

TECHNICAL MEMO

Title: **Normalization of Rational Formula to the NRCS Curve Number Method, For Use in Manhattan, Kansas (Riley County)**



From: Bill Heatherman, P.E. Ph.D., City of Manhattan

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Summary

Customized Rational Formula coefficients are derived to reasonably match the peak runoff estimates made using the more detailed Curve Number (CN) method published by the Natural Resources Conservation Service (NRCS). The recommended CN Method is based on NRCS guidance and a modified local design storm.

Background on Curve Number Method and Design Storms

The City of Manhattan is in the process of updating its Stormwater Management criteria. The current design criteria allow both the Curve Number and Rational Formula methods for estimating design flows (Manhattan, 1995). It has been found in practice that estimates made from both methods differ significantly even for the same watershed with consistent assumptions. As part of these updates, enhanced guidance for both methods are proposed.

The Curve Number method published by the NRCS, formerly the Soil Conservation Service (SCS), is a well-established method for estimating stormwater runoff. The method considers several independent factors to arrive at a volume, time-distribution, and peak value of stormwater runoff. (NRCS 2020, FHWA 2013).

The conversion of rainfall to runoff must include a parameter to account for losses, both due to infiltration in the soil and canopy interception by vegetation. The Curve Number method assumes that a single variable, the Curve Number (CN), can adequately represent the loss potential. Recommended CN values range from 30 to 98 for most conditions. More detail on the CN number and its estimation is given in a following section.

Conversion of the rainfall timing to runoff peak timing depends on the “lag time” (Tlag) of an individual watershed, which is a measure of the timeliness of a watershed’s response to rainfall. The lag time of a watershed is the time from the centroid of rainfall excess in the watershed to the centroid of direct runoff at the downstream point of interest.

The lag time is related to a separate measure of watershed responsiveness called “time of concentration” (Tc) that is more commonly used with the Rational Formula method. The time of concentration is defined as the time it takes for a quantity of runoff from the most remote portion of a watershed to reach the outlet point. Lag times will always be less than the time of concentration. Lag time is typically estimated to be 60% of the calculated time of concentration (NRCS 2020).

The final but critical element needed for any hydrology model is the design storm, which consists of an estimate of total rainfall to occur over a defined period as well as the time-distribution of the rain. The next section discusses available rainfall data and design storms in more detail.

Various software is available to manage input and perform calculations necessary for these calculations. One common software package that also serves as a reference standard for stormwater modeling is the HEC-HMS program from the U.S. Army Corps of Engineers (HEC-2018). HEC-HMS version 4.3 (Nov. 2018 release) was used for many of the calculations in this study.

Rainfall Probabilities and Selected Design Storm

The latest compilation of national rainfall probability data comes from NOAA’s Atlas 14, which presents updated exceedance probability estimates for rainfall in all regions of the United States. Chapter 8 of Atlas 14, compiled in 2013, presents data specifically for the Midwest. NOAA Atlas 14 replaces Technical Paper 40 and other data reports that had been used previously (NOAA 2013).

Data from NOAA can be exported to customized tables for individual locations. The Kansas Department of Transportation (KDOT) summarized the NOAA statistics for each county in Kansas (KDOT 2014). Table 1A presents total precipitation depth information in Riley County for various intervals useful to this study, including the 24-hour storm. Table 1B provides similar data for rainfall intensity values in inches per hour for Riley County for durations up to 90 minutes, which is the range used for the Rational Formula investigation in this study.

Table 1A: Depth-Duration-Frequency Rainfall Table for Riley County

Duration	Rainfall Depth (inches) for given Return Period						
	1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5 min	0.41	0.48	0.61	0.71	0.86	0.99	1.12
15 min	0.73	0.86	1.08	1.27	1.54	1.76	1.99
1 hr	1.35	1.59	2.00	2.36	2.89	3.32	3.78
2 hr	1.68	1.96	2.46	2.90	3.58	4.14	4.74
3 hr	1.86	2.19	2.73	3.24	4.02	4.65	5.34
6 hr	2.16	2.58	3.24	3.84	4.74	5.52	6.30
12 hr	2.52	3.00	3.72	4.44	5.40	6.24	7.08
24 hr	2.88	3.36	4.08	4.80	6.00	6.72	7.68

Table 1B: Intensity-Duration-Frequency Rainfall Table for Riley County

Duration (minutes)	Intensity (in/hr) for given Return Period						
	1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5	4.92	5.79	7.26	8.53	10.37	11.85	13.38
10	3.60	4.24	5.31	6.25	7.59	8.67	9.79
15	2.93	3.44	4.32	5.08	6.17	7.05	7.96
20	2.56	3.01	3.78	4.44	5.40	6.16	6.96
30	2.08	2.44	3.07	3.61	4.39	5.02	5.68
40	1.77	2.08	2.61	3.07	3.75	4.30	4.87
50	1.53	1.80	2.26	2.67	3.26	3.75	4.26
60	1.35	1.59	2.00	2.36	2.89	3.32	3.78
90	1.03	1.21	1.51	1.79	2.20	2.54	2.90

For time distribution in stormwater modeling, a common approach is to use a frequency-based storm. A frequency-based storm is a hypothetical design storm which aims “to define an event for which

the precipitation depths for various durations within the storm have a consistent exceedance probability” (HEC 2018).

For such a storm, the user defines the total duration of the storm and provides a table of incremental durations and depths, which are then arranged in nested fashion to produce an overall storm distribution. The peak intensity of the storm can be arranged to fall at a time midway during the storm’s duration or at some other increment. A frequency-based storm can also vary in terms of total duration modeled, with 6-hour and 24-hour durations being common. The HEC-HMS software contains embedded tools to create frequency-based storm given rainfall probability data.

Historically, the most common frequency-based storm used in the Midwest was the NRCS Type II 24-hour storm, published by the NRCS. It generalized the ratios of incremental durations from 5 minute to 24-hour for a large section of the continental United States and allowed for a standardized storm shape, varied only by the localized probabilities of a 24-hour rainfall volume.

As part of the hydrology review for this project, a few alternatives to the NRCS Type II 24-hour storm were considered. After significant testing and comparison, it is proposed that a modified storm be used for calculations related to smaller watersheds in Manhattan. Specifically, it is proposed to use a 6-hour frequency-based design storm, as developed in HEC-HMS using the precipitation data given above. A justification for this change and comparison to the NRCS Type II 24-hour storm results are given at the end of this memo.

Figure 1 shows the dimensionless cumulative distribution plot for proposed Manhattan 6-hour storm. (*all Figures and Attached Tables are found in the section following References*). The dimensionless ordinates for the same storm are given in Attached Table A. Both Figure 1 and Attached Table A were derived using the 10-year precipitation values as reference.

CN Assignment - Soil Group/Land Cover Considerations

Only a portion of the rainfall over a watershed is converted to runoff, the rest is either infiltrated into the soil or intercepted by the covering vegetation. The Curve Number (CN) is an indicator term used to calculate the net runoff. Standardized tables for a variety of land cover and soil permeability conditions are published in the National Engineering Handbook (NRCS 2020, Chapters 7, 8 & 9). To account for soil permeability, the NRCS classifies soils into four main Hydrologic Soil Groups (HSGs), with Group A being the most permeable and Group D being the least. Soil groups are typically assessed for a development site using NRCS Soil Survey data, which is now available online through the Web Soil Survey (NRCS 2021).

Within the City of Manhattan and surrounding areas, there are zones of each soil group, with Group C and Group D as more predominant in newly developing areas. Group B soils are common in the levee protected floodplain areas in the older portions of Manhattan and in the Blue Township commercial zones. Group A soils are limited to a few small alluvial zones immediately adjacent to the Kansas River or Big Blue River.

A map of HSG distribution in and near Manhattan is shown in Figure 2.

The curve number for a particular watershed is assigned based on both HSG and land cover or vegetation condition. The National Engineering Handbook (NRCS 2020) provides tables of values for a wide variety of cover conditions, including natural woods, crop land and pasture.

Paved areas are classified as impervious with CN=98, regardless of underlying soils. For watersheds with mixed land covers, the average CN weighted by land area of each cover type is calculated. For most urban land uses, the CN calculation simplifies to a weighted average between paved versus pervious areas.

Pervious areas within urban zones are often classified as “urbanized lawn”. The primary NRCS handbook suggests that such lawns be classified the same as a pasture in “good condition” for the same soil group (NRCS 2020, Chapter 9). Some NRCS tables also indicate values for lawn in “fair” or “poor” condition that match pasture of the same soil group, though the listed criterion for these conditions is vegetation density. For pasture, vegetation density could be considered a surrogate for compaction due to overgrazing.

There are reasons to doubt whether urban lawns truly correlate to pasture in good condition. Soils are subject to initial disturbances, topsoil damage and soil compaction due to construction. This damage would be especially concerning for Group A and B soils, which depend more highly on soil matrix to maintain infiltration. Urban lawns would also differ from good pasture due to shorter root-zone depths, more frequent mowing, and a more limited thatch layer.

The NRCS Engineering Handbook discusses disturbed soils, *“As a result of construction and other disturbances, the soil profile can be altered from its natural state and the listed group assignments generally no longer apply... In these circumstances, an onsite investigation should be made to determine the hydrologic soil group.”* (NRCS 2020, Chapter 7, section 630.0702)

Several manuals suggest adjustments that could be made to increase the CN factor used on urban lawns without the need for site specific studies.

The Kansas City APWA design criteria recommends that *“No soil disturbed by construction shall be assigned a Hydrologic Group classification of A or B. (KC-APWA 2011, section 5602.3.A).”* Any such soils would be treated as Group C.

The current KDOT Drainage Design Manual discusses this issue and offers the following guidance *“In areas where the soil profile has been disturbed significantly since the NRCS county soil survey was prepared, the designer may opt to use an HSG (hydrologic soil group) classification one level higher, in terms of runoff potential, than the one shown in the county soil survey (e.g., C rather than B, or D rather than C). (KDOT 2016, section 11.5.4).”*

The Federal Highway Administration’s Urban Drainage Manual (FHWA 2013, Table 3-6) lists the three category of lawn conditions for urban areas, similarly to the NRCS guidance. However, it also has a separate line listed for *“developing areas (no vegetation established)”* which assigns CN values based on conditions that are slightly worse than pasture in poor condition.

For this study, a less drastic method is proposed for urban areas.

Lawns in Group C and D soils would retain their CN value to match pasture in “good” condition, i.e., CN=74 and CN=80, unless there is specific reason to determine an adjustment. In Group B soils, the urban lawn would be rated as pasture in “fair condition”, CN=69.

Group A soils, which would be most at risk for damage by impacts during construction, would be rated at CN=62, which is between “fair and poor”, approaching “poor” This rating also happens to be about the equivalent to a pasture in “good condition” on a Group B soil, which is what an Group A soil would be adjusted to if the KDOT guidance were being used.

The City’s 1995 design criteria (Manhattan, 1995) contained a recommended table of impervious surface percentages and CN coefficients by standard land use type. This table was limited to a single specific soil-group assumption. Table 2 gives an update using the recommended value from the National Engineering Handbook for the HSGs. For urban land uses, the composite CN values reflect the adjusted values proposed above for disturbed soils.

Table 2: Composite Curve Numbers for Various Soil Groups and Land Uses

Land Use	% Impervious (Typical)	Composite Curve Number (CN) for Given HSGs, Cover Type and Impervious Coverage			
		Group A Soils	Group B Soils	Group C Soils	Group D Soils
<i>Natural and Agricultural Areas (selected classifications):</i>					
Woods (good condition w/underbrush)	0%	30	55	70	77
Woods (poor conditions, limited underbrush)	0%	45	66	77	83
Meadows (no grazing)	0%	30	58	71	78
Pasture, Good Condition	0%	39	61	74	80
Pasture, Fair Condition	0%	49	69	79	84
Pasture, Poor Condition	0%	68	79	86	89
Row Crops (good w/best practices)	0%	61	70	77	80
Row Crops (poor w/least controls)	0%	72	81	88	91
<i>(see NRCS literature for more types or details on conditions and practices)</i>					
<i>Urban and Developed Areas, w/all pervious as urban lawn (see text for discussion)</i>					
100% Impervious Surface	100%	98	98	98	98
100% Lawn (see text for values marked *)	0%	62 *	69 *	74	80
Residential - Single Family/Duplex	35%	75	79	82	86
Residential - 3 to 6 Dwelling Units per building (includes mobile homes parks)	60%	84	86	88	91
Residential - More than 6 DU/bldg.	80%	91	92	93	94
Public/Semi-Public (Schools, Govt, etc.)	70%	87	89	91	93
Industrial	75%	89	91	92	94
Commercial/Business	85%	93	94	94	95
Central Business District	95%	96	97	97	97

Results using Curve Number Method

To create a baseline of data for reference and calibration, peak flows for a variety of watershed conditions were analyzed in HEC-HMS using the Curve Number method.

The Manhattan 6-hour frequency storm distribution was used for six return period increments, ranging from 2-year through 100-year storms. Total precipitation was assigned based on the Riley County 6-hour rainfall totals listed in Table 1A. In lieu of using the storm ordinates given in Attached Table A, the frequency-based storm for each return period was built using precipitation data for that storm. This method is easier to use when working within HEC-HMS directly, and the difference is negligible.

Hydrograph lag times (T_{lag}) were set to range from 3 to 54 minutes, which corresponds to a range of 5 to 90 minutes expressed as time of concentration (T_c). Curve numbers (CN) varied from 56 to 98, in increments of 6, which was considered adequate to cover the range of interest.

The HEC-HMS program was run for each of scenarios using a standardized nominal watershed size of 100 acres. The results were then converted to unit runoff values ($q=Q/A$), as expressed in cubic feet per second per acre (cfs/acre).

Attached Table B at the end of this paper presents the unit runoff rates (q) as calculated in HEC-HMS for every scenario considered in this study.

Figure 3 displays graphical details from the full rainfall-runoff calculation results for one specific case – a 10-year storm on a nominal 100-acre watershed having $CN=86$ and $T_c=15$ min ($T_{lag}=9$ min). The top window of the graph reports the rainfall runoff depths over the watershed, with the dark blue showing net runoff and the red showing the rainfall component that was lost to infiltration or abstraction. The bottom window reports the runoff hydrograph.

Rational Formula Method

The Rational Formula is a simple technique that is used for estimating the peak runoff total for smaller watershed. It is not capable of producing realistic hydrographs and is therefore not suitable for volume-based designs, such as detention routing. It is generally restricted to use in smaller watersheds. Despite these limitations, it is commonly used for urban storm sewer designs and for the peak-flow sizing of infrastructure on small watersheds, such as roadway culverts (FHWA 2013).

The Rational Formula estimates a peak runoff rate by assuming a steady average rainfall rate over a period equal to the “time of concentration” for the watershed. This rainfall rate is modified by a single runoff coefficient “ c ” and scaled to the watershed area to estimate a peak discharge.

The relationship for Rational Formula is:

$$Q = mciA \quad \text{(Equation 1)}$$

where Q = peak runoff rate in the system, in units of cubic feet per second (cfs); i = average rainfall intensity (inches/hour) for the given frequency and duration (as determined by T_c); A = area of the watershed, in acres; c = the formula coefficient, ranging between 0.0 and 1.0; and “ m ” which is a newly proposed dimensionless adjustment factor that is

applied based on time of concentration of the watershed. All variables must be in the units given.

Rainfall intensity estimates are taken from Table 1B.

The purpose of this paper is to propose a “normalized” set of Rational Formula coefficients (“c”) and a proposed adjustment factor “m” so that results more closely correspond to those obtained from the Curve Number method in comparable scenarios.

A two-step processes of normalization was used. First, the Rational Formula “c” was normalized directly for data where the time of concentration (Tc) was 15 minutes. Second, a new adjustment factor (m) was applied to correct for differences at other time of concentration.

For the first step, the estimation of the Rational Formula coefficient “c” to be normalized to the CN method starts with a rearrangement and simplification of Equation 1, as follows:

$$c = (Q/A) / i \quad \text{(Equation 2)}$$

For Equation 2, the value of m is assumed to equal 1.0 and is restricted to that case. Through trial-and-error for best fit, a 15-minutes time of concentration was found to be the best reference point for the normalizing effort. Using the data in Table B for the 15-minute time of concentration scenario and dividing by the respective 15-minute rainfall intensity for different return periods, a normalized “c” coefficient was determined.

For example, for a 10-year storm in a watershed with CN=86 and a Tc = 15 minutes, the normalized Rational Formula coefficient would be as follows:

$$c = (Q/A)/i = (3.672 \text{ cfs, from Table B}) / (5.08 \text{ in/hour, from Table 1B}) = 0.72$$

Remaining values are shown in Table 3 and graphically on Figure 4.

When the watershed is fully impervious (CN=98), the Rational Formula c does not vary with much significance. Watersheds with more pervious cover (lower CN) values show a much larger fluctuation based on land types, cover conditions and return period of storm. The relationship between CN and Rational Formula c is not linear for more frequent storms.

The second step of normalization involved looking at the goodness-of-fit for other times of concentration.

Using the rainfall intensities (i) in Table 1B and the Rational Formula coefficients (c) in Table 3, an unadjusted unit area discharge (q) was calculated for every combination of CN and Tc each scenario in this memo using the Rational Formula. Those results are given in Attached Table C.

Table 3
Rational Formula Coefficient (Calibrated for Tc=15 min) (Rounded for Use in Design)

Curve Number (CN)	Rational Formula Coefficient (c) for Given Return Period (based on a Tc=15-minute reference scenario)						Comment
	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	
98	0.97	0.98	0.99	0.99	0.99	1.00	Imperv.
92	0.79	0.84	0.87	0.91	0.93	0.94	
86	0.58	0.67	0.72	0.78	0.82	0.85	
80	0.41	0.51	0.57	0.65	0.70	0.75	Lawn, D
74	0.26	0.36	0.43	0.52	0.58	0.63	Lawn, C
68	0.14	0.23	0.31	0.40	0.46	0.52	~ Lawn, B*
62	0.06	0.13	0.19	0.28	0.35	0.41	Lawn, A*
56	0.02	0.06	0.10	0.18	0.24	0.30	(not for design)

The variance between the Curve Number method estimates and the unadjusted Rational Formula method was then calculated, as follows:

$$\text{Variance (as \%)} = \left(q_{\text{by Rational Formula}} / q_{\text{by CN method}} \right) - 100\% \quad (\text{Equation 2})$$

The variances for individual scenarios are reported in Attached Table D, along with the average variance and standard deviation of variance for the groupings of data based on time of concentration. These variances are summarized on Table 4, along with the value of a multiplier that would have to be applied to Rational Formula results to eliminate the average variance. In addition, a plot of CN Method vs unadjusted Rational Formula coefficients for selected CN value in a 10-year storm are shown in Figure 5 for illustration.

Table 4
Analyses of Variance in Unadjusted Rational Formula Results, based on Time of Concentration

Tc	Average Variance between Unadjusted Rational Formula vs CN Method	Standard Deviation of the Variance, as shown in Attached Table D	Multiplier Required to Eliminate the Average Variance
5 min	17.8%	6.2%	84.9%
10 min	5.1%	2.9%	95.1%
15 min	0.0%	0.0%	100.0%
20 min	-1.1%	1.6%	101.1%
40 min	-3.2%	4.6%	103.3%
60 min	-5.6%	6.2%	105.9%
90 min	-6.9%	7.8%	107.4%

There are no variances for storms with a 15-minute time of concentration because this is the time base for which the coefficients are derived.

For times of concentration less than 15 minute, especially for the 5-minute interval, the variances became more pronounced, with the Rational Formula yielding the higher estimate. This appears to be related to fundamental differences in the two methods, in that the direct data on IDF from Table 1B dictates the shape of the Rational Formula trend, giving a sharper upwards trend for very small times of concentration. This trend means that the Rational Formula estimates higher flowrates than NRCS CN method in this range.

For longer times of concentration up to the 90-minute interval examined, the overall average variance between the methods remained within a range of 6% or less. When looking in greater detail at Attached Table D, the differences present are not solely driven by time of concentration, but also by variances associated with scenarios having smaller rainfall totals (i.e., more frequent storms) and lower CN values (i.e., more pervious conditions). At these values, the actual runoff volumes are quite low, with most of the rainfall having been lost to initial abstraction. The apparently large percentage variances appear to be a function of the rounding error when both values are small.

To control for these errors, the new adjustment factor (m) was proposed for design use. To keep the method relatively simple, the adjustment factor is only applied for times of concentration less than 15 minutes. The multipliers shown for correcting variances given in Table 4 at the 5-, 10- and 15-minute Times of Concentration were interpolated and rounded to give a graduated adjustment at 1-minute intervals, as shown in Table 5. In this range, the multipliers all have the effect of lowering the estimates from the Rational Formula method to better conform to the CN method results.

Table 5
Adjustment Factor, m , to Apply to Rational Formula Results
Based on Time of Concentration, T_c

Tc (minutes)	m , Adjustment Factor
5	85%
6	87%
7	89%
8	91%
9	93%
10	95%
11	96%
12	97%
13	98%
14	99%
15 and above	100%

For times of concentration greater than 15 minutes, no adjustment was proposed. In these cases, the Rational Formula would underestimate the flow relative to the CN method, but by a small factor for times of concentration in a practical range. The additional complications associated with carrying that adjustment factor into these larger watersheds was not deemed necessary.

Separately from the Time of Concentration adjustments, two added restrictions are recommended when using the Rational Formula method for design use. For CN less than 68 the relationship between CN and Rational Formula c becomes progressively nonlinear, particular for the 2-year and 5-year storms. Overall, estimates in this range are very small and less reliable. For analyses, the calculation tables were prepared down to CN=56. For design it is suggested that Rational Formula “ C ” not be related to CN for values lower than CN=62. Below this level, either the NRCS CN hydrograph method or other methods using more sophisticated infiltration equations would be better suited.

In addition, most guidance manuals on Rational Formula limit its use to smaller watersheds, with 200 acres being a common limit (FHWA 2013). The City’s current Stormwater Management Master Plan (Manhattan 1995) recommends a limit of 300 acres. This study shows that time of concentration, not watershed area, is the primary scaling factor, and that Rational Formula did well in matching peaks from the NRCS method over a wide time range. By inspection, the 300-acre limit would remain consistent within these limits, and so that limit is retained.

Example Calculations

The following example illustrates the use of these tables:

A 40-acre drainage watershed is developed as a residential subdivision, all on Group C soils. The net impervious cover is 35%, with the remainder as urban lawn. (CN=98 for impervious, CN=74 for lawn). The composite curve number is 82.4, which we interpolate from Table 3 to obtain the Rational Formula coefficients of 0.63 for the 10-year storm and 0.79 for the 100-year.

The time of concentration for flow is 15 minutes, so the rainfall intensities are 5.08 inches/hour in the 10-year and 7.96 inches/hour in the 100-year. The estimated peak flows are:

$$Q_{10} = ciA = 0.63 * 5.08 \text{ in/hour} * 40 \text{ acres} = 128 \text{ cfs}$$

$$Q_{100} = ciA = 0.79 * 7.96 \text{ in/hour} * 40 \text{ acres} = 252 \text{ cfs}$$

For the same watershed condition, if the time of concentration were $T_c=10$ minutes instead, the rainfall intensity would be 6.25 inches/hour and 9.79 inches/hr for the 10-year and 100-year storm, respectively, and the adjustment factor “ m ” would be 95%. Under those conditions, the estimated peak flows are:

$$Q_{10} = mciA = 95\% * 0.63 * 6.25 \text{ in/hour} * 40 \text{ acres} = 150 \text{ cfs}$$

$$Q_{100} = mciA = 95\% * 0.79 * 9.79 \text{ in/hour} * 40 \text{ acres} = 293 \text{ cfs}$$

Comparison to Other References and Studies

These normalized Rational Formula coefficients were compared to other references.

The Federal Highway Administration’s manual on urban stormwater, HEC-22, suggests a range for Rational Formula “ c ” from 0.05 to 0.35 on pervious soils, based on soil group and slopes. For watersheds on average slope (2-7%), it lists 0.10 to 0.15 for sandy soils and 0.18-0.22 for heavy soil. Concrete streets are listed with coefficients between 0.80-0.95. (FHWA 2013, Table 3-1).

In the Kansas City metropolitan area, the regional guidance manual specifies $C=0.30$ for pervious areas and 0.90 for impervious surfaces. The Kansas City guidance also recommends using multipliers of

1.1, 1.2 and 1.25, respectively, to adjust the composite coefficients when calculating the 25-, 50- and 100-year storms (KC-APWA 2011).

The previous version of the city's design criteria (Manhattan 1995) designated a constant $c=0.20$ for pervious areas and $C=0.85$ for impervious surfaces. The manual references a Group B-C soil (intermediate value) as being typical of the Manhattan area, which was accurate for portions of the City, but is not consistent with soils in western Manhattan currently seeing the most development. There is no referenced experimental or analytical data source to support the FHWA, Kansas City APWA or prior Manhattan values. These values have simply emerged from customary use.

The latest KDOT Drainage Manual (2016) allows for Rational Formula to be used in watersheds less than 640 acres and contains its own recommendation of "c" values. For pervious areas, the coefficients vary between Eastern and Western Kansas and show a strong trend of increasing pervious "c" in less frequent storms. For Eastern Kansas, the Rational Formula "c" for "urban open spaces (lawns, parks etc.)" varies from 0.20 in a 2-year storm to 0.60 in the 100-year storm. The 10-year storm is listed with an intermediate value of 0.40 (KDOT 2016, see Table 11.2.4-1). KDOT does not give its reference for these tables.

Efforts have been made in Kansas to calibrate the Rational Formula and NRCS CN modeling methods to available stream gaging data. The U.S. Geological Survey is responsible for the national stream gauging network and has prepared flood frequency estimates for many of their longer-serving gages, mostly in rural areas. They have also compiled regionally specific rural regression formula to provide estimates of flood frequency in ungauged rural watersheds, including equations published in 2000 and then updated in 2017 (USGS 2000, 2017).

Young & McEnroe (2014) examined data from 72 watersheds in Kansas with USGS streamflow gages. Watersheds ranged in size between 0.17 and 29.6 square miles (110 and 18,900 acres). All watersheds were rural, with at least 20 years of stream gaging record and no regulation by flood control structures. The average land cover was 62% grassland or pasture and 33% cropland, with less than 5% in forest, urban or other uses. Flood predictions were estimated for each watershed using standard USGS methods. A regression formula was then developed that was structured to follow the form of the Rational Equation, with an estimate of watershed lag time used to determine the rainfall intensity factor. The primary variable associated as a predictor for "C" was mean annual precipitation, which acts a measure of both climatic and geographic variability in Kansas.

For Riley County, the Rational coefficient predicted by Young & McEnroe would be $c=0.27$ in a 2-year storm and $c=0.97$ in a 100-year (all based on using 34 inches/year as mean annual precipitation). The intermediate value in a 10-year storm would be 0.60. These coefficients would relate to pervious areas with a similar combination of land cover. The variability of individual gage data was significant, with an estimated error band for the estimated "C" values ranging from -36% to +56% for the 2-year storm and -40% to +68% in the 100-year.

This 2014 study was an expansion on previous work to calibrate the Rational Formula in Kansas conducted by Young McEnroe and Rome (2009), and even earlier, from work on calibration using NRCS methods in Kansas with variable storm frequencies and antecedent moisture conditions (McEnroe & Gonzalez 2003).

Figure 6 presents a comparison of these selected estimates of Rational “c” on pervious areas, as a function of storm return period. The normalized Rational formula “c” values for pervious areas from this study are also shown, for cases where the corresponding CN values of 68, 74 and 80, corresponding approximately to the recommended value for urban lawns in Group B, C and D soils, respectively.

Rational coefficients proposed for use in this study are intermediate between those given in traditional references sources (FHWA, KC-APWA, Manhattan SWMMP) on the low end and those proposed by Young and McEnroe (2014) which were calibrated to rural gage data. The proposed coefficients for CN=74 mirror most closely those recommended in the KDOT 2016 drainage manual for open spaces (see lines 2 and 5 in Figure 6). The coefficients recommended in this study do show the trends towards increasing “c” value in less frequent storms, which was not predicted in the previous Manhattan SWMMP. The trend, however, is less dramatic than that predicted using the Young and McEnroe equation.

The graph makes clear how strongly the Rational Coefficient result depends upon the proper classification of the land cover CN (compare differences between lines 1, 2 and 3). This contrasts with most traditional implementations of Rational Formula, where pervious areas are treated as a single class.

The various references have their closest agreement in frequent storms, such as the 2-year.

Comparison of 6-Hour and 24-Hour Storm Duration Results

In a separate comparison, the normalized coefficients from the recommended 6-hour frequency storm are compared to results that would have been derived if the traditional NRCS Type II 24-hour storm distribution had been used. To develop this relationship, the same processes was employed as for the 6-hour storm: peak flow results were calculated in HEC-HMS, and then a Rational “c” was back-calculated using rainfall intensity data and a reference Tc of 15 minutes.

Figure 7 displays the Rational coefficients for these two design storms over the range of pervious CN values from 62 to 80. The graph also compares the results of both design storms for the impervious surfaces with CN=98.

As shown in the Figure, the differences between a 6-hour and 24-hour storms represents a shift of about 5 to 6 points on the Curve Number scale, or a shift of approximate 0.1 on average in the Rational Coefficient “C”. By coincidence, this shift is almost equivalent to a change in one Hydrologic Soil Group (HSG) level – the coefficients for a 6-hour storm on a Group C soil (CN=74) are approximately equal to that of the 24-hour storm on a Group B soil (CN=68).

Justification for the 6-Hour Storm Recommendation

The data shown in Figures 6 and 7 illustrate the considerable uncertainty that exists in making predictions about stormwater flows. To select an appropriate design storm to use for the new Manhattan engineering standards, the following factors were considered:

- The normalized Rational coefficients would be significantly larger than those used previously in Manhattan, regardless of which design storm was selected.
- The Young and McEnroe data are the only analyses based on identifiable stream gaging in Kansas and so merit being considered. The underlying rural stream gages were generally for watersheds that were larger in scale and the uncertainty band around gage data is significant.
- Handbook values used for Rational formula, such as reported in FHWA or KC-APWA, are not referenced to any known research. Despite that, similar values in this range have been used extensively for many decades throughout the Midwest and United States. Substantial amounts of infrastructure have been built based on these customary inputs.
- On smaller watersheds, it is presumed that the short burst peaking aspect of storms would likely play a more dominant role in driving peak discharges than the total volume of storm runoff. The probability of having extreme conditions for both factors in the same storm is less than either factor alone.
- The use of a 6-hour storm instead of 24-hour is not without precedent. Per informal research conducted, other cities including Kansas City, Mo. and Omaha are experimenting with storms of smaller duration for small urban watershed modeling.
- The difference between the 6-hour and 24-hour frequency-based storm was only significant for the undeveloped or pervious fraction of the watershed. As an area becomes more heavily developed, the relative difference in the methods decreased.

After significant experimentation with various storm distributions and considering the factors above, this study recommends that the 6-hour storm be utilized on smaller watersheds in Manhattan, Kansas. It represents an intermediate point between the previously assumed Rational “c” (low side) versus estimates made from traditional 24-hour NRCS storm or regional regression equations (high side).

As watersheds become larger, it would be prudent to transition to more traditional 24-hour storms or make greater use of watershed specific calibration data. The point at which this transition would occur is unknown, but a transition threshold of 1.0 square miles is suggested. This would fall closer to the lower end of the bulk of data available from stream gages and is also typically the point at which regional or area wide flood studies (such as for FEMA floodplains) are available. All these recommendations are provisional. Further research and data acquisition in this area would be helpful.

Conclusion

A method is proposed for using the Rational Formula in watersheds up to 300 acres in size. The method correlates the Rational Formula coefficient “c” to a calculated curve number (CN) for a given land cover, soil group, specific return period of storm. The method also introduces an adjustment factor “m” to use when time of concentrations are less than 15 minutes. The method is restricted to cases where the corresponding CN is 62 or greater.

Table 3 presents the recommended values of “c” in the Rational Formula for use in the City of Manhattan, based on the corresponding composite CN value. The normalization of these coefficients assumes the use of 6-hour frequency-based storm, using local rainfall data. The proposed coefficients are larger for most storm scenarios than what has been used historically in Manhattan. Table 5 provides the corresponding values of the adjustment factor “m”.

The NRCS CN method using a 6-hour storm is suggested as suitable for watersheds up to 640 acres in size, after which a transition to more traditional 24-hour storm or more detailed calibration should be considered.

References

- FHWA 2013. Federal Highway Administration. *Urban Drainage Design Manual, Hydrologic Engineering Circular No. 22, Third Edition*. Washington, DC. September 2009 with minor revisions August 2013. See Chapter 3. Available at www.fhwa.dot.gov.
- HEC 2018. Hydrologic Engineering Center, US Army Corps of Engineers. *Hydrologic Modeling System HEC-HMS User's Manual, Version 4.3 (CPD-74A)*. Davis, CA. Issued September 2018. Available at www.hec.usace.army.mil/software/hec-hms
- KC-APWA 2011. Kansas City Metropolitan Chapter of the American Public Works Association. *Division V Design Criteria – 5600 Storm Drainage Systems & Facilities*. Adopted February 16, 2011. Available at www.kcmetro.apwa.net.
- KDOT 2014. Kansas Department of Transportation. *Rainfall Intensity Tables for Counties in Kansas (in PDF & Excel formats)*. Topeka, KS. Version 2014. Available at www.kart.ksdot.org.
- KDOT 2016. Kansas Department of Transportation. *Elements of Drainage and Culvert Design, Design Manual, Volume 1 (Part C), Bureau of Road Design*. Issued December 12, 2016.
- Manhattan 1995. City of Manhattan Public Works. *1995 Stormwater Management Master Plan, including Appendix I, Stormwater Management Criteria Manual*. Prepared for the City by Burns & McDonnell and BG Consultants. 1995.
- McEnroe & Gonzalez 2003. Bruce McEnroe and Pablo Gonzales. *Storm Duration and Antecedent Moisture Conditions for Flood Discharge Estimation*. KU-Trans Final Report KU-02-4. KDOT & University of Kansas, Nov 2003.
- NOAA 2013. National Oceanic and Atmospheric Administration. *Precipitation-Frequency Atlas of the United States. Atlas 14, Volume 8, Version 2.0*. Silver Spring, MD. Issued 2013. Available at www.nws.noaa.gov

NRCS 2020 (varies by chapter). Natural Resources Conservation Service. *National Engineering Handbook, Part 630 – Hydrology*. See Chapters 4, 7, 8, 9 and 10 (issuance dates 8/2019, 1/2009, 6/2002, 7/2004, and 7/2004 respectively). Washington, DC. Available at www.nrcs.usda.gov.

NRCS, 2021. Natural Resources Conservation Service. Web Soil Survey, data, and documentation available online at <https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx> Accessed 6/17/2021.

USGS 2000. U.S. Geological Survey. *Estimation of Peak Streamflows for Unregulated Rural Streams in Kansas. Water Resources Investigations Report 00-4079*. Prepared by Patrick Rasmussen and Charles Perry, Lawrence, Kansas. 2000. (Has been superseded).

USGS 2017. U.S. Geological Survey. *Methods for Estimating Annual Exceedance-Probability Streamflows for Streams in Kansas Based on Data through Water Year 2015. Scientific Investigations Report 5063, Version 1.1*, September 2017.

Young, McEnroe & Rome 2009. C Bryan Young, Bruce McEnroe, and Anthony Rome. *Empirical Determination of Rational Formula Coefficients*. Journal of Hydrologic Engineering (14:1283-1289). ASCE, December 2009.

Young & McEnroe 2014. C. Bryan Young & Bruce McEnroe. *Evaluating the Form of the Rational Equation*. Journal of Hydrologic Engineering (19:265-269). ASCE, January 2014.

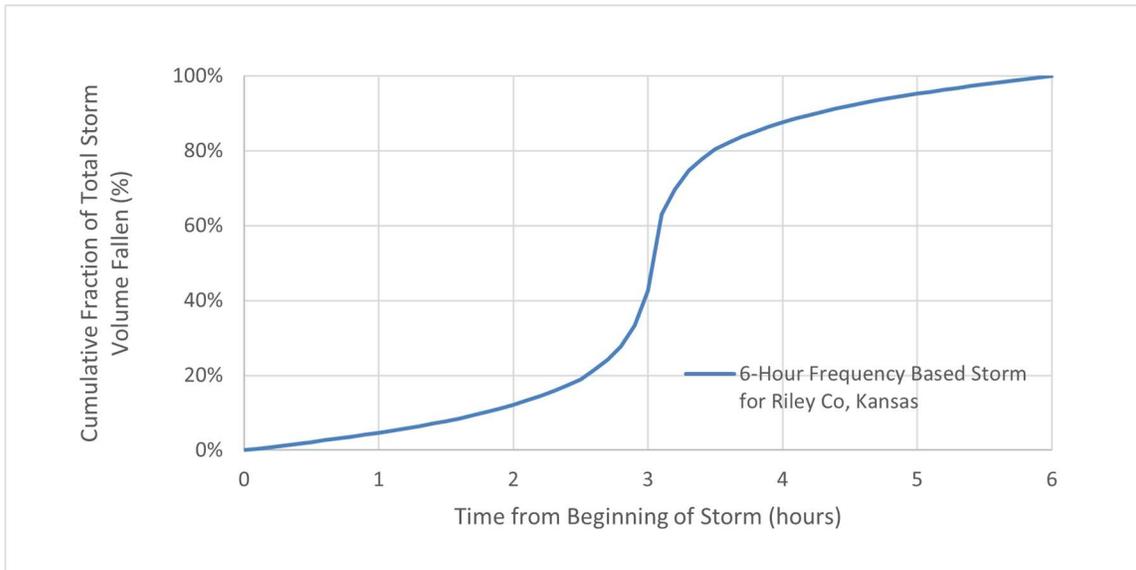


Figure 1: Cumulative Precipitation Distribution Curve for the 6-Hour Frequency Based Design Storm.

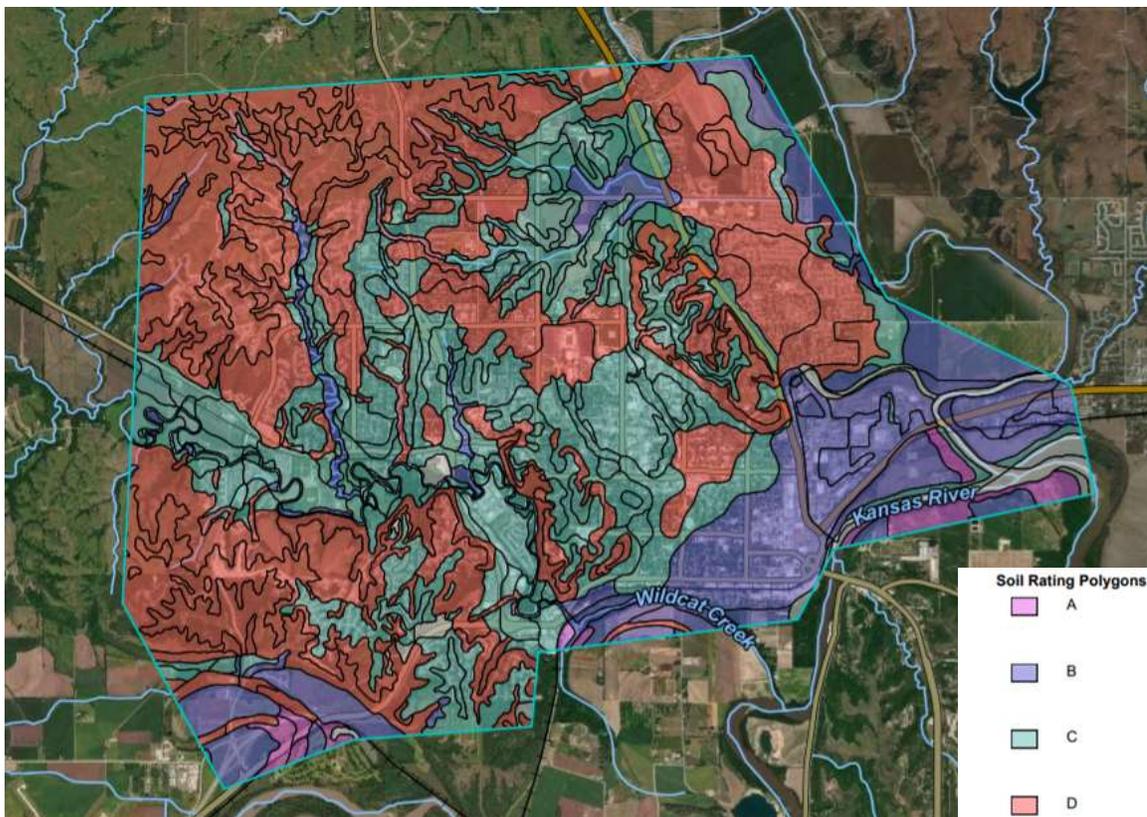
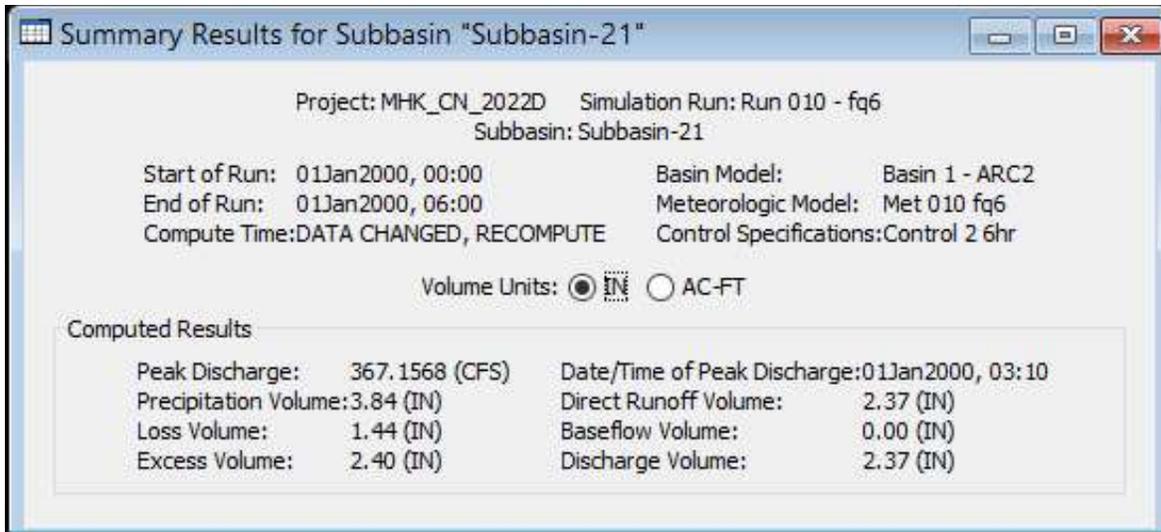
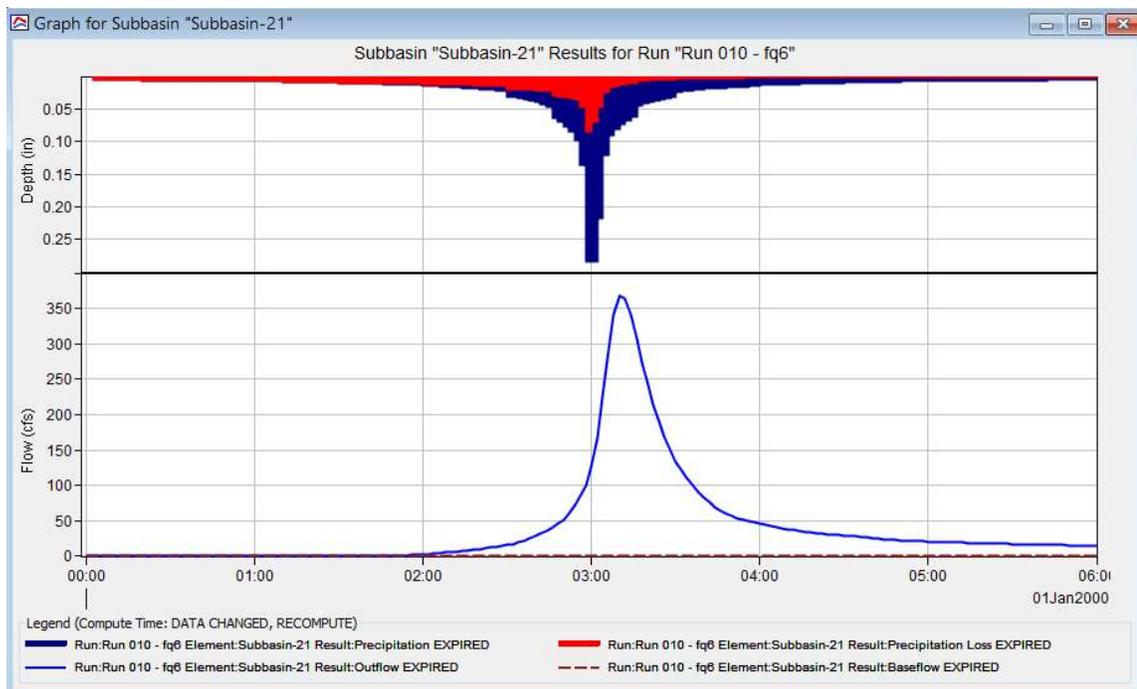


Figure 2: Distribution of Hydrologic Soil Groups in the Manhattan area, as Reported from the NRCS Web Soil Survey



(a) Summary Runoff Table



(b) Graphical Results: Rainfall, Losses, and Hydrograph

Figure 3 – Rainfall and Runoff Results from HEC-HMS for an Example Scenario

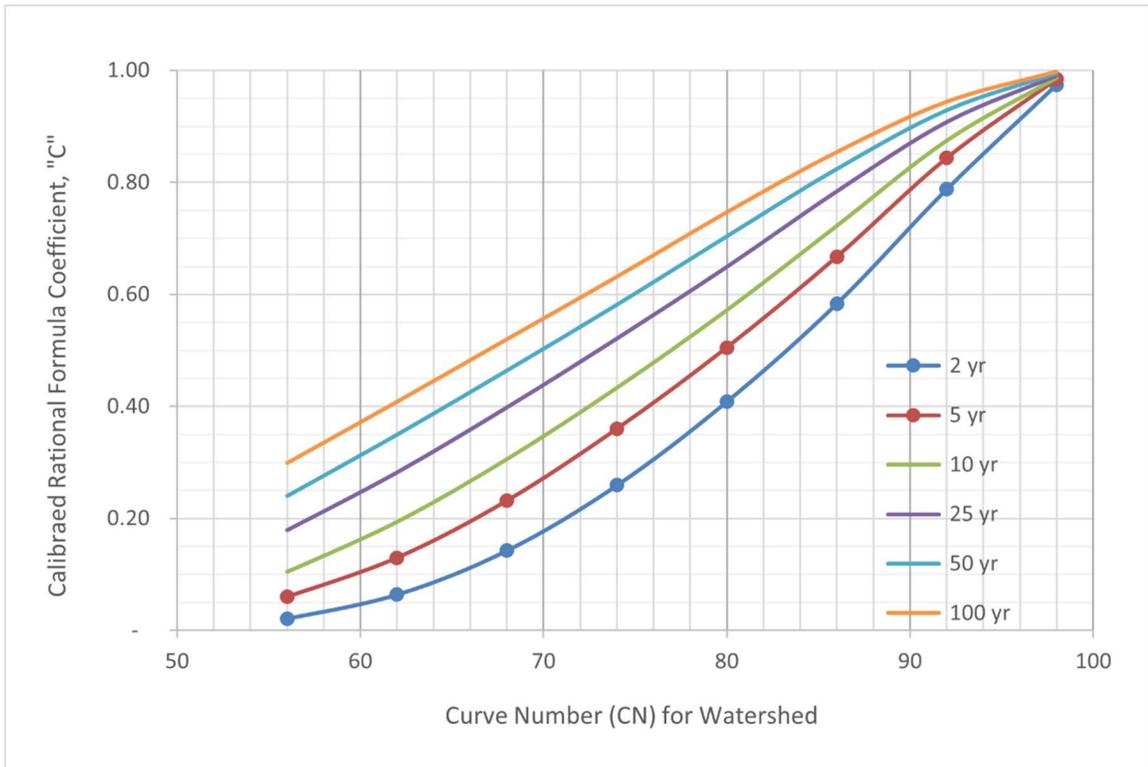


Figure 4: Rational Formula as Function of CN, for Various Return Periods (Calibrated at $T_c=15$ min)

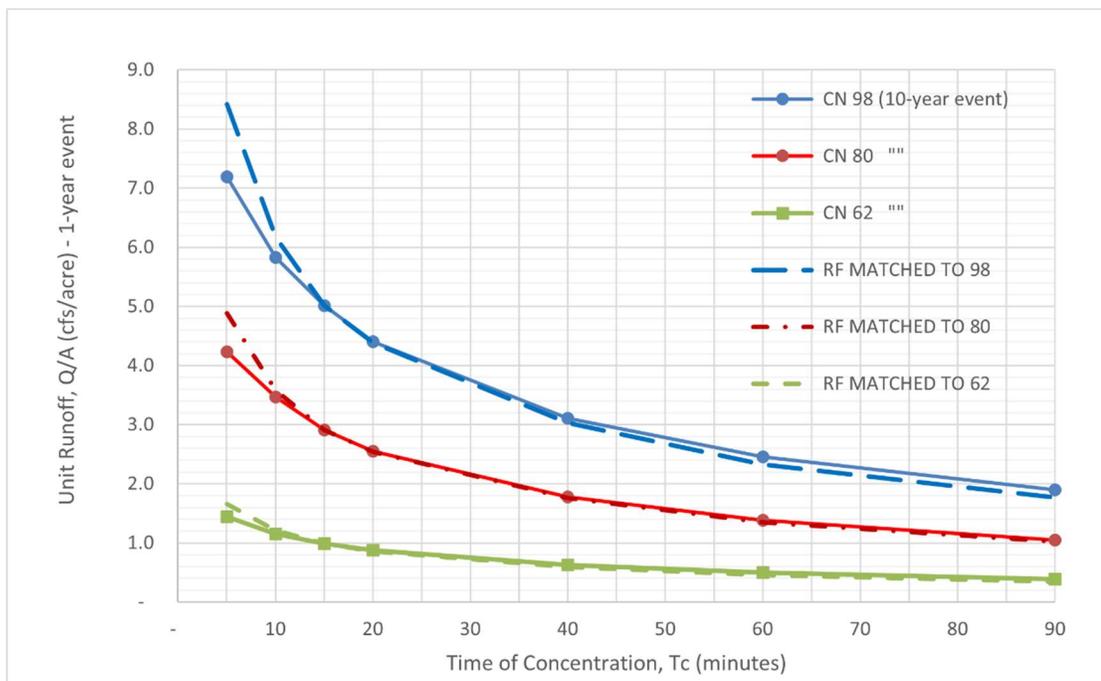


Figure 5: Comparison of Curve Number Method and Unadjusted Rational Formula Discharge Estimates, 10-year Storm, as a Function of CN and Time of Concentration.

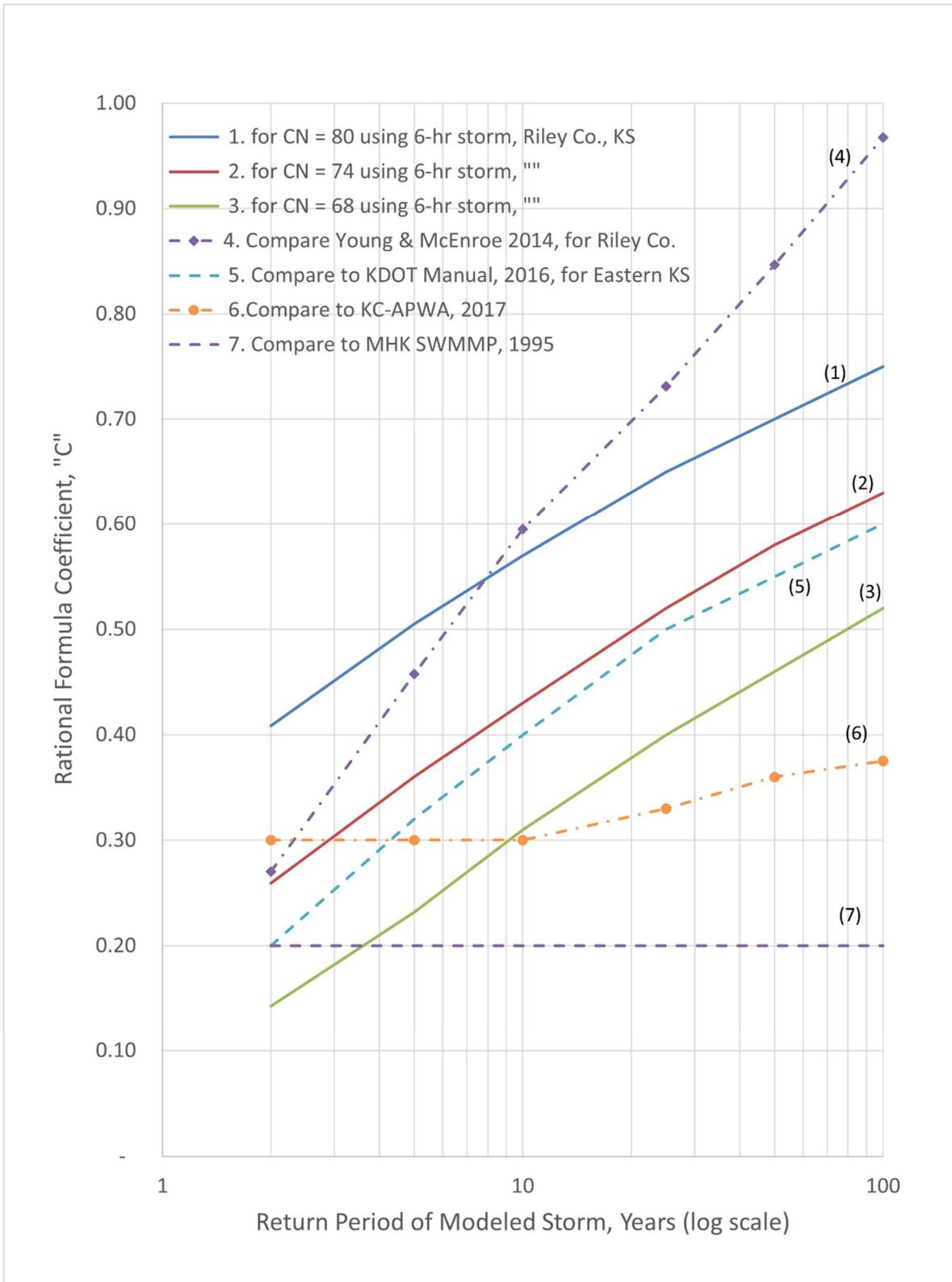


Figure 6: Comparison of Normalized Rational Formula Coefficients with Reference Values

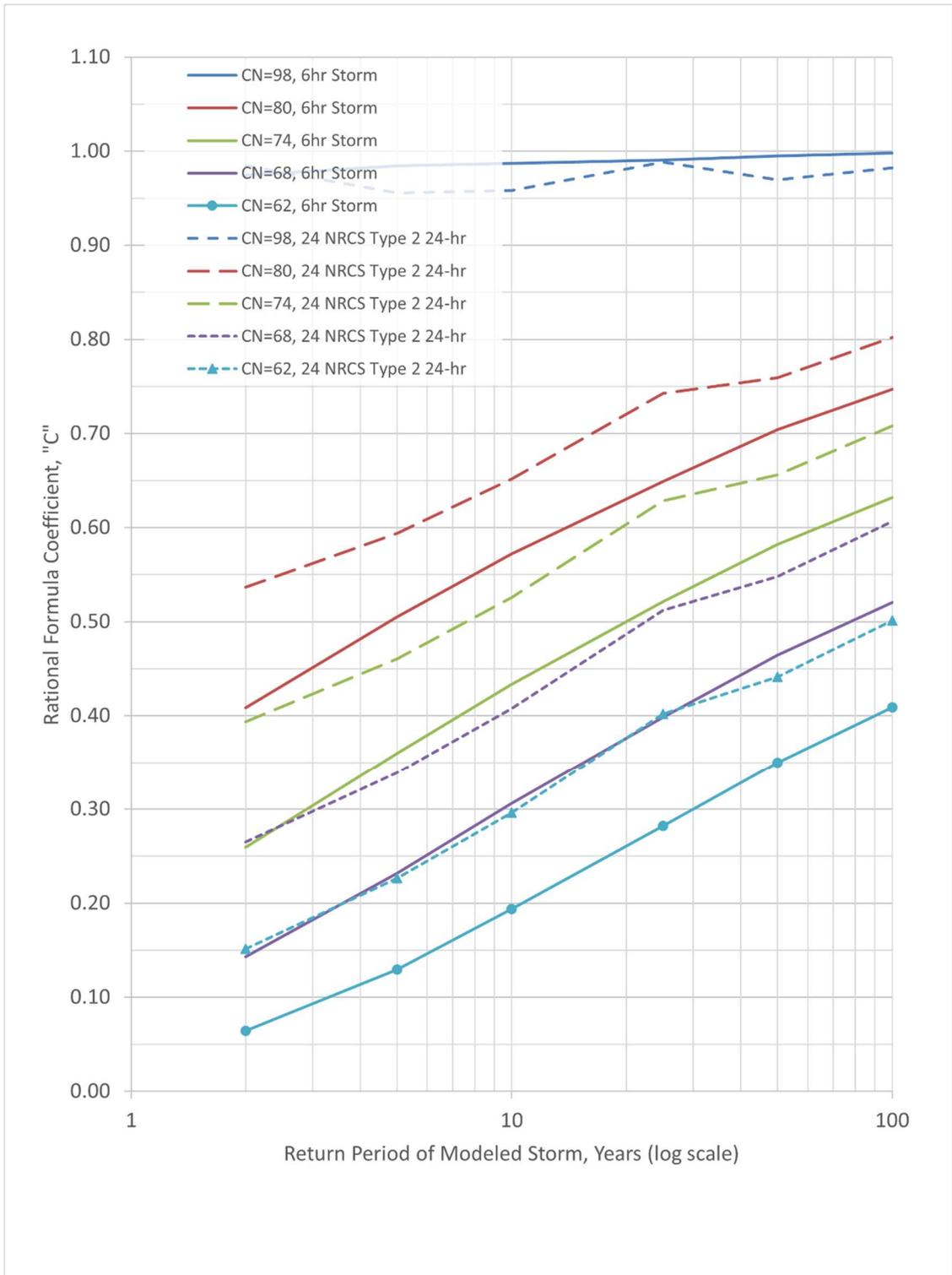


Figure 7: Normalized Rational Formula Coefficients, Comparison of 6-Hour Frequency Storm vs. NRCS Type II 24 Hour

Attached Table A
Cumulative Frequency Distribution – 6-Hour Frequency Based Storm
from NOAA 14 for Riley County (10-year Storm Base)

Time "T" (hr)	Ordinates for Time T	Time "T" (hr)	Ordinates for Time T
0	-	3	0.42580
0.1	0.00411	3.1	0.63024
0.2	0.00833	3.2	0.69661
0.3	0.01266	3.3	0.74681
0.4	0.01712	3.4	0.77785
0.5	0.02171	3.5	0.80417
0.6	0.02643	3.6	0.82183
0.7	0.03130	3.7	0.83745
0.8	0.03634	3.8	0.85153
0.9	0.04154	3.9	0.86438
1	0.04694	4	0.87624
1.1	0.05254	4.1	0.88638
1.2	0.05837	4.2	0.89586
1.3	0.06444	4.3	0.90477
1.4	0.07078	4.4	0.91319
1.5	0.07743	4.5	0.92117
1.6	0.08521	4.6	0.92798
1.7	0.09340	4.7	0.93447
1.8	0.10206	4.8	0.94067
1.9	0.11124	4.9	0.94662
2	0.12104	5	0.95233
2.1	0.13247	5.1	0.95783
2.2	0.14480	5.2	0.96313
2.3	0.15823	5.3	0.96824
2.4	0.17303	5.4	0.97320
2.5	0.18959	5.5	0.97799
2.6	0.21418	5.6	0.98265
2.7	0.24260	5.7	0.98717
2.8	0.27700	5.8	0.99156
2.9	0.33389	5.9	0.99584
		6	1.00000

Attached Table B
Runoff Estimates as Q/A (cfs/acre), Derived in HEC-HMS Using Curve Numbers, Unit Hydrographs
and the modified Manhattan Storm Distribution for Various Scenarios

Tc, Time of Conc. (min)	Tlag, Eqv. Lag Time (min)	CN, Curve Number	Q/A, Unit Discharge (cfs/acre) for each Return Period					
			2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5	3	98	4.811	6.136	7.192	8.745	10.063	11.362
5	3	92	3.931	5.303	6.421	8.058	9.439	10.791
5	3	86	2.921	4.227	5.343	7.004	8.421	9.813
5	3	80	2.019	3.183	4.229	5.833	7.231	8.621
5	3	74	1.301	2.239	3.174	4.657	5.984	7.329
5	3	68	0.715	1.477	2.238	3.525	4.742	6.000
5	3	62	0.271	0.814	1.447	2.515	3.535	4.675
5	3	56	0.086	0.306	0.734	1.614	2.477	3.417
10	6	98	3.902	4.955	5.830	7.094	8.145	9.211
10	6	92	3.200	4.293	5.215	6.545	7.646	8.754
10	6	86	2.394	3.439	4.355	5.704	6.835	7.974
10	6	80	1.671	2.607	3.466	4.769	5.887	7.023
10	6	74	1.053	1.851	2.620	3.827	4.892	5.990
10	6	68	0.572	1.181	1.840	2.917	3.897	4.926
10	6	62	0.239	0.650	1.153	2.057	2.928	3.862
10	6	56	0.077	0.278	0.595	1.288	1.999	2.816
15	9	98	3.351	4.253	5.014	6.111	7.014	7.943
15	9	92	2.710	3.644	4.444	5.599	6.548	7.514
15	9	86	2.006	2.882	3.672	4.836	5.810	6.799
15	9	80	1.405	2.183	2.906	4.004	4.963	5.945
15	9	74	0.892	1.555	2.202	3.215	4.103	5.029
15	9	68	0.491	1.001	1.554	2.457	3.275	4.141
15	9	62	0.221	0.560	0.985	1.741	2.468	3.253
15	9	56	0.073	0.258	0.531	1.104	1.695	2.382
20	12	98	2.940	3.727	4.400	5.369	6.162	6.986
20	12	92	2.382	3.197	3.904	4.922	5.754	6.610
20	12	86	1.762	2.537	3.233	4.258	5.111	5.986
20	12	80	1.230	1.905	2.552	3.535	4.375	5.242
20	12	74	0.786	1.362	1.928	2.816	3.612	4.445
20	12	68	0.440	0.886	1.366	2.156	2.870	3.632
20	12	62	0.204	0.507	0.877	1.534	2.169	2.859
20	12	56	0.070	0.238	0.483	0.986	1.502	2.101

Attached Table B (continued)

Tc, Time of Conc. (min)	Tlag, Eqv. Lag Time (min)	CN, Curve Number	Q/A, Unit Discharge (cfs/acre) for each Return Period					
			2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
40	24	98	2.071	2.627	3.110	3.813	4.384	4.988
40	24	92	1.654	2.224	2.728	3.462	4.062	4.687
40	24	86	1.222	1.759	2.247	2.975	3.580	4.213
40	24	80	0.853	1.324	1.773	2.467	3.060	3.679
40	24	74	0.553	0.945	1.340	1.969	2.526	3.118
40	24	68	0.322	0.627	0.955	1.505	2.010	2.553
40	24	62	0.158	0.373	0.627	1.082	1.519	2.007
40	24	56	0.058	0.186	0.362	0.712	1.070	1.486
60	36	98	1.634	2.074	2.459	3.024	3.484	3.971
60	36	92	1.295	1.744	2.142	2.728	3.208	3.710
60	36	86	0.953	1.371	1.755	2.335	2.821	3.327
60	36	80	0.665	1.031	1.384	1.930	2.398	2.892
60	36	74	0.434	0.738	1.045	1.538	1.978	2.446
60	36	68	0.258	0.494	0.747	1.177	1.573	2.001
60	36	62	0.131	0.300	0.496	0.850	1.192	1.574
60	36	56	0.051	0.155	0.293	0.567	0.847	1.170
90	54	98	1.260	1.600	1.899	2.344	2.707	3.093
90	54	92	0.987	1.331	1.638	2.097	2.475	2.871
90	54	86	0.724	1.043	1.337	1.786	2.163	2.559
90	54	80	0.506	0.784	1.051	1.471	1.834	2.218
90	54	74	0.334	0.563	0.795	1.173	1.511	1.873
90	54	68	0.202	0.381	0.572	0.899	1.202	1.533
90	54	62	0.107	0.236	0.384	0.655	0.916	1.208
90	54	56	0.045	0.126	0.233	0.443	0.656	0.904

Attached Table C
Runoff Estimates as Q/A (cfs/acre), Derived using Rational Formula (Unadjusted)

Tc, Time of Conc. (min)	Tlag, Eqv. Lag Time (min)	CN, Curve Number	Q/A, Unit Discharge (cfs/acre) for each Return Period					
			2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5	3	98	5.64	7.15	8.42	10.27	11.79	13.35
5	3	92	4.56	6.12	7.46	9.41	11.01	12.63
5	3	86	3.38	4.84	6.17	8.13	9.77	11.43
5	3	80	2.36	3.67	4.88	6.73	8.34	9.99
5	3	74	1.50	2.61	3.70	5.40	6.90	8.45
5	3	68	0.83	1.68	2.61	4.13	5.50	6.96
5	3	62	0.37	0.94	1.65	2.93	4.15	5.47
5	3	56	0.12	0.43	0.89	1.86	2.85	4.00
10	6	98	4.13	5.23	6.17	7.52	8.63	9.77
10	6	92	3.34	4.48	5.47	6.89	8.05	9.24
10	6	86	2.47	3.54	4.52	5.95	7.14	8.36
10	6	80	1.73	2.68	3.58	4.93	6.10	7.31
10	6	74	1.10	1.91	2.71	3.96	5.05	6.19
10	6	68	0.61	1.23	1.91	3.02	4.03	5.09
10	6	62	0.27	0.69	1.21	2.14	3.03	4.00
10	6	56	0.09	0.32	0.65	1.36	2.08	2.93
15	9	98	3.35	4.25	5.01	6.11	7.01	7.94
15	9	92	2.71	3.64	4.44	5.60	6.55	7.51
15	9	86	2.01	2.88	3.67	4.84	5.81	6.80
15	9	80	1.41	2.18	2.91	4.00	4.96	5.94
15	9	74	0.89	1.56	2.20	3.22	4.10	5.03
15	9	68	0.49	1.00	1.55	2.46	3.27	4.14
15	9	62	0.22	0.56	0.98	1.74	2.47	3.25
15	9	56	0.07	0.26	0.53	1.10	1.70	2.38
20	12	98	2.93	3.72	4.38	5.35	6.13	6.95
20	12	92	2.37	3.19	3.88	4.90	5.72	6.57
20	12	86	1.76	2.52	3.21	4.23	5.08	5.94
20	12	80	1.23	1.91	2.54	3.50	4.34	5.20
20	12	74	0.78	1.36	1.92	2.81	3.58	4.40
20	12	68	0.43	0.88	1.36	2.15	2.86	3.62
20	12	62	0.19	0.49	0.86	1.52	2.16	2.84
20	12	56	0.06	0.23	0.46	0.97	1.48	2.08

Attached Table C (continued)

Tc, Time of Conc. (min)	Tlag, Eqv. Lag Time (min)	CN, Curve Number	Q/A, Unit Discharge (cfs/acre) for each Return Period					
			2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
40	24	98	2.03	2.57	3.03	3.71	4.28	4.86
40	24	92	1.64	2.20	2.69	3.40	3.99	4.60
40	24	86	1.21	1.74	2.22	2.94	3.54	4.16
40	24	80	0.85	1.32	1.76	2.43	3.03	3.64
40	24	74	0.54	0.94	1.33	1.95	2.50	3.08
40	24	68	0.30	0.60	0.94	1.49	2.00	2.53
40	24	62	0.13	0.34	0.60	1.06	1.51	1.99
40	24	56	0.04	0.16	0.32	0.67	1.03	1.46
60	36	98	1.55	1.97	2.33	2.86	3.30	3.77
60	36	92	1.25	1.69	2.06	2.62	3.08	3.57
60	36	86	0.93	1.33	1.71	2.27	2.74	3.23
60	36	80	0.65	1.01	1.35	1.88	2.34	2.82
60	36	74	0.41	0.72	1.02	1.51	1.93	2.39
60	36	68	0.23	0.46	0.72	1.15	1.54	1.97
60	36	62	0.10	0.26	0.46	0.82	1.16	1.55
60	36	56	0.03	0.12	0.25	0.52	0.80	1.13
90	54	98	1.18	1.49	1.77	2.18	2.53	2.89
90	54	92	0.95	1.27	1.57	2.00	2.36	2.74
90	54	86	0.71	1.01	1.29	1.72	2.09	2.48
90	54	80	0.49	0.76	1.02	1.43	1.79	2.17
90	54	74	0.31	0.54	0.78	1.15	1.48	1.83
90	54	68	0.17	0.35	0.55	0.88	1.18	1.51
90	54	62	0.08	0.20	0.35	0.62	0.89	1.19
90	54	56	0.03	0.09	0.19	0.39	0.61	0.87

Attached Table D
Variance in Unadjusted Rational Formula Results from Table C,
as compared to CN Method Results in Table B.

Tc, Time of Conc. (min)	CN, Curve Number	Variance, as a percentage above or below the CN Method Results						Composite Statistics for Variance, for each Tc Group	
		1 yr	5 yr	10 yr	25 yr	50 yr	100 yr	Mean	Std Dev.
5	98	17%	16%	17%	17%	17%	18%		
5	92	16%	15%	16%	17%	17%	17%		
5	86	16%	15%	15%	16%	16%	16%		
5	80	17%	15%	15%	15%	15%	16%		
5	74	15%	17%	17%	16%	15%	15%		
5	68	16%	14%	17%	17%	16%	16%		
5	62	37%	16%	14%	16%	17%	17%	Full Range	
5	56	45%	42%	21%	15%	15%	17%	17.8	6.2%
10	98	6%	6%	6%	6%	6%	6%		
10	92	4%	4%	5%	5%	5%	6%		
10	86	3%	3%	4%	4%	5%	5%		
10	80	4%	3%	3%	3%	4%	4%		
10	74	4%	3%	3%	3%	3%	3%		
10	68	6%	4%	4%	4%	3%	3%		
10	62	14%	6%	5%	4%	4%	4%	Full Range	
10	56	17%	14%	10%	5%	4%	4%	5.1%	2.9%
15	98	0%	0%	0%	0%	0%	0%		
15	92	0%	0%	0%	0%	0%	0%		
15	86	0%	0%	0%	0%	0%	0%		
15	80	0%	0%	0%	0%	0%	0%		
15	74	0%	0%	0%	0%	0%	0%		
15	68	0%	0%	0%	0%	0%	0%		
15	62	0%	0%	0%	0%	0%	0%	Full Range	
15	56	0%	0%	0%	0%	0%	0%	0.0%	0%
20	98	0%	0%	0%	0%	-1%	-1%		
20	92	0%	0%	0%	0%	-1%	-1%		
20	86	0%	-1%	-1%	-1%	-1%	-1%		
20	80	0%	0%	0%	-1%	-1%	-1%		
20	74	-1%	0%	0%	0%	-1%	-1%		
20	68	-2%	-1%	-1%	0%	0%	0%		
20	62	-5%	-3%	-2%	-1%	-1%	0%	Full Range	
20	56	-8%	-5%	-4%	-2%	-1%	-1%	-1.1%	1.6%

Attached Table D (continued)

Tc, Time of Conc. (min)	CN, Curve Number	Variance, as a percentage above or below the CN Method Results						Composite Statistics for Variance, for each Tc Group	
		2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	Mean	Std Dev.
40	98	-2%	-2%	-3%	-3%	-2%	-3%		
40	92	-1%	-1%	-2%	-2%	-2%	-2%		
40	86	-1%	-1%	-1%	-1%	-1%	-1%		
40	80	0%	0%	-1%	-1%	-1%	-1%		
40	74	-2%	-1%	-1%	-1%	-1%	-1%		
40	68	-8%	-4%	-2%	-1%	-1%	-1%		
40	62	-16%	-9%	-5%	-2%	-1%	-1%	Full Range	
40	56	-24%	-16%	-11%	-6%	-3%	-2%	-3.2%	4.6%
60	98	-5%	-5%	-5%	-5%	-5%	-5%		
60	92	-3%	-3%	-4%	-4%	-4%	-4%		
60	86	-3%	-3%	-3%	-3%	-3%	-3%		
60	80	-2%	-2%	-2%	-3%	-3%	-2%		
60	74	-5%	-2%	-2%	-2%	-2%	-2%		
60	68	-12%	-6%	-3%	-2%	-2%	-2%		
60	62	-22%	-14%	-8%	-4%	-3%	-2%	Full Range	
60	56	-34%	-23%	-16%	-9%	-6%	-3%	-5.6%	6.2%
90	98	-6%	-7%	-7%	-7%	-7%	-6%		
90	92	-3%	-4%	-4%	-5%	-5%	-5%		
90	86	-3%	-3%	-3%	-3%	-3%	-3%		
90	80	-2%	-3%	-3%	-3%	-3%	-2%		
90	74	-6%	-3%	-2%	-2%	-2%	-2%		
90	68	-15%	-8%	-4%	-3%	-2%	-2%		
90	62	-27%	-17%	-10%	-5%	-3%	-2%	Full Range	
90	56	-42%	-29%	-20%	-11%	-7%	-4%	-6.9%	7.8%

Note: Values shaded in grade represent scenarios that vary by more than 15% from the mean for each group. See text for more discussion.