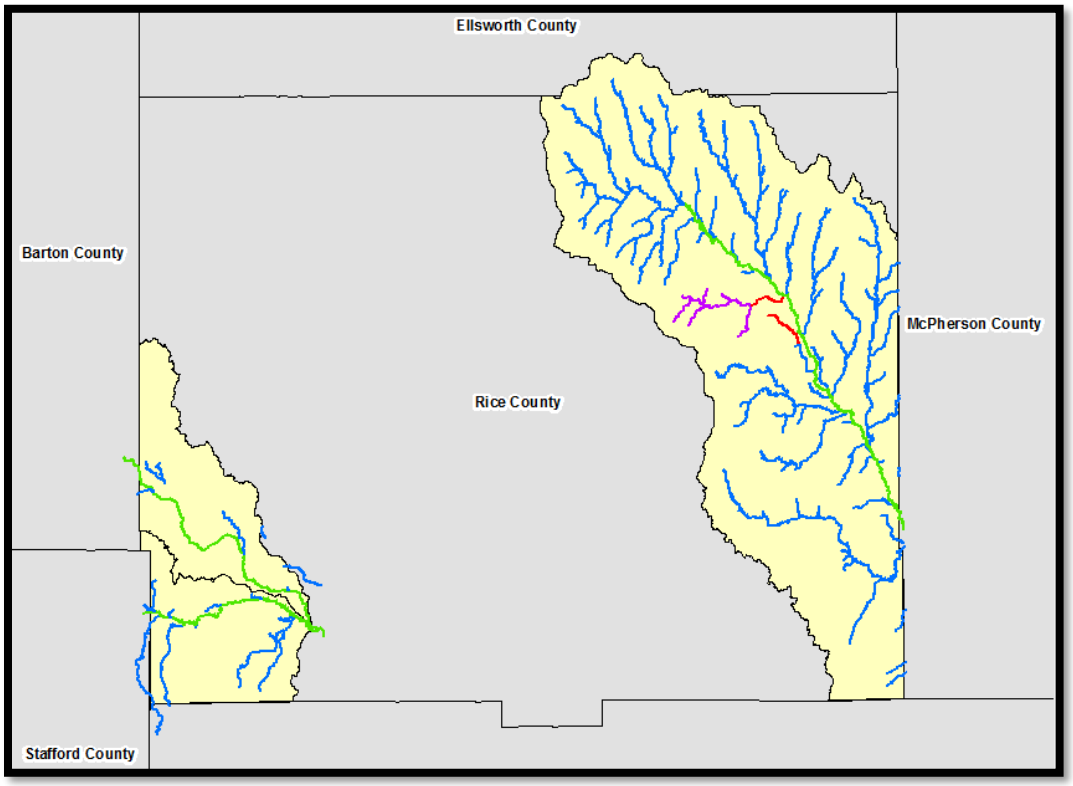
# HYDROLOGY REPORT

## RICE COUNTY (WITHIN LITTLE ARKANSAS, COON-PICKEREL, AND RATTLESNAKE WATERSHEDS)

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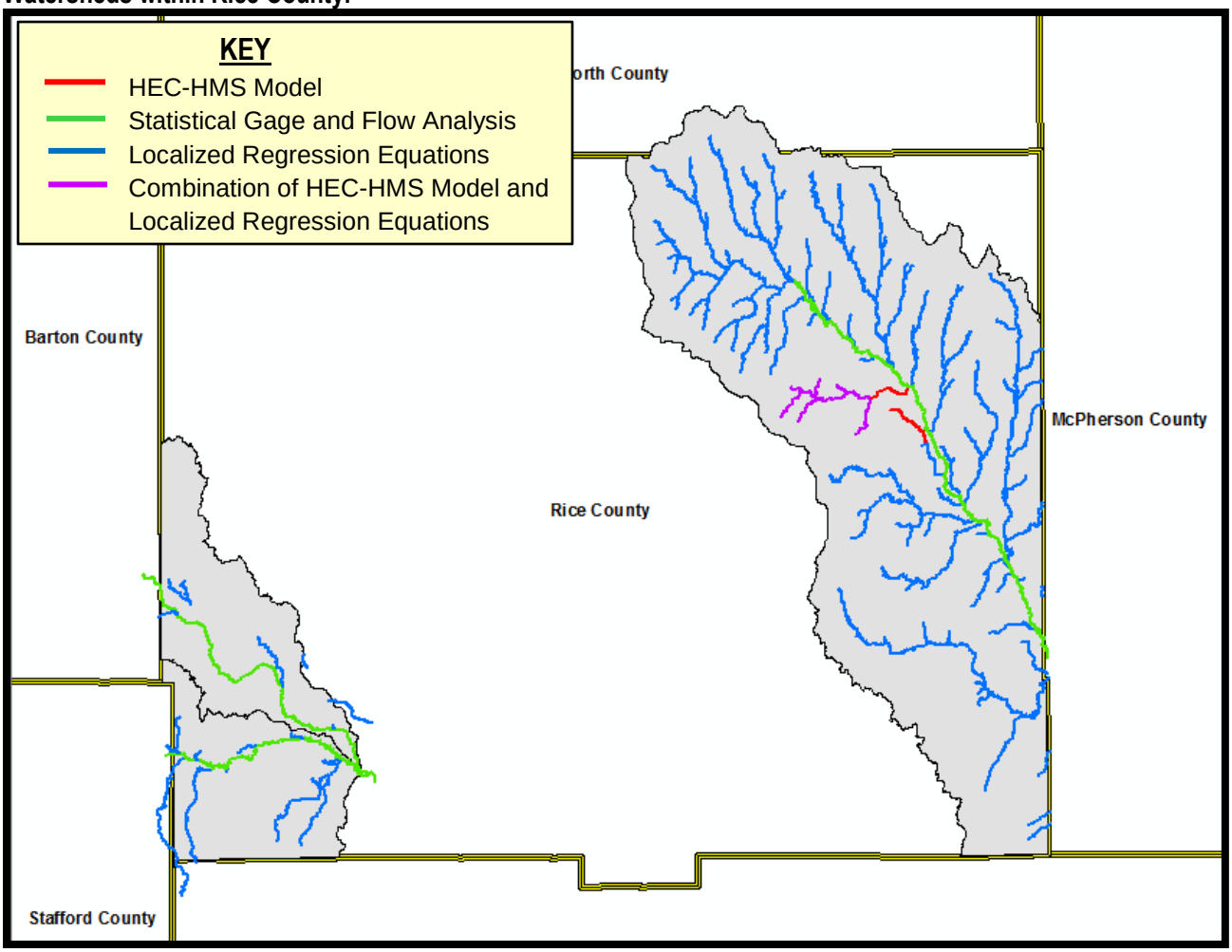
# INTRODUCTION

This report presents the hydrologic analyses for the enhanced Zone AE designated streams and approximate Zone A designated streams in Rice County that lie within the Little Arkansas River Watershed (HUC8 11030012), the Coon-Pickerel Watershed (HUC8 11030004), and the Rattlesnake Watershed (HUC8 11030009). This project consists of new hydrologic and hydraulic studies using current watershed characteristics and new detailed topography for approximately 4.1 miles of streams modeled by enhanced methods, including rainfall-runoff model hydrology and field measured structures, resulting in updated Zone AE floodplains without a floodway; and approximately 330.1 miles of streams studied by approximate methods, resulting in updated Zone A floodplains. Enhanced hydrology was performed on approximately 15.9 miles of streams, including the enhanced Zone AE streams and several additional Zone A streams within the Little Arkansas River Tributary 14 watershed, using rainfall-runoff models. In addition, statistical gage and flow analysis was performed for approximately 52.7 miles of Zone A streams, including the Arkansas River, Little Arkansas River, and Salt Creek. For streams not included in a rainfall-runoff model or statistical gage and flow analysis, Zone A stream hydrology was performed using localized regression equations that were developed for the Cow Watershed, which encompasses the majority of Rice County, and previously approved for use in this study area. A summary of the streams that were studied is shown in Table 1. A figure that shows the type of hydrologic method used for each stream is shown in Figure 1.

**Table 1: Summary of Methods**

| Study Area/Flooding Source | Stream Miles | Hydrologic Method |
|---|---|---|
| Arkansas River | 15.2 | Statistical Gage and Flow Analysis |
| Little Arkansas River | 24.5 | Statistical Gage and Flow Analysis |
| Little Arkansas River Trib 11 | 1.9 | Rainfall-Runoff Model (HEC-HMS) |
| Little Arkansas River Trib 14 | 2.2 | Rainfall-Runoff Model (HEC-HMS) |
| Salt Creek | 13.0 | Statistical Gage and Flow Analysis |
| Various Zone A Streams within Little Arkansas River Trib 14 Watershed | 11.8 | Combination of HEC-HMS and Localized Regression Equations |
| Various Zone A Streams | 265.6 | Localized Regression Equations |
| **Total** | **334.2** | - |

**Figure 1- Type of Hydrologic Modeling for Each Stream in the Little Arkansas, Coon-Pickerel, and Rattlesnake Watersheds within Rice County.**




This hydrologic study was performed to develop peak discharges for the 10%, 4%, 2%, 1%, 1%+ and 0.2% annual chance storm events. The peak discharges computed from this analyses will be used in developing the hydraulic analyses for the streams within this study.

The extents of the approximate Zone A studies include those streams currently designated by FEMA, plus the conveyances with drainage areas equal to or greater than 1-square mile of drainage area; excluding those "conveyances" that have contributing drainage areas of less than one square mile, and/or lack a defined channel. A detailed adjustment of the stream network relative to aerial photography and LiDAR was completed to ensure proper streamline alignment and extent.

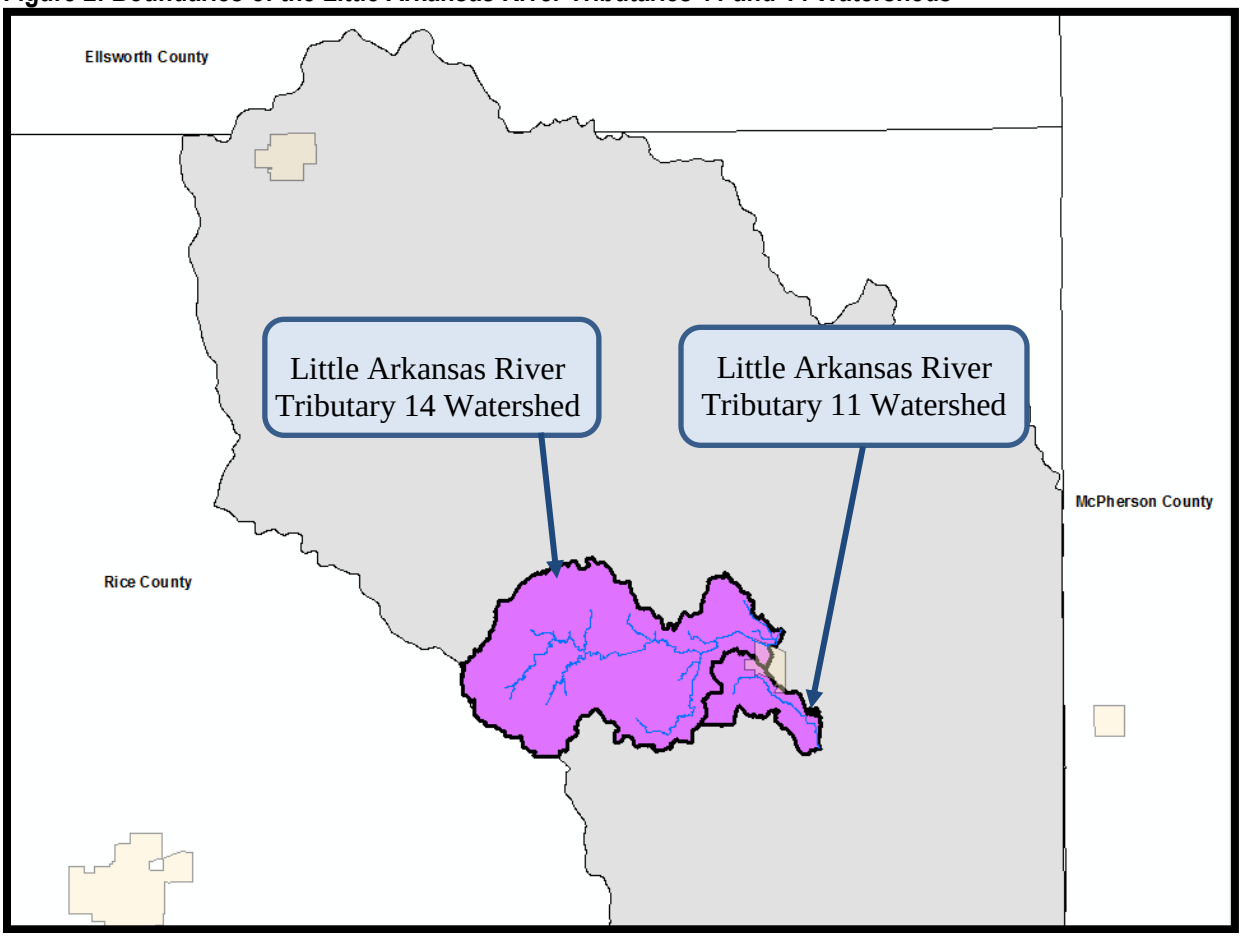
The current effective Flood Insurance Study (FIS) Report for Rice County is dated September, 1997.

## GENERAL RAINFALL-RUNOFF MODEL

The rainfall-runoff model HEC-HMS version 4.2 (Reference 2), developed by the USACE, was used for the two detailed rainfall-runoff models within this project, which include Little Arkansas River Tributary 11 and Little Arkansas River Tributary 14. Figure 2 shows the extent of these two rainfall-runoff models. Amec Foster Wheeler used HEC-HMS to generate subbasin runoff hydrographs for the 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% chance 24-hour SCS Type II rainfall events. These runoff hydrographs were routed and combined along the studied streams to produce the peak discharges.

Subbasin boundary delineations were based on topography obtained as 1-meter LiDAR through the Kansas Data Access and Support Center (DASC). Subbasin boundaries were first delineated using automated GIS processes including HEC-GeoHMS (Reference 3) and ArcHydro (Reference 4) based on LiDAR Digital Elevation Models (DEM), and then manually edited as needed based on storage considerations and the most recent aerial photography available.

**Figure 2: Boundaries of the Little Arkansas River Tributaries 11 and 14 Watersheds**




The town partially encompassed within the detailed rainfall-runoff models, Little River, has a total population of around 550 people and has minimal storm water drainage systems. Furthermore, the majority of the storm water drainage systems in which they do have were only designed to contain runoff from the smaller storm events, generally the 10% annual chance event or smaller. The

primary purpose of this mapping update is to accurately model the risk associated with the larger storm events, specifically the 1% annual chance and 0.2% annual chance flooding events. During these larger storm events, surface water does not necessarily follow the sub-surface flows of the storm water drainage systems. Therefore, the storm water drainage networks (storm sewers) were not included in the HEC-HMS models as they are considered insignificant for the larger storm events and for this particular study.

## RAINFALL

The rainfall depths, shown in Table 2, were computed using rainfall grids developed by NOAA as part of Atlas 14: Precipitation-Frequency Atlas of the United States (Reference 5). The depths represent an average of all partial-duration grid values within the areas that are included in the rainfall-runoff models. The 100-year minus and 100-year plus rainfall depths were computed by using the 100-year rainfall depth and the 95% upper confidence interval for the 100-year rainfall depth published in Atlas 14, along with the known sample size of 1,000 data sets used in Atlas 14, to compute the standard deviation. This computed standard deviation was then used to calculate the 84% lower and 84% upper confidence limits, which are the values used for the 100-year minus and 100-year plus rainfall depths, respectively.

**Table 2: SCS Type II 24-hour Rainfall Depths**

| Event | Little Arkansas River Watershed Depth (inches) |
|---|---|
| 10-year | 4.5 |
| 25-year | 5.5 |
| 50-year | 6.3 |
| 100-year | 7.2 |
| 100-year minus | 5.8 |
| 100-year plus | 8.6 |
| 500-year | 9.4 |

Rainfall values were also computed using the annual-maximum series. A comparison of these rainfall values to the partial-duration series is shown in Table 3. The mean rainfall values for each storm event are the same when using both the partial-duration grid values and the annual-maximum grid values.

**Table 3: Comparison of Rainfall for Partial-Duration and Annual-Maximum Series**

| Event | Partial-Duration Series | | | Annual-Maximum Series | | |
|---|---|---|---|---|---|---|
| | Minimum (in) | Mean (in) | Maximum (in) | Minimum (in) | Mean (in) | Maximum (in) |
| 10-year | 4.4 | 4.5 | 4.9 | 4.4 | 4.5 | 4.6 |
| 25-year | 5.4 | 5.5 | 5.7 | 5.4 | 5.5 | 5.7 |
| 50-year | 6.2 | 6.3 | 6.5 | 6.2 | 6.3 | 6.5 |
| 100-year | 7.1 | 7.2 | 7.4 | 7.1 | 7.2 | 7.4 |
| 100-year upper | 9.1 | 9.2 | 9.3 | 9.0 | 9.2 | 9.3 |
| 500-year | 9.3 | 9.4 | 9.5 | 9.3 | 9.4 | 9.5 |

## RAINFALL LOSS

The U.S. Department of Agriculture Soil Conservation Service (SCS) Curve Number (CN) Method was used to model rainfall loss (Reference 8). The curve number is a function of both hydrologic soil group and land use. The table used to determine the CN value from the soil hydrologic soil group and land use is included as Table 4. The CN tables used assume an antecedent moisture condition (AMC) of II as it is representative of typical conditions, rather than the extremes of dry conditions (AMC I) or saturated conditions (AMC III).

The value for initial abstraction was left blank in the HMS input file. Per the HMS documentation, doing so will cause the program to calculate the initial abstraction as 0.2 times the maximum potential retention (S) which is calculated from the curve number as S = (1000/CN) – 10. This method is based on empirical relationships developed from the study of many small experimental watersheds, and is a commonly accepted method of estimating the initial abstraction.

### SOILS DATA

Soils data was obtained in shapefile and database format from the United Stated Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) website (Reference 6). Typical soils in the study area consist of hydrologic soil groups B, C and D.

### LAND USE

Land use was determined using a combination of data from the National Land Cover Dataset (NLCD) website (Reference 7) and aerial photography. Fifteen land use designations were utilized to develop the CN values for each subbasin. The CN values were taken from "TR-55 Urban Hydrology for Small Watersheds" Table 2-2 (Reference 8). The land use designations are located in Table 4. As previously mentioned, the CN values were first calculated using AMC II conditions, as represented in Table 4.

**Table 4: CN Land Use and Soil Drainage Class Table**

| Land Use Description | Weighted CN (Includes Impervious) | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Open Water | 98 | 98 | 98 | 98 |
| Developed, Open Space | 51 | 68 | 79 | 84 |
| Developed, Low Intensity | 57 | 72 | 81 | 86 |
| Developed, Medium Intensity | 77 | 85 | 90 | 92 |
| Developed, High Intensity | 89 | 92 | 94 | 95 |
| Deciduous Forest | 30 | 55 | 70 | 77 |
| Shrub/Scrub | 43 | 65 | 76 | 82 |
| Herbaceous | 43 | 65 | 76 | 82 |
| Hay/Pasture | 49 | 69 | 79 | 84 |
| Cultivated Crops | 65 | 75 | 82 | 86 |
| Woody Wetlands | 36 | 60 | 73 | 79 |
| Emergent Herbaceous Wetlands | 36 | 60 | 73 | 79 |

The soil and land use data were combined using GIS processes in which specific curve numbers were defined for each soil-land use relationship shown in the CN Land Use and Soil Drainage Class Table (Table 4). Area-weighted curve number values were computed for each subbasin using GIS processes. The area weighted CN values were used in the HEC-HMS models.

## RAINFALL TRANSFORM (HYDROGRAPH)

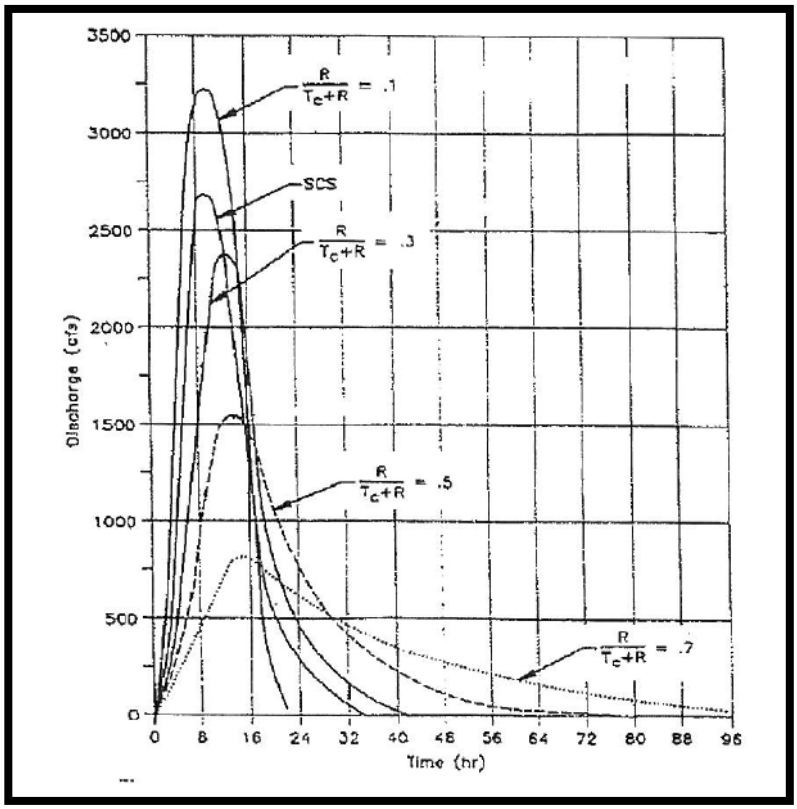
The time of concentration for each subbasin was calculated using the methodology outlined in TR-55 Urban Hydrology for Small Watersheds (Reference 8) and Chapter 15: Time of Concentration of the National Engineering Handbook (Reference 9). A GIS process was utilized to calculate the longest flow path within any given subbasin. The longest flow paths were then manually edited based on contour data and visual inspection of aerial photography to produce an effective time of concentration line. The total time of concentration consists of the sum of the travel times for sheet flow, shallow concentrated flow, and channel flow. Sheet flow lengths were assigned to be approximately 300 feet or less, using the aerial imagery as a guide, based on information described in TR-55 Urban Hydrology for Small Watersheds (Reference 8). The areas within the HEC-HMS models are relatively flat, rural areas. Therefore, in most cases it is appropriate to allow the maximum length of sheet flow for the majority of the subbasins. The division between shallow concentrated flow and channel flow was defined based on watershed features exhibited on the aerial images and topography. In certain situations, it was necessary to define multiple shallow concentrated and channel flow regimes for a given longest flow path. Time of concentration over water bodies was calculated using wave velocity.

The parameters of flow area and wetted perimeter are required inputs for calculating the flow velocity used in the channel time of concentration calculations. Typical channel cross sections were defined for each subbasin, and trapezoidal cross-sections were defined from the project topography. In order to calculate the flow area and wetted perimeter, several factors need to be considered. For open channel flow, a trapezoidal channel shape was selected based on examination of aerial photography and topography. Channel width was approximated by close visual inspection of the aerial photography and LiDAR topography.

The runoff was transformed into a hydrograph using the Clark Unit Hydrograph method. The project area contains many small farm ponds in addition to the larger dams/storage areas included in the models. The Clark Unit Hydrograph method allows the models to account for surface storage attenuation where the inclusion of detailed storage areas is not feasible. Based on this method, a clark's ratio is determined for each subbasin based on differing land use types in order to control the runoff hydrograph shape. The clark's ratio is applied to the time of concentration, using the equation shown on the following page, to determine a storage/concentration coefficient, which is then entered into the hydrograph equation. Figure 3, which is from Chapter 7: Precipitation Excess-Runoff Transformation of the US Army Corps of Engineers's Flood-Runoff Analysis Engineer Manual (Reference 16), illustrates the effects of various storage/concentration coefficients on the hydrograph shape.

Table 5, shown on the following page, was derived using the methodology described in Chapter 7: Precipitation Excess-Runoff Transformation of the US Army Corps of Engineers's Flood-Runoff Analysis Engineer Manual (Reference 16), and represents the clark's ratio classification that was used to define the clark's ratio for each subbasin. The clark's ratio is based on basin slope, storage considerations, and land use type.

**Figure 3: Storage/Concentration Coefficient Hydrograph Curves**




SC=Tc*Ratio/(1-Ratio)

Where:
SC = Storage/Concentration Coefficient
Tc = Time of Concentration
Ratio = Clark's Ratio

| Table 5: Classification To Define Clark's Ratio | | | |
|---|---|---|---|
| **Subbasin Description** | **Minimum % Slope[1]** | **Maximum % Slope[1]** | **Clarks Ratio** |
| Highly Developed | 0 | 3 | 0.3 |
| Highly Developed | 3 | 6 | 0.25 |
| Highly Developed | 6 | - | 0.2 |
| Residential | 0 | 3 | 0.35 |
| Residential | 3 | 6 | 0.3 |
| Residential | 6 | - | 0.25 |
| High Storage Residential[2] | 0 | 3 | 0.4 |
| High Storage Residential[2] | 3 | 6 | 0.35 |
| High Storage Residential[2] | 6 | - | 0.3 |
| Rural Steepland | 4 | 8 | 0.45 |
| Rural Steepland | 8 | - | 0.4 |
| Rural Flatland | 0 | 2 | 0.6 |
| Rural Flatland | 2 | 4 | 0.5 |
| High Storage Rural Steepland[2] | 4 | 8 | 0.5 |
| High Storage Rural Steepland[2] | 8 | - | 0.45 |
| High Storage Rural Flatland[2] | 0 | 2 | 0.65 |
| High Storage Rural Flatland[2] | 2 | 4 | 0.55 |

1- Percent Slope is based on the average slope of the basin.
2- Storage areas that are represented separately within the HMS model are not considered when evaluating Basins with "High Storage"

## HYDROGRAPH ROUTING

The Muskingum-Cunge channel routing method was used for routing runoff through all reaches in the modeling. The channel geometry, slope, and hydraulic roughness were assigned, based on the LiDAR data and the aerial images. Eight-point cross sections were developed, based on examination of aerial photography and topography. Manning's channel roughness values for the routing reaches were selected based off the aerial photography.

## LITTLE ARKANSAS RIVER TRIBUTARIES 11 AND 14 WATERSHEDS

The HEC-HMS model of the Little Arkansas River Tributary 11 watershed has a total drainage area of approximately 1.45 square miles. The model includes seven subbasins, ranging from 47 to 174 acres. Two of the subbasins contain residential areas within the city of Little River, while the remaining areas are predominately rural.

The HEC-HMS model of the Little Arkansas River Tributary 14 watershed has a total drainage area of approximately 9.9 square miles. The model includes 40 subbasins, ranging from 14 to 561 acres. One subbasin contains primarily urbanized areas within the city of Little River, one subbain contains a small portion of residential area within the city of Little River, and the remaining areas are predominately rural.

### Rainfall and Areal Reduction

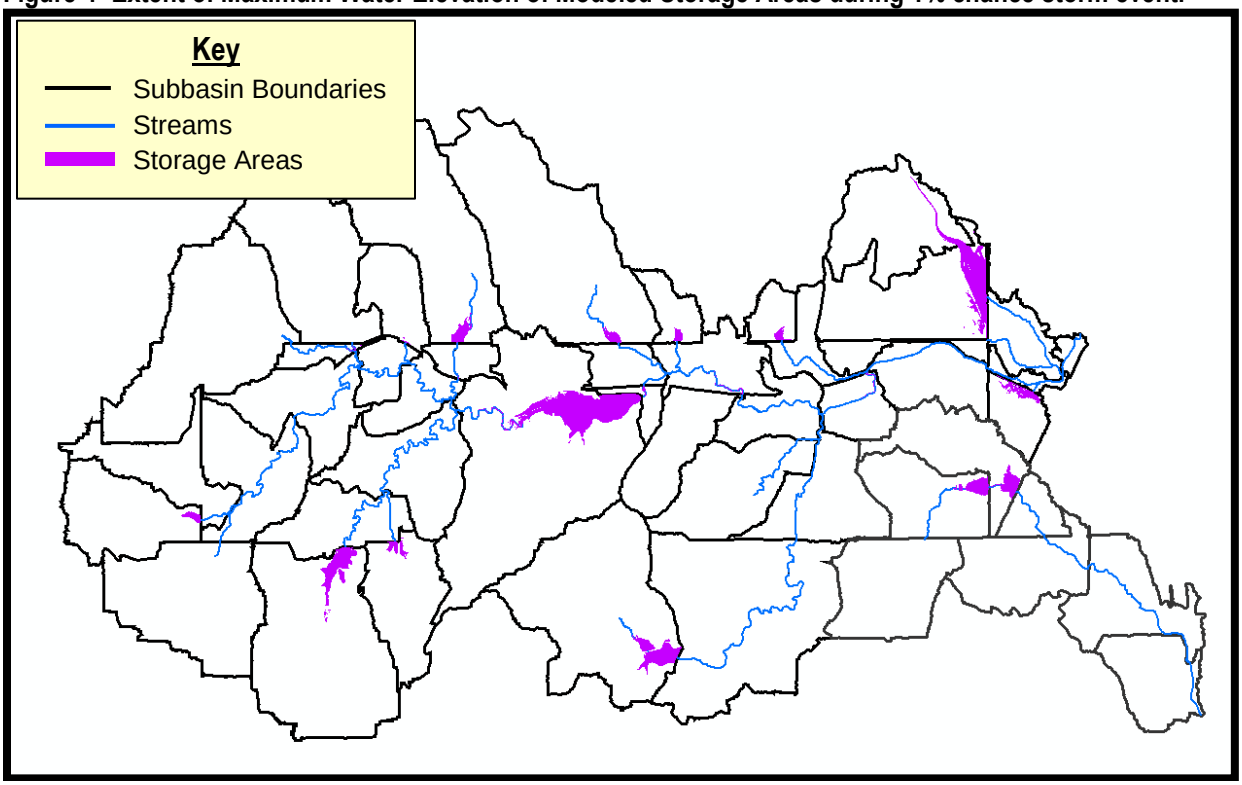
Areal reduction of the point rainfall depths was not deemed necessary for the Little Arkansas River Tributary 11 and Little Arkansas River Tributary 14 watershed studies since the contributing drainage area would have resulted in insignificant rainfall depth reductions based on the area-depth curves of TP-40.

### Storage Routing

Two storage areas were modeled in the Little Arkansas River Tributary 11 hydrologic model. These two storage areas represent storage behind road embankments, located along the stream. Seventeen storage areas were modeled in the Little Arkansas River Tributary 14 hydrologic model. Three of the storage areas represent storage behind significant dams located within the watershed, and fourteen storage areas represent storage behind road/railroad embankments within the watershed. The criteria for including storage areas within the model was based on the storage type and the storage volume. Specifications for dam tops, associated spillways, and associated outlet structures were included in the HEC-HMS model, where applicable. Survey information, obtained by Amec Foster Wheeler, was used for the outlet structures, where access to the structures was available. Information on the dam tops and spillways of these storage areas were obtained using LiDAR topography.

Figure 4, shown on the next page, illustrates the extent of the maximum water elevation during the 1% annual chance storm event for all the storage areas included in the HEC-HMS models for the Little Arkansas River Tributary 11 and Little Arkansas River Tributary 14 watersheds, along with subbasin boundaries.

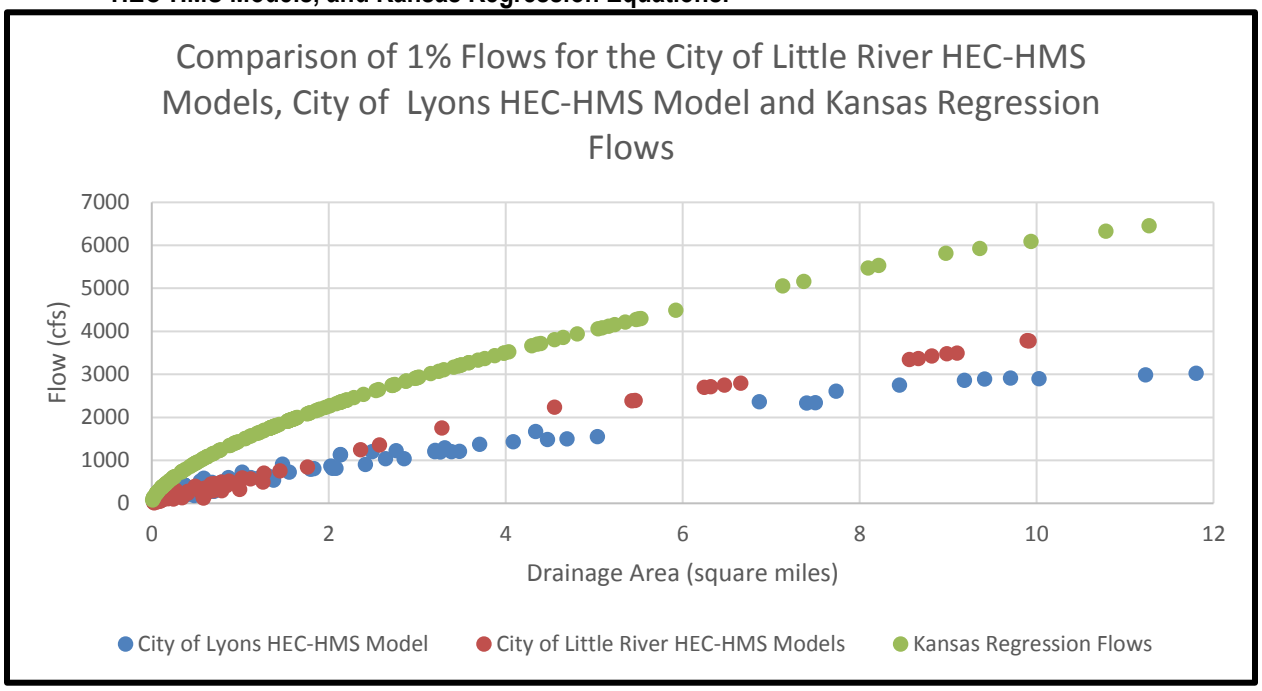
**Figure 4- Extent of Maximum Water Elevation of Modeled Storage Areas during 1% chance storm event.**




## FLOW COMPARISON

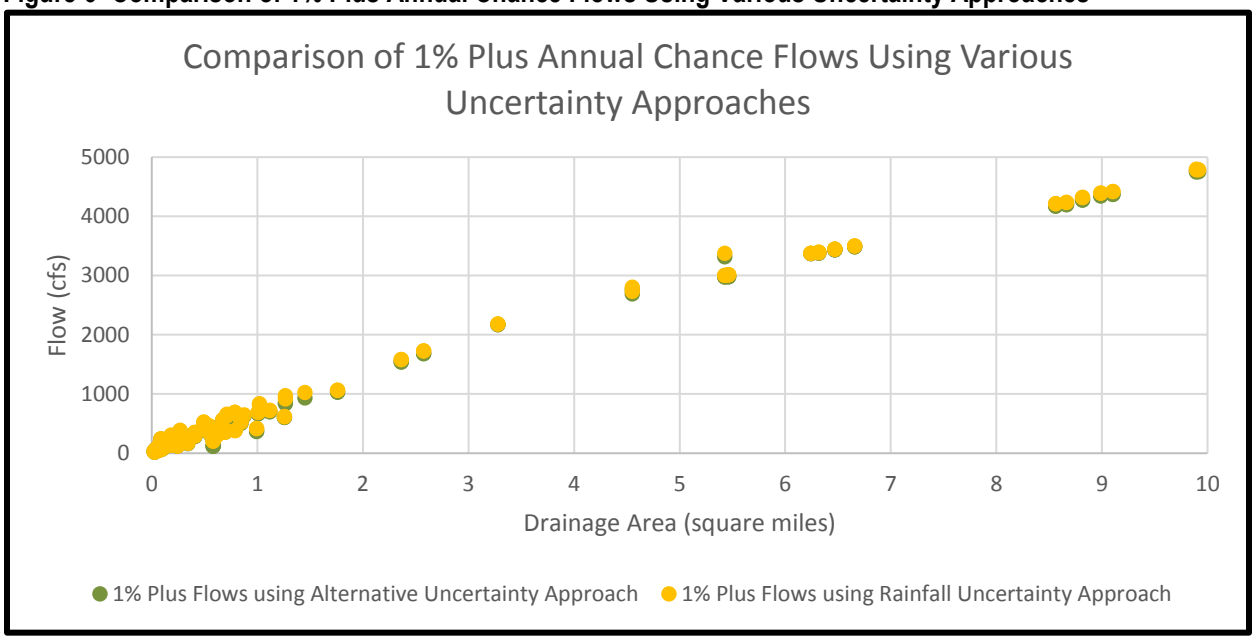
There is not an effective FIS Report for the City of Little River, Kansas. The peak discharges from these HEC-HMS models were compared to the peak discharges from the HEC-HMS models for the Cow Watershed and the Kansas Regression Equations. The Cow Watershed encompasses the majority of Rice County and is described in detail in the Hydrology Report for the Cow Watershed (Reference 15). Figure 5 shows a comparison between the 1% annual chance flows from the HEC-HMS models for the City of Little River, which encompasses the Little Arkansas River Tributaries 11 and 14 watersheds; the 1% annual chance flows from the HEC-HMS models for the City of Lyons, which encompasses the Owl Creek, Salt Creek, and Surprise Creek Watersheds; and the Kansas Regression Flows. The flows from the HEC-HMS models for the City of Little River fall well below the Kansas Regression Flows, and closely align to the flows from the HEC-HMS models for the City of Lyons. Lyons is the county seat for Rice County, and is located near the center of the County, southeast of Little River.

**Figure 5- Comparison of 1% Annual Chance Flows from City of Little River HEC-HMS Models, City of Lyons HEC-HMS Models, and Kansas Regression Equations.**




The 1% plus annual chance flows generated by the HEC-HMS models, which accounts for variability that exists in the statistics of the rainfall calculations by using a 1% plus rainfall depth, were compared to the 1% plus annual chance flows calculated using an alternative method that combines the procedures described in Bulletin 17B (Reference 10) and the US Army Corps of Engineer's Risk-Based Analysis for Flood Damage Reduction Studies Engineer Manual (Reference 17), which utilizes the 50%, 10%, and 1% annual chance peak flows from the HEC-HMS models and an equivalent record length. Figure 6 shows the comparison between the two different uncertainty approaches. The calculations for the alternative uncertainty approach uses an equivalent record length of 30 years, which is an appropriate equivalent record length for calibrated rainfall-runoff models based on the guidance. The 1% plus annual chance flows using the rainfall uncertainty approach are nearly identical to the 1% plus annual chance flows using the alternative uncertainty approach with an equivalent record length of 30 years. While 30 is documented as the maximum equivalent record length to be used in the calculations, it still falls within an appropriate range for the modeling done and aligns with the 1% plus annual chance flows generated by the HEC-HMS model, using the 1% plus rainfall depth. This, combined with the fact that the 1% plus flows for the Cow Watershed, which encompasses the majority of Rice County and has been previously approved by FEMA, were determined using the rainfall uncertainty approach, it was deemed appropriate to utilize that same approach for the streams included in the HEC-HMS models for this project.

**Figure 6- Comparison of 1% Plus Annual Chance Flows Using Various Uncertainty Approaches**




## GAGE ANALYSIS

Seven USGS gage stations were analyzed as part of this study. There are three gages on the Little Arkansas River; one near Geneseo, Kansas; one near Little River, Kansas; and one at Alta Mills, Kansas The gage near Geneseo is located at 22nd Road. The gage near Little River is located at 26th Road, just below the confluence with Horse Creek. The gage at Alta Mills is located at North River Park Road. The gage on Rattlesnake Creek is located downstream of NE 80th Avenue, near Zenith, Kansas; which is upstream of the area included in this study. Rattlesnake Creek changes name to Salt Creek approximately 2.5 miles upstream of its entrance into Rice County, as the direction of the stream changes to a more easterly direction. A summary of these four gages is shown in Table 6. Annual peak flow records were obtained from the USGS Water Resources website (Reference 14). The gages on Little Arkansas River at Alta Mills and Rattlesnake Creek near Zenith have significant period of record in which a confident peak flow frequency analysis was computed. The gage near Little River has just enough years of record in which a confident peak flow frequency analysis could be computed. The gage near Geneseo does not have enough years of record for a confident peak flow frequency analysis.

Three USGS gage stations located on the Arkansas River were analyzed as part of this study. The furthest upstream gage that was analyzed is located just downstream of Highway 281, in Great Bend, Kansas. The next gage is located just upstream of West 82nd Avenue, near Nickerson, Kansas. The furthest downstream gage that was analyzed is located just downstream of Haven Road, southeast of Hutchinson, Kansas. A summary of these gages is shown in Table 6, as well. Annual peak flow records were obtained from the USGS Water Resources website (Reference 14). The gages at Great Bend and near Hutchinson have significant periods of record in which a confident peak flow frequency analysis could be computed. The gage near Nickerson does not have enough years of record for a confident peak flow frequency analysis.

| Table 6: Summary of USGS Stream Gages | | | |
|---|---|---|---|
| **USGS Gage Number** | **Gage Description** | **Drainage Area ($mi^2$)** | **Period of Record** |
| 07143500 | Little Arkansas River near Geneseo, KS | 25 | 1957-1977 |
| 07143600 | Little Arkansas River near Little River, KS | 71 | 1960-1985 |
| 07143665 | Little Arkansas River at Alta Mills, KS | 681 | 1973-2015 |
| 07142575 | Rattlesnake Creek near Zenith, KS | 519 | 1973-2015 |
| 07141300 | Arkansas River at Great Bend, KS | 34,356 | 1941-2015 |
| 07142680 | Arkansas River near Nickerson, KS | 36,015 | 1997-2015 |
| 07143330 | Arkansas River near Hutchinson, KS | 38,910 | 1960-2015 |

Gage analyses were performed on these USGS gages using Bulletin 17B parameters (Reference 10), utilizing the USACE HEC-SSP software (Reference 11).

*USGS 07143500- Little Arkansas River near Geneseo, KS*
USGS Station 07143500 is located near Geneseo, Kansas and has 21 years of record, dating from 1957 to 1977. Frequency flow estimates were calculated for this site, but were not used as there is not enough years of record for a confident analysis to be performed, and as the record ended 40 years ago.

*USGS 07143600- Little Arkansas River near Little River, KS*
USGS Station 07143600 is located near Little River, Kansas and has 27 years of record, dating from 1960 to 1985. Frequency flow estimates were calculated for this site. The record for 1973 did not include a peak flow, and was thus removed from the analysis. For this study, the expected probability values were selected over the computed curve values because the expected probability produces values higher, thus more conservative, than the computed curve and is recommended for use by Bulletin 17B.

*USGS 07143665- Little Arkansas River at Alta Mills, KS*
USGS Station 07143665 is located at Alta Mills, Kansas and has 43 years of record, dating from 1973 to 2015, suitable for computing frequency flow estimates. The record for 2013 was removed from the analysis as it was labeled as being affected by regulation. For this study, the expected probability values were selected over the computed curve values because the expected probability produces values higher, thus more conservative, than the computed curve and is recommended for use by Bulletin 17B. It should be noted that this gage is downstream of the study area for this project.

*USGS 07142575- Rattlesnake Creek near Zenith, KS*
USGS Station 07142575 is located near Zenith, Kansas and has 43 years of record, dating from 1973 to 2015, suitable for computing frequency flow estimates. The record for 2006 was removed from the analysis as it was labeled as being an estimate. For this study, the expected probability values were selected over the computed curve values because the expected probability produces values higher, thus more conservative, than the computed curve and is recommended for use by Bulletin 17B. Rattlesnake Creek changes name to Salt Creek approximately 2.5 miles before entering Rice County, where the direction of the stream changes from a northerly direction to a

more easterly direction. It should be noted that this gage is slightly upstream of the study area for this project.

*USGS 07141300- Arkansas River at Great Bend, KS*
USGS Station 07141300 is located at Great Bend, Kansas and has 77 years of record, dating from 1921 to 2015. The first year of record was removed from the analysis as its date was unknown, and it was disconnected from the later years of record. The records for 1941 and 1942 were removed from the analysis as discharge in the stream was affected by a diversion beginning in 1943. The record for 1998 was removed from the analysis as there was no flow recorded. In the late 1980s and early 1990s a flood control project was completed for the City of Great Bend, which conveys flood waters from the Arkansas River around the city and into the Walnut River. The completion of the project invalidates the records from the time period that is prior to the construction for use with current studies. Thus, frequency flow estimates were calculated for this site, but were ultimately used for comparison purposes only. It should be noted that this gage is upstream of the study area for this project.

*USGS 07142680- Arkansas River near Nickerson, KS*
USGS Station 07142680 is located near Nickerson, Kansas and has 18 years of record, dating from 1997 to 2015. Frequency flow estimates were calculated for this site, but were not used as there is not enough years of record for a confident analysis to be performed, and as the record ended 28 years ago. It should be noted that this gage is downstream of the study area for this project.

*USGS 07143330- Arkansas River near Hutchinson, KS*
USGS Station 07143330 is located near Hutchinson, Kansas and has 56 years of record, dating from 1960 to 2015. Frequency flow estimates were calculated for this site, but were ultimately used for comparison purposes only as a detailed study was previously completed for the portion of the Arkansas River near Hutchison, Kansas. It should be noted that this gage is downstream of the study area for this project.

## STATISTICAL GAGE ANALYSIS RESULTS

A station, weighted and regional skew was evaluated for all seven of the gages selected for analysis. Table 7 shows a comparison of the 1% annual chance event using the three methods of skew.

**Table 7: 1% Annual Chance Comparison of Skew Methods**

| USGS ID | DA (sq mi) | Station Skew (cfs) | Weighted Skew (cfs) | Regional Skew (cfs) |
|---|---|---|---|---|
| 07143500 | 25 | 1,886 | 2,174 | 2,486 |
| 07143600 | 71 | 22,663 | 12,793 | 7,128 |
| 07143665 | 681 | 41,959 | 44,098 | 48,892 |
| 07142575 | 519 | 37,039 | 21,467 | 10,250 |
| 07141300 | 34,356 | 16,395 | 27,773 | 61,666 |
| 07142680 | 36,015 | 9,409 | 9,759 | 10,152 |
| 07143330 | 38,910 | 30,829 | 30,797 | 30,701 |

The wide range of results in the three skew methods for the gage at Great Bend is the result of a flood control project that was completed in the middle of the period of record, making a significant part of the record invalid for a frequency analysis. Therefore, the results from this analysis were not incorporated into the hydrology for the Arkansas River.

The weighted skew method is generally considered the most appropriate skew for Kansas streams. In addition, the flows for the weighted skew method were close to the average of all the results and appeared the most appropriate for all gages analyzed. Using the weighted skew is also consistent with other FEMA studies in this part of the state that were recently completed; including the neighboring counties of Barton County, Reno County, Harvey County and Sedgwick County.

## LITTLE ARKANSAS RIVER

The effective FIS Report for Rice County, KS does not list flows for the Little Arkansas River. The results from the gage analysis of the Little River gage and the Alta Mills gage were interpolated and extrapolated to produce flows at various locations along the Little Arkansas River. The weighted skew method results were chosen for the gages, as the flows were close to the average of all the results and appeared the most appropriate for all gages analyzed. Two different methods were used for determining the flows upstream of the Little River gage and the flows downstream of the Little River gage, in which the most appropriate method available was applied for each situation. The Drainage Transfer Method was used for determining the flows upstream of the Little River gage, where interpolation was based on only one gage. The Uncontrolled Segment Interpolation Procedure was used for determining the flows downstream of the Little River gage, where interpolation was based on two gages. Various methods for interpolation of the flows were analyzed, as appropriate; including the Drainage Transfer Method, the Uncontrolled Segment Interpolation Procedure for one gage, the Uncontrolled Segment Interpolation Procedure for two gages, the Controlled Segment Interpolation Procedure for one gage, the Controlled Segment Interpolation Procedure for two gages, and utilization of localized regression equations.

The Drainage Transfer Method was utilized to interpolate flows upstream of the Little River gage, beginning at the confluence with Little Arkansas River Tributary 22 and extending downstream to the gage location. The flows were computed using the following equation for unregulated streams, described in *The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites* (Reference 13), which utilizes flows from only the Little River gage.

$$Q_u = Q_d * (DA_u / DA_d)^b$$

Where:

$Q_u$ = peak discharge at the upstream drainage point of interest, in cubic feet per second

$Q_d$ = peak discharge at the downstream gage location, in cubic feet per second

$DA_u$ = total area that contributes runoff to the upstream drainage point of interest, in square miles

$DA_d$ = total area that contributes runoff to the downstream gage location, in cubic feet per second.

b = Area Transfer Coefficient from the USGS Regression Equations for Kansas (Reference 1)

*For example, b equals 0.462 for the following Kansas regression equation:* $Q_{1\%}=1.16(A)^{0.462}(P)^{2.250}$

*For a selected basin, the average mean annual precipitation (P) is the same and the flow ratio between two locations can be described as follows.* $Q_1 / Q_2 = (DA_1 / DA_2)^{0.462}$

Since there is no USGS Kansas Regression Equation for the 0.2% annual chance storm event, the Area Transfer Coefficient was extrapolated for the 0.2% storm event using the best-fit curve for the coefficients of the other storm events.

Due to the sizeable drainage area of the Little Arkansas River Tributary 22 watershed, it is not appropriate to extrapolate the flows from the Little River gage upstream of the confluence with Little Arkansas River Tributary 22 for the Little Arkansas River. Therefore, localized regression equations will be utilized to determine the flow of the Little Arkansas River upstream of the confluence with Little Arkansas River Tributary 22.

The Uncontrolled Segment Interpolation Procedure for two gages was utilized to interpolate flows downstream of the Little River gage. It should be noted that the extent of this study ends at the Rice County line. The flows were computed using the following parameters, which are described in Table 4 of the USGS Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations (Reference 12).

$$B_s = \frac{B_u(DA_d - DA_s) + B_d(DA_s - DA_u)}{DA_d - DA_u}$$

$$Q_{sb} = Q_{sr} + B_s$$

Where:

B = bias; measured/calculated flow minus regression equation flow, in cfs

DA = total area that contributes runoff to the location of interest, in square miles

$Q_{sr}$ = regression equation flow for ungaged drainage point of interest, in cfs

$Q_{sb}$ = calculated flow for ungaged drainage point of interest, in cfs

Since there is no USGS Kansas Regression Equation for the 0.2% annual chance storm event, Regression Equations for the 0.2% annual chance storm event were determined by an extrapolation procedure that utilizes the other USGS Kansas Regression Equations.

Table 8, shown on the next page, represents the peak discharges computed as part of this statistical analysis, which incorporates analysis from the Little River gage and the Alta Mills gage.

| Table 8: Statistical Analysis Results for the Little Arkansas River | | | | | | | |
|---|---|---|---|---|---|---|---|
| Location | Drainage Area (sq. mi.) | Peak Annual Chance Discharges (CFS) | | | | | |
| | | 10% Annual Chance | 4% Annual Chance | 2% Annual Chance | 1% Annual Chance | 1%+ Annual Chance | 0.2% Annual Chance |
| At Confluence with Little Arkansas River Tributary 22 | 40.8 | 2,824 | 4,769 | 6,915 | 9,907 | 11,602 | 22,531 |
| At Confluence with Little Arkansas River Tributary 17 | 51.1 | 3,145 | 5,298 | 7,675 | 10,988 | 12,867 | 24,977 |
| USGS Gage near Little River | 71.0 | 3,683 | 6,182 | 8,944 | 12,793 | 14,981 | 29,061 |
| At Confluence with Little Arkansas River Tributary 12 | 95.1 | 4,582 | 7,575 | 10,773 | 15,116 | 18,155 | 32,339 |
| At Confluence with Dry Creek | 121.7 | 5,457 | 8,926 | 12,540 | 17,351 | 21,176 | 35,488 |
| At Confluence with the North Fork | 152.0 | 6,357 | 10,313 | 14,348 | 19,626 | 24,217 | 38,691 |

## Salt Creek

The effective FIS Report for Rice County, KS does not list flows for Salt Creek. The results from the gage analysis of the Rattlesnake Creek gage near Zenith was interpolated and extrapolated to produce flows at various locations along Salt Creek. Rattlesnake Creek changes name to Salt Creek approximately 2.5 miles before entering Rice County, where the direction of the stream changes from a northerly direction to a more easterly direction. The weighted skew method results were chosen for the gage, as the flows were close to the average of all the results and appeared the most appropriate for all gages analyzed. The Drainage Transfer Method was used for determining the flows along Salt Creek, which is downstream of the Zenith gage, where interpolation was based on only one gage. The flows were computed using the equation for unregulated streams, described in *The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites*, previously explained, which utilizes flows from only the Zenith gage. Various methods for interpolation of the flows were analyzed, as appropriate; including the Drainage Transfer Method, the Uncontrolled Segment Interpolation Procedure for one gage, the Controlled Segment Interpolation Procedure for one gage, and utilization of localized regression equations.

Table 9, represents the peak discharges computed as part of this statistical analysis.

| Table 9: Statistical Analysis Results for Salt Creek | | | | | | | |
|---|---|---|---|---|---|---|---|
| Location | Drainage Area (sq. mi.) | Peak Annual Chance Discharges (CFS) | | | | | |
| | | 10% Annual Chance | 4% Annual Chance | 2% Annual Chance | 1% Annual Chance | 1%+ Annual Chance | 0.2% Annual Chance |
| At Rice County/Barton County line | 632.3 | 3,124 | 7,293 | 13,257 | 23,517 | 30,487 | 84,714 |
| Approximately 3,350 feet downstream of 4th Road | 661.7 | 3,194 | 7,450 | 13,540 | 24,017 | 31,134 | 86,507 |
| At Confluence with Salt Creek Tributary 3 | 746.3 | 3,383 | 7,883 | 14,320 | 25,390 | 32,914 | 91,430 |

## ARKANSAS RIVER

The FIS Report for Rice County does not list a flooding source location for the Arkansas River within Rice County. The revised draft FIS Report for Reno County, Kansas, with approved hydrology and hydraulics, lists flows for the Arkansas River at Hutchinson, which is downstream of the portion of the Arkansas River that is included in this study. The FIS Report for Barton County lists flows for the Arkansas River just downstream of its confluence with Wet Walnut Creek, which is near Great Bend and upstream of the portion of the Arkansas River that is included in this study.

Only the gage near Hutchinson, Kansas resulted in a confident flow frequency analysis, based on the years of record and relative consistency of the results for the various skew methods. However, the flows listed in the revised draft FIS report for Reno County, which are based on a detailed study conducted in 2010, lists flows that are slightly higher than the flows resulting from the gage analysis. A section of the Arkansas River, downstream of the portion that is included in this study, was included in a 2016 project for the Cow Watershed. The flows listed in the revised draft FIS report were chosen for use in the 2016 study's hydraulic analyses as they were slightly more conservative and consistent with Reno County, and very little drainage area was added within the area studied. Additional details can be found in the Cow Watershed Hydrology Report (Reference 15). It was determined, however, that it is not appropriate to utilize these flows for the entire portion of the Arkansas River included in this study, as there is a sizeable change in drainage area due mainly to Salt Creek's watershed.

The flows listed for the Arkansas River in the FIS Report for Barton County are significantly higher than the flows listed in the draft FIS Report for Reno County. For example, the 1% annual chance flow for the Arkansas River near Great Bend, downstream of the confluence with Walnut Creek, is approximately 24% higher than the 1% annual chance flow listed for the Arkansas River in the draft FIS Report for Reno County. While we do believe that there is justification for the flows near Great Bend to be higher than the flows near Hutchinson, we do not believe that there is truly a 24% flow reduction difference. Furthermore, the validation status for the section of the Arkansas River in Barton County is deemed "unverified" in FEMA's current Coordinated Needs Management Strategy (CNMS) database, leading us to believe that the hydrology is invalid.

Streamflow statistics of flow duration and peak-discharge frequency were estimated by the USGS at various locations along streams listed in the 1999 Kansas Surface Water Register, and documented in a 2004 publication titled *Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations* (Reference 12). The publication lists estimated peak discharge values for the 50%, 20%, 10%, 4%, 2%, and 1% annual chance storm events for each location studied. Based on the publication, the 1% annual chance flow of the Arkansas River, downstream of the confluence with Walnut Creek, is approximately 36,300 cfs. This represents a small decrease in flow, approximately 3%, between Great Bend and Hutchinson, which is realistic based on characteristics of the stream and surrounding areas. The publication also lists a 1% annual chance flow of 35,900 cfs for the Arkansas River, downstream of the confluence with Salt Creek (Rattlesnake Creek), which is very similar to the flow used in the 2016 study and described in the draft FIS Report for Reno County. Based on all the information analyzed, the flows listed in the *Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations* were determined to be the best estimate of flows

for the Arkansas River between the upstream boundary of this study, which is the Rice County/Barton County line, and the confluence with Salt Creek.

The tables listed in the *Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations* do not include flows for the 0.2% annual chance storm event or the 1% plus chance storm event. Therefore, the 0.2% annual chance flow was extrapolated using the best-fit curve for the flows from the other storm events. When determining the 1% plus annual chance flow for the portion of the Arkansas River included in the 2016 study, the 1% plus weighted skew method results for the gage near Hutchinson, Kansas were compared to the 1% weighted skew method results. A multiplier was developed for the1% plus storm event by calculating the percent difference in the 1% plus flow as compared to the 1% flow. This multiplier was then applied to the effective 1% annual chance flow for the portion of the Arkansas River included in the 2016 study, to determine the peak flow used for the 1% plus annual chance storm event. This was determined to be an acceptable method; therefore, it was used to determine the 1% plus flow for the portion of the Arkansas River included in this study. Table 10, represents the peak discharges determined as part of this statistical analysis, which is based on the existing detailed studies and information in the *Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations*.

**Table 10: Peak Discharges for the Arkansas River**

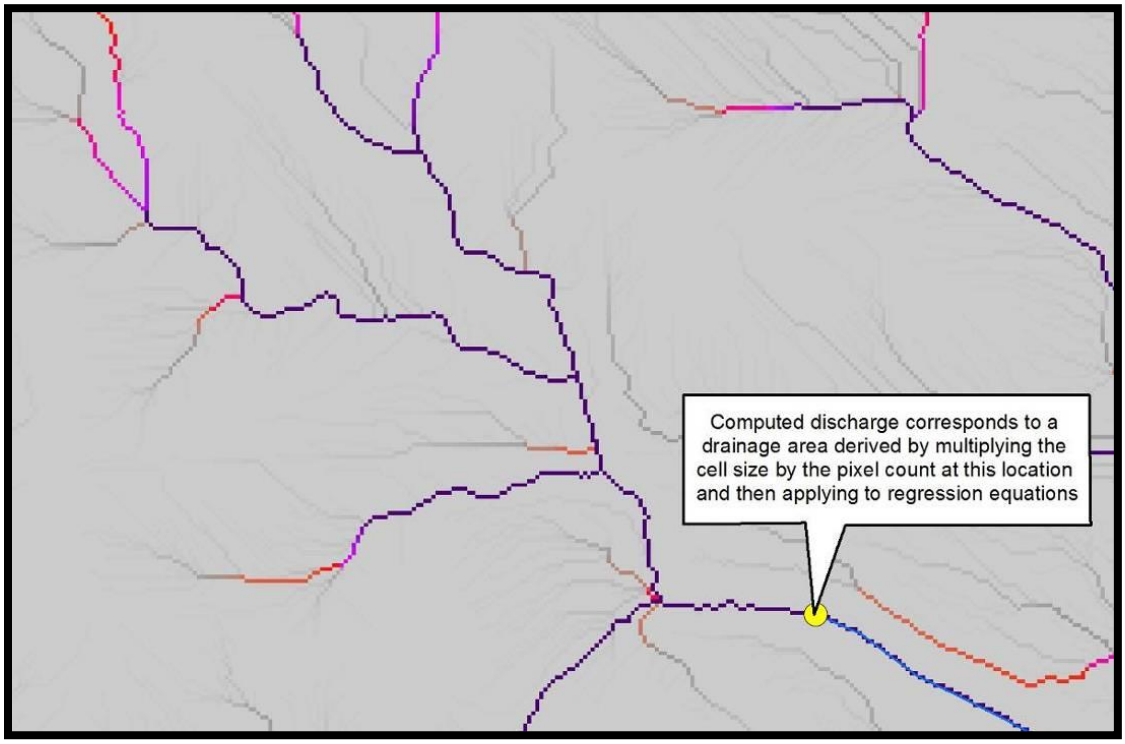
| Location | Drainage Area (sq. mi.) | Peak Annual Chance Discharges (CFS) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10% Annual Chance | 4% Annual Chance | 2% Annual Chance | 1% Annual Chance | 1%+ Annual Chance | 0.2% Annual Chance |
| At Barton County/Rice County line | 34,960 | 15,200 | 22,300 | 29,100 | 36,300 | 42,880 | 49,000 |
| At Confluence with Salt Creek | 36,015 | 15,270 | 23,000 | 28,270 | 35,080 | 41,440 | 54,240 |

## APPROXIMATE HYDROLOGIC ANALYSIS

The hydrology for the Zone A streams that are not modeled by a detailed hydrologic method was developed by using localized regression equations that were developed for the Cow Watershed, which encompasses the majority of Rice County, and deemed suitable for use in this study area. Details regarding the hydrologic development of the localized regression equations can be found in the Cow Watershed Hydrology Report (Reference 15).

To prepare the drainage network, the scoped streams were adjusted based on LiDAR elevation data and aerial imagery obtained through the Kansas Data Access and Support Center. A flow accumulation grid was developed from the LiDAR data which provides a “pixel count” at desired flow change locations that represents the number of pixels flowing into it. A simple calculation is used to convert this pixel count into square miles. Figure 7 illustrates how the drainage points correspond to the flow accumulation grid.

**Figure 7: Regression Analysis Discharge Calculation Example**




The drainage points were located using automated processes along the stream centerline, generated from the DEM. The points were intersected with the accompanying flow accumulation grid to establish a contributing drainage area. Initial drainage points were generated every 300 feet along the stream network. Flows for the 1% annual chance storm event were then calculated for each drainage point, based on the USGS regression equations for Kansas (Reference 1).

1) For larger drainage areas: $Q_{1\%}=1.16(CDA)^{0.462}(P)^{2.250}$
2) For smaller drainage areas: $Q_{1\%}=19.80(CDA)^{0.634}(P)^{1.288}$

Where:

Contributing Drainage Area (CDA) = is the total area that contributes runoff to the stream site of interest, in square miles.

Precipitation (P) = average mean annual precipitation for the subbasin, in inches.

*The Study Area was separated into two subbasins, the Northeast Area and the Southwest Area, to determine the average mean annual precipitation for each subbasin, which was then used in the regression equations.*

*The intersection of the two regression equations is used to determine the contributing drainage area in which to transition from the smaller drainage area equation to the larger drainage area equation.*

After flows were developed using the previously described equations, the drainage point file was filtered to produce the final drainage point file that represents points at or approximately at a 10% change in flows. To establish flow change location; filtering begins at the most upstream drainage point and subsequent downstream drainage points are evaluated. The next flow change location is set to the larger of drainage point values where their percentile difference relative to previous flow value envelops a 10% change. The process is repeated until the end of the stream is reached.

In an effort to generate more accurate flows for the Zone A streams within Rice County, localized regression equations were utilized. The use of localized, area-weighted regression equations has been approved by FEMA in the past for determining peak flows for use in approximate studies in neighboring watersheds and counties; which have similar topography, soil types, and land use types; including the Cow Watershed, which encompasses the majority of Rice County, along with portions of Barton County, Ellsworth County, and Reno County. It was determined at the start of this project that the use of localized regression equations would produce a more appropriate determination of peak flows for Rice County, rather than the USGS Kansas regression equations, which are known to over predict flows in this region of Kansas.

The localized regression equations for the Cow Watershed were based on the results from two sizeable HEC-HMS models. Gage information in one of the watersheds provided a calibration point and added confidence in the accuracy of the localized regression equations. In addition, the percentage difference between the flows from the Kansas regression equations and the flows from the localized regression equations compared very similarly to studies that have been completed in neighboring watersheds within Sedgwick County, which were all based on calibrated HMS models to actual runoff events. Characteristics of the Rice County; such as the annual precipitation, flat terrain, sandy soil types, and land use types; are all contributing factors to the variation from the USGS Kansas regression equation flows.

The peak flows from the HEC-HMS models developed for Little Arkansas River Tributary 11 and Little Arkansas River Tributary 14 were compared to the peak flows from the HEC-HMS models developed in the Cow Watershed and the associated localized regression equations; and were determined to be within an appropriate tolerance, with some of the flows from the Little Arkansas River Tributaries 11 and 14 watersheds being above and below the localized regression equation trendlines. It should be noted that the maximum drainage area within the Little Arkansas River Tributaries 11 and 14 watersheds is 9.9 square miles. In addition, the weighted skew method results for the Little Arkansas River gage near Little River, Kansas (USGS ID 07143600) were compared to the localized regression equation flows developed for the Cow Watershed. The 1% annual chance flow determined by the localized regression equation closely corresponds to the weighted skew method result for the Little River gage.

The similarities in terrain, soil, and land use type between all the watersheds within Rice County; the similarities in peak flows between the HEC-HMS models in both studies, the similarities in peak flows between the localized regression equations and the gage analysis, and the needs of the community; all deemed it appropriate to utilize one set of localized regression equations when determining peak flows for the approximate Zone A streams included in this project and included in the Cow Watershed project. Having one set of localized regression equations for the county will also be very beneficial for all of the communities within Rice County moving forward.

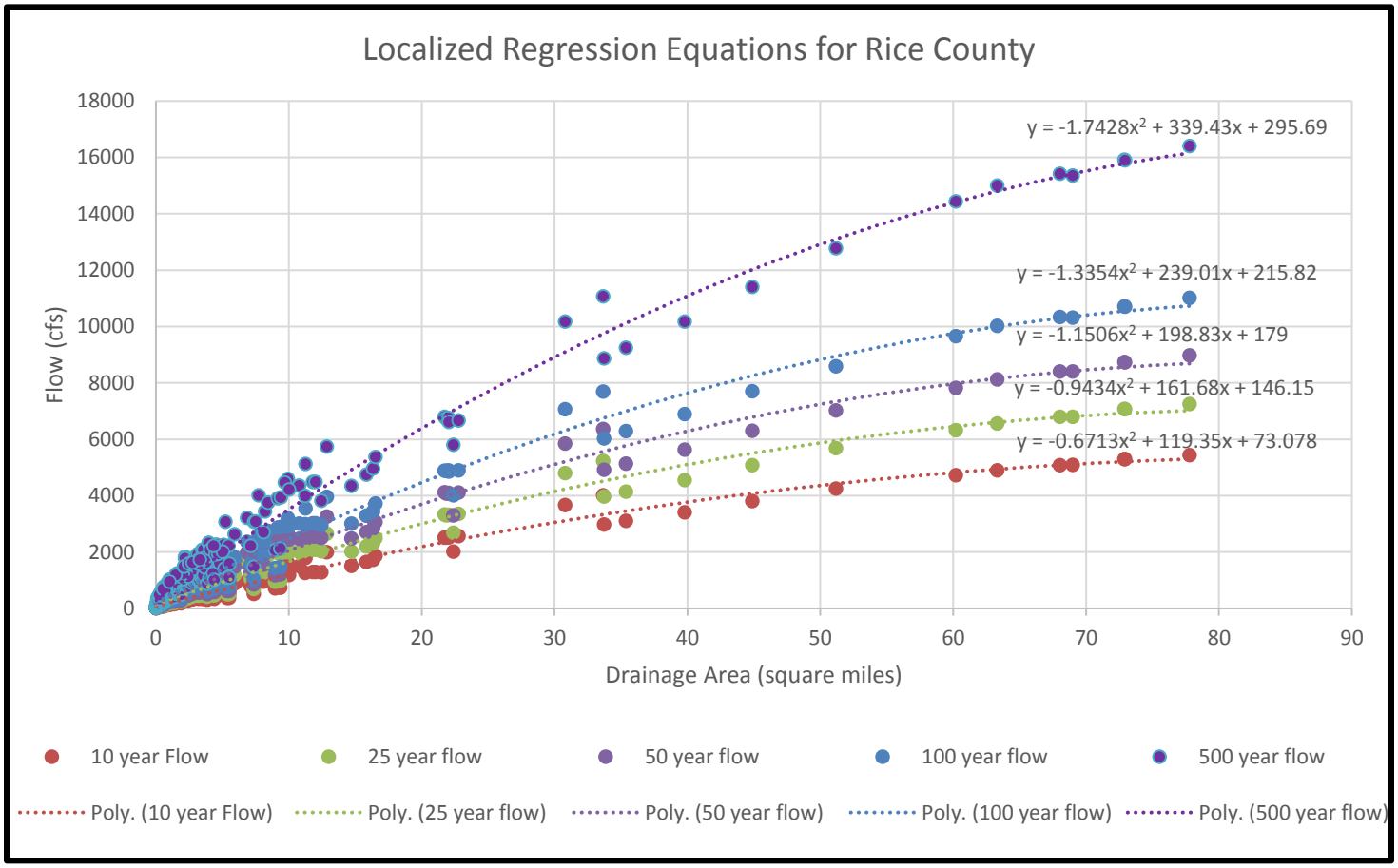
The localized regression equations are as follows, and are also represented in Figure 8:

1) $Q_{10\%} = -0.6713(CDA)^2 + 119.35(CDA) + 73.078$
2) $Q_{4\%} = -0.9434(CDA)^2 + 161.68(CDA) + 146.15$
3) $Q_{2\%} = -1.1506(CDA)^2 + 198.83(CDA) + 179.0$
4) $Q_{1\%} = -1.3354(CDA)^2 + 239.01(CDA) + 215.82$
5) $Q_{0.2\%} = -1.7428(CDA)^2 + 339.43(CDA) + 295.69$

Where:

Contributing Drainage Area (CDA) = is the total area that contributes runoff to the stream site of interest, in square miles.

**Figure 8: Localized Regression Equations for Rice County**




The peak flows for the 1% plus annual chance storm event for the Zone A streams were calculated using a combination of procedures described in Bulletin 17B (Reference 10) and the US Army Corps of Engineer's Risk-Based Analysis for Flood Damage Reduction Studies Engineer Manual (Reference 17). A localized regression equation was developed for the 1% plus chance storm event utilizing discharges calculated from the localized regression equations for the 50%, 10%, and 1% annual chance storm events, and an equivalent record length of 10 years. It was determined that 10 years was the most appropriate equivalent record length to use for the calculations, based on the guidance and the fact that the localized regression equations were developed from trendlines

of the calibrated rainfall-runoff models. The 1% plus annual chance flows developed using this procedure were compared to the peak flows calculated using the Kansas regression equations, along with the model standard error of predictions for the Kansas regression equations. It was determined that the alternative uncertainty approach is the most suitable in determining the peak flows for the 1% plus chance storm event for the Zone A streams included in this study that are not included in a detailed hydrology study, based on the methodology utilized to determine the peak flows for the other storm events. It was also determined to not include the flows for the 1% minus storm event in the hydrology for the Zone A streams that are not included in a detailed hydrologic study.

The localized regression equation for the 1% plus annual chance storm event is as follows.

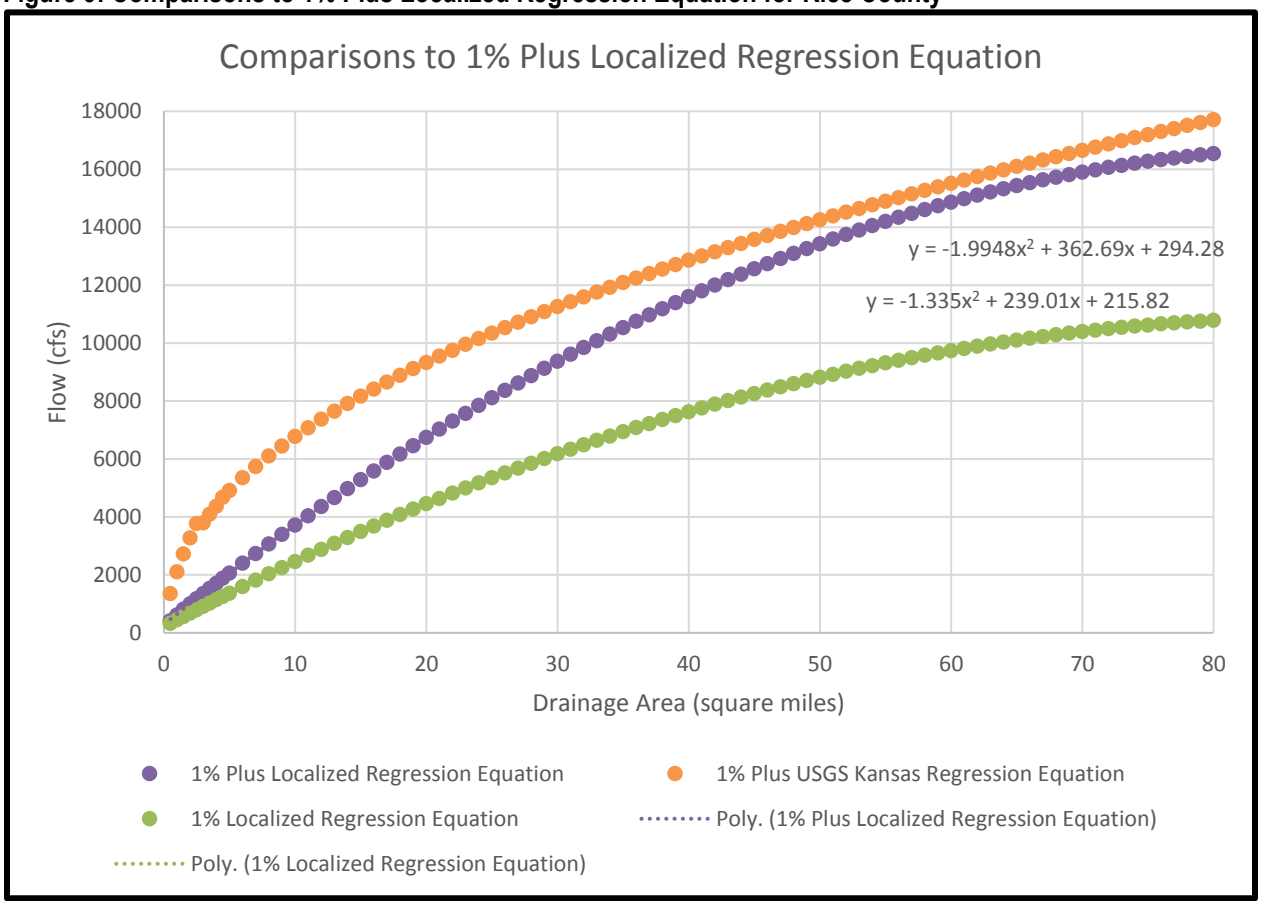
1) $Q_{1\%\ Plus} = -1.9948(CDA)^2 + 362.69(CDA) + 294.28$

Where:

Contributing Drainage Area (CDA) = is the total area that contributes runoff to the stream site of interest, in square miles.

Figure 9 shows a comparison between the 1% localized regression equation flows, the 1% plus localized regression equation flows, and the 1% plus USGS Kansas regression equation flows.

**Figure 9: Comparisons to 1% Plus Localized Regression Equation for Rice County**



Peak flows were then calculated for each drainage point within the previously described filtered points file that was generated for the approximate Zone A streams, using the localized regression equations developed for the 10%, 4%, 2%, 1%, 1% plus and 0.2% annual chance storm events.

## CONCLUSION

As a result of this hydrologic analyses, peak discharges have been developed for the 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% annual chance storm events for the enhanced Zone AE streams and the 10%, 4%, 2%, 1%, 1% + and 0.2% annual chance storm events for the approximate Zone A streams. Peak discharges for the enhanced Zone AE streams, developed by the enhanced hydrologic analyses described in this report, are represented in Table 11 – Summary of Discharges.

| TABLE 11 – SUMMARY OF DISCHARGES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PEAK ANNUAL CHANCE DISCHARGES (CFS) | | | | | | |
| FLOODING SOURCE AND LOCATION | DRAINAGE AREA (sq. miles) | 10% Annual Chance | 4% Annual Chance | 2% Annual Chance | 1% Annual Chance | 1% - Annual Chance | 1% + Annual Chance | 0.20% Annual Chance |
| Little Arkansas River Tributary 11 | | | | | | | | |
| At 26th Road | 0.49 | 190 | 226 | 311 | 393 | 260 | 510 | 575 |
| At KS Highway 46 | 0.71 | 252 | 310 | 380 | 457 | 337 | 630 | 722 |
| At Mouth | 1.45 | 395 | 509 | 625 | 757 | 551 | 1,023 | 1,175 |
| Little Arkansas River Tributary 14 | | | | | | | | |
| At 26th Road | 8.99 | 1,697 | 2,350 | 2,886 | 3,476 | 2,552 | 4,391 | 4,953 |
| At Mouth | 9.92 | 1,817 | 2,532 | 3,123 | 3,775 | 2,755 | 4,787 | 5,404 |

*Disclaimer: As mapping tasks are completed, the potential for minor changes to the information submitted in the hydrology submission and within this report may become necessary. The data provided in this submission and report may not be completely representative of the hydraulics used to produce the final map product. Therefore, this report and the hydraulics submission should be considered as draft. This submission should be considered a complete step in progress but not necessarily the final product since the post preliminary process is not yet completed and the floodplain maps are not yet effective.*

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