Interagency Flood Risk Management (InFRM)

Watershed Hydrology Assessment for the Little River Basin

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INTERAGENCY FLOOD RISK MANAGEMENT

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The InFRM Team

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

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

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

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

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

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

EXECUTIVE SUMMARY

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

This study was funded by the Federal Emergency Management Agency (FEMA) RegionVI in November 2019. The statistical analysis of regulated flow frequencies was developed by the Hydrology and Hydraulics Branch, U.S. Army Corps of Engineers (USACE) Tulsa District.

This report summarizes new analyses that were completed as part of a study to estimate the 1% annual chance (100-yr) flow, along with other frequency flows, for various stream reaches in the Little River Basin. This study was conducted for FEMA Region VI by an Interagency Flood Risk Management (InFRM) team. The InFRM team is a federal partnership and includes subject matter experts (SME) from FEMA, the U.S. Army Corps of Engineers (USACE), the U.S. Geological Survey (USGS), and the National Weather Service (NWS)

This report is the product of a significant investment towards increasing resiliency against flood hazards given the extent: of existing information that was utilized, of updated and extensive analysis performed, and of interagency collaboration. The InFRM team used several different methods, including statistical hydrology, rainfall-runoff modeling, and reservoir period-of-record simulations, to calculate the 1% annual chance (100-yr) flow and then compared those results to one another. The purpose of the study is to produce 100-yr flow values that are consistent and defendable across the basin. The InFRM team used up-to-date statistical analysis along with state-of-the-art rainfall-runoff watershed modeling and reservoir modeling to estimate the 1% annual chance (100-yr) flow values throughout the Little River Basin. Statistical modeling involved use of Tulsa District's RiverWare (RW) period of record modeling of the Red River Basin. The period of record encompasses the years from 1939-2017. Simulated data from RiverWare is checked against observed data to ensure the model ran correctly. The simulated data was then input into USACE Hydrologic Engineering Center's Statistical Software Package (HEC-SSP) where Bulletin 17C tools were used to determine the 1% annual chance flow along, with other frequency flows. For points of high regulation Bulletin 17C cannot be used and graphical analysis was used instead. Regulated and unregulated flow datasets were created for the entire Little River Basin.

Rainfall-runoff watershed modeling was utilized as well to compare against the RiverWare results. The Riverware model is not as detailed with fewer points of control broken out. This study wanted to provide more points of analysis, so USACE HEC Hydrologic Modeling System (HEC-HMS) was used to compare where points did overlap and to provide the added points where RiverWare was not available.

1 Study Background and Purpose

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

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

The NFIP program is administered by the FEMA within the Department of Homeland Security. The NFIP is charged with determination of the 1% annual chance flood risk and with mapping that flood risk on the Flood Insurance Rate Maps (FIRMs). FEMA Region VI has an inventory of hundreds of thousands of river miles that are in need of flood risk mapping updates or validation. FEMA has historically maintained the FIRMs at a community and county level, but recently shifted (2010) to analyzing flood analysis at a watershed level. This transition to watershed based analysis requires a broader flood risk assessment than has historically been undertaken.

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

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

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

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

1.1 STUDY TEAM MEMBERS

The following table lists the primary InFRM team members who participated in the development of the Little River Basin Watershed Hydrology Assessment. In addition to those listed, the InFRM team would also like to acknowledge the many others who served supervisory and support roles during this study.

Maranda Blankenship, P.E

SarahHarris, P.H

David J. Williams, Ph.D., P.E., D.WRE

Matthew Wunsch

Jordan McQueen

1.2 TECHNICAL REVIEW PROCESS

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

2 Little River Basin

2.1 WATERSHED AND RIVER SYSTEM DESCRIPTION

The Little River watershed spans southeastern Oklahoma and southwestern Arkansas and is a tributary of the Red River which confluences near Fulton, Arkansas. Tulsa District Corps has operational responsibility for two reservoirs in the upper watershed and Little Rock District has responsibility for four reservoirs in the lower watershed. The district boundary is the Oklahoma-Arkansas state line. On the Little River main stem there is a regulation point of interest near the Horatio stream gage that predominately governs project releases. The Little River watershed encompasses Le Flore, Pushmataha, Choctaw and McCurtain counties in Oklahoma and Sevier and Polk County in Arkansas where it joins the Red River near Fulton, Arkansas. For this study only the portion of the basin that Tulsa District controls was studied. This includes the main stem of the Little River as well as the tributaries of Glover Creek, Mountain Fork and Rolling Fork. The studied basin is approximately 4,300 square miles. Corps operated projects include Pine Creek and Broken Bow. The flood control project at DeQueen is operated by the Little Rock District and has minimal flows at Horatio compared to releases from Pine Creek and Broken Bow as well as local contributions from uncontrolled runoff.

The headwaters of the Little River are in excess of 1,500 feet and decrease to about elevation 235 feet near the mouth of Little River at Fulton. The lower reaches of the Little River and its tributaries have considerable overflow area. The channel slope varies from about 9 feet per mile in the upper reaches to about 1 foot per mile in the lower reach. The valley side slopes are very steep, with some of the lower valley in cultivation or pasture land. Wooded areas are prevalent along the channel and in the river bottom in the lower reaches of the stream. The elevation of the headwaters for Mountain Fork is in excess of 1,700 feet. From this point the land descends to about and elevation of 290 feet at the confluence with the Little River. There is considerable overflow area near the mouth of the Mountain Fork River. The channel slope varies from about 12 feet per mile in the upper reaches to about 4 feet per mile in the lower reach. Figure 2.1 shows a basin map of the Little River with the HEC-HMS subbasin breakouts and shaded with the DEM.

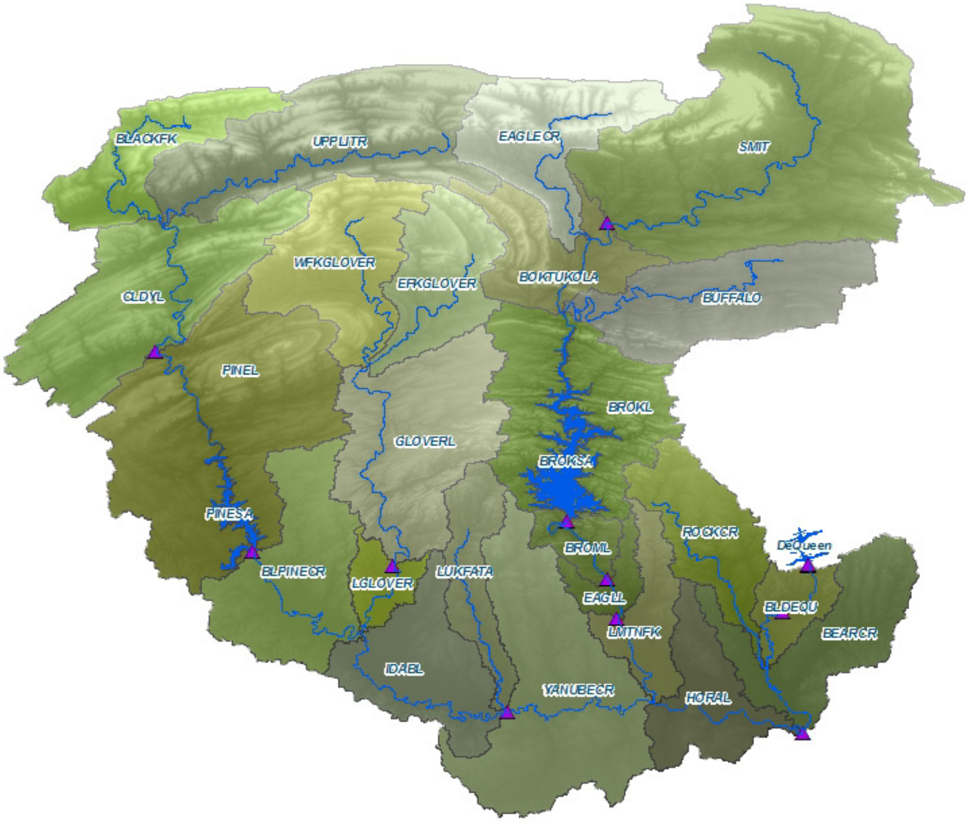

Figure 2.1: Little River basin map with HEC-HMS subbasins, and DEM.

2.2 PREVIOUS MODLEING

The hydrology of the Little River and its tributaries has been analyzed many times over the years. Data and models from several existing hydrologic and hydraulic studies were available at the time of this study. Table 2.1 below summarizes the most notable existing studies, models, and hydrologic information that were previously performed in the Little River basin.

Table 2.1: Previous Hydrologic Studies in the Little River Basin

Study Name	River Extents	Frequency Flows	Hydrologic Methods	Description
Red River Period of Record	Red River from Denison Dam to Shreveport, LA	No	RiverWare Flood Control	Base model used for developing data for statistical studies.
CWMS Little River Watershed	Little River headwaters to Horatio, AR	No	HEC-HMS	Operational forecasting model with updated loss parameters

2.3 CURRENTLY EFFECTIVE FEMA FLOWS

No current FEMA studies have been developed in the Little River Basin.

3 Methodology

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

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

The multi-layered analysis for the current study of the basin consists of three main components: (1) extended period-of-record modeling in RiverWare, (2) rainfall-runoff watershed modeling in the Hydraulic Engineering Center's Hydrologic Modeling System (HEC-HMS), and (3) statistical analysis of the stream gages using the USGS StreamStats tools for gages not included in RiverWare models. After completing all of these different types of analyses, their results were then compared to each other and to the existing published frequency flows within the basin. Frequency flow recommendations were then made after consideration of all the known hydrologic information.

The Little River and Mountain Fork River are regulated by U.S. Army Corps of Engineers (USACE) flood-control dams in Oklahoma and Arkansas. In many cases, the effects of regulation are significant enough that the distribution of observed annual maximum flows no longer maintain a curve shape similar to unregulated or "natural" conditions. Analytical methods are therefore not usually appropriate for highly regulated streams. Bulletin 17B explicitly excluded watersheds that were "…appreciably altered byreservoir regulation" (ICWD, 1982). Bulletin 17C, which is a major revision to Bulletin 17B, states that other methods such as "…simulated floods, graphical frequency analyses, and total probability concepts must be used for regulated streams" (Kubik, 1990; Sanders et al., 1990; USACE, 1993; as cited in England, et al., 2018). All three ofthese methods were used in the development of this report.

This study was based on simulated period-of-record stream flow from a comprehensive RiverWare model that was developed and is maintained by the USACE Tulsa District. RiverWare is a robust river and reservoir period-of-record modeling tool developed by theCenter for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado with sponsorship from the Tennessee Valley Authority, the Bureau of Reclamation and USACE. It is a general river basin modeling environment for operations and planning that allows a high degree of flexibility for users to model any river basin, manage data input and output efficiently enough for near real- time operations, and provide a selection of solution algorithms (CADSWES, 2020). It provides a modeling environment to meet all the modeling needs of managers and operators of river and reservoir systems.

Peak flow transform had limited application in this study. The premise behind peak flow transform is that unregulated flows can be converted to regulated flows while maintainingthe probabilistic distribution of the unregulated data set by using linear regression (Ergish, 2010). A previous study by the USACE Tulsa District used peak flow transform for a study of frequency flows along the Red River at Shreveport, Louisiana, and found that the method worked well. In the Shreveport study, the magnitude of the 1% AEP flow that was calculated using the peak flow transform method differed from a graphical frequencyanalysis by less than 5%. In this study, however, the peak flow transform method generally performed poorly. This was attributed to the significant amount of downstreamregulation along many of the streams that were analyzed. Therefore, peak flow transformwas only used for sites along Bird Creek, where the effects of regulation were not as pronounced.

The Lower Red River model, which consists of reservoirs, control points, confluence objects, routing reaches, and data objects, extends from headwater reservoirs on the Red River and its tributaries in Oklahoma, Arkansas, and

Louisiana downstream to Shreveport, Louisiana. The model includes reservoirs along the Red River and major tributariesincluding the Little River, Glover River, Mountain Fork River, Kiamichi River, Muddy Boggy River, Sulphur River, and Big Cypress Bayou. It is a daily time-step model with a period of record beginning in 1938 that has been updated through 2017.

The model can be used to simulate regulated and unregulated conditions. The regulated simulation assumes that all reservoirs are in place for the entire specified period of record,with current operational criteria used for the entire period. Period-of-record headwater flows and intervening area flows are developed based on historic data, through preprocessing techniques, before any rule-based simulation is done. Preprocessing to generate intervening area flows includes running a local RiverWare model that uses observed headwater flows and observed releases from reservoirs, which are then routeddownstream and subtracted from observed flow data at downstream gage sites. The local flows are incorporated into the rules-based simulation model. The unregulated simulation assumes that all reservoirs are in place for the entire specified period of record,with current operational criteria used for the entire period.

The Lower Red River model contains physical and operational input data including spillway and outlet works rating curves, established pool limits, and regulation criteria to model system operational constraints; hydropower, water supply, and water quality criteria are also incorporated as applicable. When the model is run, preprocessed hydrologic data is routed through the river system beginning at the headwater reservoirs, based on the input data and operational rules. Subsequent releases, which assume perfect knowledge, are determined based on current and future forecast downstream conditions. Simulated releases are routed downstream and combined with intervening area flows until all hydrologic flows for the period of record are routed through the model extent. Mandatory releases, which initially use rule functions, are required to maintain structural integrity at each reservoir. These releases are made from each reservoir and routed to downstream control points. By rule directives, each downstream control point is evaluated forregulation criteria or limitations; the control points are used to determine how much channel space is projected to be filled based on incoming intervening area flow as well as known upstream mandatory releases. This sets the reach storage parameters for actual simulated releases for flood control and conservation purposes. Initial flood-control releases from the reservoirs are then simulated. The goal of the rules-based simulation is to maximize use of system channel storage space and minimize flooding so that flood-control releases are given priority. The simulated flood-control releases are then routed downstream. Next, conservation pool releases (such as low-flow or environmental releases) and diversions for water supply are simulated for each reservoir. Finally, for hydropower projects, daily load requirements are analyzed, and any additional releases required to meet the load are made. The required mandatory releases (flood-control andlow-flow) are made through hydropower when possible. Water supply diversions are taken directly from the reservoirs and typically not returned to the model. Depending on hydropower requirements, system excess or dump energy as well as thermal purchase energy required to meet system loads are simulated. In addition to the previously described requirements, through several iterations of the rule-based simulation, the Lower Red River model attempts to achieve a target uniform balance between competing reservoirs during the evacuation of system flood storage.

All of the regulated stream flow locations that were included in this study were also analyzed in conjunction with their corresponding unregulated period-of-record annual maximum flow datasets. This part of the analysis used an analytical curve that was developed in accordance with the methodology described in Bulletin 17C (England et al.,2019). A significant benefit of also looking at unregulated flow probabilities is the ability to show the impacts that flood-control dams provide to downstream reaches. This effectis most pronounced immediately below a dam.

Stochastic methods were used to define the upper ends of the probabilistic curves at most locations. This was achieved by incorporating the relationship between the stage of a reservoir and its corresponding outflow. In the case of dams with uncontrolled spillways,this was a straightforward approach where the outflow was computed for any given stagein conjunction with the geometry of the spillway itself by using the weir equation:

$$Q = CLH^{3/2}$$

In this equation, outflow (Q) is a function of the length of the spillway crest (L), the height of the reservoir pool above the spillway crest (H), and a coefficient based on the geometric characteristics of the spillway crest (C).

Dams with controlled spillways, which are most typically tainter gates at USACE Tulsa District projects, have more complex operational rules. With this type of spillway, a relationship between inflow, outflow, and reservoir stage has been defined based on theauthorized operation of the project. If the probability of a reservoir stage is known alongwith the inflow into the reservoir with the same probability, then the corresponding probabilistic outflow from the reservoir can be estimated.

Once the probabilities of reservoir stages had been estimated, those corresponding to the 1%, 0.5%, and 0.2% AEP were then identified on the spillway rating curve* for each respective project (*referred to as the "spillway gate regulation schedule inflow parameter"curve for controlled spillways). For uncontrolled spillways, the intersection of the probabilistic stage and the spillway rating curve corresponded to the outflow with the same AEP based on the weir equation. This method also required knowledge of the probabilistic inflow if a controlled spillway is being analyzed. In this case, the probabilisticinflow coupled with the reservoir stage with the same probability were identified on the spillway gate regulation schedule inflow parameter curve. The corresponding outflow with the same AEP was then estimated. The spillway rating curve was accessed from the water control manual for each respective reservoir project.

The statistical analysis was performed using HEC-SSP. This is a statistical software tool developed by the USACE Hydrologic Engineering Center (HEC) that can perform flood analyses using Bulletin 17C procedures and graphical techniques (USACE, 2019). Unregulated period-of-record annual maximum stream flow was analyzed using Bulletin 17C methodology. Since most of the regulated period-of-record annual maximum stream flow data sets were so heavily influenced by upstream dams that the application of Bulletin 17C was inappropriate, graphical frequency analysis was used. HEC-SSP incorporates order statistics, which allows for an estimation of the 5% and 95% confidence intervals. The order statistic approach was limited to calculating uncertainty in the estimated frequency curve for the range of observed data (which was an 81-year equivalent length of record for the RiverWare simulated data sets) (USACE, 1997). Asymptotic approximation was used to extrapolate the estimates beyond the equivalent length of record. The order statistic and asymptotic estimates were matched at the limits of the simulated data.

Since the RiverWare model uses a daily time step, the same duration was also used for this analysis. Comparison between average daily flows and instantaneous peak flows was made at a few downstream locations along the Little River and its tributaries. Given the duration of releases from flood-control dams during major floods, very little difference was observed between the two (typically less than 5%). Therefore, no peaking factor was applied.

Further Analysis was done using the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) to supplement findings from RiverWare as well as add frequency analysis calculations at points not included in the Lower Red River RiverWare model. The calibrated HEC-HMS model for the Little River that was developed in 2015 from the Tulsa District's operational Corps Water Management System (CWMS) was used as a starting point (USACE, 2015). The CWMS model has been used in real-time forecasting and updated as needed. Additional calibrations were run to get an updated default set of loss rates. The current HEC-HMS model along with 24-hour duration Atlas 14 frequency rainfall, and Soil Conservation Service (SCS) Type-II rainfall distribution were used to create peak frequency flows in the Little River watershed. To better estimate operations at the controlled reservoirs in the Little River watershed initial modeled runoff was shown to the current Water Manager to create release plans at each frequency that would best mimic real-time operations. Both reservoirs were set to top of conservation pool at the start of each simulation run and both reservoirs were set to zero releases. Pine Creek was allowed to hold all inflows as long as there was downstream flooding, and the pool was below 482.8'. Releases were the based on the water control manual and to keep the pool below 485'. Releases at Broken Bow were kept at zero until the pool reached 627.5' and used releases up to full hydropower until gated releases were required to keep the pool 632.5'. Each reservoir used the same release plan across model variations for a given frequency event. All releases from the reservoir that is not controlled by USACE Tulsa District were set to zero to remove effects of other operations at the downstream control point. Further analysis was done to judge the sensitivity to runoff creation based on basin loss-rates, intensity of rain, and timing of rainfall on the basin. Uniform rain depths and rain distributions were used in each HEC-HMS scenario across the basin. To simplify the model a central point in the watershed was selected to gather rainfall data for Atlas 14 and applied uniformly across the basin. Sensitivity in rainfall depths were based on the upper and lower confidence intervals of Atlas 14. The hourly 24-hour storm SCS Type II distribution was used to apply the rainfall. Sensitivity runs were created based on shifting the time to peak of the standard distribution +/- 6 hours. The initial and constant loss rates from HEC-HMS were used along with a range from zero losses to 5 times the calibrated losses to show sensitivity in peak flows. The HEC-HMS results were compared to RiverWare where points between the two methods overlapped. For unregulated points not in the RiverWare model comparisons were made with the USGS StreamStats tool based on gage locations. HEC-HMS modeling parameters were as follows.

- Losses – Initial and Constant
- Transform – Snyder Unit Hydrograph (Tulsa) and Unit Hydrographs for lake surface areas
- Baseflow – Recession
- Routing – Lag, Modified Plus, and Muskingum
- Computation Interval – 60 minutes

A total of 10 points were analyzed. Eight gaged sites and two ungagged confluence points. Figure 3.1 shows where these points lie in the Little River Basin. The gage site at BROM was not analyzed as it is highly regulated from the Broken Bow releases as well as the reregulation dam at that site. Eagletown was analyzed, but due to the regulation above its statistical analysis was done via graphical analysis tools in HEC-SSP. Dequeen Lake was not included in this analysis as Tulsa District does not operate that project. Dequeen has limited channel capacity and releases were set to zero for this study. The downstream gage at DEQR was also not analyzed. The confluence of the Glover River with the Little River and the confluence of the Mountain Fork and Little River were studied.

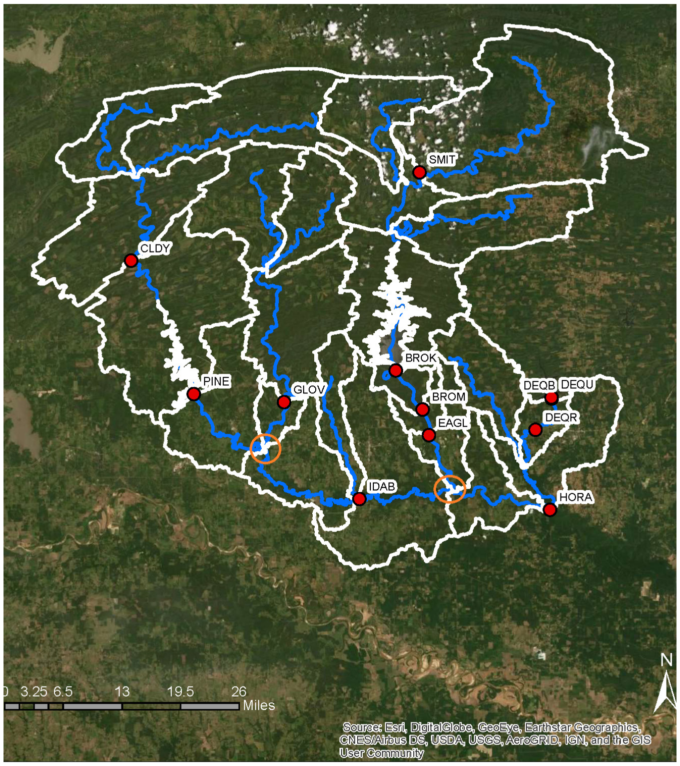

Figure 3.1: Little River Basin with HEC-HMS subbasin outlines. Gage sites in red and ungagged confluences in orange.

3.1 RIVERWARE AND HEC-SSP

RiverWare is developed at the University of Colorado as part of the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) group. This application uses observed and simulated data to compute flows across a watershed following the flood control rules that were developed as part of the Tulsa Districts previous SUPER program. The simulated period of record is run using the flood control rules as well as running a separate simulation to generate unregulated flows. These two data sets were then exported into HEC-SSP for statistical analysis. All points of interest were analyzed using Bulletin 17C. For points below reservoirs the regulated and unregulated data sets were used to corelate the unregulated 17C results back into regulated frequency flows. Reservoir outflows were calculated based on methods described in Section 1.2. One gage site at Eagletown was analyzed using graphical methods as the gage is very close to two regulating structures.

3.2 HEC-HMS

HEC-HMS was used to provide another comparison to fill out points of interest that weren't available in the RiverWare model. HMS used a combination of calibrated basin characteristics from the Tulsa District's real-time model along with frequency rainfall depths provided by NOAA Atlas-14. HEC-HMS calibrations were run for the following events: Dec 14-23, 2001, Apr 7-11, 2002, Mar 18-22 2008, and Jan 24-29 2012. Figures 3.2 through 3.5 show HEC-HMS results at Horatio from the four calibration events. The calibration parameters were then averaged and used in all HEC-HMS modeling, see Tables 6.1 and 6.2 for final HEC-HMS parameters. Using these precipitation events along with various rainfall distributions and loss rate scenarios a series of frequency flows were developed. Results from all of these methods are discussed in Sections 5, 6, and 7.

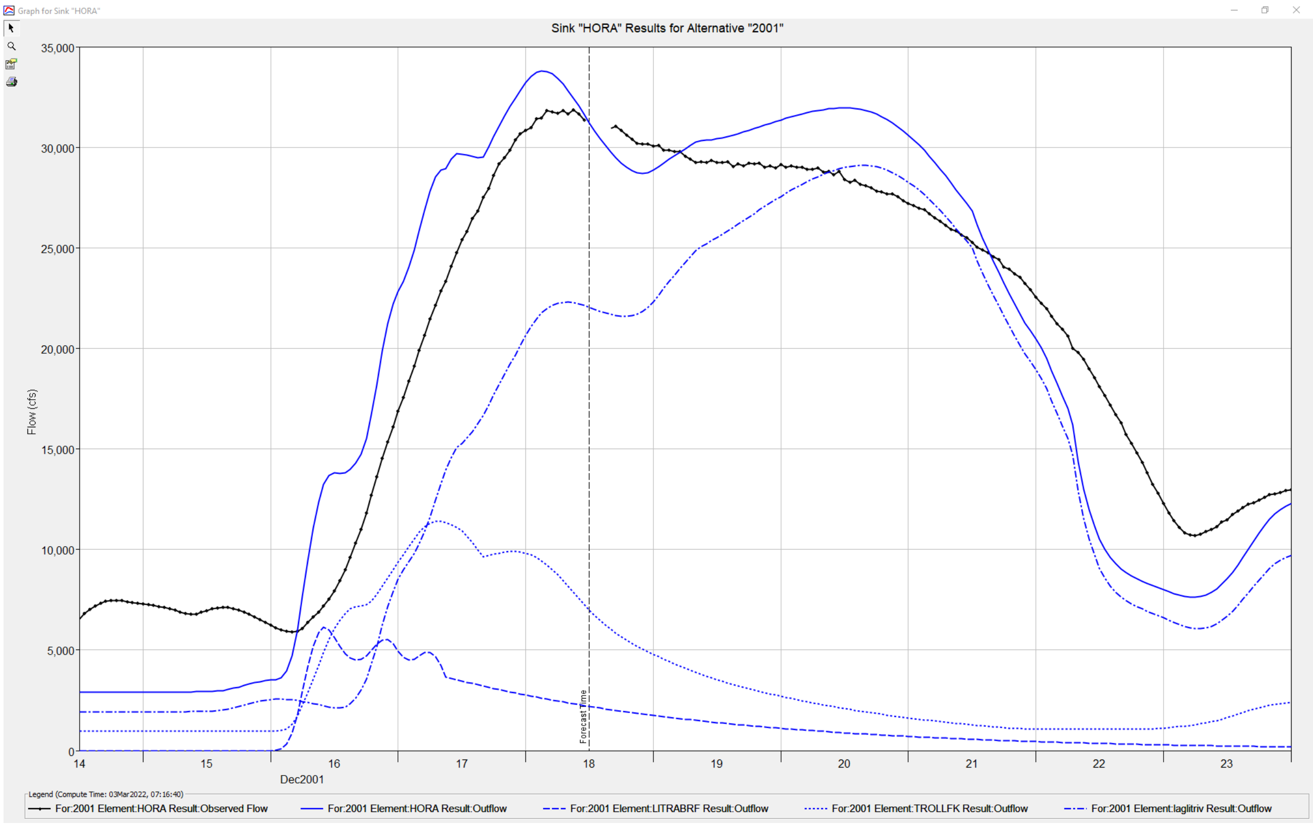

Figure 3.2: HEC-HMS results from the Dec 2001 calibration.

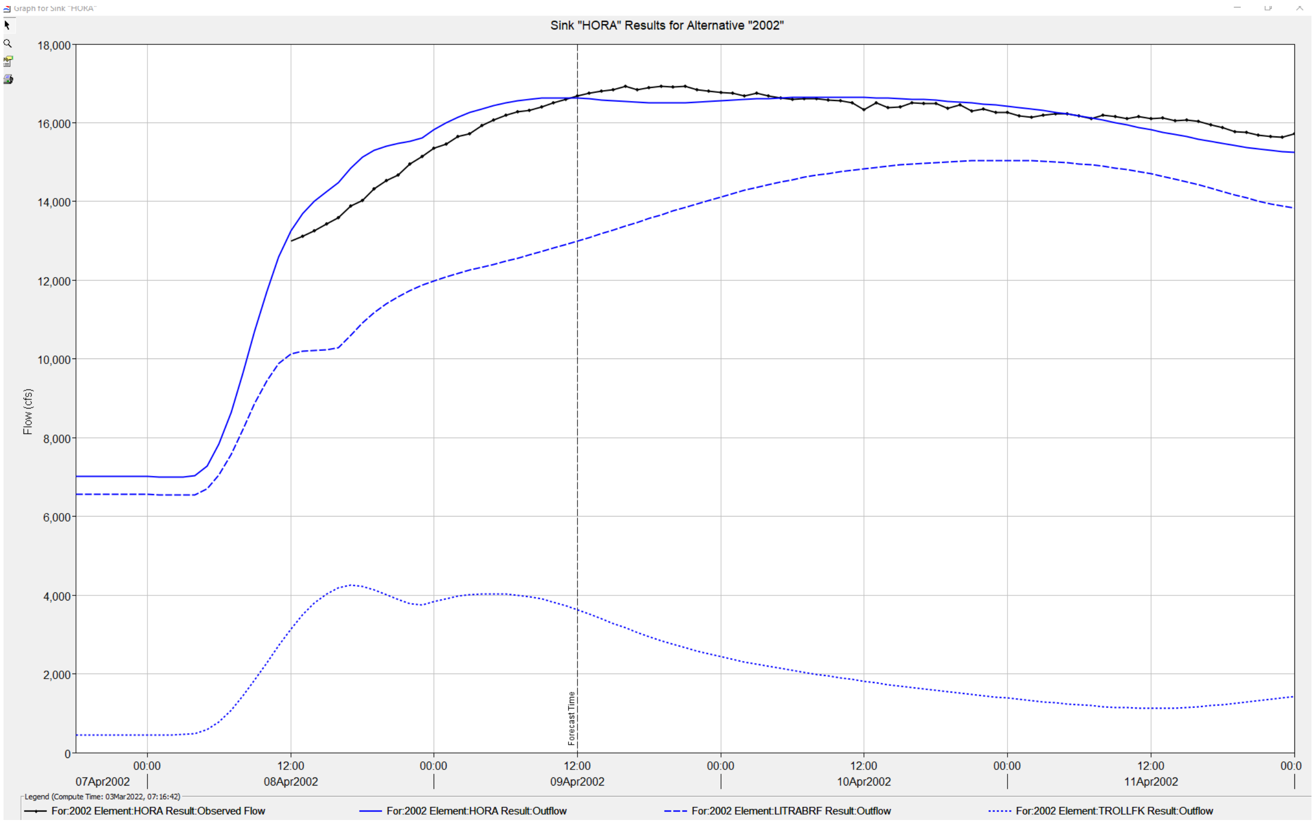

Figure 3.3: HEC-HMS results from the Apr 2002 calibration.

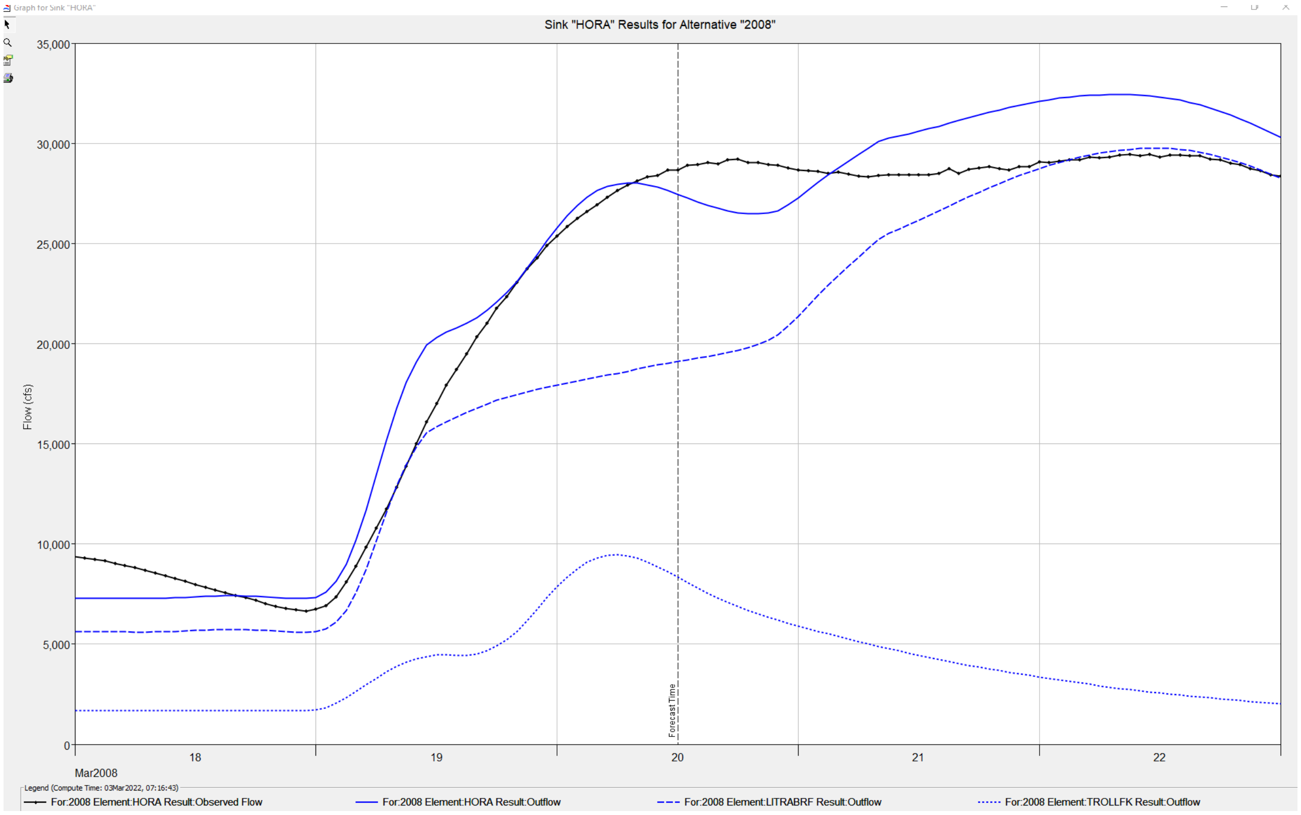

Figure 3.4: HEC-HMS results from the Mar 2008 calibration.

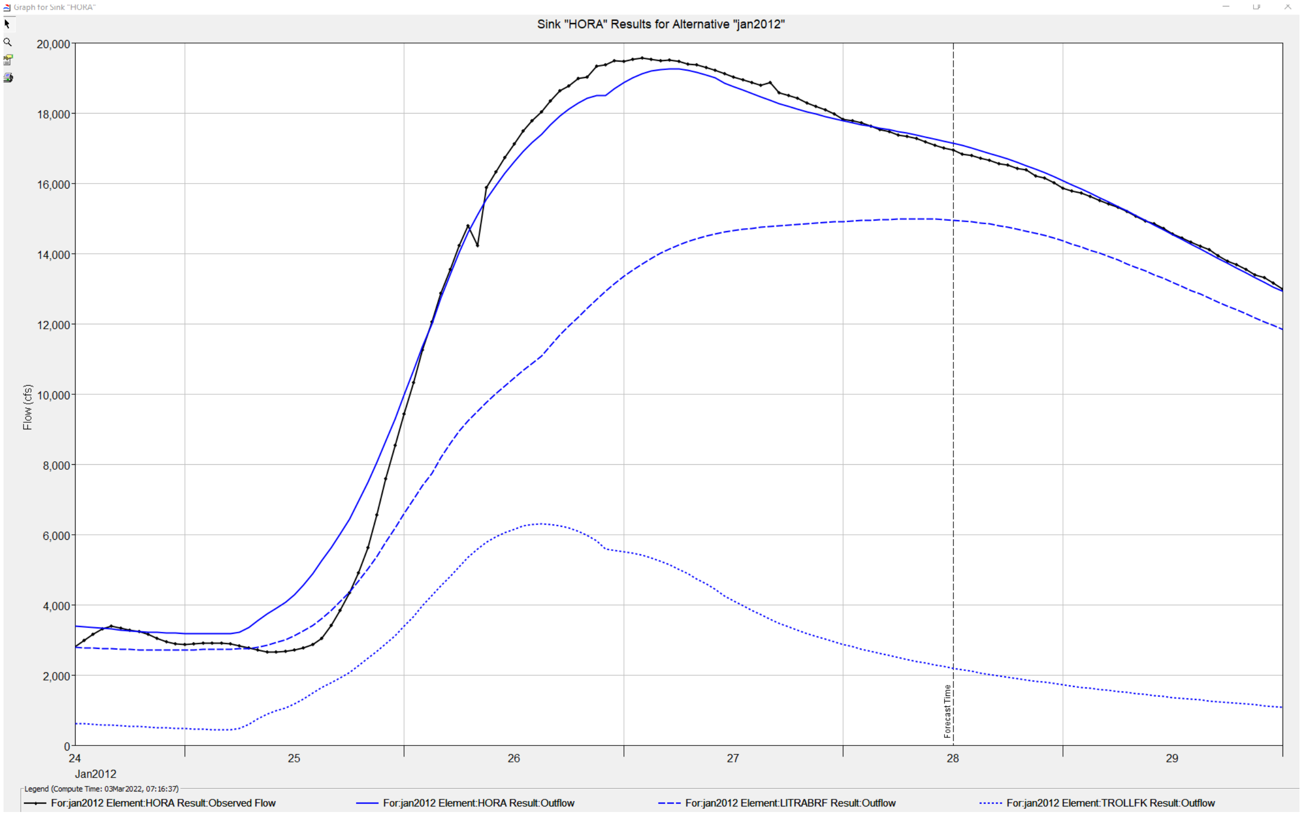

Figure 3.4: HEC-HMS results from the Jan 2012 calibration.

3.3 USGS STREAM STATS

The USGS web tool uses physical land and precipitation data to solve regional regression equations to compute frequency flows as shown in Section 7.1. The web tool will only work for areas that are unregulated, and as a result only two gaged locations above the reservoirs were able to be used. These results were compared against results from HEC-HMS, as neither gage site is included in the RiverWare period of record model.

4 Data Sources

This section summarizes the data that was collected, reviewed, or utilized in the InFRM Watershed Hydrology Assessment of the Little River Basin, including geospatial and climatic information, field observations and previous reports for the Little River Basin.

This chapter provides a general summary of the data that was collected, reviewed, or utilized in the InFRM Watershed Hydrology Assessment of the Little River Basin, including geospatial and climatic information, field observations and previous reports.

4.1 SPATIAL TOOLS AND REFERENCE

ArcGIS version 10.4.1 (developed by ESRI) was used to create the vector and raster datasets when developing the HEC-HMS model. The geographic projection parameters used for this study are listed below:

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

4.2 DIGITAL ELEVATION MODEL (DEM)

The Arkansas Basin mapping team member obtained a 10-meter DEM from the seamless USGS National Elevation Dataset (NED, accessed January 2013) for the study watershed from the http://nationalmap.gov/viewer.html website. NED is available in spatial resolutions of 1 arc-second (roughly 30 meters), 1/3 arc-second (roughly 10 meters), and 1/9 arc-second (roughly 3 meters). The data model is logically seamless but uses an internal tile structure initially selected as a 1- by 1-degree area. The NED dataset currently achieves complete national coverage by integrating the "best" available data. Even with the "best" available, there could be a wide range of source dates and some artifacts in the source data, such as Level 1 30 DEM's. The system filters production artifacts and performs any necessary datum conversions and coordinate transformations. The NED data is only as good as the original source data. Individual files are appended together into the larger tile structure specified for the database. Edge matching, a 6 pixel overlap to ensure no gaps or issues when users perform functions like re-projection to the data, and metadata generation are applied lastly in assembling each NED tile. NED Homepage is http://ned.usgs.gov

4.3 VECTOR AND RASTER GEOSPATIAL DATA

All geospatial data is from the CWMS modeling effort.

Raster Data includes the National Land Cover Database, Impervious Surfaces and the NRCS Soil Data.

The CWMS Mapping team member utilized web mapping services and downloaded the U.S. Dept. of Agriculture, Natural Resources Conservation Service

The Impervious Surface Area raster layer was extracted from the Multi-Resolution Land Characteristics Consortium (MLRC) website at: http://www.mrlc.gov/nlcd06_data.php website, accessed November 2013. The 30-m cell resolution NLCD 2006 impervious surface product was derived from circa 2006 Landsat imagery. Values range from 1 to 100% and represent the proportion of urban impervious surface estimated from each 10-m cell.

The National Land Cover Database (NLCD 2006) is a 16-class land cover classification applied across the conterminous United States at a spatial resolution of 30 meters. The data is based primarily on circa 2006 Landsat satellite data and quantifies land cover change between the years 2001 – 2006. The layer was downloaded from http://www.mrlc.gov/nlcd2006.php

Vector data includes USGS hydrologic polygonal unit boundaries; from these, the regional basins required for the project are extracted. The source link is: WBDHU8_November2012.gdb. ArcGIS version 10.1 (ESRI), with ArcHydro and HEC-GeoHMS version 10.1 were used to process and analyze the data necessary for hydrologic modeling and to generate the final sub-basin boundaries to be used for mapping and geospatial analysis.

The Federal Agency Gages point layer was downloaded from the Hydrometeorological Automated Data System (HADS) website at: http://www.nws.noaa.gov/oh/hads/

The CWMS Mapping team member downloaded the U.S. National Inventory of Dams (NID) using ProjectWise Explorer. The link is given here:

pw:\\nwk-ap-ed-pwint.nwk.ds.usace.army.mil:PWNWK00\Documents\Programsand Activities \MMC2\National Data Sets\CWMS National Datasets\ National_NLD_GDB

Vector Boundary Layers also include the Basin Study Area (SA) which was created by establishing a 10-mile buffer around the perimeter of the combined sub-basin boundaries. Several political boundaries, (States, Cities, Counties) and other vector datasets were downloaded from the Online ESRI Database: ArcGIS on services.arcgisonline.com and were originally extracted from the U.S. Census Bureau, TIGER Data files, 2010.

4.4 AERIAL IMAGES

The CWMS Team utilized current high resolution (1 meter) imagery. The files were received from the USDA, Aerial Photography Field Office website:
http://gis.apfo.usda.gov/arcgis/services/NAIP/Oklahoma_2013_1m_NC/ImageServer

4.5 SOIL DATA

Online link: http://websoilsurvey.nrcs.usda.gov

This data was developed by the National Cooperative Soil Survey and supersedes the STATSGO dataset published in 1994. The data set was

created by generalizing more detailed soil survey maps. Map unit composition was determined by transecting or sampling areas on the more detailed maps and expanding the data statistically to characterize the whole map unit. The map data were collected in 1-by 2-degree topographic quadrangle units and merged into a seamless national data set. Data were collected as part of the National Cooperative Soil Survey. These data are intended for geographic display and analysis at the state, regional, and national level. The data should be displayed and analyzed at scales appropriate for 1:250,000-scale data.

4.6 PRECIPITATION DATA

4.6.1 Radar Data for Observed Storms

Precipitation data were taken from gridded radar files from the National Weather Service.

4.6.2 NOAA Atlas 14 Frequency Point Rainfall Depths

Frequency point rainfall depths of various durations and recurrence intervals were collected for the Little River basin from National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Volume 8: Precipitation Frequency Atlas of the United States, Oklahoma, published in 2013 (NOAA, 2013). The point rainfall depths dis not significantly throughout the basin. A single depth was approximately taken from the center of the basin. Watershed subbasins were assigned the point rainfall depth. A point near the center of the basin was chosen to represent the entire basin for the HMS modeling. The 1% annual chance (100-yr) value chosen for the 24- hour duration was 5.64 inches. The complete list of precipitation values can be found in the Appendix B – Rainfall Runoff Modeling in HEC-HMS. The frequency precipitation depths were utilized as point rainfall depths in the frequency storms for the final HEC-HMS rainfall runoff model.

4.7 RESERVOIR PHYSICAL DATA

For the two USACE reservoirs within the Little River Basin, the Elevation-Storage tables, spillway rating curves, and outlet structure rating curves were all provided from the USACE Tulsa District.

4.8 SOFTWARE

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

Table 4.1: List of Software Used in this Hydrology Study

Program	Version	Capability	Developer
ArcGIS	10.4.1	Geographical Information System	ESRI
HEC-DSSVue	3.0.1	Plot, tabulate, edit and manipulate data in HEC-DSS format	HEC
HEC-METVUE	3.1.0.396	Processing and viewing precipitation data	HEC
HEC-HMS	4.5	Rainfall-runoff Simulation	HEC
HEC-SSP	2.2	Statistical Software Package	HEC
Riverware	8.3	River and Reservoir Simulation	CADSWES

5 Statistical Hydrology

This chapter provides a general summary of the data, analyses and results of the statistical analyses of the stream gages that were completed for the InFRM Watershed Hydrology Assessment of the Little River Basin, but additional details on the statistical analyses are available in.

5.1 STATISTICAL METHODS

Using the simulated data from the Little River RiverWare period of record model, which runs from January 1938 through December 2017 flow data was input into HEC-SSP to run Bulletin 17C analysis for each gage site as well as at project inflow and outflows. All Bulletin 17C analysis used the program generated station skew values for generating frequency flows. For locations with highly regulated flows graphical analysis was used in place of Bulletin 17C. The results from HEC-SSP provided the frequency flows at 2, 5, 10, 25, 100, 200, and 500 years and accompanied by the 95-percent confidence limits. Inflows and regulated outflows were analyzed at USACE projects. Flows at gages upstream of projects were investigated, and downstream of gages both regulated and unregulated flows were analyzed.

5.2 STREAM GAGE DATA AND STATISTICAL FLOW FREQUENCY RESULTS

Table 5.1 contains the results from RiverWare and HEC-SSP.

Table 5.1: Peak frequency flows in the Little River using RiverWare simulated data and HEC-SSP.

17C Analysis using RiverWare Results		50%	20%	10%	5%	2%	1%	0.50%	0.20%
Location Description	HMS Element Name	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR
Little River near Cloudy	CLDY	Point not analyzed in RiverWare. StreamStats and HEC-HMS to be used.							
Little River at Pine Creek Dam (Inflow)	PINE	25,175	40,598	50,794	60,341	72,270	80,883	89,194	99,765
Glover River near Glover	GLOV	Point not analyzed in RiverWare. StreamStats and HEC-HMS to be used.							
Confluence of Little and Glover Rivers	LITRGLOV	Regulated point not analyzed in RiverWare. HEC-HMS to be used.							
Little River near Idabel	IDAB	13,453	21,283	28,817	38,200	54,140	69,459	88,164	119,118
Mountain Fork River near Smithville	SMIT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mountain Fork River at Broken Bow Lake (inflow)	BROK	35,925	56,243	70,587	84,839	103,940	118,734	133,897	154,573
Mountain Fork River near Eagletown	EAGL	8,530	9,377	9,960	10,800	19,502	24,445	30,762	41,874
Confluence of Little and Mountain Fork Rivers	LITRMF	Regulated point not analyzed in RiverWare. HEC-HMS to be used.							
Little River near Horatio	HORA	20,649	29,109	36,098	43,398	53,202	60,484	67,429	75,745
Graphical analysis used instead of 17C due to highly regulated just below Broken Bow									

6 Rainfall-Runoff Modeling in HEC-HMS

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

In this phase of the multi-layered hydrologic analysis, a watershed model was built for the Little River Basin with input parameters that represented the physical characteristics of the watershed. The rainfall-runoff model for the basin was completed using the basin-wide HEC-HMS model developed for the 2015 Little River Basin CWMS Implementation as a starting point. This model was further refined by adding additional detailed data, updating the land use, and calibrating the model to multiple recent flood events. Through calibration, the updated HEC-HMS model was verified to accurately reproduce the response of the watershed to multiple recent observed storm events. Finally, frequency storms were built in HEC-HMS and the latest published frequency rainfall depths from Atlas 14. These frequency storms were run through the verified model, yielding consistent estimates of the 1% annual chance (100-yr) and other frequency peak flows at various locations throughout the basin.

This chapter provides a general summary of the model development, calibration and results of the HEC-HMS rainfall runoff modeling that was completed for the InFRM Watershed Hydrology Assessment of the Little River Basin.

6.1 EXISTING HEC-HMS MODELS

The existing operational forecast model used in the CWMS watershed was the base model used for HMS study. This model is broken into more detail compared to the existing RiverWare model. See Figure 2.1 for a HEC-HMS model map.

6.2 UPDATES TO THE HEC-HMS MODEL

The only changes to the existing HEC-HMS model was to update the default loss rates to account for use in operational forecasting. Four additional events were chosen to recalibrate and validate the HEC-HMS model.

6.3 HEC-HMS MODEL PARAMETERS

Tables 6.1-3 show the model parameters used to run the various HEC-HMS models. Figure 6.1 shows the various rainfall distributions used. Figures 6.1 and 6.2 show the releases that were used based on the modeled inflow and following water control manual guidelines on releases. If an AEP isn't shown in a plot then there were no releases made during the model run. One release was applied across all loss rates and rainfall distributions for a given return frequency.

Table 6.1: Loss rates for HEC-HMS model runs

Updated Calibrated Loss Rates			Max Calibrated Loss Rates			Multiplied 2.5x Loss Rates			Multiplied 5x Loss Rates		
Subbasin	Initial	Constant	Subbasin	Initial	Constant	Subbasin	Initial	Constant	Subbasin	Initial	Constant
UPPLITR	0.6625	0.04	UPPLITR	1	0.05	UPPLITR	1.65625	0.1	UPPLITR	3.3125	0.2
BLACKFK	0.75	0.04075	BLACKFK	1	0.05	BLACKFK	1.875	0.101875	BLACKFK	3.75	0.20375
CLDYL	0.8125	0.04	CLDYL	1	0.05	CLDYL	2.03125	0.1	CLDYL	4.0625	0.2
PINEL	0.725	0.025	PINEL	1.25	0.04	PINEL	1.8125	0.0625	PINEL	3.625	0.125
PINESA	0	0	PINESA	0	0	PINESA	0	0	PINESA	0	0
BLPINECR	0.35	0.05	BLPINECR	0.5	0.09	BLPINECR	0.875	0.125	BLPINECR	1.75	0.25
WFKGLOVER	0.7	0.075	WFKGLOVER	1	0.1	WFKGLOV	1.75	0.1875	WFKGLOV	3.5	0.375
EFKGLOVER	0.675	0.075	EFKGLOVER	1	0.1	EFKGLOVE	1.6875	0.1875	EFKGLOVE	3.375	0.375
GLOVERL	0.725	0.075	GLOVERL	1	0.1	GLOVERL	1.8125	0.1875	GLOVERL	3.625	0.375
LGLOVER	0.325	0.03875	LGLOVER	0.5	0.065	LGLOVER	0.8125	0.096875	LGLOVER	1.625	0.19375
IDABL	0.275	0.03	IDABL	0.5	0.06	IDABL	0.6875	0.075	IDABL	1.375	0.15
LUKFATA	0.35	0.045	LUKFATA	0.5	0.06	LUKFATA	0.875	0.1125	LUKFATA	1.75	0.225
YANUBECR	1.6875	0.16875	YANUBECR	2	0.2	YANUBECI	4.21875	0.421875	YANUBECI	8.4375	0.84375
SMIT	0.7375	0.0125	SMIT	1.1	0.03	SMIT	1.84375	0.03125	SMIT	3.6875	0.0625
EAGLECR	0.7375	0.025	EAGLECR	1.25	0.05	EAGLECR	1.84375	0.0625	EAGLECR	3.6875	0.125
BUFFALO	0.7375	0.025	BUFFALO	1.25	0.05	BUFFALO	1.84375	0.0625	BUFFALO	3.6875	0.125
BOKTUKOLA	0.7375	0.025	BOKTUKOLA	1.25	0.05	BOKTUKO	1.84375	0.0625	BOKTUKO	3.6875	0.125
BROKL	0.675	0.0175	BROKL	1	0.03	BROKL	1.6875	0.04375	BROKL	3.375	0.0875
BROKSA	0	0	BROKSA	0	0	BROKSA	0	0	BROKSA	0	0
BROML	0.75	0.01875	BROML	1	0.075	BROML	1.875	0.046875	BROML	3.75	0.09375
EAGLL	1.1875	0.03125	EAGLL	1.5	0.075	EAGLL	2.96875	0.078125	EAGLL	5.9375	0.15625
LMTNFK	0.85	0.08125	LMTNFK	2	0.2	LMTNFK	2.125	0.203125	LMTNFK	4.25	0.40625
HORAL	0.9	0.06875	HORAL	2	0.15	HORAL	2.25	0.171875	HORAL	4.5	0.34375
ROCKCR	0.525	0.04375	ROCKCR	0.6	0.05	ROCKCR	1.3125	0.109375	ROCKCR	2.625	0.21875
BLDEQU	0.525	0.08125	BLDEQU	0.6	0.2	BLDEQU	1.3125	0.203125	BLDEQU	2.625	0.40625
BEARCR	0.65	0.07625	BEARCR	1	0.18	BEARCR	1.625	0.190625	BEARCR	3.25	0.38125

Table 6.2: HEC-HMS default model parameters.

HMS Element	Drainage Area	Snyder Transform		Recession	
	(Sq Mi)	Lag (Hr)	Peaking Coefficient	Recession Constant	Ratio to Peak
UPPLITR	160.605	10.45	0.73	0.507	0.2
BLACKFK	71.983	8.34	0.72	0.507	0.2
CLDYL	152.368	7.01	0.7	0.507	0.2
PINEL	238.429	3.5	0.66	0.507	0.1
PINESA	6.186	N/A	N/A	0.112	0.001
BLPINECR	114.288	9.65	0.73	0.507	0.6
WFKGLOVER	104.78	7.12	0.7	0.507	0.2
EFKGLOVER	75.421	6.58	0.7	0.507	0.2
GLOVERL	140.245	8.81	0.72	0.507	0.2
LGLOVER	24.047	4.5	0.67	0.507	0.5
IDABL	88.44	11.66	0.74	0.507	0.4
LUKFATA	49.988	8.24	0.71	0.507	0.4
YANUBECR	176.577	9.95	0.73	0.507	0.5
SMIT	322.28	11.6	0.74	0.507	0.2
EAGLECR	92.755	6.56	0.7	0.634	0.15
BUFFALO	118.605	12.11	0.74	0.634	0.15
BOKTUKOLA	69.268	5.41	0.69	0.634	0.15
BROKL	131.339	1.9	0.62	0.634	0.15

HMS Element	Drainage Area	Snyder Transform		Recession	
	(Sq Mi)	Lag (Hr)	Peaking Coefficient	Recession Constant	Ratio to Peak
BROKSA	22.391	N/A	N/A	0.795	0.001
BROML	23.102	3.5	0.66	0.507	0.3
EAGLL	19.816	3.29	0.66	0.507	0.5
LMTNFK	46.367	6.52	0.7	0.507	0.5
HORAL	64.259	6.6	0.7	0.634	0.6
ROCKCR	73.272	8.16	0.71	0.634	0.6
BLDEQU	29.858	7.3	0.71	0.634	0.5
BEARCR	88.615	11.31	0.74	0.507	0.5
Lake Surface Areas used specified unit hydrographs					

6.4 POINT RAINFALL DEPTHS FOR THE FREQUENCY STORMS

Table 6.3 shows the Atlas 14 24-hour storm total depths used in the HMS model, and Figure 6.1 shows the three distributions used to apply the rainfall across the basin.

Table 6.3: Atlas 14 rainfall data for the 24-hour duration including upper and lower confidence intervals.

Atlas 14 Rainfall			
AEP	Rainfall (in)	CI Lower (in)	CI Upper (in)
0.5	4.64	3.9	5.51
0.2	5.77	4.83	6.88
0.1	6.78	5.64	8.12
0.05	8.27	6.68	10.3
0.02	9.51	7.47	12
0.01	10.8	8.18	14
0.005	12.2	8.83	16.2
0.002	14.2	9.83	19.4

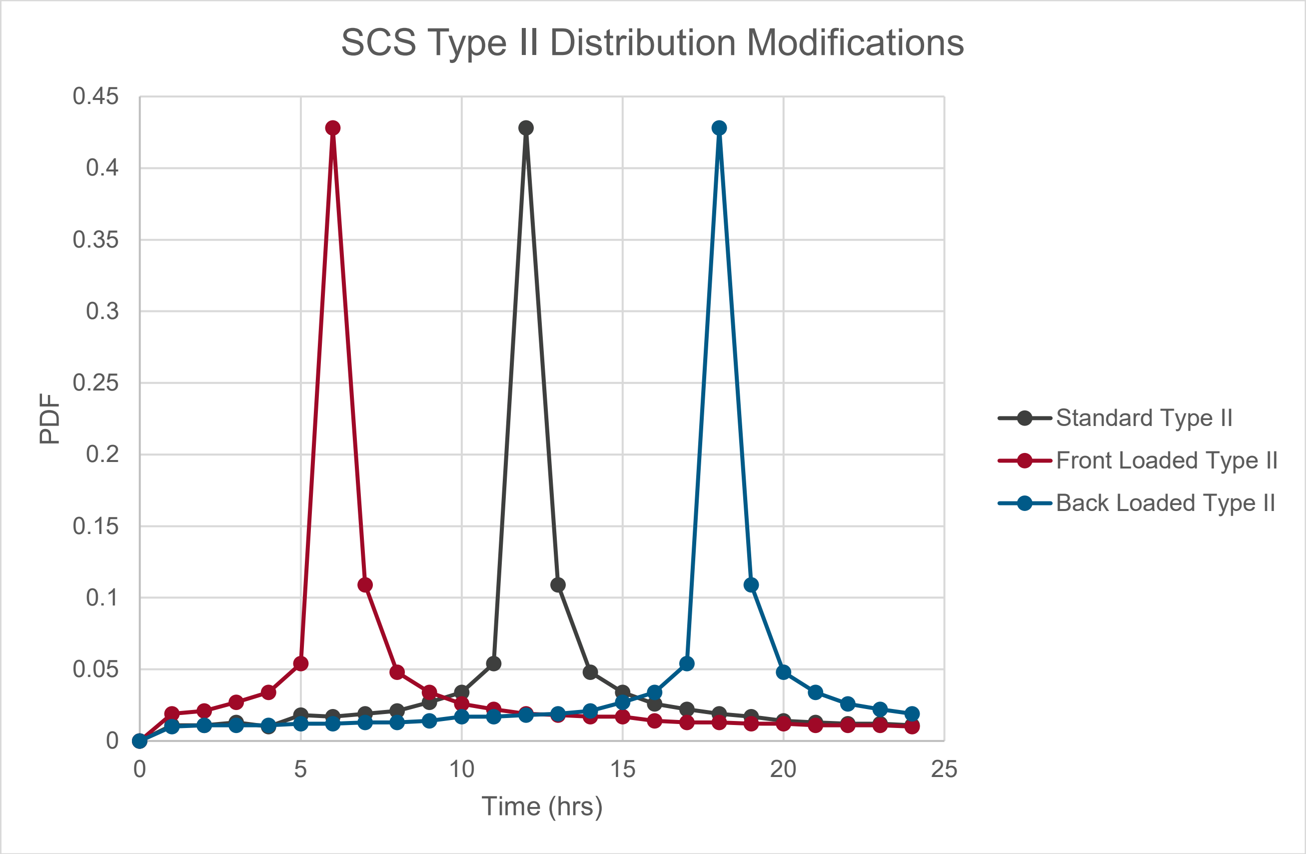

Figure 6.1: Atlas 14 rainfall distributions using SCS Type II and shifted in time for sensitivity analysis.

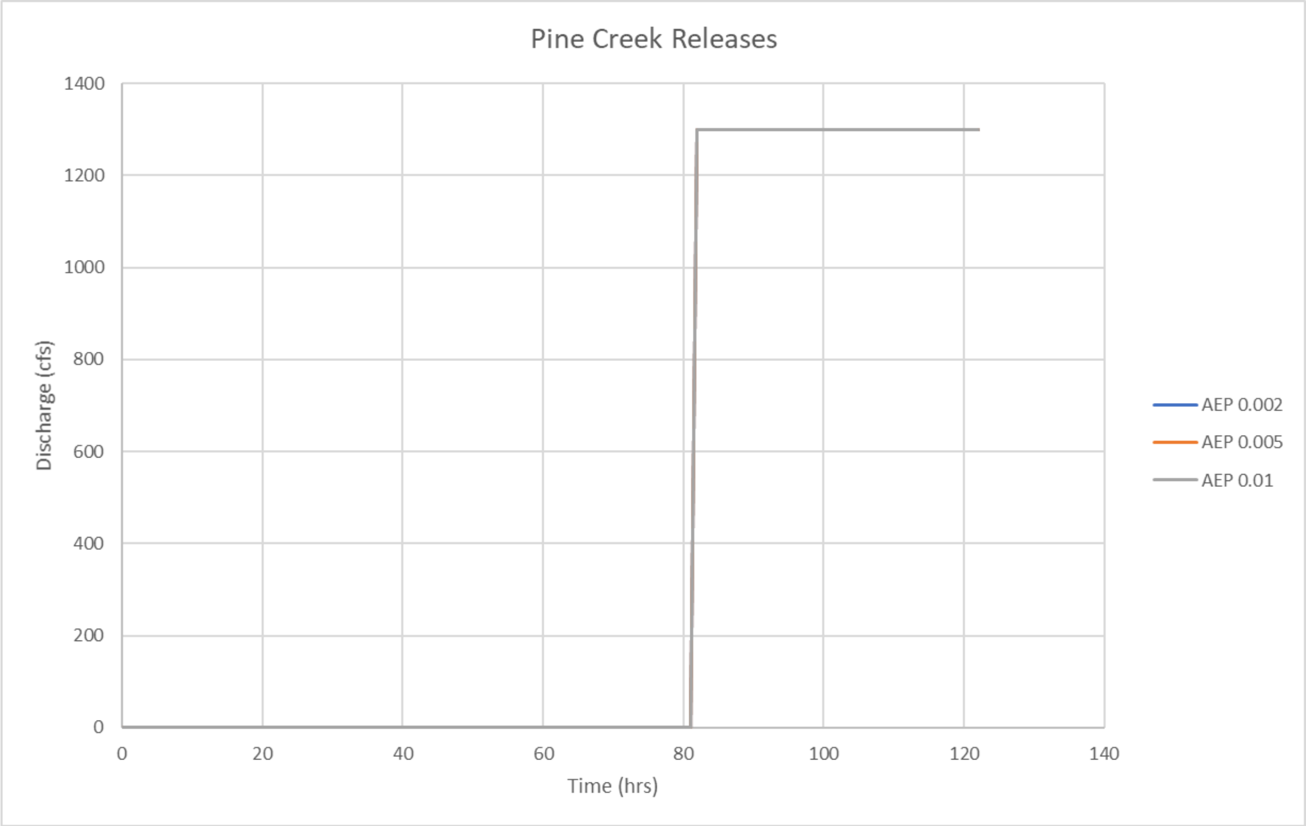

Figure 6.2: Pine Creek releases from HEC-HMS. For AEP intervals not shown no gate releases were made.

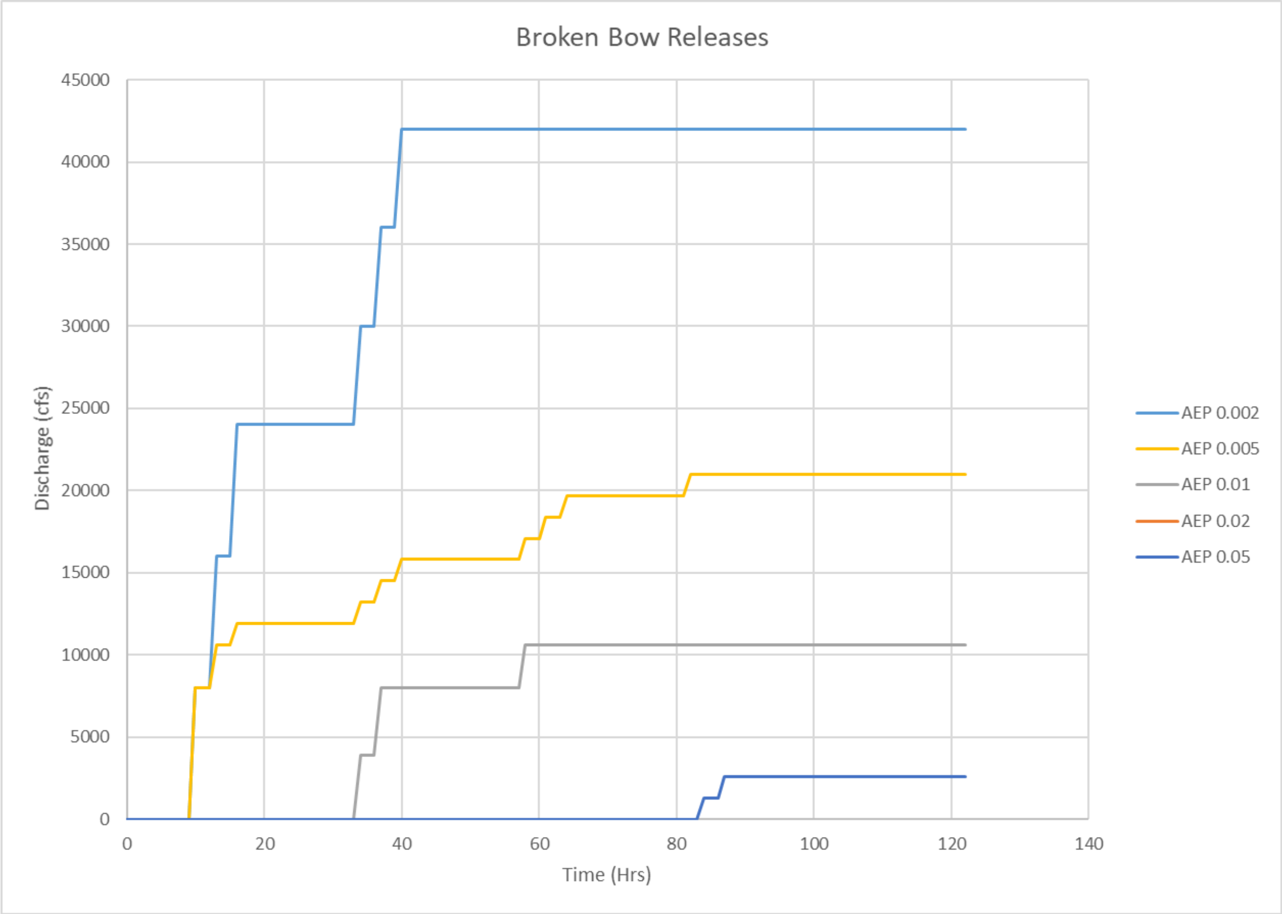

Figure 6.3: Broken Bow releases from HEC-HMS. For AEP intervals not shown no releases were made

6.5 FREQUENCY STORM RESULTS – UNIFORM RAINFALL METHOD

The frequency flow values were then calculated in HEC-HMS by applying the frequency rainfall depths to the final watershed model. This rainfall pattern is known as the uniform rainfall method because the same rainfall depths are applied uniformly over the entire watershed. The final HEC-HMS frequency peak discharges from the uniform rainfall method for significant locations throughout the watershed model can be seen in Table 6.7. These results will later be compared to the statistical frequency storm results from HEC-SSP and USGS methods from this study.

In some cases, one may observe that the simulated discharge decreases in the downstream direction. It is not an uncommon phenomenon to see decreasing frequency peak discharges for some river reaches as flood waters spread out into the floodplain and the hydrograph becomes dampened as it moves downstream. This can be due to a combination of peak attenuation due to river routing as well as the difference in timing between the peak of the main stem river versus the runoff from the local tributaries and subbasins. Tables 6.4-6 display results across the basin for the 0.01 AEP when using the different rainfall distributions along with the various loss rate scenarios.

Table 6.4: HEC-HMS annual exceedance probability of 0.01 showing results at the 8 gage sites when using the standard SCS Type II distribution.

Cloudy					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	94,380	82,370	78,640	64,300	33,790
Standard Normal	122,780	110,710	107,030	93,630	63,060
Standard Upper	156,880	144,850	140,860	127,720	98,930

Smithville					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	93,540	87,300	81,930	73,800	46,380
Standard Normal	123,500	117,550	112,340	105,440	78,810
Standard Upper	160,090	154,390	149,290	143,300	118,520

Pine Creek Inflows					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	185,770	168,220	160,800	143,010	83,580
Standard Normal	246,500	227,340	220,500	203,520	148,690
Standard Upper	320,640	300,470	293,360	276,090	228,840

Broken Bow Inflows					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	178,750	164,780	152,760	137,310	83,290
Standard Normal	236,630	222,780	210,720	196,110	144,110
Standard Upper	305,580	293,050	281,700	268,490	219,260

Glover					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	113,400	97,520	92,290	76,370	38,910
Standard Normal	149,720	133,670	128,260	111,780	74,540
Standard Upper	194,090	177,980	172,420	155,380	120,330

Eagletown					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	21,220	18,130	15,650	12,870	11,460
Standard Normal	32,380	29,930	27,090	23,890	12,610
Standard Upper	45,860	43,380	40,520	37,320	26,250

Idabel					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	73,530	55,130	48,990	40,640	30,280
Standard Normal	108,250	88,140	80,620	66,560	44,460
Standard Upper	152,640	130,910	121,980	105,490	77,620

Horatio					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Standard Lower	128,850	96,430	86,640	71,270	43,060
Standard Normal	171,080	139,970	127,790	108,330	72,920
Standard Upper	237,550	203,260	187,770	163,240	115,590

Table 6.5: HEC-HMS annual exceedance probability of 0.01 showing results at the 8 gage sites when using the front loaded SCS Type II distribution.

Cloudy					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	90,010	77,180	72,970	57,020	25,910
Front Normal	116,720	104,230	100,250	85,500	52,560
Front Upper	147,020	135,230	131,500	117,870	86,490

Smithville					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	90,240	81,690	75,400	65,660	38,450
Front Normal	119,150	110,950	104,850	95,580	67,960
Front Upper	154,450	146,430	140,480	131,770	104,410

Pine Creek Inflows					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	175,630	157,730	146,640	124,710	64,700
Front Normal	232,280	214,380	204,010	184,350	123,500
Front Upper	301,710	283,270	273,970	254,670	195,910

Broken Bow Inflows					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	172,330	154,200	140,810	122,650	67,730
Front Normal	227,790	209,610	196,030	179,210	124,090
Front Upper	295,110	277,280	264,290	248,220	192,970

Glover					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	110,080	92,730	86,370	66,810	28,790
Front Normal	145,330	127,890	121,550	102,700	60,780
Front Upper	188,400	170,770	164,460	145,480	102,140

Eagletown					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	21,070	16,640	14,690	12,200	11,090
Front Normal	31,680	28,150	25,520	20,530	11,930
Front Upper	44,750	40,770	38,090	34,320	21,260

Idabel					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	69,850	51,730	45,890	36,780	27,110
Front Normal	102,610	83,290	75,490	60,360	40,610
Front Upper	144,680	123,640	115,370	98,130	66,090

Horatio					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Front Lower	123,340	89,700	79,680	60,700	32,320
Front Normal	162,460	130,440	117,880	97,050	60,160
Front Upper	224,070	189,180	174,370	148,530	98,130

Table 6.6: HEC-HMS annual exceedance probability of 0.01 showing results at the 8 gage sites when using the back loaded SCS Type II distribution.

Cloudy					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	97,030	85,600	82,000	69,770	41,490
Back Normal	127,100	116,030	112,460	99,510	73,060
Back Upper	162,140	151,890	148,730	135,830	110,530

Smithville					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	93,650	89,520	85,130	79,220	53,640
Back Normal	123,650	119,710	115,520	111,070	88,000
Back Upper	160,280	156,470	152,410	148,850	128,930

Pine Creek Inflows					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	194,680	175,210	168,950	154,710	102,230
Back Normal	257,310	238,500	231,060	215,160	173,580
Back Upper	333,570	315,880	308,480	289,550	254,200

Broken Bow Inflows					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	179,760	168,400	158,410	146,700	100,840
Back Normal	238,410	226,160	216,110	205,770	164,280
Back Upper	309,260	296,300	286,810	277,680	238,690

Glover					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	113,890	98,870	94,100	80,360	48,910
Back Normal	150,370	135,210	130,290	114,760	88,080
Back Upper	194,930	179,670	174,640	158,210	130,500

Eagletown					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	21,380	19,240	16,230	14,050	11,980
Back Normal	32,830	30,760	27,900	26,950	14,930
Back Upper	45,710	44,840	41,710	41,090	31,410

Idabel					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	74,380	56,180	50,160	42,220	31,390
Back Normal	109,790	89,570	82,300	68,890	49,280
Back Upper	155,330	132,940	124,310	108,340	83,290

Horatio					
Distribution	Losses				
	Zero	Calibriated	Max Calibrated	2.5x Calibrated	5x Calibrated
Back Lower	130,880	99,790	90,680	77,540	50,000
Back Normal	175,990	144,110	132,420	114,910	82,030
Back Upper	242,320	208,600	193,440	170,900	127,290

Table 6.7: Summary of HEC-HMS peak frequency flows (cfs).

HMS with Standard SCS, Calibrated Losses		50%	20%	10%	5%	2%	1%	0.50%	0.20%
Location Description	HMS Element Name	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR
Little River near Cloudy	CLDY	41,810	54,920	66,670	83,380	96,910	110,710	125,710	146,990
Little River at Pine Creek Dam (Inflow)	PINE	88,600	114,100	136,790	170,240	198,150	227,340	259,230	305,080
Glover River near Glover	GLOV	49,070	64,480	78,290	98,760	115,850	133,670	153,040	180,750
Confluence of Little and Glover Rivers	LITRGLOV	30,930	50,000	73,290	107,600	136,860	160,620	196,800	240,030
Little River near Idabel	IDAB	22,990	32,900	40,980	56,180	71,460	88,140	106,300	133,740
Mountain Fork River near Smithville	SMIT	45,990	59,320	71,100	88,330	102,660	117,550	133,690	156,690
Mountain Fork River at Broken Bow Lake (inflow)	BROK	86,260	111,550	133,980	166,730	193,840	222,780	253,680	297,260
Mountain Fork River near Eagletown	EAGL	8,090	10,960	13,580	18,560	24,360	29,930	48,760	62,850
Confluence of Little and Mountain Fork Rivers	LITRMF	30,020	43,550	55,650	73,230	88,040	112,110	142,990	205,500
Little River near Horatio	HORA	43,750	55,390	72,960	96,870	116,900	139,970	174,800	241,720

Using the standard rainfall depth from Atlas 14 and the standard distribution as a baseline, sensitivity in the depth of rainfall using the 5 and 95% confidence interval showed flows could vary on average +/-25% across the basin. When comparing zero losses to the calibrated results the average increase in flows was 15% across the basin and when looking at other loss rates (Calibrated, Max Calibrated, 2.5x Calibrated, and 5x Calibrated) the average reduction in flows increased to 49% when 5x Calibrated was used. When comparing the timing of the peak hourly rainfall due to shifting the Type-II distribution the change in peak flows was +/- 6%. These results can be seen in Tables 6.4-6.6 for the AEP 0.01 results. The sensitivity analysis reinforces the idea that any runoff modeling is highly variable to watershed conditions, and these changing conditions make determining frequency flows with HMS less preferable to other methods.

7 USGS StreamStats Analysis

7.1 INTRODUCTION TO STREAMSTATS MODELING

For gage sites that do not have upstream regulation and are also not in the RiverWare period of record model the USGS StreamStats web tool was used to generate frequency flows as a way to compare results from HMS. The 2010 USGS report by Lewis was used for generating the frequency flows. This report used a generalized least squares regression model to develop the regression equations used for the State of Oklahoma. The frequency regression equations use are summarized as follows with CONTDA equaling the contributing drainage area in square miles, PRECIP equaling the mean-annual precipitation, and CSL10_85fm being the main-channel slope at the 10 and 85 precent end points in feet per mile. The values for X, a, b, and c are in Table 7.1 for each frequency.

$$Q_{AEP} = X(CONTDA)^a(PRECIP)^b(CSL10\_85fm)^c$$

TABLE 7.1: Summary of variables used in the Oklahoma frequency regression flows for StreamStats.

AEP	X	a	b	c
0.5	0.064	0.66	2.06	0.16
0.2	0.574	0.66	1.63	0.19
0.1	1.74	0.66	1.42	0.21
0.04	4.9	0.66	1.24	0.23
0.02	13.18	0.66	1.05	0.21
0.01	26.9	0.65	0.92	0.21
0.002	126	0.64	0.64	0.19

7.1.1 **USGS StreamStats Results**

Table 7.2: Results of peak frequency flows (cfs) for points analyzed with StreamStats.

StreamStats Results		50%	20%	10%	5%	2%	1%	0.50%	0.20%
Location Description	HMS Element Name	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR
Little River near Cloudy	CLDY	15,500	30,800	44,400	63,000	84,900	99,900	N/A	165,000
Little River at Pine Creek Dam (Inflow)	PINE	In RiverWare							
Glover River near Glover	GLOV	13,200	26,100	37,600	53,200	71,500	84,100	N/A	138,000
Confluence of Little and Glover Rivers	LITRGLOV	Regulated point not analyzed in RiverWare. StreamStats cannot be used							
Little River near Idabel	IDAB	In RiverWare							
Mountain Fork River near Smithville	SMIT	13,900	27,500	39,700	56,400	76,000	89,400	N/A	147,000
Mountain Fork River at Broken Bow Lake (inflow)	BROK	In RiverWare							
Mountain Fork River near Eagletown	EAGL	In RiverWare							
Confluence of Little and Mountain Fork Rivers	LITRMF	Regulated point not analyzed in RiverWare. StreamStats cannot be used							
Little River near Horatio	HORA	In RiverWare							

8 Comparison of Frequency Flow Estimates

When comparing methods and modeling results using RiverWare along with HEC-SSP, HEC-HMS, and USGS StreamStats there is a large range of flows at each site. When evaluating results, the RiverWare and HEC-SSP methods provide a best estimate of peak flows as the results are most closely based on the entire period of record and current operational conditions. No current Flood Insurance Studies (FIS) exist along the Little River or its main tributaries. Tables 8.1, 8.2, and 8.3 contain the results from various study methods.

Table 8.1: Frequency results across the Little River Basin when using RiverWare and HEC-SSP 17C analysis.

17C Analysis using RiverWare Results		50%	20%	10%	5%	2%	1%	0.50%	0.20%
Location Description	HMS Element Name	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR
Little River near Cloudy	CLDY	Point not analyzed in RiverWare. StreamStats cannot be used							
Little River at Pine Creek Dam (Inflow)	PINE	25,175	40,598	50,794	60,341	72,270	80,883	89,194	99,765
Glover River near Glover	GLOV	Point not analyzed in RiverWare. StreamStats cannot be used							
Confluence of Little and Glover Rivers	LITRGLOV	Regulated point not analyzed in RiverWare. StreamStats cannot be used							
Little River near Idabel	IDAB	13,453	21,283	28,817	38,200	54,140	69,459	88,164	119,118
Mountain Fork River near Smithville	SMIT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mountain Fork River at Broken Bow Lake (inflow)	BROK	35,925	56,243	70,587	84,839	103,940	118,734	133,897	154,573
Mountain Fork River near Eagletown	EAGL	8,530	9,377	9,960	10,800	19,502	24,445	30,762	41,874
Confluence of Little and Mountain Fork Rivers	LITRMF	Regulated point not analyzed in RiverWare. StreamStats cannot be used							
Little River near Horatio	HORA	20,649	29,109	36,098	43,398	53,202	60,484	67,429	75,745
Graphical analysis used instead of 17C due to highly regulated just below Broken Bow									

Table 8.2: Frequency results across the Little River Basin when using HEC-HMS analysis.

HMS with Standard SCS, Calibrated Losses		50%	20%	10%	5%	2%	1%	0.50%	0.20%
Location Description	HMS Element Name	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR
Little River near Cloudy	CLDY	41,810	54,920	66,670	83,380	96,910	110,710	125,710	146,990
Little River at Pine Creek Dam (Inflow)	PINE	88,600	114,100	136,790	170,240	198,150	227,340	259,230	305,080
Glover River near Glover	GLOV	49,070	64,480	78,290	98,760	115,850	133,670	153,040	180,750
Confluence of Little and Glover Rivers	LITRGLOV	30,930	50,000	73,290	107,600	136,860	160,620	196,800	240,030
Little River near Idabel	IDAB	22,990	32,900	40,980	56,180	71,460	88,140	106,300	133,740
Mountain Fork River near Smithville	SMIT	45,990	59,320	71,100	88,330	102,660	117,550	133,690	156,690
Mountain Fork River at Broken Bow Lake (inflow)	BROK	86,260	111,550	133,980	166,730	193,840	222,780	253,680	297,260
Mountain Fork River near Eagletown	EAGL	8,090	10,960	13,580	18,560	24,360	29,930	48,760	62,850
Confluence of Little and Mountain Fork Rivers	LITRMF	30,020	43,550	55,650	73,230	88,040	112,110	142,990	205,500
Little River near Horatio	HORA	43,750	55,390	72,960	96,870	116,900	139,970	174,800	241,720

Table 8.3: Frequency results across the Little River Basin when using USGS StreamStats analysis.

StreamStats Results		50%	20%	10%	5%	2%	1%	0.50%	0.20%
Location Description	HMS Element Name	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR
Little River near Cloudy	CLDY	15,500	30,800	44,400	63,000	84,900	99,900	N/A	165,000
Little River at Pine Creek Dam (Inflow)	PINE	In RiverWare							
Glover River near Glover	GLOV	13,200	26,100	37,600	53,200	71,500	84,100	N/A	138,000
Confluence of Little and Glover Rivers	LITRGLOV	Regulated point not analyzed in RiverWare. StreamStats cannot be used							
Little River near Idabel	IDAB	In RiverWare							
Mountain Fork River near Smithville	SMIT	13,900	27,500	39,700	56,400	76,000	89,400	N/A	147,000
Mountain Fork River at Broken Bow Lake (inflow)	BROK	In RiverWare							
Mountain Fork River near Eagletown	EAGL	In RiverWare							
Confluence of Little and Mountain Fork Rivers	LITRMF	Regulated point not analyzed in RiverWare. StreamStats cannot be used							
Little River near Horatio	HORA	In RiverWare							

9 Frequency Flow Recommendations

The final recommendations for the InFRM Watershed Hydrology Assessments are formulated through a rigorous process which requires technical feedback and collaboration between all of the InFRM subject matter experts. This process includes the following steps at a minimum: (1) comparing the results of the various hydrologic methods to one another, (2) performing an investigation into the reasons for the differences in results at each location in the watershed, (3) selecting of the draft recommended methods, (4) performing internal and external technical reviews of the hydrologic analyses and the draft recommendations, and finally, (5) finalizing the study recommendations.

After completing this process for the Little River basin, the frequency discharges that were recommended for adoption by the InFRM team were a combination of the results from the following methods: For any point included in the RiverWare model that was analyzed the results from RiverWare and 17C was used. For points not in RiverWare but which needed to be included in the study, a drainage area ratio (DA ratio) was used to corelate results from RiverWare into final recommendations. Results from this DA ratio analysis were checked against the HMS results to ensure hydrologic continuity. A detailed breakout of the recommended discharges for each location in the watershed is given in Table 9.1.

Table 9.1: Final Little River Frequency Flow Recommendations.

Final Frequency Analysis Flows (cfs)	50%	20%	10%	5%	2%	1%	0.50%	0.20%
	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR
Little River near Cloudy	15,000	25,000	31,000	37,000	44,000	49,000	55,000	61,000
Little River at Pine Creek Dam (Inflow)	25,000	41,000	51,000	60,000	72,000	81,000	89,000	100,000
Glover River near Glover	19,000	31,000	42,000	55,000	78,000	100,000	127,000	172,000
Confluence of Little and Glover Rivers	15,000	24,000	32,000	43,000	60,000	77,000	98,000	133,000
Little River near Idabel	13,000	21,000	29,000	38,000	54,000	69,000	88,000	119,000
Mountain Fork River near Smithville	27,000	42,000	52,000	63,000	77,000	88,000	99,000	115,000
Mountain Fork River at Broken Bow Lake (inflow)	36,000	56,000	71,000	85,000	104,000	119,000	134,000	155,000
Mountain Fork River near Eagletown	9,000	9,000	10,000	11,000	20,000	24,000	31,000	42,000
Confluence of Little and Mountain Fork Rivers	19,000	26,000	32,000	39,000	48,000	54,000	61,000	68,000
Little River near Horatio	21,000	29,000	36,000	43,000	53,000	60,000	67,000	76,000

Estimated from RiverWare using DA ratios

10 Conclusions

After analyzing all of the various data sets and methods that produced the frequency flows the data in Table 9.1. The results from RiverWare and HEC-SSP were used wherever available as they provide values that best mimic the current regulated system. For values not in the RiverWare model values were best derived using data from RiverWare and then applying drainage area ratios to keep results consistent. For flows along the Glover River and below the confluence of the Glover and Little Rivers results actually decrease as flows move through the watershed. These results mimic what we see in the Tulsa District's real-time forecasting due to extreme attenuation of flows as the channel geometry changes drastically and goes from a steeper narrow channel upstream to more open and lower channel slopes. As such flows were allowed to show higher flows upstream when calculating the drainage area ratios.

11 References and Resources

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12 Terms of Reference

BFE	base flood elevations
cfs	cubic feet per second
CWMS	Corps Water Management System
DDF	Depth Duration Frequency
DEM	digital elevation model
DSS	data storage system
EM	Engineering Manual
EMA	expected moment algorithm
ERDC	Engineering Research & Development Center of USACE
FEMA	Federal Emergency Management Agency
FIS	flood insurance study
GeoHMS	Geospatial Hydrologic Model System extension
GIS	Geographic Information Systems
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
IACWD	Interagency Advisory Committee on Water Data
InFRM	Interagency Flood Risk Management
LiDAR	Light (Laser) Detection and Range
LOC	Line of organic correlation
LPIII	Log Pearson III
MMC	Modeling, Mapping, and Consequences Production Center
NA14	NOAA Atlas 14
NAD 83	North American Datum of 1983
NCDC	National Climatic Data Center
NED	National Elevation Dataset
NGVD 29	National Geodetic Vertical Datum of 1929
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
NWS	National Weather Service
PDSI	Palmer Drought Severity Index
QPF	Quantitative Precipitation Forecast
RAS	River Analysis System
ResSIM	Reservoir System Simulation
RFC	River Forecast Center
SCS	Soil Conservation Service
SHG	Standard Hydrologic Grid
SI	Structure Inventory
SME	subject matter expert
SOP	Standard Operating Procedures
sq mi	square miles
SSURGO	Soil Survey Geographic Database
TLS	Total-Least Squares
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WCM	Water Control Manual

13 Appendix A

This section contains more detailed model results for each location given in Table 9.1 along with the 5% and 95% confidence limits.

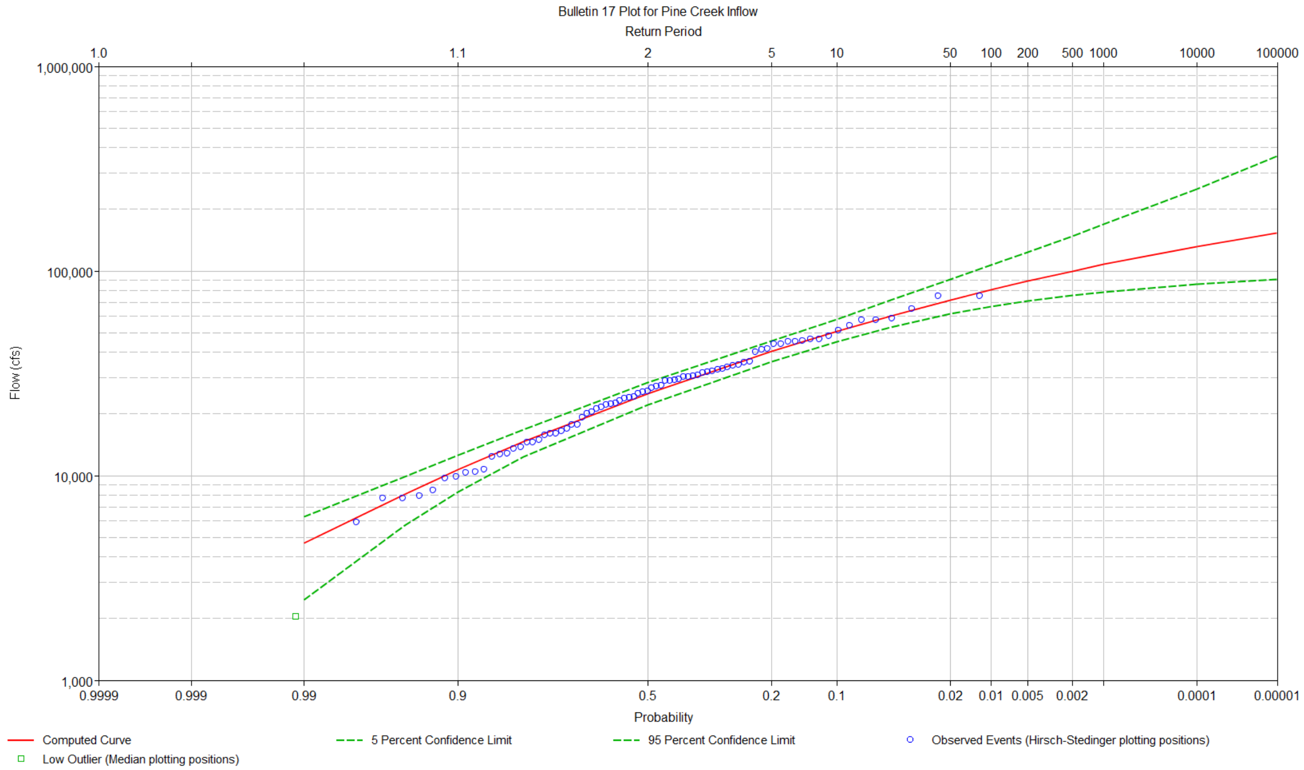
13.1 CLOUDY

Based on RiverWare		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	61,006	90,470	46,244
0.5	54,542	75,448	43,370
1	49,460	65,111	40,735
2	44,193	55,532	37,584
5	36,898	43,814	32,384
10	31,060	35,557	27,551
20	24,826	27,865	22,056
50	15,394	17,359	13,564

DA ratio Based on RW results from PINE Inflows.

13.2 PINE CREEK INFLOW

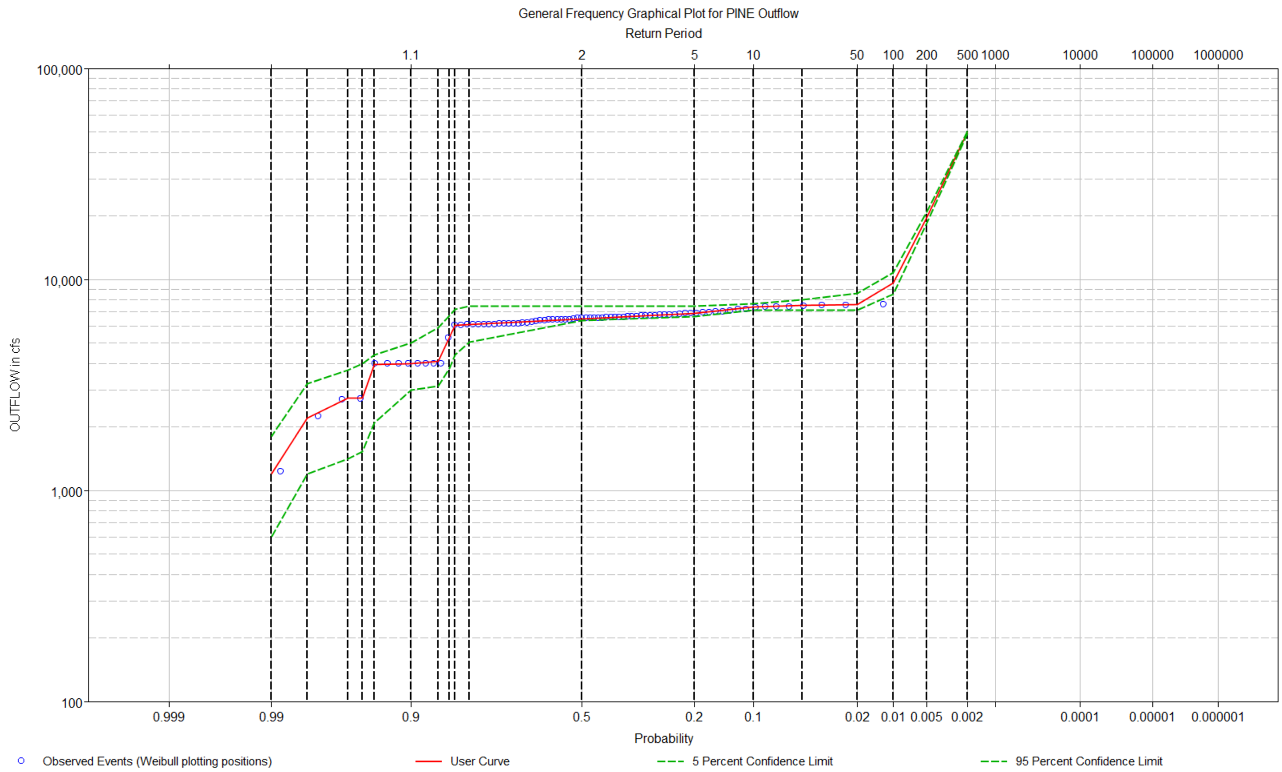
RiverWare Inflows 17C		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.001	153,047	363,533	90,709
0.01	131,419	251,621	86,076
0.1	107,470	168,858	78,782
0.2	99,765	148,312	75,810
0.5	89,194	123,685	71,098
1	80,883	106,739	66,779
2	72,270	91,037	61,613
5	60,341	71,826	53,088
10	50,794	58,290	45,166
20	40,598	45,680	36,157
50	25,175	28,458	22,236
80	14,591	16,745	12,310
90	10,668	12,544	8,345
95	8,116	9,876	5,722
99	4,682	6,312	2,467



13.3 PINE CREEK OUTFLOWS

RiverWare Graphical Outflow		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	49,800	50,539	49,061
0.5	19,700	20,867	18,533
1	9,650	10,772	8,528
2	7,600	8,576	7,176
5	7,500	7,983	7,176
10	7,400	7,646	7,154
20	6,900	7,448	6,676
50	6,500	7,448	6,389
80	6,100	7,448	5,030
83	6,050	7,201	4,373
84	5,300	6,710	3,784
86	4,100	5,890	3,118
90	4,000	5,007	2,993
94	3,950	4,376	2,094
95	2,750	3,978	1,522
96	2,730	3,718	1,412

98	2,200	3,205	1,195
99	1,200	1,798	602



PINE Elevations	
% Exceedance	Elevation (ft)
0.2	487.0
0.5	485.0
0.1	483.0
2	481.0
5	477.0
10	473.0
20	465.0
50	457.0
Reported in NGVD 29 and converted to NAVD 88	

13.4 GLOVER

DA ratio based on RW results from IDAB and LITGLOV.

Based on RiverWare		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	171,588	466,147	105,080
0.5	127,000	277,446	85,525
1	100,055	187,015	72,040
2	77,988	126,004	59,688
5	55,028	75,103	45,125
10	41,510	51,308	35,502
20	30,658	35,457	27,127
50	19,380	21,209	17,842

13.5 CONFLUENCE OF LITTLE AND GLOVER RIVERS

DA ratio based on RW results from IDAB.

Based on RiverWare		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	132,559	360,117	81,179
0.5	98,113	214,338	66,072
1	77,297	144,477	55,654
2	60,249	97,343	46,112
5	42,511	58,020	34,861
10	32,068	39,637	27,426
20	23,685	27,392	20,957
50	14,971	16,384	13,784

13.6 IDABEL

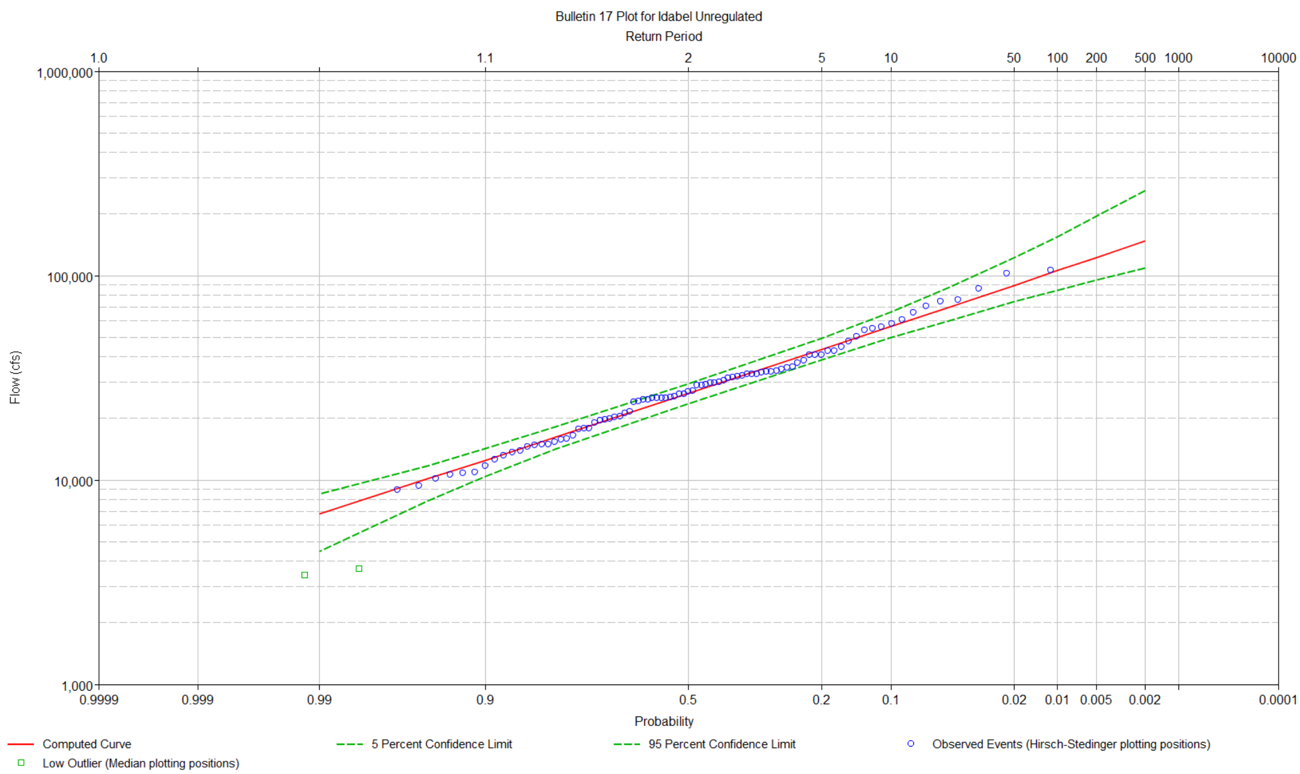
Transformed Regulated 17C Flows			
		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	119,118	323,602	72,947
0.5	88,164	192,605	59,372
1	69,459	129,827	50,011
2	54,140	87,473	41,436
5	38,200	52,137	31,326

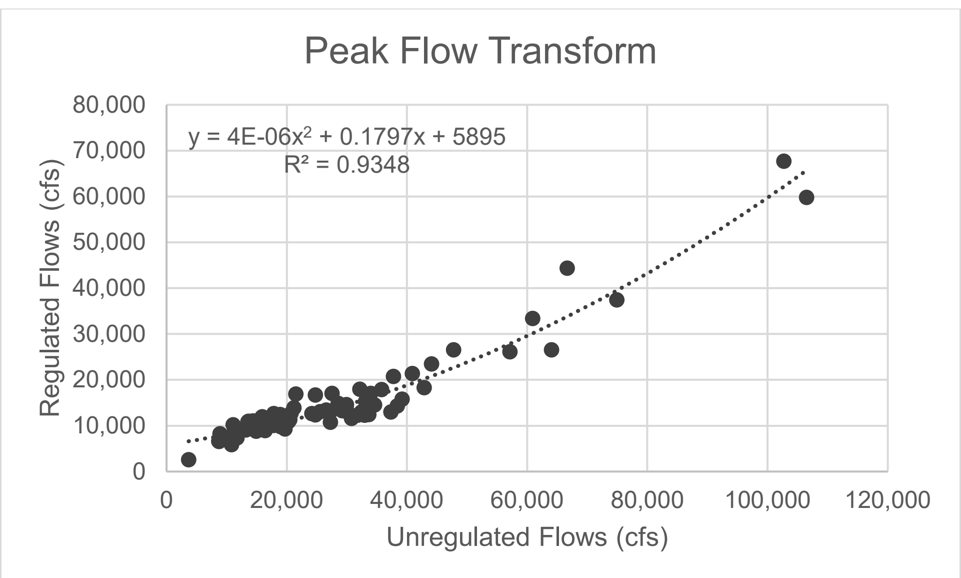
10	28,817	35,618	24,646
20	21,283	24,615	18,832
50	13,453	14,723	12,386
80	9,846	10,470	9,246
90	8,771	9,254	8,206
95	8,129	8,558	7,562
99	7,313	7,726	6,778

Based on unregulated RW results then transformed through peak flow transform.

Unregulated 17C Flows			
		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	147,273	260,259	108,944
0.5	122,699	194,752	95,325
1	105,583	154,985	84,932
2	89,635	122,103	74,439
5	70,171	87,379	60,377
10	56,500	66,618	49,594
20	43,504	49,541	38,683
50	26,468	29,610	23,661
80	16,169	18,137	14,174
90	12,517	14,203	10,436
95	10,141	11,748	7,891
99	6,846	8,558	4,471

Bulletin 17C unregulated flows based on RW period of record.





Peak flow transform for Idabel to convert unregulated flows into regulated.

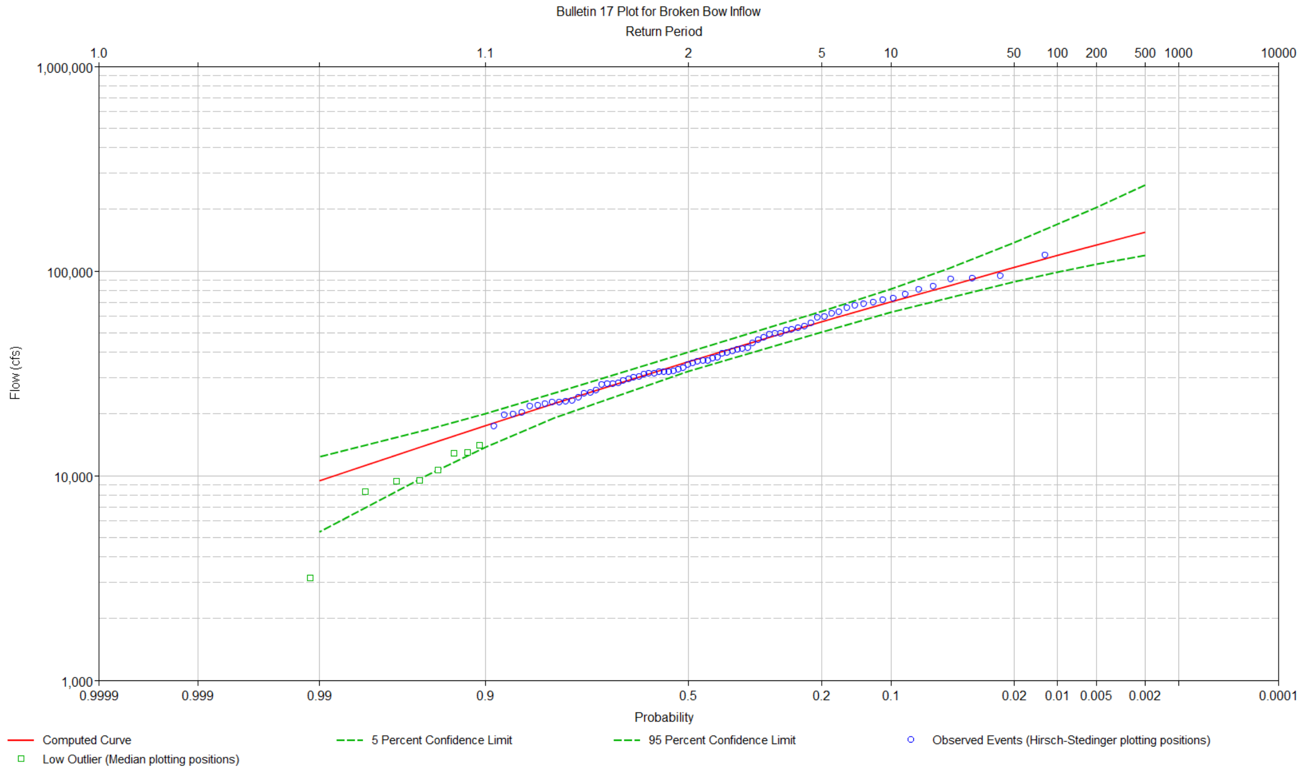
13.7 SMITHVILLE

Based on RiverWare		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	54,022	91,920	41,728
0.5	46,796	71,852	37,735
1	41,496	59,153	34,481
2	36,326	48,229	31,001
5	2,965	36,169	26,006
10	34,669	28,652	21,930
20	19,657	22,202	17,615
50	12,555	14,016	11,279

DA ratio based on RW results from Broken Bow inflows.

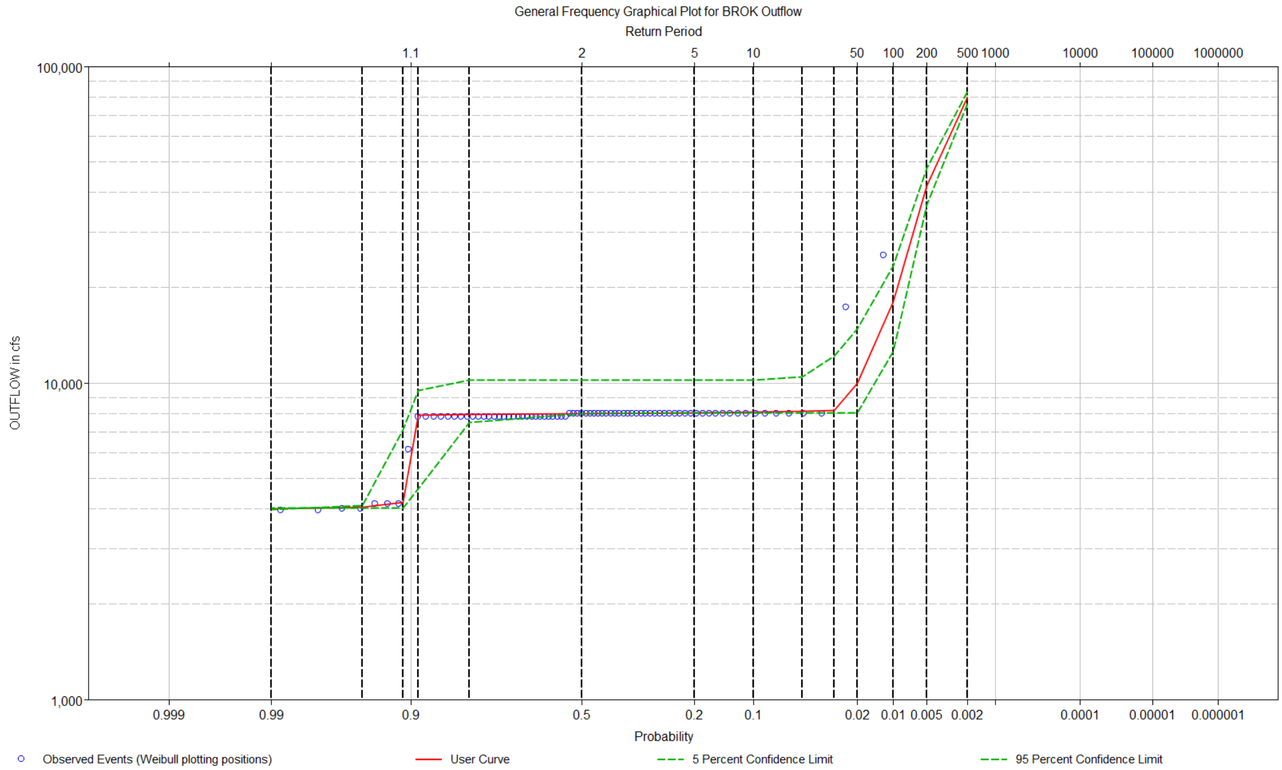
13.8 BROKEN BOW INFLOWS

RiverWare Inflows 17C		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	154,573	262,629	119,224
0.5	133,897	205,291	107,813
1	118,734	169,010	98,518
2	103,940	137,796	88,575
5	84,839	103,340	74,302
10	70,587	81,864	62,657
20	56,243	63,433	50,330
50	35,925	40,045	32,225
80	22,532	25,265	19,272
90	17,527	20,022	13,756
95	14,189	16,726	10,089
99	9,457	12,306	5,307



13.9 BORKEN BOW OUTFLOWS

RiverWare Outflows Graphical		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	80,000	83,504	76,496
0.5	42,000	47,532	36,468
1	18,000	23,400	12,600
2	10,000	14,776	8,028
3	8,200	12,129	8,028
5	8,150	10,452	8,028
10	8,100	10,235	8,028
20	8,050	10,235	8,026
50	8,000	10,235	7,986
80	7,950	10,235	7,516
89	7,900	9,473	4,641
91	4,200	7,105	4,019
95	4,050	4,098	4,019
99	4,000	3,981	4,019

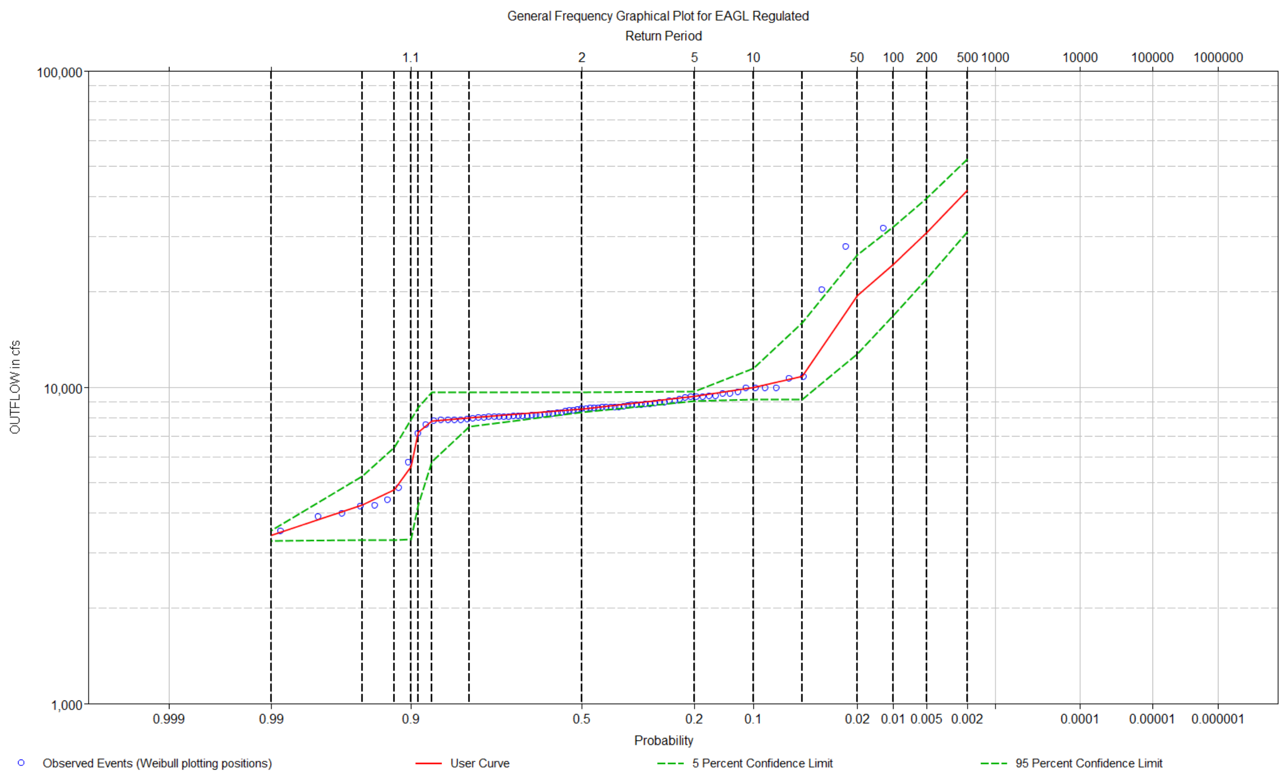


BROK Elevations	
% Exceedance	Elevation (ft)
0.2	631.5
0.5	631.0
0.1	630.0
2	628.8
5	626.5
10	623.0
20	616.5
50	609.7
Reported in NGVD 29 and converted to NAVD 88	

13.10 EAGLETOWN

RiverWare Graphical		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	41,874	52,681	31,067
0.5	30,762	39,547	21,976
1	24,445	32,081	16,809
2	19,502	26,239	12,765
5	10,800	15,965	9,158
10	9,960	11,456	9,158
20	9,377	9,698	9,056
50	8,530	9,655	8,335
80	7,975	9,655	7,480
87	7,800	9,655	5,814
89	7,200	8,601	4,233
90	5,600	7,906	3,294
92	4,750	6,435	3,286
95	4,250	5,220	3,280
99	3,400	3,529	3,271

Eagletown is extremely regulated from Broken Bow and the Broken Bow re-regulation dam.



13.11 CONFLUCENCE OF LITTLE RIVER AND MOUNTAIN FORK

Based on RiverWare		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	39,090	46,892	31,531
0.5	34,798	44,840	28,766
1	31,214	40,211	26,393
2	27,456	34,483	23,764
5	22,396	26,678	19,923
10	18,629	21,330	16,851
20	14,055	16,733	13,818
50	10,656	11,481	10,116

DA ratio based on RW results from HORA.

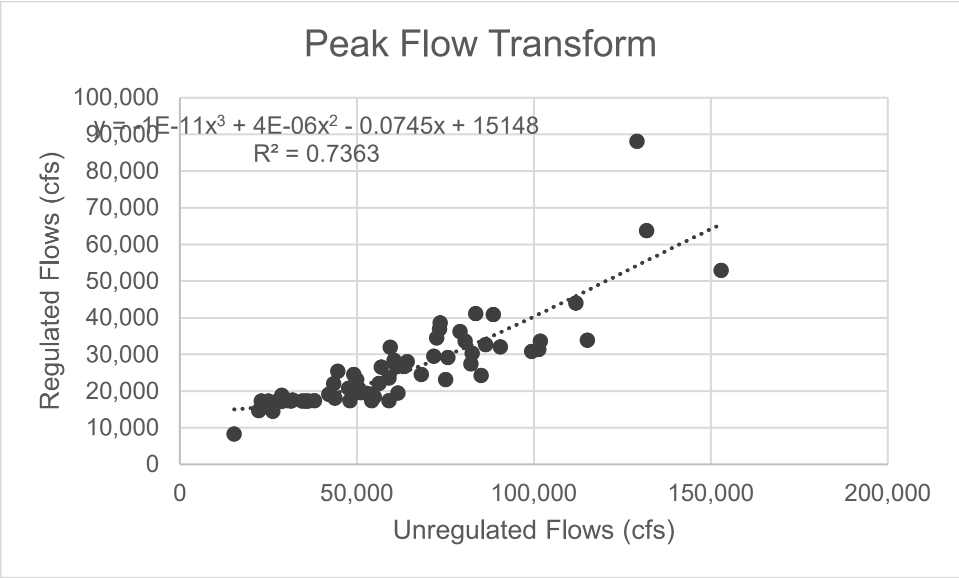
13.12 HORATIO

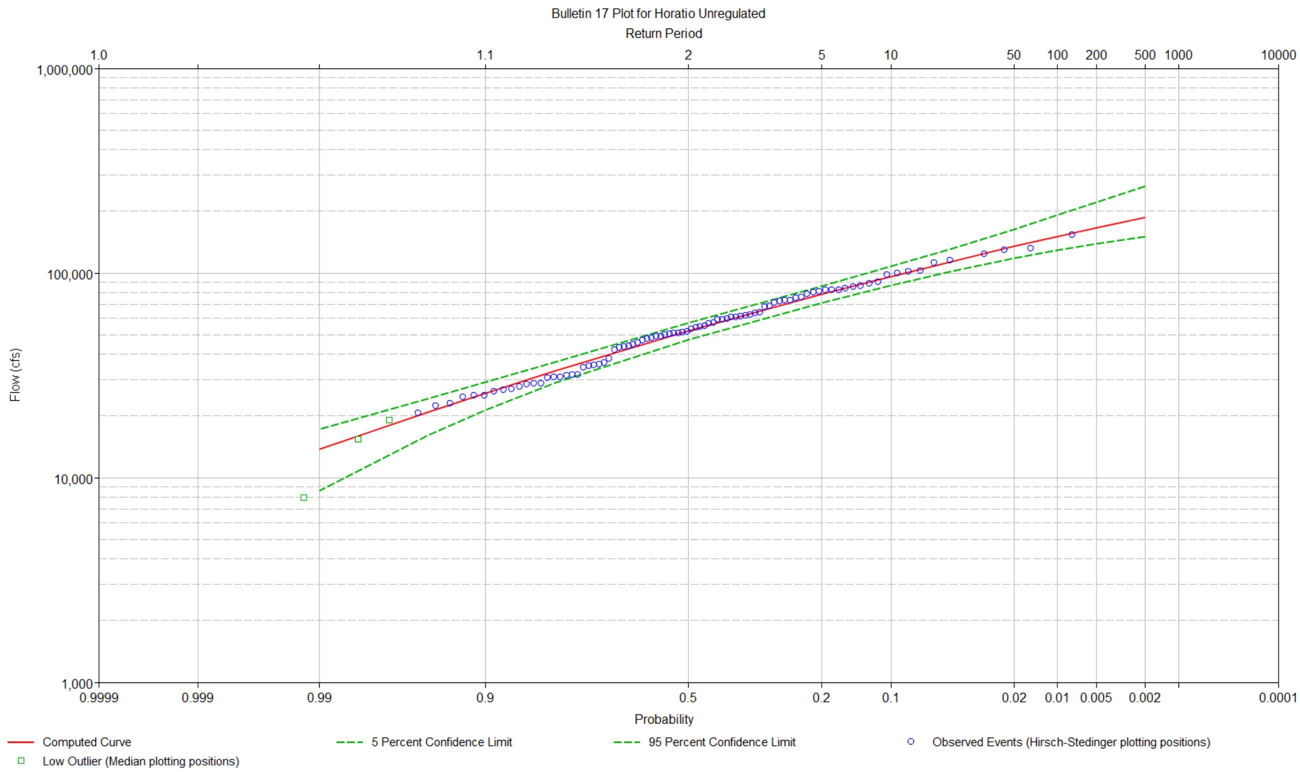
Transformed Regulated 17C Flows			
		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	75,745	90,177	60,636
0.5	67,429	86,230	55,319
1	60,484	77,328	50,756
2	53,202	66,314	45,699
5	43,398	51,304	38,313
10	36,098	41,019	32,406
20	29,109	32,178	26,573
50	20,649	22,079	19,454
80	16,706	17,327	16,116
90	15,722	16,135	15,284
95	15,247	15,548	14,938
99	14,855	15,003	14,797

Based on unregulated RW results then transformed through peak flow transform.

Unregulated 17C Flows			
		Confidence Limits (cfs)	
% Exceedance	Flow (cfs)	0.05	0.95
0.2	187,120	265,502	150,918
0.5	166,392	221,533	139,215
1	150,581	191,460	129,264
2	134,598	163,789	118,169

5	113,047	130,460	101,442
10	96,204	107,678	87,123
20	78,494	86,545	71,379
50	51,865	57,117	47,042
80	33,125	36,810	29,062
90	25,844	29,203	21,356
95	20,902	24,218	15,973
99	13,786	17,265	8,591





Bulletin 17 Plot for Horatio Unregulated
Return Period
1.0
1.1
2
5
10
50
100
200
500
1000
10000
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.9999
0.999
0.99
0.9
0.5
0.2
0.1
0.02
0.01
0.005
0.002
0.0001
Probability
Computed Curve
5 Percent Confidence Limit
95 Percent Confidence Limit
Observed Events (Hirsch-Stedinger plotting positions)
Low Outlier (Median plotting positions)