Predictability Assessment of Flushing Storm Event

Matilija Dam Removal 65 Percent Design Planning Study

Ventura County Watershed Protection District

Final Version – November 2022

300 Lakeside Dr. Suite 400
Oakland, CA 94612

Revision History

Revision	Revision date	Details	Name	Position
0	October 24, 2019	Initial Draft	Phillip Mineart	Hyd. Engineer
1	January 2, 2019	CMT Review Revisions	Phillip Mineart	Hyd. Engineer
2	April 14, 2020	VCWPD Review Revisions	Phillip Mineart	Hyd. Engineer
3	November 1, 2022	VCWPD Further Revisions	Brian Person	Project Manager

Prepared for:

Ventura County Watershed Protection District
800 S Victoria Ave,
Ventura, CA 93009

Prepared by:

AECOM
300 Lakeside Drive, Suite 400
Oakland, CA 94612
aecom.com

This Technical Memorandum was prepared in accordance with the standard of care commonly used as state-of-practice in the engineering profession. Standard of care is defined as the ordinary diligence exercised by other practitioners in the same geographical area performing the same services under similar circumstances during the same period.

AECOM does not attest to the accuracy, completeness, or reliability of geotechnical borings, concrete cores, or other subsurface and laboratory data by others that are included in this report. AECOM has not performed independent validation or verification of data by others. The data presented in this report are compiled for the Matilija Dam Removal Project only and should not be extended or used for any other purposes.

By:

______________________________ **11/9/22**

Seth Gentzler, P.E.
Vice President

Date

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1. Introduction

1.1 Project Background

Matilija Dam is located on Matilija Creek, a tributary to the Ventura River, approximately four miles northwest of Ojai, CA, within the Los Padres National Forest. The dam is an arched concrete structure, originally constructed in 1947 to a height of 198 feet, with an original storage capacity of just over 7,000 acre-feet. The primary purposes of the dam included water storage and flood control. Due to structural stability concerns, the height of the center section of the dam, which functions as the spillway, was reduced to 168 feet after two phases of notching in 1965 and 1977. It is estimated that over 8 million cubic yards of coarse and fine sediment has accumulated within the reservoir, preventing its transport downstream to maintain the streambed and beach at the mouth of the Ventura River, and commensurately diminishing the reservoir water storage capacity. The dam also prevents the passage of native fish species, primarily steelhead, to and from prime rearing habitat upstream of the dam.

Recognizing that its original purposes are no longer being realized, and due to structural stability concerns and adverse impacts to the Matilija Creek and Ventura River ecosystems, studies of dam removal were initiated as early as 1998. The study described in this technical memorandum advances the study effort, as described in the next section.

1.2 Objectives

Prior to physical dam removal, the current project plan includes maximizing sediment passage through the dam during the initial event, which involves boring two large-diameter orifices through the dam along the original streambed alignment. The upstream end of the orifices would remain intact until a "flushing storm event" is forecast to occur, and the unexcavated sections would be removed with explosive charges in the early stages of the event. Alternatively, control gates would be installed at the upstream orifice openings, and the gates would be opened to initiate flushing.

Recent sediment transport modeling concluded that a flushing storm event would ideally provide a minimum flow rate of approximately 1,700 cubic feet per second (cfs) through the dam for a period of at least 24 hours. A flow rate substantially less than that value and/or for a shorter duration during the initial breach would mobilize less sediment during the early stages, thereby prolonging the period of reduced water quality, downstream sediment deposition management, and other challenges.

For this subtask, AECOM collected and reviewed historical weather forecast and hydrologic event data to assess the reliability of forecast-based streamflow. That information was used to estimate the probability of over-predicting a minimum flushing flow storm event, along with describing the risk in terms of compromising the efficacy of the initial flushing event.

2. Predicting Streamflow

2.1 General

The general procedure for predicting future stream flows consists of two steps:

1. Find the probabilities that the predicted rainfall will exceed the actual rainfall. The National Weather Service (NWS) generally provides detailed rainfall projections 3 days in advance and more general forecasts 6 days in advance. The Ventura County Watershed Protection District (VCWPD) uses a private weather forecasting service that provides a 5-day forecast.
2. Find the probabilities that for a given precipitation volume the streamflow model will over-predict the actual streamflow.

There is a risk of initiating the flushing sequence during, or in advance of, a period when the actual streamflow is lower than the minimum flushing flow described above. The risk is two-fold: the predicted precipitation may exceed the actual precipitation that occurs, and/or the hydrology model may over-predict the actual stream flow even if the precipitation forecast is accurate. Thus, the primary purpose of this subtask to provide an estimate of the likelihood of the streamflow over-prediction.

2.2 Data Sources

Data sources include observed streamflow and observed and predicted rainfall. Stream flow data was provided by the United States Geologic Survey (USGS) and the VCWPD; these data include observed stream flows in the Ventura River, Matilija Creek, and the North Fork of Matilija Creek (NFMC).
Table 1 shows the flow data available near the project area (including period of record) and Figure 1 shows gaging station locations. Measured precipitation was obtained from the VCWPD rain gages (Table 2). Their locations are shown in Figure 2. No National Weather Service gages were identified in the project area.

Predicted precipitation data were obtained from the NWS and consisted of Quantitative Precipitation Forecasts (QPF). The QPF data are generated every 6 or 12 hours and consist of 6-hour precipitation totals for a 72-hour period (i.e., 12 6 hour totals every 6 or 12 hours). These data can be obtained from the NWS for 5 km square blocks. Figure 3 shows the location of the blocks within the Matilija watershed. The average value of the precipitation associated with each block, weighted by the fraction of the block located within the watershed, is used to represent the predicted precipitation.

Daily precipitation measured at VCWPD gages is recorded from 8:00 AM to 8:00 AM, whereas the predicted precipitation is from midnight to midnight. This inconsistency between measured and predicted rainfall sometimes resulted in the predicted maximum precipitation for a storm event being one day earlier than observed precipitation. To partially account for this inconsistency, a “weighted” observed precipitation was used in the analysis. Weighted precipitation consisted of the sum of 2/3 of the precipitation from the day before plus 1/3 of the precipitation of the nominal day.

In order to predict the occurrence of a flushing event as defined earlier, investigators developed a relationship between precipitation and flow. A review of the data shows that sometimes a flow event will exceed 1,700 cfs (or any other selected value) for just a single day or multiple days in a row. A flow exceeding the flushing flow rate for multiple days in a row was considered a single opportunity for flushing. Therefore, the data were analyzed to extract the number of possible flushing events in the record data by grouping the data into storm events

The period during which a flushing storm event occurred was defined as the time between when the flow exceeded the flushing flow (i.e., 1,700 cfs) to when the flow dropped below the flushing flow for at least 1 day. Figure 4 shows the number of possible flushing events and number of days that exceeded specified flow rates. For a cutoff of 1,700 cfs, there have been 32 possible flushing events since 1950 (earliest flow data); however, there have only been 16 such events since 1985 (the earliest precipitation data). In order to utilize the entire streamflow record, the precipitation record was increased by relating the precipitation measured at Ojai to the precipitation measured at Matilija. Figure 5 shows the comparison between precipitation at Ojai to precipitation at Matilija.

3. Analysis

3.1 Overview

The analysis consists of two parts:

1. Find the probabilities that the predicted rainfall will exceed the actual rainfall.
2. Find the probabilities that for a given precipitation volume the streamflow model will over-predict the actual streamflow.

These two probabilities will be combined to determine the likelihood that for a given storm prediction the actual streamflow will be over-predicted.

3.2 Probability That Predicted Rainfall Will Exceed Actual Rainfall

A relationship between predicted and observed rainfall in the Matilija watershed was developed using NWS QPF precipitations and VCWPD predicted and observed precipitation data (see Figure 6). This relationship was used to develop the likelihood of over-estimating the actual precipitation. Only precipitation volumes above a cutoff value of 1 in/day were used. Smaller storm events do not produce enough runoff for a flushing event and including them introduced a significant amount of noise into the analysis.

The QPF data consistently underestimates the actual rainfall as indicated by the best fit line included on Figure 6. The standard error for the fit is 1.62 inches. Factors contributing to the under-prediction include:

- The predicted storm data does not have has many intense storm events as the observed data and none of the extremely intense events in the observed data. In the 17 years of predicted data there were only 4 days with a daily precipitation more than 4 inches but 28 days in the observed record. The rainfall record had 9 days with more than 9 inches of rainfall in one day, and none in the predicated data.
- The predicted data were reported from midnight to midnight, whereas the observed data were reported from 8:00 AM to 8:00 AM. Any storms that occurred overnight would be split between two days in the predicted and 1 day in the observed.
- The predicted data represent rainfall on a 5 km square grid. This may result in the prediction missing thunderstorms and cloud bursts smaller than that.

Figure 7 shows the time series of cumulative rainfall from the year 2000 to 2017. The plot in the figure shows the predicted cumulative rainfall and the predicted cumulative rainfall with the 28 highest rainfall days replaced with the actual values for those days (approximately 3 days every 2 years were changed). The prediction consistently under-predicts the measured rainfall, however, correcting just the highest rainfall days in the record results in a prediction that closely follows the actual rainfall (sometime more sometime less). This indicates that the predictions are primarily missing just a few intense thunderstorms that can occur in the region.[1]

The rainfall predictions were reviewed to check for any temporal trends in accuracy and none were found.

3.3 Probabilities that for a Given Precipitation Volume the Streamflow Model will Over-Predict the Actual Streamflow

The VCWPD developed a real-time hydrology model to calculate runoff upstream of Matilija Reservoir based on predicted rainfall; however, the period of record for the VCWPD is short and includes several drought years. Therefore, a relationship between actual rainfall and actual runoff above Matilija Reservoir was developed. If the VCWPD model is used in the future to predict runoff from predicted rainfall, the associated error or uncertainty will be less than the uncertainty developed from the relationship described below.

To expand the data set and bracket the proposed flushing flow of 1,700 cfs, all storms with maximum flows greater than 750 cfs were initially used in the analysis. The following variables were considered in developing the relationship between rainfall and runoff for a day:

- Flow the day before
- Precipitation on the selected day
- Precipitation the day before
- Total precipitation on the given day and the two preceding days.

The streamflow in the NFMC was also considered as a predictive variable; however, it was not deemed to be good predictor of future streamflow due to the NFMC's flashy nature.

Figure 8 shows the relationship between each variable and the flow. The prediction of flushing flow into Matilija Reservoir will need to be made a minimum of three days before the flushing flow occurs to allow time to prepare and to remove the plugs from the orifices; thus, predicted flows are based on precipitation predicted several days prior. A multiple linear regression between the variables listed above and flow indicated that precipitation on the day of the flushing flow, along with the 3-day total precipitation (day with flushing flow plus two previous days) were the variables with the greatest correlation to flow. Though these two variables had the best fit, the regression tended to under-predict large flows (> ~4,000 cfs) and over-predict smaller flows (1,000 to 4,000 cfs). That is, the residuals of the regression were not uniformly distributed around zero but were negative for small flows and positive for large flows. Limiting the data to between 1,200 cfs and 6,000 cfs, which reduced the data to only 37 values, resulted in errors were more evenly spread throughout the range of flows. The resulting equation is shown below.

Equation 1

$$Q = 0.351 Qt - 1 + 190.05 P3t + 187.9\, P + \in$$

Where:

Q = predicted flushing flow (cfs)

Q_{t-1} = flow day before predicted flushing flow (cfs)

[1] The measured data were assumed to be accurate.

P_{3t} = Total 3 day precipitation for flushing flow day and 2 days previous

P = Predicted precipitation for day with flushing flow.

ε = error in prediction. The error is made up of the regression error and the error in the precipitation prediction.

The adjusted R-squared value for the model is 0.892 with a standard error of 904 cfs based on 37 events. Figure 9 compared the predicted flows to the observed flows for the 37 events used in the regression.

To test the ability of Equation 1 to predict flushing flows, the model was used to predict flows based on precipitation records from 1965 to present (precipitation before 1965 is based on the Ojai gage). A review of the data shows how variable the precipitation can be to result in a streamflow of about 1,700 cfs. In some cases, rainfall of less than 2 inches resulted in streamflow exceeding 1,700 cfs; at other times, daily rainfall over 4 inches or 10 inches over three days resulted in a flow less than 1,700 cfs. Based on Equation 1, if the daily precipitation exceeds about 4.5 inches or the total 3-day flow exceeds about 8 inches Equation 1 will predict flow exceeding 1,700 cfs

Two types of errors can occur when trying to predict a flushing flow:

1. a flushing flow occurs and was not predicted (false negative or Type II error), or
2. a flushing flow is predicted to occur but does not occur (false positive or Type I error).

There are just over 20 events since 1960 that exceed the 1,700 cfs flushing flow (occurring in 18 different years) or a recurrence interval of approximately 3 years. Appendix A provides plots of the predicted and observed flows for events that exceed 1,700 cfs. The comparison indicates that the first type of error (false negative) is rare: flushing events that have occurred would have been predicted to occur. The NWS precipitation predictions (only available since year 2000) were generally less than the actual precipitation for most storms that produced flushing flows. The use of the NWS predicted precipitation tended to result in lower prediction of the flow. Smaller flushing flows (e.g., less than 3,000 cfs) were more likely to be missed if the predicted precipitation data were not corrected for under-predicting.

Appendix B provides plots comparing predicted and observed flows for events that were predicted to exceed flushing flows but did not (false positive). This occurred about 20 times since 1960, however, only about 10 flows were greater than 2,500 cfs. Generally, the false positives tended to occur when the maximum daily rainfall was less than 5 inches and the three-day total rainfall was less than 8 inches, though sometimes a false positive would occur for larger events. In contrast, the 1,700 cfs flushing flows occurred at a wide range of daily rainfall amounts, but the 3-day total rainfall amounts were generally greater than 10 inches, though sometimes they were as small as 5 inches. About 50% of the total predicted flushing flows were false positives, with the average predicted flow about 2,100 cfs.

The total seasonal rainfall that occurred before a storm with an observed or predicted peak flow greater than 1,700 cfs was reviewed. The total seasonal rainfall prior to storms with an observed flow greater than 1,700 cfs were all greater than 15 inches. In one case the total seasonal rainfall before a multiday storm was less than 15 inches but the front end of the storm brought the total to greater than 15 inches, resulting in a peak flow greater than 1,700 cfs at the end of the storm. For cases where the predicted flow was greater than 1,700 cfs but the observed flow was less than 1,700 cfs the total seasonal precipitation before the storm was less than 15 inches. In several cases during a series of storms, with a least one dry day between storms, the peak flow for each event remained less than 1,700 cfs until the total rainfall exceeded

15 inches. This indicates, based on a review of about 20 different storm events, that at least 15 inches of rainfall is required to saturate the watershed before a storm with a peak flow of at least 1,700 cfs occurs.

Appendix C provides a comparison between the predicted and observed precipitation time series from January 1, 2000 to October 2018. In general, the predictions tend to be lower than the observed as discussed above. Comparing storms larger than 4 inches, the predictions look to have better captured these events after October 2010 than before. There is only storm after 2010 producing more than 6 inches of total precipitation, and it was captured moderately well. Prior to 2010 there were 12 storms larger than 6 inches, only one of which was captured. It is possible that the predictions have improved over time, but the lack of large storm events since 2010 makes this determination uncertain.

The relationship defined by equation 1 provides the most likely value of flow. To reduce the likelihood of false positives, the prediction intervals for 95% and 90% were calculated. The prediction interval is the interval likely to contain the next prediction with a specified probability (e.g., 95% or 90%). For example, using a prediction interval of 90% means that there is a 90% chance that the next prediction will be in the interval (5% chance it will be higher and 5% chance it will be lower). Using a 90% prediction interval reduced the occurrence of false positives but increases the occurrence of false negatives. However, the flows mostly likely to be missed are the lowest flushing flows (e.g., < 3,000 cfs).

3.4 Implementation of Prediction Model

The above analysis provides a method to predict the occurrence of flushing flows based on a prediction of rainfall 3 days in advance. The model is based on a comparison between measured precipitation and flow rates. The VCWPD has a streamflow prediction model driven by predicted precipitation provided by a private weather forecasting firm. The model provides a prediction of streamflow in Matilija Creek upstream of Matilija Reservoir. There was not enough historic data on model results to calculate the error associated with the VCWPD model, however, it is likely to have a lower error than the model described in this report.

To account for the error in the model Figure 10 was developed. Figure 10 provides the lower prediction intervals (LPI) for flow estimates using equation 1. The diagonal lines on the figure represent the low prediction interval with a given percentage of the predictions. For example, the 95% prediction line represents the flows that that will be exceeded for 95% of the predictions. To use the plot, select a flow on the y (vertical) access to be exceeded. Move horizontally to the diagonal line representing the desired exceedance probability then select the value on the x (horizontal) axis representing the needed prediction. For example, there is a 90% chance that a prediction of 3,100 cfs would exceed 1,700 cfs. On the other hand, for a prediction of 1,700 cfs (1,700 cfs on the horizontal axis), there is a 25% chance the flow will be less than 1,000 cfs (and a 75% chance it will be greater than 1,000 cfs based on the 75% LPI line).

The results shown in Figure 10 assume that the inputs to Equation 1 are known, but there is also uncertainty with those inputs. To account for this uncertainty, the results shown in Figure 10 were recalculated by including uncertainty or “errors” in the input parameters. The standard error in the prediction of the “flow the day before” was assumed to be the same as the standard error for equation 1. For precipitation, the error was assumed to equal the error in the regression between observed and predicted precipitation as shown in Figure 6. Since Equation 1 is linear, the total error can be estimated as a linear combination of the errors for each term in the equation. If it is assumed that the correlation between terms in Equation 1 is small, the standard error can be estimated as the square root of the sum of each term’s error squared. Figure 11 shows the LPI for flow estimates using Equation 1 including the error in precipitation prediction.

4. Tables

Table 1: Stream flow gaging stations in the Ventura River Watershed

No.	Name	USGS Gage No. (VCWPD Gage No.)	Location Relative to Matilja Dam	Status	Period of Record
1	MATILIJA C NR RES NR MATILIJA HOT SPRINGS CA	11114495 (603A)	Upstream	Active	02-15-2002to 10-04-2018
2	MATILIJA C AB RES NR MATILIJA HOT SPRINGS CA	11114500 (603)	Upstream	Inactive	06-01-1948 to 09-29-1969
3	NF MATILIJA C A MATILIJA HOT SPRINGS CA	11116000 (604)	East of Dam	Inactive	10-01-1928 to 09-29-1983
4	MATILIJA C A MATILIJA HOT SPRINGS	11115500 (602, 602b)	Just downstream	Inactive	10-01-1927 to 09-29-1988
5	VENTURA R NR OJAI CA	11116500	Downstream, on Ventura River	Inactive	10-01-1911 to 06-30-1924
6	VENTURA R NR MEINERS OAKS CA	11116550	Downstream, on Ventura River	Inactive	06-01-1959 to 9-29-1988
	Ventura R nr Ventura CA	11118500 (608)	Downstream on Ventura River near Mouth	Active	10-1-1988 to present

Table 2: VCWPD Precipitation Gages near Matilija Dam Watershed

No.	Name	Gage No.	Location Relative to Matilija Dam	Status	Period of Record
1	Matilijia Canyon	207B	Upstream	Inactive	1985-09-30 to 2008-09-30
2	Matilijia Canyon	207C	Upstream	Active	2017-09-30 to 2018-06-01
3	Matilija Dam	134B	Just Downstream	Active	2017-09-30 to 2018-04-25
4	Matilija Hot Springs at No Fork (Type B)	304	Ventura River	Inactive	2010-09-30 to 2017-01-10

5. Figures

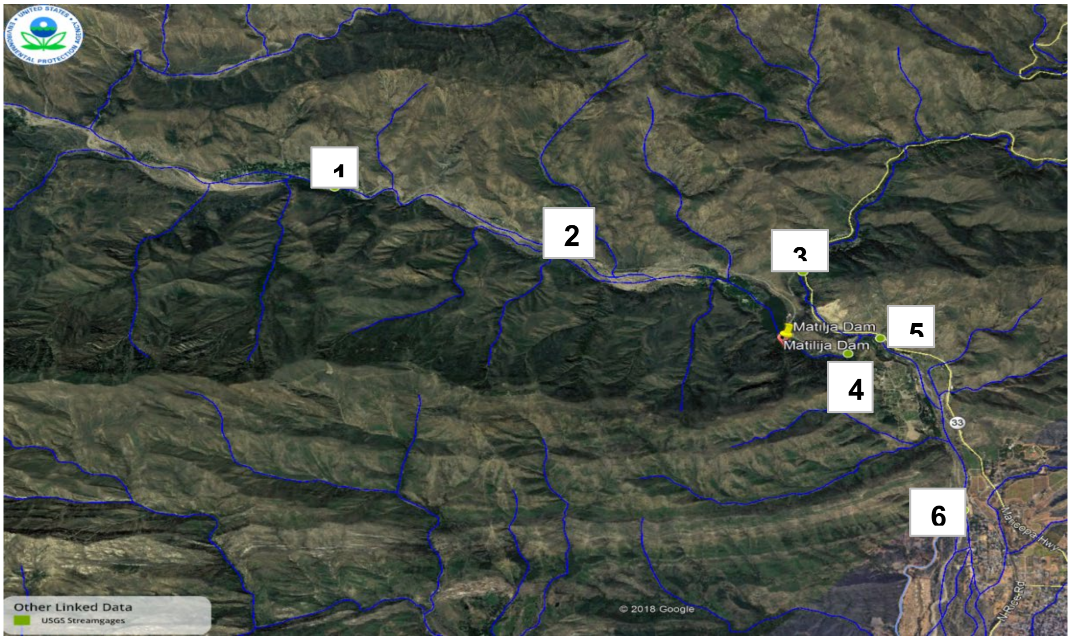


Figure 1: Locations of Stream Flow Gage Station near Matilija Dam

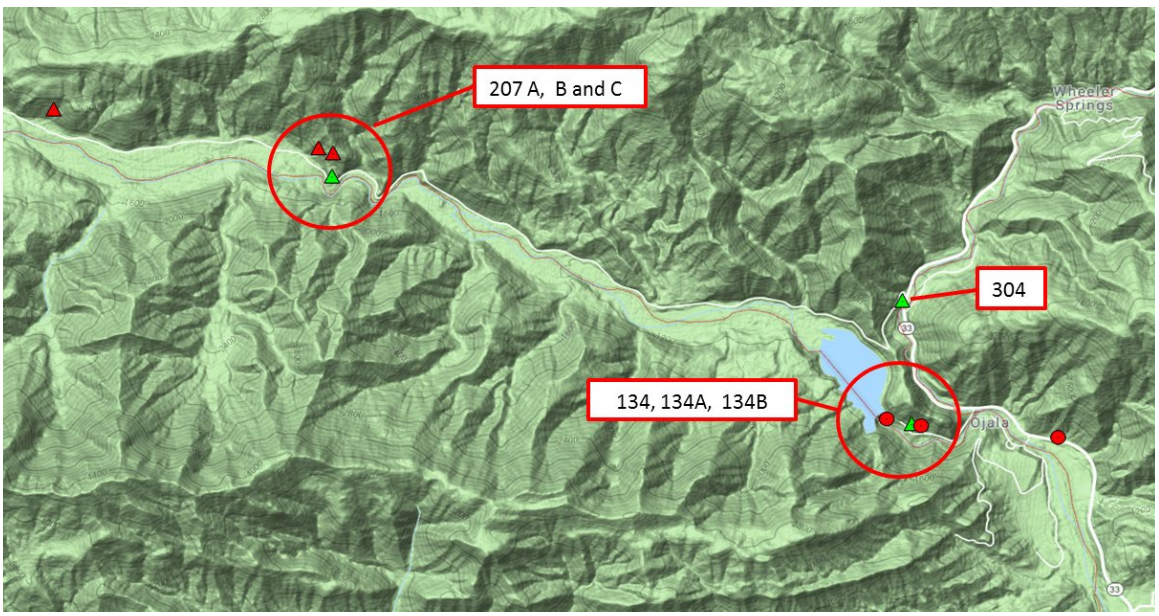


Figure 2: Locations of VCWPD Precipitation Gages near the Matilija Dam Watershed

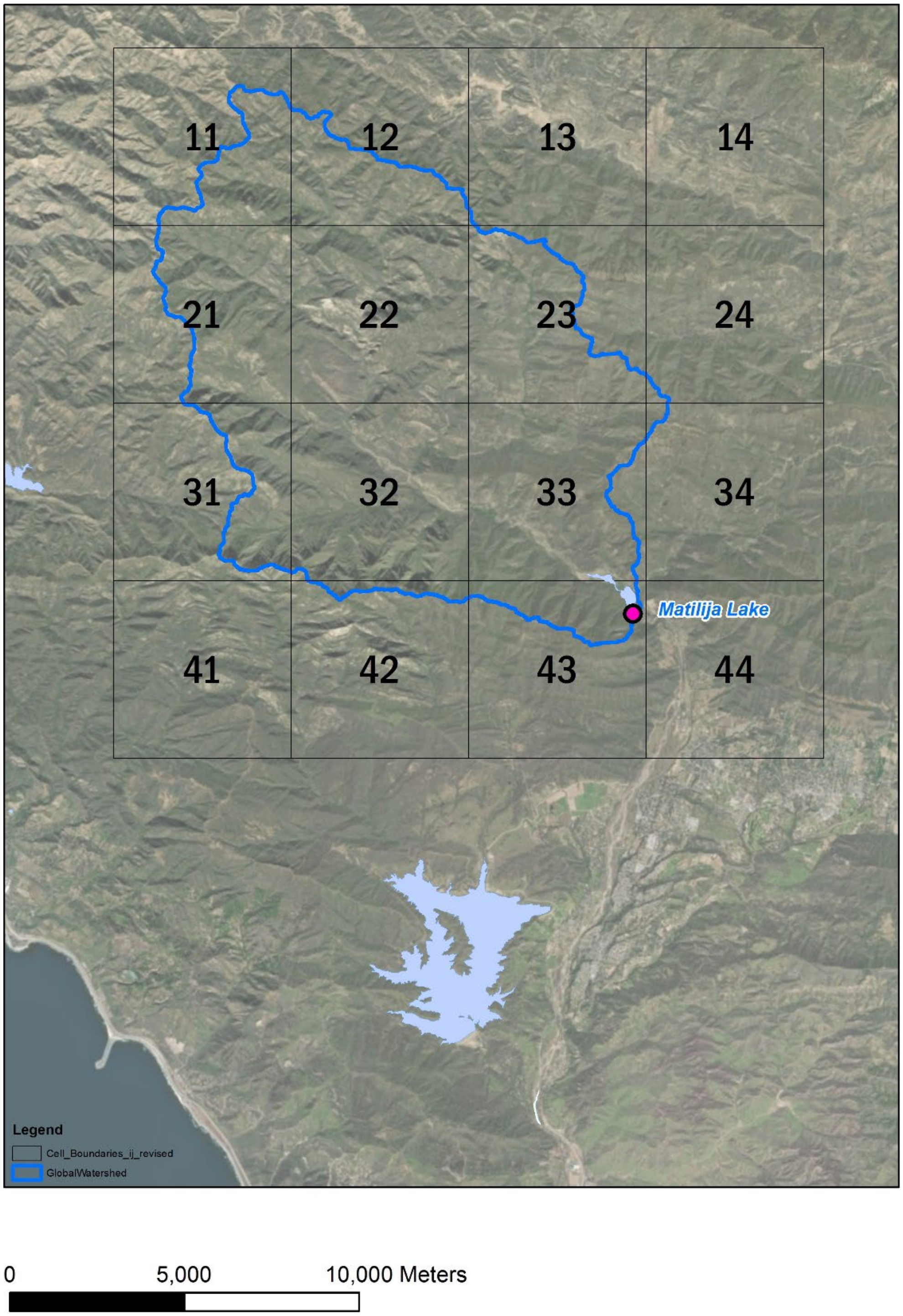


Figure 3: Quantitative Precipitation Forecast (QPF) Blocks

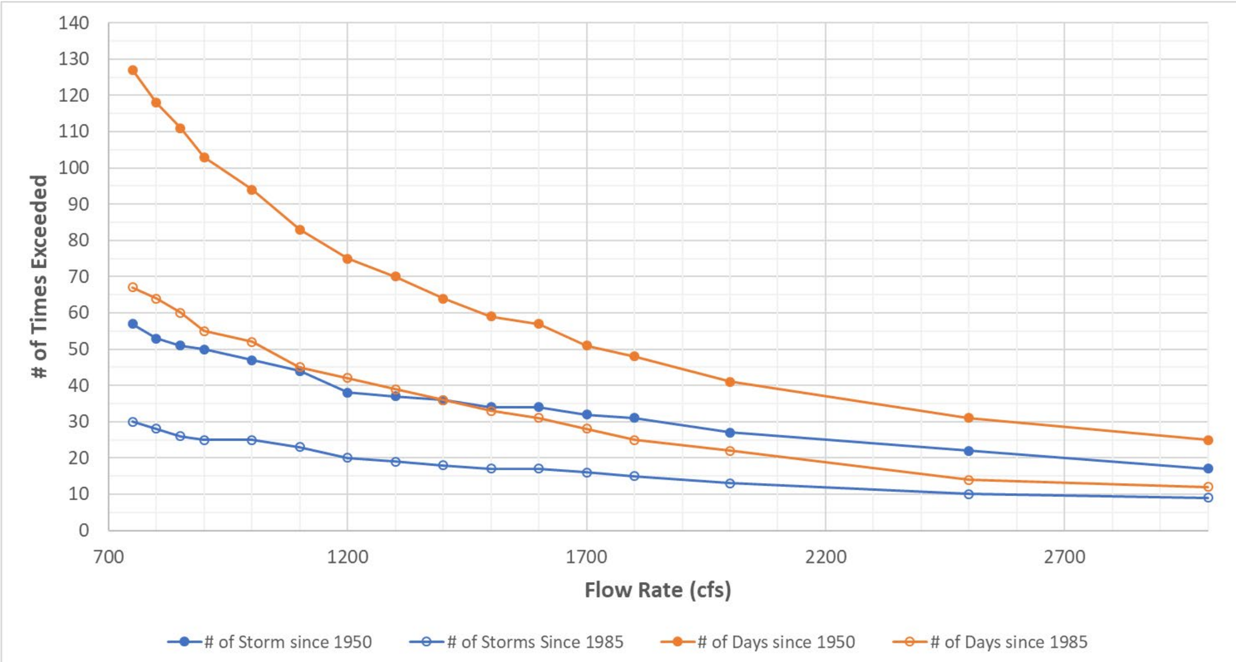


Figure 4: Number of Data Points Available for Analysis

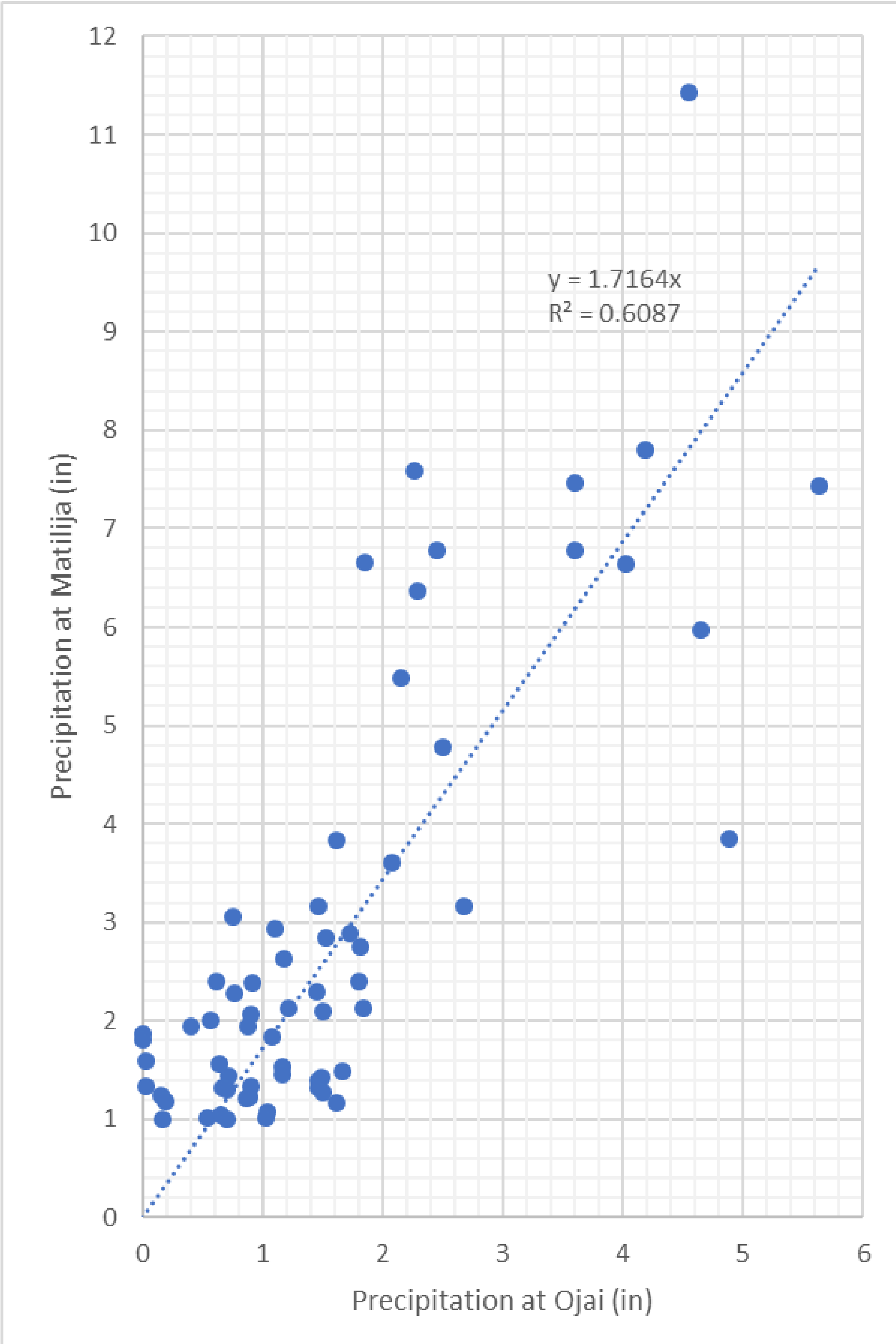
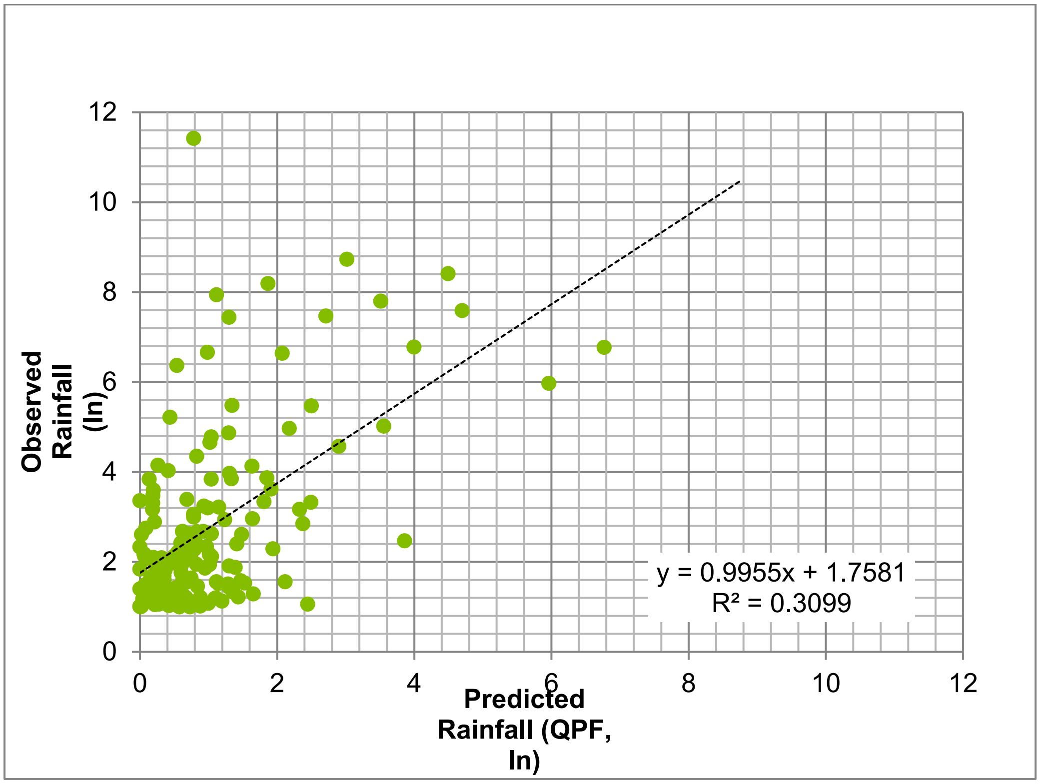


Figure 5: Comparison between Precipitation at Ojai to Precipitation at Matilija



3-day Advanced Prediction vs Observed Rainfall

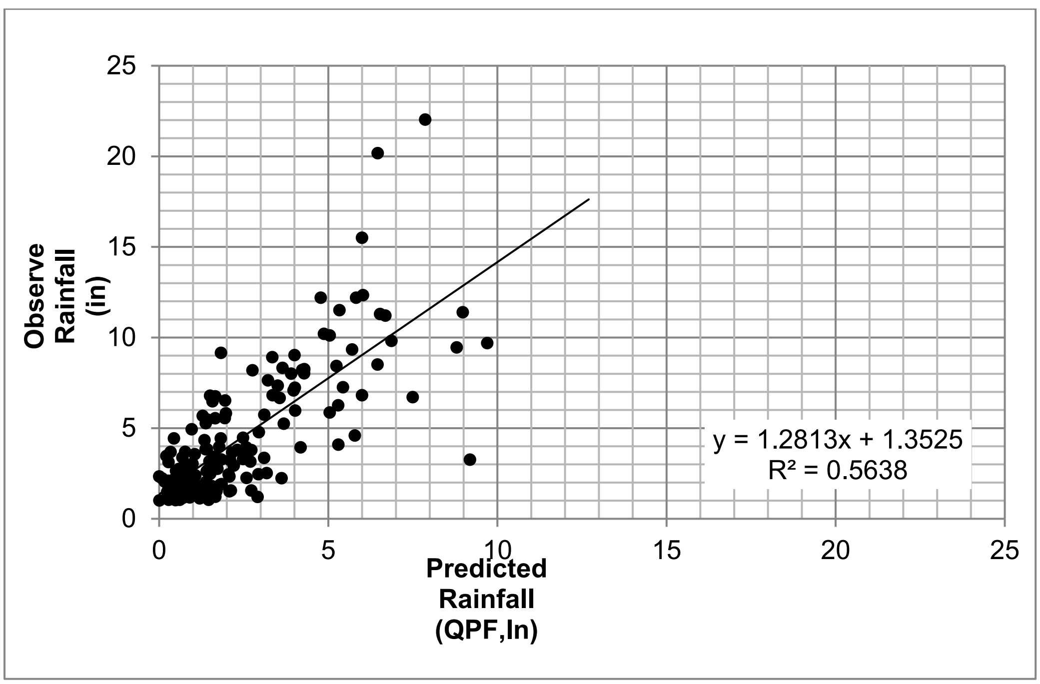


Figure 6: Relationship between observed and predicted rainfall. (observed rainfall at gages 207 and 134, predicted NWS QPF)

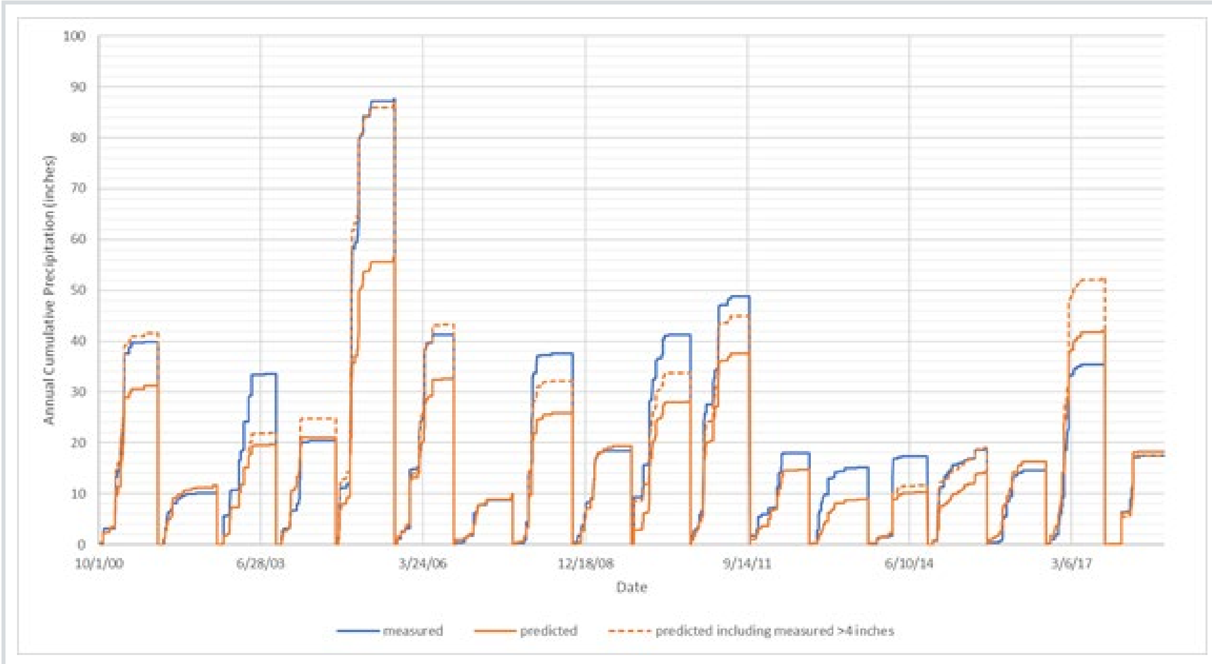


Figure 7. Comparison between Observed and Predicted Cumulative Precipitation

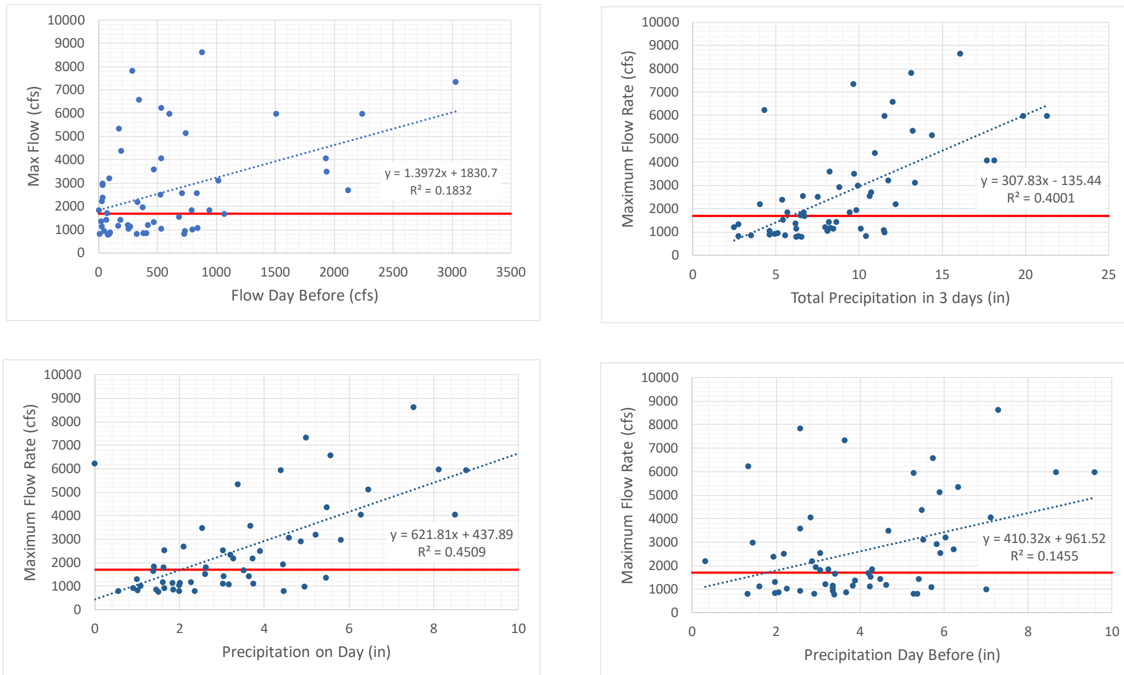


Figure 8 Relationship between Prediction Variables and Flow Rate

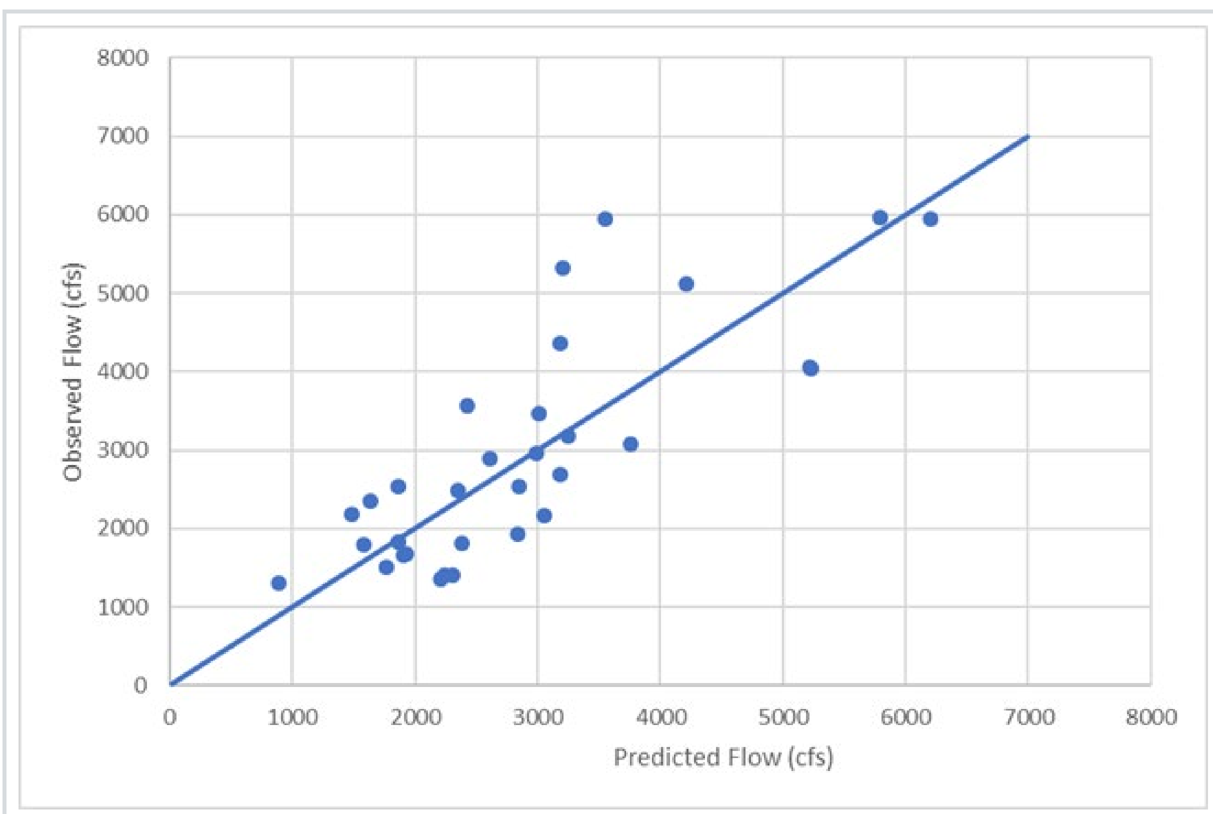


Figure 9. Comparison between Predicted and Observed Flow Rates into Matilija Reservoir

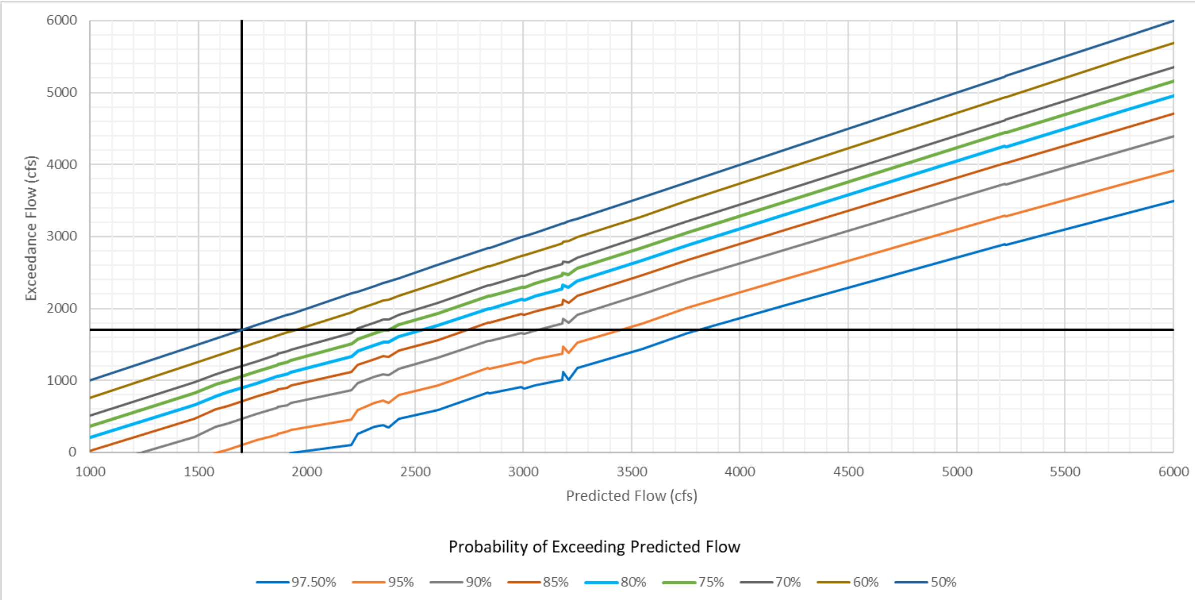


Figure 10. Prediction Intervals for Determining Selected Flow Event based on Error in Equation 1

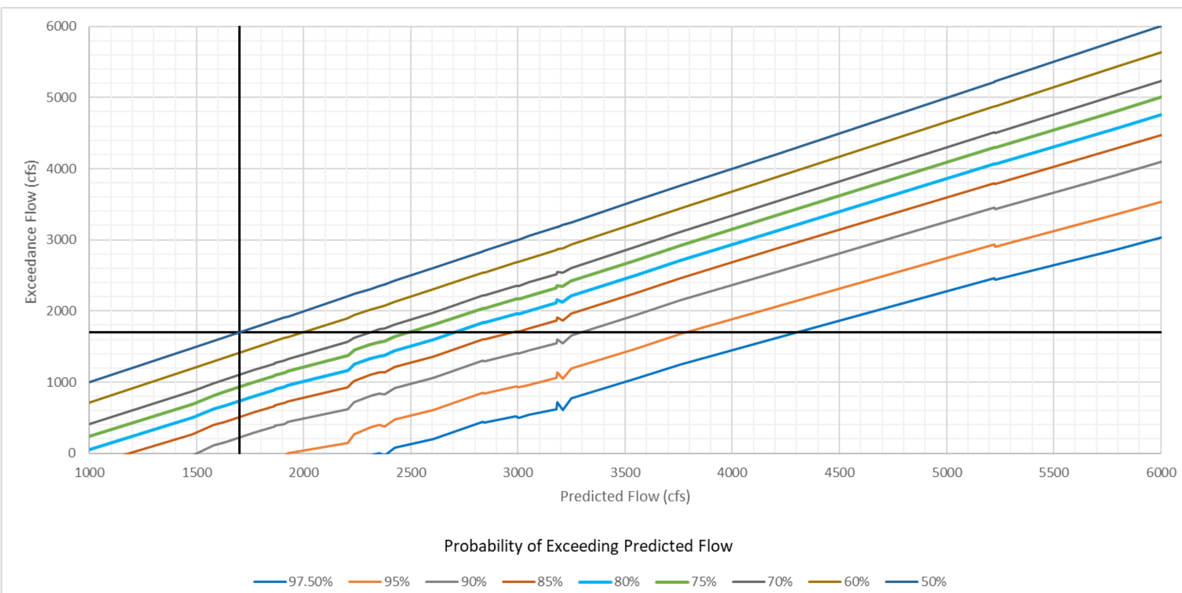
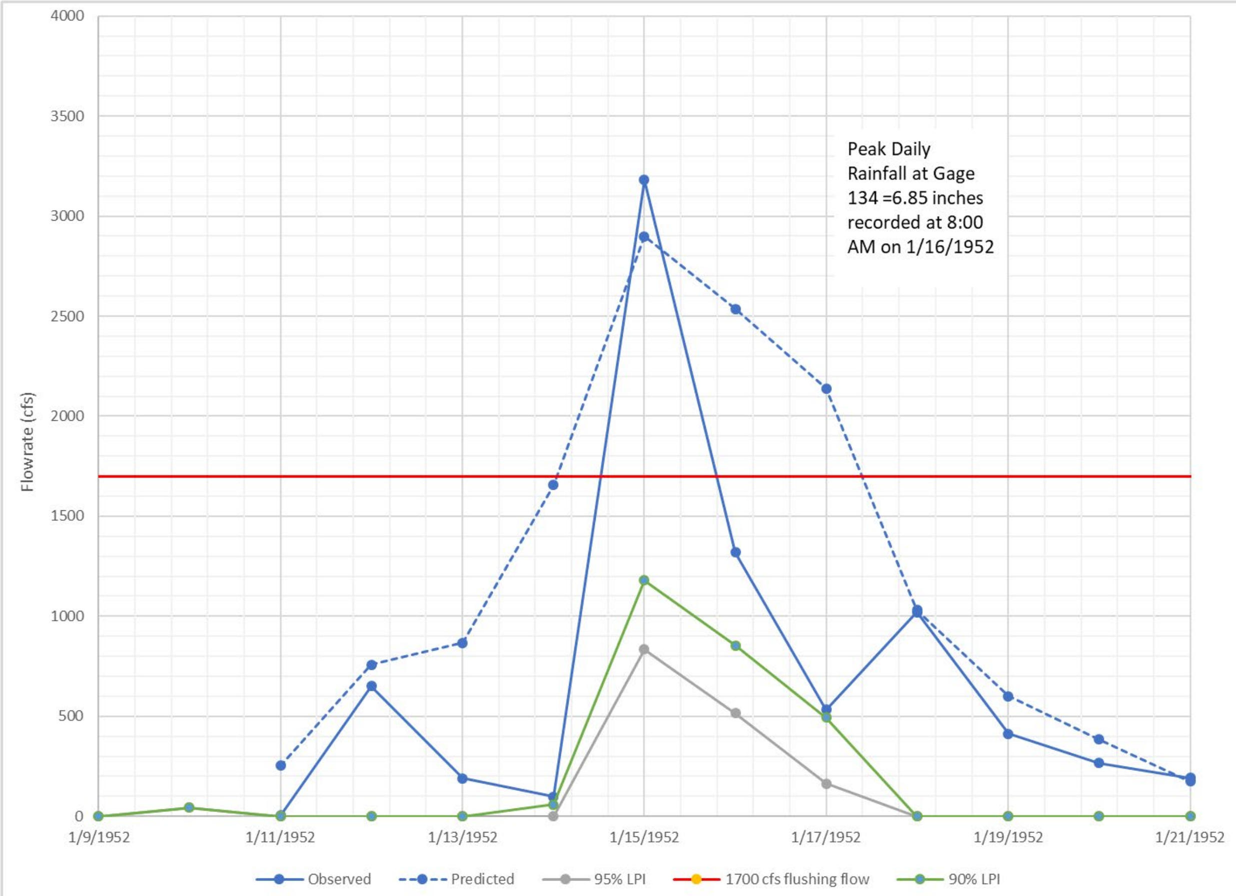
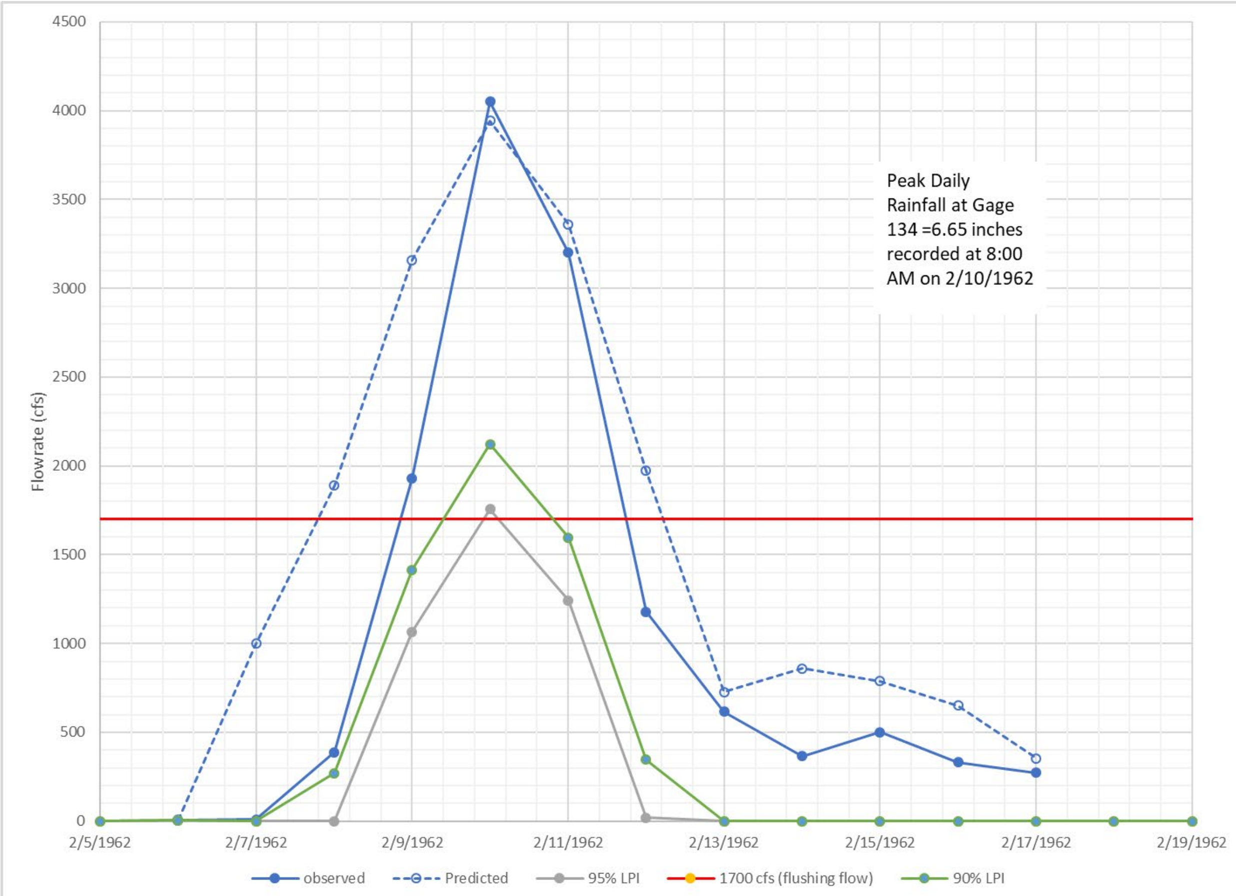
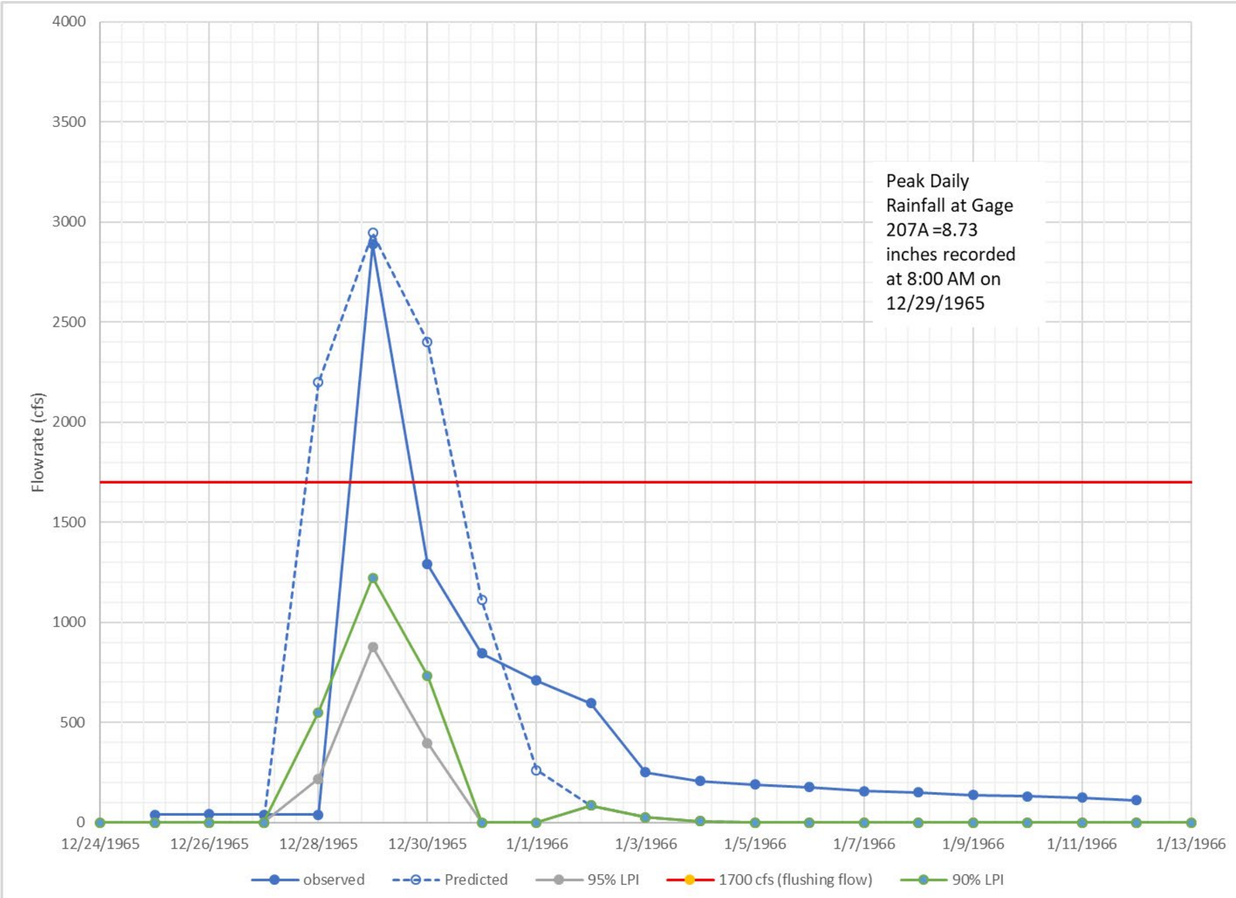


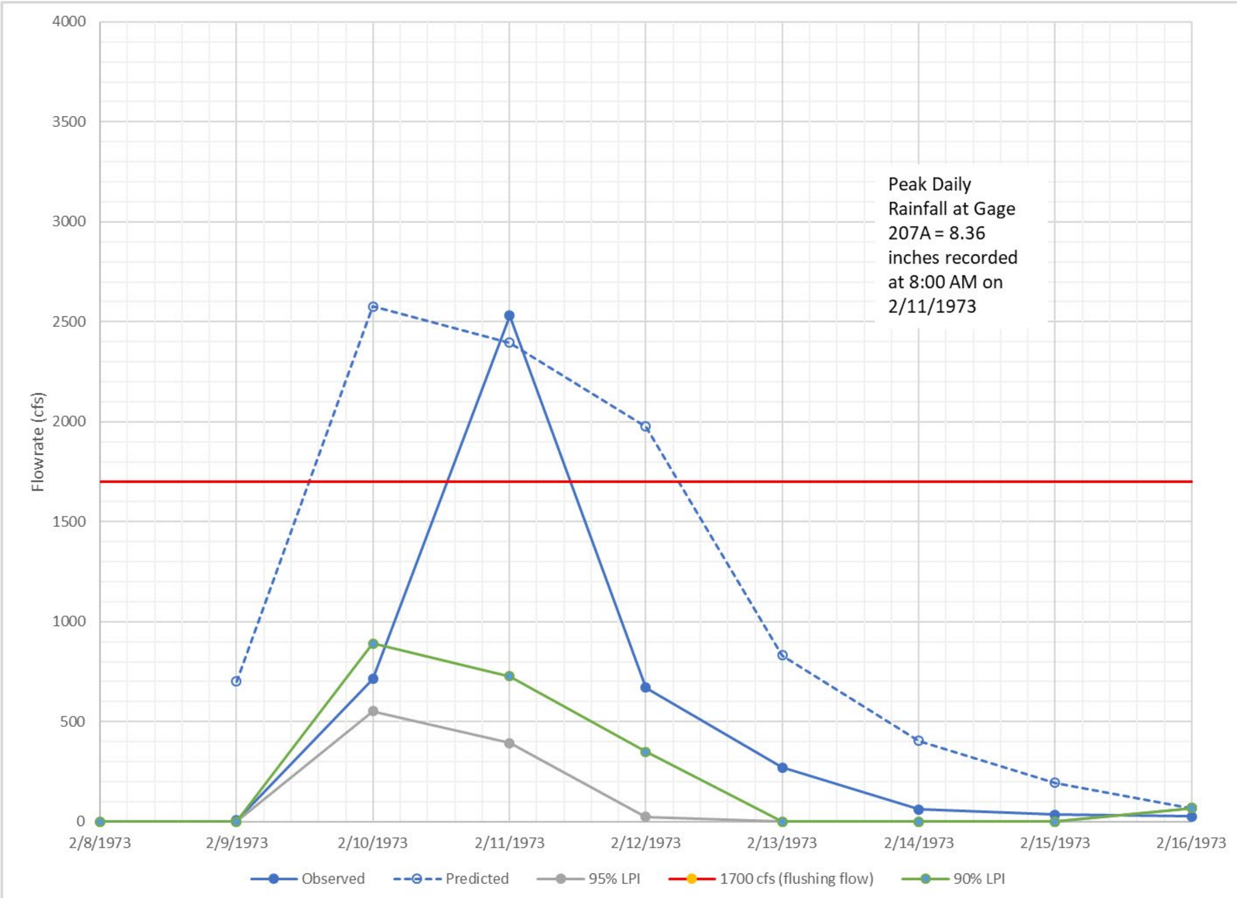
Figure 11. Prediction Intervals for Determining Selected Flow Event based on Error in Equation 1 and Equation Inputs

Appendix A - Predicted and Observed Flows Exceeded 1,700 cfs

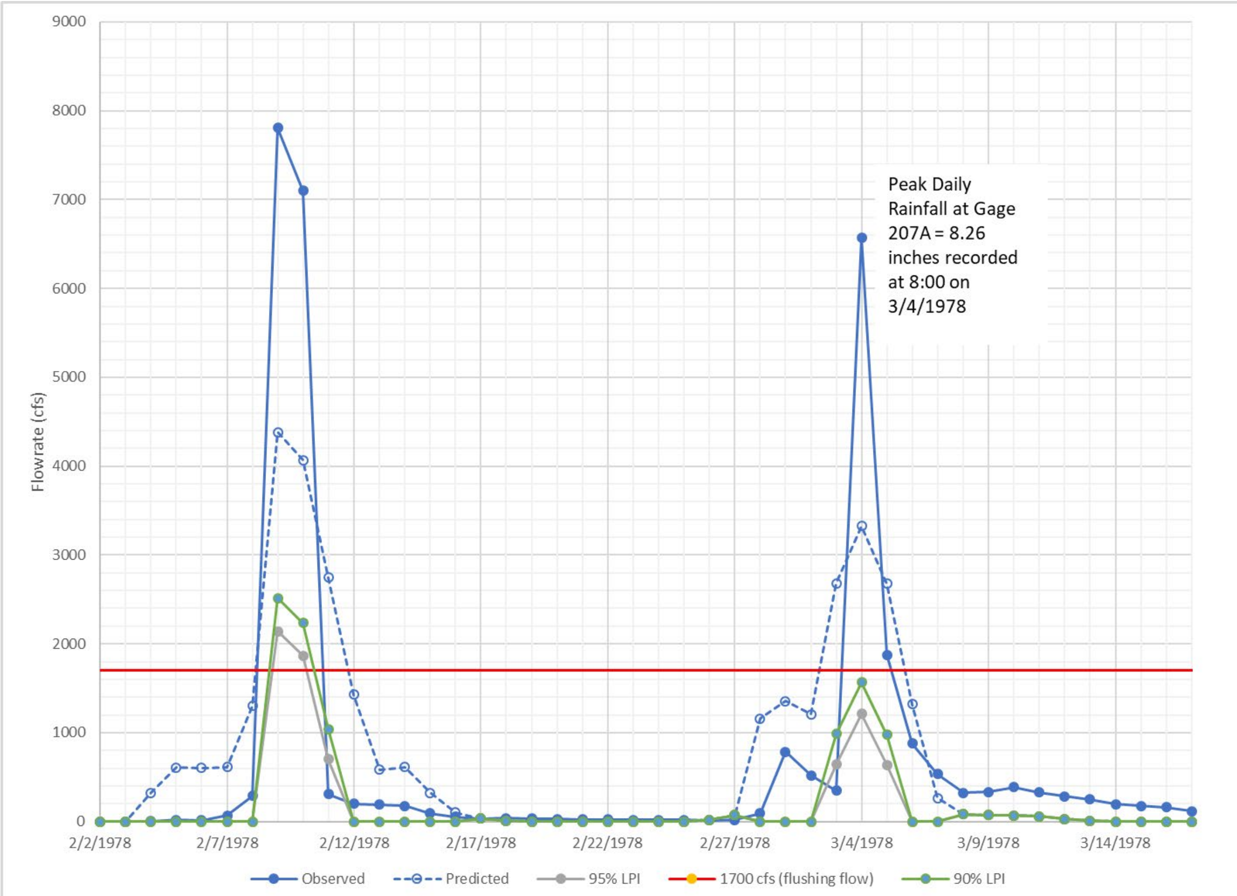


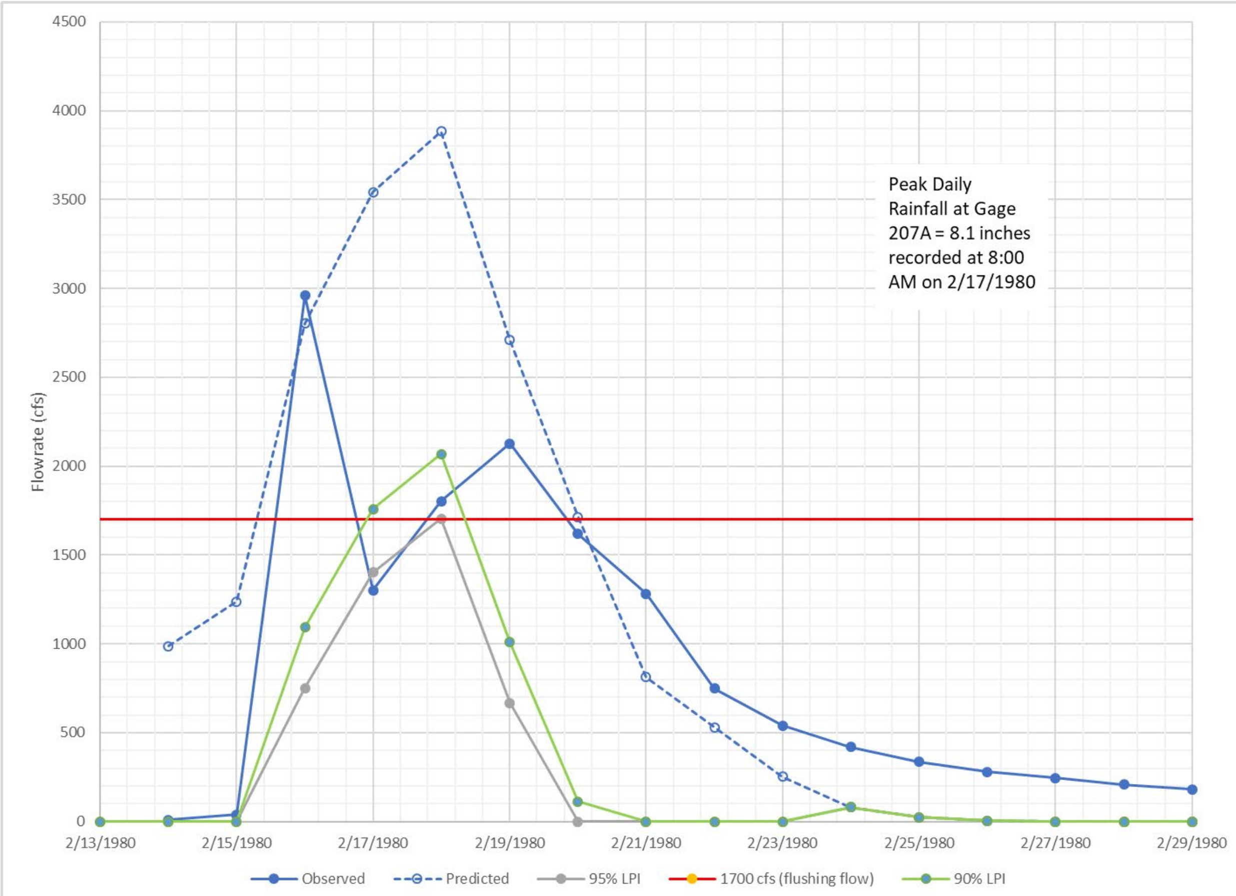

4500
4000
3500
3000
2500
2000
1500
1000
500
0
Flowrate (cfs)
Peak Daily Rainfall at Gage 134 =6.65 inches recorded at 8:00 AM on 2/10/1962
2/5/1962
2/7/1962
2/9/1962
2/11/1962
2/13/1962
2/15/1962
2/17/1962
2/19/1962
observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI

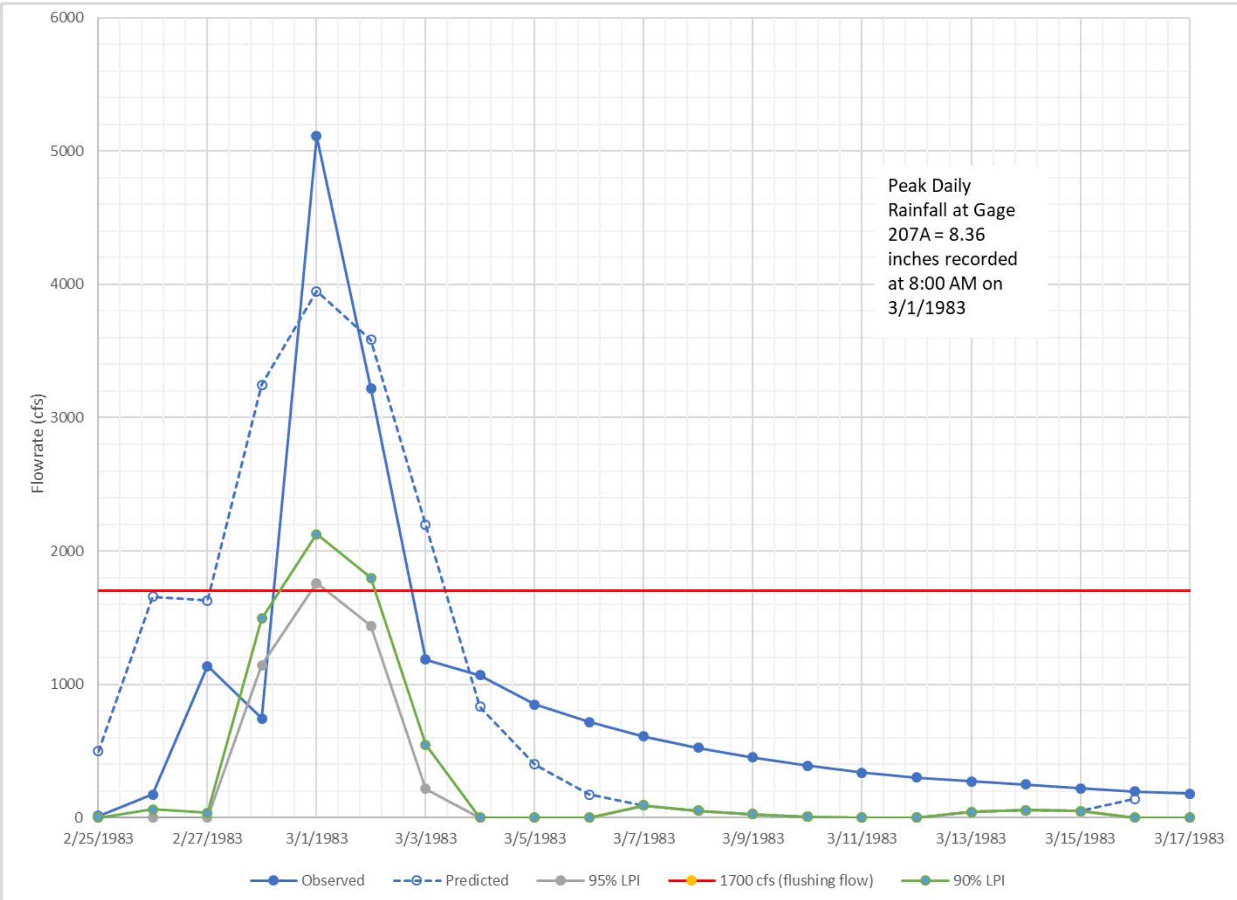

4000
3500
3000
2500
2000
1500
1000
500
0
Flowrate (cfs)
Peak Daily Rainfall at Gage 207A =8.73 inches recorded at 8:00 AM on 12/29/1965
12/24/1965
12/26/1965
12/28/1965
12/30/1965
1/1/1966
1/3/1966
1/5/1966
1/7/1966
1/9/1966
1/11/1966
1/13/1966
observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI



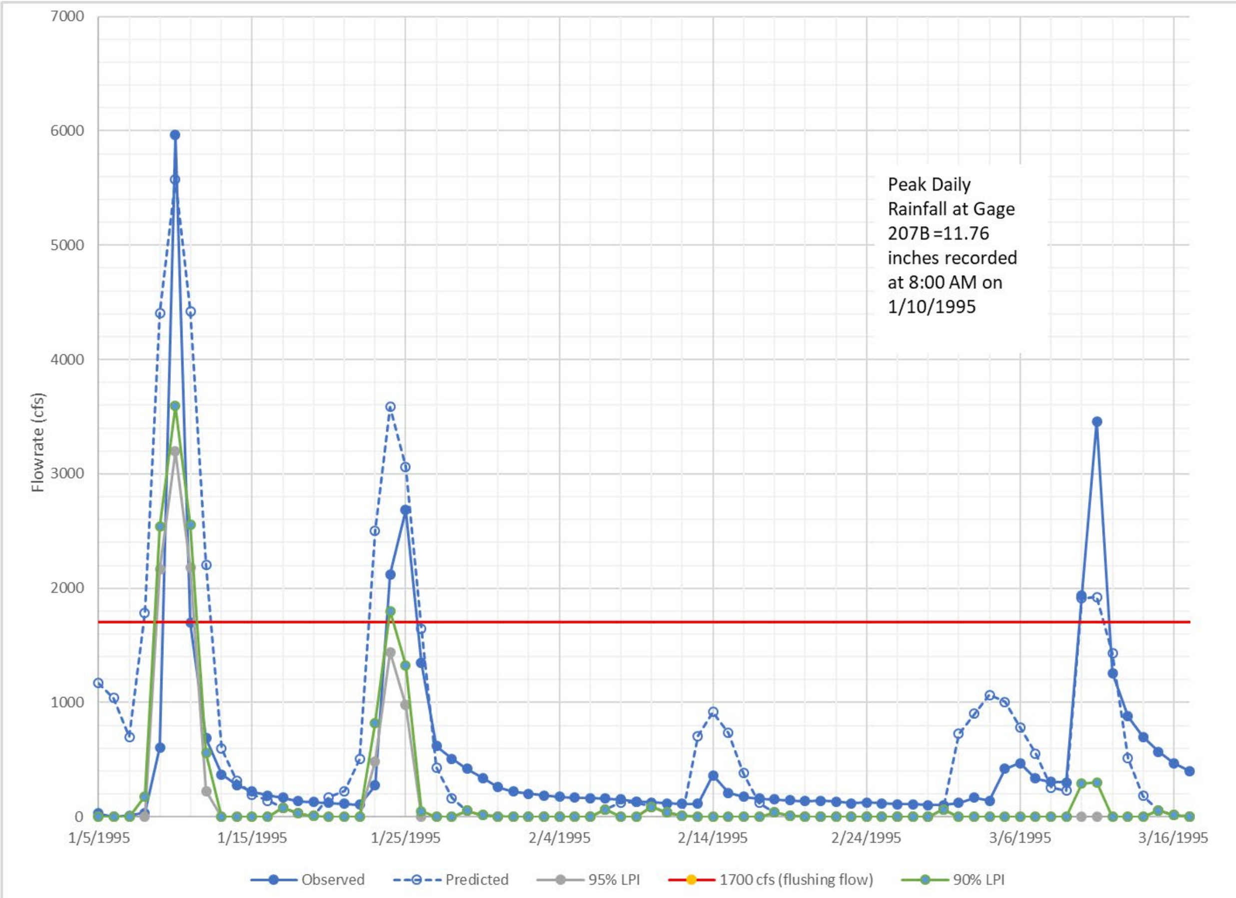
4000
3500
3000
2500
2000
1500
1000
500
0
Flowrate (cfs)
Peak Daily Rainfall at Gage 207A = 8.36 inches recorded at 8:00 AM on 2/11/1973
2/8/1973
2/9/1973
2/10/1973
2/11/1973
2/12/1973
2/13/1973
2/14/1973
2/15/1973
2/16/1973
Observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI

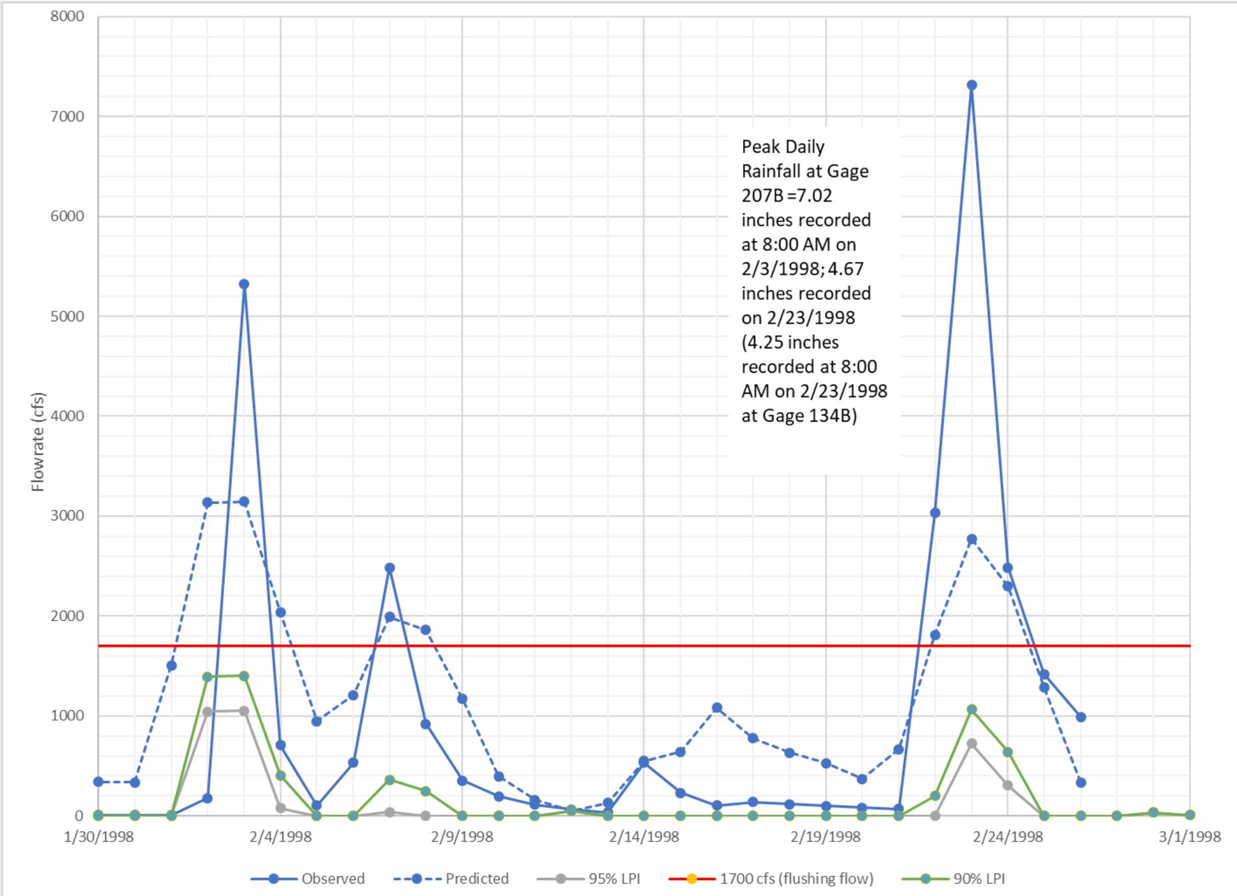

9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Flowrate (cfs)
2/2/1978
2/7/1978
2/12/1978
2/17/1978
2/22/1978
2/27/1978
3/4/1978
3/9/1978
3/14/1978
Peak Daily Rainfall at Gage 207A = 8.26 inches recorded at 8:00 on 3/4/1978
Observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI


4500
4000
3500
3000
2500
2000
1500
1000
500
0
Flowrate (cfs)
2/13/1980
2/15/1980
2/17/1980
2/19/1980
2/21/1980
2/23/1980
2/25/1980
2/27/1980
2/29/1980
Peak Daily Rainfall at Gage 207A = 8.1 inches recorded at 8:00 AM on 2/17/1980
Observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI

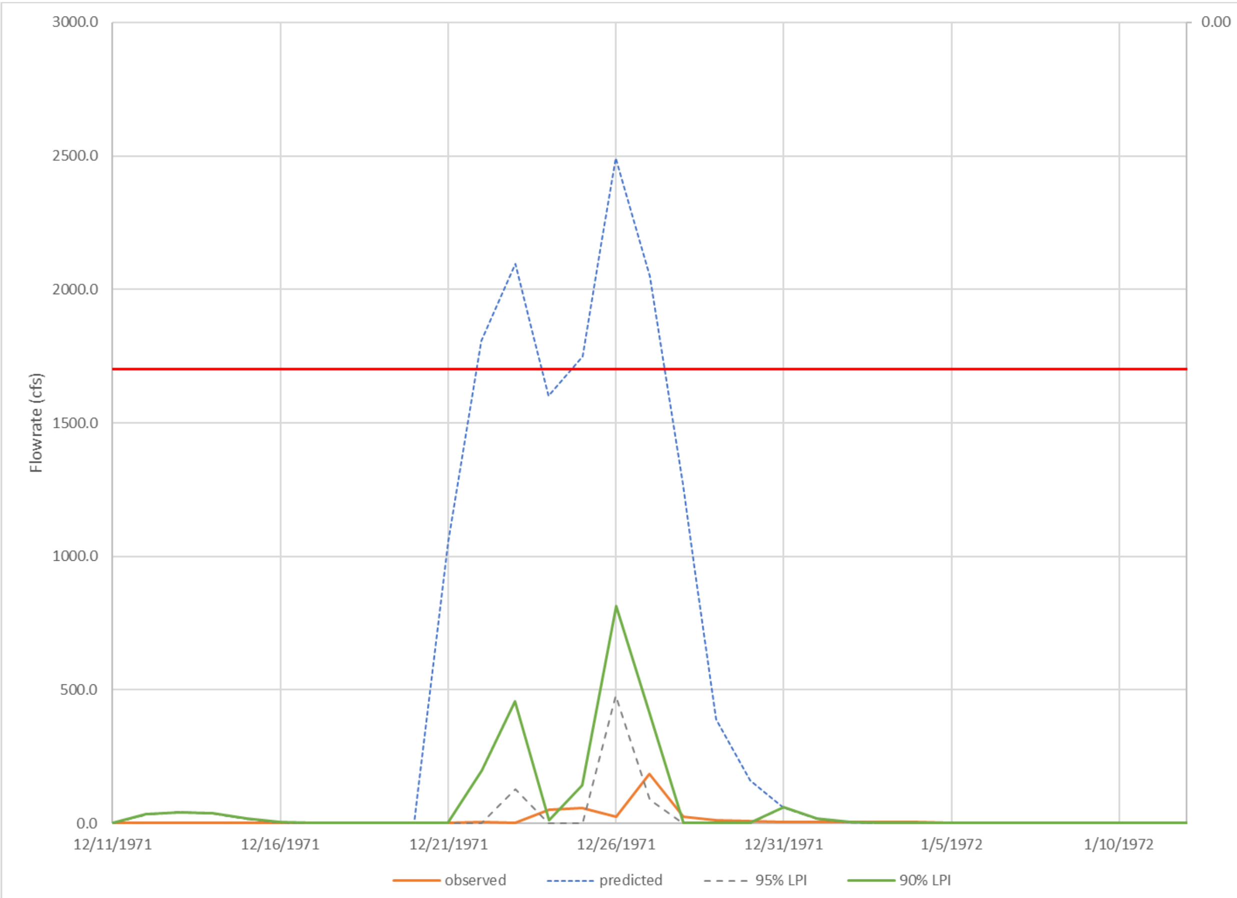


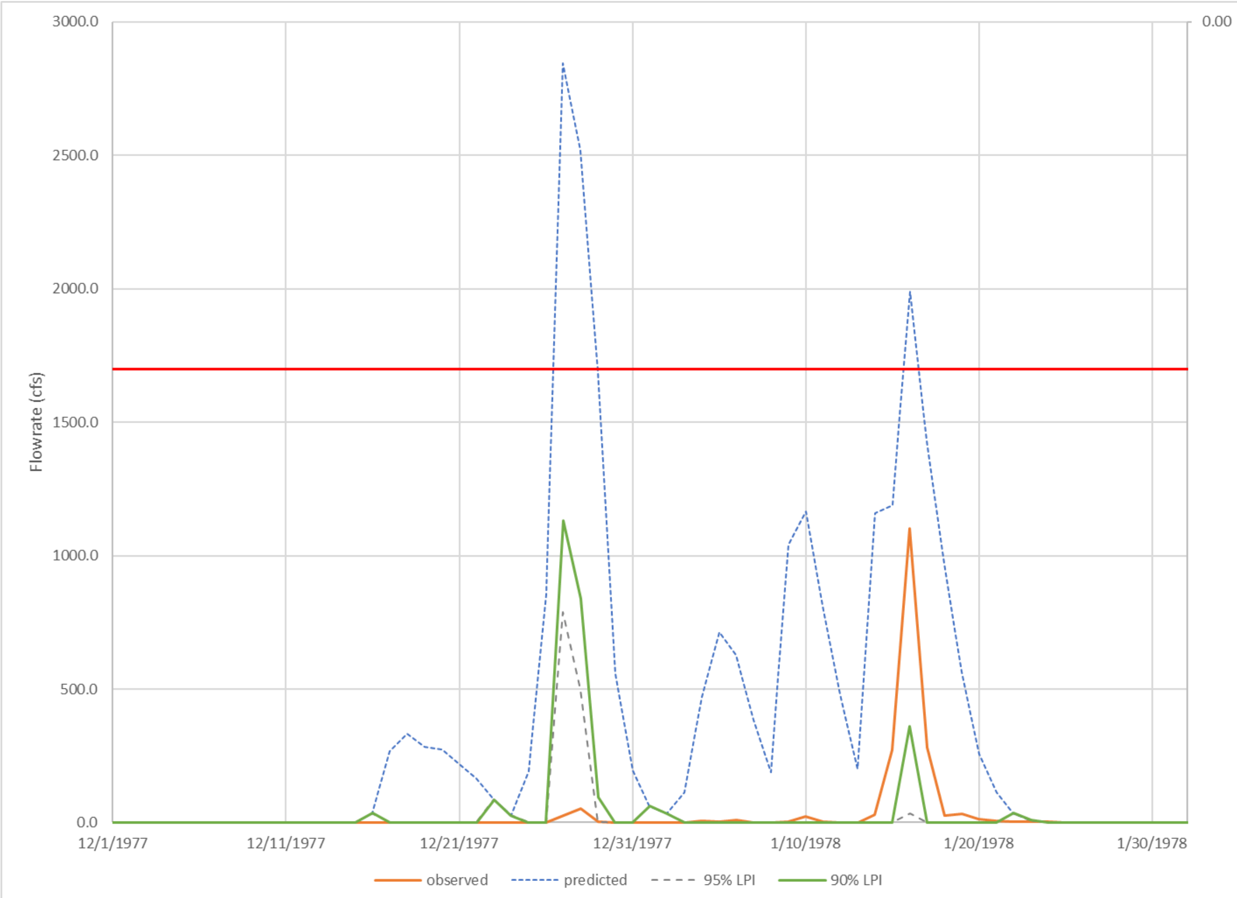
6000
5000
4000
3000
2000
1000
0
Flowrate (cfs)
Peak Daily Rainfall at Gage 207A = 8.36 inches recorded at 8:00 AM on 3/1/1983
2/25/1983
2/27/1983
3/1/1983
3/3/1983
3/5/1983
3/7/1983
3/9/1983
3/11/1983
3/13/1983
3/15/1983
3/17/1983
Observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI

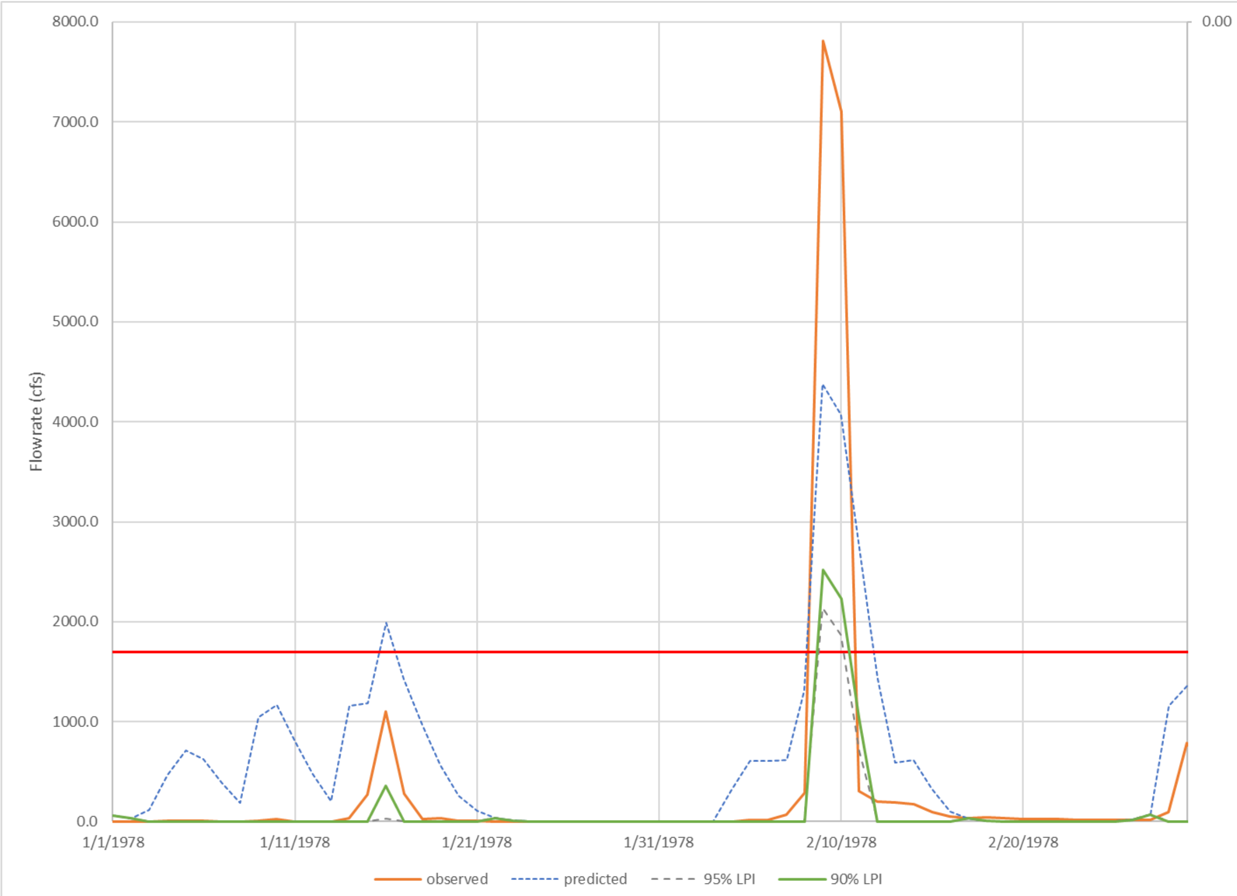

7000
6000
5000
4000
3000
2000
1000
0
Flowrate (cfs)
1/5/1995
1/15/1995
1/25/1995
2/4/1995
2/14/1995
2/24/1995
3/6/1995
3/16/1995
Peak Daily Rainfall at Gage 207B =11.76 inches recorded at 8:00 AM on 1/10/1995
Observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI

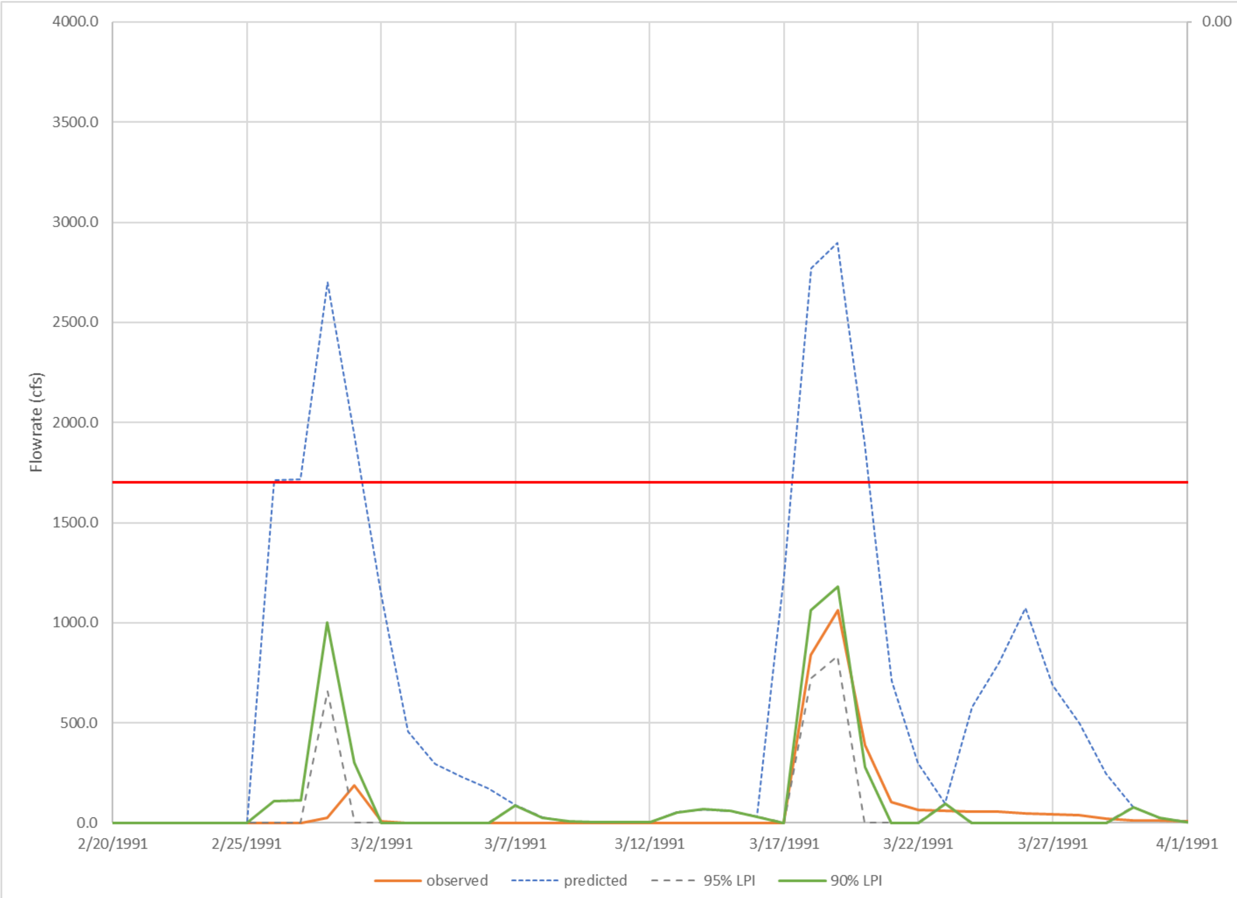

8000
7000
6000
5000
4000
3000
2000
1000
0
Flowrate (cfs)
1/30/1998
2/4/1998
2/9/1998
2/14/1998
2/19/1998
2/24/1998
3/1/1998
Peak Daily Rainfall at Gage 207B =7.02 inches recorded at 8:00 AM on 2/3/1998; 4.67 inches recorded on 2/23/1998 (4.25 inches recorded at 8:00 AM on 2/23/1998 at Gage 134B)
Observed
Predicted
95% LPI
1700 cfs (flushing flow)
90% LPI

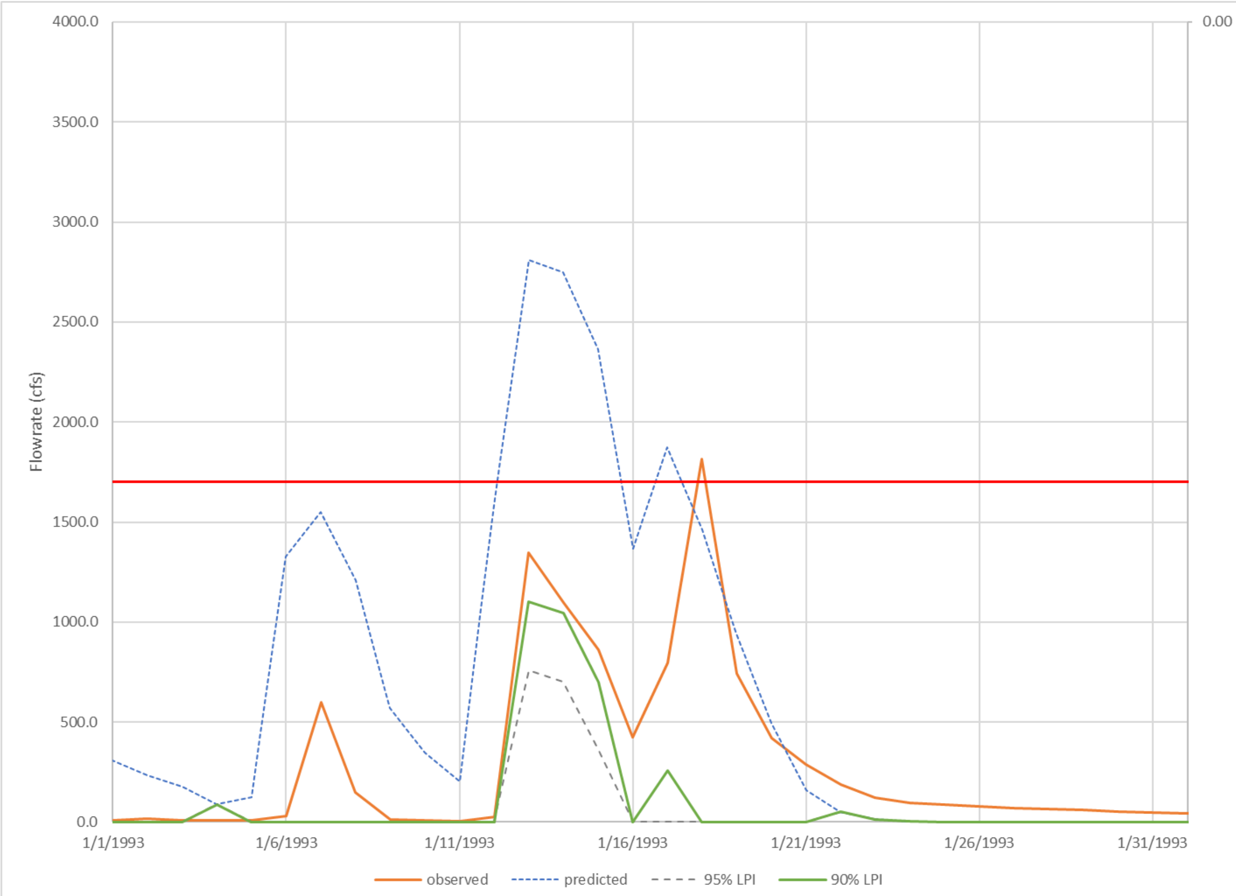
Appendix B - Plots Comparing Predicted and Observed Flows for False Positive Events

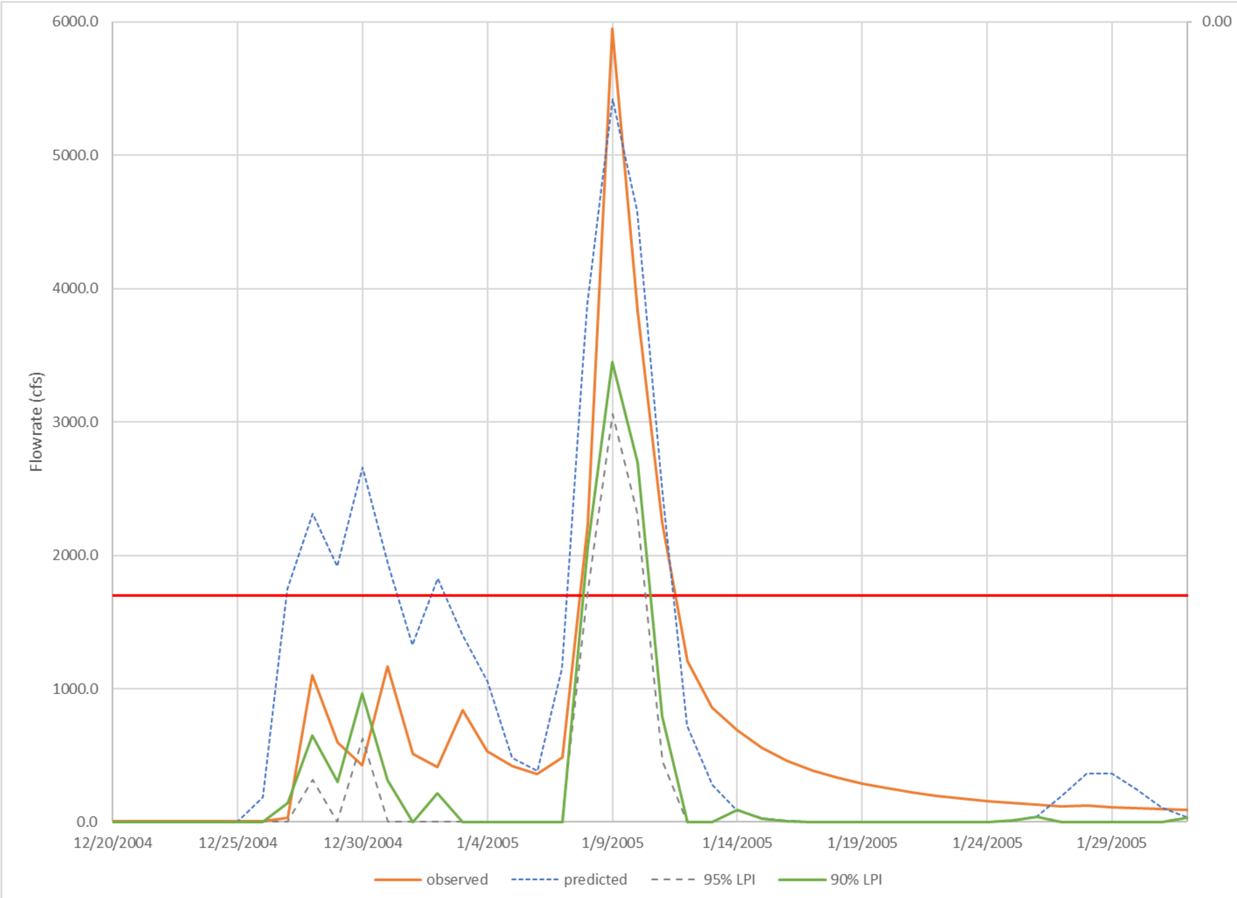


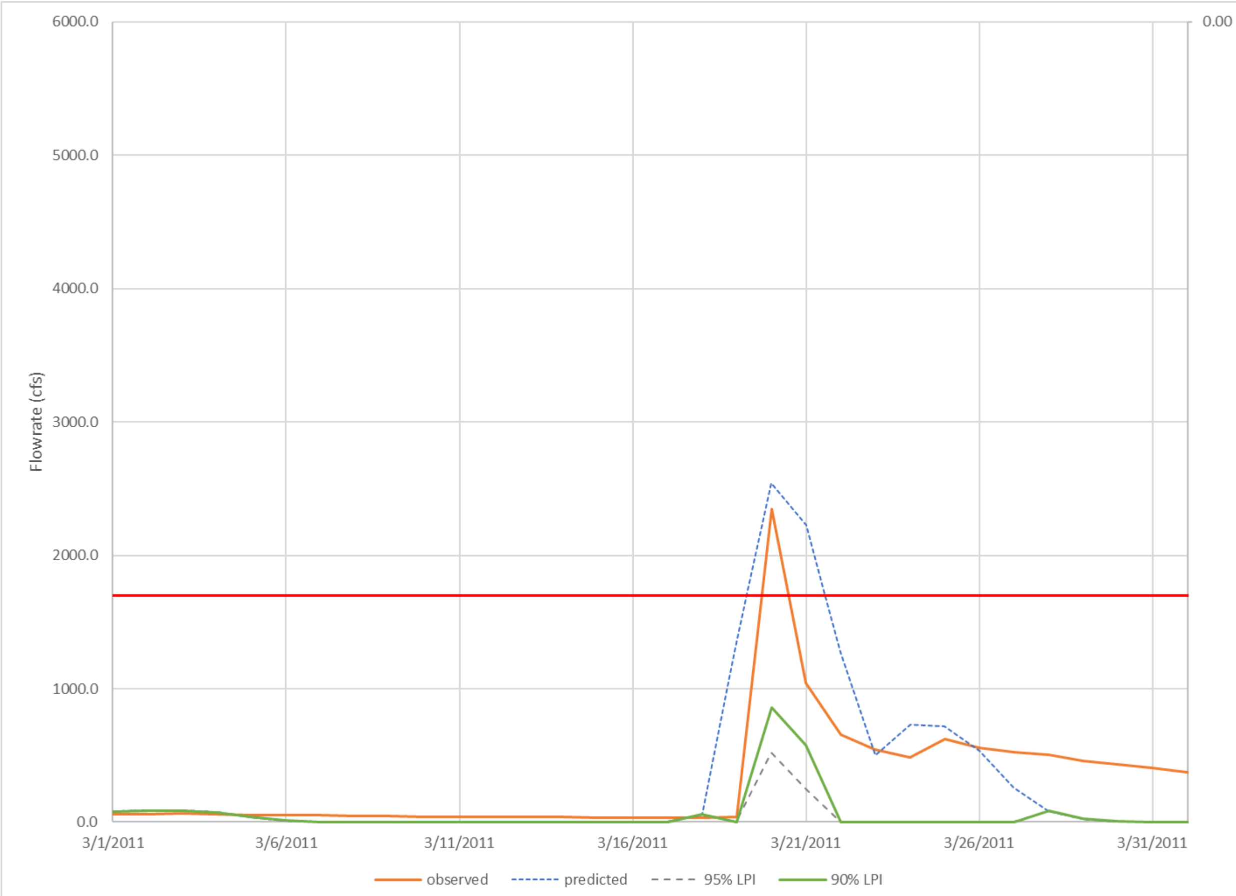

3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
0.00
Flowrate (cfs)
12/1/1977
12/11/1977
12/21/1977
12/31/1977
1/10/1978
1/20/1978
1/30/1978
observed
predicted
95% LPI
90% LPI

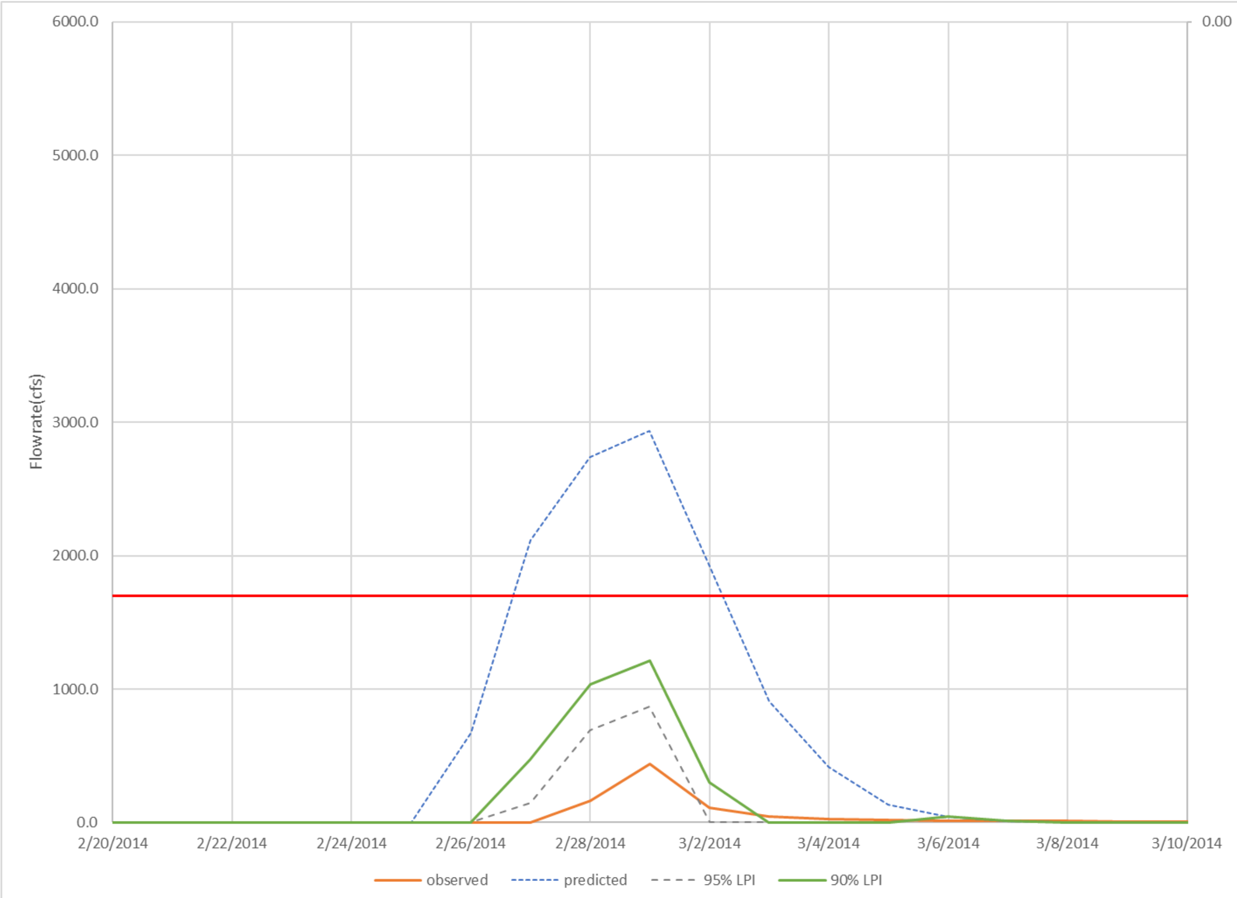

8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Flowrate (cfs)
0.00
1/1/1978
1/11/1978
1/21/1978
1/31/1978
2/10/1978
2/20/1978
observed
predicted
95% LPI
90% LPI

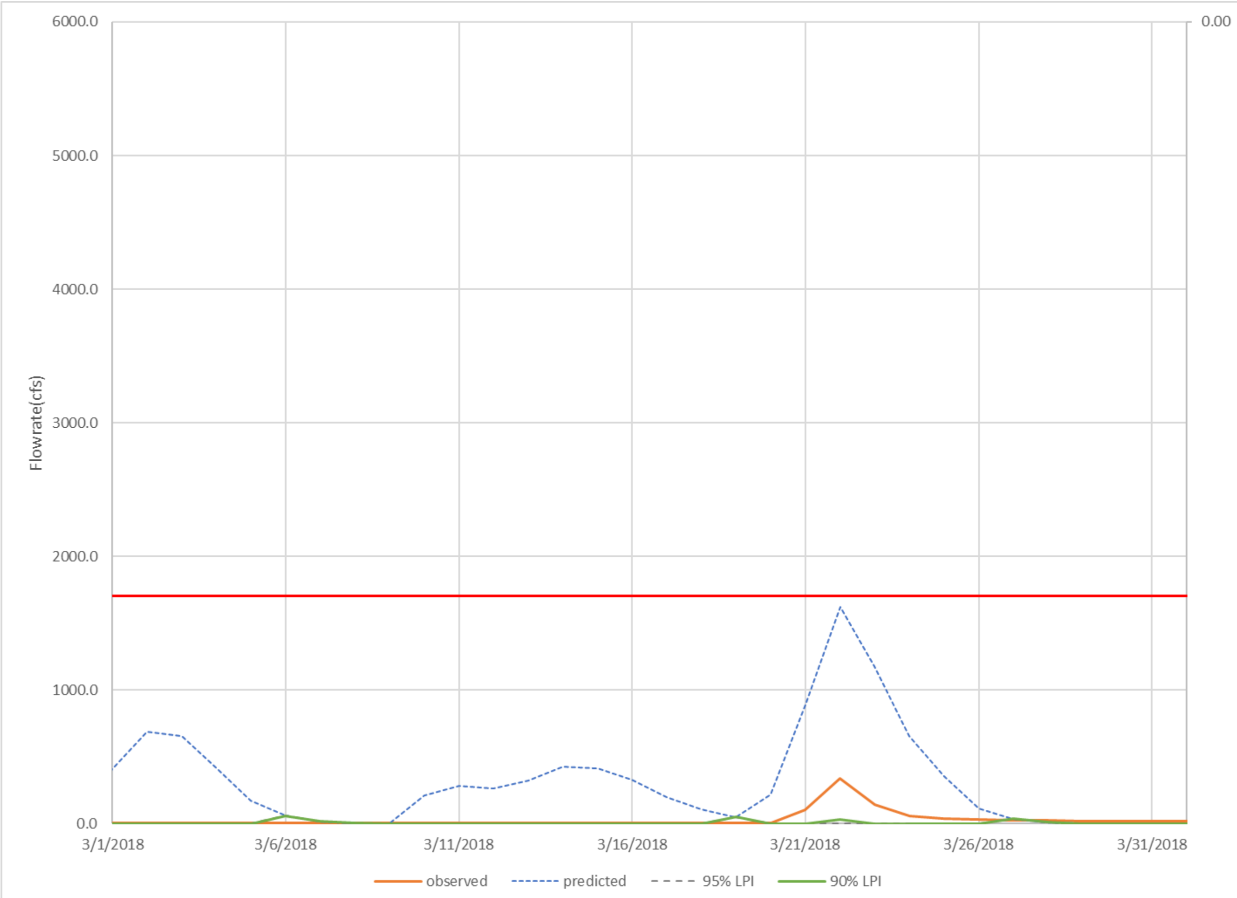

4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
Flowrate (cfs)
0.00
2/20/1991
2/25/1991
3/2/1991
3/7/1991
3/12/1991
3/17/1991
3/22/1991
3/27/1991
4/1/1991
observed
predicted
95% LPI
90% LPI

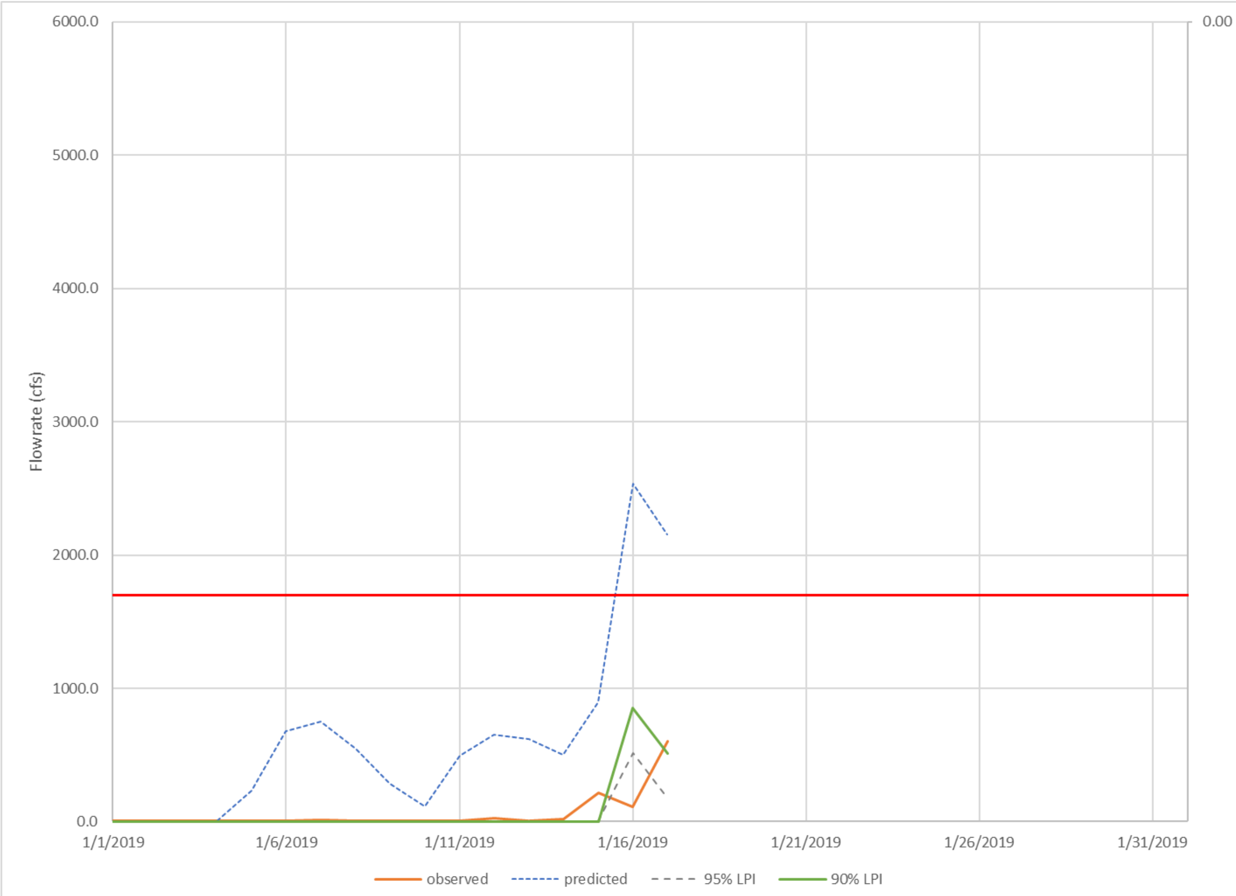

4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
Flowrate (cfs)
0.00
1/1/1993
1/6/1993
1/11/1993
1/16/1993
1/21/1993
1/26/1993
1/31/1993
observed
predicted
95% LPI
90% LPI


6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
0.00
Flowrate (cfs)
12/20/2004
12/25/2004
12/30/2004
1/4/2005
1/9/2005
1/14/2005
1/19/2005
1/24/2005
1/29/2005
observed
predicted
95% LPI
90% LPI

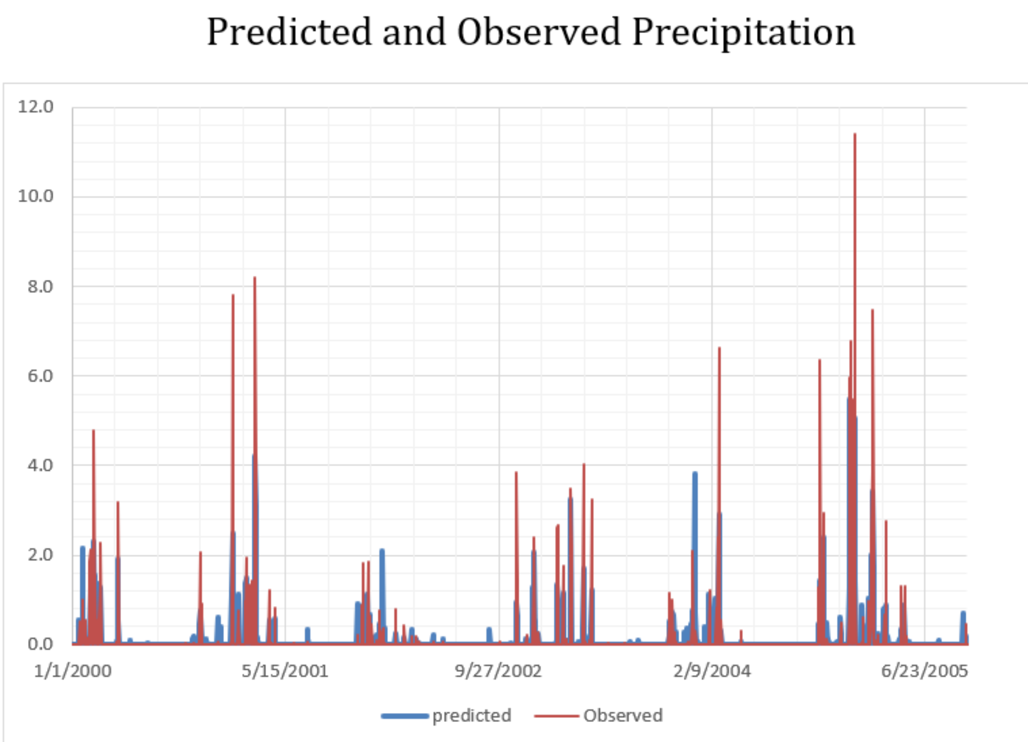

6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
0.00
Flowrate (cfs)
3/1/2011
3/6/2011
3/11/2011
3/16/2011
3/21/2011
3/26/2011
3/31/2011
observed
predicted
95% LPI
90% LPI

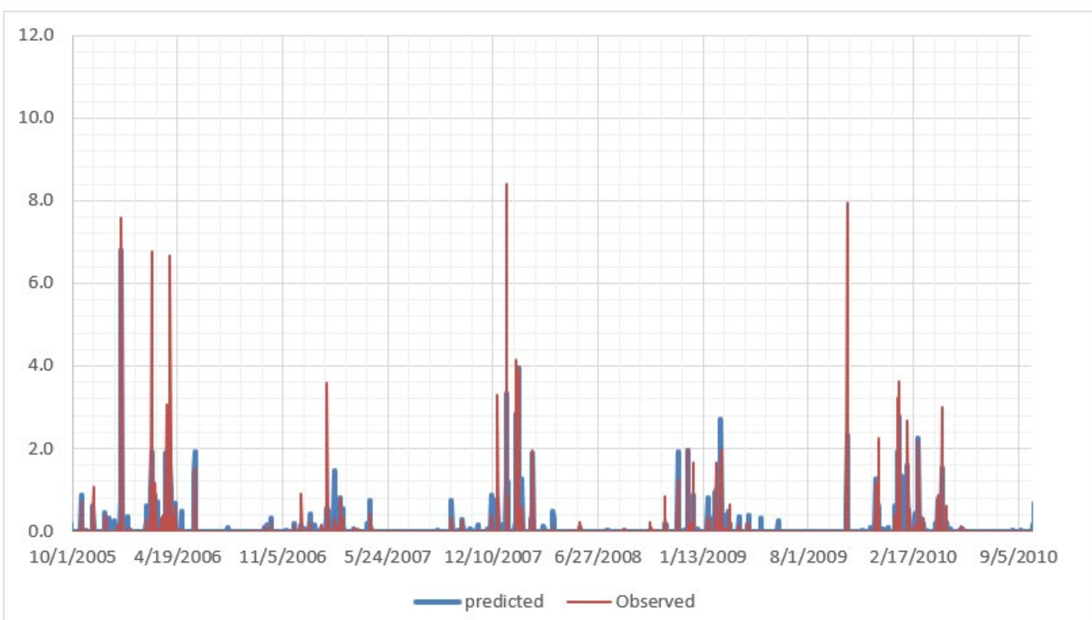

6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
0.00
Flowrate(cfs)
2/20/2014
2/22/2014
2/24/2014
2/26/2014
2/28/2014
3/2/2014
3/4/2014
3/6/2014
3/8/2014
3/10/2014
observed
predicted
95% LPI
90% LPI

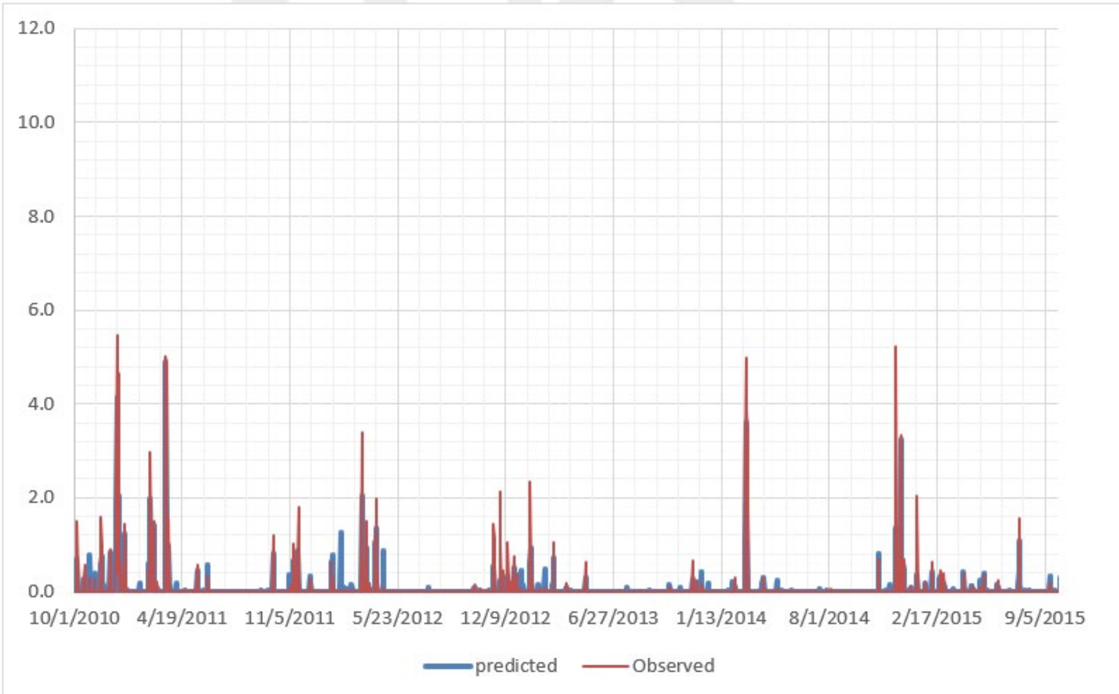

6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
0.00
Flowrate(cfs)
3/1/2018
3/6/2018
3/11/2018
3/16/2018
3/21/2018
3/26/2018
3/31/2018
observed
predicted
95% LPI
90% LPI

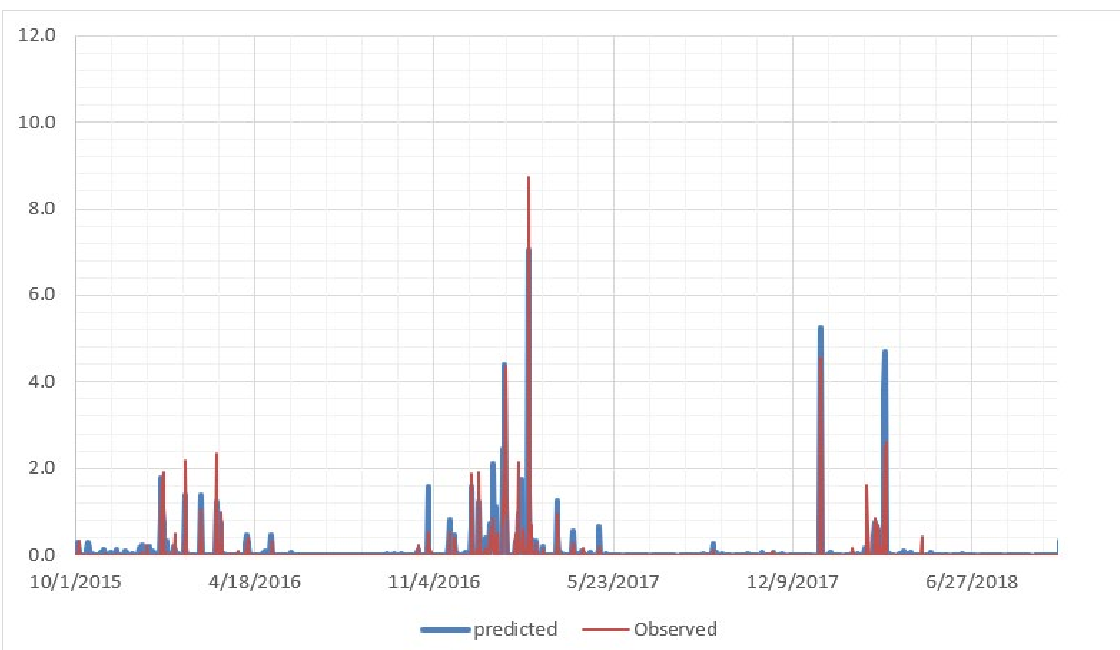

6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
0.00
Flowrate (cfs)
1/1/2019
1/6/2019
1/11/2019
1/16/2019
1/21/2019
1/26/2019
1/31/2019
observed
predicted
95% LPI
90% LPI

Appendix C - Predicted and Observed Precipitation






12.0
10.0
8.0
6.0
4.0
2.0
0.0
10/1/2010
4/19/2011
11/5/2011
5/23/2012
12/9/2012
6/27/2013
1/13/2014
8/1/2014
2/17/2015
9/5/2015
predicted
Observed


12.0
10.0
8.0
6.0
4.0
2.0
0.0
10/1/2015
4/18/2016
11/4/2016
5/23/2017
12/9/2017
6/27/2018
predicted
Observed