conservation Pool of 909.00 FT.

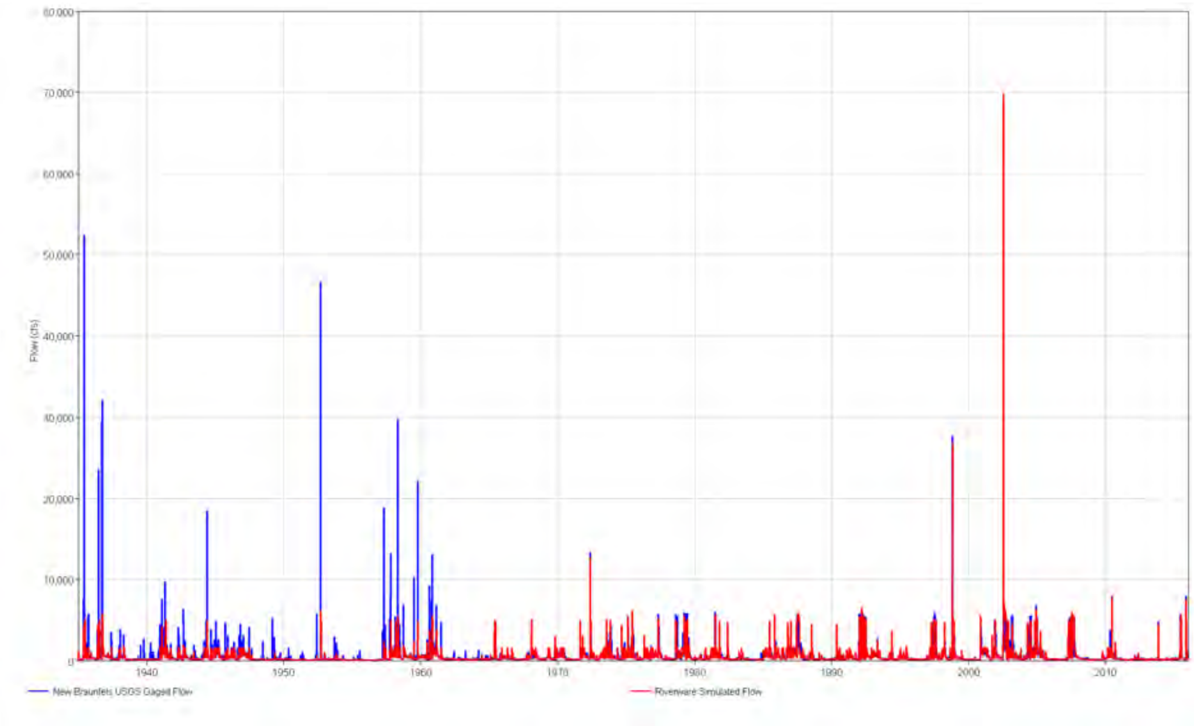


Figure 8.20: Simulated flow compared to historical gaged flow at USGS Gage 08168500 Guadalupe Rv abv Comal Rv at New Braunfels, TX for POR 1935-2015

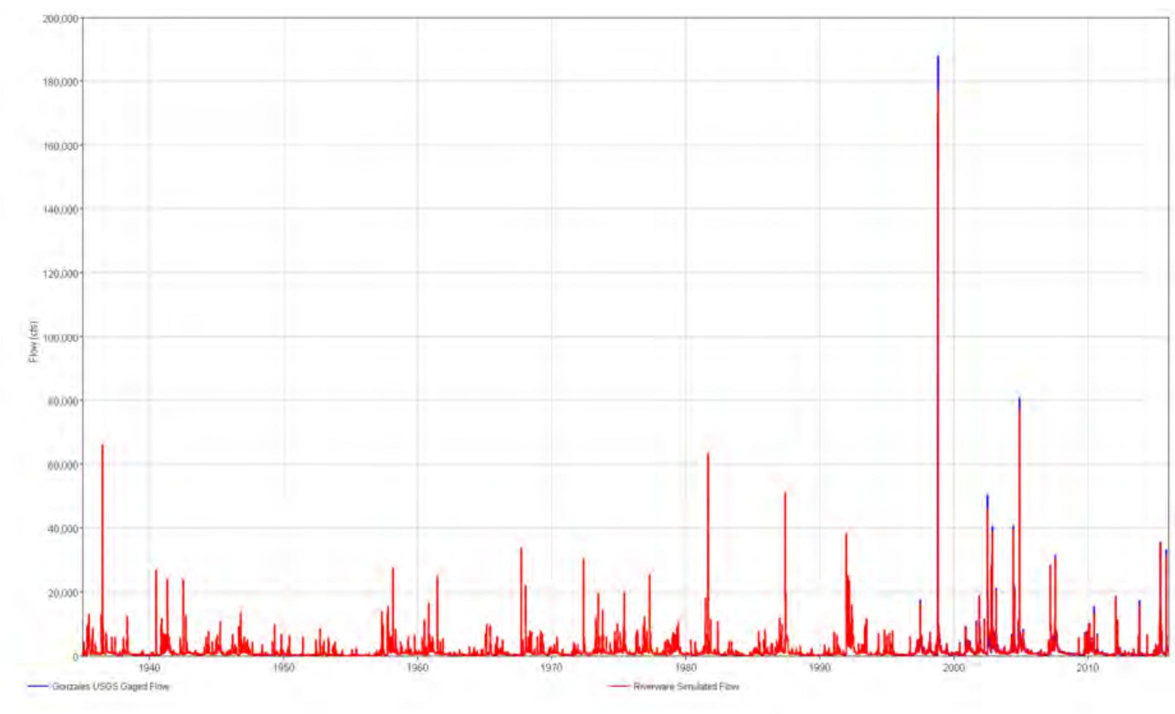


Figure 8.21: Simulated flow compared to historical gaged flow at USGS Gage 08173900 Guadalupe Rv at Gonzales, TX for POR 1935-2015

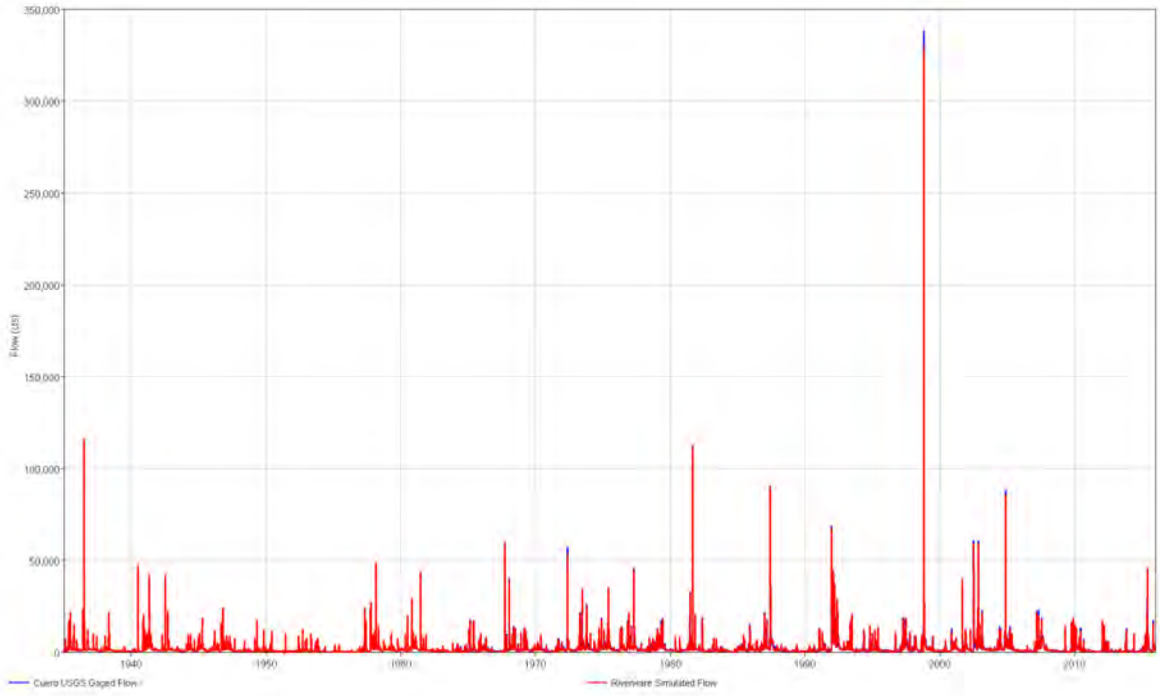


Figure 8.22: Simulated flow compared to historical gaged flow at USGS Gage 08175800 Guadalupe Rv at Cuero, TX for POR 1935-2015

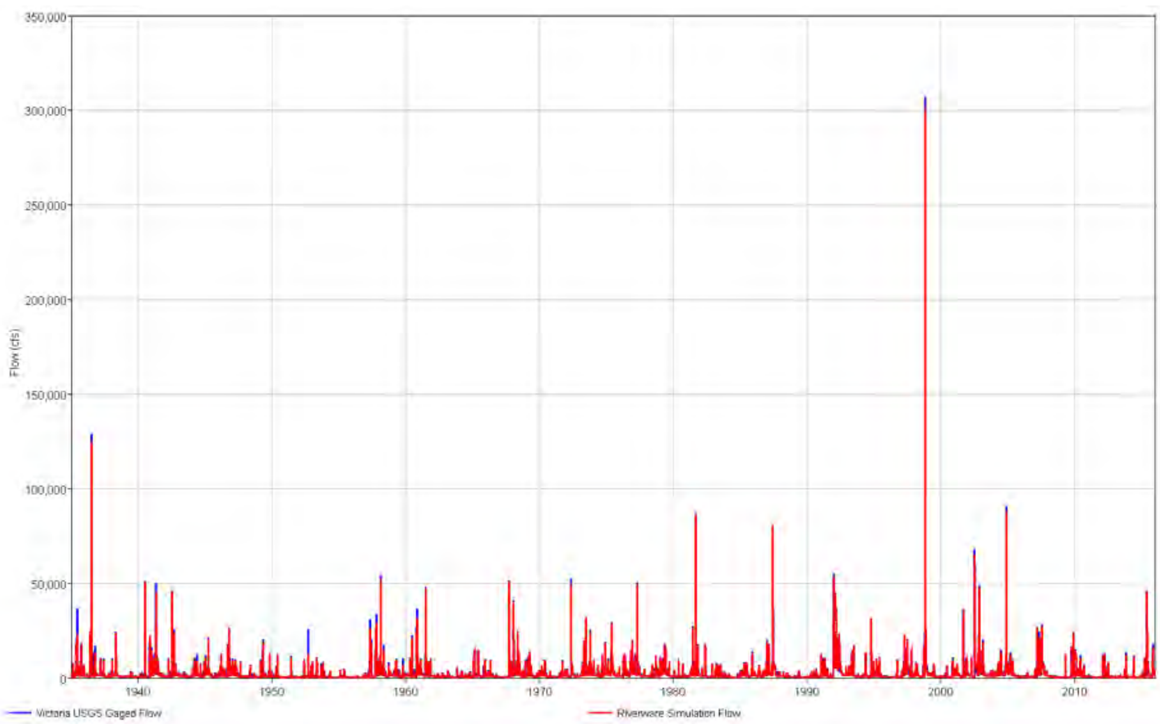


Figure 8.23: Simulated flow compared to historical gaged flow at USGS Gage 08176500 Guadalupe Rv at Victoria, TX for POR 1935-2015

8.7 RIVERWARE MODEL RESULTS AND DISCUSSION

The final product of this analysis is the Period of Record Pool Elevation for Canyon Reservoir from Jan 1935 to Dec 2015, as well as the simulated downstream control points. The differences between the historical pool elevation and final RiverWare developed pool elevation can be viewed in Figure 8.19. As previously noted, this comparison plot starts 13APR1968, which is the date at which the impoundment of Canyon Reservoir reached the conservation pool elevation of 909.00 FT. The datasets and numerical methods were vetted and the results were crosschecked with the historical datasets. The final results from the Riverware model will be used to estimate flow frequency at selected locations through additional statistical analysis of the simulated record.

8.8 STREAMGAGE DATA AND STATISTICAL FLOOD FLOW FREQUENCY RESULTS

For the statistical analysis of the RiverWare modeling results, USGS staff analyzed the simulated instantaneous peak streamflow for four USGS streamflow-gaging (streamgages) stations in the RiverWare model: 08168500 Guadalupe River above the Comal River at New Braunfels, Tex. (New Braunfels gage), 08173900 Guadalupe River at Gonzales, Tex. (Gonzales gage), 08175800 Guadalupe River at Cuero, Tex. (Cuero gage), and 08176500 Guadalupe River at Victoria, Tex. (Victoria gage). A peaking factor, described in detail above, was applied to the RiverWare daily time-step data to convert the peak flows to instantaneous peak flows. Peak streamflow frequency analyses were conducted at the gages using the instantaneous annual peak flow data for the entire period of record available from the model. In addition to the analyses performed on the simulated hourly peaks, the same analyses were repeated for the simulated daily peaks and then compared to the flood flow frequency results for the USGS historic analysis performed in chapter 5. Increased scrutiny will be directed towards the simulated instantaneous peak data in the results, with a comparison to simulated daily peak and historic peak analyses thereafter.

The Interagency Advisory Committee on Water Information (IACWD, 1982) provides guidance in so-called Bulletin 17B to compute peak streamflow frequency. The Bulletin 17B guidance was recently updated to Bulletin 17C (England and others, 2018,) and Bulletin 17C is already implemented in USACE HEC-SSP software (USACE, 2016). Bulletin 17C incorporates the expected moments algorithm (EMA), which allows for the incorporation of more complicated or subjective measurements such as paleo-hydrology, interval peaks, and sophisticated gap-infill for years of missing annual peak streamflow records. The 17C analysis also uses the multiple Grubbs-Beck low outlier test, which is capable of identifying very many potentially influencing low floods (PILFs). The multiple Grubbs-Beck test is an improvement on the single Grubbs-Beck test used in Bulletin 17B (Grubbs and Beck, 1972). The presence of low outliers is endemic in Texas flood hydrology (Asquith and others, 1995). Low outliers within a time series of peak streamflow are anticipated to be too small to be representative of large rainfall and runoff events. The multiple Grubbs-Beck test (MGBT), which is available in the aforementioned USACE software package, is suitable for Texas hydrology. In the statistical computations, low outliers are conditionally truncated, but not removed, from the sample. Overall improved fit of the LPIII in the right or high magnitude tail of the fitted distribution is achieved by low outlier detection.

Peak streamflow analyses for this study were made using the HEC-SSP software (USACE, 2016). The HEC-SSP software uses the three-parameter, log-Pearson type III (LPIII) probability distribution, and the use of this distribution represents a type of standard of practice in the United States and is consistent between Bulletins 17B and 17C. The first and second parameters of the LPIII are the arithmetic mean and standard deviation, and the third parameter of the LPIII is skew. For the estimate of skew, the sample skew computed for the data at each gage location was used by HEC-SSP using the "station skew" option. Other skew definitions could be used, but the period of record available for the Gonzales, Cuero, and Victoria gages was deemed sufficient enough not to be weighted with a generalized or regional skew value. After a brief analysis of the New Braunfels gage data, it was determined that the MGBT low outlier test truncated a portion of the period of record large enough that the "station skew" option was not sufficient. Therefore, the New Braunfels gage data was weighted by a regional skew value to account for this truncated period of record. A regional skew value calculated by Judd and others (1996) was applied to the simulated New Braunfels data, although this value should be taken with some uncertainty because of the use of simulated instead of historic peak streamflow data for the gage. The weighted regional skew option was applied to both the simulated instantaneous and daily peak flow data at the New Braunfels gage, but not the USGS historic gage data because not as many low outliers were truncated from that dataset.

Because regulation has the potential to affect peak streamflow in such a way that distributional properties may vary from those expected by the LPIII, the LPIII distribution may not be applicable as the fitted distribution for the New Braunfels gage peak streamflow data. For example, a reservoir's engineered releases during storm events may produce peak streamflows centered on the pre-determined release capacities, resulting in a more step-wise rather than smooth peak frequency curve. As a result, three other probability distributions were fit as a visual comparison to the fitted LPIII distribution. The three probability distributions assessed are the generalized extreme value (GEV), generalized normal (GNO), and the generalized Pareto (GPA). These distributions were chosen for their previous use in extreme value and statistical hydrology analyses, and because by having three parameters, the fit of these distributions can be directly compared to the LPIII distribution. The GEV has been used in hydrological frequency analyses, especially in depth-duration frequency analyses of annual maximum rainfall (Gumbel, 1958; Dey and others, 2016; Salvadori and others, 2007, chapter 1). The GNO is considered useful because it is closely related to the two-parameter and three-parameter log-normal distributions, which has led to its use in extreme value analyses in natural environments. The GPA is unique in that it is generally utilized for peaks-over-threshold analyses, but its inherently low kurtosis provides a uniquely shaped distribution compared to the LPIII, GEV, and GNO (Stedinger and others, 1993; Dey and others, 2016).

A single-purpose script was written in the R programming language (R Core Team, 2016) to fit the alternative distributions for the New Braunfels peak streamflow data. The lmomco package (Asquith, 2016) in R was used to compute the sample L-moments (Hosking and Wallis, 1997) and then convert those L-moments to the parameters of the fitted distributions. Low-outlier thresholds were set to the same MGBT values computed by or manually entered into HEC-SSP and are discussed in further detail in the statistical analyses results below.

08168500 Guadalupe River above the Comal River at New Braunfels, Tex.

The simulated streamgage record for the New Braunfels gage is 1935–2016. Because the peaking factor for the New Braunfels gage was developed using gage data that had been filtered for sustained reservoir releases, the conversion of daily to instantaneous peak flows resulted in some unrealistic peak flows for the New Braunfels simulated gage. The 1999 and 2002 peak flow events were removed from the peaking factor formulation and were subsequently removed from the period of record because of the peaking factor's failure to compute realistic instantaneous peak flows for those two events. To retain the complete period of record, these two events were substituted with USGS hourly flow data for the same two events. Even though these two data points came from the historic dataset, the differences between the two datasets have been mitigated. The 1999 and 2002 peak flow events both occurred after the construction of Canyon Lake and both the simulated and historic peak flows occurred on the same day, indicating that they are associated with the same event.

After the substitution of the extreme events, the 1999 simulated instantaneous peak streamflow was 90,000 cubic feet per second (ft^3/s), which is the simulated peak of record. Figure 8.24 shows the peak streamflow data for the simulated and historic datasets as well as the impoundment of Canyon Lake. The New Braunfels gage is located several miles downstream of Canyon Lake, a flood control and water conservation reservoir. The lake began impoundment in 1968, which had a noticeable influence on historic flows at the New Braunfels gage (Figure 8.24). RiverWare simulated the operations of Canyon Lake throughout the entire simulated period of record, so pre-regulation flows are not observed in the simulated data.

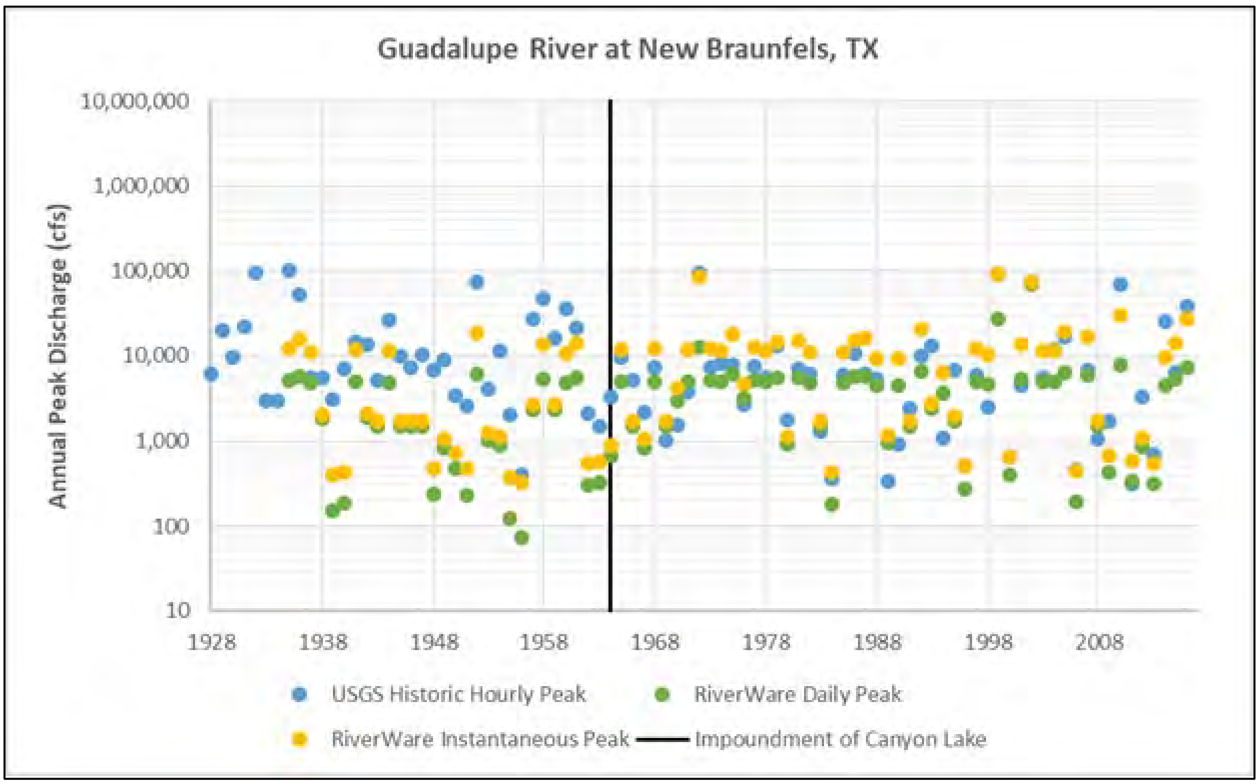


Figure 8.24: USGS historic hourly peak flows, RiverWare daily peak flows, and RiverWare instantaneous peak flow data for the streamgage 08168500 Guadalupe River above the Comal River at New Braunfels, Tex. The impoundment of Canyon Lake is also demarcated on the plot.

The LPIII computed peak streamflow frequency curve for the New Braunfels gage simulated instantaneous data is shown in Figure 8.25. For the New Braunfels gage, the HEC-SSP software computed a low-outlier threshold of 6,500 ft³/s. While this threshold removes approximately half of the simulated peak flow events, it may be considered a reasonable threshold as it is located at an inflection in the curve where flow drops noticeably. The removal of a large portion of the simulated data is why a weighted regional skew value was adopted for the New Braunfels gage. Because of the effects of regulation, the LPIII distribution appears to have some difficulty fitting the New Braunfels gage data.

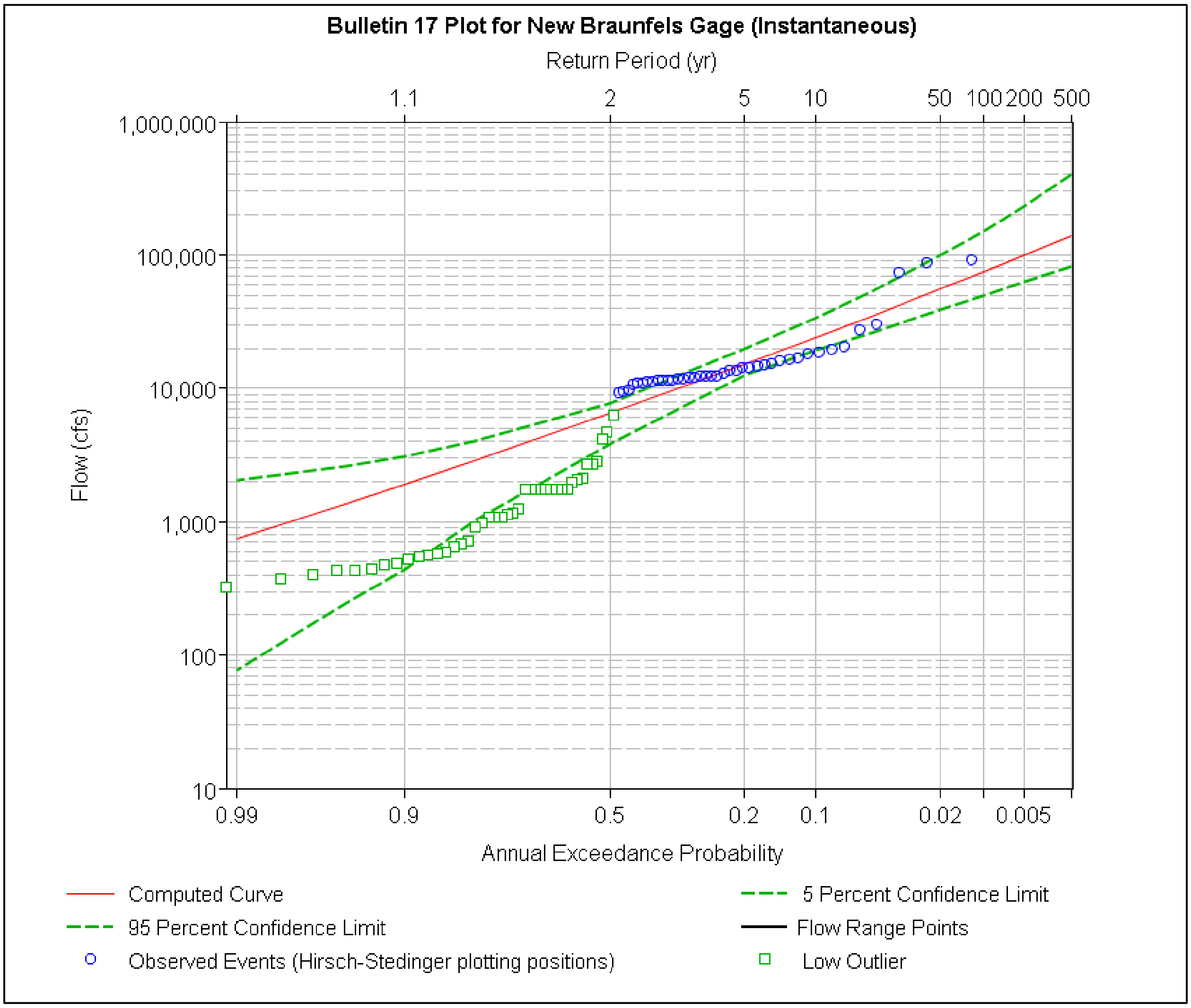


Figure 8.25. Peak streamflow frequency using log-Pearson type III distribution for streamgage 08168500 Guadalupe River above the Comal River at New Braunfels, Tex. instantaneous RiverWare output from screenshot of USACE HEC-SSP software.

Figure 8.26 shows the three alternative probability distributions for the New Braunfels gage. Visually, all three distributions exhibit an improved fit over the LPIII. The curvature of the alternative distributions better match the right tail of the observed peaks, except for the 1972 peak streamflow event, which plots well above the alternative fitted distributions. This event could possibly be a more rare event than its 0.013 Annual Exceedance Probability (AEP) plotting position. The 1972 event appears to be an extreme event, and its plotting position may not be accurate given that the peak flow is nearly three times greater than the second highest event. However, it could be that flow characteristics create a steeper frequency curve for events greater than 30,000 ft^3/s. Without further data in this peak streamflow range, it is difficult to determine which peak streamflow frequency curve is closer to the "true" distribution.

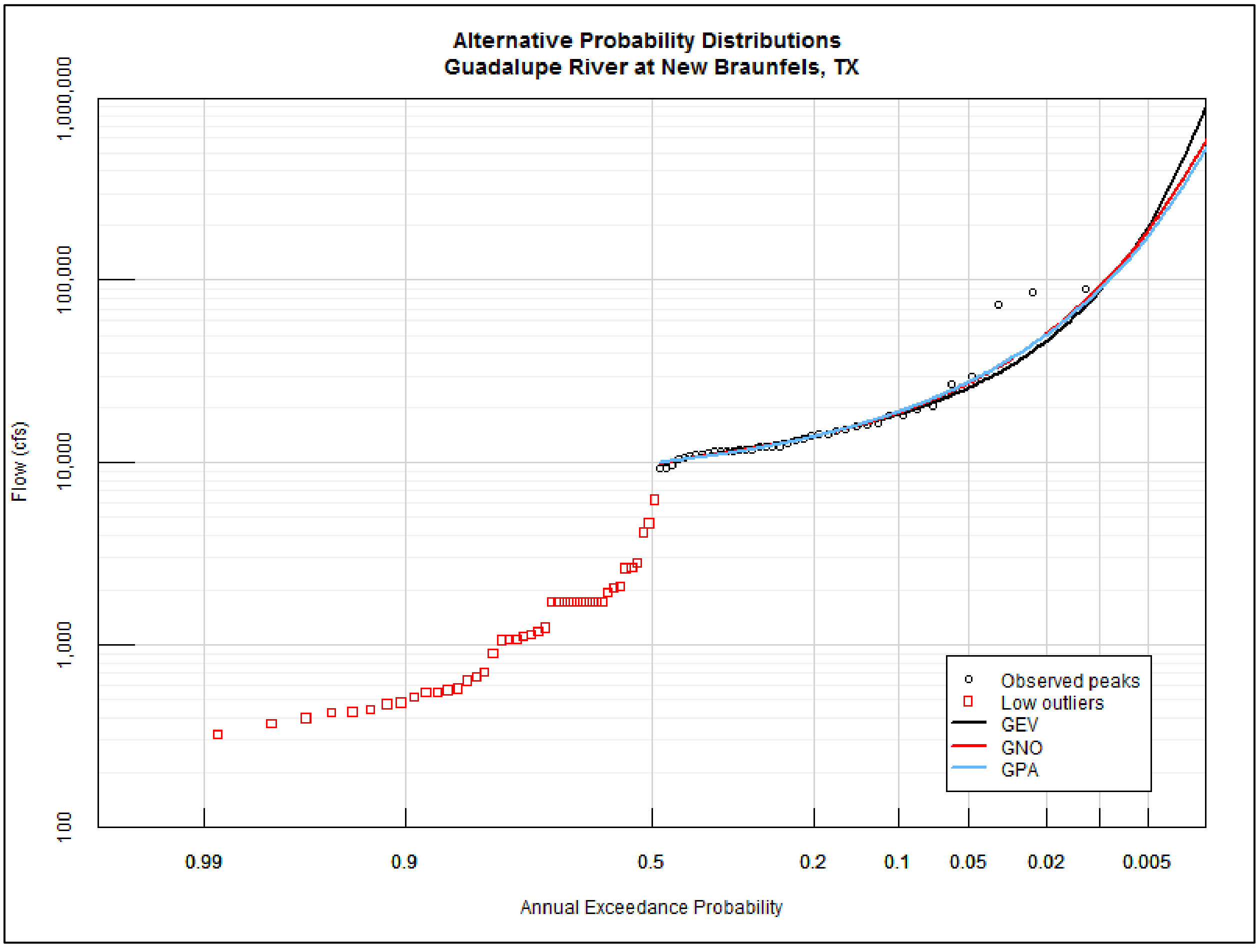


Figure 8.26: Comparison of alternative curve fits for streamgage 08168500 Guadalupe River above the Comal River at New Braunfels, Tex. The observed peaks and low outliers are plotted with the fitted generalized extreme value (GEV), generalized normal (GNO), and generalized Pareto (GPA) distributions.

Figure 8.27 compares the LPIII computed peak streamflow frequency curves for the simulated instantaneous, simulated daily, and USGS historic peak streamflow data at the New Braunfels gage. Extending the regulated period of record back to 1935 through simulation in RiverWare results in a decrease in the frequency curve for the New Braunfels gage, especially in the high flow range. The analysis of USGS historic data was also restricted to peak flows since the construction of Canyon Lake in 1964 so as to not mix regulated and unregulated peak flows. Because of this restriction of the historic data, there is not expected to be a large difference between the historic and simulated instantaneous peak datasets. However, the simulated period of record extends back to 1935, providing further data points for the peak streamflow frequency analysis and leading to a presumably more reliable curve.

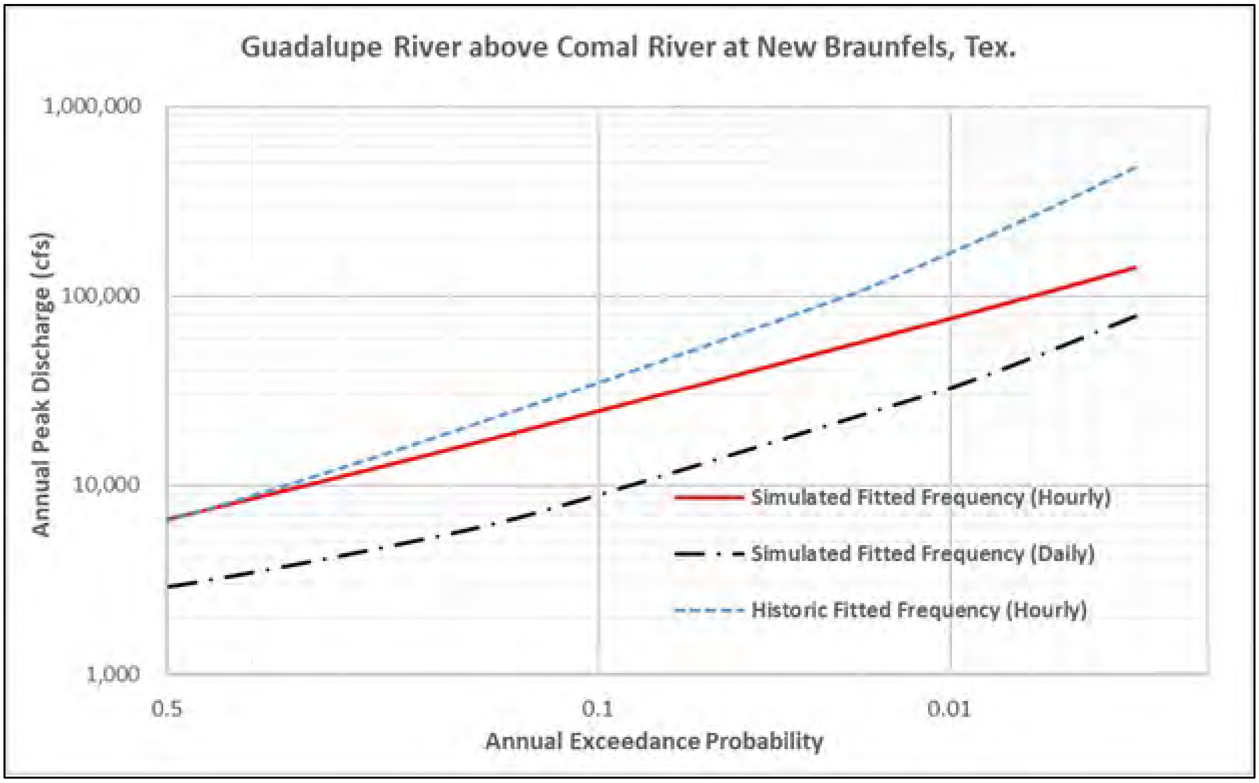


Figure 8.27. Comparison of log-Pearson type III computed peak streamflow frequency curves for the simulated daily, simulated instantaneous, and historic instantaneous datasets for streamgage 08168500 Guadalupe River above the Comal River at New Braunfels, Tex.

08173900 Guadalupe River at Gonzales, Tex.

The simulated streamgage record for the Gonzales gage is 1935–2016. The 1999 instantaneous peak streamflow for the regulated dataset was 308,609 ft³/s, which is the simulated peak of record. Figure 8.28 shows the peak streamflow data for the simulated and historic datasets as well as the impoundment of Canyon Lake. The Gonzales gage was installed in 1977, which means that RiverWare modeling greatly extends the period of record available for analysis.

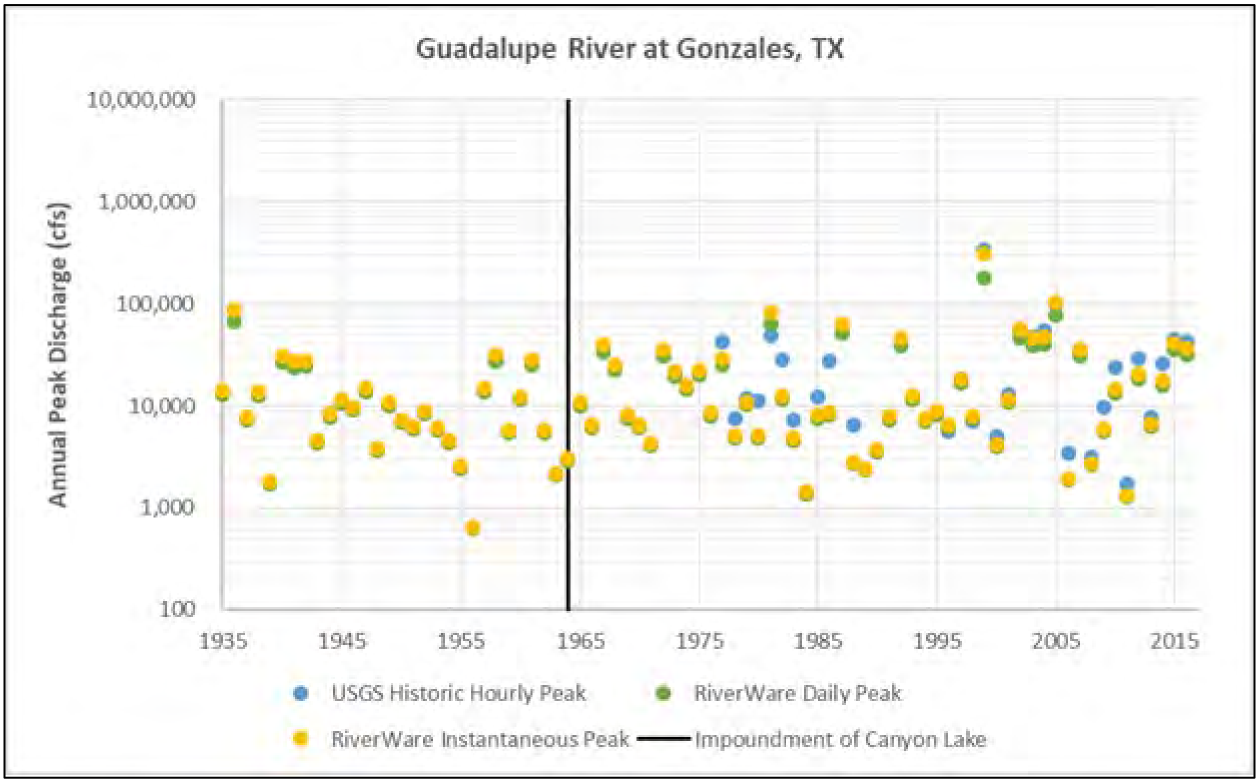


Figure 8.28: USGS historic hourly peak flows, RiverWare daily peak flows, and RiverWare instantaneous peak flow data for streamgage 08173900 Guadalupe River at Gonzales, Tex. The impoundment of Canyon Lake is also demarcated on the plot.

The LPIII computed peak streamflow frequency curve for the Gonzales gage simulated instantaneous data is shown in Figure 8.29. A low-outlier threshold was manually set to 3,500 ft³/s in HEC-SSP. The San Marcos River joins the Guadalupe River just upstream of the Gonzales gage, and it does appear to have an impact on the flow. Evidence of this change in flow characteristics from the New Braunfels gage to the Gonzales gage may be seen in the change in shape of the peak streamflow frequency curves and the plotting of the ordered peak streamflow events seen in Figures 8.25 and 8.29. A large portion of the flow at the Gonzales gage most likely originates from the San Marcos River.

The 1999 event appears to be an extreme event, and its plotting position may not be accurate given that the peak flow is over 200,000 ft³/s greater than the second highest event. Instead of an 82 year return period (0.0122 AEP), it is possible that this could be a much less common event. Even though RiverWare simulation helps to extend the period of record from 1935 to 2016, this still only provides 82 years of peak flow data. An 82-year period of record does not guarantee a peak streamflow event with an 82-year recurrence interval, nor does it preclude the possibility of an event with a 100-year or greater recurrence interval. Therefore, it is entirely possible that the 1999 peak streamflow event could be higher, even a 500-year event, for example.

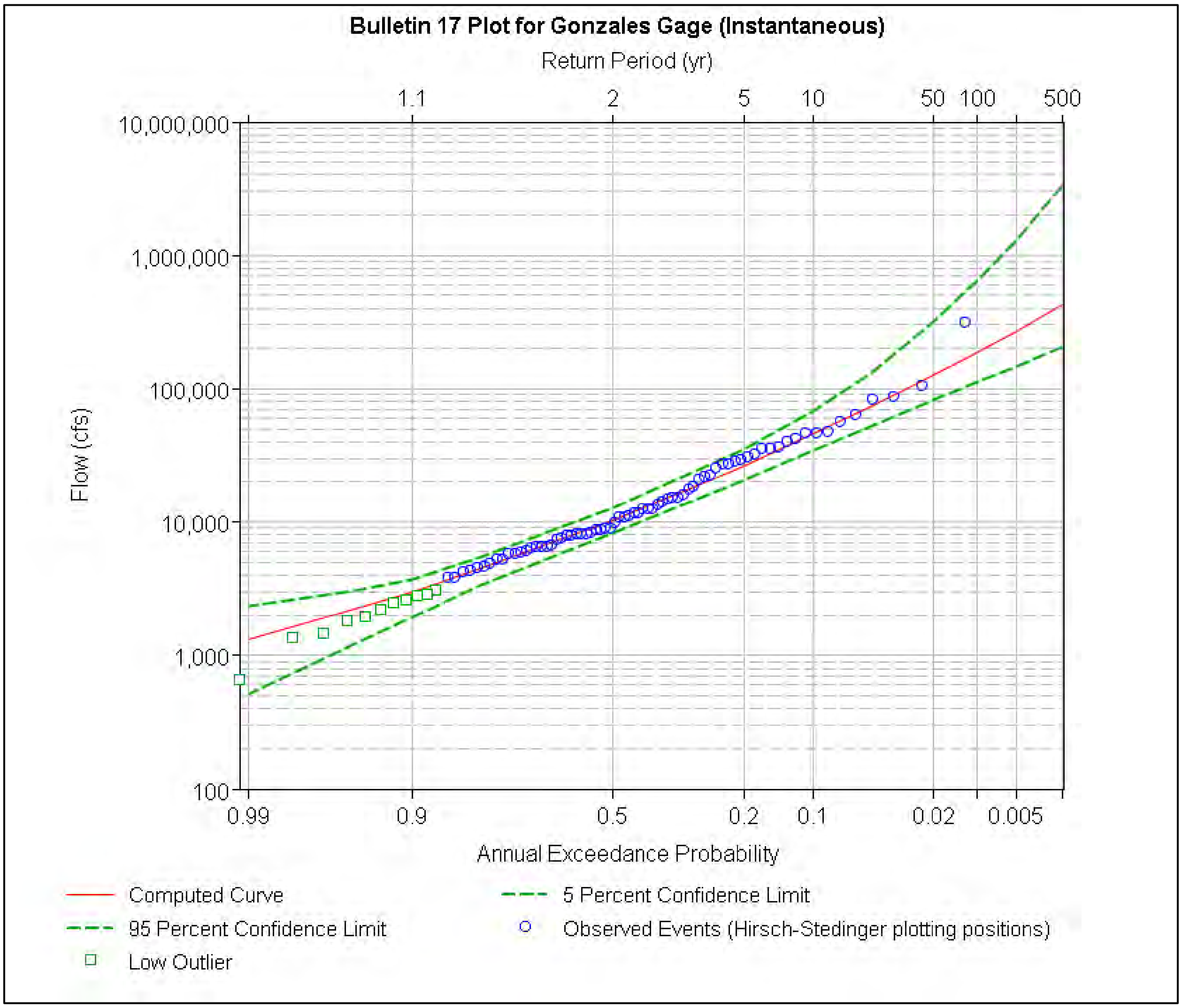


Figure 8.29. Peak streamflow frequency using log-Pearson type III distribution for streamgage 08173900 Guadalupe River at Gonzales, Tex. instantaneous RiverWare output from screenshot of USACE HEC-SSP software.

Figure 8.30 compares the LPIII computed peak streamflow frequency curves for the simulated instantaneous, simulated daily, and USGS historic peak streamflow data at the Gonzales gage. There appears to be little difference between the simulated daily and instantaneous peak streamflow frequency curves, another indication of changing stream characteristics between the New Braunfels gage and the Gonzales gage. By the time the Guadalupe River reaches Gonzales, it has grown in size and is less susceptible to flash flooding. Streamflow rises and falls slower here than it does at the New Braunfels gage, leading to a broader hydrograph. With a less “peaky” hydrograph, peak streamflows are not as greatly underestimated by looking at daily peak streamflows versus hourly data.

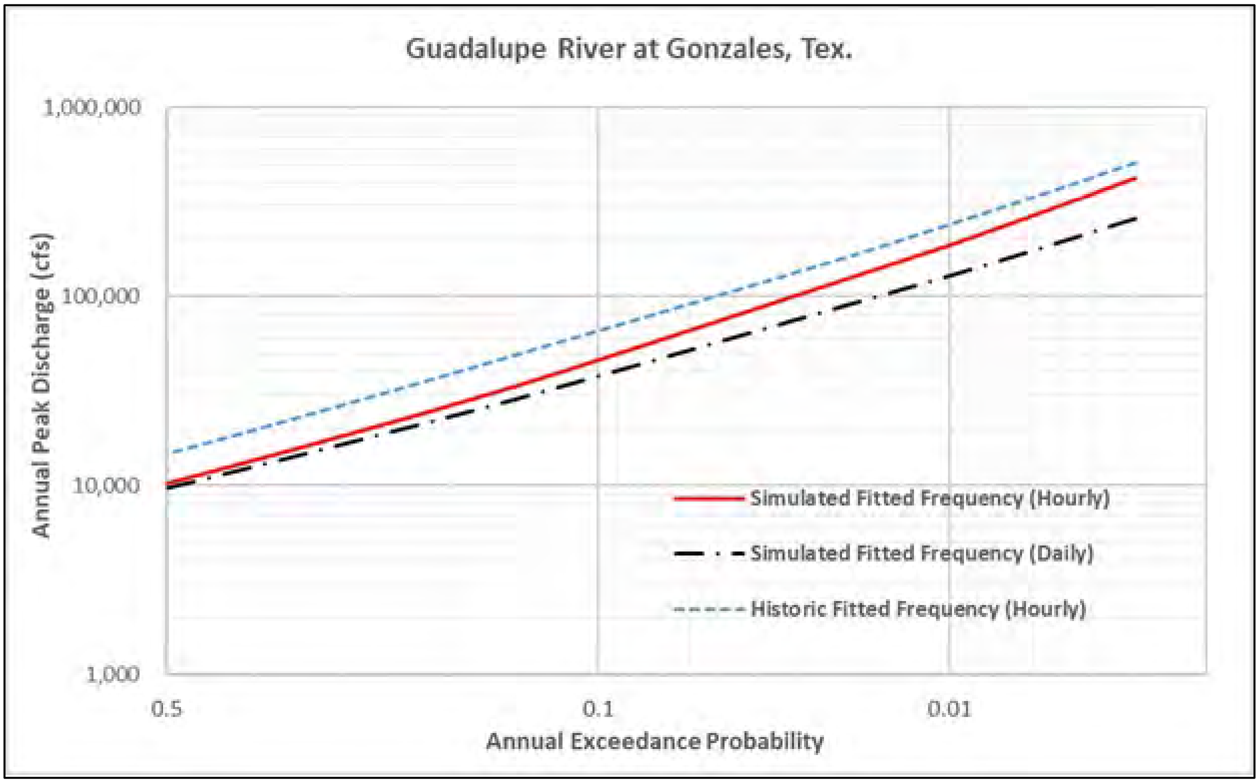


Figure 8.30. Comparison of log-Pearson type III computed peak streamflow frequency curves for the simulated daily, simulated instantaneous, and historic instantaneous datasets for streamgage 08173900 Guadalupe River at Gonzales, Tex.

08175800 Guadalupe River at Cuero, Tex.

The simulated stream gage record for the Cuero gage is 1935–2016. The 1999 peak streamflow for the simulated instantaneous dataset was 455,331 ft³/s, which is the simulated peak of record. Figure 8.31 shows the peak streamflow data for the simulated and historic datasets as well as the impoundment of Canyon Lake. The Cuero gage was installed in 1964, which means that RiverWare modeling greatly extends the period of record available for analysis.

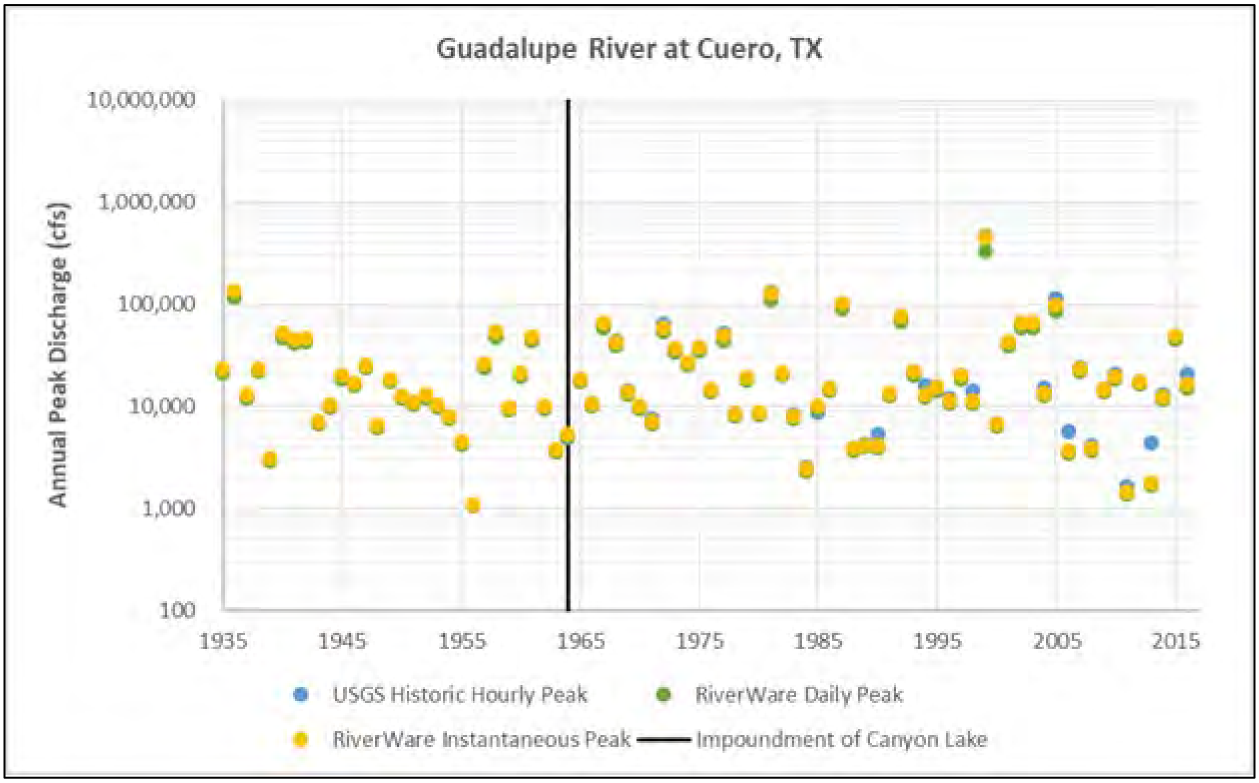


Figure 8.31: USGS historic hourly peak flows, RiverWare daily peak flows, and RiverWare instantaneous peak flow data for streamgage 08175800 Guadalupe River at Cuero, Tex. The impoundment of Canyon Lake is also demarcated on the plot.

The LPIII computed peak streamflow frequency curve for the Cuero gage simulated instantaneous data is shown in Figure 8.32. A low-outlier threshold of 5,000 ft³/s was manually set in HEC-SSP. The peak streamflow frequency curve for the Cuero gage is highly correlated with the Gonzales gage as it is located downstream on the Guadalupe and no major confluences or flood control structures appear to modify the flow between the two gages. A shift in the data appears at approximately 30,000 ft³/s, indicating possible population mixing. As was the case with the Gonzales gage, the 1999 event appears to be an extreme event, and its plotting position may not be accurate given that the peak flow is over 300,000 ft³/s greater than the second highest event. Instead of an 83 year return period (0.012 AEP), it is possible that this could be a much less common event.

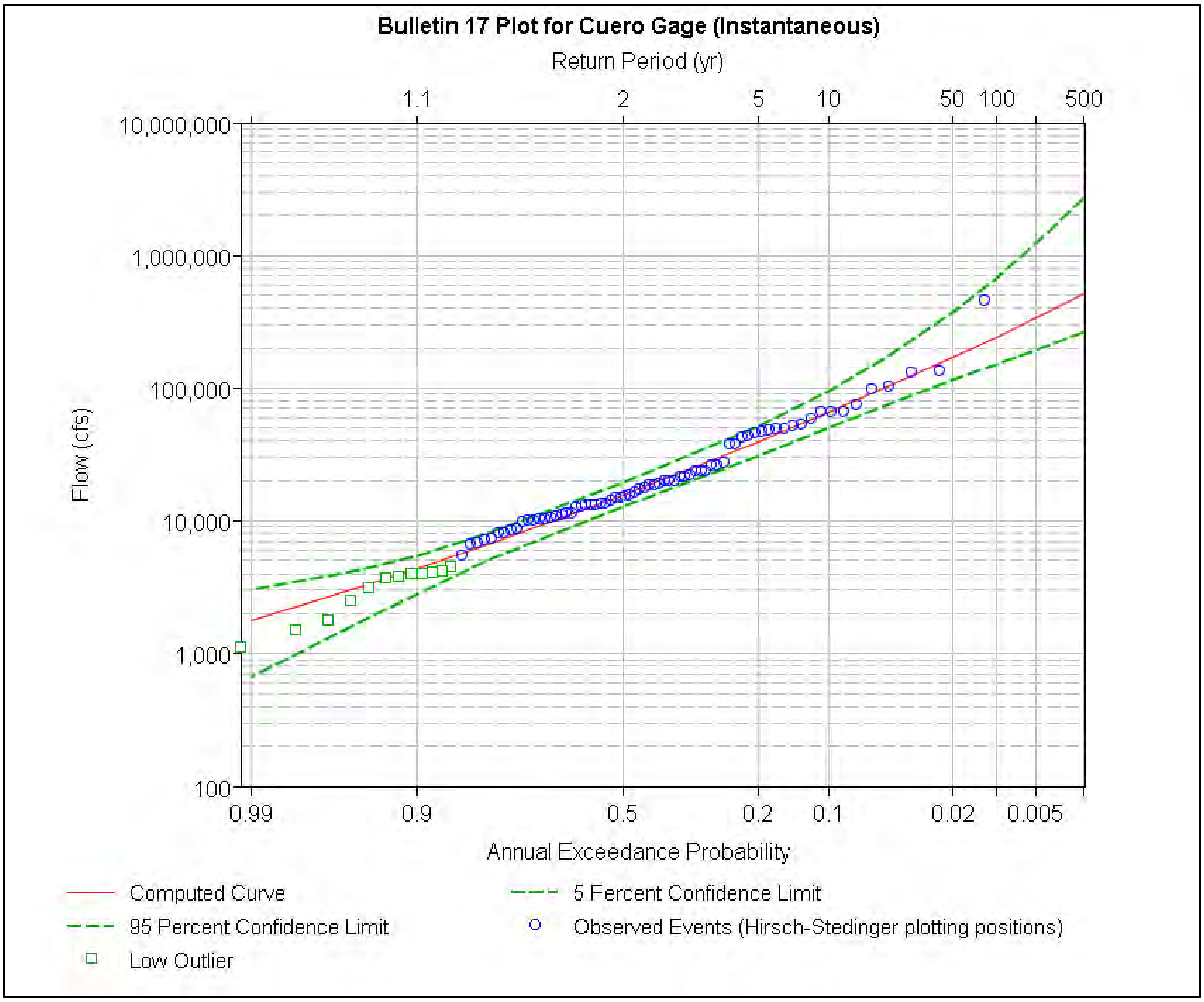


Figure 8.32. Peak streamflow frequency using log-Pearson type III distribution for streamgage 08175800 Guadalupe River at Cuero, Tex. instantaneous RiverWare output from screenshot of USACE HEC-SSP software.

Figure 8.33 compares the LPIII computed peak streamflow frequency curves for the simulated instantaneous, simulated daily, and USGS historic peak streamflow data at the Cuero gage. Moving further downstream, there is less difference in the three frequency curves at the Cuero gage than at the Gonzales gage. This indicates that there is a diminished difference between daily peak flows and instantaneous peak flows on this broader, downstream section of the Guadalupe River. Additionally, the lack of difference between the historic frequency curve and the simulated curves indicates that extending the regulated period of record for Canyon Lake upstream has a minimal effect on gages this far downstream. Though Canyon Lake provides flood mitigation for communities upstream, its impact has diminished this far downstream.

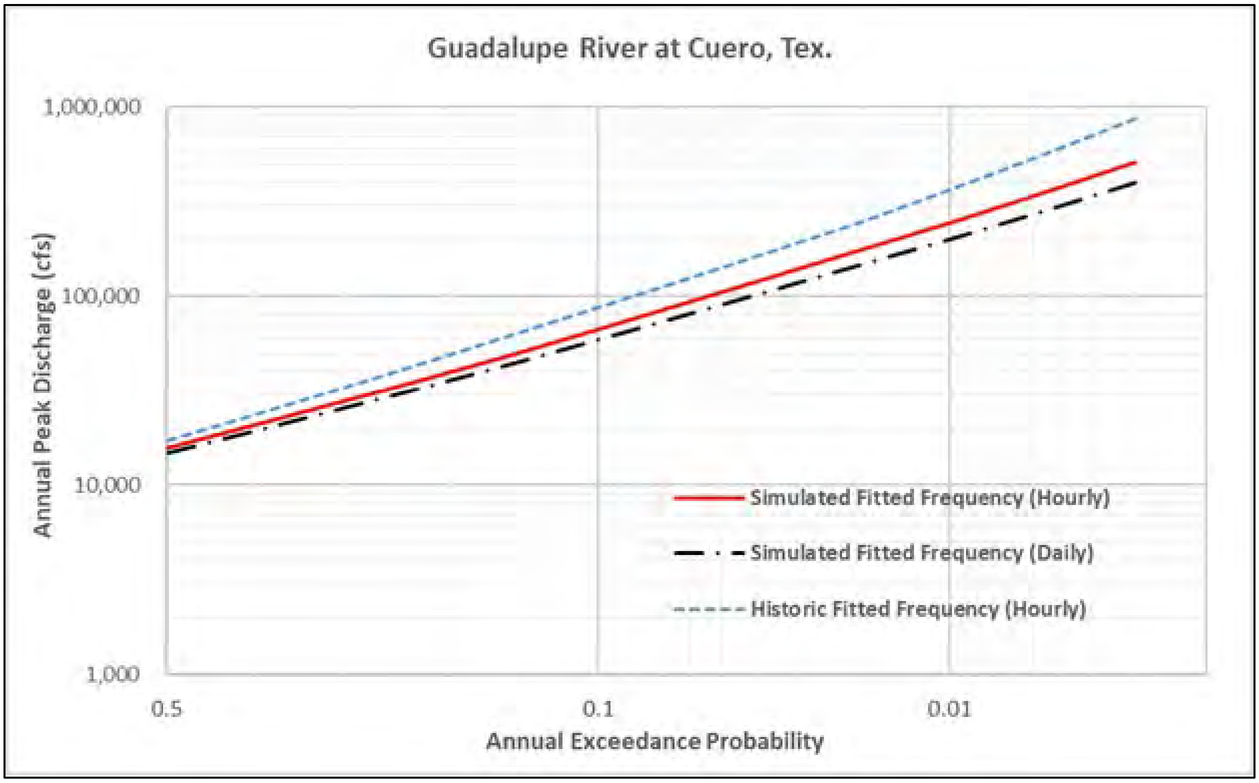


Figure 8.33. Comparison of log-Pearson type III computed peak streamflow frequency curves for the simulated daily, simulated instantaneous, and historic instantaneous datasets for streamgage 08175800 Guadalupe River at Cuero, Tex.

08176500 Guadalupe River at Victoria, Tex.

The simulated stream gage record for the Victoria gage is 1935–2016. The 1999 peak streamflow for the simulated instantaneous dataset was 495,104 ft^3/s, which is the simulated peak of record. Figure 8.34 shows the peak streamflow data for the simulated and historic datasets as well as the impoundment of Canyon Lake.

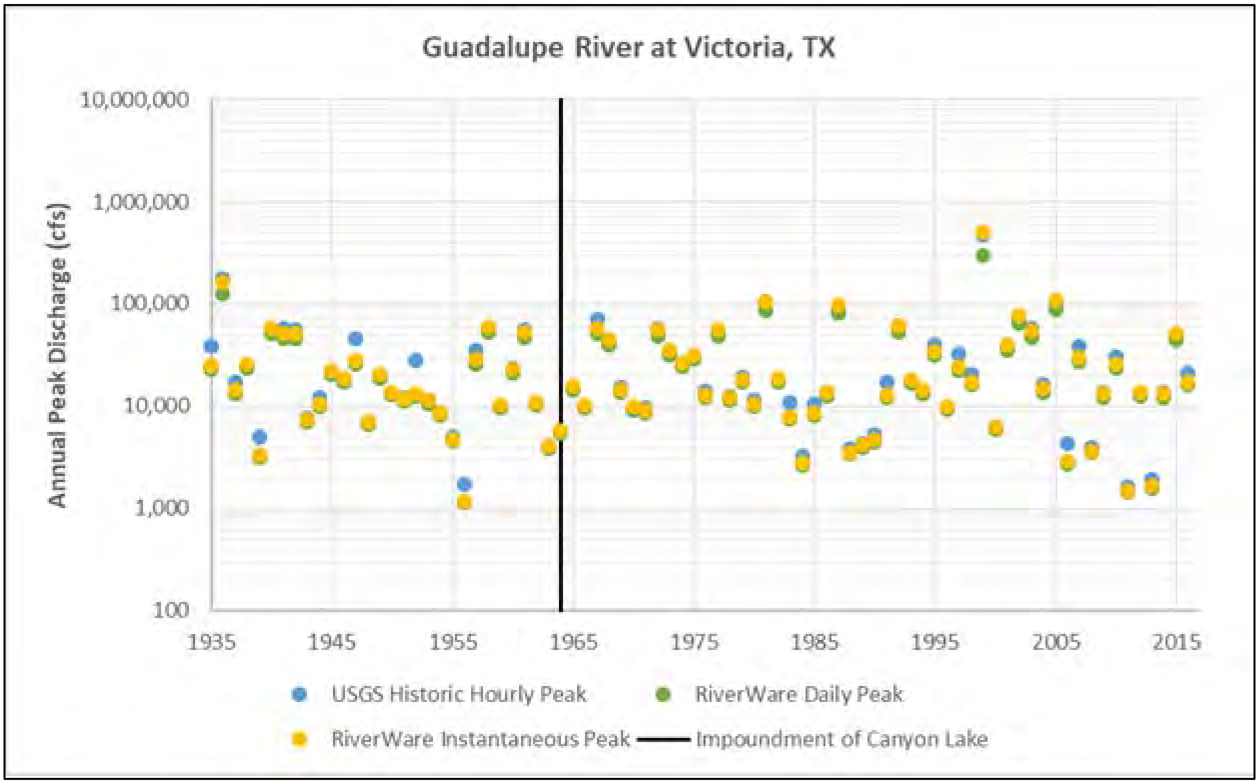


Figure 8.34: USGS historic hourly peak flows, RiverWare daily peak flows, and RiverWare instantaneous peak flow data for streamgage 08176500 Guadalupe River at Victoria, Tex. The impoundment of Canyon Lake is also demarcated on the plot.

The LPIII computed peak streamflow frequency curve for the Victoria gage simulated instantaneous data is shown in Figure 8.35. A low-outlier threshold of 5,000 ft^3/s was manually set in HEC-SSP. The peak streamflow frequency curve for the Victoria gage is highly correlated with the Cuero gage as it is located downstream on the Guadalupe and no major confluences or flood control structures appear to modify the flow between the two gages. An inflection in the curve similar to that seen in the Cuero data appears at approximately 40,000 ft^3/s, indicating possible population mixing. However, this inflection does not appear to be as sharp as that seen in the Cuero data. As was the case with the Cuero and Gonzales gages, the 1999 event appears to be an extreme event, and its plotting position may not be accurate given that the peak flow is over 300,000 ft^3/s greater than the second highest event. Instead of an 83 year return period (0.012 AEP), it is possible that this could be a much less common event.

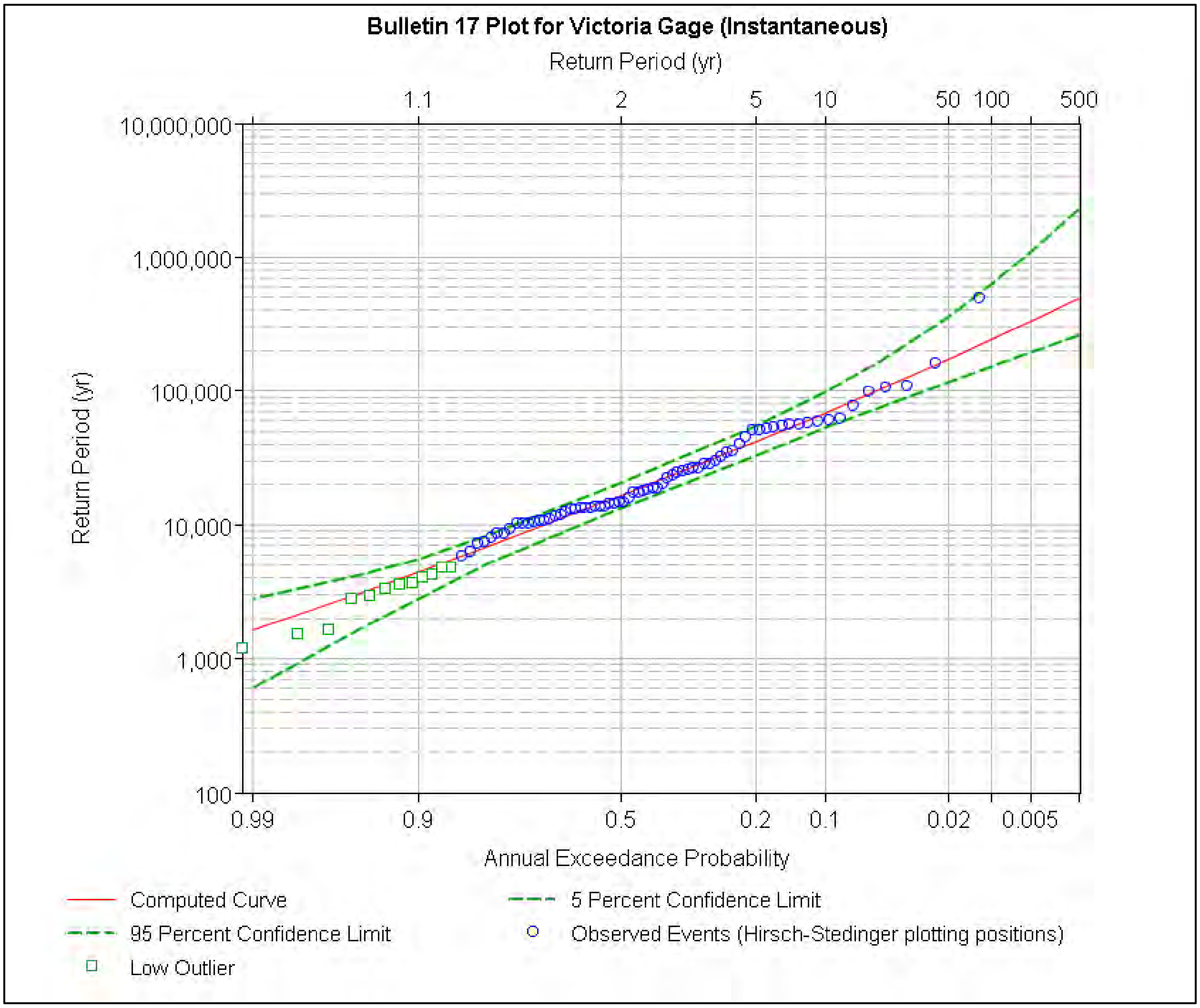


Figure 8.35. Peak streamflow frequency using log-Pearson type III distribution for streamgage 08176500 Guadalupe River at Victoria, Tex. gage instantaneous RiverWare output from screenshot of USACE HEC-SSP software.

Figure 8.36 compares the LPIII computed peak streamflow frequency curves for the simulated instantaneous, simulated daily, and USGS historic peak streamflow data at the Victoria gage. The difference in the peak streamflow frequency curves for the Victoria gage is small, indicating that the difference between daily peaks and instantaneous peaks has a negligible effect on the curve except for lower exceedance probabilities. Additionally, the lack of difference between the historic frequency curve and the simulated curves indicates that extending the regulated period of record for Canyon Lake has a minimal effect on gages this far downstream.

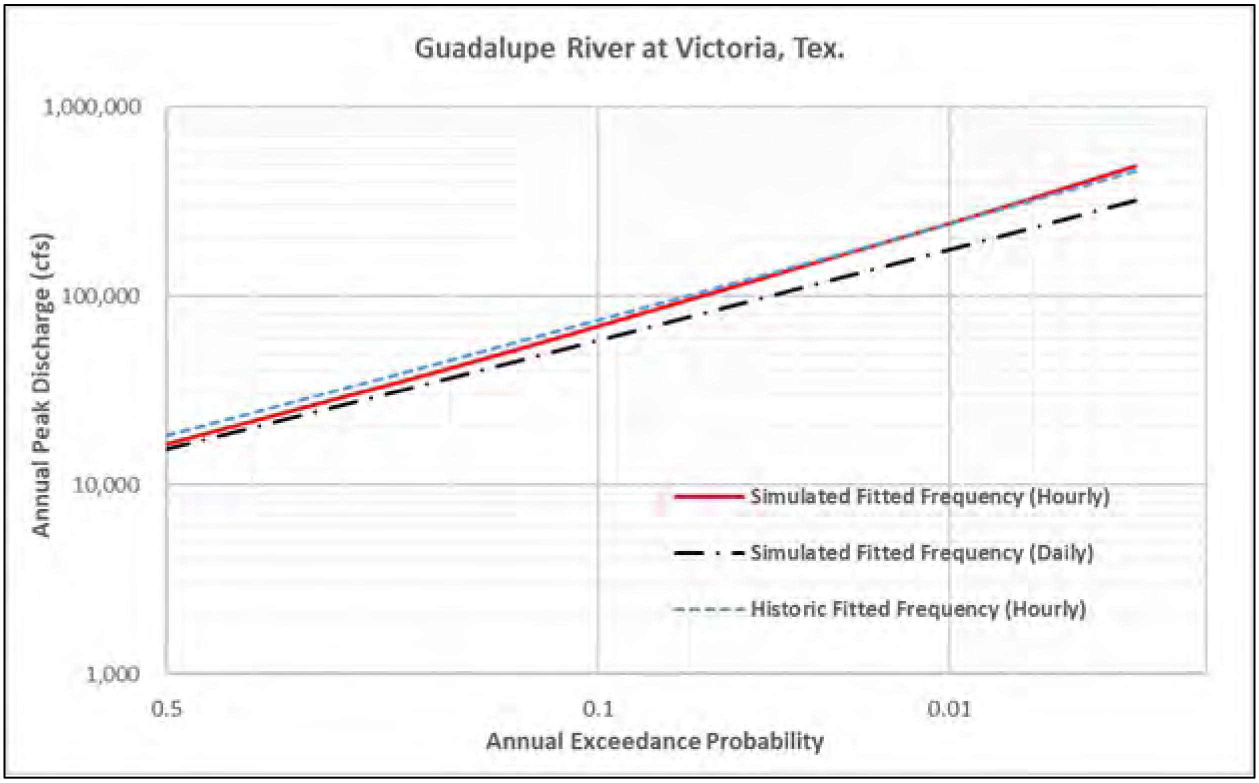


Figure 8.36. Comparison of log-Pearson type III computed peak streamflow frequency curves for the simulated daily, simulated instantaneous, and historic instantaneous datasets for streamgage 08176500 Guadalupe River at Victoria, Tex.

Table 8.3 summarizes the results of the frequency analysis for the instantaneous peak streamflows for the New Braunfels, Gonzales, Cuero, and Victoria gages on the Guadalupe River in central Texas. LPIII computed peak streamflow increases incrementally downstream until it appears to reach an equilibrium at the Cuero gage. There is very little difference in estimated peak streamflow frequency between the Cuero and Victoria gages, possibly due to the lack of any major tributaries joining the river between these two gages. In fact, the contributing drainage area of the Guadalupe River increases by approximately 41% between the Gonzales and Cuero gages, but the drainage area only increases by 5% between the Cuero and Victoria gages, a marked difference.

Differences between the simulated instantaneous and daily peak streamflow frequency curves diminish downstream, a signal of changing stream characteristics. Streamflow at the New Braunfels gage may be subject to flash flooding with streamflows peaking for less than 24 hours. Downstream at the Victoria gage, the Guadalupe River is a broader, larger river than it was at New Braunfels, and peak streamflows are sustained for longer. Therefore, the daily peak streamflow values are closer to the true instantaneous peak streamflow further downstream.

The effects of regulation on the watershed also diminish downstream on the Guadalupe River. The ordered peak streamflow events at the New Braunfels gage show clear evidence of regulation with grouping of peak events at specific streamflows (Figure 8.25). The three alternative distributions appear to provide a better visual fit to the New Braunfels peak streamflow data, although it is difficult to definitively determine the best fit distribution (Figure 8.26). By the Gonzales gage, the evidence of regulation is no longer evident. There are no flood control reservoirs below New Braunfels of a similar magnitude to Canyon Lake, so the addition of additional tributaries between New Braunfels and Gonzales diminishes the effect of Canyon Lake on peak streamflow.

Table 8.3 Statistically estimated annual peak streamflow frequency results for the four U.S. Geological Survey streamflow-gaging stations on the Guadalupe River, central Texas based on USACE HEC-SSP B17C computations.

Station number and name and streamflow estimate type	Flood Flow Frequency by Annual Exceedence Probability (AEP)							
	AEP 0.500 (ft^3/s)	AEP 0.200 (ft^3/s)	AEP 0.100 (ft^3/s)	AEP 0.050 (ft^3/s)	AEP 0.020 (ft^3/s)	AEP 0.010 (ft^3/s)	AEP 0.005 (ft^3/s)	AEP 0.002 (ft^3/s)
Guadalupe River at New Braunfels, Tex.								
Lower 95%-CI	3,843	12,626	19,135	26,762	38,990	49,983	62,553	81,708
Estimate	**6,524**	**15,308**	**24,250**	**35,721**	**55,687**	**75,229**	**99,405**	**139,942**
Upper 95%-CI	7,690	19,644	33,668	54,699	99,044	152,152	232,036	404,418
Guadalupe River at Gonzales, Tex.								
Lower 95%-CI	8,352	20,759	34,412	52,184	82,963	112,561	148,403	206,807
Estimate	**10,320**	**26,531**	**45,488**	**72,739**	**126,705**	**186,376**	**268,333**	**423,478**
Upper 95%-CI	12,854	35,266	67,180	129,064	317,506	638,033	1,290,918	3,294,811
Guadalupe River at Cuero, Tex.								
Lower 95%-CI	12,671	31,126	50,418	74,624	114,778	151,778	194,943	262,288
Estimate	**15,628**	**39,431**	**65,901**	**102,313**	**170,777**	**242,781**	**337,437**	**507,603**
Upper 95%-CI	19,395	51,627	94,146	169,686	373,021	678,082	1,230,062	2,691,132
Guadalupe River at Victoria, Tex.								
Lower 95%-CI	13,278	32,803	52,826	77,613	117,936	154,282	195,836	259,128
Estimate	**16,418**	**41,500**	**68,799**	**105,586**	**173,035**	**242,223**	**331,184**	**486,951**
Upper 95%-CI	20,401	54,097	97,262	171,548	362,270	634,123	1,102,364	2,267,436

9 Reservoir Study of Canyon Dam

9.1 INTRODUCTION

This section of the report describes the methods used to update the pool frequency curve for Canyon Lake and Dam developed to represent the current reservoir control plan and watershed conditions (2016). A frequency analysis is a statistical method of prediction that consists of studying past events that are characteristic of a particular hydrology process in order to determine the probabilities of occurrence of these events in the future. A Stage-Frequency curve estimates the annual chance of exceedance (ACE) for reservoir pool elevations. For example, if a reservoir pool at the spillway crest has an ACE of 1/50, then the reservoir has a 2% chance of the reservoir pool elevation equaling or exceeding the spillway crest elevation at any given year. The stage-frequency curve can be determined using empirical (observed or measured) data, however, the reservoir pool elevations associated with 1% ACE (100-year) or 0.2% ACE (500-year) occurrence are typically beyond the observed reservoir pool elevation period of record. Models serve the purpose of extrapolating reservoir pool elevation frequencies beyond the observed record.

For this study, a stage frequency curve representing current conditions was developed to evaluate Canyon Lake pool elevations resulting from the 50% ACE (2-year) to 0.2% ACE (500-year) events. This study incorporates available reservoir inflow and pool data (historical period from 1869 – 2016) into statistical software, and it apples statistical methods to estimate a 4-day critical inflow duration and simulate inflow and elevation period of record. The Hydrologic Engineering Center-Statistical Software Package (HEC-SSP) was used to compute volume duration frequency curves from the annual maximum peak reservoir inflows. An empirical stage frequency curve was developed from the available reservoir pool annual maximum series. An event based stochastic Monte Carlo simulation model (Risk Management Center-Reservoir Frequency Analysis, RMC-RFA) was used to extrapolate the stage frequency curve beyond the limits of empirical stage frequency curve. RiverWare was used to develop a current condition POR for reservoir inflows and elevations. The Annual Maximum Series (AMS) derived from the Riverware results was used to create the empirical stage frequency curve. The Empirical stage-frequency curve was used to validate RFA model simulation results, the results showed adequate validation to the upper tail end of the empirical stage frequency curve and is believed to be a reasonable extrapolation for frequency of rare pool events.

Pool frequencies for Canyon Lake were last estimated in 1983 (FEMA, 1995) (FEMA, 2009). It should be noted that the 1983 pool frequencies have not been changed, and are used throughout the most recent FEMA reports. The current FEMA pool frequencies in NGVD are 924-, 940-, 946-, and 949.7-feet for the 10%, 2%, 1%, and 0.2% ACE, respectively. In this report, main emphasis were put to compare the updated 1%ACE (100-year) and 0.2%ACE (500-year) events by utilizing the RMC-RFA program through WY 2016 to the Federal Emergency Management Agency (FEMA) adopted pool frequencies of 1983. In addition, a set of pool frequency comparison generated by HEC-HMS program is compared against the RMC-RFA program results to assure the accuracy of the newly adopted results. Details about the HEC-HMS model description and results, which was built for the Guadalupe River and Canyon basin can be found in Chapter 6.

9.2 WATERSHED DESCRIPTION

Canyon Lake is located on the Guadalupe River Basin, River Mile 303, and about 12 miles northwest of New Braunfels, Texas, in Comal County. The lake drains about 1,432 square miles, just downstream of USGS 08167500 Guadalupe River near Spring Branch, TX (drainage area of 1,315 square miles). The Guadalupe watershed is relatively long and narrow, having an over-all length of approximately 237 miles and a maximum width of about 50 miles, with an area of about 6,032 square miles. The general elevation of the watershed increases from sea level at the mouth to an elevation of about 2,400 feet in the extreme headwater area. The Guadalupe River is formed by the confluence of the North and South Forks of the Guadalupe River at a point about 10 miles west of Kerrville, Texas. From its source, the Guadalupe River flows in an easterly direction for a distance of about 184 miles to the Balcones Escarpment near the city of New Braunfels. Then turning southeasterly, the river flows for about 280 miles to an outlet into San Antonio Bay, an estuary of the Gulf of Mexico.

9.3 CLIMATE

The climate over the Guadalupe River Basin is generally mild. In summers, the days are hot and the nights cool. Normally, the winter periods are short and comparatively mild, but occasional cold periods of short duration result from the rapid movement of cold, high-pressure air masses from the northwestern polar regions and the continental western highlands. Freezing temperatures occur yearly over a large portion of the headwater area, and snowfall is experienced occasionally. Wind movements during December, January, and February are usually northerly, being influenced by continental high-pressure areas. During the remainder of the year, southerly or southeasterly winds from the Gulf of Mexico are dominant. The mean annual temperature over the basin is about 68 degrees Fahrenheit. January, the coldest month, has an average minimum daily temperature of 42 degrees; August, the warmest month, has an average minimum daily temperature of 94 degrees. Temperatures in the basin have ranged from a maximum of 112 degrees to a minimum of -7 degrees. The mean annual precipitation is 32.7 inches, and varies from about 36 inches near the mouth to about 29 inches in the headwaters. The mean annual precipitation over the watershed lying above Canyon Dam is 30.1 inches.

9.4 RUNOFF

The steep gradients of the streams, the thin layer of topsoil with frequent outcroppings of rock, and the well-defined valleys in the watershed above Canyon Dam produce rapid runoff during storm periods. Extreme and rapid variations in the flow, ranging from a few discharge amounts to large floods for short durations. The stream has a low normal flow. The highest average monthly flows usually occur in May, June, July, and September. Flood flows, however, may occur during any month.

9.5 METHODS

9.5.1 Empirical Stage-Frequency

For the evaluation of hydrologic loading, an extreme-value series of annual maximum stages needed to be generated from the observed and/or simulated period of record. An empirical stage-frequency curve was then be constructed by the ranking annual maximum data, assigning the data a plotting position, and then plotting the data on probability paper using a plotting formula. Many plotting position formulas can be used for the creation of an empirical frequency curve, but a plotting position formula that is flexible and makes the fewest assumptions is preferred (USACE, 2017). Gumbel summarizes five conditions that a plotting position should satisfy (Gumbel, 1958):

1. The plotting position must be such that all observations can be plotted.
2. The plotting position should lie between the observed frequencies of $(m-1)/n$ and m/n where m is the rank of the observations beginning with $m = 1$ for the largest value and n is the number of years of record or the number of observations.
3. The return period of a value equal to or larger than the largest observation and the return period of a value equal to or smaller than the smallest observation should converge toward n.
4. The observations should be equally spaced on the frequency scale.
5. The plotting position should have an intuitive meaning, be analytically simple, and easy to use.

The most practical plotting position formula which satisfies all five of Gumble's conditions is the Weibull plotting position. A rank-order method is used to plot the annual maxima. This involves ordering the data from the largest event to the smallest event, assigning a rank of 1 to the largest event and a rank of n to the smallest event, and using rank (i) of the event to obtain a probability plotting position. The Weibull plotting position formula is an unbiased estimator of exceedance probability for all distributions, and is used to plot the stage data for constructing an empirical stage-frequency curve:

$$P_i = \frac{i}{n+1}$$

Where i is the rank of the event, n is the sample size, and P_i is the exceedance probability for an event with rank i.

9.5.2 Volume-Sampling Approach

A common method for estimating a hydrologic loading curve for a dam is by volume-based sampling. In this method, a large number of flood events is generated using random sampling of flood volumes, the associated flood hydrographs routed through a reservoir, and the peak reservoir elevation for each event is recorded.

The general workflow for a volume-based hydrologic loading analysis is as follows:

1. Choose a stage for the reservoir to begin the flood event
2. Choose an inflow flood hydrograph to scale
3. Sample a flood volume from the reservoir inflow frequency curve
4. Scale the selected flood hydrograph to match the sampled flood volume
5. Route the scaled flood hydrograph through the reservoir using an operations model
6. Record the peak stage that occurred during the event

For the stochastic model, RMC-RFA, choices made in steps 1-3 are made using random selection from a probability distribution. The choice is random in the sense that it occurs without pattern, but the relative frequency of the outcomes in the long term is defined by a probability distribution. Reservoir stages for starting the simulation come from a *pool duration curve*, which is a probability distribution for the elevation of the reservoir pool. They may be seasonally-based, in which case first the season of the flood event occurrence is selected at random, and then a starting stage is selected at random from the pool duration curve for that particular season. Sampled flood volumes come from the familiar flow frequency curve produced by fitting an analytical probability distribution to an annual maximum series of river discharges. In the volume-based approach, instead of analyzing instantaneous peak discharge (as is typically the case in a Bulletin 17B/C-type analysis), the analysis is performed on a longer-duration volume (such as three (3) or four (4) day average discharge.)

When steps 1-6 are performed a large number of times (for example, 10,000 *samples*), the resulting peak stages are ranked and plotted, producing a stage-frequency curve for the reservoir. However, substantial uncertainty exists in several of the inputs to the model, especially the inflow frequency curve. To account for these uncertainties, steps 1-6 are performed a large number of times with different parameters for the inputs. The input parameters are varied across *realizations*, and for each realization, steps 1-6 are repeated over a large number of *samples.* Thus, the full simulation with uncertainty will contain a number of events equal to the number of realizations times the number of samples.

By varying parameters across realizations, the uncertainty in the probability of an event, for example reaching spillway crest elevation, can be assessed. Each realization will produce an estimate of the probability of reaching this elevation based on the parameters used to drive the realization. Percentiles (for example the 5^{th} and 95^{th} percentiles) of these probabilities produce a confidence interval for the probability of reaching the spillway. If the mean probability of exceeding any stage is taken, then the result is the *expected frequency curve*, which is the single best estimate for the probability of exceeding a particular stage.

9.5.3 Risk Management Center - Reservoir Frequency Analysis

RMC-RFA software was developed by the US Army Corps of Engineers Risk Management Center for use in dam safety risk assessments. It can produce a stage-frequency curve with confidence bounds using a stochastic model with the volume-sampling approach.

The model functions best in situations where dam operations are relatively simple, especially when the spillway is not regulated using gates. A simplification of the operational rules is assumed through the use of an elevation-discharge table which is based on a combination of dam discharge structures and calibration to historical releases.

Development of model inputs is aided by tools within the program that allow the user to estimate inputs, such as flood seasonality or pool duration curves, in a consistent and automated manner. Other inputs, such as the volume frequency curve or reservoir operations, are developed by the user independently.

9.6 DATA ANALYSIS AND MODEL INPUT

9.6.1 Inflow Hydrograph and Pool Stage

Estimate of daily average flows and pool elevations at Canyon Lake were retrieved from the USACE water management database system for 01 January 1935 through 31 December 2016. Records prior to Canyon Lake Dam construction (*i.e.* prior to July 1964) were simulated using RiverWare. RiverWare software mimics a watershed by modeling its features as linked objects, including storage or power reservoir objects, stream reach objects, groundwater storage objects, or diversion objects. In a simple model, these objects simulate basic hydrologic processes through mass balance calculations and can be linked to one another through inflow-outflow calculations. More advanced modeling is achieved by selecting object-specific methods that further define the hydrologic processes associated with each object. Additionally, RiverWare may operate under a rule-based simulation, which creates logic-based interdependency of objects through user-defined rules. These rules may look forwards and backwards in time, and given priorities in one rule may supersede others depending on the importance defined by the user. These detailed yet simple modeling techniques allow RiverWare to simulate Canyon Reservoir pool elevations and inflow accurately and efficiently. More information on the RiverWare model is contained in Chapter 8 of this report. The water management section inspected the dataset for quality before being used in the analyses. The instantaneous (hourly) lake inflows were gathered from 01 May 1997 through 23 June 2017. The hourly records contained many gaps. The gaps are for times when real time recording was missing. Data with missing records were not used in the analyses.

Figure 9.1 shows the simulated pre-dam construction daily average inflow and post dam construction pool elevation records for Canyon Lake and Dam. In addition, the instantaneous (hourly) inflow records are illustrated in Figure 9.2.

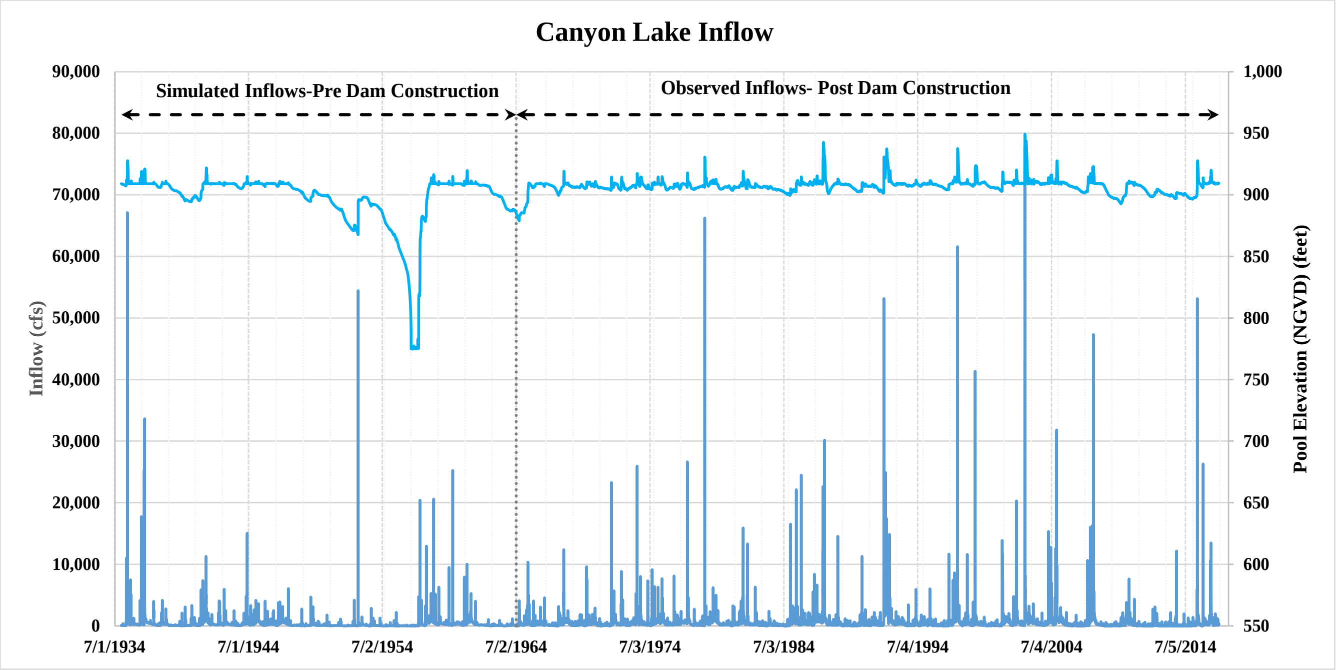


Figure 9.1 Canyon Lake Daily Average Inflows and Elevations

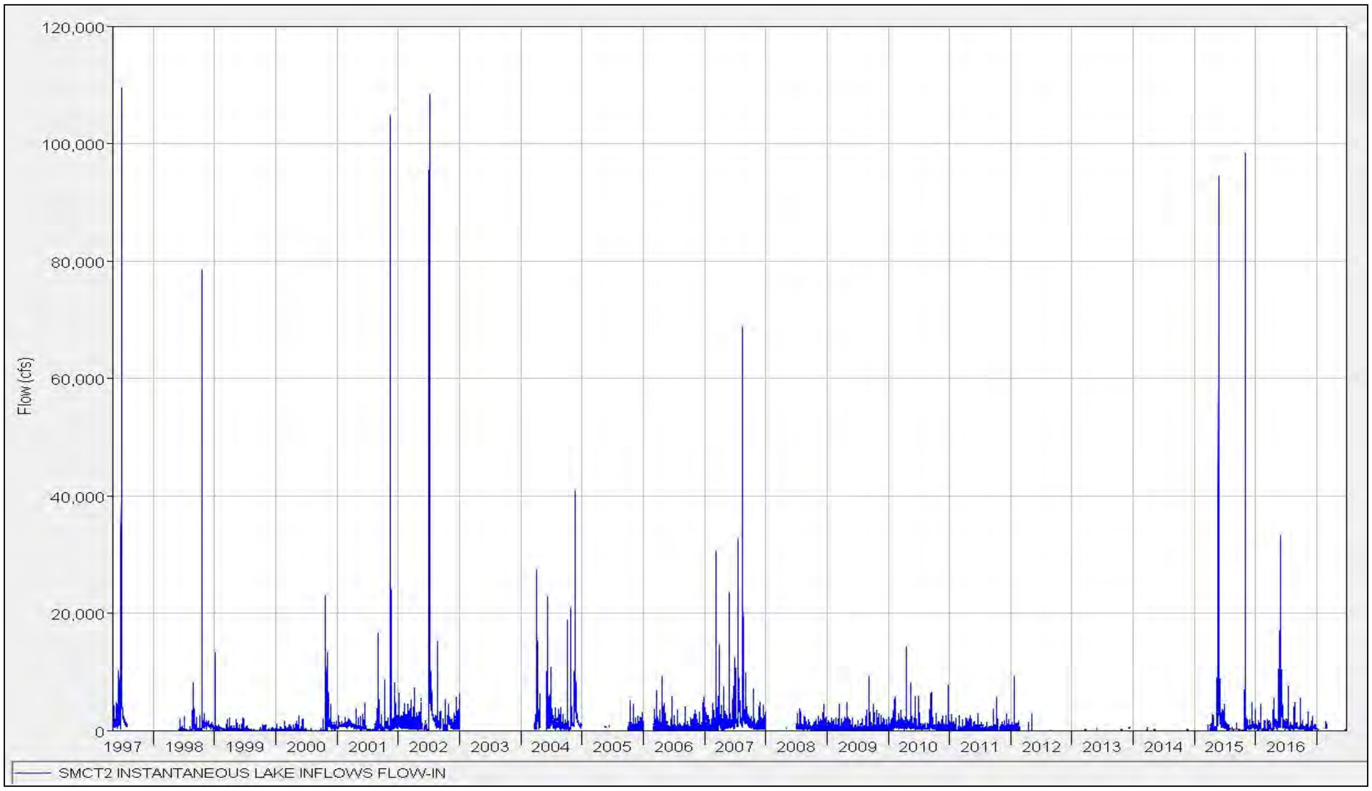


Figure 9.2 Canyon Lake Hourly Inflows

9.6.2 Instantaneous Peak Estimates

An extract of the 1-day average maximum annual peaks for Canyon Lake was made available for the analysis. The lake inflow systematic record contains a mixed population of observed (recorded) post-dam construction flows and pre-dam construction synthetic flow years generated using RiverWare. The unrecorded historical peaks at the lake were developed by establishing a discharge peak correlation with USGS 08167500 Guadalupe River near Spring Branch, TX. The USGS gage was selected due to its close location in relation to the lake, its drainage area captures about 92% of flows leading to Canyon Lake (1,315 square miles at USGS 08167500 versus 1,432 square miles at Canyon Lake). In addition, the observed hydrographs entering the reservoir, mimic similar patterns of those observed at the gage location. Historical peaks (i.e. 1869 and 1900) at the USGS were generated by establishing a relationship between stage, where historical high water marks were captured, and discharge peaks. A strong polynomial (trendline) correlation was maintained, with a R^2 value of 0.967. The predicted peaks are shown in Figure 9.3. Accordingly, the Canyon Lake historical inflows were generated from USGS near Spring Branch. Results from an existing calibrated rainfall runoff model (Hydrologic Engineering Center-Hydrologic Modeling System HEC-HMS)[2], part of the Corps Water Management System (CWMS)[5] model for Guadalupe River, showed peak attenuation between Spring Branch USGS gage and Canyon Lake. Several attempts were made to better justify the most predictable peaks. First, the drainage area to peak ratio method was applied to calculate peaks at Canyon Lake. The method was found inapplicable for the Guadalaupe River watershed system since observed peaks do not increase with increased drainage area. Some intermittent storms may cause the peaks to increase at Canyon Lake, which invalidates the approach taken. See Table 9.1 for pattern inconsistency.

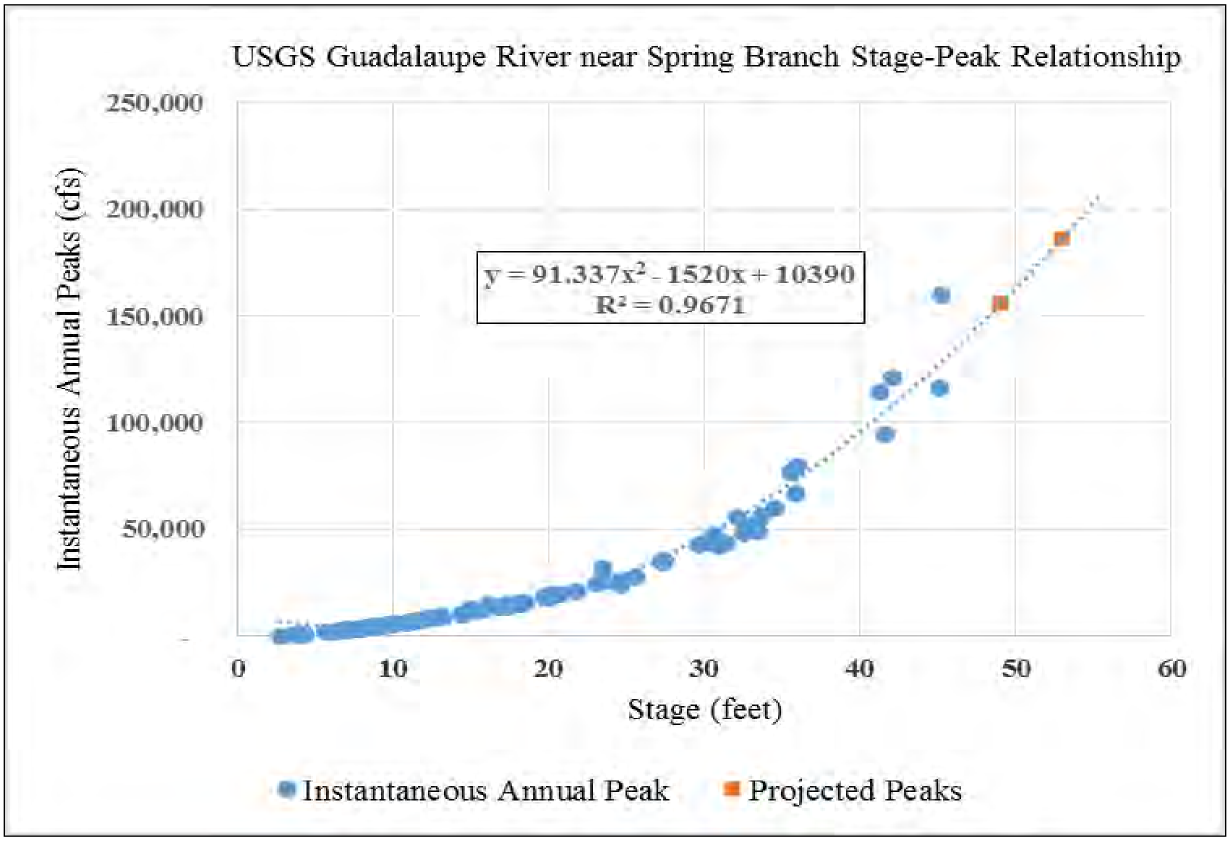


Figure 9.3 Predicted Peaks at USGS 08167500 Guadalupe River near Spring Branch, TX

Table 9.1 Peak flow comparison between USGS 08167500 and Canyon Lake

Date	Inst. Peak USGS Flow (cfs)	Inst. Peak Canyon Lake Inflow Flow (cfs)	Peak Increase or Reduction Δ (%)
5/29/1929	18,600	19,700	-6%
7/3/1932	121,000	95,200	21%
6/15/1935	114,000	140,000	-23%
9/28/1936	48,600	52,800	-9%
9/11/1952	66,900	72,900	-9%
4/24/1957	25,600	27,000	-5%
8/3/1978	160,000	150,000	6%
6/22/1997	116,000	109,553	6%
10/17/1998	51,400	78,470	-53%
6/11/2000	739	2,004	-171%
10/24/2000	35,100	22,874	35%
7/5/2002	94,400	108,351	-15%
4/7/2004	31,600	27,275	14%
11/17/2004	34,800	40,823	-17%
5/5/2006	2,090	4,562	-118%
8/17/2007	56,400	68,747	-22%
10/23/2007	808	7,142	-784%
3/13/2009	527	4,411	-737%
4/17/2010	14,700	14,315	3%
1/11/2011	173	807	-366%
1/25/2012	6,110	9,122	-49%
5/23/2015	59,800	94,480	-58%

The second method applied to predict historical peaks at Canyon Lake is the Maintenance of Variance Extension (MOVE I) Method (Hirsch, 1982). This method is used to extend gage record in time by exploiting the interstation correlation between the station of interest (Canyon Lake) and some nearby (long-term) base station (USGS 08167500). It transfer the characteristics of distribution shape, serial correlation, and seasonality from the base station to the short-record station with adjustments to locations of locations and scale appropriate to the short-record station. This method maintains the sample mean and variance, and applies the basic equation for record extension: $\bar{Y_i} = Y_{avg} + S_y/S_x\ (X_i - X_{avg})$ Where: $\bar{Y_i}$ is the peak discharge value to be filled, Y_{avg} is the mean of peak discharge for the short record, S_y is the standard deviation of peak discharge for the short record, S_x is the standard deviation of peak discharge for the long record, X_i is the peak discharge value for the long record, and X_{avg} is the mean of peak discharge for the long record. The predicted historical peaks at Canyon Lake showed significant variations in the results when comparing the trendline pattern of peak data before and after applying MOVE I between observed peaks at Canyon Lake and observed peaks at USGS gage near Spring Branch. See Figure 9.4. The application of using this method was found inapplicable for flows in this type of watershed; therefore, results were not considered for the analysis.

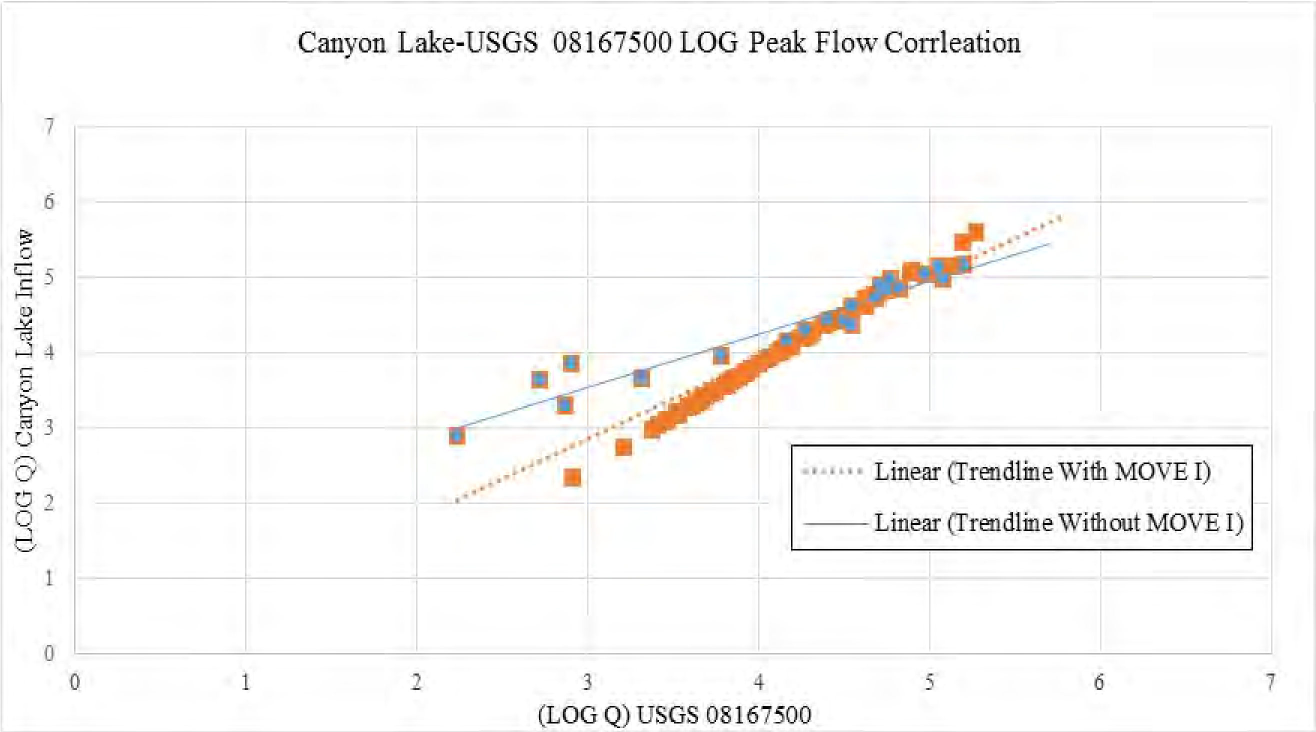


Figure 9.4 Trendline Comparison of Correlation Between Peaks at Canyon Lake and USGS 08167500

The third (selected) method used to predict discharge peaks at Canyon Lake was based on the power trendline fit between the USGS gage data and Canyon Lake inflows. Two (2) trendlines were generated once a relationship was established. Both the linear and power trendlines showed a strong correlation with R^2 values of 0.921 and 0.933, respectively. However, extrapolating the power trendline tended to produce better results and capture the less frequent events better. The correlation selection process was done on a case by case basis. Peaks for extreme events don't necessary increase linearly with stage increase, rather a shift in their position can be observed due to increased attenuation and losses within or beyond floodplain boundaries. For example, the large historical peaks obtained by applying the power trendline, mimicked the Corps Water Management System (CWMS) calibrated HEC-HMS model results for Canyon Lake and Dam (i.e. routing the calibrated 1978 peak event of 160,000cfs at USGS 08167500 to Canyon Lake produced a peak of 150,000cfs at the lake; this is an attenuation of 6.25%); whereas, peaks obtained from the linear trendline over predicted the same peak years. For this study, it was assumed that no additional storms would have contributed flows into the lake other than the attenuated observed flows captured in the Guadalupe River at USGS 08167500. The correlated tendlines at Canyon Lake were captured in Figure 9.5, and the adopted instantaneous peaks at Canyon Lake are listed in Table 9.2.

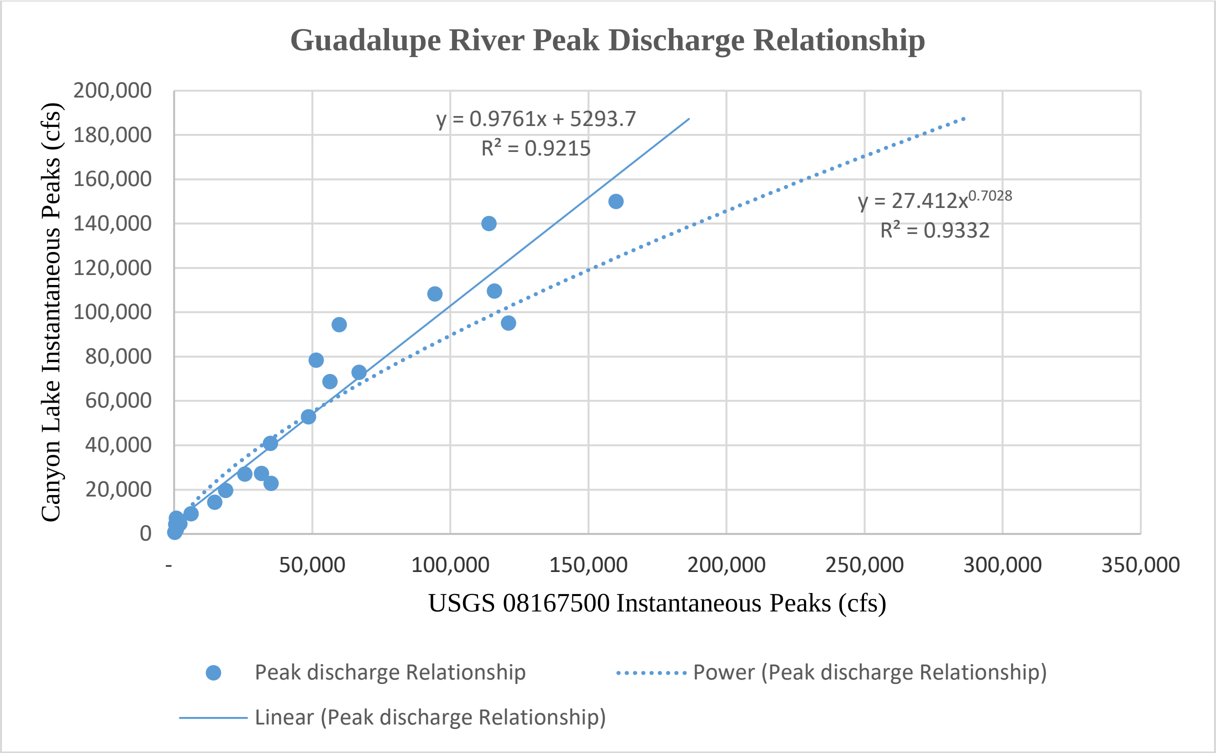


Figure 9.5 Guadalupe River above Canyon Lake Peak Discharge Relationship

Table 9.2 Adopted Instantaneous Peaks at Canyon Lake

Date	Canyon Lake Inflow Instantaneous Peaks (cfs)	Date	Canyon Lake Inflow Instantaneous Peaks (cfs)	Date	Canyon Lake Inflow Instantaneous Peaks (cfs)	Date	Canyon Lake Inflow Instantaneous Peaks (cfs)
1/1/1869	138,677	6/5/1943	8,194	1/20/1968	22,029	1/19/1993	7,327
7/1/1900	121,932	5/27/1944	36,593	5/16/1969	10,220	5/14/1994	19,219
12/1/1913	140,000	9/30/1945	17,872	10/6/1969	29,795	5/30/1995	14,240
4/1/1915	31,700	5/16/1946	13,910	8/14/1971	49,954	9/24/1996	11,390
9/1/1919	42,100	6/25/1947	17,872	5/12/1972	23,489	6/22/1997	109,553
9/19/1923	27,035	6/24/1948	14,864	7/16/1973	53,368	3/16/1998	24,149
5/26/1924	10,827	2/26/1949	15,884	10/14/1973	26,616	10/17/1998	78,470
5/29/1925	6,471	5/16/1950	10,409	5/24/1975	22,369	6/11/2000	2,004
4/21/1926	28,684	5/16/1951	9,855	4/18/1976	24,259	10/24/2000	22,874
6/5/1927	13,910	9/11/1952	72,900	4/16/1977	48,577	7/5/2002	108,351
3/9/1928	13,211	9/4/1953	9,839	8/3/1978	150,000	2/20/2003	7,454
5/29/1929	19,700	5/1/1954	8,367	3/21/1979	19,937	4/7/2004	27,275
6/12/1930	19,937	7/18/1955	11,375	9/8/1980	15,661	11/17/2004	40,823
10/7/1930	32,836	8/20/1956	3,034	6/17/1981	33,316	5/5/2006	4,562
7/3/1932	95,200	4/24/1957	27,000	10/14/1981	34,266	8/17/2007	68,747
5/26/1933	9,517	5/2/1958	58,962	6/5/1983	8,401	10/23/2007	7,142
4/18/1934	8,315	6/27/1959	23,930	10/9/1983	8,142	3/13/2009	4,411
6/15/1935	140,000	10/5/1959	49,065	6/6/1985	53,054	4/17/2010	14,315
9/28/1936	52,800	10/29/1960	23,044	10/20/1985	59,187	1/11/2011	807
6/1/1937	12,741	6/4/1962	8,367	7/18/1987	74,161	1/25/2012	9,122
4/27/1938	13,140	4/5/1963	9,967	7/12/1988	42,893	5/25/2013	6,886
7/14/1939	9,107	9/25/1964	16,635	5/17/1989	4,938	10/31/2013	21,341
10/10/1939	14,729	5/16/1965	28,480	5/4/1990	27,658	5/23/2015	94,480
2/1/1941	23,930	8/14/1966	27,864	9/16/1991	11,748	10/10/2016	49,551
9/8/1942	21,915	9/3/1967	13,534	12/21/1991	76,059		

9.6.3 Daily Average Annual Peak Estimates

The Canyon Lake missing daily average annual maximum peak inflows were generated by establishing a linear trendline relationship with the instantaneous peaks listed in Table 9.2. The linear correlation fitted best for the 1-day, 2-day, and 3-day average. The 4-day, 5-day, and 7-day average correlated better with a power trendline fit against the instantaneous peaks due to smoothing. Table 9.3 shows the correlation type and fit of the developed historical peaks for all annual peaks. Figure 9.6 shows the correspondent 4-day annual average peak-instantaneous peaks relationship.

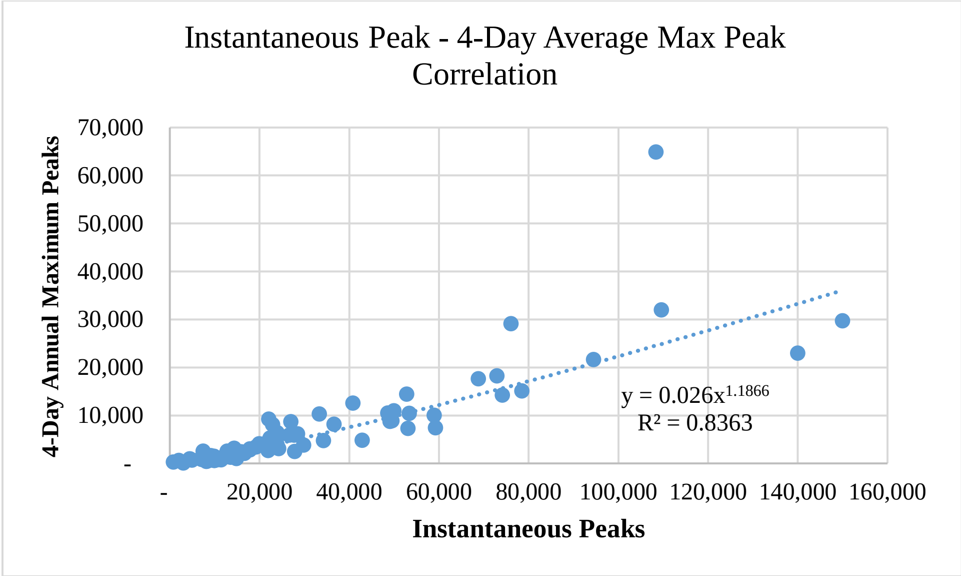


Figure 9.6: Correspondent 4-Day Annual Average Peak-Instantaneous Peaks Relationship

Table 9.3: Statistical Results and Correlation for Canyon Lake Inflow Peaks

Peak	Inst. Peak	1-Day	2-Day	3-Day	4-Day	5-Day	7-Day
Correlation Type	Power	Linear	Linear	Linear	Power	Power	Power
R^2	0.933	0.918	0.873	0.783	0.836	0.824	0.800

9.7 CRITICAL INFLOW DURATION ANALYSIS

The critical inflow duration for Canyon Lake is the inflow duration that results in the highest water surface elevations for the reservoir. Due to the project location, the reservoir peak stage is highly affected by rain-runoff, which has a significant short duration when compared to snowmelt runoff, and can be seen more pronounced during flood seasons. Many flood events were used for the analysis, because when flood events are considered, they would properly identify the highest peak stages to accurately assess the reservoir stage-frequency. The critical inflow duration estimate was looked at in two (2) ways; first, fourteen (14) historical inflow events with daily peak inflow greater than 20,000 cfs were identified as seen in Figure 9.7 and Table 9.4. The best-estimate inflow duration for the reservoir was estimated by taking the average hydrograph of the major events specified. A best-estimate of 4 days was selected based on the majority hydrograph durations. Like other major events, the 2002 extreme event was included in the data set to ensure that the selected critical duration is unbiased. The 2002 storm was recorded to have the largest volume of all recorded events. The 2002 hydrographwas caused by a significant amount of rain that stretched over the course of multiple days. Most other major events were caused by a single rainfall duration (Figure 9.7). In addition to critical inflow duration estimate, this analysis is more to have a better understanding of the runoff response from large single rain events. It helps establish what volume discharge frequency curves need to be examined.

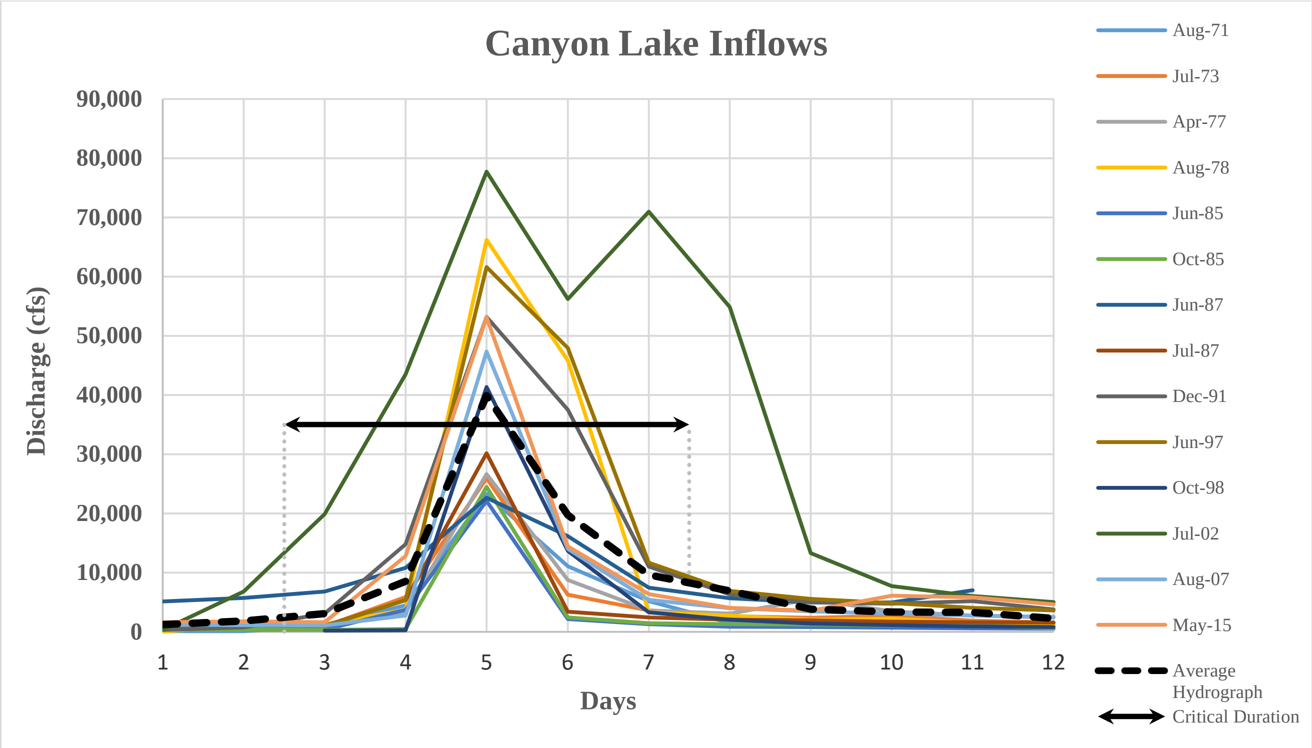


Figure 9.7 Inflow Duration Analysis for 14 Unregulated Lake Inflows

Table 9.4 Canyon Lake and Dam Historical Peak Flow Event

Date	Peak (cfs)	Date	Peak (cfs)
14Aug1971	23,284	18Jul1987	30,151
16Jul1973	25,930	21Dec1991	53,153
16Apr1977	26,626	22Jun1997	61,578
03Aug1978	66,219	17Oct1998	41,333
06Jun1985	22,101	03Jul2002	77,714
20Oct1985	24,473	17Aug2007	47,305
04Jun1987	22,623	24May2015	53,135

The second method to determine the critical inflow duration was done by observing the inflow and outflow hydrographs in the reservoir, and plotting for the major events for different high water years (*i.e.* 1997, 2002, 2007, and 2010) inflow events (Figures 9.8, 9.9, 9.10, and 9.11). The critical duration can be approximated as the duration from the start of the inflow hydrograph event to the point at which the inflow hydrograph crosses or coincide with the outflow hydrograph. For Canyon Lake's selected events, the reservoir pool elevation peaks within four to five days, soon after peak inflow is reached. This is due to the fact that Canyon Lake has the ability to store huge volumes up to the spillway crest elevation (maximum capacity) before making releases through the outlet works. From the inflow-outflow comparison, the critical duration is between four and five days for Canyon Lake Dam. A four day inflow duration was selected for the final stage-frequency curve.

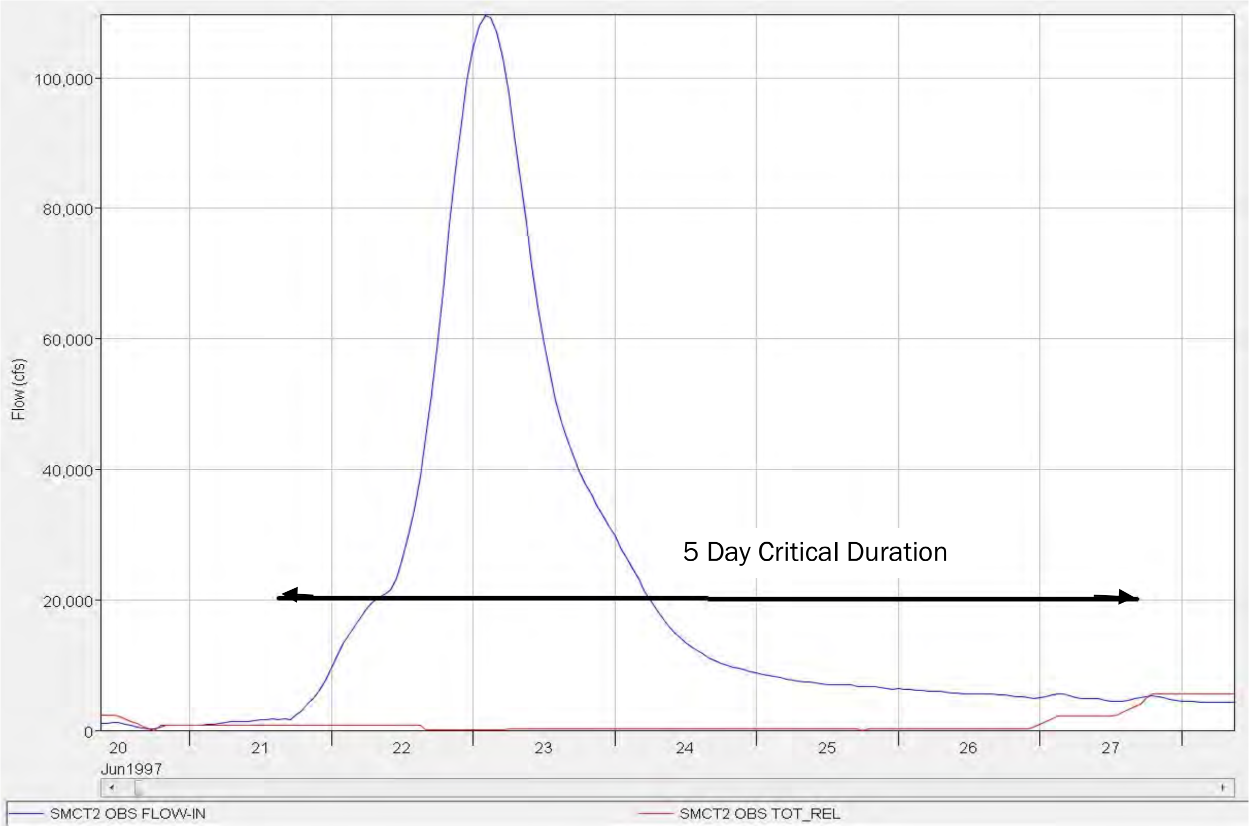


Figure 9.8 June 1997 Inflow-Outflow Hydrograph

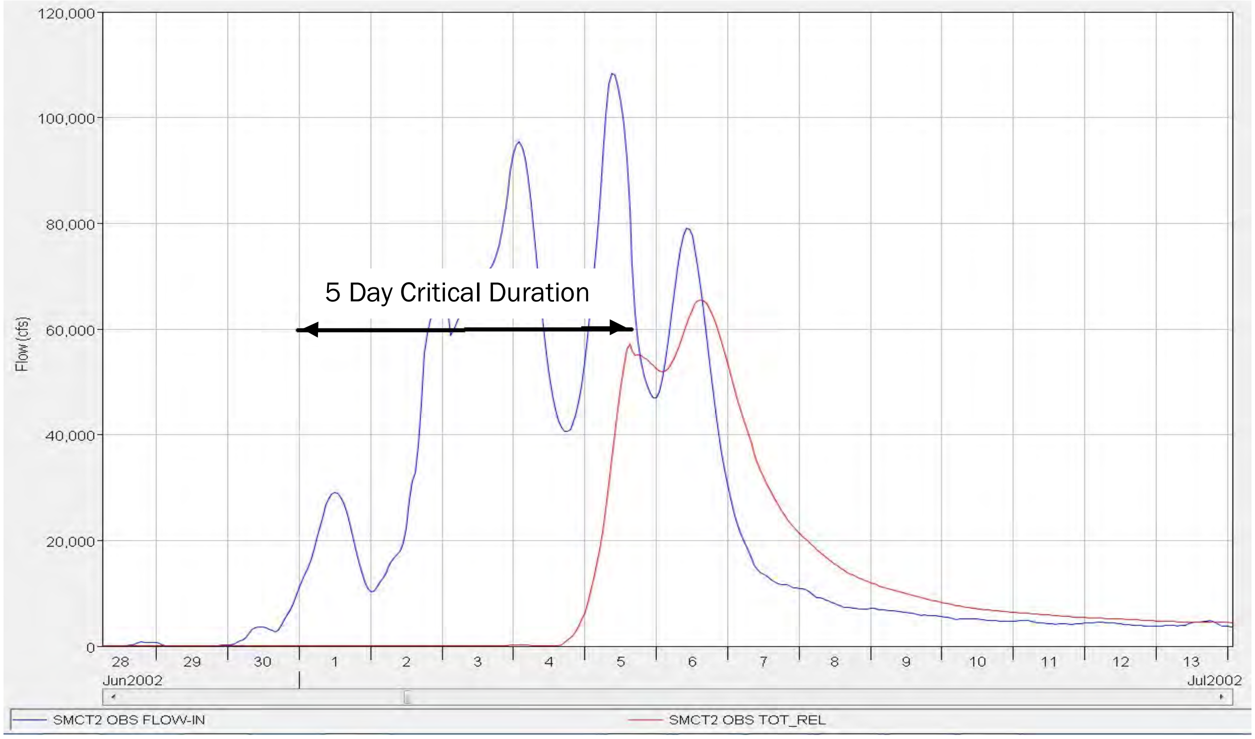


Figure 9.9 July 2002 Inflow-Outflow Hydrograph

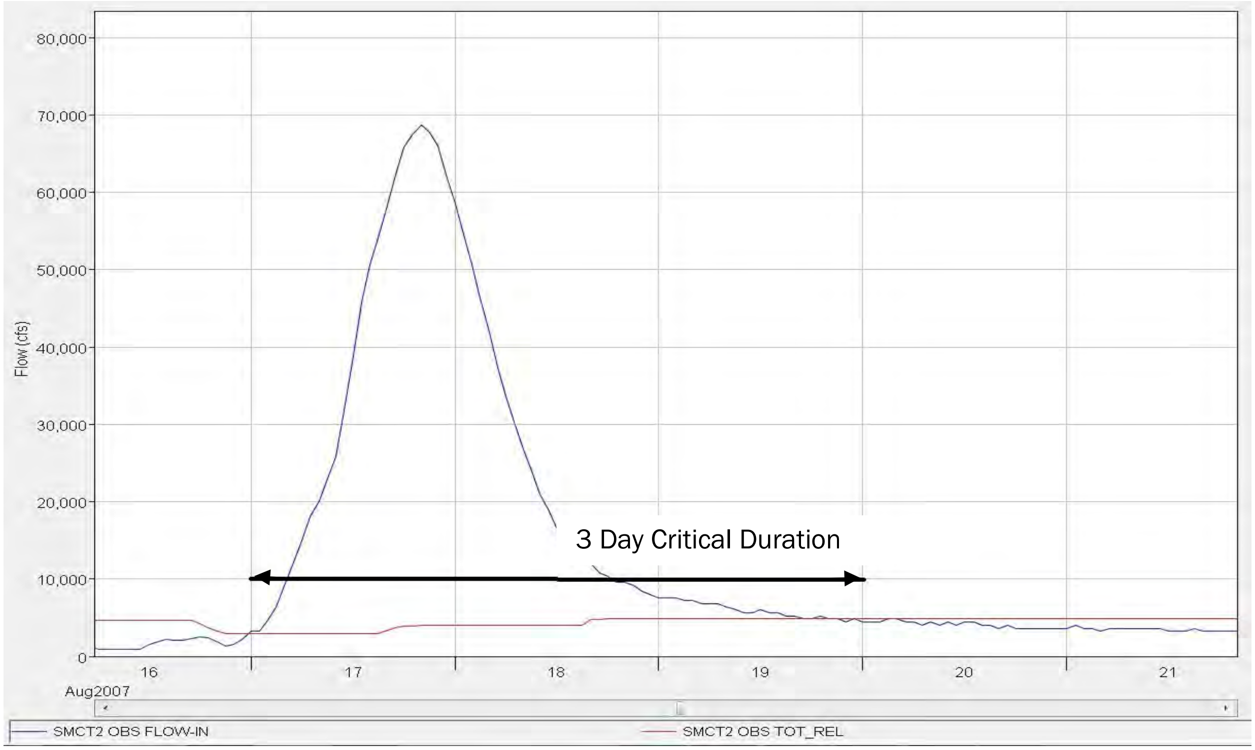


Figure 9.10 August 2007 Inflow-Outflow Hydrograph

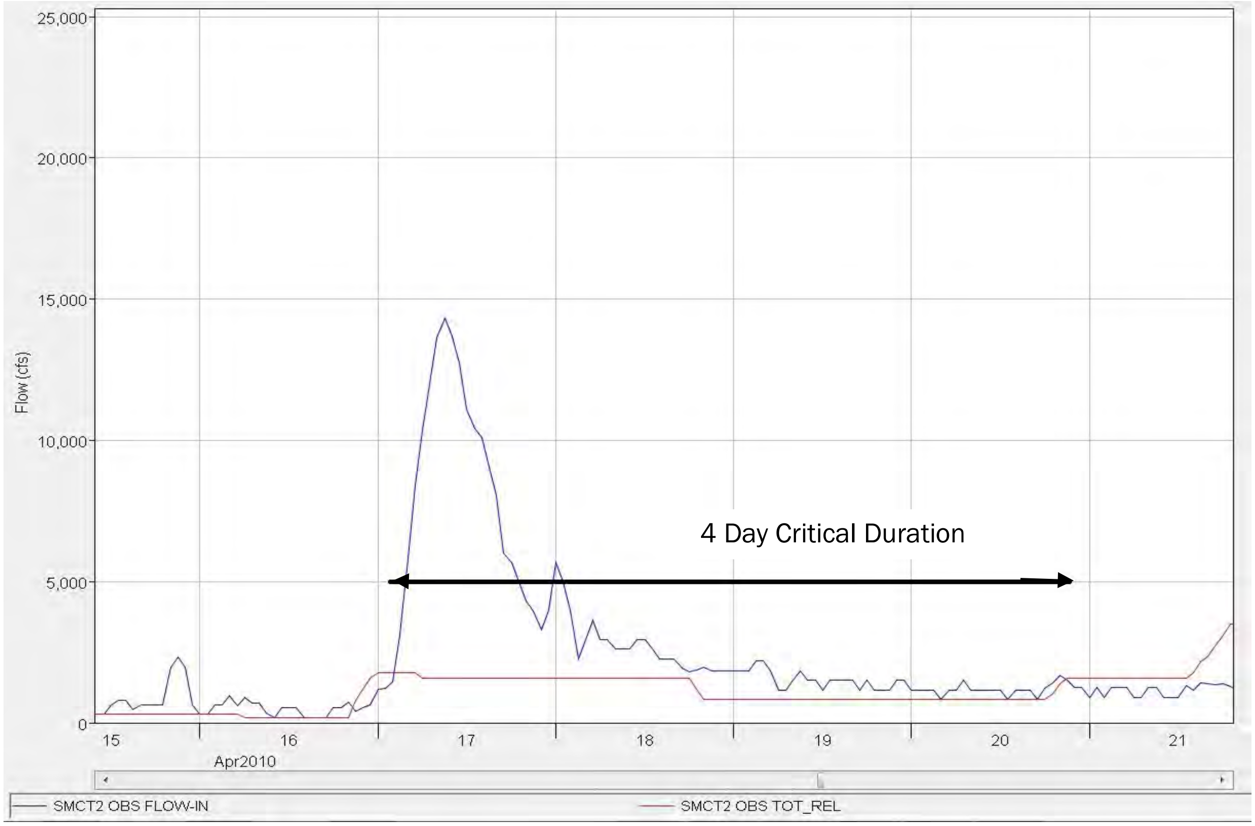


Figure 9.11 April 2010 Inflow-Outflow Hydrograph

9.7.1 Volume/Flow Frequency Statistical Analysis

The volume/flow frequency analyses for Canyon Lake were estimated by following Bulletin 17C guidelines and procedures (statistical techniques) to determine exceedance probabilities associated with specific flow rates utilizing HEC-SSP 2.1.1. The observed and developed daily average annual maximum peaks were used to establish a relationship between flow magnitude and frequency. In this report, the term volume/flow frequency refers to the frequency with which a flow over a given duration, such as 1-, 2-, 3-, 4-, 5-, and 7-day expected to be equaled or exceeded. The duration selection was based on inspecting the shape of the hydrographs. On average, hydrographs observed during major events in the Guadalupe River upstream Canyon Lake tend to peak about half way in a 5-day duration. A 7-day duration was included to cover long hydrograph durations. To adequately assess the risk associated with the Canyon Lake Dam structures in question, flow and volume frequency curves were combined to create a family of frequency curves for the various critical inflow durations. The family of curves (Figure 9.16) was used to construct hypothetical inflow frequency events, routed through Canyon Lake Dam to estimate reservoir stage-frequency curves.

9.7.2 Bulletin 17C

The use of bulletin 17C guidance allows for computations of the annual instantaneous and daily average peaks, using the Expected Moments Algorithm (EMA). It estimates distribution parameters based on sample moment in a more integrated manner that incorporates non-standard, censored, or historical data at once, rather than as a series of adjustment procedures (Cohn, Lane, & Baier, 1997). In this report, two (2) events were assigned as historical peaks (*i.e.* 1869 and 1900). A value of perception threshold from the 1869, 1900, and 1913 storms, which were historical record peaks, were set for 1870-1899, 1901-1913, and 1916-1922, respectively. The set of threshold peaks define the range of stream flow for which a flood event could have been observed; consequently years for which an event was not observed and recorded must have had a peak flow rate outside of the perception threshold. The use of bulletin 17C procedures provide confidence intervals for the resulting frequency curve that incorporate diverse information appropriately, as historical data and censored values impact the uncertainty in the estimated frequency curve (Cohn, Lane, & Stedinger, 2001). Within the 17C EMA methodology, every annual peak flow in the analysis period, whether observed or not, is represented by a flow range that range might simply be limited to the gaged value when one exists. However, it could also reflect an uncertain flow estimate. The Computed flows from HEC-SSP are listed in Table 9.5. The statistical Parameters generated based on applying the 17C EMA method, station skew, and a low outlier test for Multiple Grubbs-Beck are listed in Table 9.6.

Table 9.5 Canyon Lake Bulletin 17C Computed Median Inflows

N	ACE	Computed Average Daily Peaks (cfs) based on Bulletin 17C EMA					
Yrs	%	1-Day	2-Day	3-Day	4-Day	5-Day	7-Day
500	0.2	257,746	169,171	126,226	100,532	84,790	65,444
200	0.5	176,466	117,885	88,345	70,763	59,878	46,430
100	1	129,086	87,437	65,779	52,934	44,912	34,965
50	2	91,730	63,035	47,633	38,524	32,782	25,639
20	5	54,946	38,527	29,323	23,891	20,420	16,088
10	10	34,846	24,839	19,035	15,610	13,394	10,625
5	20	20,074	14,571	11,266	9,310	8,027	6,424
2	50	6,988	5,222	4,115	3,449	3,001	2,446
1.25	80	2,432	1,857	1,495	1,270	1,115	928
1.11	90	1,401	1,079	879	752	663	559
1.05	95	888	688	566	487	431	367
1.01	99	378	294	248	215	192	167

Table 9.6 Canyon Lake Bulletin 17C Computed Median Inflow Statistics

Statistics	1-Day	2-Day	3-Day	4-Day	5-Day	7-Day
Mean	3.844	3.715	3.613	3.536	3.475	3.387
Adjusted (Adopted) Mean	3.844	3.715	3.613	3.536	3.475	3.387
Standard Deviation	0.545	0.532	0.521	0.514	0.509	0.499
Adjusted (Adopted) Standard Deviation	0.545	0.532	0.521	0.514	0.509	0.499
Station Skew	-0.001	-0.026	-0.018	-0.02	-0.021	-0.013
Adjusted (Adopted) Station Skew	-0.001	-0.026	-0.018	-0.02	-0.021	-0.013
Historical Events	2	2	2	2	2	2
Low Outliers	1	1	1	1	1	1
Missing Flows	49	49	49	49	49	49
Systematic Events	97	97	97	97	97	97
Effective Record Length	144	144	144	144	144	144

9.8 RMC-RFA DATA INPUT

9.8.1 Inflow Hydrographs

Four (4) inflow hydrographs were selected to route through RMC-RFA. Hourly reservoir inflow data for large events were available for the June 1997, October 1998, July 2002, and August 2007. No other hydrographs were used in the stage-frequency curve development. The four (4) hydrographs selected represent different hydrograph shapes present in the Guadalupe River (Canyon Lake inflow) data (Figures 9-12, 9-13, 9-14, and 9-15). The character of the selected hydrographs are different, as they cover different types of inflow events (from peaky to large volume events).

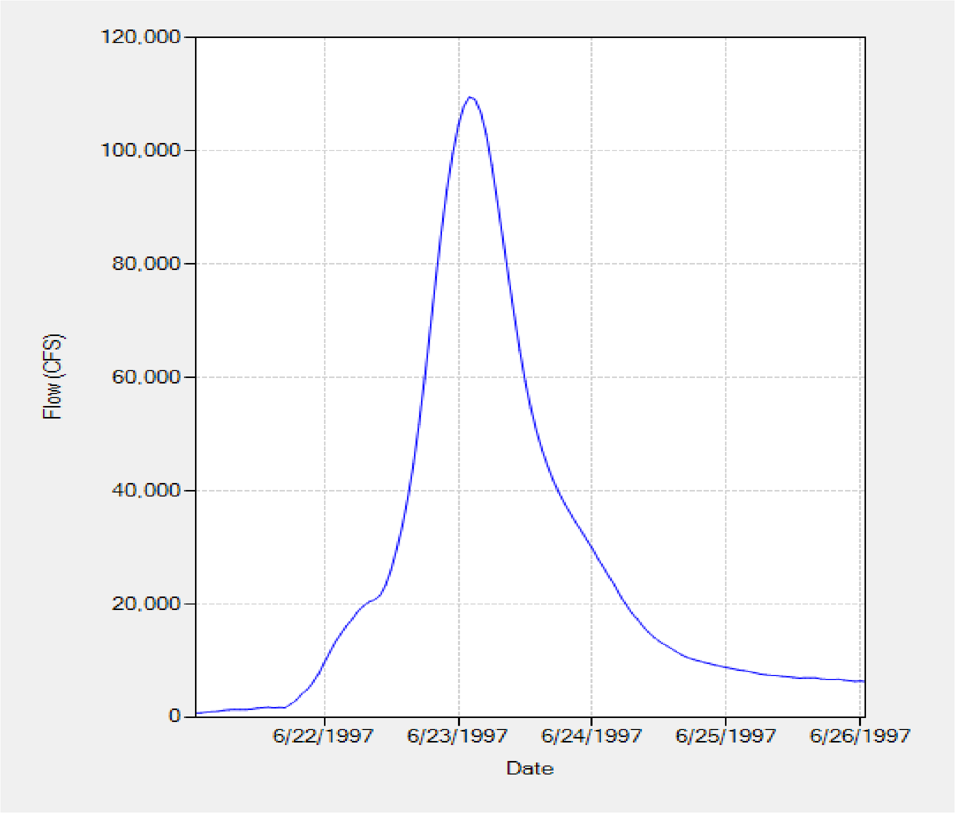


Figure 9.12 Canyon Lake Inflow Hydrographs for June 1997

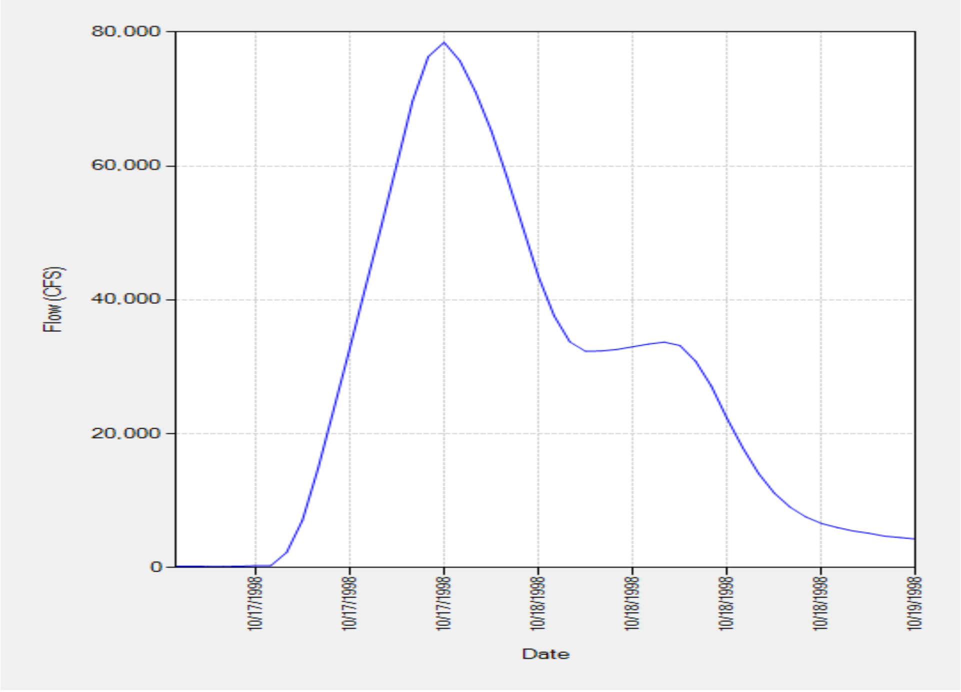


Figure 9.13 Canyon Lake Inflow Hydrographs for October 1998

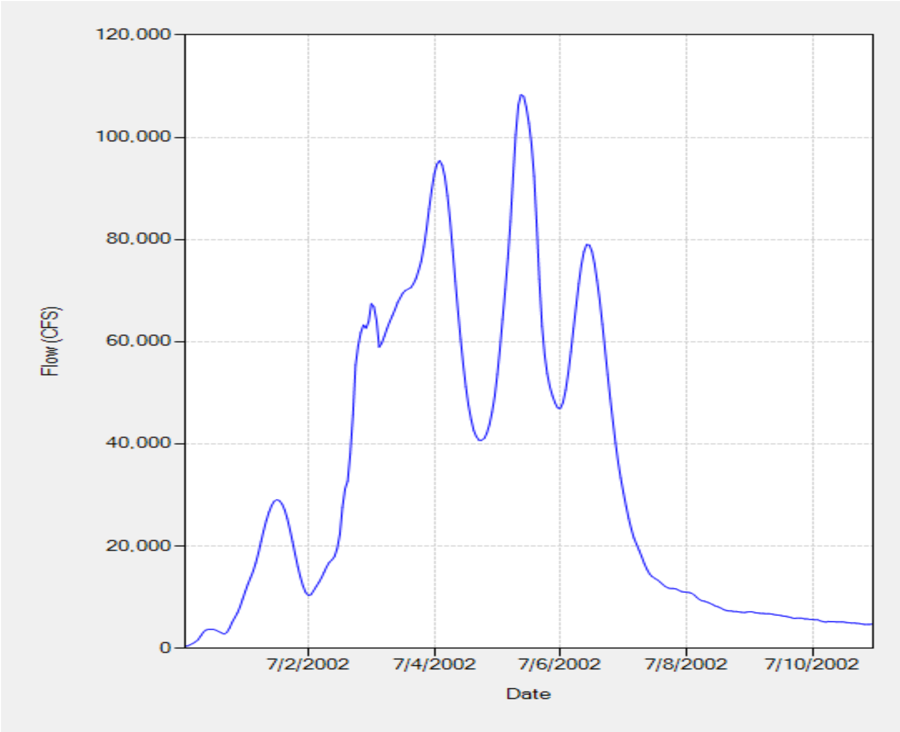


Figure 9.14 Canyon Lake Inflow Hydrographs for July 2002

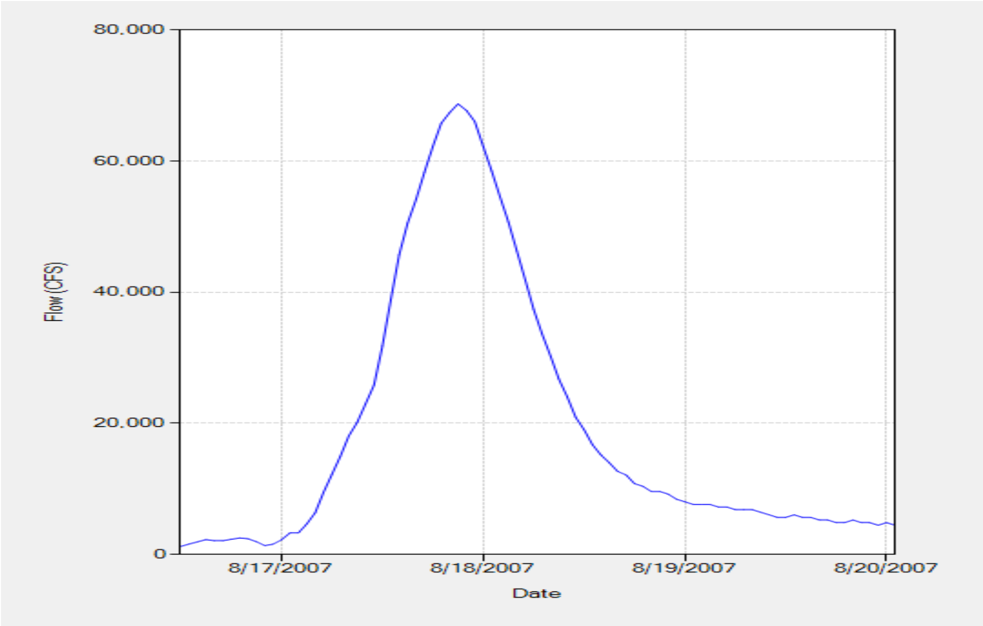


Figure 9.15 Canyon Lake Inflow Hydrographs for August 2007

9.8.2 Volume Frequency Curve Computation

The computed volume frequency statistical parameters found in Table 9.6 were introduced to the RMC-RFA program to produce the 1-, 2-, 3-, 4-, 5-, and 7-day durations. The volume discharge frequencies were created using bulletin 17C analysis method, and incorporated the 82 years of systematic inflow record created by RiverWare (1935-2016). The computed volume frequency curves for Canyon Lake are shown in Figure 9.16. No adjustments were made to the statistical parameters as curves were not crossing each other. The computed statistical values (*i.e.* mean, Standard deviation, and Skew) are presented in Table 9.6.

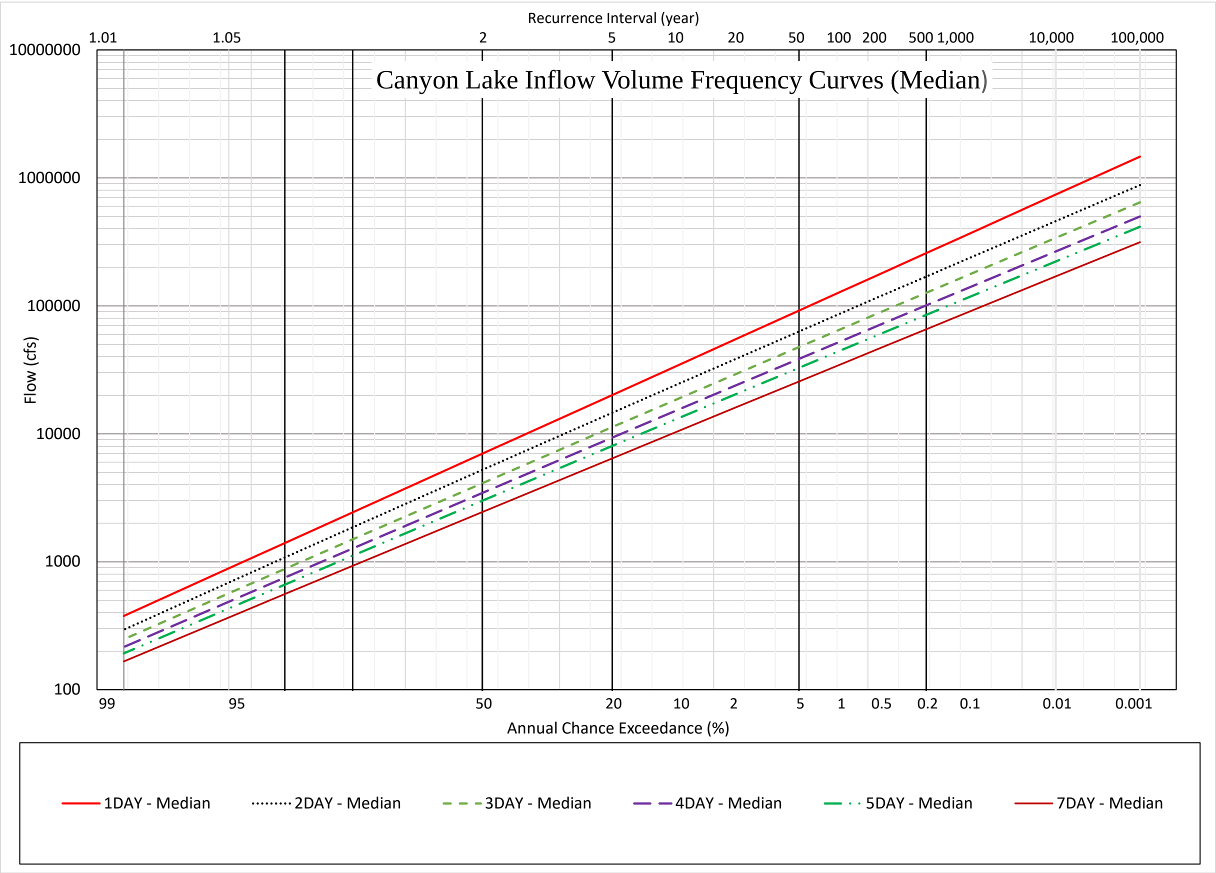


Figure 9.16 Canyon Lake Computed Volume Frequency Curves

9.9 RMC-RFA ANALYSES

9.9.1 Flood Seasonality

Many reservoirs have operations (pool level) that vary by season in response to the cyclical changes in meteorology and hydrology throughout the year. The inflow pattern at Canyon Lake has two distinct mechanisms that raise the pool elevation: thunderstorms and tropical storms. Thunderstorms can occur at any time of the year and tropical storms can happen between June and November. Due to meteorological and hydrologic conditions, most significant floods in the Guadalupe River watershed occur during late spring, summer, and fall months.

The term *flood seasonality* is intended to describe the frequency of occurrence of rare floods on a seasonal basis, where a rare flood is defined as any event where the flow exceeds some user specified threshold for a specified flow duration. In the RMC-RFA model operation, a month of flood occurrence is first selected at random according to the relative frequency. Once the month of flood occurrence is known, a starting pool elevation for the event can be determined from the reservoir stage-duration curve for that particular month. This keeps the seasonal variation in reservoir operations as a part of the peak-stage simulation.

For this analysis the critical 4-day flood seasonality analysis was performed. The threshold flow was set to 10,000 ft^3/s, the critical duration varies, but a 4-day duration was found the most applicable based on the critical duration analysis with a minimum of 45 days between events, and three (3) events per year were accepted. The selection of 45 days period ensures that small storms were ignored, and only major storm events with peaks greater than 10,000cfs were accounted for. With these criteria, a total of eighteen (18) flood events were located, four (4) of which occur in June, the most common month for flooding for 4-day duration (Figure 9.17). It should be noted that flood events for the months of January through March may encounter durations less than 4 days.

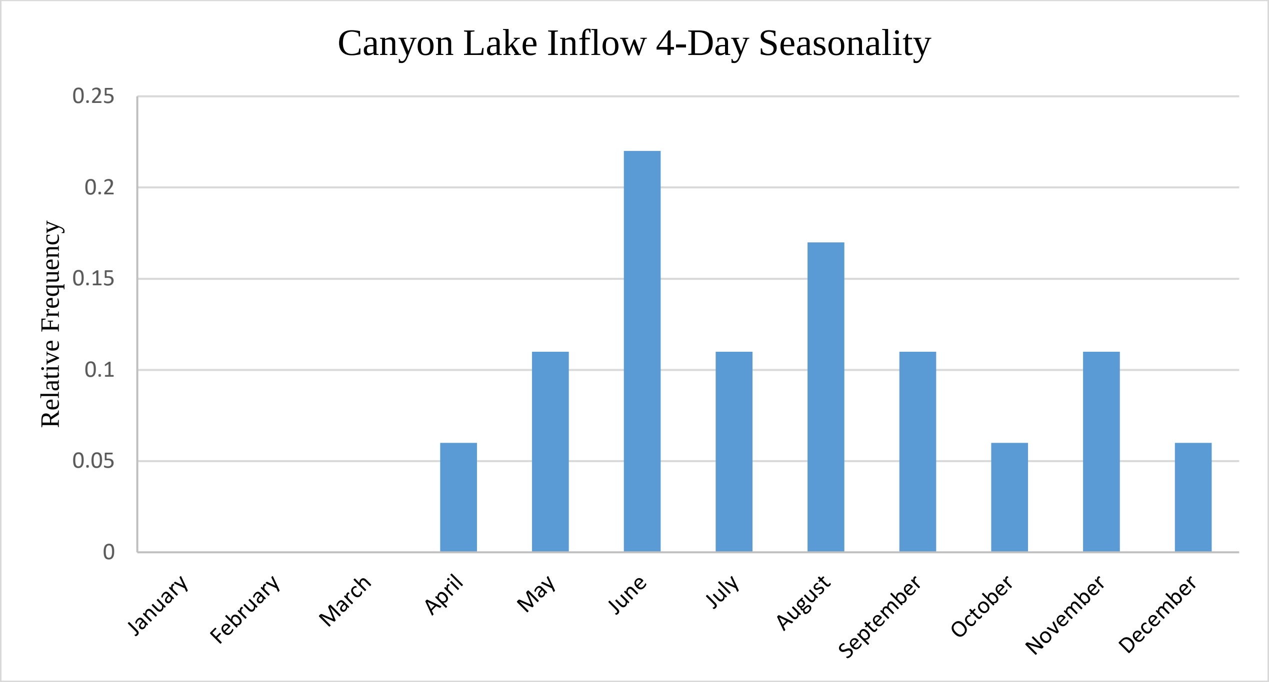


Figure 9.17 RMC-RFA Canyon Lake Inflow Flood Seasonality Analysis

9.9.2 **Reservoir Starting Stage Duration**

Reservoir starting pool duration curves represent the percent of time during which antecedent reservoir pools are exceeded. An inflow threshold method was used to establish starting pool duration curves based on an inflow threshold value, which is normally selected to meet the value that falls under the estimated n-day critical duration and its most frequent event (volume) value. By doing so, all inflow hydrographs into the lake only consider rising limbs responsible for raising the pool. The final duration curve is illustrated in Figure 9.18, and the associated starting pool values are listed in Table 9.7. The starting pool duration curves showed consistent patterns of pool changes of when pool was exceeded between 40% and 70% of the time for all months. Several starting pool duration curves were generated based on varying inflow threshold peak values. The 487cfs threshold peak was selected to generate starting pools prior to routing inflows through the RMC-RFA model for Canyon Lake. The 487cfs threshold is the 4-Day inflow duration curve for the 95% ACE (~1-year event).

Table 9.7 Canyon Lake Starting Elevation Pool for the RMC-RFA Reservoir Simulation Model

Probability	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.999	896.6	885.6	775.3	818	865.4	874.9	863.2	890.8	867.7	881.8	896	895.9
0.995	896.6	885.6	775.3	818	865.6	874.9	863.2	890.8	867.7	881.8	896	895.9
0.99	897	885.7	854.5	820.7	867.1	877.3	863.9	890.8	867.7	881.8	896	896.2
0.95	901.3	902.3	903.7	898.6	895	902	907	904.1	879.7	895	901	899.9
0.9	904.5	906.4	906.1	902.9	902.3	906.1	908.3	904.8	893.8	896.2	907	905.5
0.5	909	909	909	909	909	909.8	910.1	909.7	908.9	908.8	909.5	909.2
0.1	911	911.2	911.1	913.6	911.7	916.9	928.3	931.2	912.7	912.1	919.6	912.1
0.05	915.9	911.9	911.7	916.6	914.1	919.3	943	942.5	915.8	914.3	922.8	917.5
0.01	923.2	929.8	931.2	926.4	921.3	941.6	945.8	943.8	927.3	923.4	927.3	930.1
0.005	924.2	930.1	934	926.9	925.4	942.5	945.8	943.8	927.3	923.4	927.5	930.4
0.002	924.2	930.1	934	926.9	925.7	942.5	945.8	943.8	927.3	923.4	927.5	930.4
0.001	924.2	930.1	934	926.9	925.7	942.5	945.8	943.8	927.3	923.4	927.5	930.4

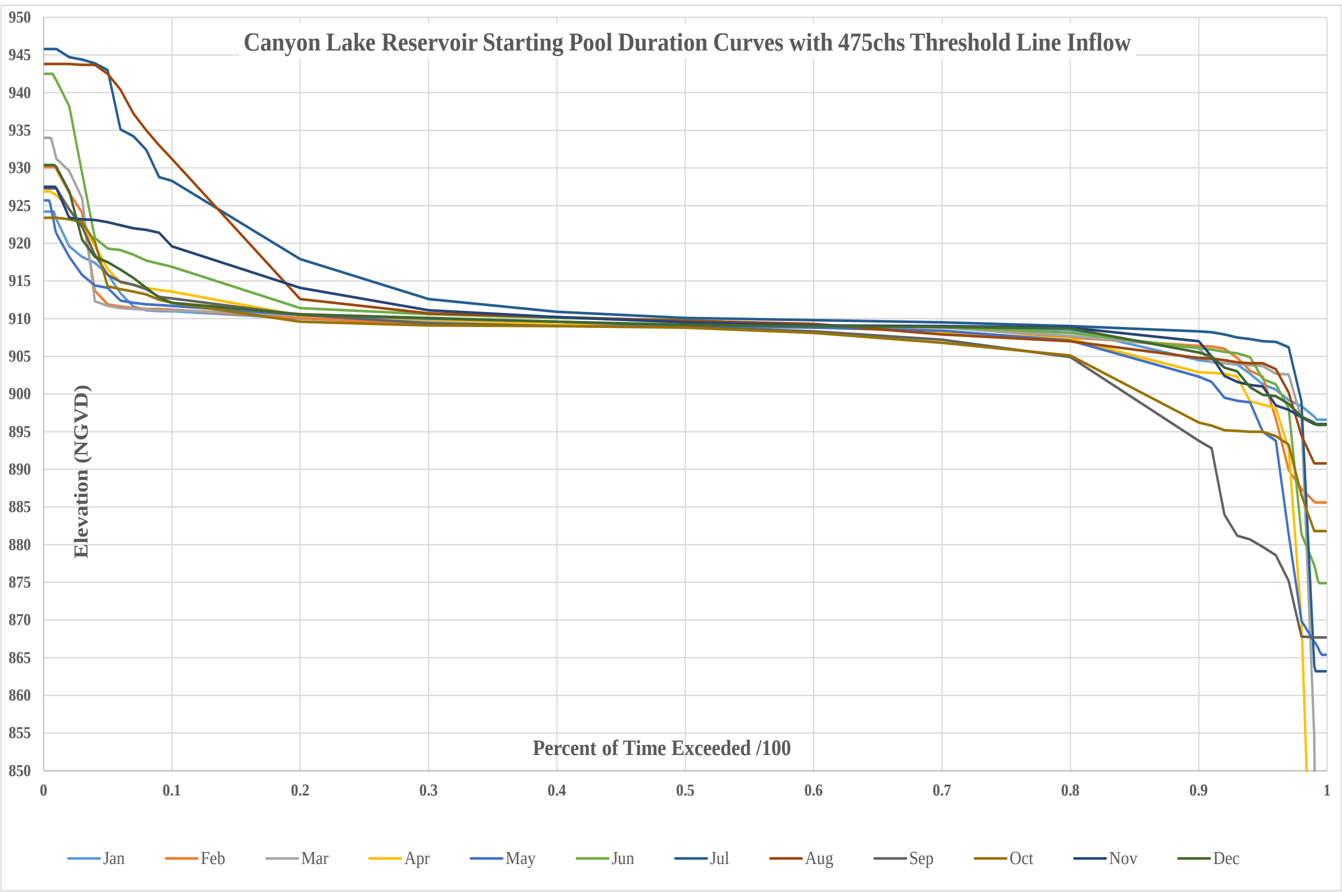


Figure 9.18 Canyon Lake Starting Pool Durations

9.9.3 **Empirical Frequency Curve**

For the evaluation of hydrologic hazards, an extreme-value series of annual maximum stages were generated from the observed period of record (1965 to 2016) and the current condition RiverWare simulated POR (1935 to 2016). Each POR annual maximum series (AMS) was determined, the AMS was ranked, and plotted on normal probability paper using Weibull plotting position formula (Figure 9.19). The objective of using probability paper is to linearize the distribution so that the plotted data can be easily analyzed for comparison purposes.

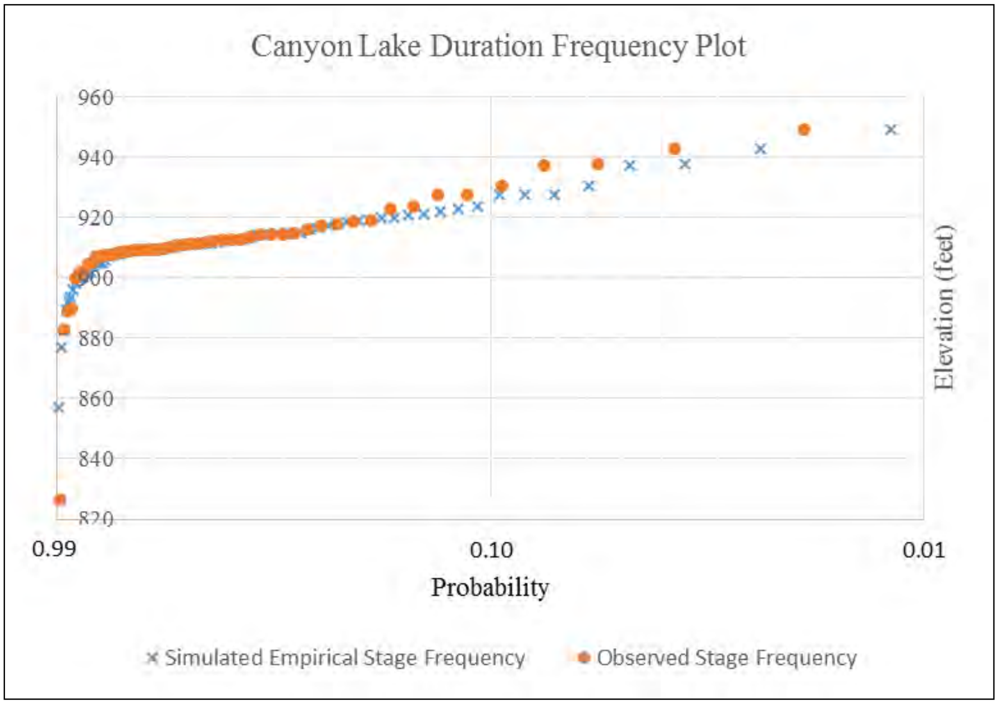


Figure 9.19 Stage Duration Frequency Plot for Canyon Lake

9.9.4 **Reservoir Model**

The reservoir details such as the stage-storage-discharge function and top of dam, spillway, and inflow design flood elevations were obtained from the Corps Water Control Manual (WCM). The information is needed in order for the simulation to run. Canyon Lake releases are directly stage-dependent. Therefore, a stage-storage-discharge function can be estimated. The WCM storage-elevation and discharge-elevation curves for the project are shown in Figures 9.20 and 9.21. More details about reservoir features are listed in Table 9.8.

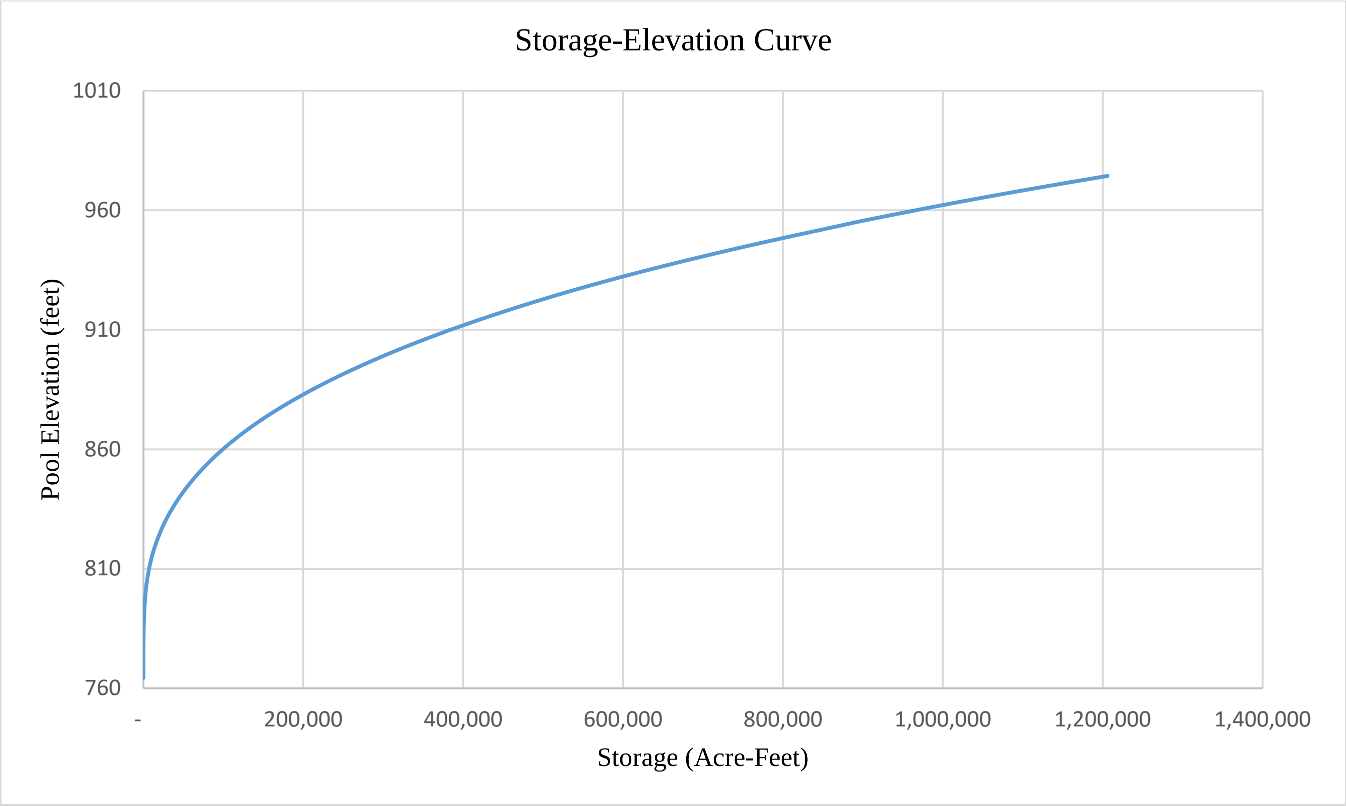


Figure 9.20 Canyon Lake Storage-Elevation Curve

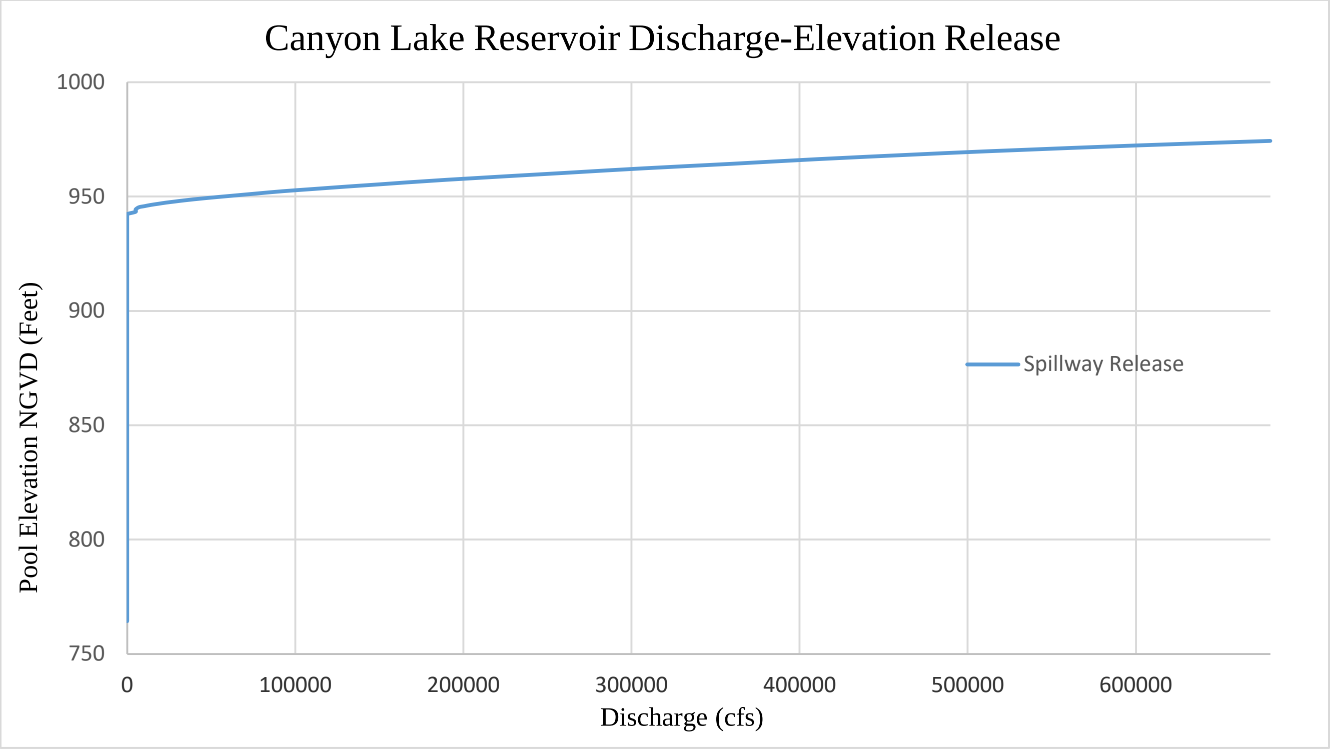


Figure 9.21 Canyon Lake Pool-Discharge Curve

Table 9.8 Canyon Lake Features

Top of Dam (Feet)	Spillway (Feet)	Inflow Design Flood (Feet)
974	943	969.1

The discharge elevation curve accuracy is one of the key components in the RMC-RFA program to obtain accurate results. Figure 9.22 illustrates the reservoir discharge-elevation curve for different operation plans. The conservation pool release term refers to releases based on current operations. The conservation pool elevation-discharge curve was adjusted at key elevation points to ensure smooth transition as the pool approaches the conservation top pool and the spillway top crest level. Several efforts were made to utilize the best curve that would mimic observed points at the dam. The best generated curve was obtained by routing the flow POR through the dam in HEC-HMS. The final adopted curve was then adjusted, so the best resulted elevation points at the dam produced comparable results of probability-stage distribution when compared to the observed data points (see Figure 9.22). The adopted conservation pool release curve was then used for simulation. The adopted curve (HEC-HMS based curve) is illustrated in Figure 9.23.

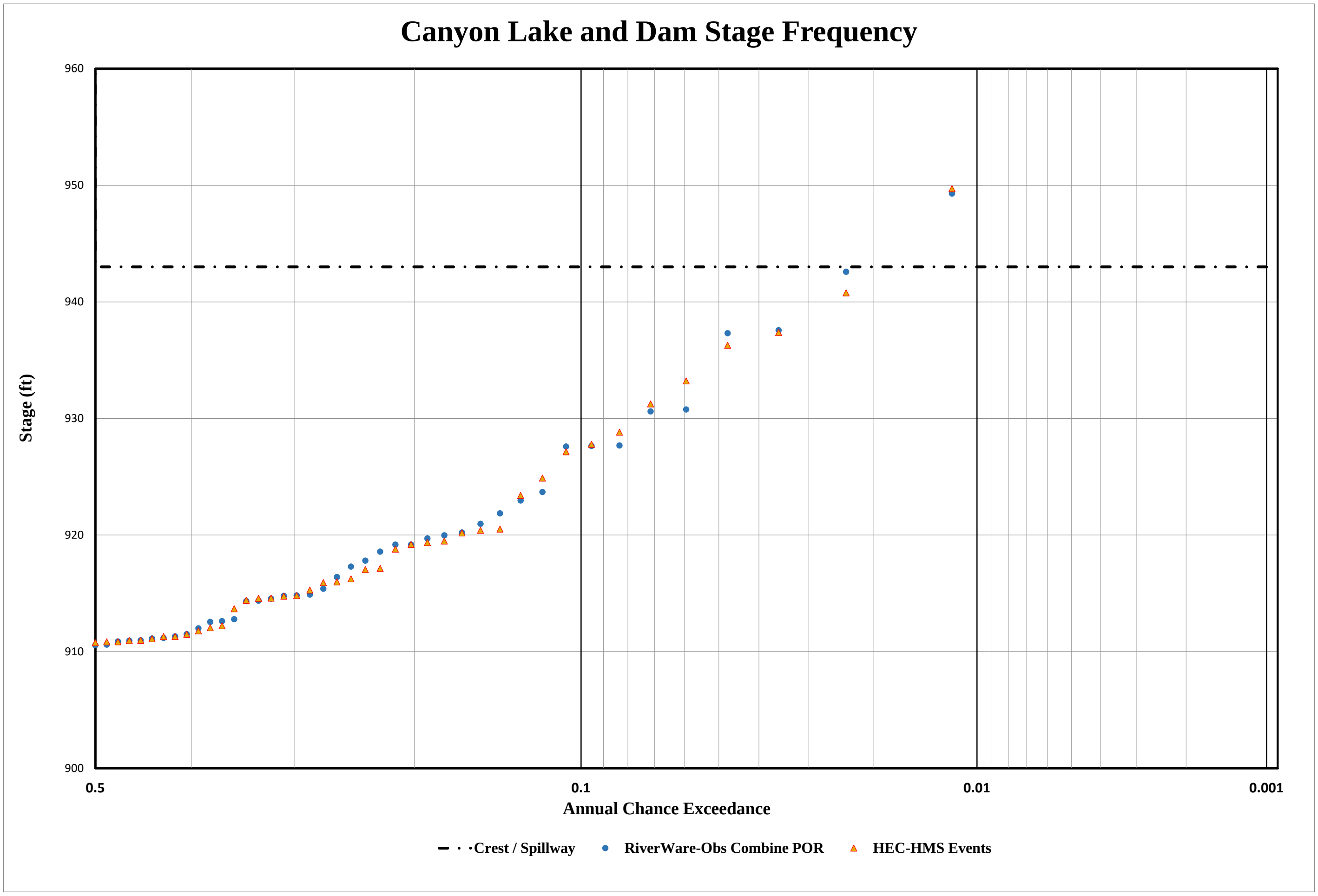


Figure 9.22 Stage Frequency Comparison at Canyon Lake and Dam

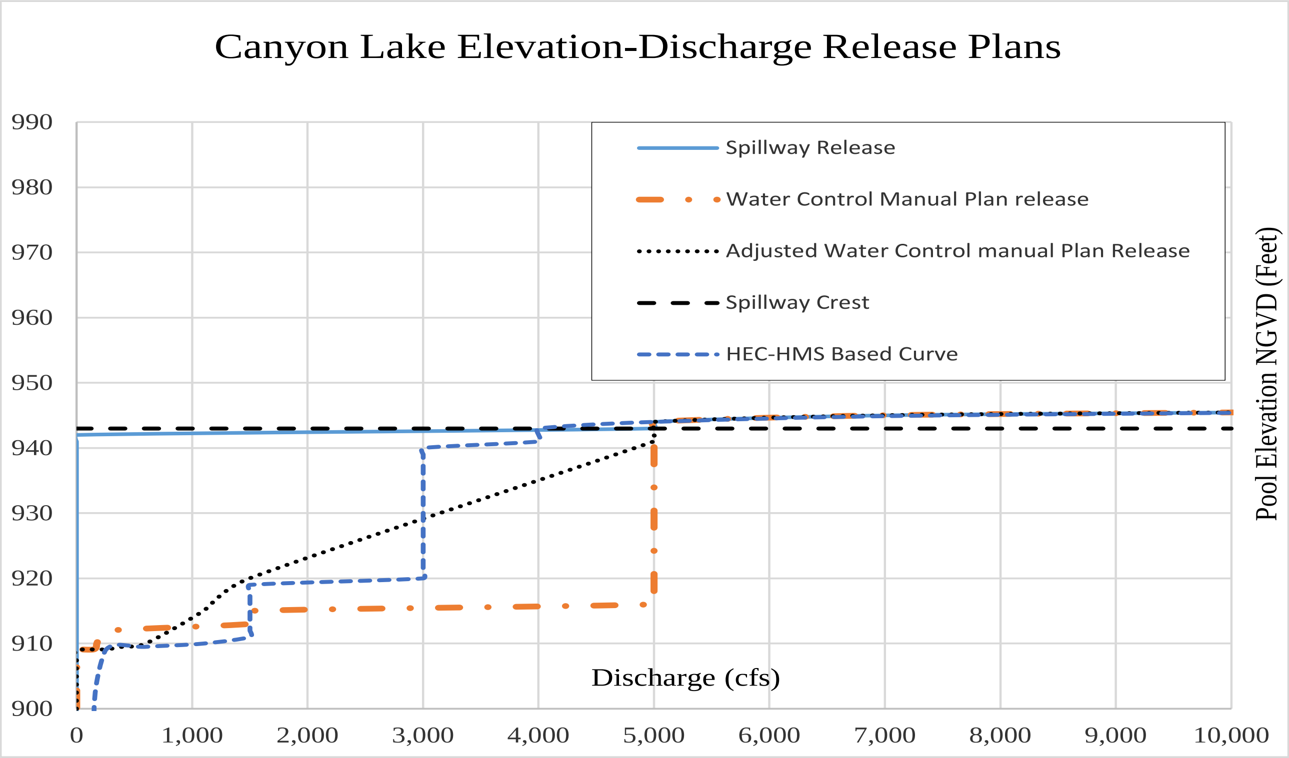


Figure 9.23 Canyon Lake Pool-Discharge Comparison

9.10 RESULTS AND DISCUSSION

The RMC-RFA program was used to simulate rainfall floods using the inflow-frequency curve and the adopted flood seasonality. The 1997, 1998, 2002, and 2007 inflow hydrographs are weighted equally to account for each unique shape (*i.e.* volume and peak). A routing time window of 5 days was specified to calculate the full size of storms routed through the reservoir on hourly basis. One thousand (1,000) realizations were iterated to capture flow events with Annual Chance of Exceedance (ACE) greater than 99%. The uncertainty limit bounds of 90% were captured. Results showed that the rainfall simulation agreed with the stage frequency curve created by the empirical distribution of the observed points. Figure 9.24 shows the expected probability curve (mean hazard curve) for rainfall simulations, which demonstrates good results through the high stage observed points. The curve shows more conservative results towards the more frequent events (less than 10% ACE (10-year)). For the purpose of dam safety studies, more emphasis are put on the less frequent events (*i.e.* 1% ACE (100-year) and 0.2% ACE (500-year).

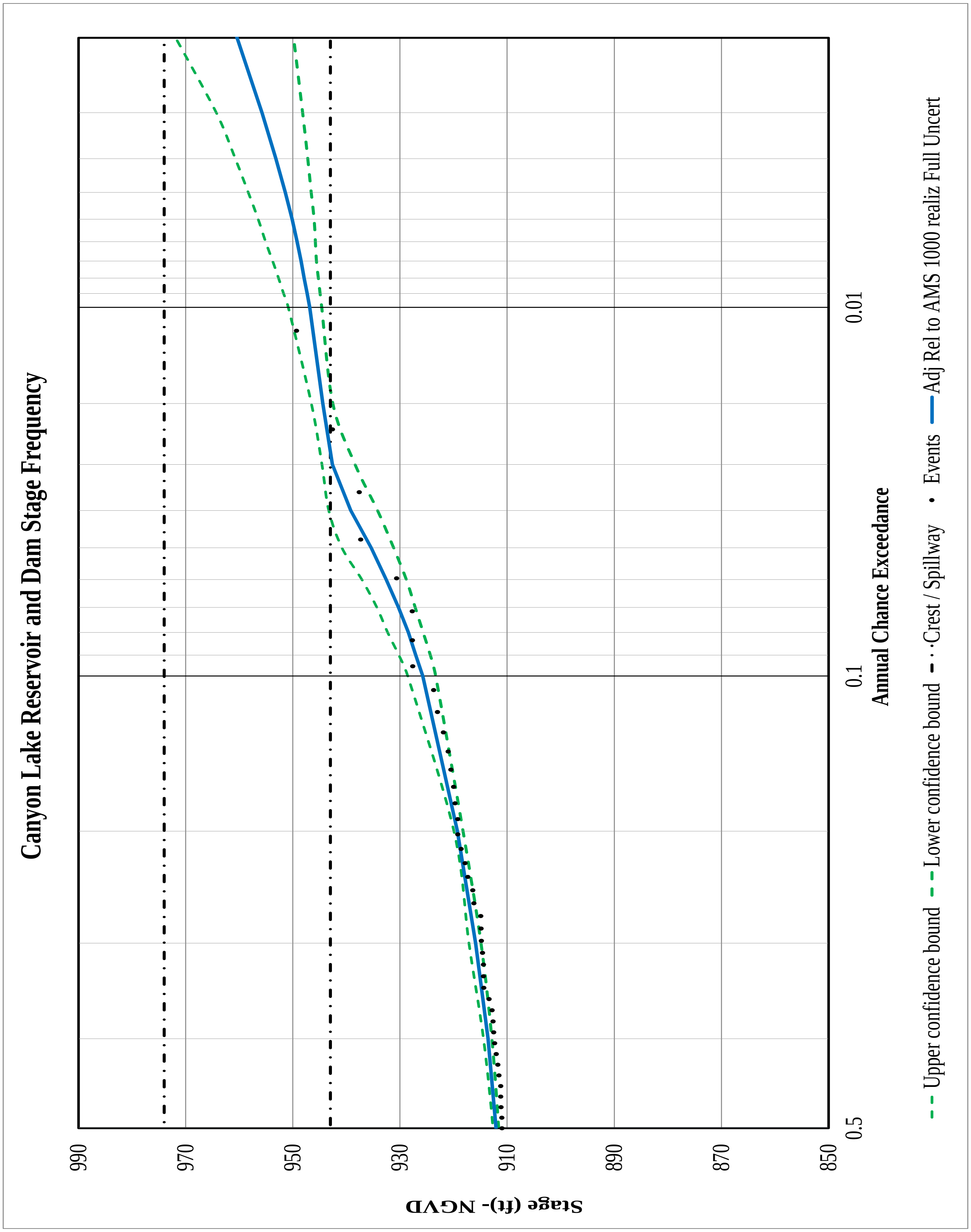


Figure 9.24 Stage-Frequency Curve Comparison Between Rainfall Simulation and RiverWare Simulated Historical Peaks

The 90% uncertainty bounds increase towards the coarser empirical (observed) data points near the less frequent events (*i.e.* 1% ACE or 100-year event). The 2% (10-year) through 0.2% ACE (500-year) pool frequency curve computations is listed in Table 9.9.

Table 9.9: 2016 Canyon Lake Computed Pool Elevation Frequency

N	ACE	Upper	Lower	Best Estimate
Year	%	Elevation (NGVD) feet		
2	50	912.6	911.6	912.1
5	20	919.9	918.2	919.3
10	10	929.1	924.1	926.4
25	4	943.4	934.3	939.3
50	2	946.1	942.7	944.4
100	1	950.8	944.8	946.8
250	0.4	958.2	946.5	951.4
500	0.2	964.6	948.4	955.7

In addition, Table 9.11 and Figure 9.25 are added to compare computed pool elevation frequencies between results obtained from the HEC-HMS model and the expected frequencies from the RMC-RFA analysis.

The HEC-HMS model was built for the Guadalupe River watershed, and captured Canyon Lake discharge and pool frequencies applying simplified uniform rainfall runoff method. The model was calibrated to real time events, and the annual chance of exceedances were generated accordingly. The same hydrologic parameters developed for real time calibration were used to generate the frequencies of interest. HEC-HMS model uniform rain frequency results are listed in Table 9.11.

The RMC-RFA expected curve tends to produce good fit through the empirical points. The fit tends to shift downward and passes through the lower end of the points after it hits the spillway crest. The HEC-HMS frequency curve results underestimated the more frequent events and fit better through the observed high pool points. The RMC-RFA expected curve showed more abrupt change in its trend as it approaches the spillway crest as opposed to the HEC-HMS results, where spill change is smoother over the crest.

To better determine what results performed best, 2-Day balanced hydrographs of the 1% ACE (100-year) were inspected and compared against the observed 2-Day 1% ACE (100-year) volume frequency curve at Canyon Lake. The HEC-HMS model volume results were overestimating the 2 Day-1% ACE actual volume (see Table 9.10), which led to the inference that pool frequencies were overestimated. The 2-Day actual volume compares relatively close to the 2-Day volume discharge frequency used to generate pool frequencies for the RMC-RFA run. As a result, the computed RMC-RFA pool frequencies are adopted for this study, and will be used to describe stage frequencies for Canyon Lake and Dam.

Table 9.10 2-Day 1% ACE (100-year) Volume Frequency Comparison

HEC-HMS Uniform Rain Results	Volume Frequency Analysis - Bulletin (17C)	August 2007 Balanced Hydrographs	October 1998 Balanced Hydrographs
105,000 cfs	87,500 cfs	86,700 cfs	86,200 cfs

Table 9.11 2016 Canyon Lake Computed Pool Elevation Frequency Comparison

N-Year	ACE %	RMC-RFA Expected	HEC-HMS	Change in Pool (feet)
10	10	926.36	923.87	2.5
25	4	939.26	936.91	2.4
Spillway Crest Elevation (feet)				943
50	2	944.44	946.48	-2.0
100	1	946.79	950.6	-3.8
250	0.4	951.36	954.86	-3.5
500	0.2	955.71	957.92	-2.2

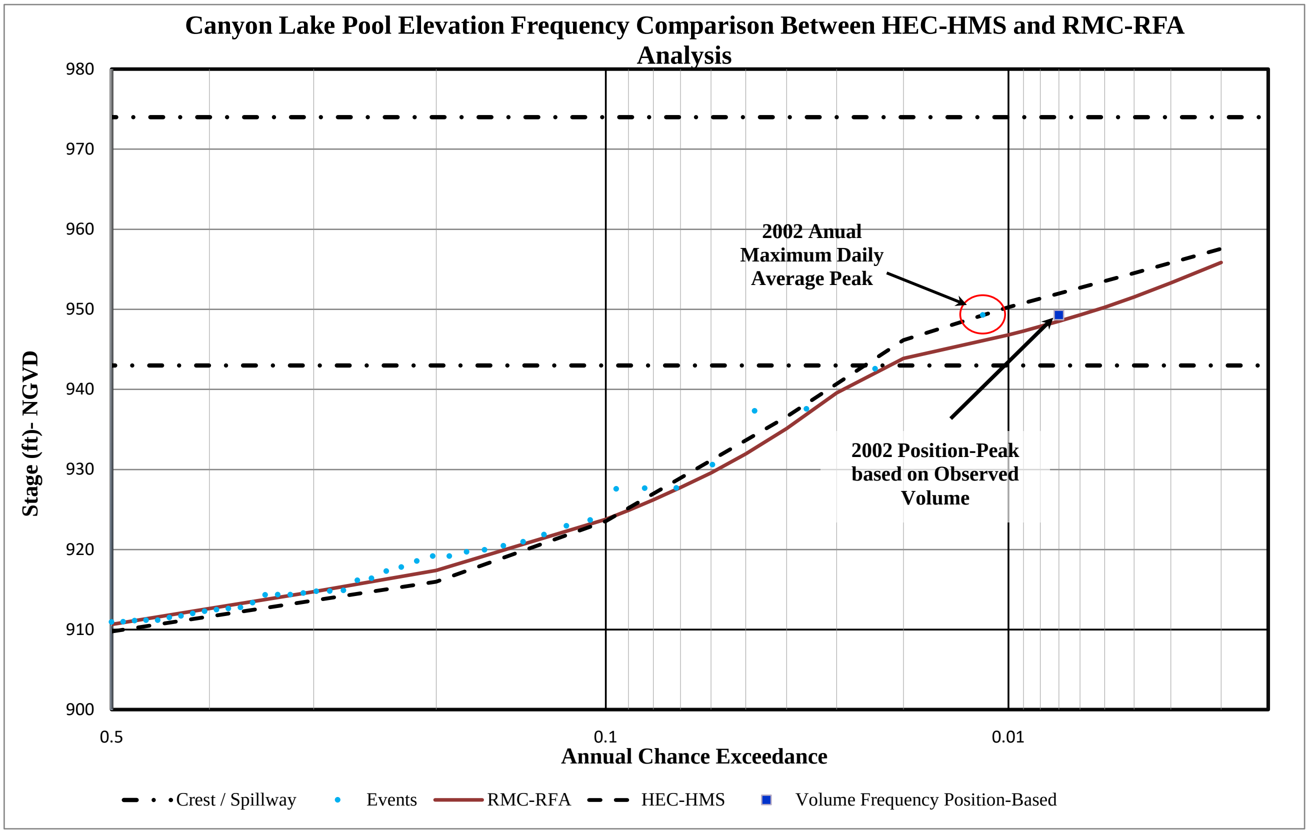


Figure 9.25 2016 Elevation Frequency Curve Comparison at Canyon Lake

The adopted curve RMC-RFA produced; particularly the pool frequency fitting near the record annual daily average peak observed in 2002 (see Figure 9.24), was found to agree with the pool frequency the same peak falls under with the estimated 4-Day volume of the observed hydrograph. In other words, the 4-Day volume of the 2002 event is roughly estimated at 60,400cfs; this value falls between the 1%ACE (100-year) and 0.2%ACE (500-year) events in the 4-Day volume frequency curve produced applying Bulletin 17C procedures. In terms of pool frequencies, this is about 0.7% ACE (140-year) event.

Applying the Weibull plotting position to the period of record, positioned the 2002 peak event to read below the 1% ACE (100-year) event, which may not agree with the aforementioned computed and observed volumes of the same event. It is more appropriate to rely on the RMC-RFA curve reading than suggested by the empirical point for the 2002 event. As a result, it is anticipated that the 2% ACE (50-year) event will overtop the spillway.

A comparison of the new pool frequency elevations produced utilizing RMC-RFA is made against the effective FEMA elevations (Table 9.12).

Table 9.12 2016 Canyon Lake Computed Pool Elevation Frequency Comparison with FEMA Elevations

N-Year	ACE %	RMC-RFA* Best Estimate	FEMA* Effective	Change in Pool (feet)
10	10	926.36	924	2.4
25	4	939.26	-	
Spillway Crest Elevation (feet)				943
50	2	944.44	940	4.4
100	1	946.79	946	0.8
250	0.4	951.36	-	
500	0.2	955.71	949.7	6.0

* Elevations are in NGVD29.

Results shown in Table 9.12 suggest that changes in the reservoir elevations are more conservative with the current best estimate. For example, the 10% ACE (10-year) event is about 2.7 feet higher than FEMA's 10% ACE effective pool frequency value. Changes in pool levels for the 2% ACE (50-year), 1% ACE (100-year), and 0.2% ACE (500-year) pool frequencies are higher than the documented FEMA's effective pool frequencies by 4.8, 1.1, and 6.4 feet, respectively. Spillway overtopping is anticipated to occur just above the 2% ACE (50 year) event, which is a change from FEMA's estimate, where overtopping would have occurred between the 2% ACE (50-year) and 1% ACE (10-year) events.

Canyon Lake and Dam has a flowage easement elevation of 948 feet (NGVD). The flowage easement land is privately owned land on which the U.S. Army Corps of Engineers has acquired certain perpetual rights. Namely the right to flood it in connection with the operation of the reservoir, the right to prohibit construction or maintenance of any structure for human habitation, the right to approve all other structures constructed on flowage easement land, except fencing. Properties located above elevation 948 NGVD-feet keep from what would become damageable property out of the flood pool, so that the reservoir can be operated with a full focus upon downstream conditions and the concern for dam safety. To put things more to perspective about the flowage easement, Figure 9.26 was included to illustrate easement elevation reference in relation to the reservoir pool frequencies, spillway crest elevation, and top of dam.

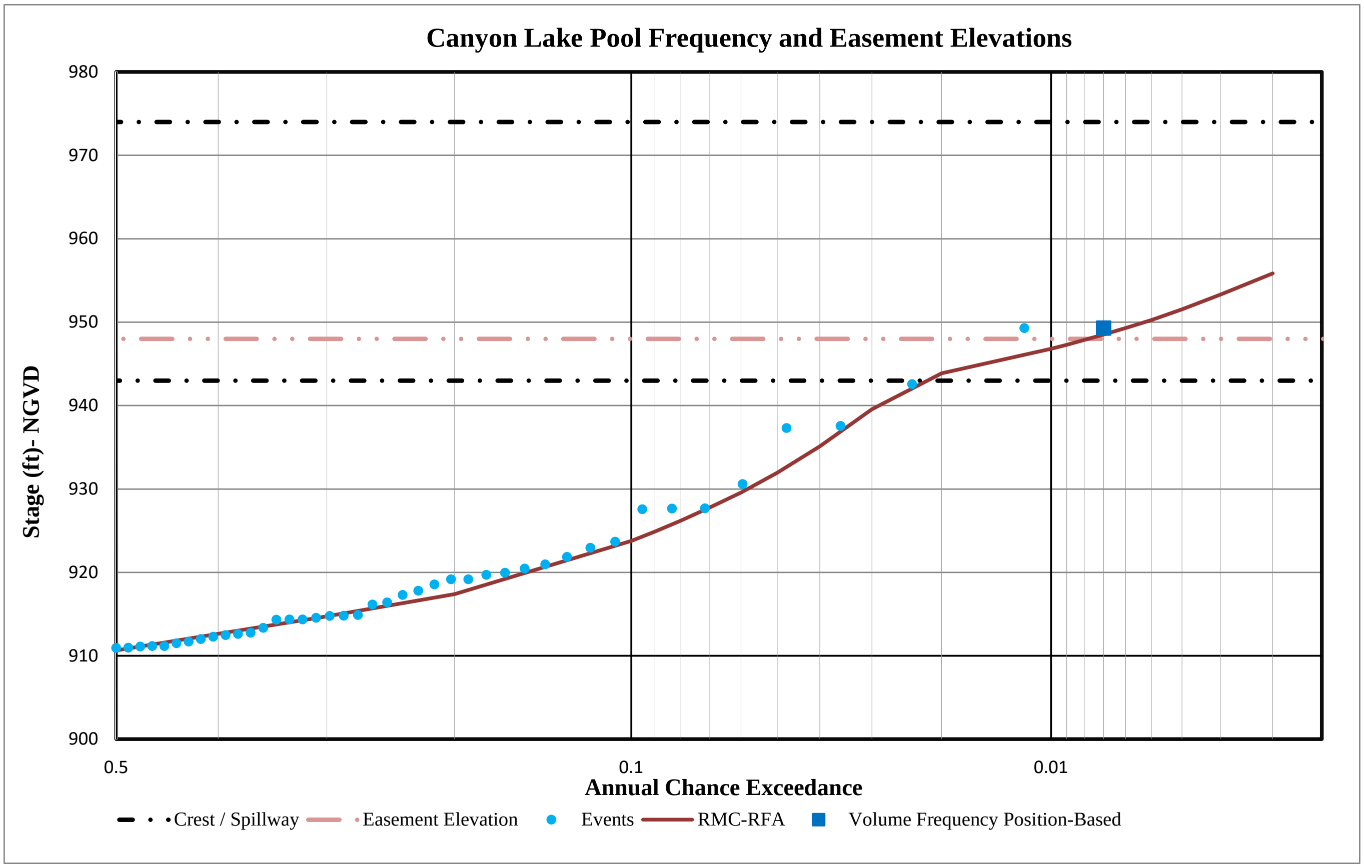


Figure 9.26 Canyon Lake Easement Elevation in Relation To Pool Frequency Elevations

Table 9.13 illustrates current project release comparison with FEMA's values as mentioned in the 2009 Comal Flood Insurance Study (FIS). The comparison is made for the 10-, 2-, 0.1, and 0.2% ACE events.

Table 9.13: 2016 Canyon Lake Computed Release Frequency Comparison with FEMA's

N-Year	ACE %	RMC-RFA Best Estimate (cfs)	FEMA Effective (cfs)
2	50	695	
5	20	1,380	
10	10	2,500	5,500
25	4	4,285	
50	2	5,000	5,900
100	1	21,100	14,000
250	0.4	82,580	
500	0.2	164,000	130,000

9.11 CANYON LAKE POOL FREQUENCY TREND

The pool frequency trend was examined every 10 years to assess impacts of changes in record length on the 1% ACE (100-year) pool elevation. The process was done in an iterative manner, where the event of interest was estimated using RMC-RFA for 81, 71, 61, 51, 41, 31, and 21-years. The 81-year record consisted of inflow and stage data for 1935-2015. The 71-year record on the other hand consisted of data for 1935-2005, and so on. The minimum number of years was set at 21 as any lesser data points would not be adequate for statistics. The same RMC-RFA model described in the report above was sued to generate the frequencies with one exception, calculate the flood seasonality frequency based on annual maximum series peaks instead of calculating those frequencies based on specific threshold flow, maximum events per year, and minimum days between events. This allows for modeling different years in a consistent manner. Each analyzed parameter input in the model corresponds to its assigned POR. The 1% ACE (100-year) pool peaks are illustrated in Figure 9.27. The project pool changes every 10 years are listed in Table 9.14.

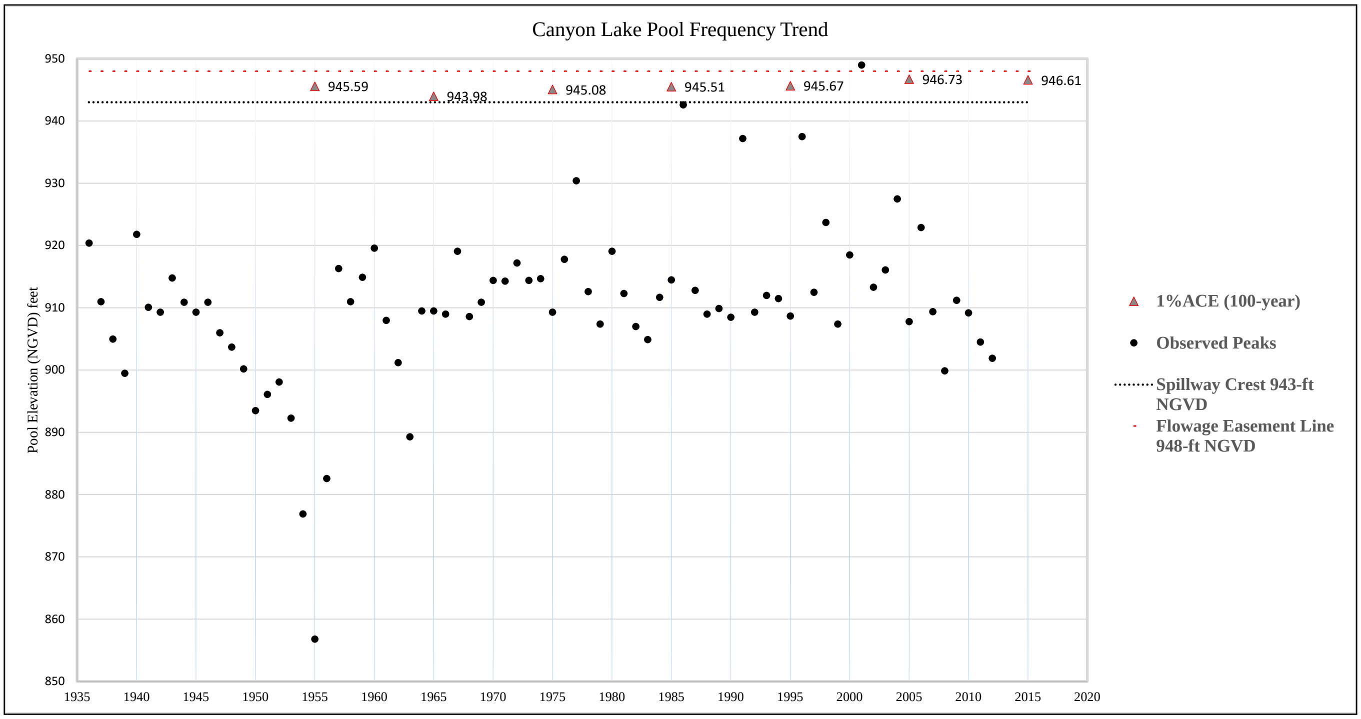


Figure 9.27 1% ACE (100-year) Pool Frequency Changes Over Time

Table 9.14 Canyon Lake Pool Fluctuation

POR	Elevation-ft (NGVD)	Changes in feet
1935-1955	945.59	
1935-1965	943.98	-1.61
1935-1975	945.08	1.1
1935-1985	945.51	0.43
1935-1995	945.67	0.16
1935-2005	946.73	1.06
1935-2015	946.61	-0.12

Note: An elevation change by 1.06 feet reflects the 2002 flood event.

10 Rainfall Runoff Modeling in HEC-HMS with NOAA Atlas 14 Rainfall Depths

NOAA Atlas 14 contains precipitation frequency estimates for the United States along with their associated lower and upper 90% confidence bounds. The Atlas is divided into volumes based on geographic sections of the country. NOAA Atlas 14 is intended as the U.S. Government source of precipitation frequency estimates.

NOAA Atlas 14 Volume 11, which covers the state of Texas, was published in September of 2018 while this hydrology study was nearing its completion (NOAA, 2018). Therefore, the InFRM team decided to update the Guadalupe HEC-HMS modeling with the new rainfall depths that were published in NOAA Atlas 14 (NA14). This chapter will document (1) the magnitude of the new NA14 precipitation frequency estimates for the Guadalupe River basin, (2) how that rainfall was applied within HEC-HMS for both uniform and elliptical frequency storms, and (3) the results of the HEC-HMS analyses with the NA14 rainfall.

10.1 NOAA ATLAS 14 PRECIPITATION FREQUENCY ATLAS FOR TEXAS

NOAA Atlas 14 Volume 11 was developed by the Hydrometeorological Design Studies Center (HDSC) within the Office of Water Prediction of the National Oceanic and Atmospheric Administration's National Weather Service. NOAA Atlas 14 Volume 11 provides precipitation frequency estimates for durations of 5-minute through 60-day at average recurrence intervals of 1-year through 1,000-year for the State of Texas. The precipitation frequency estimates in NA14 Volume 11 supersede the estimates published in the following NOAA publications:

- NOAA Technical Memorandum NWS HYDRO-35 (Frederick et al., 1977)
- Weather Bureau Technical Paper No. 40 (TP40) (Hershfield, 1961)
- Weather Bureau Technical Paper No. 49 (Miller, 1964)

NA14 Volume 11 included denser precipitation gage networks and much longer records than were available during those previous studies. For example, 60 additional data years were potentially available at the stations used in TP40 for the NA14 analysis, since TP40 was published in 1961 with data collected through 1957.

In 2004, the USGS published a more recent study of precipitation frequency estimates of various durations and recurrence intervals in Texas in its Atlas of Depth-Duration Frequency (DDF) of Precipitation for Texas (Asquith, 2004), herein referred to as the 2004 USGS Rainfall Atlas. However, the USGS fully supports the use of NOAA Atlas 14 Volume 11 as the most up-to-date precipitation frequency study in Texas.

10.1.1 Overview of NOAA Atlas 14 Volume 11 Methodology

NA14 obtained precipitation measurements for 11,934 gage stations from a number of federal, state, and local agencies. The majority of the stations were from the NWS Cooperative Observer Program (COOP) database maintained by the National Centers for Environmental Information (NCEI). Over 3,900 stations were selected for frequency analysis due to the length and reliability of their precipitation records. Only stations with more than 30 years of data at daily durations or 20 years of data at sub-daily durations were used in the frequency analysis for NA14, except in some data sparse areas. In areas of high importance or scarce data, additional precipitation data were also collected from the NCEI (Climate Database Modernization Program (CDMP) dataset and were digitized to improve analysis by extending record lengths and/or including extreme historic events missing in the available digitized datasets.

The annual maximum series (AMS) were then extracted from precipitation gage stations for a range of durations between 15-minute and 60-day from precipitation measurements recorded at variable or constant time increments from 1-minute to 1-day. AMS for each station were obtained by extracting the highest precipitation amount for a particular duration in each successive year. Based on the distribution of heavy precipitation events for this project area, calendar year was used rather than a standard water year (October - September) so that a year begins and ends during a relatively dry season.

The precipitation frequency estimates in Volume 11 were computed using a regional frequency analysis approach based on L-moment statistics calculated from the annual maximum series. L-moments statistics are less susceptible to the presence of outliers in the data than conventional moments and are well suited for the analysis of data that exhibit significant skewness, such as rainfall in Texas.

The regional frequency approach of NA14 uses data from several nearby stations to calculate frequency estimates at one station. The region-of-influence approach used in NA14 assigned each station its own region with a potentially unique combination of nearby stations, and regional frequency statistics were then calculated by averaging corresponding station-specific frequency estimates weighted by their record lengths. When determining the maximum allowable distance and selecting an optimal number of stations to assign to a target station's region, NA14 scientists aimed to include enough stations to smooth variability in at-station estimates, but also still adequately represent local conditions. In Volume 11 for Texas, regions were typically made up of 15 to 25 stations with at least 1,000 cumulative data years for daily durations and 500 cumulative years for smaller durations. This regional statistical approach helped to reduce the uncertainty in rare frequency estimates and to smooth out anomalies where a significant rainfall event may have been captured by one station but not by another station nearby, either due to a gage being out-of-service or being randomly missed by that event. The regional frequency approach used in NA14 thereby produces more reliable frequency estimates of rainfall.

For the final product, NOAA applied a dynamic filter to the precipitation frequency grids to smooth out rainfall contours that were concentrated around particular stations. Parameters of the filter, which control the amount of smoothing, are a function of elevation gradients and proximity to the coastline. Parameters were selected such that no smoothing was applied in the mountains, some smoothing was applied along the coast, maximum smoothing was applied in flat terrain, and the transition from one to another was gradual. This smoothing provided more visually appealing maps while still preserving rainfall gradients where appropriate.

The preliminary precipitation frequency estimates for NA14 went through a rigorous peer review process. Experts from various federal, state, and local agencies across the State of Texas were invited to participate in the review process, and their review provided critical feedback that improved the final estimates. The final NOAA Atlas 14 precipitation frequency estimates are available in digital form in various formats from the Precipitation Frequency Data Server (PFDS), which provides a point-and-click web portal for the precipitation frequency estimates and associated information for Texas.

10.1.2 NOAA Atlas 14 Precipitation Frequency Depths for the Guadalupe River Basin

Figures 10.1 to 10.5 illustrate the final NA14 100-yr rainfall depths for the 1, 3, 6, 12, and 24 hour durations across the Guadalupe River basin. These figures show that the largest rainfall depths were consistently shown in two areas: (1) the eastern portion of the Hill Country, which includes most of Hays County and Comal County along with the cities of Wimberley and San Marcos, Texas, and (2) the very downstream portion of the basin nearest to the coast. Geographically, it makes sense that these two areas would receive the most rainfall. Areas near the coast tend to receive more rainfall than inland areas due to their proximity to the large source of moisture at the Gulf of Mexico. Traveling further inland, the first orographic feature that moisture from the Gulf encounters is the Balcones Escarpment, which is located along the eastern edge of the Hill Country. The orographic uplift caused by that escarpment tends to result in more rainfall in the eastern Hill Country than in the surrounding areas, and the analysis of the historic rainfall records in NA14 confirmed that pattern.

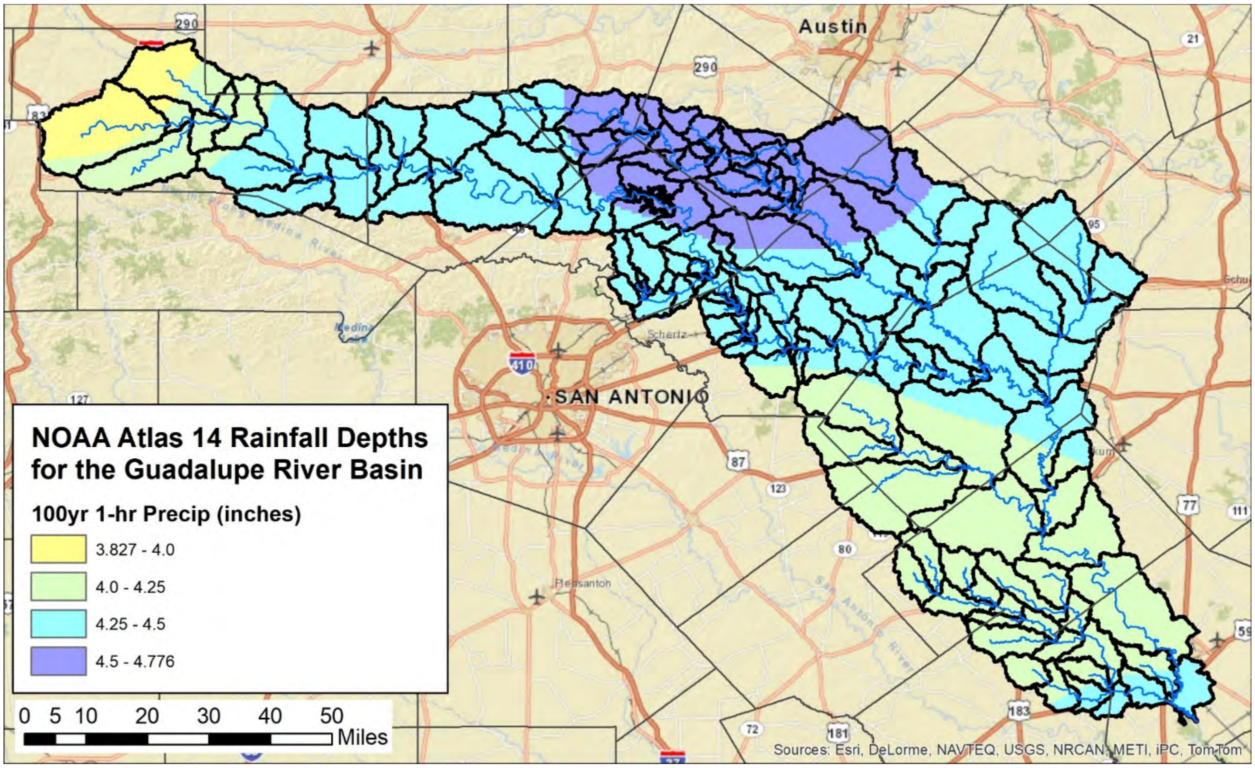


Figure 10.1: 100-yr, 1-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

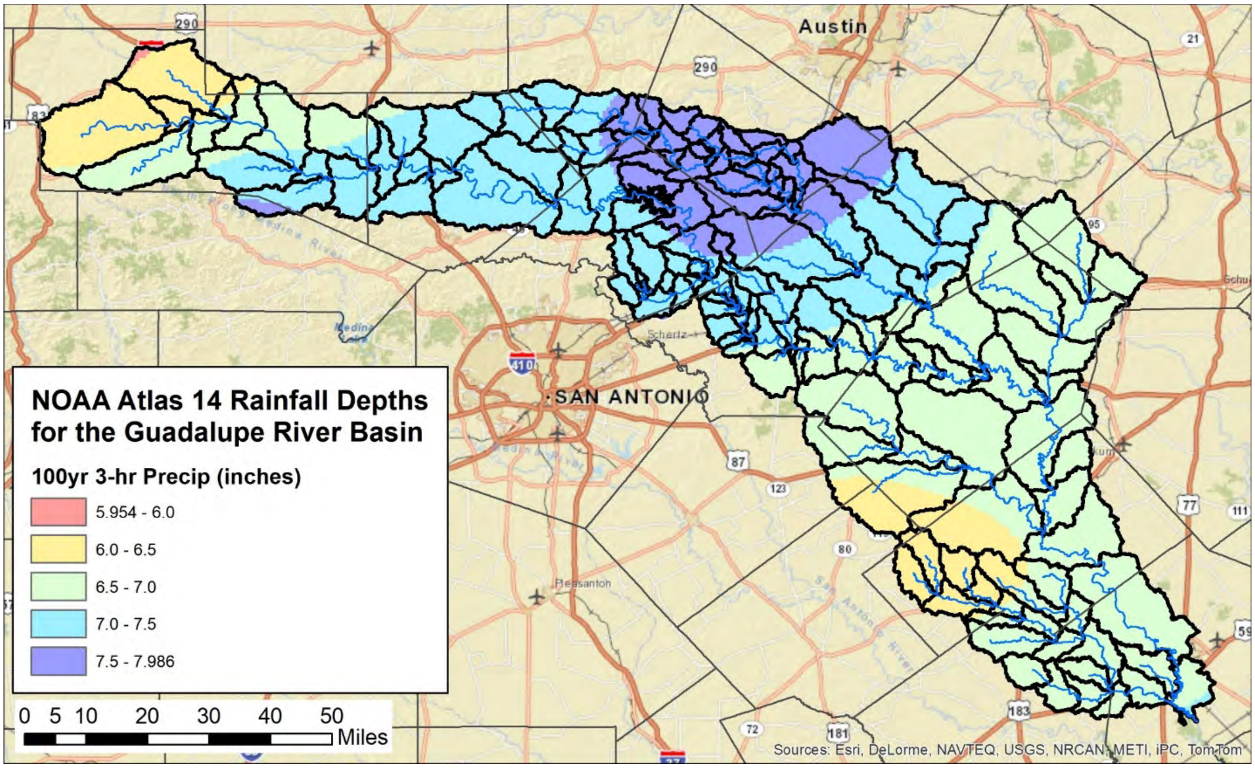


Figure 10.2: 100-yr, 3-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

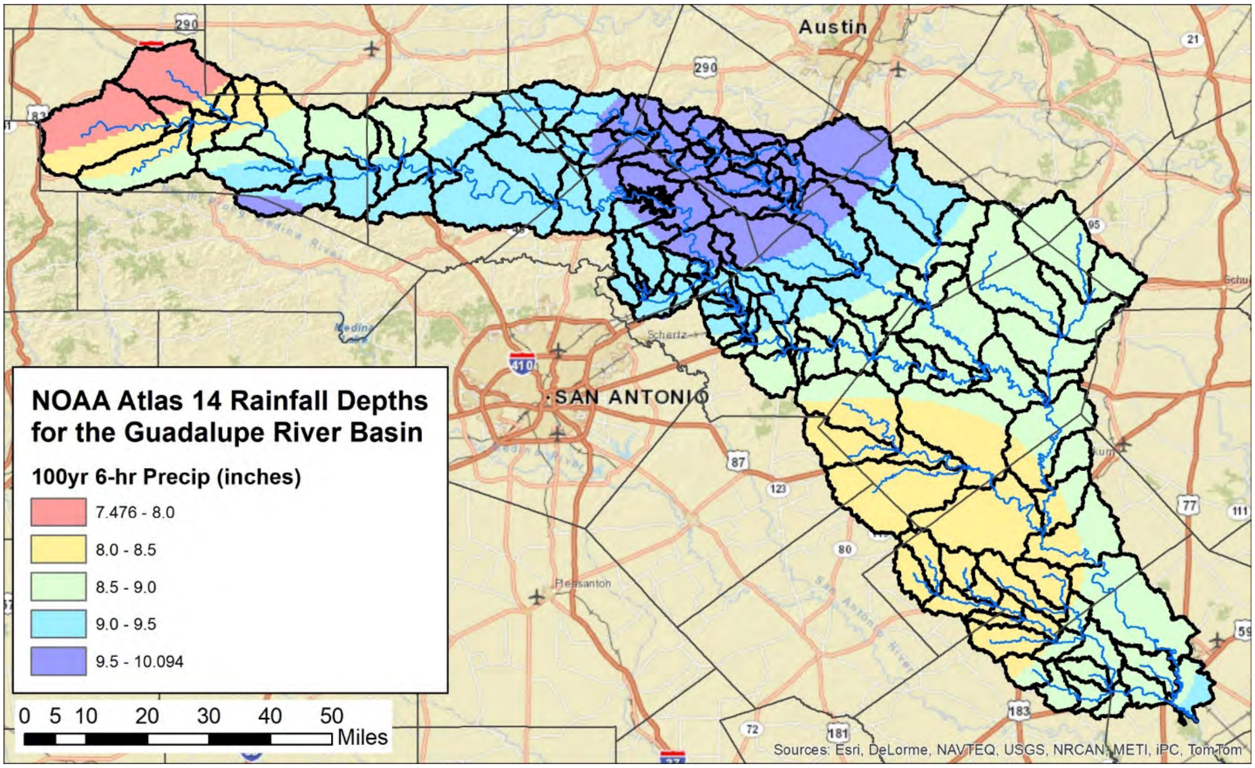


Figure 10.3: 100-yr, 6-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

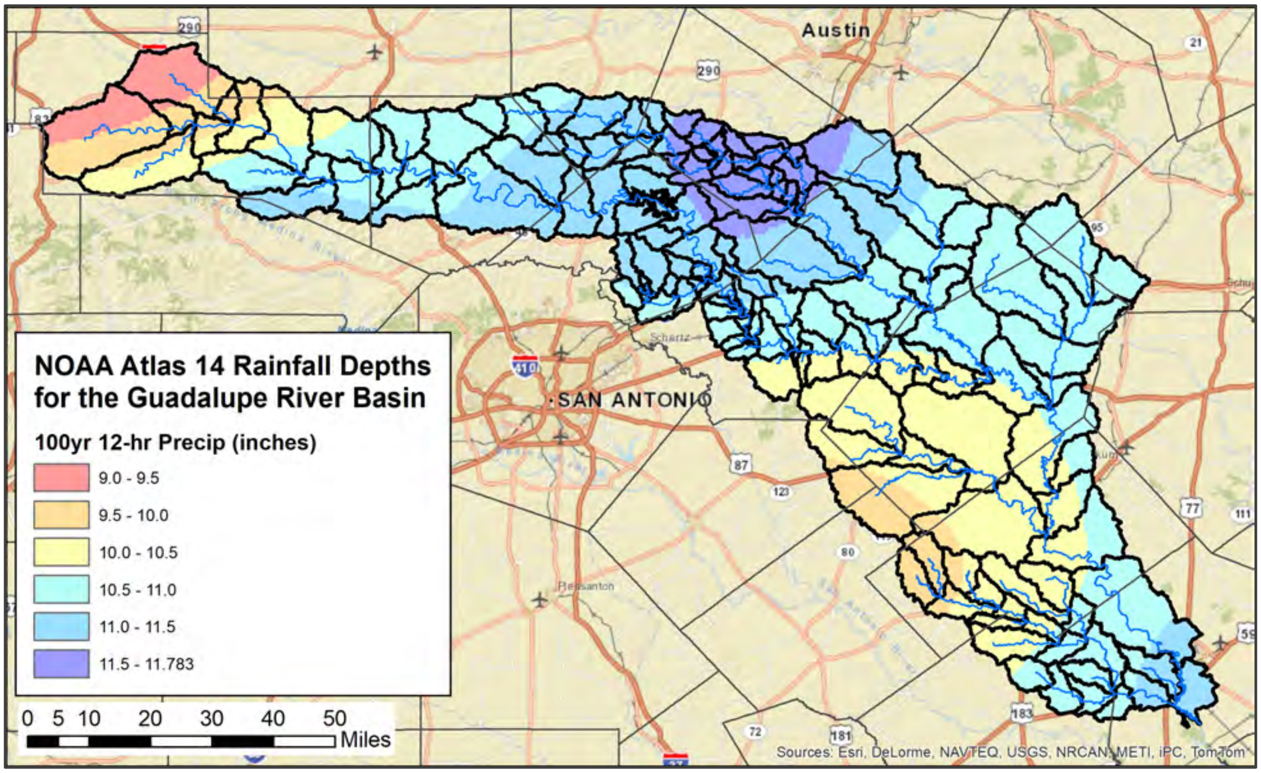


Figure 10.4: 100-yr, 12-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

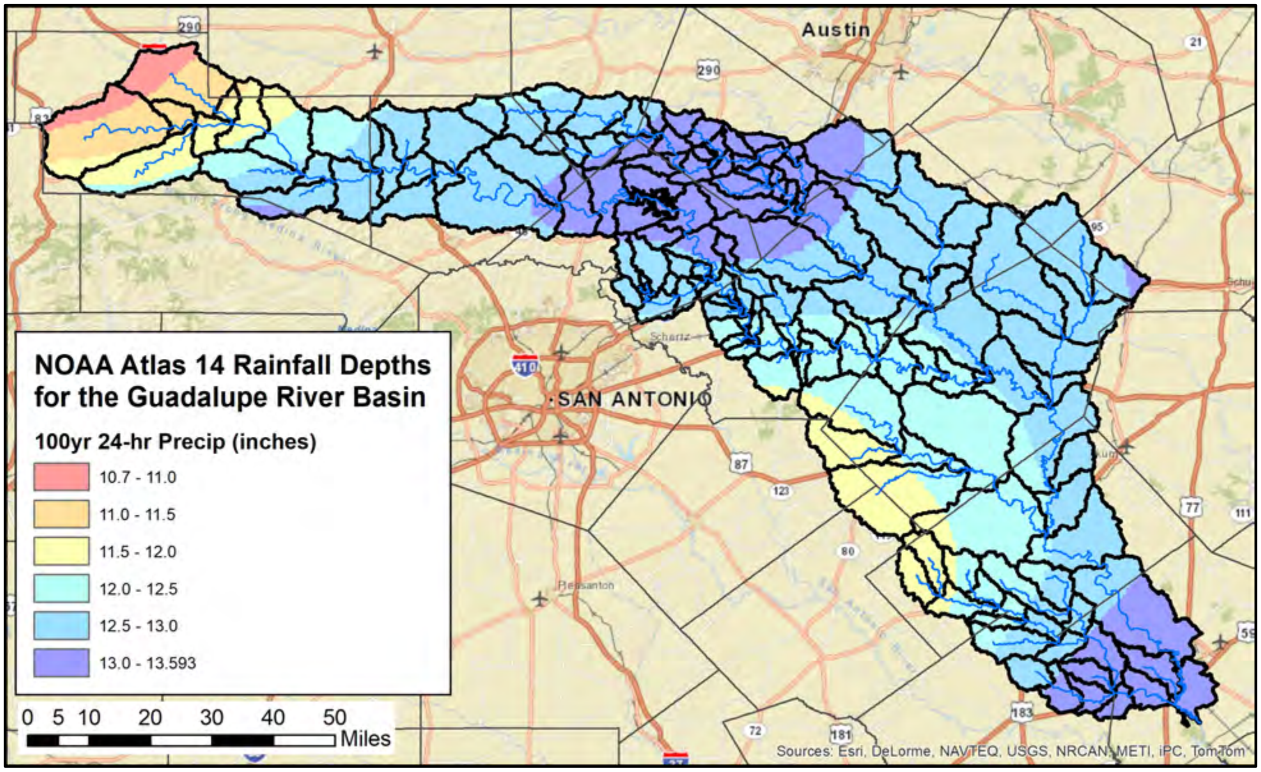


Figure 10.5: 100-yr, 24-hour Rainfall Depths for the Guadalupe River Basin from NOAA Atlas 14

Substantial increases in rainfall were also seen in the eastern Hill Country when the NA14 100-yr rainfall depths were compared to the previous 100-yr rainfall depths from the 2004 USGS Rainfall Atlas. Figures 10.6 and 10.7 show the relative increase in the 100-yr 24-hr and 6-hr rainfall depth, respectively, relative to the previous estimates from the 2004 USGS Rainfall Atlas. Please note that San Marcos, Texas saw an increase of about 3 inches in the 100-yr, 6-hour rainfall, and New Braunfels, Texas had an increase of about 2.5 inches at the 6-hr duration. This 6-hour duration will drive many of the increases in flow in the downstream watershed that are shown later in this chapter.

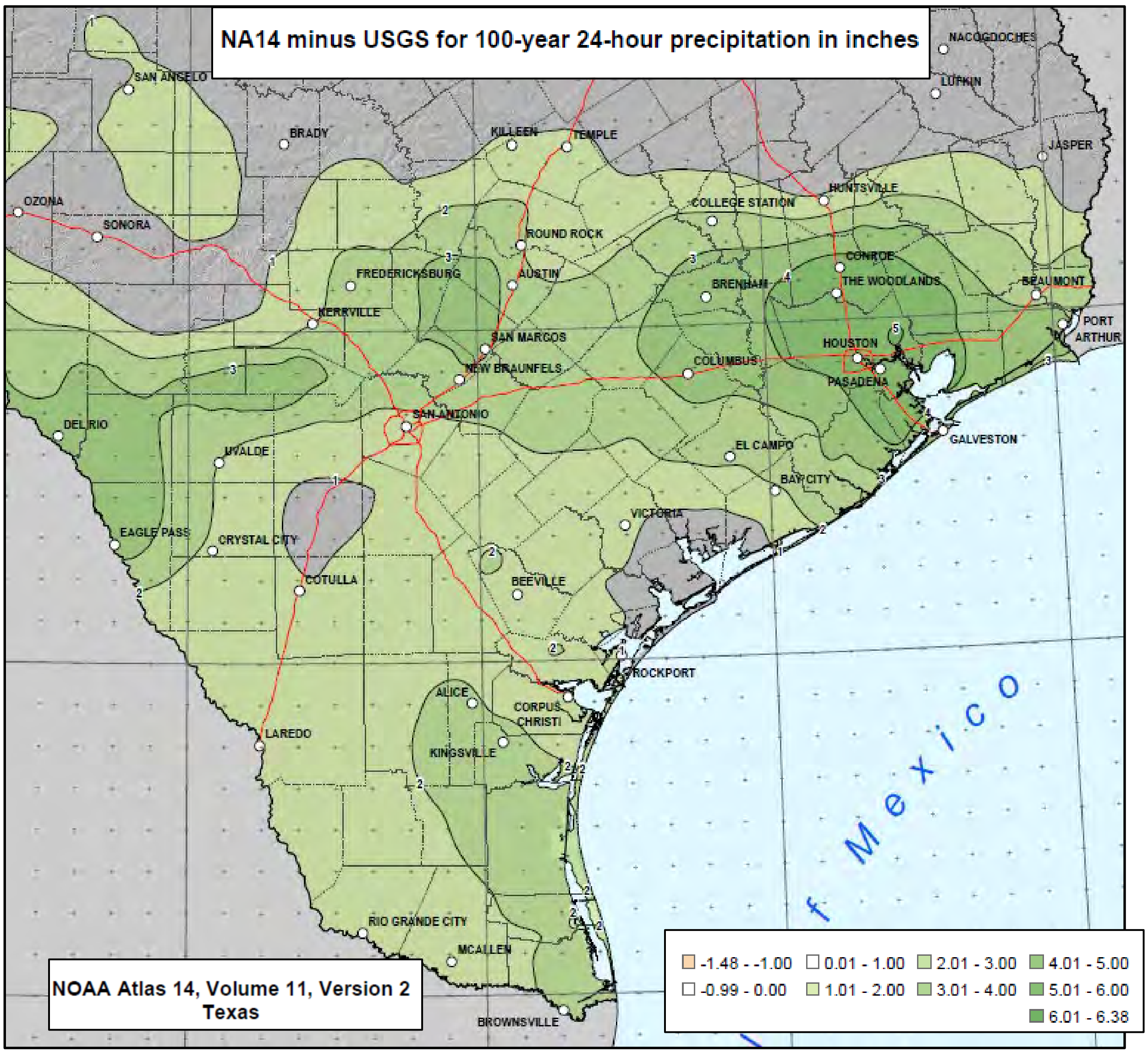


Figure 10.6: Increase in 100-yr, 24-hr Precipitation (inches) between NA14 and 2004 USGS Atlas

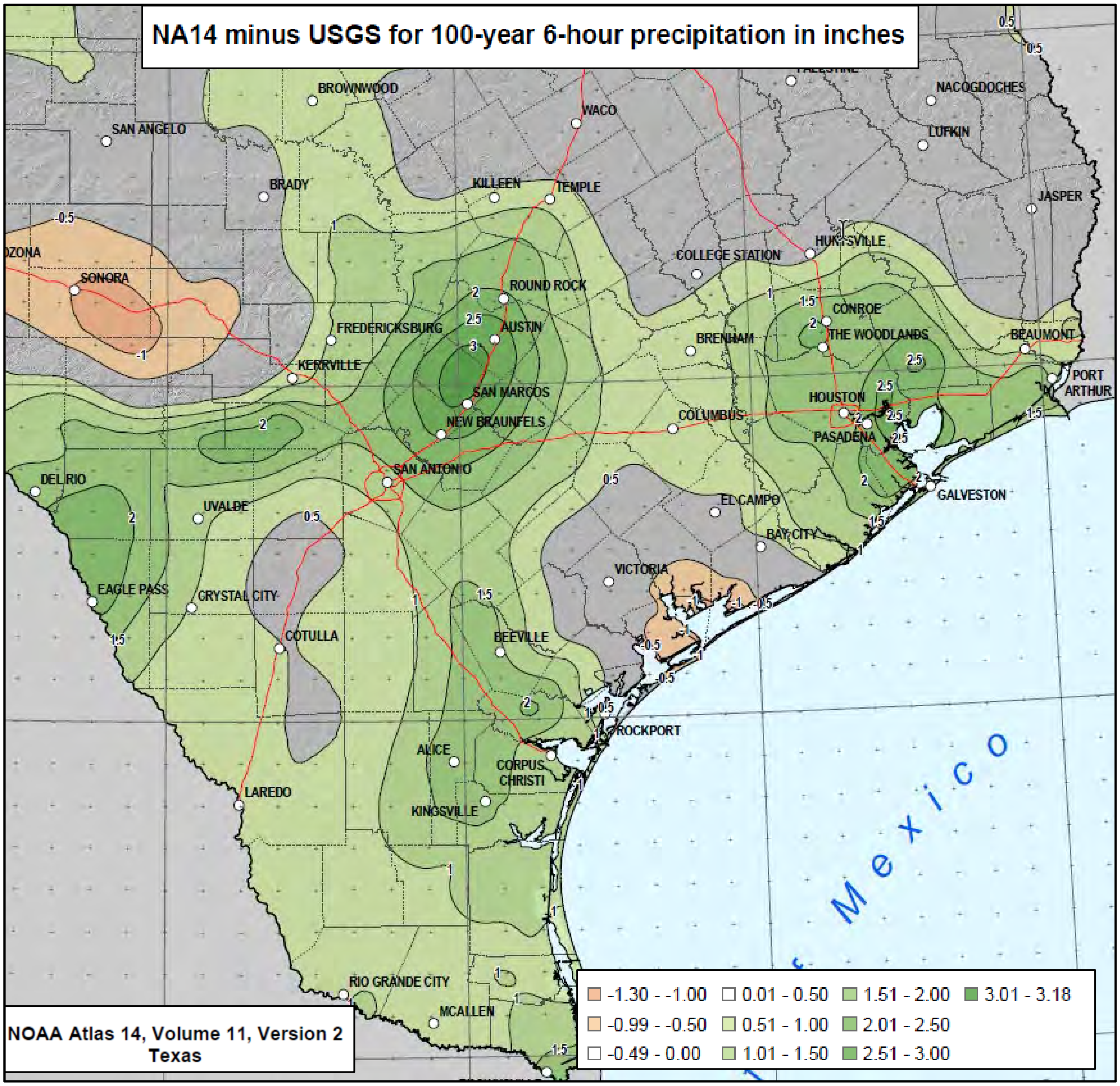


Figure 10.7: Increase in 100-yr, 6-hr Precipitation (inches) between NA14 and 2004 USGS Atlas

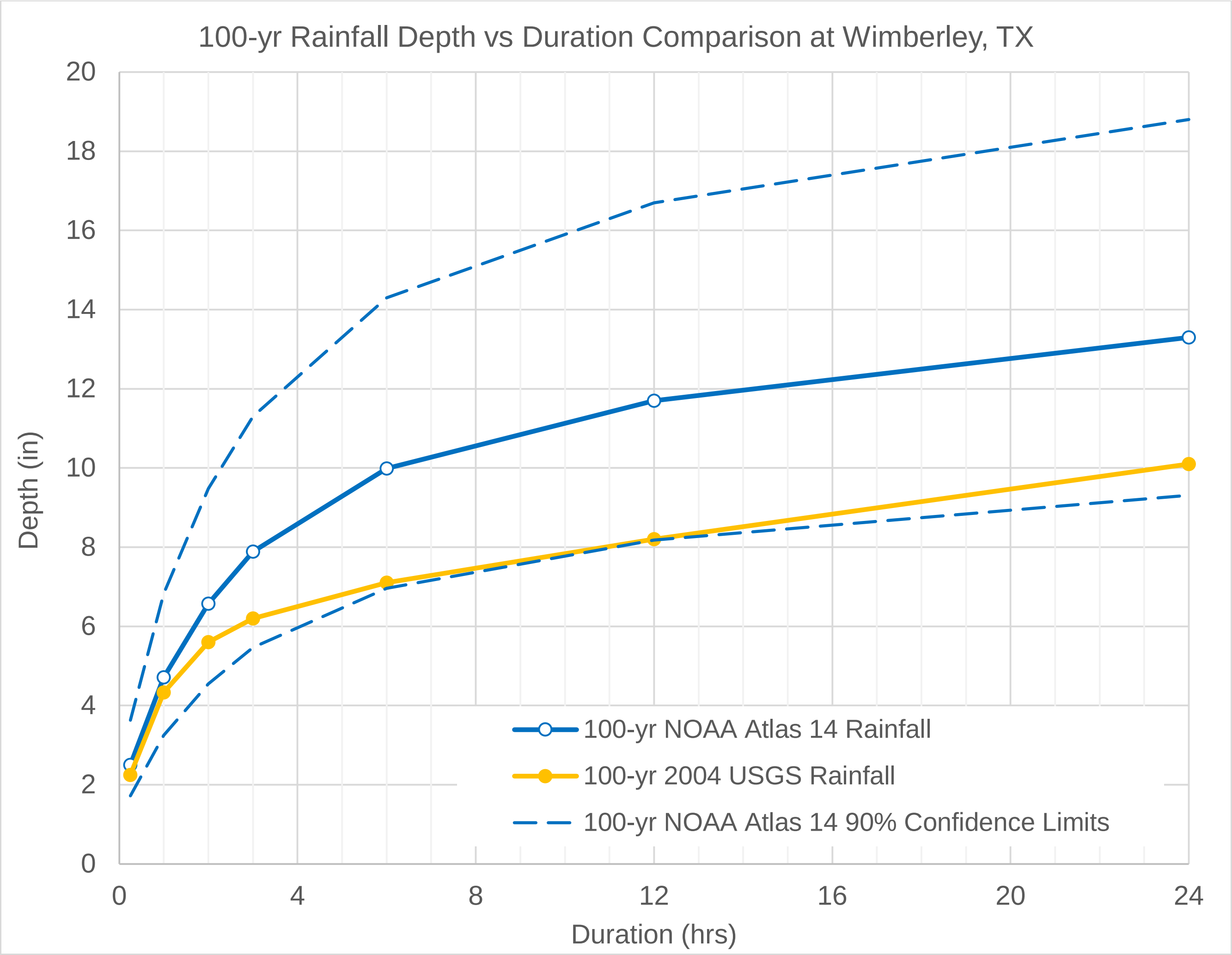


Figure 10.8: 100-yr Rainfall Depth versus Duration Comparison at Wimberley, TX

Figures 10.8 and 10.9 give an example of how the NA14 rainfall depths change with duration and frequency at Wimberley, Texas. The previous rainfall depths from the 2004 USGS Rainfall Atlas are also plotted on these graphs as a comparison. Figure 10.8 shows rainfall depth versus duration for the 100-yr return interval. From this graph, one can see that NA14 added an additional 3+ inches to the 100-yr rainfall from the 6-hour to the 24-hour duration when compared to the 2004 USGS Rainfall Atlas. Furthermore, looking across the 10-inch line for rainfall depth, one can see that 10 inches of rainfall is now expected to fall in 6-hours instead of 24-hours during a 100-yr storm. These increases in the 100-yr rainfall depth and intensity would be expected to cause a substantial increase in the 100-yr peak flows when applied to a rainfall runoff model.

Looking at the 5% and 95% confidence limits in Figure 10.8 gives an idea of the range of uncertainty associated with the NOAA Atlas 14 100-yr rainfall values. For example, this graph shows that the true 100-yr rainfall, 24-hr depth at Wimberley, Texas could be anywhere between 9.5 inches and 18.5 inches. It also shows that the 2004 USGS 100-yr rainfall depths are now approaching the lower 5% confidence limit. This means that, at the 12-hr duration, for example, there is a 95% chance that the true depth is greater than the 2004 USGS rainfall depth.

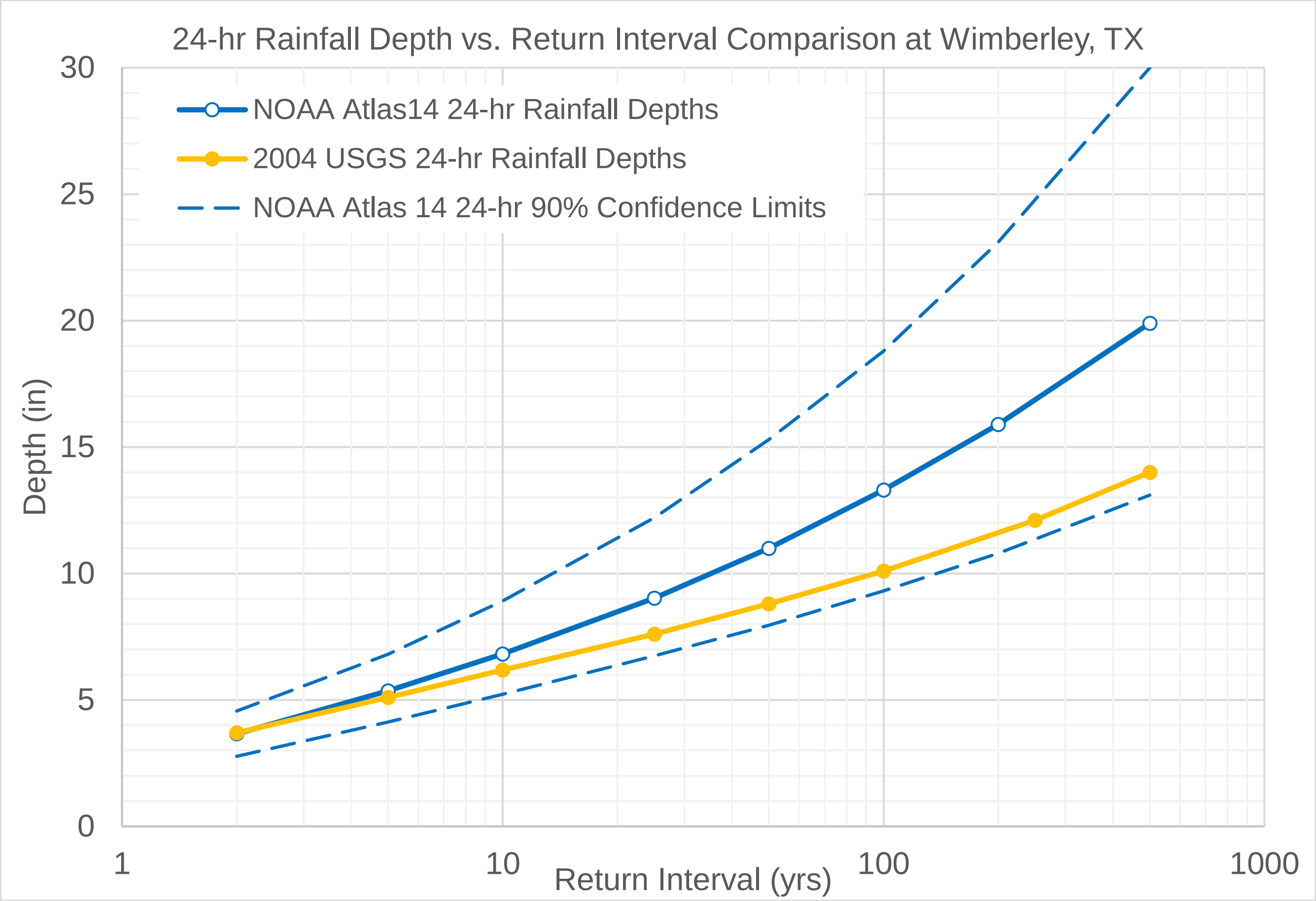


Figure 10.9: 24-hr Rainfall Depth versus Return Interval Comparison at Wimberley, TX

Figure 10.9 shows rainfall depth versus frequency for the 24-hour duration. From this graph, one can see that there is not much change in the rainfall depths for the 2, 5 and 10-yr return intervals. The increase in rainfall between NA14 and the USGS gets larger and larger for the rarer frequencies. For this example at Wimberley, there is a 3 inch increase in the 100-yr depth, and a 6-inch increase in the 500-yr depth. The confidence limits and the associated uncertainty also get wider and wider at the rarer frequencies, which is to be expected.

10.1.3 Why Did Rainfall Depths Increase in the Guadalupe Basin?

The NA14 data showed that portions of the Texas Hill Country, including the areas around San Marcos and Wimberley, are prone to more extreme rainfall than had been estimated in previous studies. The 100-year, 24-hour precipitation depths increased by 3 to 4 inches over large portions of the Blanco and Guadalupe River basins in Hays County and Comal County. Differences between NOAA Atlas 14's frequency results and the results of previous rainfall frequency studies in Texas, such as TP40 and the 2004 USGS Rainfall Atlas, can be attributed to several factors.

First, differences in data quality control procedures and frequency analysis methods affect estimates, especially for the higher return intervals such as the 100-yr and greater. NOAA Atlas 14 used the most rigorous data quality control procedures and the most state-of-the-art statistical methods available to analyze Texas' rainfall data. For example, the regional statistical approach used in NA14 Volume 11 helped to reduce the uncertainty in the rare frequency estimates by regionalizing each estimate with data from 15 to 25 stations with at least at least 1,000 cumulative years of data for daily durations and 500 cumulative years for smaller durations. The NA14 regional statistical approach also helped to smooth out anomalies where a significant rainfall event may have been captured by one station but not by another station nearby, either due to a gage being out-of-service or being randomly missed by that event.

Second, differences in spatial interpolation techniques impact frequency estimates at ungauged locations. Interpolation techniques in previous studies were based solely on station data without accounting for orographic effects from topographic features; whereas NA14 accounted for those orographic effects in Texas by using PRISM products that integrate topography into its spatial interpolation techniques. This techniques allowed for significant improvements in the frequency estimates of areas with complex terrain, like the Texas Hill Country, when compared to TP40 and the 2004 USGS Rainfall Atlas. The orographic uplift caused by the Balcones escarpment tends to result in more rainfall in the eastern Hill Country than in the surrounding areas; therefore, the spatial interpolation techniques of NA14 are better suited for capturing variations in that region.

Finally, the increase in the amount of available rainfall data for NA14, both in the number of stations and in their record lengths, had a considerable effect on frequency estimates, especially for rare events such as the 100-yr return interval. For example, TP40 only used 250 daily gages within Texas with an average record length of 23 years, while NA14 used data from more than 2,500 gages in Texas with an average record length of 60 years for daily durations. Lack of stations with adequate data resulted in very smooth spatial patterns in TP40, but because of that it failed to reproduce the local characteristics of extreme precipitation that are of interest in hydrology studies such as this one. The NA14 analysis for Texas also included rainfall data through December 2017. This represents an 60 additional years of data compared to TP40, which only included data through 1957, and an additional 23 years of data compared to the 2004 USGS Rainfall Atlas, which only included data through 1994.

10.1.4 Potential Climate Change Impacts to NOAA Atlas 14 Rainfall Depths

Current NOAA Atlas 14 frequency analysis methods assume that both the historical rainfall data and the climate conditions producing that rainfall are stationary. NOAA tested that assumption of stationarity in NA14 by applying various statistical tests to the annual maximum series data. So far in Texas, the tests have shown no statistically significant trends in the observed data. However, there is a growing concern that the assumption of stationarity in the NA14 products may not be appropriate in the presence of non-stationary climate. To understand the potential impact of non-stationary climate conditions on precipitation frequency estimates, NOAA's HDSC has been tasked with developing a method that will allow non-stationary climate effects to be integrated into the NA14 process and that will, at the same time, produce credible precipitation frequency estimates which can be relied upon by Federal water agencies. However, there is still tremendous uncertainty associated with the effects of climate change on future extreme precipitation, especially at the high resolution needed for NA14 products, both spatially and temporally. At this time, NOAA does not have a definite answer as to whether a non-stationary approach is advantageous for the NA14 process.

10.2 THE UNIFORM RAINFALL METHOD IN HEC-HMS WITH NOAA ATLAS 14 RAINFALL DEPTHS

10.2.1 Basin Model Parameters in HEC-HMS

The updated Guadalupe HEC-HMS model runs with the NOAA Atlas 14 rainfall depths were completed using the same final basin model parameters as were described in Chapter 6 of this report. See Section 6.5 for a complete list of the final basin model parameters. The only basin parameters that were updated for the NA14 runs were the loss rates for the frequent events. As described in Chapter 6, the default initial and constant losses for the 2-yr through 10-yr storms were adjusted for each given frequency in order to have a better correlation with the statistical frequency curves estimated from the USGS gage records. This was done because of the increased confidence level in the statistical frequency curve for the 2 through 10-yr recurrence intervals. The 25-yr losses were adjusted when needed to create a smooth transition between the 50-yr to the 10-yr values. This process of adjustment was repeated as needed for the updated rainfall depths that were applied from NA14. Since the NA14 2-yr rainfall depth were generally similar to the 2004 USGS rainfall depths, the adjustments were also relatively small. The loss rates that were applied for the 50-yr through 500-yr events did not change from those listed in Chapter 6. The final loss rates used for each frequency storm event with the NA14 Uniform Rainfall method are given in Tables 10.1 and 10.2.

Table 10.1: Initial and Constant Losses for the 2-yr to 25-yr NA14 Uniform Rain Frequency Storms

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
NF_Guad_S010	2.30	0.23	2.20	0.22	1.84	0.21	0.97	0.12
NF_Guad_S020	2.15	0.28	2.10	0.27	2.16	0.25	1.69	0.22
SF_Guad_S010	2.15	0.28	2.10	0.27	2.16	0.25	1.68	0.22
Guad_S010	3.00	0.35	3.00	0.35	3.00	0.35	1.27	0.13
JohnsonCr_S010	2.42	0.33	2.90	0.32	3.00	0.33	1.98	0.28
JohnsonCr_S020	3.00	0.35	3.00	0.35	3.00	0.35	1.26	0.13
Guad_S020	3.00	0.35	3.00	0.35	3.00	0.35	1.27	0.13
Guad_S030	2.15	0.28	1.89	0.22	1.84	0.15	1.75	0.14
TurtleCr_S010	2.15	0.28	1.59	0.22	1.43	0.15	1.25	0.14
Guad_S040	2.10	0.28	1.74	0.22	1.54	0.15	1.35	0.15
VerdeCr_S010	2.10	0.28	1.97	0.22	1.94	0.15	1.87	0.14
Guad_S050	2.10	0.28	1.71	0.22	1.54	0.15	1.37	0.14
CypressCr_GR_S010	2.10	0.28	1.62	0.22	1.45	0.15	1.27	0.14
Guad_S060	1.90	0.25	1.80	0.27	2.00	0.27	1.70	0.21
BlockCr_S010	1.90	0.25	1.80	0.27	2.00	0.27	1.64	0.20
Guad_S070	1.90	0.25	1.80	0.27	2.00	0.27	1.72	0.21
JoshuaCr_S010	1.90	0.25	1.80	0.27	2.00	0.27	1.65	0.20
Guad_S080	1.90	0.25	1.80	0.27	2.00	0.27	1.70	0.21
SisterCr_S010	1.90	0.25	1.80	0.27	2.00	0.27	1.64	0.20
Guad_S090	1.90	0.25	1.80	0.27	2.00	0.27	1.64	0.20

Subbasin Name	2-yr	2-yr	5-yr	5-yr	10-yr	10-yr	25-yr	25-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
CurryCr_S010	1.90	0.25	1.80	0.27	2.00	0.27	1.64	0.20
Guad_S100	1.90	0.25	1.80	0.27	2.00	0.27	1.64	0.20
Guad_S110	1.56	0.21	1.38	0.16	1.21	0.14	1.05	0.12
Guad_S120	1.53	0.20	1.32	0.16	1.14	0.14	0.97	0.12
CanyonLk_S010	1.50	0.20	1.30	0.16	1.12	0.14	0.95	0.12
Blanco_S010	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
Blanco_S020	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
Blanco_S030	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
Blanco_S040	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
Blanco_S050	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
LittleBlanco_S010	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
LittleBlanco_S020	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
LittleBlanco_S030	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
LittleBlanco_S040	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
Blanco_S060	1.86	0.214	1.83	0.212	1.71	0.207	1.28	0.148
WanslowCr_BR_S010	1.86	0.214	1.82	0.211	1.71	0.207	1.27	0.148
Blanco_S070	1.84	0.212	1.81	0.21	1.7	0.206	1.27	0.147
Blanco_S080	1.82	0.21	1.8	0.209	1.69	0.205	1.26	0.146
CarpersCr_BR_S010	1.87	0.215	1.84	0.213	1.72	0.208	1.28	0.149
Blanco_S090	1.85	0.213	1.82	0.211	1.71	0.207	1.27	0.147
Blanco_S100	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
WilsonCr_BR_S010	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
Blanco_S110	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
CypressCr_BR_S010	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
CypressCr_BR_S020	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
CypressCr_BR_S030	1.7	0.21	1.7	0.21	1.7	0.21	1.5	0.19
Blanco_S120	2.8	0.3	2.3	0.25	1.72	0.208	1.28	0.148
Blanco_S130	2.8	0.3	2.3	0.25	1.72	0.208	1.28	0.149
LoneManCr_BR_S010	2.8	0.3	2.3	0.25	1.74	0.21	1.3	0.15
Blanco_S140	2.8	0.3	2.3	0.25	1.71	0.207	1.28	0.148
HalifaxCr_BR_S010	2.8	0.3	2.3	0.25	1.66	0.202	1.23	0.144
Blanco_S150	2.8	0.3	2.3	0.25	1.67	0.203	1.23	0.144
Blanco_S160	1.55	0.18	1.55	0.18	1.55	0.18	1.21	0.142
Blanco_S170	1.55	0.18	1.55	0.18	1.55	0.18	1.3	0.15
SinkCk_S010	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SinkCk_S020	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SinkCk_S030	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SinkCk_S040	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
SanMarcos_S005	2.2	0.24	2.2	0.24	2.2	0.24	1.37	0.17

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
SanMarcos_S008	2.48	0.33	2.41	0.3	2.07	0.26	1.37	0.17
PurgatoryCr_S010	1.4	0.19	1.22	0.15	1.16	0.14	0.99	0.12
SanMarcos_S010	1.55	0.18	1.55	0.18	1.55	0.18	1.03	0.13
SanMarcos_S020	1.55	0.18	1.55	0.18	1.55	0.18	1.06	0.13
YorkCr_S010	1.9	0.27	1.78	0.22	1.7	0.21	1.44	0.18
SanMarcos_S030	1.55	0.18	1.55	0.18	1.55	0.18	1.1	0.13
SanMarcos_S040	3	0.35	3	0.35	3	0.35	1.17	0.14
PlumCr_S010	2	0.23	2	0.23	2	0.22	1.5	0.16
PlumCr_S020	1.5	0.19	1.5	0.17	1.5	0.17	1.3	0.15
TenneyCr_S010	1.5	0.19	1.5	0.17	1.5	0.17	1.3	0.15
PlumCr_S030	1.5	0.19	1.5	0.17	1.5	0.17	1.3	0.15
PlumCr_S040	3	0.35	3	0.3	3	0.3	1.01	0.12
SanMarcos_S050	3	0.35	3	0.3	3	0.3	1.18	0.14
DryComalCk_S010	2.05	0.24	2	0.21	1.6	0.2	1.26	0.15
DryComalCk_S020	1.95	0.23	1.9	0.21	1.6	0.2	1.17	0.14
WFk_DryComalCk_S010	2.05	0.25	2	0.21	1.6	0.2	1.28	0.15
WFk_DryComalCk_S020	1.95	0.23	1.9	0.21	1.6	0.2	1.19	0.14
WF_Trib_S010	2.05	0.24	2	0.21	1.6	0.2	1.25	0.15
WF_Trib_S020	1.95	0.23	1.9	0.21	1.6	0.2	1.16	0.14
WFk_DryComalCk_S030	2.05	0.24	2	0.21	1.6	0.2	1.22	0.14
DryComalCk_S030	2.05	0.24	2	0.21	1.6	0.2	1.27	0.15
BearCk_S010	2.05	0.24	2	0.21	1.6	0.2	1.23	0.14
DryComalCk_S040	1.95	0.22	1.9	0.21	1.6	0.2	1.14	0.14
DCCk_Trib14_S010	1.95	0.24	1.9	0.21	1.6	0.2	1.22	0.14
DryComalCk_S050	1.95	0.21	1.9	0.21	1.6	0.2	1.09	0.13
DryComalCk_S060	1.95	0.22	1.9	0.21	1.6	0.2	1.15	0.14
BliedersCk_S010	2.05	0.24	2	0.21	1.6	0.2	1.22	0.14
Comal_S010	3	0.35	3	0.35	3	0.35	1.26	0.15
Comal_S020	3	0.35	3	0.35	3	0.35	1.27	0.15
Comal_S030	1.5	0.2	1.5	0.2	1.4	0.17	1.21	0.14
Guad_S130	1.6	0.21	1.55	0.21	1.5	0.16	0.95	0.12
BearCr_S010	1.6	0.21	1.55	0.21	1.5	0.16	0.95	0.12
Guad_S140	1.6	0.21	1.55	0.21	1.5	0.16	0.95	0.12
Guad_S142	1.76	0.23	1.51	0.18	1.28	0.16	1.1	0.13
Guad_S144	1.98	0.25	1.7	0.2	1.42	0.17	1.23	0.14
Guad_Trib22_S010	1.63	0.21	1.41	0.17	1.2	0.15	1.02	0.13
Guad_S145	2.04	0.25	1.75	0.2	1.46	0.18	1.26	0.15
LongCk_S010	1.58	0.21	1.36	0.17	1.17	0.15	0.99	0.12
Guad_S147	1.94	0.24	1.67	0.2	1.4	0.17	1.21	0.14

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
Guad_Trib20_S010	1.63	0.21	1.41	0.17	1.2	0.15	1.03	0.13
Guad_S149	1.88	0.24	1.62	0.19	1.36	0.17	1.17	0.14
Guad_S152	2.05	0.26	1.76	0.21	1.47	0.18	1.27	0.15
YoungsCk_S010	1.54	0.2	1.33	0.16	1.15	0.14	0.97	0.12
Guad_S154	1.85	0.24	1.59	0.19	1.34	0.16	1.15	0.14
CottonwoodCkS_S010	1.51	0.2	1.31	0.16	1.13	0.14	0.96	0.12
Guad_S156	1.94	0.24	1.67	0.2	1.4	0.17	1.21	0.14
Little_MillCk_S010	1.67	0.22	1.44	0.17	1.22	0.15	1.05	0.13
Guad_S158	1.83	0.23	1.58	0.19	1.33	0.16	1.14	0.14
DeadmanCk_S010	1.58	0.21	1.37	0.17	1.17	0.15	1	0.12
Guad_S160	1.78	0.23	1.53	0.18	1.3	0.16	1.11	0.13
CottonwoodCk_S010	2.04	0.25	1.75	0.21	1.46	0.18	1.27	0.15
Guad_S162	2.01	0.25	1.72	0.2	1.44	0.17	1.25	0.15
AlligatorCk_S010	1.88	0.24	1.61	0.19	1.36	0.17	1.17	0.14
GeronimoCk_S010	1.54	0.2	1.33	0.16	1.14	0.14	0.97	0.12
GeronimoCk_S020	1.56	0.21	1.35	0.16	1.16	0.14	0.98	0.12
GeronimoCk_S030	1.74	0.22	1.5	0.18	1.27	0.16	1.09	0.13
Guad_S164	1.91	0.24	1.64	0.19	1.38	0.17	1.19	0.14
CantauCk_S010	1.98	0.25	1.7	0.2	1.43	0.17	1.23	0.14
Guad_S166	2.06	0.26	1.77	0.21	1.48	0.18	1.28	0.15
MillCk_S010	1.82	0.23	1.58	0.19	1.34	0.16	1.16	0.14
Guad_S168	2.09	0.26	1.87	0.21	1.63	0.18	1.46	0.15
NashCk_S010	2.05	0.25	1.76	0.21	1.47	0.18	1.27	0.15
Guad_S170	2.02	0.25	1.73	0.2	1.45	0.17	1.25	0.15
Guad_S172	1.9	0.24	1.64	0.19	1.38	0.17	1.19	0.14
Guad_S174	1.82	0.23	1.57	0.19	1.32	0.16	1.14	0.14
Guad_S176	1.98	0.25	1.7	0.2	1.43	0.17	1.23	0.14
Guad_S200	1.55	0.2	1.39	0.18	1.35	0.16	1.3	0.13
PeachCr_S010	1.55	0.19	1.55	0.19	1.55	0.19	1.28	0.14
BigFiveMileCr_S010	1.55	0.19	1.55	0.19	1.55	0.19	1.18	0.13
PeachCr_S020	1.55	0.19	1.55	0.19	1.55	0.19	1.12	0.13
SandyFork_S010	1.55	0.19	1.55	0.19	1.55	0.19	1.27	0.15
PeachCr_S030	1.55	0.19	1.55	0.19	1.55	0.19	1.16	0.13
PeachCr_S040	1.5	0.2	1.37	0.19	1.29	0.16	1.1	0.13
Guad_S210	1.5	0.2	1.49	0.2	1.38	0.17	1.19	0.14
McCoyCr_S010	1.5	0.2	1.45	0.2	1.39	0.17	1.2	0.14
Guad_S220	1.5	0.2	1.46	0.2	1.46	0.2	1.8	0.14
SandiesCr_S010	1.8	0.23	1.7	0.24	1.5	0.2	1.3	0.15
ClearForkCr_S010	1.8	0.23	1.7	0.24	1.5	0.2	1.25	0.14

Subbasin Name	2-yr	2-yr	5-yr	5-yr	10-yr	10-yr	25-yr	25-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
SandiesCr_S020	1.8	0.23	1.7	0.24	1.5	0.2	1.21	0.14
ElmCr_S010	1.8	0.23	1.7	0.24	1.5	0.2	1.2	0.13
SandiesCr_S030	1.8	0.23	1.7	0.24	1.5	0.2	1.12	0.13
SandiesCr_S040	1.5	0.2	1.5	0.2	1.43	0.17	1.28	0.14
Guad_S230	1.5	0.2	1.5	0.2	1.4	0.18	1.37	0.15
Guad_S240	1.5	0.2	1.46	0.2	1.42	0.17	1.23	0.14
DryCk_S010	1.62	0.21	1.61	0.19	1.36	0.16	1.17	0.14
SmithCk_S010	1.9	0.25	1.9	0.25	1.9	0.25	1.5	0.2
ThomasCk_S010	1.9	0.25	1.9	0.25	1.9	0.25	1.5	0.2
SmithCk_S020	1.9	0.25	1.9	0.25	1.9	0.25	1.5	0.2
YorktownCk_S010	1.9	0.25	1.9	0.25	1.9	0.25	1.5	0.2
YorktownCk_S020	1.9	0.25	1.9	0.25	1.9	0.25	1.5	0.2
FifteenmileCk_S010	1.9	0.25	1.9	0.25	1.9	0.25	1.5	0.2
HoosierCk_S010	1.9	0.25	1.9	0.25	1.9	0.25	1.5	0.2
FifteenmileCk_S020	1.6	0.22	1.6	0.22	1.5	0.2	1.28	0.15
EighteenmileCk_S010	1.6	0.22	1.6	0.22	1.5	0.2	1.25	0.15
FifteenmileCk_S030	1.6	0.22	1.6	0.22	1.5	0.2	1.26	0.15
TwelvemileCk_S010	1.6	0.22	1.6	0.22	1.5	0.2	1.27	0.15
FivemileCk_S010	1.6	0.22	1.6	0.22	0.6	0.1	1.29	0.15
TwelvemileCk_S020	1.6	0.22	1.6	0.22	1.6	0.22	1.5	0.18
ColetoCk_S010	1.5	0.15	1.5	0.15	1.5	0.15	1.21	0.14
ColetoCk_S020	1.5	0.15	1.5	0.15	1.5	0.15	1.2	0.14
PerdidoCk_S010	2.1	0.26	2.1	0.26	2.1	0.26	1.9	0.2
PerdidoCk_S020	1.5	0.15	1.5	0.15	1.5	0.15	1.21	0.14
PerdidoCk_S030	1.5	0.15	1.5	0.15	1.5	0.15	1.17	0.14
ColetoCk_S030	1.5	0.15	1.5	0.15	1.5	0.15	1.13	0.14
ColetoCk_S040	1.66	0.21	1.66	0.21	1.38	0.17	1.19	0.14
Guad_S250	1.55	0.2	1.55	0.19	1.31	0.16	1.13	0.14

Table 10.2: Initial and Constant Losses for the 50-yr to 500-yr NA14 Uniform Rain Frequency Storms

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
NF_Guad_S010	0.85	0.10	0.76	0.07	0.61	0.06	0.50	0.05
NF_Guad_S020	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
SF_Guad_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
Guad_S010	0.93	0.11	0.80	0.08	0.65	0.07	0.53	0.06
JohnsonCr_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
JohnsonCr_S020	0.92	0.11	0.80	0.08	0.65	0.07	0.53	0.06
Guad_S020	0.93	0.11	0.81	0.08	0.66	0.07	0.55	0.06
Guad_S030	1.44	0.11	1.31	0.08	1.16	0.07	1.04	0.06
TurtleCr_S010	0.91	0.11	0.79	0.08	0.64	0.07	0.53	0.06
Guad_S040	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
VerdeCr_S010	1.57	0.11	1.43	0.08	1.28	0.07	1.16	0.06
Guad_S050	1.02	0.11	0.88	0.08	0.72	0.07	0.60	0.06
CypressCr_GR_S010	0.93	0.11	0.80	0.08	0.65	0.07	0.53	0.06
Guad_S060	0.92	0.11	0.80	0.08	0.64	0.07	0.53	0.06
BlockCr_S010	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S070	0.93	0.11	0.80	0.08	0.65	0.07	0.54	0.06
JoshuaCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S080	0.92	0.11	0.80	0.08	0.64	0.07	0.53	0.06
SisterCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S090	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
CurryCr_S010	0.88	0.10	0.77	0.07	0.63	0.06	0.52	0.05
Guad_S100	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S110	0.94	0.10	0.84	0.07	0.70	0.06	0.59	0.05
Guad_S120	0.85	0.10	0.76	0.07	0.61	0.06	0.50	0.05
CanyonLk_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Blanco_S010	1.06	0.125	0.87	0.095	0.71	0.084	0.58	0.075
Blanco_S020	1.06	0.126	0.88	0.096	0.71	0.084	0.59	0.076
Blanco_S030	1.04	0.123	0.86	0.093	0.7	0.082	0.58	0.073
Blanco_S040	1.03	0.121	0.86	0.091	0.69	0.08	0.57	0.071
Blanco_S050	1.02	0.12	0.85	0.09	0.69	0.079	0.57	0.07
LittleBlanco_S010	1.06	0.126	0.88	0.096	0.71	0.084	0.59	0.076
LittleBlanco_S020	1.05	0.125	0.87	0.095	0.71	0.083	0.58	0.075
LittleBlanco_S030	1.02	0.121	0.86	0.091	0.69	0.08	0.57	0.071
LittleBlanco_S040	1.07	0.127	0.88	0.097	0.72	0.085	0.59	0.077
Blanco_S060	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
WanslowCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.086	0.59	0.078
Blanco_S070	1.07	0.127	0.89	0.097	0.72	0.086	0.59	0.077

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
Blanco_S080	1.07	0.126	0.88	0.096	0.71	0.085	0.59	0.076
CarpersCr_BR_S010	1.09	0.129	0.89	0.099	0.72	0.087	0.6	0.079
Blanco_S090	1.08	0.127	0.89	0.097	0.72	0.086	0.59	0.077
Blanco_S100	1.07	0.127	0.89	0.097	0.72	0.086	0.59	0.077
WilsonCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
Blanco_S110	1.08	0.127	0.89	0.097	0.72	0.086	0.59	0.077
CypressCr_BR_S010	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
CypressCr_BR_S020	1.09	0.128	0.89	0.098	0.72	0.087	0.59	0.078
CypressCr_BR_S030	1.08	0.128	0.89	0.098	0.72	0.086	0.59	0.078
Blanco_S120	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
Blanco_S130	1.09	0.129	0.89	0.099	0.72	0.087	0.6	0.079
LoneManCr_BR_S010	1.1	0.13	0.9	0.1	0.73	0.088	0.6	0.08
Blanco_S140	1.08	0.128	0.89	0.098	0.72	0.087	0.59	0.078
HalifaxCr_BR_S010	1.05	0.124	0.87	0.094	0.7	0.083	0.58	0.074
Blanco_S150	1.05	0.124	0.87	0.094	0.71	0.083	0.58	0.074
Blanco_S160	1.03	0.122	0.86	0.092	0.7	0.081	0.57	0.072
Blanco_S170	1.1	0.13	0.9	0.1	0.73	0.089	0.6	0.08
SinkCk_S010	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S020	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S030	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SinkCk_S040	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SanMarcos_S005	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
SanMarcos_S008	0.86	0.1	0.76	0.07	0.61	0.06	0.51	0.05
PurgatoryCr_S010	0.87	0.1	0.77	0.07	0.61	0.06	0.51	0.05
SanMarcos_S010	0.9	0.11	0.78	0.08	0.63	0.06	0.52	0.06
SanMarcos_S020	0.92	0.11	0.8	0.08	0.64	0.07	0.53	0.06
YorkCr_S010	1.27	0.15	1.14	0.11	0.92	0.09	0.75	0.08
SanMarcos_S030	0.95	0.11	0.81	0.08	0.65	0.07	0.54	0.06
SanMarcos_S040	1	0.12	0.84	0.09	0.68	0.08	0.56	0.07
PlumCr_S010	0.82	0.1	0.76	0.07	0.61	0.06	0.51	0.05
PlumCr_S020	0.85	0.1	0.78	0.08	0.63	0.06	0.52	0.06
TenneyCr_S010	0.92	0.11	0.83	0.09	0.66	0.07	0.55	0.07
PlumCr_S030	0.86	0.1	0.79	0.08	0.63	0.07	0.53	0.06
PlumCr_S040	0.92	0.11	0.82	0.08	0.66	0.07	0.55	0.06
SanMarcos_S050	1.01	0.12	0.85	0.09	0.68	0.08	0.57	0.07
DryComalCk_S010	1.07	0.13	0.88	0.10	0.71	0.08	0.59	0.08
DryComalCk_S020	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
WFk_DryComalCk_S010	1.09	0.13	0.89	0.10	0.72	0.09	0.60	0.08
WFk_DryComalCk_S020	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
WF_Trib_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
WF_Trib_S020	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
WFk_DryComalCk_S030	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S030	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
BearCk_S010	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S040	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
DCCk_Trib14_S010	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
DryComalCk_S050	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
DryComalCk_S060	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
BliedersCk_S010	1.04	0.12	0.87	0.09	0.70	0.08	0.58	0.07
Comal_S010	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
Comal_S020	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Comal_S030	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Guad_S130	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
BearCr_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S140	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S142	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06
Guad_S144	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
Guad_Trib22_S010	0.89	0.11	0.78	0.08	0.63	0.06	0.52	0.06
Guad_S145	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
LongCk_S010	0.87	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S147	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Guad_Trib20_S010	0.90	0.11	0.78	0.08	0.63	0.07	0.52	0.06
Guad_S149	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
Guad_S152	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
YoungsCk_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
Guad_S154	0.99	0.12	0.84	0.09	0.68	0.08	0.56	0.07
CottonwoodCkS_S010	0.84	0.10	0.75	0.07	0.61	0.06	0.50	0.05
Guad_S156	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
Little_MillCk_S010	0.91	0.11	0.79	0.08	0.64	0.07	0.53	0.06
Guad_S158	0.98	0.12	0.83	0.09	0.68	0.08	0.56	0.07
DeadmanCk_S010	0.88	0.10	0.77	0.07	0.62	0.06	0.51	0.05
Guad_S160	0.96	0.11	0.82	0.08	0.66	0.07	0.55	0.06
CottonwoodCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Guad_S162	1.06	0.13	0.88	0.10	0.71	0.08	0.58	0.08
AlligatorCk_S010	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
GeronimoCk_S010	0.86	0.10	0.76	0.07	0.62	0.06	0.51	0.05
GeronimoCk_S020	0.87	0.10	0.76	0.07	0.62	0.06	0.51	0.05
GeronimoCk_S030	0.95	0.11	0.81	0.08	0.66	0.07	0.54	0.06

Subbasin Name	50-yr Initial (in)	50-yr Constant (in/hr)	100-yr Initial (in)	100-yr Constant (in/hr)	250-yr Initial (in)	250-yr Constant (in/hr)	500-yr Initial (in)	500-yr Constant (in/hr)
Guad_S164	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
CantauCk_S010	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
Guad_S166	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
MillCk_S010	1.01	0.12	0.86	0.09	0.70	0.07	0.58	0.07
Guad_S168	1.28	0.13	1.09	0.10	0.92	0.09	0.79	0.08
NashCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
Guad_S170	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
Guad_S172	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
Guad_S174	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
Guad_S176	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
Guad_S200	1.16	0.11	1.02	0.08	0.86	0.07	0.74	0.06
PeachCr_S010	1.11	0.12	0.94	0.09	0.78	0.08	0.66	0.07
BigFiveMileCr_S010	1.03	0.11	0.89	0.08	0.73	0.07	0.62	0.06
PeachCr_S020	0.97	0.11	0.84	0.08	0.68	0.07	0.57	0.06
SandyFork_S010	1.08	0.13	0.89	0.10	0.73	0.08	0.60	0.08
PeachCr_S030	1.01	0.11	0.87	0.08	0.71	0.07	0.59	0.06
PeachCr_S040	0.95	0.11	0.82	0.08	0.66	0.07	0.54	0.06
Guad_S210	1.02	0.12	0.86	0.09	0.70	0.08	0.57	0.07
McCoyCr_S010	1.03	0.12	0.86	0.09	0.69	0.08	0.57	0.07
Guad_S220	1.67	0.12	1.49	0.09	1.33	0.08	1.21	0.07
SandiesCr_S010	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
ClearForkCr_S010	1.08	0.12	0.91	0.09	0.75	0.08	0.63	0.07
SandiesCr_S020	1.04	0.12	0.87	0.09	0.71	0.08	0.59	0.07
ElmCr_S010	1.05	0.11	0.90	0.08	0.75	0.07	0.63	0.06
SandiesCr_S030	0.97	0.11	0.82	0.08	0.67	0.07	0.55	0.06
SandiesCr_S040	1.10	0.12	0.92	0.09	0.76	0.08	0.63	0.07
Guad_S230	1.17	0.13	0.97	0.10	0.80	0.09	0.67	0.08
Guad_S240	1.05	0.12	0.87	0.09	0.70	0.08	0.58	0.07
SmithCk_S010	1.04	0.12	0.86	0.09	0.70	0.08	0.58	0.07
ThomasCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
SmithCk_S020	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
YorktownCk_S010	1.02	0.12	0.86	0.09	0.69	0.08	0.57	0.07
YorktownCk_S020	1.07	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S010	1.05	0.12	0.87	0.09	0.71	0.08	0.58	0.07
HoosierCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S020	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08
EighteenmileCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
FifteenmileCk_S030	1.07	0.13	0.88	0.10	0.72	0.09	0.59	0.08
TwelvemileCk_S010	1.08	0.13	0.89	0.10	0.72	0.09	0.59	0.08

Subbasin Name	50-yr	50-yr	100-yr	100-yr	250-yr	250-yr	500-yr	500-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
FivemileCk_S010	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
TwelvemileCk_S020	1.10	0.13	0.90	0.10	0.73	0.09	0.60	0.08
ColetoCk_S010	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
ColetoCk_S020	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
PerdidoCk_S010	1.06	0.13	0.88	0.10	0.71	0.08	0.59	0.08
PerdidoCk_S020	1.03	0.12	0.86	0.09	0.70	0.08	0.57	0.07
PerdidoCk_S030	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
ColetoCk_S030	0.98	0.12	0.83	0.09	0.67	0.07	0.55	0.07
ColetoCk_S040	1.02	0.12	0.85	0.09	0.69	0.08	0.57	0.07
DryCk_S010	1.00	0.12	0.84	0.09	0.68	0.08	0.56	0.07
Guad_S250	0.97	0.12	0.83	0.09	0.67	0.07	0.55	0.07

10.2.2 Application of NOAA Atlas 14 Point Rainfall Depths in HEC-HMS

NOAA Atlas 14 point rainfall depths from the annual maximum time series for various durations and recurrence intervals were collected from the NA14 Precipitation Frequency Data Server (PFDS) for the centroid of each subbasin. This method resulted in 165 separate point rainfall tables being applied in the Guadalupe River basin, one for each subbasin. The appropriate point rainfall depth table was assigned to each subbasin within the HEC-HMS frequency storm editor. It should be noted that precipitation frequency estimates from NOAA Atlas 14 are point estimates and are not directly applicable to larger areas. The conversion of a point to an areal estimate was accomplished for the uniform rainfall method by using the depth area analyses in HEC-HMS. The final frequency results were then computed in HEC-HMS through the depth-area analyses of the applied frequency storms.

10.2.3 NOAA ATLAS 14 FREQUENCY STORM RESULTS – UNIFORM RAINFALL METHOD

The frequency flow values were then calculated in HEC-HMS by applying the NOAA Atlas 14 frequency rainfall depths to the final watershed model through a series of depth-area analyses. This rainfall pattern is known as the uniform rainfall method because the same rainfall depths are applied uniformly over the entire watershed. The final NA14 HEC-HMS frequency flows for significant locations throughout the watershed model can be seen in Table 10.3. These results will later be compared to elliptical shaped storm results from HEC-HMS along with other methods from this study.

In some cases, one may observe that the simulated peak discharge decreases in the downstream direction. It is not an uncommon phenomenon to see decreasing frequency peak discharges for some river reaches as flood waters spread out into the floodplain and the hydrograph becomes dampened as it moves downstream. This can be due to a combination of peak attenuation due to river routing as well as the difference in timing between the peak of the main stem river versus the runoff from the local tributaries and subbasins.

Table 10.3: Summary of Discharges (cfs) from the NOAA Atlas 14 HEC-HMS Uniform Rainfall Method

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
North Fork Guadalupe River near Hunt TX (USGS Gage)	NF_Guad_nr_Hunt	168.2	3,800	20,800	39,800	69,900	88,900	107,800	126,300	152,400
North Fork Guadalupe River above South Fork Guad River	NF_Guad_abv_SFGuad	189.2	3,600	20,300	38,900	69,200	90,500	110,600	130,200	157,800
Guadalupe River below South Fork Guad River near Hunt (USGS Gage)	NF_Guad+SF_Guad	286.6	6,200	31,700	57,200	99,500	136,500	167,400	197,500	240,200
Guadalupe River above Johnson Creek	Guad_abv_JohnsonCr	311.4	5,600	28,900	52,300	94,900	132,000	163,300	193,900	237,000
Johnson Creek near Ingram TX (USGS Gage)	JohnsonCr_nr_Ingram	113.5	1,400	8,000	24,900	60,700	89,100	105,200	121,100	143,600
Johnson Creek above Guadalupe River	JohnsonCr_abv_Guad	126.8	1,200	7,400	24,100	62,400	92,000	109,300	126,300	150,400
Guadalupe River below Johnson Creek	Guad+JohnsonCr	438.1	5,700	30,000	56,700	117,900	176,500	218,900	260,200	318,600
Guadalupe River at Kerrville (USGS Gage)	Guad_at_Kerrville	485.7	5,400	28,700	55,200	120,100	180,400	225,500	269,400	331,600
Guadalupe River above Turtle Creek	Guad_abv_TurtleCr	563.8	5,300	27,600	54,600	122,600	185,300	233,800	280,900	348,200
Guadalupe River below Turtle Creek	Guad+TurtleCr	634.3	8,300	32,300	61,300	139,800	207,700	262,700	316,600	392,900
Guadalupe River above Verde Creek	Guad_abv_VerdeCr	652.4	7,500	29,600	59,700	136,200	203,000	257,800	311,300	387,200
Guadalupe River below Verde Creek	Guad+VerdeCr	708.6	10,300	38,000	68,300	143,900	213,800	272,700	330,300	412,100
Guadalupe River above Cypress Creek	Guad_abv_CypressCr	763.5	9,800	36,400	66,200	139,400	209,000	268,800	327,100	409,800
Guadalupe River below Cypress Creek at Comfort (USGS Gage)	Guad+CypressCr	837.0	12,700	47,700	82,100	146,800	219,300	283,700	346,700	435,900
Guadalupe River above Block Creek	Guad_abv_BlockCr	865.1	11,900	44,300	77,700	145,300	216,900	281,200	344,200	433,700
Guadalupe River below Block Creek	Guad+BlockCr	909.7	13,100	47,400	81,600	146,300	219,600	286,200	350,900	443,200
Guadalupe River above Joshua Creek	Guad_abv_JoshuaCr	929.7	12,100	43,400	76,100	142,800	213,800	279,000	342,900	433,900
Guadalupe River below Joshua Creek	Guad+JoshuaCr	971.3	12,400	44,100	76,900	143,800	215,100	281,500	346,700	439,600
Guadalupe River above Sister Creek	Guad_abv_SisterCr	983.9	12,400	43,700	76,500	143,200	214,200	280,200	345,100	437,800
Guadalupe River below Sister Creek	Guad+SisterCr	1048.2	14,900	44,400	77,500	144,600	216,100	283,200	349,800	445,000

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
Guadalupe River above Curry Creek	Guad_abv_CurryCr	1197.2	12,100	39,300	70,100	129,600	195,700	257,400	319,100	407,300
Guadalupe River below Curry Creek	Guad+CurryCr	1266.4	12,300	39,800	70,800	130,700	197,300	259,500	321,600	410,400
Guadalupe River near Spring Branch TX (USGS Gage)	Guad_nr_Springbranch	1313.7	12,300	39,900	70,800	130,100	196,200	258,100	320,000	408,400
Guadalupe River above Canyon Lake	Guad_abv_CanyonLk	1360.0	12,400	40,100	71,000	129,900	195,700	257,400	319,200	407,500
Peak Inflow into Canyon Lake	Canyon_Inflow	1431.1	15,500	40,700	71,900	131,100	197,300	259,300	321,400	410,300
	NOTE - The below Drainage Areas for the Guadalupe River do not include the area above Canyon Dam									
Guadalupe River above Bear Creek	Guad_abv_BearCr	36.0	7,100	16,100	23,600	33,200	41,200	48,600	57,300	70,200
Bear Creek above Guadalupe River	BearCr_S010	16.7	3,800	8,500	12,400	17,100	21,000	24,600	28,900	35,400
Guadalupe River below Bear Creek	Guad+BearCr	52.8	10,000	23,100	34,000	47,500	59,000	69,400	81,800	100,300
Guadalupe River above the Comal River (USGS Gage)	Guad_abv_Comal	88.3	7,300	22,500	37,400	57,600	74,400	88,300	104,800	130,400
Dry Comal Creek below the Wests Fork	DryComalCk+WFk	54.0	700	2,000	3,000	4,500	10,400	18,700	26,900	37,600
Dry Comal Creek above Bear Creek	DryComalCk_abv_BearCk	55.4	600	2,000	3,300	5,200	10,200	18,400	26,700	37,400
Dry Comal Creek below Bear Creek	DryComalCk+BearCk	68.7	700	2,000	3,300	5,200	10,700	19,600	28,900	41,300
Dry Comal Creek above Tributary 14	DryComalCk_abv_Trib14	89.0	1,900	5,600	9,400	14,800	18,700	25,100	33,100	44,400
Dry Comal Creek below Tributary 14	DryComalCk+DCCk_Trib14	94.7	2,200	6,700	10,700	16,200	20,100	26,600	36,900	50,900
Dry Comal Creek at Loop 337 near New Braunfels (USGS Gage)	DryComalCk_J020	107.3	2,300	7,000	11,700	18,700	23,700	30,100	39,600	54,200
Dry Comal Creek above Comal Rivr	DryComalCk_abv_Comal	111.2	2,100	6,700	11,400	18,500	23,500	29,900	38,500	51,400
Comal River below Dry Comal Creek	Comal+DryComalCk	128.3	2,500	7,400	12,700	22,500	29,700	39,200	50,500	67,400
Comal River at New Braunfels (USGS Gage)	Comal_at_New_Braunfels	129.5	2,600	7,400	12,700	22,500	29,800	39,400	50,700	67,600
Comal River above Guadalupe River	Comal_abv_Guad	130.1	2,600	7,400	12,800	22,500	29,800	39,400	50,700	67,600
Guadalupe River below the Comal River	Guad+Comal	218.4	8,600	27,400	46,900	75,300	97,700	119,000	143,800	181,700
Guadalupe River at Lake Dunlap	Lake_Dunlap	233.4	9,100	27,500	44,600	69,200	89,500	110,000	135,900	170,900
Guadaulupe River above Tributary 22	Guad_abv_Trib22	234.1	9,000	27,400	44,500	69,100	89,500	109,900	135,900	171,000
Guadaulupe River below Tributary 22	Guad+Trib22	238.6	9,100	27,700	45,000	69,800	90,500	111,200	137,500	173,000

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
Guadalupe River above Long Creek	Guad_abv_LongCk	239.6	8,900	26,700	43,900	68,200	88,900	109,600	135,700	171,100
Guadaupe River below Long Creek	Guad+LongCk	251.1	9,300	28,000	46,000	71,500	93,200	115,100	142,300	179,300
Guadalupe River above Tributary 20	Guad_abv_Trib20	251.5	9,300	27,900	45,800	71,100	92,500	114,000	141,000	178,600
Guadaupe River below Tributary 20	Guad+Trib20	260.4	9,400	28,400	46,700	72,600	94,400	116,500	144,200	182,900
Guadalupe River at Lake McQueeney	Lake_McQueeney	264.0	9,400	28,000	44,600	68,100	87,500	109,900	136,400	175,000
Guadalupe River above Youngs Creek	Guad_abv_YoungsCk	264.7	9,400	28,000	44,600	68,000	87,400	109,700	136,200	174,600
Guadalupe River below Youngs Creek	Guad+YoungsCk	279.4	9,600	28,500	45,300	69,200	89,100	112,400	139,700	178,900
Guadalupe River above the smaller Cottonwood Ck	Guad_abv_CottonwoodCkS	279.7	9,600	28,500	45,300	69,200	89,100	112,400	139,700	178,800
Guadalupe River below the smaller Cottonwood Ck	Guad+CottonwoodCkS	285.7	9,700	28,600	45,500	69,700	89,800	113,400	141,000	180,400
Guadalupe River above Little Mill Ck	Guad_abv_LittleMillCk	286.3	9,700	28,400	45,200	69,300	89,400	112,600	140,000	179,600
Guadalupe River below Little Mill Ck	Guad+LittleMillCk	295.0	9,800	28,800	45,800	70,200	90,600	114,300	142,200	182,400
Guadalupe River above Deadman Ck	Guad_abv_DeadmanCk	296.4	9,800	28,700	45,400	69,600	90,000	113,600	141,400	182,000
Guadalupe River below Deadman Ck	Guad+DeadmanCk	304.9	10,500	28,900	45,700	69,900	90,500	114,600	142,600	183,800
Guadalupe River at Lake Placid	Lake_Placid	304.9	10,500	28,800	45,400	69,600	90,400	114,500	142,600	183,700
Guadalupe River at Meadow Lake	Meadow_Lake	327.2	11,500	29,200	44,200	66,200	86,500	111,000	139,100	179,700
Guadalupe River above Cottonwood Ck	Guad_abv_CottonwoodCk	327.2	11,500	29,200	44,200	66,200	86,500	111,000	139,100	179,700
Guadalupe River below Cottonwood Ck	Guad+CottonwoodCk	368.3	12,000	33,600	50,000	72,200	94,400	122,800	154,100	199,200
Guadalupe River above Geronimo Ck	Guad_abv_GeronimoCk	369.5	11,500	33,200	49,600	72,000	93,900	121,600	152,700	197,600
Geronimo Ck at I-10 near Seguin	GeronimoCk_J020	59.7	4,500	11,600	16,900	24,200	30,600	38,400	46,900	59,400
Geronimo Ck above Guadalupe River	GeronimoCk_abv_Guad	69.7	2,900	8,600	13,700	21,700	29,900	38,200	47,500	62,500
Guadalupe River below Geronimo Ck	Guad+GeronimoCk	439.2	13,800	40,100	60,200	86,200	109,700	141,100	178,400	231,700
Guadalupe River above Cantau Ck	Guad_abv_CantauCk	443.5	12,900	38,500	59,000	85,400	109,300	140,300	177,200	230,100
Guadalupe River at FM 1117 near Seguin	Guad_nr_Seguin	450.1	12,900	38,600	59,300	85,700	109,600	140,900	178,100	231,400
Guadalupe River above Mill Ck	Guad_abv_MillCk	481.8	10,300	33,200	55,300	83,900	109,400	141,300	179,300	235,200

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
Guadalupe River below Mill Ck	Guad+MillCk	521.2	10,700	34,900	58,200	89,000	116,400	150,500	191,700	251,400
Guadalupe River above Nash Creek	Guad_abv_NashCk	553.7	8,100	31,100	54,900	86,500	115,200	150,800	193,600	255,500
Guadalupe River below Nash Creek	Guad+NashCk	580.2	8,100	31,300	55,500	87,500	116,900	153,800	198,200	262,200
Guadalupe River at Lake Gonzales	Lake_Gonzales	615.9	7,300	26,800	50,000	85,300	117,500	156,800	204,600	273,200
Guadalupe River at Wood Lake	Wood_Lake	667.4	6,800	22,400	40,800	76,200	109,000	149,600	201,100	273,200
Guadalupe River above the San Marcos River	Guad_J340	671.8	6,400	20,100	38,200	72,800	106,400	147,600	197,700	270,900
Blanco River below Little Blanco	Blanco+LittleBlanco	237.8	8,800	35,900	61,400	103,400	147,300	187,500	227,200	284,500
Blanco River above Wanslow Creek	Blanco_abv_WanslowCr	239.0	8,700	35,800	61,200	103,300	147,100	187,700	227,100	284,600
Blanco River below Wanslow Creek	Blanco+WanslowCr	252.4	8,700	36,100	62,100	105,900	151,600	193,700	235,300	295,400
Blanco River at Fischer Store Rd (USGS Gage)	Blanco_FischerStoreRd_Gage	268.8	8,500	35,500	61,300	105,500	152,800	196,100	238,400	299,800
Blanco River above Carpers Creek	Blanco_abv_CarpersCr	274.7	8,500	35,100	60,700	104,800	152,100	195,400	237,800	299,000
Blanco River below Carpers Creek	Blanco+CarpersCr	290.0	8,500	35,400	61,600	107,200	156,400	201,200	245,300	308,700
Blanco River above Wilsoon Creek	Blanco_abv_WilsonCr	310.7	8,300	34,700	60,600	106,100	155,600	202,300	247,900	312,800
Blanco River below Wilson Creek	Blanco+WilsonCr	316.0	8,300	34,800	60,600	106,100	155,900	203,000	248,800	314,100
Blanco River above Cypress Creek	Blanco_abv_Cypress	316.9	8,300	34,800	60,700	106,000	155,900	203,000	248,600	314,100
Blanco River at Wimberley (USGS Gage)	Blanco+CypressCr	355.1	8,500	35,300	61,600	108,000	161,100	211,300	259,900	329,800
Blanco River above Lone Man Creek	Blanco_abv_LoneManCr	370.5	8,300	34,800	60,900	106,800	159,500	210,300	259,900	330,300
Blanco River below Lone Man Creek	Blanco+LoneManCr	382.9	8,300	35,000	61,500	108,000	161,600	213,500	264,000	335,900
Blanco River above Halifax Creek	Blanco_abv_HalifaxCr	392.7	8,200	34,600	61,100	107,600	161,200	213,600	264,900	337,300
Blanco River below Halifax Creek	Blanco+HalifaxCr	405.6	8,200	34,800	61,600	108,600	162,900	216,500	268,800	342,600
Blanco River near Kyle (USGS Gage)	Blanco_nr_Kyle_Gage	412.3	8,100	34,400	61,000	107,500	162,000	216,500	269,300	343,500
Blanco River at I-35 Bridge near San Marcos, TX	Blanco_at_I-35	432.7	7,800	33,200	59,300	103,500	157,100	213,900	269,100	344,400
Blanco River above San Marcos River	Blanco_abv_SanMarcos	436.2	7,200	31,900	55,500	99,700	149,700	207,000	256,800	328,100
Below SCS Dam No. 5	SCS Dam No. 5	37.1	800	4,000	9,200	16,300	21,900	28,200	34,400	43,100

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
San Marcos River at San Marcos (USGS Gage)	SanMarcos_at_SanMarcos	49.0	500	1,800	2,900	4,800	9,600	18,600	28,300	42,200
San Marcos River below Purgatory Cr	SanMarcos+Purgatory	87.1	1,100	3,900	9,300	17,200	25,400	36,200	52,000	76,700
San Marcos River above Blanco River	SanMarcos_J020	95.1	2,500	5,200	9,100	17,200	25,800	36,800	52,200	77,300
San Marcos River below Blanco River	SanMarcos+Blanco	531.3	8,100	33,700	58,400	103,900	160,400	228,400	284,900	362,900
San Marcos River above York Creek	SanMarcos_J040	613.6	7,700	31,400	55,500	96,300	144,400	205,700	273,900	357,600
York Creek above San Marcos River	YorkCr_S010	142.9	3,100	12,900	21,100	34,700	46,900	61,800	77,600	99,600
San Marcos River below York Creek	SanMarcos+YorkCr	756.6	8,400	33,500	59,300	101,800	151,600	219,900	298,200	392,700
San Marcos River at Luling (USGS Gage)	SanMarcos_at_Luling	838.9	10,100	31,900	57,600	100,200	149,300	217,600	295,700	393,500
San Marcos River above Plum Creek	SanMarcos_J070	861.8	8,400	29,200	54,100	96,700	144,200	207,500	283,100	383,400
Plum Creek at Lockhart (USGS Gage)	PlumCr_at_Lockhart	111.3	3,800	13,200	21,500	37,200	51,300	64,200	78,100	97,900
Plum Creek above Tenney Creek	PlumCr_J020	194.6	5,700	13,400	19,400	33,000	57,800	79,700	103,700	137,500
Plum Creek below Tenney Creek	PlumCr+TenneyCr	234.4	8,100	19,200	28,100	43,000	65,200	91,100	120,000	160,100
Plum Creek near Luling (USGS Gage)	PlumCr_nr_Luling	351.5	6,700	16,800	31,000	53,900	80,900	112,000	149,600	205,100
Plum Creek above San Marcos River	PlumCr_J050	388.8	5,900	15,600	27,300	49,600	79,100	110,300	148,000	203,600
San Marcos River below Plum Creek	SanMarcos+PlumCr	1250.6	13,600	41,500	72,900	132,900	198,100	288,600	398,300	531,400
San Marcos River above the Guadalupe River	SanMarcos_J090	1359.0	10,900	33,200	61,200	121,400	186,000	266,700	363,900	495,100
Guadalupe River below the San Marcos River at Gonzales (USGS Gage)	Guad+SanMarcos	2030.8	16,900	51,100	97,900	194,200	289,700	409,200	539,000	723,000
Guadalupe River above Peach Creek	Guad_J360	2100.3	14,900	48,600	93,300	187,200	284,000	403,300	533,300	718,000
Peach Creek below Dilworth	PeachCr_bl_Dilworth	459.8	6,000	16,300	26,100	48,700	69,100	96,600	123,700	162,900
Peach Creek above the Guadalupe River	PeachCr_J060	482.5	5,800	15,600	24,400	47,300	67,600	95,100	122,800	162,300
Guadalupe River below Peach Creek	Guad+PeachCr	2582.8	15,900	54,000	106,200	216,500	328,300	472,100	628,800	847,000
Guadalupe River above McCoy Ck	Guad_J380	2705.2	15,200	51,200	100,300	208,900	319,500	462,500	614,400	830,800
Guadalupe River below McCoy Ck	Guad+McCoyCr	2737.8	15,300	51,400	100,600	209,400	320,200	463,300	615,500	832,100

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
Guadalupe River above Sandies Ck	Guad_J400	2786.2	15,100	48,600	93,400	197,900	307,200	452,600	605,600	820,200
Sandies Ck near Westhof (USGS Gage)	SandiesCr_nr_Westhof	549.4	3,700	11,900	21,800	43,000	62,800	90,100	116,300	161,700
Sandies Ck abv the Guadalupe River	SandiesCk_abv_Guad	711.1	3,600	10,800	20,400	40,600	59,400	87,500	120,600	180,200
Guadalupe River below Sandies Ck at Cuero (USGS Gage)	Guad+SandiesCr	3497.4	15,500	52,900	106,600	230,100	360,600	536,500	713,100	959,800
Guadalupe River at Victoria (USGS Gage)	Guad_at_Victoria	3767.1	15,600	49,000	93,400	211,400	338,200	512,400	694,400	938,800
Guadalupe River above Coleto Creek	Guad_abv_ColetoCk	3802.7	15,200	48,800	92,600	208,800	329,000	501,600	690,700	935,300
Fifteenmile Ck near Weser (USGS Gage)	FifteenmileCk_WeserTX	164.5	2,200	7,600	12,100	21,400	32,500	42,900	53,500	67,700
Fifteenmile Ck abv Eighteenmile Ck	FifteenmlCk_abv_EighteenmlCk	182.5	2,100	7,300	11,800	20,700	31,600	41,900	52,400	66,500
Eighteenmile Ck abv Fifteenmile Ck	EighteenmileCk_S010	48.0	3,100	6,400	9,600	14,800	18,900	23,600	28,400	34,500
Fifteenmile Ck blw Eighteenmile Ck	FifteenmileCk+EighteenmileCk	230.5	4,300	10,300	16,000	26,000	35,300	45,400	56,100	70,200
Fifteenmile Ck abv Twelvemile Ck	FifteenmlCk_abv_TwelvemlCk	250.3	5,500	13,000	20,000	32,300	42,900	54,700	66,800	83,000
Twelvemile Ck abv Fifteenmile Ck	TwelvemlCk_abv_FifteenmlCk	105.9	3,800	8,600	15,500	21,700	28,700	37,400	45,700	57,300
Coleto Creek at Arnold Rd nr Schroeder (USGS Gage)	ColetoCkAtArnoldRdCrsg	356.2	7,200	17,100	27,800	43,900	59,900	78,700	98,500	125,600
Coleto Creek above Perdido Ck	ColetoCk+ColetoCk	417.7	10,200	24,700	37,700	58,300	76,700	98,400	121,000	152,400
Perdido Ck at FM 622 nr Fannin (USGS Gage)	PerdidoCkAtFM622_FanninTX	27.7	3,000	8,800	13,300	19,900	25,200	29,600	34,000	39,700
Perdido Ck below Road Ck	PerdidoCk_J020	55.2	4,800	11,200	16,400	24,700	32,100	39,200	46,100	55,500
Perdido Ck above Coleto Ck	PerdidoCk_abv_ColetoCk	76.3	6,700	15,000	21,800	32,400	41,900	51,200	60,200	72,300
Coleto Ck Reservoir near Victoria	ColetoCkRes_VictoriaTX	494.1	11,800	29,300	44,300	67,800	90,300	115,900	142,100	178,100
Coleto Creek nr Victoria (USGS Gage)	ColetoCk_VictoriaTX	511.3	11,800	29,200	44,300	67,800	90,800	117,200	143,800	180,200
Coleto Creek above Guadalupe River	ColetoCk_abv_Guadalupe	540.4	8,500	24,100	40,100	64,100	89,100	115,900	144,600	183,400
Guadalupe River near Bloomington (USGS Gage)	GuadalupeRv_BloomingtonTX	4382.5	15,200	49,300	93,400	209,300	332,600	508,500	703,600	954,800

10.3 ELLIPTICAL FREQUENCY STORMS IN HEC-HMS WITH NOAA ATLAS 14 RAINFALL DEPTHS

10.3.1 Introduction to Elliptical Storms

As previously mentioned, precipitation frequency estimates from NOAA Atlas 14 are point estimates and are not directly applicable to larger watershed areas. The uniform rainfall method results in the previous section use the depth-area analyses in HEC-HMS to convert point to areal rainfall depths. However, as discussed in Chapter 7, the depth area reduction factors programmed within HEC-HMS do not support storms beyond 400 square miles. The program will still calculate the peak discharge, but the software issues a warning which implies that the calculated volume of the storm may not be appropriate for larger drainage areas.

Since the Guadalupe hydrology study involves calculating frequency discharges for points with up to several thousand square miles of drainage area, the InFRM team performed an additional analysis in HEC-HMS using elliptical frequency storms for points with drainage areas greater than 400 square miles. In these elliptical frequency storms, the same NOAA Atlas 14 point rainfall depths and durations were applied as in the uniform rainfall method of the preceding section, but the spatial distribution of the rainfall varied in an elliptical shaped pattern. For more background on the development of elliptical shaped storms, please refer to Section 7.1 of this report.

10.3.2 Elliptical Storm Parameters

The NOAA Atlas 14 elliptical storms used the same storm area and ellipse ratio as in the previous elliptical storms described in Chapter 7. The Guadalupe River basin elliptical storms used a maximum storm extent was of 10,000 square miles, and an ellipse ratio of 3:1. These storm parameters provided sufficient rainfall coverage over the whole basin and better matched its long and thin basin shape.

10.3.2.1 Point Rainfall Depths from NOAA Atlas 14

Elliptical storm were designed for eight frequency events, which encompassed the following annual exceedance probabilities (AEP): 50%, 20%, 10%, 4%, 2%, 1%, 0.5% and 0.2%. Point rainfall depths and durations were applied from NOAA Atlas 14, Volume 11 (NOAA, 2018). The elliptical storms used the same point rainfall tables as were applied in the uniform rainfall method. The point precipitation values were that applied to each elliptical storm were based on the storm center's location, not the location of the outlet of interest.

10.3.2.2 Storm Temporal Pattern

Historically, storms have varying intensities and temporal distributions and many studies have been done to document storm patterns. Section 7.2.4 described the various temporal storm distributions that were tested for this study, but varying the temporal pattern had little effect on peak discharge (generally less than 5%). Ultimately, the 50% intensity frequency rainfall distribution was adopted for consistency with the uniform rainfall method and the 2004 USGS rainfall HEC-HMS runs. Figure 10.10 compares the typical temporal distribution from the NOAA Atlas 14 storms to one applied from the 2004 USGS Rainfall Atlas. As one can see from this plot, the rainfall in the central 6-hours is significantly more intense for the NA14 rainfall than for the USGS rainfall. This pattern is a result of significant increases in the 6-hour duration for NOAA Atlas 14, as shown in Figure 10.7.

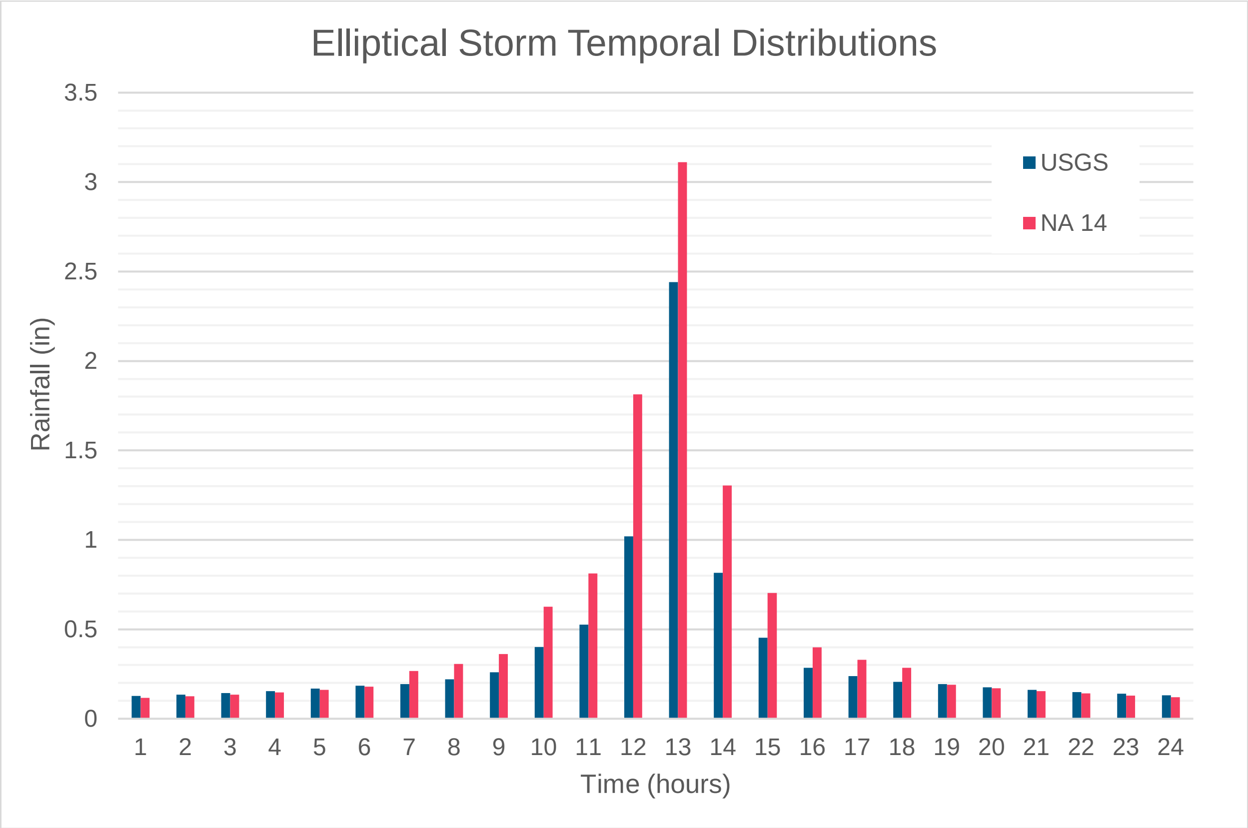


Figure 10.10: Elliptical Storm Temporal Distributions

Testing was also performed for shorter and longer storm durations. However, it was found that shorter storm durations produced lower peak discharges due to not all the watershed contributing and longer storm durations did not add much additional flow to the peak as compared with the 24 hour duration. For this study, the 24 hour storm duration was used throughout the watershed.

10.3.2.3 Depth Area Reduction Factors

The term depth area reduction factor refers to a storm that has been spatially normalized to a unit depth at the storm center. Thus the remainder of the storm is a percentage of the storm center. For the elliptical frequency storms, the depth area reduction curve, or set of factors, are applied to the storm to find the rainfall depths at each ellipse. A large amount of research and analysis went into the determination of the appropriate depth area reduction curve for this study, including the analysis of several observed storms local to the Guadalupe watershed. Figure 10.11 illustrates the range of depth area reduction curves of observed storms that were analyzed for this study, which are further described in Section 7.2.5 of this report.

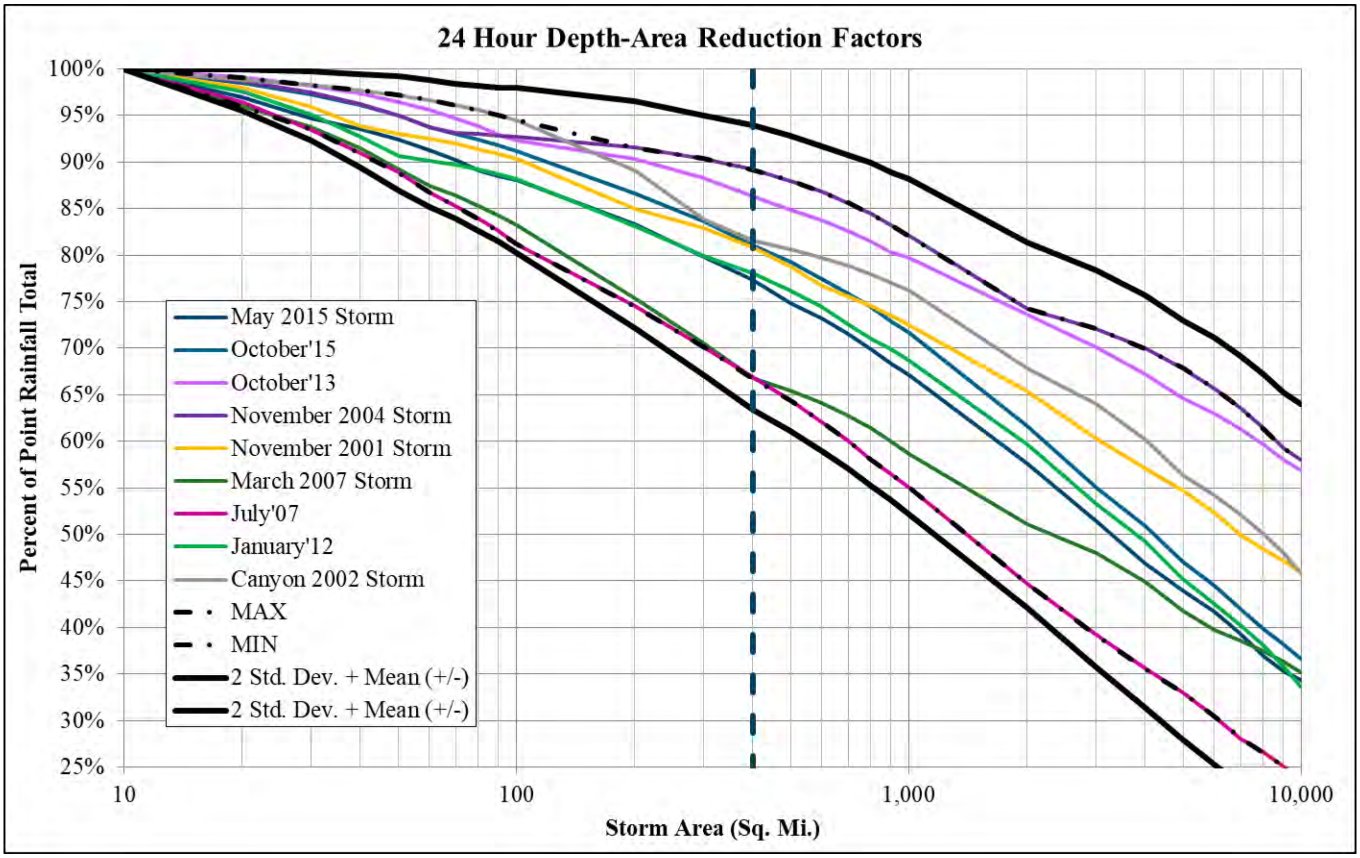


Figure 10.11: Depth Area Reduction Curves from Observed Storms

Based on the range of observed storms, an adopted depth area reduction curve was initially chosen for the 2004 USGS Rainfall elliptical storms. While performing the NOAA Atlas 14 rainfall update, the InFRM team took a second look at that adopted curve. Since the new NA14 rainfall depths were so much higher than the previous rainfall depths, the adopted curve was re-examined to ensure that it wasn't too conservative based on the observed data. The previously adopted curve followed the pattern from Figure 15 of TP40 for the first 100 square miles and then transitioned to follow the pattern of the maximum observed storms. After further examination, the InFRM team decided to adjust the adopted curve for the NA14 rainfall by patterning it after the October 2013 storm after the first 100 square miles. October 2013 was the second highest observed storm on Figure 10.11 in terms of area reduction. It also had point rainfall totals between 12 and 13 inches, which is similar to the NA14 100-yr point rainfall depths in the Guadalupe basin, and it had a spatial pattern that was similar to the elliptical storms (see Figure 6.19). This adjustment resulted in an adopted curve that was about 5% lower than the previously adopted curve for the larger drainage areas. Figure 10.12 compares the previous adopted depth area reduction curve from the 2004 USGS Rainfall elliptical storms in Chapter 7 to the new adopted curve for the NOAA Atlas 14 elliptical storms.

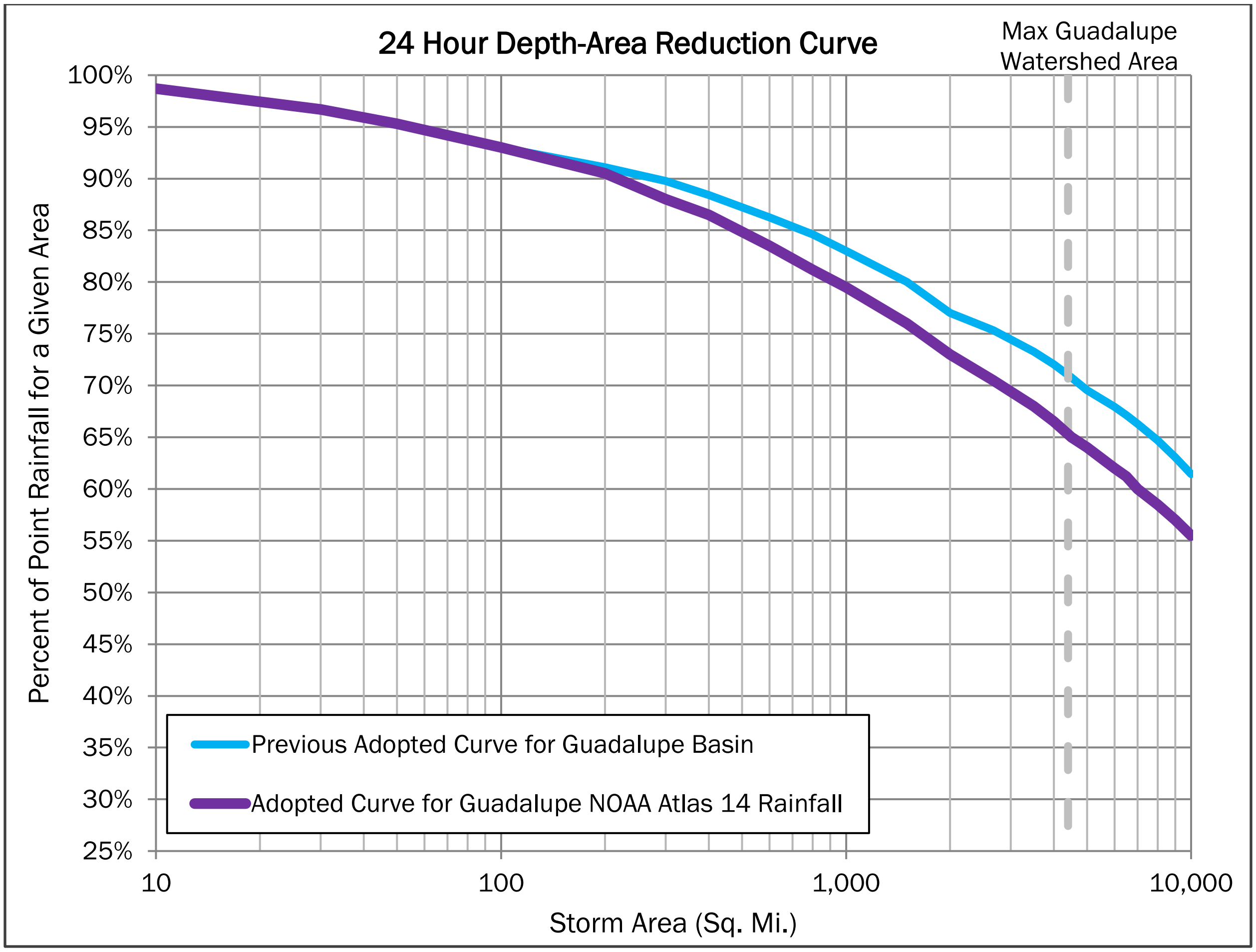


Figure 10.12: Adopted Depth Area Reduction Curves for the Guadalupe River Basin Study

Figure 10.13 gives an example of what the elliptical storms look like once the depth area curve is applied to the NA14 point rainfall depths. This figure shows the 100-yr storm for the Guadalupe River at Victoria. At the storm center, which is located near San Marcos, Texas, the rainfall depth is close to the point rainfall value of 12.9 inches. The rainfall depth is then reduced as one moves away from the center. Depths at the outer edges of the storm are reduced by almost half, which is 7.1 inches compared to 12.9 inches at the center.

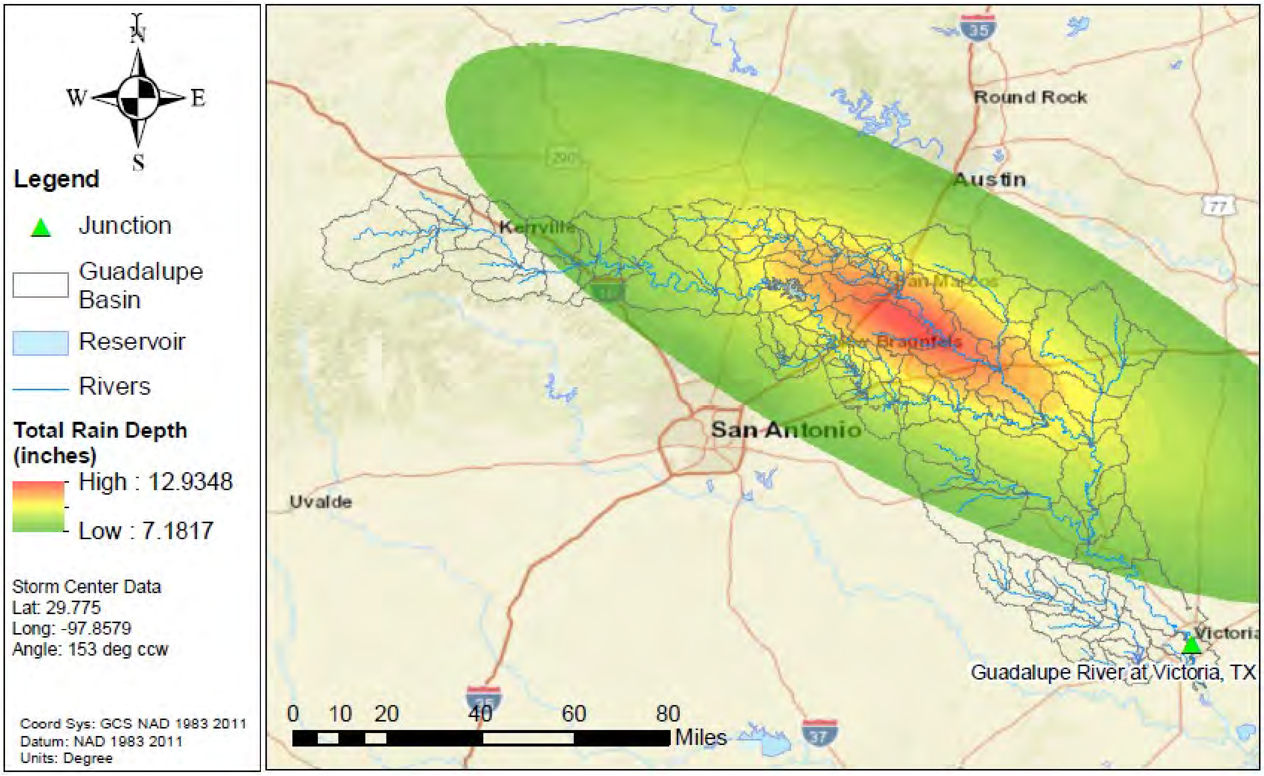


Figure 10.13 Applied Depth Area Reduction in the NA14 100-yr Elliptical Storm for Victoria, TX

10.3.3 Elliptical Storm Center Locations & Rotations

The storm center locations and rotations were optimized with the 2004 USGS Rainfall for each junction in the model. See Section 7.3 of Chapter 7 for details on the optimization process. For the NOAA Atlas 14 rainfall update, the same storm center locations and rotations were used for each node of interest as were calculated in Chapter 7. Only the rainfall depths were adjusted according to the new NA14 tables. See Table 7.2 in Chapter 7 for a complete list of the final optimized storm center locations (x, y) and rotations (ɵ) for every node of interest in the Guadalupe watershed.

Figure 10.14 illustrates the elliptical storm center locations for some of the major gages in the basin relative to the NA14 100-yr 24-hour rainfall depths. From this figure, one may note that the storm centers for Wimberley, San Marcos at Luling, Gonzales, Cuero and Victoria are all located in or near the area where the Texas hill country transitions to the coastal plains. This is also in the area of the highest NA14 precipitation values in the Guadalupe Basin. The final 1% annual chance (100-yr) elliptical frequency storms for selected gage locations in the Guadalupe watershed are illustrated in Figures 10.15 to 10.22.

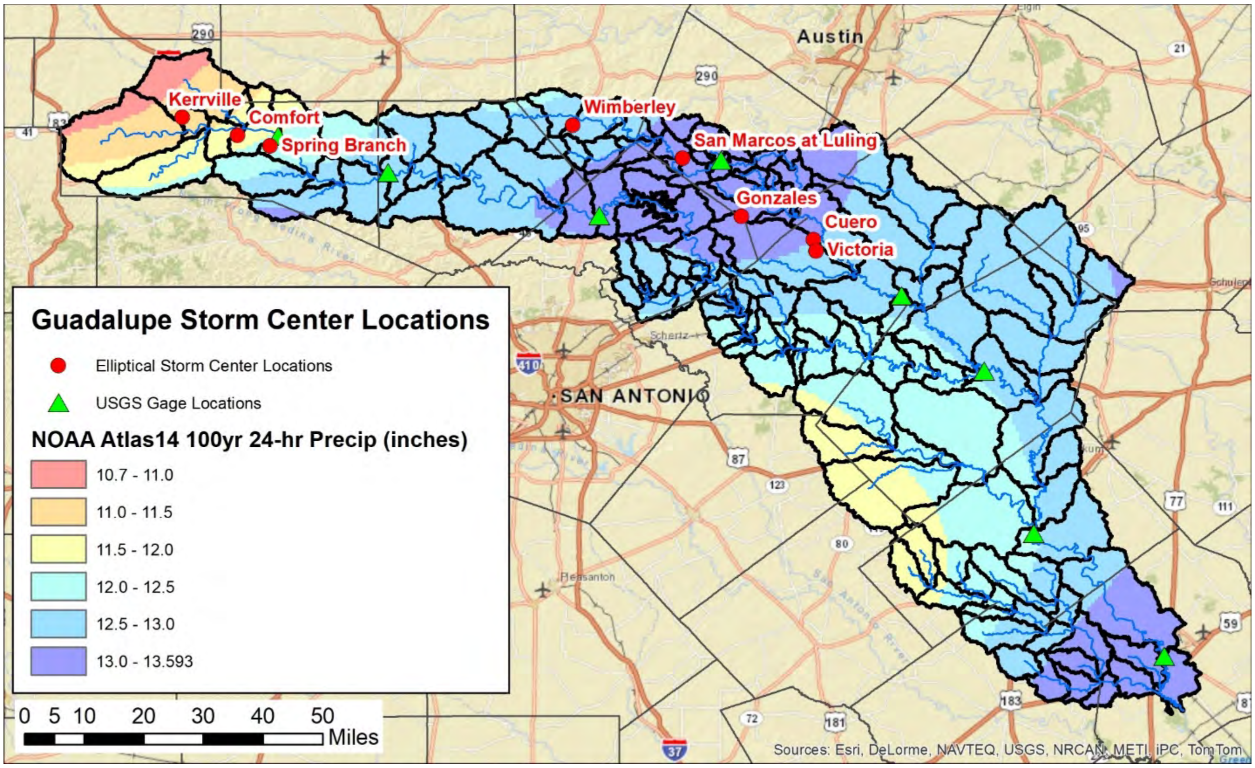


Figure 10.14: Elliptical Storm Center Locations relative to NA14 Precipitation Depths

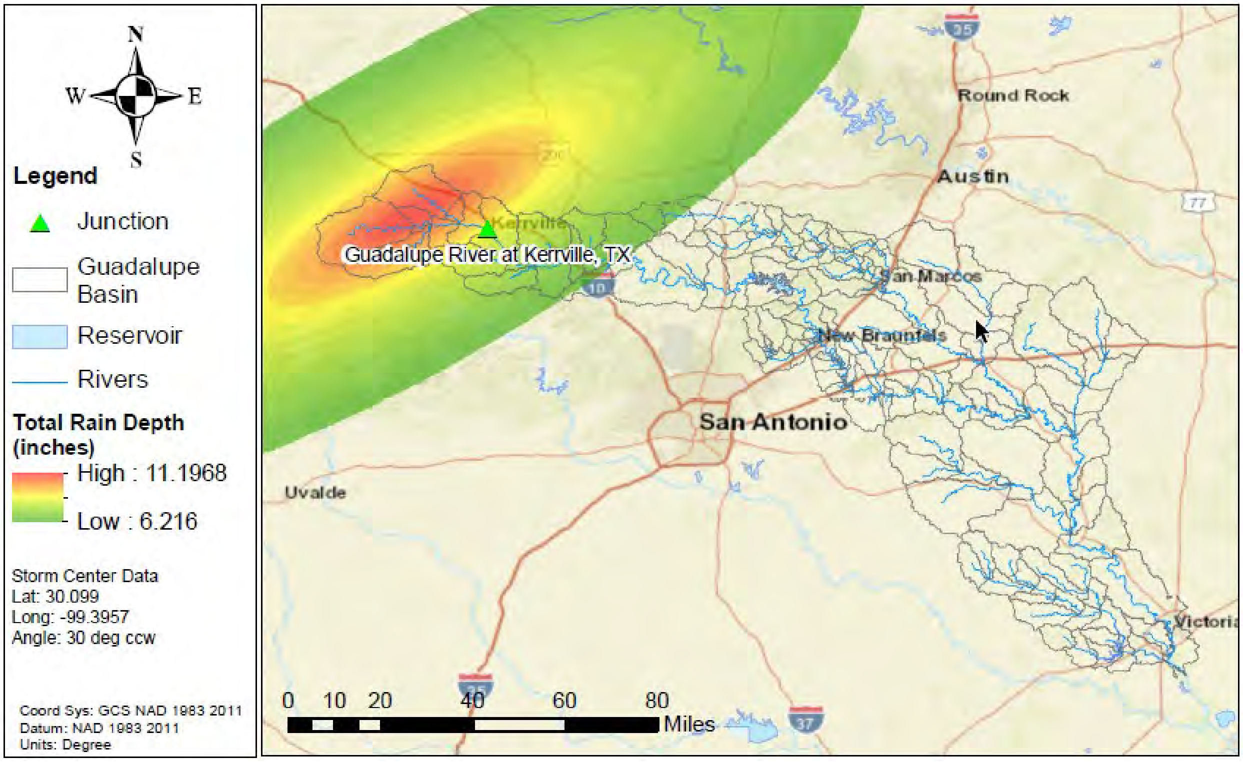


Figure 10.15: NOAA Atlas 14 1% ACE Elliptical Storm for the Guadalupe River at Kerrville

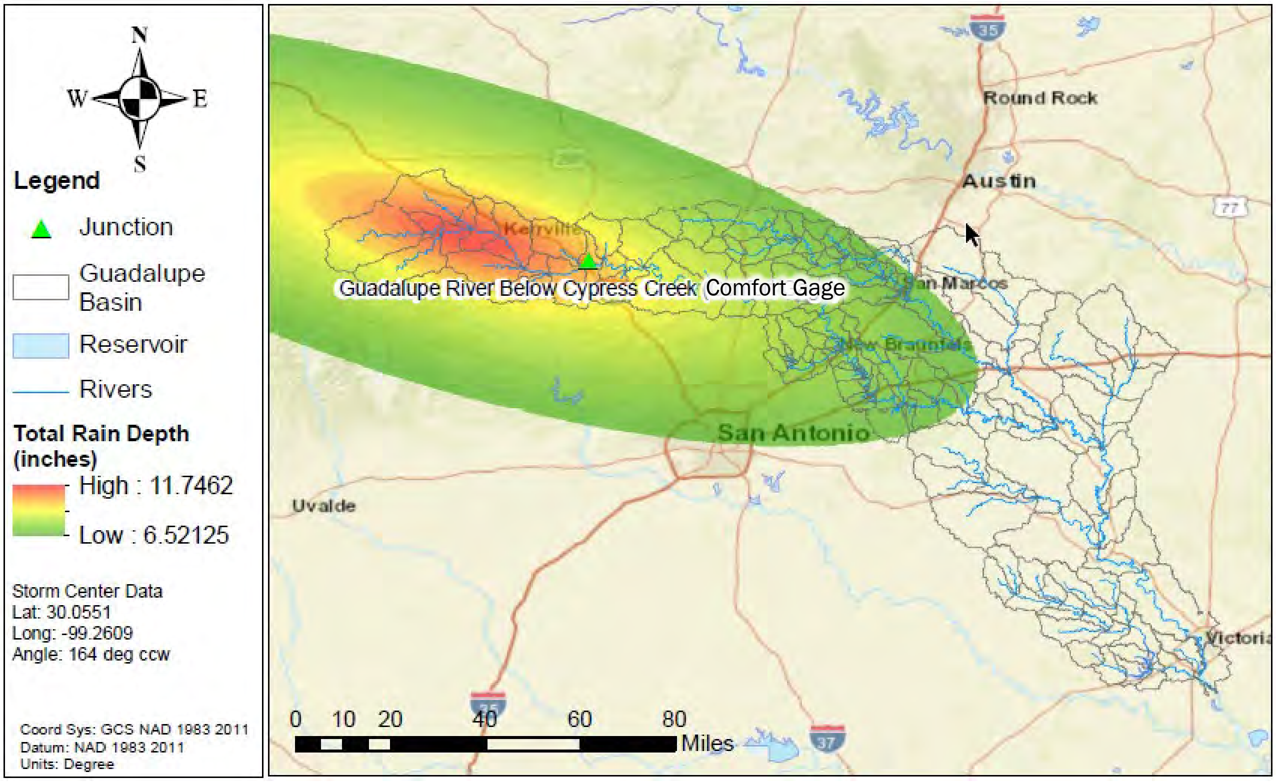


Figure 10.16: NOAA Atlas 14 1% ACE Elliptical Storm for the Guadalupe River at Comfort

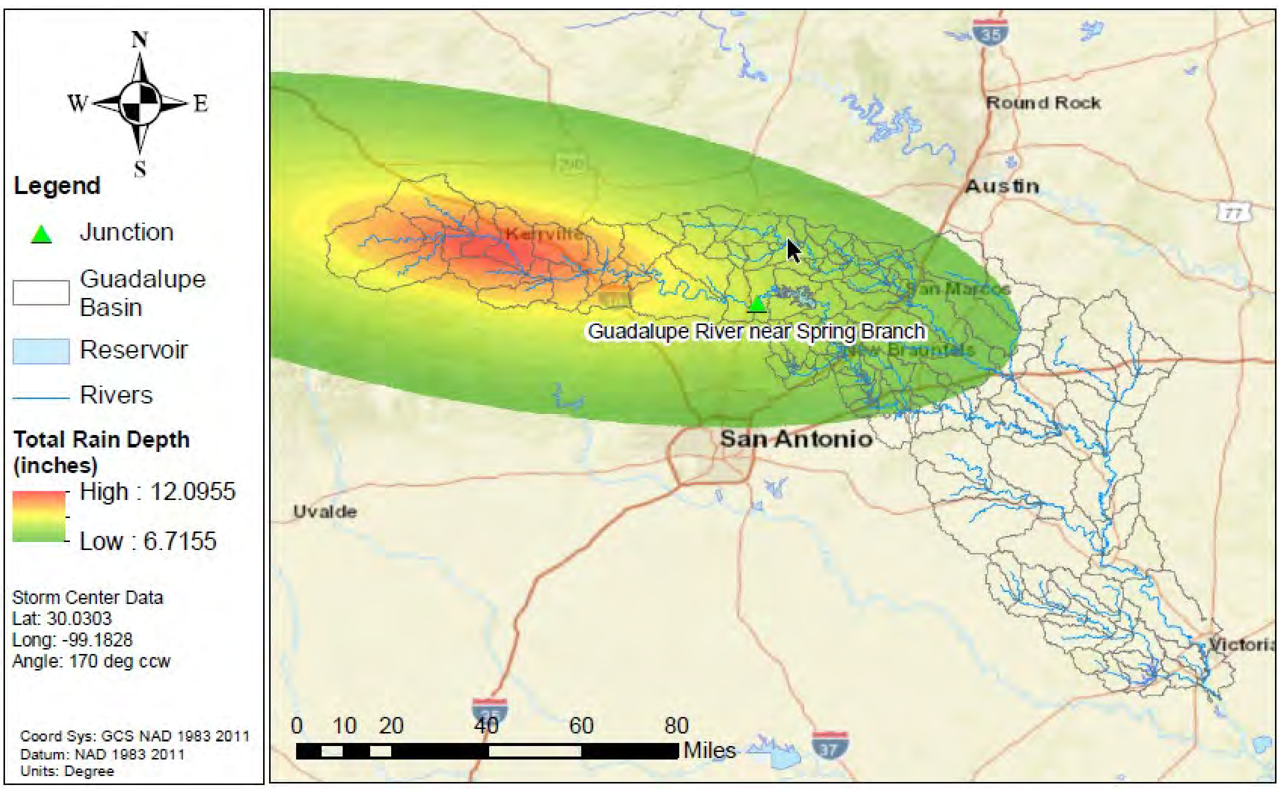


Figure 10.17: NOAA Atlas 14 1% ACE Elliptical Storm for the Guadalupe River nr Spring Branch

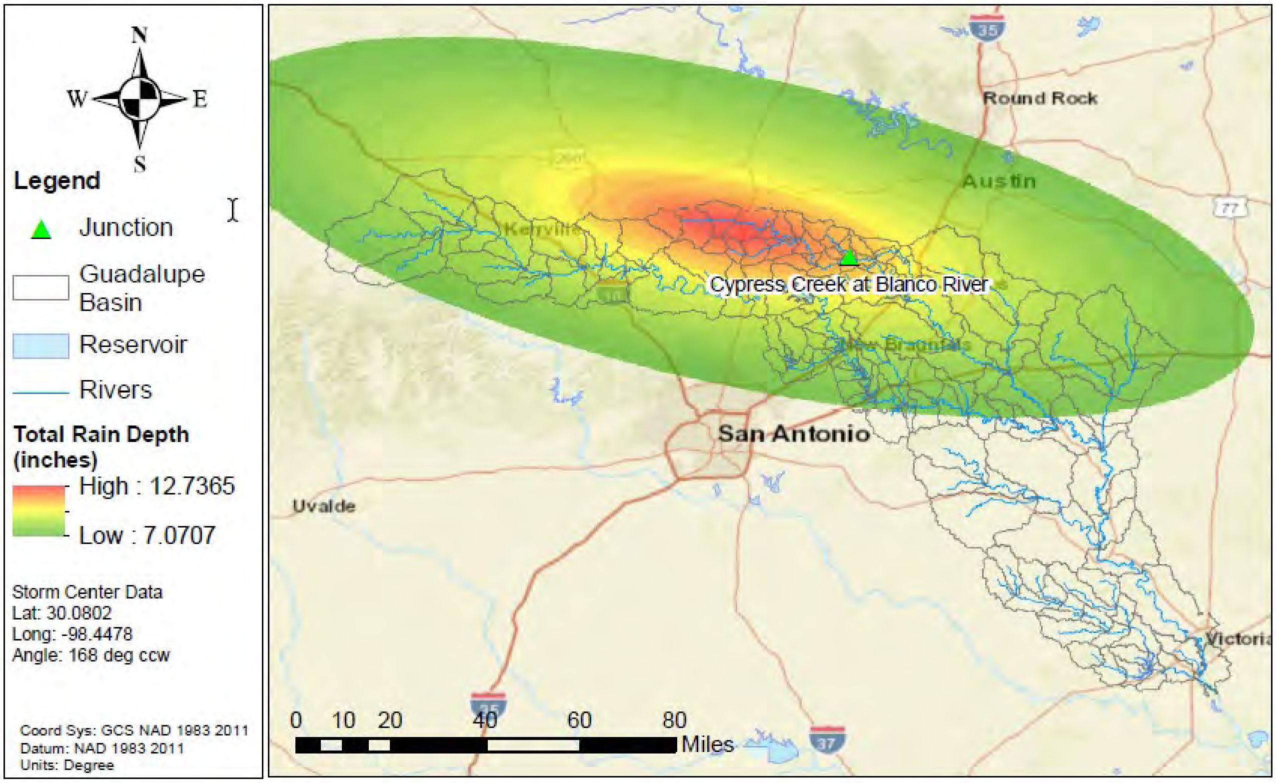


Figure 10.18: NOAA Atlas 14 1% ACE Elliptical Storm for the Blanco River at Wimberley

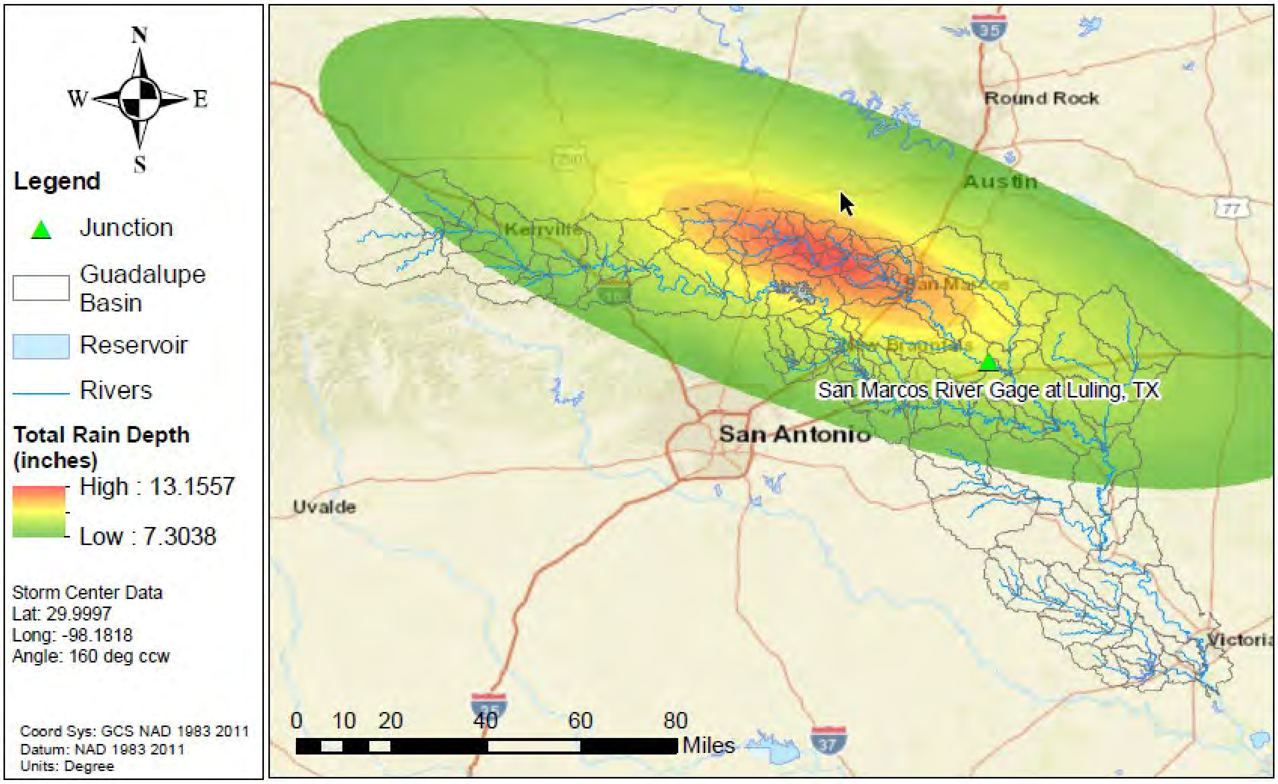


Figure 10.19: NOAA Atlas 14 1% ACE Elliptical Storm for the San Marcos River at Luling

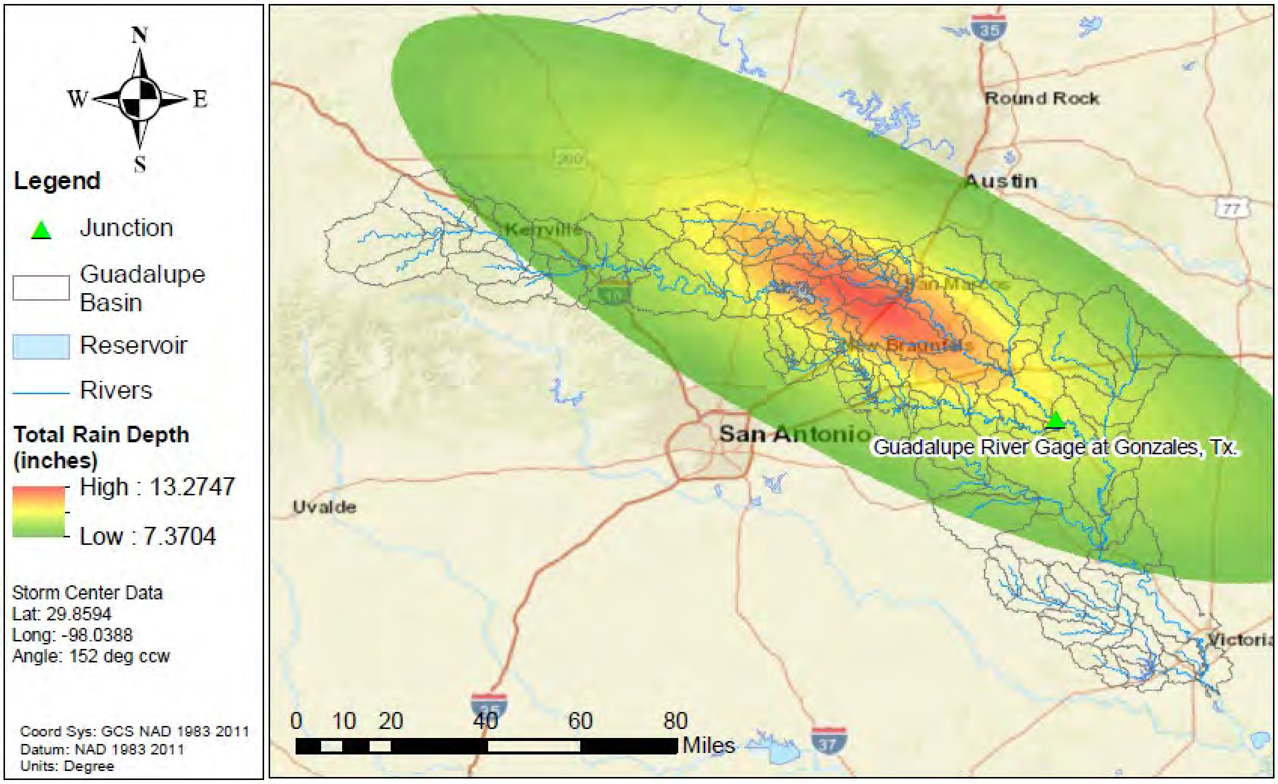


Figure 10.20: NOAA Atlas 14 1% ACE Elliptical Storm for the Guadalupe River at Gonzales

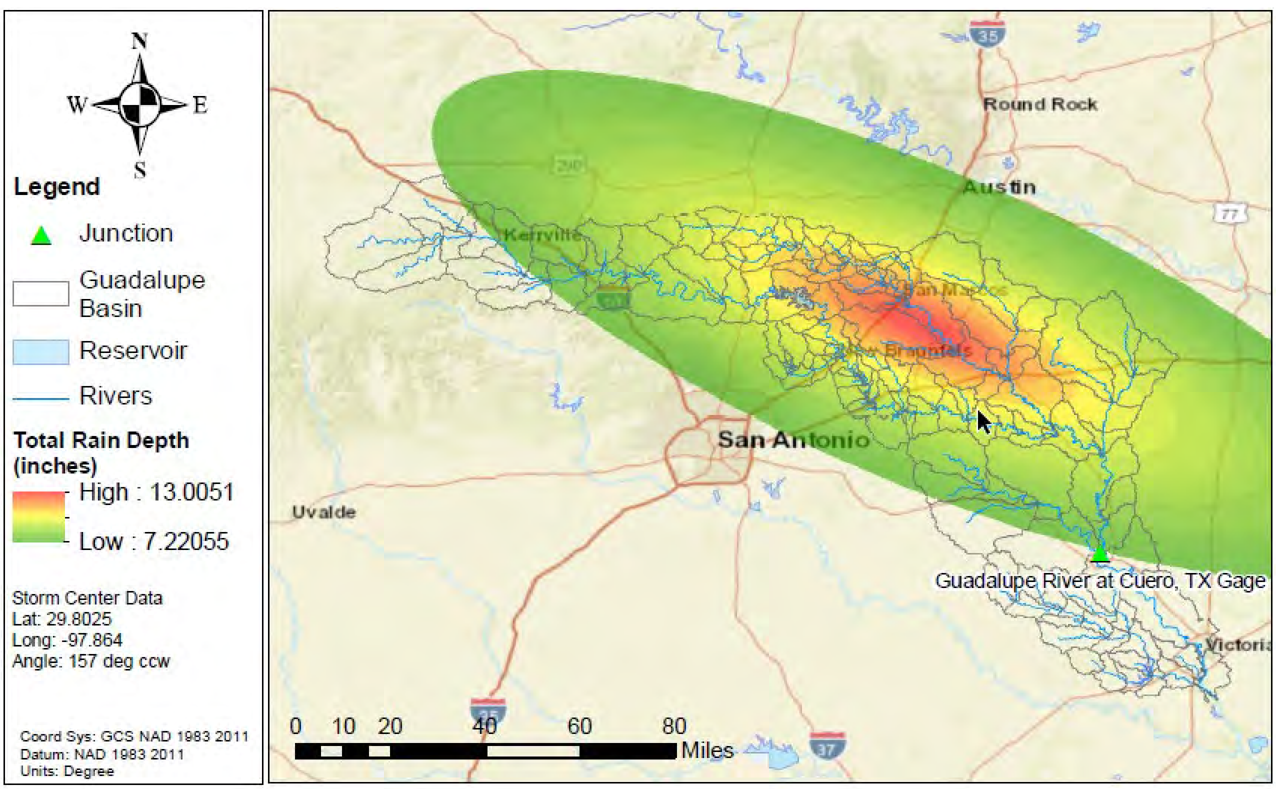


Figure 10.21: NOAA Atlas 14 1% ACE Elliptical Storm for the Guadalupe River at Cuero

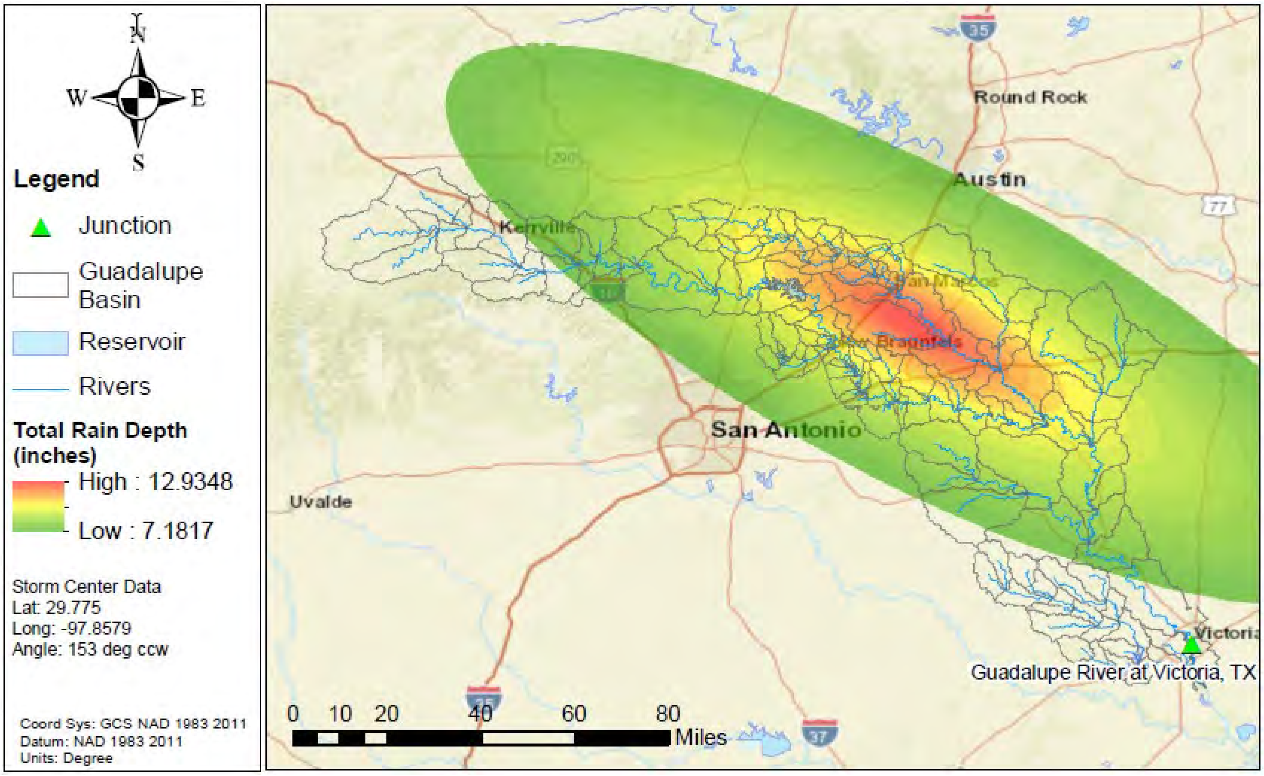


Figure 10.22: NOAA Atlas 14 1% ACE Elliptical Storm for the Guadalupe River at Victoria

10.3.4 NA14 Elliptical Frequency Storm Loss Rates

The NOAA Atlas 14 elliptical frequency storms were then applied to the same HEC-HMS basin model with the same frequency loss rates that were used for the uniform rainfall method described earlier in this chapter. In some cases, the 2-yr through 10-yr losses had to be re-adjusted to account for the elliptical storms' lower total volume and in order to maintain consistency with the frequent end of the statistical frequency curves at the USGS gages. This final adjustment was performed because of the increased level of confidence in the statistical frequency curve for the 2 through 10-yr recurrence intervals. The 25-yr losses were also adjusted when needed to create a smooth transition between the 50-yr to the 10-yr values. The final 2-yr through 25-yr loss rates used for the NOAA Atlas 14 elliptical frequency storm events are given in Table 10.4. The final 50-yr through 500-yr loss rates are the same as those used for the uniform rainfall method and can be seen in Table 10.2.

Table 10.4: Initial and Constant Losses for the 2-yr to 25-yr NA14 Elliptical Frequency Storms

Subbasin Name	2-yr	2-yr	5-yr	5-yr	10-yr	10-yr	25-yr	25-yr
	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)	Initial (in)	Constant (in/hr)
NF_Guad_S010	2.03	0.21	2.12	0.21	1.99	0.20	0.97	0.12
NF_Guad_S020	2.47	0.27	2.35	0.27	2.35	0.25	1.69	0.22
SF_Guad_S010	2.46	0.27	2.35	0.26	2.35	0.25	1.68	0.22
Guad_S010	1.91	0.28	2.47	0.28	1.90	0.24	1.27	0.13
JohnsonCr_S010	2.54	0.31	2.94	0.31	2.45	0.31	1.98	0.28
JohnsonCr_S020	1.79	0.28	2.46	0.28	1.74	0.24	1.26	0.13
Guad_S020	1.77	0.28	2.45	0.27	1.74	0.24	1.27	0.13
Guad_S030	1.80	0.22	1.74	0.20	1.64	0.17	1.55	0.14
TurtleCr_S010	1.67	0.22	1.44	0.19	1.23	0.17	1.05	0.14
Guad_S040	1.85	0.23	1.59	0.21	1.34	0.18	1.15	0.15
VerdeCr_S010	1.84	0.22	1.82	0.20	1.74	0.18	1.67	0.14
Guad_S050	1.79	0.23	1.56	0.20	1.34	0.18	1.17	0.14
CypressCr_GR_S010	1.70	0.22	1.47	0.20	1.25	0.17	1.07	0.14
Guad_S060	1.35	0.22	1.35	0.22	1.23	0.21	1.06	0.16
BlockCr_S010	1.27	0.21	1.27	0.21	1.17	0.21	1.00	0.15
Guad_S070	1.38	0.22	1.38	0.22	1.26	0.21	1.08	0.16
JoshuaCr_S010	1.28	0.21	1.28	0.21	1.18	0.21	1.01	0.15
Guad_S080	1.35	0.22	1.35	0.22	1.24	0.21	1.06	0.16
SisterCr_S010	1.28	0.21	1.28	0.21	1.18	0.21	1.00	0.15
Guad_S090	1.27	0.21	1.27	0.21	1.17	0.21	1.00	0.15
CurryCr_S010	1.28	0.21	1.28	0.21	1.18	0.21	1.00	0.15
Guad_S100	1.27	0.21	1.27	0.21	1.17	0.21	1.00	0.15
Guad_S110	1.56	0.21	1.38	0.16	1.21	0.14	1.05	0.12
Guad_S120	1.53	0.20	1.32	0.16	1.14	0.14	0.97	0.12
CanyonLk_S010	1.50	0.20	1.30	0.16	1.12	0.14	0.95	0.12
Blanco_S010	1.86	0.208	1.86	0.207	1.86	0.203	1.24	0.145
Blanco_S020	1.87	0.209	1.87	0.208	1.87	0.204	1.25	0.146
Blanco_S030	1.82	0.204	1.82	0.203	1.82	0.201	1.22	0.143
Blanco_S040	1.79	0.201	1.79	0.201	1.79	0.199	1.2	0.141
Blanco_S050	1.77	0.199	1.77	0.199	1.77	0.197	1.19	0.14
LittleBlanco_S010	1.88	0.21	1.88	0.208	1.88	0.204	1.25	0.146
LittleBlanco_S020	1.85	0.207	1.85	0.206	1.85	0.203	1.24	0.145
LittleBlanco_S030	1.78	0.2	1.78	0.2	1.78	0.198	1.2	0.141
LittleBlanco_S040	1.89	0.211	1.89	0.209	1.89	0.206	1.26	0.147
Blanco_S060	1.92	0.214	1.92	0.212	1.92	0.207	1.28	0.148
WanslowCr_BR_S010	1.92	0.214	1.92	0.211	1.92	0.207	1.27	0.148
Blanco_S070	1.9	0.212	1.9	0.21	1.9	0.206	1.27	0.147

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
Blanco_S080	1.88	0.21	1.88	0.209	1.88	0.205	1.26	0.146
CarpersCr_BR_S010	1.93	0.215	1.93	0.213	1.93	0.208	1.28	0.149
Blanco_S090	1.91	0.213	1.91	0.211	1.91	0.207	1.27	0.147
Blanco_S100	1.9	0.212	1.9	0.21	1.9	0.206	1.27	0.147
WilsonCr_BR_S010	1.93	0.215	1.93	0.212	1.93	0.208	1.28	0.148
Blanco_S110	1.91	0.213	1.91	0.211	1.91	0.206	1.27	0.147
CypressCr_BR_S010	1.92	0.214	1.92	0.212	1.92	0.207	1.28	0.148
CypressCr_BR_S020	1.93	0.215	1.93	0.212	1.93	0.208	1.28	0.148
CypressCr_BR_S030	1.91	0.213	1.91	0.211	1.91	0.207	1.27	0.148
Blanco_S120	1.86	0.214	1.83	0.212	1.32	0.208	1.28	0.148
Blanco_S130	1.87	0.215	1.84	0.213	1.32	0.208	1.28	0.149
LoneManCr_BR_S010	1.9	0.218	1.86	0.215	1.34	0.21	1.3	0.15
Blanco_S140	1.86	0.214	1.83	0.212	1.31	0.207	1.28	0.148
HalifaxCr_BR_S010	1.78	0.206	1.76	0.205	1.26	0.202	1.23	0.144
Blanco_S150	1.79	0.207	1.77	0.206	1.27	0.203	1.23	0.144
Blanco_S160	1.26	0.203	1.24	0.202	1.21	0.142	1.21	0.142
Blanco_S170	1.4	0.218	1.34	0.215	1.3	0.15	1.3	0.15
SinkCk_S010	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SinkCk_S020	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SinkCk_S030	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SinkCk_S040	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SanMarcos_S005	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
SanMarcos_S008	1.7	0.2	1.45	0.2	1.37	0.17	1.37	0.17
PurgatoryCr_S010	1	0.19	0.99	0.14	0.99	0.12	0.99	0.12
SanMarcos_S010	1.07	0.19	1.06	0.14	1.03	0.13	1.03	0.13
SanMarcos_S020	1.12	0.2	1.08	0.14	1.06	0.13	1.06	0.13
YorkCr_S010	1.48	0.27	1.47	0.19	1.44	0.18	1.44	0.18
SanMarcos_S030	1.18	0.2	1.12	0.14	1.1	0.13	1.1	0.13
SanMarcos_S040	1.58	0.21	1.45	0.17	1.36	0.16	1.17	0.14
PlumCr_S010	1.3	0.18	1.14	0.14	1.04	0.13	0.88	0.11
PlumCr_S020	1.36	0.19	1.19	0.14	1.08	0.13	0.92	0.11
TenneyCr_S010	1.53	0.21	1.32	0.16	1.18	0.14	1.02	0.12
PlumCr_S030	1.39	0.19	1.21	0.15	1.09	0.14	0.93	0.11
PlumCr_S040	1.61	0.21	1.31	0.16	1.17	0.14	1.01	0.12
SanMarcos_S050	1.71	0.22	1.47	0.17	1.37	0.17	1.18	0.14
DryComalCk_S010	1.03	0.10	1.03	0.10	1.03	0.10	1.26	0.15
DryComalCk_S020	0.99	0.09	0.99	0.09	0.99	0.09	1.17	0.14
WFk_DryComalCk_S010	1.04	0.10	1.04	0.10	1.04	0.10	1.28	0.15

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
WFk_DryComalCk_S020	1.00	0.10	1.00	0.10	1.00	0.10	1.19	0.14
WF_Trib_S010	1.03	0.10	1.03	0.10	1.03	0.10	1.25	0.15
WF_Trib_S020	0.99	0.09	0.99	0.09	0.99	0.09	1.16	0.14
WFk_DryComalCk_S030	1.02	0.10	1.02	0.10	1.02	0.10	1.22	0.14
DryComalCk_S030	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
BearCk_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
DryComalCk_S040	0.98	0.09	0.98	0.09	0.98	0.09	1.14	0.14
DCCk_Trib14_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.22	0.14
DryComalCk_S050	0.96	0.09	0.96	0.09	0.96	0.09	1.09	0.13
DryComalCk_S060	0.99	0.09	0.99	0.09	0.99	0.09	1.15	0.14
BliedersCk_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.22	0.14
Comal_S010	1.03	0.10	1.03	0.10	1.03	0.10	1.26	0.15
Comal_S020	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
Comal_S030	1.01	0.10	1.01	0.10	1.01	0.10	1.21	0.14
Guad_S130	0.90	0.08	0.90	0.08	0.90	0.08	0.95	0.12
BearCr_S010	0.90	0.08	0.90	0.08	0.90	0.08	0.95	0.12
Guad_S140	0.90	0.08	0.90	0.08	0.90	0.08	0.95	0.12
Guad_S142	0.96	0.09	0.96	0.09	0.96	0.09	1.10	0.13
Guad_S144	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
Guad_Trib22_S010	0.93	0.08	0.93	0.08	0.93	0.08	1.02	0.13
Guad_S145	1.04	0.10	1.04	0.10	1.04	0.10	1.26	0.15
LongCk_S010	0.92	0.08	0.92	0.08	0.92	0.08	0.99	0.12
Guad_S147	1.01	0.10	1.01	0.10	1.01	0.10	1.21	0.14
Guad_Trib20_S010	0.93	0.08	0.93	0.08	0.93	0.08	1.03	0.13
Guad_S149	1.00	0.09	1.00	0.09	1.00	0.09	1.17	0.14
Guad_S152	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
YoungsCk_S010	0.91	0.08	0.91	0.08	0.91	0.08	0.97	0.12
Guad_S154	0.99	0.09	0.99	0.09	0.99	0.09	1.15	0.14
CottonwoodCkS_S010	0.90	0.08	0.90	0.08	0.90	0.08	0.96	0.12
Guad_S156	1.01	0.10	1.01	0.10	1.01	0.10	1.21	0.14
Little_MillCk_S010	0.94	0.08	0.94	0.08	0.94	0.08	1.05	0.13
Guad_S158	0.98	0.09	0.98	0.09	0.98	0.09	1.14	0.14
DeadmanCk_S010	0.92	0.08	0.92	0.08	0.92	0.08	1.00	0.12
Guad_S160	0.97	0.09	0.97	0.09	0.97	0.09	1.11	0.13
CottonwoodCk_S010	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
Guad_S162	1.03	0.10	1.03	0.10	1.03	0.10	1.25	0.15
AlligatorCk_S010	0.99	0.09	0.99	0.09	0.99	0.09	1.17	0.14
GeronimoCk_S010	0.91	0.08	0.91	0.08	0.91	0.08	0.97	0.12

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
GeronimoCk_S020	0.92	0.08	0.92	0.08	0.92	0.08	0.98	0.12
GeronimoCk_S030	0.96	0.09	0.96	0.09	0.96	0.09	1.09	0.13
Guad_S164	1.00	0.10	1.00	0.10	1.00	0.10	1.19	0.14
CantauCk_S010	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
Guad_S166	1.04	0.10	1.04	0.10	1.04	0.10	1.28	0.15
MillCk_S010	1.01	0.09	1.01	0.09	1.01	0.09	1.16	0.14
Guad_S168	1.24	0.10	1.24	0.10	1.24	0.10	1.46	0.15
NashCk_S010	1.04	0.10	1.04	0.10	1.04	0.10	1.27	0.15
Guad_S170	1.03	0.10	1.03	0.10	1.03	0.10	1.25	0.15
Guad_S172	1.00	0.10	1.00	0.10	1.00	0.10	1.19	0.14
Guad_S174	0.98	0.09	0.98	0.09	0.98	0.09	1.14	0.14
Guad_S176	1.02	0.10	1.02	0.10	1.02	0.10	1.23	0.14
Guad_S200	1.17	0.09	1.17	0.18	1.17	0.18	1.30	0.13
PeachCr_S010	1.44	0.20	1.28	0.19	1.28	0.17	1.13	0.12
BigFiveMileCr_S010	1.30	0.19	1.18	0.17	1.18	0.16	1.03	0.11
PeachCr_S020	1.25	0.18	1.12	0.17	1.12	0.16	0.97	0.11
SandyFork_S010	1.52	0.21	1.27	0.19	1.27	0.17	1.12	0.13
PeachCr_S030	1.30	0.19	1.16	0.17	1.16	0.16	1.01	0.11
PeachCr_S040	0.97	0.09	0.97	0.18	0.97	0.14	1.10	0.13
Guad_S210	1.01	0.10	1.01	0.19	1.01	0.15	1.19	0.14
McCoyCr_S010	1.01	0.10	1.01	0.20	1.01	0.15	1.20	0.14
Guad_S220	1.44	0.10	1.44	0.20	1.44	0.15	1.80	0.14
SandiesCr_S010	2.00	0.26	1.60	0.21	1.40	0.16	1.10	0.13
ClearForkCr_S010	1.82	0.24	1.50	0.19	1.35	0.15	1.08	0.12
SandiesCr_S020	1.81	0.24	1.48	0.19	1.31	0.15	1.04	0.12
ElmCr_S010	1.71	0.23	1.45	0.18	1.30	0.14	1.05	0.11
SandiesCr_S030	1.69	0.23	1.40	0.18	1.22	0.14	0.97	0.11
SandiesCr_S040	1.07	0.10	1.07	0.20	1.07	0.15	1.28	0.14
Guad_S230	1.12	0.11	1.12	0.21	1.12	0.16	1.37	0.15
Guad_S240	1.02	0.10	1.02	0.20	1.02	0.15	1.23	0.14
DryCk_S010	1.22	0.20	1.22	0.19	1.36	0.16	1.17	0.14
SmithCk_S010	1.86	0.25	1.86	0.24	1.76	0.21	1.22	0.14
ThomasCk_S010	1.91	0.25	1.91	0.24	1.79	0.21	1.25	0.15
SmithCk_S020	1.89	0.25	1.89	0.24	1.78	0.21	1.24	0.14
YorktownCk_S010	1.83	0.24	1.83	0.24	1.74	0.21	1.20	0.14
YorktownCk_S020	1.92	0.25	1.91	0.24	1.80	0.21	1.25	0.15
FifteenmileCk_S010	1.89	0.25	1.89	0.24	1.78	0.21	1.24	0.14
HoosierCk_S010	1.91	0.25	1.91	0.24	1.79	0.21	1.25	0.15

Subbasin Name	2-yr Initial (in)	2-yr Constant (in/hr)	5-yr Initial (in)	5-yr Constant (in/hr)	10-yr Initial (in)	10-yr Constant (in/hr)	25-yr Initial (in)	25-yr Constant (in/hr)
FifteenmileCk_S020	1.34	0.26	1.33	0.25	1.32	0.16	1.28	0.15
EighteenmileCk_S010	1.31	0.25	1.29	0.24	1.29	0.15	1.25	0.15
FifteenmileCk_S030	1.32	0.25	1.30	0.24	1.30	0.15	1.26	0.15
TwelvemileCk_S010	1.33	0.25	1.31	0.24	1.30	0.16	1.27	0.15
FivemileCk_S010	1.36	0.26	1.35	0.25	1.33	0.16	1.29	0.15
TwelvemileCk_S020	1.37	0.26	1.36	0.25	1.34	0.16	1.30	0.15
ColetoCk_S010	1.26	0.21	1.26	0.20	1.25	0.17	1.21	0.14
ColetoCk_S020	1.25	0.21	1.25	0.20	1.24	0.17	1.20	0.14
PerdidoCk_S010	1.82	0.25	1.82	0.25	1.81	0.19	1.25	0.15
PerdidoCk_S020	1.27	0.20	1.27	0.20	1.26	0.17	1.21	0.14
PerdidoCk_S030	1.22	0.20	1.22	0.19	1.21	0.16	1.17	0.14
ColetoCk_S030	1.18	0.19	1.18	0.19	1.17	0.16	1.13	0.14
ColetoCk_S040	1.24	0.20	1.24	0.19	1.23	0.17	1.19	0.14
Guad_S250	1.17	0.19	1.17	0.19	1.16	0.16	1.13	0.14

10.3.5 NOAA Atlas 14 Elliptical Frequency Storm Results

The frequency peak flow values were then calculated in HEC-HMS by applying the appropriate elliptical frequency storm to the final HEC-HMS basin model with the appropriate loss rates. The final HEC-HMS frequency flows for the calculated locations throughout the watershed model can be seen in Table 10.5. These results will later be compared to the uniform rain results from HEC-HMS along with other methods from this study.

In some cases, one may observe that the simulated peak discharge decreases in the downstream direction. It is not an uncommon phenomenon to see decreasing frequency peak discharges for some river reaches as flood waters spread out into the floodplain and the hydrograph becomes dampened as it moves downstream. This can be due to a combination of peak attenuation due to river routing as well as the difference in timing between the peak of the main stem river versus the runoff from the local tributaries and subbasins.

Table 10.5: Summary of Discharges (cfs) from HEC-HMS with the NOAA Atlas 14 Elliptical Frequency Storms

Location Description	HEC-HMS Element Name	Drainage Area sq mi	50% 2-YR	20% 5-YR	10% 10-YR	4% 25-YR	2% 50-YR	1% 100-YR	0.50% 200-YR	0.20% 500-YR
Guadalupe River below Johnson Creek	GUAD+JOHNSONCR	438.14	1,700	20,200	46,600	109,100	166,800	211,100	255,800	318,500
Guadalupe River at Kerrville (USGS Gage)	GUAD_AT_KERRVILLE	485.67	4,100	21,100	46,400	111,000	169,400	215,300	261,400	325,800
Guadalupe River above Turtle Ck	GUAD_ABV_TURTLECR	563.83	4,600	23,700	49,700	114,000	174,300	223,900	272,900	341,500
Guadalupe River below Turtle Ck	GUAD+TURTLECR	634.31	9,900	36,300	64,300	130,100	196,000	252,100	307,900	386,200
Guadalupe River above Verde Creek	GUAD_ABV_VERDECR	652.44	11,000	37,300	66,500	134,100	201,300	259,400	317,600	399,800
Guadalupe River below Verde Creek	GUAD+VERDECR	708.60	10,100	38,000	66,800	131,500	198,000	256,300	314,400	395,200
Guadalupe River above Cypress Creek	GUAD_ABV_CYPRESSCR	763.48	9,000	35,200	62,700	126,100	190,500	248,200	305,300	385,200
Guadalupe River below Cypress Creek	GUAD+CYPRESSCR	836.97	11,800	41,200	70,500	133,200	201,000	263,900	325,800	412,000
Guadalupe River above Block Ck	GUAD_ABV_BLOCKCR	865.07	15,200	47,100	78,800	144,700	216,300	284,400	351,700	446,600
Guadalupe River below Block Ck	GUAD+BLOCKCR	909.72	11,600	40,500	69,200	131,800	198,400	260,600	322,500	409,200
Guadalupe River above Joshua Ck	GUAD_ABV_JOSHUACR	929.67	11,500	40,100	69,500	131,100	197,000	259,600	322,100	409,800
Guadalupe River below Joshua Ck	GUAD+JOSHUACR	971.33	11,800	40,300	69,600	131,100	196,500	258,800	320,200	407,000
Guadalupe River above Sister Ck	GUAD_ABV_SISTERCR	983.91	12,100	40,900	70,500	132,100	197,700	260,300	322,700	410,400
Guadalupe River below Sister Ck	GUAD+SISTERCR	1048.21	12,100	41,200	71,000	133,100	198,900	261,900	324,700	412,800
Guadalupe River above Curry Ck	GUAD_ABV_CURRYCR	1197.22	10,200	35,800	62,500	116,200	172,700	228,700	285,100	364,000
Guadalupe River below Curry Ck	GUAD+CURRYCR	1266.37	11,200	37,800	65,500	120,900	179,200	237,300	295,800	378,100
Guadalupe River near Springbranch	GUAD_NR_SPRINGBRANCH	1313.74	11,100	37,700	65,200	120,100	177,900	235,800	294,000	375,800
Guadalupe River above Canyon Lake	GUAD_ABV_CANYONLK	1360.02	10,900	37,300	64,700	119,200	176,300	233,600	291,200	372,300
Guadalupe River inflow to Canyon Lake	CANYON_INFLOW	1431.05	11,500	38,400	66,300	121,800	179,800	238,700	297,500	380,300
Guadalupe River Outflow to Canyon Lake	CANYON_DAM_OUTFLOW	1431.05	2,100	10,300	12,000	12,000	30,500	96,400	168,300	263,600
Blanco River at Wimberley (USGS Gage)	BLANCO+CYPRESSCR	355.07	8,000	28,100	54,700	110,900	151,400	200,300	248,700	319,600
Blanco River above Lone Man Creek	BLANCO_ABV_LONEMANCR	370.50	7,900	28,100	54,500	110,700	150,800	199,700	249,800	321,400
Blanco River below Lone Man Creek	BLANCO+LONEMANCR	382.87	7,900	28,300	55,000	111,700	152,400	202,300	253,200	326,100
Blanco River above Halifax Creek	BLANCO_ABV_HALIFAXCR	392.72	7,600	27,700	54,200	110,600	151,000	201,000	252,300	325,000

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
Blanco River below Halifax Creek	BLANCO+HALIFAXCR	405.64	7,700	27,900	54,600	111,500	152,400	203,300	255,300	329,100
Blanco River near Kyle (USGS Gage)	BLANCO_NR_KYLE_GAGE	412.28	7,900	28,200	55,100	112,000	153,500	206,100	258,800	333,500
Blanco River at I-35 Bridge near San Marcos	BLANCO_AT_I-35	432.67	7,600	27,100	53,100	106,300	145,900	201,600	255,400	331,000
Blanco River above San Marcos River	BLANCO_ABV_SANMARCOS	436.24	7,000	26,300	49,600	101,700	141,600	194,100	245,300	319,600
San Marcos River below Blanco River	SANMARCOS+BLANCO	531.30	8,700	29,400	54,200	108,700	153,300	216,700	273,500	358,800
San Marcos River above York Creek	SANMARCOS_J040	613.63	8,500	26,700	50,600	98,000	135,600	191,600	259,300	344,000
San Marcos River below York Creek	SANMARCOS+YORKCR	756.55	9,000	28,500	54,100	102,800	142,800	204,200	278,700	371,400
San Marcos River at Luling (USGS Gage)	SANMARCOS_AT_LULING	838.93	8,900	27,500	52,600	100,600	140,700	201,900	274,700	370,400
San Marcos Rivere above Plum Creek	SANMARCOS_J070	861.82	7,800	24,600	48,600	94,400	132,800	188,000	258,900	355,700
Plum Creek near Luling (USGS Gage)	PLUMCR_NR_LULING	351.49	5,600	18,900	33,600	57,100	77,100	108,700	146,000	202,300
Plum Creek above San Marcos River	PLUMCR_J050	388.83	5,600	17,300	30,500	53,800	75,500	106,300	142,100	198,400
San Marcos River below Plum Creek	SANMARCOS+PLUMCR	1250.65	12,000	38,200	71,000	130,700	183,100	262,900	366,000	497,200
San Marcos River above Guadalupe River	SANMARCOS_J090	1359.02	10,500	30,400	58,400	114,000	165,400	238,000	325,600	451,300
	NOTE - The below Drainage Areas for the Guadalupe River do not include the area above Canyon Dam.									
Guadalupe River below Geronimo Ck	Guad+GeronimoCk	439.21	29,900	51,300	66,800	82,200	103,600	135,400	172,200	224,800
Guadalupe River above Cantau Ck	Guad_abv_CantauCk	443.48	28,300	50,400	66,000	81,400	102,800	134,100	170,200	222,400
Guadalupe River near Seguin (USGS Gage)	Guad_nr_Seguin	450.12	28,400	50,500	66,300	81,700	103,100	134,600	171,000	223,500
Guadalupe River above Mill Ck	Guad_abv_MillCk	481.81	23,300	46,200	63,100	79,300	102,000	133,800	170,800	225,200
Guadalupe River below Mill Ck	Guad+MillCk	521.23	24,400	48,100	66,100	83,200	107,600	141,500	181,200	239,300
Guadalupe River above Nash Ck	Guad_abv_NashCk	553.73	20,500	44,000	63,000	80,500	105,900	140,700	181,700	241,700
Guadalupe River below Nash Ck	Guad+NashCk	580.24	20,600	44,400	63,600	81,300	107,100	143,000	185,200	247,100
Guadalupe River at Lake Gonzales	Lake_Gonzales	615.95	18,000	38,700	58,200	78,400	106,300	144,800	189,900	255,800
Guadalupe River at Wood Lake	Wood_Lake	667.37	15,300	31,000	48,000	68,100	97,900	137,600	184,900	254,500
Guadalupe River at Gonzales (USGS Gage)	Guad+SanMarcos	2030.79	17,500	50,300	88,900	158,800	236,700	338,800	460,700	625,500
Guadalupe River above Peach Creek	Guad_J360	2100.31	16,100	47,000	83,900	152,200	229,600	333,300	456,000	622,100
Guadalupe River below Peach Creek	Guad+PeachCr	2582.81	16,400	50,200	93,300	173,100	259,100	378,600	522,500	718,600

Location Description	HEC-HMS Element Name	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%
		sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR
Guadalupe River above McCoy Creek	Guad_J380	2705.18	15,300	47,500	87,900	165,500	248,800	367,100	507,200	700,800
Guadalupe River below McCoy Creek	Guad+McCoyCr	2737.77	15,400	47,600	88,200	165,900	249,300	367,700	507,900	701,600
Guadalupe River above Sandies Creek	Guad_J400	2786.21	15,100	44,300	81,000	154,600	236,600	354,800	495,100	689,100
Guadalupe River at Cuero (USGS Gage)	Guad+SandiesCr	3497.36	15,100	45,900	88,500	173,000	264,600	401,500	563,000	787,100
Guadalupe River at Victoria (USGS Gage)	Guad_at_Victoria	3767.11	14,800	41,600	76,300	153,200	240,400	372,100	533,500	764,400
Guadalupe River above Coleto Creek	Guad_abv_ColetoCk	3802.65	14,200	41,400	75,600	148,900	236,700	361,900	522,600	760,700
Guadalupe River near Bloomington TX	GuadalupeRv_BloomingtonTX	4382.46	14,100	41,500	75,700	148,600	236,400	365,000	526,900	770,500
Peach Creek below Dilworth (USGS Gage)	PeachCr_bl_Dilworth	459.76	6,100	16,700	27,100	48,900	64,700	89,900	115,600	153,500
Peach Creek above Guadalupe River	PeachCr_J060	482.50	5,700	15,500	24,600	46,500	61,900	86,100	112,100	150,100
Sandies Creek near Westhoff (USGS Gage)	SandiesCr_nr_Westhof	549.35	3,600	12,500	23,400	43,400	58,900	84,600	110,500	152,400
Sandies Creek above Guadalupe River	SANDIESCK_ABV_GUAD	711.14	4,000	10,800	20,300	37,500	50,800	74,000	99,600	151,100
Coleto Creek Reservoir near Victoria TX	ColetoCkRes_VictoriaTX	494.06	9,600	26,400	44,200	68,300	90,000	116,600	142,500	178,400
Coleto Creek near Victoria TX (USGS Gage)	COLETOCK_VICTORIATX	511.28	9,700	26,500	44,300	68,400	90,200	117,100	143,400	179,500
Coleto Creek above Guadalupe River	COLETOCK_ABV_GUADALUPE	540.41	6,800	20,400	38,500	62,600	85,000	111,600	138,600	176,700

10.4 COMPARISON OF HEC-HMS RESULTS FROM NOAA ATLAS 14 VERSUS THE 2004 USGS RAINFALL DEPTHS

Figures 10.23 and 10.24 illustrate the increases in the 100-yr peak discharges from HEC-HMS due to the increased rainfall depths from NOAA Atlas 14 when compared to the previous HEC-HMS runs with the 2004 USGS Rainfall depths. The corresponding NOAA Atlas 14 100-yr, 24-hr rainfall depths for the Guadalupe River basin are shown in Figure 10.25.

For the Guadalupe River above Canyon Lake, the increases were moderate, generally varying from less than 10% upstream of Kerrville to about 20% near Canyon Lake. The peak discharges on the upper Guadalupe River are generally being driven by an area in the headwaters of the basin where the NOAA Atlas 14 100-yr rainfall depths were more moderate, varying from 10.7 inches to 12.0 inches, as shown in Figure 10.25.

For the Blanco and San Marcos River, the increases in the 100-yr discharge were quite large, varying from 30% to 50% in the downstream direction. These increases in flow are being driven by the area with the largest increases in rainfall in Guadalupe Basin, near Wimberley and San Marcos, Texas as shown in Figure 10.25.

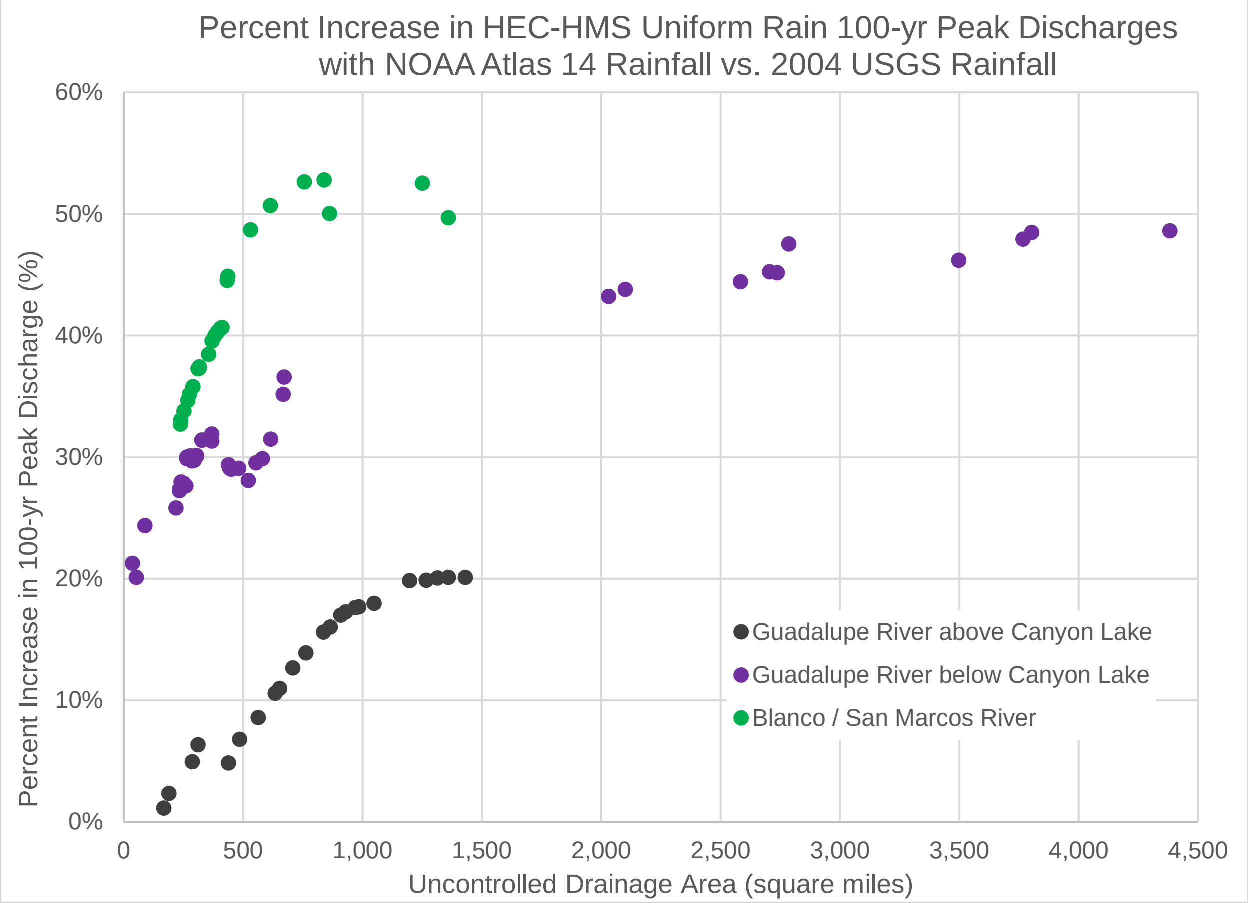


Figure 10.23: Increase in the HEC-HMS Uniform Rain 100-yr Discharges from NOAA Atlas 14

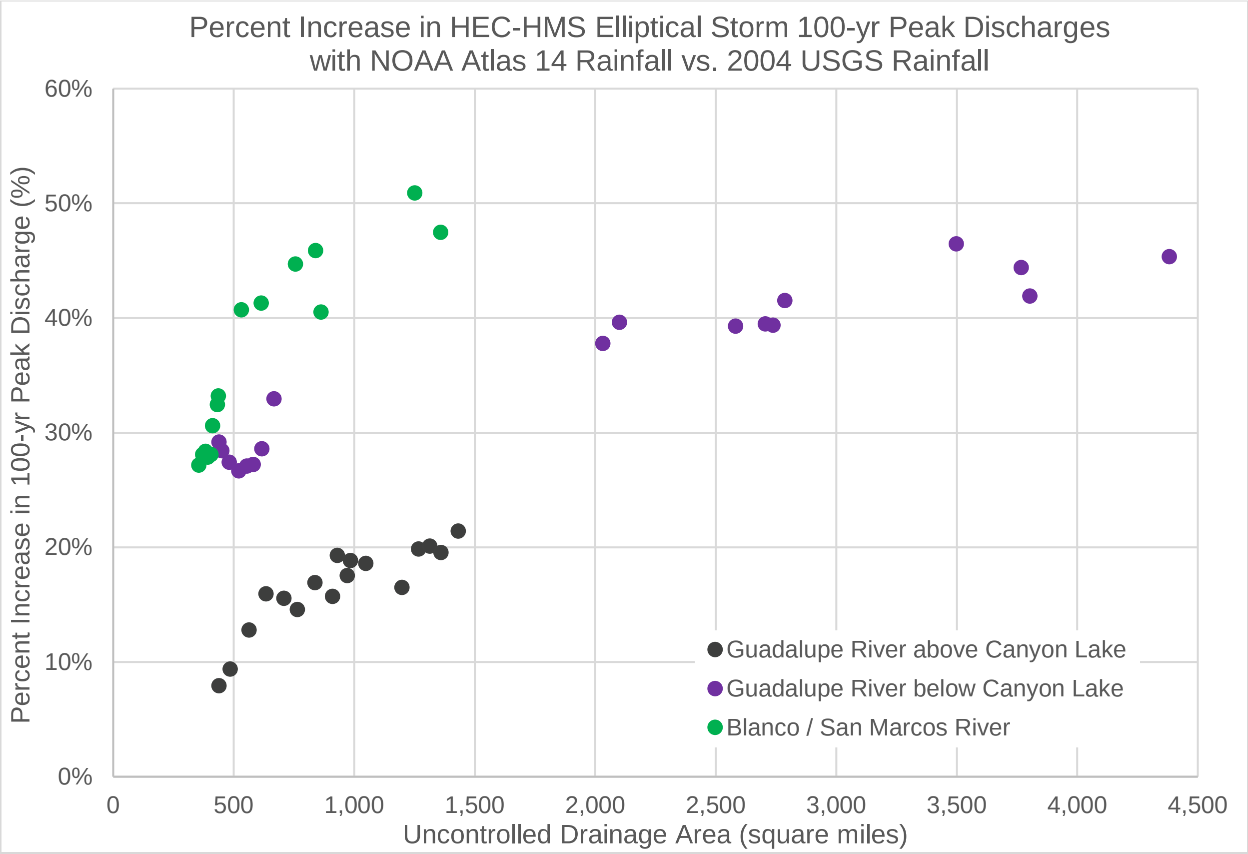


Figure 10.24: Increase in the HEC-HMS Elliptical Storm 100-yr Discharges from NOAA Atlas 14

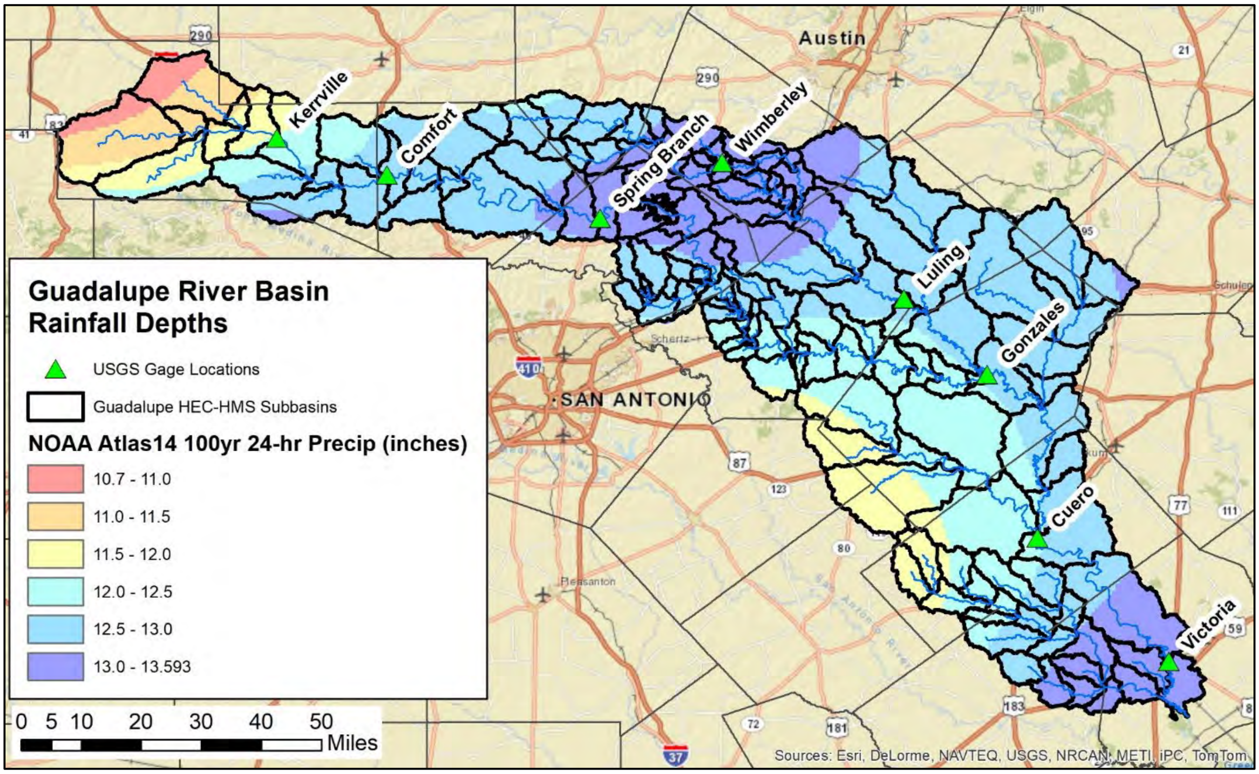


Figure 10.25: 100-yr, 24-hour Rainfall Depths in the Guadalupe River Basin from NOAA Atlas 14

For the Guadalupe River below Canyon Lake, the increases in flow vary from 20% to 35% between Canyon Dam and the San Marcos River. Then, below the San Marcos River, they increase by 40% to 48%. Those larger peak discharges on the Guadalupe River below the San Marcos River are driven by storm center locations near San Marcos, Texas with large increases in rainfall, as was shown in Figure 10.14. This is a critical area that drives peak discharges for a long distance downstream in both the uniform rain and elliptical storm methods.

Additional comparisons of the NOAA Atlas 14 HEC-HMS results with other hydrologic methods will be shown in Chapter 11.

11 Comparison of Frequency Flow Estimates

After completing the hydrologic analyses by all the various methods described in this report, their results were compared to one another in terms of frequency peak discharge estimates at the USGS stream gage locations. These comparisons of frequency flow estimates are given in Tables 11.1 to 11.25. Figures 11.1 through 11.25 plot the estimated frequency curves at each gage along with their confidence limits and the previous published discharges from the effective FEMA Flood Insurance Studies (FIS).

For the first two gages at the headwaters of the Guadalupe basin, the North Fork Guadalupe River near Hunt and the Guadalupe River River at Hunt (Tables and Figures 11.1 and 11.2), no existing FIS flows were available. The statistical record at these gages is of medium length with about 50 years of record, so there is still a fair amount of uncertainty in the 1% (100-yr) estimates. However, the results of the 2016 statistical analysis and the calibrated HEC-MHS watershed model with both sets of rainfall data showed a high level of agreement with each other at these locations. In this area of the watershed, which is at the headwaters of the basin, there was not much difference in the NOAA Atlas 14 rainfall values from the previous 2004 USGS rainfall values.

For Johnson Creek near Ingram (Table and Figure 11.3), the existing FIS flows are significantly lower than both the statistical and the HEC-HMS watershed modeling results at the 50-yr and 100-yr recurrence intervals. The statistical curves and the HEC-HMS watershed modeling results agree with one another for the more common (2-yr through 50-yr) events, but then the statistical curves trend significantly higher than the watershed model for the 100-yr and 500-yr recurrence internals. With only 114 square miles of drainage area, the 0.2% (500-yr) results from the watershed model seem more reasonable than the statistical results, which exceed 440,000 cfs at this site. Once again, the NOAA Atlas 14 rainfall values made very little difference in the results from the previous rainfall estimates.

For the Guadalupe River at Kerrville (Table and Figure 11.4), the existing FIS flows are very close to the calibrated HEC-HMS watershed modeling results. In this case, the NOAA Atlas 14 rainfall values resulted in a small increase in the HEC-HMS results. The statistical results at this location have higher 100-yr and 500-yr estimates, but with only 30-years of record at this site, not much confidence can be put into the statistical estimates beyond the 10-yr or 25-yr recurrence interval. Of the HEC-HMS results, the elliptical storm yielded slightly lower discharges than the uniform rain method, probably due to the slightly lower total rainfall volume in the elliptical storm.

Continuing downstream to the Guadalupe River at Comfort (Table and Figure 11.5), the existing 1% (100-yr) FIS flow is slightly higher than the calibrated HEC-HMS watershed modeling results with the 2004 USGS rainfall, but once the NOAA Atlas 14 rainfall estimates were incorporated, the 1% flows rose slightly higher than the existing FIS flow. With 82 years of record, this is a fairly long record gage, and the HEC-HMS NOAA Atlas 14 elliptical storm results follow closely with the statistical curve without historic information through the 1% discharge. Once again, the elliptical storms yielded slightly lower discharges than the uniform rain method in HEC-HMS.

At the Guadalupe River near Spring Branch (Table and Figure 11.6), the existing FIS flows are significantly lower than the statistical and all of the HEC-HMS watershed modeling results. With 94 years of record, Spring Branch is one of the longest record gages in the watershed, which means there is a higher level of confidence in the statistical results, relative to other gages. Both the statistical and the watershed model results indicate a decrease in frequency peak flows between Comfort and Spring Branch. This decrease in peak flow was also observed in several of the observed calibration flood events and is primarily due to river routing, as most of the large observed floods originate higher up in the watershed and are routed downstream with no major intervening tributaries. Spring Branch is also far enough downstream that the NOAA Atlas 14 rainfall values are beginning to show a larger difference in the flow estimates. The HEC-HMS elliptical storm frequency curves are slightly lower than their respective uniform rain results.

Table 11.1: Frequency Flow Results Comparison for the North Fork Guadalupe River near Hunt

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis (cfs)	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500		149,200	153,100	152,400
0.004	200*		129,400	129,100	126,300
0.01	100		111,600	106,600	107,800
0.02	50		91,480	87,100	88,900
0.04	25		69,740	71,400	69,900
0.1	10		40,610	41,700	39,800
0.2	5		21,000	22,200	20,800
0.5	2		3,692	4,500	3,800

*2004 USGS reports 250-yr

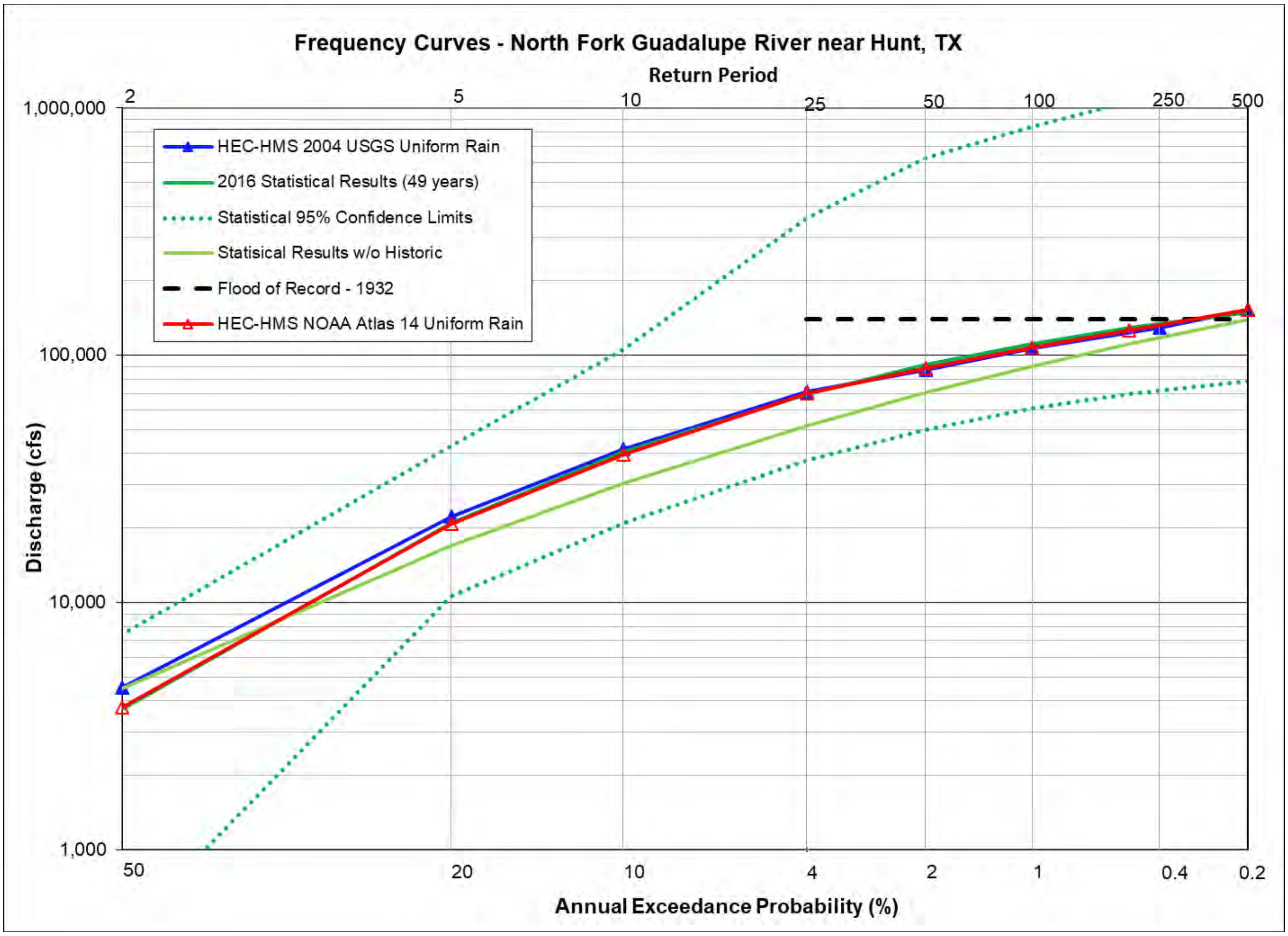


Figure 11.1: Flow Frequency Curve Comparison for the North Fork Guadalupe River near Hunt

Table 11.2: Frequency Flow Results Comparison for the Guadalupe River at Hunt

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500		236,300	229,900	240,200
0.004	200*		194,300	193,400	197,500
0.01	100		160,900	159,500	167,400
0.02	50		127,000	129,400	136,500
0.04	25		93,650	97,400	99,500
0.1	10		53,310	55,800	57,200
0.2	5		28,110	28,400	31,700
0.5	2		5,916	5,900	6,200

*2004 USGS reports 250-yr

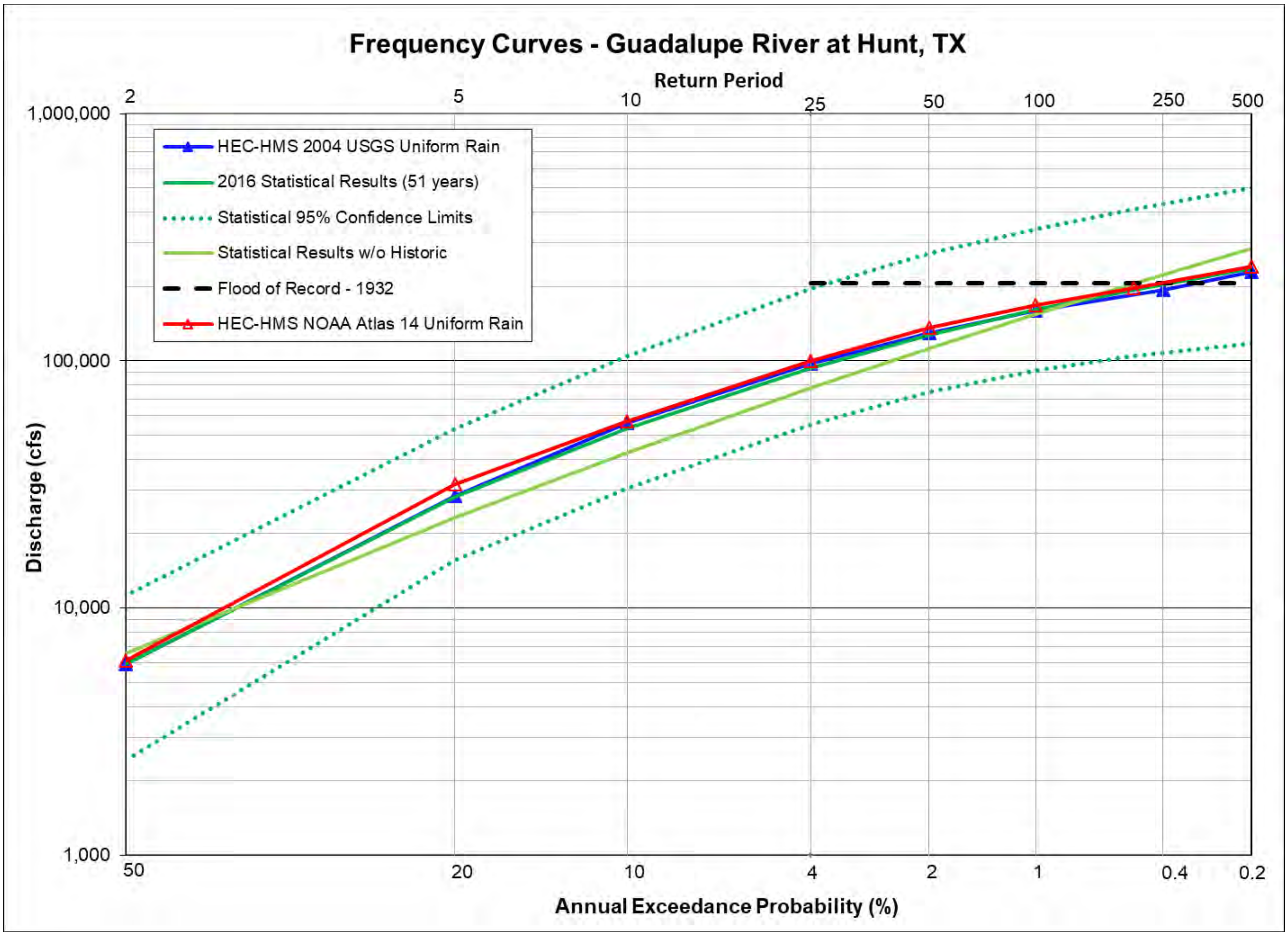


Figure 11.2: Flow Frequency Curve Comparison for the Guadalupe River at Hunt

Table 11.3: Frequency Flow Results Comparison for Johnson Creek near Ingram

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500	167,000	440200	156,100	143,600
0.004	200*		243300	133,200	121,100
0.01	100	85,800	148900	110,300	105,200
0.02	50	60,700	86890	91,900	89,100
0.04	25		47630	60,800	60,700
0.1	10	23,700	18690	23,800	24,900
0.2	5		7733	7,800	8,000
0.5	2		1408	1,300	1,400

*2004 USGS reports 250-yr

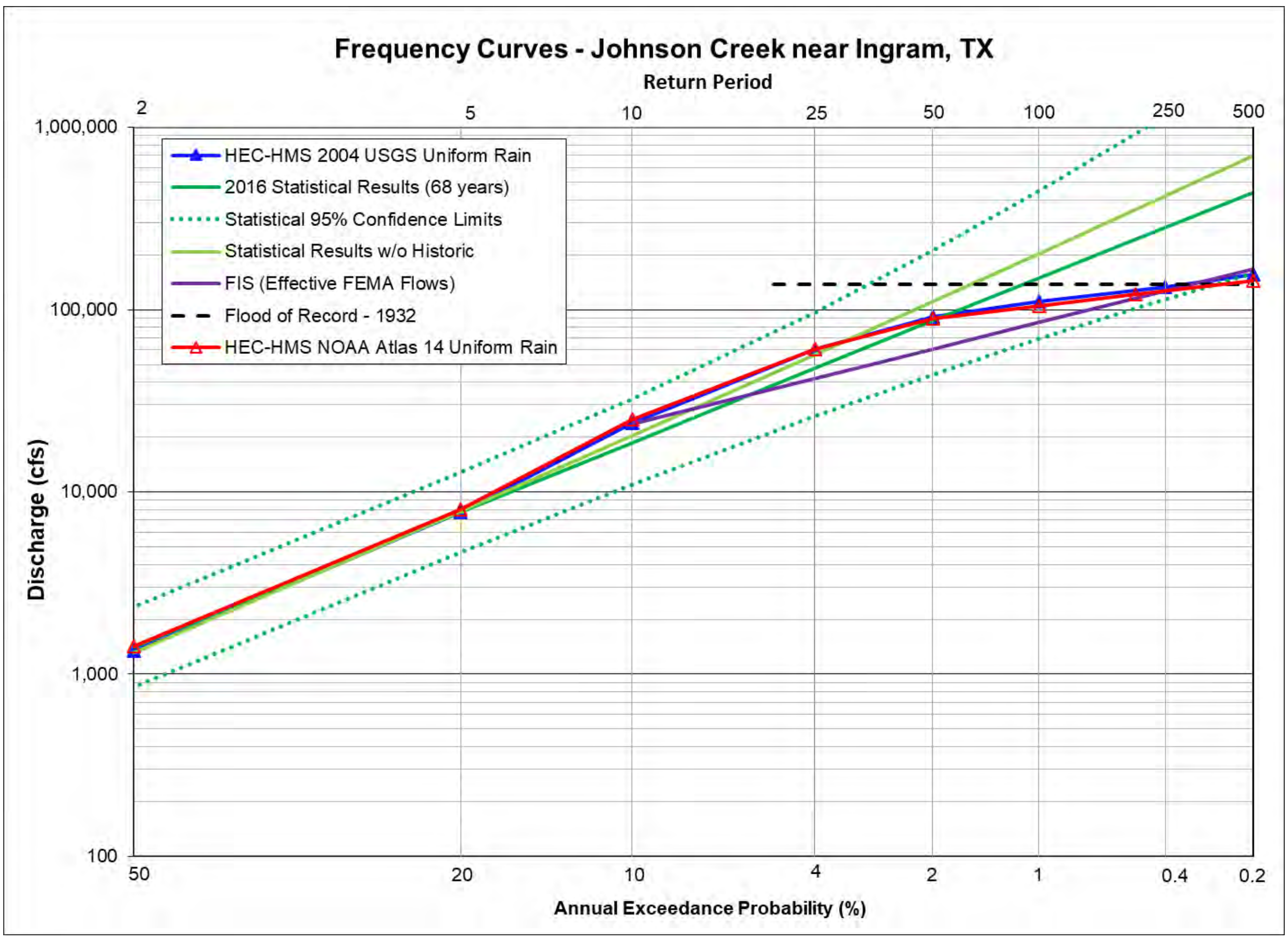


Figure 11.3: Flow Frequency Curve Comparison for Johnson Creek near Ingram

Table 11.4: Frequency Flow Results Comparison for the Guadalupe River at Kerrville

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	360,000	620,900	308,000	281,800	331,600	325,800
0.004	200*		393,000	257,400	236,700	269,400	261,400
0.01	100	215,000	266,500	211,200	196,800	225,500	215,300
0.02	50	163,000	172,200	168,700	156,300	180,400	169,400
0.04	25		104,400	115,700	108,500	120,100	111,000
0.1	10	67,200	46,700	59,000	55,600	55,200	46,400
0.2	5		21,200	26,500	24,600	28,700	21,100
0.5	2		4,255	5,200	4,500	5,400	4,100

*2004 USGS reports 250-yr

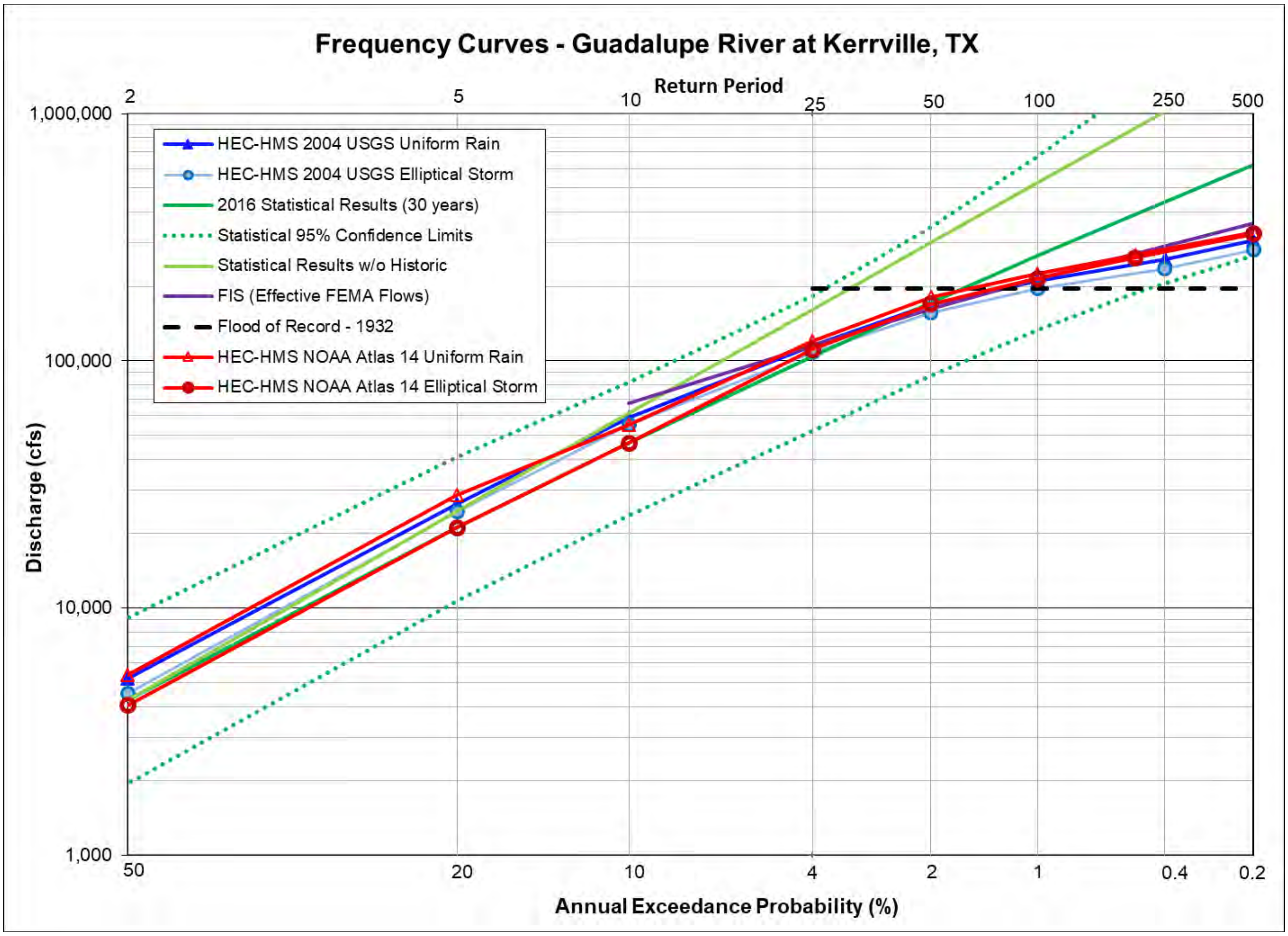


Figure 11.4: Flow Frequency Curve Comparison for the Guadalupe River at Kerrville

Table 11.5: Frequency Flow Results Comparison for the Guadalupe River at Comfort

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	563,500	267,300	364,100	332,800	435,900	412,000
0.004	200*		232,300	301,700	276,100	346,700	325,800
0.01	100	247,600	201,900	245,400	225,700	283,700	263,900
0.02	50	166,800	168,300	189,900	172,900	219,300	201,000
0.04	25		132,300	131,100	119,400	146,800	133,200
0.1	10	56,800	83,380	78,000	71,100	82,100	70,500
0.2	5		48,430	44,400	41,900	47,700	41,200
0.5	2		12,230	13,200	13,300	12,700	11,800

*2004 USGS reports 250-yr

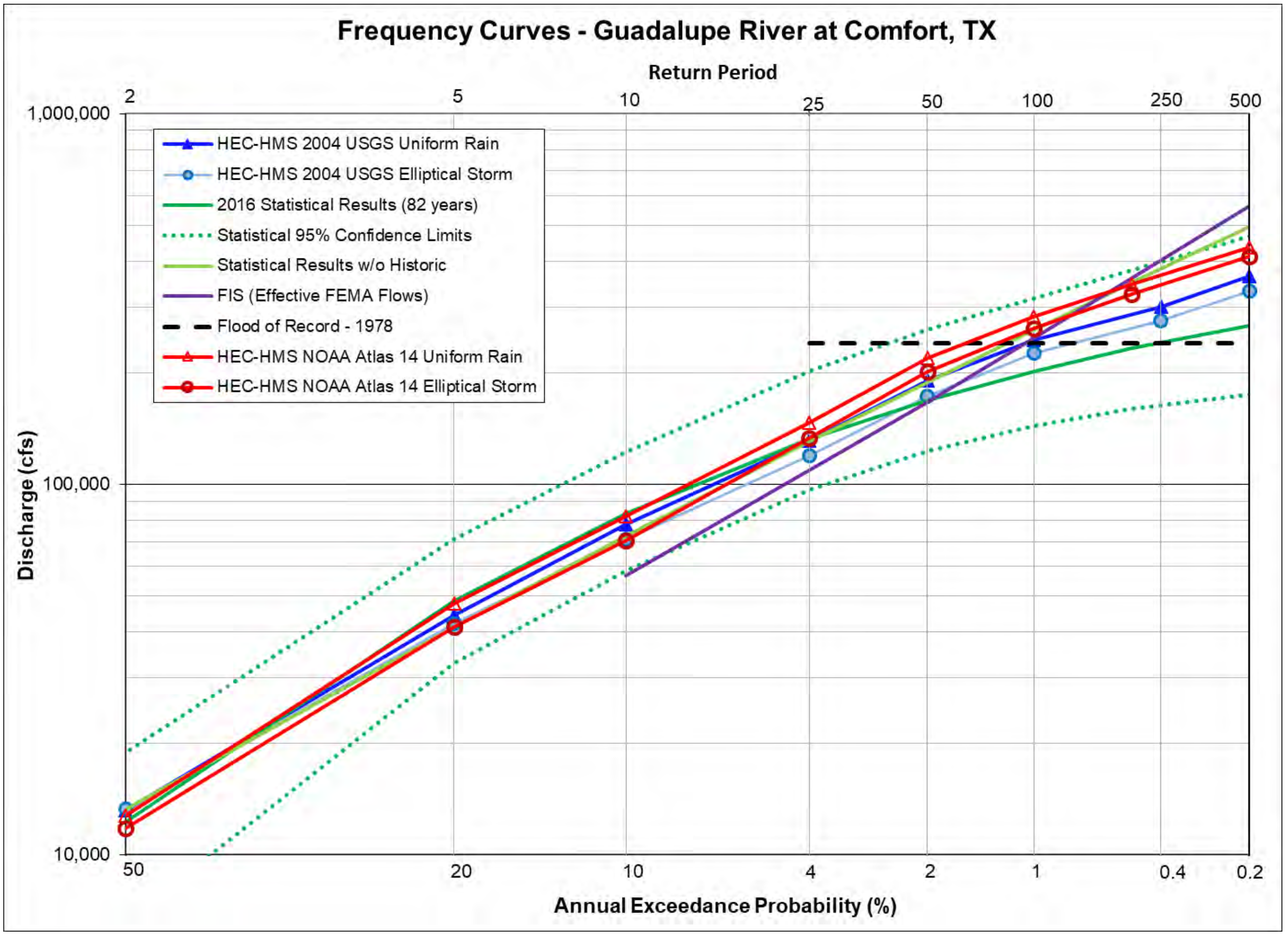


Figure 11.5: Flow Frequency Curve Comparison for the Guadalupe River at Comfort

Table 11.6: Frequency Flow Results Comparison for the Guadalupe River near Spring Branch

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	315,730	289,800	322,100	295,700	408,400	375,800
0.004	200*		221,700	265,600	242,900	320,000	294,000
0.01	100	160,570	175,900	215,000	196,300	258,100	235,800
0.02	50	115,860	135,100	165,600	148,300	196,200	177,900
0.04	25		99,490	114,900	104,600	130,100	120,100
0.1	10	47,230	60,210	70,300	63,600	70,800	65,200
0.2	5		36,410	38,400	36,300	39,900	37,700
0.5	2		12,730	12,600	13,500	12,300	11,100

*2004 USGS reports 250-yr

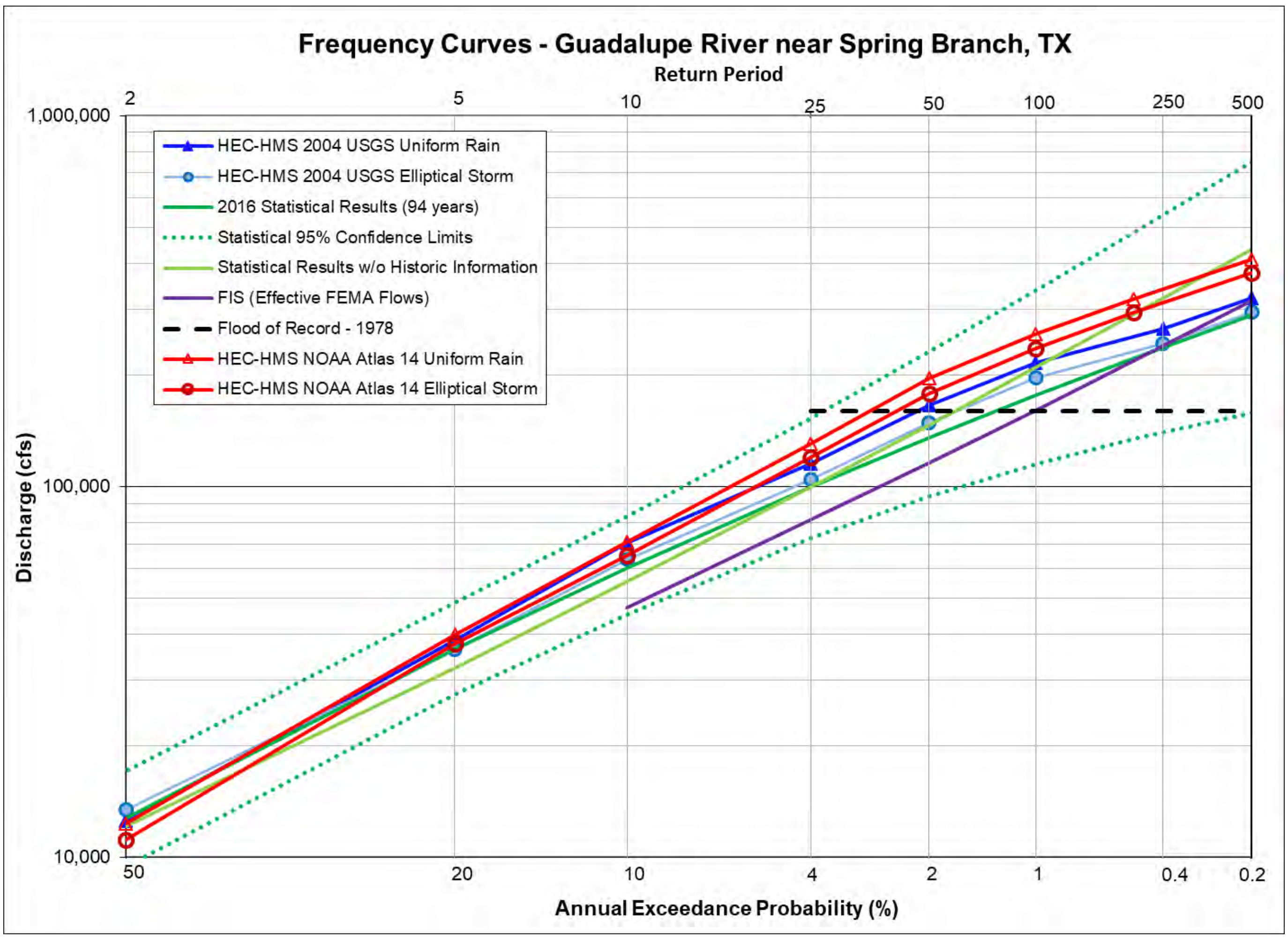


Figure 11.6: Flow Frequency Curve Comparison for the Guadalupe River near Spring Branch

The gage for the Guadalupe River at Sattler (Table and Figure 11.7) is located just below Canyon Dam and is heavily influenced by releases from the reservoir. The effective FIS flows at this location are based on earlier estimates of the frequency peak releases from the dam. The heavily regulated nature of this site does not lend itself well to traditional statistical analysis. Since the observed peak annual flows do not follow a typical log-Pearson distribution, as shown in Figure 5.15 of Chapter 5, the statistical results are highly uncertain, even beyond what is shown in the 95% confidence bounds. The HEC-HMS results at this location are based on elliptical storms located above Canyon Dam and the resulting releases from the dam, but it represents only one possible scenario of reservoir conditions and operations. The Canyon Dam reservoir study results are based on a comprehensive look at the operations of the dam, including a stochastic analysis of its inflow volumes and starting pool elevations, as detailed in Chapter 9. Therefore, the reservoir study results would be considered the best estimate of the frequency peak releases from the dam. The reservoir study results are slightly higher than the effective FIS flows at the 100-yr and 500-yr levels, but they are considerably lower than the HEC-HMS results at this location. The reservoir study results are considered more reliable than the other methods at this particular locations due to the longer period of record and more comprehensive analyses involved at the reservoir itself.

For the Guadalupe River above the Comal River at New Braunfels (Table and Figure 11.8), statistical results from Riverware were available in addition to the normal statistical and HEC-HMS watershed modeling results. This is a long record gage; however, Canyon Dam came online in 1964, which calls into question the early part of the statistical record. The advantage of the Riverware model is that it generates a simulated period of record with the flows that would have occurred if Canyon Dam had been in place all the way back to 1935. From Figure 11.8, once can see that the Riverware 1% ACE (100-yr) estimate is substantially lower than the green statistical curves. In addition, the HEC-HMS modeling results are lining up fairly well with the Riverware results. In this case, the NOAA Atlas 14 rainfall values resulted in a modest increase in the flow frequency estimates such that the NOAA Atlas 14 results from HEC-HMS happen to line up very closely with the effective FIS values. From this figure, one can also see that the 0.2% ACE (500-yr) release from the Canyon Dam reservoir study still dominates the HEC-HMS model results at this location for the local area downstream of the dam.

The Comal River at New Braunfels (Table and Figure 11.9) is a complicated location. From Figure 11.9, one can see that the 2004 USGS HEC-HMS modeling results were substantially lower than both the effective FIS flows and the statistical results, but the new NOAA Atlas 14 rainfall values brought the HEC-HMS results at this location into better alignment with portions of the FIS and statistical values. While the stastical results were based on a relatively long period of record of 87 years, there are several factors that call parts of that record into question. First, of the 130 square miles of drainage area above the gage, 62% is controlled by NRCS style flood retention structures which were built during the middle of the period of record (1950s to 1980s). Therefore, some of the earlier peak annual flows may no longer be applicable to current conditions. Second, the USGS remarks in its records for that site that the gage readings are sometimes affected by backwater from the Guadalupe River and that its discharge estimates for flows above 1,000 cfs are poor. Basically, when the Guadalupe River is high, the Comal River at New Braunfels gage is so close to the confluence that it will also record a high stage and thereby a high discharge. Therefore, backwater from the Guadalupe may have cause some of the recorded annual peak discharges in the statistical record to be overestimated. These backwater effects at the gage were also noticable in the HEC-HMS model calibrations, as discussed in Section 6.4.3. In the HEC-HMS model, all of the NRCS flood retention structures were modeled in detail, and at the next upstream gage, Dry Comal Creek at Loop 377, the model calibration results matched the observed hydrographs well. As a result of all these factors, the NOAA Atlas 14 HEC-HMS model results are considered more reliable than the statistical results at this location.

The gage just below the confluence of the Comal, the Guadalupe River at New Braunfels (Table and Figure 11.10), has a shorter statistical record (53 years) than the upstream gages, but it is also not affected by the backwater issues of the upstream gages. Figure 11.10 shows better agreement between the HEC-HMS modeling results and the statistical results. Once again, the NOAA Atlas 14 rainfall resulted in a modest increase in the HEC-HMS results and brought the HEC-HMS flow values very close to the effective FIS flow values. At this point in the watershed and with the new NOAA Atlas 14 rainfall, the releases from the Canyon Dam reservoir study no longer dominate the HEC-HMS model results for the local areas downstream of the dam.

Table 11.7: Frequency Flow Results Comparison for the Guadalupe River at Sattler

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)	Canyon Lake Releases from Reservoir Study
0.002	500	130,000	53,900	176,800	263,600	164,000
0.004	200*		41,140	112,100	168,300	82,600
0.01	100	14,000	32,370	55,600	96,400	21,100
0.02	50	5,900	24,480	12,500	30,500	5,000
0.04	25		17,540	12,000	12,000	4,300
0.1	10	5,500	9,968	12,000	12,000	2,500
0.2	5		5,551	10,500	10,300	1,380
0.5	2		1,545	2,800	2,100	700

*2004 USGS and Canyon Lake study report 250-yr

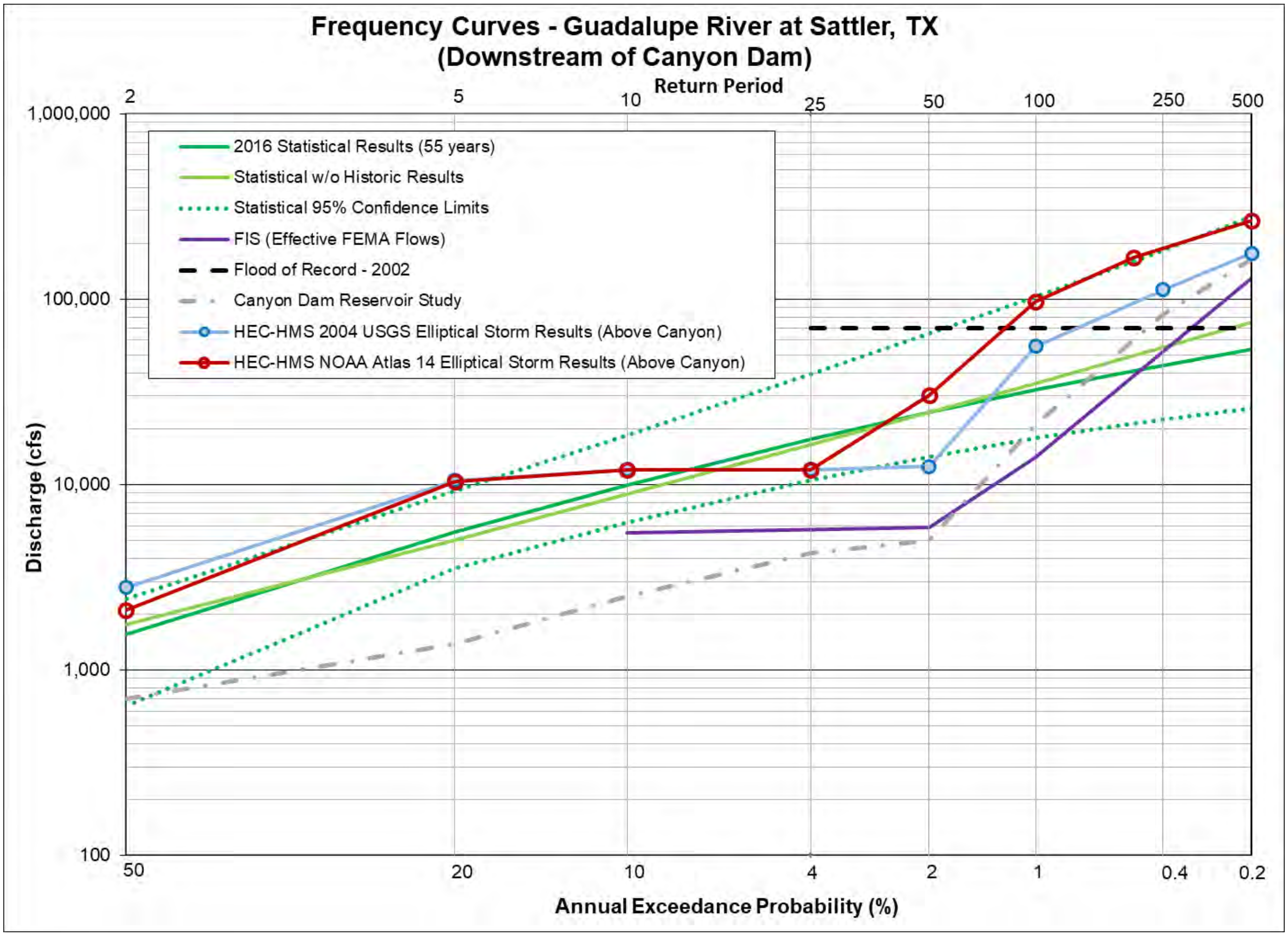


Figure 11.7: Flow Frequency Curve Comparison for the Guadalupe River at Sattler

Table 11.8: Frequency Flow Results Comparison for the Guadalupe River above the Comal River at New Braunfels

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	Riverware POR Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	Canyon Lake Releases from Reservoir Study
0.002	500	132,918	477,600	129,800	100,100	130,400	164,000
0.004	200*		266,700	94,500	85,800	104,800	82,600
0.01	100	85,458	168,900	72,800	71,000	88,300	21,100
0.02	50	71,559	105,100	54,700	61,200	74,400	5,000
0.04	25		63,890	35,700	47,000	57,600	4,300
0.1	10	39,233	31,420	24,500	31,500	37,400	2,500
0.2	5		17,230	15,500	20,100	22,500	1,380
0.5	2		6,458	6,500	7,400	7,300	700

*2004 USGS and Canyon Lake study report 250-yr

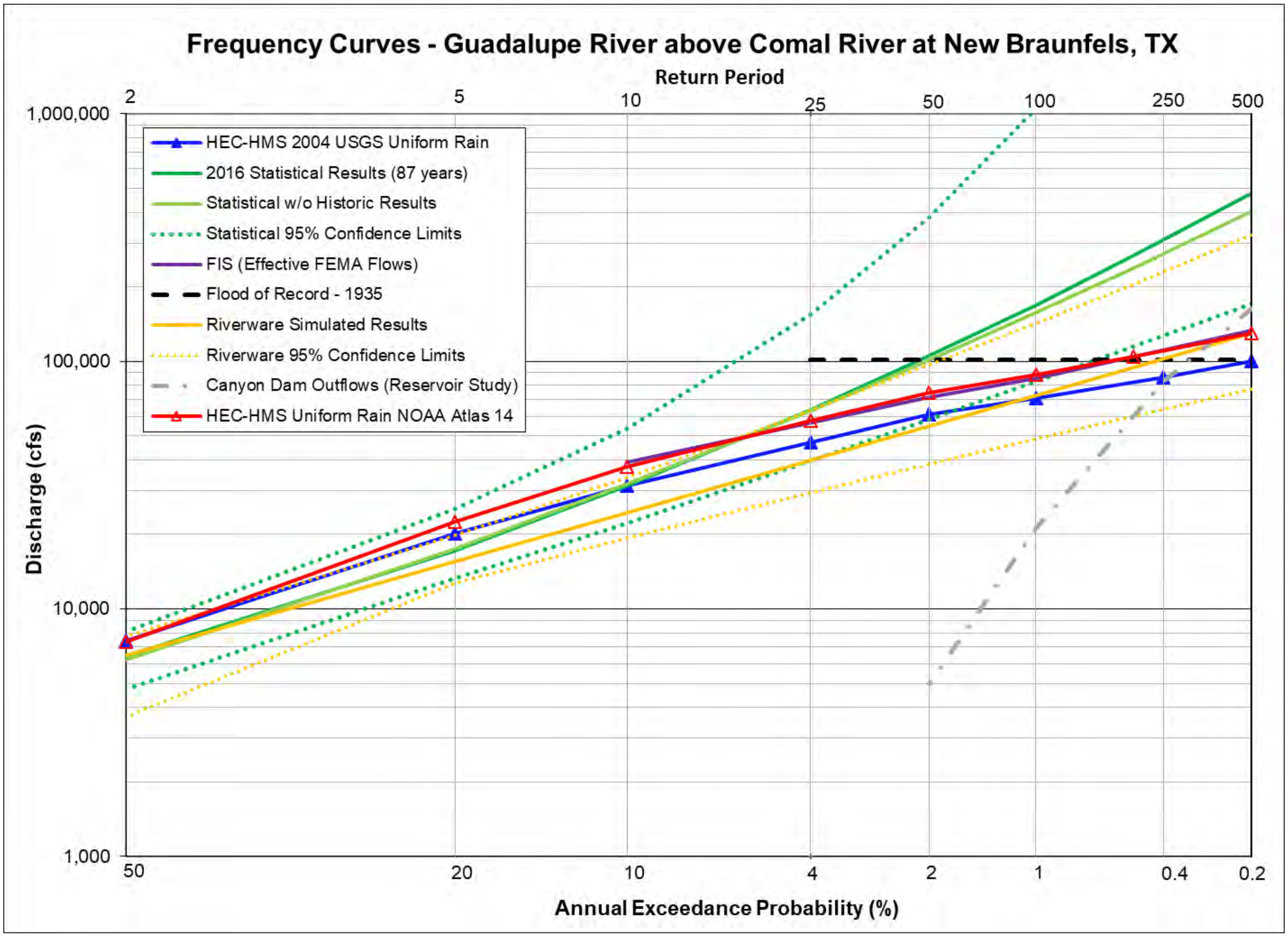


Figure 11.8: Flow Frequency Curve Comparison for the Guadalupe River above the Comal River at New Braunfels

Table 11.9: Frequency Flow Results Comparison for the Comal River at New Braunfels

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500	67,238	126,900	47,200	67,600
0.004	200*		77,510	38,500	50,700
0.01	100	43,670	52,410	29,900	39,400
0.02	50	36,846	34,700	23,400	29,800
0.04	25		22,360	18,100	22,500
0.1	10	21,648	11,760	11,900	12,700
0.2	5		6,708	7,500	7,400
0.5	2		2,554	2,900	2,600

*2004 USGS reports 250-yr

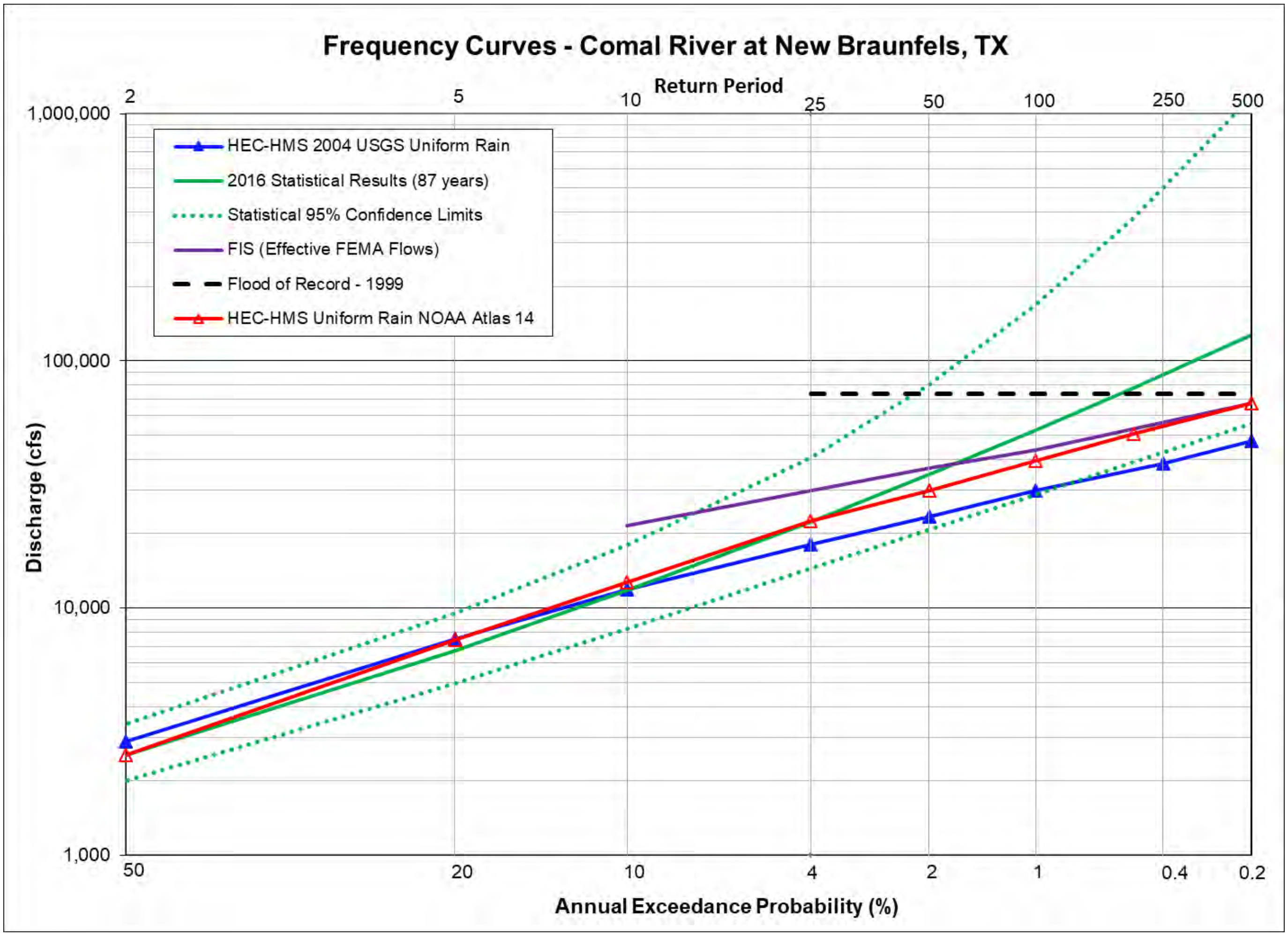


Figure 11.9: Flow Frequency Curve Comparison for the Comal River at New Braunfels

Table 11.10: Frequency Flow Results Comparison for the Guadalupe River at New Braunfels

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	Canyon Lake Releases from Reservoir Study
0.002	500	188,253	242,200	136,700	181,700	164,000
0.004	200*		154,000	116,100	143,800	82,580
0.01	100	120,962	107,800	94,600	119,000	21,100
0.02	50	102,133	74,300	79,600	97,700	5,000
0.04	25		50,200	61,500	75,300	4,300
0.1	10	58,588	28,570	40,500	46,900	2,500
0.2	5		17,650	25,300	27,400	1,380
0.5	2		7,928	9,000	8,600	700

*2004 USGS and Canyon Lake Study report 250-yr

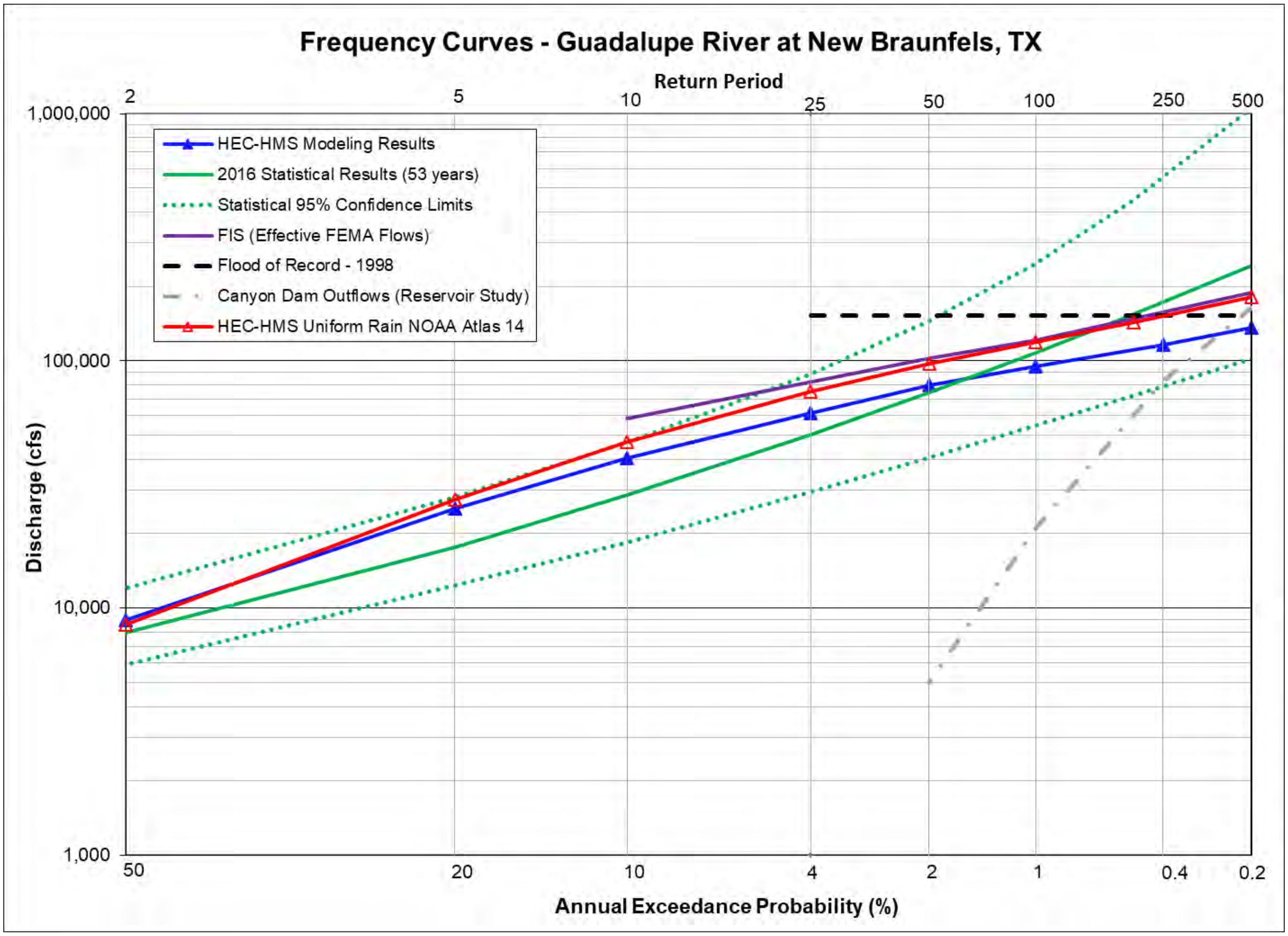


Figure 11.10: Flow Frequency Curve Comparison for the Guadalupe River at New Braunfels

For most of the gages in the Blanco / San Marcos River basin (Figures 11.11 to 11.16), the results of the statistical analysis and the HEC-MHS watershed model showed very good agreement with each other. Both sets of results were also significantly higher than the flows on the currently effective FEMA Flood Insurance Studies (FIS) (FEMA, 2005), which were based on regression equations at most of these locations. This is not surprising since the regression equations for this area tended to underestimate the 1% annual chance (100-yr) flow values due to the limited period of record that was available during the early 1990s which did not include the major flood events between 1998 and 2015, as discussed in Section 2.4.

For the Blanco River at Wimberley and near Kyle and the San Marcos River at Luling (Figures 11.11, 11.12 and 11.14, respectively), the HEC-HMS modeling and the statistical results generally showed a high degree of agreement with each other. However, the NOAA Atlas 14 rainfall values resulted in modest increases in the HEC-HMS results, which led them closer to the statistical curves without historic information at Wimberley and Kyle. At Luling, the NOAA Atlas 14 HEC-HMS results trended higher than the statistical results for the rare frequencies. However, as illustrated by the change over time plots in section 5.3, the statistical estimates of the 1% annual chance (100-yr) continue to vary as each new year of data is added to the record. At all three gages, the differences between the elliptical and the uniform rain results were insignificant, as the peaks for both methods were driven by rapid runoff from the same areas of the Blanco watershed.

For the San Marcos River at San Marcos (Table and Figure 11.13), there is some separation between the statistical and modeling results. However, the statistical results at this location are based on only 21 years of record (1995 to 2016). This is a relatively short period of record, which yields a low degree of confidence in the 1% annual chance (100-yr) statistical estimate. The gage record is also dominated by one large flood event (1998) which produced a peak of 21,500 cfs at the gage, as shown previously in Chapter 5. The rest of the recorded annual peaks are much lower in magnitude, at less than 3,000 cfs. The HEC-HMS model with the 2004 USGS rainfall estimated a 1% ACE (100-yr) discharge that was significantly lower that the statistical analysis, but was very similar to the effective FIS discharge, which was also based on a watershed model at this location. The modeling estimates are largely influenced by the effects of the three NRCS dams upstream of the gage which control over 90% of the drainage area at this location. Therefore, the watershed model provides the best available representation of the physical processes in the watershed at this location. When the new NOAA Atlas 14 rainfall values were added to HEC-HMS, the watershed model showed significantly higher spills from the NRCS dams, which resulted in significantly higher estimates of the 2% through 0.2% ACE (50-yr through 500-yr) discharges. However, these values are still well below the statistical estimate.

For the Plum Creek gage at Lockhart, there is good agreement between the latest HEC-HMS modeling and the statistical results (Table and Figure 11.15). Once again, the peak flows at Lockhart are influenced by the presence of about 20 NRCS dams that control about 60% of the drainage area above Lockhart. These 20 dams were not modeled in detail in HEC-HMS, but they were accounted for in the calibration of the loss rates, peaking coefficients and lag times. The statistical estimate at this gage is based on a fairly long period of record (57 years), dating back to 1959. The flood of record at Lockhart occurred in October 1998, with a peak discharge of 47,200 cfs. The plotting positions of the statistical analysis would place that event at approximately a 50 to 60-yr frequency based on its 57 years of record. However, the basin average rainfall totals upstream Lockhart would indicate that the October 1998 storm was likely a less frequent event than the statistics would imply. The HEC-HMS model calibration showed that the 1998 storm generated approximately 10-inches of runoff at the Lockhart gage, which is on the order of a 1% annual chance (100-yr) rainfall. Likewise, the model's frequency curve results place the 1998 storm at closer to a 1% annual chance (100-yr) at Lockhart. Therefore, the watershed model is believe to provide a better estimate of the 1% annual chance (100-yr) discharge at Lockhart.

For the Plum Creek gage near Luling (Table and Figure 11.16), there was good agreement between the modeling and the statistical results using the 2004 USGS rainfall. However, once the NOAA Atlas 14 rainfall was added, the HEC-HMS model results trended higher for the 2% through 0.2% ACE (50-yr through 500-yr) discharges. The statistical estimate at this gage is based on a fairly long period of record, dating back to 1930 at Luling, but as shown previously in Section 5.3, the exact statistical estimate at Luling continues to vary from year to year with each new peak that is added to the record. One point of weakness in the statistical data at Luling is the fact that the gage was not in service during what was likely the flood of record at that location. The October 1998 flood event is believed to be the flood of record at Luling, which occurred during the seven year period (1994 to 2000) that the Plum Creek near Luling gage was not in service. The statistical curve does include an interval estimate of what the 1998 peak might have been, as shown in the highest green vertical lines on Figures 5.34 and 5.35, but those estimates are plotted with a large range of uncertainty. The calibrated HEC-HMS model reproduced the observed hydrographs well at Luling, and the upstream routing in between the Lockhart and Luling gages was also well calibrated to the observed attenuation between those gages during the October 2015 event. Therefore, greater weight is given toward the modeling results with the most recent rainfall estimates. The differences between the HEC-HMS elliptical storm and uniform rain results at this location were insignificant.

Table 11.11: Frequency Flow Results Comparison for the Blanco River at Wimberley

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	203,800	269,400	238,500	238,100	329,800	319,600
0.004	200*		199,300	196,800	199,800	259,900	248,700
0.01	100	112,800	153,700	152,600	157,500	211,300	200,300
0.02	50	86,200	114,400	116,600	123,300	161,100	151,400
0.04	25		81,200	88,600	94,700	108,000	110,900
0.1	10	36,800	46,400	51,600	51,600	61,600	54,700
0.2	5		26,500	31,000	31,800	35,300	28,100
0.5	2		8,280	8,900	8,700	8,500	8,000

*2004 USGS reports 250-yr

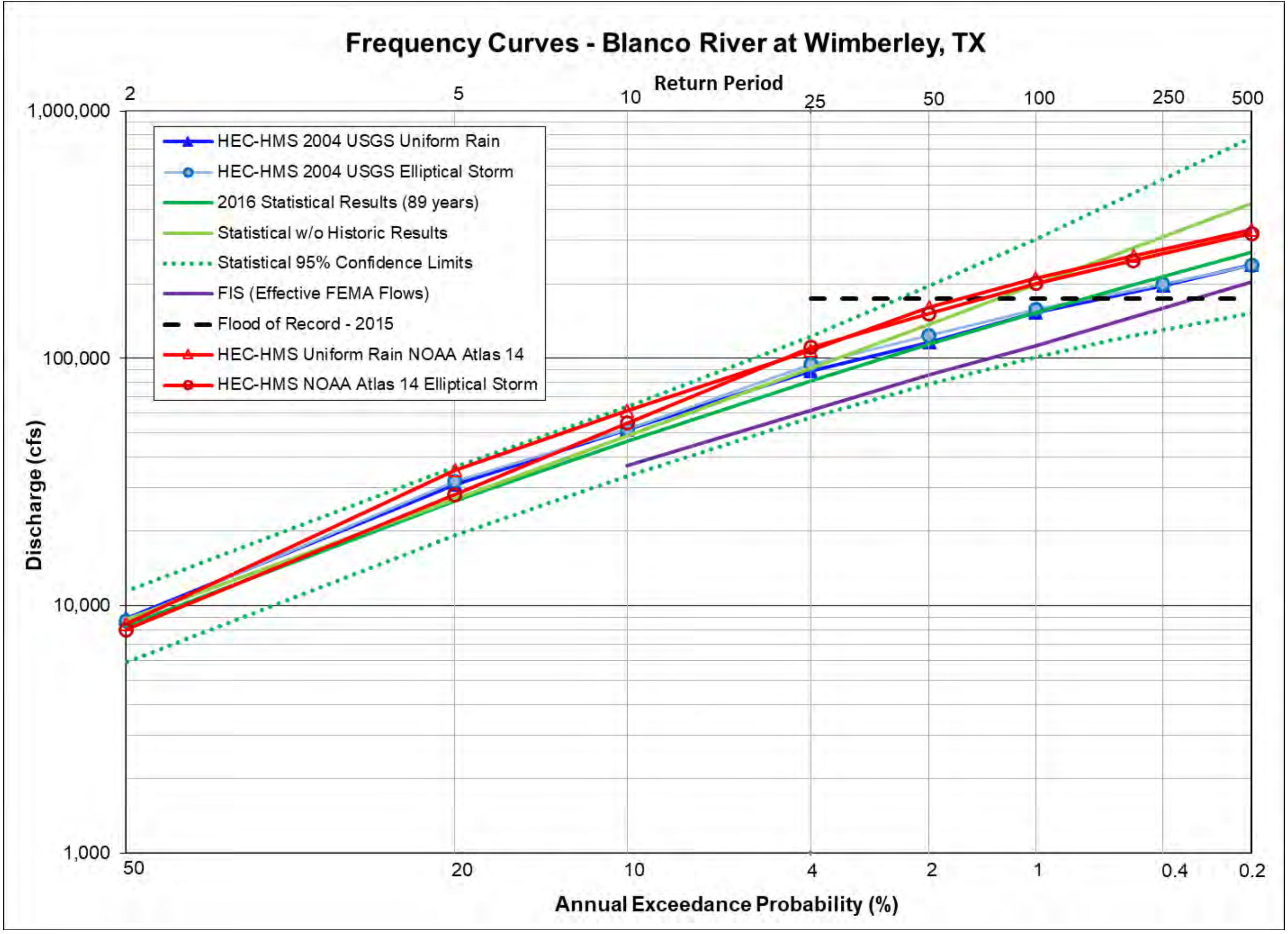


Figure 11.11: Flow Frequency Curve Comparison for the Blanco River at Wimberley

Table 11.12: Frequency Flow Results Comparison for the Blanco River near Kyle

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	219,100	271,100	244,900	242,900	343,500	333,500
0.004	200*		212,500	199,300	201,700	269,300	258,800
0.01	100	122,600	170,400	153,900	157,800	216,500	206,100
0.02	50	93,900	131,100	116,300	121,900	162,000	153,500
0.04	25		95,290	88,100	93,300	107,500	112,000
0.1	10	40,600	54,810	50,700	50,400	61,000	55,100
0.2	5		30,450	30,300	30,700	34,400	28,200
0.5	2		8,110	8,600	8,100	8,100	7,900

*2004 USGS reports 250-yr

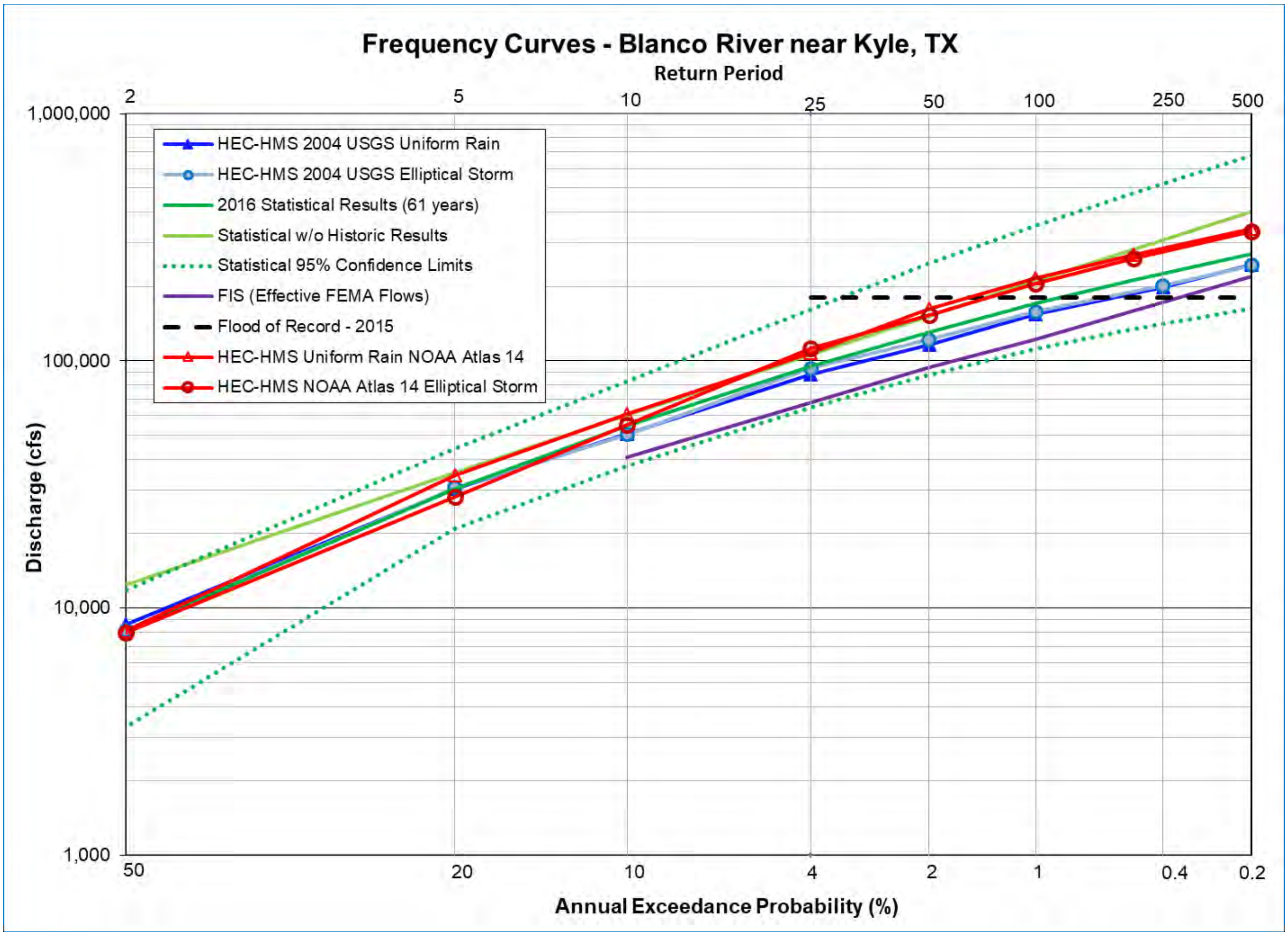


Figure 11.12: Flow Frequency Curve Comparison for the Blanco River near Kyle

Table 11.13: Frequency Flow Results Comparison for the San Marcos River at San Marcos

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500	20,290	139,700	21,100	42,200
0.004	200*		57,140	14,800	28,300
0.01	100	7,660	28,980	7,860	18,600
0.02	50	6,220	14,650	5,160	9,600
0.04	25		7,370	4,100	4,800
0.1	10	3,680	2,940	2,530	2,900
0.2	5		1,450	1,380	1,800
0.5	2		550	310	500

*2004 USGS reports 250-yr

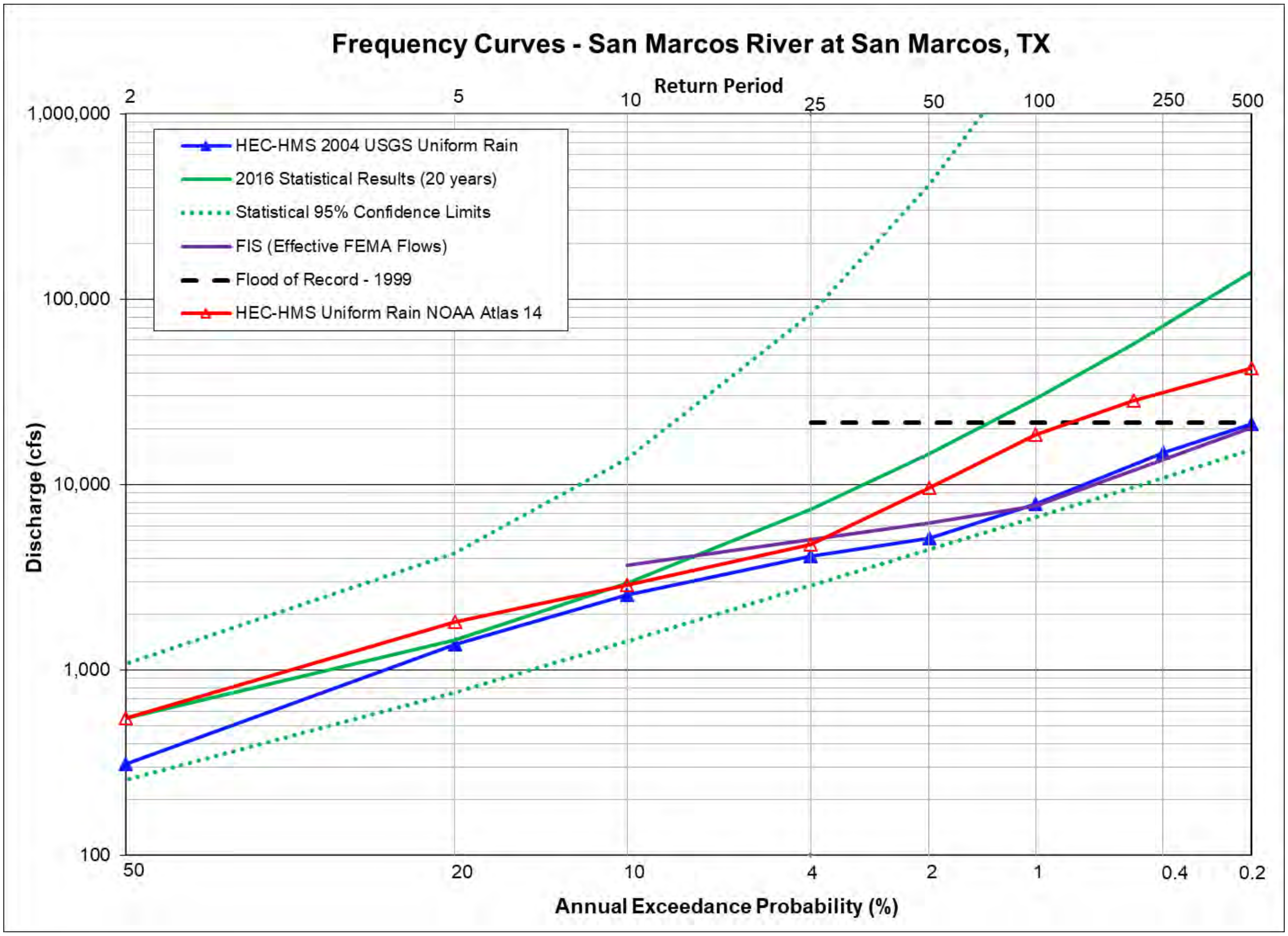


Figure 11.13: Flow Frequency Curve Comparison for the San Marcos River at San Marcos

Table 11.14: Frequency Flow Results Comparison for the San Marcos River at Luling

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm
0.002	500	183,000	253,500	253,100	242,700	393,500	370,400
0.004	200*		186,100	193,100	185,800	295,700	274,700
0.01	100	110,000	143,600	142,400	138,400	217,600	201,900
0.02	50	85,100	107,600	103,900	103,000	149,300	140,700
0.04	25		77,500	78,400	78,800	100,200	100,600
0.1	10	40,000	46,100	47,400	43,300	57,600	52,600
0.2	5		27,900	28,300	26,700	31,900	27,500
0.5	2		10,250	10,400	10,900	10,100	8,900

*2004 USGS reports 250-yr

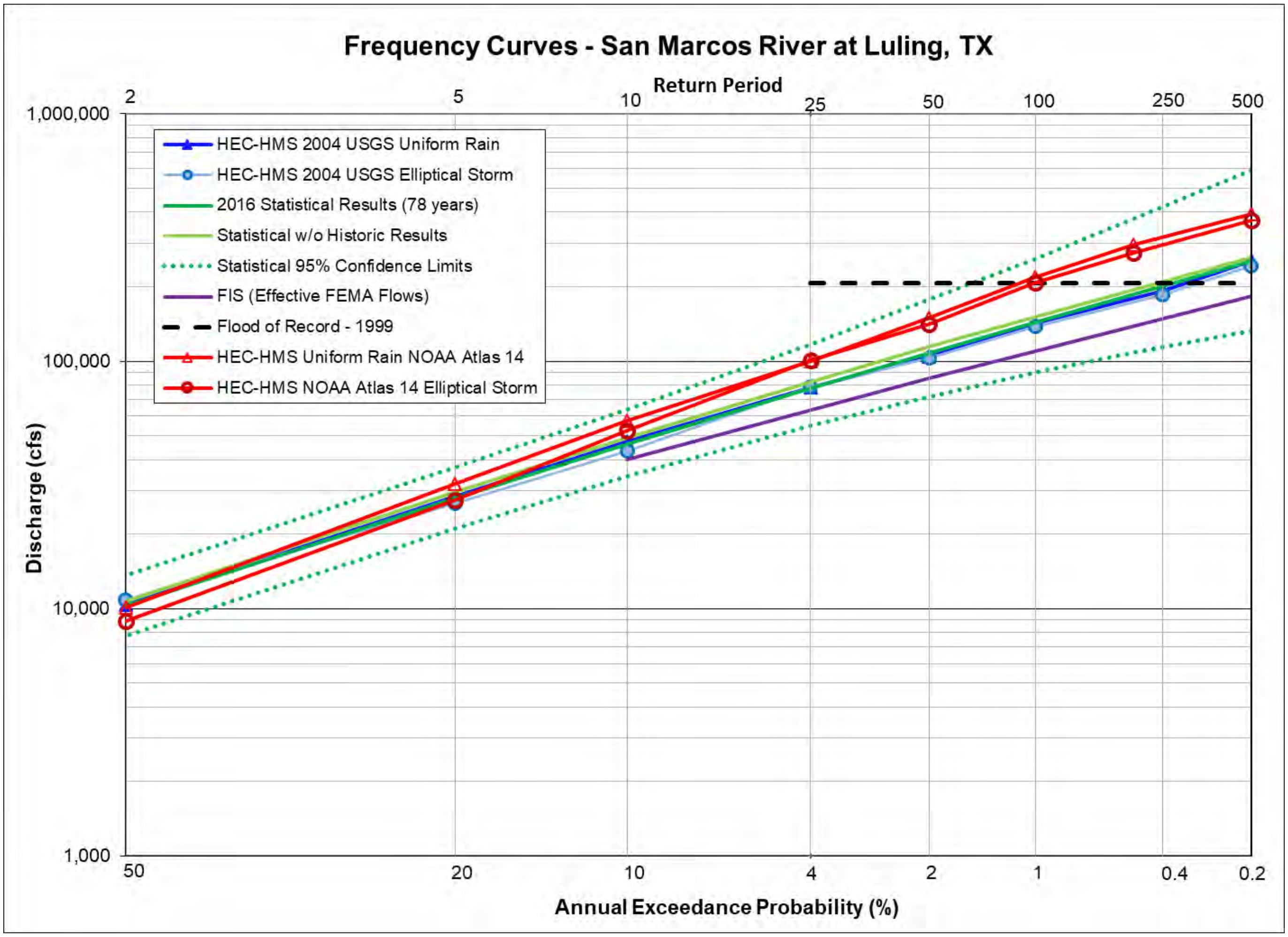


Figure 11.14: Flow Frequency Curve Comparison for the San Marcos River at Luling

Table 11.15: Frequency Flow Results Comparison for Plum Creek at Lockhart

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500		98020	71,600	97,900
0.004	200*		75130	60,900	78,100
0.01	100		59600	48,900	64,200
0.02	50		45700	39,800	51,300
0.04	25		33480	32,200	37,200
0.1	10		19990	20,600	21,500
0.2	5		11850	12,200	13,200
0.5	2		3915	3,830	3,800

*2004 USGS reports 250-yr

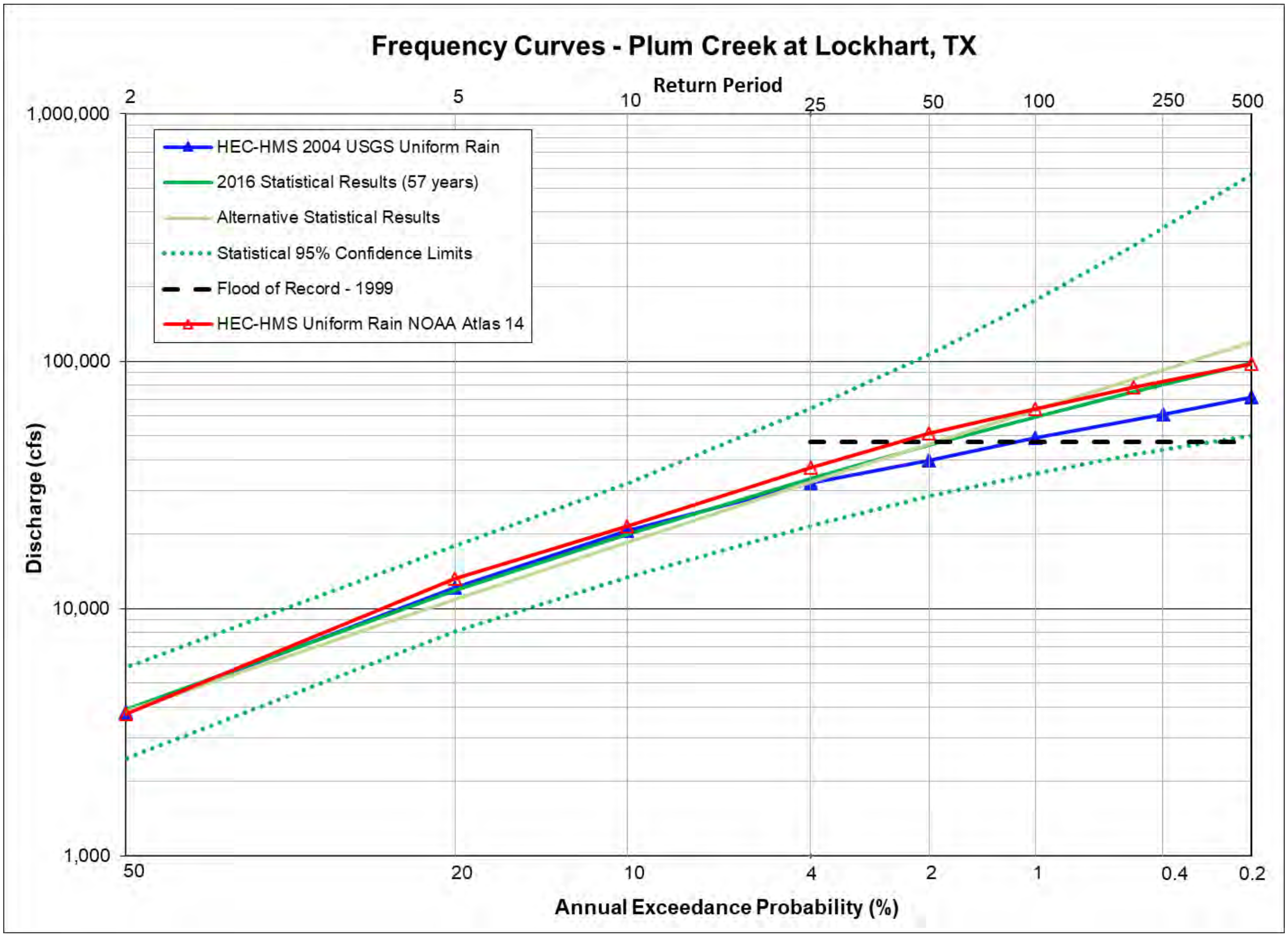


Figure 11.15: Flow Frequency Curve Comparison for Plum Creek at Lockhart

Table 11.16: Frequency Flow Results Comparison for Plum Creek near Luling

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500		102600	132,100	127,500	205,100	202,300
0.004	200*		85430	106,300	104,100	149,600	146,000
0.01	100		72480	78,600	79,200	112,000	108,700
0.02	50		59580	60,600	61,700	80,900	77,100
0.04	25		46850	45,900	47,300	53,900	57,100
0.1	10		30610	29,600	30,600	31,000	33,600
0.2	5		19190	17,700	19,100	16,800	18,900
0.5	2		6370	6,600	6,600	6,700	5,600

*2004 USGS reports 250-yr

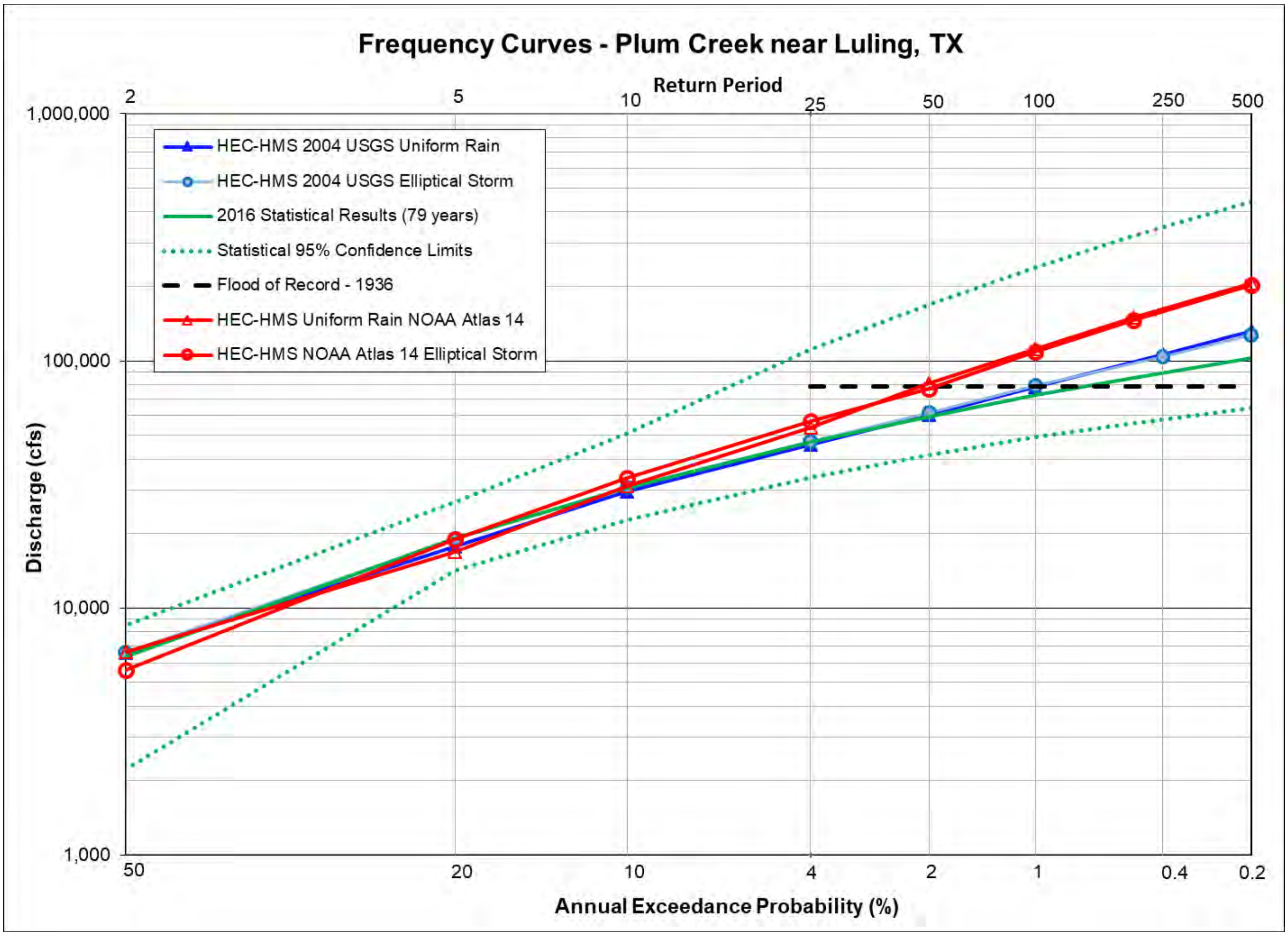


Figure 11.16: Flow Frequency Curve Comparison for Plum Creek near Luling

The Guadalupe River at Gonzales gage (Table and Figure 11.17) is located just downstream of the confluence of the Guadalupe River with the San Marcos River and has over 2,000 square miles of uncontrolled drainage area. The period of record at the gage is only 29 years, so the statistical results have a higher degree of uncertainty. The Riverware model simulates a longer period of record, but the simulated flows at this location have more uncertainty than other locations due to the limited period of observed data used for comparison. In the HEC-HMS watershed model results, one notices more significant differences between the uniform rain and the elliptical storm results due to the size of the watershed's drainage area at this point. At this watershed size, the elliptical storm results should be more accurate in that they result from a focused 1% ACE (100-yr) storm on a critical location in the watershed, whereas the uniform rain assumptions may overestimate peak flows by producing runoff from all the tributaries simultaneously. For this location, the NOAA Atlas 14 (NA14) rainfall resulted in a significant increase in the HEC-HMS results. This is due to the critical storm center for Gonzales being located near San Marcos, Texas within the area of NA14's highest rainfall values, as discussed in Chapter 10. Peak flows at Gonzales from the uniform rain method are also driven by flows from this area.

Peach Creek below Dilworth (Table and Figure 11.18), on the other hand, has only 460 square miles of drainage area, so the diffrerences between the HEC-HMS uniform rain and elliptical storm results are much less significant. This gage also has a relaltively short period of record of 33 years, but an alternate statistical analysis was performed where discharges were estimated for an additional 20 years of record when the gage was out of service, which likely included three additional large flood events, as discussed in Section 5.2. The new HEC-HMS results with the NOAA Atlas 14 rainfall depths match well with the alternate statistical analysis. Similarly, for Sandies Creek near Westhoff (Table and Figure 11.19), the gage has a medium length record of 58 years, and the NOAA Atlas 14 HEC-HMS watershed model results and the statistical results line up well with each other.

For the Guadalupe River at Cuero (Table and Figure 11.20), the gage has a medium length of record of 54 years. However, one can see from the difference between the 2016 and 2017 statistical results that the statistical estimates are still a moving target. In the HEC-HMS watershed model results, there is once again a more significant difference between the uniform rain and the elliptical storm results due to the 3,500 square miles of uncontrolled drainage area above this point. The volume of runoff in the uniform rain results may overestimate peak flows at this location by producing runoff from all the tributaries in the watershed simultaneously, whereas the elliptical storm results from a focused 1% ACE (100-yr) storm on a critical location in the watershed. Once again, the NOAA Atlas 14 (NA14) rainfall data resulted in a significant increase in the HEC-HMS results. This is due to the critical storm center for Cuero being located near the area of NA14's highest rainfall values on the San Marcos watershed, as discussed in Chapter 10. However, the NOAA Atlas 14 elliptical storm results still line up well with the 2017 statistical analysis at this location.

For the Guadalupe River at Victoria (Table and Figure 11.21), the gage has a longer period of record of 83 years, which is almost identical to the Riverware period of record. The HEC-HMS uniform rain results would tend to overestimate peak flows due to the size of the uncontrolled drainage area at this location (3,767 square milles). The statistical, Riverware and 2004 USGS HEC-HMS elliptical storm results all lined up well with one another, while the NOAA Atlas 14 HEC-HMS elliptical results were significantly higher at the rare frequencies. However, the NOAA Atlas 14 study had (1) an additional 23 years of rainfall data available compared to the 2004 USGS study, (2) a regional statistical approach that incorporated at least 1,000 cumulative years of daily data and 500 cumulative years of sub-daily data into each station's frequency rainfall estimate, and (3) better spatial interpolation techniques that accounted for the orographic effects of the Texas Hill Country. For these reasons, the HEC-HMS NOAA Atlas 14 elliptical storm method yields the most complete accounting of both the historic rainfall data and the physical proceses in the watershed. One can also see from the plot that the effective FIS and preliminary 2010 FIS flows were substantially underestimated at this location.

Table 11.17: Frequency Flow Results Comparison for the Guadalupe River at Gonzales

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	Riverware POR Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	560,000	506600	423500	471,300	405,200	723,000	625,500
0.004	200*		333900	268300	385,000	329,700	539,000	460,700
0.01	100	287,000	238600	186400	285,700	245,900	409,200	338,800
0.02	50	205,000	166700	126700	210,200	173,100	289,700	236,700
0.04	25		113100	72700	149,300	121,400	194,200	158,800
0.1	10	83,000	63330	45500	83,100	78,600	97,900	88,900
0.2	5		37620	26500	49,900	51,100	51,100	50,300
0.5	2		14760	10300	18,700	18,200	16,900	17,500

*2004 USGS reports 250-yr

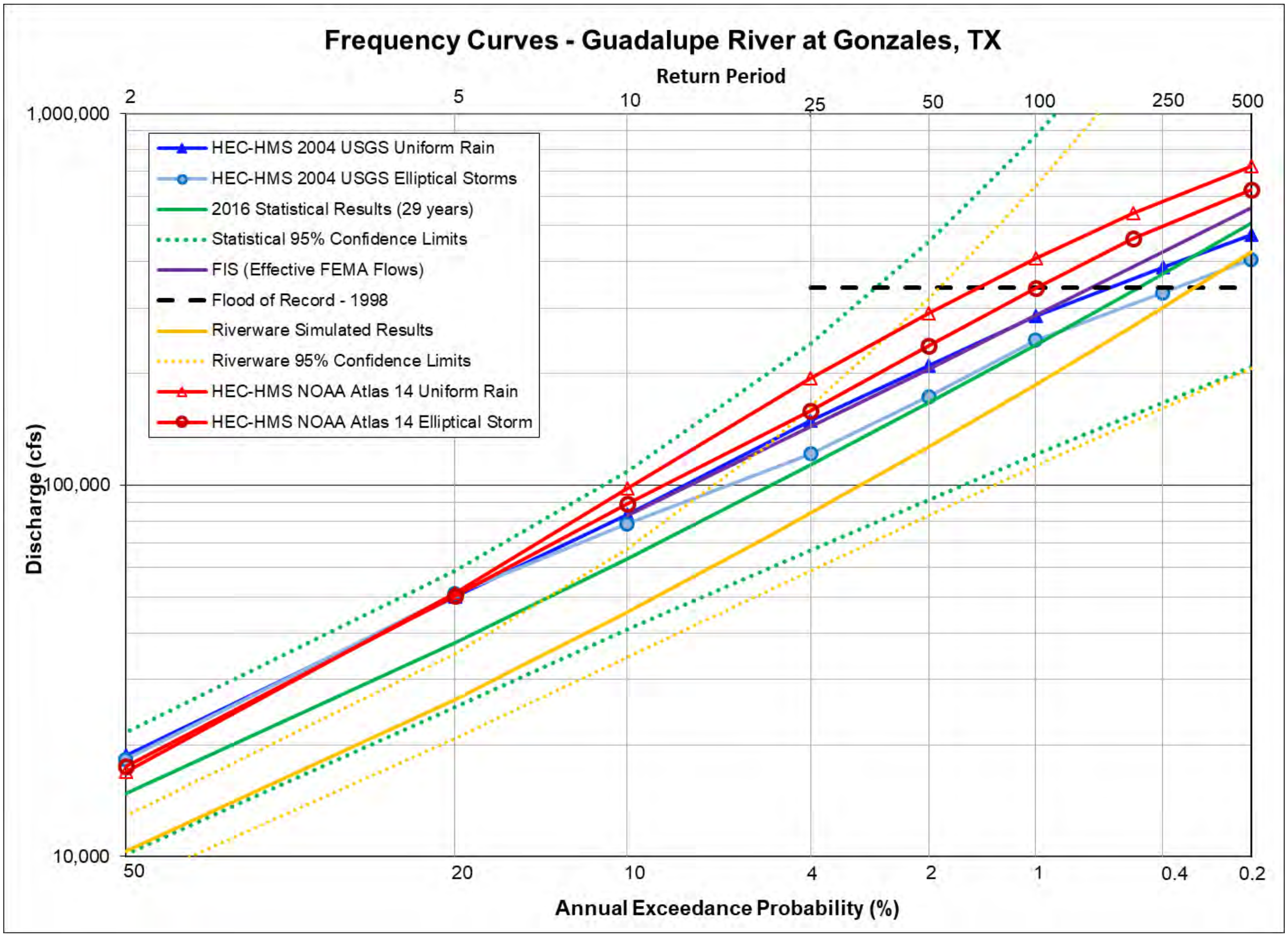


Figure 11.17: Flow Frequency Curve Comparison for the Guadalupe River at Gonzales

Table 11.18: Frequency Flow Results Comparison for Peach Creek below Dilworth

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500		120,300	113,100	107,400	162,900	153,500
0.004	200*		90,110	96,000	90,600	123,700	115,600
0.01	100		70,740	72,000	67,300	96,600	89,900
0.02	50		54,080	52,100	48,000	69,100	64,700
0.04	25		39,920	37,300	36,600	48,700	48,900
0.1	10		24,690	23,800	23,200	26,100	27,100
0.2	5		15,550	14,000	14,200	16,300	16,700
0.5	2		6,220	5,500	5,700	6,000	6,100

*2004 USGS reports 250-yr

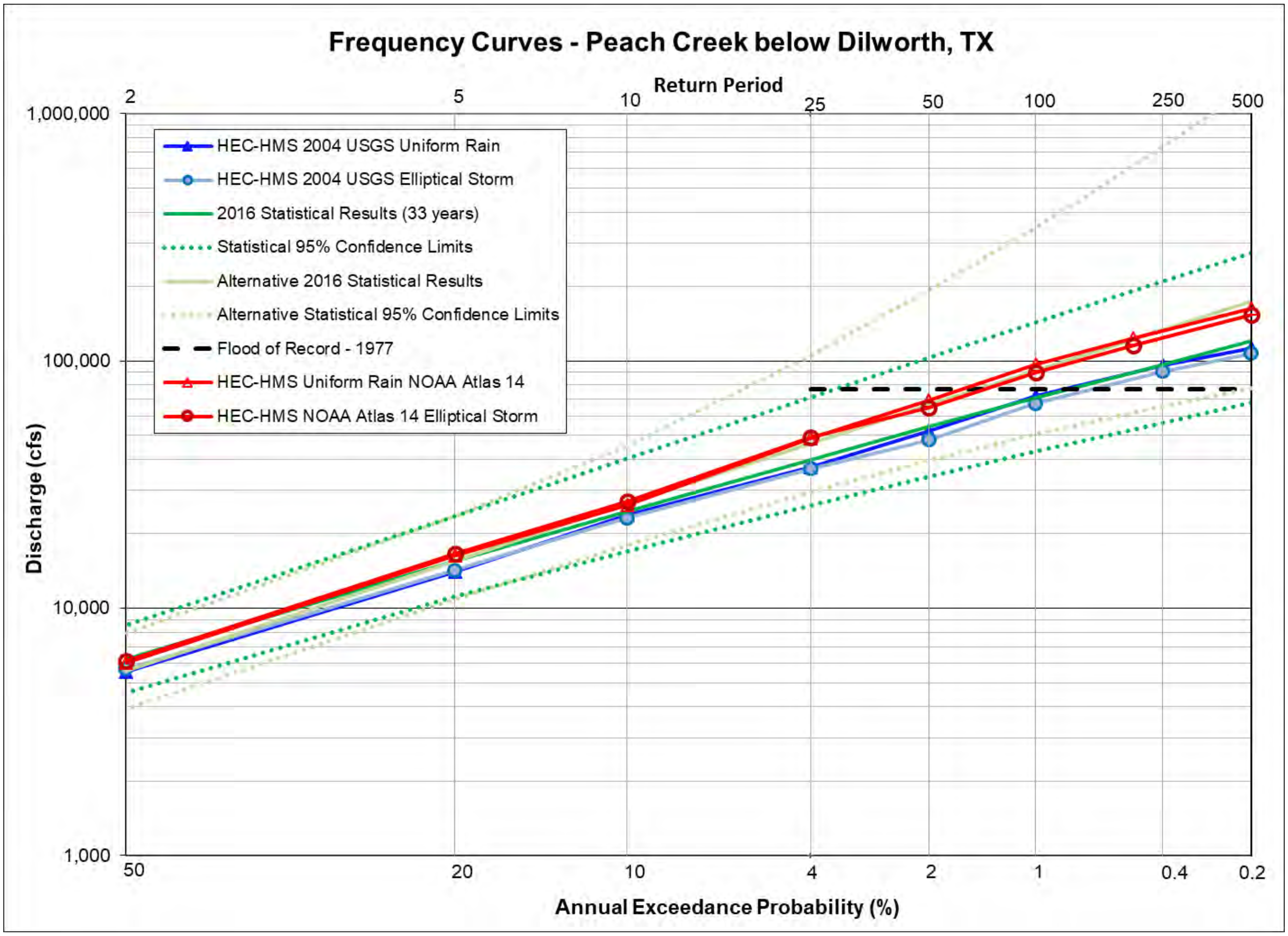


Figure 11.18: Flow Frequency Curve Comparison for Peach Creek below Dilworth

Table 11.19: Frequency Flow Results Comparison for Sandies Creek near Westhoff

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500		197,100	116,600	109,300	161,700	152,400
0.004	200*		132,300	96,600	89,900	116,300	110,500
0.01	100		94,890	71,700	65,800	90,100	84,600
0.02	50		65,750	50,800	45,500	62,800	58,900
0.04	25		43,530	35,800	34,600	43,000	43,400
0.1	10		22,770	22,400	21,700	21,800	23,400
0.2	5		12,280	12,700	12,300	11,900	12,500
0.5	2		3,657	3,900	3,900	3,700	3,600

*2004 USGS reports 250-yr

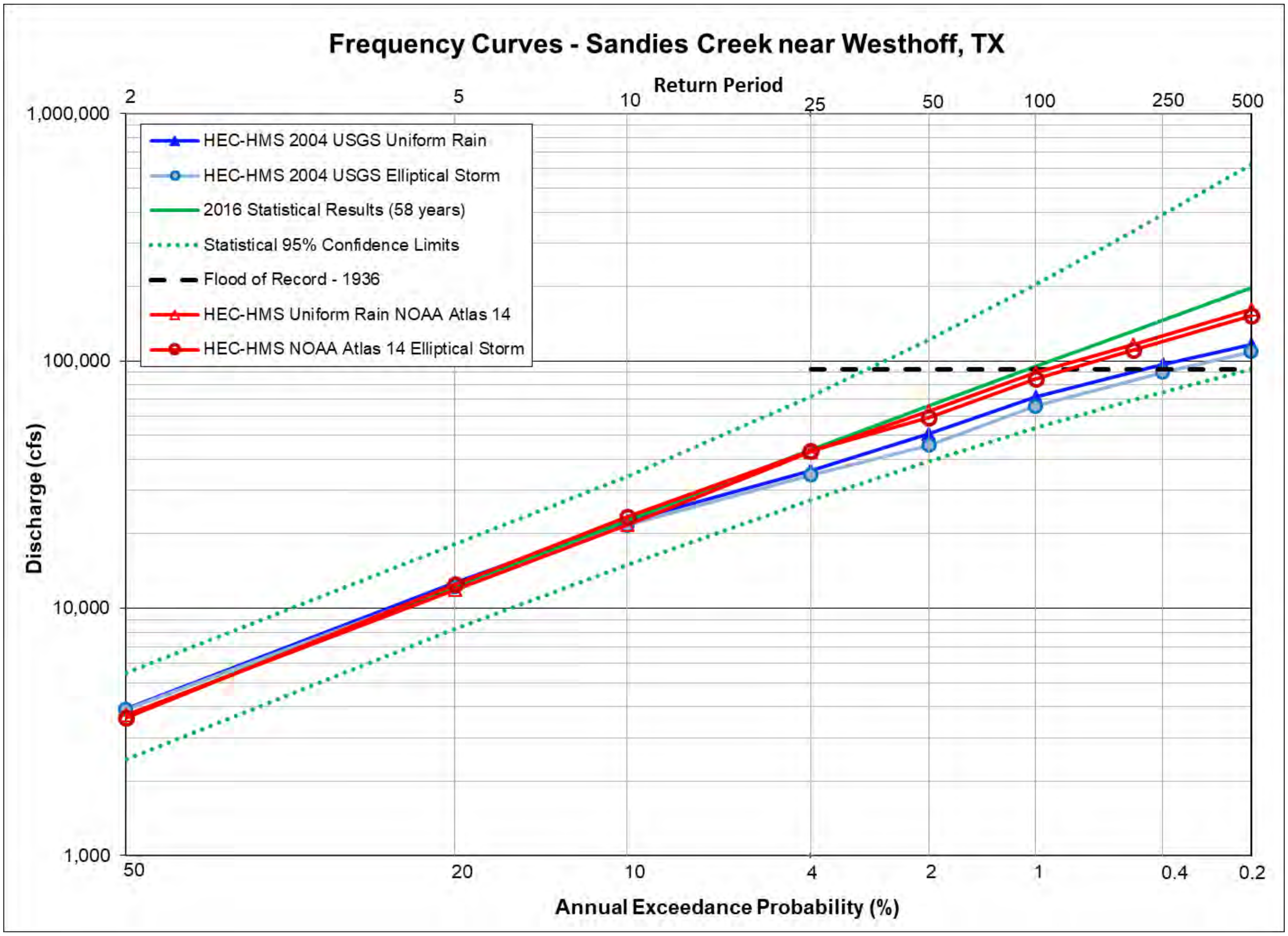


Figure 11.19: Flow Frequency Curve Comparison for Sandies Creek near Westhoff

Table 11.20: Frequency Flow Results Comparison for the Guadalupe River at Cuero

Annual Exceedance Probability (AEP)	Return Period (years)	USACE Lower Guadalupe Feasibility Study	2017 Statistical Analysis (with Harvey)	Riverware POR Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	481,000	858,000	507,600	642,500	486,200	959,800	787,100
0.004	250*		532,000	337,400	518,500	388,000	713,100	563,000
0.01	100	242,000	363,000	242,800	367,000	274,100	536,500	401,500
0.02	50	174,000	242,000	170,800	253,900	188,000	360,600	264,600
0.04	25		157,000	102,300	174,100	130,700	230,100	173,000
0.1	10	70,100	82,500	65,900	96,200	79,100	106,600	88,500
0.2	5		46,800	39,400	54,200	48,100	52,900	45,900
0.5	2		17,200	15,600	17,000	16,700	15,500	15,100

*2004 USGS reports 250-yr

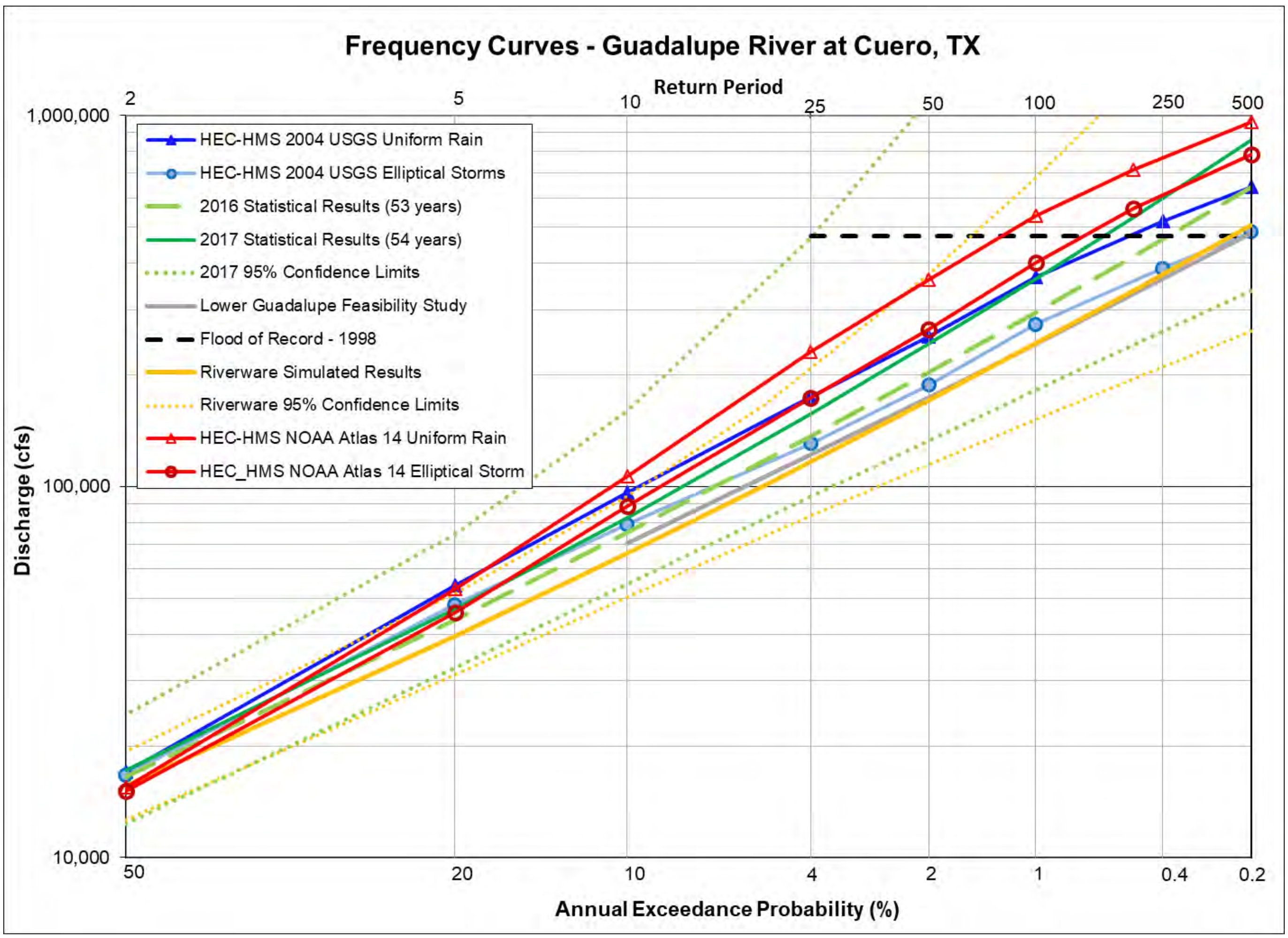


Figure 11.20: Flow Frequency Curve Comparison for the Guadalupe River at Cuero

Table 11.21: Frequency Flow Results Comparison for the Guadalupe River at Victoria

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	Preliminary FIS (2010)	USACE Lower Guadalupe Feasibility Study	2017 Statistical Analysis (with Hurricane Harvey)
0.002	500	219,000	347,000	347,000	454,300
0.004	200*				319,900
0.01	100	129,000	192,000	187,000	240,100
0.02	50	99,000	145,000	142,000	176,000
0.04	25				125,000
0.1	10	48,000	65,700	65,700	73,800
0.2	5				45,400
0.5	2				18,300

Annual Exceedance Probability (AEP)	Return Period (years)	Riverware POR Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	487,000	623,800	469,100	938,800	764,400
0.004	200*	331,200	495,600	369,900	694,400	533,500
0.01	100	242,200	346,400	257,700	512,400	372,100
0.02	50	173,000	234,900	171,700	338,200	240,400
0.04	25	105,600	157,900	118,000	211,400	153,200
0.1	10	68,800	86,100	69,500	93,400	76,300
0.2	5	41,500	50,400	44,000	49,000	41,600
0.5	2	16,400	17,000	16,400	15,600	14,800

*2004 USGS reports 250-yr

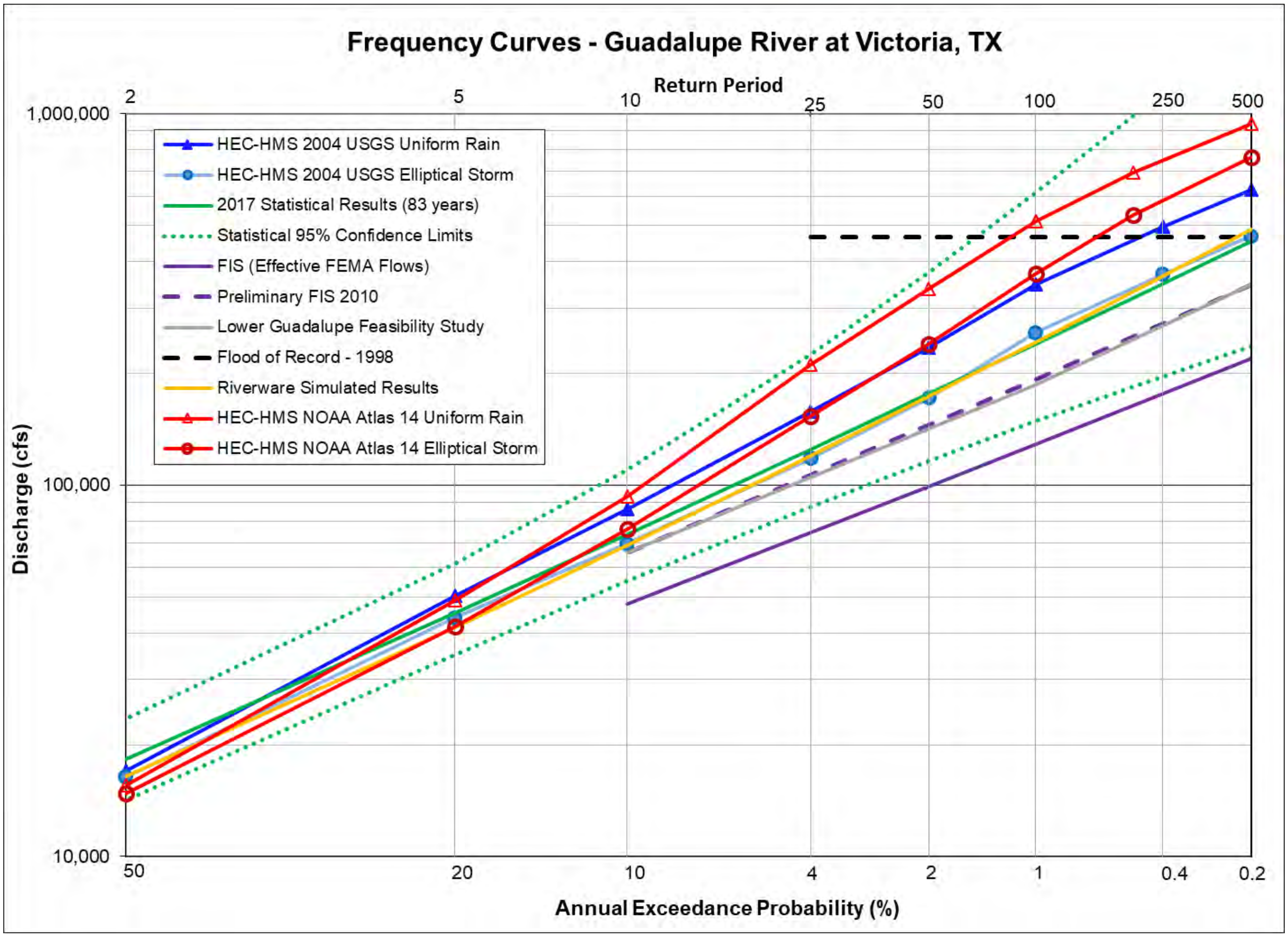


Figure 11.21: Flow Frequency Curve Comparison for the Guadalupe River at Victoria

For Fifteenmile Creek near Weser (Table and Figure 11.22), the statistical results are based on a relatively short period of record (31 years). The calibrated HEC-HMS watershed model was able to reproduce the observed timing of the tributaries above this gage and should be more reliable. At this location, there was very little difference between the HEC-HMS results from NOAA Atlas 14 versus the 2004 USGS rainfall. The HEC-HMS results also happen to be fairly consistent with the regional regression equations in this part of the watershed.

For Coleto Creek at Arnold Crossing (Table and Figure 11.23), this gage also has a relatively short period of record (37 years). An alternative statistical analysis was performed that combined this gage record with the record of a discontinued gage, Coleto Creek near Schroeder. That analysis extended the combined record to 68 years and had the effect of lowering the 1% ACE (100-yr) peak flow estimate. In this location, the NOAA Atlas 14 rainfall resulted in a modest increase in the HEC-HMS results, which lined up better with the alternate statistical analysis results. The flood of record at this location was Hurricane Beulah in 1967, which dumped almost 25 inches of rain upstream of Schroeder over a two day period (USGS, 1974), and the new NOAA Atlas 14 HEC-HMS results would put that event's discharge at close to a 500-yr frequency.

For Perdido Creek at FM 622 near Fannin (Table and Figure 11.24), the statistical record is about 37 years and does not include any estimates from Hurricane Beulah. At this location, there was very little difference between the HEC-HMS results from NOAA Atlas 14 versus the 2004 USGS rainfall. The 1% ACE (100-yr) peak flow estimates from HEC-HMS happen to line up well with the statistical curve and the flood of record in 2004. Since Perdido Creek is a flashier watershed with quicker response times than the rest of the Coleto Creek watershed, its peak flow estimates are significantly higher than what the regional regression equations would estimate.

The gage for Coleto Creek near Victoria (Table and Figure 11.25) is located just downstream of Coleto Creek reservoir. The gage has a medium length record (55 years), but Hurricane Beulah has a pronounced effect on upper end of the statistical frequency curve. In addition, the USGS rated its measurement of the historic peak for Hurricane Beulah of 236,000 cfs as poor, so there is significant uncertainty in the magnitude of that peak flow. In this location, the NOAA Atlas 14 rainfall resulted in a modest increase in the HEC-HMS results, but there is no significant difference between the uniform rain and the elliptical storm results for this drainage area.

Table 11.22: Frequency Flow Results Comparison for Fifteenmile Creek near Weser

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	USGS Regression Equation	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500		64,400	28,400	57,000	67,700
0.004	200*		49,500	24,700	48,700	53,500
0.01	100		39,800	21,600	37,800	42,900
0.02	50		31,300	18,300	28,600	32,500
0.04	25		24,100	14,800	22,200	21,400
0.1	10		16,000	10,100	12,900	12,100
0.2	5		11,100	6,500	7,820	7,600
0.5	2		5,000	2,300	2,360	2,200

*2004 USGS reports 250-yr

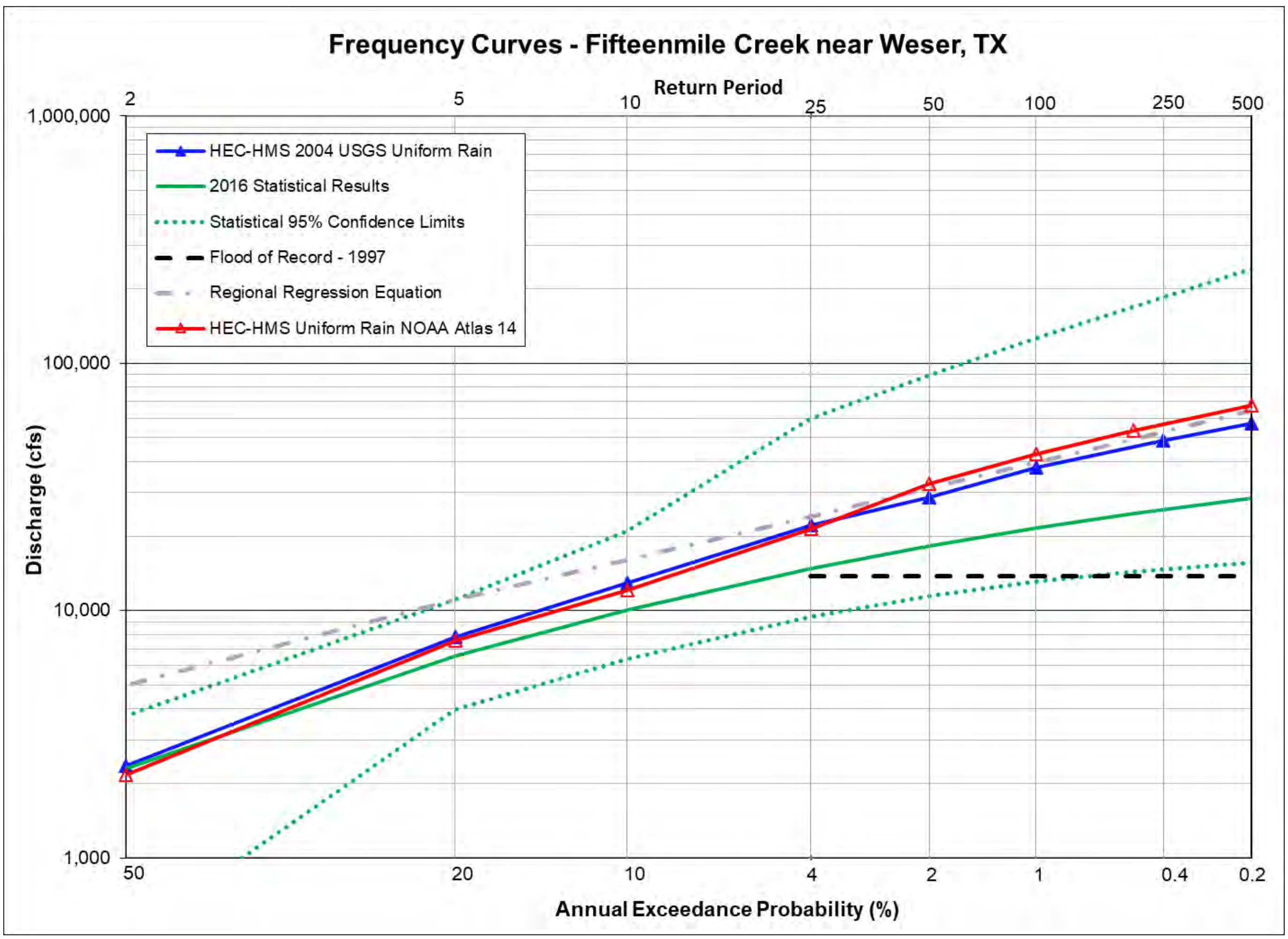


Figure 11.22: Flow Frequency Curve Comparison for the Fifteenmile Creek near Weser

Table 11.23: Frequency Flow Results Comparison for Coleto Creek at Arnold Crossing

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	USGS Regression Equation	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500		105,000	148,800	103,400	125,600
0.004	200*		81,100	119,700	87,900	98,500
0.01	100		65,300	98,680	67,200	78,700
0.02	50		51,500	78,830	50,300	59,900
0.04	25		39,700	60,340	38,600	43,900
0.1	10		26,600	38,410	26,900	27,800
0.2	5		18,600	24,080	19,000	17,100
0.5	2		8,400	8,710	8,790	7,200

*2004 USGS reports 250-yr

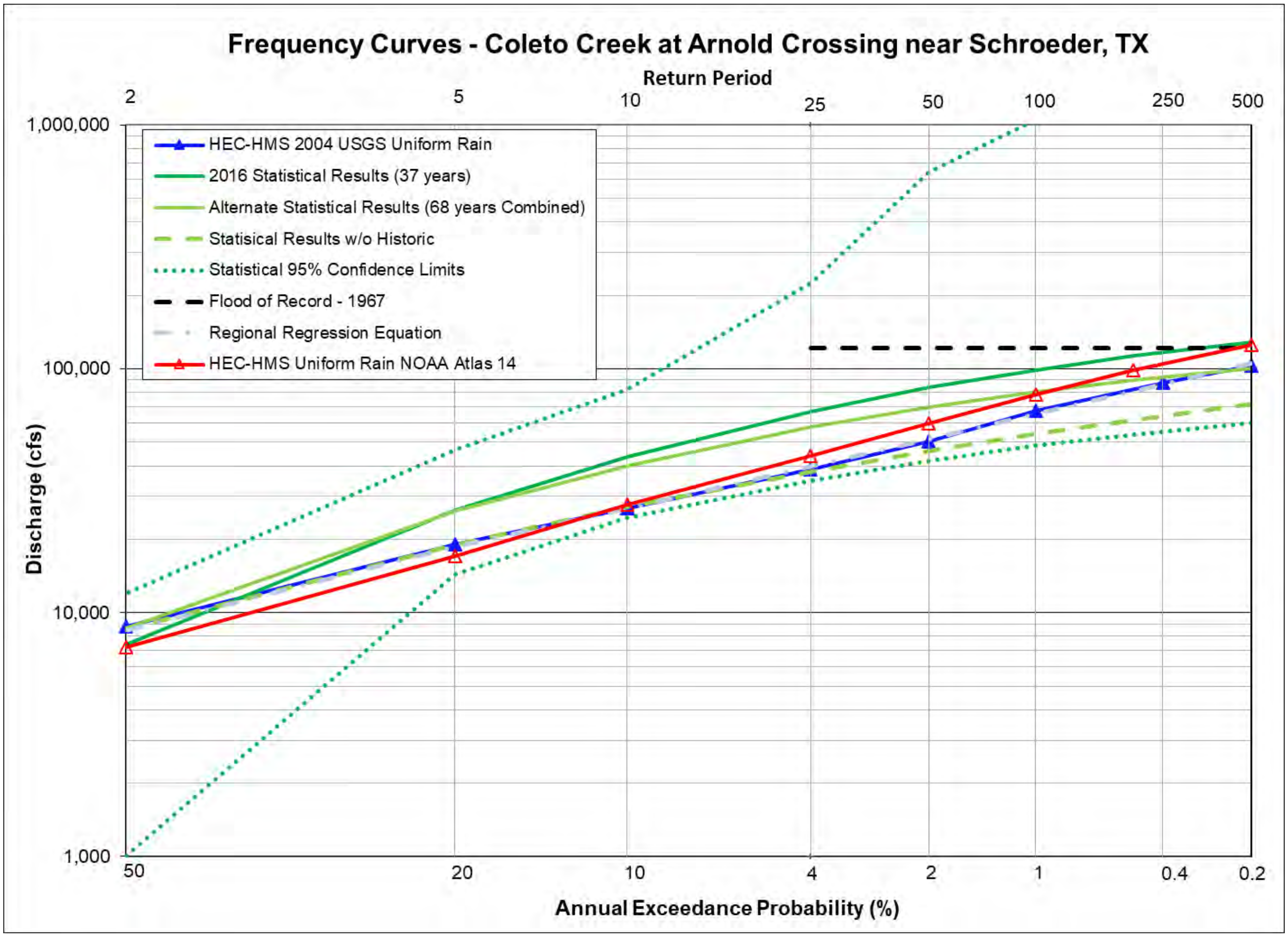


Figure 11.23: Flow Frequency Curve Comparison for Coleto Creek at Arnold Crossing

Table 11.24: Frequency Flow Results Comparison for Perdido Creek at FM 622 near Fannin

Annual Exceedance Probability (AEP)	Return Period (years)	Currently Effective FEMA FIS	USGS Regression Equation	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)
0.002	500		22,800	62,140	38,900	39,700
0.004	200*		17,900	42,690	34,000	34,000
0.01	100		14,200	31,650	28,300	29,600
0.02	50		11,200	23,080	23,700	25,200
0.04	25		8,700	16,470	19,800	19,900
0.1	10		5,800	10,030	12,700	13,300
0.2	5		4,100	6,491	8,570	8,800
0.5	2		1,800	3,049	3,080	3,000

*2004 USGS reports 250-yr

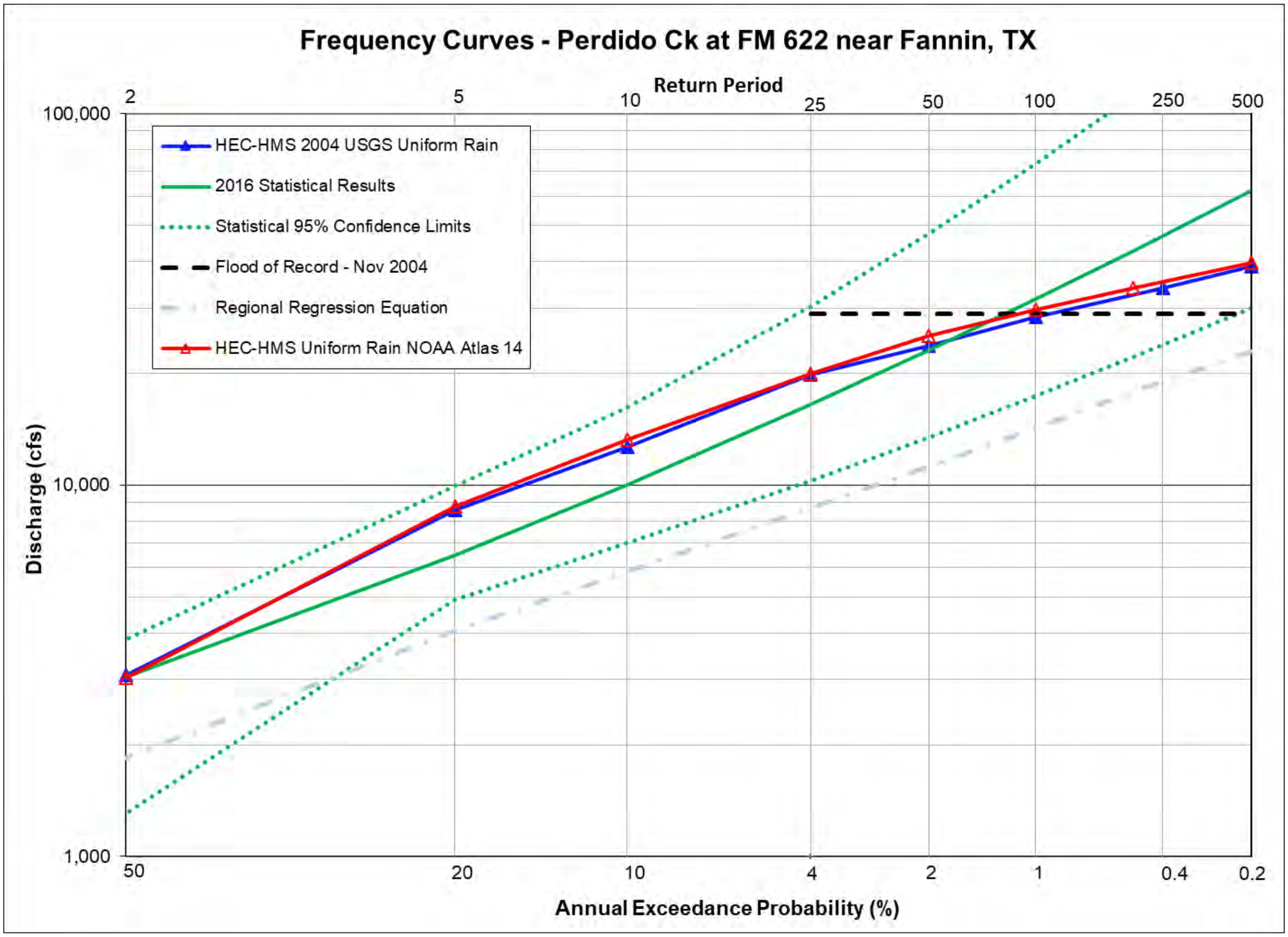


Figure 11.24: Flow Frequency Curve Comparison for Perdido Creek at FM 622 near Fannin

Table 11.25: Frequency Flow Results Comparison for Coleto Creek near Victoria

Annual Exceedance Probability (AEP)	Return Period (years)	USGS Regression Equation	2016 Statistical Analysis	HEC-HMS Model 2004 USGS Uniform Rain (cfs)	HEC-HMS Model 2004 USGS Elliptical Storm	HEC-HMS Model NOAA Atlas 14 Uniform Rain (cfs)	HEC-HMS Model NOAA Atlas 14 Elliptical Storm (cfs)
0.002	500	129,100	276,300	148,000	146,000	180,200	179,500
0.004	200*	100,200	190,200	126,500	125,000	143,800	143,400
0.01	100	80,900	140,900	98,800	96,600	117,200	117,100
0.02	50	64,000	102,400	72,100	73,300	90,800	90,200
0.04	25	49,500	72,530	59,000	56,800	67,800	68,400
0.1	10	33,300	43,410	41,100	40,200	44,300	44,300
0.2	5	23,400	27,440	27,100	26,000	29,200	26,500
0.5	2	10,700	12,110	10,600	10,700	11,800	9,700

*2004 USGS reports 250-yr

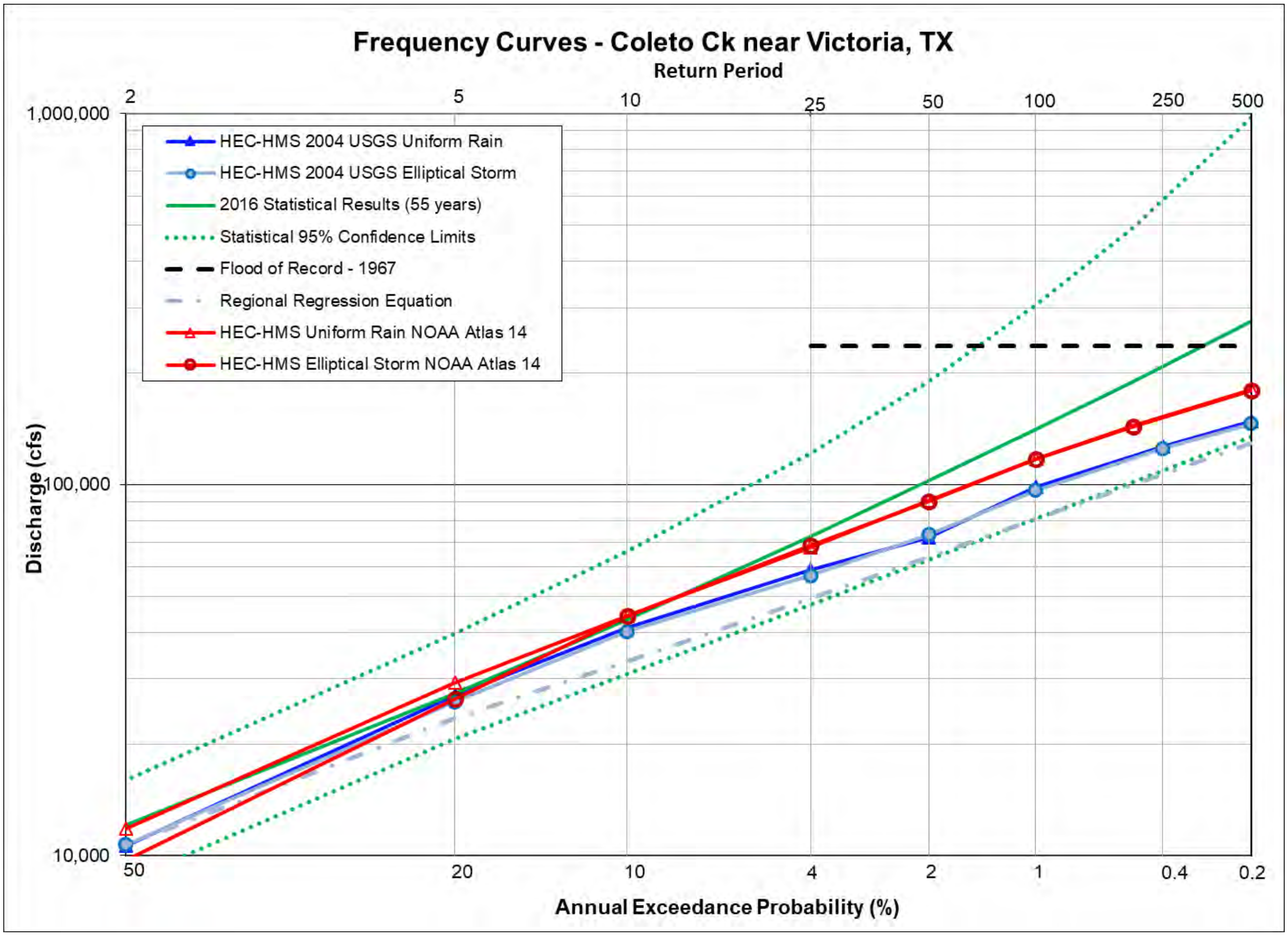


Figure 11.25: Flow Frequency Curve Comparison for Coleto Creek near Victoria

12 Frequency Flow Recommendations

The final recommendations for the InFRM Watershed Hydrology Assessments are formulated through a rigorous process which requires technical feedback and collaboration between all of the InFRM subject matter experts. This process includes the following steps at a minimum: (1) comparing the results of the various hydrologic methods to one another, (2) performing an investigation into the reasons for the differences in results at each location in the watershed, (3) selecting of the draft recommended methods, (4) performing interal and external technical reviews of the hydrologic analyses and the draft recommendations, and finally, (5) finalizing the study recommendations.

After completing this process for the Guadalupe River basin, the frequency discharges that were recommended for adoption by the InFRM team were a combination of the results from the following methods: HEC-HMS NOAA Atlas 14 uniform rain (Chapter 10.2), HEC-HMS NOAA Atlas 14 Elliptical Storms (Chapter 10.3), and the Canyon Dam Reservoir Study (Chapter 9). A detailed breakout of the recommended discharges for each node in the watershed is given in Table 12.1.

The statistical results from Chapter 5 and the Riverware statistical results from Chapter 8 were used as a point of comparison, especially at the frequent end of the curves, but the InFRM team chose not to adopt the statistical flow frequency results directly. One reason for this decision was the tendency of the statistical results to change after each significant flood event, as demonstrated in the change over time plots in Section 5.3. In addition, climate variability from wet to dry may result in non-representative samples in the gage record. Rainfall runoff modeling, on the other hand, is based on physical watershed characteristics, such as drainage area and stream slope, that do not tend to change as much over time. Climate variability can also be accounted for in the watershed model by adjusting soil loss rates to be consistent with observed storms and with the rarity of the event in question. Another reason for the selection of the HEC-HMS modeling discharges was the ability to directly calculate frequency discharges for other locations within the Guadalupe River watershed that do not coincide with a stream gage. The statistical frequency analyses and Riverware results support the HEC-HMS modeling results by demonstrating that they are within the confidence limits, especially for the 1% and 0.2% AEP events of interest for FEMA floodplain mapping.

Rainfall-runoff modeling in HEC-HMS was used to simulate the physical processes that occur in the watershed during storm events, such as the movement of water across the land surface and through the streams and rivers. The HEC-HMS model for the Guadalupe River basin underwent extensive calibration to accurately simulate the response of the watershed to a range of observed flood events, including large events similar to a 1% ACE (100-yr) flood. In fact, a total of twenty recent storm events were used to fine tune the HEC-HMS model; thereby bestowing a high degree of confidence in the HEC-HMS model's results.

Within the HEC-HMS modeling results, the frequency discharges resulting from the NOAA Atlas 14 rainfall depths in Chapter 10 (NOAA, 2018) were recommended over the results from the 2004 USGS rainfall depths (USGS, 2004) in Chapters 6 and 7. There are several factors that make NOAA Atlas 14 the most accurate, up-to-date, and comprehensive study of rainfall depths in Texas. First, the NOAA Atlas 14 study contained an additional 23 years of rainfall data compared to the 2004 USGS study, which only included data through 1994. Some of the largest storms on record in the Guadalupe River basin have occurred within the last 23 years, and the 2004 USGS rainfall study did not include any data from large Guadalupe flood events like 1998, 2002, and 2015. Secondly, NOAA Atlas 14 used a regional statistical approach that incorporated at least 1,000 cumulative years of daily data and 500 cumulative years of sub-daily data into each station's rainfall frequency estimate. This regional approach yielded better estimates of rare rainfall depths such as the 1% and 0.2% AEP (100-yr and 500-yr) depths. Finally, NOAA Atlas 14 employed better spatial interpolation techniques that accounted for the orographic effects of the Texas Hill Country. The orographic uplift caused by the Balcones escarpment tends to result in more intense rainfall in the eastern Hill Country than in the surrounding areas; therefore, the spatial interpolation techniques of NOAA Atlas 14 are better suited for capturing rainfall variations in the Guadalupe River basin. For these reasons, the calibrated HEC-HMS watershed modeling with the NOAA Atlas 14 rainfall depths was adopted as having the most complete accounting of both the historic rainfall data and the physical processes at work in the watershed.

Between the uniform rain and the elliptical storm HEC-HMS results presented in Chapter 10, the uniform rain method is simpler and well suited for smaller drainage areas, while the elliptical storm method is more complex and better suited for larger drainage areas. As discussed in Section 7.9, the results from the uniform rainfall method in HEC-HMS generally appeared to be reasonable up to at least 1,000 square miles. For larger drainage areas in the Guadalupe River basin, which ranged from 1,000 to 4,400 square miles, the elliptical storm results from HEC-HMS did a better job of producing reasonable runoff volumes and subsequently peak stream flows. The elliptical storms also did a better job of reproducing the observed flood hydrograph attenuation in the upper Guadalupe River basin above Canyon Dam and on the San Marcos River below the Blanco River. Therefore, the InFRM team recommended that the NOAA Atlas 14 HEC-HMS elliptical storm results be adopted for three areas: (1) the upper Guadalupe River from below Johnson Creek to Canyon Lake, (2) the San Marcos River from below the Blanco River to the Guadalupe River, and (3) the Guadalupe River from below the San Marcos River to Bloomington, Texas. For all other stream reaches, the NOAA Atlas 14 HEC-HMS uniform rain results are recommended. The only exception are the Guadalupe River reaches immediately downstream of Canyon Dam.

For the reaches of the Guadalupe River just downstream of Canyon Dam, there are two distinct sources of flooding: (1) a large release from Canyon Dam and (2) local rainfall runoff from the drainage area downstream of Canyon Dam. For the first flooding source, the frequency of releases from Canyon Dam were calculated in the reservoir study in Chapter 9. The reservoir study for Canyon Dam took the most detailed and comprehensive look at the operations of the dam, the frequency and volumes of the inflow hydrographs, and expected frequency of its pool elevations. The resulting recommended frequency pool elevations for Canyon Lake are shown in Table 12.2. The corresponding frequency outflows from Canyon Dam are shown in Table 12.1 under the Guadalupe River at Sattler location. For the second flooding source, peak flows from the local rainfall runoff were calculated in the HEC-HMS model with the NOAA Atlas 14 rainfall in Chapter 10. The frequency peak flows from these two flooding sources were then compared to one another for each reach of the river, and the higher of the two peak flows were recommended for adoption. In general, the results showed that releases from Canyon Dam dominate the Guadalupe River discharges immediately downstream of the dam, and then as one continues downstream, the flows from the local rainfall runoff increase and eventually become dominant. By the time one reaches the Guadalupe River below the Comal River, the HEC-HMS results completely dominate the reservoir releases. This is shown in Table 12.1 below.

Table 12.1: Summary of Recommended Frequency Flows for the Guadalupe River Basin

Location Description	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%	Hydrologic Method
	sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR	
North Fork Guadalupe River near Hunt TX (USGS Gage)	168.2	3,800	20,800	39,800	69,900	88,900	107,800	126,300	152,400	HEC-HMS NA14 Uniform Rain
North Fork Guadalupe River above South Fork Guad River	189.2	3,600	20,300	38,900	69,200	90,500	110,600	130,200	157,800	HEC-HMS NA14 Uniform Rain
Guadalupe River below South Fork Guad River near Hunt (USGS Gage)	286.6	6,200	31,700	57,200	99,500	136,500	167,400	197,500	240,200	HEC-HMS NA14 Uniform Rain
Guadalupe River above Johnson Creek	311.4	5,600	28,900	52,300	94,900	132,000	163,300	193,900	237,000	HEC-HMS NA14 Uniform Rain
Johnson Creek near Ingram TX (USGS Gage)	113.5	1,400	8,000	24,900	60,700	89,100	105,200	121,100	143,600	HEC-HMS NA14 Uniform Rain
Johnson Creek above Guadalupe River	126.8	1,200	7,400	24,100	62,400	92,000	109,300	126,300	150,400	HEC-HMS NA14 Uniform Rain
Guadalupe River below Johnson Creek	438.1	1,700	20,200	46,600	109,100	166,800	211,100	255,800	318,500	HEC-HMS NA14 Elliptical Storm
Guadalupe River at Kerrville (USGS Gage)	485.7	4,100	21,100	46,400	111,000	169,400	215,300	261,400	325,800	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Turtle Creek	563.8	4,600	23,700	49,700	114,000	174,300	223,900	272,900	341,500	HEC-HMS NA14 Elliptical Storm
Guadalupe River below Turtle Creek	634.3	9,900	36,300	64,300	130,100	196,000	252,100	307,900	386,200	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Verde Creek	652.4	11,000	37,300	66,500	134,100	201,300	259,400	317,600	399,800	HEC-HMS NA14 Elliptical Storm
Guadalupe River below Verde Creek	708.6	10,100	38,000	66,800	131,500	198,000	256,300	314,400	395,200	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Cypress Creek	763.5	9,000	35,200	62,700	126,100	190,500	248,200	305,300	385,200	HEC-HMS NA14 Elliptical Storm
Guadalupe River below Cypress Creek at Comfort (USGS Gage)	837.0	11,800	41,200	70,500	133,200	201,000	263,900	325,800	412,000	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Block Creek	865.1	15,200	47,100	78,800	144,700	216,300	284,400	351,700	446,600	HEC-HMS NA14 Elliptical Storm
Guadalupe River below Block Creek	909.7	11,600	40,500	69,200	131,800	198,400	260,600	322,500	409,200	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Joshua Creek	929.7	11,500	40,100	69,500	131,100	197,000	259,600	322,100	409,800	HEC-HMS NA14 Elliptical Storm
Guadalupe River below Joshua Creek	971.3	11,800	40,300	69,600	131,100	196,500	258,800	320,200	407,000	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Sister Creek	983.9	12,100	40,900	70,500	132,100	197,700	260,300	322,700	410,400	HEC-HMS NA14 Elliptical Storm
Guadalupe River below Sister Creek	1048.2	12,100	41,200	71,000	133,100	198,900	261,900	324,700	412,800	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Curry Creek	1197.2	10,200	35,800	62,500	116,200	172,700	228,700	285,100	364,000	HEC-HMS NA14 Elliptical Storm
Guadalupe River below Curry Creek	1266.4	11,200	37,800	65,500	120,900	179,200	237,300	295,800	378,100	HEC-HMS NA14 Elliptical Storm

Location Description	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%	Hydrologic Method
	sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR	
Guadalupe River near Spring Branch TX (USGS Gage)	1313.7	11,100	37,700	65,200	120,100	177,900	235,800	294,000	375,800	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Canyon Lake	1360.0	10,900	37,300	64,700	119,200	176,300	233,600	291,200	372,300	HEC-HMS NA14 Elliptical Storm
Peak Inflow into Canyon Lake	1431.1	11,500	38,400	66,300	121,800	179,800	238,700	297,500	380,300	HEC-HMS NA14 Elliptical Storm
	NOTE: Drainage Areas below do NOT include the area above Canyon Dam									
Guadalupe River at Sattler (USGS Gage below Canyon Dam)	4.0	700	1,400	2,500	4,300	5,000	21,100	82,600	164,000	Canyon Reservoir Study
Guadalupe River above Bear Creek	36.0	7,100	16,100	23,600	33,200	41,200	48,600	82,600	164,000	HEC-HMS NA14 Uniform Rain + Canyon Reservoir Study
Bear Creek above Guadalupe River	16.7	3,800	8,500	12,400	17,100	21,000	24,600	28,900	35,400	HEC-HMS NA14 Uniform Rain
Guadalupe River below Bear Creek	52.8	10,000	23,100	34,000	47,500	59,000	69,400	82,600	164,000	HEC-HMS NA14 Uniform Rain + Canyon Reservoir Study
Guadalupe River above the Comal River (USGS Gage)	88.3	7,300	22,500	37,400	57,600	74,400	88,300	104,800	164,000	HEC-HMS NA14 Uniform Rain + Canyon Reservoir Study
Dry Comal Creek below the Wests Fork	54.0	700	2,000	3,000	4,500	10,400	18,700	26,900	37,600	HEC-HMS NA14 Uniform Rain
Dry Comal Creek above Bear Creek	55.4	600	2,000	3,300	5,200	10,200	18,400	26,700	37,400	HEC-HMS NA14 Uniform Rain
Dry Comal Creek below Bear Creek	68.7	700	2,000	3,300	5,200	10,700	19,600	28,900	41,300	HEC-HMS NA14 Uniform Rain
Dry Comal Creek above Tributary 14	89.0	1,900	5,600	9,400	14,800	18,700	25,100	33,100	44,400	HEC-HMS NA14 Uniform Rain
Dry Comal Creek below Tributary 14	94.7	2,200	6,700	10,700	16,200	20,100	26,600	36,900	50,900	HEC-HMS NA14 Uniform Rain
Dry Comal Creek at Loop 337 near New Braunfels (USGS Gage)	107.3	2,300	7,000	11,700	18,700	23,700	30,100	39,600	54,200	HEC-HMS NA14 Uniform Rain
Dry Comal Creek above Comal Rivr	111.2	2,100	6,700	11,400	18,500	23,500	29,900	38,500	51,400	HEC-HMS NA14 Uniform Rain
Comal River below Dry Comal Creek	128.3	2,500	7,400	12,700	22,500	29,700	39,200	50,500	67,400	HEC-HMS NA14 Uniform Rain
Comal River at New Braunfels (USGS Gage)	129.5	2,600	7,400	12,700	22,500	29,800	39,400	50,700	67,600	HEC-HMS NA14 Uniform Rain
Comal River above Guadalupe River	130.1	2,600	7,400	12,800	22,500	29,800	39,400	50,700	67,600	HEC-HMS NA14 Uniform Rain
Guadalupe River below the Comal River	218.4	8,600	27,400	46,900	75,300	97,700	119,000	143,800	181,700	HEC-HMS NA14 Uniform Rain
Guadalupe River at Lake Dunlap	233.4	9,100	27,500	44,600	69,200	89,500	110,000	135,900	170,900	HEC-HMS NA14 Uniform Rain
Guadaulupe River above Tributary 22	234.1	9,000	27,400	44,500	69,100	89,500	109,900	135,900	171,000	HEC-HMS NA14 Uniform Rain
Guadaulupe River below Tributary 22	238.6	9,100	27,700	45,000	69,800	90,500	111,200	137,500	173,000	HEC-HMS NA14 Uniform Rain
Guadalupe River above Long Creek	239.6	8,900	26,700	43,900	68,200	88,900	109,600	135,700	171,100	HEC-HMS NA14 Uniform Rain

Location Description	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%	Hydrologic Method
	sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR	
Guadaupe River below Long Creek	251.1	9,300	28,000	46,000	71,500	93,200	115,100	142,300	179,300	HEC-HMS NA14 Uniform Rain
Guadalupe River above Tributary 20	251.5	9,300	27,900	45,800	71,100	92,500	114,000	141,000	178,600	HEC-HMS NA14 Uniform Rain
Guadaupe River below Tributary 20	260.4	9,400	28,400	46,700	72,600	94,400	116,500	144,200	182,900	HEC-HMS NA14 Uniform Rain
Guadalupe River at Lake McQueeney	264.0	9,400	28,000	44,600	68,100	87,500	109,900	136,400	175,000	HEC-HMS NA14 Uniform Rain
Guadalupe River above Youngs Creek	264.7	9,400	28,000	44,600	68,000	87,400	109,700	136,200	174,600	HEC-HMS NA14 Uniform Rain
Guadalupe River below Youngs Creek	279.4	9,600	28,500	45,300	69,200	89,100	112,400	139,700	178,900	HEC-HMS NA14 Uniform Rain
Guadalupe River above the smaller Cottonwood Ck	279.7	9,600	28,500	45,300	69,200	89,100	112,400	139,700	178,800	HEC-HMS NA14 Uniform Rain
Guadalupe River below the smaller Cottonwood Ck	285.7	9,700	28,600	45,500	69,700	89,800	113,400	141,000	180,400	HEC-HMS NA14 Uniform Rain
Guadalupe River above Little Mill Ck	286.3	9,700	28,400	45,200	69,300	89,400	112,600	140,000	179,600	HEC-HMS NA14 Uniform Rain
Guadalupe River below Little Mill Ck	295.0	9,800	28,800	45,800	70,200	90,600	114,300	142,200	182,400	HEC-HMS NA14 Uniform Rain
Guadalupe River above Deadman Ck	296.4	9,800	28,700	45,400	69,600	90,000	113,600	141,400	182,000	HEC-HMS NA14 Uniform Rain
Guadalupe River below Deadman Ck	304.9	10,500	28,900	45,700	69,900	90,500	114,600	142,600	183,800	HEC-HMS NA14 Uniform Rain
Guadalupe River at Lake Placid	304.9	10,500	28,800	45,400	69,600	90,400	114,500	142,600	183,700	HEC-HMS NA14 Uniform Rain
Guadalupe River at Meadow Lake	327.2	11,500	29,200	44,200	66,200	86,500	111,000	139,100	179,700	HEC-HMS NA14 Uniform Rain
Guadalupe River above Cottonwood Ck	327.2	11,500	29,200	44,200	66,200	86,500	111,000	139,100	179,700	HEC-HMS NA14 Uniform Rain
Guadalupe River below Cottonwood Ck	368.3	12,000	33,600	50,000	72,200	94,400	122,800	154,100	199,200	HEC-HMS NA14 Uniform Rain
Guadalupe River above Geronimo Ck	369.5	11,500	33,200	49,600	72,000	93,900	121,600	152,700	197,600	HEC-HMS NA14 Uniform Rain
Geronimo Ck at I-10 near Seguin	59.7	4,500	11,600	16,900	24,200	30,600	38,400	46,900	59,400	HEC-HMS NA14 Uniform Rain
Geronimo Ck above Guadalupe River	69.7	2,900	8,600	13,700	21,700	29,900	38,200	47,500	62,500	HEC-HMS NA14 Uniform Rain
Guadalupe River below Geronimo Ck	439.2	13,800	40,100	60,200	86,200	109,700	141,100	178,400	231,700	HEC-HMS NA14 Uniform Rain
Guadalupe River above Cantau Ck	443.5	12,900	38,500	59,000	85,400	109,300	140,300	177,200	230,100	HEC-HMS NA14 Uniform Rain
Guadalupe River at FM 1117 near Seguin (USGS Gage)	450.1	12,900	38,600	59,300	85,700	109,600	140,900	178,100	231,400	HEC-HMS NA14 Uniform Rain
Guadalupe River above Mill Ck	481.8	10,300	33,200	55,300	83,900	109,400	141,300	179,300	235,200	HEC-HMS NA14 Uniform Rain
Guadalupe River below Mill Ck	521.2	10,700	34,900	58,200	89,000	116,400	150,500	191,700	251,400	HEC-HMS NA14 Uniform Rain
Guadalupe River above Nash Creek	553.7	8,100	31,100	54,900	86,500	115,200	150,800	193,600	255,500	HEC-HMS NA14 Uniform Rain

Location Description	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%	Hydrologic Method
	sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR	
Guadalupe River below Nash Creek	580.2	8,100	31,300	55,500	87,500	116,900	153,800	198,200	262,200	HEC-HMS NA14 Uniform Rain
Guadalupe River at Lake Gonzales	615.9	7,300	26,800	50,000	85,300	117,500	156,800	204,600	273,200	HEC-HMS NA14 Uniform Rain
Guadalupe River at Wood Lake	667.4	6,800	22,400	40,800	76,200	109,000	149,600	201,100	273,200	HEC-HMS NA14 Uniform Rain
Guadalupe River above the San Marcos River	671.8	6,400	20,100	38,200	72,800	106,400	147,600	197,700	270,900	HEC-HMS NA14 Uniform Rain
Blanco River below Little Blanco	237.8	8,800	35,900	61,400	103,400	147,300	187,500	227,200	284,500	HEC-HMS NA14 Uniform Rain
Blanco River above Wanslow Creek	239.0	8,700	35,800	61,200	103,300	147,100	187,700	227,100	284,600	HEC-HMS NA14 Uniform Rain
Blanco River below Wanslow Creek	252.4	8,700	36,100	62,100	105,900	151,600	193,700	235,300	295,400	HEC-HMS NA14 Uniform Rain
Blanco River at Fischer Store Rd (USGS Gage)	268.8	8,500	35,500	61,300	105,500	152,800	196,100	238,400	299,800	HEC-HMS NA14 Uniform Rain
Blanco River above Carpers Creek	274.7	8,500	35,100	60,700	104,800	152,100	195,400	237,800	299,000	HEC-HMS NA14 Uniform Rain
Blanco River below Carpers Creek	290.0	8,500	35,400	61,600	107,200	156,400	201,200	245,300	308,700	HEC-HMS NA14 Uniform Rain
Blanco River above Wilsoon Creek	310.7	8,300	34,700	60,600	106,100	155,600	202,300	247,900	312,800	HEC-HMS NA14 Uniform Rain
Blanco River below Wilson Creek	316.0	8,300	34,800	60,600	106,100	155,900	203,000	248,800	314,100	HEC-HMS NA14 Uniform Rain
Blanco River above Cypress Creek	316.9	8,300	34,800	60,700	106,000	155,900	203,000	248,600	314,100	HEC-HMS NA14 Uniform Rain
Blanco River at Wimberley (USGS Gage)	355.1	8,500	35,300	61,600	108,000	161,100	211,300	259,900	329,800	HEC-HMS NA14 Uniform Rain
Blanco River above Lone Man Creek	370.5	8,300	34,800	60,900	106,800	159,500	210,300	259,900	330,300	HEC-HMS NA14 Uniform Rain
Blanco River below Lone Man Creek	382.9	8,300	35,000	61,500	108,000	161,600	213,500	264,000	335,900	HEC-HMS NA14 Uniform Rain
Blanco River above Halifax Creek	392.7	8,200	34,600	61,100	107,600	161,200	213,600	264,900	337,300	HEC-HMS NA14 Uniform Rain
Blanco River below Halifax Creek	405.6	8,200	34,800	61,600	108,600	162,900	216,500	268,800	342,600	HEC-HMS NA14 Uniform Rain
Blanco River near Kyle (USGS Gage)	412.3	8,100	34,400	61,000	107,500	162,000	216,500	269,300	343,500	HEC-HMS NA14 Uniform Rain
Blanco River at I-35 Bridge near San Marcos, TX	432.7	7,800	33,200	59,300	103,500	157,100	213,900	269,100	344,400	HEC-HMS NA14 Uniform Rain
Blanco River above San Marcos River	436.2	7,200	31,900	55,500	99,700	149,700	207,000	256,800	328,100	HEC-HMS NA14 Uniform Rain
Below SCS Dam No. 5	37.1	800	4,000	9,200	16,300	21,900	28,200	34,400	43,100	HEC-HMS NA14 Uniform Rain
San Marcos River at San Marcos (USGS Gage)	49.0	500	1,800	2,900	4,800	9,600	18,600	28,300	42,200	HEC-HMS NA14 Uniform Rain
San Marcos River below Purgatory Cr	87.1	1,100	3,900	9,300	17,200	25,400	36,200	52,000	76,700	HEC-HMS NA14 Uniform Rain

Location Description	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%	Hydrologic Method
	sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR	
San Marcos River above Blanco River	95.1	2,500	5,200	9,100	17,200	25,800	36,800	52,200	77,300	HEC-HMS NA14 Uniform Rain
San Marcos River below Blanco River	531.3	8,700	29,400	54,200	108,700	153,300	216,700	273,500	358,800	HEC-HMS NA14 Elliptical Storm
San Marcos River above York Creek	613.6	8,500	26,700	50,600	98,000	135,600	191,600	259,300	344,000	HEC-HMS NA14 Elliptical Storm
York Creek above San Marcos River	142.9	3,100	12,900	21,100	34,700	46,900	61,800	77,600	99,600	HEC-HMS NA14 Uniform Rain
San Marcos River below York Creek	756.6	9,000	28,500	54,100	102,800	142,800	204,200	278,700	371,400	HEC-HMS NA14 Elliptical Storm
San Marcos River at Luling (USGS Gage)	838.9	8,900	27,500	52,600	100,600	140,700	201,900	274,700	370,400	HEC-HMS NA14 Elliptical Storm
San Marcos River above Plum Creek	861.8	7,800	24,600	48,600	94,400	132,800	188,000	258,900	355,700	HEC-HMS NA14 Elliptical Storm
Plum Creek at Lockhart (USGS Gage)	111.3	3,800	13,200	21,500	37,200	51,300	64,200	78,100	97,900	HEC-HMS NA14 Uniform Rain
Plum Creek above Tenney Creek	194.6	5,700	13,400	19,400	33,000	57,800	79,700	103,700	137,500	HEC-HMS NA14 Uniform Rain
Plum Creek below Tenney Creek	234.4	8,100	19,200	28,100	43,000	65,200	91,100	120,000	160,100	HEC-HMS NA14 Uniform Rain
Plum Creek near Luling (USGS Gage)	351.5	6,700	16,800	31,000	53,900	80,900	112,000	149,600	205,100	HEC-HMS NA14 Uniform Rain
Plum Creek above San Marcos River	388.8	5,900	15,600	27,300	49,600	79,100	110,300	148,000	203,600	HEC-HMS NA14 Uniform Rain
San Marcos River below Plum Creek	1250.6	12,000	38,200	71,000	130,700	183,100	262,900	366,000	497,200	HEC-HMS NA14 Elliptical Storm
San Marcos River above the Guadalupe River	1359.0	10,500	30,400	58,400	114,000	165,400	238,000	325,600	451,300	HEC-HMS NA14 Elliptical Storm
Guadalupe River below the San Marcos River at Gonzales (USGS Gage)	2030.8	17,500	50,300	88,900	158,800	236,700	338,800	460,700	625,500	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Peach Creek	2100.3	16,100	47,000	83,900	152,200	229,600	333,300	456,000	622,100	HEC-HMS NA14 Elliptical Storm
Peach Creek below Dilworth (USGS Gage)	459.8	6,000	16,300	26,100	48,700	69,100	96,600	123,700	162,900	HEC-HMS NA14 Uniform Rain
Peach Creek above the Guadalupe River	482.5	5,800	15,600	24,400	47,300	67,600	95,100	122,800	162,300	HEC-HMS NA14 Uniform Rain
Guadalupe River below Peach Creek	2582.8	16,400	50,200	93,300	173,100	259,100	378,600	522,500	718,600	HEC-HMS NA14 Elliptical Storm
Guadalupe River above McCoy Ck	2705.2	15,300	47,500	87,900	165,500	248,800	367,100	507,200	700,800	HEC-HMS NA14 Elliptical Storm
Guadalupe River below McCoy Ck	2737.8	15,400	47,600	88,200	165,900	249,300	367,700	507,900	701,600	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Sandies Ck	2786.2	15,100	44,300	81,000	154,600	236,600	354,800	495,100	689,100	HEC-HMS NA14 Elliptical Storm
Sandies Ck near Westhof (USGS Gage)	549.4	3,700	11,900	21,800	43,000	62,800	90,100	116,300	161,700	HEC-HMS NA14 Uniform Rain
Sandies Ck above the Guadalupe River	711.1	3,600	10,800	20,400	40,600	59,400	87,500	120,600	180,200	HEC-HMS NA14 Uniform Rain

Location Description	Drainage Area	50%	20%	10%	4%	2%	1%	0.50%	0.20%	Hydrologic Method
	sq mi	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR	500-YR	
Guadalupe River below Sandies Ck at Cuero (USGS Gage)	3497.4	15,100	45,900	88,500	173,000	264,600	401,500	563,000	787,100	HEC-HMS NA14 Elliptical Storm
Guadalupe River at Victoria (USGS Gage)	3767.1	14,800	41,600	76,300	153,200	240,400	372,100	533,500	764,400	HEC-HMS NA14 Elliptical Storm
Guadalupe River above Coleto Creek	3802.7	14,200	41,400	75,600	148,900	236,700	361,900	522,600	760,700	HEC-HMS NA14 Elliptical Storm
Fifteenmile Ck near Weser (USGS Gage)	164.5	2,200	7,600	12,100	21,400	32,500	42,900	53,500	67,700	HEC-HMS NA14 Uniform Rain
Fifteenmile Ck above Eighteenmile Ck	182.5	2,100	7,300	11,800	20,700	31,600	41,900	52,400	66,500	HEC-HMS NA14 Uniform Rain
Eighteenmile Ck above Fifteenmile Ck	48.0	3,100	6,400	9,600	14,800	18,900	23,600	28,400	34,500	HEC-HMS NA14 Uniform Rain
Fifteenmile Ck below Eighteenmile Ck	230.5	4,300	10,300	16,000	26,000	35,300	45,400	56,100	70,200	HEC-HMS NA14 Uniform Rain
Fifteenmile Ck above Twelvemile Ck	250.3	5,500	13,000	20,000	32,300	42,900	54,700	66,800	83,000	HEC-HMS NA14 Uniform Rain
Twelvemile Ck above Fifteenmile Ck	105.9	3,800	8,600	15,500	21,700	28,700	37,400	45,700	57,300	HEC-HMS NA14 Uniform Rain
Coleto Creek at Arnold Rd nr Schroeder (USGS Gage)	356.2	7,200	17,100	27,800	43,900	59,900	78,700	98,500	125,600	HEC-HMS NA14 Uniform Rain
Coleto Creek above Perdido Ck	417.7	10,200	24,700	37,700	58,300	76,700	98,400	121,000	152,400	HEC-HMS NA14 Uniform Rain
Perdido Ck at FM 622 nr Fannin (USGS Gage)	27.7	3,000	8,800	13,300	19,900	25,200	29,600	34,000	39,700	HEC-HMS NA14 Uniform Rain
Perdido Ck below Road Ck	55.2	4,800	11,200	16,400	24,700	32,100	39,200	46,100	55,500	HEC-HMS NA14 Uniform Rain
Perdido Ck above Coleto Ck	76.3	6,700	15,000	21,800	32,400	41,900	51,200	60,200	72,300	HEC-HMS NA14 Uniform Rain
Coleto Ck Reservoir near Victoria	494.1	11,800	29,300	44,300	67,800	90,300	115,900	142,100	178,100	HEC-HMS NA14 Uniform Rain
Coleto Creek near Victoria (USGS Gage)	511.3	11,800	29,200	44,300	67,800	90,800	117,200	143,800	180,200	HEC-HMS NA14 Uniform Rain
Coleto Creek above Guadalupe River	540.4	8,500	24,100	40,100	64,100	89,100	115,900	144,600	183,400	HEC-HMS NA14 Uniform Rain
Guadalupe River near Bloomington (USGS Gage)	4382.5	14,100	41,500	75,700	148,600	236,400	365,000	526,900	770,500	HEC-HMS NA14 Elliptical Storm

Table 12.2: Recommended Frequency Pool Elevations for Canyon Lake

Annual Chance of Exceedance	Return Period	Canyon Lake Pool Elevation
%	years	feet (NGVD)
50%	2	912.1
20%	5	919.3
10%	10	926.4
4%	25	939.3
2%	50	944.4
1%	100	946.8
0.4%	250	951.4
0.2%	500	955.7

13 Conclusions

Previous FEMA Flood Insurance Studies (FIS) in the Guadalupe River Basin differed significantly from the new flow frequency results of this study in many locations. In many locations, the new flow frequency results were significantly higher than the effective FIS values. Figures 13.1 to 13.3 below compare the recommended hydrology results with the effective FIS flows and the flood of record at some key locations within the basin.

In most cases the increase in flow frequency estimates is due to a combination of factors including (1) additional gage record length, (2) better calibration of the watershed model, and (3) increased rainfall estimates from NOAA Atlas 14. First, the new flow frequency results from this study are higher than the effective flood insurance values because there have been new floods in the gage record, that when included in the statistical hydrology, produce higher flows. Second, the rainfall-runoff watershed model underwent extensive calibration to accurately simulate the response of the watershed to a range of recent observed flood events, including large events similar to a 1% annual chance (100-yr) flood. The frequency flow results of the calibrated rainfall-runoff watershed model exposed that some of the values calculated in the past using statistical hydrology were not reasonable and did not accurately reflect the response of the watershed to a 1% annual chance (100-yr) storm event. Finally, NOAA Atlas 14's study of rainfall depths in Texas revealed that previous estimates of the 100-yr 24-hr rainfall in the Guadalupe basin had been underestimated by 3 to 4 inches in some areas. This additional rainfall led to significantly higher peak flows on portions of the Blanco, San Marcos, and Guadalupe Rivers.

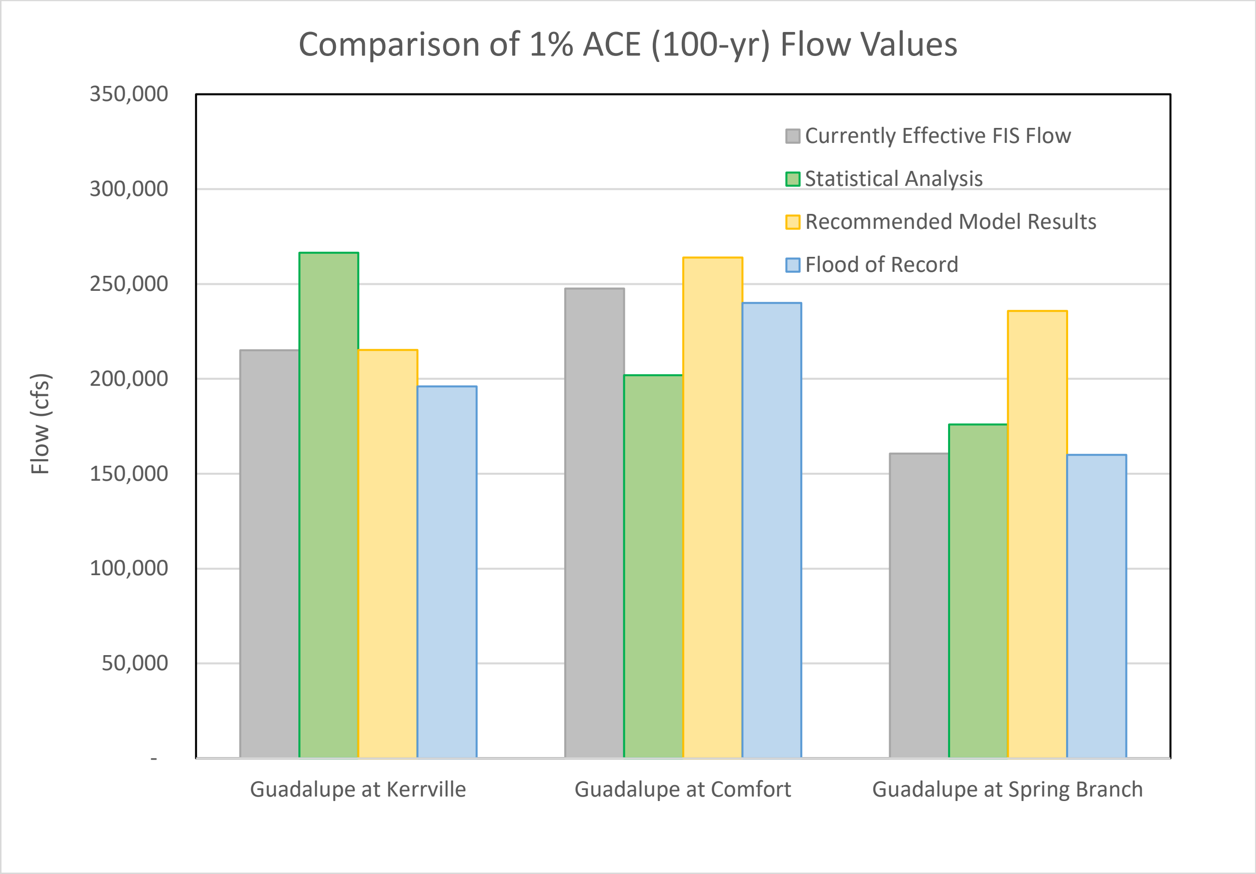


Figure 13.1: Comparison of 1% Annual Chance (100-yr) Flow Results on the Upper Guadalupe River

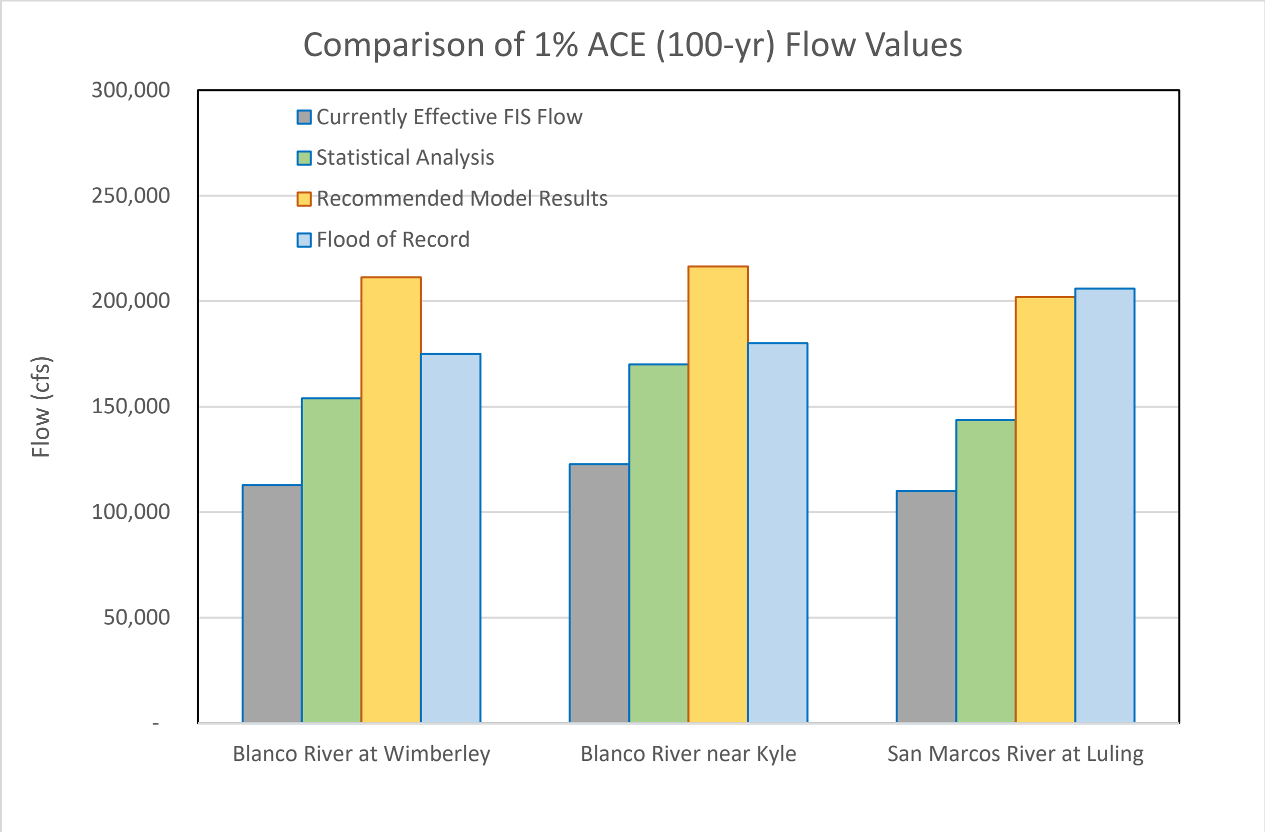


Figure 13.2: Comparison of 1% Annual Chance (100-yr) Flow Results in the San Marcos River Basin

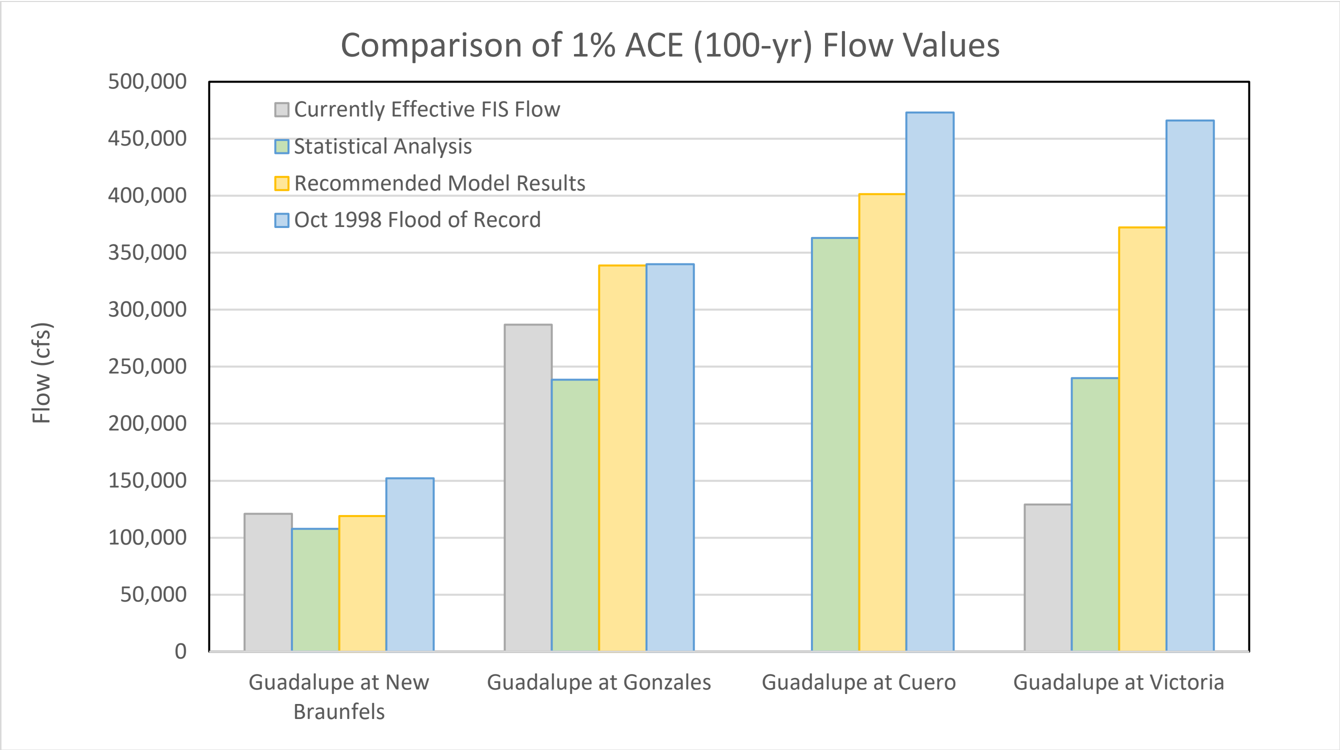


Figure 13.3: Comparison of 1% Annual Chance (100-yr) Flow Results on the Lower Guadalupe River

The flow results that were recommended for adoption came from a combination of the NOAA Atlas 14 watershed model results using uniform rain, elliptical storms, and the Canyon Dam reservoir study. Other methods, such as the statistical and Riverware results, were used as points of comparison to fine tune the model for the frequent storms, but they were not adopted directly due to their tendency to change after each significant flood event. Since the calibrated watershed model simulates the physical processes that occur during a storm event, it can produce more reliable and consistent estimations of the flow expected during a 1% annual chance (100-yr) storm. In addition, NOAA Atlas 14 shed new light on the depths and frequency of rainfall that could be expected in the Guadalupe basin. Both uniform rain and elliptical shaped frequency storms were run in the watershed model. The elliptical frequency storm results were generally recommended for certain river reaches with large drainage areas, while the uniform rain results were recommended for the smaller drainage areas. Dam operations for Canyon Lake were also examined in detail for this study, and the frequency dam releases and pool elevations that resulted from that reservoir study were recommended for the reaches immediately upstream and downstream of the dam.

Given the severe loss of life and property that occurred during recent flood events, it is imperative that future updates to the flood insurance rate maps for the Guadalupe River Basin accurately reflect the known levels of flood risk in the basin. The recommended flows represent the best available estimate of flood risk for the larger rivers in the Guadalupe basin based on a range of hydrologic methods performed by an expert team of engineers and scientists from multiple federal agencies. For the smaller tributaries, the new flows from the watershed model provide a good starting point which could be further refined by adding additional subbasins and using methodologies that are consistent with this study. The updated flows presented in this report can be used to revise flood insurance rate maps to help inform residents on flood risk impacts, which is important for the protection of life and property.

14 References and Resources

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15 Terms of Reference

BFE	base flood elevations
cfs	cubic feet per second
CWMS	Corps Water Management System
DDF	Depth Duration Frequency
DEM	digital elevation model
DSS	data storage system
EM	Engineering Manual
EMA	expected moment algorithm
ERDC	Engineering Research & Development Center of USACE
FEMA	Federal Emergency Management Agency
FIS	flood insurance study
GeoHMS	Geospatial Hydrologic Model System extension
GIS	Geographic Information Systems
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
IACWD	Interagency Advisory Committee on Water Data
InFRM	Interagency Flood Risk Management
LiDAR	Light (Laser) Detection and Range
LOC	Line of organic correlation
LPIII	Log Pearson III
MMC	Modeling, Mapping, and Consequences Production Center
NA14	NOAA Atlas 14
NAD 83	North American Datum of 1983
NCDC	National Climatic Data Center
NED	National Elevation Dataset
NGVD 29	National Geodetic Vertical Datum of 1929
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
NWS	National Weather Service
PDSI	Palmer Drought Severity Index
PeakFQ	Peak Flood Frequency
PFDS	Precipitation Frequency Data Server
QPF	Quantitative Precipitation Forecast
RAS	River Analysis System
ResSIM	Reservoir System Simulation
RFC	River Forecast Center
SCS	Soil Conservation Service
SHG	Standard Hydrologic Grid
SI	Structure Inventory
SME	subject matter expert
SOP	Standard Operating Procedures
sq mi	square miles
SSURGO	Soil Survey Geographic Database
TLS	Total-Least Squares
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WCM	Water Control Manual
WGRFC	West Gulf River Forecast Center