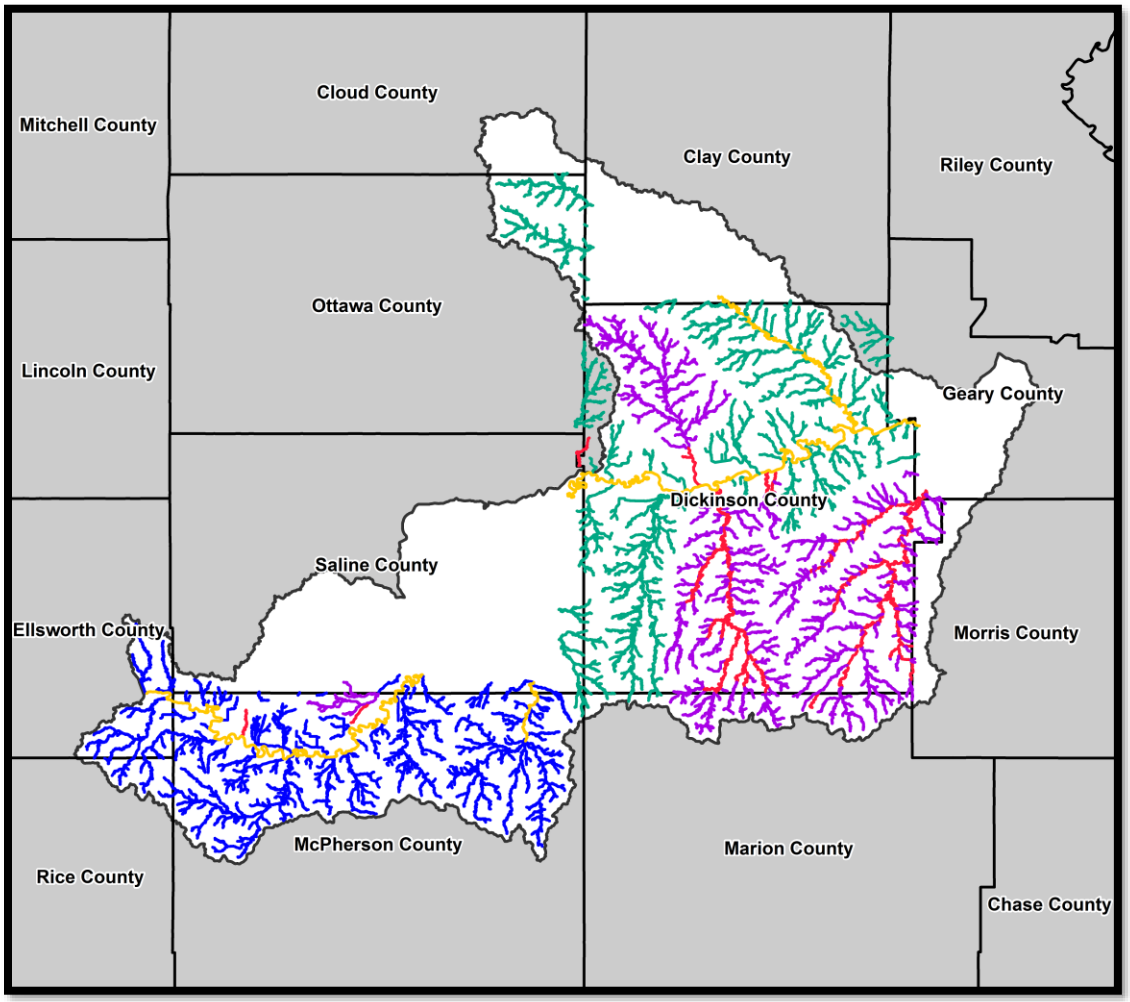
HYDROLOGY REPORT
LOWER SMOKY HILL WATERSHED



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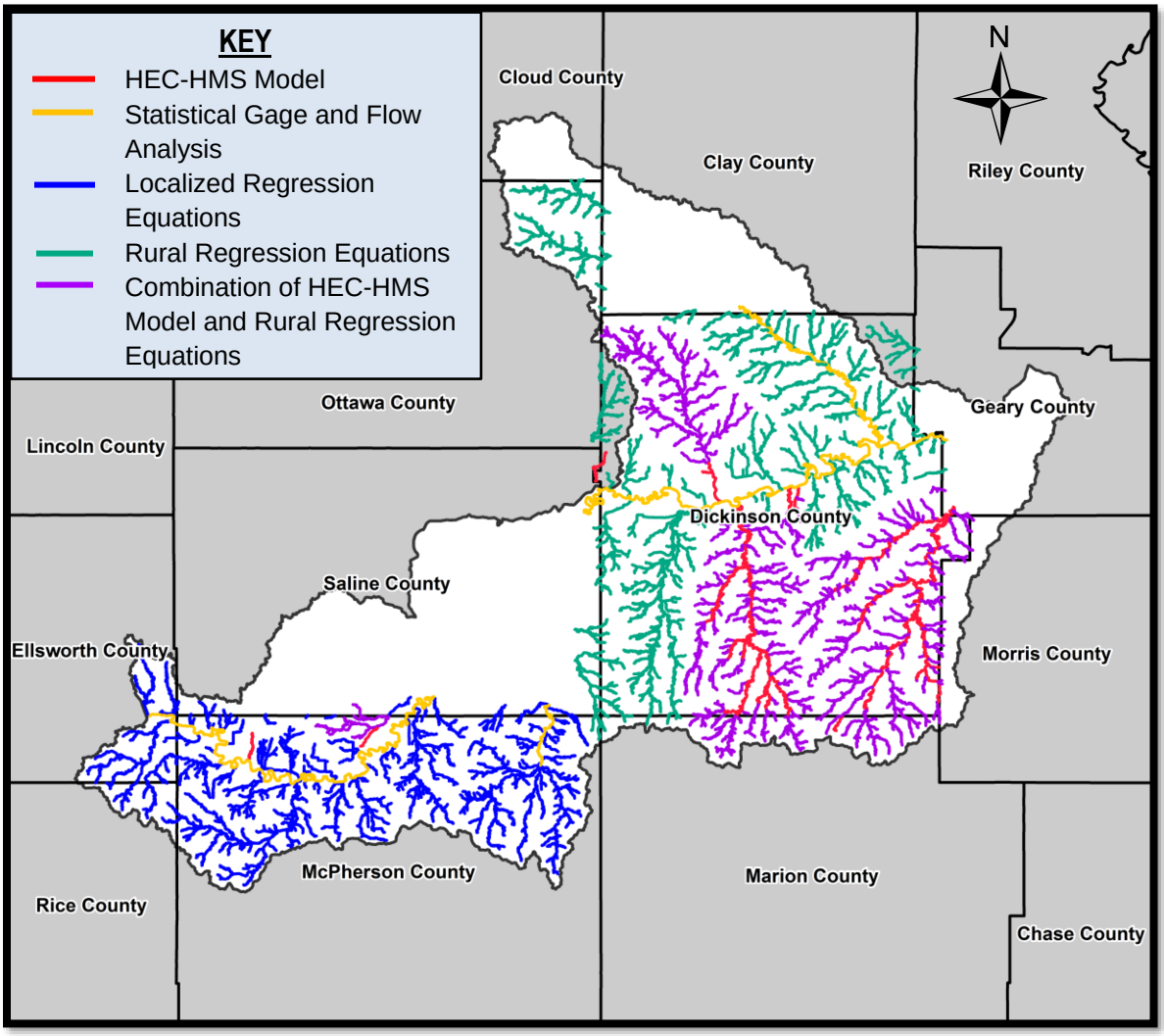
INTRODUCTION

This report presents the hydrologic analyses for the designated streams in the Lower Smoky Hill Watershed (HUC8 10260008), which lies within the Kansas Counties of Clay, Cloud, Dickinson, Ellsworth, Geary, Marion, McPherson, Morris, Ottawa, Rice, and Saline. While portions of Clay, Cloud, Geary, Morris, and Saline Counties are within the Lower Smoky Hill Watershed these areas were previously mapped, considered valid, and were therefore not included as part of this project. This project consists of new detailed hydrologic and hydraulic studies using current watershed characteristics and new detailed topography for 100 stream miles of streams that will be modeled by detailed methods resulting in Zone AE floodplains with a floodway, 167 stream miles of streams that will be modeled by limited detailed methods resulting in Zone AE floodplains without floodways, and 2,154 stream miles of streams that will be studied resulting in updated Zone A floodplains. In addition, statistical gage analyses were performed for Chapman Creek, the Smoky Hill River, and Mud Creek. Gage analyses were also performed for Gypsum Creek which is a Zone A study to support the development of localized regression equations for McPherson, Rice, and Ellsworth Counties. For streams not included in a detailed hydrologic study, approximate Zone A hydrology was performed using USGS rural regression equations or localized regression equations generated from the results of the detailed rainfall-runoff models that were developed for this watershed. A summary of the streams that were studied is shown in Table 1. Figure 1 shows the type of hydrologic modeling used for each stream.

Table 1. Summary of Methods

Study Area/Flooding Source	Stream Miles	Hydrologic Method
Chapman Creek	26.6	Statistical Gage Analysis
Cow Creek Watershed (McPherson County)	2.4	Rainfall-Runoff Model (HEC-HMS)
Smoky Hill Enterprise Tributary 1	2.7	Rainfall-Runoff Model (HEC-HMS)
Smoky Hill Enterprise Tributary 2	4.0	Rainfall-Runoff Model (HEC-HMS)
Smoky Hill River Tributary No. 1 (McPherson County)	3.4	Rainfall-Runoff Model (HEC-HMS)
Lyon Creek Watershed	96.2	Rainfall-Runoff Model (HEC-HMS)
Mud Creek Watershed	4.9	Rainfall-Runoff Model (HEC-HMS) & Statistical Gage Analysis
Smoky Hill River	112.9	Statistical Gage Analysis
Solomon River Tributary Watershed (Dickinson County)	4.5	Rainfall-Runoff Model (HEC-HMS)
Turkey Creek Watershed	80.1	Rainfall-Runoff Model (HEC-HMS)
Various Zone A Streams (Dickinson, Marion, & Ottawa Counties)	1331.8	USGS Rural Regression Equations & Rainfall-Runoff Model Weighted
Various Zone A Streams (McPherson, Rice, & Ellsworth Counties)	692.8	Localized Regression Equations

Figure 1. Hydrologic Modeling Type for Each Stream in Lower Smoky Hill Watershed



This study does not include new hydrologic analyses for the Solomon River located within Dickinson County, KS. The current effective hydrologic analysis for the Solomon River at the very east end of Saline County, down to its confluence with the Smoky Hill River in Dickinson County, was deemed to be valid when Saline County Mapping was previously completed and will be carried forward as is for Dickinson County.

Mud Creek Tributary 2 was identified in the scoping phase as needing new hydrologic analyses. However, upon further review this stream is located entirely within the Mud Creek floodplain, did not previously have a detailed study, and does not have one square mile of contributing drainage area. Therefore, for this project discharges were not established for Mud Creek Tributary 2 and further review will be performed in the hydraulic phase to ensure analyses are not necessary.

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 these analyses will be used in developing the hydraulic analyses for the streams within this study.

The extents of the Zone A studies include those streams currently having floodplains mapped 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, have an average flood depth of less than one foot, 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 Dickinson County is dated June 2, 2004. The current effective FIS Report for Ellsworth County is dated August, 2009. The current effective FIS Report for Ottawa County is dated November, 2009. The current effective FIS Report for Rice County is dated September, 1997. The current effective FIS Report for McPherson County is dated January, 2009. The current effective FIS Report for Marion County is dated March, 2011.

GAGE AND EFFECTIVE FLOW ANALYSIS

There are seven USGS gage stations located within the Lower Smoky Watershed that have sufficient period of record in which a confident peak flow frequency analysis could be computed; one located on the Mud Creek, one located on Gypsum Creek, one located on Chapman Creek, and four located on Smoky Hill River. The gage on Mud Creek is located just downstream of NW 14th street, near Abilene, Kansas. The gage on Gypsum Creek is located just upstream of East Lapsley Road, near Gypsum, Kansas. The gage on Chapman Creek is located just upstream of KS-18, near Chapman, Kansas. The first gage on Smoky Hill River is located just downstream of 29th Road, near Kanopolis Lake, Kansas. The second gage on Smoky Hill River is located just downstream of East Highway K4, near Mentor, Kansas. The third gage on Smoky Hill River is located just downstream of North Niles Road, near New Cambria, Kansas. The fourth gage on Smoky Hill River is located just downstream of KS-43, near Enterprise, Kansas. A summary of the seven gages analyzed is shown in Table 2. Annual peak flow records were obtained from the USGS Water Resources website (Reference 1).

Table 2. Summary of USGS Stream Gages Identified and Sufficient for Statistical Analyses

USGS Gage Number	Gage Description	Drainage Area (mi^2)	Period of Record
06865500	Smoky Hill River, near Langley, KS	7,857	1950-2015
06866500	Smoky Hill River, near Mentor, KS	8,341	1947-2010
06870200	Smoky Hill River, at New Cambria, KS	11,730	1973-2007
06877600	Smoky Hill River, at Enterprise, KS	19,260	1973-2015
06878000	Chapman Creek, near Chapman, KS	300	1970-2010
06870300	Gypsum Creek, near Gypsum, KS	117	1903-2007
06877120	Mud Creek, near Abilene, KS	87	1951-2015

Gage analysis were performed on these USGS gages using Bulletin 17C parameters (Reference 2), utilizing the USACE HEC-SSP software (Reference 3).

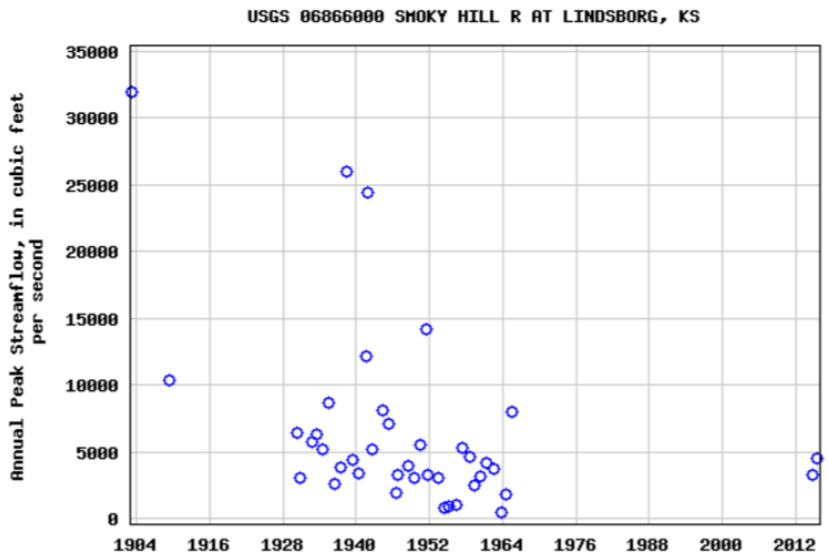
In addition to those gages identified above, a total of ten USGS gages were identified but did not have a sufficient period of record in which a confident statistical analysis could be performed; two gages in the Lyon Creek Watershed, four gages in the Turkey Creek Watershed, and four gages along the Smoky Hill River. In review of the period of record it was determined that these gages either did not have a sufficient consecutive period of record and/or the period of record was too old to be representative of today's watershed runoff response. Table 3 below depicts additional gages identified as part of this project but not utilized because the period of record was not sufficient for confident statistical gage analyses.

Table 3. Summary of USGS Stream Gages Identified but Insufficient for Statistical Analyses

USGS Gage Number	Gage Description	Drainage Area (mi^2)	Period of Record
06866000	Smoky Hill River, near Lindsborg, KS	8,110	1904-2015 (42)
06877000	Smoky Hill River, At Solomon, KS	8,830	1903-1951 (19)
06870500	Smoky Hill River, near New Cambria, KS	1,980	N/A
06879000	Smoky Hill River, at Junction City, KS	19,900	N/A
06877500	Turkey Creek, near Abilene, KS	143	1951-1990 (33)
06877300	East Turkey Creek, near Dillon, KS	82	N/A
06877200	West Turkey Creek, near Elmo, KS	26.6	1957-1977 (21)
06877400	Turkey Creek, near Elmo, KS	2.48	1957-1977 (21)
06878500	Lyon Creek, near Woodbine, KS	230	1951-1973 (22)
06878600	Lyon Creek, near Junction City, KS	258	2004-2015 (5)

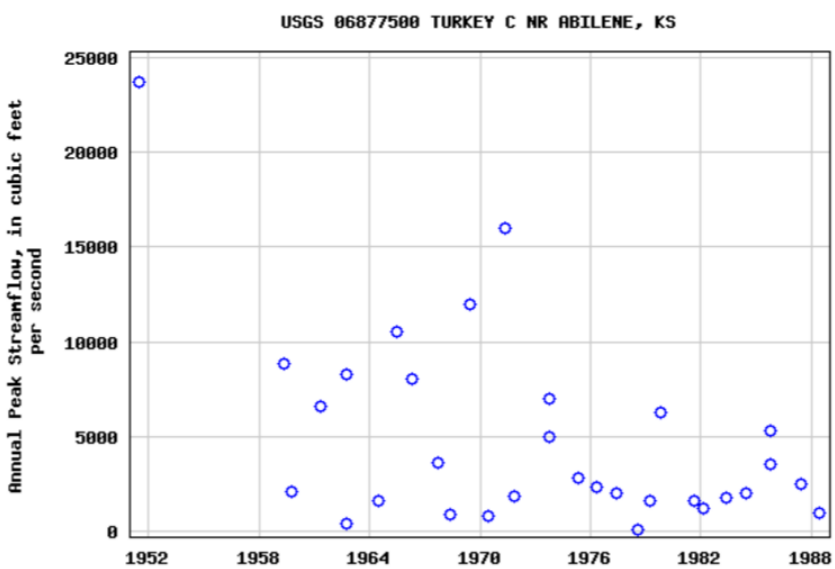
While USGS 06866000 has records from 1904 to 2015, the period of record has significant gaps in the record. As shown in Figure 2 below the period of record is missing data between 1965 and 2013. In addition, since this is the period following the construction of a number of Federal Reservoirs on the river, the period that is most relevant to the period of record is the period that is missing.

Figure 2. UGS 06866000 Period of Record



While USGS 06877500 had a total of 32 consecutive records the period of record was prior to 1990 and during the period in which multiple watershed dams were being established and therefore deemed insufficient to develop a confident statistical gage analysis for this study. Figure 3 below depicts the period of record for USGS 06877500.

Figure 3. USGS 06877500 Period of Record



The following sections discuss details of the statistical gage analyses performed as part of this project.

USGS 06865500- Smoky Hill River, near Langley, KS
USGS Station 06865500 is located near Langley, Kansas and has 76 years of record, dating from 1938 to 2015. Statistical gage analyses were performed, reviewed, and approved by FEMA in 2012 as part of the Saline County, KS floodplain mapping study (unpublished). As this study was just recently completed it was brought forward and utilized as part of this watershed study.

USGS 06866500- Smoky Hill River, near Mentor, KS
USGS Station 06866500 is located near Mentor, Kansas and has 81 years of record, dating from 1903 to 2015. Statistical gage analyses were performed, reviewed, and approved by FEMA in 2012 as part of the Saline County, KS floodplain mapping study. As this study was just recently completed it was brought forward and utilized as part of this watershed study.

USGS 06870200- Smoky Hill River, at New Cambria, KS
USGS Station 06870200 is located near New Cambria, Kansas and has 45 years of record, dating from 1963 to 2007. Statistical gage analyses were performed, reviewed, and approved by FEMA in 2012 as part of the Saline County, KS floodplain mapping study (unpublished). As this study was just recently completed it was brought forward and utilized as part of this watershed study.

USGS 06877600- Smoky Hill River, at Enterprise, KS
USGS Station 06877600 is located near Enterprise, Kansas and has 85 years of record dating from 1903 to 2015, suitable for computing frequency flow estimates. Statistical gage analyses were performed, reviewed, and approved by FEMA in 2014 as part of the Geary County, KS floodplain mapping study (unpublished). As this study was just recently completed it was brought forward and utilized as part of this watershed study.

USGS 06878000- Chapman Creek, near Chapman, KS
USGS Station 06878000 is located at Chapman, Kansas and has 63 years of record, dating from 1951 to 2015. No significant flood control dams were identified that would influence the period of record; therefore the entire period of record was utilized for the statistical gage analyses. Bulletin 17C procedures was utilized to compute the flow frequency analyses. Since the watershed is highly uncontrolled it was decided to use weighted skew coefficient methods which weights the station skew computed from the period of record with a regionalized skew coefficient of -0.2 derived from Bulletin 17B (Reference 4) which is representative of the surrounding statistical gage location data.

USGS 06870300- Gypsum Creek, near Gypsum, KS
USGS Station *06870300* is located near Gypsum, Kansas and has 47 years of record, dating from 1955 to 2007. No significant flood control dams were identified that would influence the period of record; therefore the entire period of record was utilized for the statistical gage analyses. Bulletin 17C procedures was utilized to compute the flow frequency analyses. Since the watershed is highly uncontrolled it was decided to use weighted skew coefficient methods which weights the station skew computed from the period of record with a regionalized skew coefficient of -0.2 derived from Bulletin 17B (Reference 4) which is representative of the surrounding statistical gage location data.

USGS 06877120- Mud Creek, near Abilene, KS

USGS Station 06877120 is located near Abilene, Kansas and has 41 years of record, dating from 1970 to 2010. No significant flood control dams were identified that would influence the period of record; therefore the entire period of record was utilized for the statistical gage analyses. Bulletin 17C procedures was utilized to compute the flow frequency analyses. Since the watershed is highly uncontrolled it was decided to use weighted skew coefficient methods which weights the station skew computed from the period of record with a regionalized skew coefficient of -0.2 derived from Bulletin 17B (Reference 4) which is representative of the surrounding statistical gage location data.

STATISTICAL GAGE ANALYSIS RESULTS

A station, weighted and regional skew was evaluated for all seven of the gages selected for analysis. Table 4 shows a comparison of the 1% annual chance event using the three methods of skew.

Table 4. 1% Annual Chance Comparison of Skew Methods

USGS ID	DA (sq mi)	Station Skew (cfs)	Weighted Skew (cfs)	Regional Skew (cfs)
06865500	7857	8,863	11,269	14,274
06866500	8341	20,680	20,670	20,620
06870200	11730	34,210	34,750	35,830
06877600	19260	48,220	51,420	55,220
06878000	300	25,560	24,960	23,670
06870300	117	8,860	11,270	14,270
06877120	87	20,160	20,060	19,900

The weighted skew method is generally considered the most appropriate skew for Kansas streams that are not heavily affected by significant flood control regulation and have extended periods of record. Previous statistical analyses were performed tor the Smoky Hill River USGS Gages 06865500, 06866500, 06870200, and 06877600. These statistical gage analyses were previously reviewed and approved by FEMA and therefore were utilized as part of this study. The HEC-SSP model of this submission includes duplicated analysis runs from the previous studies with notes to distinguish them from analyses performed as part of this study. In addition the unchanged, submitted, and approved models and reports from the previous analyses are provided in the supplemental data folder of this submission and should be reviewed for detailed information regarding those gage analyses.

SMOKY HILL RIVER

Statistical gage analyses along the Smoky Hill River were previously developed, reviewed, and approved by FEMA as part of the Saline County & Geary County floodplain studies. For USGS Gage 06865500, 06866500 and 06870200 the 0.2% annual chance discharges are much higher that the statistical analyses due to impacts from upstream large reservoirs. Specifics of how these flows were developed are contained with the Saline County Hydrologic Study report included in the supplemental data folder of this submission. These approved statistical analyses were utilized in this watershed study to develop peak discharges throughout McPherson and Dickinson Counties.

The computed peak discharges at the statistical gage analysis locations were utilized to extrapolate and interpolate the peak discharges throughout the study area in McPherson and Dickinson Counties using drainage area weighting methods as approved in the Saline County and Geary County floodplain studies. In McPherson, Rice, and Ellsworth Counties, peak discharges were interpolated using statistical gage analysis flows from USGS Gages 06865500 and 06866500. The peak discharge at the ungaged location was computed using the following equation taken from USGS SIR 2004-5033, Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations, 2004 (Reference 5).

$$Q_s = \frac{Q_u(DA_d - DA_s) + Q_d(DA_s - DA_u)}{DA_d - DA_u}$$

Where:

Q_s = peak discharge at the ungaged segment, in cubic feet per second

Q_u = peak discharge at the upstream gage location, 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 gage location, in square miles

DA_d = total area that contributes runoff to the downstream gage location, in square miles

DA_s = total area that contributes runoff to the ungaged segment, in square miles

The peak discharges within Dickinson County were developed by extrapolating the statistical gage analysis peak discharges at USGS 06877600. Interpolating the peak discharges using USGS 06870200 was not deemed to be appropriate since the Solomon River confluences with the Smoky Hill River at the western-most Dickinson County boundary downstream of USGS 06870200. The Solomon River has a contributing drainage area of 6770 square miles compared to the Smoky Hill River at approximately 11730 square miles making up nearly 35% of the combined contributing drainage area.

Just as performed, reviewed, and approved by FEMA in the Saline County and Geary County flood studies the controlled segment extrapolation procedure outlined in USGS SIR 2004-5033, Estimates of Flow Duration, Mean Flow, and Peak-Discharge Frequency Values for Kansas Stream Locations, 2004 (Reference 5) was utilized to extrapolate peak discharges from USGS 06877600 at Enterprise from the western boundary to the eastern boundary of Dickinson County.

$$Q_s = \frac{Q_u}{DA_u} \times DA_s \quad \text{or}$$

$$Q_s = \frac{Q_d}{DA_d} \times DA_s$$

Where:

Q_s = peak discharge at the ungaged segment, in cubic feet per second

DA_u = total area that contributes runoff to the upstream gage location, in square miles

DA_d = total area that contributes runoff to the downstream gage location, in square miles

DA_s = total area that contributes runoff to the ungaged segment, in square miles

Table 5 represents the peak discharges computed as part of this statistical analysis, which incorporates analysis from the gages and existing detailed studies from the Saline County and Geary County flood studies.

Table 5. Statistical Analysis Results for Smoky Hill River

USGS #	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
06865500[1]	Smoky Hill River, near Langley, KS Just downstream of 29th Road	7,857.0	4,390	5,630	6,450	7,160	8,770	27,500
n/a[3]	Approximately 2.4 miles upstream of Wells Fargo Road	7,914.3	5,160	6,730	7,850	8,910	10,710	30,220
n/a[3]	Downstream of confluence with Wolf Creek near Marquette, KS	7,952.5	5,670	7,470	8,790	10,070	12,010	32,040
n/a[3]	Just downstream of Sharps Creek Confluence	8,053.9	7,040	9,420	11,270	13,160	15,440	36,860
06866000[3,4]	Smoky Hill River, at Lindsborg, KS	8,110.0	7,790	10,500	12,640	14,870	17,340	39,530
n/a[3]	At McPherson/Saline County Boundary	8,153.6	8,380	11,340	13,710	16,200	18,820	41,610
06866500[1]	Smoky Hill River, near Mentor, KS Just downstream of East Highway K4	8,341.0	10,900	14,950	18,290	21,910	25,170	50,520
06870200[1]	Smoky Hill River, at New Cambria, KS Just downstream of North Niles Road	11,730.0	15,380	22,250	28,170	34,780	41,360	75,870
n/a[3]	Just DS of Solomon River Confluence	18,883.0	27,210	37,210	45,480	54,470	62,770	78,540
06877600[2]	Smoky Hill River, at Enterprise, KS Just downstream of KS-43	19,260.0	27,750	37,950	46,390	55,560	64,020	80,110
n/a[2]	Just downstream of Chapman Creek Confluence	19,660.0	28,330	38,740	47,350	56,710	65,350	81,770
n/a[2]	Just downstream of Lyon Creek Confluence	19,990.0	28,800	39,390	48,150	57,670	66,450	83,150

[1]Gage analysis results taken from the hydrologic analysis of Saline County Floodplain Mapping project.

[2]Gage analysis results taken from the hydrologic analysis of Geary County Floodplain Mapping project.

[3]Discharge location was derived using SIR 2004-5033 interpolation/extrapolation procedures based on gage location results.

[4]USGS gage data did not have a sufficient period of record to perform a statistical analysis.

CHAPMAN CREEK

The statistical gage analyses for USGS 06878000 was utilized to extrapolate peak discharges upstream and downstream of the gage location; from the confluence with the Smoky Hill River up to a contributing drainage area of approximately 120 square miles. Upstream of 120 square miles the Zone A discharges were derived using USGS rural regression equations.

The Drainage Transfer Method was utilized to compute flows 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 6). The drainage areas in which this was provided are greater than 120 square miles and therefore the component 0.462 component of the larger drainage area equation was utilized for Chapman Creek.

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

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; 0.462 for large drainage areas and 0.634 for smaller drainage areas (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. Table 6 below depicts the peak discharges computed as a result of this statistical gage analysis.

Table 6. Peak Discharges for Chapman Creek

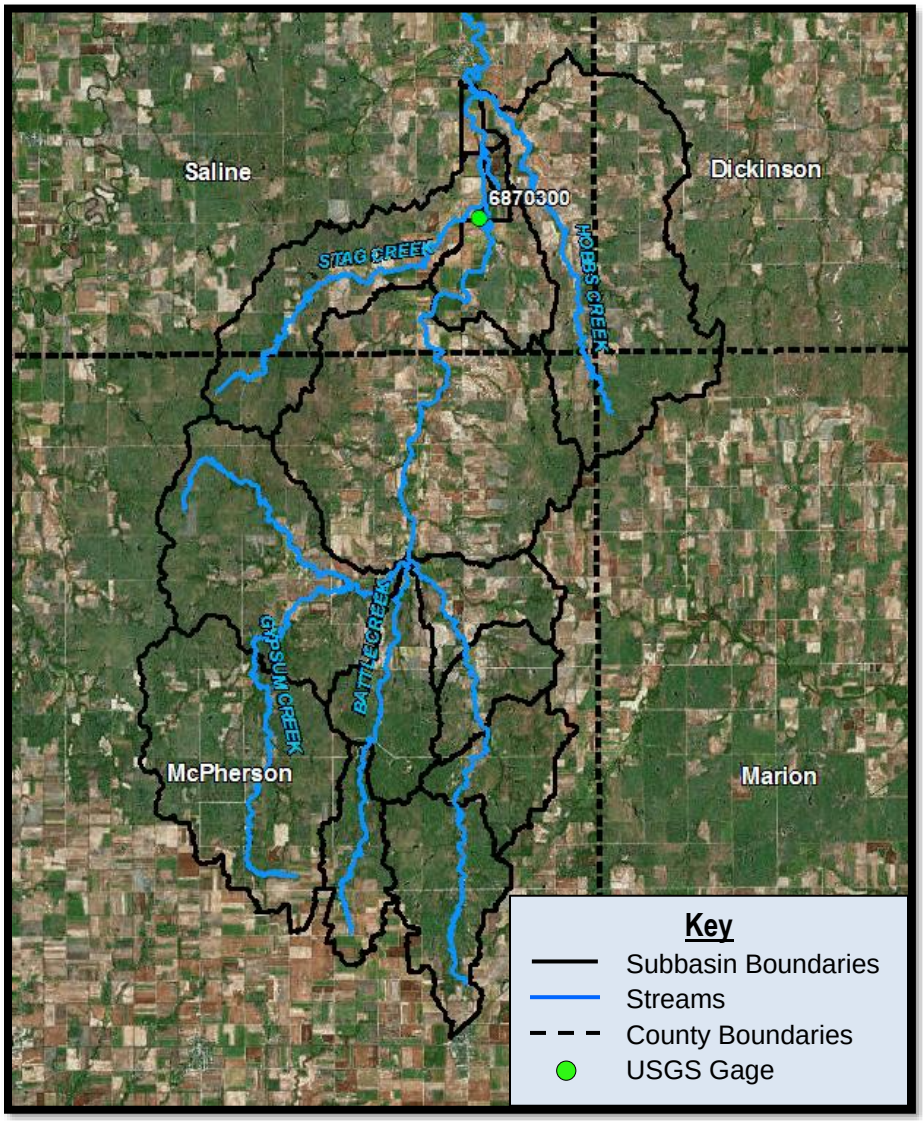
USGS #	Location	Drainage Area (sq. mi.)	Peak Annual Chance Discharges (CFS)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1%+ Annual Chance	0.2% Annual Chance
n/a[1]	At Dickinson & Clay County boundary	197.4	8,640	12,810	16,460	20,570	27,710	32,060
n/a[1]	Approximately 3.5 miles upstream of Mink Road	244.8	9,550	14,150	18,180	22,720	30,610	35,410
06878000	Just upstream of KS-18	300.0	10,490	15,550	19,970	24,960	33,630	38,900
n/a[1]	Approximately 1.3 miles upstream of Quail Road	310.4	10,650	15,790	20,290	25,350	34,160	39,520
n/a[1]	Just downstream of Interstate 70	324.0	10,870	16,110	20,700	25,860	34,850	40,310
n/a[1]	At mouth	327.0	10,910	16,180	20,780	25,970	34,990	40,480

[1]Discharge location flows was derived using NSS Drainage Transfer Method.

GYPSUM CREEK

Statistical gage analyses were completed as part of Saline County Floodplain Study for USGS 06870300 located within Saline County. These statistical gage analyses were previously reviewed and approved by FEMA. As shown in Figure 4, a large portion of the Gypsum Creek watershed is located within McPherson County.

Figure 4. Gypsum Creek Watershed



The statistical gage analyses developed as part of the Saline County Floodplain Study was used to support the development of regionalized local regression equations and derive peak discharges along the main channel of Gypsum Creek for this project within McPherson County. In review of the hydrologic contributing drainage areas three significant areas including Gypsum Creek, Battle Creek, and South Gypsum Creek all converge upstream of Smoky Valley Road in McPherson County. The combination of these significant contributing drainage areas are represented in the

statistical gage analyses of USGS 06870300 because it is located downstream of the confluences; however, individual response for each contributing area is not appropriately represented. Therefore, the Saline County Floodplain Study statistical gage analysis for USGS 06870300 was extrapolated upstream by taking the ratio of computed gage flow to rural regression flow times the rural regression flow. This extrapolation process was utilized, reviewed, and approved as part of the Saline County, KS floodplain mapping study. This process was then applied to areas in McPherson County as part of this project between the county boundary up to the confluence of Gypsum Creek, Battle Creek, and South Gypsum Creek. Areas upstream of the confluence of these contributing areas were computed using the regional localized regression equations that was developed as part of this project. Table 7 depicts the peak discharges utilized for Gypsum Creek from the confluence of Gypsum Creek, Battle Creek, and South Gypsum Creek to the county boundary within McPherson County.

Table 7. Peak Discharges used for the Flow Distribution along Gypsum Creek

USGS #	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
n/a[1]	Just downstream of confluence of South Gypsum Creek	79.1	4,910	6,730	8,080	10,870	14,450	14,010
n/a[1]	Just downstream of Saline & McPherson County Boundary	110.2	5,760	7,860	9,430	10,960	14,570	14,350
06870300	Just upstream of East Lapsley Road	117.0	5,924	8,088	9,696	11,269	14,979	14,751

[1]Discharge location flows derived using ratio of statistical gage flow to rural regression flow at gage site times the rural regression flow. This method was utilized, review, and approved as part of the Saline County Floodplain Mapping Study.

MUD CREEK

A detailed rainfall-runoff HEC-HMS model was developed for Mud Creek. In addition statistical gage analyses were computed for USGS 06877120 as part of this study. Results of this statistical gage analysis were approximately 16% lower than the initial results of the HEC-HMS model. As will be discussed in the rainfall runoff model section of this report the HEC-HMS model was calibrated to this statistical gage analysis. The peak discharges computed as part of this statistical gage analysis are shown in Table 8.

Table 8. Peak Discharges used for the Flow Distribution along Mud Creek

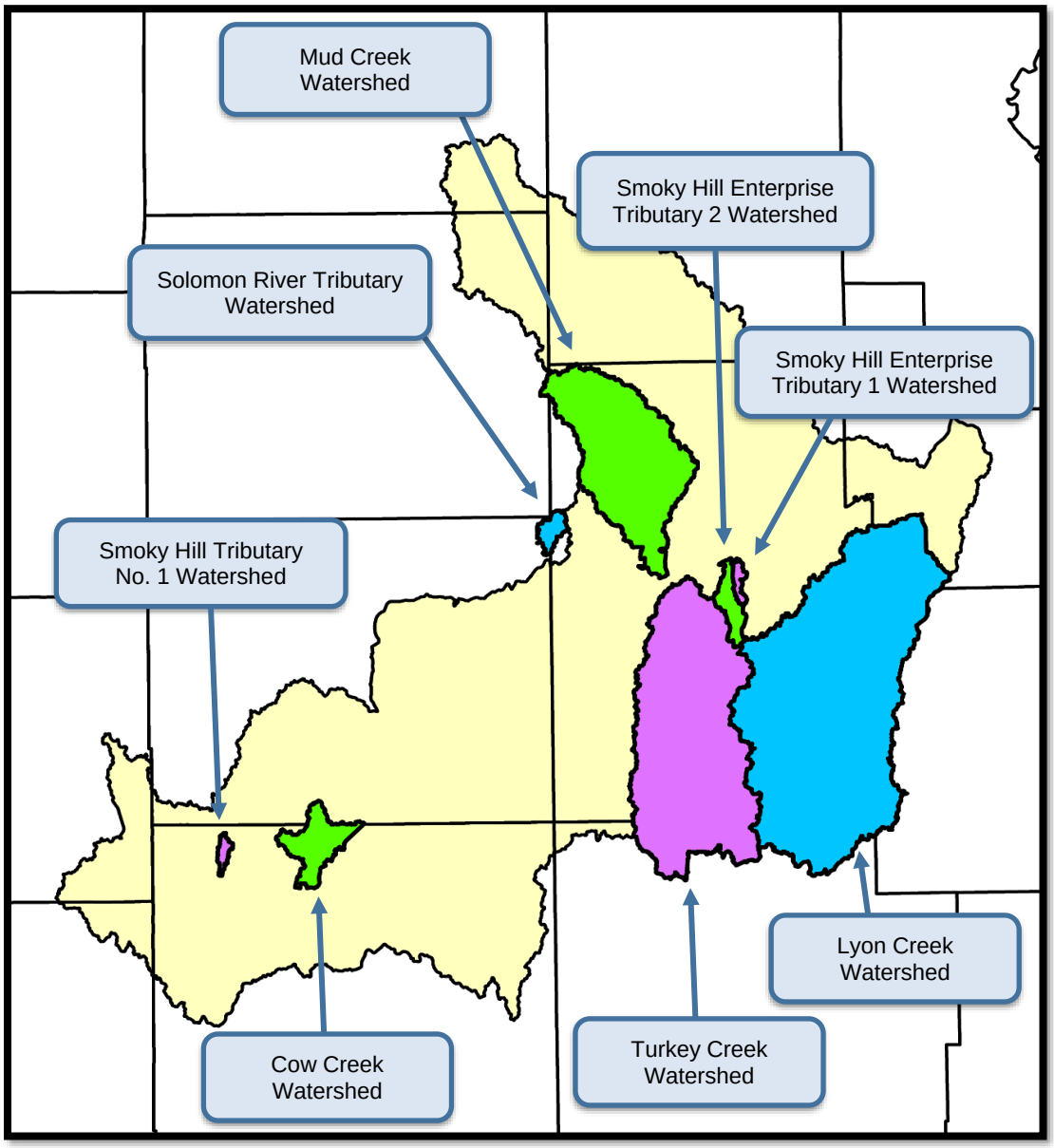
USGS #	Location	Drainage Area (sq. mi.)	Peak Annual Chance Discharges (CFS)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1%+ Annual Chance	0.2% Annual Chance
06877120	Just downstream of NW 14th street	87	8,420	12,530	16,090	20,060	29,190	30,970

GENERAL RAINFALL-RUNOFF MODEL

The rainfall-runoff model HEC-HMS version 4.2 (Reference 7), developed by the USACE, was used for the detailed rainfall-runoff models within this project. Figure 5 shows the extent of the rainfall-runoff models. Amec Foster Wheeler used HEC-HMS to generate subbasin runoff hydrographs for the 10%, 4%, 2%, 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 8) and ArcHydro (Reference 9) 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 5. Boundaries of the Rainfall-Runoff Watershed Models



The towns encompassed within the detailed rainfall-runoff models include Abilene, Chapman, Enterprise, Woodbine, Hope, Herington, Ramona, Solomon, Lindsborg, and Marquette. The majority of these towns have storm water drainage systems where they 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 model the risk associated with the larger storm events, specifically the 1% chance and 0.2% 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, in general the storm water drainage networks (storm sewers) were not included in the HEC-HMS models as they have a minimal impact for the larger storm events. The City of Abilene has numerous stormwater drainage systems. Several systems are conveyed through a levee system into Mud Creek. These systems include flap gates and sluice gates which prevent

backwater into low lying areas adjacent to the levee system. Since these stormwater systems control and are important to the contributing flow into Mud Creek they were included in the rainfall-runoff model of the Mud Creek Watershed.

RAINFALL

The rainfall depths were computed using rainfall grids developed by NOAA as part of Atlas 14: Precipitation-Frequency Atlas of the United States (Reference 10). The depths represent an average of all partial-duration grid values for the 24hr duration within the Lower Smoky Hill Watershed that are included in the rainfall-runoff models. Due to the varying rainfall values across the Lower Smoky Hill Watershed, separate rainfall depths were determined for each rainfall-runoff model to provide more accuracy to the models.

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 9. Since the calculations for the annual-maximum series rely on only one flood event for each year, and since the lower storm events are more likely to have multiple flood events in a given year, the partial-duration series is more appropriate for lower frequency events. In addition, since the two values are predominately the same for the higher storm events, we determined that the partial-duration rainfall values are appropriate for all storm events in this study.

As consistent with past detailed studies in Saline and Geary County the SCS Type II rainfall distribution was utilized to temporally distribute the rainfall depths shown in Table 10.

Table 9. Comparison of Rainfall for Partial-Duration and Annual-Maximum Series

Event	Partial-Duration Series			Annual-Maximum Series		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Cow Creek Watershed						
10-year	4.55	4.56	4.56	4.50	4.50	4.50
25-year	5.55	5.55	5.56	5.53	5.53	5.53
50-year	6.37	6.38	6.38	6.36	6.36	6.37
100-year	7.25	7.25	7.25	7.25	7.25	7.25
500-year	9.48	9.49	9.49	9.48	9.49	9.49
Smoky Hill Enterprise Tributary 1 & 2 Watersheds						
10-year	4.89	4.89	4.90	4.83	4.84	4.84
25-year	5.95	5.96	5.96	5.93	5.93	5.94
50-year	6.82	6.82	6.83	6.81	6.81	6.81
100-year	7.73	7.73	7.73	7.73	7.73	7.73
500-year	10.02	10.02	10.03	10.02	10.02	10.03
Smoky Hill Tributary 1 Watershed						
10-year	4.54	4.54	4.54	4.48	4.48	4.49
25-year	5.55	5.55	5.55	5.52	5.52	5.53
50-year	6.38	6.38	6.38	6.36	6.37	6.37
100-year	7.25	7.26	7.26	7.25	7.26	7.26

Event	Partial-Duration Series			Annual-Maximum Series		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
500-year	9.50	9.51	9.51	9.50	9.51	9.51
Lyon Creek Watershed						
10-year	4.91	4.98	5.06	4.85	4.93	5.00
25-year	5.97	6.05	6.14	5.95	6.03	6.11
50-year	6.84	6.92	7.00	6.82	6.90	6.99
100-year	7.74	7.82	7.90	7.74	7.82	7.90
500-year	10.03	10.08	10.14	10.03	10.08	10.14
Mud Creek Watershed						
10-year	4.70	4.80	4.87	4.64	4.74	4.81
25-year	5.74	5.85	5.93	5.72	5.83	5.91
50-year	6.61	6.72	6.80	6.59	6.70	6.79
100-year	7.52	7.63	7.70	7.52	7.63	7.70
500-year	9.86	9.94	9.99	9.86	9.94	9.99
Solomon River Tributary Watershed						
10-year	4.70	4.71	4.72	4.64	4.66	4.67
25-year	5.75	5.76	5.77	5.72	5.73	5.75
50-year	6.61	6.62	6.64	6.60	6.61	6.63
100-year	7.52	7.54	7.55	8.51	8.52	8.53
500-year	9.88	9.89	9.90	9.88	9.89	9.90
Turkey Creek Watershed						
10-year	4.82	4.89	5.00	4.76	4.84	4.94
25-year	5.87	5.95	6.07	5.84	5.93	6.05
50-year	6.73	6.82	6.94	6.72	6.80	6.93
100-year	7.63	7.72	7.84	7.63	7.72	7.84
500-year	9.92	10.01	10.10	9.92	10.01	10.10

Table 10. SCS Type II 24-hour Rainfall Depths

Event	Cow Creek Watershed Depth (inches)	Lower Smoky Hill Enterprise Tributary 1 & 2 Watersheds Depth (inches)	Smoky Hill Tributary 1 Watershed Depth (inches)	Lyon Creek Watershed Depth (inches)	Mud Creek Watershed Depth (inches)	Solomon River Tributary Watershed Depth (inches)	Turkey Creek Watershed Depth (inches)
10-year	3.88	4.89	4.54	4.98	4.80	4.71	4.89
25-year	4.56	5.95	5.55	6.05	5.86	5.76	5.95
50-year	5.55	6.82	6.38	6.92	6.73	6.62	6.81
100-year	6.38	7.72	7.26	7.82	7.63	7.54	7.71
500-year	9.49	10.02	9.95	10.08	9.95	9.89	10.00

RAINFALL LOSS

The U.S. Department of Agriculture Soil Conservation Service (SCS) Curve Number (CN) Method was used to model rainfall loss (Reference 11). The curve number is a function of both hydrologic soil group and land use. Table 11 was used to determine the CN value from the soil hydrologic soil group and land use. The curve number 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 12). Typical soils in the study area vary greatly from the east to west side of the watershed. In the eastern counties including Dickinson, Ottawa, and Marion Counties the typical soil hydrologic groups are C and D. In the western counties including McPherson, Rice, and Ellsworth Counties the typical soil hydrologic groups are B and C. This information coupled with typical watershed slopes indicate that the watershed runoff response in the eastern counties would be significantly different and likely greater as compared to those in the western watersheds without flood control considerations.

Land Use

Land use was determined using a combination of data from the National Land Cover Dataset (NLCD) website (Reference 13) 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 11). The land use designations are depicted in Table 11. It should be noted that the CN values were calculated using AMC II conditions, as represented in Table 11.

Table 11. CN Land Use and Soil Drainage Class Tables

Land Use Description	Weighted CN (Includes Impervious)			
	A	B	C	D
Open Water	100	100	100	100
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
Barren Land	77	86	91	94
Deciduous Forest	30	55	70	77
Evergreen Forest	30	55	70	77
Mixed 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	30	55	70	77
Emergent Herbaceous Wetlands	43	65	76	82

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 11). 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)

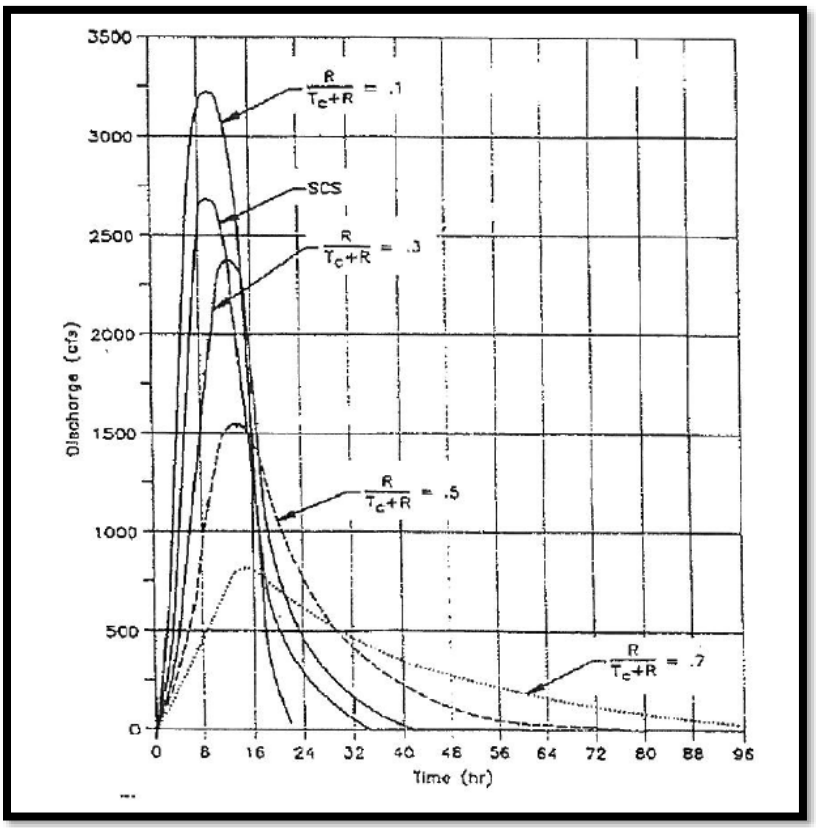
The time of concentration for each subbasin was calculated using the methodology outlined in Chapter 15: Time of Concentration of the National Engineering Handbook (Reference 14). A GIS process was utilized to calculate the longest flow path within any given subbasin. The longest flow paths were then manually edited based on topographic 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 information described in Chapter 15: Time of Concentration of the National Engineering Handbook (Reference 14) as a guide. Chapter 15 indicates that the sheet flow length is primarily a function of surface roughness and travel path slope. Many areas within the HEC-HMS models (especially in McPherson County) are very flat, rural areas. Therefore, in many cases it is appropriate to allow the maximum length of sheet flow for some 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 below, to determine a storage/concentration coefficient, which is then entered into the hydrograph equation. Figure 6, which is from Hoggan, 1996, illustrates the effects of various storage/concentration coefficients on the hydrograph shape.

Figure 6. Storage/Concentration Coefficient Hydrograph Curves (*Hoggan,* 1996)



SC=Tc*Ratio/(1-Ratio)

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

Table 12 was derived using information from Hoggan, 1996, 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.

Table 12. 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.

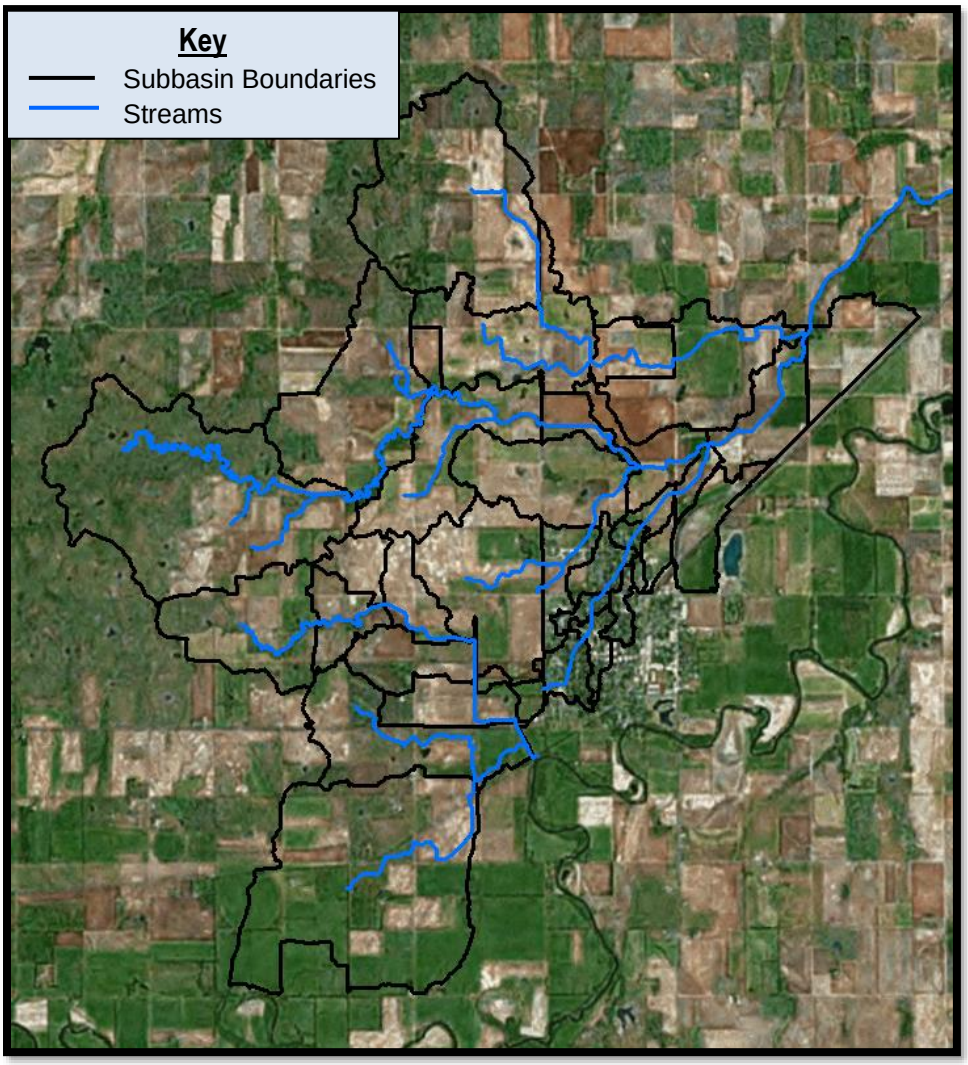
Baseflow was not included in the hydrologic analysis as it was assumed to have negligible impacts on the peak discharge of the design storm.

COW CREEK WATERSHED

The Cow Creek Watershed is located in north central McPherson County and Cow Creek travels through the City of Lindsborg. Much of the watershed is extremely flat and included in the historic floodplain of the Smoky Hill River. This area includes the detailed Zone AE stream which travels through the City of Lindsborg. It is also includes several Zone A streams and a diversion channel located to the southwest of the City of Lindsborg. The City of Lindsborg has experienced significant flooding issues in the recent past. In July 2013, a heavy rain storm dropped approximately 5.0" to 6.0" in about 6 hours depending on the rain gage location. This rainfall depth would correlate to between a 50 to 100-year storm event depending on the observed storm duration. As a result of the heavy rainfall several areas in and around the City of Lindsborg experienced flash flooding. The drainage system located in the northwest corner of the City between 13th Avenue and W Garfield Street experienced flooding conditions that inundated several

homes and low lying areas. Excess runoff from contributing drainage areas upstream of 12th Avenue and Wells Fargo Road exceeded the channel capacity and overflowed to the west away from the diversion channel located at Kansas Highway 4. Some of the overflow entered the drainage system at 13th Avenue while some entered the primary Cow Creek channel at Western Line Road through the City of Lindsborg. Figure 7 below depicts the Cow Creek Watershed and primary conveyance paths through the City of Lindsborg.

Figure 7. Cow Creek Watershed



Given the flat nature of the topography and supported by observed past storm events, surface runoff is very complex and difficult to capture using purely a 1-dimensional approach. Due to the unique characteristics of the Cow Creek Watershed, Amec Foster Wheeler developed a HEC-HMS model for the entire area which will be routed with a 1D/2D unsteady flow HEC-RAS model in and around the City of Lindsborg during the hydraulic modeling portion of the project. The detailed hydrologic study has a total drainage area of approximately 17.6 square miles. The watershed was divided into 33 subbasins, ranging from 0.06 square mile to 2.33 square miles, with the majority of the subbasins being rural. Eight of the subbasins contain urbanized areas within the City of

Lindsborg. An unsteady-state 1D/2D HEC-RAS model will be developed in the hydraulic phase of this project in order to adequately route excess surface runoff ensuring that the distribution of water is realistic as observed in past storm events.

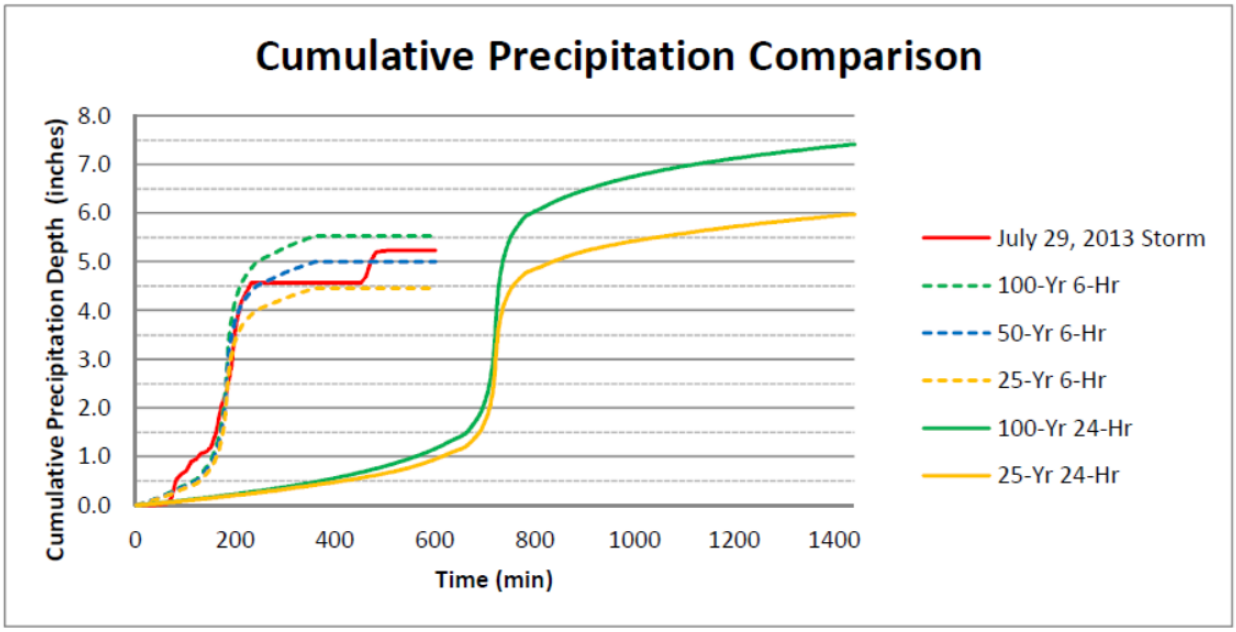
Rainfall and Areal Reduction

Areal reduction of the point rainfall depths was not deemed necessary for the Cow Creek watershed study since the contributing drainage area is less than 17.6 square miles.

Lindsborg NW Drainage Study – Wilson & Company – July 29, 2013 Storm

The City of Lindsborg indicated that a large storm event on July 29, 2013 caused significant flooding to the City and surrounding areas. As a result of the significant flooding the City of Lindsborg retained services from Wilson & Company to perform the "Lindsborg NW Drainage Study" dated February 2015. As part of that drainage study Wilson & Company obtained NEXRAD radar and point rainfall data in and around the City of Lindsborg. Point rainfall depths were not available in the City of Lindsborg however data was available at surrounding rain gage locations which indicated that between 5.0" to 6.0" of rainfall fell in approximately a 6-hour duration. Wilson & Company utilized the NEXRAD temporal resolution and coupled that with the surrounding point rainfall data to develop a rainfall distribution for the City of Lindsborg. Figure 8 below depicts a figure excerpt from the Wilson & Company drainage study that shows a comparison of the cumulative precipitation between the July 29, 2013 storm and SCS Type II 6-hr and 24-hr rainfall distributions.

Figure 8. Cumulative Precipitation Comparison



Cumulative precipitation comparison for July 29, 2013 storm event and multiple frequency based rainfall distributions generated by HEC-HMS for McPherson County, Kansas. Note: A 10-hour storm duration is shown for the July 29, 2013 storm event and 6-hour frequency based distributions to fully illustrate cumulative rainfall for this storm.

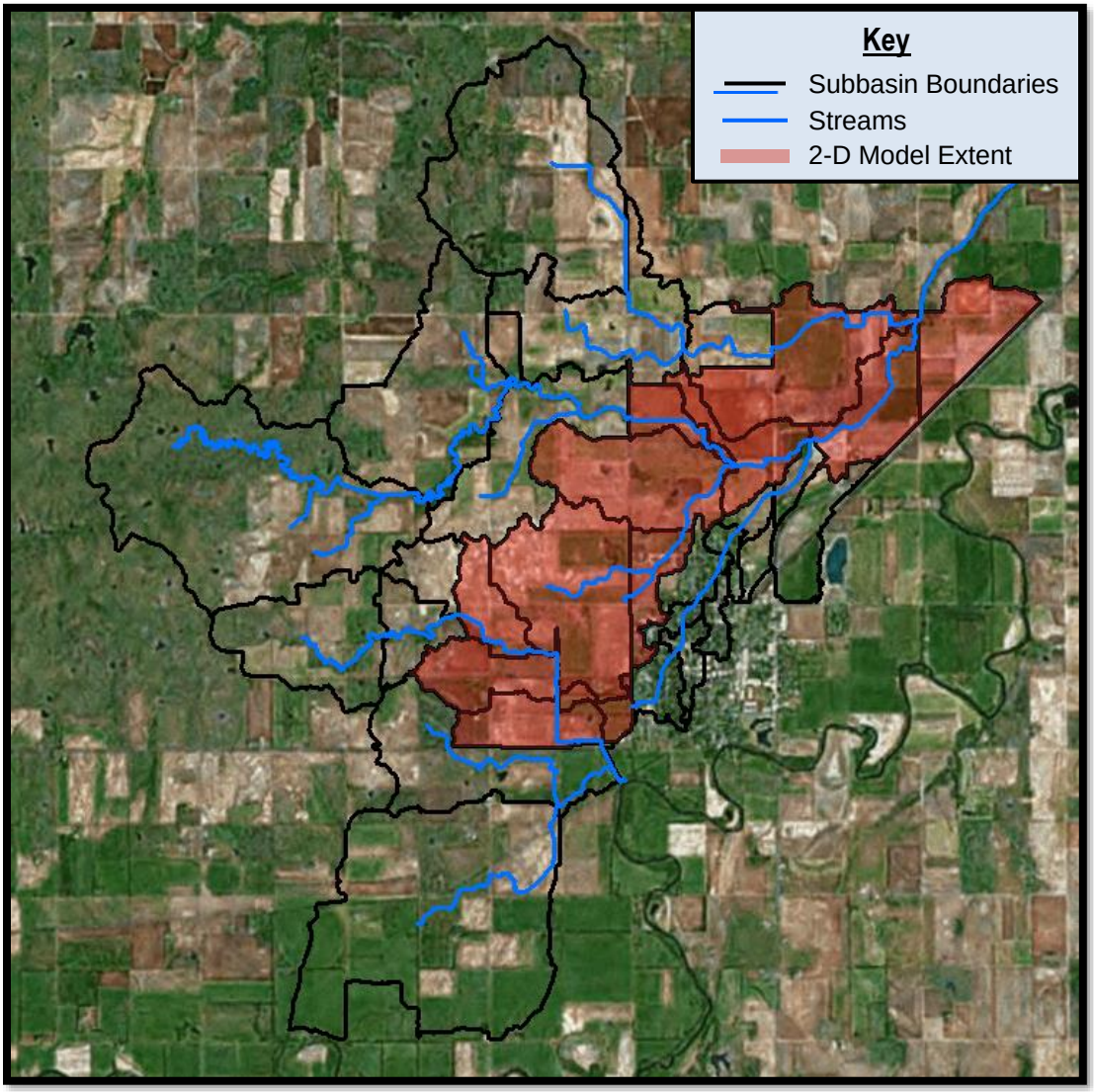
In addition to rainfall data Wilson and Company also documented a high-water mark and field observations. The rainfall data and field observations documented by Wilson & Company will be

utilized in the hydraulic phase of this project to ensure that the model response is representative of the actual event.

2-D HEC-RAS Model Development

As previously discussed, the surface runoff in and around the City of Lindsborg is too complex for utilizing just a 1-D approach. Therefore, a 2-D HEC-RAS model will be developed in the hydraulic phase of this project to route the rainfall-runoff model subbasin results. The 2-D model will be coupled with a 1-D unsteady-State HEC-RAS model of just Cow Creek through the City of Lindsborg. Figure 9 below depicts the approximate extent of the 2-D model area.

Figure 9. 2-D Model Extent for the Cow Creek Watershed



Flow Comparison

Table 13 provides a comparison of 1% annual chance peak discharges for Cow Creek through the City of Lindsborg from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 13. Comparison of 1% Annual Change Discharges for the Cow Creek Watershed

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Localized Regression*
Cow Creek					
Just downstream of 14th Ave	N/A	0.86	N/A	460	540
800 feet downstream of N 1st St	0.54	0.71	700	410	460
150 feet upstream of E Garfield St	N/A	0.60	N/A	360	400
70 feet downstream of N 2nd St	N/A	0.49	N/A	290	330
Just upstream of E Swensson St	0.4	0.42	620	250	290
Just upstream of W Green St	N/A	0.38	N/A	240	270
Just downstream of W Madison St	N/A	0.35	N/A	220	250
Just downstream of W Saline St	N/A	0.27	N/A	160	200
70 feet downstream of N 3rd St	N/A	0.25	N/A	140	190
Just downstream of W State St	0.24	0.25	380	140	190
100 feet downstream of N Chestnut St	N/A	0.23	N/A	130	170
Just upstream of W Lincoln St	N/A	0.20	N/A	105	150
60 feet downstream of W Grant St	N/A	0.19	N/A	100	150
80 feet upstream of W Grant St	0.54	0.18	N/A	90	140
130 feet upstream of W Union St	N/A	0.13	N/A	50	110
420 feet downstream of Coronado Ave	N/A	0.11	N/A	35	95
Coronado Avenue	0.11	0.10	110	30	85
*Discussion of regression equations is included later in the report.					

Flow values for Cow Creek are quite different than those depicted in the effective FIS Report. The HEC-HMS results compare well to the the localized regression equations that were computed as part of this study. The effective FIS Report indicates the upstream contributing drainage area is approximately 0.11 square miles at Coronado Avenue. In review of the topography of this contributing drainage it implies that the diversion channel to the southwest of the City would not overflow and contribute to Cow Creek. Past storm events have proven that overflow does occur from the diversion channel and therefore does influence the peak discharges. Therefore as previously discussed in this report it was determined that a 2-dimensional model will be developed in the hydraulic phase of this project as shown in Figure 9. Upon completion of the hydraulic phase the peak discharges shown in Table 13 through the detailed study area will be updated. Flow values for Zone A streams are not included in the effective FIS report.

SMOKY HILL ENTERPRISE TRIBUTARY 1 & 2 WATERSHEDS

The detailed hydrologic study of the Smoky Hill Enterprise Tributary 1 watershed in Dickinson County, Kansas has a total drainage area of approximately 2.41 square miles. This detailed study includes Smoky Hill Enterprise Tributary 1. The Smoky Hill Enterprise Tributary 1 watershed was divided into 13 subbasins. Four of the subbasins contain urbanized areas within the City of Enterprise, while the remaining subbasins are predominately rural areas. The subbasins range from 0.063 to 0.42 square miles.

The detailed hydrologic study of the Smoky Hill Enterprise Tributary 2 watershed in Dickinson County, Kansas has a total drainage area of approximately 7.85 square miles. This detailed study includes Smoky Hill Enterprise Tributary 2. The Smoky Hill Enterprise Tributary 2 watershed was divided into 19 subbasins. Four of the subbasins contain urbanized areas within the City of Enterprise, while the remaining subbasins are predominately rural areas. The subbasins range from 0.08 to 0.80 square miles.

Rainfall and Areal Reduction

Areal reduction of the point rainfall depths was not deemed necessary for the Smoky Hill Enterprise 1 and Smoky Hill Enterprise 2 watershed studies since the contributing drainage areas of these watersheds are approximately 2.41 and 7.85 square miles, respectively.

Storage Routing

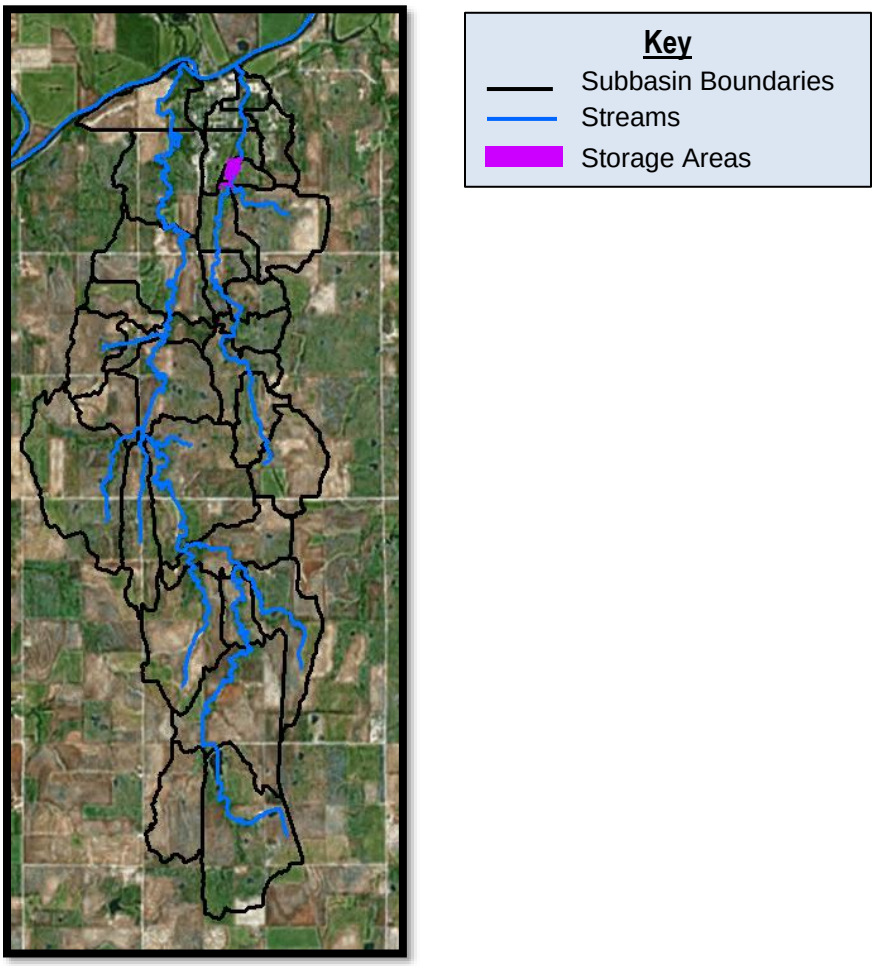
A total of one storage area was modeled in the Smoky Hill Enterprise Tributary 1 and Smoky Hill Enterprise Tributary 2 watershed hydrologic model. This area represent storage behind a privately owned dam that is located along the extent of the limited detailed study area and will therefore also be included in the hydraulic HEC-RAS model and profiles. The criteria for including storage areas within the model was defined by the Kansas Department of Agriculture. Storage areas are limited to those dams that were designed for flood control or public use purposes, significant road embankments, and located along detailed study or limited detailed study extents which impact the runoff response of the watershed. Preliminary selection criteria allowed for storage areas in the most upstream portions of the watersheds to be excluded from the model, and represented using the Clark Unit Hydrograph method previously described. Using a higher Clark's Ratio will adequately compensate for restrictions on the outlet hydrograph by a storage area located at or near the outlet of a subbasin.

Table 14. Storage Elevations within the Smoky Hill Enterprise Tributary 1 & 2 Watersheds (feet NAVD88)

Dam Name		10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% Plus Annual Chance	0.2% Annual Chance
Unnamed Dam on Smoky Hill Enterprise Tributary 1	Dickinson County Unicorporated Areas	1,148.4	1,149	1,149.4	1,149.9	1,150.5	1,150.9

Figure 10 depicts Smoky Hill Enterprise Tributary 1 and Smoky Hill Enterprise Tributary 2 watersheds.

Figure 10. Extent of Maximum Water Elevation of Modeled Storage Areas in the Smoky Hill Enterprise Tributary 1 and 2 Watersheds during 1% change storm event



Flow Comparison

Table 15 provides the 1% annual chance peak discharges developed as part of this detailed study. Smoky Hill Enterprise Tributary 1 and Smoky Hill Enterprise Tributary 2 were not analyzed in the previous FIS.

Table 15. Comparison of 1% Annual Change Discharges for the Smoky Hill Enterprise Tributary 1 and 2 Watersheds

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
Smoky Hill Enterprise Tributary 1					
At confluence of Smoky Hill Enterprise Tributary 1.1	N/A	1.85	N/A	2,070	2,540
Just downstream of 2000 Ave	N/A	1.27	N/A	1,540	2,000
3,400 feet upstream of 2000 Ave	N/A	1.1	N/A	1,380	1,830
Smoky Hill Enterprise Tributary 2					
Approximately 4,500 feet downstream of 1900 Ave	N/A	6.5	N/A	3,540	5,630

The resulting HEC-HMS peak discharges are generally slightly lower than rural regression equations but within the standard error of the regression equations. The primary differences in peak discharges are likely a result of higher levels of detailed analyses coupled with the fact that the hydrologic models specifically analyze the characteristics of each watershed.

SMOKY HILL TRIBUTARY NO. 1 WATERSHED

The hydrologic study of the Smoky Hill Tributary No. 1 watershed in McPherson County, Kansas has a total drainage area of approximately 2.03 square miles. Smoky Hill Tributary No. 1 was divided into 1.5 river miles modeled as detailed study on the downstream end, and 1.8 river miles modeled as approximate study on the upstream end. The entire watershed was divided into 6 subbasins. Three of these subbasins are included in the detailed study, of which two subbasins contain urbanized areas within the City of Marquette, and one subbasin contains predominately rural areas. The three subbasins included in the approximate study cover predominately rural areas. The subbasins range from 0.03 to 0.68 square miles.

Rainfall and Areal Reduction

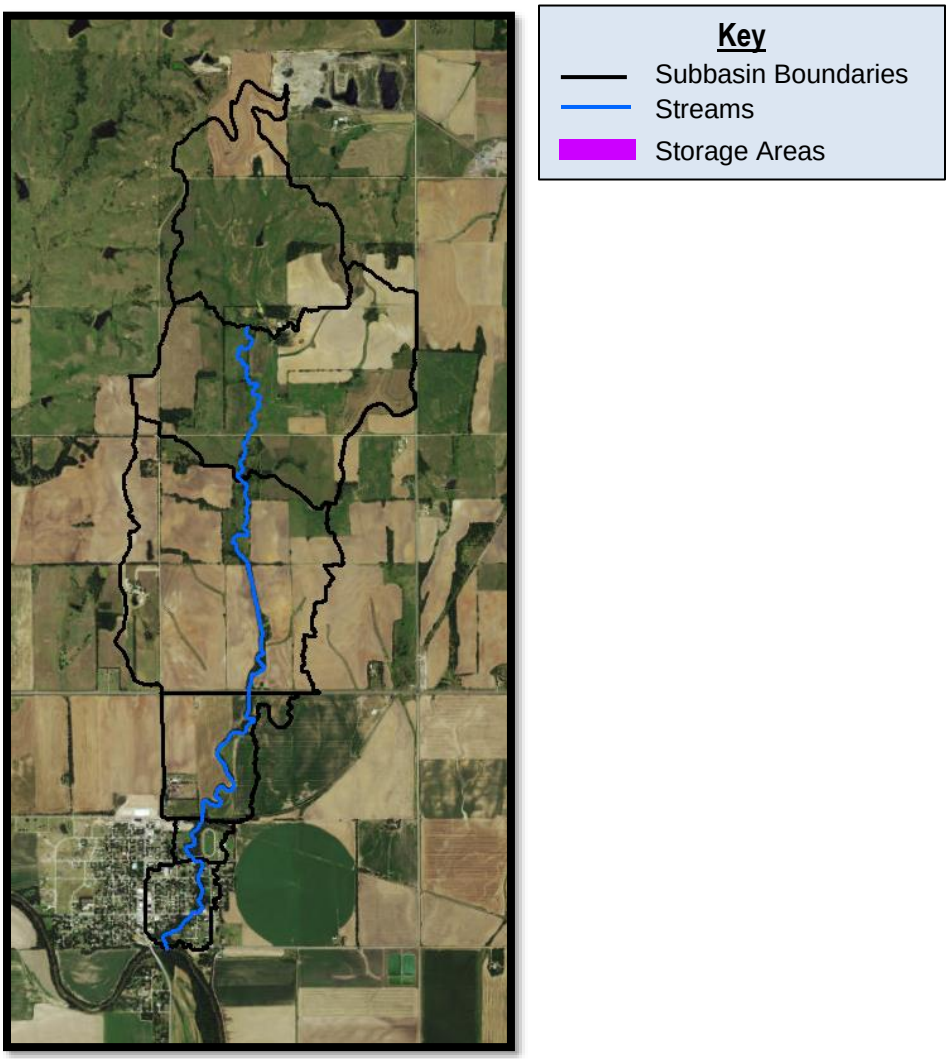
Areal reduction of the point rainfall depths was not deemed necessary for the Smoky Hill Tributary No. 1 watershed study since the contributing drainage area is approximately 2.03 square miles.

Storage Routing

No storage areas were included in the Smoky Hill Tributary No. 1 watershed hydrologic model. The criteria for including storage areas within the model was defined by the Kansas Department of Agriculture. Storage areas are limited to those dams that were designed for flood control or public use purposes, significant road embankments, and located along detailed study or limited detailed study extents which impact the runoff response of the watershed. Preliminary selection criteria allowed for storage areas (such as farm ponds) in the most upstream portions of the watersheds to be excluded from the model, and represented using the Clark Unit Hydrograph method previously described. Using a higher Clark's Ratio will adequately compensate for restrictions on the outlet hydrograph by a storage area located at or near the outlet of a subbasin.

Figure 11. Smoky Hill River Tributary No. 1 Watershed depicts the Smoky Hill Tributary No. 1 watershed extent.

Figure 11. Smoky Hill River Tributary No. 1 Watershed



Flow Comparison

Table 16 provides a comparison of 1% annual chance peak discharges from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 16. Comparison of 1% Annual Change Discharges for the Smoky Hill River Tributary No. 1 Watershed

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Localized Regression*
Smoky Hill River Tributary No. 1					
Mouth at Smoky Hill River in Marquette	1.87	2.03	2,030	1,210	1,100
Approximately 255 feet upstream of 2nd Street	N/A	1.97	N/A	1,190	1,070
Fifth Street in Marquette	1.78	1.94	1,980	1,180	1,060
At Missouri Pacific Railroad	N/A	1.91	N/A	1,170	1,040
At State Highway 4	1.60	1.72	1,870	1,080	960
*Discussion of regression equations is included later in the report.					

Drainage areas in this detailed study are similar to the drainage areas in the effective FIS. Drainage area was calculated using LiDAR, in which the more detailed topography allowed for added drainage area in the watershed than was previously determined. The upper part of the watershed is agricultural, with terraces directing flow into the watershed that may not have influenced flows before. The modeled flows in this detailed study are lower than reported in the effective FIS but comparable to the localized rural regression flows computed as part of this project. The effective FIS calculated flows for Smoky Hill Tributary No. 1 using regression equations published by the Kansas Water Resources Board in Technical Report No. 11 (Reference 15). The lower flows are most likely a result of newer modeling techniques and utilizing the Clark's Unit Hydrograph to account for attenuation of flow that the regression equations would not have considered. Flow values for Zone A streams are not included in the effective FIS report.

LYON CREEK WATERSHED

The detailed hydrologic study of the Lyon Creek watershed in Dickinson County, Kansas has a total drainage area of approximately 266.9 square miles. This detailed study includes Lyon Creek, Carry Creek, West Branch Lyon Creek, Unnamed Tributary – Ramona, Lime Creek, and Lime Creek Tributary No. 4. The Lyon Creek watershed was divided into 185 subbasins. Ten of the subbasins contain urbanized areas within the City of Herrington, while the remaining subbasins are predominately rural areas. The subbasins range from 0.045 to 5.5 square miles.

Rainfall and Areal Reduction

Areal reduction of the point rainfall depths was used for the Lyon Creek watershed study because the contributing drainage area is 266 square miles. Areal reduction of 0.95 was used for subbasins with a contributing drainage area of more than 40 square miles but less than 100 square miles, Areal reduction of .93 was used for subbasins with a contributing drainage area of more than 100 sq. miles but less than 200 sq. miles, and areal reduction of .91 was used for subbasins with a contributing drainage area greater than 200 square miles. These areal reduction ratios were taken from the rainfall depth reductions based on area-depth curves given in TP-40 (Reference 16). These areal reduction ratios were applied to all modeled meteorological storm events using the following plans within the rainfall-runoff model:

"*[Frequency]_Clarks*" – no application of areal reduction for drainage area < 40 mi^2
"*[Frequency]_40_Clarks*" – applies areal reduction for 40 mi^2 < drainage area < 100 mi^2
"*[Frequency]_100_Clarks*" – applies areal reduction for 100 mi^2 < drainage area < 200 mi^2
"*[Frequency]_200_Clarks*" – applies areal reduction for drainage area > 200 mi^2

Storage Routing

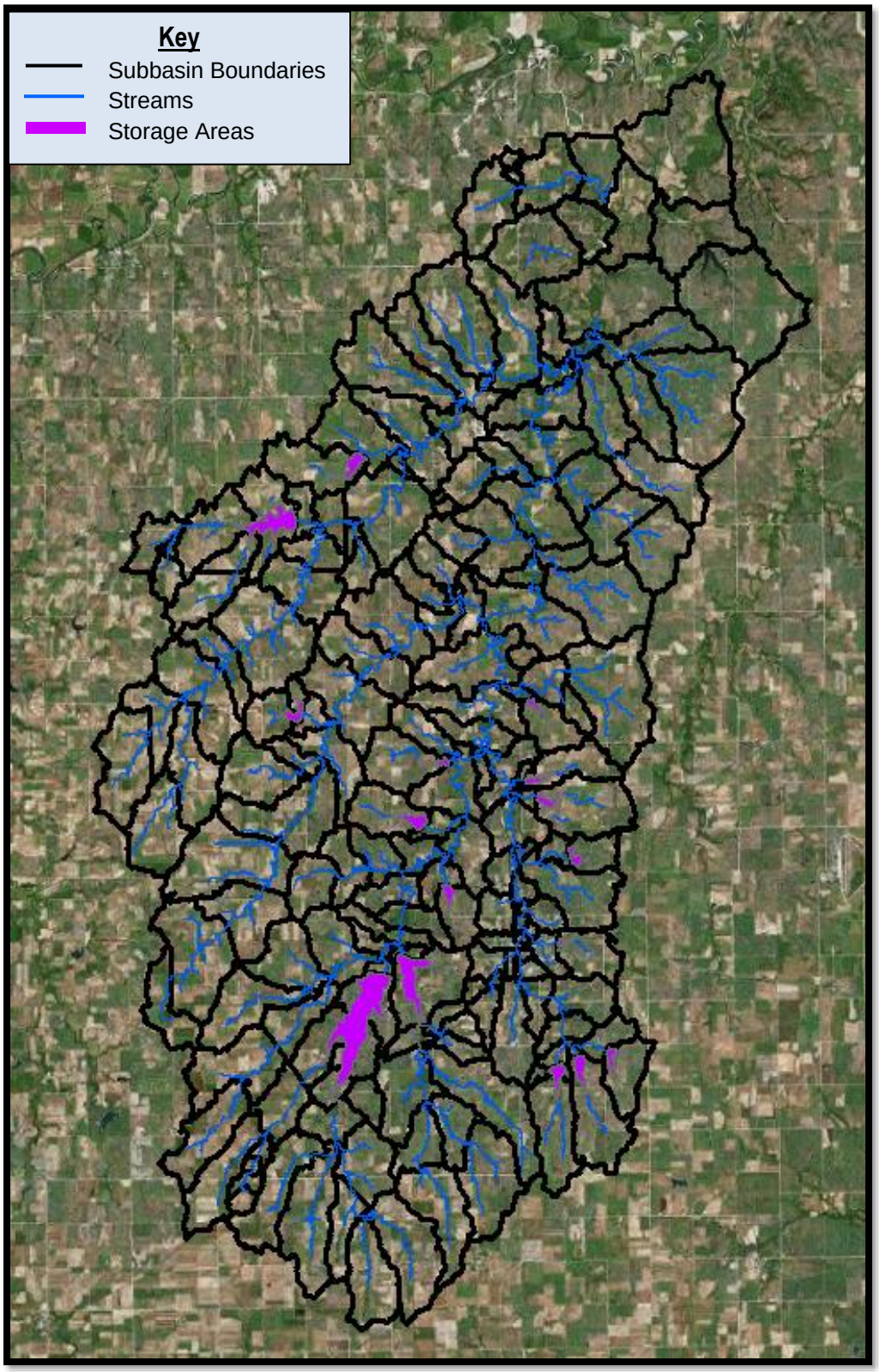
A total of sixteen storage areas were modeled in the Lyon Creek watershed hydrologic model. These areas represent storage behind dams and road/railroad embankments within the model. Three of the storage areas are in Morris County and one storage area is behind US-77. The criteria for including storage areas within the model was defined by the Kansas Department of Agriculture. Storage areas are limited to those dams that were designed for flood control or public use purposes, significant road embankments, and located along detailed study or limited detailed study extents which impact the runoff response of the watershed. Preliminary selection criteria allowed for storage areas (such as farm ponds) in the most upstream portions of the watersheds to be excluded from the model, and represented using the Clark Unit Hydrograph method previously

described. Using a higher Clark's Ratio will adequately compensate for restrictions on the outlet hydrograph by a storage area located at or near the outlet of a subbasin.

Specifications for dam tops, associated spillways, and associated outlet structures were obtained from the Kansas Department of Agriculture as-built information and included in the HEC-HMS model where applicable. Survey information, obtained by Amec Foster Wheeler, was also used to supplement outlet structures of the storage areas located along the Zone AE designated streams, where access to the structures was available. In addition information on the dam tops and spillways of these storage areas were further verified by comparing as-built information to LiDAR topography.

Figure 12 illustrates the extent of the maximum water elevation during the 1% annual chance storm event for all the storage areas included in the Lyon Creek watersheds HEC-HMS model, along with subbasin boundaries.

Figure 12. Extent of Maximum Water Elevation of Modeled Storage Areas in the Lyon Creek Watershed during 1% chance storm event



Flow Comparison

Table 17 provides a comparison of 1% annual chance peak discharges from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 17. Comparison of 1% Annual Chance Discharges for the Lyon Creek Watershed

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
Carry Creek					
At mouth	53.4	53.92	13,460	9,390	17,830
6,900 feet upstream of Wolf Rd	N/A	53.43	N/A	9,640	17,750
Just downstream of confluence of Carry Creek Tributary No. 3	N/A	50.36	N/A	8,750	17,280
About 4.47 miles upstream of mouth at County Highway	46.4	46.84	10,880	7,400	16,700
Just downstream of confluence of Carry Creek Tributary No. 8	37.7	37.86	10,560	7,380	15,150
Just upstream of confluence of Carry Creek Tributary No. 8	33.5	33.63	10,090	7,010	14,330
Just downstream of confluence of Carry Creek Tributary No. 12	28.4	28.54	8,800	6,730	13,280
Just upstream of confluence of Carry Creek Tributary No. 12	19.8	19.84	6,370	5,700	11,410
3,500 feet downstream of 1300 Ave Rd	N/A	16.90	N/A	5,460	10,320
3,175 feet upstream of 1300 Ave	N/A	15.10	N/A	4,990	9,610
1,900 feet downstream of 1200 Ave	N/A	12.80	N/A	4,430	8,660
Lime Creek					
At mouth	30.2	30.27	13,910	9,010	13,660
Just downstream of confluence of Lime Creek Tributary No. 3	N/A	23.36	N/A	8,710	12,120
At State Highway 4 and Oklahoma Kansas and Texas Railroad	18.6	18.84	9,010	7,040	11,040
Just downstream of confluence of Lime Creek Tributary No. 13	17.7	18.51	8,950	6,980	10,930
Just downstream of confluence of Lime Creek Tributary No. 2	16.8	17.02	8,620	6,530	10,360
Just downstream of confluence of Lime Creek Tributary No. 4	14.4	14.49	7,900	5,120	9,370
Just downstream of Lime Creek Trib 8	N/A	12.44	N/A	4,030	8,480
1,110 feet downstream of Wind road	N/A	10.40	N/A	3,020	7,590
At E-W Road Near Dickinson-Morris county line	9.1	9.86	2,960	2,810	7,350
Just downstream of Lime Creek Trib 9	N/A	9.70	N/A	2,690	7,260
Just downstream of Lime Creek Trib 10	N/A	9.40	N/A	2,360	7,120
3,200 feet downstream of 300 Ave	N/A	8.40	N/A	1,480	6,630
2,000 feet downstream of 300 Ave	N/A	8.10	N/A	1,350	6,480
Just downstream of confluence with Lime Creek Tributary No. 12	7.74	7.72	2,910	1,110	6,270
670 feet downstream of Wolf road	N/A	2.90	N/A	320	3,380
Just downstream of Wolf road	N/A	2.80	N/A	280	3,300
870 feet upstream of Wolf road	N/A	2.70	N/A	220	3,230

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
1,330 feet upstream of Wolf road	N/A	2.70	N/A	200	3,230
1,550 feet upstream of Wolf road	N/A	2.70	N/A	190	3,230
Just downstream of Lyon Creek Watershed Dam 3 (DDK-0127A)	N/A	2.59	N/A	130	3,150
2,275 feet downstream of 200 Ave	N/A	2.28	N/A	1,280	2,910
Lime Creek Trib. 2					
At mouth	1.9	2.08	1,690	1,580	2,750
Just upstream of confluence of Lime Creek Tributary branch No. 6.1	1.4	1.98	1,180	1,490	2,670
Just downstream of N F street	N/A	1.42	N/A	1,220	2,410
Just downstream of U.S. Highway 77	1.2	2.08	989	1,010	2,130
Just upstream of U.S. Highway 77	1.2	2.08	2,300	1,430	2,130
Lime Creek Trib. 4					
Just downstream of N-S Union Pacific Railroad	1.5	1.65	1,660	1,670	2,320
Just upstream of the N-S Union Pacific Railroad	N/A	1.65	N/A	1,840	2,320
Just downstream of 9th Street	1.4	1.49	1,450	1,680	2,220
1,630 feet downstream of Union Pacific Railroad	N/A	1.40	N/A	1,550	2,130
1,130 feet downstream of Union Pacific Railroad	N/A	1.00	N/A	1,210	1,720
Just downstream of Union Pacific Railroad	0.9	0.93	764	960	1,610
1,175 feet upstream of Union Pacific Railroad	N/A	0.90	N/A	920	1,610
1,450 feet upstream of Union Pacific Railroad	N/A	0.61	N/A	810	1,240
Lyon Creek					
At USGS gage No. 06878500, near Woodbine, Kansas	237	237.29	39,720	24,680	35,350
Just downstream of confluence of Carry Creek	227	228.06	38,640	24,700	34,710
Just upstream of confluence of Carry Creek	173	174.14	29,880	20,470	30,640
Just downstream of confluence of West Branch Lyon Creek	146	146.09	30,640	21,650	28,260
Just upstream of confluence of West Branch Lyon Creek	115	115.24	22,880	15,390	25,320
Just downstream of confluence of Lime Creek	102	102.47	22,650	15,800	23,990
Just upstream of confluence of Lime Creek	71.9	72.21	17,330	11,690	20,400
At State Highway 4	57.4	57.71	17,970	12,270	18,400
Just downstream of confluence of Kohl's Creek	54.8	54.99	17,910	12,550	17,990
Just upstream of confluence of Kohls Creek	37.4	37.42	8,390	5880	15,060
Just downstream of confluence of Lyon Creek Tributary 21	N/A	36.97	N/A	5,910	14,980

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
At 500 Ave	N/A	24.75	N/A	440	12,450
Just downstream of the Herington Reservoir Dam (DDK-0138)	24.6	24.55	500	320	12,410
Just downstream of confluence with Lyon Creek Tributary No. 22	N/A	23.06	N/A	14,780	12,050
200 feet downstream of County Road 857	N/A	14.20	N/A	8,450	9,240
Unnamed Tributary - Ramona					
Just downstream of Quail Creek Rd	N/A	0.90	N/A	1,070	1,610
Just downstream of 1/2 Mile Rd	N/A	0.72	N/A	870	1,370
Just downstream of 5th St	N/A	0.66	N/A	810	1,370
Just downstream of C St	N/A	0.59	N/A	730	1,240
Just downstream of 1st St	N/A	0.40	N/A	520	960
410 feet downstream of the Union Pacific Railroad	N/A	0.35	N/A	460	960
Just downstream of the Union Pacific Railroad	N/A	0.29	N/A	390	800
200 feet upstream of the Union Pacific Railroad	N/A	0.25	N/A	360	800
410 feet upstream of the Union Pacific Railroad	N/A	0.20	N/A	310	620
800 feet upstream of the Union Pacific Railroad	N/A	0.16	N/A	270	620
1,100 feet upstream of the Union Pacific Railroad	N/A	0.14	N/A	250	400
West Branch Lyon Creek					
At mouth	30.5	30.85	8,490	7,450	13,780
Just downstream of confluence of West Branch Lyon Tributary No. 5	20	22.80	8,840	7,010	11,980
Just upstream of confluence of West Branch Lyon Creek Tributary No. 7	18.1	20.16	8,280	7,000	11,560
Just downstream of West Branch Lyon Creek Tributary No. 8	17.4	18.58	8,490	6,660	10,970
Just downstream of West Branch Lyon Creek Tributary No. 10	17.4	16.65	8,490	6,870	10,240
1,500 feet downstream of Quail road	N/A	13.20	N/A	5,790	8,830

Flow values for Lyon Creek are lower than the flows described in the effective FIS Report and the rural regression equations. This is likely caused by the inclusion of storage areas behind road embankments and watershed dams in the HEC-HMS model, which results in a more accurate representation of flows in flat drainage areas such as these, which were most likely not included in the previous study. This may also be due to more detailed topography and the incorporation of new modeling methods. Flow values for Zone A streams are not included in the effective FIS report.

As previously discussed two stream gage stations were identified within the Lyon Creek watershed including USGS 06878500 and 06878600. Neither of these gage locations included a recent period of record sufficient for computing a confident statistical gage analysis that would have reflected

impacts to the runoff response as a result of significant flood control dams that were constructed throughout the watershed.

Table 18 below depicts the watershed and flood control dams included in this hydrologic study along with the computed 1% annual chance water surface elevations from this study, which are located in Dickinson County. These water surface elevations will be reevaluated during the hydraulic phase of this project once more detailed hydraulic routing is completed using HEC-RAS.

Table 18. Storage Elevations within the Lyon Creek Watershed (feet NAVD88)

Dam Name	Location	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% Plus Annual Chance	0.2% Annual Chance
Lyon Creek Watershed Dam 7 (DDK-0107)	Dickinson County Unicorporated Areas	1,310.8	1,312.2	1,313.1	1,314.1	1,315.6	1,315.3
Lyon Creek Watershed Dam 12 (DDK-0108)	Dickinson County Unicorporated Areas	1,297.8	1,299.0	1,299.9	1,300.5	1,301.9	1,301.5
Lyon Creek Watershed Dam 11 (DDK-0113)	Dickinson County Unicorporated Areas	1,296.8	1,299.0	1,300.6	1,301.3	1,303.8	1,302.4
Lyon Creek Watershed Dam 13 (DDK-0114)	Dickinson County Unicorporated Areas	1,278.1	1,281.1	1,281.9	1,282.7	1,286.1	1,284.6
Lyon Creek Watershed Dam 3 (DDK-0127A)	Dickinson County Unicorporated Areas	1,396.0	1,397.9	1,399.2	1,400.6	1,402.7	1,403.6
Lyon Creek Watershed Dam 16 (DDK-0132)	Dickinson County Unicorporated Areas	1,250.5	1,251.9	1,252.9	1,253.5	1,255.1	1,254.4
Lyon Creek Watershed Dam 10 (DDK-0135)	Dickinson County Unicorporated Areas	1,305.3	1,307.2	1,307.8	1,308.5	1,310.7	1,309.9
Herington Reservoir Multiple Purpose Dam #6 (DDK-0138)	Dickinson County Unicorporated Areas	1,340.6	1,342.3	1,343.5	1,344.8	1,346.4	1,346.5
Lyon Creek Watershed Dam 14 (DDK-0140)	Dickinson County Unicorporated Areas	1,282.6	1,284.9	1,285.7	1,286.2	1,288.6	1,287.3
Lyon Creek Watershed Dam 17 (DDK-0144)	Dickinson County Unicorporated Areas	1,276.0	1,277.5	1,278.1	1,278.6	1,280.3	1,279.9

Dam Name	Location	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% Plus Annual Chance	0.2% Annual Chance
Lake Herington (DDK-0150)	Dickinson County Unicorporated Areas	1,326.9	1,327.6	1,328.1	1,328.6	1,329.3	1,329.8
Lyon Creek Watershed Dam 19 (DDK-0170C)	Dickinson County Unicorporated Areas	1,320.4	1,321.8	1,322.3	1,322.7	1,324.2	1,323.9

MUD CREEK WATERSHED

The hydrologic study of the Mud Creek watershed in Dickinson County, Kansas has a total drainage area of approximately 93.8 square miles. The watershed is divided into 144.3 stream miles to be modeled by approximate methods, and 4.9 stream miles to be modeled by detailed methods. The streams to be modeled by detailed methods include Mud Creek and Mud Creek Tributary No. 1. The entire watershed study includes a total of 128 subbasins, which range from 0.02 to 1.98 square miles. 10 of these subbasins cover predominately urban areas of the City of Abilene. The other 118 subbasins cover predominately rural areas, of which three subbasins cover the City of Manchester. The City of Abilene is located in the historic Smoky Hill River floodplain, resulting in flat, low-lying areas of the city. To mitigate against flooding, the City has a levee system along Mud Creek and a stormwater system to direct flows. The 10 urban subbasins that cover the City of Abilene were drawn according to the levee system and stormwater network.

Rainfall and Areal Reduction

Due to the large size of the Mud Creek watershed, areal reduction of the point rainfall depths was deemed necessary for the detailed hydrologic model. TP-40 and TR-60 include methods for identifying rainfall depth reduction ratios based on the area-depth curves. The total contributing drainage area of Mud Creek is approximately 93 square miles. Based on TP-40 and TR-60 areal reduction ratios could vary between 0.95 and 0.78, respectively. Given the wide range of acceptable areal reduction ratios that could be applied it was determined that the selection of the areal reduction ratio would be based on calibration to peak discharges computed from the statistical gage analysis of USGS 06877120. As a result of calibration to USGS 06877120 an areal reduction ratio of 0.86 was utilized. This areal reduction ratio falls within the range of acceptable reduction ratios as defined by TP-40 and TR-60 and was therefore deemed to be appropriate. To select areal reduction ratios the distribution of points and the contributing drainage areas were evaluated. Based on that evaluation no areal reduction ratio was applied between 0 and 30 square miles. A ratio of 0.88 was applied for drainage areas between 30 square miles and 60 square miles. A ratio 0.86 was applied for drainage areas greater than 60 square miles. These areal reduction ratios were applied to all modeled meteorological storm events using the following plans within the rainfall-runoff model:

"*[Frequency]*" – no application of areal reduction for drainage area < 30 mi^2
"*[Frequency]_30sq*" – applies areal reduction for 30 mi^2 < drainage area < 60 mi^2
"*[Frequency]_60sq*" – applies areal reduction for drainage area > 60 mi^2

Storage Routing

The criteria for including storage areas within the model was defined by the Kansas Department of Agriculture. Storage areas are limited to those dams that were designed for flood control or public use purposes, significant road embankments, and located along detailed study or limited detailed study extents which impact the runoff response of the watershed.. A levee system along Mud Creek exists to minimize flooding within the City of Abilene. Seven storage areas are included in the detailed hydrology model to represent outlets along this levee system. Specifications on these outlet structures were obtained from the Operation and Maintenance Manual for the system by USACE (Reference 17) and the Phase 1 – Storm Sewer Project Identification Study Final Report by GBA Architects Engineers Consultants (Reference 18). Information on the overflow of these outlet structures were obtained using LiDAR topography. No other structures exist within the Mud Creek watershed for flood control; therefore, use of the Clark Unit Hydrograph method was used to represent structures that may cause attenuation of flow, such as farm ponds or large road embankments.

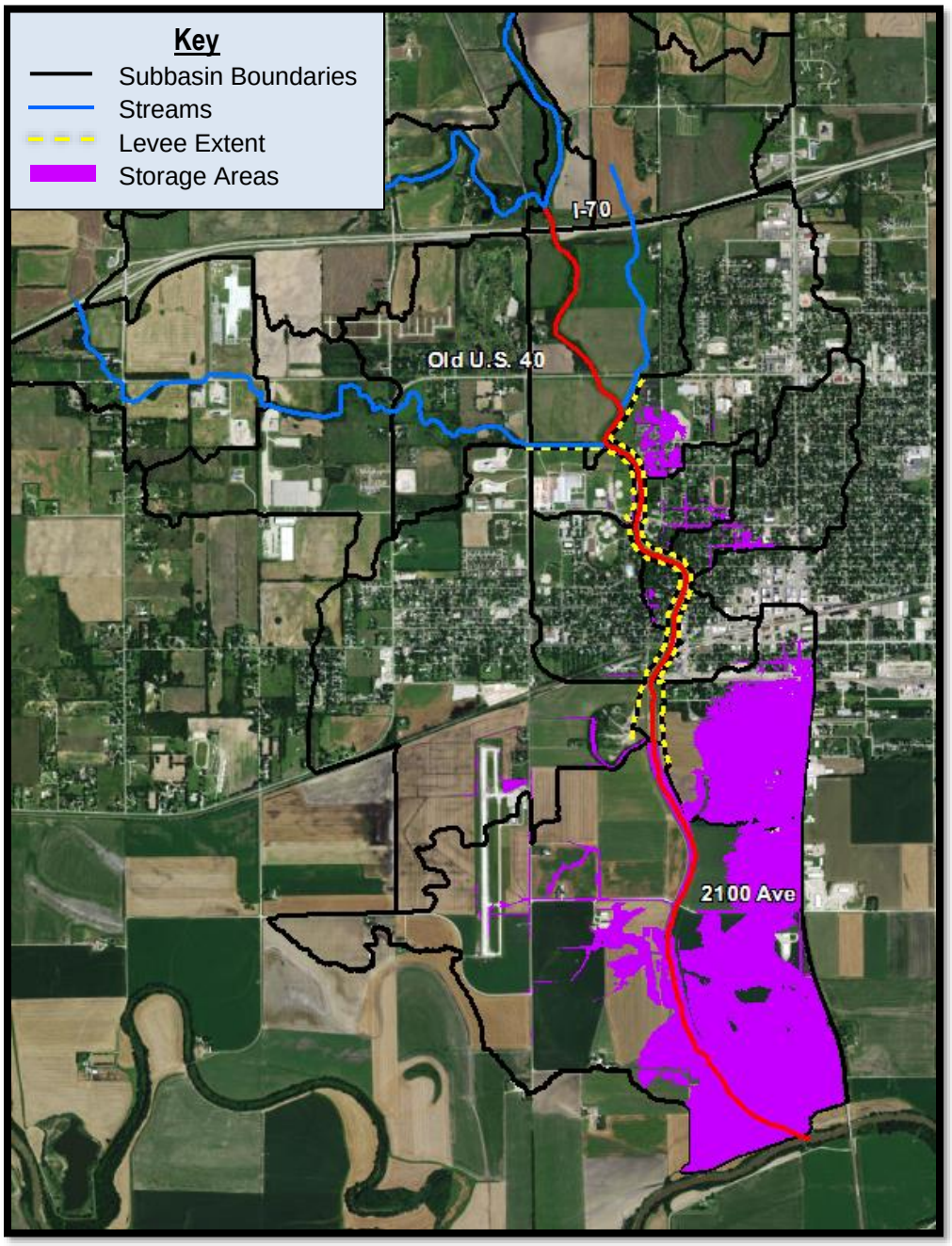
The Mud Creek valley becomes greater than 0.75 miles in width as it approaches the City of Abilene. The levee system along Mud Creek in the City of Abilene greatly reduces the conveyance area of the Mud Creek floodplain. The Muskingum-Cunge routing method becomes unsuitable to produce accurate results in this area using HEC-HMS. To develop accurate flows, a 1-D unsteady HEC-RAS model will be utilized in hydraulics for routing the primary channel including just upstream of the I-70 Interstate to the confluence of Mud Creek and the Smoky Hill River. Figure 13 depicts the anticipated extent of the 1-D unsteady-state HEC-RAS model that will be developed in the hydraulic phase of this project.

Figure 13. 1-D Unsteady Routing Extent to be modeled in Mud Creek Watershed.

Figure 14 illustrates the extent of the maximum water elevation during the 1% annual chance storm event for all the storage areas that are adjacent to the levee system within the HEC-HMS model. The intent of these storage areas are to simulate the storage and attenuation affect that these contributing areas have on Mud Creek. While sufficient to simulate the impacts on Mud Creek it is not intended that these ponding areas be included as part of the mapping. Further analyses as a

function of levee certification/accreditation would need to be performed in order to sufficiently establish the static water surface elevations adjacent to the levee system, which is beyond the scope of this study.

Figure 14. Extent of Maximum Water Elevation of Modeled Storage Areas Adjacent to the Mud Creek Levee System in Abilene, KS during 1% chance storm event



Flow Comparison

Table 19 provides a comparison of 1% annual chance peak discharges from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 19. Comparison of 1% Annual Chance Discharges for the Mud Creek Watershed

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
Mud Creek					
Just downstream of confluence of Mud Creek Tributary No. 1	89.0	89.87	17,000	20,200	22,570
At USGS Gage No. 06877120	87.1	87.64	16,800	20,070	22,310
Just downstream of confluence of Mud Creek Trib 3	N/A	86.62	N/A	20,700	22,190
Mud Creek Tributary No. 1					
Just upstream of confluence of Mud Creek	1.6	1.72	2,300	940	2,420
At N Washington Street	N/A	1.72	N/A	940	2,420
Approximately 1,500 feet downstream of Old U.S. 40	N/A	1.27	N/A	830	2,000

The effective FIS calculated flows for Mud Creek and Mud Creek Tributary No. 1 using regression equations published by the Kansas Water Resources Board in Technical Report No. 11 (Reference 15). The flow values for Mud Creek are higher than the effective FIS flows, while the flow value for Mud Creek Tributary No. 1 is lower than the effective FIS. As previously discussed statistical gage analyses were performed on USGS 06877120 located just downstream of I-70 and upstream of the levee system. The statistical gage analyses resulted in a 1% annual chance peak discharge of 20,060 cfs that was developed from a significant period of record. Initial input parameters into the HEC-HMS model without consideration of the gage analysis resulted in a 1% annual chance peak discharge of 23,300 cfs which is approximately 16% higher than the results of the statistical gage analysis. The Mud Creek watershed is a large watershed with 93 square miles of contributing drainage area and generally linearly oriented north and south. Historically storms generally track from west to east therefore given the orientation of the watershed and size there is likely some reasonable variation of areal reduction ratio's that should be considered. After evaluating the areal reduction methods in TP-40 and TR-60 the areal reduction ratio could vary between 0.95 to 0.78. Based on this variation the results of the HEC-HMS model were calibrated to the statistical gage analyses by adjusting the areal reduction ratio to 0.86 resulting in the 1% annual chance peak discharge of 20,070 cfs.

To further refine the flows through the levee system an unsteady-state 1D HEC-RAS model will developed in the hydraulic phase of the project.

The decrease in HEC-HMS flow for Mud Creek Tributary No. 1 is most likely due to the differing modeling techniques accounting for detailed runoff response that are not accounted for in regression equations. Much of the individual subbasins contain highly permeable (hydrologic group A & B) soils that result in very low runoff response compared to typical rural regression areas. Flow values for Zone A streams are not included in the effective FIS report.

SOLOMON RIVER TRIBUTARY WATERSHED

The hydrologic study of the Solomon River Tributary watershed in Dickinson County, Kansas has a total drainage area of approximately 4.5 square miles. Solomon River Tributary was divided into 1.5 river miles modeled as detailed study on the downstream end, and 3.0 river miles modeled as approximate study on the upstream end. The entire watershed was divided into 8 subbasins. Four of these subbasins are included in the detailed study, of which three subbasins contain urbanized areas within the City of Solomon, and one subbasin contains predominately rural areas. The four subbasins included in the approximate study cover predominately rural areas. The subbasins range from 0.06 to 1.18 square miles.

Rainfall and Areal Reduction

Areal reduction of the point rainfall depths was not deemed necessary for the Smoky Hill Tributary No. 1 watershed study since the contributing drainage area is approximately 4.5 square miles.

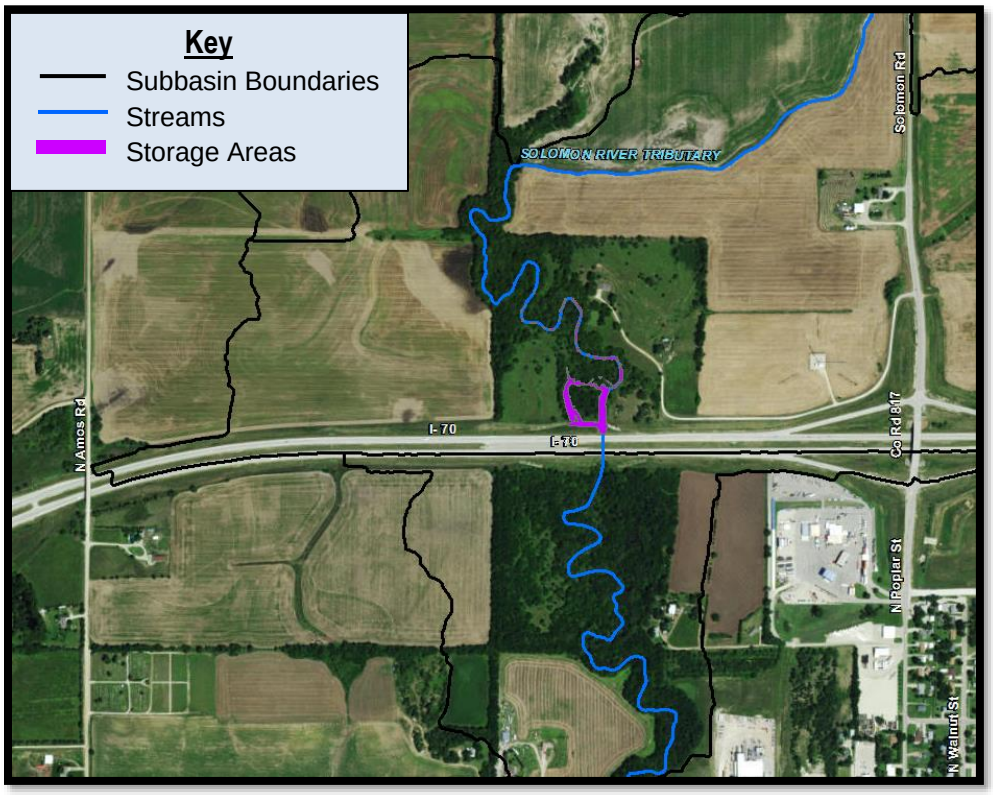
Storage Routing

One storage area was modeled in the Solomon Tributary watershed hydrologic model. This storage area represents significant storage behind Interstate 70. There are no dams specifically designed for flood control in this watershed; therefore attenuation of flow from smaller structures, like farming ponds, are taken into account using Clark's Unit Hydrograph method.

Specifications for the outlet structure were obtained from KDOT, and information regarding overtopping of the structure was obtained using LiDAR topography.

Figure 15 illustrates the extent of the maximum water elevation during the 1% annual chance storm event for the storage area included in the Solomon River Tributary watershed HEC-HMS model, along with subbasin boundaries.

Figure 15. Extent of Maximum Water Elevation of Modeled Storage Areas in the Solomon Tributary Watershed during 1% chance storm event



Flow Comparison

Table 20 provides a comparison of 1% annual chance peak discharges from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 20. Comparison of 1% Annual Chance Discharges for the Solomon River Tributary Watershed

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
Solomon River Tributary					
At Union Pacific Railroad	4.4	4.44	1,062	3,070	4,420
At 7th Street at Solomon	4.3	4.29	1,685	3,110	4,330
Just Downstream of Interstate 70	3.7	3.91	3,165	3,110	4,080

Flow values for Solomon River Tributary are greater than the flows described in the effective FIS Report upstream of Interstate 70 but similar downstream of Interstate 70. The resulting discharges are lower than the current rural regression flows. The effective FIS calculated flows for Solomon River Tributary using regression equations published by the Kansas Water Resources Board in Technical Report No. 11 (Reference 15). However, the effective FIS flows reported appear to be given in error, as the flows decrease with increasing drainage area. Despite this, the greater flows resulting from the hydrologic HEC-HMS model could be due to newer modeling techniques and

more accurate LiDAR, and the regression equations used to calculate the effective FIS may underestimate flows. Flow values for Zone A streams are not included in the effective FIS report.

TURKEY CREEK WATERSHED

The hydrologic study of the Turkey Creek watershed in Dickinson and Marion Counties, Kansas has a total drainage area of approximately 164.8 square miles. The watershed is divided into 220.5 stream miles to be modeled by approximate methods, and 80.1 stream miles to be modeled by detailed methods. The streams to be modeled by detailed methods include Turkey Creek, Turkey Creek Tributary No. 1, Turkey Creek Tributary No. 2, East Turkey Creek, East Turkey Creek Tributary No. 1, East Turkey Creek Tributary No. 2, Middle Branch Turkey Creek, West Turkey Creek, and West Branch Turkey Creek. The entire watershed study includes a total of 128 subbasins, which range from 0.23 to 7.67 square miles. All of the subbasins cover predominately rural areas.

Rainfall and Areal Reduction

Due to the large size of the Mud Creek watershed, areal reduction of the point rainfall depths was deemed necessary for the detailed hydrologic model. Rainfall depth reduction ratios were based on the area-depth curves of TP-40 (Reference 10). No areal reduction ratio was applied between 0 and 50 square miles, a ratio of 0.94 was applied for drainage areas between 50 square miles and 100 square miles, and a ratio of 0.92 was applied for drainage areas greater than 100 square miles. These areal reduction ratios were applied to all modeled meteorological storm events using the following plans within the rainfall-runoff model:

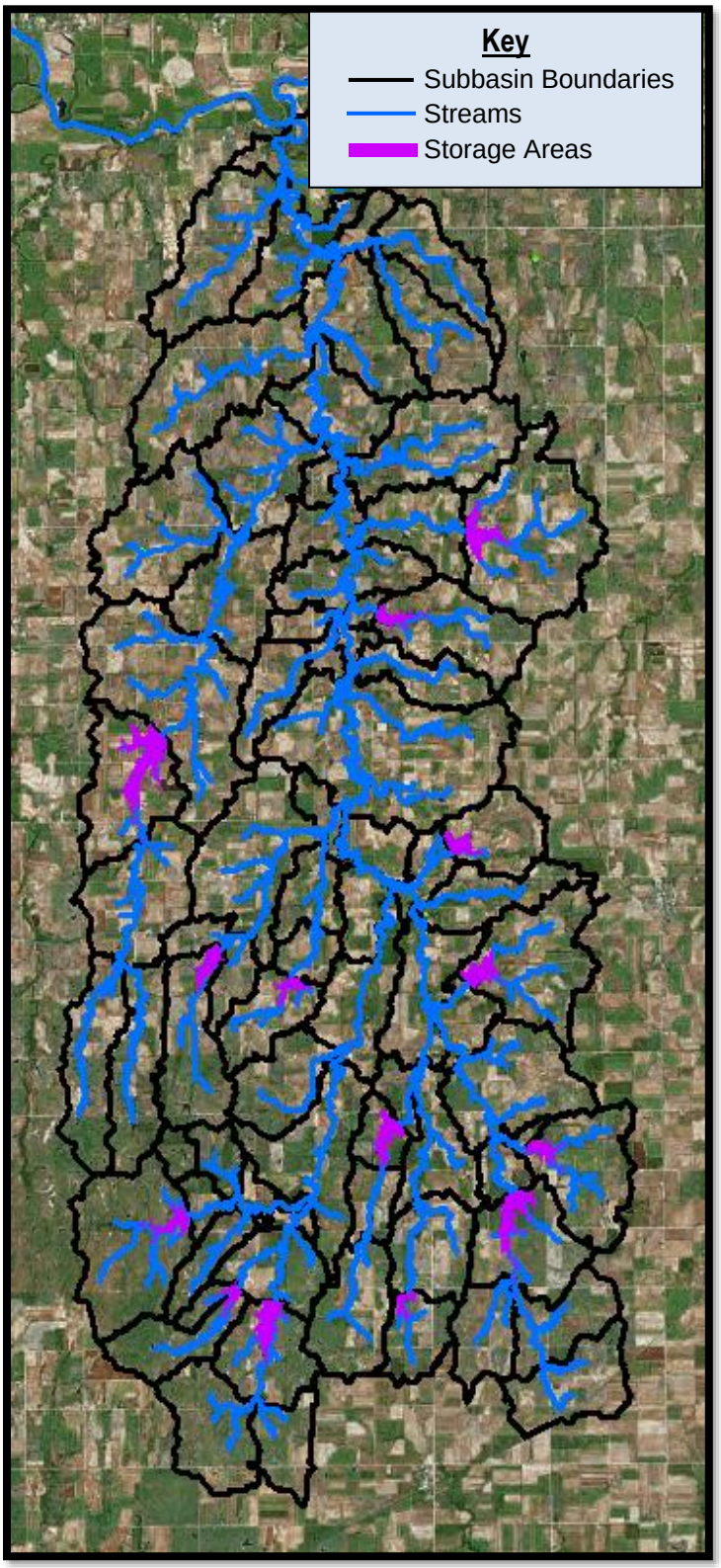
"*[Frequency]*" – no application of areal reduction for drainage area < 50 mi^2
"*[Frequency]_50sq*" – applies areal reduction for 50 mi^2 < drainage area < 100 mi^2
"*[Frequency]_100sq*" – applies areal reduction for drainage area > 100 mi^2

Storage Routing

A total of fourteen storage areas were modeled in the Turkey Creek watershed hydrologic model. These storage areas represent watershed dams designed for flood control that may significantly affect runoff response. Those privately owned and maintained impoundments that were not designed for flood control were not included in the hydrologic model as storage areas. The Clark's Unit Hydrograph method is used to account for attenuation as a result from structures not modeled. Specifications for dam tops, associated spillways, and associated outlet structures were included in the HEC-HMS model, where applicable. The information for dam tops and spillways were obtained by Amec Foster Wheeler using LiDAR topography, and the information for outlet structures were obtained from the Kansas Department of Agriculture.

Figure 16 illustrates the extent of the maximum water elevation during the 1% annual chance storm event for all the storage areas included in the Turkey Creek watershed HEC-HMS model, along with subbasin boundaries.

Figure 16. Extent of Maximum Water Elevation of Modeled Storage Areas in the Turkey Creek Watershed during 1% chance storm event



Flow Comparison

Table 21 provides a comparison of 1% annual chance peak discharges from the effective FIS Report and peak discharges developed as part of this detailed study.

Table 21. Comparison of 1% Annual Chance Discharges for the Turkey Creek Watershed

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
East Turkey Creek					
Just Upstream of Confluence of West Turkey Creek	36.4	39.31	7,150	5,710	15,410
At Confluence with East Turkey Creek Trib 16	N/A	36.51	N/A	5,630	14,890
Just Downstream of Confluence of East Turkey Creek Tributary No. 1	32.9	32.08	6,730	5,000	14,030
At Confluence of East Turkey Creek Trib 4	N/A	21.23	N/A	2,800	11,590
Just Upstream of Confluence of East Turkey Creek Trib 5	16.9	16.41	3,450	2,300	10,130
Approximately 4,170 Feet Downstream of 300 Avenue	N/A	14.4	N/A	1,800	9,330
Just Downstream of Confluence of East Turkey Creek Trib 7	12.8	12.89	3,340	1,430	8,690
At Turkey Creek Watershed Dam 6 (DDK-0128)	8.7	8.8	1,500	990	6,820
Approximately 1,800 Feet Upstream of 100 Avenue	N/A	6.46	N/A	5,840	5,610
East Turkey Creek Tributary No. 1					
Just Upstream of Confluence of East Turkey Creek	11.4	10.85	3,790	2,760	7,790
Just Downstream of Confluence of East Turkey Creek Tributary No. 2	10.6	10.85	3,500	2,800	7,790
Just Upstream of Confluence of East Turkey Creek Tributary No. 2	5.3	5.72	3,480	2,380	5,190
At Confluence of East Turkey Creek Trib 1.1	N/A	5.13	N/A	2,130	4,830
Approximately 3,320 Feet Downstream of 200 Avenue	N/A	4.29	N/A	1,790	4,330
At Confluence of East Turkey Creek Trib 1.2	N/A	3.67	N/A	1,530	3,920
East Turkey Creek Tributary No. 2					
Approximately 3,290 Feet Upstream of Confluence of East Turkey Creek Tributary No. 1	N/A	5.13	N/A	550	4,850
At Turkey Creek Watershed Dam 8 (DDK-0109)	N/A	4.43	175	390	4,420
At 200 Avenue	N/A	3.57	N/A	1,950	3,850
Middle Branch Turkey Creek					
Just Upstream of Confluence of West Turkey Creek	10.8	10.82	5,380	2,350	7,780
At Dickinson-Marion County Boundary	10.5	10.48	5,110	2,370	7,620
Turkey Creek					

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
Just Upstream of Confluence of Smoky Hill River	164	164.83	25,385	12,040	29,880
At USGS Gage No. 06877500, Near Abilene, Kansas	140	140.2	21,520	12,920	27,720
Just Upstream of Confluence of West Branch Turkey Creek	112	111.93	15,090	9,410	24,980
Just Downstream of Confluence of Turkey Creek Trib 11	106	106.87	17,930	9,540	24,460
Just Downstream of Confluence of Turkey Creek Trib 14	96.1	97.19	17,020	9,720	23,410
Just Downstream of Confluence of Turkey Creek Tributary No. 1	81	81.75	13,920	9,670	21,610
Just Downstream of Confluence of East and West Turkey Creek	66.7	66.26	12,010	9,730	19,610
Turkey Creek Tributary No. 1					
Just Downstream of Confluence of Turkey Creek Tributary No. 2	12.3	12.53	8,270	3,640	8,540
Just Upstream of Confluence of Turkey Creek Tributary No. 2	8.5	8.58	6,250	2,500	6,720
Just Downstream of Confluence of Turkey Creek Tributary 1.1	N/A	7.73	N/A	2,270	6,270
Just Downstream of Confluence of Turkey Creek Tributary 1.2	N/A	6.56	N/A	1,940	5,690
Just Downstream of Confluence of Turkey Creek Tributary 1.3	N/A	5.55	N/A	1,660	5,120
At State Highway 4	4.5	4.36	4,490	1,330	4,370
Turkey Creek Tributary No. 2					
Just Upstream of Confluence with Turkey Creek Tributary No. 1	3.7	3.95	2,980	1,390	4,110
AT 700 Avenue	N/A	3.62	N/A	1,200	3,890
Approximately 650 Feet Upstream of Confluence of Turkey Creek Tributary 2.1	N/A	3.0	N/A	810	3,450
Approximately 2,900 Feet Downstream of State Highway 4	N/A	2.8	N/A	730	3,300
Just Downstream of State Highway 4	2.5	2.61	2,150	620	3,160
West Branch Turkey Creek					
Just Upstream of Confluence of Turkey Creek	28.4	28.27	2,980	6,560	13,230
Just Downstream of Confluence of West Branch Turkey Creek Trib 4	24.9	25.11	8,760	5,860	12,520
Just Upstream of Confluence of West Branch Turkey Creek Trib 4	N/A	21.27	N/A	4,020	11,600
At Confluence with West Branch Turkey Creek Trib 7	N/A	18.33	N/A	3,240	10,870
At Confluence with West Branch Turkey Creek Trib 11	N/A	14.15	N/A	1,830	9,240
At Turkey Creek Watershed Dam 15 (DDK-0148)	N/A	12.09	N/A	1,130	8,350
West Turkey Creek					
Just Upstream of Confluence of East and West Turkey Creek	27.8	26.95	7,210	5,100	12,940

Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)		
	FIS	HMS	FIS	HMS	Rural Regression
At State Highway 4	27	24.54	7,770	4,580	12,390
At 400 Avenue	N/A	22.44	N/A	4,380	11,890
Just Downstream of Confluence of Middle Branch Turkey Creek	19	18.88	11,720	3,860	11,070
Just Upstream of Confluence of Middle Branch Turkey Creek	8.1	8.06	6,970	1,950	6,460
At Confluence of West Turkey Creek Trib 3	N/A	7.52	N/A	1,780	6,180
At Confluence of West Turkey Creek Trib 4	N/A	6.41	N/A	1,280	5,580

Flow values for all of the modeled rivers in HEC-HMS have lower flows than reported in the effective FIS, except for the calculated flow at East Turkey Creek Tributary No. 2 located at Turkey Creek Dam No. 8, and West Branch Turkey Creek just upstream of the confluence of Turkey Creek. Modeled storage areas impact downstream flows significantly in this watershed. Specifically at Turkey Creek Watershed Dam 6, the 0.2% annual discharge decreases by 5,960 cfs due to the outlet structure size restriction and attenuation of upstream flow into the reservoir (see Table 25). The effective FIS calculated flows using a TR-20 computer model generated in 1983. The watershed still maintains a rural agriculture land use in which agricultural practices may have likely altered the runoff response. Flows may have also decreased due to better modeling techniques and more accurate LiDAR data, as well as modeling storage areas along with the Clark's Unit Hydrograph method for storage areas not modeled. Flow values for Zone A streams are not included in the effective FIS report.

As previously discussed a total of fourteen watershed and flood control dams were included in the HEC-HMS model which significantly impact the runoff response of the watershed. Table 22 below depicts the watershed and flood control dams included in this hydrologic study along with the computed 1% annual chance water surface elevations from this study. These water surface elevations will be reevaluated during the hydraulic phase of this project once more detailed hydraulic routing is completed using HEC-RAS.

Table 22. Storage Elevations within the Turkey Creek Watershed (feet NAVD88)

Dam Name	Location	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% Plus Annual Chance	0.2% Annual Chance
Turkey Creek Watershed Dam 3 (DDK-0086)	Dickinson County Unicorporated Areas	1,294.5	1,295.7	1,296.6	1,297.1	1,297.6	1,298.2
Turkey Creek Watershed Dam 13 (DDK-0087)	Dickinson County Unicorporated Areas	1,303.6	1,304.9	1,305.8	1,306.3	1,306.9	1,307.6
Turkey Creek Watershed Dam 5 (DDK-0092)	Dickinson County Unicorporated Areas	1,337.3	1,339.0	1,339.7	1,340.4	1,341.2	1,342.2

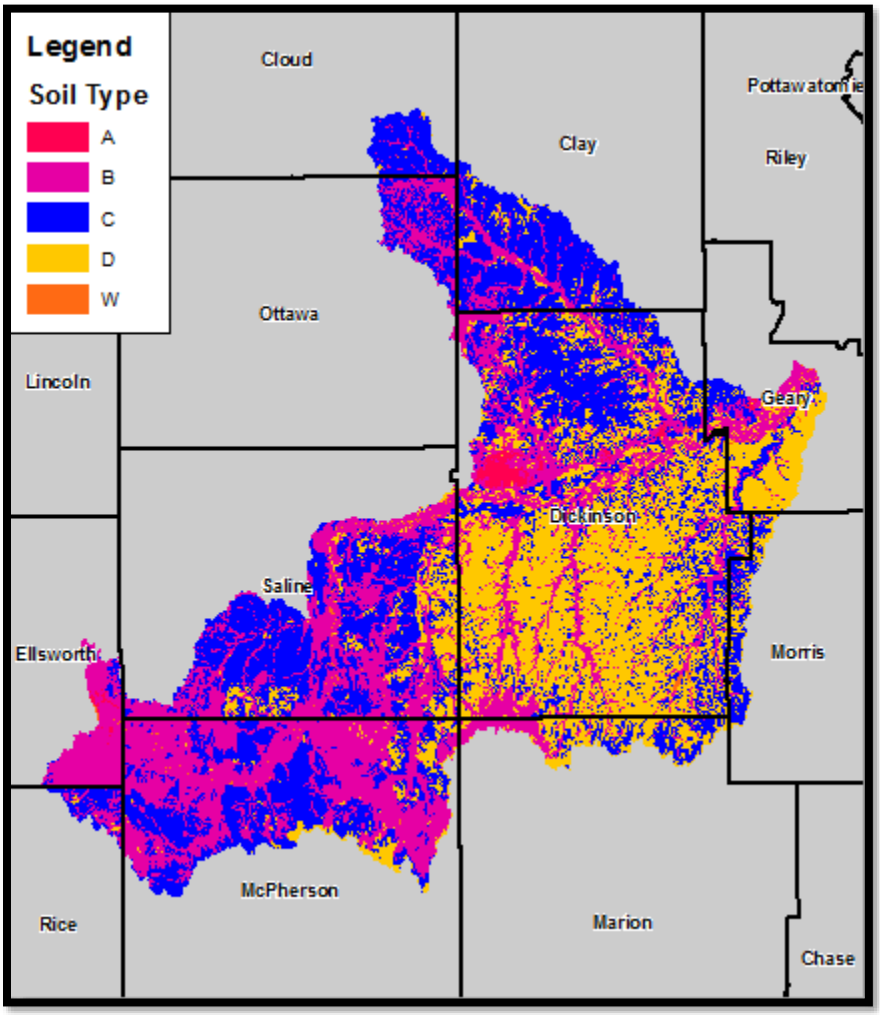
Dam Name	Location	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% Plus Annual Chance	0.2% Annual Chance
Turkey Creek Watershed Dam 11 (DDK-0093)	Dickinson County Unicorporated Areas	1,378.5	1,380.8	1,382.4	1,384.0	1,385.4	1,386.1
Turkey Creek Watershed Dam 4 (DDK-0100)	Dickinson County Unicorporated Areas	1,300.6	1,301.2	1,301.6	1,301.9	1,302.2	1,302.6
Turkey Creek Watershed Dam 12 (DDK-0101)	Dickinson County Unicorporated Areas	1,312.0	1,313.7	1,315.0	1,315.8	1,316.1	1,316.7
Turkey Creek Watershed Dam 1 (DDK-0102)	Dickinson County Unicorporated Areas	1,255.9	1,257.7	1,259.1	1,260.1	1,260.7	1,261.3
Turkey Creek Watershed Dam 2 (DDK-0103)	Dickinson County Unicorporated Areas	1,233.1	1,235.1	1,236.7	1,237.5	1,238.0	1,238.7
Turkey Creek Watershed Dam 8 (DDK-0109)	Dickinson County Unicorporated Areas	1,316.6	1,318.2	1,319.1	1,319.8	1,320.5	1,321.4
Turkey Creek Watershed Dam 6 (DDK-0128)	Dickinson County Unicorporated Areas	1,340.5	1,342.6	1,343.6	1,344.5	1,345.4	1,346.6
Turkey Creek Watershed Dam 15 (DDK-0148)	Dickinson County Unicorporated Areas	1,273.8	1,275.9	1,277.2	1,277.8	1,278.5	1,279.2
Turkey Creek Watershed Dam 9 (DMN-0031)	Dickinson County Unicorporated Areas	1,374.8	1,376.5	1,377.8	1,378.5	1,379.3	1,380.2
Turkey Creek Watershed Dam 10 (DMN-0034)	Dickinson County Unicorporated Areas	1,361.2	1,363.2	1,364.7	1,366.1	1,367.0	1,368.2
Turkey Creek Watershed Dam 7 (DMN-0040)	Dickinson County Unicorporated Areas	1,382.2	1,383.7	1,384.8	1,385.5	1,386.2	1,387.0

APPROXIMATE HYDROLOGIC ANALYSIS

The hydrology for the Zone A streams that are not modeled by a detailed hydrologic method was developed by using a combination of USGS Rural Regression Equations (Reference 19) and localized regression equations. For Dickinson, Ottawa, and Marion Counties the rainfall-runoff modeling that was developed as part of this project indicate that the runoff response is similar to

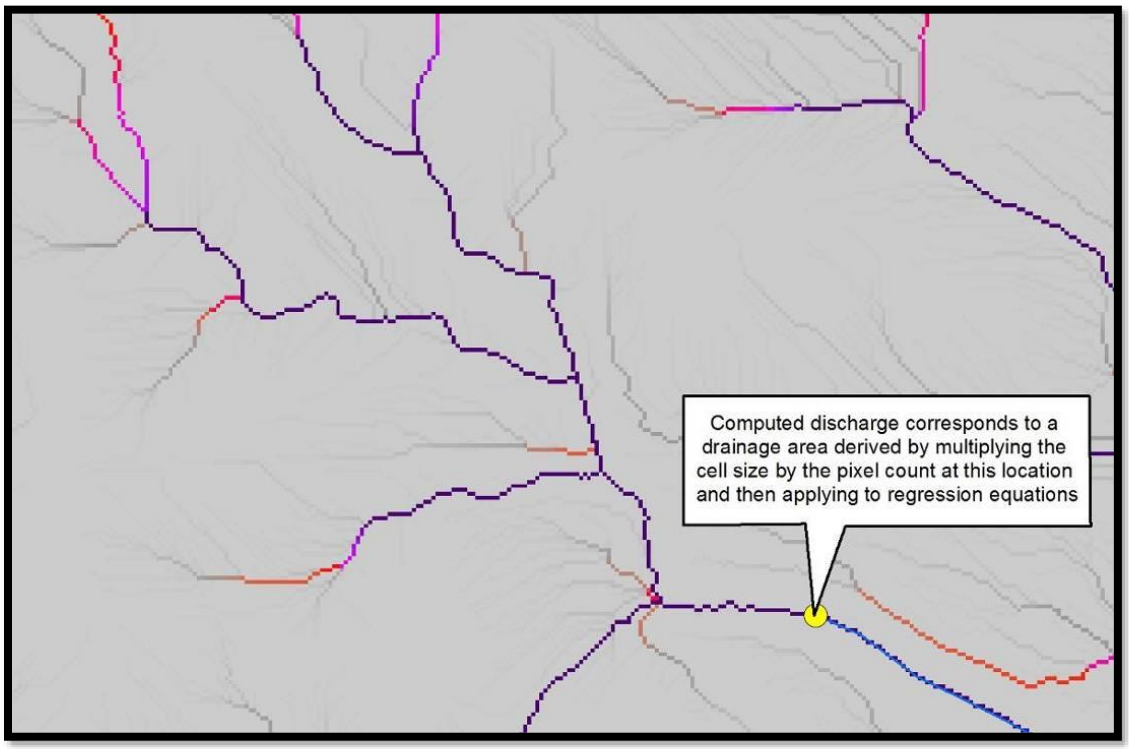
that of the USGS Rural Regression Equations. However, the rainfall-runoff modeling in McPherson and Saline Counties indicate that the runoff response of these watersheds is much lower than the USGS Rural Regression Equations. Further review was performed including an evaluation of SSURGO soils data. The SSURGO soil data indicate that the watersheds in Dickinson, Ottawa, and Marion County are made up of primarily C and D soil hydrogroups. However, the SSURGO soil data indicates that McPherson, Rice, and Ellsworth Counties are made up of primarily B and C soil hydrogroups which has more infiltration capacity compared to those watersheds in Dickinson, Ottawa, and Marion Counties. Figure 17 below depicts the variation of soil hydrogroups throughout the Lower Smoky Hill Watershed. This information, coupled with that of the rainfall-runoff model results, support that the regression equations of McPherson, Rice, and Ellsworth Counties should be developed rather than using the USGS Rural Regression Equations. Therefore: for McPherson, Rice, and Ellsworth Counties, localized regression equations were developed from the results of the detailed rainfall-runoff models and statistical gage analyses developed for the Lower Smoky Hill Watershed.

Figure 17. Distribution of Soil Hydrogroups throughout the Lower Smoky Hill Watershed



To prepare the drainage network for regression analyses, 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 18 illustrates how the drainage points correspond to the flow accumulation grid.

Figure 18. 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.

Once the drainage points were developed, the flows for the 10%, 4%, 2%, and 1% annual chance events were generated for each drainage point. Within Dickinson, Ottawa, and Marion Counties the flows were computed based on the USGS regression equations for Kansas (Reference 1). The USGS Rural Regression Equations for Kansas are as follows:

1) For larger drainage areas:

$$Q10 = 0.039\,(CDA)^{0.480}\,(P)^{2.931}$$
$$Q25 = 0.195\,(CDA)^{0.469}\,(P)^{2.603}$$
$$Q50 = 0.508\,(CDA)^{0.465}\,(P)^{2.411}$$
$$Q100 = 1.160\,(CDA)^{0.462}\,(P)^{2.250}$$

2) For smaller drainage areas:

$$Q10 = 1.224\,(CDA)^{0.611}\,(P)^{1.844}$$
$$Q25 = 4.673\,(CDA)^{0.622}\,(P)^{1.572}$$
$$Q50 = 10.26\,(CDA)^{0.628}\,(P)^{1.415}$$
$$Q100 = 19.80\,(CDA)^{0.634}\,(P)^{1.288}$$

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 Lower Smoky Hill Watershed was separated into two areas to determine the average mean annual precipitation, which was then used in the regression equations. A mean annual precipitation of 32.0 inches was used for Dickinson and Marion Counties. A mean annual precipitation of 30.0 inches was used for Ottawa, McPherson, Rice, and Ellsworth Counties.

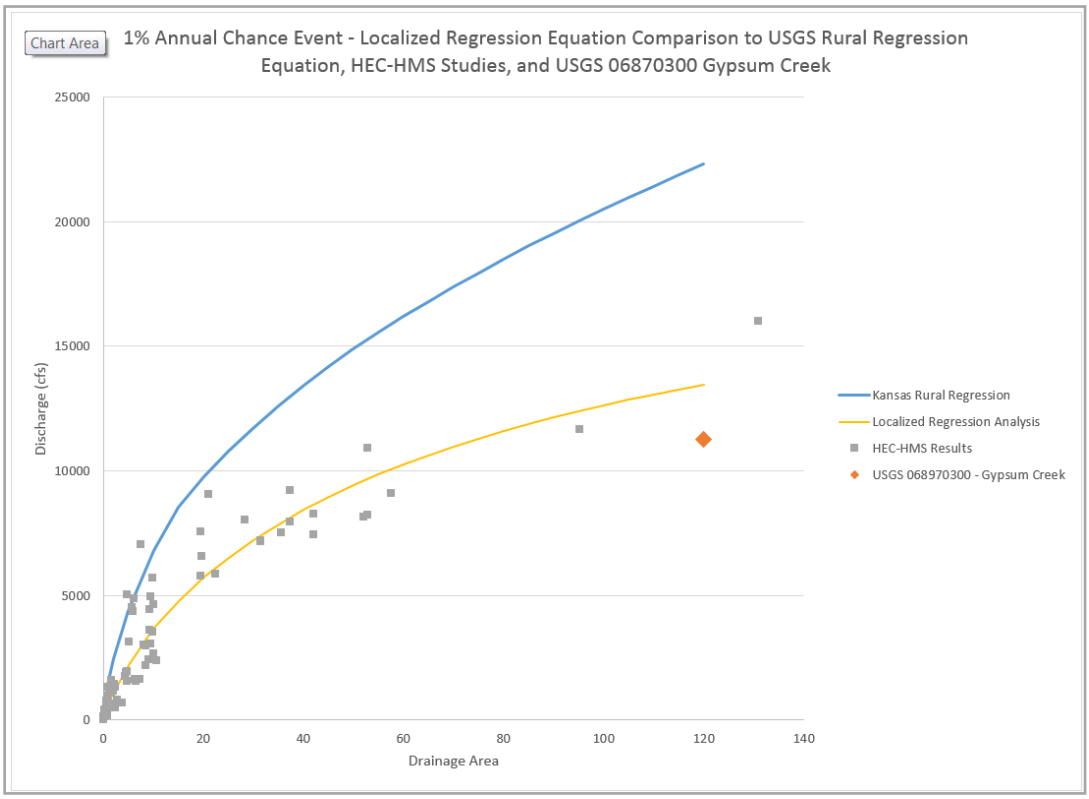
The intersection of the two regression equations is used to determine the contributing drainage area in which to transition from the smaller drainage area equation to the larger drainage area equation. For Dickinson and Marion Counties with a mean annual precipitation of 32 inches the breakpoint between the large and small drainage area equations is 18 square miles. For Ottawa, McPherson, Rice, and Ellsworth Counties with a mean annual precipitation of 30 inches the breakpoint between the large and small drainage area equations is 12.5 square miles.

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 the previous flow value envelops a 10% change. The process is repeated until the end of the stream is reached.

To generate more accurate flows for the Zone A streams within McPherson, Rice, and Ellsworth Counties within the Lower Smoky Hill Watershed, localized regression equations were developed, using the flows computed in three HEC-HMS models in the area including the Cow Creek Watershed, Smoky Hill River Tributary No. 1 Watershed, and the Dry Creek Diversion Watershed (completed and approved as part of the Saline County Floodplain Mapping Study). In addition to the detailed HEC-HMS rainfall-runoff models statistical gage analyses of USGS gage 06870300 on Gypsum Creek in Saline County with a contributing drainage area of 120 square miles was also utilized as part of this analysis. The contributing drainage area of much of the Gypsum Creek gage is within McPherson County. 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 to the Lower Smoky Hill Watershed; which have similar topography, soil types, and land use types. These counties include, Rice, Barton, Sedgwick and Harvey Counties. It was determined at the start of this project that this approach would produce a more appropriate determination of peak flows for these areas, rather than the USGS Kansas regression equations, which are known to over predict flows in this region of Kansas. Thus, the peak discharge and contributing drainage area for each subbasin, junction, storage area, and sink within the HEC-HMS models were evaluated, and a graph was developed to compare the peak discharge verses the contributing drainage area for the 10%, 4%, 2%, 1%, and 0.2% annual chance storm events. Figure 19 shows a comparison between the peak flows generated in the HEC-HMS models, statistical gage analysis of USGS 06870300 on Gypsum Creek and the peak flows calculated using the USGS

regression equations for Kansas for the 1% annual chance storm event. It should be noted that the visible outliers were removed from the dataset when comparing the localized regression equations to the Kansas regression equations.

Figure 19. Comparison of Flows from HEC-HMS Models and Kansas Regression Equations



The peak flows from the HEC-HMS models are generally slightly lower than the calculated flows from the USGS Kansas regression equations at smaller drainage areas. The gap between the two curves increases as the drainage area becomes larger. Characteristics of the Lower Smoky Hill Watershed; 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 percentage difference between the flows from the Kansas regression equations and the flows from the localized regression equations compares very similarly to the studies that have been completed in the neighboring watersheds in Rice and Sedgwick Counties, which were all based on calibrated HEC-HMS models to actual runoff events. Therefore, Amec Foster Wheeler and the Kansas Department of Agriculture determined that it was more suitable to utilize locally derived regression equations based on HEC-HMS models within the watershed when determining peak flows for the remaining Zone A streams within McPherson, Rice, and Ellsworth Counties in the Lower Smoky Hill Watershed. The peak flows for the 10%, 4%, 2%, 1%, and 0.2% annual chance storm events from the HEC-HMS models were plotted, excluding the visible outliers. A best-fit trendline was then plotted for each storm event, and was used as the localized regression equation for the associated storm event.

Several best fit trendlines were evaluated including exponential, polynomial, and linear trends. Upon review of the information the best fit trendline with an average root mean square error

(RMSE) of .94 was used to convert the results to a natural log scale and then plotting a third polynomial trendline through the points. The computed localized regression equations are as follows, and are also represented in Figures 20 through 24:

1) $Q_{10\%} = e \wedge (-0.004 \ln(CDA)^3 - 0.0125 \ln(CDA)^2 + 0.8458 \ln(CDA) + 5.6925)$
   (RMSE = 0.9454)

2) $Q_{4\%} = e \wedge (-0.0047 \ln(CDA)^3 - 0.0134 \ln(CDA)^2 + 0.8468 \ln(CDA) + 6.0201)$
   (RMSE = 0.9452)

3) $Q_{2\%} = e \wedge (-0.005 \ln(CDA)^3 - 0.0145 \ln(CDA)^2 + 0.8447 \ln(CDA) + 6.2295)$
   (RMSE = 0.9436)

4) $Q_{1\%} = e \wedge (-0.0052 \ln(CDA)^3 - 0.0158 \ln(CDA)^2 + 0.8414 \ln(CDA) + 6.4128)$
   (RMSE = 0.9414)

5) $Q_{0.2\%} = e \wedge (-0.0058 \ln(CDA)^3 - 0.0174 \ln(CDA)^2 + 0.837 \ln(CDA) + 6.7718)$
   (RMSE = 0.9332)

Where:

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

Figure 20. 10% Annual Chance Localized Regression Equations for McPherson, Rice, and Ellsworth Counties of the Lower Smoky Hill Watershed

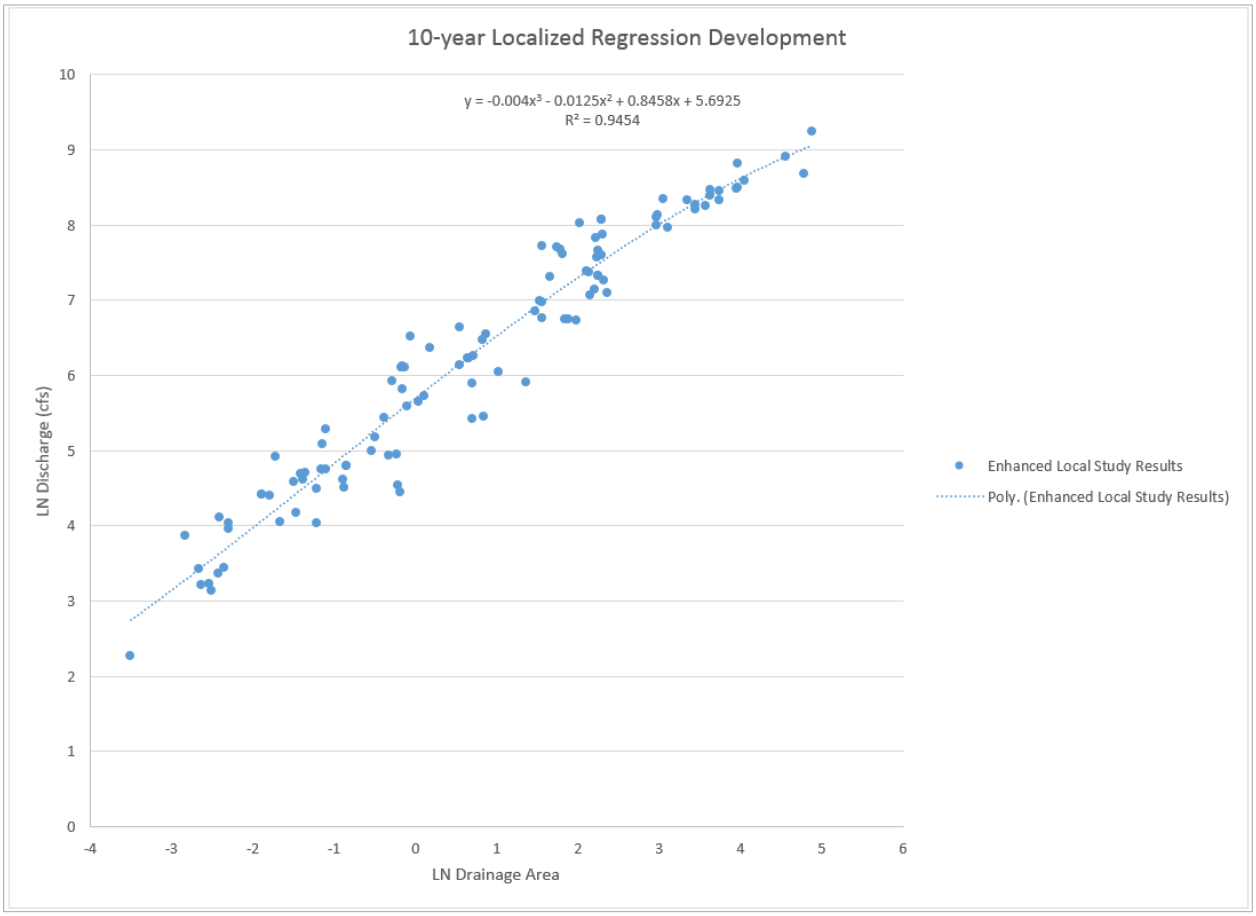


Figure 21. 4% Annual Chance Localized Regression Equations for McPherson, Rice, and Ellsworth Counties of the Lower Smoky Hill Watershed

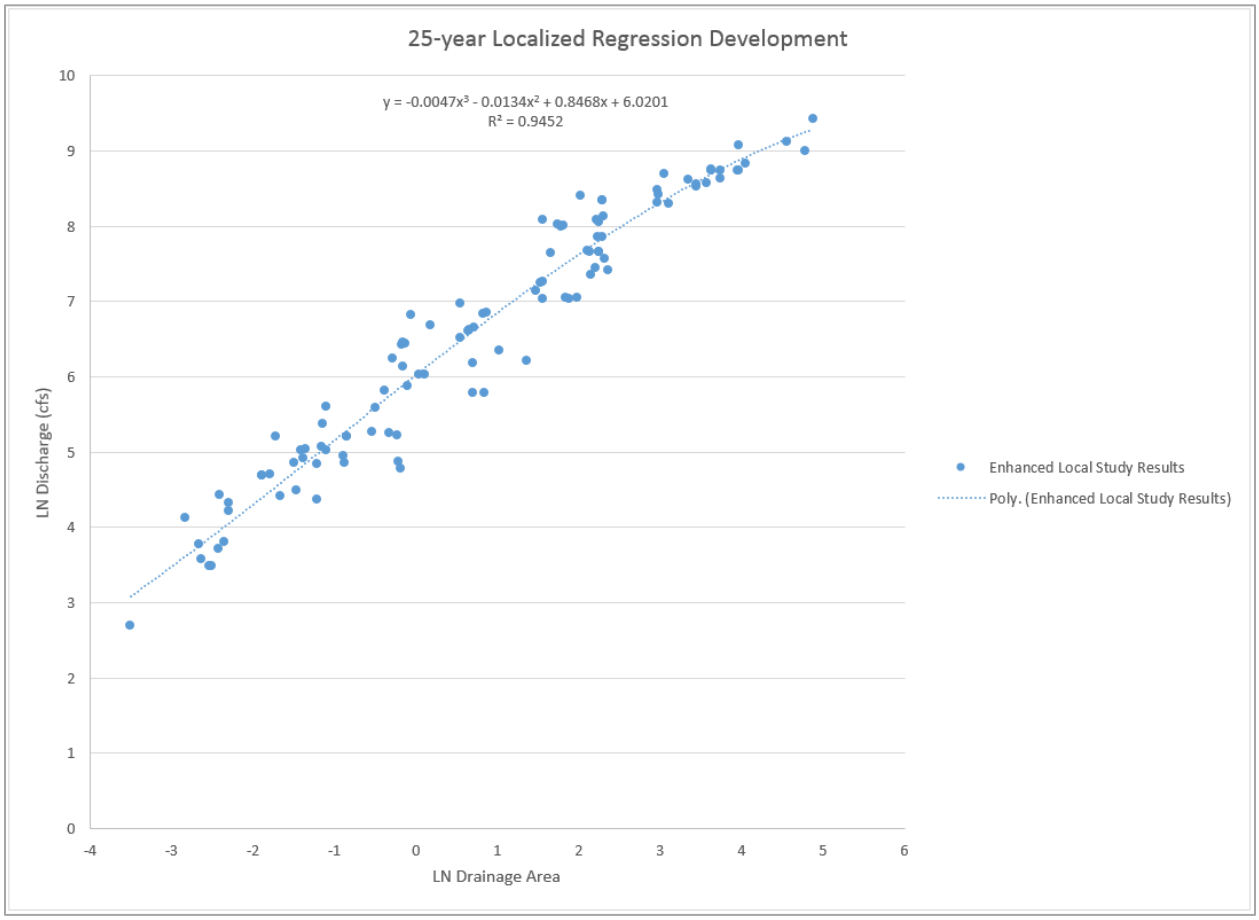


Figure 22. 2% Annual Chance Localized Regression Equations for McPherson, Rice, and Ellsworth Counties of the Lower Smoky Hill Watershed

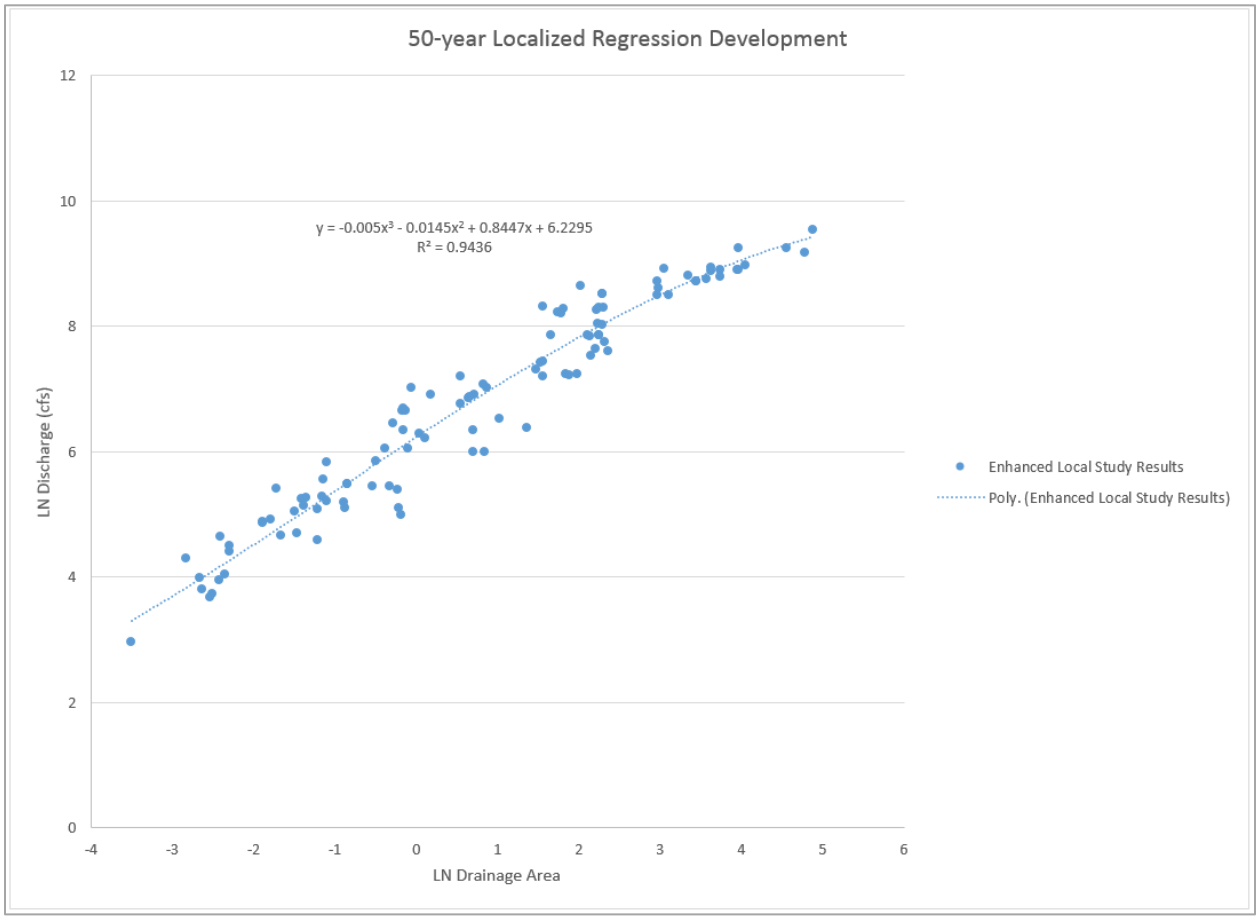


Figure 23. 1% Annual Chance Localized Regression Equations for McPherson, Rice, and Ellsworth Counties of the Lower Smoky Hill Watershed

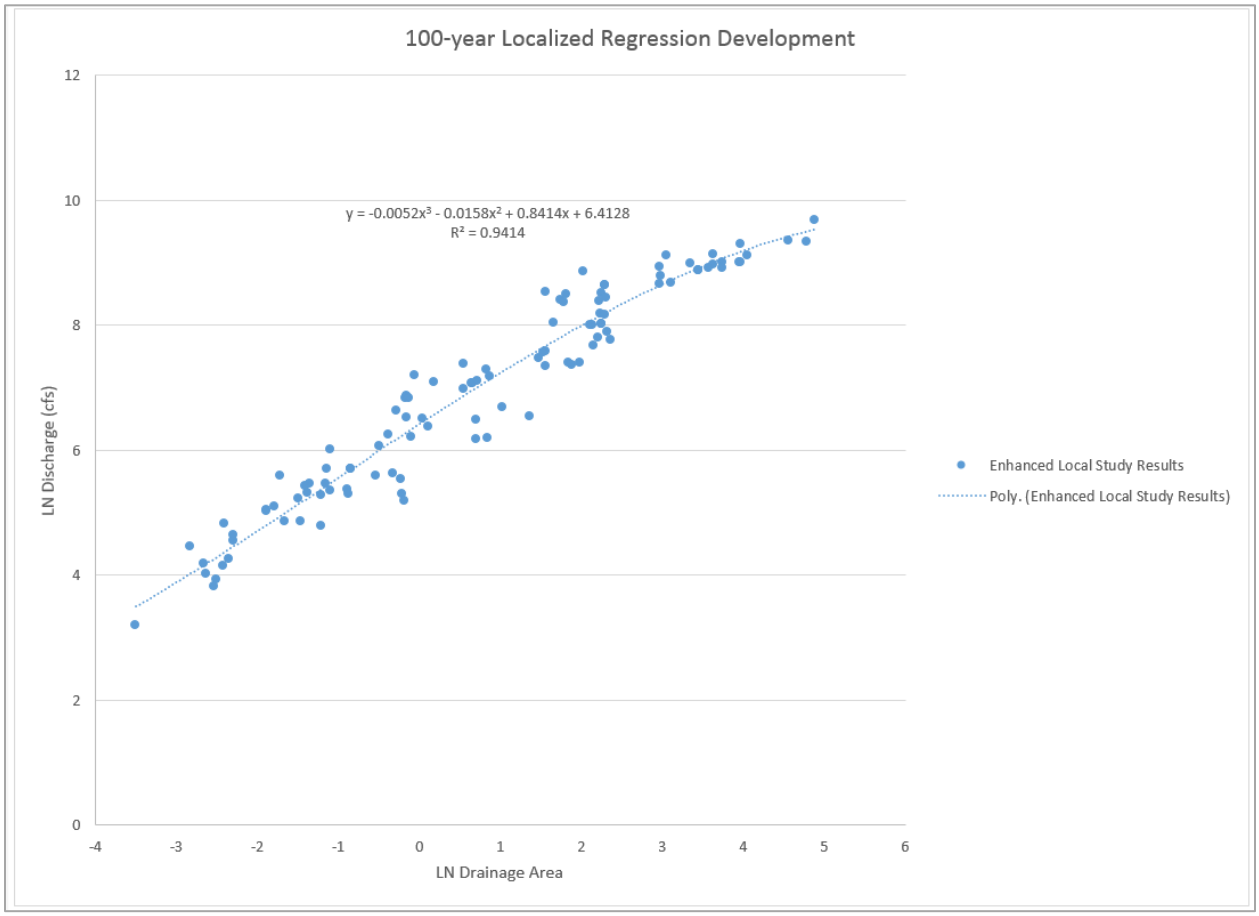
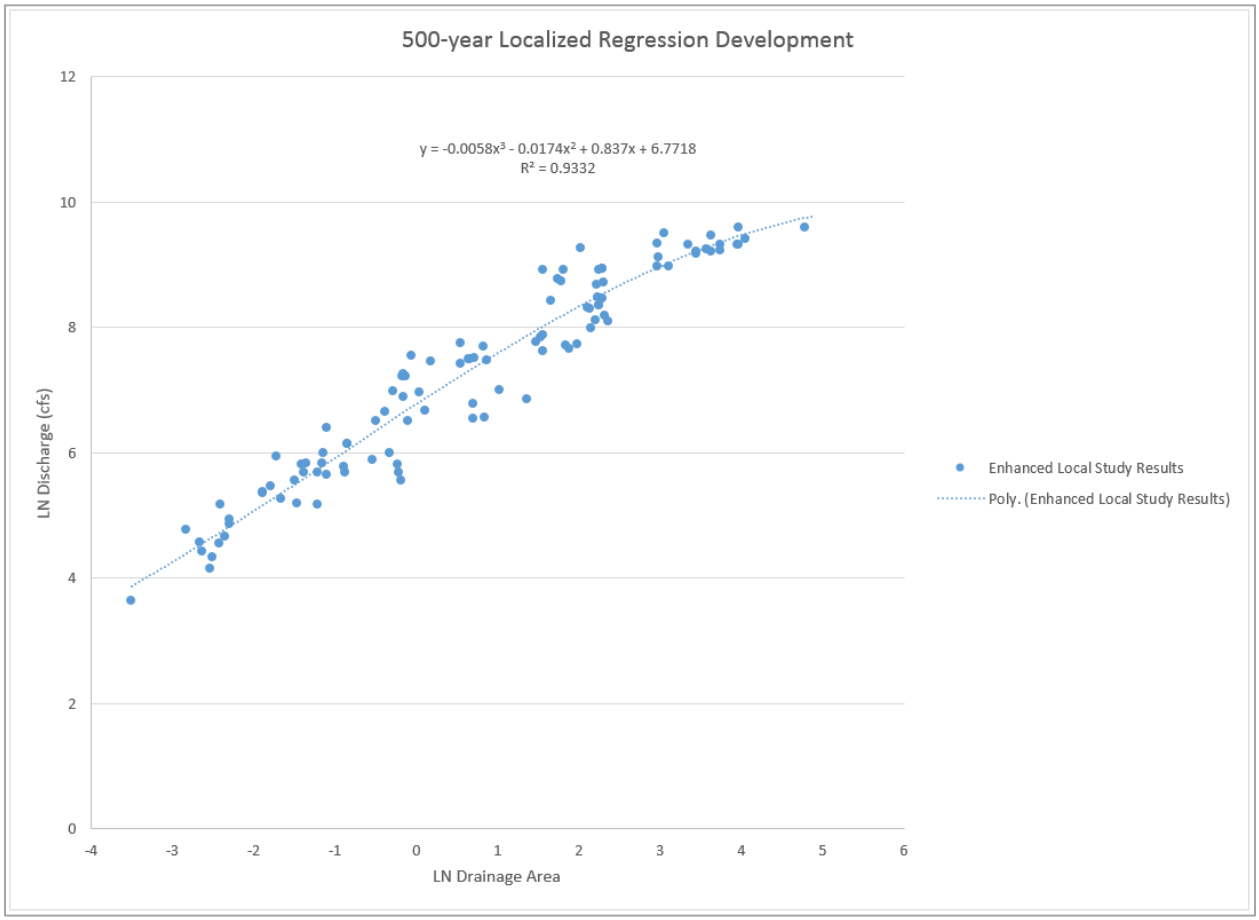


Figure 24. 0.2% Annual Chance Localized Regression Equations for McPherson, Rice, and Ellsworth Counties of the Lower Smoky Hill Watershed



1% PLUS EVENT DEVELOPMENT

The 1% plus flood event is defined as a 1% annual chance flood elevation computed using the predictive error inherent from the hydrologic modeling methods that are utilized. The method from computing the 1% plus flood event is dependent on the hydrologic study methods that were utilized. For statistical gage analyses, it is defined as the upper 84-percent confidence limit that is computed within the HEC-SSP statistical software. For drainage areas using USGS Rural Regression methods the 1% Plus event was computed using the standard error of prediction that is published with the USGS Rural Regression Equations. For smaller drainage areas the upper limit standard error of prediction is 71% whereas the upper limit model standard error of prediction for the larger drainage areas is 47%.

Two methods were utilized to verify the 1% plus flood event flows of the rainfall-runoff modeling. The first method utilized, referred to in this document as "Method 1," was to derive the 1% Plus rainfall depth from Atlas 14 statistical data. The 1%-plus rainfall depths were computed by using the 1% annual-chance rainfall depth and the 95% upper confidence limit 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 16% lower and 84% upper confidence limits, which are the values used for the 1%-plus rainfall depths. Table 23 below

depicts the 1% Plus rainfall depths for each watershed utilized this method. The resulting 1% Plus rainfall depths were then simulated through the rainfall-runoff models to compute the 1% Plus discharges.

Table 23. 1% Plus Rainfall Depths

Rainfall-Runoff Watersheds	100-year Plus Rainfall Depth (inches)
Cow Creek Watershed	8.65
Lower Smoky Hill Enterprise Tributary 1 & 2 Watersheds	9.26
Smoky Hill Tributary 1 Watershed	8.25
Lyon Creek Watershed	9.29
Mud Creek Watershed	8.72
Solomon River Tributary Watershed	8.55
Turkey Creek Watershed	8.72

The second method was used as a comparison to the Method 1 1% Plus discharges for rainfall-runoff models and was utilized for the localized regression equations. This method is referred to in this document as "Method 2" using a combination of procedures from Bulletin 17B (Reference 4) and EM-1110-2-1619 (Reference 20). The following steps outline the process utilized for Method 2.

Step 1: Arrange the discharge-frequency data for the each subbasin in the watershed so obtained from the HEC-HMS model. List all the peak flow estimates corresponding to their probability of exceedance (P[X>x] = 1/T). Synthetic sample statistics (mean, standard deviation and skew) will be computed using the log-discharge values corresponding to 0.01, 0.10 and 0.50 exceedance probabilities.

Step 2: Use Equation 5-3 in Appendix 5 of Bulletin 17B and the data set from step 1 to calculate synthetic logarithmic skew coefficient (G_s).

$$G_s = -2.50 + 3.12 \frac{Log(Q_{0.01}/Q_{0.10})}{Log(Q_{0.10}/Q_{0.50})} \quad \text{..... Eqn. 5-3}$$

Where: $Q_{0.01}$, $Q_{0.10}$ and $Q_{0.50}$ are peak flow estimates from HEC-HMS respectively for the 1-, 10- and 50-percent annual chance flood event.

Step 3: Use Equation 5-4 in Appendix 5 of Bulletin 17B and the data set from step 1 to calculate sample standard deviation. Also, obtain values of the frequency factors from a table in Appendix 3 of Bulletin 17B, corresponding to each frequency and the skewness coefficient obtained at step 2.

$$S_s = \frac{Log(Q_{0.01}/Q_{0.50})}{K_{0.01} - K_{0.50}} \quad \text{.... Eqn. 5-4}$$

Where: $K_{0.01}$, and $K_{0.50}$ are frequency factors obtained from table in Appendix 3 of Bulletin 17B for Log-Pearson III distribution.

Step 4: Use Equation 5-5 in Appendix 5 of Bulletin 17B to calculate sample mean

$$\boxed{\overline{X_s} = Log(Q_{0.50}) - K_{0.50}S_s} \ldots \text{ Eqn. 5-5}$$

Step 5: Use Equations 9-4a, 9-5, and 9-6 of Appendix 5 of Bulletin 17B to calculate the 84% upper confidence limit. Use values of frequency factors corresponding to the probability of exceedance (*p*) and skew coefficient from table in Appendix 3 of Bulletin 17B.The K_{GW} parameter in Equation 9-4a is based on the weighted skew (station and generalized skew). If the watershed is regulated, then station skew (based on the Rainfall-Runoff modeling) from Equation 5-3 is applicable (please refer to Bulletin 17B pages 12 through-14 for information on the weighted skew coefficient).

$$\boxed{K_{p,c}^{U} = \frac{K_{Gw,p} + \sqrt{K_{Gw,p}^2 - ab}}{a}} \ldots \text{Eqn. 9-4a}$$

Where values of a and b are defined in Equations 9-5 and 9-6 in Appendix 9 of Bulletin 17B. Zc and N are the standard normal frequency factor corresponding to the given upper confidence limit (c) in this case 84% and equivalent length of record (N) obtained from Table 4-5 of the EM 1110-2-1619 of the USACE as shown below.

$$\boxed{a = 1 - \frac{Z_c^2}{2(N-1)}} \quad \ldots \text{ Eqn. 9-5}$$

$$\boxed{b = K_{Gw,P}^2 - \frac{Z_c^2}{N}} \quad \ldots \text{Eqn. 9-6}$$

Table 4-5
Equivalent Record Length Guidelines

Method of Frequency Function Estimation	Equivalent Record Length[1]
Analytical distribution fitted with long-period gauged record available at site	Systematic record length
Estimated from analytical distribution fitted for long-period gauge on the same stream, with upstream drainage area within 20% of that of point of interest	90% to 100% of record length of gauged location
Estimated from analytical distribution fitted for long-period gauge within same watershed	50% to 90% of record length
Estimated with regional discharge-probability function parameters	Average length of record used in regional study
Estimated with rainfall-runoff-routing model calibrated to several events recorded at short-interval event gauge in watershed	20 to 30 years
Estimated with rainfall-runoff-routing model with regional model parameters (no rainfall-runoff-routing model calibration)	10 to 30 years
Estimated with rainfall-runoff-routing model with handbook or textbook model parameters	10 to 15 years

[1] Based on judgment to account for the quality of any data used in the analysis, for the degree of confidence in models, and for previous experience with similar studies.

Step 6: From the standard normal distribution table find the corresponding value (Zc) for the one-standard deviation (i.e. 0.84 significance levels)

Step 7: Calculate the upper confidence limit for the sub-watershed whose discharge-frequency data were used at step 1. This is the 1-percent plus estimate in log-scale

$$U_{0.01,0.84}(Q) = \overline{X} + SK^{U}_{0.01,0.92}$$

Step 8: Transform the log-scale computed above to a natural-scale and that will be the 1-percent plus flow estimate for the subbasin whose discharge-frequency relationship were considered at step 1.

$$Q_{1\%Plus} = 10^{U_{0.01,0.84}(Q)}$$

Step 9: Finally, repeat steps 2 to 9 to calculate the 1-percent plus for all the subbasins in the watershed.

The 1% Plus flow results from Method 1 & 2 were then compared to validate the 1% plus results. Table 24 depicts an example comparison of the Method 1 1% Plus peak discharges compared to the results of Method 2 using both 10 and 30 year equivalent length of records. Generally, this comparison was consistent for each watershed.

Table 24. Example Comparison of 1% Plus Methods – Lyon Creek Watershed

HMS Element	Method 1 1% Plus Rainfall Depth Process Peak Discharge (cfs)	Method 2 Bulletin 17B & EM-1110-2-1619 Combined Process 10-yr Length of Record Peak Discharge (cfs)	Method 2 Bulletin 17B & EM-1110-2-1619 Combined Process 30-yr Length of Record Peak Discharge (cfs)
J1023	11,984	10,478	12,501
J1024	5,031	4,910	6,031
J1025	4,484	4,382	5,400
J1026	20,430	18,291	21,904
J1027	20,597	18,046	21,355
J1029	5,998	5,909	7,387
J1030	27,753	25,118	30,124
J1031	2,749	2,698	3,332
J1032	26,890	24,404	29,169
J1033	1,004	981	1,204
J1035	9,701	8,907	10,663
J1037	1,749	1,628	1,987
J4342	9,201	7,931	9,389
J4345	485	473	568
J4348	9,072	7,869	9,353
J4353	27,763	25,090	30,055

The results of Method 1 generally fall between the results of Method 2 using a range of equivalent length of record (N) between 10 to 30 years. This indicates that Method 1 is within the acceptable range of 1% Plus values and is therefore applicable for this study. Therefore, for this study, the 1% Plus peak discharges were computed using the Method 1.

CONCLUSION

As a result of these detailed analyses, peak discharges have been developed for the 10%, 4%, 2%, 1%, 1% + and 0.2% annual chance storm events for the detailed Zone AE and Zone A streams. Peak discharges for the detailed Zone AE streams, developed by the detailed hydrologic analyses described in this report, are represented in Table 25. Summary of Discharges.

In general, the drainage points for those Zone AE stream will be found within the rainfall-runoff watershed and gage analysis folders of the DCS submission, whereas the drainage points for those Zone A streams will be found within the Zone A watershed folder of the DCS submission.

Table 25. Summary of Discharges

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Carry Creek	6,900 feet upstream of Wolf Rd	53.43	5,380	6,930	8,260	9,640	11,880	13,070
Carry Creek	Just downstream of confluence of Carry Creek Tributary No. 3	50.36	5,030	6,460	7,590	8,750	10,630	11,730
Carry Creek	Just downstream of confluence of Carry Creek Tributary No. 8	37.86	3,960	4,700	5,890	7,380	10,070	11,560
Carry Creek	Just downstream of confluence of Carry Creek Tributary No. 12	28.54	3,400	4,220	5,390	6,730	9,070	10,370
Carry Creek	3,500 feet downstream of 1300 Ave Rd	16.90	3,080	3,940	4,670	5,460	6,850	7,620
Carry Creek	3,175 feet upstream of 1300 Ave	15.10	2,720	3,550	4,240	4,990	6,280	6,980
Carry Creek	1,900 feet downstream of 1200 Ave	12.80	2,290	3,070	3,730	4,430	5,600	6,230
Chapman Creek	Approximately 450 feet upstream of Old Highway 40	327	10,910	16,180	20,780	25,970	34,990	40,480
Chapman Creek	Just upstream of Interstate 70	324	10,870	16,110	20,700	25,860	34,850	40,310
Cow Creek	Just downstream of 14th Ave	0.86	230	310	380	460	580	660
Cow Creek	800 feet downstream of N 1st St	0.71	210	280	350	410	520	590
Cow Creek	150 feet upstream of E Garfield St	0.60	190	260	310	360	460	510
Cow Creek	70 feet downstream of N 2nd St	0.49	150	200	250	290	370	410
Cow Creek	Just upstream of E Swensson St	0.42	130	170	210	250	320	350
Cow Creek	Just upstream of W Green St	0.38	120	160	200	240	300	330

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Cow Creek	Just downstream of W Madison St	0.35	110	150	180	220	270	300
Cow Creek	Just downstream of W Saline St	0.27	80	110	130	160	200	220
Cow Creek	70 feet downstream of N 3rd St	0.25	70	95	120	140	180	200
Cow Creek	Just downstream of W State St	0.25	70	100	120	140	180	200
Cow Creek	100 feet downstream of N Chestnut St	0.23	65	85	110	130	165	180
Cow Creek	Just upstream of W Lincoln St	0.20	50	70	90	105	135	150
Cow Creek	60 feet downstream of W Grant St	0.19	50	65	85	100	130	140
Cow Creek	80 feet upstream of W Grant St	0.18	45	60	80	90	120	130
Cow Creek	130 feet upstream of W Union St	0.13	25	35	45	50	70	75
Cow Creek	420 feet downstream of Coronado Ave	0.11	15	20	30	35	45	50
Cow Creek	Coronado Avenue	0.10	13	18	25	30	40	45
East Turkey Creek	At confluence with East Turkey Creek Trib 16	36.51	2,780	3,920	4,780	5,630	6,640	8,690
East Turkey Creek	At confluence of East Turkey Creek Tributary No. 1	32.08	2,760	3,630	4,320	5,000	5,830	8,080
East Turkey Creek	Just upstream of confluence of East Turkey Creek Trib 4	21.23	1,340	1,760	2,120	2,800	3,970	5,620
East Turkey Creek	At confluence of East Turkey Creek Trib 5	16.41	1,140	1,550	1,910	2,300	2,930	4,260
East Turkey Creek	Approximately 4,170 feet downstream of 300 Avenue	14.4	730	1,000	1,310	1,800	2,500	3,680
East Turkey Creek	At confluence of East Turkey Creek Trib 7	12.89	430	590	860	1,430	2,180	3,240
East Turkey Creek	At Turkey Creek Watershed Dam 6 (DDK-0128)	8.8	230	300	590	990	1,530	2,290

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
East Turkey Creek	Approximately 1,800 feet upstream of 100 Avenue	6.46	2,960	4,020	4,910	5,840	6,890	8,250
East Turkey Creek Tributary No. 1	At confluence of East Turkey Creek Tributary No. 2	10.85	1,460	1,950	2,360	2,800	3,270	3,880
East Turkey Creek Tributary No. 1	Just upstream of confluence of East Turkey Creek Tributary No. 2	5.72	1,230	1,660	2,010	2,380	2,800	3,350
East Turkey Creek Tributary No. 1	At confluence of East Turkey Creek Trib 1.1	5.13	1,100	1,490	1,800	2,130	2,510	3,000
East Turkey Creek Tributary No. 1	Approximately 3,320 feet downstream of 200 Avenue	4.29	920	1,240	1,510	1,790	2,100	2,510
East Turkey Creek Tributary No. 1	At confluence of East Turkey Creek Trib 1.2	3.67	790	1,060	1,290	1,530	1,800	2,150
East Turkey Creek Tributary No. 2	Approximately 3,290 feet upstream of confluence of East Tukey Creek Tributary No. 1	5.13	290	390	470	550	640	890
East Turkey Creek Tributary No. 2	At Turkey Creek Watershed Dam 8 (DDK-0109)	4.43	70	120	250	390	570	810
East Turkey Creek Tributary No. 2	At 200 Avenue	3.57	1,020	1,370	1,650	1,950	2,290	2,730

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Lime Creek	2,500 feet upstream of 800 Ave	23.36	4,600	6,100	7,380	8,710	10,980	12,270
Lime Creek	Just downstream of confluence of Lime Creek Tributary No. 13	18.51	3,670	4,850	5,890	6,980	8,940	10,060
Lime Creek	Just downstream of confluence of Lime Creek Tributary No. 2	17.02	3,370	4,440	5,460	6,530	8,430	9,490
Lime Creek	Just downstream of confluence of Lime Creek Tributary No. 4	14.49	2,490	3,410	4,200	5,120	6,780	7,710
Lime Creek	4,700 feet downstream of Wind road	12.44	1,990	2,740	3,370	4,030	5,300	5,960
Lime Creek	1,110 feet downstream of Wind road	10.40	1,520	2,070	2,530	3,020	3,870	4,330
Lime Creek	Just downstream of Lime Creek Trib 9	9.70	1,370	1,860	2,260	2,690	3,400	3,780
Lime Creek	Just downstream of Lime Creek Trib 10	9.40	1,210	1,630	1,980	2,360	2,980	3,310
Lime Creek	3,200 feet downstream of 300 Ave	8.40	780	1,040	1,260	1,480	1,860	2,060
Lime Creek	2,000 feet downstream of 300 Ave	8.10	710	950	1,150	1,350	1,690	1,870
Lime Creek	Just downstream of confluence with Lime Creek Tributary No. 12	7.72	600	790	950	1,110	1,380	1,530
Lime Creek	670 feet downstream of Wolf road	2.90	180	240	280	320	400	430
Lime Creek	Just downstream of Wolf road	2.80	160	210	240	280	340	370
Lime Creek	870 feet upstream of Wolf road	2.70	140	180	200	220	270	300
Lime Creek	1,330 feet upstream of Wolf road	2.70	130	170	180	200	240	280
Lime Creek	1,550 feet upstream of Wolf road	2.70	120	160	170	190	220	260

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Lime Creek	Just downstream of DDK-0127A Dam	2.59	100	120	120	130	140	180
Lime Creek	2,275 feet downstream of 200 Ave	2.28	660	890	1,080	1,280	1,600	1,780
Lime Creek Tributary No. 2	Just upstream of confluence of Lime Creek Tributary branch No. 6.1	1.98	930	1,160	1,340	1,490	1,720	1,830
Lime Creek Tributary No. 2	Just downstream of N F street	1.70	780	970	1,110	1,220	1,380	1,470
Lime Creek Tributary No. 2	Just downstream of U.S. Highway 77	1.42	670	830	930	1,010	1,130	1,190
Lime Creek Tributary No. 2	Just upstream of U.S. Highway 77	1.42	760	1,010	1,210	1,430	1,780	1,970
Lime Creek Tributary No. 4	At mouth	1.65	880	1,190	1,420	1,670	2,070	2,280
Lime Creek Tributary No. 4	Just upstream of the N-S Union Pacific Railroad	1.65	960	1,280	1,550	1,840	2,320	2,580
Lime Creek Tributary No. 4	Just downstream of 9th Street	1.49	880	1,170	1,420	1,680	2,120	2,350
Lime Creek Tributary No. 4	1,630 feet downstream of Union Pacific Railroad	1.40	810	1,080	1,310	1,550	1,960	2,170
Lime Creek Tributary No. 4	1,130 feet downstream of Union Pacific Railroad	1.00	630	850	1,030	1,210	1,550	1,730
Lime Creek Tributary No. 4	Just downstream of Union Pacific Railroad	0.93	500	670	810	960	1,240	1,390

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Lime Creek Tributary No. 4	1,175 feet upstream of Union Pacific Railroad	0.90	480	650	780	920	1,190	1,330
Lime Creek Tributary No. 4	1,450 feet upstream of Union Pacific Railroad	0.61	430	570	690	810	1,010	1,120
Lyon Creek	Just downstream of confluence of Carry Creek	228.06	13,670	17,410	20,630	24,700	32,480	36,890
Lyon Creek	Just downstream of confluence of West Branch Lyon Creek	146.09	11,630	14,820	17,810	21,650	28,560	32,420
Lyon Creek	Just downstream of confluence of Lime Creek	102.47	8,770	11,090	13,300	15,800	20,700	23,550
Lyon Creek	Just downstream of confluence of Kohl's Creek	54.99	6,400	8,350	10,260	12,550	15,990	17,780
Lyon Creek	Just downstream of confluence of Lyon Creek Tributary 21	36.97	3,180	4,170	5,040	5,910	7,320	8,080
Lyon Creek	At 500 Ave	24.75	250	310	380	440	1,510	2,220
Lyon Creek	Just downstream of the Herington Reservoir Dam (DDK-0138)	24.55	240	270	300	320	1,510	2,220
Lyon Creek	Just downstream of confluence with Lyon Creek Tributary No. 22	23.06	7,820	10,300	12,430	14,780	18,700	20,770
Lyon Creek	200 feet downstream of County Road 857	14.20	4,390	5,830	7,100	8,450	10,650	11,760
Middle Branch Turkey Creek	At Dickinson-Marion County Boundary	10.48	1,190	1,620	1,990	2,370	2,800	3,350
Mud Creek	Just Downstream of confluence of Mud Creek Trib 3	86.62	9,690	13,720	16,990	20,700	24,740	28,990

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Mud Creek Tributary No. 1	At N Washington Street	1.72	410	600	760	940	1,170	1,430
Mud Creek Tributary No. 1	Approximately 1,500 feet downstream of Old U.S. 40	1.27	360	530	670	830	1,010	1,230
Smoky Hill Enterprise Tributary 1	At confluence of Smoky Hill Enterprise Tributary 1.1	1.85	1,150	1,490	1,770	2,070	2,580	2,830
Smoky Hill Enterprise Tributary 1	Just downstream of 2000 Avenue	1.27	840	1,090	1,290	1,510	1,890	2,070
Smoky Hill Enterprise Tributary 1	3,400 feet upstream of 2000 Avenue	1.1	780	1,000	1,180	1,380	1,710	1,880
Smoky Hill Enterprise Tributary 2	Approximately 4,500 feet downstream of 1900 Avenue	6.5	1,790	2,420	2,950	3,540	4,550	5,050
Smoky Hill River	Approximately 6,000 feet downstream of Rain Road, near Chapman, Kansas	19,660	28,330	38,740	47,350	56,710	65,350	81,770
Smoky Hill River	At USGS Gage No. 06877600	19,260	27,750	37,950	46,390	55,560	64,020	80,110
Smoky Hill River	Just upstream of Solomon Road, near Solomon, Kansas	18,883	27,210	37,210	45,480	54,470	62,770	78,540
Smoky Hill River	Just downstream of Old Mill Road, near Lindsborg, Kansas	8,110	7,790	10,500	12,640	14,870	17,340	39,530
Smoky Hill River	Approximately 10,250 feet downstream of Smoky Valley Road	7,952.5	5,670	7,470	8,790	10,070	12,010	32,040
Smoky Hill Tributary No. 1	At Missouri Pacific Railroad	1.97	520	760	970	1,190	1,450	1,810

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Smoky Hill Tributary No. 1	At State Highway 4	1.72	460	680	870	1,080	1,330	1,670
Solomon River (Previous FIS, June, 2004)	At mouth	6,875	19,100	N/A	40,000	52,400	N/A	91,400
Solomon River (Previous FIS, June, 2004)	At USGS gage 06876900, at Niles, Kansas	6,770	18,300	N/A	38,600	50,700	N/A	89,100
Solomon Tributary	Just downstream of Interstate 70	3.91	1,720	2,360	2,910	3,500	4,160	5,070
Turkey Creek	At USGS Gage No. 06877500, near Abilene, Kansas	140.2	6,810	9,100	10,980	12,920	14,850	17,820
Turkey Creek	Just downstream of confluence of East and West Turkey Creek	66.26	4,880	6,610	8,100	9,730	11,760	14,670
Turkey Creek Tributary No. 1	At confluence of Turkey Creek Tributary No. 2	12.53	1,970	2,590	3,110	3,640	4,250	5,030
Turkey Creek Tributary No. 1	Just upstream of confluence of Turkey Creek Tributary No. 2	8.58	1,260	1,650	2,060	2,500	3,000	3,670
Turkey Creek Tributary No. 1	At confluence of Turkey Creek Tributary 1.1	7.73	1,150	1,510	1,880	2,270	2,710	3,300
Turkey Creek	At confluence of Turkey Creek Tributary 1.2	6.56	1,000	1,310	1,620	1,940	2,310	2,790

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Tributary No. 1								
Turkey Creek Tributary No. 1	Just downstream of confluence of Turkey Creek Tributary 1.3	5.55	870	1,150	1,400	1,660	1,960	2,360
Turkey Creek Tributary No. 1	At State Highway 4	4.36	720	950	1,140	1,330	1,550	1,840
Turkey Creek Tributary No. 2	Just upstream of confluence with Turkey Creek Tributary No. 1	3.95	720	970	1,170	1,390	1,630	1,950
Turkey Creek Tributary No. 2	At 700 Avenue	3.62	620	840	1010	1200	1410	1690
Turkey Creek Tributary No. 2	Approximately 650 feet upstream of confluence of Turkey Creek Tributary 2.1	2.95	420	570	680	810	950	1,150
Turkey Creek Tributary No. 2	Approximately 2,900 feet downstream of State Highway 4	2.8	380	500	610	730	850	1,030
Turkey Creek Tributary No. 2	At State Highway 4	2.61	320	430	520	620	720	880
Unnamed Tributary - Ramona	Just downstream of Quail Creek Rd	0.90	580	760	910	1,070	1,330	1,470

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
Unnamed Tributary - Ramona	Just downstream of 1/2 Mile Rd	0.72	480	610	730	870	1,080	1,200
Unnamed Tributary - Ramona	Just downstream of 5th St	0.66	430	570	680	810	1,010	1,120
Unnamed Tributary - Ramona	Just downstream of C St	0.59	370	510	620	730	920	1,010
Unnamed Tributary - Ramona	Just downstream of 1st St	0.40	280	370	440	520	640	710
Unnamed Tributary - Ramona	410 feet downstream of the Union Pacific Railroad	0.35	250	330	400	460	570	630
Unnamed Tributary - Ramona	Just downstream of the Union Pacific Railroad	0.29	220	280	340	390	480	530
Unnamed Tributary - Ramona	200 feet upstream of the Union Pacific Railroad	0.25	200	260	310	360	440	490
Unnamed Tributary - Ramona	410 feet upstream of the Union Pacific Railroad	0.20	170	230	270	310	380	420
Unnamed Tributary - Ramona	800 feet upstream of the Union Pacific Railroad	0.16	150	200	240	270	340	370
Unnamed Tributary - Ramona	1,100 feet upstream of the Union Pacific Railroad	0.14	140	180	210	250	310	340
West Branch Lyon Creek	Just downstream of West Branch Lyon Creek Tributary No. 10	16.65	3,460	4,710	5,760	6,870	8,740	9,750

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
West Branch Lyon Creek	1,500 feet downstream of Quail road	13.20	2,990	4,030	4,890	5,790	7,300	8,100
West Branch Turkey Creek	Just upstream of confluence with Turkey Creek	28.27	3,430	4,640	5,650	6,560	7,470	8,580
West Branch Turkey Creek	At confluence of West Branch Turkey Creek Trib 4	25.11	3,190	4,240	5,110	5,860	6,570	7,410
West Branch Turkey Creek	Just upstream of confluence with West Branch Turkey Creek Trib 4	21.27	2,280	3,020	3,640	4,020	4,440	4,840
West Branch Turkey Creek	At confluence with West Branch Turkey Creek Trib 7	18.33	1,760	2,310	2,770	3,240	3,770	4,440
West Branch Turkey Creek	At confluence with West Branch Turkey Creek Trib 11	14.15	800	1,000	1,350	1,830	2,410	3,180
West Branch Turkey Creek	At Turkey Creek Watershed Dam 15 (DDK-0148)	12.09	330	360	650	1,130	1,740	2,560
West Turkey Creek	Just upstream of confluence of East and West Turkey Creek	26.95	2,530	3,390	4,190	5,100	6,100	7,460
West Turkey Creek	At 400 Avenue	22.44	2,050	2,900	3,620	4,380	5,240	6,360
West Turkey Creek	At confluence of Middle Branch Turkey Creek	18.88	1,920	2,670	3,260	3,860	4,540	5,430
West Turkey Creek	Just upstream of confluence of Middle Branch Turkey Creek	8.06	970	1,330	1,640	1,950	2,310	2,760

FLOODING SOURCE	LOCATION	DRAINAGE AREA (sq. miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% + Annual Chance	0.2% Annual Chance
West Turkey Creek	At confluence of West Turkey Creek Trib 3	7.52	890	1,220	1,490	1,780	2,110	2,520
West Turkey Creek	At confluence of West Turkey Creek Trib 4	6.41	630	870	1,070	1,280	1,520	1,830

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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