Interagency Flood Risk Management (InFRM)

Watershed Hydrology Assessment for the Nueces River Basin
Appendix D: RiverWare Analyses

March 2025

INTERAGENCY FLOOD RISK MANAGEMENT

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1 Riverware Analyses

For the RiverWare portion of the analysis, a new US Army Corps of Engineers (USACE) Period of Record (POR) model in RiverWare (CADSWES, 2020) was created for the Nueces River Basin. The POR data was generated from Water Year (WY) 1942 to 2019. RiverWare was then used to generate a regulated POR by simulating the basin as if the reservoirs and their current rule sets had been present in the basin for the entire time period. This analysis was used to extend flow records at various stream gaging stations within the basin from their observed records, using nearby observed stream gaging stations to an extended simulated record of 1942 to 2019. Statistical flow frequency analyses according to Bulletin 17C were then performed on the extended record. The statistical results from the RiverWare model were later compared with the results of other methods from this study. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

1.1 Introduction to Riverware Modeling

RiverWare is a river system modeling tool developed by CADSWES (Center of 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 homogeneous regulated POR 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 Nueces River Basin.

The RiverWare model described in this chapter presents development of the Nueces River Basin hydrology, which mimics current operational conditions. The use of the RiverWare program allows for data extension to periods prior to dam construction. The utilization of longer gage record improves discharge frequency results and increases the confidence of the analysis being performed. The modeling evaluation criteria are: (1) evaluate output based on validating policies and functions, and (2) prioritize operation based on surcharge and flood control. A detailed explanation of the Nueces River Basin POR hydrology will be in a later section.

Calibration results will also be shown that illustrate the overall model performance for the POR. The time window simulation run is for October 01, 1942 – September 30, 2019. This time window captures all big events occurred over the Nueces River basin. Each simulated water year was inspected individually to better validate the results. Historical pool elevations along with observed inflows and outflows were compared against the model simulated results.

1.1.1 USACE Models

Two new RiverWare models were constructed for the Nueces River basin at the onset of this study. The USACE Fort Worth District (SWF) Nueces RiverWare models are: 1) the RiverWare hydrology model, 2) the RiverWare study model. The models were developed with functionalities of algorithms and consolidate object methods, defined functions, and other utilities in the RiverWare program. The hydrology was first simulated (beginning October 01, 1942) utilizing the RiverWare hydrology model, and then simulated results were fed into the RiverWare study model. The latter was used to validate operations and mimic observed data throughout the Nueces River Basin. The concept of using two separate models was to generate local flows from the hydrology model that can be processed in the study model. The algorithmic based functions embedded in the hydrology model, enable the user to apply the right mass balance functions, and route flows throughout the network. The routing procedures capture lag/travel time and peak attenuation. The parameters applied in the hydrology model are normally set after performing several iterations. Observed flows were used for timing and peaks calibrations. The hydrology model would also provide an accountability of producing incremental and cumulative local flows for further processing. The RiverWare study model network is shown in Figure D.1.

1.1.2 Model Description

The Nueces River Basin model was developed in RiverWare for non-Corps lakes operation. Choke Canyon Reservoir is owned by the Bureau of Reclamation and operated by the City of Corpus Christi. Lake Corpus Christi on the other hand, is owned and operated by the City of Corpus Christi. The upstream modeling boundary is Choke Canyon Dam located on the Nueces River. This boundary site is represented in RiverWare as a reservoir object with imported Deterministic Incremental Local Inflow slot values. The downstream modeling boundary is the Nueces River at Calallen, Tex., USGS Stream gaging station 08211500, located near Gulf of Mexico. There are additional local inflow points located throughout the model mainstem.

Rules in the model adapted the RiverWare USACE-SWD regulation policies. The USACE-SWD rules solve the basin as a system and use algorithms for flood control releases, conservation pool operations, and hydropower releases if applicable. The USACE-SWD rules also disaggregate local inflows and forecast cumulative inflows, in which the forecasted flows are used in the network algorithms. Table D.1 shows model element names and types.

Table D.1 Nueces River Basin Model Elements and Types

Element Name	Type	Element Name	Type
Choke Canyon Water Supply	Pump	Lake Corpus Christi _Divert	Diversion
Lake Choke Canyon_Divert	Diversion	Lake Corpus Christi	Storage Reservoir Object
Lake Choke Canyon	Storage Reservoir Object	Lake Corpus Christi Outflow	Control Point
Lake Choke Canyon Outflow	Control point	Near Mathis_Near Bluntzer	Reach
Choke Canyon Outflow_Three Rivers	Reach	Nueces River nr Bluntzer	Control point
Nueces River nr Three Rivers	Control point	Near Bluntzer_At Calallen	Reach
Three Rivers_Corpus Christi Inflow	Reach	Nueces Rv at Calallen	Control Point
Lake Corpus Christi Water Supply	Pump		

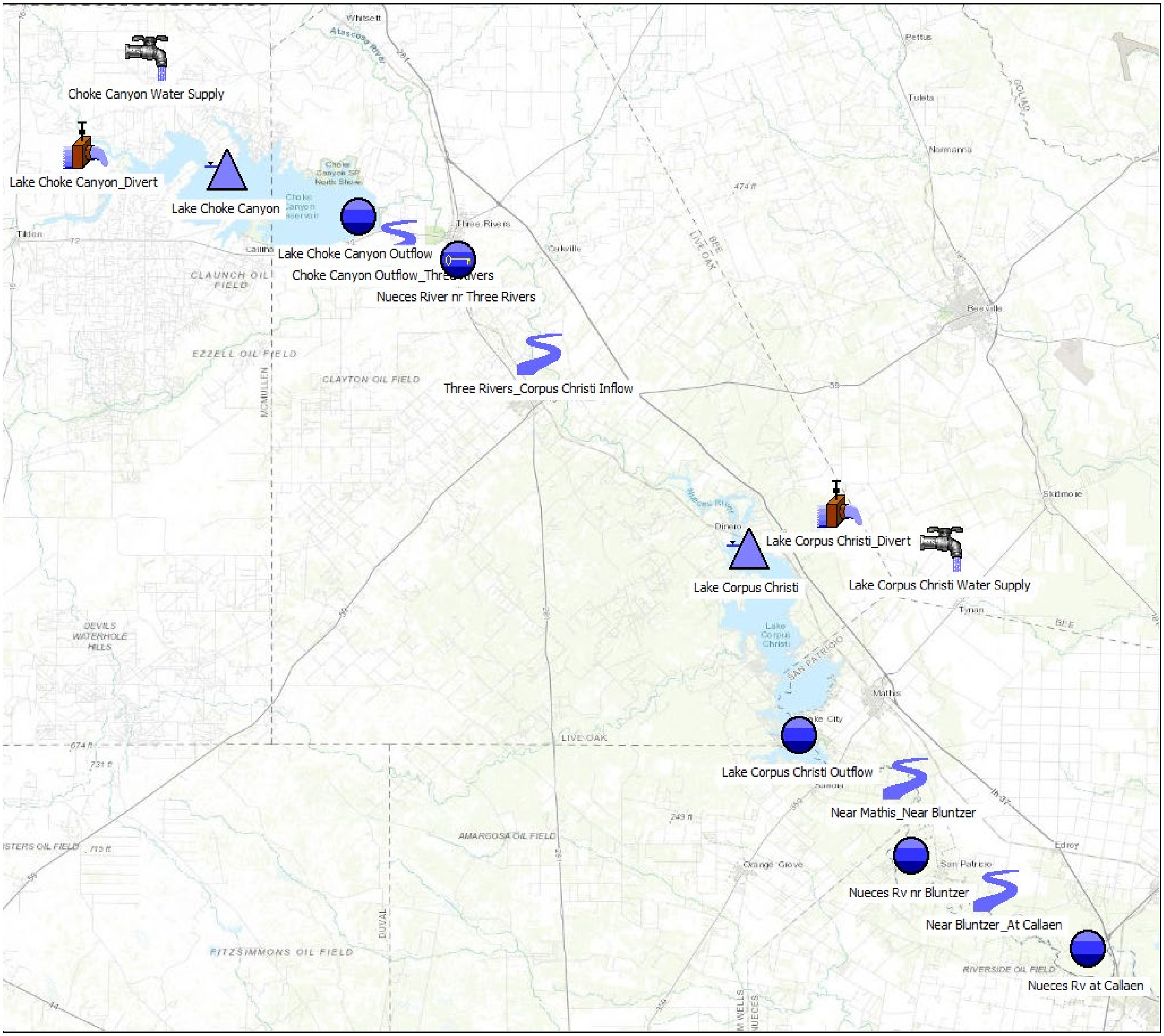

Figure D.1: RiverWare Nueces River Basin Network

1.2 Data Sources Used in the Riverware Model

The modeling efforts in the study area heavily rely upon sound hydrology. Accurate hydrologic analyses reflect more realistic runoff conditions in the watershed, which can change overtime due to urbanization, population growth, agricultural demands, and climate change (e.g., drought or increased flooding due to changes in precipitation conditions). The developed hydrology was based on using the USGS stream gaging stations data at locations of interest. Stream gaging stations with the longest POR were used as the basis for developing gages with missing flow records around the basin. Moreover, data consist of observed USGS discharges, which are measured by the USGS, and pool elevation, adjusted inflow, gated flows, evaporation rates, and water use, which are maintained by the Bureau of Reclamation and the City of Corpus Christi. Table D.2 lists all gaged data used in the RiverWare models. The locations of the USGS gages in the Nueces River Basin are shown in Figure D.2.

A significant amount of reservoir volume loss is through evaporation for both lakes. The monthly evaporation rates data were retrieved from the National Oceanic and Atmospheric Administration (NOAA) website. Evaporation rates were then divided and distributed equally over each day of the month before being fed to the RiverWare study model.

In addition, and for Lake Choke Canyon, loss rates through water usage were retrieved from the Bureau of Reclamation Oklahoma-Texas area office water supply data file link (https://www.usbr.gov/gp-bin/custom.pl?SWE221A&ccdt). Lake Corpus Christi water use data was obtained from the Nueces River Authority website (https://www.nueces-ra.org/CP/CITY/pipeline.php). The monthly water usage data was also divided and distributed equally over each day of the month before being simulated.

Due to some data format limitations in this flood control study, the use of monthly data was justifiable since monthly volumes were preserved regardless of how they were distributed to daily. By inspection, daily loss rates are generally small and have minimum to no impact on flood discharge peaks or flood pool peaks during rare flood events (e.g., 1% ACE or 100-year and greater).

Table D.2: USGS Streamgages Used in the RiverWare Model

Location	Data Type (Units)	Source
Choke Canyon Dam Site Inflow (San Miguel near Tilden, Frio River at Tilden, Tex.)	Discharge (cubic feet per second)	USGS 08206700 USGS 08206600
Frio Rv at Calliham, Tex.	Discharge (cubic feet per second)	USGS 08207000
Choke Canyon Dam Outflow (Choke Canyon Res nr Three Rivers, Tex.)	Discharge (cubic feet per second)	USGS 08206910
Atascosa Rv at Whitsett, Tex.	Discharge (cubic feet per second)	USGS 08208000
Nueces Rv nr Tilden, Tex.	Discharge (cubic feet per second)	USGS 08194500
Nueces River nr Three Rivers, Tex.	Discharge (cubic feet per second)	USGS 08210000
Lake Corpus Christi Inflow (Nueces River nr Three Rivers, Tex.)	Discharge (cubic feet per second)	USGS 08210000
Lake Corpus Christi Outflow (Nueces River nr Mathis, Tex.)	Discharge (cubic feet per second)	USGS 08211000
Nueces River nr Bluntzer, Tex.)	Discharge (cubic feet per second)	USGS 08211200
Nueces River at Calallen, Tex.)	Discharge (cubic feet per second)	USGS 08211500
Choke Canyon Pool	Elevation (NGVD-29 feet)	City of Corpus Christi database
Corpus Christi Pool	Elevation (NGVD-29 feet)	City of Corpus Christi database

Note: NGVD = National Geodetic Vertical Datum of 1929

Figure D.2: Enlarged Map of USGS Gage Locations in the Nueces River Basin Network

1.3 Period of Record Hydrology Development

1.3.1 Methodology Used to Develop Period of Record Hydrology

The important methods used to develop the POR hydrology for the Nueces River Basin in this chapter are the Drainage-Area-ratio method, reservoir inflow calculation, and reservoir inflow smoothing algorithm. This section describes the methodology used in developing the POR.

Rarely is there a POR watershed study where sufficient and consistent gage datasets exist. Incomplete streamgage datasets for stream gaging stations and reservoirs gages can be attributed to budget limitations and anthropogenic changes (*i.e.,* installation of reservoirs). Once discharge estimates were established for each gage, a few years with missing flows were observed. To reconcile the inconsistent dataset, the missing discharges were generated using selected USGS stream gaging stations with continuous records.

Maintenance of Variance extension (MOVE I) (Hirsch, R.M): This method augments daily peak flows using a linear-regression technique to extend gages with short records, utilizing nearby gages of similar hydrologic characteristics with long observed flow records (Equation 1). USGS 08207000 Frio Rv at Calliham, Tex., is a discontinued gage located on the Frio River downstream of the confluence with San Miguel Creek, was used for Choke Canyon Lake inflow from 01 October 1942 to 24 March 1981. Lake inflow for the period of record between 24 March 1981 to 30 September 2019 was the combined flows of USGS 8206600 Frio River at Tilden, Tex., and USGS 8206700 San Miguel near Tilden, Tex. USGS 8206600 Frio River at Tilden was used to extend USGS 8206700 flows from 24 March 1981 to 30 September 1989 since the gage flow recording is missing records (Figure 8.3). Quality control was performed, and the maximum discharge peaks were adjusted to account for attenuation. Extreme discharge peaks greater than the average discharge peak value for the POR were adjusted, by utilizing a correlation resulting from establishing peak to peak flow relationship between the selected USGS gages. The combined inflow was inspected to ensure significant pool elevation rises are directly influenced by high discharge peaks at the lake.

$$Y_{i} = Y_{Avg} + S_Y / S_X \, (X_i - X_{Avg})$$

Equation 1: MOVE I Equation Method

Y_i is the estimated logarithm of the discharge at the study streamgage for day *i [L³/T]*.
Y_{Avg} is the mean of the log-transformed observed discharges at the study streamgage *[L³/T].*
S_Y is the standard deviation of the log-transformed observed discharges at the study streamgages *[L³/T].*
S_X is the standard deviation of the log-transformed observed discharges at the study streamgage *[L³/T]*.
X_i is the log-transformed daily discharge at the reference streamgage for daily *I [L³/T].,* and
X_{Avg} is the mean of the log-transformed observed discharge at the reference streamgage *[L³/T]*.

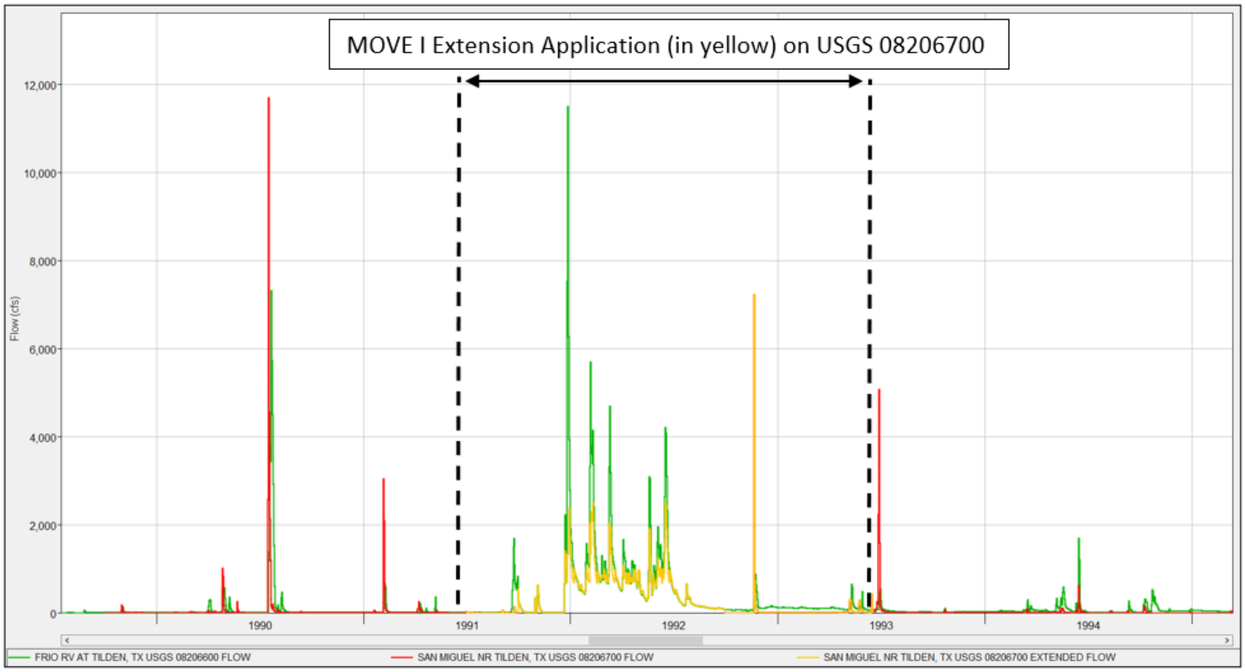

Figure D.3: Example of USGS 08206700 Gage Record Extension from USGS 08206600

The remainder of the discharge peak estimates in the Nueces River Basin were based on applying the Drainage-Area ratio method and routing to capture travel time and attenuation.

The Drainage-Area-ratio method provides a numerical approximation of the missing gage data, using gage datasets upstream or downstream on the same river (Equation 2).

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

Equation 2: Drainage-Area-Ratio Method

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

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

$A_y = Drainage\ area\ of\ ungaged\ site\ [L^2]$

$A_x = Drainage\ area\ of\ available\ gaged\ site\ X\ \ [L^2]$

The numerous arrays of reservoir inflow calculations tolerate for thoroughness, as well as discontinuity. All reservoir inflow calculations share the 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 method 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 3: Evaporation Reservoir Inflow Method

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

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

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

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

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 4, Equation 5, Equation 6, and Equation 7). There are additional inflow smoothing methods available, but this method is sufficient to resolve negative reservoir inflows in this case and depending on the month, imparts only minimal positive bias.

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

Equation 4: Monthly Total Inflow Method

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

Equation 5: Nonnegative Inflow Method

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

Equation 6: Monthly Total Nonnegative Inflow Method

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

Equation 7: Smoothed Inflow Method

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

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

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

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

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

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

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

The methods presented above along with the RiverWare modeling software have permitted for the development of POR hydrology for the Nueces River Basin. 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.

1.3.2 Period of Record Hydrology for the Nueces River Basin

The POR hydrology needed to evaluate the Nueces River Basin requires the use of numerical models. RiverWare version 8.0.1 (January 08, 2020) was used to analyze the hydrology and hydraulic processes of Choke Canyon Reservoir and Lake Corpus Christi, and the river reaches within the Nueces River Basin. The hydrology and hydraulic analysis include the use of a multiple-run and simulation-run RiverWare models. The multiple-run RiverWare model produced the POR hydrology from October 01, 1942 to September 30, 2019 for all streams and reservoirs 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 the entire Nueces River basin reservoirs pool elevations 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 gaging stations 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 to be incorporated into a simulation-run RiverWare model. The reservoir operational policies and rule sets applied to reservoirs can then 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.

1.4 Water Control Plans for the Nueces River Basin Operated Reservoirs

Table D.3 lists some main operational procedures, flood control key points, and objectives of each modeled reservoir in RiverWare.

Purpose/Downstream Control points/Pool zones	Choke Canyon	Corpus Christi
Dam Type	Storage	Storage
Purpose	Fish and wildlife, general recreation, and water supply.	Water supply and general recreation
Control Point **Located downstream of each project**	5,300cfs at USGS 08210000 Nueces River near Three Rivers, Tex.	None, forecast based
Pool zone	Elevation (NGVD-ft)	Elevation (NGVD-ft)
Top of conservation	220.50	Below 94.00
Top of flood	Above 220.5	94.00
Surcharge	220.5	South side 94.00
Top of Spillway Crest		North side 94.50
Top of Dam	241.14	106.0
Initial Impoundment Date	January 1982	January 1952

Table D.3 Highlights from the Nueces River Lakes Water Management Plan

Note: Some pool zone adjustments were made in the model as follows:

1- Conservation zone was set at 221 ft-NGVD to match top of observed pool above surcharge.
2- Top of flood was set at 222.5 ft-NGVD to mimic observed surcharge.

In RiverWare, policies and functions were written to reflect the current reservoir regulation schedule for each lake. Table D.4 lists the Lakes' release schedules. Release procedures in this table were also included in the RiverWare model for simulation.

Choke Canyon Reservoir		Lake Corpus Christi	
Pool Elevation (NGVD-feet)	**Maximum Allowable Release**	**Pool Elevation (NGVD-feet)**	**Maximum Allowable Release**
136.40 - 220.50	No flood control release Low flow requirements of 16cfs.	Below 94.00	No flood control release Daily releases for water supply and bays and estuaries varies from 20 to 110cfs.
220.50	2,000cfs	94.00 – 94.50	Close high-pressure gates (Outlet works) and release according to south side spillway gate operating curve
220.50 – 221.00	Close high-pressure gates (Outlet works) and release according to spillway gate operating curve	Above 94.50	Release according to south side spillway gates operating curve and North side (emergency gates) if needed
Above 221.0	Surcharge release		

Table D.4: Nueces River Operated Lakes Release Schedule

1.5 Riverware Operational Model Application

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 time steps 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.

The Nueces River Basin RiverWare model includes policies implemented as rules. Rule number 1 is the highest priority rule and executes last (e.g., hydropower release rule) while the rule with the highest number is the lowest priority rule and executes first (e.g., Surcharge rule). Figure D.4 below shows the priority list of policies implemented in the model. As seen, the flood control policies execute first and this is mainly to control flooding at damage center locations downstream.

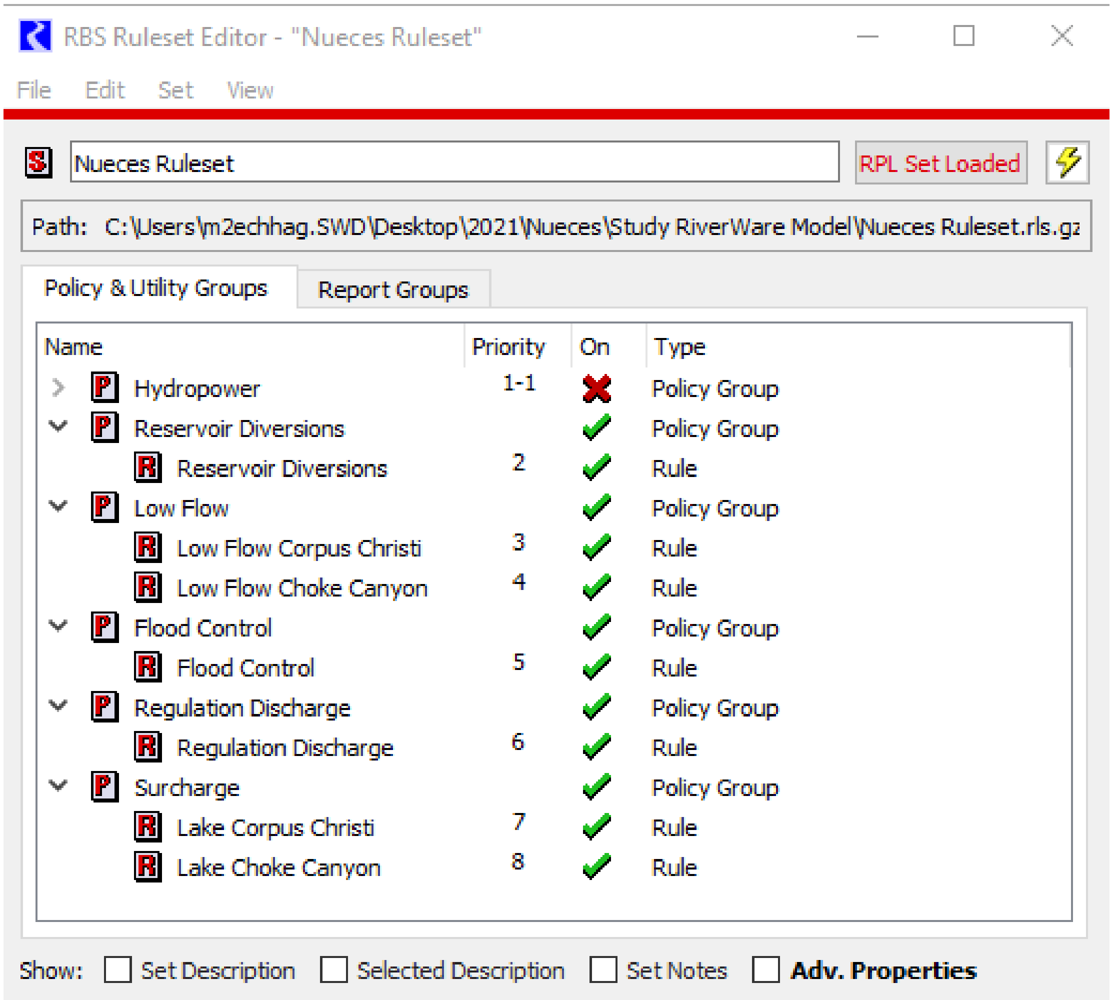

Figure D.4: Nueces River Basin Rule-based Simulation Groups

The built-in rules in USACE-SWD conservation pool operations apply to Corps and non-Corps dams since RiverWare triggers specific elevations in the operating level table. These generic operating level tables reflect dams' conditions with or without flood storage. The other rules (e.g., Regulation discharge, flood control, reservoir diversion, and hydropower, if applicable, and release rules) kick in based on priority.

1.6 Model Performance and Discussion of Results

Overall, the model displays satisfactory results between simulated and observed considering operation limitations. The rules used for simulation do not always produce matching results of the historical (observed) flows, because real-time operation is normally based on real-time forecasting, which causes release deviations from operations' schedule. The model uses the deterministic flow with a simple forecasting technique and a set of policies. The surcharge, regulating discharge, and flood control rules execute first while also accounting for low flows at each reservoir. Data availability can also contribute to deviations from observed conditions.

The following is a discussion of results for Choke Canyon Reservoir and Lake Corpus Christi.

1.6.1 Choke Canyon Reservoir Model Performance

The simulated pool for Choke Canyon reservoir showed satisfactory results against observe pool. The comparison is for the period post initial dam impoundment *(i.e.,* 1987) through 2019 (Figure D.5). To match observed pool, top of pool was set above conservation (221.0ft-NGVD). Although the project has no authorized flood control purposes, a flood control policy that is consistent with the SWD-USACE operation criteria was added to the RiverWare model to mimic observed conditions. The written flood control policy trigger releases based on pool elevations; the assumed pool elevation would be referred to as the flood control pool (222.5ft-NGVD). This flood control pool provides a buffer zone between conservation and surcharge. Releases between 220.5 NGVD-ft and 221.0 NGVD-ft were limited to 2,000cfs. Surcharge conditions mimicked observed pool in the years of 1992, 2002, 2003, 2004, and 2007. Project release was according to the discharge-elevation rating curve for controlled and uncontrolled spill (Table D.5). For surcharge simulation, the flat top surcharge method was selected. This method uses a perfect knowledge forecast technique and daily time steps. With a minimum timestep of one day being used, the model releases more than observed keeping the peak elevations lower. Release adjustments were made to improve simulated peaks (Table D.5). Simulated drawdown synchronized well with observed pool. Depletions were according to pumpage data and evaporation rates obtained from water supply monthly reports for January 1983 – October 2019. The simulated pool stayed above observed on the drawdown side. This can be related to the way available data were processed. The monthly evaporation loss rates and water usage data feed are evenly distributed over each day of the month. Lack of data from other losses can add to deviations from observed steep drawdowns.

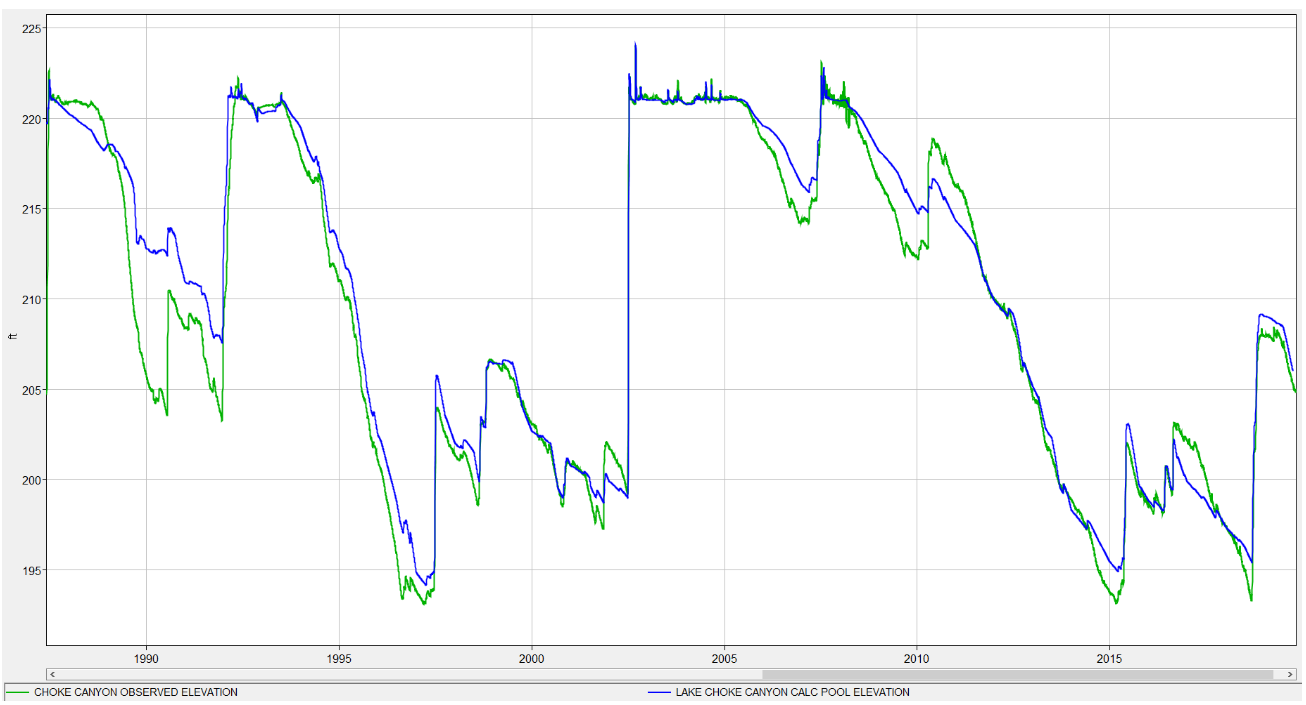

Figure D.5: Choke Canyon's Reservoir Simulated Pool Comparison with Observed

- **Table D.5: Choke Canyon Reservoir Controlled and Uncontrolled Maximum Release**

Pool	Release	Pool	Release	Pool	**Adjusted Release**
NGVD-Feet	CFS	NGVD-Feet	CFS	NGVD-Feet	CFS
135.3	-	217.5	2,000	217.5	2,000
199.5	20	218	2,000	218	2,000
199.9	257	218.5	2,000	218.5	2,000
200	487	219	2,000	219	2,000
200.1	658	219.5	2,000	219.5	2,000
200.2	727	220	2,000	220	2,000
200.4	1,063	220.5	2,000	220.5	2,000
200.6	1,423	221	141,956	221	**2,000**
200.8	1,794	221.5	145,251	221.5	**3,000**
201.2	2,000	222	148,473	222	**5,000**
201.4	2,000	222.5	151,626	222.5	**10,000**
201.8	2,000	223	154,715	223	**15,000**
202.6	2,000	223.5	157,744	223.5	**25,000**
203.5	2,000	224	160,715	224	**30,000**
204.5	2,000	224.5	163,633	224.5	163,633
205.5	2,000	225	166,499	225	166,499
206.5	2,000	225.5	169,317	225.5	169,317
207.5	2,000	226	172,088	226	172,088
208.5	2,000	226.5	174,816	226.5	174,816
209.5	2,000	227	177,502	227	177,502
210.6	2,000	227.5	180,148	227.5	180,148
211	2,000	228	182,756	228	182,756
211.5	2,000	228.5	185,326	228.5	185,326
212	2,000	229	187,862	229	187,862
212.5	2,000	229.5	190,364	229.5	190,364
213	2,000	230	192,833	230	192,833
213.5	2,000	230.5	195,272	230.5	195,272
214	2,000	231	197,680	231	197,680
214.5	2,000	231.5	200,059	231.5	200,059
215	2,000	232	202,410	232	202,410
215.5	2,000	232.5	204,734	232.5	204,734
216	2,000	233	207,032	233	207,032
216.5	2,000	241	242,200	241	242,200
217	2,000				

NOTE: Some situational releases did occur under 220.5 in previous flood events, but releases are not required below elevation 220.5. Releases in this table were adjusted from the original plan to improve simulation.

USGS 08206910 (Nueces Choke Canyon Reservoir near Three Rivers) is located at the reservoir outlet, but the rating curve of this gage is limited to measuring flows with a maximum stage of 10 feet, which equates to about 2,000cfs. A snipped of discharge at this gage is shown in Figure D.6. Notice USGS gage flow discontinuity.

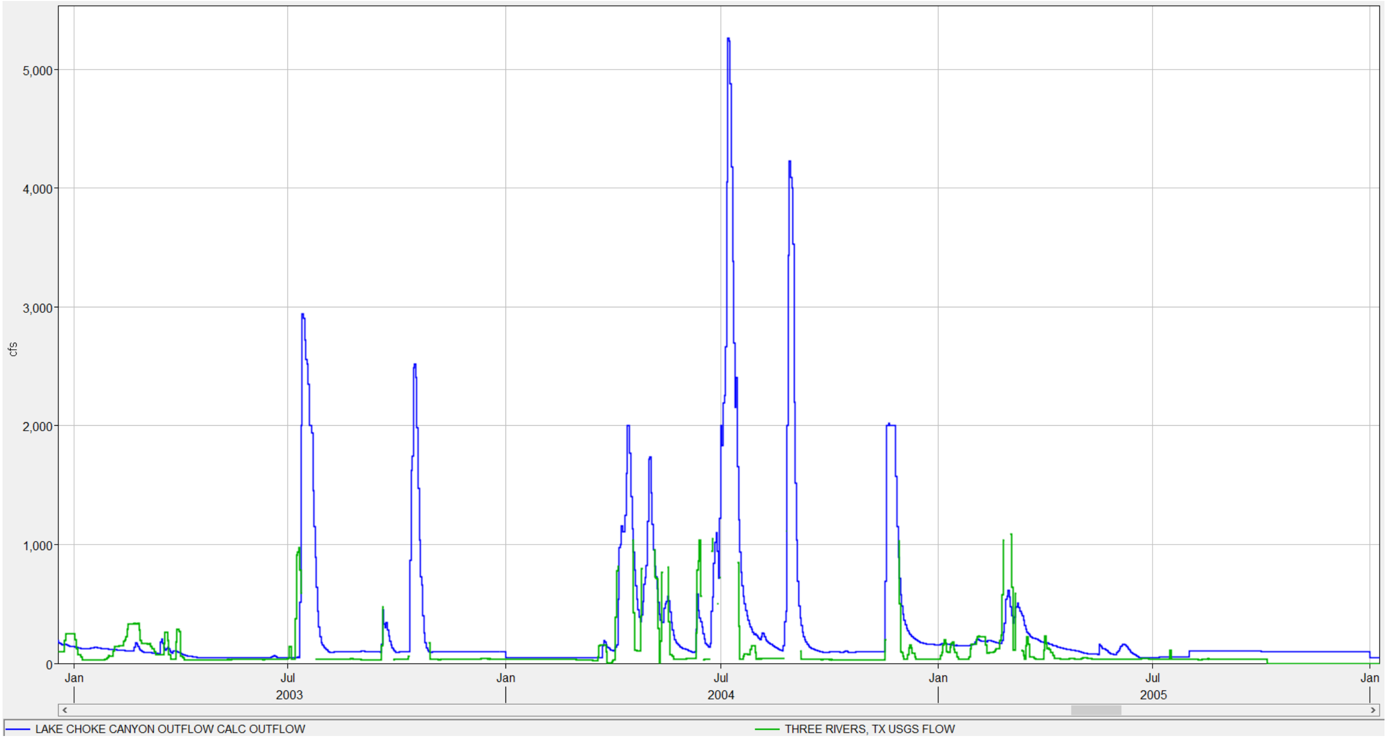

Figure D.6: Simulated-Observed Release Comparison at Choke Canyon Reservoir Outlet

USGS 08210000 (Nueces River near Three Rivers) was also used to evaluate model results. This gage is located between Choke Canyon Reservoir and Lake Corpus Christi. It also captures flows from USGS 08208000 Atascosa Rv at Whitsett and USGS 08194500 Nueces Rv nr Tilden. The validation of simulated releases from Choke Canyon Reservoir captured release routings downstream of the dam, as well as, peaking at USGS 0821000. The flows at this gage were also routed to Lake Corpus Christi. Figures D.7 and D.8 illustrate how well the model performs at this location for 2004 – 2019.

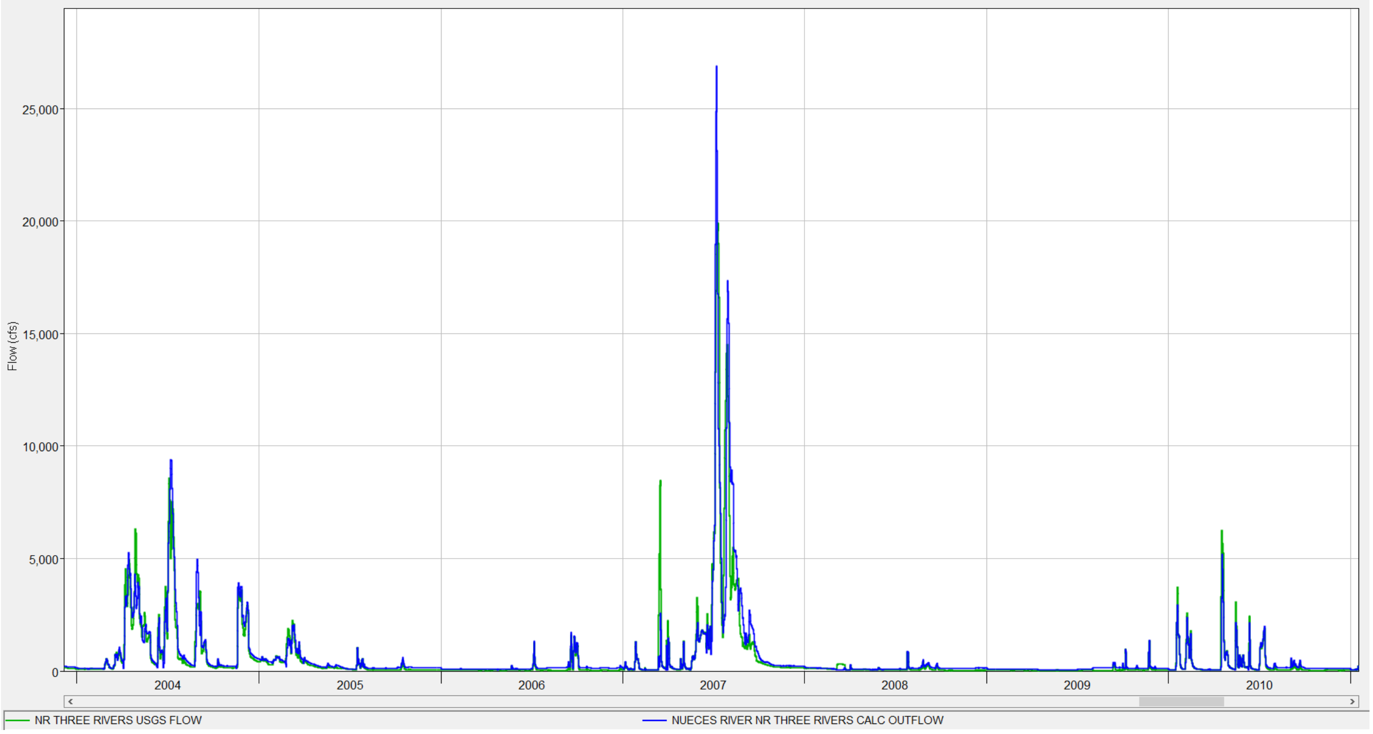

Figure D.7: (2004-2010) Validation of Simulated Flows at USGS 08210000

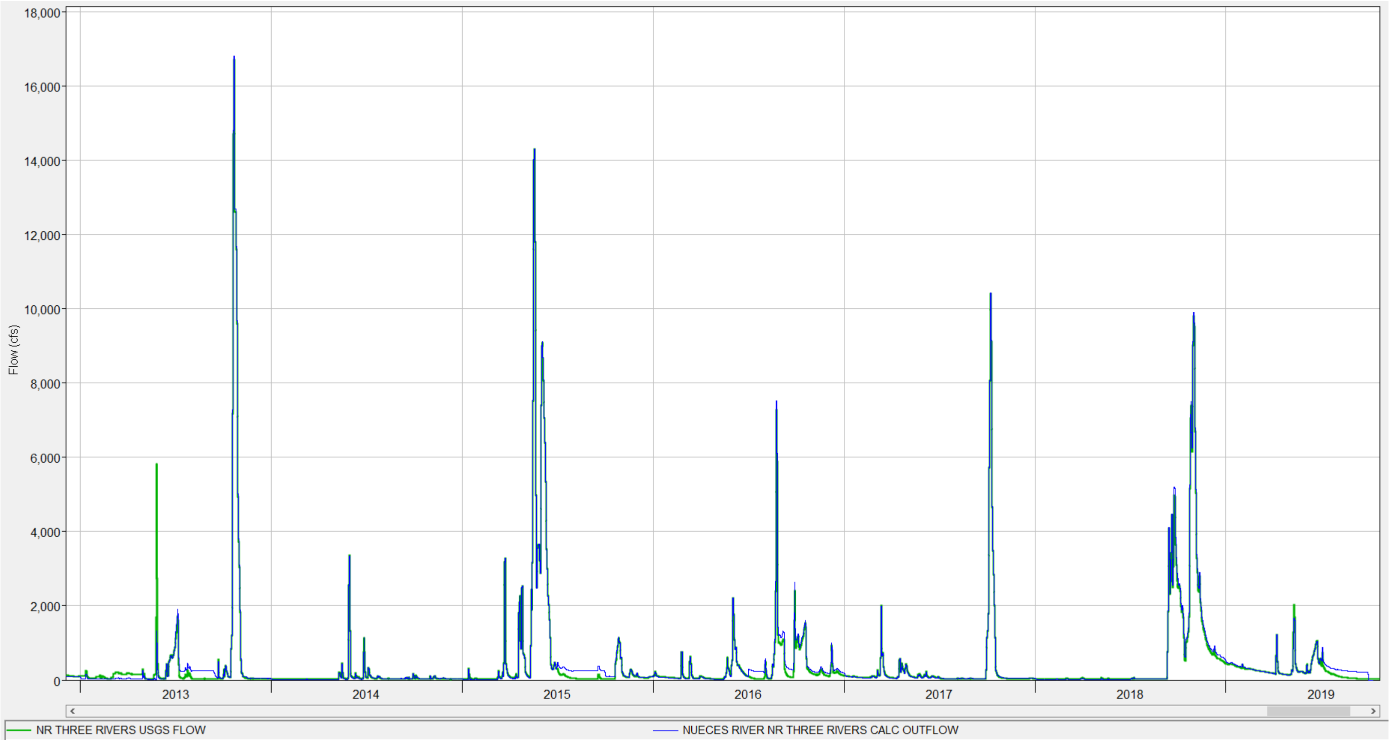

Figure D.8: (2013-2019) Validation of Simulated Flows at USGS 08210000

Figure D.9 shows selected sensitivity analysis performed for Choke Canyon Reservoir pool prior to adopting the best performed operation. The flat top surcharge method was selected over the specified surcharge release method. The model tends to be more stable when the flat top surcharge method is selected. The method eliminates oscillations seen in the surcharge zone and reservoir releases. Those oscillations are associated with the specified surcharge release method when selected. The adjusted release flat top surcharge method results associated with the more realistic operation were considered for this study.

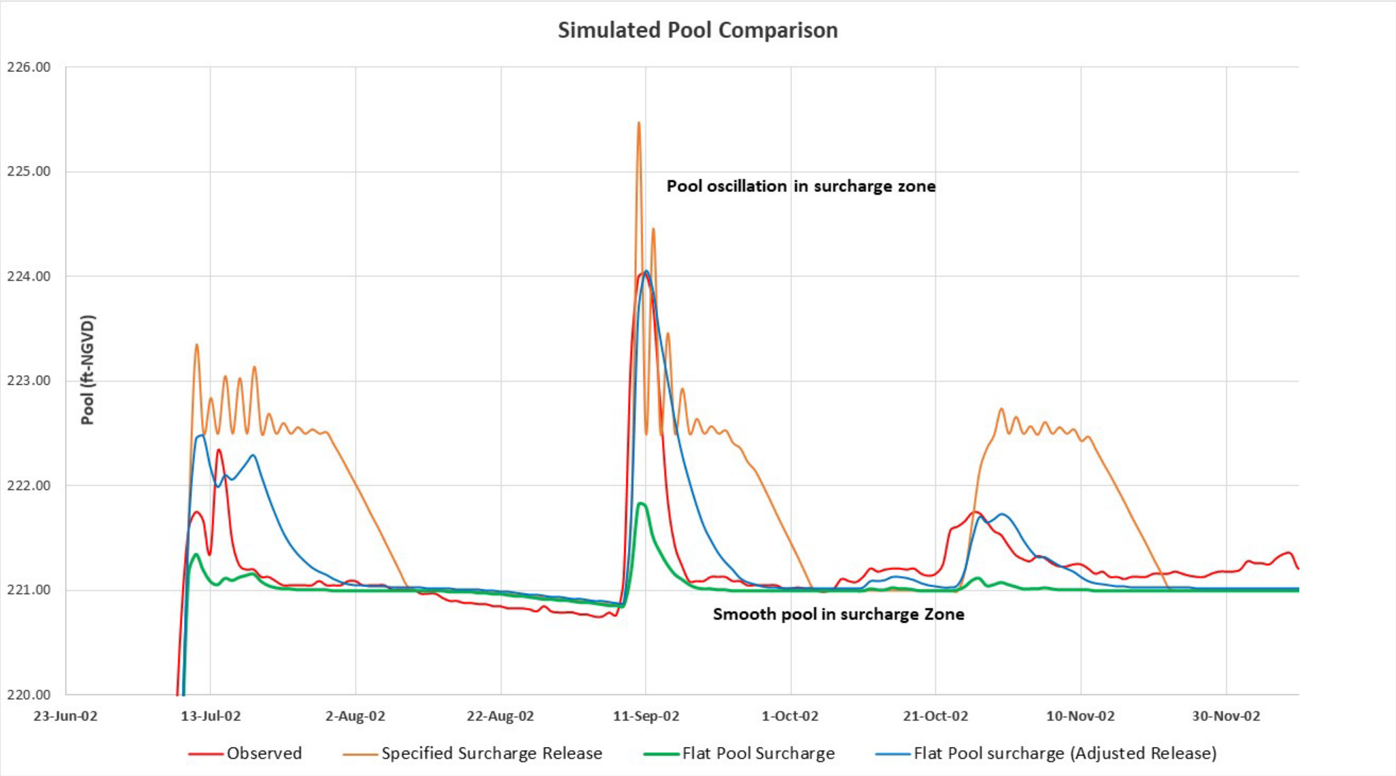

Figure D.9 Sensitivity Analysis for Choke Canyon Reservoir Pool Simulation

Figure D.10 illustrates the Weibull plotting position distribution of the lake between water years 2000 and 2020. The last 20 years of operation were analyzed, because they reflect current operational standards. The simulated peaks above 221.5 ft-NGVD were lower than observed due to the selected surcharge method, which tends to flatten the top of flood pool. For this lake, the observed pool will be selected over simulated when available during the statistical analysis, but simulated pool peaks will be included for periods prior to dam initial impoundment. Figure D.11 illustrates the corresponding relationship between observed and simulated pool for Lake Choke Canyon for water years 2000-2020. The strong relationship increases confidence in the adopted simulated results.

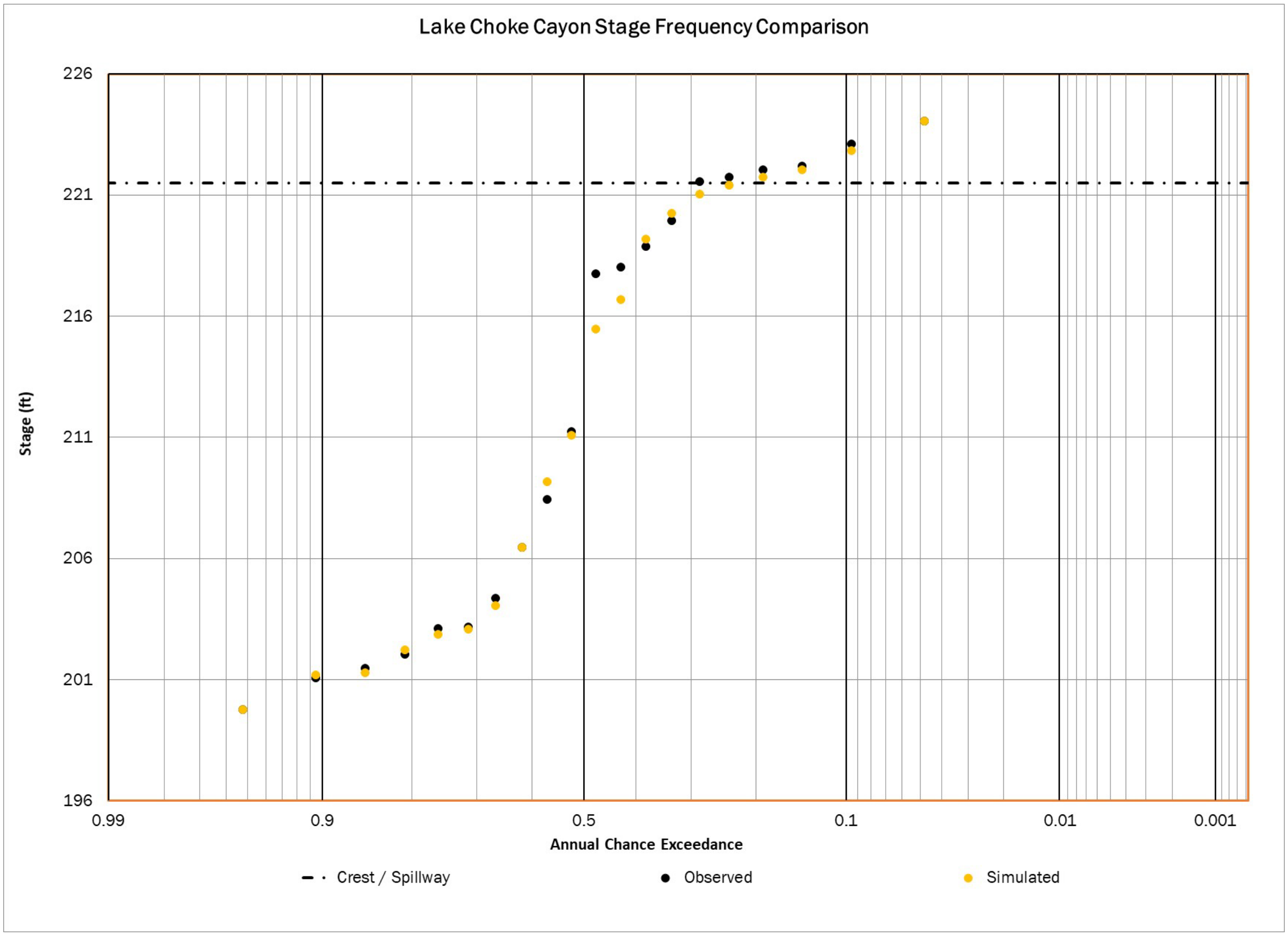

Figure D.10: Choke Canyon's Stage Frequency Peak Comparison (Annual Maximum Peaks) for WY 2000-2020

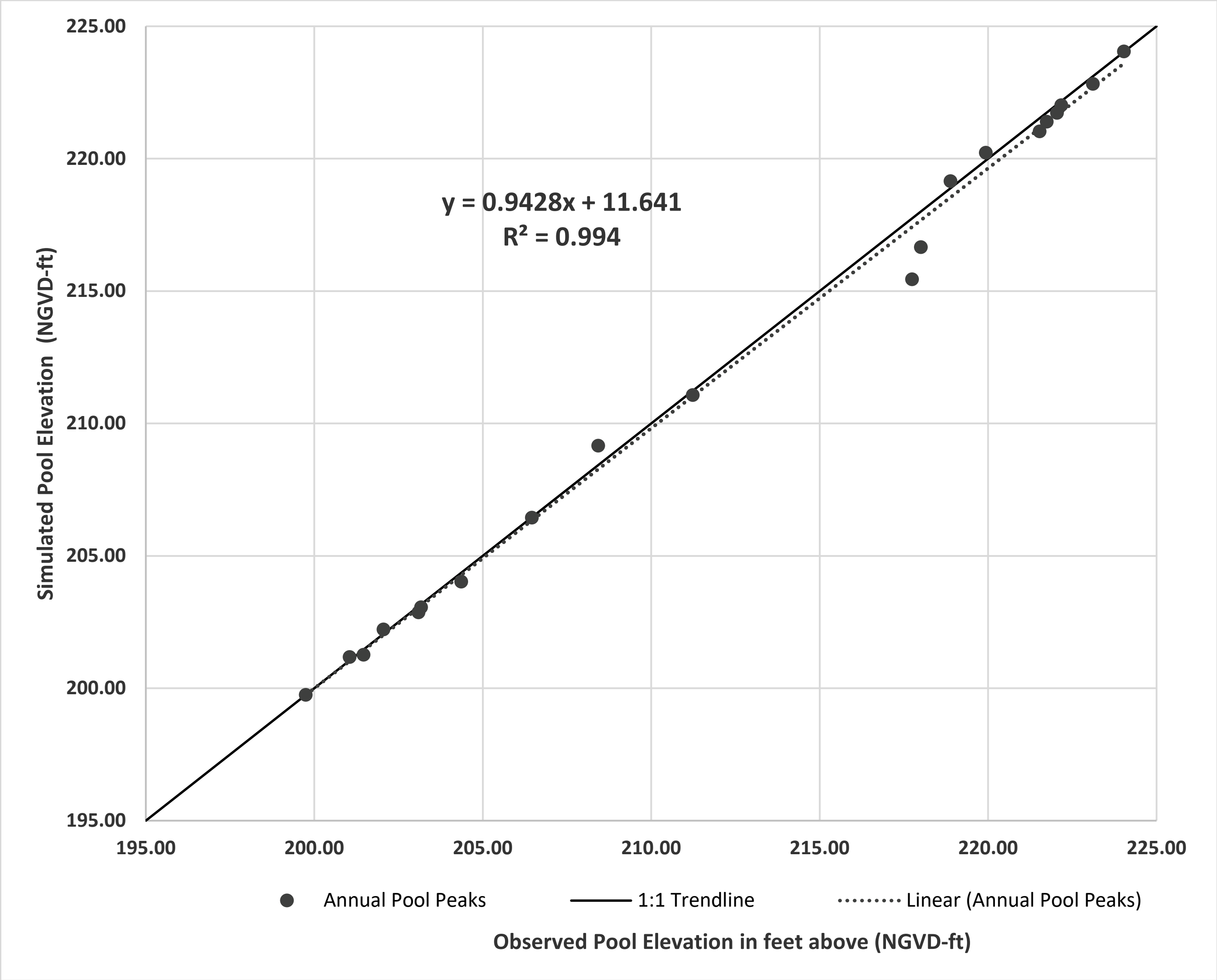

Figure D.11: Observed Vs. Simulated Pool Annual Maximum Peak for Choke Canyon Lake (WY 2000-2020)

Pool simulation for WY (1943-2019) is shown in Figure D.12. Despite applying the same operation conditions for the entire POR, more drawdowns can be seen during the last 30 years (1987-2019) than the prior 45 years (1943-1987). The last 30 years was the period since dam initial impoundment, where observed loss data were available. Population growth coupled with recent severe droughts due to temperature increase *(i.e.,* increase in evaporation rates) have played major factors in the steep drawdowns seen in the last years. Years prior to 1987, had not seen as many drawdowns. Pool bottom stayed above 211ft-NGVD except during 1967. The simulated pool in those early years were significantly impacted by the assumed losses. Figure D.13 illustrates observed and assumed water supply demand in cubic feet per second (green line and can be read from the right Y-axis) and the evaporation rates in inches per day (line in brown and can be read from the left Y-axis. Missing data were estimated from the observed using the average. Estimated losses appear with a more consistent trend in the figure. Drawdown operations can be improved in future studies, but there is high confidence in the use of the flood peaks for flood frequency analysis from this study.

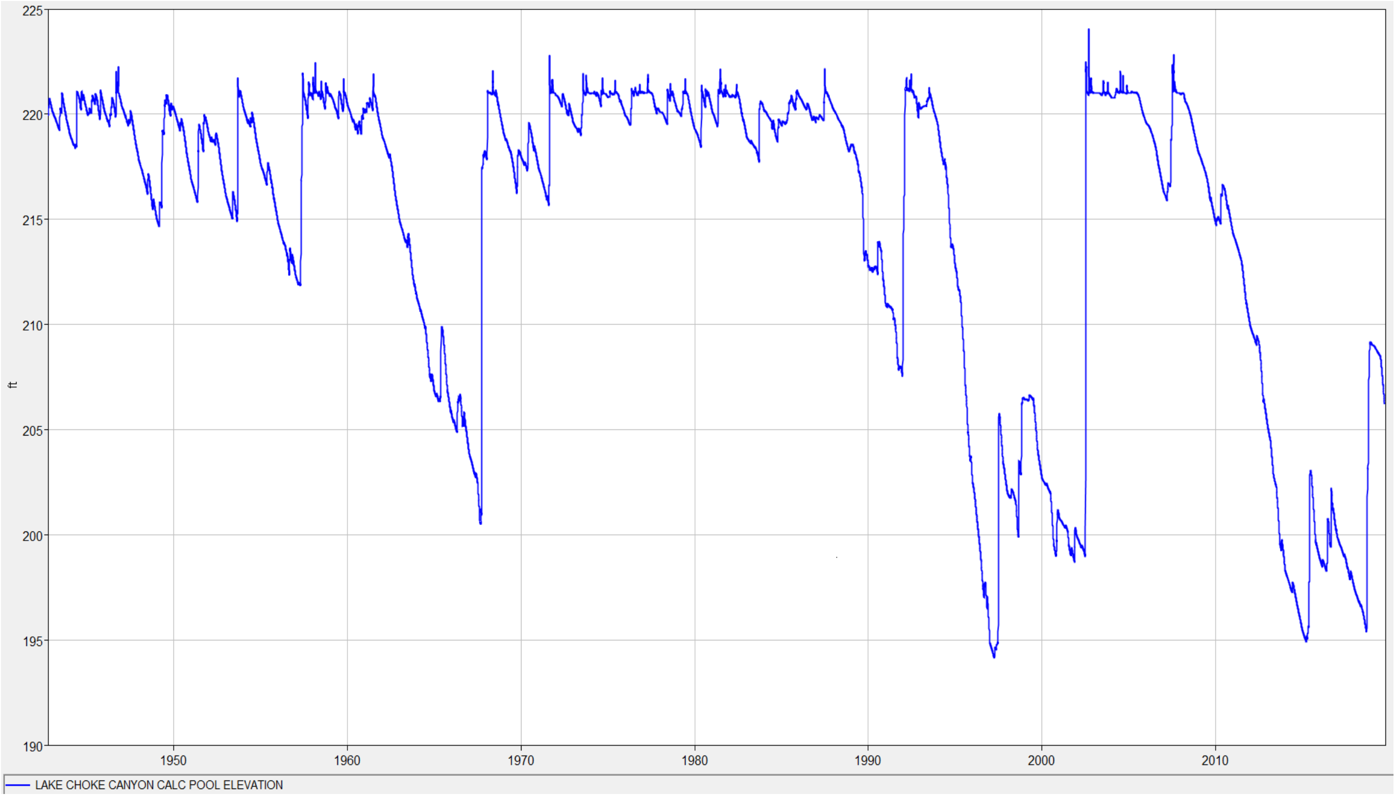

Figure D.12: Lake Choke Canyon Simulated Pool

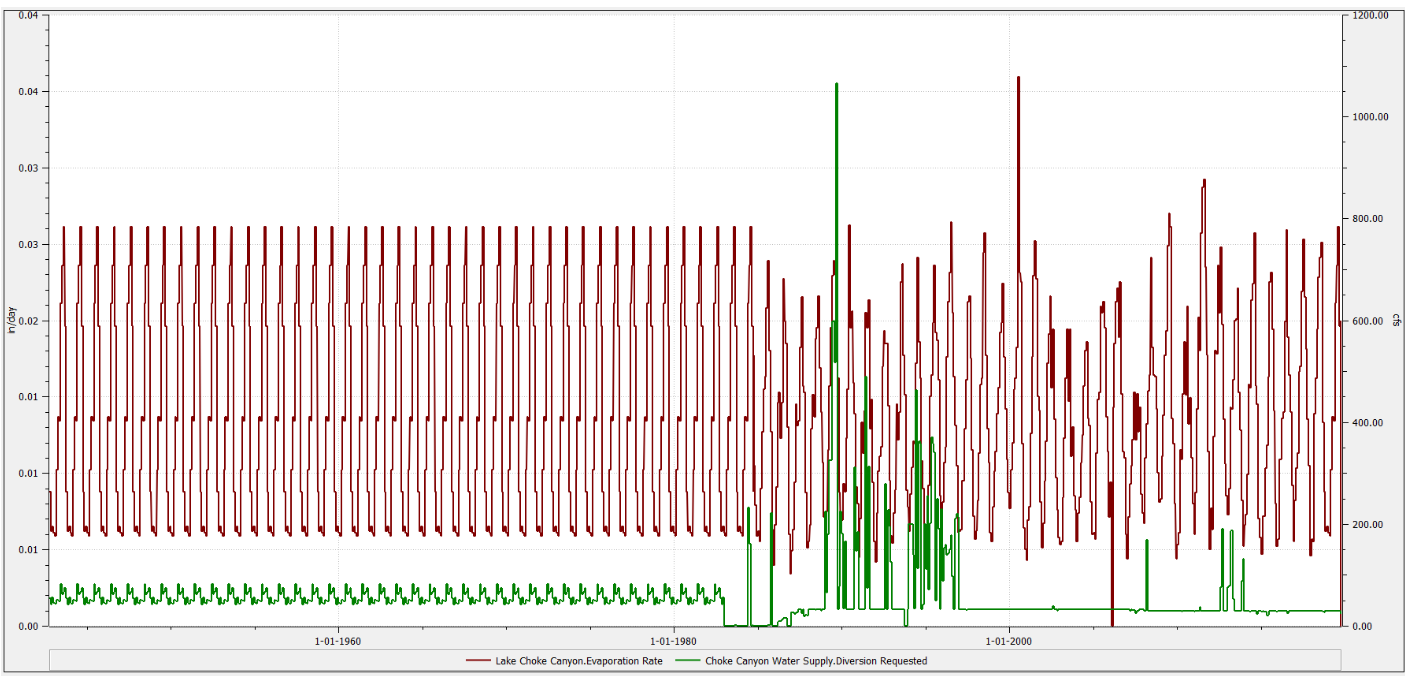

Figure D.13 Observed and Estimate Water Supply Demand Losses and Evaporation Rates Losses for Lake Coke Canyon

1.6.2 Lake Corpus Christi Model Performance

Overall, the simulated results performed well for this lake. The evaluation was based on applying current operation schedules that would reflect normal and flood conditions. For surcharge simulation, the flat top surcharge method was selected. This method uses a perfect knowledge forecast technique and daily time steps. With a minimum timestep of one day being used, the model releases more than observed keeping the peak elevations lower. Rating curve release adjustments were made to improve simulated release and pool peaks. This method keeps surcharge pool attenuated and somewhat flat near top of flood zone line.

The RiverWare modeling efforts for the Nueces River Basin WHA study in this section were designed to put emphasis on the last 20 years of operations (2000-2020), simulating flood control conditions, rather than rigorously simulate water supply and drought conditions. Plots D.20-D.25 validate the current operations been applied. The plots show good matching simulation results with observed. The same current rules were then applied across the entire POR to simulate historical events. The following paragraphs illustrate comparisons of historical model simulations with observed. Reasonings behind deviations from historical events are also captured in great details.

It should be noted that background information about the project and a narrative of historical events throughout the life of the project, which were obtained from personnel of the City of Corpus Christi, were used to justify model performances against observed events. The dam has a long history of instability issues, which mandated multiple requests for emergency drawdowns, change in operation, and maintenance. For example, since the dam initial impoundment between 1955 and 1958, and over the years, Lake Corpus Christi was impacted by several droughts that dropped the lake significantly. Damages occurred to the project due to big flood events (e.g., the 1965 flood), instability mandated keeping the pool at low levels. The following figures are comparisons of simulated versus observed pool over the years.

The observed pool in Figure D.14 shows pool levels of the lake when the project was first constructed. After construction was completed, drought occurred between 1955-1957, which limited reservoir filling. The reservoir essentially started filling post 1958 due to heavy rain and flooding. Since simulation began on 01 October 1942, the simulation does not account for the filling period during initial impoundment and assumes a reasonable starting pool condition. The initial pool was set at conservation (below 94.0ft-NGVD). The simulated pool remained flat and dropped some but stayed above 87.0ft-NGVD. The lake filled quickly, following the flood events occurred between 1958 and 1960, and stayed at conservation through 1960.

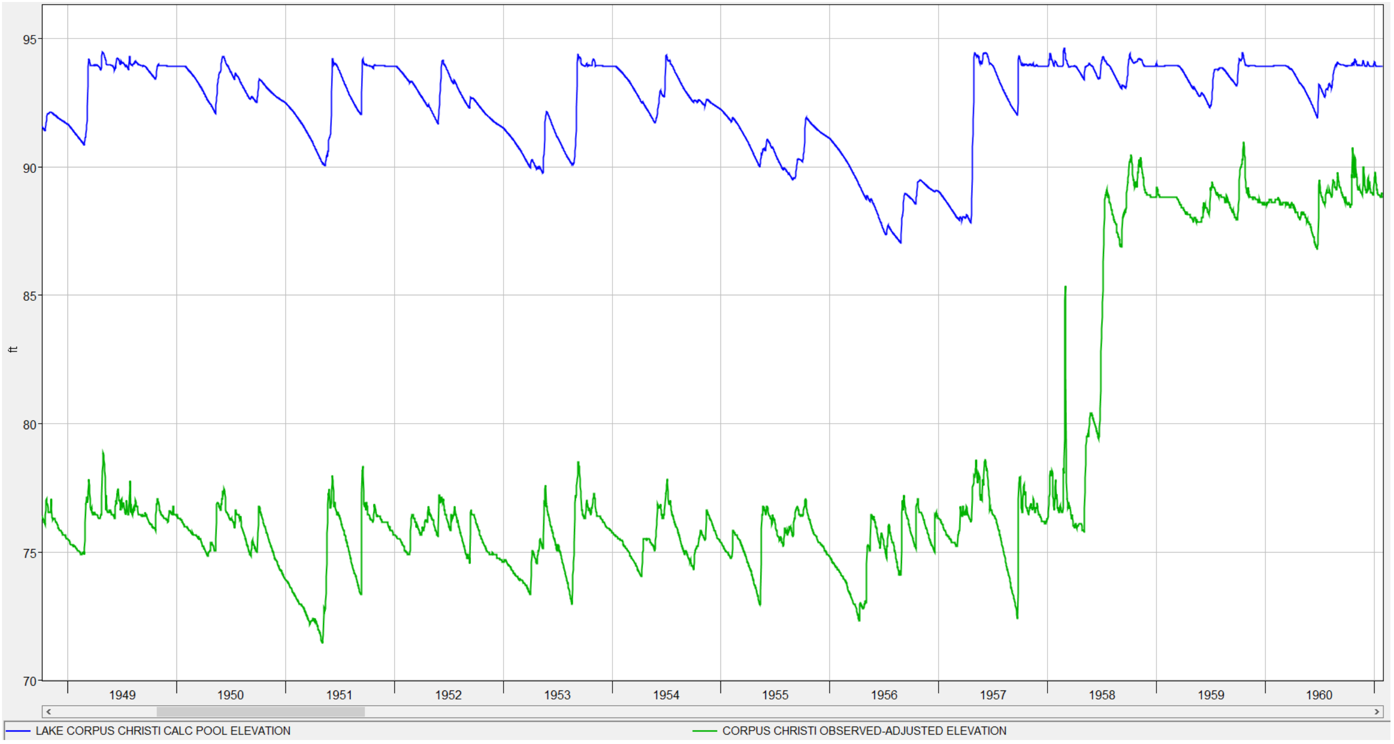

Figure D.14: Validation of Lake Corpus Christi Simulated Pool During Dam Initial Impoundment

Another dry period occurred between 1960 and 1967. This period was captured by the model in 1964. During hurricane Beulah (1967) a high observed water mark was recorded (approximately 96.22ft-NGVD). During the hurricane event, all spillway gates were engaged, and a discharge was approximately 128,000cfs. The model captured the hurricane affect by raising the pool to surcharge (above 94ft-NGVD). The simulated release was about 107,800cfs from the project (Figure D.16). The peak release difference was associated with the difference between observed and simulated pool (1.40 feet difference) due to the flat top surcharge method being used to simulate reservoir during surcharge. In addition, flood release is based on perfect knowledge that the model trigger releases and keep pool from reaching elevations above 95.0 ft-NGVD. It should also be noted that in 1965, a storm did a significant damage to the system, where the automated gates were replaced by 1967 with manually and hydraulically operated gates. As a result, gate operation policy was developed and a 6 feet drawdown from 1965 until all gates were restored in 1967. Lake was operated according to the 1967 gate operating plan until the stability issues developed. At that time, lake was already low due to drought. It is clear the model is not designed to mimic such unusual conditions, and for that reason the lake wasn't drawn down to the observed level (early 1965 to mid-1967), see Figure D.15.

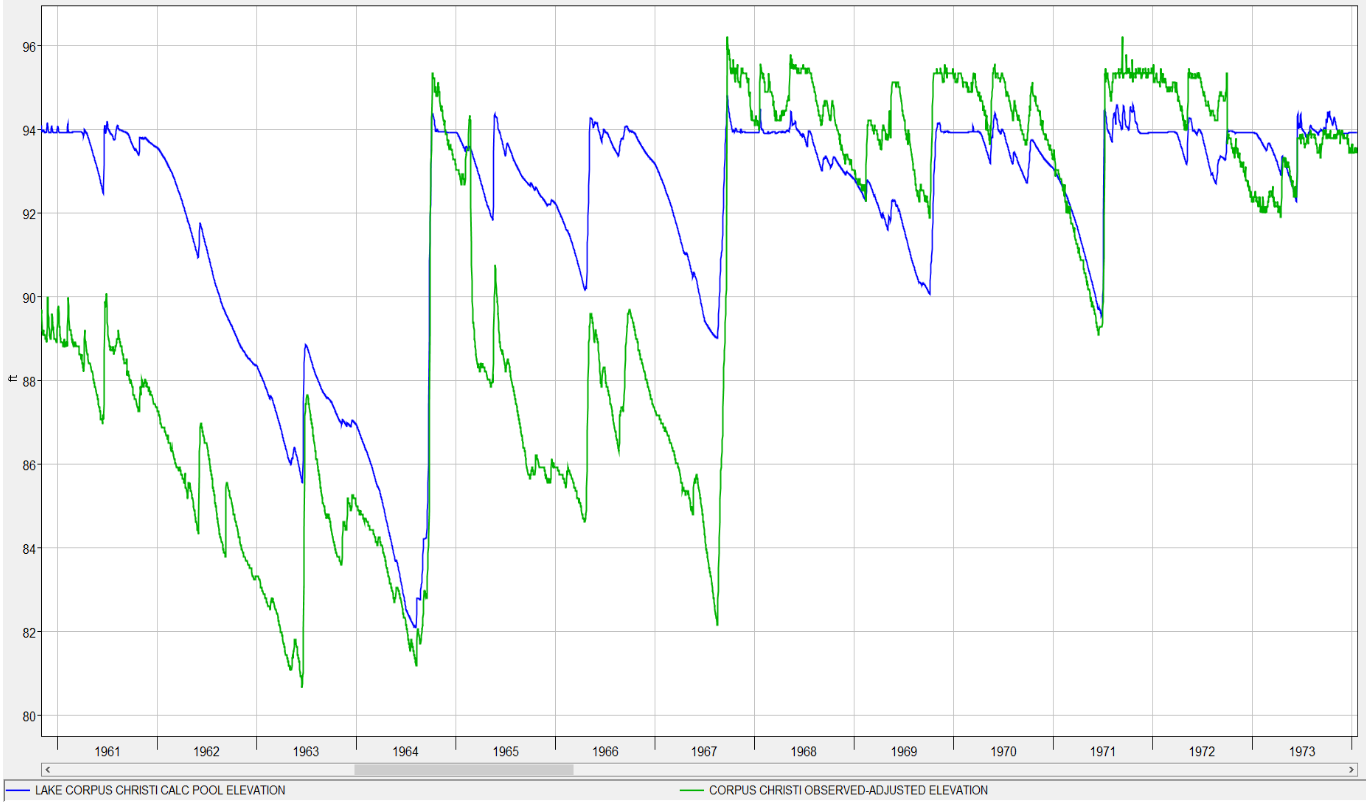

Figure D.15: Validation of Lake Corpus Christi Simulated Pool During Hurricane Beulah

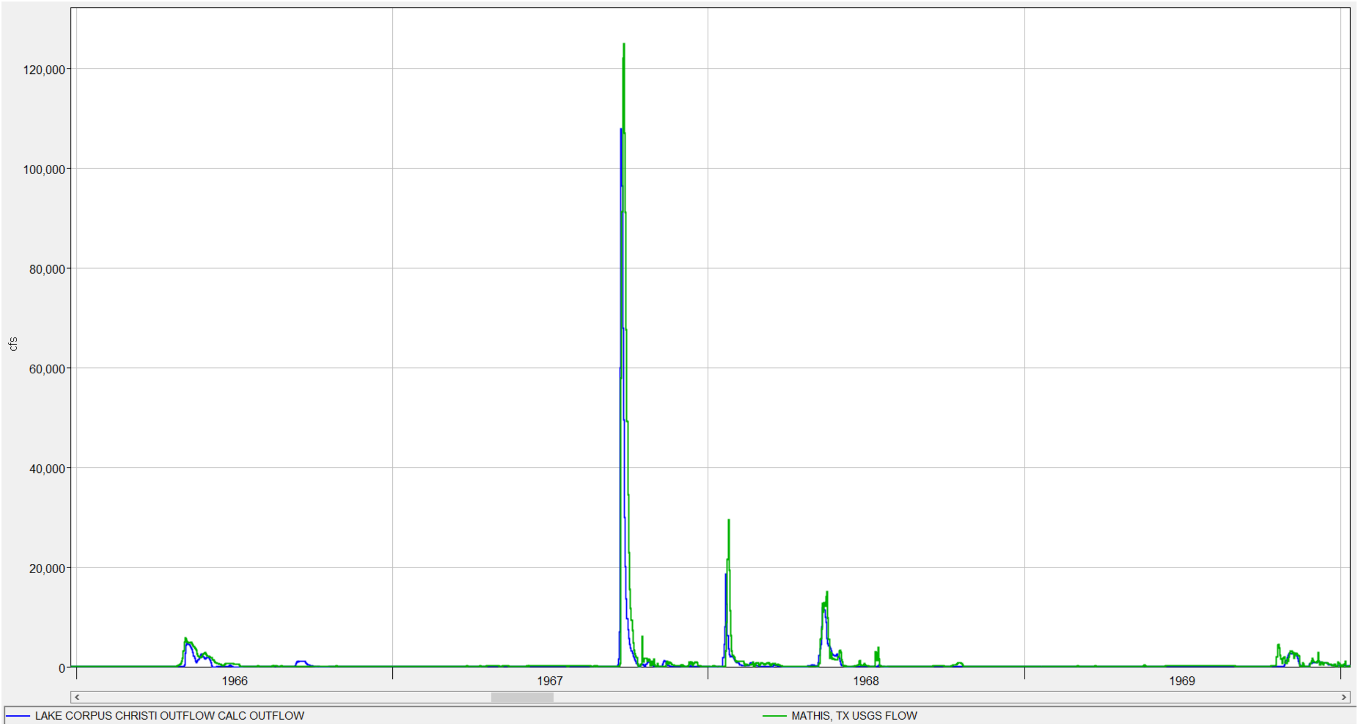

Figure D.16 Hurricane Beulah Simulated Release from Lake Corpus Christi

The model stays flat at conservation during normal operation years (Figure D.17). Some simulated pool deviations from observed were seen during 1978, 1980, 1981, 1983, and 1985. Drawdown in those years was high likely due to increased evaporation rates (some 6 feet annually), municipal and industrial use, and required environmental flows. Model results synchronized with observed to mimic drawdown. The differences are associated with the methods being used to develop data and convert from monthly to daily for reservoir depletion rates. Average daily release rates were distributed evenly over the entire period when actual data were not available. Lack of other depletion data may have contributed as well.

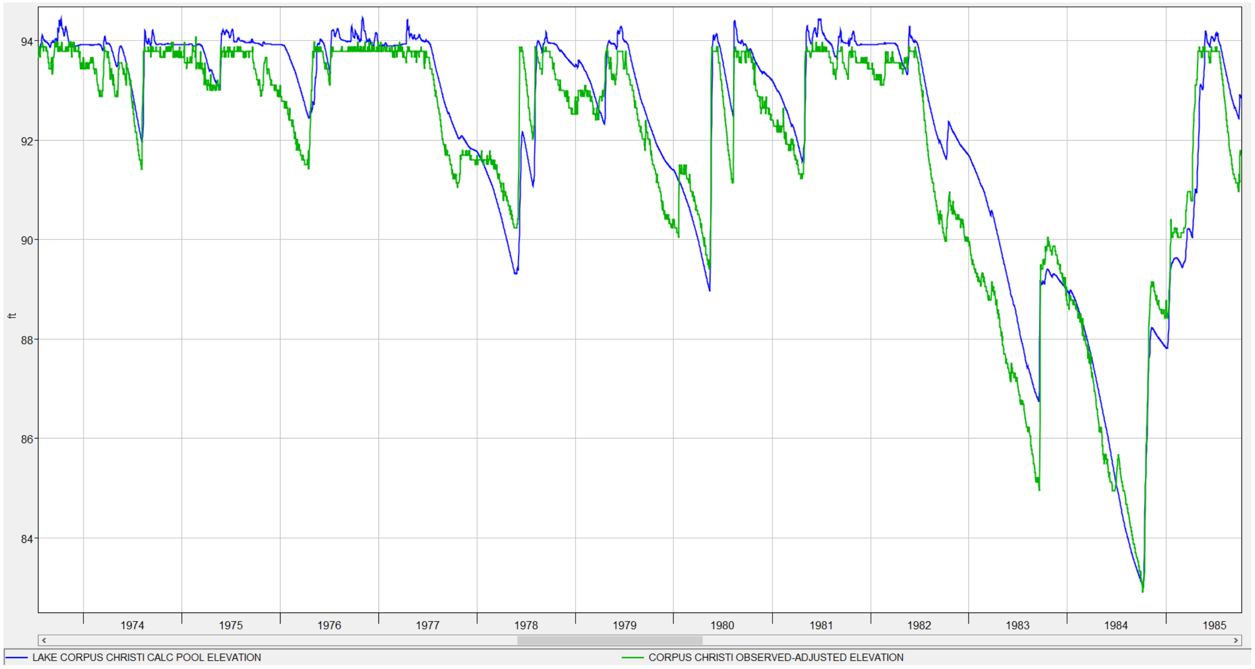

Figure D.17: Validation of Lake Corpus Christi Simulated Pool During Normal Operating Conditions

No information is available for the observed period between 1986 and 1996 that would explain operation procedures for those years (Figure D.18). Drawdown could be related to a period of severe drought in conjunction with high water supply demand during this period. The model deviated some but stayed flat for the most part. More investigation would possibly improve results. A comparison between simulated and observed releases are shown in Figure D.19 at the project outlet. The 1987 simulated peak was due to surcharge. The model released according to surcharge (Table D.6), where release is maximum.

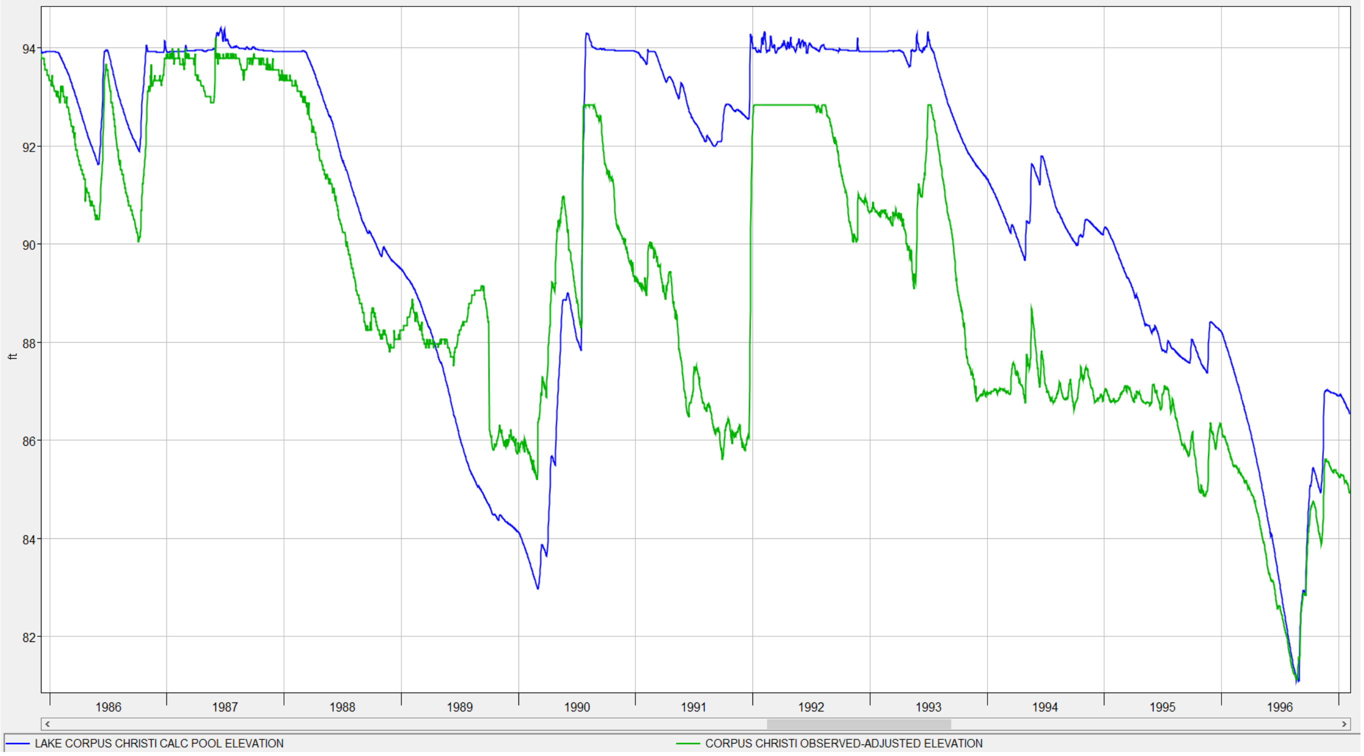

Figure D.18: Validation of Lake Corpus Christi Simulated Pool During Severe Drought Conditions

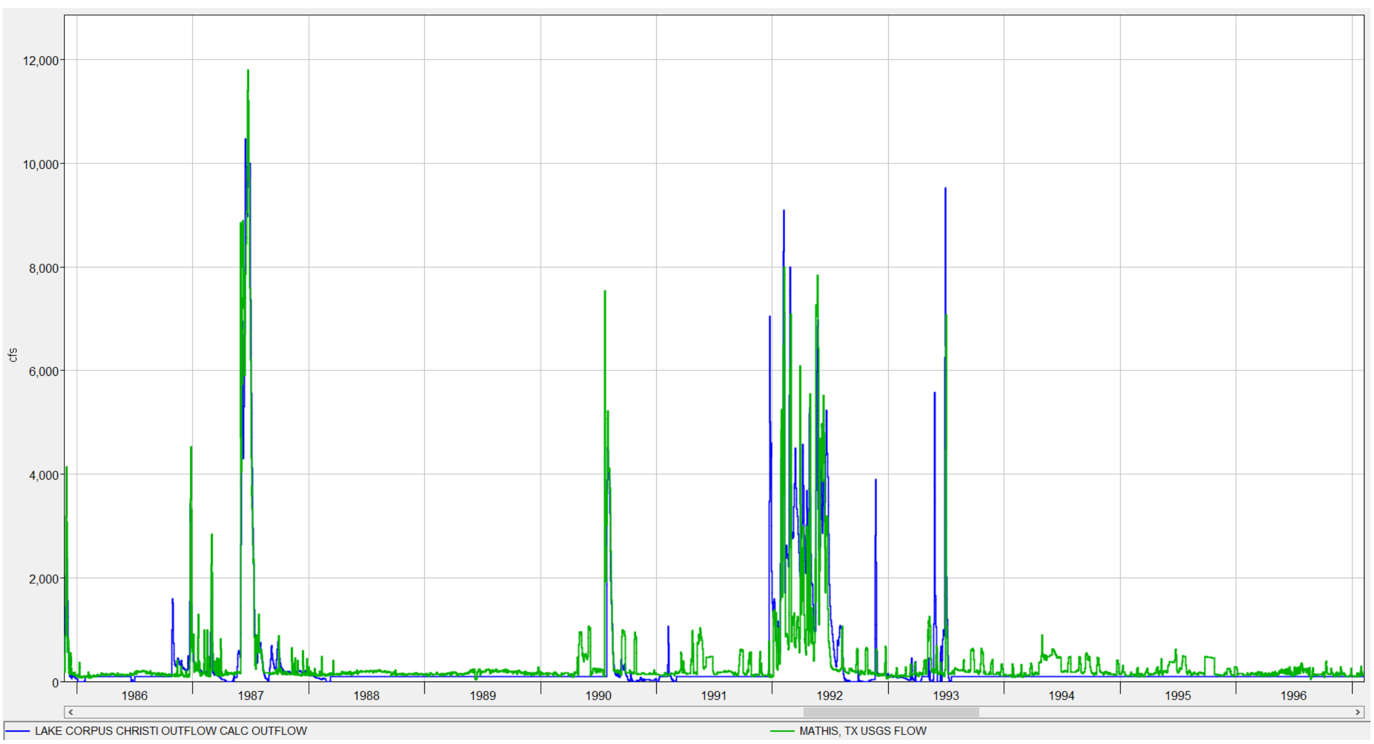

Figure D.19: Model Results Validation at Lake Corpus Christi Outlet (USGS 0211000 Near Mathis)

Table D.6: Lake Corpus Christi Controlled and Uncontrolled Maximum Release

Pool NGVD-ft	Release CFS	Pool NGVD-ft	Release CFS
38	-	95	142,993
55	1,000	96	177,362
80	10,000	97	215,900
90	20,526	98	254,791
90.85	34,173	99	292,633
91.06	40,514	100	331,800
92.35	67,795	101	380,400
92.56	74,547	102	425,100
92.83	79,211	103	475,500
93.55	97,183	106	620,100
93.58	98,767	108	715,800
94	114,491	110	813,000

The simulated pool for the period between 1995 and 2019 is shown in Figure D.20. This period reflects changes in operations since Choke Canyon Reservoir was completed in 1982. Choke Canyon Reservoir controls more than 5,000 square miles of Wesley Seale drainage area, holding 700,000 acre-feet versus 256,000 acre-feet in Lake Corpus Christi. The period between 2002 through 2019 shows good match near conservation top pool. Pool levels for 1997-2000 are special case due to instability drawdown. Stability repairs were made and completed in 2000. Yet, the model performed well mimicking drawdown for 2000-2001. During 2010-2011, lake level fell to 17%. Simulated pool dropped below 80ft-NGVD and synchronized with the observed pool moving forward. Environmental flow requirements per 1988 agreed order with TCEQ (Texas Commission of Environmental Quality), required annual release of approximately 95,000 acre-feet, following seasonal rainfall variation. It also dictated flow level as high as 37,000 acre-feet per month. Daily release for water supply and bays and estuaries, are from 20cfs to 110cfs. Because of the long-simulated POR, an approximate current operation of constant low flow was assumed. This low flow release is an average release value based rather than observed daily rates. The model maintains a minimum flow from the lake to 100cfs (Figure D.21).

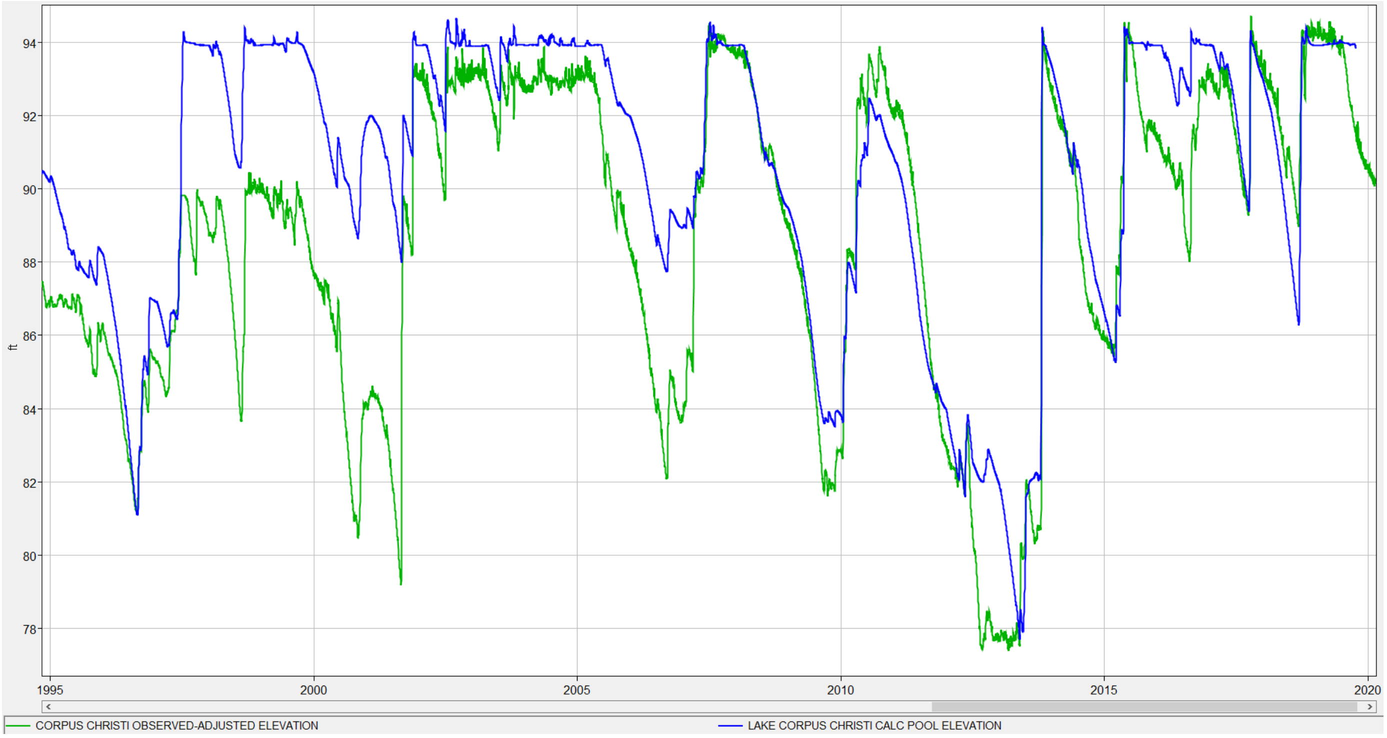

Figure D.20: Validation of Lake Corpus Christi Simulated Pool for 1996-2019

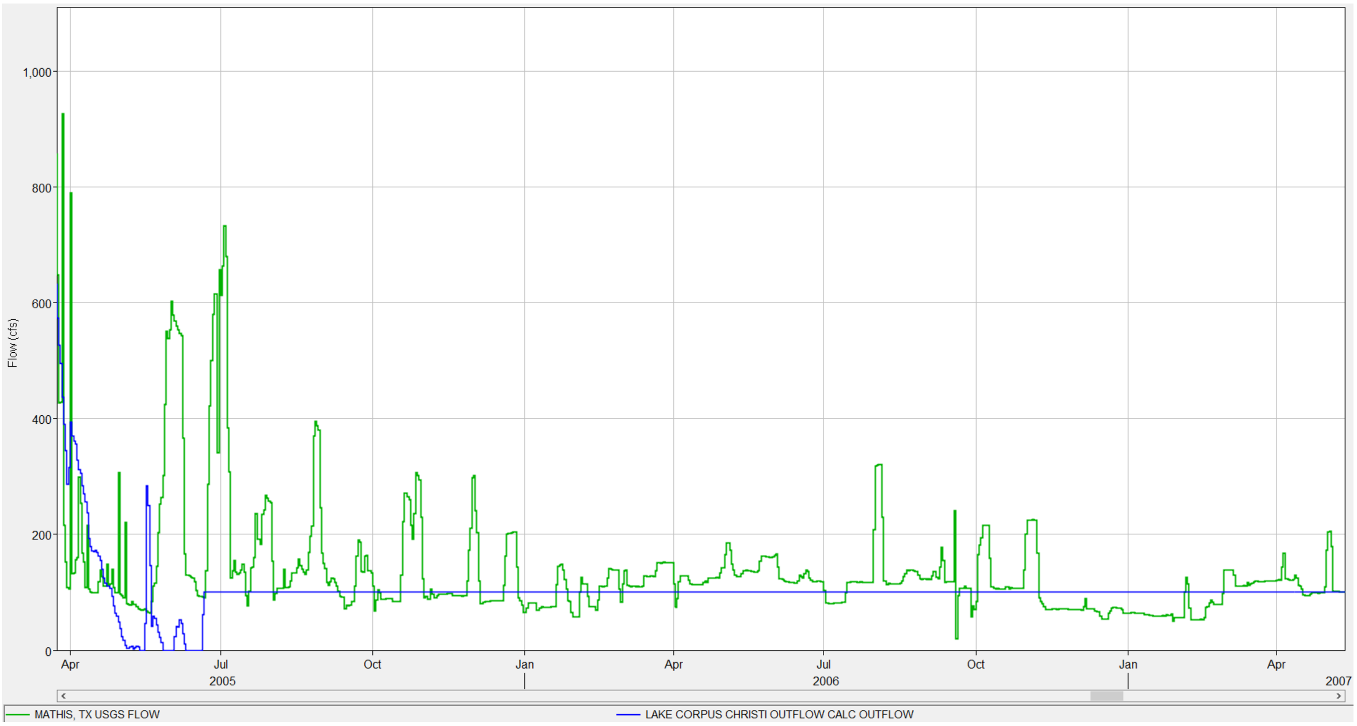

Figure D.21: Validation of Lake Corpus Christi Minimum Release for Environmental Requirements

Comparisons between the simulated model results and USGS 08211200 Nueces River nr Bluntzer and USGS 08211500 Nueces River at Calallen are shown in Figures D.22 and D.23 for the years of 2002 through 2005. The two gages have many years with discontinued discharge records and gaps. However, model routings and peaking compared very well to observed.

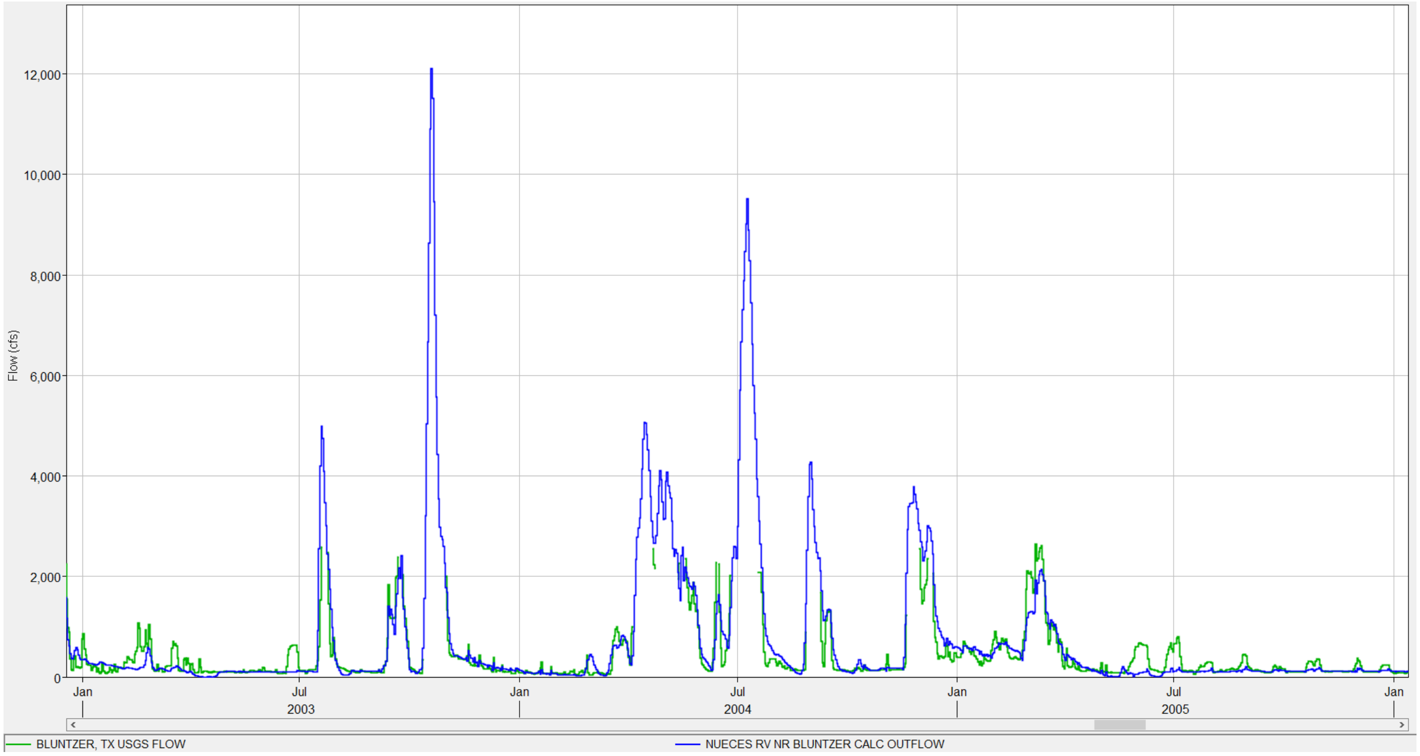

Figure D.22: Model Results Validation at USGS 0211200 Nueces Rv nr Bluntzer

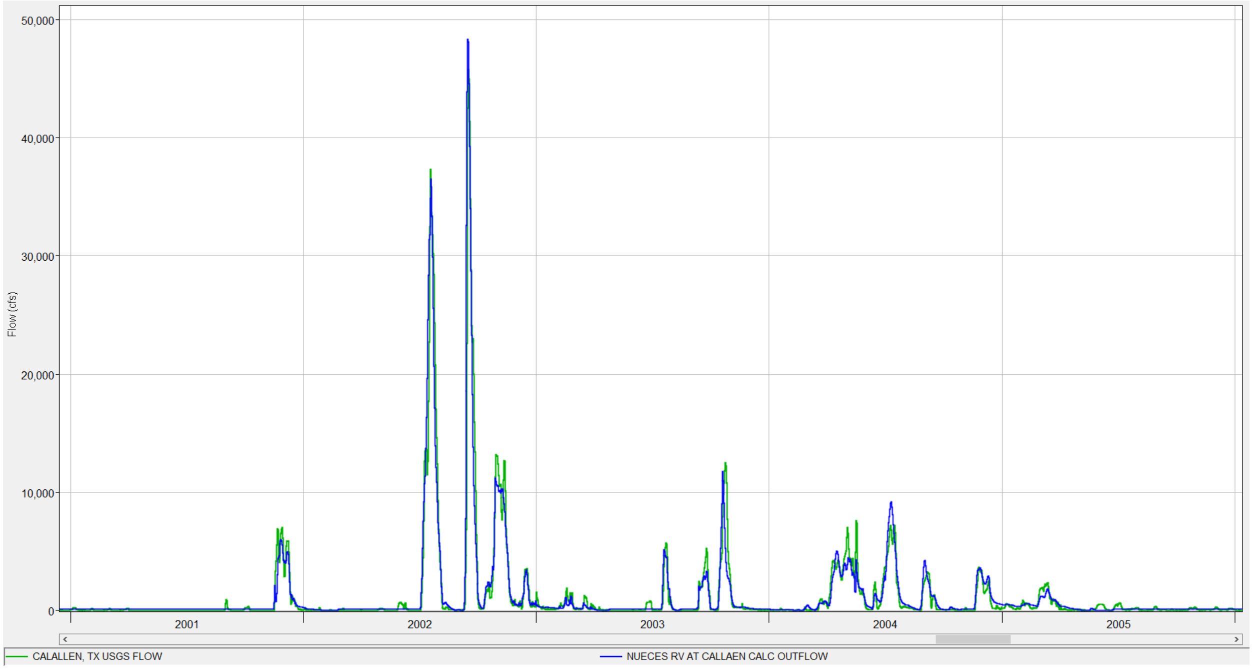

Figure D.23: Model Results Validation at USGS 0211500 Nueces Rv at Calallen

Figure D.24 illustrates the Weibull plotting position distribution of Lake Corpus Christi between water years 2000 and 2020. The last 20 years of operation were analyzed, because they reflect current operational standards. Those years were also less impacted by emergency drawdowns, which could impact the analysis. Some of the most extreme simulated peaks near elevation 95.0ft-NGVD were lower than observed due to the selected surcharge method, which tends to flatten the top of flood pool. For this lake, the observed pool for the period of WY2007 through WY2020 will be selected over simulated to perform statistical analysis, but simulated pool peaks will be analyzed for periods prior to WY2007. This approach ensures that the analyzed data is homogenous and valid for statistical analysis. Figure D.25 illustrates the corresponding relationship between observed and simulated pool for Lake Corpus Christi for water years 2000-2020. The strong relationship increases confidence in the use of selected simulated results prior to WY2000.

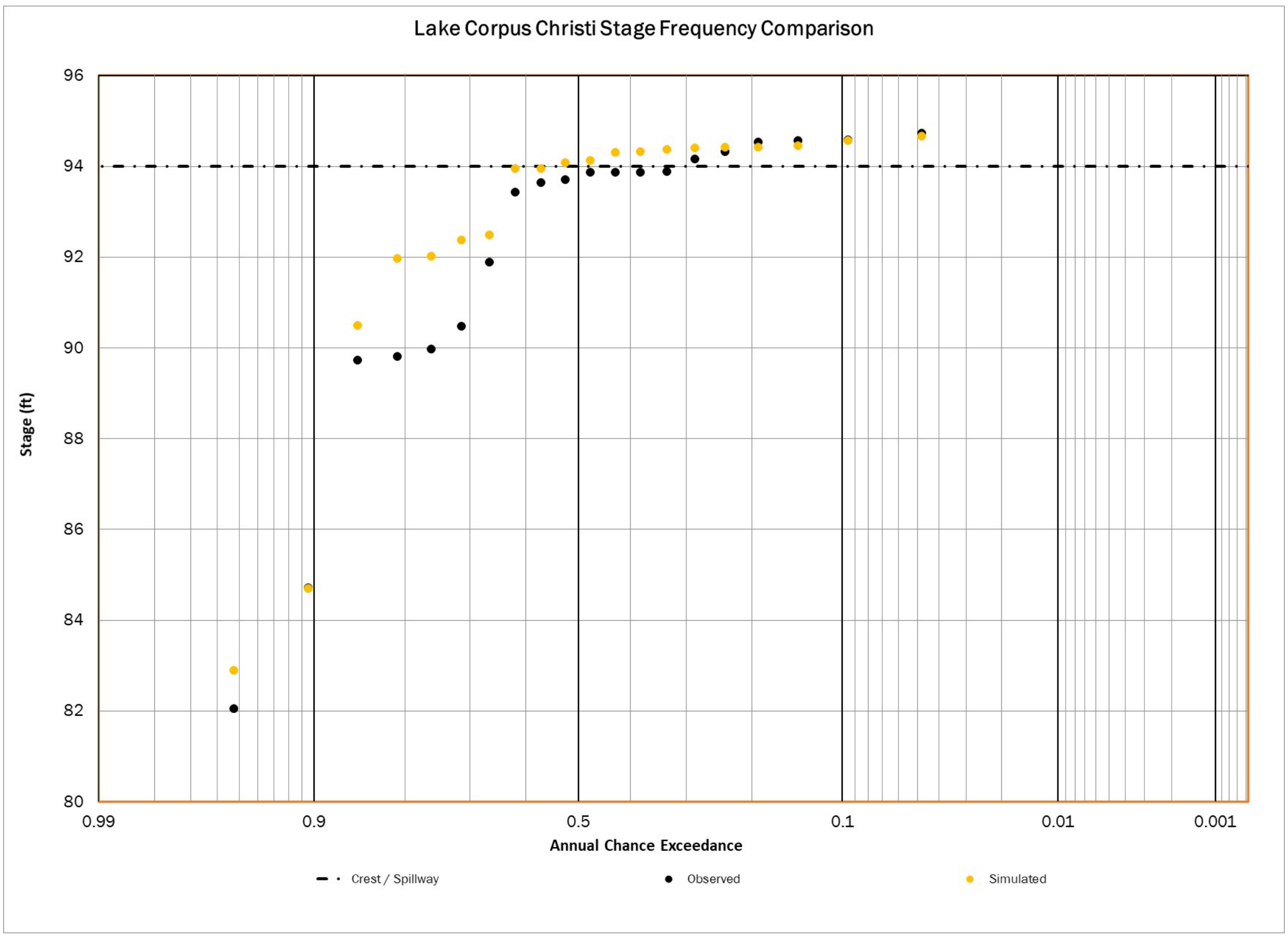

Figure D.24: Corpus Christi's Stage Frequency Peak Comparison (Annual Maximum Peaks) for WY 2000-2020

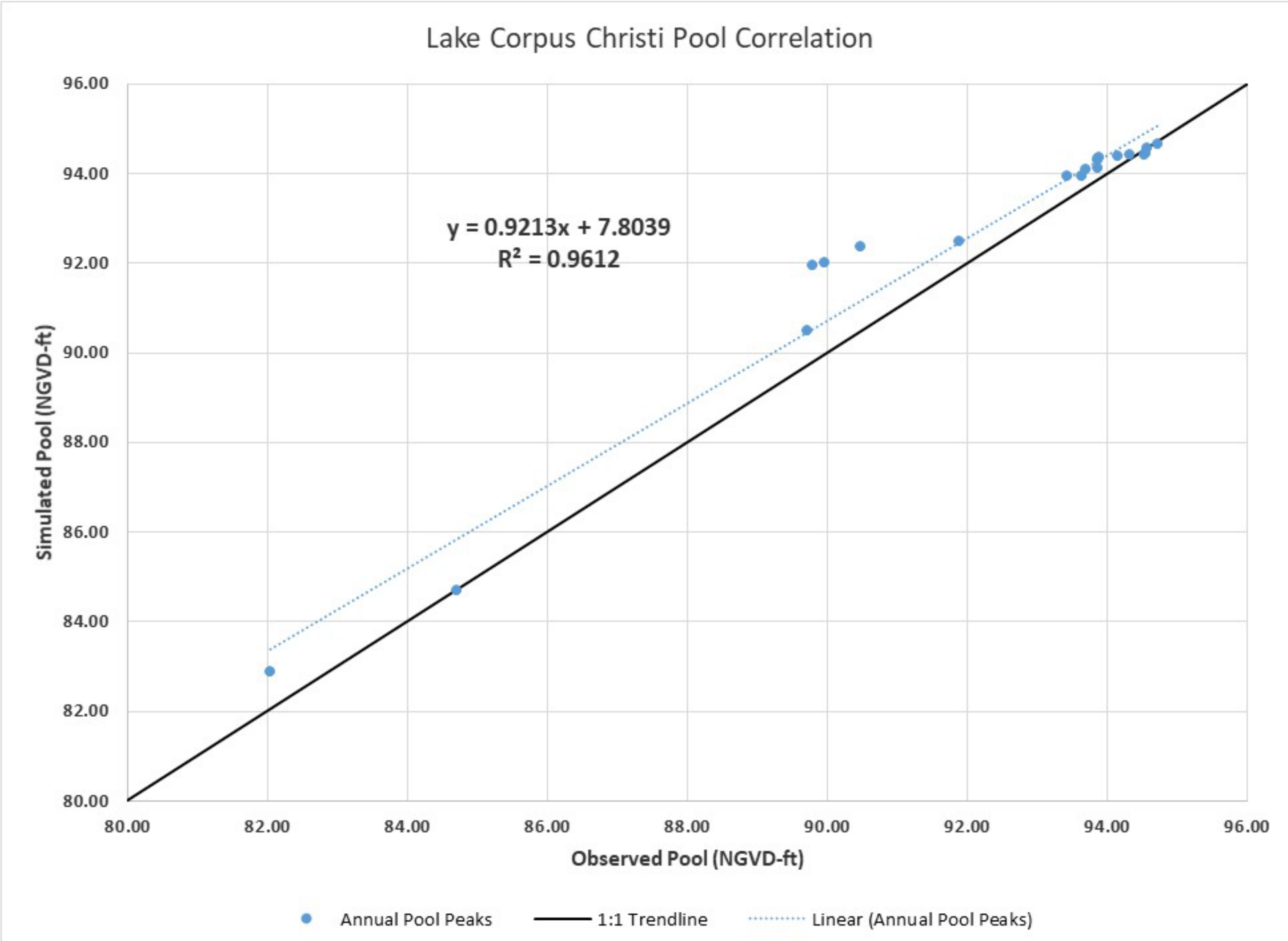

Figure D.25: Observed Vs. Simulated Pool Annual Maximum Peak for Lake Corpus Christi for (WY 2000- 2020)

1.7 Final Riverware Model Period of Record Results

The final RiverWare simulation runs for the POR (e.g., October 1, 1942 – September 30, 2019) are shown in the following figures. The plots reflect good operational results and similarities with stream gaged (observed) data for the most part.

The data in each plot was used in a tabular format as input to the flow frequency analyses described in the next sections.

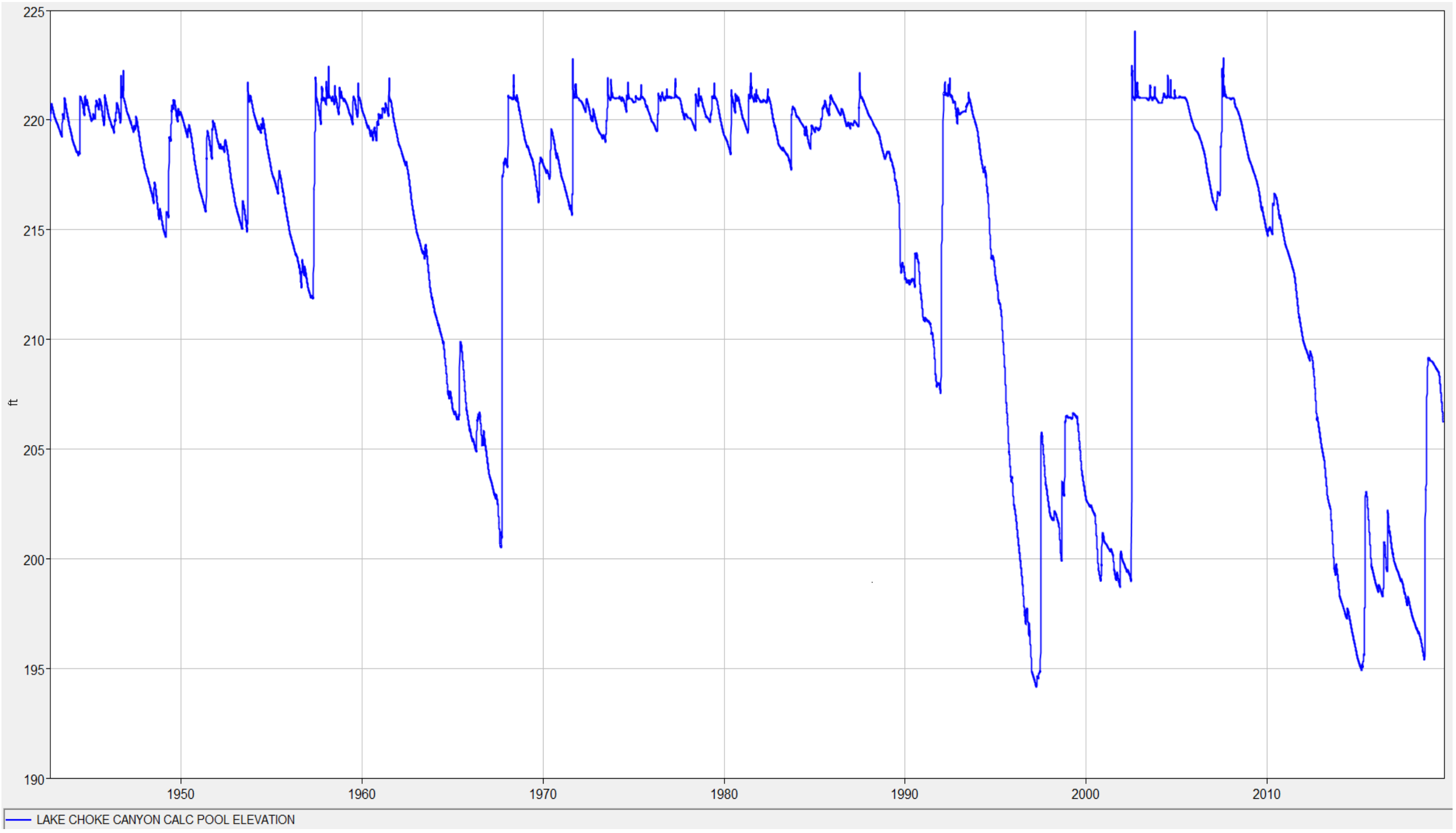

Figure D.26: Simulated POR Results for Choke Canyon Reservoir

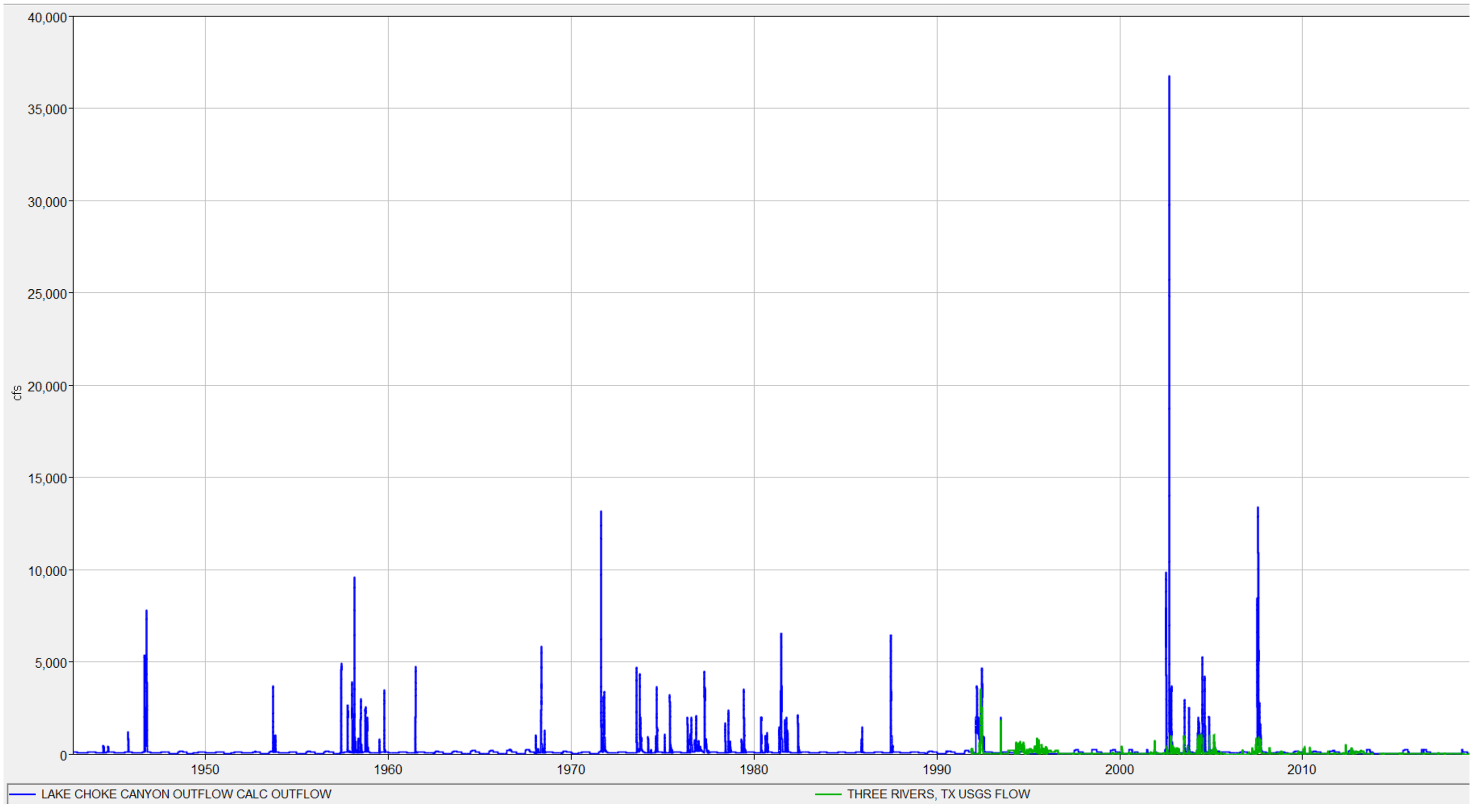

Figure D.27: RiverWare Model Results Comparison for USGS streamgage station 08206910 Choke Canyon Reservoir nr Three Rivers, Tex.

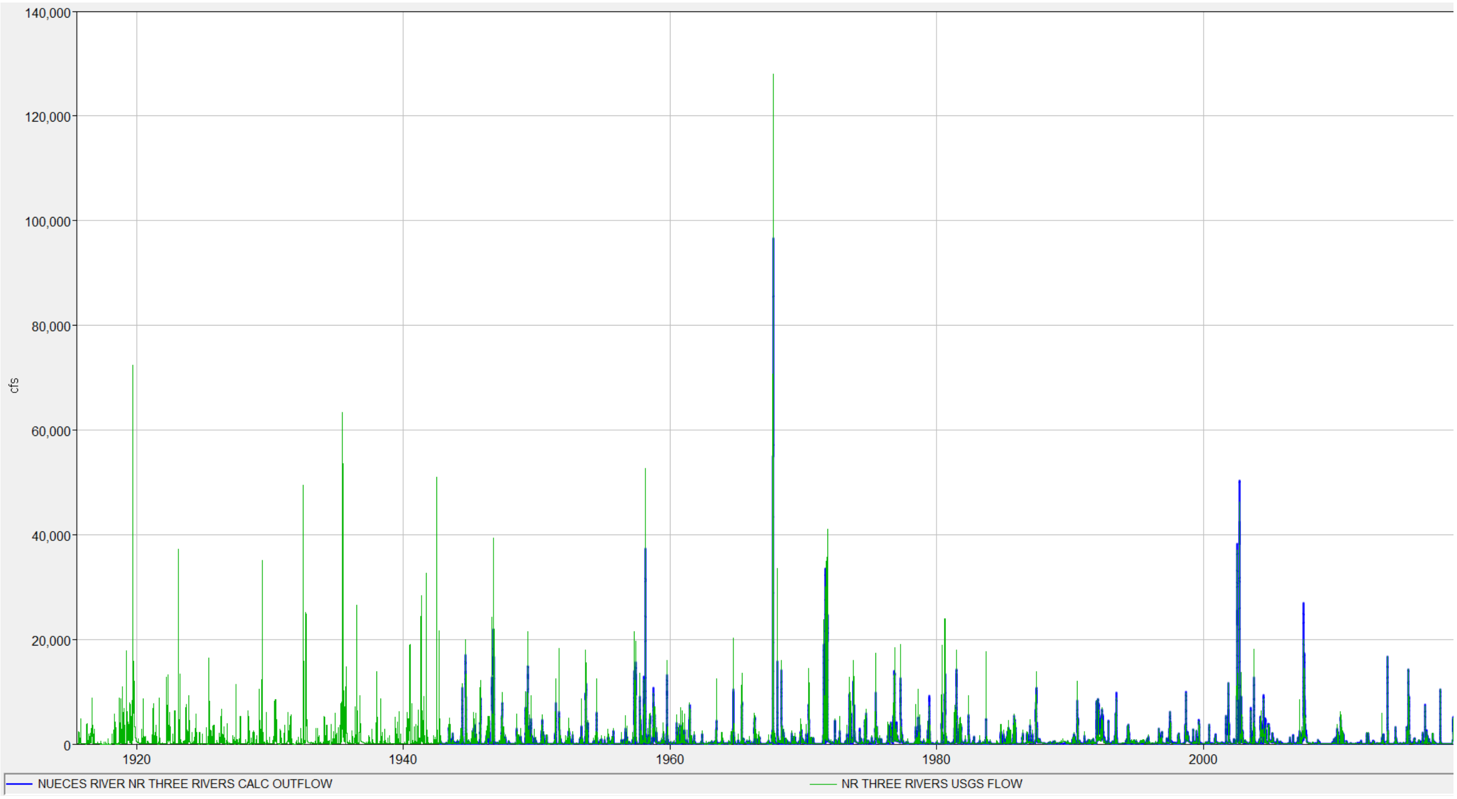

Figure D.28: RiverWare Model Results Comparison for USGS streamgage station 08210000 Nueces River Near Three Rivers, Tex.

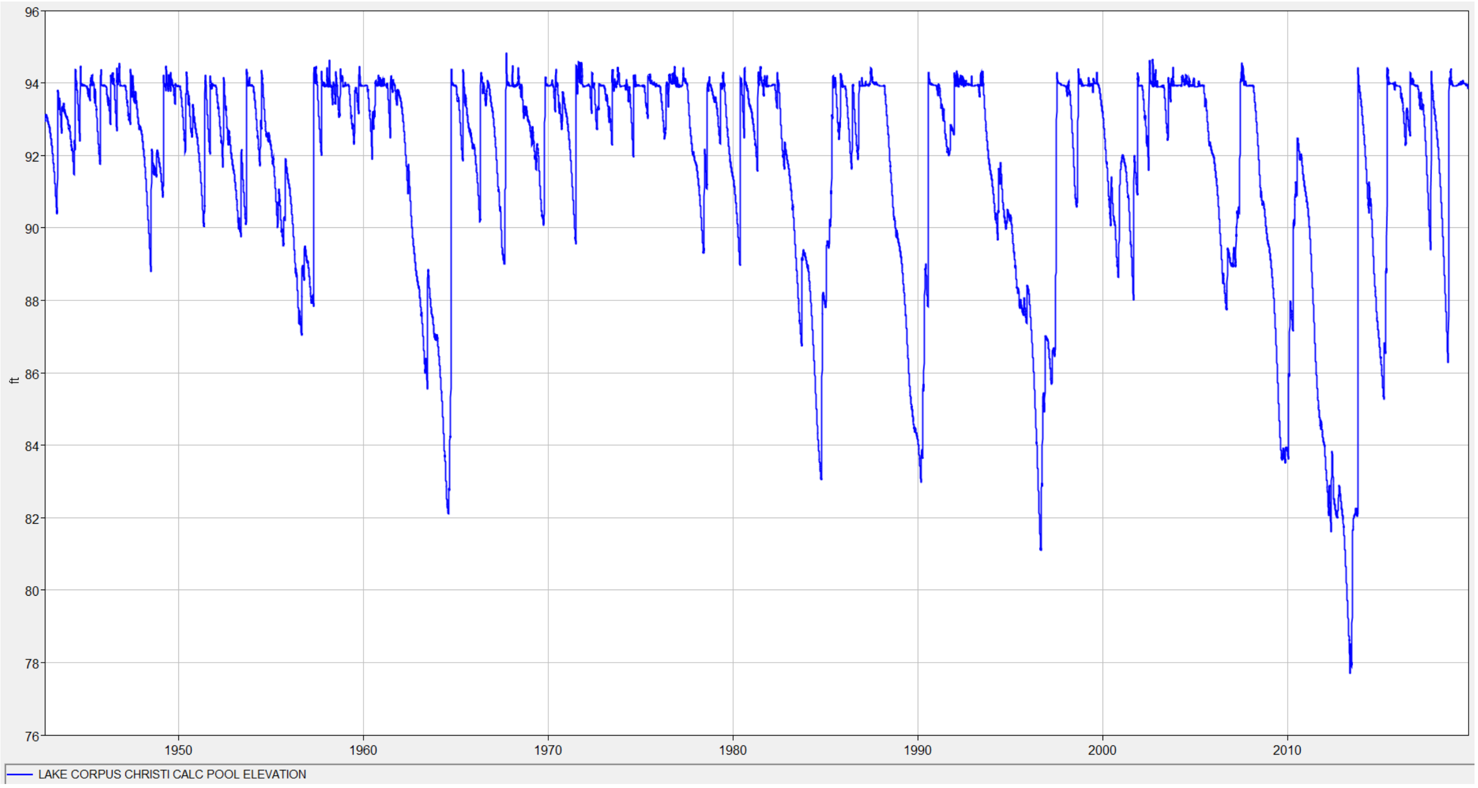

Figure D.29: Simulated POR Results for Lake Corpus Christi Pool Elevation

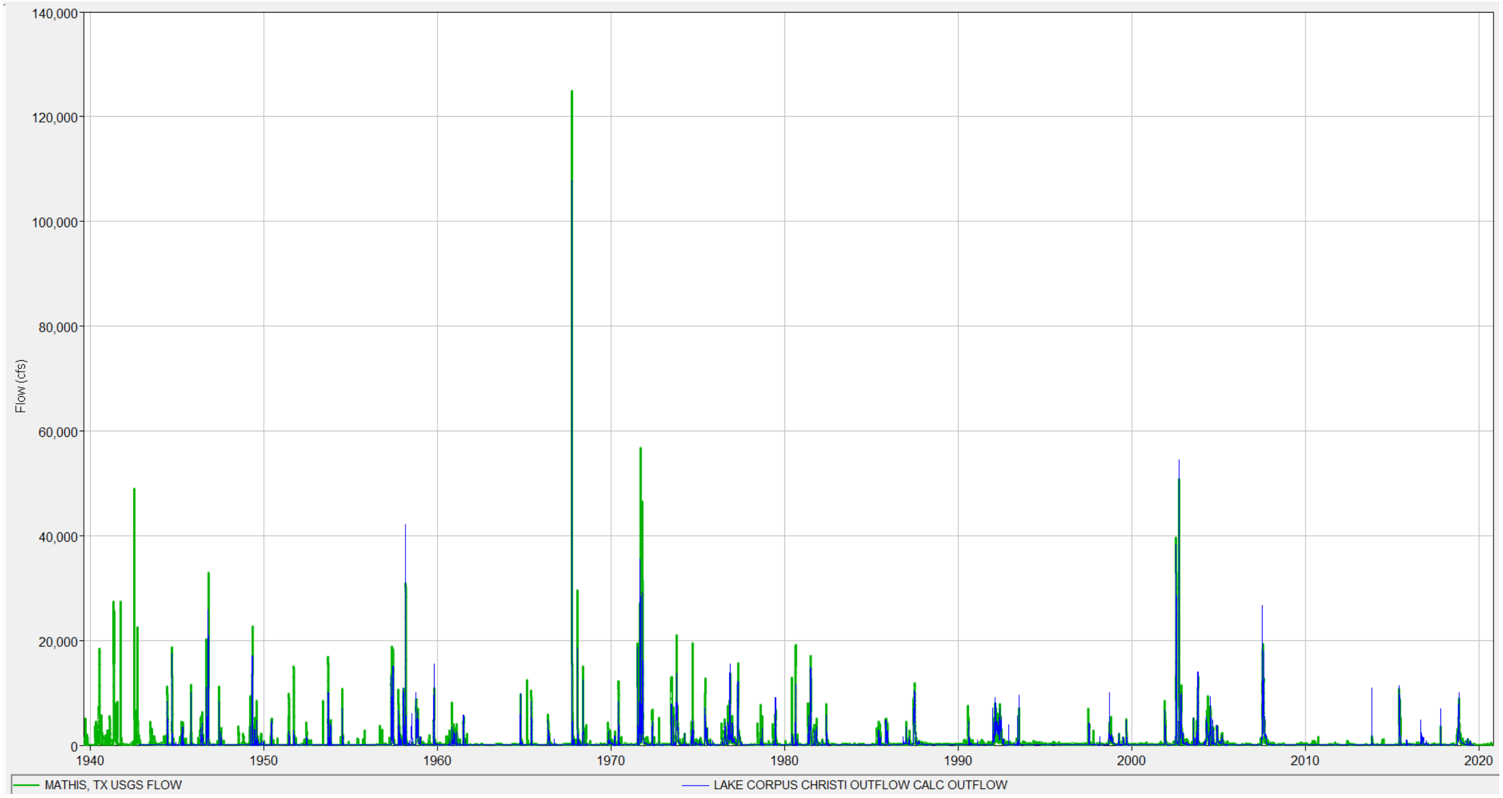

Figure D.30: RiverWare Model Results Comparison for USGS stream gaging station 08211000 Nueces River near Mathis, Tex.

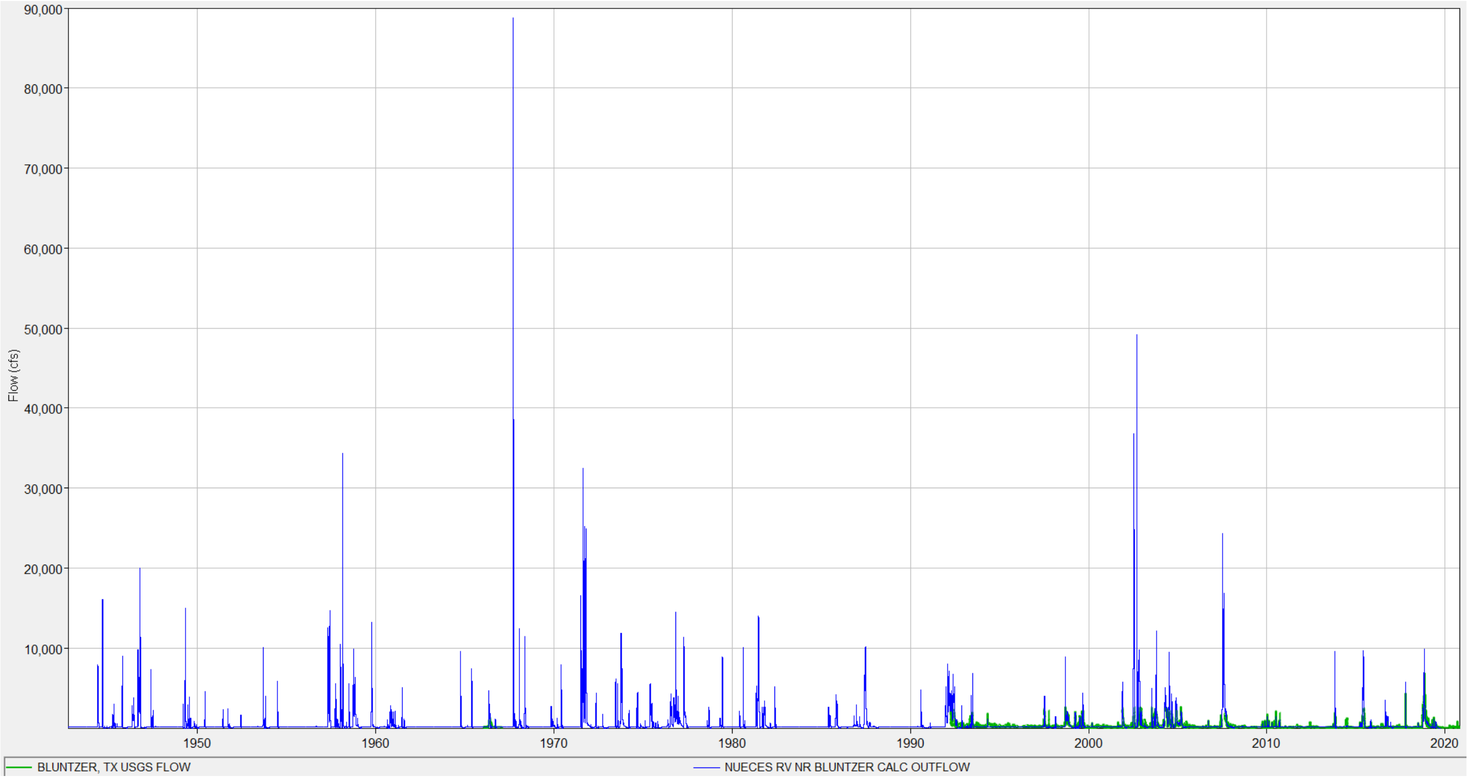

Figure D.31: RiverWare Model Results Comparison for USGS streamgage Station 08211200 Nueces River near Bluntzer, Tex.

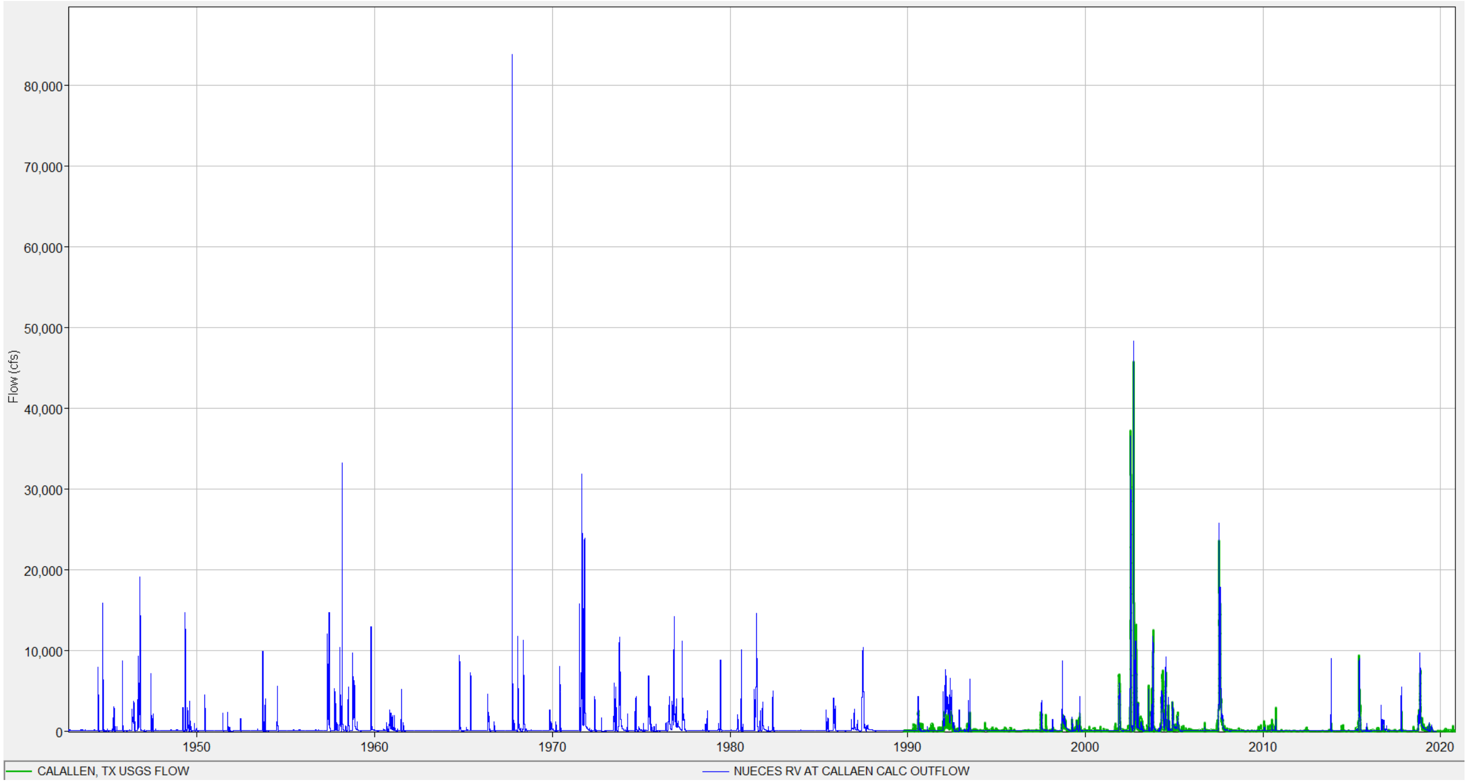

Figure D.32: RiverWare Model Results Comparison for USGS Streamgage Station 0821500 Nueces River at Calallen, Tex.

1.8 Conversion of Daily Flows to Peak Instantaneous Discharges

While the RiverWare model runs on a daily time step, peak instantaneous discharges are needed for flow frequency analysis. Therefore, a comparison of USGS observed instantaneous peaks and the corresponding USGS daily average discharges were made to convert the RiverWare daily discharges to an equivalent peak instantaneous discharge for each streamgage of interest. A plot of instantaneous discharges versus USGS daily average peak discharges were made, and a regression equation was fit to each dataset. The regression equations were then applied to the daily peak flows from RiverWare to transform them into instantaneous peaks. Figures D.33 through D.37 illustrate the corresponding relationship between datasets used to generate peaking factors to transform peaks. The corresponding period of record for each site is indicated below each figure.

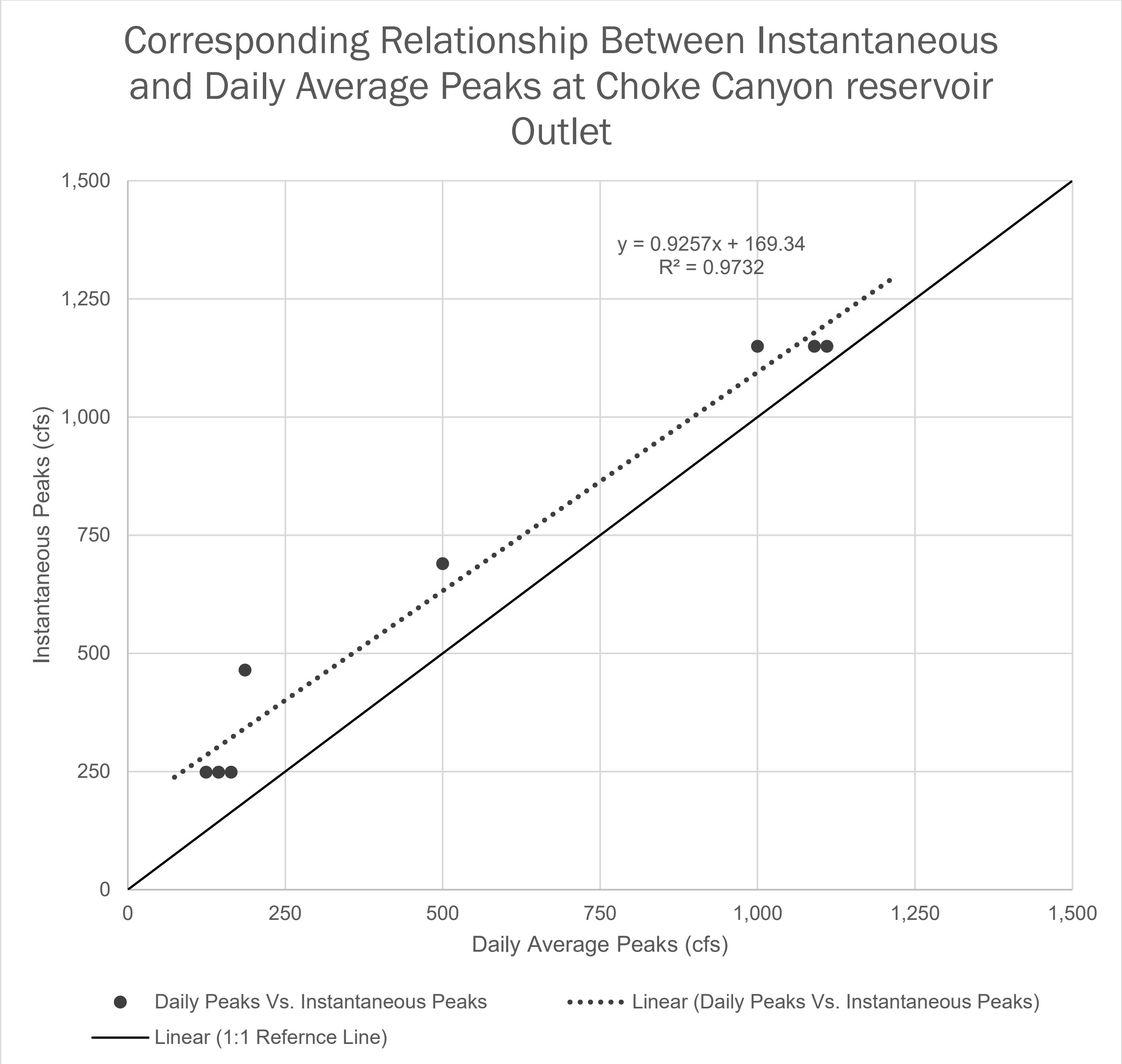

Figure D.33: Instantaneous vs. Daily Average Peak Discharges for USGS 08206910 Streamgage Station Choke Canyon Reservoir nr Three Rivers, TX., for 2001, 2003-2006, 2008, 2011-2012.

Since its installment in November 1991, this gage has many gaps and is not reliable to gather high discharge peaks from, especially during mid to high releases. Extreme caution should be used in generating a correlation for its daily average peaks. There are eight (8) discharge peaks used to develop a strong corresponding relationship. The gage should be noted to have high uncertainty with it when developing high discharge frequencies.

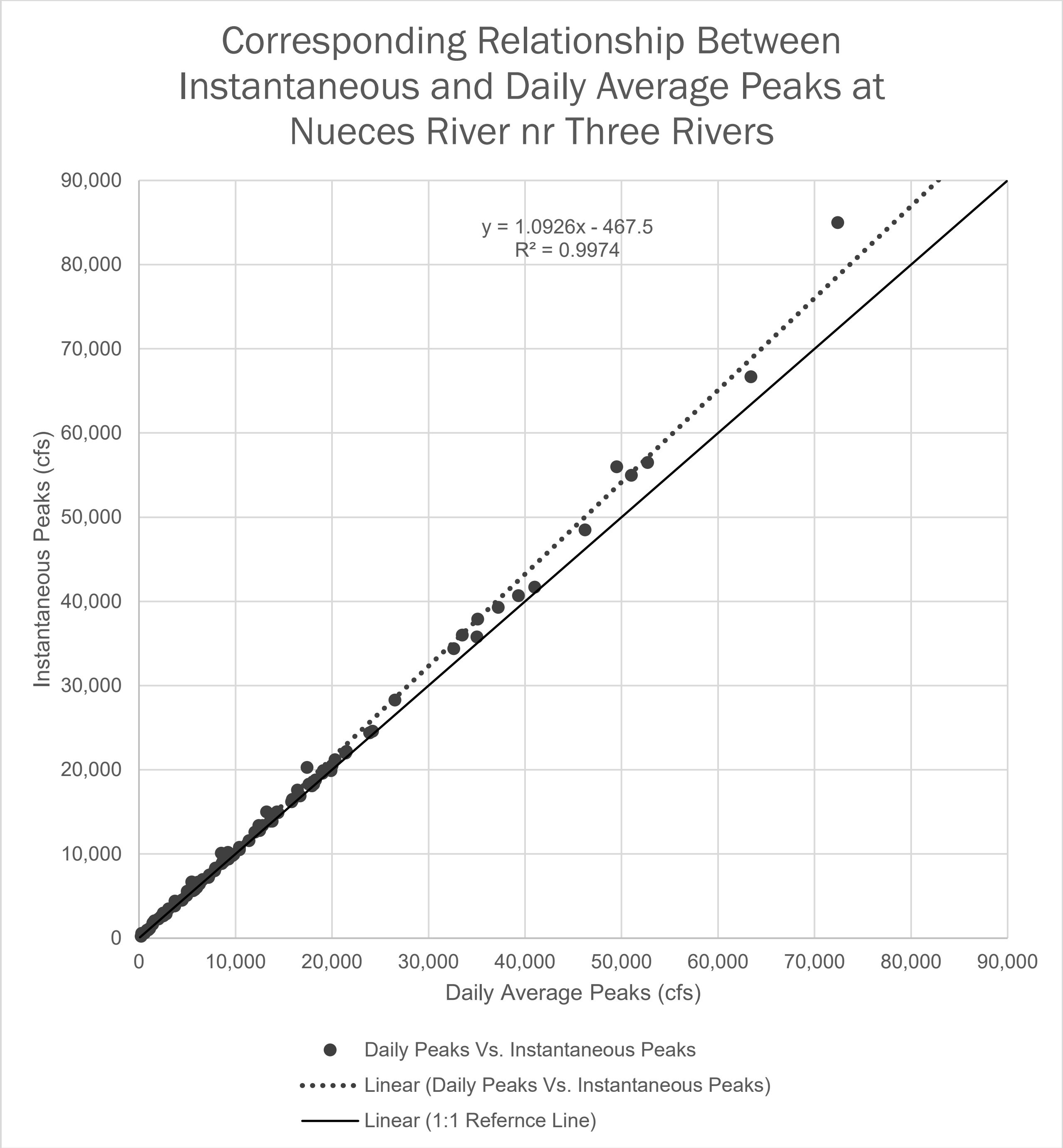

Figure D.34: Instantaneous vs. Daily Average Peak Discharges for USGS 08210000 Streamgage Station Nueces River nr Three Rivers, TX. POR (1916-2019)

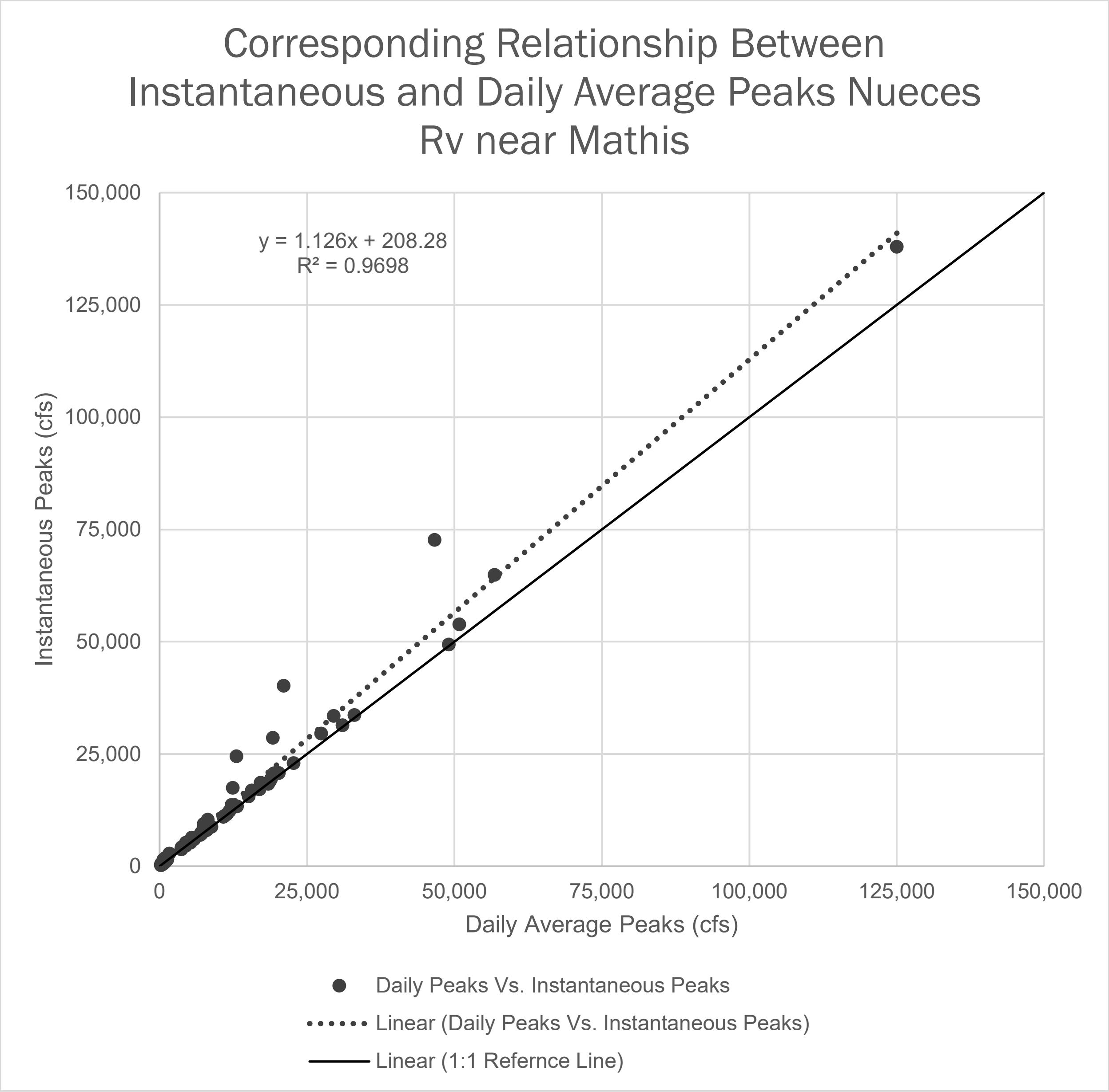

Figure D.35: Instantaneous vs. Daily Average Peak Discharges for USGS 08211000 Streamgage Station Nueces River nr Mathis, TX. POR (1940-2019)

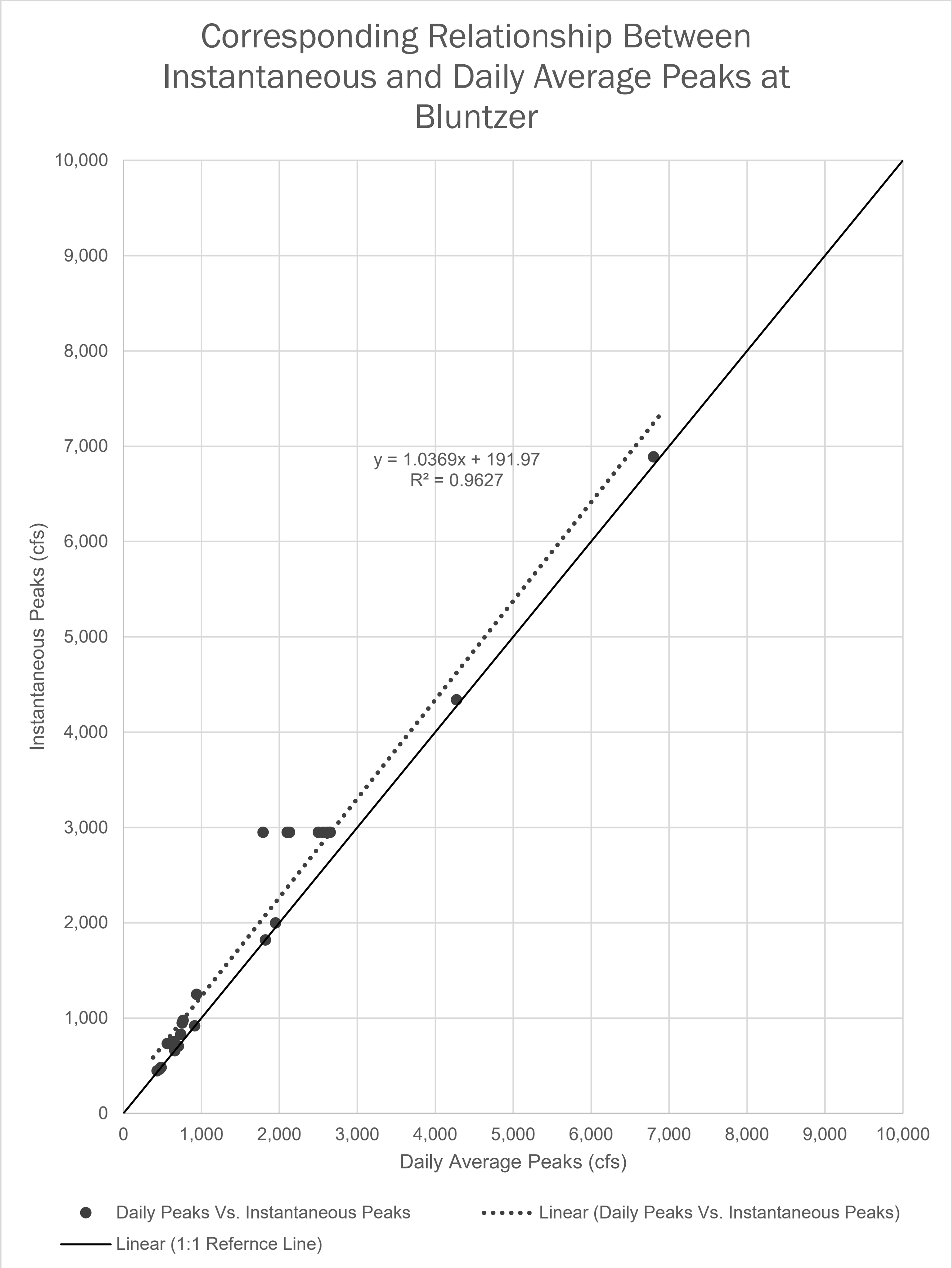

Figure D.36: Instantaneous vs. Daily Average Peak Discharges for USGS 08211200 Streamgage Station Nueces River near Bluntzer, TX. POR (1994-2019).

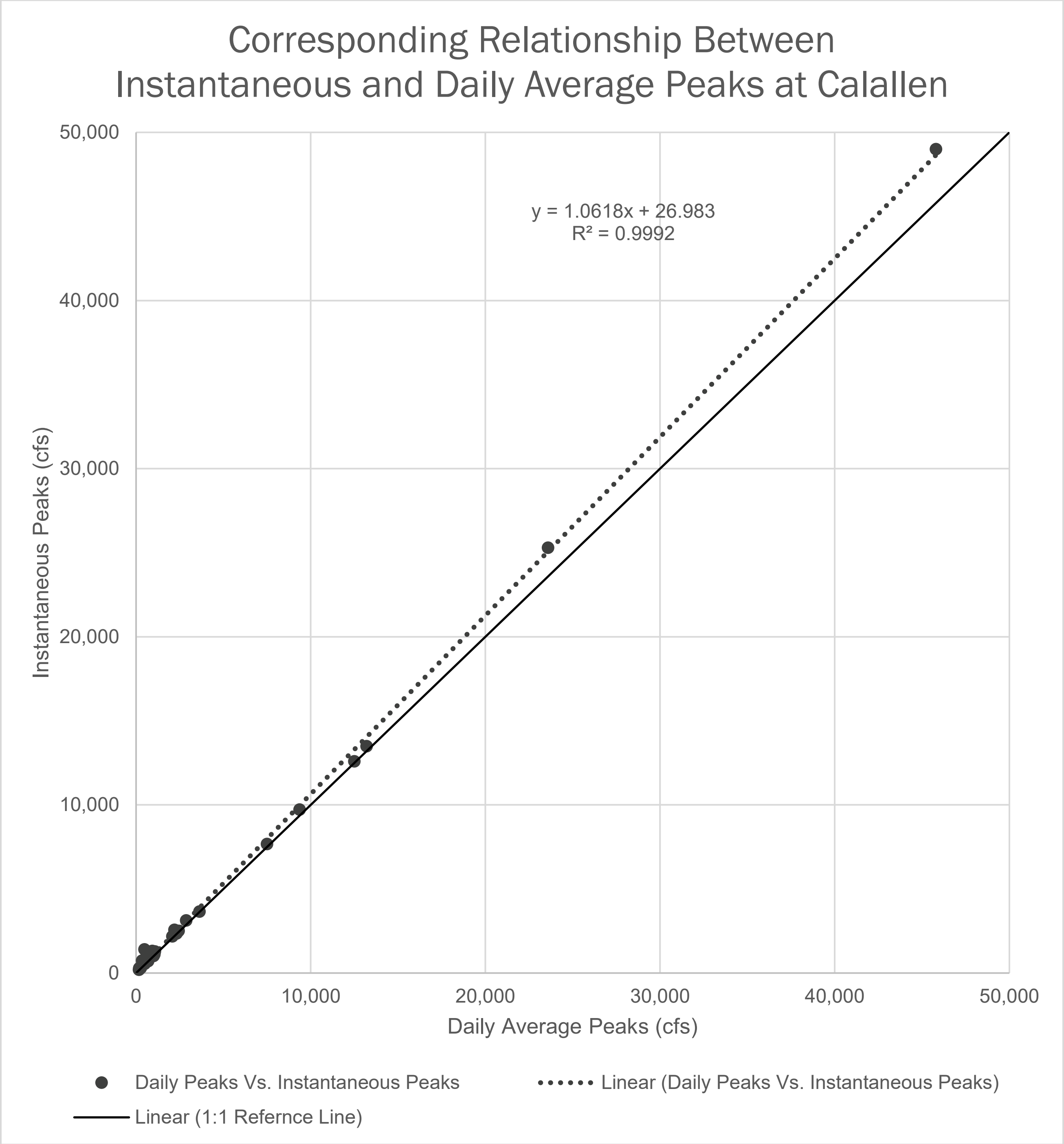

Figure D.37: Instantaneous vs. Daily Average Peak Discharges for USGS 08211500 Streamgage Station Nueces River at Calallen, TX. POR (1992-2019).

Further analyses were made in the model network to validate simulated peaks by comparing them to the USGS observed peaks. A set of peak flow extracted from the RiverWare model output was compared against the observed peaks of the same exact date of when the observed peaks occurred. This type of analysis helps for future development and improves the model functionality. Ultimately, the goal is to increase confidence in using the extended discharge peaks used to generate peak discharge frequency curves. Figures D.38 through D.42 show that the simulated peaks improve as flows move farther downstream, away from the dams. In some cases, observed discharge peaks at Choke Canyon Reservoir outlet, Bluntzer, and Calallen, these gages have missing discharge peaks for the inspected years (short records). The local inflows tend to improve the attenuated peaks. More statistical outputs were generated and displayed in Table D.7. Figure D.43 was added to illustrate simulated and observed daily average peak discharge correlation (R^2 values) of gage samples located in the Nueces River Basin.

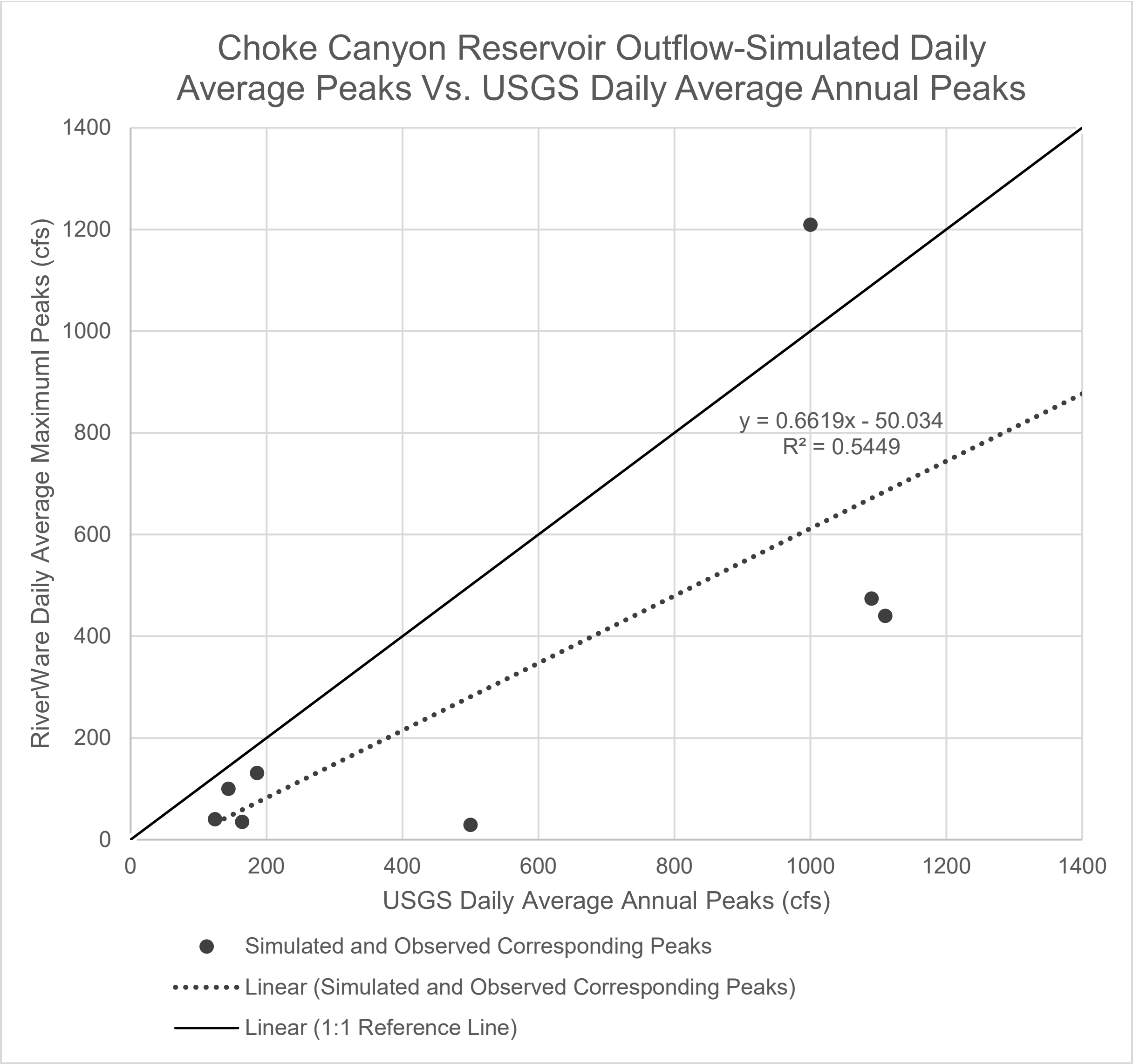

Figure D.38: Simulated vs. Daily Average Peak Discharges for USGS 08206910 Streamgage Station Nueces River at Choke Canyon Reservoir nr Three Rivers, Tex., for 2001, 2003-2006, 2008, 2011-2012.

The poor correlation seen in Figure D.38 can be contributed to the analyzed short POR used for comparison. Like reasons explained in Figure D.33 pertaining to conditions of the gage, other contributing factors such as model operations, release assumptions during normal and low flow conditions can reflect on results. The comparison doesn't account for significant flood events since gage data are missing for the most part. The gage should be noted to have high uncertainty with it when developing high discharge frequencies.

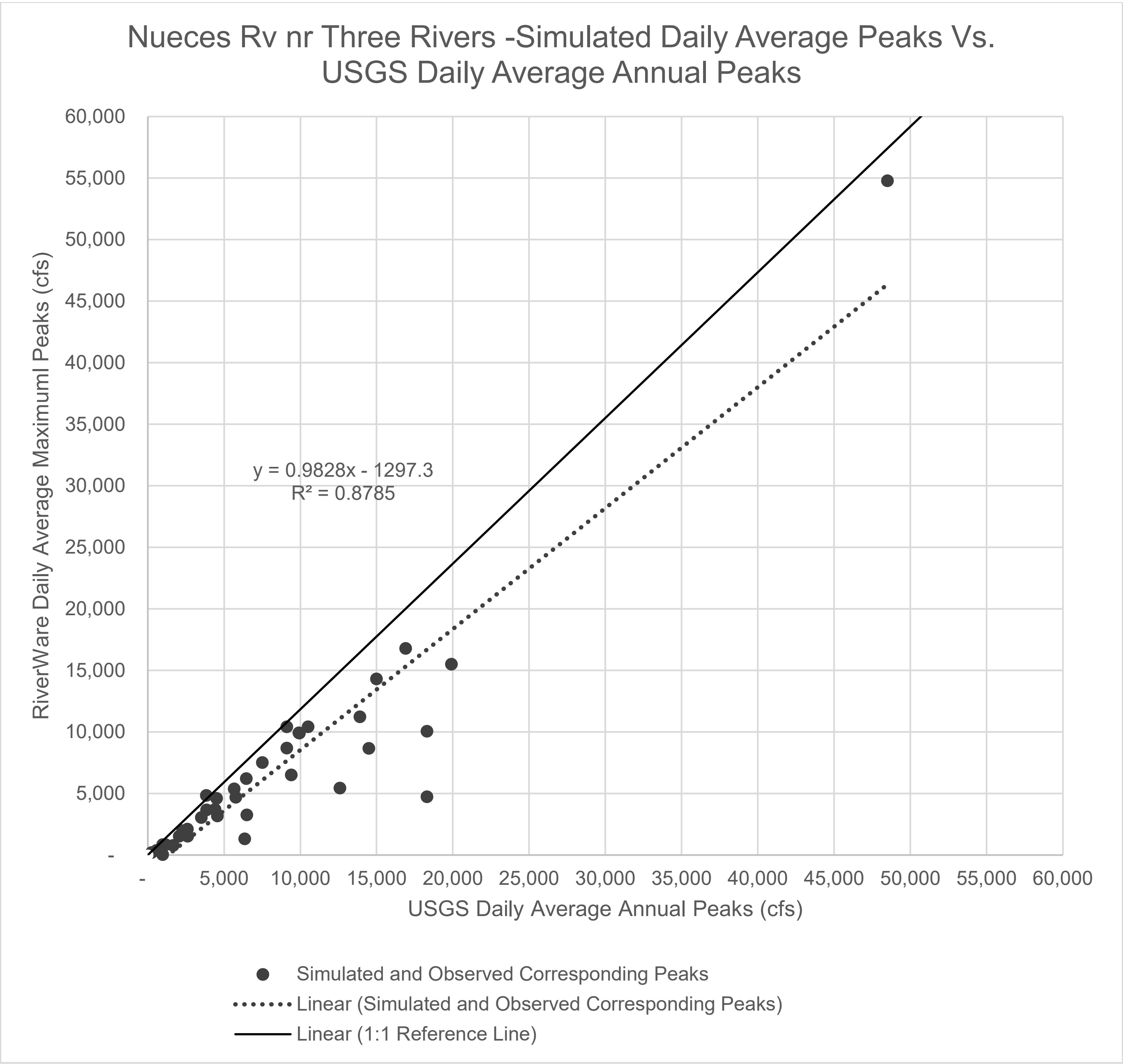

Figure D.39: Simulated vs. Daily Average Peak Discharges for USGS 08210000 Streamgage Station Nueces River Near Three Rivers, Tex., for POR (1982-2019).

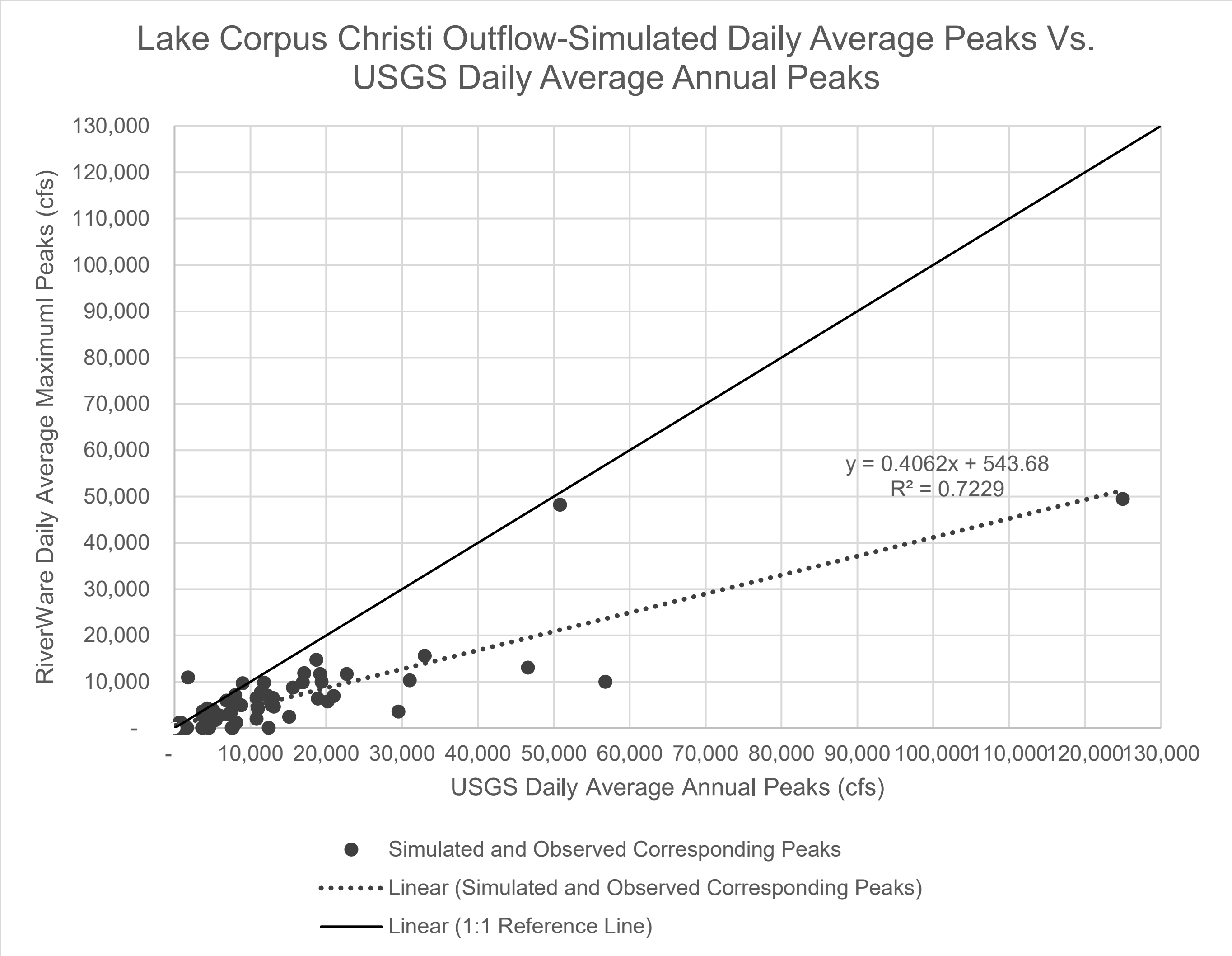

Figure D.40: Simulated vs. Daily Average Peak Discharges for USGS 08211000 Streamgage Station Nueces River nr Mathis, Tex., for POR (1943-2019).

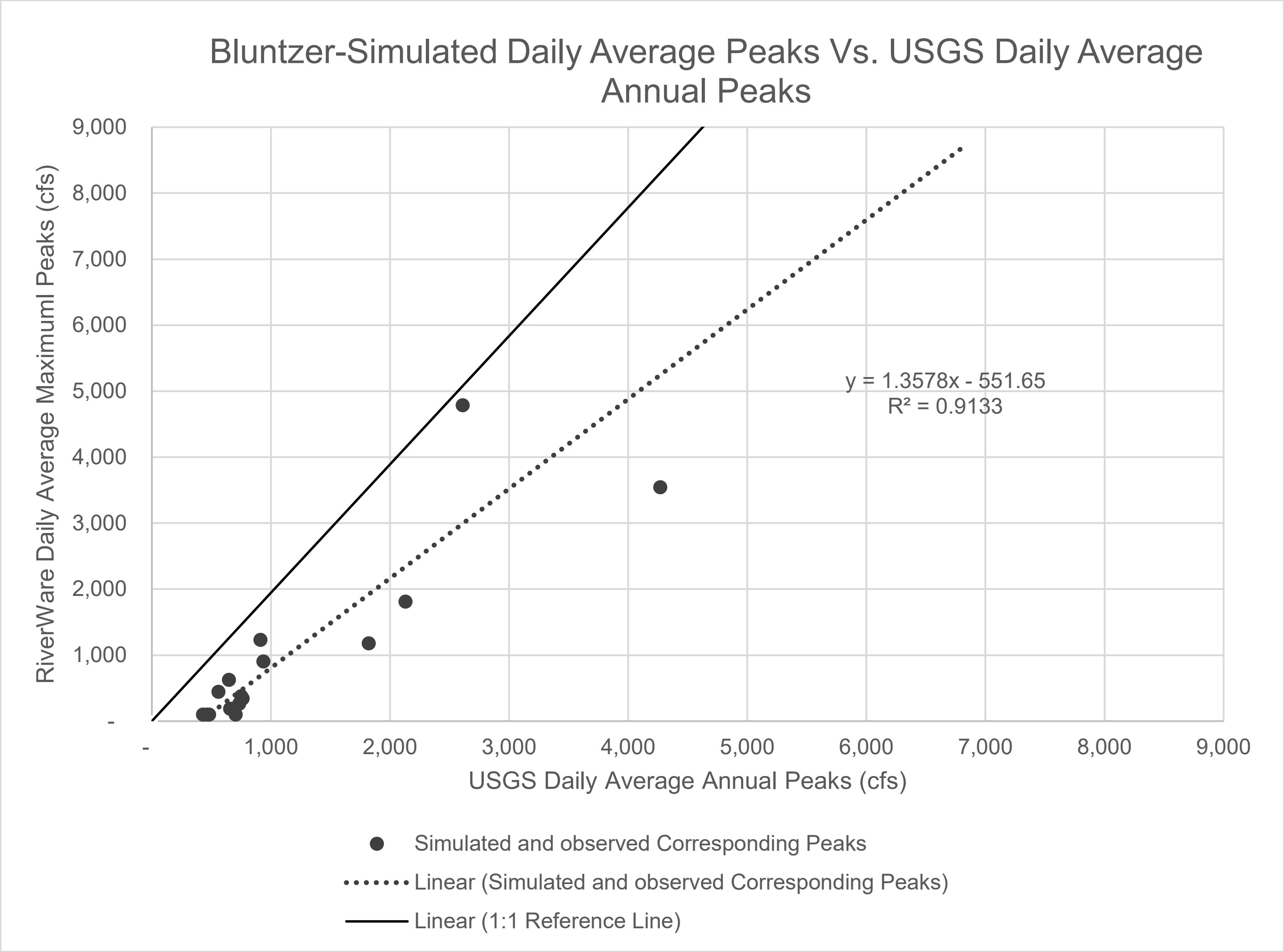

Figure D.41: Simulated vs. Daily Average Peak Discharges for USGS 08211200 Streamgage Station Nueces River Near Bluntzer, Tex., for 1994-1996, 1998-2001, 2006, 2008-2009, 2011-2014, 2016-2019.

Bluntzer gage has short discharge peak records and many gaps between 1994 and 2019. 17 years of discharge peaks were used to validate simulated peaks. Low observed discharge peaks were compared against simulated as historical flood peaks for the years of 1997, 2002, 2003, 2004, 2005, 2007, and 2015 were not captured by the gage. The available compared data showed good correlation. It should be noted that one exception was observed discharge peak occurred on October 27, 2013 didn't match with simulated (1,950cfs vs 8,900cfs) that was due to simulated pool rise above 94ft-NGVD (surcharge). The observed pool reached 91.8ft-NGVD. The simulated peak was not included in the figure above. However, it can be modeled as a standalone event and lowered as desired.

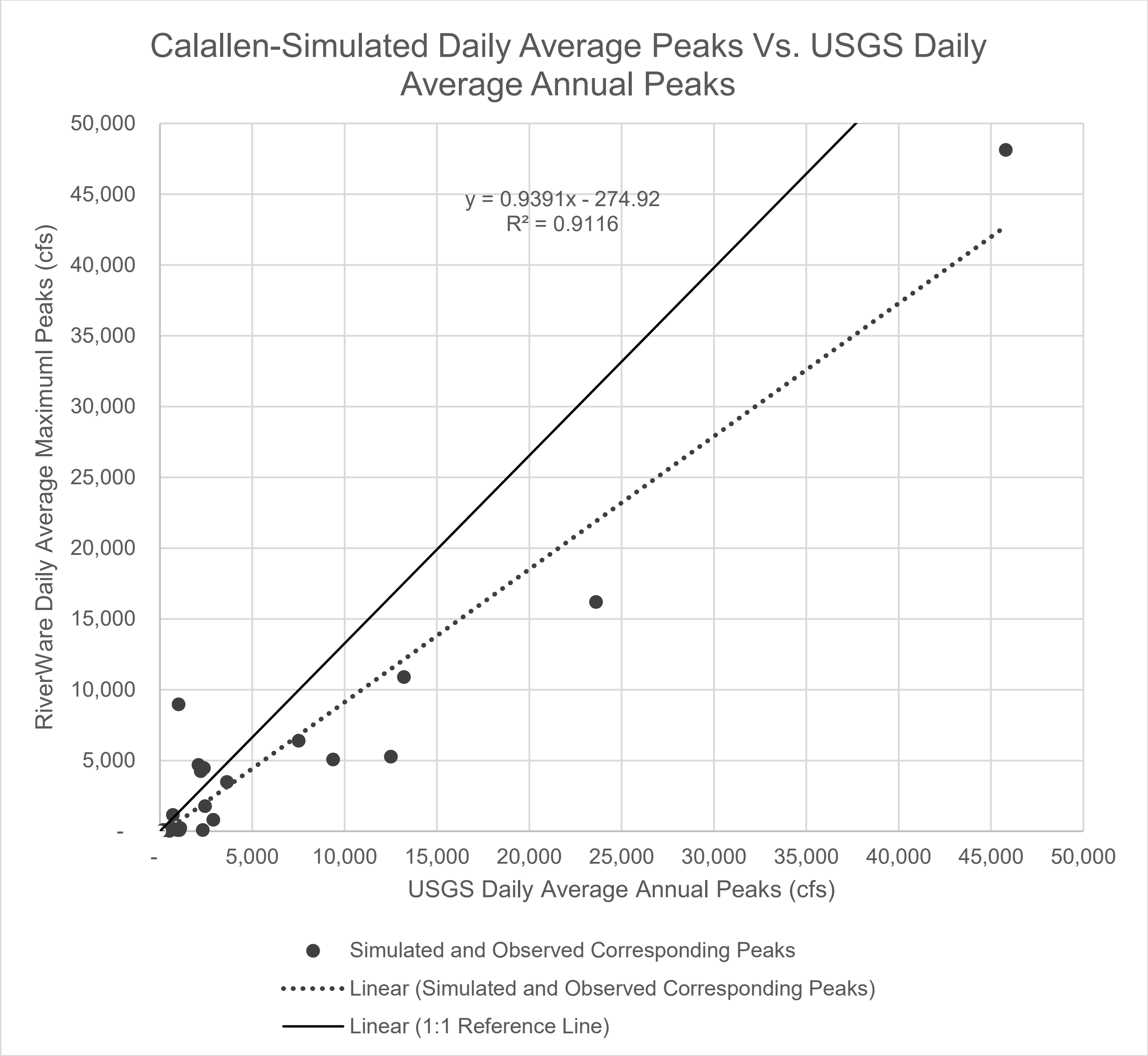

Figure D.42: Simulated vs. Daily Average Peak Discharges for USGS 08211500 Streamgage Station Nueces River at Calallen, Tex., for POR (1991-2019).

Table D.7: Peak comparison Between RiverWare Simulated Peaks and the USGS Observed Peaks

Junction	Observed Period of Record (Years)	Simulated Period of Record (Years)	No. of Years when USGS Peaks Exceeded RiverWare Peaks	R^2
Choke Canyon Outlet	8	77	7 (88% of the time)	0.54
Three Rivers	38	77	32 (84% of the time)	0.88
Mathis (Lake Corpus Christi Outlet)	76	77	72 (95% of the time)	0.72
Bluntzer	17	77	14 (82% of the time)	0.91
Calallen	27	77	21 (78% of the time)	0.91

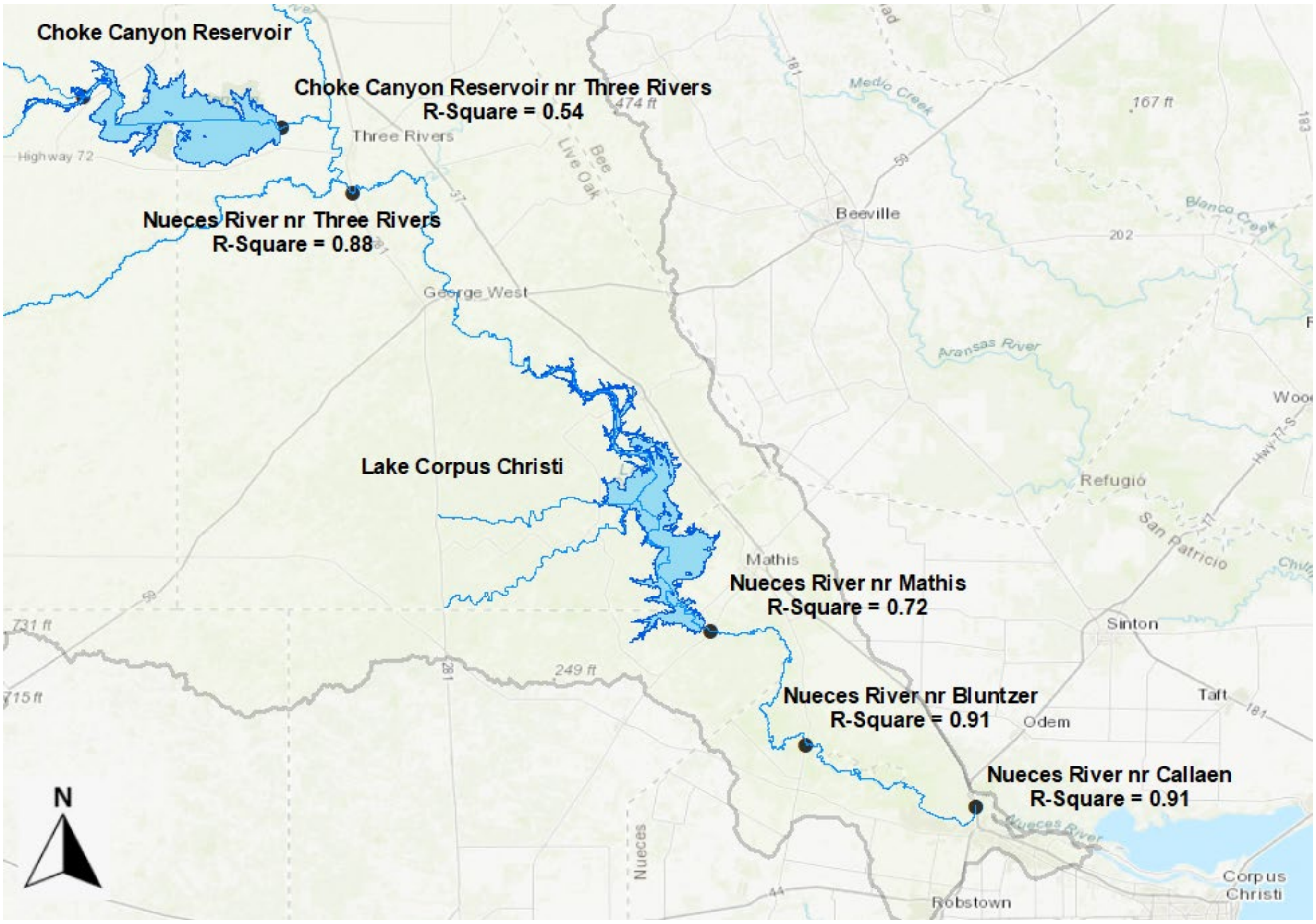

Figure D.43 Correlation values of Selected Gages in the Nueces River Basin

The finalized discharge peaks, which will be used to develop the instantaneous annual maximum peaks, consist of simulated RiverWare peaks and the USGS instantaneous observed peaks, downloaded from the USGS National Water Information System (NWIS) database (USGS, 2019). The general practice in developing instantaneous annual maximum flow for each water year is to use the observed peaks first but filled with the simulated RiverWare peaks when USGS peaks were missing.

1.9 Streamgage Data and Statistical Flood Flow Frequency Results

For the statistical analysis of the RiverWare modeling results, the simulated instantaneous peak streamflow was analyzed for five USGS streamgages in the RiverWare model (Table D.8). The U.S. Geological Survey contributed to the InFRM team's efforts by performing the statistical analysis of the simulated record and authored this section of the Appendix to the Nueces River Watershed Hydrology Assessment. A peaking factor was applied to the RiverWare daily time-step data to convert daily peak streamflow to instantaneous peak streamflow. The RiverWare output is a daily average streamflow and must be converted to match the instantaneous peak streamflow recorded by the U.S. Geological Survey (USGS) and stored in the USGS National Water Information System (NWIS) (USGS, 2022). A simple linear regression between observed instantaneous USGS streamflow and daily mean USGS streamflow was performed to determine a 'peaking factor' to convert the RiverWare daily streamflow to instantaneous streamflow. More information on the linear regression performed at each analyzed streamgage may be found in section D.8. In this way, the annual peak streamflow was determined for each water year in the period of record (POR) for a given streamgage. The terms "flow," "streamflow," and "discharge" are synonymous and are used interchangeably in this report. All three terms refer to the volume of water that passes a given point within a given period of time; all are expressed in units of cubic feet per second.

For regulated streamflow conditions in the POR, USGS-observed peak streamflow data obtained from NWIS (USGS, 2022) are considered to be the most reliable source of data because these data recorded actual events and are not simulated streamflow. However, the streamflow in many streams in Texas is currently (2023) regulated by impoundments (dams). Regulation of a watershed, especially the impoundment of a stream, typically leads to an attenuation in streamflow. This means that in general lower annual peak streamflows are more likely in a regulated stream than in the same stream without regulation. Because the attenuating effects of dams on peak streamflow are accounted for in the simulated streamflow data, RiverWare-simulated annual peak streamflow data computed by the U.S. Army Corps of Engineers (USACE) were substituted for USGS annual peak values obtained prior to when a dam was built on a given stream. Hereinafter, "observed record (or dataset)" refers to a record consisting solely of USGS observed peak streamflow values, whereas "simulated record (or dataset)" refers to the combined RiverWare and USGS peak streamflow record. The site-specific details of the POR for each streamgage are described in the individual writeups for each streamgage that follow in this section.

Flood flow frequency analyses were done following the same methodology as is used in the analysis of the observed POR defined in Appendix A. Bulletin 17C guidelines (England and others, 2019), with some caveats. For example, the expected moments algorithm and the sophisticated interpretation of historical peak streamflow, thresholds, and so forth described in Bulletin 17C were either of limited usefulness or not needed because the combination of observed USGS peak data and RiverWare peak data results in a fairly homogeneous dataset. Flow frequency analyses performed on RiverWare datasets are done in the USACE Hydrologic Engineering Center's Statistical Software Package (HEC-SSP) software, which has flexible data input requirements (USACE, 2016).

Asquith and Slade (p. 1, 1995) explained "the Interagency Advisory Committee on Water Data (IACWD) (1982) provides a standard procedure for peak-streamflow frequency calculation that involves a standard frequency distribution—the log-Pearson Type III (LPIII) distribution. The LPIII distribution uses systematic and historical peak-streamflow values to define its frequency distribution. The curvature in the distribution is defined by a skew coefficient used in the calculation procedure." Skew coefficients can be site-specific (station skew coefficients) or regional in nature (regional skew coefficients). The use of the skew coefficients is emphasized in IACWD (1982) to mitigate for the extreme variance in annual peak streamflows found in streamgage records of varying lengths. The regional skew coefficient is a built-in feature of the USACE HEC-SSP software but can be overridden by the user. Asquith and others (2021) developed generalized (regional) skew coefficients for Texas, and these estimates may be considered contemporary, and therefore valid, for this study (2023). The period of record for an analysis may not characterize the range of peak streamflow well for various reasons. For example, (1) there might have been few or no appreciable floods (for example, floods exceeding bank-full conditions) during the available period of record, (2) the period of record might have been truncated as a result of substantial removal of “potentially influential low floods” (England and others, 2019), (3) or the period of record might represent a unique flood distribution influenced by regulation or site-specific features such as the shape of the floodplain (Judd and others, 1996; Asquith and others, 2021). Citing the work of others, Ryberg and others (p. 24, 2020) explain “small floods may be the result of a different hydrologic process than the larger floods with low annual exceedance probabilities (AEPs) and they can have a large effect on the distribution fitting procedure (Cohn and others, 2013; England and others, 2019), hence the name ’potentially influential low floods.’” It was decided to weight the HEC-SSP computed skew of one streamgage in the Nueces River Basin, USGS streamgage 08211200 Nueces River at Bluntzer, Tex. (hereinafter referred to as the “Nueces River at Bluntzer gage”), with the regional skew value obtained from Asquith and others’ (2021) plots of regional skew for Texas, Oklahoma, and eastern New Mexico (Table D.8). In order to use the regional skew values, the weighted-skew option in HEC-SSP software was required in conjunction with manual entry of skew information (USACE, 2016). Although a calculated station skew that differs greatly from the regional skew estimate is cause for further investigation, it is not necessarily justification for weighting by the regional skew value. This is because the gaged location may have hydrological characteristics that differ from the greater regionalized hydrology (Asquith and others, 2021).

Low outliers within a time series of peak streamflow, such as annual peak streamflow that were likely not storm flows or highly localized storm flow, often need special consideration during the analysis by using a form of conditional probability adjustment (England and others, 2019). HEC-SSP incorporates the Multiple Grubbs Beck Test (MGBT) to detect potentially influential low floods (Cohn and others, 2013). The MGBT was used to identify and partially exclude potentially influential low floods from the analysis (the potentially influential low floods are retained in the dataset, but partially excluded from analysis). Within HEC-SSP, those peaks identified as potentially influential low floods are recoded as less than a threshold streamflow and treated as interval data in the expected moments algorithm because potentially influential low floods do not convey meaningful information about the magnitude of floods with low AEPs (0.01 or less); but if retained in the analysis, they can influence the frequency estimates of very low AEP floods. See appendix 7 of Bulletin 17C (England and others, 2019) for more information on the treatment of potentially influential low floods in the expected moments algorithm. For streamgage-specific reasons, the analyst can manually specify a low-outlier threshold. Low-outlier threshold values for each streamgage are identified in and discussed further in the individual writeups for each streamgage that follows in this section. Although the ultimate decision for specifying a low-outlier threshold to identify influential low floods is based on engineering judgment, Bulletin 17C provides some general guidelines for choosing an appropriate threshold (England and others, 2019). For each flood frequency analysis, the computed curve is evaluated for its fit to the data. If the data appear to have a clear inflection point or shift in the ordered peaks that the MGBT did not identify, then the low outlier may be adjusted (England and others, 2019).

At each site a cursory sensitivity analysis was done to determine the effects of the selected low-outlier threshold and selected skew on the flood frequency curve. For the low-outlier threshold, factors were considered whether the threshold could be adjusted to improve the station skew, and if the threshold could be adjusted to bring the estimates more in line with flood frequency curves from upstream and downstream streamgages. These factors along with others are considered for the low-outlier threshold for each gaged location analyzed. Low-outlier threshold values for each streamgage are identified in the analysis section for each streamgage below. The sensitivity analysis considered (1) if the station skew value deviated appreciably from published regional skew values, (2) if the calculated flood frequency curve did not appear to fit the ordered peak floods well, or (3) if the calculated flood frequency curve produced estimates inconsistent with flood frequency estimates at upstream and downstream streamgages. Although a station skew value calculated by using PeakFQ that differs greatly from the regional skew estimate is cause for further investigation, it is not necessarily justification for weighting by the regional skew value. This is because the gaged location may have site-specific hydrological characteristics that differ from regional hydrological characteristics (Asquith, 2021). If a weighted skew value was used at a given streamgage, the details of how the weighted skew was determined as well as the selection of the low-outlier threshold are discussed in the analysis section for each streamgage below. Because of the inclusion of RiverWare data in this analysis, low-outlier thresholds for the streamgages discussed in this section of the report are generally different from the low-outlier thresholds shown in Appendix A.

Table D.8: Summary of the five U.S. Geological Survey (USGS) Streamgages used in the RiverWare model of the Nueces River Basin Study Area, Texas with Ancillary Information Concerning Statistical Analyses.

[OWC, outlet works channel]

USGS station number	Streamgage name	RiverWare model element[1]	Simulated period of record used in analysis (WY)[2]	Observed period of record used in analysis (WY)[2]	Station Skew (--)	Regional skew (Asquith and others, 2021) (--)
08206910	Choke Canyon Reservoir OWC near Three Rivers, Tex.	Choke Canyon Outflow	1943–2016	2017–2020	-1.18	-0.20
08210000	Nueces River near Three Rivers, Tex.	Nueces River near Three Rivers	1943–1982	1983–2020	0.11	-0.19
08211000	Nueces River near Mathis, Tex.	Lake Corpus Christi Outflow	1943–1982	1983–2020	-0.28	-0.09
08211200	Nueces River at Bluntzer, Tex.	Nueces River near Bluntzer	1943–1993	1994–2020	-0.99	-0.06
08211500	Nueces River at Calallen, Tex.	Nueces River at Calallen	1943–1982	1983–2020	-0.63	-0.04

[1]The name of the model element in RiverWare from which the streamflow data is derived as denoted in Section 1.1, Figure D.1 and Table D.1
[2]The years listed in the period of record refer to water years. A water year is a 12-month period from October 1 of the first year to September 30 of the following year and is designated by the calendar year in which it ends.

08206910 Choke Canyon Reservoir OWC near Three Rivers, Tex.

The POR used in the flood flow frequency analysis for USGS streamgage 08206910 Choke Canyon Reservoir outlet works channel [OWC] near Three Rivers, Tex. (hereinafter referred to as the “Choke Canyon Outflows gage”) was from 1943 through 2020 (USGS, 2022). RiverWare-simulated annual peak streamflow values were substituted for USGS annual peak values for all years prior to 2017 when annual peak streamflow data became available for the Choke Canyon gage. In the resulting combined dataset of observed and simulated data (hereinafter referred to the as the “simulated dataset”), the 1967 simulated peak streamflow of 51,500 cubic feet per second (cfs) is the largest peak of record. A log-normal plot of the peak streamflows for each water year is presented in Figure D.44. The flood flow frequency for the Choke Canyon Outflows gage-simulated dataset is shown in Figure D.45, and the tabulated results are listed in Table D.9.

A low-outlier threshold of 834 cfs was computed by applying the MGBT in HEC-SSP, and the initial station skew computed in HEC-SSP was used as the skew (a regional skew weighting factor was not applied) (Table D.8). During the computation of the low-outlier threshold, a total of 39 low outliers (potentially influential low floods) were identified. Streamflow at the Choke Canyon gage is completely regulated as it only measures outflows from Choke Canyon Reservoir, meaning that Bulletin 17C methodology is not well suited to the dataset (England and others, 2019). There were only four observed annual peak streamflow values, and these peaks were all relatively small, ranging from 600 to 1,000 cfs. The bifurcated distribution of the simulated streamflow and the inability to match the observed peaks to the simulated streamflow highlights both the highly regulated nature of the Frio River immediately downstream from the dam and the apparent poor performance of the peaking factor determined for this streamgage.

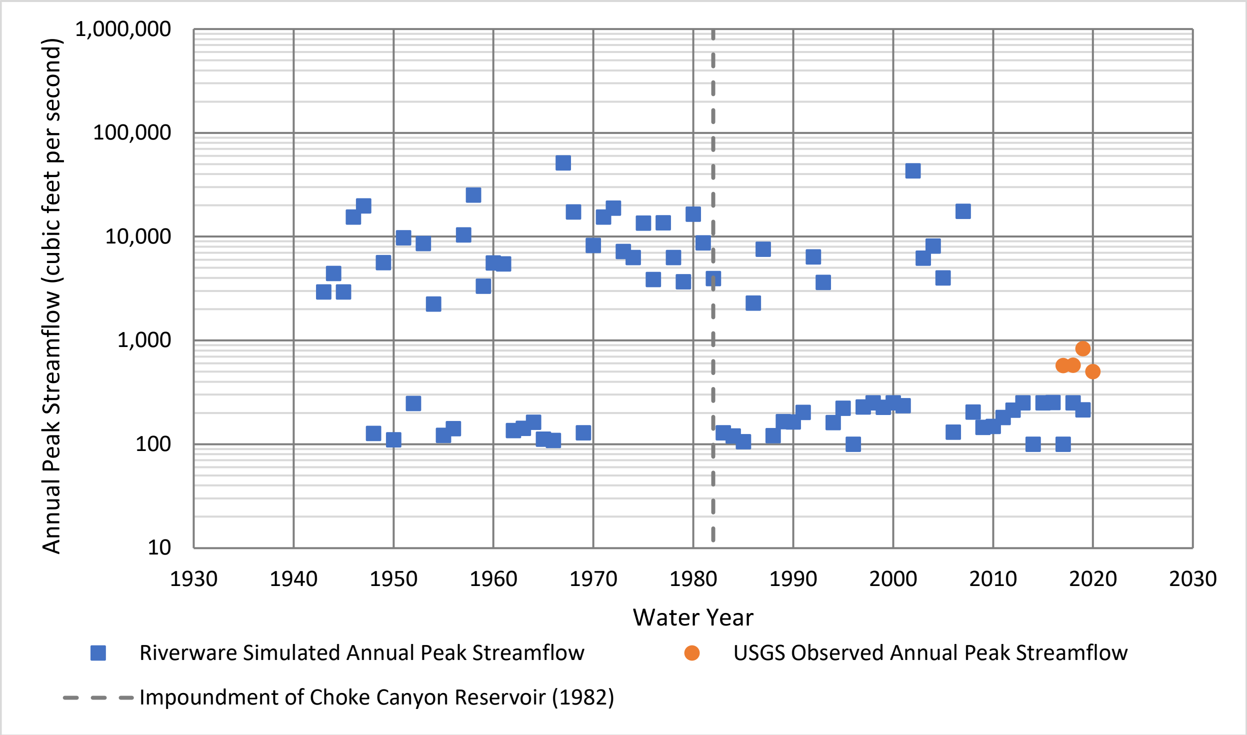

Figure D.44: Simulated RiverWare and Observed U.S. Geological Survey (USGS) Annual Peak Streamflow for USGS Streamgage 08206910 Choke Canyon Reservoir OWC near Three Rivers, Texas.

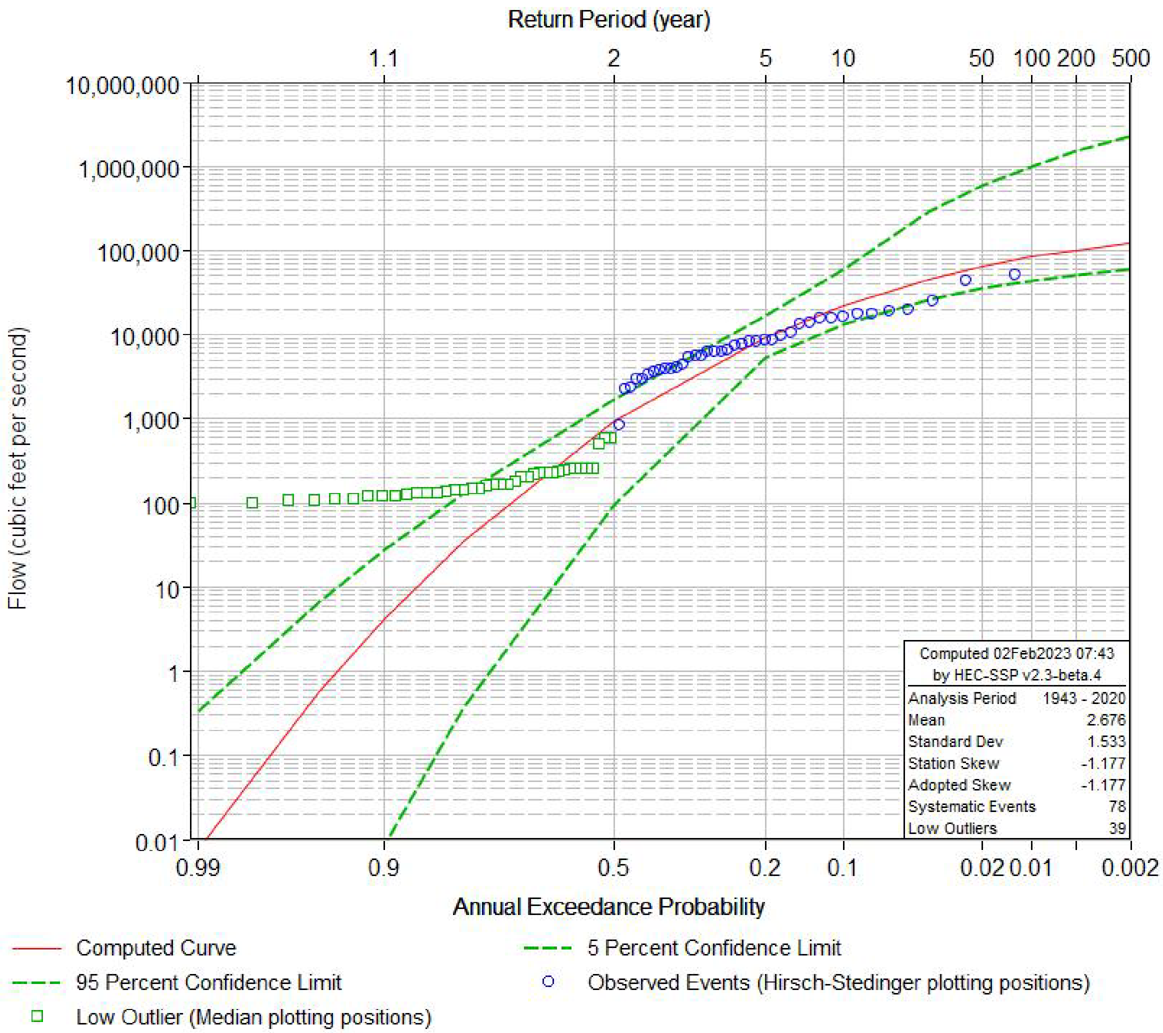

Figure D.45: Simulated Flood Flow Frequency using log-Pearson Type III Distribution for U.S. Geological Survey Streamgage 08206910 Choke Canyon Reservoir OWC near Three Rivers, Texas.

08210000 Nueces River near Three Rivers, Tex.

The POR used in the flood flow frequency analysis for USGS streamgage 08210000 Nueces River near Three Rivers, Tex. (hereinafter referred to as the “Nueces River near Three Rivers gage”) was from 1943 through 2020 (USGS, 2022). RiverWare-simulated annual peak streamflow values were substituted for USGS annual peak values obtained prior to the impoundment of Choke Canyon Reservoir in May of 1982 (TWDB, 2022). In the resulting combined dataset of observed and simulated data, the 1967 simulated peak streamflow of 107,000 cfs is the largest peak of record. A log-normal plot of the peak streamflows for each water year is presented in Figure D.46. The flood flow frequency for the Nueces River near Three Rivers gage-simulated dataset is shown in Figure D.47, and the tabulated results are listed in Table D.9. A low-outlier threshold of 7,000 cfs was manually set in HEC-SSP, and the station skew computed in HEC-SSP was used as the skew (Table D.8). During the computation of the low-outlier threshold, a total of 35 low outliers were identified. The low-outlier threshold of 7,000 cfs is different than the one set for the Nueces River near Three Rivers gage dataset in Appendix A because the inclusion of RiverWare data in this analysis results in a different set of ordered events (Figure D.46) and therefore a different flood flow frequency analysis.

A comparison of the simulated flood flow frequency analysis from this section and the computed flood flow frequency distribution (curve) from Appendix A is shown in Figure D.48. The difference between the simulated and observed flood flow frequency curves is substantial. Although RiverWare simulates the operation of Choke Canyon Reservoir prior to its actual impoundment in 1982, it appears that the simulated annual peak streamflow for 1982 and prior years is still higher on average than the observed annual peak streamflow beginning in 1983 (Figure D.46). The mean simulated annual peak streamflow from 1943 through 1982 is 16,000 cfs, whereas the mean observed annual peak streamflow from 1983 through 2020 is 8,080 cfs.

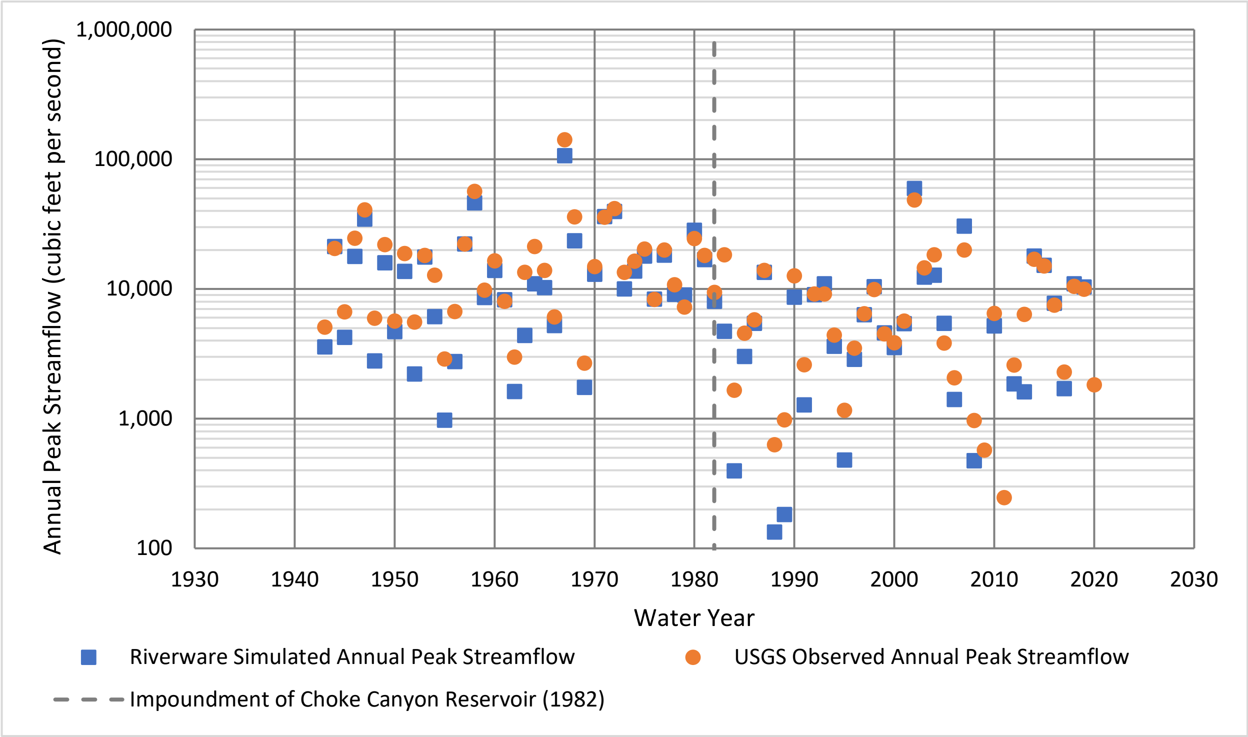

Figure D.46: Simulated RiverWare and Observed U.S. Geological Survey (USGS) Annual Peak Streamflow for USGS Streamgage 08210000 Nueces River near Three Rivers, Texas.

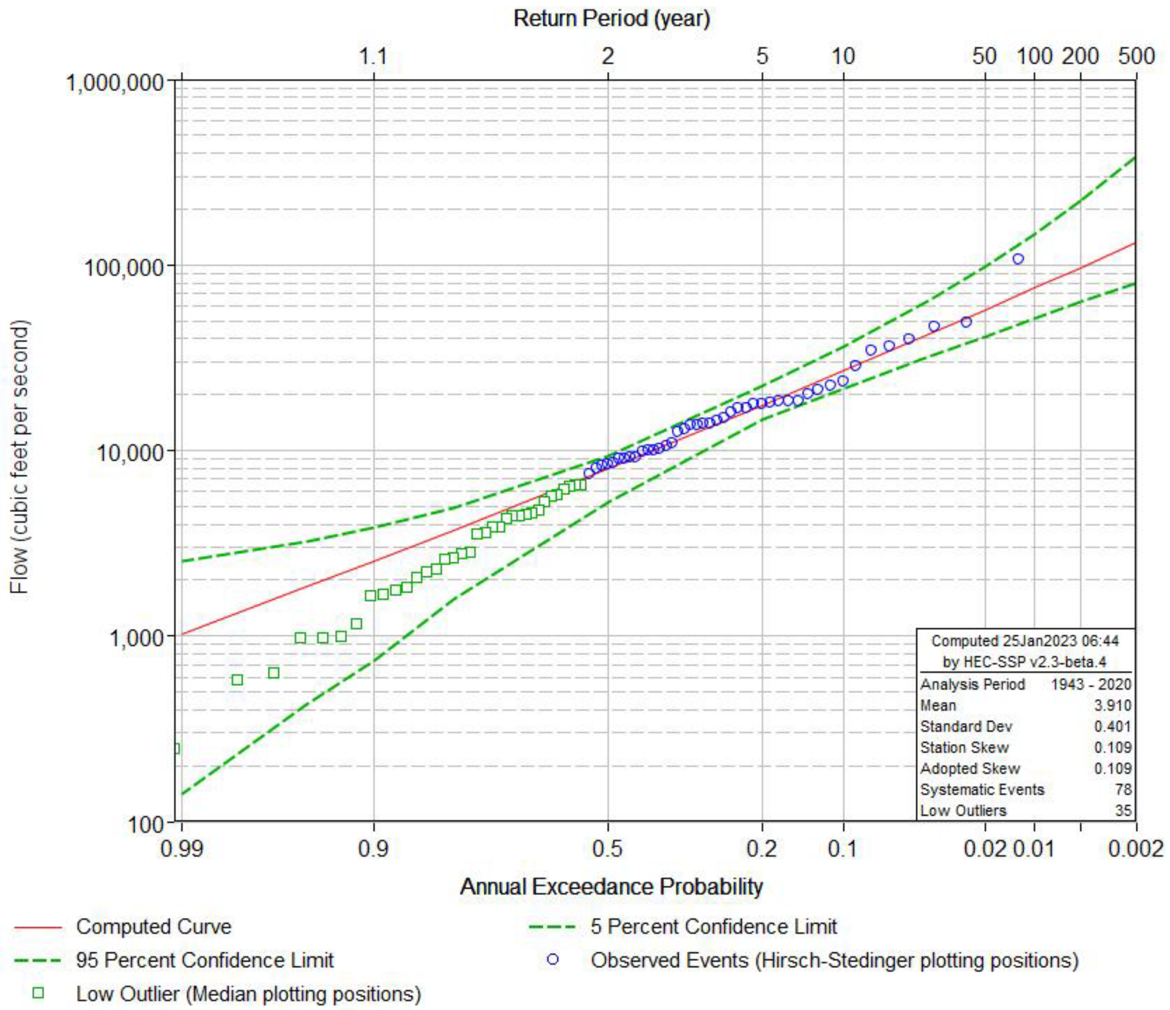

Figure D.47: Simulated Flood Flow Frequency using log-Pearson Type III Distribution for U.S. Geological Survey Streamgage 08210000 Nueces River near Three Rivers, Texas.

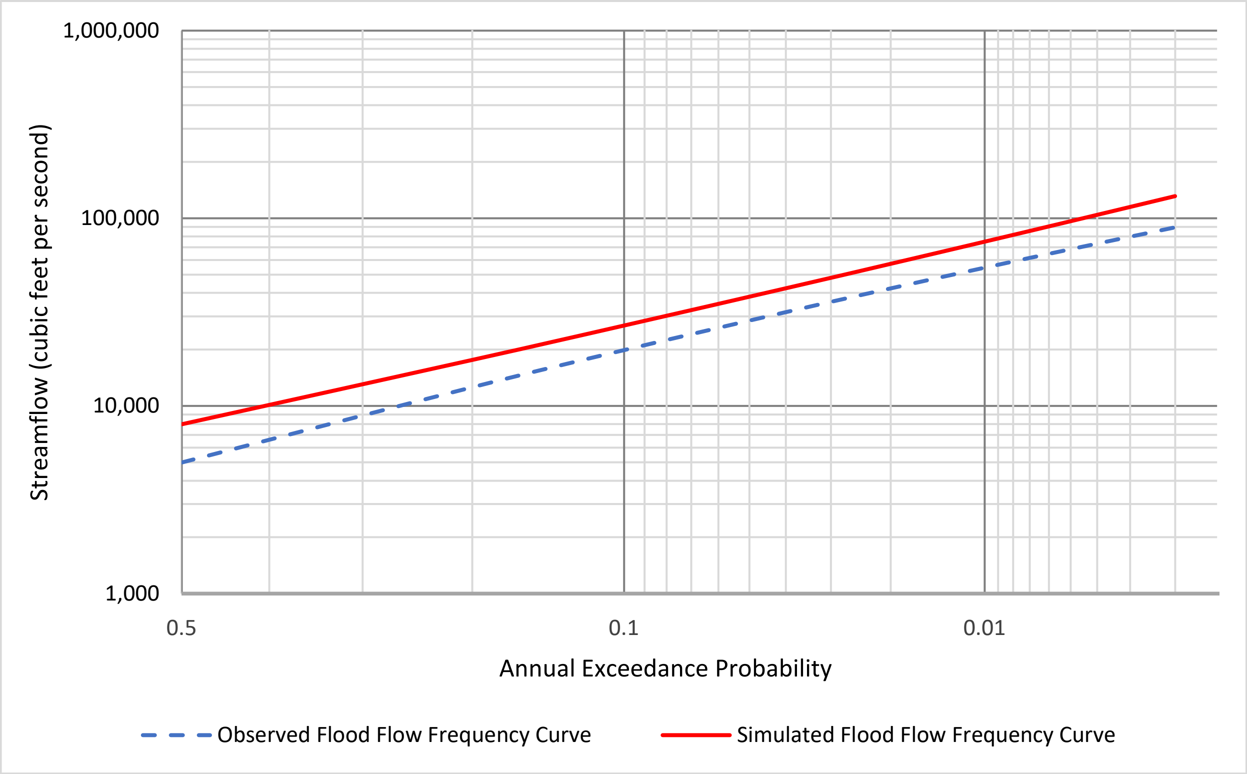

Figure D.48: Comparison of Flood Flow Frequency Curves for the Observed (1983-2020) and Simulated (1943-2020) Datasets for U.S. Geological Survey Streamgage 08210000 Nueces River near Three Rivers, Texas.

08211000 Nueces River near Mathis, Tex.

The POR used in the flood flow frequency analysis for USGS streamgage 08211000 Nueces River near Mathis, Tex. (hereinafter referred to as the “Nueces River near Mathis gage”) was from 1943 through 2020 (USGS, 2022). RiverWare simulated annual peak streamflow values were substituted for USGS annual peak values obtained prior to the impoundment of Choke Canyon Reservoir in May of 1982 (TWDB, 2022). In the resulting combined dataset of observed and simulated data, the 1967 simulated peak streamflow of 119,000 cfs is the largest peak of record. A log-normal plot of the peak streamflows for each water year is presented in Figure D.49.

The flood flow frequency for the Nueces River near Mathis gage simulated dataset is shown in Figure D.50, and the tabulated results are listed in Table D.9. A low-outlier threshold of 4,000 cfs was computed by applying the MGBT in HEC-SSP, and the station skew computed in HEC-SSP was used as the skew (Table D.8). During the computation of the low-outlier threshold, a total of 30 low outliers were identified. The low-outlier threshold of 4,000 cfs is different than the one set for the Nueces River near Mathis gage dataset in Appendix A because the inclusion of RiverWare data in this analysis results in a different set of ordered events (Figure D.49) and therefore a different flood flow frequency analysis.

A comparison of the simulated flood flow frequency analysis from this section and the computed flood flow frequency distribution (curve) from Appendix A is shown in Figure D.51. The difference between the simulated and observed flood flow frequency curves is substantial. Although RiverWare was used to simulate the operation of Choke Canyon Reservoir and Lake Corpus Christi prior to its actual impoundment in 1982, it appears as though simulated annual peak streamflow prior to that date is still higher on average than the observed annual peak streamflow beginning in 1983 (Figure D.49), just as was seen with the Nueces River near Three Rivers gage. The mean simulated annual peak streamflow from 1943 through 1982 is 15,300 cfs, whereas the mean observed annual peak streamflow from 1983 through 2020 is 5,650 cfs. The 0.02 annual exceedance probability (AEP) estimate at the Nueces River near Mathis gage does match better than at the Nueces River near Three Rivers gage, possibly as a result of the more positive skew value at Mathis for the statistical analysis in Appendix A.

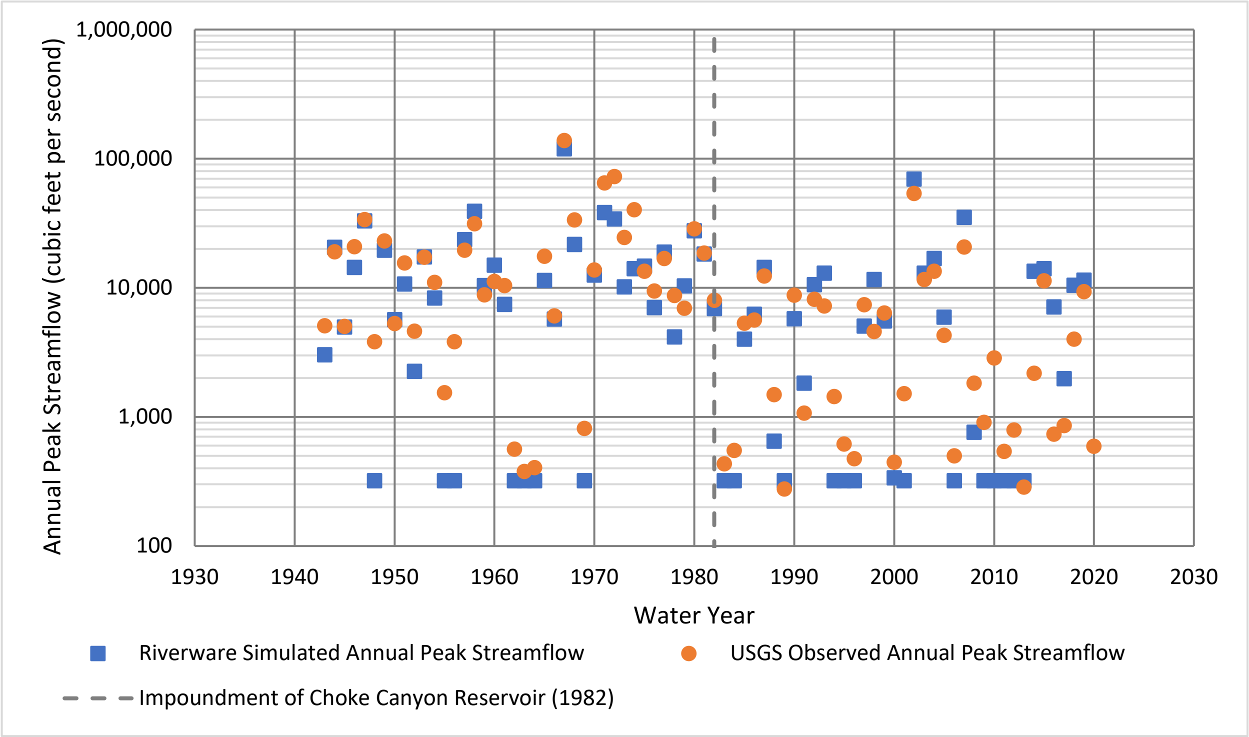

Figure D.49: Simulated RiverWare and Observed U.S. Geological Survey (USGS) Annual Peak Streamflow for USGS Streamgage 08211000 Nueces River near Mathis, Texas.

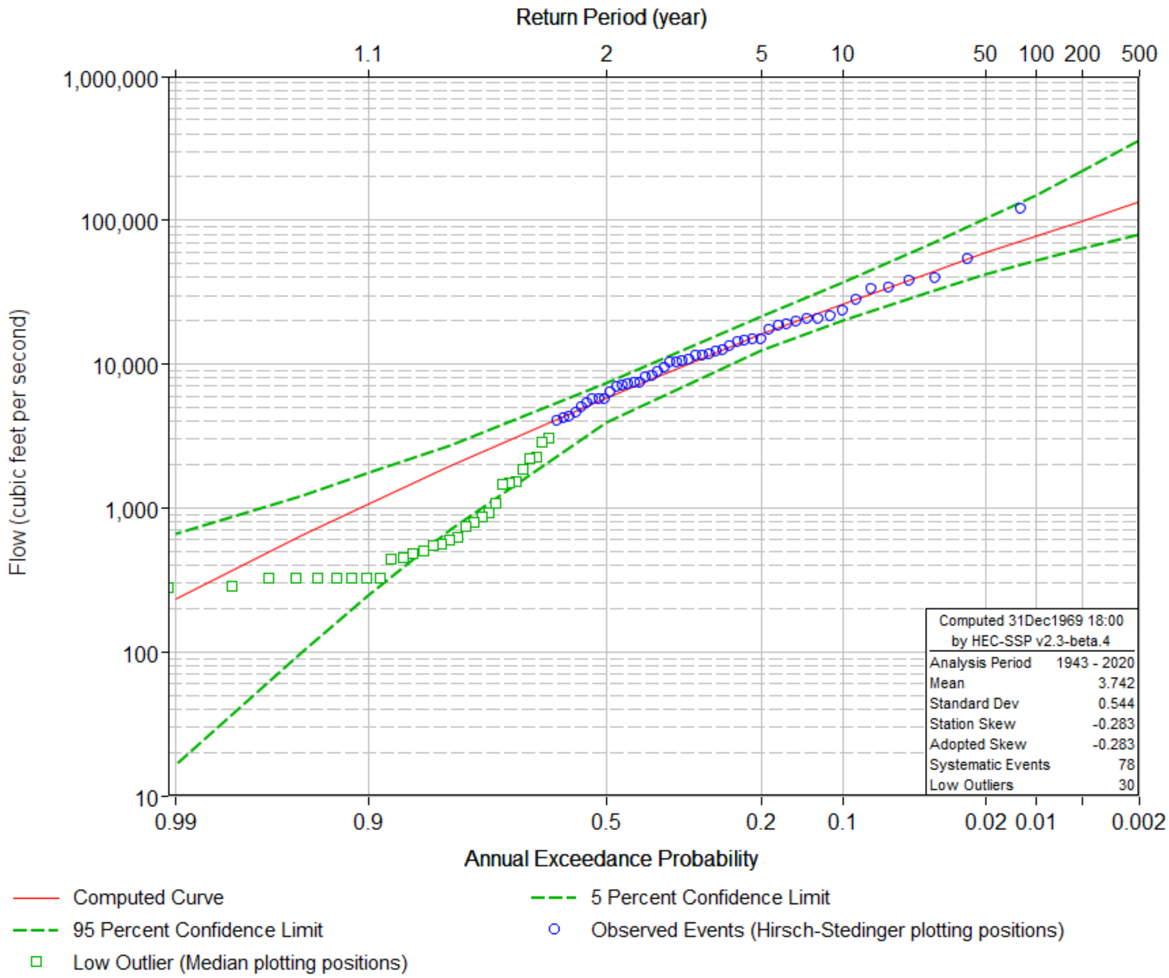

Figure D.50: Simulated Flood Flow Frequency using log-Pearson Type III Distribution for U.S. Geological Survey Streamgage 08211000 Nueces River near Mathis, Texas.

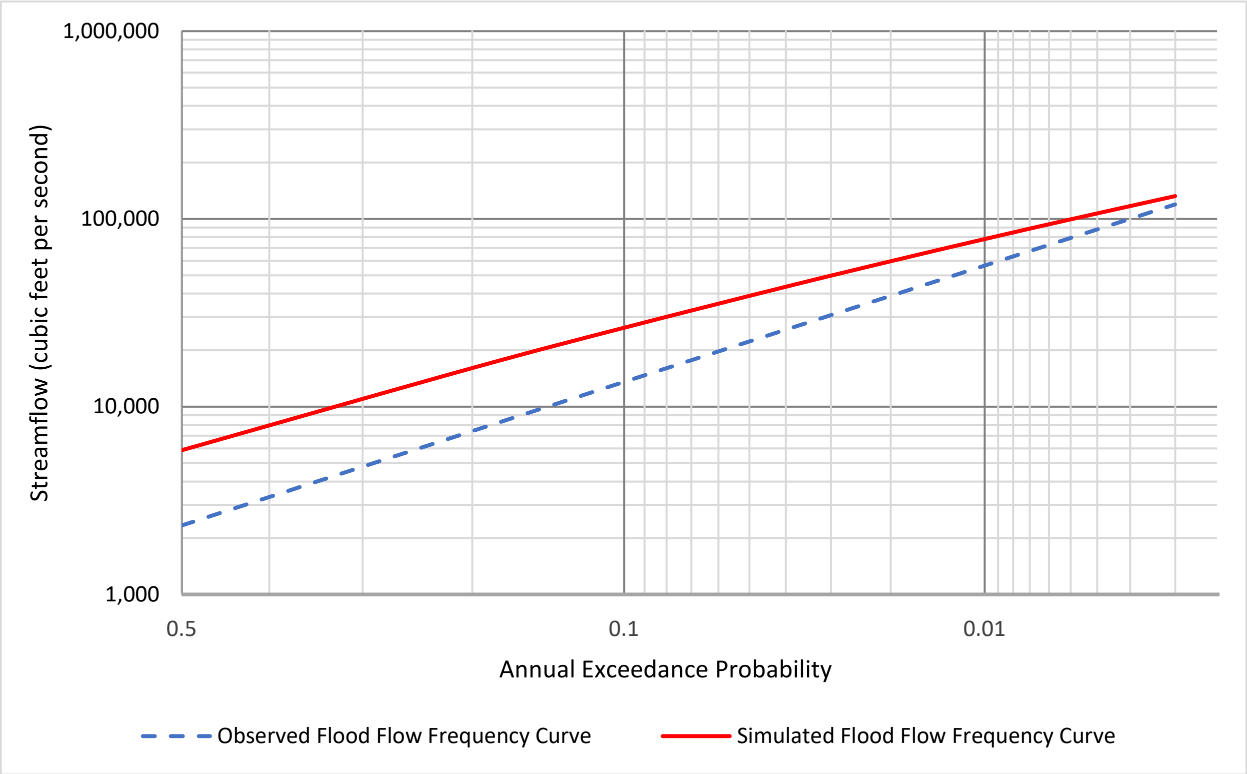

Figure D.51: Comparison of Flood Flow Frequency Curves for the Observed (1983-2020) and Simulated (1943-2020) Datasets for U.S. Geological Survey Streamgage 08211000 Nueces River near Mathis, Texas.

08211200 Nueces River at Bluntzer, Tex.

The POR used in the flood flow frequency analysis for the Nueces River at Bluntzer gage was from 1943 through 2020 (USGS, 2022). RiverWare simulated annual peak streamflow values were substituted for USGS annual peak values obtained prior to the availability of annual peak streamflow data at the gage beginning in water year 1994. Additionally, the Nueces River at Bluntzer gage only measures streamflow beyond a specific threshold, in this case 2,950 cfs. When the annual peak streamflow exceeded this value, it was replaced by the RiverWare simulated annual peak streamflow in the analysis except for two water years, 2018 and 2019, when the peak streamflow was measured by a field crew. In the resulting combined dataset of observed and simulated data, the 1967 simulated peak streamflow of 90,600 cfs is the largest peak of record. A log-normal plot of the peak streamflows for each water year is presented in Figure D.52.

The flood flow frequency for the Nueces River near Mathis gage-simulated dataset is shown in Figure D.53, and the tabulated results are listed in Table D.9. A low-outlier threshold of 2,340 cfs was computed by applying the MGBT in HEC-SSP, and the station skew computed in HEC-SSP was weighted by a regional skew value by Asquith and others (2021) (Table D.8). The adopted weighted skew value was -0.40. During the computation of the low-outlier threshold, a total of 28 low outliers were identified. A comparison of the simulated flood flow frequency analysis from this section and the computed flood flow frequency distribution (curve) from Appendix A is not available for the Bluntzer gage because the gage was not analyzed in Appendix A because the period of record was not long enough to perform a reliable flood frequency analysis.

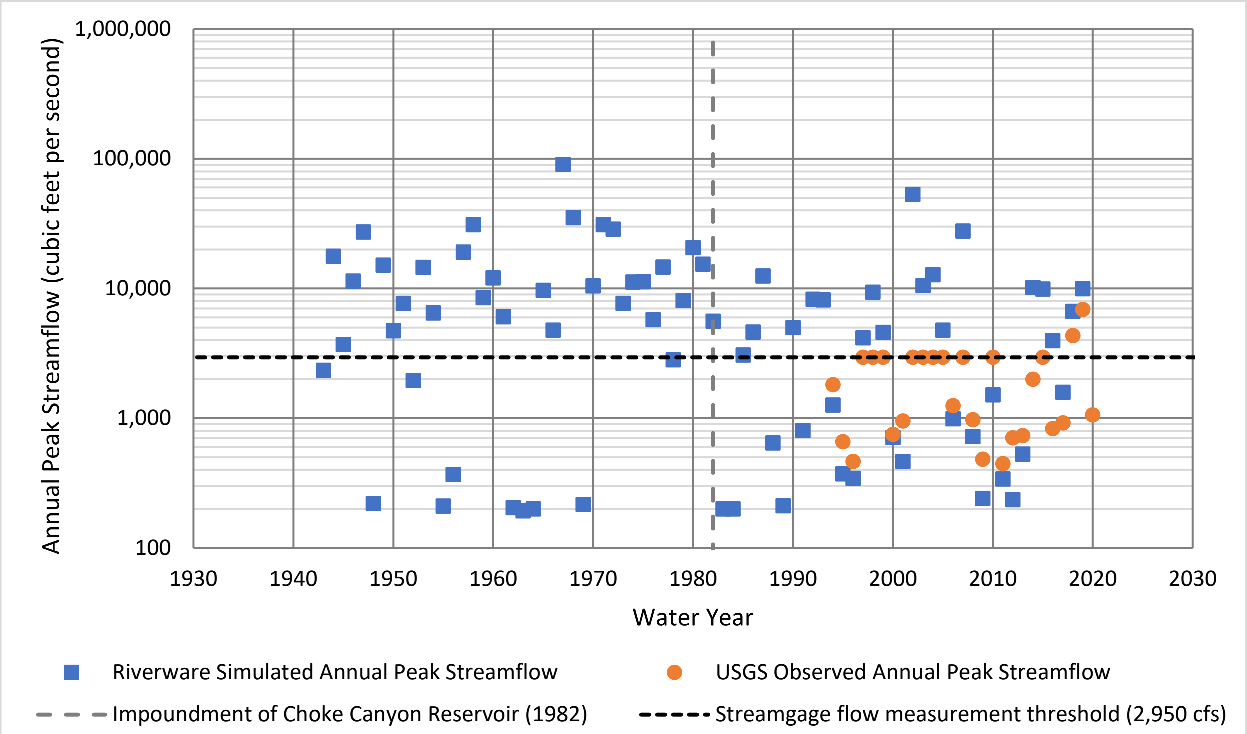

Figure D.52: Simulated RiverWare and Observed USGS Annual Peak Streamflow for U.S. Geological Survey (USGS) Streamgage 08211200 Nueces River at Bluntzer, Texas.

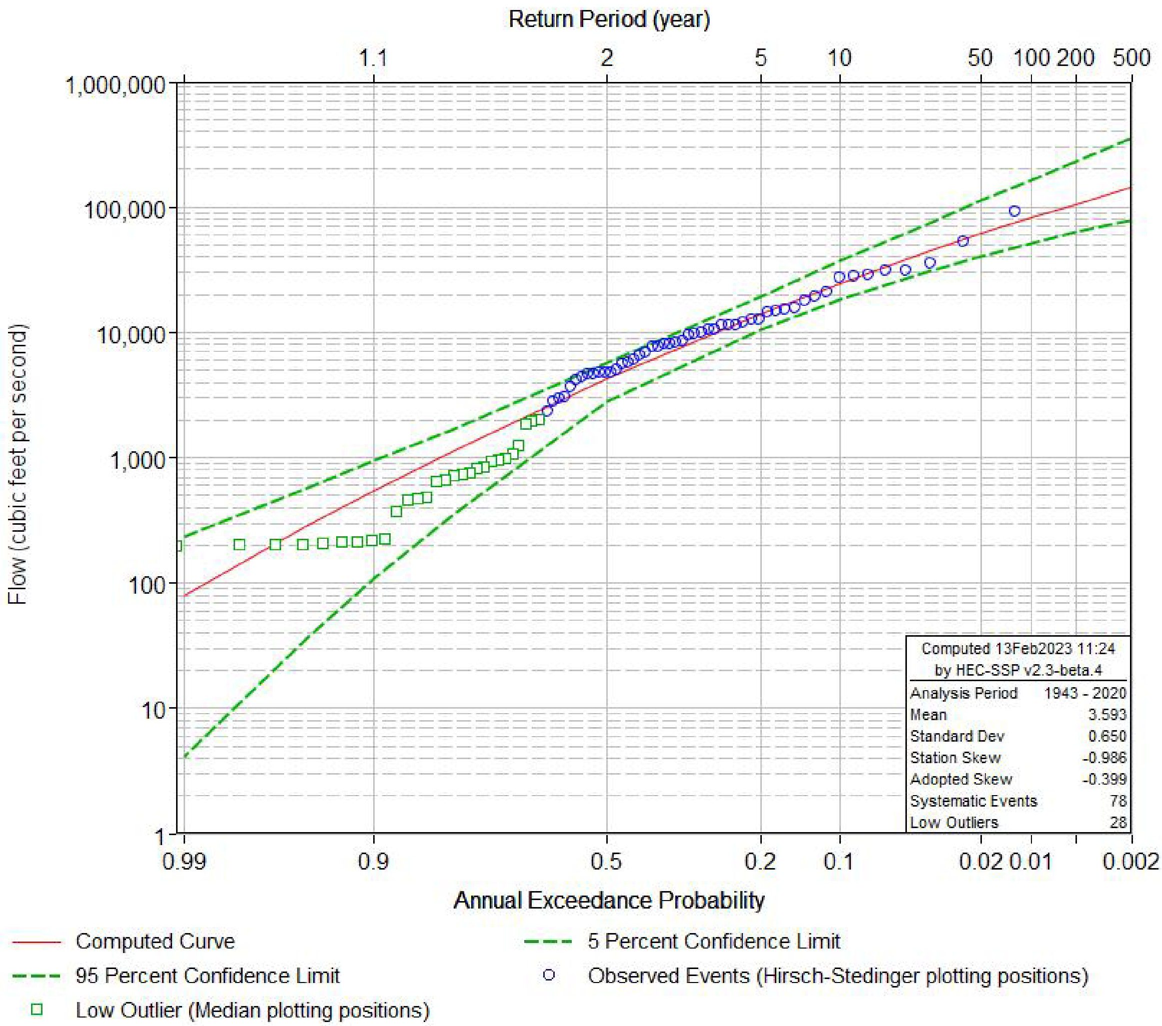

Figure D.53: Simulated Flood Flow Frequency using log-Pearson Type III Distribution for U.S. Geological Survey Streamgage 08211200 Nueces River at Bluntzer, Texas.

08211500 Nueces River at Calallen, Tex.

The POR used in the flood flow frequency analysis for USGS streamgage 08211500 Nueces River at Calallen, Tex. (hereinafter referred to as the “Nueces River at Calallen gage”) was from 1943 through 2020 (USGS, 2022). RiverWare-simulated annual peak streamflow values were substituted for USGS annual peak values obtained prior to the impoundment of Choke Canyon Reservoir in May 1982 (TWDB, 2022). In the resulting combined dataset of observed and simulated data, the 1967 simulated peak streamflow of 92,900 cfs is the largest peak of record. A log-normal plot of the peak streamflows for each water year is presented in Figure D.54.

The flood flow frequency for the Nueces River at Calallen gage-simulated dataset is shown in Figure D.55, and the tabulated results are listed in Table D.9. A low-outlier threshold of 1,940 cfs was computed by applying the MGBT in HEC-SSP, and the station skew computed in HEC-SSP was used as the skew (Table D.8). During the computation of the low-outlier threshold, a total of 27 low outliers were identified. The low-outlier threshold of 1,940 cfs is different than the one set for the Nueces River at Calallen gage dataset in Appendix A because the inclusion of RiverWare data in this analysis results in a different set of ordered events (Figure D.54) and, as a result, a different flood flow frequency analysis.

A comparison of the simulated flood flow frequency analysis from this section and the computed flood flow frequency distribution (curve) from Appendix A is shown in Figure D.56. The difference between the simulated and observed flood flow frequency curves is substantial. Although RiverWare simulates the operation of Choke Canyon Reservoir and Lake Corpus Christi from 1940 through 2019, it appears as though simulated annual peak streamflow prior to the impoundment of Choke Canyon Reservoir in 1982 is still higher on average than the observed annual peak streamflow beginning in 1983 (Figure D.49), just as was seen with the Nueces River near Three Rivers and Nueces River near Mathis gages. The mean simulated annual peak streamflow from 1943 through 1982 is 13,400 cfs, whereas the mean observed annual peak streamflow from 1983 through 2020 is 4,580 cfs.

The 0.002 annual exceedance probability (AEP; 500-year) estimate of 123,000 cfs at the Nueces River at Calallen gage is less than the 0.02 AEP estimate of 187,000 cfs described in Appendix A (Figure D.56). The difference in estimates for the 0.002 AEP estimate is likely because a more negative skew value was used in the simulated analysis than in the observed analysis of annual peak streamflows described in Appendix A.

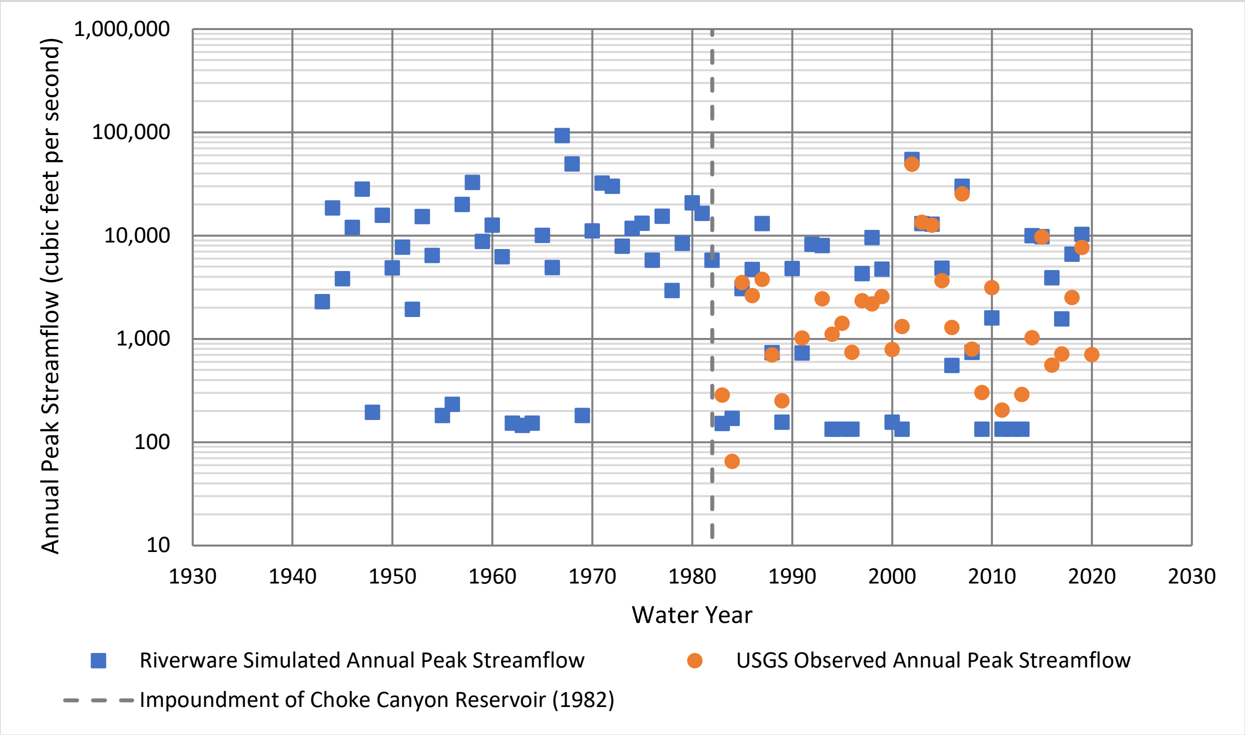

Figure D.54: Simulated RiverWare and Observed U.S. Geological Survey (USGS) Annual Peak Streamflow for USGS Streamgage 08211500 Nueces River at Calallen, Texas.

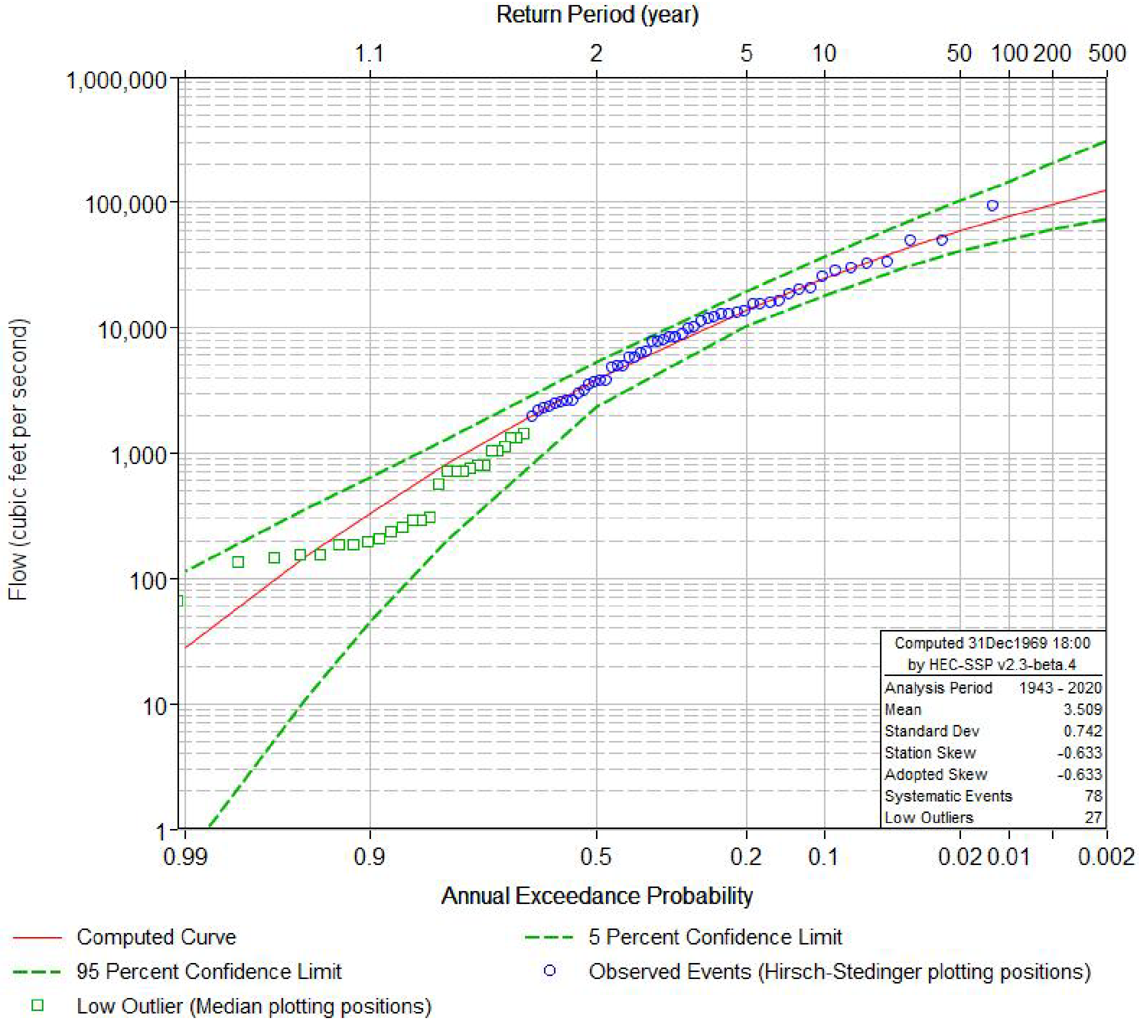

Figure D.55: Simulated Flood Flow Frequency using log-Pearson Type III Distribution for U.S. Geological Survey Streamgage 08211500 Nueces River at Calallen, Texas.

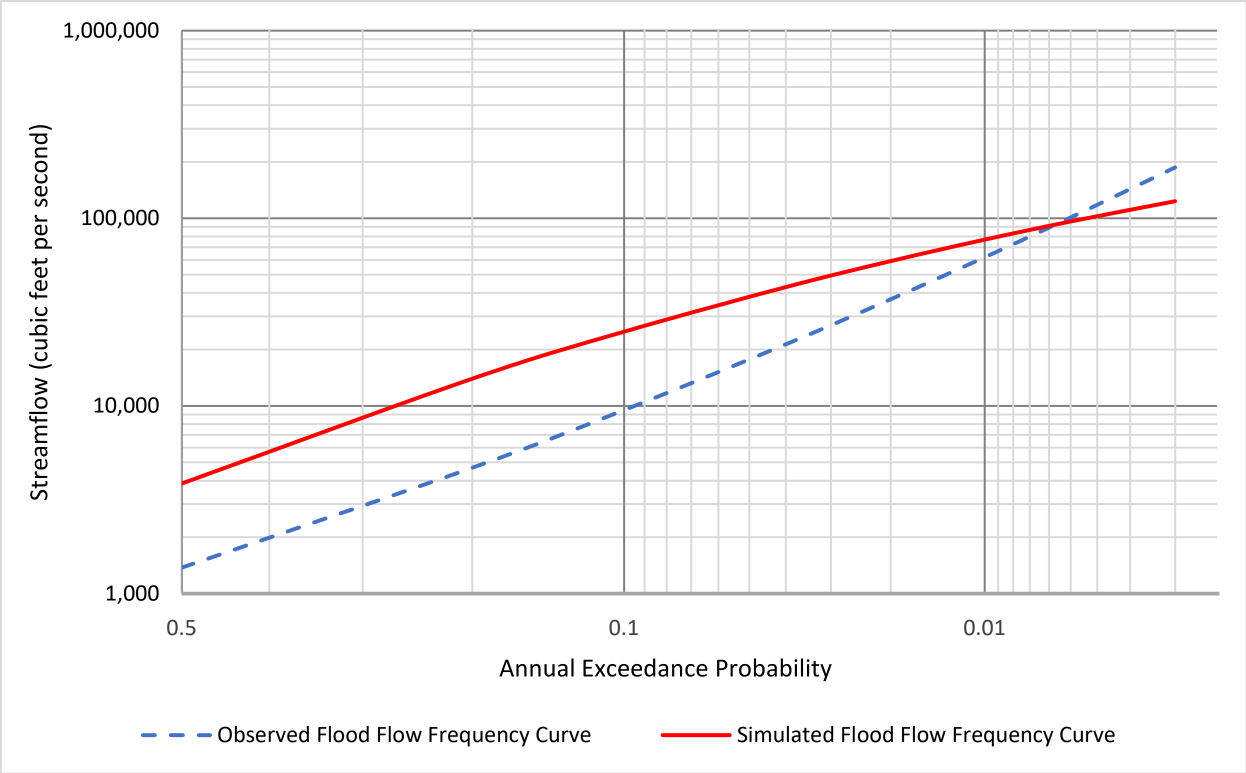

Figure D.56: Comparison of Flood Flow Frequency Curves for the Observed (1983-2020) and Simulated (1943-2020) Datasets for U.S. Geological Survey Streamgage 08211500 Nueces River at Calallen, Texas.

Table D.9: Statistically Estimated Annual Flood Frequency Results and Confidence Intervals Simulated for five U.S. Geological Survey Streamgages in the Nueces River Basin, Texas, determined by Hydrologic Engineering Center-Statistical Software Package

[cfs, cubic feet per second; %, percent; CI, confidence interval; Note, table contents derived from EXP file (file extension name) of USACE HEC-SSP software output (USACE, 2016). The estimates are of primary interest and are accentuated using a bold typeface.]

Station number and name	Flood flow frequency by corresponding average return period (recurrence interval) in years							
	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)
08206910 Choke Canyon Reservoir OWC near Three Rivers, Tex.								
Lower 95%-CI	96	5,330	13,400	25,800	35,100	43,900	51,500	59,800
Estimate	**933**	**9,360**	**22,300**	**45,300**	**64,600**	**83,600**	**101,000**	**121,000**
Upper 95%-CI	1,730	16,900	60,100	295,000	595,000	998,000	1,500,000	2,280,000
08210000 Nueces River near Three Rivers, Tex.								
Lower 95%-CI	5,270	14,600	21,400	31,900	41,200	51,600	63,100	79,900
Estimate	**8,000**	**17,600**	**26,800**	**42,400**	**57,200**	**75,000**	**96,500**	**131,000**
Upper 95%-CI	9,400	22,300	36,300	64,600	97,600	147,000	221,000	381,000
08211000 Nueces River near Mathis, Tex.								
Lower 95%-CI	3,960	12,600	20,100	31,800	41,800	52,600	64,000	79,600
Estimate	**5,860**	**16,100**	**26,300**	**43,500**	**59,500**	**78,100**	**99,500**	**132,000**
Upper 95%-CI	7,400	21,300	36,800	67,400	102,000	150,000	220,000	359,000
08211200 Nueces River at Bluntzer, Tex.								
Lower 95%-CI	2,800	10,600	18,100	30,100	40,300	51,400	62,800	78,400
Estimate	**4,330**	**14,100**	**24,700**	**43,300**	**60,900**	**81,600**	**106,000**	**142,000**
Upper 95%-CI	5,710	19,500	37,000	72,700	112,000	164,000	232,000	356,000
08211500 Nueces River at Calallen, Tex.								
Lower 95%-CI	2,320	10,200	18,000	30,300	40,400	50,700	60,700	73,100
Estimate	**3,860**	**14,000**	**24,900**	**43,000**	**59,100**	**76,900**	**96,100**	**123,000**
Upper 95%-CI	5,300	19,500	36,400	68,800	103,000	147,000	205,000	309,000

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