CALIBRATION OF RUNOFF CURVE NUMBERS AND RATIONAL RUNOFF COEFFICIENTS FOR THE KANSAS CITY METROPOLITAN AREA

By

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Abstract

The runoff curve number (CN) and the rational runoff coefficient (C) for undeveloped land are key inputs to common methods for estimating flood quantiles. This document describes the calibration of these inputs with Kansas City-area streamflow data and recommends changes to the current Section 5600 storm-drainage design criteria for the Kansas City area.

Runoff curve numbers and rational runoff coefficients for undeveloped land were calibrated to give the best possible estimates of flood quantiles. The curve numbers and runoff coefficients were considered frequency-dependent, so separate calibrations were performed for annual exceedance probabilities of 50%, 20%, 10%, 4%, 2% and 1%. The calibrations were performed on 28 gaged rural watersheds in the Kansas City area. In aggregate, these watersheds have physical characteristics that are similar to those of undeveloped land and urban open space in the Kansas City area. Basin lag times and times of concentration were computed with the new calibrated equations for the Kansas City area developed by the University of Kansas (McEnroe et al., 2015). Rainfall frequency estimates from NOAA Atlas 14 Volume 8 (2013) were used in all calibrations.

Runoff curve numbers were calibrated for use in the Baseline Unit Hydrograph Method in Section 5600. Using generalized least-squares regression, regional flood-frequency equations were developed from the peak-flow records for the 28 gaged watersheds. The curve numbers were calibrated so that the Baseline UH Method yields the same peak flows as regional flood-frequency equations. A second set of curve-number calibrations were performed using HEC frequency storms of 24-hour duration in place of the 24-hour NRCS Type 2 storms specified in Section 5600.

Rational runoff coefficients for each frequency of interest were calibrated by fitting the rational equation to the log-transformed data for the 28 gaged watersheds by least-squares regression.

On average, the calibrated curve numbers for the NRCS 24-hr Type 2 storm and the HEC storm of 24-hr duration fall below the CN value of 74 used in Section 5600 for undeveloped land and urban green space. Calibrated curve numbers decrease slightly with decreasing annual exceedance probability. The calibrated rational runoff coefficients are strongly frequency-dependent and generally higher than the values recommended for undeveloped land in the Section 5600 design criteria.

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Chapter 1

Introduction

1.1. Background

Stormwater projects and flood studies require estimates of peak flows of certain frequencies. These peak flows depend on the physical characteristics of the watershed and regional meteorological and climatic characteristics. Peak flows for storm sewers and other small drainage structures are usually estimated by the rational method. Hydrographs for stormwater facilities design and flood studies are normally developed by the hydrologic methods of the Natural Resources Conservation Service (NRCS). The runoff coefficient, C, in the rational method and the runoff curve number, CN, in the NRCS rainfall-runoff method are key inputs related to the physical characteristics of the watershed.

Most cities in the Kansas City area have adopted the Section 5600 storm-drainage design criteria of the Kansas City Metro Chapter, American Public Works Association (KC-APWA). KC-APWA's Section 5600 design guidance (2011) provides instructions for application of the rational and NRCS hydrologic methods for the Kansas City area. For the rational method, Section 5600 specifies rational C values of 0.90 for all impervious surfaces and 0.30 for all pervious surfaces regardless of land use or soil type. A frequency-dependent multiplier, K, is applied to the composite (area-weighted) runoff coefficient to increase its effective value for annual exceedance probabilities below 10%.

Section 5600 allows for flood hydrograph simulation by two methods termed, the Baseline Unit Hydrograph Method and the Kansas Calibrated Method (used by the Kansas Department of Transportation). The Baseline Method uses the NRCS Type 2 design storm of 24-hour duration, while the Kansas Calibrated Method uses a HEC frequency-based storm with a duration of 6, 12, or 24 hours. The Baseline Method uses a CN value of 74 for all undeveloped land and urban green space. The specified CN of 74 is the NRCS-recommended value for pasture and urban open space in good condition with group C soils and an average antecedent moisture condition (AMC 2). In the Baseline Method, the CN value of 74 is applied to the pervious portion of the watershed, regardless of the soil classification or the frequency of the design event (AMC 2 is assumed for all frequencies). In the Kansas Calibrated Method, the storm duration and the AMC used to determine the CN depend on the frequency of the event and the location within Kansas (eastern or western region).

1.2. Overview

This document develops calibrated values of the NRCS CN and the rational C for undeveloped land and urban open space for the Kansas City area. The CN and C values for undeveloped land are calibrated by comparing simulated peak flows with estimates obtained from regional flood-frequency equations developed from USGS stream-gaging records for stations within 75 miles of downtown Kansas City. The calibrated CN and C values represent average values for undeveloped land in the Kansas City area, without reference to specific land uses or soil types.

This document also investigates the HEC frequency-based rainfall distribution as an alternative to the NRCS Type 2 distribution in the Baseline Method. The Type 2 distribution is a fixedshape distribution with the k%-chance, 24-hour depth as the only input. The HEC frequency-based rainfall distributions account for local rainfall frequency characteristics for multiple durations from 5 minutes to the duration of the storm.

1.3. Summary of calibration methodology

Runoff curve numbers and rational runoff coefficients for undeveloped land were calibrated to give the best possible estimates of peak flow. The calibration methodology for the runoff curve number did not consider runoff volumes. The curve numbers and runoff coefficients were considered frequency-dependent. Separate calibrations were performed for annual exceedance probabilities (AEPs) of 50%, 20%, 10%, 4%, 2% and 1%.

The calibrations were performed on 28 gaged rural watersheds in the Kansas City area. Collectively, these watersheds have physical characteristics that are similar to those of undeveloped land and urban open space in the Kansas City area. Basin lag times and times of concentration were computed with the new calibrated equations for the Kansas City area developed by the University of Kansas (McEnroe et al., 2015). Rainfall frequency estimates from NOAA Atlas 14 Volume 8 (2013) were used in all calibrations.

Runoff curve numbers were calibrated for use in the Baseline Unit Hydrograph Method in Section 5600. Regional flood-frequency equations were developed from the peak-flow records for the 28 gaged watersheds. The curve numbers were calibrated so that the Baseline UH Method yields the same peak flows as regional flood-frequency equations. A second set of curve-number calibrations were performed using HEC frequency storms of 24-hour duration in place of the 24-

hour NRCS Type 2 storms specified in Section 5600. Rational runoff coefficients for each frequency of interest were calibrated by fitting the log-transformed rational equation to the data for the 28 gaged watersheds by least-squares regression.

Chapter 2

Streamflow Stations and Watershed Characteristics

2.1. Selection of USGS streamflow stations

This study focuses on the area within a 75-mile radius of downtown Kansas City shown in Figure 2-1. USGS-gaged watersheds within this area were chosen for this study based on record length, drainage area, and land use. The requirements for inclusion were a minimum record length of 10 years, a maximum drainage area of 30 mi^2, and a predominantly rural watershed with no significant impoundments. A watershed was considered predominantly rural if less than 5% of the area is covered by impervious surfaces. The 28 USGS gage sites that met these criteria are listed in Table 2-1. These gages are located in 22 different counties: 13 in Kansas and 15 in Missouri. The drainage areas at these gage sites range from 250 acres to 29 mi^2.

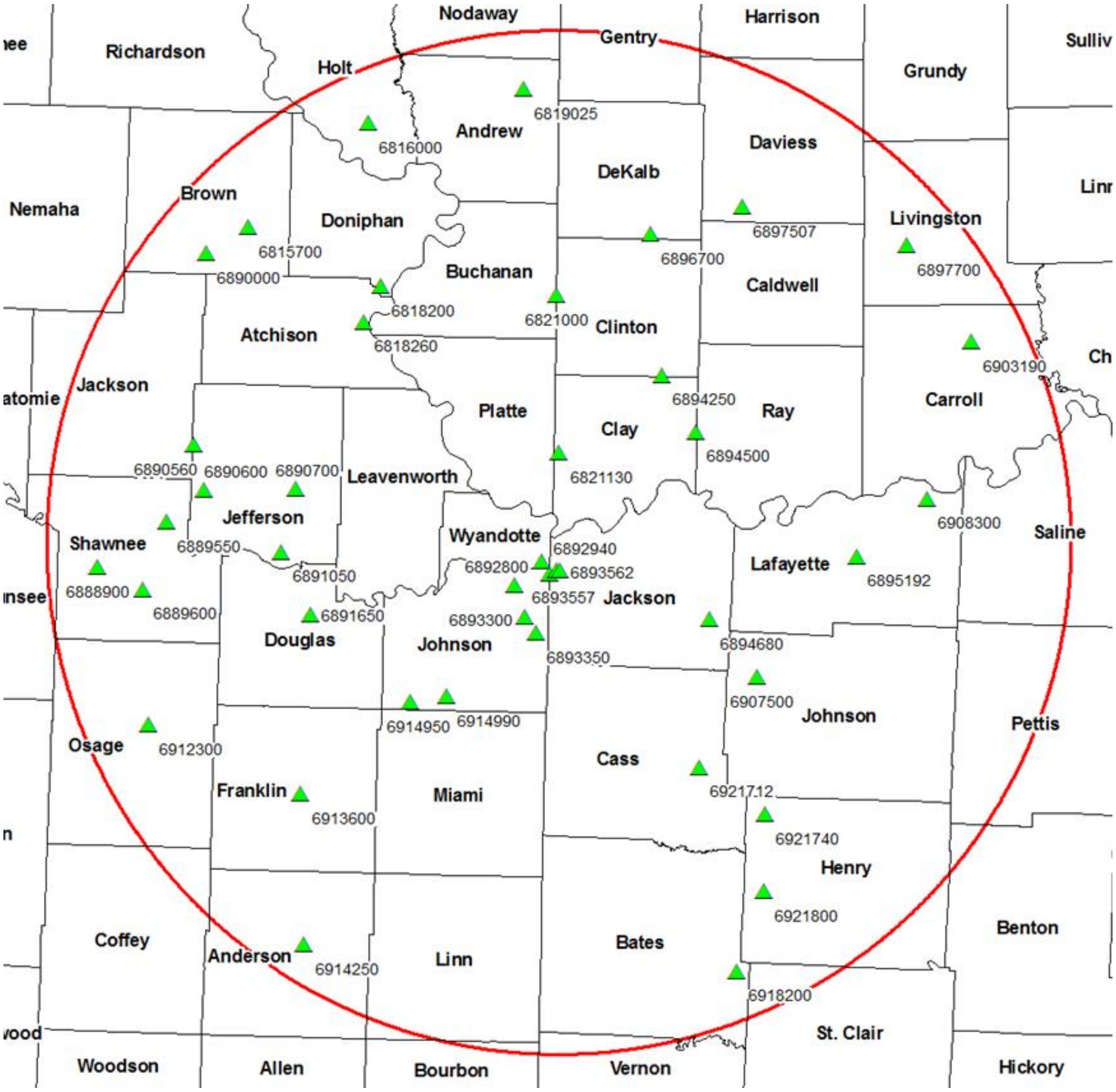

Figure 2-1. Study area and selected USGS stream gages

Table 2-1. Selected gaged watersheds

Site number	Site name	Years of record	Drainage area (mi^2)
6815700	BUTTERMILK C NR WILLIS, KS	52	3.7
6816000	MILL C AT OREGON, MO	27	5.0
6818200	DONIPHAN C AT DONIPHAN, KS	11	4.1
6819025	AGEE C NR SAVANNAH, MO	18	6.5
6821000	JENKINS BRANCH AT GOWER, MO	27	2.6
6888900	BLACKSMITH C TR NR VALENCIA, KS	33	0.8
6889550	INDIAN C NR TOPEKA, KS	43	9.8
6890000	L DELAWARE R NR HORTON, KS	12	19.1
6890560	ROCK C 6 MILES N OF MERIDEN, KS	14	1.9
6890600	ROCK C NR MERIDEN, KS	14	22.1
6890700	SLOUGH C TR NR OSKALOOSA, KS	21	0.9
6891050	STONE HOUSE CR AT WILLIAMSTOWN, KS	26	13.2
6894250	NEW HOPE C NR HOLT, MO	17	6.7
6894500	E FORK FISHING RIVER AT EXCELSIOR SPRINGS, MO	22	20.1
6894680	SNI-A-BAR C NR TARSNEY, MO	11	27.7
6895192	TABO C NR HIGGINSVILLE, MO	18	23.9
6897507	MARROWBONE C NR GALLATIN, MO	18	17.9
6897700	GRAND RIVER TR NR UTICA, MO	24	1.4
6903190	ROCK BRANCH NR CARROLLTON, MO	18	4.7
6907500	SOUTH FORK BLACKWATER RIVER NR ELM, MO	27	16.6
6908300	TRENT BRANCH NR WAVERLY, MO	15	1.0
6912300	DRAGOON C TR NR LYNDON, KS	34	3.7
6913600	ROCK C NR OTTAWA, KS	21	10.2
6914250	SF POTTAWATOMIE C TR NR GARNETT, KS	46	0.4
6914950	BIG BULL C NR EDGERTON, KS	21	29.0
6921712	CLEAR C NR HARRISONVILLE, MO	18	11.1
6921740	BRUSHY C NR BLAIRSTOWN, MO	20	1.2
6921800	GRANDDADDY C NR URICH, MO	27	0.9

2.2. Watershed physical characteristics, lag times and times of concentration

Certain physical characteristics of the watersheds are needed for regional flood-frequency analysis, flood hydrograph simulation, and a general understanding of hydrologic behavior. The following physical characteristics were determined for each watershed:

Drainage area (A) in acres

Length of longest flow path (L) in feet

Average width of watershed (W), defined as A/L in feet

Average slope of longest flow path (S) in feet per foot

Fraction of watershed area covered by impervious surfaces (R_i)

Fraction of channel length with paved bottom (R_c)

The values of A, L, R_i, and S were computed with the ArcHydro extension for ArcGIS using elevation data with a resolution of 1/3 arc-second resolution obtained from The National Elevation Dataset (2013). The values of R_i were computed from interpolation of the impervious data from the 2011 National Land Cover Database (NLCD). R_c values were set to zero and confirmed with aerial imagery.

The lag time in minutes, T_L, for each watershed was computed with the KU lag-time equation calibrated for the Kansas City area (McEnroe, Young and Gamarra, 2015). This equation is:

$$T_L = 0.0112 \left[\frac{L (1 - 0.75R_c)}{\sqrt{S}} \right]^{0.87} [W (1 + 2.0R_i)]^{-0.26} \tag{2-1}$$

The time of concentration in minutes, T_c, for each watershed was computed from lag time using the following widely accepted approximation (NRCS, 2010):

$$T_c = \frac{5}{3} T_L \tag{2-2}$$

Table 2-2 shows the computed lag times, times of concentration, and related physical characteristics for the 28 gaged watersheds.

Table 2-2. Lag times, times of concentration and related watershed characteristics

Site number	T_L (min)	T_c (min)	L (ft)	S (ft/ft)	W (ft)	R_i (%)	R_c (%)
6815700	87	145	23400	0.004	4380	0.4	0.0
6816000	60	100	21400	0.006	6470	1.0	0.0
6818200	55	92	21000	0.008	5510	0.3	0.0
6819025	80	133	27000	0.005	6750	0.6	0.0
6821000	51	85	15800	0.006	4660	0.5	0.0
6888900	36	60	10800	0.011	1960	3.7	0.0
6889550	127	212	41800	0.004	6540	4.1	0.0
6890000	215	359	60400	0.002	8830	0.4	0.0
6890560	52	86	16300	0.008	3290	0.3	0.0
6890600	248	414	71800	0.002	8580	0.8	0.0
6890700	32	54	9500	0.009	2530	0.5	0.0
6891050	99	165	41800	0.006	8820	0.6	0.0
6894250	88	147	30000	0.005	6260	1.6	0.0
6894500	169	281	64700	0.005	8640	2.6	0.0
6894680	153	255	55600	0.003	13900	1.9	0.0
6895192	247	411	68000	0.002	9810	0.7	0.0
6897507	167	278	47500	0.002	10500	1.0	0.0
6897700	33	54	11100	0.010	3470	2.6	0.0
6903190	81	135	25400	0.005	5180	0.7	0.0
6907500	161	268	52300	0.003	8850	2.3	0.0
6908300	27	45	9600	0.013	2760	0.7	0.0
6912300	46	76	16600	0.008	6170	1.1	0.0
6913600	218	364	50300	0.002	5640	0.9	0.0
6914250	14	24	5300	0.021	2090	2.0	0.0
6914950	147	246	53200	0.003	15200	3.3	0.0
6921712	140	233	36200	0.002	8530	0.4	0.0
6921740	31	52	11000	0.012	3050	0.4	0.0
6921800	56	94	13100	0.006	1940	1.0	0.0

2.3. Rainfall depths and intensities

Rainfall depths and intensities for the centroids of the 28 watersheds were obtained from the National Oceanic and Atmospheric Administration’s (NOAA) Precipitation Frequency Data

Server for six different AEPs (50%, 20%, 10%, 4%, 25, and 1%). The PFDS-provided rainfall tables for locations in Kansas and Missouri are derived from NOAA Atlas 14 Volume 8 (2013). Depths and intensities corresponding to the watershed's time of concentration were interpolated from the tabular values by the cubic spline interpolation method.

2.4. Flood-frequency analysis

A flood-frequency analysis was performed on the record of annual peak flows for each gaged watershed. The analysis was performed with the U.S Army Corps of Engineers' HEC-SSP (U. S. Army Corps of Engineers, 2010). HEC-SSP implements the U.S.-standard Bulletin 17B procedures (IACWD, 1982). These analyses yielded estimates of discharges for annual exceedance probabilities of 50%, 20%, 10%, 4%, 2%, and 1%.

2.5. Land uses and soil types

This section presents an analysis of the land uses and soil types in the 28 selected watersheds in order to put results of the calibration in context. In the NRCS hydrologic method, the depth of runoff depends on the depth of rainfall and the runoff curve number. The runoff curve number in turn depends on land use, soil characteristics, and antecedent moisture condition.

In this section, runoff curve numbers for average antecedent moisture conditions (AMC 2) are estimated by standard NRCS methods for later comparison with the calibrated curve numbers in Chapter 4. In Section 2.5.3, the land-cover and soils data are combined to determine an area-weighted curve number value of average antecedent moisture condition for each watershed following NRCS guidance.

2.5.1. Data sources and treatment

The land-cover data were obtained from the 2011 edition of the NLCD land-cover dataset. The NLCD contains eight different classes of land cover: water, developed, barren, forest, shrubland, herbaceous, planted/cultivated, and wetlands. These classes are further divided into the more specific categories shown in Table 2-3.

In this analysis, land-cover classes were combined to form three categories: grasslands, woodland, and cultivated crops. The grasslands category is made up of the entire herbaceous class, pasture/hay of the planted/cultivated class, and emergent herbaceous wetlands of the wetlands class. The woodland category is made up of the entire forest class, the shrubland class, and woody wetlands of the wetlands class. The cropland category includes only the cultivated crops class. The rest of the land-cover classes were omitted because of their insignificant representation in the 28 watersheds.

The soils data were obtained from the NRCS's Web Soil Survey. The NRCS hydrologic soil group was extracted from the soils data and categorized into A, B, C, or D group soils. In the NRCS system, group A soils have the lowest runoff potential and group D soils have the highest runoff potential.

2.5.2. Results

The land cover and soils data were analyzed in ArcGIS to obtain the percentages of coverage for each watershed. Table 2-4 shows the percentages of coverage for the land-cover classes and hydrologic soil groups for the 28 gaged watersheds. The overall averages at the bottom of the table are not area-weighted, consistent with the procedures applied in the rest of the report. Most of the watersheds have a high percentage of group D soils with high runoff potential. Several have a high percentage of group C soil, and just a few have a significant amount of group B soils. The watersheds have a relatively diverse distribution of land cover. Sixteen watersheds contain mostly grassland, and ten contain mostly cropland. No watershed is mostly woodland, but all watersheds include some woodland.

Table 2-3. NLCD land-cover class codes and descriptions

Class/Value	Classification description
Water	
11	Open Water
12	Perennial Ice/Snow
Developed	
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed, High Intensity
Barren	
31	Barren Land (Rock/Sand/Clay)
Forest	
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
Shrubland	
51	Dwarf Scrub
52	Shrub/Scrub
Herbaceous	
71	Grassland/Herbaceous
72	Sedge/Herbaceous
73	Lichens
74	Moss
Planted/Cultivated	
81	Pasture/Hay
82	Cultivated Crops
Wetlands	
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

Table 2-4. Soil group and land-cover summary for the watersheds

Site number	% coverage by NRCS soil group				% coverage by land-cover category		
	A	B	C	D	Woodland	Grassland	Cropland
6815700	0.0	68.6	14.0	17.4	3.9	10.8	85.3
6816000	0.0	99.6	0.2	0.2	7.4	1.3	91.3
6818200	0.0	95.9	2.1	2.1	17.6	22.2	60.1
6819025	0.0	3.0	32.2	64.8	9.3	35.2	55.6
6821000	0.0	0.0	95.9	4.1	5.1	18.9	76.1
6888900	0.0	0.0	0.0	100.0	9.6	75.7	14.7
6889550	0.7	2.9	7.9	88.5	21.1	76.3	2.6
6890000	0.0	62.5	33.0	4.5	3.4	29.2	67.4
6890560	0.0	6.1	0.8	93.1	9.4	70.2	20.3
6890600	0.0	2.9	11.9	85.2	12.0	76.3	11.7
6890700	0.0	0.0	75.3	24.7	4.8	68.6	26.6
6891050	0.0	4.2	14.9	80.9	33.3	61.2	5.5
6894250	0.0	4.8	17.7	77.5	22.7	62.8	14.4
6894500	0.6	5.1	37.4	57.0	29.7	57.8	12.5
6894680	0.0	0.5	52.7	46.8	41.1	45.7	13.2
6895192	0.1	6.1	63.1	30.7	13.6	26.8	59.6
6897507	0.0	0.0	36.8	63.2	10.0	54.2	35.8
6897700	0.0	0.0	47.3	52.7	20.6	36.5	42.9
6903190	2.4	4.8	39.9	53.0	13.9	52.7	33.4
6907500	0.2	6.1	39.4	54.3	32.0	55.3	12.7
6908300	0.0	44.1	49.0	6.9	18.3	14.3	67.4
6912300	0.0	5.5	31.4	63.1	7.3	83.2	9.5
6913600	0.2	8.5	7.4	84.0	7.5	53.9	38.6
6914250	1.1	1.1	1.1	96.6	9.5	90.5	0.0
6914950	0.0	8.5	33.4	58.1	6.8	51.6	41.6
6921712	0.3	3.5	8.5	87.7	9.3	28.0	62.7
6921740	0.0	2.4	51.8	45.8	12.6	73.8	13.6
6921800	0.2	0.2	61.2	38.4	5.1	6.5	88.4
Average	0.2	16.0	30.9	52.9	14.2	47.8	38.0

According to NRCS guidance, urban open spaces (lawns, parks, golf courses, cemeteries, etc.) are hydrologically equivalent to rural grassland (NRCS, 1986). A comparison of the NRCS-recommended curve numbers for grasslands, woodlands, and croplands indicates that, for a given climate and soil type, croplands yield more runoff than grasslands, and grasslands yield more runoff than woodlands. Because the 28 rural watersheds contain much more cropland than woodland, one would expect these watersheds to yield more runoff per unit area than urban open space.

2.5.3. CN for AMC 2 by NRCS guidance

The average CN for AMC 2 for each watershed was computed following NRCS guidance and using the land cover and soils data. The soils and land cover grids were combined in ArcGIS and then each cell was converted into a CN value for an average antecedent moisture condition (AMC 2) following NRCS guidance. The NRCS-recommended value of CN for AMC 2 is denoted as CN_2. Table 2-5 shows the spatially averaged CN_2 for each watershed. The prevalence of group D soils and cropland land cover makes these NRCS-recommended CNs for AMC 2 considerably higher than the CN of 74 specified for all pervious surfaces in Section 5600. For comparison, Chapter 4 explores the calibration of curve numbers using the regional flood-frequency equations for the Kansas City area.

Table 2-5. Runoff curve numbers for AMC 2 based on NRCS guidance

Station number	CN_2
6815700	78.9
6816000	76.1
6818200	73.1
6819025	83.7
6821000	83.3
6888900	84.5
6889550	82.6
6890000	78.0
6890560	83.7
6890600	83.0
6890700	81.3
6891050	81.3
6894250	82.0
6894500	80.9
6894680	80.1
6895192	82.3
6897507	83.2
6897700	82.3
6903190	82.4
6907500	80.4
6908300	78.1
6912300	81.8
6913600	83.9
6914250	83.2
6914950	82.8
6921712	85.9
6921740	81.2
6921800	84.2
Average	81.6

Chapter 3

Regional Flood-Frequency Equations and Rational Runoff Coefficient

3.1. Kansas City regional flood-frequency equations

Regional flood-frequency equations relate discharge of a specific frequency to physical and climatic characteristics of the watershed. The form of equation used for this study was:

$$Q_k = \alpha \cdot MAP^{\beta} \, (i_k \cdot A)^{\gamma} \tag{3-1}$$

where

Q_k = peak discharge with an annual exceedance probability of k% in cfs

MAP = mean annual precipitation in inches

i_k = rainfall intensity for a duration equal to the time of concentration and an annual exceedance probability of k% in inches per hour

A = drainage area in mi^2

α, β, γ = regression constants

This form is supported by the findings from a regional flood-frequency study for small watersheds in Kansas (McEnroe et al., 2013). In the 2013 study, a principal components analysis led to the selection of MAP and $i \cdot A$ as independent variables. The 2013 study found that MAP and $i \cdot A$ are strongly correlated with discharge and not strongly correlated with each other.

However, our regression analysis showed the MAP was not a significant explanatory variable for the Kansas-City area because MAP does not vary enough across the 75-mile radius. Consequently, the $\alpha \cdot MAP^{\beta}$ term in Eqn. 3-1 simplifies to a single regression constant.

Regional flood-frequency equations for the Kansas City area were developed from the single-station flood-frequency estimates and the watershed characteristics. These equations were fitted to the data by the generalized-least-squares (GLS) regression method using the U.S. Geological Survey's Weighted-Multiple-Linear Regression (WREG) program. GLS regression was chosen over ordinary-least-squares (OLS) regression for two reasons. First, GLS regression weights the gages differently based on their lengths of record, giving longer records a larger weight. Second, GLS regression takes into account the cross-correlations of peak flows based on the proximity of the stations with overlapping records.

Following the usual practice for regional flood-frequency analysis, logarithmic transformations were applied to the dependent and independent variables.

3.2. Inputs for regression

GLS regression requires not only the values of the dependent and independent variables, but also several other inputs. Required information for each station includes latitude and longitude, a regional skew coefficient, and the water year corresponding to each annual peak flow.

3.3. Regression results

Table 3-1 lists the flood-frequency equations and their standard errors of prediction (S_p) in percent. The exponents on i·A vary only slightly over the range of AEPs. Also, note that exponents on i·A do not differ much from 1.0 (1.0 is within half of a standard deviation from the mean of the exponents), which supports the general form of the rational formula.

Table 3-1. Flood-frequency equations for rural watersheds in the study region

AEP	Equation	S_p
50%	$Q_{50\%} = 166.0\ (i_{50\%} \cdot A)^{1.096}$	40.6%
20%	$Q_{20\%} = 257.0\ (i_{20\%} \cdot A)^{1.024}$	45.7%
10%	$Q_{10\%} = 316.2\ (i_{10\%} \cdot A)^{0.986}$	51.1%
4%	$Q_{4\%} = 389.0\ (i_{4\%} \cdot A)^{0.944}$	58.0%
2%	$Q_{2\%} = 446.7\ (i_{2\%} \cdot A)^{0.916}$	63.6%
1%	$Q_{1\%} = 512.9\ (i_{1\%} \cdot A)^{0.891}$	68.9%

3.4. Calibrated rational method for the Kansas City area

Rational-form equations calibrated with regional data are a type of regional regression equation where the exponent on the independent variable i·A is set to one. In this section, the rational method presented Section 5600 is examined and values of the rational runoff coefficient for undeveloped land and urban open space are calibrated with Kansas City-area data.

In the KC-APWA Section 5600 design criteria, the rational method is to be used to estimate peak flows for watersheds smaller than 200 acres. The rational formula in Section 5600 is written as:

$$Q = K\ C\ i\ A \tag{3-2}$$

where

Q = discharge for a specified AEP in cfs

K = AEP-dependent coefficient (Section 5600 specified values shown in Table 3-2)

C = rational runoff coefficient corresponding to the specified AEP (Section 5600 specifies C = 0.30 for all pervious surfaces regardless of land use or soil type and C = 0.90 for all impervious surfaces.)

i = rainfall intensity in inches per hour for the specified AEP and a duration equal to the time of concentration

A = drainage area in acres

Table 3-2. Values of rational K specified in Section 5600

AEP	K
50%	1.0
20%	1.0
10%	1.0
4%	1.1
2%	1.2
1%	1.25

Previous research on the regional flood-frequency relations for Kansas streams has shown that the rational method works well for watersheds up to 30 mi^2 provided that an aerial reduction factor is applied to the point rainfall intensity and the runoff coefficient is properly calibrated for local/regional conditions (Young and McEnroe, 2014; Young, McEnroe and Rome, 2009).

In this study, the data from the 28 watersheds in the Kansas City area were used to calibrate the values of the product K·C for undeveloped land for AEPs from 50% to 1%. The product K·C is termed the frequency-dependent runoff coefficient. The calibration of K·C for each AEP was performed by fitting Equation 3-3 (the logarithmic transformation of Equation 3-2) to the values of log(Q) and log(i·A) for the 28 watersheds by least-squares linear regression.

$$\log(Q) = \log(K\cdot C) + \log(i\cdot A) \tag{3-3}$$

The logarithmic transformation was applied to improve the homoscedasticity of the relationship between the dependent and independent variables. The calibrated value of K·C for each AEP was obtained by inverse logarithmic transformation of the linear regression equation.

Figure 3-1 shows the data for AEP = 10% and the relationship fitted by least-squares linear regression. For comparison, this graph also shows the relationship for undeveloped land and AEP = 10% specified in Section 5600.

Table 3-3 shows the calibrated values of K·C for rural watersheds in the Kansas City area for AEPs from 50% to 1%. The values of K·C specified in Section 5600 for undeveloped land are shown for comparison. The calibrated values of this product are considerably higher than the values specified in Section 5600 for all AEPs less than 50%. It is important to note that the calibrated K·C values were computed using lag times from Equation 2-1 and rainfall intensities from NOAA Atlas 14.

The calibrated values of K·C increase with decreasing AEP. In other words, in very frequent rainfall events (AEP approaching 100%), most of the precipitation is either infiltrated or intercepted, resulting in very little runoff. As the frequency decreases, rainfall intensity increases, which results in a larger fraction of the rainfall becoming runoff, generating larger discharges.

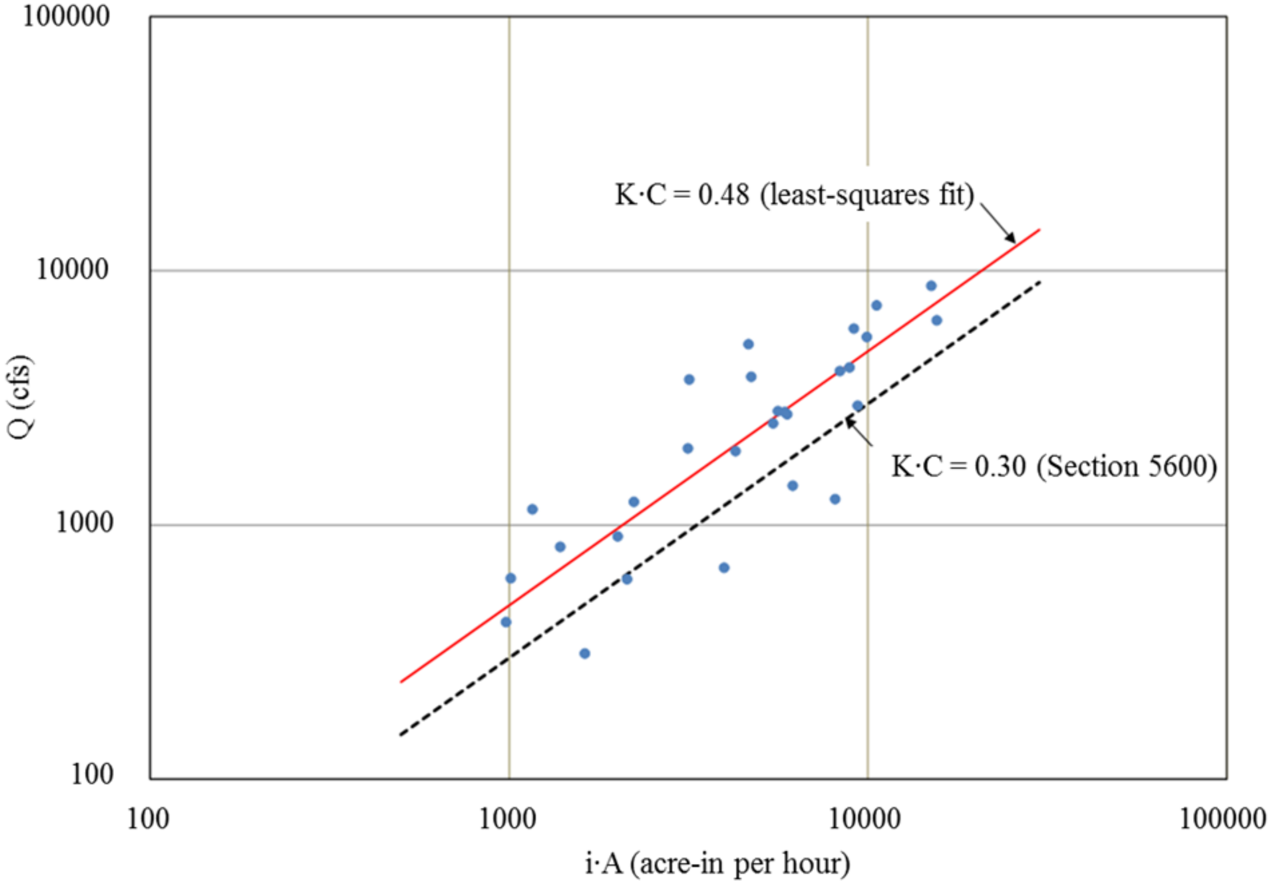

Figure 3-1. Calibration of the rational K·C for AEP = 10%

Table 3-3. Comparison of calibrated and Section 5600 values of K·C for undeveloped land in the Kansas City area

AEP	K·C	
	Calibrated with KC-area data	Section 5600
50%	0.30	0.30
20%	0.42	0.30
10%	0.48	0.30
4%	0.55	0.33
2%	0.59	0.36
1%	0.63	0.375

We suggest changes to the rational-method guidance in Section 5600. The frequency adjustment factor, K, is currently applied to the composite runoff coefficient, which is an area-weighted average of the separate C values for pervious and impervious surfaces. In effect, the frequency adjustment is applied to the C value for impervious surfaces as well as the C value for pervious surfaces. In reality, the runoff coefficient for impervious surfaces does not vary significantly with frequency. A better approach would be to omit the K from the rational formula and to compute the composite runoff coefficient value with a frequency-dependent C value for pervious surfaces and the frequency-independent C value of 0.90 for impervious surfaces. The calibration results suggest the frequency-dependent C values for pervious surfaces in Table 3-4.

Table 3-4. Suggested C values for pervious surfaces based on calibration results

AEP	C
50%	0.30
20%	0.42
10%	0.48
4%	0.55
2%	0.59
1%	0.63

Chapter 4

Curve-Number Calibration

4.1. Procedure

Runoff curve numbers for use in the KC-APWA's Baseline Unit Hydrograph Method were calibrated for each station in the dataset and each AEP of interest. A curve number was considered calibrated if the peak flow obtained by the flood hydrograph simulation matched the peak flow calculated from the regional flood-frequency equations. Calibrated curve numbers were rounded to the nearest whole curve number. For each station in the dataset, runoff curve numbers were calibrated for each combination of six AEPs (50%, 20%, 10%, 4%, 2%, 1%). Imperviousness (1.3% on average) was neglected. Rainfall inputs were obtained from NOAA's Precipitation Frequency Data Server (Atlas 14). The calibrations were also repeated substituting the HEC frequency storm of 24-hour duration for the NRCS Type 2 storm in the Baseline UH Method. The flood hydrograph simulations were performed with the U. S. Army Corps of Engineers' HEC-HMS hydrologic modeling software (U. S. Army Corps of Engineers, 2010).

4.2. Calibration results

Table 4-1 and 4-2 present the calibrated CNs for each watershed and AEP, with summary statistics for each AEP. The average calibrated curve numbers for the Baseline UH Method with the NRCS Type 2 storm are all less than 74, the curve number specified in Section 5600 for undeveloped land and urban open space. The calibrated CN values for the more frequent events are more certain than the values for the less frequent events. Figure 4-1 shows the variability of the NRCS Type 2 storm calibrated curve numbers in the form of a boxplot. Overall, these results indicate that the use of a curve number of 74 for undeveloped land and urban open space in the Kansas City area is slightly conservative. Considering the uncertainties inherent in flood frequency estimation, a degree of conservatism seems appropriate.

The calibrated curve numbers for the HEC frequency storms are similar to those for the NRCS Type 2 storms but exhibit more variability with AEP. Peak-flow estimates from the Baseline UH Method would not be improved by switching to the HEC frequency storm. As the design storm for the Baseline UH Method, the NRCS Type 2 storm may be preferable to the HEC frequency storm for two practical reasons: it requires only one rainfall input (the 24-hr depth) and it is the only option offered in some widely used hydrologic simulation programs.

Table 4-1. Calibrated curve numbers for the 24-hr NRCS Type 2 storm

	Calibrated CN					
	AEP					
Site number	50%	20%	10%	4%	2%	1%
6815700	73	74	73	73	72	72
6816000	72	74	73	71	75	69
6818200	72	72	71	70	68	67
6819025	74	74	73	72	70	69
6821000	70	71	71	70	69	68
6888900	69	70	71	71	71	72
6889550	72	73	72	70	69	68
6890000	74	75	74	72	71	70
6890560	70	70	70	69	68	69
6890600	74	74	73	71	70	68
6890700	69	69	69	68	68	69
6891050	73	72	71	69	67	65
6894250	71	72	71	69	68	67
6894500	73	73	71	69	67	65
6894680	73	71	69	65	62	60
6895192	73	74	74	71	69	67
6897507	73	73	72	70	69	68
6897700	70	71	70	70	69	69
6903190	71	72	72	71	71	70
6907500	72	72	70	67	65	62
6908300	69	70	70	69	68	67
6912300	71	71	70	68	67	65
6913600	71	72	71	70	69	69
6914250	66	66	65	63	63	62
6914950	73	72	70	68	66	64
6921712	72	71	69	66	63	61
6921740	69	69	68	66	64	63
6921800	68	69	69	68	67	66
Mean	71.3	71.6	70.8	69.1	68.0	66.8
Median	72.0	72.0	71.0	69.5	68.0	67.5
Std. Dev.	2.0	2.0	2.0	2.3	2.9	3.2

Table 4-2. Calibrated curve numbers for the 24-hr HEC frequency storm

	Calibrated CN					
	AEP					
Site number	50%	20%	10%	4%	2%	1%
6815700	75	73	71	70	69	68
6816000	75	73	71	68	67	65
6818200	75	72	70	68	66	66
6819025	76	73	71	69	67	66
6821000	74	72	70	68	67	67
6888900	73	72	71	71	71	72
6889550	75	72	70	69	67	66
6890000	76	73	71	68	67	65
6890560	74	71	70	68	68	68
6890600	77	73	71	69	67	66
6890700	73	71	70	70	70	71
6891050	76	71	70	67	65	64
6894250	75	72	70	67	66	65
6894500	76	72	70	67	64	63
6894680	76	72	68	65	62	60
6895192	76	73	71	68	66	64
6897507	76	72	70	67	65	63
6897700	74	72	70	70	69	70
6903190	75	73	71	69	68	67
6907500	75	72	69	66	64	62
6908300	74	72	71	70	70	70
6912300	75	72	69	67	66	65
6913600	74	71	70	68	67	67
6914250	72	70	69	69	70	71
6914950	76	72	69	66	64	62
6921712	75	71	69	66	64	63
6921740	73	71	69	69	68	68
6921800	72	70	69	69	69	70
Mean	74.8	71.9	70.0	68.1	66.9	66.2
Median	75.0	72.0	70.0	68.0	67.0	66.0
Std. Dev.	1.3	0.9	0.9	1.5	2.2	3.1

Table 4-3. Average calibrated curve numbers for undeveloped land in the Kansas City area

AEP	Average Calibrated CN	
	24-hr NRCS Type 2 storm	24-hr HEC frequency storm
50%	71.3	74.8
20%	71.6	71.9
10%	70.8	70.0
4%	69.1	68.1
2%	68.0	66.9
1%	66.8	66.2

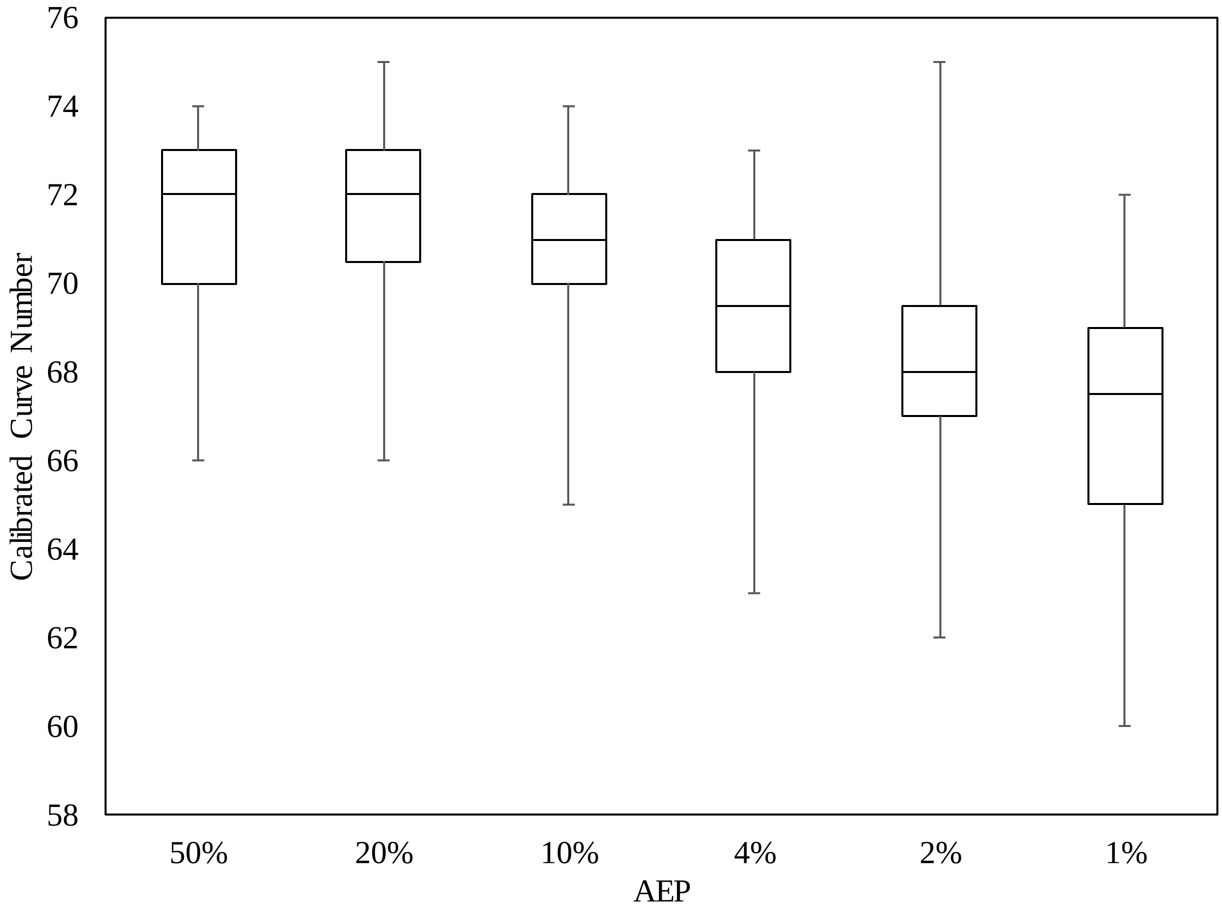

Figure 4-1. Boxplots of curve numbers calibrated for 24-hr NRCS Type 2 storm

4.3. Calibration trend analysis

The calibrated curve numbers exhibit a surprising trend. Unlike the calibrated rational runoff coefficients, as AEP decreases, the calibrated curve numbers decrease slightly. The explanation for this trend can be partially explained by the fact that in the NRCS rainfall-runoff equation, the relationship between runoff depth and rainfall depth is markedly non-linear. In the rational method, there is a direct relationship between runoff depth and precipitation intensity, so the rational runoff coefficient must increase with decreasing AEP to account for the non-linear relationship between runoff and rainfall.

4.4. Recommendations

We recommend that KC-APWA retain the Baseline Unit Hydrograph Method in Section 5600. The 24-hour HEC frequency storm could be substituted for the 24-hour NRCS Type 2 storm since they yield similar results. We also recommend retaining the current CN value of 74 for undeveloped land and urban open space.

Chapter 5

Conclusions

This research project led to several conclusions:

1. The curve-number calibrations for the Baseline UH Method resulted in average CN values of approximately 71 for annual exceedance probabilities (AEPs) from 50% to 10% and slightly lower values for AEPs below 10%. The calibrated CN values fall slightly below the value of 74 that Section 5600 recommends for undeveloped land and urban open space. The use of a curve number of 74 for all frequencies appears to be appropriately conservative.

2. Curve number values for average antecedent conditions obtained from NRCS guidance based on land uses and soil types were significantly higher than the calibrated curve numbers and are not frequency-dependent.

3. The calibrated curve numbers for the HEC frequency storms are similar to those for the NRCS Type 2 storms. Either type of storm could be used with the Baseline UH Method. However, the NRCS Type 2 storm may be preferable to the HEC frequency storm for two practical reasons: it requires only one rainfall input (the 24-hr depth) and it is the only option offered in some widely used hydrologic simulation programs.

4. The calibrated rational runoff coefficients are strongly frequency-dependent and generally higher than the values recommended for undeveloped land in KC-APWA's Section 5600.

All of these results were obtained using NOAA Atlas 14 rainfall data and the new calibrated equations for lag time and time of concentration for the Kansas City area developed by the University of Kansas (McEnroe et al., 2015).

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Appendix

Development of NOAA Atlas 14 Rainfall Tables for Counties in the Kansas City Area[1]

A.1. Introduction

In 2013, the National Weather Service (NWS) Hydrometeorological Design Studies Center released *NOAA Atlas 14 Volume 8* (Perica et al. 2013), which provides new precipitation frequency estimates for Kansas, Missouri, and nine other Midwestern states. These estimates are accessible online through NWS's Precipitation Frequency Data Server. The Atlas 14 estimates supersede the previous estimates for durations from 5 to 60 minutes in NWS's *Technical Memorandum HYDRO-35* (Frederick et al. 1977) and for longer durations in the U.S. Weather Bureau's *Technical Paper No. 40* (TP-40) (Hershfield 1961). The NWS Precipitation Frequency Data Server displays rainfall depths and intensities for durations from 5 minutes to 60 days and annual exceedance probabilities from 50% to 0.1% for any selected location.

This appendix documents the development of the new rainfall tables and equations for counties in the Kansas City area based on Atlas 14. Section A.3 summarizes the Atlas 14 products and the

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[1] Some of the material in this appendix was borrowed from the report titled *Development of New Precipitation Frequency Tables for Counties in Kansas using NOAA Atlas 14* (McEnroe et al., 2014) with permission of the authors.

methodology by which NWS developed the Atlas 14 estimates. Section A.4 explains how the new rainfall tables and equations for counties in the Kansas City metropolitan area were developed and provides guidance for their use.

A.2. Precipitation frequency estimates

NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, is an ongoing project of the Hydrometeorological Design Studies Center (HSDC) of the National Weather Service. Volume 8 (2013) provides updated precipitation frequency estimates for 11 Midwestern states: Colorado, Iowa, Kansas, Michigan, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota and Wisconsin.

The Atlas 14 precipitation estimates are provided on NWS's Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/) through an interactive map-based tool. The user selects the location of interest on the map or specifies the latitude and longitude. The user also selects the desired output type (depth or intensity), units (English or metric) and time-series type (partial duration or annual maximum). If the partial-duration time series is selected, the data server returns a table of precipitation estimates for all combinations of 19 durations and 10 average recurrence intervals. The 19 durations range from 5 minutes to 60 days, and the 10 average recurrence intervals range from 1 to 1000 years. If the annual-maximum time series is selected, the data server returns precipitation estimates for all combinations of the 19 durations and 9 annual exceedance probabilities ranging from 0.001 to 0.5.

The Atlas 14 precipitation estimates are provided on a 30 arc-second spatial grid. The average dimensions of a 30 arc-second grid cell in Kansas are 2360 ft (E-W) by 3030 ft (N-S). The data server also offers complete gridded data sets for all combinations of duration and frequency in ArcGIS format.

A.3. Atlas 14 methodology

The final report for Atlas 14 Volume 8 (Perica et al. 2013) fully explains the development of the new precipitation frequency estimates. A summary of the methodology is provided in this section. In brief, frequency analyses were performed on the data records from individual field recording stations in the study area. The gridded precipitation estimates were developed through spatial interpolation and smoothing of the results for the individual stations.

NWS initially collected precipitation records from field stations. These records were examined for length, completeness and consistency. Annual-maximum series (AMS) for durations of 15 minutes and longer (≥ data recording interval) were developed for the selected field stations. The annual maxima were screened for reasonableness with outlier tests. Statistical tests of stationarity were applied to daily and hourly AMS of sufficient length. No annual maximum series were developed for the 10-minute and 5-minute durations due to data limitations.

Frequency analyses were performed by fitting three-parameter generalized extreme value (GEV) probability distributions to the AMS data by the method of L-moments. For durations of 60 minutes and longer, the fitting method used the local 1st-order L-moment and higher-order L-moments computed from the local 1st-order L-moment and regional estimates of three L-moment ratios: L-CV, L-skewness and L-kurtosis. The regional L-moment ratios for each station were computed by averaging station-specific values for 8-16 nearby stations. A different fitting method was used for the 30-minute and 15-minute durations due to data limitations. Frequency-analysis results were adjusted to obtain smooth depth-duration curves for the AEPs of interest.

Grids of precipitation depth and intensity for all combinations of the selected durations and frequencies were developed from the station-specific results. The grid development process included extensive use of PRISM modeling, a hybrid statistical-geographic approach that considers elevation and terrain characteristics. The grids for the 30-minute and 15-minute durations were developed by a different process than the grids for the longer durations "due to concerns about the soundness of at-station precipitation frequency estimates computed directly from AMS for sub-hourly durations" (Perica 2013). The precipitation frequency grids for the 10-minute and 5-minute durations were generated by a more approximate method due to more severe data limitations. The 10-minute and 5-minute precipitation depths were assumed to equal 82% and 57% respectively of the 15-minute depths throughout the 11-state study area. These percentages were developed from analyses of the relative few available n-minute records.

A.4. Development of precipitation tables and equations

Atlas 14 provides precipitation estimates on a 30 arc-second grid, with an average grid-cell size of approximately 160 acres. Spatially averaged precipitation estimates were computed for each county in the Kansas City metropolitan area by averaging the precipitation estimates for all grid cells with centroids located within the county boundaries. These spatially averaged values were computed for all combinations of durations up to 24 hours and annual exceedance probabilities up to 1%.

NOAA Atlas 14 has precipitation estimates for durations of 5, 10, 15, 30 and 60 minutes and 2, 3, 6, 12 and 24 hours, plus some longer durations. KC-APWA requires precipitation estimates for intermediate durations. Intermediate duration estimates were computed by cubic-spline interpolation. In this method of interpolation, a separate third-order polynomial is fitted to the interval between each pair of adjacent points. The cubic-spline method solves for the polynomial coefficients so that the first and second derivatives are continuous across the interior points. An additional condition must be specified for the interval at each end. We required the third derivative to be constant across the last two intervals at each end (the so-called "not-a-knot" end condition). An example of the results is displayed for the average precipitation depths with six different AEPs for Johnson County in Figure A-1.

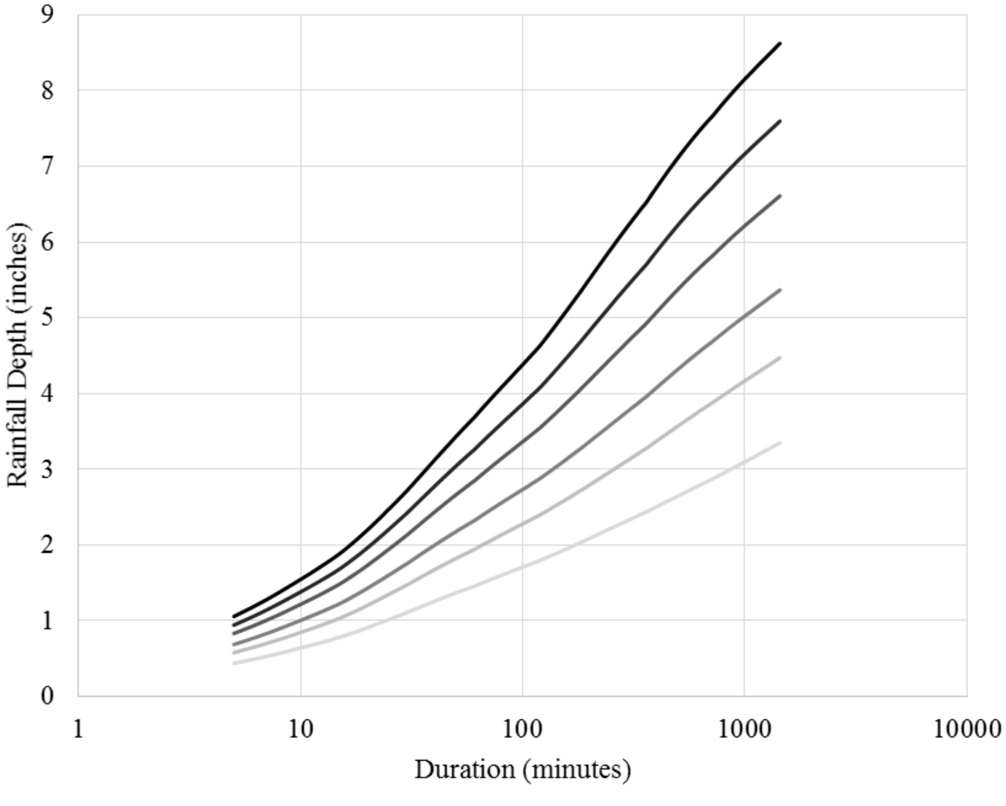

Figure A-1. Rainfall depth-duration curves for AEPs from 50% to 1% for Johnson County

Depth-duration and intensity-duration equations for AEPs from 50% to 1% were developed for each county. Separate equations were developed for duration ranges of 5 to 20 minutes and 20 to 60 minutes. Table A-1 shows the forms of the fitted equations, in which:

i = rainfall intensity in inches/hour

D = rainfall depth in inches

t = duration in minutes

a_1, b_1, and c_1 = regression constants in equations for $5 \text{ min} \leq t \leq 20 \text{ min}$

a_2, b_2, and c_2 = regression constants in equations for $20 \text{ min} < t \leq 60 \text{ min}$

Table A-1. Rainfall intensity and depth equations for counties in the Kansas City area

Duration	$5 \text{ min} \leq t \leq 20 \text{ min}$	$20 \text{ min} < t \leq 60 \text{ min}$
Intensity	$i = \dfrac{a_1}{(t + b_1)^{c_1}}$	$i = \dfrac{a_2}{(t + b_2)^{c_2}}$
Depth	$D = \dfrac{t \cdot a_1}{60\,(t + b_1)^{c_1}}$	$D = \dfrac{t \cdot a_2}{60\,(t + b_2)^{c_2}}$

Tables A-2 through A-11 show the fitted values of the constants in the rainfall depth and intensity equations for the ten counties.

Table A-2. Regression constants in rainfall depth and intensity equations for Buchanan County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	14.19	18.95	22.74	27.78	31.78	35.82
b_1	1.37	1.37	1.39	1.37	1.37	1.36
c_1	0.544	0.545	0.546	0.545	0.545	0.544
a_2	61.43	69.58	73.72	88.72	107.60	126.33
b_2	18.43	18.10	17.13	17.19	17.98	18.38
c_2	0.857	0.815	0.787	0.782	0.793	0.802

Table A-3. Regression constants in rainfall depth and intensity equations for Cass County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	15.56	19.70	22.89	27.13	30.55	34.05
b_1	1.72	1.52	1.44	1.37	1.38	1.40
c_1	0.565	0.553	0.548	0.544	0.545	0.546
a_2	42.59	73.94	98.33	120.77	127.42	128.87
b_2	13.29	16.48	18.01	18.58	18.09	17.26
c_2	0.783	0.838	0.861	0.864	0.849	0.829

Table A-4. Regression constants in rainfall depth and intensity equations for Clay County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	15.07	19.86	23.71	29.04	33.10	37.63
b_1	1.68	1.68	1.69	1.70	1.68	1.70
c_1	0.563	0.563	0.563	0.564	0.563	0.564
a_2	41.30	48.91	53.72	79.42	66.53	74.50
b_2	12.94	13.00	12.50	15.41	11.37	11.27
c_2	0.783	0.753	0.733	0.769	0.705	0.702

Table A-5. Regression constants in rainfall depth and intensity equations for Jackson County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	16.11	20.60	24.52	29.36	33.45	37.51
b_1	1.88	1.79	1.83	1.77	1.79	1.79
c_1	0.574	0.569	0.571	0.568	0.569	0.569
a_2	39.03	50.15	57.72	67.20	73.56	73.15
b_2	11.47	11.94	12.01	11.97	11.81	10.50
c_2	0.770	0.762	0.754	0.744	0.735	0.709

Table A-6. Regression constants in rainfall depth and intensity equations for Johnson County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	15.02	19.47	22.95	27.71	31.41	35.25
b_1	1.58	1.48	1.45	1.43	1.43	1.44
c_1	0.557	0.551	0.549	0.548	0.548	0.549
a_2	48.38	72.74	83.66	90.45	91.98	100.13
b_2	14.50	16.45	16.53	15.85	15.06	15.34
c_2	0.812	0.835	0.826	0.799	0.773	0.764

Table A-7. Regression constants in rainfall depth and intensity equations for Leavenworth County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	14.57	19.24	22.97	27.84	31.62	35.52
b_1	1.49	1.45	1.46	1.43	1.41	1.41
c_1	0.552	0.549	0.550	0.548	0.547	0.547
a_2	50.96	61.39	72.73	89.44	101.59	113.56
b_2	15.64	15.25	15.63	16.24	16.50	16.68
c_2	0.823	0.797	0.793	0.792	0.790	0.787

Table A-8. Regression constants in rainfall depth and intensity equations for Miami County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	13.70	17.67	20.83	25.05	28.36	31.67
b_1	1.14	1.04	1.03	1.03	1.06	1.08
c_1	0.531	0.525	0.524	0.525	0.526	0.528
a_2	85.68	137.96	160.44	167.81	160.85	142.18
b_2	22.94	25.37	25.51	24.45	23.03	20.72
c_2	0.916	0.955	0.951	0.920	0.886	0.837

Table A-9. Regression constants in rainfall depth and intensity equations for Platte County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	14.94	19.92	23.59	28.77	32.62	36.69
b_1	1.65	1.67	1.62	1.60	1.55	1.53
c_1	0.561	0.562	0.559	0.558	0.555	0.554
a_2	45.63	52.20	54.25	68.80	77.98	95.85
b_2	14.08	13.78	12.57	13.43	13.42	14.54
c_2	0.804	0.765	0.732	0.737	0.734	0.751

Table A-10. Regression constants in rainfall depth and intensity equations for Ray County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	16.06	21.13	24.97	30.19	34.33	38.75
b_1	1.98	1.97	1.92	1.86	1.83	1.82
c_1	0.580	0.579	0.577	0.573	0.571	0.571
a_2	32.74	33.24	36.34	42.48	49.30	55.51
b_2	10.04	8.07	7.54	7.43	7.87	7.97
c_2	0.737	0.673	0.651	0.638	0.639	0.636

Table A-11. Regression constants in rainfall depth and intensity equations for Wyandotte County

	Annual exceedance probability					
Constants	50%	20%	10%	4%	2%	1%
a_1	15.05	19.76	23.50	28.55	32.53	36.83
b_1	1.66	1.62	1.61	1.59	1.58	1.60
c_1	0.561	0.559	0.559	0.557	0.557	0.558
a_2	43.29	53.56	63.50	77.61	78.85	90.54
b_2	13.46	13.52	13.99	14.61	13.45	14.03
c_2	0.792	0.773	0.769	0.765	0.739	0.741

A.5. Comparison of rainfall frequency estimates

The changes in the rainfall frequency estimates for annual exceedance probabilities of 10% and 1% deserve particular attention. In the Section 5600 design criteria, enclosed systems for stormwater conveyance are sized for the 10% AEP, overflow systems are sized for the 1% AEP, and detention facilities must control peak flows for AEPs of 50%, 10% and 1% (default strategy). The 1%-annual-chance flood is basis for most floodplain regulations.

Table A-2 compares the old and new rainfall estimates for the 10% AEP. In general, the differences are not large. The largest changes in percentage terms are at the 5-minute duration, where depths increased by 12% on average. The depths for durations of 15, 30 and 60 minutes decreased slightly in all counties. For the other durations, depths decreased slightly in some counties and increased slightly in others.

The rainfall depths for the 10% AEP exhibit little geographic variability except at the 24-hour duration. The 24-hour depths range from 5.01 inches in Buchanan County to 5.50 inches in Jackson County, a 10% difference.

Table A-12. Comparison of rainfall depths for 10% AEP

Duration	Rainfall depth (inches) for 10% AEP										
	Current Sec. 5600*	New Buch.	New Plat.	New Ray	New Clay	New Leav.	New Jack.	New Wyan.	New John.	New Cass	New Miam.
5 min	0.61	0.69	0.68	0.68	0.68	0.69	0.68	0.68	0.69	0.69	0.68
10 min	1.01	1.01	1.00	1.00	0.99	1.00	1.00	1.00	1.01	1.01	0.99
15 min	1.29	1.23	1.22	1.22	1.21	1.22	1.22	1.22	1.23	1.23	1.21
30 min	1.89	1.77	1.73	1.71	1.72	1.75	1.72	1.73	1.75	1.75	1.76
60 min	2.47	2.40	2.34	2.33	2.32	2.34	2.28	2.32	2.32	2.30	2.33
2 hr	3.02	3.03	2.95	2.95	2.92	2.93	2.85	2.90	2.88	2.85	2.89
3 hr	3.30	3.45	3.37	3.40	3.35	3.33	3.25	3.31	3.26	3.21	3.25
6 hr	3.90	4.07	4.05	4.10	4.05	3.98	3.98	4.02	3.96	3.90	3.92
12 hr	4.60	4.54	4.63	4.67	4.69	4.59	4.75	4.71	4.69	4.66	4.65
24 hr	5.26	5.01	5.19	5.22	5.30	5.18	5.51	5.34	5.37	5.37	5.32

*10-year ARI (9.5% AEP)

Table A-3 compares the old and new rainfall estimates for the 1% AEP. The new rainfall are significantly higher for all durations except 15, 30 and 60 minutes. The largest changes are at durations of 5 minutes and 3, 6, 12 and 24 hours. Averaged over the 10 counties, the new 5-minutes depths are 23% higher and the new depths for the durations from 3 to 24 hours are 12% to 14% higher. The 1%-AEP rainfalls exhibit considerable geographic variability. The depths for the 24-hour duration range from 8.14 inches in Buchanan County to 9.12 inches in Jackson

County, a 12% difference. The new 24-hour rainfall depth of 9.12 inches for Jackson County is 19% higher than the current value of 7.64 inches.

Table A-13. Comparison of rainfall depths for 1% AEP

Duration	Precipitation Depth (inches) for 1% AEP										
	Current Sec. 5600	New Buch.	New Plat.	New Ray	New Clay	New Leav.	New Jack.	New Wyan.	New John.	New Cass	New Miam.
5 min	0.86	1.09	1.08	1.08	1.07	1.07	1.05	1.07	1.06	1.03	1.02
10 min	1.43	1.60	1.58	1.58	1.57	1.57	1.54	1.57	1.55	1.51	1.49
15min	1.84	1.95	1.93	1.93	1.91	1.91	1.88	1.91	1.89	1.84	1.81
30 min	2.76	2.81	2.76	2.73	2.72	2.75	2.65	2.73	2.71	2.63	2.65
60 min	3.68	3.82	3.75	3.77	3.70	3.72	3.57	3.72	3.67	3.49	3.58
2 hr	4.34	4.82	4.74	4.80	4.69	4.69	4.50	4.71	4.64	4.36	4.51
3 hr	4.78	5.50	5.43	5.56	5.40	5.35	5.20	5.42	5.32	4.97	5.15
6 hr	5.69	6.53	6.56	6.76	6.60	6.46	6.49	6.62	6.52	6.18	6.31
12 hr	6.73	7.36	7.53	7.72	7.69	7.44	7.84	7.71	7.67	7.58	7.49
24 hr	7.64	8.14	8.39	8.59	8.65	8.30	9.12	8.63	8.62	8.86	8.51

To compare runoff depths resulting from the old precipitation depths, several sample flood hydrograph simulations were performed using Jackson County's 24-hour precipitation depth, Buchanan County's 24-hour depth, and the current Section 5600 24-hour depth as inputs to a NRCS 24-hour storm. All other inputs to the sample simulations were held the same for each trial.

Jackson County's new 24-hour precipitation depth, having the highest 24-hour precipitation depth at 9.12" (19% higher than the current Section 5600 24-hour precipitation depth), resulted in 29% higher runoff depths compared to the runoff depth generated by the current Section 5600

24-hour precipitation depth. Buchanan County, having the lowest 24-hour precipitation depth at 8.14” (6.5% higher than the current Section 5600 24-hour precipitation depth), yielded a runoff depth 9.7% higher than the runoff depth using the current Section 5600 24-hour precipitation depth. All of the counties’ new 24-hour precipitation depths yield between 9.7-29% more runoff than the current Section 5600 24-hour depths. Resulting discharges computed using the new rainfall values in the Section 5600 Baseline Unit Hydrograph method will be significantly higher than discharges computed using the current Section 5600 precipitation depths.