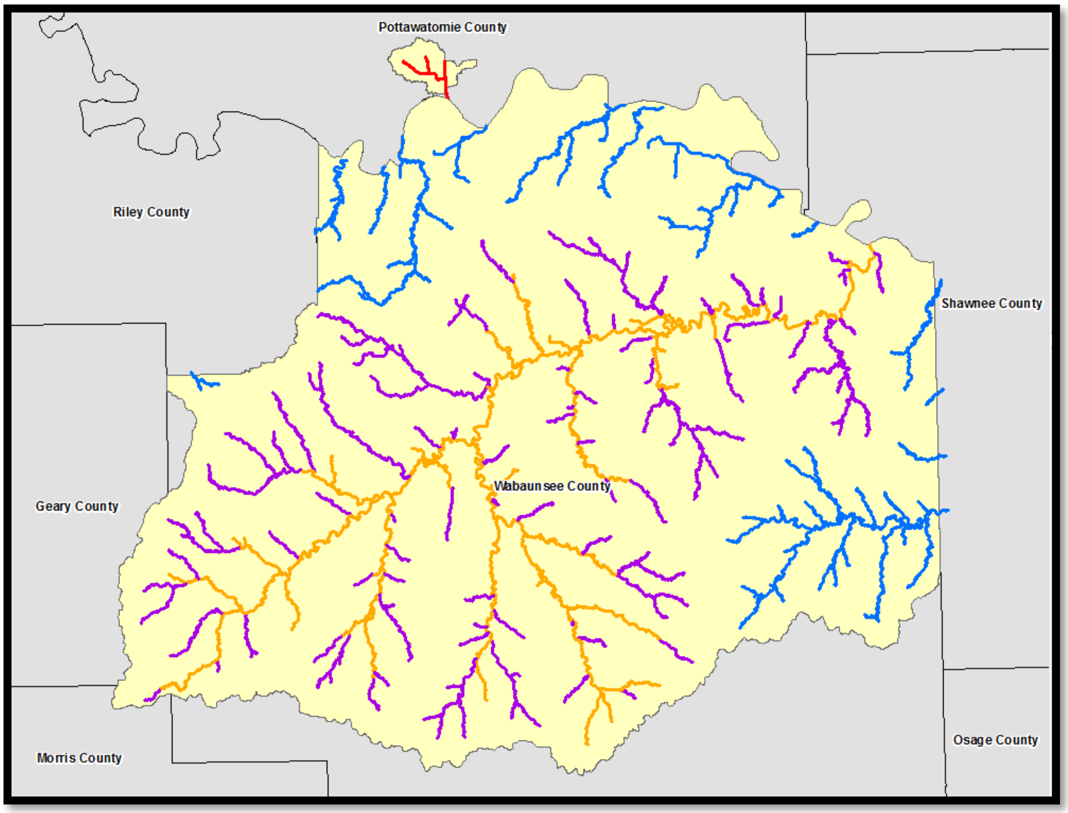
HYDROLOGY REPORT

MIDDLE KANSAS WATERSHED
(WITHIN WABAUNSEE COUNTY AND CITY OF WAMEGO)



UNDER CONTRACT WITH:
KANSAS DEPARTMENT OF AGRICULTURE
Division of Water Resources
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INTRODUCTION

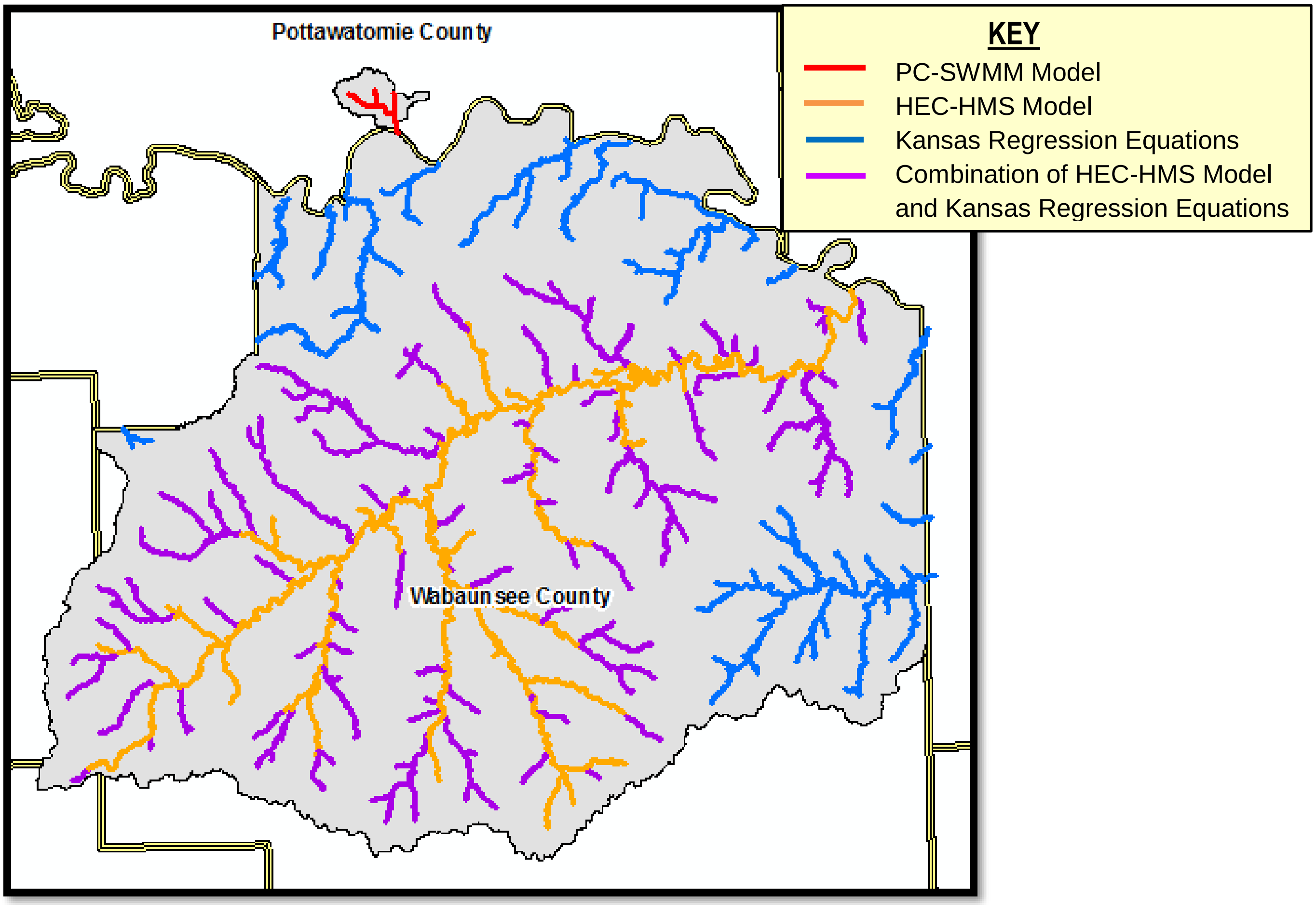
This report presents the hydrologic analyses for the detailed Zone AE/AH streams that lie within the City of Wamego, and the enhanced Zone AE designated streams and approximate Zone A designated streams in Wabaunsee County that lie within the Middle Kansas Watershed (HUC8 10270102). The City of Wamego, which is located in Pottawatomie County, is also located within the Middle Kansas Watershed. This project consists of new hydrologic and hydraulic studies using current watershed characteristics and new detailed topography for approximately 4.4 miles of streams modeled by detailed methods, resulting in updated Zone AE/AH floodplains; approximately 3.5 miles of streams modeled by enhanced methods, including rainfall-runoff model hydrology and field measured structures, resulting in updated Zone AE floodplains without a floodway; and approximately 615.8 miles of streams studied by approximate methods, resulting in updated Zone A floodplains. Enhanced hydrology was performed on approximately 435 miles of streams; including the detailed Zone AE/AH streams, the enhanced Zone AE streams, and additional Zone A study streams within the Mill Creek watershed; using rainfall-runoff models. In addition, statistical gage analysis was performed for two gages within the Mill Creek watershed for comparison purposes. For streams not included in an enhanced hydrology model, Zone A stream hydrology was performed using USGS Rural Regression Equations for Kansas. A summary of the streams that were studied is shown in Table 1. A figure that shows the type of hydrologic method used for each stream is shown in Figure 1.

A portion of the Kansas River lies within Wabaunsee County, within the Middle Kansas Watershed. However, the Kansas River was not included in this hydrologic analysis. A request to perform detailed hydrologic and hydraulic analysis of the portion of the Kansas River within Pottawatomie and Wabaunsee Counties was submitted to FEMA for approval, with data development to be done next year, during the FY 2017 round of funding. Therefore, no work will be done on the Kansas River until that time, when the entire Kansas River will be completed as a detailed study.

Table 1: Summary of Methods

Study Area/Flooding Source	Stream Miles	Hydrologic Method
East Unnamed Creek	3.0	Rainfall-Runoff Model (PC-SWMM)
East Unnamed Creek Tributary 1	0.7	Rainfall-Runoff Model (PC-SWMM)
East Unnamed Creek Tributary 2	0.7	Rainfall-Runoff Model (PC-SWMM)
Mill Creek	2.8	Rainfall-Runoff Model (HEC-HMS)
Mulberry Creek Tributary 1	0.7	Rainfall-Runoff Model (HEC-HMS)
Various Zone A Streams within Mill Creek Watershed	427.1	Combination of HEC-HMS and Kansas Regression Equations
Various Zone A Streams	188.7	Kansas Regression Equations
Total	**623.7**	-

Figure 1- Type of Hydrologic Modeling Used for Each Stream in the Middle Kansas Watershed, within Wabaunsee County and the City of Wamego.



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

The extents of the Zone A studies include those streams currently designated by FEMA, plus the conveyances with drainage areas equal to or greater than 1-square mile of drainage area. 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 Pottawatomie County and the City of Wamego is dated March 16, 2015. There is no current FIS Report for Wabaunsee County.

Gage Analysis

Two USGS gage stations were analyzed as part of this study. The gage on Mill Creek is located at Snokomo Road; near Paxico, Kansas. The gage on Dry Creek is located at Keene Eskridge Road; near Maple Hill, Kansas. A summary of these two gages is shown in Table 2. Annual peak flow records were obtained from the USGS Water Resources website (Reference 14). The gage on Mill Creek has significant period of record in which a confident peak flow frequency analysis could be computed. The gage on Dry Creek does not have enough years of record for a confident peak flow frequency analysis, but can be used for comparison purposes.

Table 2: Summary of USGS Stream Gages			
USGS Gage Number	Gage Description	Drainage Area (mi^2)	Period of Record
06888500	Mill Creek near Paxico, KS	318	1951-2015
06888600	Dry Creek near Maple Hill, KS	15.6	1957-1977

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

USGS 06888500- Mill Creek near Paxico, KS

USGS Station 06888500 is located near Paxico, Kansas and has 63 years of record, dating from 1951 to 2015. Frequency flow estimates were calculated for this site. The 1951 flow was labeled as the historical peak. Appropriate flow ranges per Bulletin 17C guidelines were applied to the 1952 and 1953 flows that were missing, the 2005 flow that was affected by backwater, and the 2014 flow that was an estimate. In the late 1980s and early 1990s, a large number of watershed district dams were constructed in the Mill Creek watershed, which likely had an impact on the flows at the Paxico gage. Therefore, frequency flow estimates were calculated for this site for three different time intervals; including the entire period of record, 1992 and prior, and 1993 and after. The frequency flow estimates were then used for comparison purposes to the Mill Creek watershed HEC-HMS model.

A station and weighted skew was evaluated for all three time intervals described above for the Paxico gage. A regional skew was not evaluated as part of this analysis as the gage has significant period of record and is an active gage. Table 3 shows a comparison of the 1% annual chance storm event for each time interval, using the two methods of skew.

Table 3: 1% Annual Chance Comparison of Time Intervals and Skew Methods for USGS ID 06888500					
Entire Period of Record		1951-1992		1993-2015	
Station Skew (cfs)	Weighted Skew (cfs)	Station Skew (cfs)	Weighted Skew (cfs)	Station Skew (cfs)	Weighted Skew (cfs)
56,065	58,261	63,507	62,455	54,744	57,094

After taking into consideration that at least seventeen watershed dams were constructed in the Mill Creek watershed after 1986, it was concluded that the period of record from 1993 to 2015 most accurately represents the flows at the present time and into the future. The weighted skew method is generally considered the most appropriate skew for Kansas streams, and is appropriate to use in this case since the period of record was shortened to reflect post dam construction. It should be noted that the weighted skew results for the 1993-2015 period of record and the entire period of record are very similar. It should also be reiterated that the results from this gage analysis are only being used for comparison purposes to the Mill Creek watershed HEC-HMS Model.

USGS 06888600- Dry Creek near Maple Hill, KS
USGS Station 06888600 is located near Maple Hill, Kansas and has 21 years of record, dating from 1957 to 1977. Frequency flow estimates were calculated for this site, but were only used for comparison purposes as the number of years of record is on the low end of what would be considered suitable to perform a confident analysis, and as the record ended 40 years ago.

A station, weighted and regional skew was evaluated for the Maple Hill gage. Table 4 shows a comparison of the 1% annual chance storm event using the three methods of skew.

Table 4: 1% Annual Chance Comparison of Skew Methods for USGS ID 06888600		
Station Skew (cfs)	Weighted Skew (cfs)	Regional Skew (cfs)
13,546	11,389	9,364

Considering the relatively short period of record and the fact that the record ended in 1977, it was concluded that the regional skew method is the most appropriate skew method to use for the Maple Hill gage. However, it should be noted that the results from this gage analysis are only being used for comparison purposes to the Mill Creek watershed HEC-HMS model.

GENERAL RAINFALL-RUNOFF MODEL

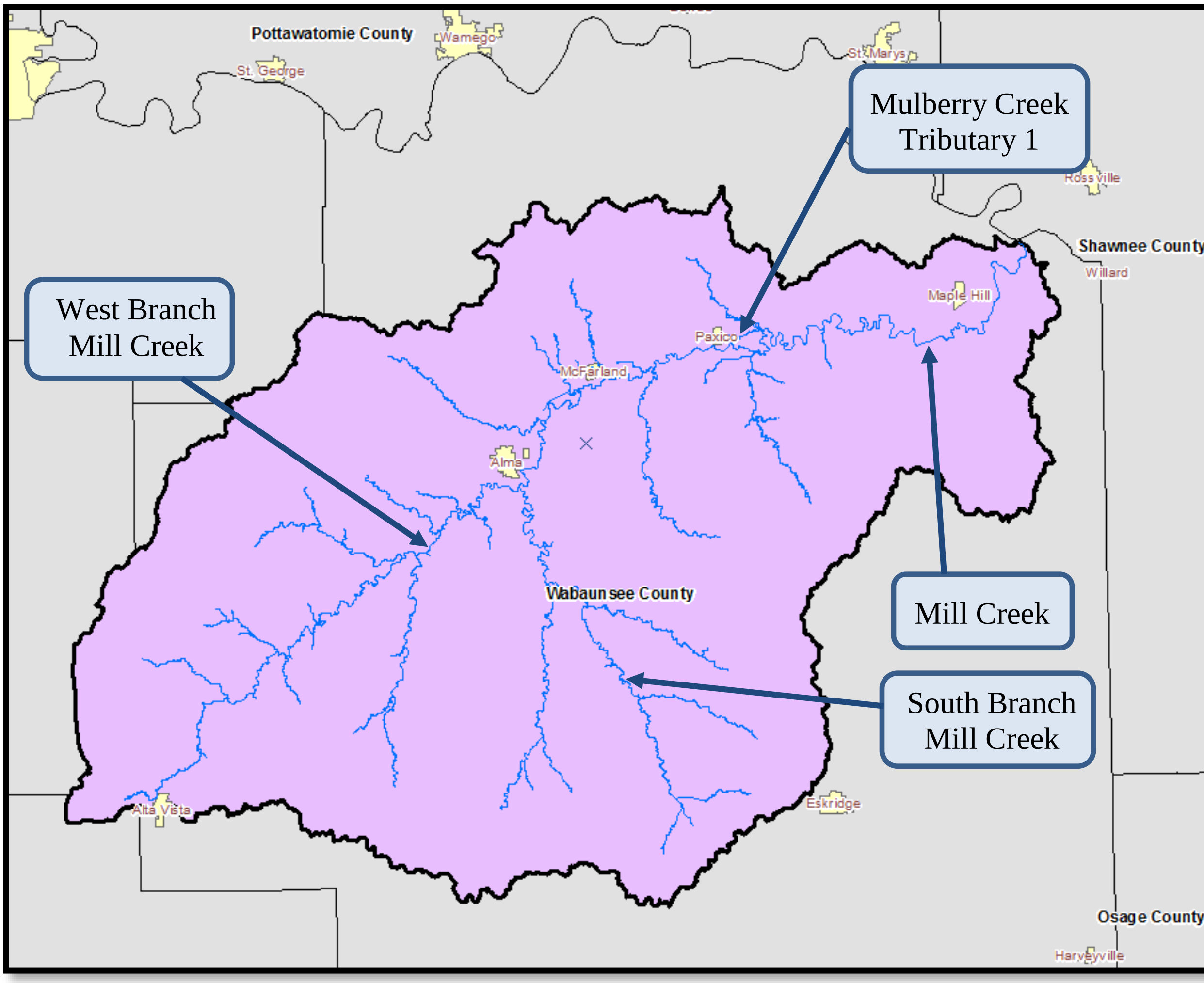
The rainfall-runoff model HEC-HMS version 4.2 (Reference 2), developed by the USACE, was used for the Mill Creek watershed detailed rainfall-runoff model. Figure 2 shows the extent of the rainfall-runoff model. It should be noted that Mulberry Creek Tributary 1 is included in the Mill Creek Watershed model, partially within the City of Paxico. Amec Foster Wheeler used HEC-HMS to generate subbasin runoff hydrographs for the 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% chance 24-hour SCS Type II rainfall events. These runoff hydrographs were routed and combined along the studied streams to produce the peak discharges.

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

The HEC-HMS model of the Mill Creek watershed has a total drainage area of approximately 437.5 square miles. The model includes 101 subbasins, ranging from .02 square miles to 20.4 square miles. Thirteen of the subbasins contain residential areas within small towns, while the remaining areas are predominately rural.

The towns partially encompassed within the HEC-HMS model have minimal storm water drainage systems. Furthermore, the majority of the storm water drainage systems in which they do have were only designed to contain runoff from the smaller storm events, generally the 10% annual chance event or smaller. The primary purpose of this mapping update is to accurately model the risk associated with the larger storm events, specifically the 1% annual chance and 0.2% annual chance flooding events. During these larger storm events, surface water does not necessarily follow the sub-surface flows of the storm water drainage systems. Therefore, the storm water drainage networks (storm sewers) were not included in the HEC-HMS model as they are considered insignificant for the larger storm events and for this particular study.

Figure 2: Boundary of the Mill Creek Watershed HEC-HMS Model



RAINFALL

The rainfall depths, shown in Table 5, were computed using rainfall grids developed by NOAA as part of Atlas 14: Precipitation-Frequency Atlas of the United States (Reference 5). The depths represent an average of all partial-duration grid values within the areas that are included in the rainfall-runoff models. The 100-year minus and 100-year plus rainfall depths were computed by using the 100-year rainfall depth, the 95% lower confidence limit 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 84% lower and 84% upper confidence limits, which are the values used for the 100-year minus and 100-year plus rainfall depths, respectively.

Table 5: SCS Type II 24-hour Rainfall Depths for Mill Creek Watershed	
Event	Mill Creek Watershed Depth (inches)
10-year	5.1
25-year	6.1
50-year	7.0
100-year	7.8
100-year minus	6.8
100-year plus	8.9
500-year	10.0

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 6. 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 would be more appropriate for lower frequency events. In addition, since the two values are the same for the higher storm events, it was determined that the partial-duration rainfall values would be appropriate for all storm events in this study.

Table 6: Comparison of Rainfall for Partial-Duration and Annual-Maximum Series						
Event	Partial-Duration Series			Annual-Maximum Series		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
10-year	5.0	5.1	5.1	4.9	5.0	5.0
25-year	6.0	6.1	6.2	6.0	6.1	6.1
50-year	6.8	7.0	7.0	6.8	6.9	7.0
100-year	7.7	7.8	7.9	7.7	7.8	7.9
100-year lower	5.8	5.9	6.0	5.8	5.9	6.0
100-year upper	9.7	10.0	10.2	9.7	10.0	10.2
500-year	9.8	10.0	10.0	9.8	10.0	10.0

Rainfall Loss

The U.S. Department of Agriculture Soil Conservation Service (SCS) Curve Number (CN) Method was used to model rainfall loss (Reference 8). The curve number is a function of both hydrologic soil group and land use. The table used to determine the CN value from the soil hydrologic soil group and land use is included as Table 7. The CN tables used assume an antecedent moisture condition (AMC) of II as it is representative of typical conditions, rather than the extremes of dry conditions (AMC I) or saturated conditions (AMC III).

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

Soils Data

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

Land Use

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

Table 7: CN Land Use and Soil Drainage Class Table

Land Use Description	Weighted CN (Includes Impervious)			
	A	B	C	D
Open Water	98	98	98	98
Developed, Open Space	51	68	79	84
Developed, Low Intensity	57	72	81	86
Developed, Medium Intensity	77	85	90	92
Developed, High Intensity	89	92	94	95
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	36	60	73	79
Emergent Herbaceous Wetlands	36	60	73	79

The soil and land use data were combined using GIS processes in which specific curve numbers were defined for each soil-land use relationship shown in the CN Land Use and Soil Drainage Class Table (Table 7). Area-weighted curve number values were computed for each subbasin using GIS processes. The area weighted CN values were used in the HEC-HMS models.

Rainfall Transform (Hydrograph)

The time of concentration for each subbasin was calculated using the methodology outlined in TR-55 Urban Hydrology for Small Watersheds (Reference 8) and Chapter 15: Time of Concentration of the National Engineering Handbook (Reference 9). A GIS process was utilized to calculate the longest flow path within any given subbasin. The longest flow paths were then manually edited based on contour data and visual inspection of aerial photography to produce an effective time of concentration line. The total time of concentration consists of the sum of the travel times for sheet flow, shallow concentrated flow, and channel flow. Sheet flow lengths were assigned to be approximately 300 feet or less, using the aerial imagery as a guide, based on information described in TR-55 Urban Hydrology for Small Watersheds (Reference 8). The areas within the HEC-HMS models are rural areas. Therefore, it was determined that a maximum sheet length of 300 feet was acceptable for the majority of the subbasins in the model. 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 SCS Unit Hydrograph method. This method makes use of lag time, which is estimated as 0.6 times the time of concentration. The project area is located in the Flint Hills of Kansas, where surface storage attenuation does not generally need to be accounted for in typical subbasins. Therefore, it was determined that the SCS Unit Hydrograph is the most appropriate transform method to use for this study area.

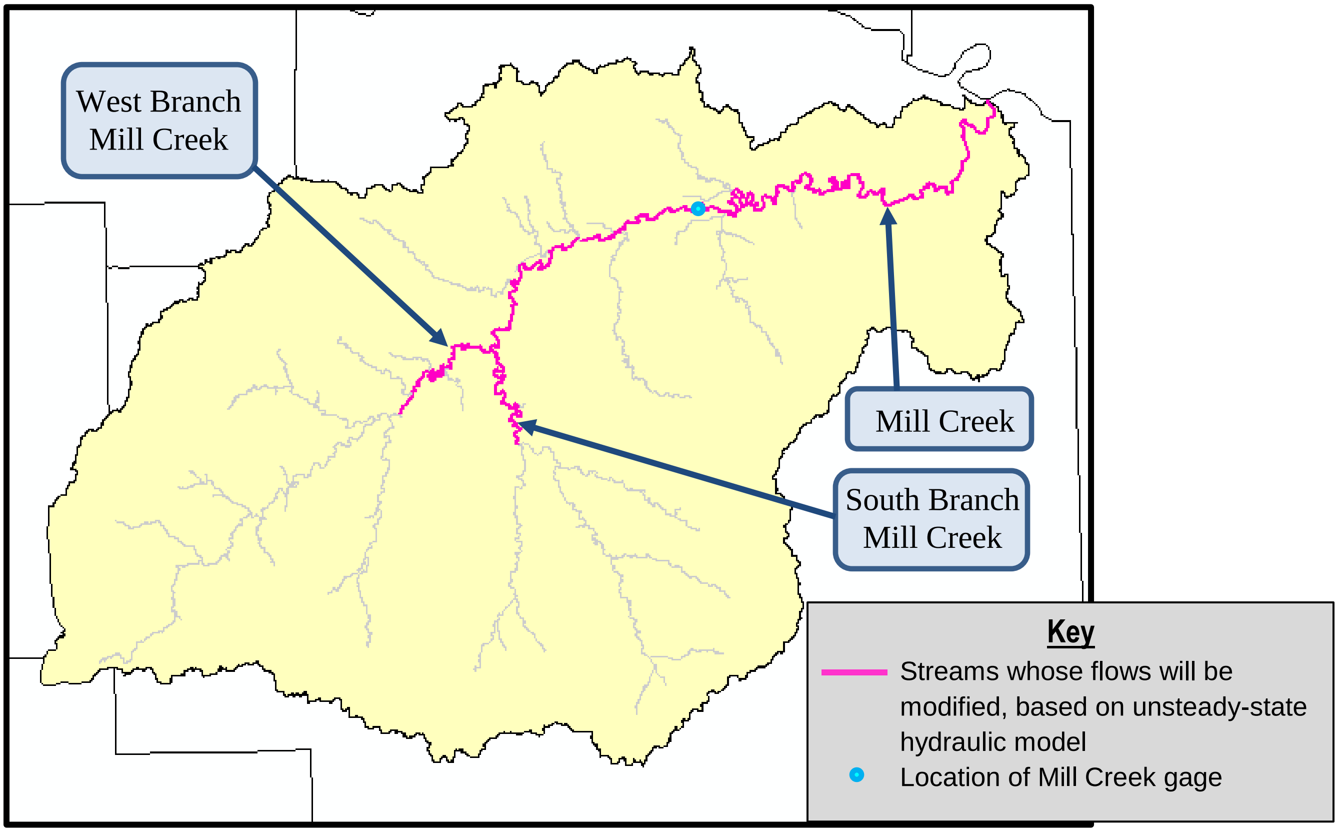
ROUTING

The Muskingum-Cunge channel routing method was used for routing runoff through all reaches in the model. 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. Further explanation on use of the Muskingum-Cunge channel routing method for the large streams is included in the Flow Comparison section.

Rainfall and Areal Reduction

Areal reduction of the watershed’s rainfall depths was applied to those streams that have a drainage area greater than 90 square miles. An areal adjustment ratio of 78% was applied to Mill Creek, the downstream portion of West Branch Mill Creek and the downstream portion of South Branch Mill Creek, based on the methodology described in Natural Resource Conservation Service (NRCS) Technical Release 60- Earth Dams and Reservoirs (Reference 17). Figure 3 illustrates the streams in which areal rainfall reduction was applied. The location of the Mill Creek gage near Paxico is also included in Figure 3.

Figure 3: Streams in which Areal Rainfall Reduction was Applied

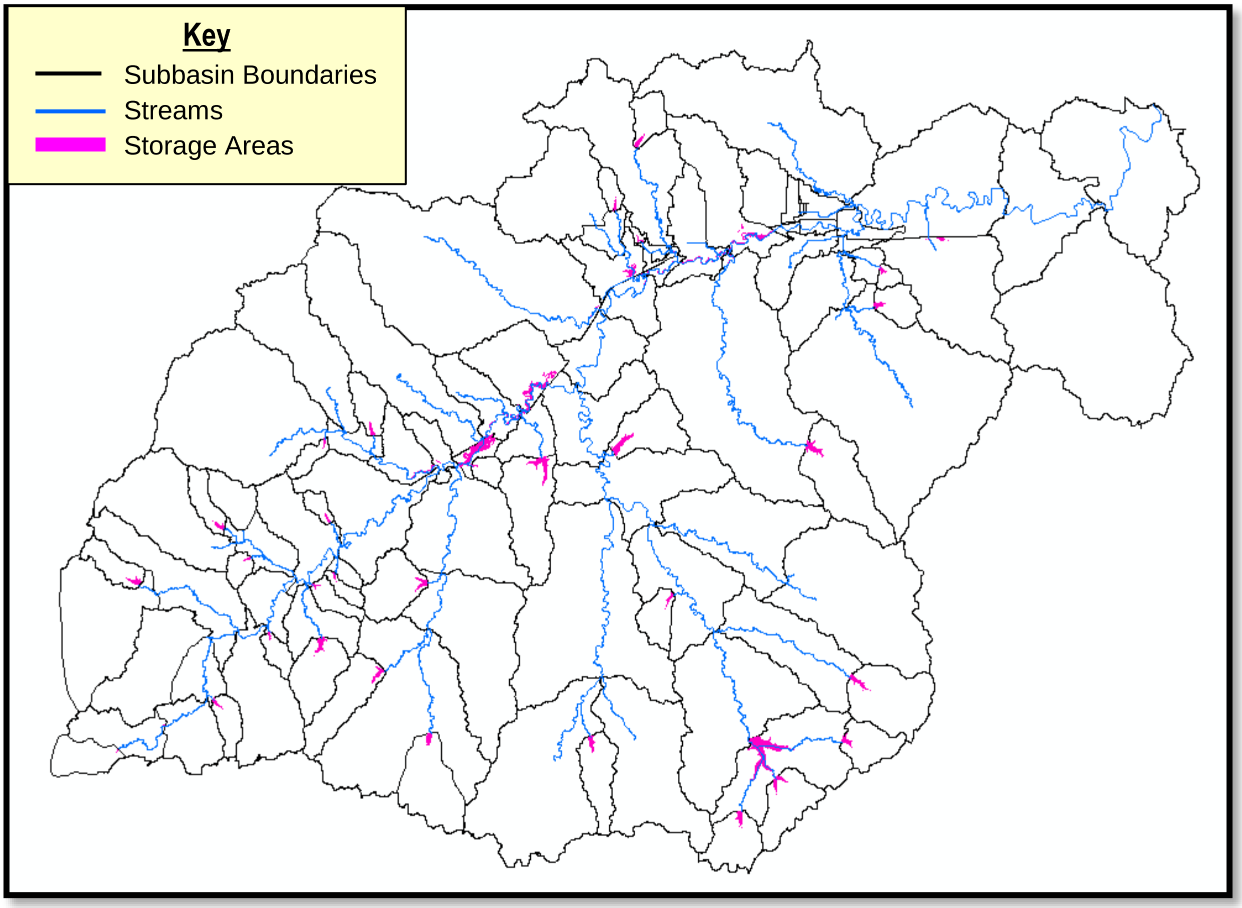


Storage Routing

Forty one storage areas were modeled in the Mill Creek Watershed hydrologic model. Twenty nine of the storage areas represent storage behind significant dams located within the watershed, and twelve storage areas represent storage behind significant road/railroad embankments within the watershed. The criteria for including storage areas within the model was based on the storage type and the storage volume. Specifications for dam tops, associated spillways, and associated outlet structures were included in the HEC-HMS model, where applicable. As-built plan information obtained from the Kansas Department of Agriculture was used for the outlet structures, spillways, and dam tops for the state permitted dams. Information on the outlet structures and dam tops of the storage areas behind road/railroad embankments were obtained using LiDAR topography and aerial imagery. Depth-storage rating curves were estimated from LiDAR topography using an automated area-volume tool within GIS, at a minimum of 0.5-foot intervals.

Figure 4, illustrates the extent of the maximum water elevation during the 1% annual chance storm event for all the storage areas included in the HEC-HMS model, along with subbasin boundaries and streamlines.

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



FLOW COMPARISON

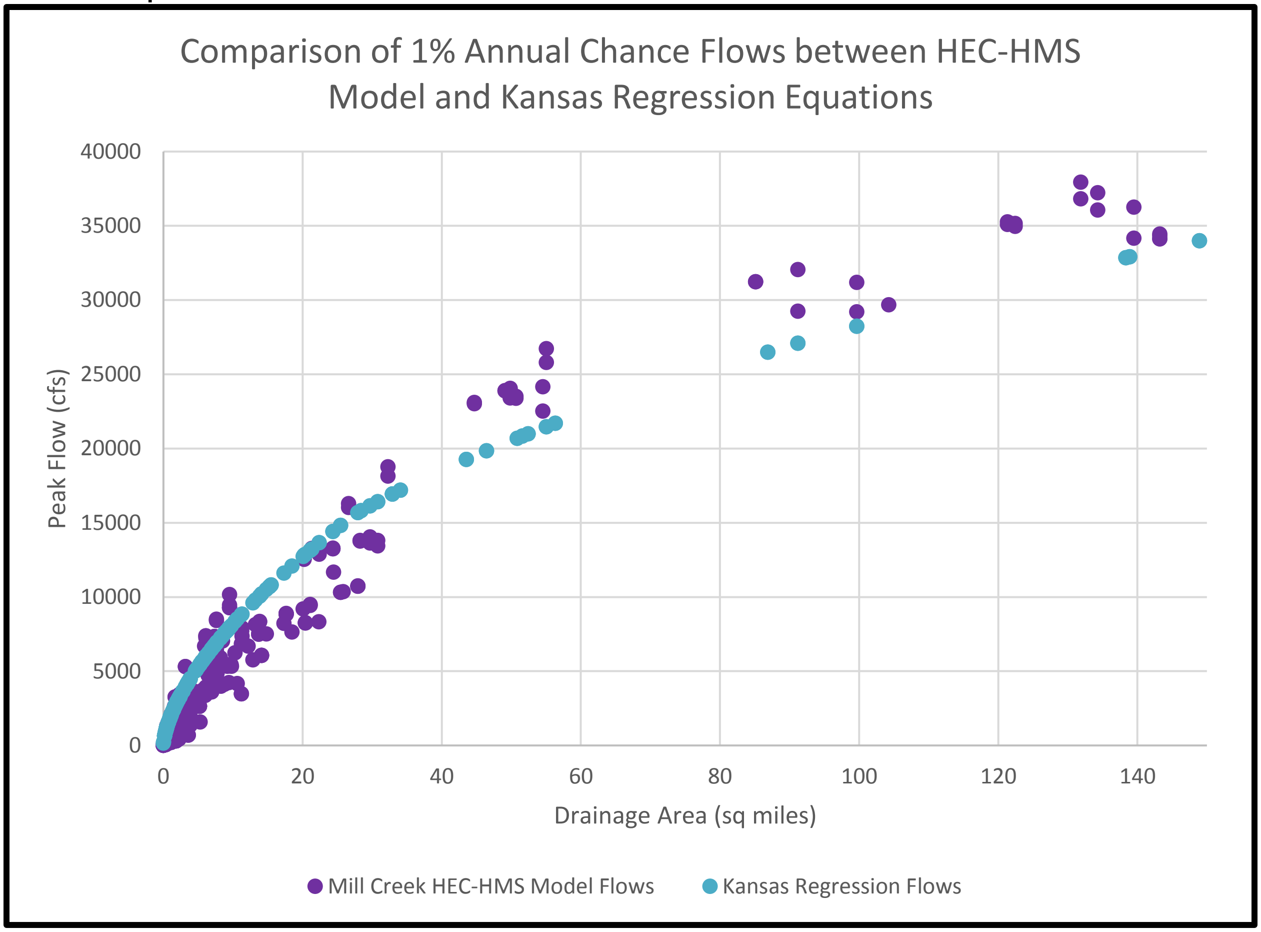
There is not an effective FIS Report for Wabaunsee County. The peak discharges from the HEC-HMS model were compared to the peak discharges from the gage analyses that was performed and the Kansas Regression Equations.

The 1% annual chance flow in the HEC-HMS model for the downstream end of Dry Creek, which has a drainage area of approximately 17.4 square miles, is 8,227 cfs. When interpolating the 1% annual chance flow from the Dry Creek gage at Maple Hill to the downstream end of the stream, the flow is 9,847 cfs. The gage analysis flow is slightly higher than the HEC-HMS model flow. However, this is somewhat expected as characteristics of the Dry Creek watershed have likely changed since the last peak flow was recorded in 1977.

The 1% annual chance flow in the HEC-HMS model at the location of the Mill Creek gage near Paxico, which has a drainage area of approximately 324 square miles, is 57,653 cfs. This corresponds very well to the weighted skew method results for the Paxico gage for the period of record from 1993 to 2015, which is 57,094 cfs. This provides a calibration point and added confidence in the accuracy of the flows that were generated in the HEC-HMS model, as the two flows are within less than 1% of each other.

Figure 5 shows a comparison between the 1% annual chance flows in the Mill Creek watershed HEC-HMS model and the 1% annual chance flows calculated using the Kansas Regression Equations, for those drainage areas less than 150 square miles.

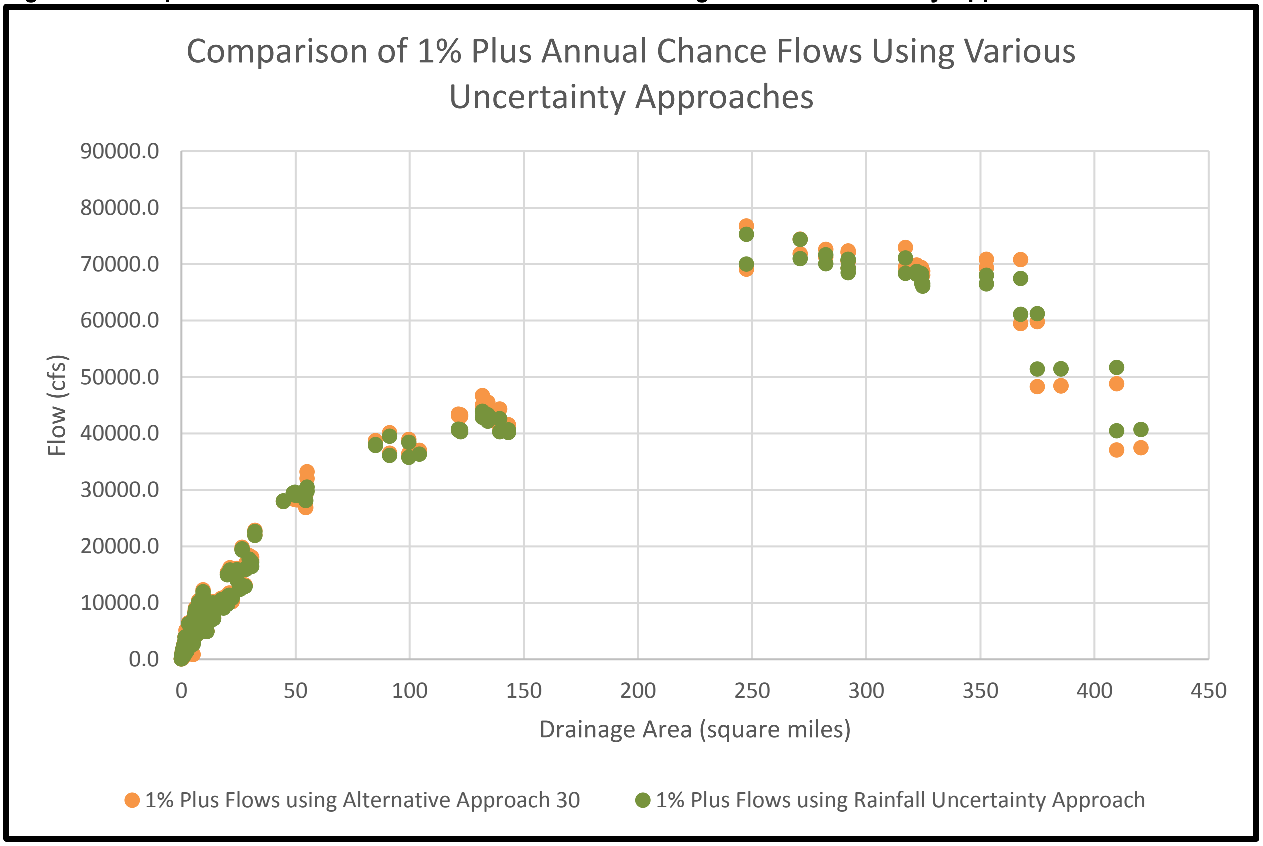
Figure 5- Comparison of 1% Annual Chance Flows between the HEC-HMS Model and Kansas Regression Equations



The HEC-HMS flows for the drainage areas less than 150 square miles fall closely in line with the Kansas Regression Flows, with some flows from the HEC-HMS model being above and below the Regression Flows. The streams with greater than 150 square miles of drainage area flow directly into Mill Creek, which has been calibrated to the Paxico gage.

The 1% plus annual chance flows generated by the HEC-HMS model, which accounts for variability that exists in the statistics of the rainfall calculations by using a 1% plus rainfall depth, were compared to the 1% plus annual chance flows calculated using an alternative method that combines the procedures described in Bulletin 17B (Reference 20) and the US Army Corps of Engineer's Risk-Based Analysis for Flood Damage Reduction Studies Engineer Manual (Reference 19), which utilizes the 50%, 10%, and 1% annual chance peak flows from the HEC-HMS model and an equivalent record length. Figure 6 shows the comparison between the two different uncertainty approaches. The calculations for the alternative uncertainty approach uses an equivalent record length of 30 years, which is an appropriate equivalent record length for calibrated rainfall-runoff models based on the guidance. The 1% plus annual chance flows using the rainfall uncertainty approach closely align to the 1% plus annual chance flows using the alternative uncertainty approach with an equivalent record length of 30 years. While 30 is documented as the maximum equivalent record length to be used in the calculations, it still falls within an appropriate range for the modeling done and aligns with the 1% plus annual chance flows generated by the HEC-HMS model, using the 1% plus rainfall depth. Therefore, it was deemed appropriate to utilize the rainfall uncertainty approach to determine the 1% plus annual chance flows for the streams included in the HEC-HMS model for this project.

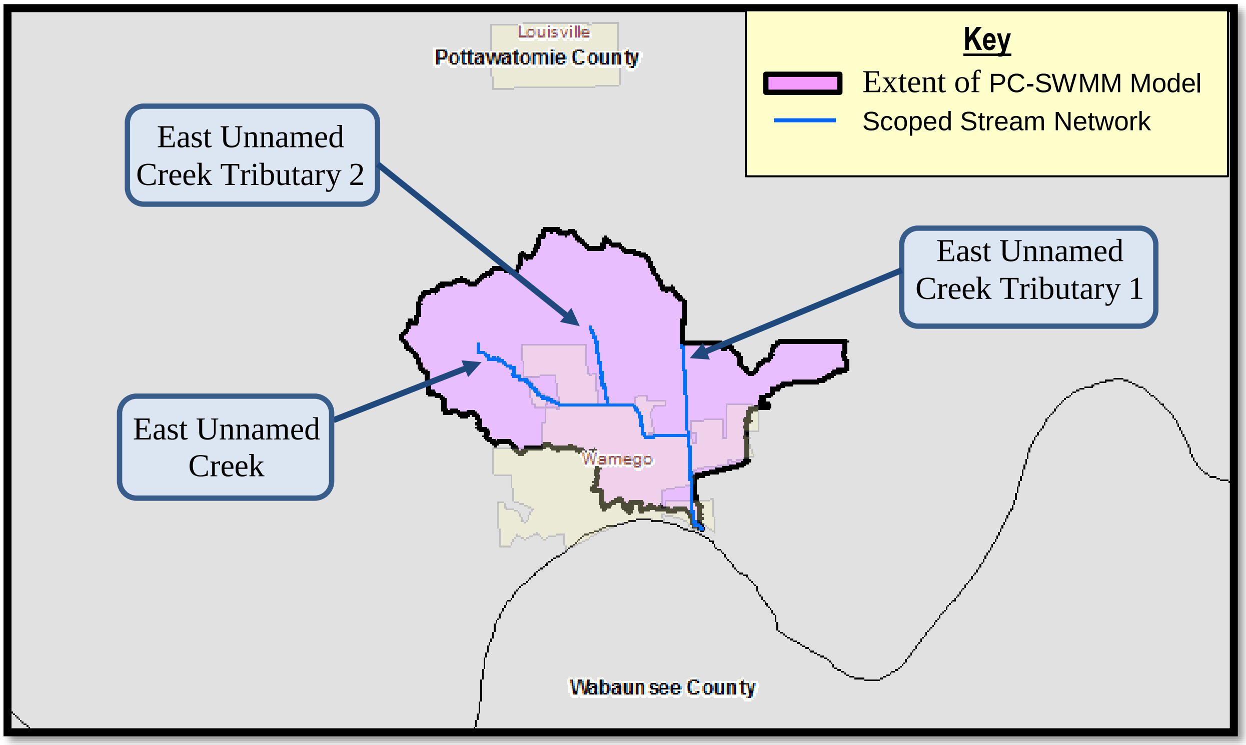
Figure 6- Comparison of 1% Plus Annual Chance Flows Using Various Uncertainty Approaches



RAINFALL-RUNOFF/STORM WATER MODEL

The detailed hydrology for the three scoped streams located within the City of Wamego were modeled within PC-SWMM using SWMM5 methodology (Reference 15). This detailed study includes East Unnamed Creek, East Unnamed Creek Tributary 1, and East Unnamed Creek Tributary 2. It was determined that the drainage system within the City of Wamego would have a significant impact on the 1% and 0.2% annual chance storm events for the streams included in this study. Therefore, modeling was conducted to incorporate updated topographic data, community stormwater data, and necessary modeling methodologies to analyze the unique features of this study area. Figure 7 shows the extent of the East Unnamed Creek Watershed PC-SWMM model. Runoff hydrographs for the 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% chance 24-hour SCS Type II rainfall events were generated, and used to produce the peak discharges.

Figure 7: Boundary of the East Unnamed Creek Watershed PC-SWMM Model



PC-SWMM version 6.3.2223 software was used to perform the interior drainage runoff and hydrologic analysis. The PC-SWMM model runs on the US EPA SWMM5 engine and requires the same input files; therefore, these models can be opened and run within EPA SWMM5, which is a free downloadable program. The required inputs and data sources for the model are listed below. All elevations represented in this report and throughout this analysis are in the NAVD88 vertical datum. All shapefiles and supporting data was developed and projected in the horizontal projection of State Plane NAD83 Kansas North feet.

Drainage Area Delineations

Drainage area delineations were based on topography obtained as 1-meter LiDAR through the Kansas Data Access and Support Center. Drainage areas were first delineated using automated GIS processes including HEC-GeoHMS (Reference 3) and ArcHydro (Reference 4) based on LiDAR Digital Elevation Models (DEM). Delineations were then checked and manually edited, as necessary, based on detailed LIDAR topography, aerial imagery, storage considerations, and the City of Wamego stormwater data. The PC-SWMM model for the East Unnamed Creek Watershed includes 56 subbasins, ranging from approximately 2 acres to 194 acres.

Hydrology Transform Method

PC-SWMM hydrology uses the runoff block method to transform rainfall to runoff. This method uses flow length, basin width, and basin slope to determine the shape of the runoff hydrograph. The flow length parameter is not an exact measurement, but is used to approximate overland flow length and a portion of sheet and shallow concentrated flow. The flow length was computed as the length of the TR-55 sheet and shallow concentrated flow regimes of the longest flow path. Flow width is automatically calculated by dividing subbasin area by flow length. Basin slope was calculated for each subbasin using the LiDAR topography data. Some areas that were not representative of the overall basin were removed from this calculation; including road embankments, stream banks, and other anomalies.

INFILTRATION METHOD

The PC-SWMM runoff block method allows the utilization of a form of the Curve Number infiltration method, based on Natural Resource Conservation District (NRCS) Technical Release TR-55 (Reference 8). Land use was determined using a combination of data from the National Land Cover Dataset (NLCD) website (Reference 7) and aerial photography. Fifteen land use designations were used to represent the project area. The land use designations were joined with soil data to generate an area-weighted curve number for each subbasin. Soil data was obtained in shapefile and database format from the United Stated Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) website (Reference 6). Typical soils in the study area consist primarily of hydrologic soil groups C and D. Table 7 displays the associated curve numbers used for each land use category and soil type, with the exception of adjustments made to the CN for residential areas with 1/4 acre lots and 1/8 acre lots. Area-weighted curve number values were computed for each subbasin using GIS processes. The area weighted CN values were used in the PC-SWMM model.

ROUTING METHOD

The dynamic wave routing method was used so the model can properly estimate reverse flow in pipes, backwater flows, open channel flows, and interconnected ponding areas.

Links

Links are used to represent open channels, pipe networks, pumps, weirs, and orifices. Pipe lengths, pipe diameters, roughness coefficients, and entrance and exit loss coefficients were established; based on detailed survey information obtained by Amec Foster Wheeler and information provided in the 2008 Wamego Stormwater Master Plan and associated spatial files, conducted by Wilson & Company. Cross-section shapes and weir dimensions were obtained using LiDAR topography and GIS processes, and adjusted as necessary based on engineering judgment.

Nodes

Nodes are used to assign junctions, storage areas, and outfalls. Junction invert and maximum depth elevations were taken from the detailed survey information obtained by Amec Foster Wheeler, the spatial files associated with the 2008 Wamego Stormwater Master Plan, or estimated using the LiDAR topography.

Storage nodes were used to represent significant storage behind dams and road embankments. In locations where storage was deemed significant, a storage node was used with an associated depth-storage rating curve. Depth-storage rating curves were estimated from LiDAR topography using an automated area-volume tool within GIS, at a minimum of 0.5-foot intervals. Eleven storage areas were included in the East Unnamed Creek watershed PC-SWMM model. Three of the storage areas represent storage behind significant dams located within the watershed, and eight storage areas represent storage behind significant road embankments within the watershed. The criteria for including storage areas within the model was based on the storage type and the storage volume.

RAINFALL

The rainfall depths, shown in Table 8, were computed using rainfall grids developed by NOAA as part of Atlas 14: Precipitation-Frequency Atlas of the United States (Reference 5) in the same manner that was described on pages 6 and 7 of this report.

Table 8: SCS Type II 24-hour Rainfall Depths for City of Wamego	
Event	City of Wamego Depth (inches)
10-year	4.9
25-year	6.0
50-year	6.8
100-year	7.7
100-year minus	6.8
100-year plus	8.7
500-year	9.9

FLOW COMPARISON

Table 9 provides a comparison of 1% annual chance peak discharges from the effective FIS report and peak discharges developed as part of this detailed study for East Unnamed Creek and East Unnamed Creek Tributary 2. East Unnamed Creek Tributary 1 is not currently included in the effective FIS report.

Table 9: Comparison of 1% Annual Chance Discharge				
Location	Drainage Area (mi^2)		1% Annual Chance Discharge (cfs)	
	FIS	AMEC	FIS	AMEC
East Unnamed Creek				
At Confluence with Kansas River	2.50	3.61	3,240	1,741
350 Feet Upstream of 8th Street	1.94	2.20	2,850	1,726
1000 Feet Upstream of Highway 99	1.13	1.26	2,150	1,232
500 Feet Downstream of Say Road	0.39	0.35	690	509
East Unnamed Creek Tributary 2				
At Confluence with East Unnamed Creek	0.74	0.69	1,040	428
Just downstream of Say Road	0.55	0.54	880	750

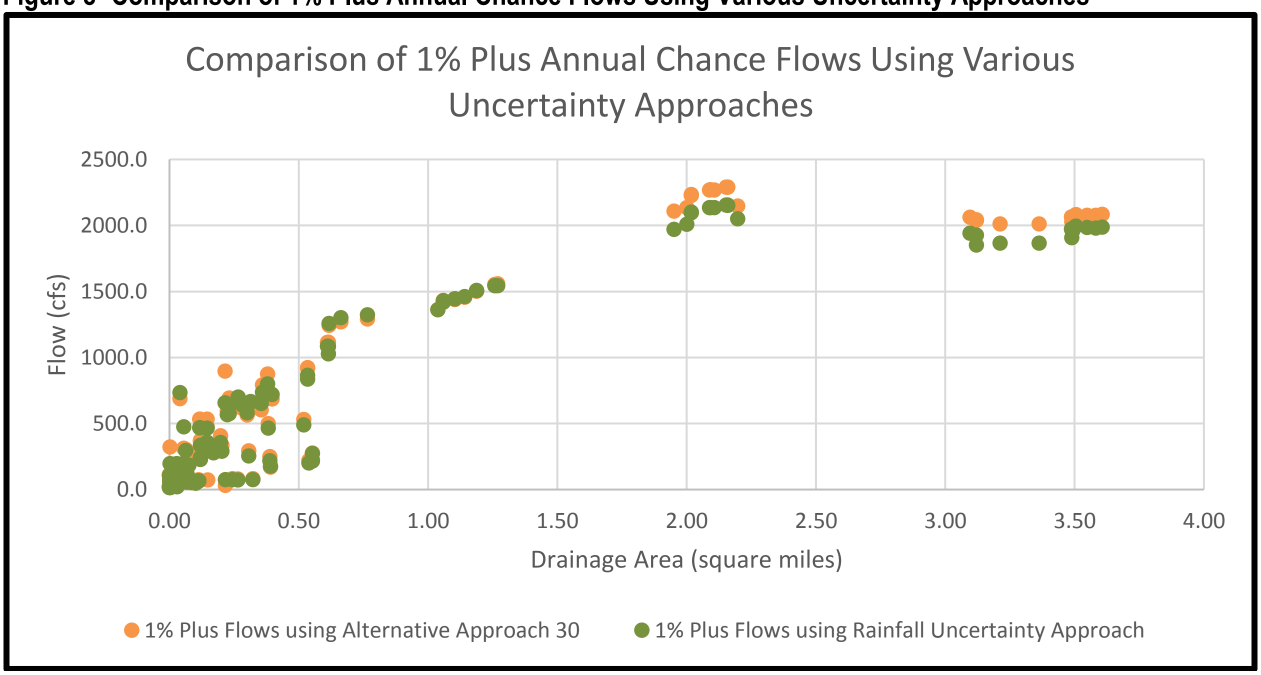
**Comparison to Rural Regression estimates are not appropriate for this study area.*

Flow values for East Unnamed Creek and East Unnamed Creek Tributary 2 are lower than the flows described in the effective FIS Report. This is likely caused by the inclusion of storage areas, subsurface drainage systems, and lateral weirs in the PC-SWMM model; which were most likely not included in the previous study. This is also likely due to more detailed topography and the incorporation of new modeling methods. A comparison to rural regression estimates were not made because the characteristics of the area modeled by the PC-SWMM model are not similar to those characteristics in which the rural regression equations were developed, and thus would not be applicable.

It should be mentioned that East Unnamed Creek, East Unnamed Creek Tributary 1, and East Unnamed Creek Tributary 2 all have areas in which the peak flow decreases while moving downstream, going through areas of town. This is due to water overtopping roads and weirs, the incorporation of the subsurface drainage system, and attenuation from the use of storage areas; which were all reasons for using the PC-SWMM model to represent this study area.

The 1% plus annual chance flows generated by the PC-SWMM model, which accounts for variability that exists in the statistics of the rainfall calculations by using a 1% plus rainfall depth, were compared to the 1% plus annual chance flows calculated using an alternative method that combines the procedures described in Bulletin 17B (Reference 20) and the US Army Corps of Engineer's Risk-Based Analysis for Flood Damage Reduction Studies Engineer Manual (Reference 19), which utilizes the 50%, 10%, and 1% annual chance peak flows from the PC-SWMM model and an equivalent record length. Figure 8 shows the comparison between the two different uncertainty approaches. The calculations for the alternative uncertainty approach uses an equivalent record length of 30 years, which is an appropriate equivalent record length for calibrated rainfall-runoff models based on the guidance. The 1% plus annual chance flows using the rainfall uncertainty approach closely align to the 1% plus annual chance flows using the alternative uncertainty approach with an equivalent record length of 30 years, with some flows being above and below the alternative uncertainty approach flows. While 30 is documented as the maximum equivalent record length to be used in the calculations, it still falls within an appropriate range for the modeling done and aligns closely with the 1% plus annual chance flows generated by the PC-SWMM model, using the 1% plus rainfall depth. Therefore, it was deemed appropriate to utilize the rainfall uncertainty approach to determine the 1% plus annual chance flows for the streams included in the PC-SWMM model for this project.

Figure 8- Comparison of 1% Plus Annual Chance Flows Using Various Uncertainty Approaches

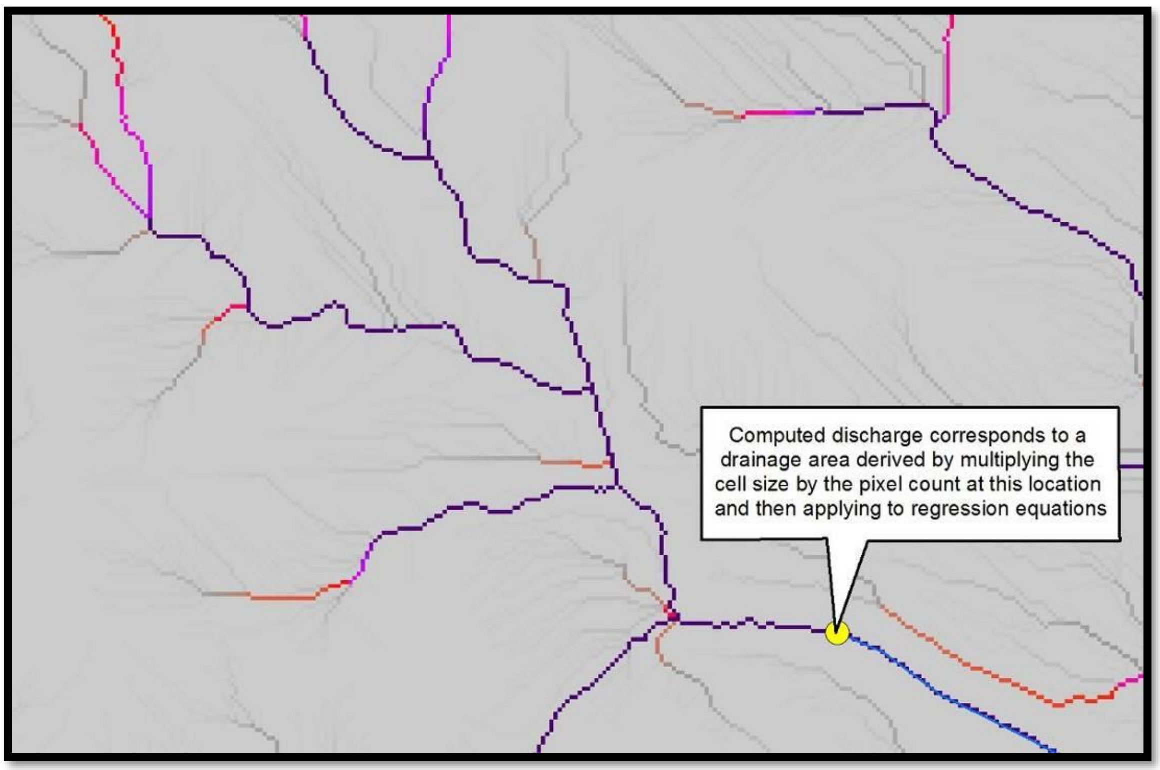


APPROXIMATE HYDROLOGIC ANALYSIS

The hydrology for the Zone A streams that are not modeled by a detailed hydrologic method was developed using USGS Rural Regression Equations for Kansas.

To prepare the drainage network, the scoped streams were adjusted based on LiDAR elevation data and aerial imagery obtained through the Kansas Data Access and Support Center. A flow accumulation grid was developed from the LiDAR data which provides a "pixel count" at desired flow change locations that represents the number of pixels flowing into it. A simple calculation is used to convert this pixel count into square miles. Figure 9 illustrates how the drainage points correspond to the flow accumulation grid.

Figure 9: Regression Analysis Discharge Calculation Example



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

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

Where:

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

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

The 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. This intersection is generally at 30 square miles of drainage area.

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

The peak flows from the Mill Creek watershed HEC-HMS model were compared to the flows calculated using the USGS Rural Regression Equations for Kansas, and were determined to be within an appropriate tolerance range, with some of the flows in the Mill Creek watershed model being above and below the Rural Regression flows. Therefore, it was concluding that the Kansas Regression Equations were suitable to use for the Zone A streams not modeled by a detailed hydrologic method. 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 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. This intersection is generally at 30 square miles of drainage area.

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

The peak flows for the 1% minus and 1% plus annual chance storm events were determined using the upper and lower limit model standard error of prediction for the 1% annual chance USGS Rural Regression Equations for Kansas (Reference 1). The upper limit model standard error of prediction is +71% for the smaller drainage areas and +47% for the larger drainage areas. The lower limit model standard error of prediction is -44% for the smaller drainage areas and -32% for the larger drainage areas.

Peak flows were then calculated for each drainage point within the filtered points file that was generated for the approximate Zone A streams, using the Kansas Regression Equations for the 10%, 4%, 2%, 1%, 1% Minus, and 1% Plus annual chance storm events and the extrapolated 0.2% annual chance storm event.

For the Zone A streams included in the Mill Creek watershed HEC-HMS model, a weighting approach was done along the Kansas Regression line, using the known flows from the HEC-HMS model, for each drainage point within the filtered points file that was originally generated for the 10%, 4%, 2%, 1%, 1% Minus, 1% Plus, and 0.2% annual chance storm events.

CONCLUSION

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

TABLE 10 – SUMMARY OF DISCHARGES

		PEAK ANNUAL CHANCE DISCHARGES (CFS)						
FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% - Annual Chance	1% + Annual Chance	0.20% Annual Chance
East Unnamed Creek								
At Confluence with Kansas River	3.61	982	1,292	1,515	1,741	1,515	1989	2,260
At 4th Street	3.49	978	1,280	1,504	1,717	1,504	1,956	2,232
At 8th Street	3.12	936	1,244	1,495	1,715	1,495	1,927	2,208
At Pine Street	2.16	835	1,207	1,507	1,819	1,507	2,156	2,554
At KS Highway 99	2.02	800	1,165	1,460	1,765	1,460	2,096	2,486
At Kaw Valley Road	1.06	421	668	901	1,136	901	1,431	1,785
At Say Road	0.31	165	299	405	516	405	663	836
East Unnamed Creek Tributary 1								
At Confluence with East Unnamed Creek	0.55	176	201	230	259	230	275	286
At US Highway 24	0.39	152	153	154	159	154	178	250
At Spencer Street	0.38	304	446	554	671	554	801	961
East Unnamed Creek Tributary 2								
At Confluence with East Unnamed Creek	0.69	253	334	375	428	375	428	465
At Say Road	0.54	428	568	656	750	656	867	985
Mill Creek								
At Snokomo Road	324.8	37,011	45,785	52,372	57,583	51,002	66,555	79,665

TABLE 10 – SUMMARY OF DISCHARGES								
		PEAK ANNUAL CHANCE DISCHARGES (CFS)						
FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% - Annual Chance	1% + Annual Chance	0.20% Annual Chance
At Interstate 70 / US Highway 40	322.1	37,456	46,222	53,407	58,355	52,029	68,537	81,166
Mulberry Creek Tributary 1								
At Emporia Avenue	0.48	310	405	493	572	473	681	792
At Topeka Avenue	0.46	317	414	502	581	482	690	800
At Newbury Avenue	0.42	329	426	514	593	495	702	811

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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