3.0 HYDROLOGY

Highway drainage structures and roadside channels are generally designed to convey flows with specified recurrence intervals. The design flow for a drainage structure or channel is determined by means of a hydrologic analysis. This section presents the recommended procedures for the determination of design flows.

3.1 HYDROLOGIC METHODS

Peak discharges and hydrographs for drainage design can be computed by the Rational method, Three Variable Regression Equations, the USGS regression equations for Kansas, or flood hydrograph simulation. Table 3.1-1 provides guidelines for selection of the most appropriate method.

Table 3.1-1 Guidelines for Selection of Hydrologic Methods

Method	Limitations and Uses
Rational Method	Drainage area ≤ 640 ac. Unregulated stream No analysis of detention storage at structure
Three Variable Regression Equations	Rural areas Drainage area > 640 acres and < 30 mi^2 Unregulated stream
USGS Regression Method for Kansas	Rural areas Drainage area > 640 ac. Unregulated stream No analysis of detention storage at structure Generally used for bridge structures only
Flood Hydrograph Simulation Method (by specified procedures)	Circumstances in which the other methods are not applicable, or consideration of timing and storage effects is warranted. Examples include determination of peak flow on a stream controlled by a constructed device and/or natural diversion or when detention storage analysis is warranted.

3.2 RATIONAL METHOD

3.2.1 Rational Formula

The Rational method should be used to compute design flows for drainage structures with drainage areas up to 640 ac where analysis of detention storage is not required. The Rational formula is

$$Q = C\ i\ A \quad (3\text{-}1)$$

where: Q = discharge with the design recurrence interval (cfs)

C = composite runoff coefficient (dimensionless)

i = point rainfall intensity with a duration equal to the time of concentration and the same recurrence interval as the design flow (in./hr)

A = drainage area (ac)

3.2.2 Time of Concentration

Times of concentration (T_c) for grass-lined and aggregate-lined road ditches and medians should be computed with Equation 3-2. Times of concentration for concrete-lined road ditches should be computed with Equation 3-3. Use a 5-minute (minimum) time of concentration for curb and gutter inlets. The time of concentration for a storm sewer is the sum of the inlet time and the pipe-flow time from the farthest inlet to the design point.

The time of concentration for a crossroad drainage structure should be computed with Equation 3-2 or 3-3. If no more than 3% of the drainage area is impervious, (impervious ratio (R_i) < 0.03), use Equation 3-2. If the impervious percentage is greater than 3%, use Equation 3-3. If the computed T_c is shorter than 5 minutes, use T_c = 5 minutes.

Equation 3-2 should be used for grass-lined medians, regardless of the overall impervious percentage, since most of the longest flow path would consist of flow through a wide shallow grass channel.

$$T_c = 0.0368 \left[\frac{L}{\sqrt{Sl}}\right]^{0.66} \quad \text{for } R_i < 0.03 \qquad (3\text{-}2)$$

$$T_c = 0.0187 \left[\frac{L(1 - 0.75R_c)}{\sqrt{S}}\right]^{0.87} [W(1 + 2.0R_i)]^{-0.26} \quad \text{for } R_i > 0.03 \text{ or } R_c > 0.03 \qquad (3\text{-}3)$$

where: T_c = time of concentration (minutes)

A = drainage area (acres)

L = length of the longest flow path (ft), measured from a point on the drainage divide to the watershed outlet or design point.

S = slope of longest flow path (ft/ft), defined as the total fall in elevation divided by the flow-path length

Sl = average slope of the longest flow path (ft/ft), defined as the elevation difference between two points on the drainage path, located at 10% and 85% of the path length (measured from the design point), divided by the path length between the points (0.75 L).

W = average width of the watershed (ft), defined as A/L

R_c = channel development ratio (dimensionless), defined as the fraction of the longest flow path with low frictional resistance (e.g., pavements, gutters, enclosed conduits, and channels with paved bottoms)

R_i = impervious area ratio (dimensionless), defined as the fraction of the drainage area covered by impervious surfaces = (impervious area) / (total drainage area)

3.2.3 Rainfall Intensity

The point rainfall intensities used in the Rational formula should be obtained from KDOT's *Rainfall Intensity Tables for Counties in Kansas (2014)*. These tables provide rainfall intensities for durations from 5 minutes to 24 hours and various recurrence intervals from 1 to 500 years.

3.2.4 Runoff Coefficients

Different factors affect the runoff coefficient. These factors include land use, recurrence interval, soil type, saturation conditions, and land slope. Table 3.2.4-1 and 3.2.4-2 show the recommended runoff coefficients for different land uses and recurrence intervals.

The recommended runoff coefficients increase with recurrence interval to account for the greater percentage of runoff for larger storms.

The designer may opt to use slightly higher or lower runoff coefficients to account for local conditions. Higher runoff coefficients might be appropriate for soils with low permeability on steep slopes or thin soils with little water-storage capacity. Lower runoff coefficients might be appropriate for soils with high permeability and for flat terrain. The recommended runoff coefficients for the eastern and western hydrologic regions of Kansas may be found in the tables below. See Figure 3.5.3-1 for the eastern and western hydrologic regions.

Table 3.2.4-1 Recommended Runoff Coefficients for Eastern Kansas

Land Use	Runoff Coefficient, C					
	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
Impervious surfaces	0.80	0.86	0.90	0.93	0.94	0.95
Pervious surfaces within highway right-of-way	0.20	0.32	0.40	0.50	0.55	0.60
Urban open space (lawns, parks, etc.)	0.20	0.32	0.40	0.50	0.55	0.60
Pasture or range	0.20	0.32	0.40	0.50	0.55	0.60
Cultivated agricultural land	0.25	0.40	0.50	0.63	0.69	0.75
Woods	0.15	0.24	0.30	0.38	0.41	0.45

Table 3.2.4-2 Recommended Runoff Coefficients for Western Kansas

Land Use	Runoff Coefficient, C					
	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
Impervious surfaces	0.80	0.86	0.90	0.93	0.94	0.95
Pervious surfaces within highway right-of-way	0.10	0.18	0.24	0.36	0.42	0.48
Urban open space (lawns, parks, etc.)	0.10	0.18	0.24	0.36	0.42	0.48
Pasture or range	0.10	0.18	0.24	0.36	0.42	0.48
Cultivated agricultural land	0.12	0.23	0.30	0.45	0.53	0.60
Woods	0.07	0.14	0.18	0.27	0.32	0.36

The runoff coefficient, C, in the Rational formula is the area-weighted average of the runoff coefficients for the different land uses within the watershed. The example in Section 3.2.5 shows how to compute the composite runoff coefficient, time of concentration, and peak runoff. Note the composite runoff coefficient in the Remarks or Data column in the Hydrology section of the Drainage Data Sheet (e.g., C = 0.48).

3.2.5 Example: Design Flow by Rational Method

Problem:

Determine the 25-year design flow for a culvert in rural Shawnee County. The drainage area is 90 ac, which comprises 40 ac of cultivated agricultural land, 30 ac of pasture and 20 ac of woods. The length of the longest flow path to culvert is 2630 ft. The average slope (Sl) of this flow path, as defined in Section 3.2.2, is 0.004 ft/ft. Impervious area is less than 3%.

Solution:

Obtain the runoff coefficients for the individual land uses from Table 3.2.4-1, and compute the composite runoff coefficient as follows:

Land Use	**C**	**Area, A (ac)**	**A · C**
Cultivated agricultural land	**0.63**	**40**	**25.2**
Pasture	**0.50**	**30**	**15.0**
Woods	**0.38**	**20**	**7.6**
Totals		**90**	**47.8**

$$\text{Composite C} = \frac{\sum(A \cdot C)}{\sum A} = \frac{47.8}{90} = 0.53$$

The watershed is less than 3% impervious, so compute the time of concentration with Equation 11-2.

$$T_c = 0.0368\left[\frac{L}{\sqrt{Sl}}\right]^{0.66} = 0.0368\left[\frac{2630}{\sqrt{0.004}}\right]^{0.66} = 41 \text{ minutes}$$

Obtain the rainfall intensity for a duration of 41 minutes and a recurrence interval of 25 years from the rainfall intensity table for Shawnee County in KDOT's *Rainfall Intensity Tables for Counties in Kansas (2014)*.

$i = 3.66$ in./hr

Compute the 25-year design flow with the Rational formula (Equation 3-1).

$Q_{25} = C\,i\,A = 0.53\,(3.66)\,(90) = 175$ cfs

3.2.6 Example: Application of T_c for Impervious Area more than 3%

In this example, equation 3-3 is used to estimate the time of concentration for a watershed with the following characteristics:

Drainage area = 711 acres, of which 149 acres is impervious
Length of longest flow path = 10,440 feet, of which 1120 feet is paved or enclosed
Flowline elevation at watershed outlet = 865 feet
Flowline elevation at upper end of longest flow path = 934 ft

The required inputs to equation 3-3 are computed from these characteristics.

$$S = \frac{934\text{ ft} - 865\text{ ft}}{10,440\text{ ft}} = 0.0066\text{ ft/ft}$$

$$W = \frac{711\text{ ac} \times 43,560\text{ ft}^2/\text{ac}}{10,440\text{ ft}} = 2967\text{ ft}$$

$$R_c = \frac{1120\text{ ft}}{10,440\text{ ft}} = 0.107$$

$$R_i = \frac{149\text{ ac}}{711\text{ ac}} = 0.210$$

These values are inserted into equation 3-3 to obtain:

$$T_c = 0.0187\left[\frac{10,440(1 - 0.75 \times 0.107)}{\sqrt{0.0066}}\right]^{0.87} [2967(1 + 2.0 \times 0.210)]^{-0.26}$$

$$= 55\text{ minutes}$$

3.3 THREE-VARIABLE REGRESSION EQUATIONS

The Three-Variable Regression equations should be used to compute design flows for drainage structures on unregulated rural streams with contributing drainage areas greater than 640 ac but less than 30 mi^2. The Three-Variable Regression equations, shown in Equations 3-4 to 3-9, were developed as part of research Report No. FHWA-KS-15-12, "Updated Regional Flood Frequency Equations for Small, Rural, Unregulated Watersheds in Kansas (2015)."

The Three-Variable Regression equations may be used as a check or comparison of the USGS regression equations (Section 3.4) for bridge structures. For culverts (see definition, Section 1.2) the peak flow should be determined by these equations.

3.3.1 Three-Variable Regression Equations for Flood Discharge

Note: Applicable to unregulated rural streams with drainage areas greater than 640 ac and under 30 mi^2 in Kansas.

Recurrence Interval	Equation	
2 year	$Q_2 = 0.0105 \cdot P^{2.720} \cdot (Ia_2 \cdot A)^{1.000}$	(3-4)
5 year	$Q_5 = 0.269 \cdot P^{1.968} \cdot (Ia_5 \cdot A)^{1.002}$	(3-5)
10 year	$Q_{10} = 1.12 \cdot P^{1.636} \cdot (Ia_{10} \cdot A)^{1.004}$	(3-6)
25 year	$Q_{25} = 4.47 \cdot P^{1.310} \cdot (Ia_{25} \cdot A)^{1.004}$	(3-7)
50 year	$Q_{50} = 9.77 \cdot P^{1.120} \cdot (Ia_{50} \cdot A)^{1.004}$	(3-8)
100 year	$Q_{100} = 19.1 \cdot P^{0.959} \cdot (Ia_{100} \cdot A)^{1.005}$	(3-9)

where: Q_T = discharge for recurrence interval of T years (cfs)

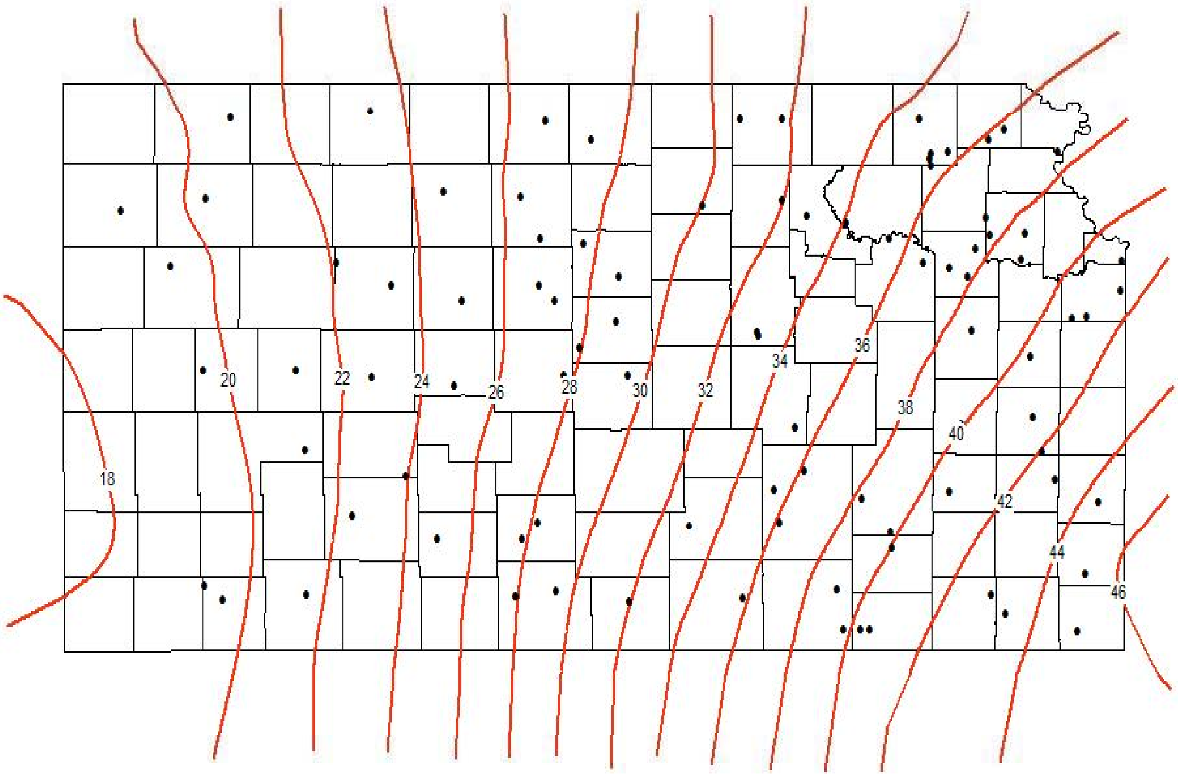
P = mean annual precipitation (inches)

Ia_T = basin-average rainfall intensity for recurrence interval of T years (in/hr)

A = drainage area (mi^2)

The mean annual precipitation is obtained from Figure 3.3.1-1. Locate the centroid of the watershed on the map and find the mean annual precipitation (P) in inches at the centroid by interpolation.

Figure 3.3.1-1 Mean Annual precipitation (inches) using the Three-Variable Regression Equations.



(Produced by the Weather Data Library, Department of Agronomy, Kansas State University from 1981-2010 climate normals)

3.3.2 Basin-Average Rainfall Intensity

When a watershed is larger than a few hundred acres, the relevant rainfall intensity for hydrologic analyses is the basin-average rainfall intensity, rather than the point-rainfall intensity. The time of concentration, T_c, in minutes is computed using Equations 3-2 or 3-3 as appropriate and point rainfall intensity, i, obtained from KDOT's *Rainfall Intensity Tables for Counties in Kansas (2014)*.

The equations for basin-average rainfall intensity are as follows:

$$Ia = i \cdot [1 - BV \cdot (1 - e^{-0.015 \cdot A})] \quad (3\text{-}10)$$

$$BV = 0.355 \cdot D^{-0.428} \quad (3\text{-}11)$$

where:

i = point rainfall intensity with duration equal to time of concentration and the same recurrence interval as the basin-average rainfall intensity.

A = drainage area (mi^2)

BV = maximum reduction of point rainfall, varies with duration

D = duration of rainfall event, set equal to t_c (in hours)

3.3.3 Example Application

Problem

A stream crossing in southwestern Nemaha County has a drainage area of 9.87 mi^2. The length of the main channel is 34,530 ft and the average slope of the main channel is 0.0032 ft/ft. Compute the 50-year discharge (Q_{50}) using the three-variable regression equation for Q_{50}.

Solution

1. The main channel length is 34,530 ft and the average slope is 0.0032 ft/ft.
2. Compute the time of concentration with Eq. 3-2.

$$T_c = 0.0368 \left[\frac{L}{\sqrt{Sl}}\right]^{0.66} = 0.0368 \left[\frac{34530}{\sqrt{0.0032}}\right]^{0.66} = 242.3 \text{ minutes} = 4.04 \text{ hr}$$

3. Obtain the 50-year point-rainfall intensity for a duration of 4.04 hours by interpolation in KDOT's *Rainfall Intensity Tables for Counties in Kansas (2014)* for Nemaha County.

$$i = 1.29 + (1.23 - 1.29) \cdot \frac{4.04 - 4.00}{4.25 - 4.00} = 1.28 \text{ in./hr}$$

4. Compute the corresponding 50-year rainfall intensity over the 9.87-mi^2 watershed with Equations 3-10 and 3-11.

$$BV = 0.355 \cdot D^{-0.428} = 0.355(4.04)^{-0.428} = 0.195$$

$$Ia = i \cdot [1 - BV \cdot (1 - e^{-0.015 \cdot A})]$$

$$= 1.28 \cdot [1 - 0195 \cdot (1 - e^{-0.015 \cdot 9.87})] = 1.25 \text{ in./hr}$$

5. Refer to Figure 3.3.1-1 to obtain the mean annual precipitation for the watershed.

$$P = 34.9 \text{ in.}$$

Compute the 50-year discharge with Eq. 3-8.

$$Q_{50} = 9.77 \cdot P^{1.120} \cdot (Ia_{50} \cdot A)^{1.004}$$

$$= 9.77 \cdot (34.9)^{1.120} \cdot (1.25 \cdot 9.87)^{1.004}$$

$$= 6510 \text{ cfs} \quad \text{(rounded to three significant figures)}$$

3.4 USGS REGRESSION METHOD FOR KANSAS

The regression equations Water Resources Investigations Report 00-4079 of the U. S. Geological Survey (USGS) (Rasmussen and Perry, 2000) should be used to estimate design flows for drainage structures on unregulated rural streams with drainage areas over 640 ac. If the contributing drainage area (CDA) at drainage structure is less than 30 mi^2, the equations in Section 3.4.1 may be used. The Three-Variable Regression equations may be used as a check or comparison of the USGS regression equations (Section 3.4.1) for bridge structures. For culverts (see definition, Section 1.2) the peak flow should be determined by the Three-Variable Regression equations. If the contributing drainage area is 30 mi^2 or more, use the equations in Section 3.4.2. In most locations, the contributing drainage area is the same as total drainage area of the watershed. If the topographic map of the watershed shows substantial areas of depression that would not contribute runoff to the design point, these areas should be excluded from the contributing drainage area.

3.4.1 Regression Equations for CDA less than 30 square miles

Equations 3-12 through 3-18 are applicable to unregulated rural streams in Kansas with contributing drainage areas from 640 ac to 30 mi^2.

$$Q_2 = 0.0126\,(CDA)^{0.579}\,(P)^{2.824} \quad (3\text{-}12)$$

$$Q_5 = 0.300\,(CDA)^{0.600}\,(P)^{2.138} \quad (3\text{-}13)$$

$$Q_{10} = 1.224\,(CDA)^{0.611}\,(P)^{1.844} \quad (3\text{-}14)$$

$$Q_{25} = 4.673\,(CDA)^{0.622}\,(P)^{1.572} \quad (3\text{-}15)$$

$$Q_{50} = 10.26\,(CDA)^{0.628}\,(P)^{1.415} \quad (3\text{-}16)$$

$$Q_{100} = 19.80\,(CDA)^{0.634}\,(P)^{1.288} \quad (3\text{-}17)$$

$$Q_{200} = 34.68\,(CDA)^{0.640}\,(P)^{1.181} \quad (3\text{-}18)$$

where: Q_T = discharge with recurrence interval of T years (cfs)

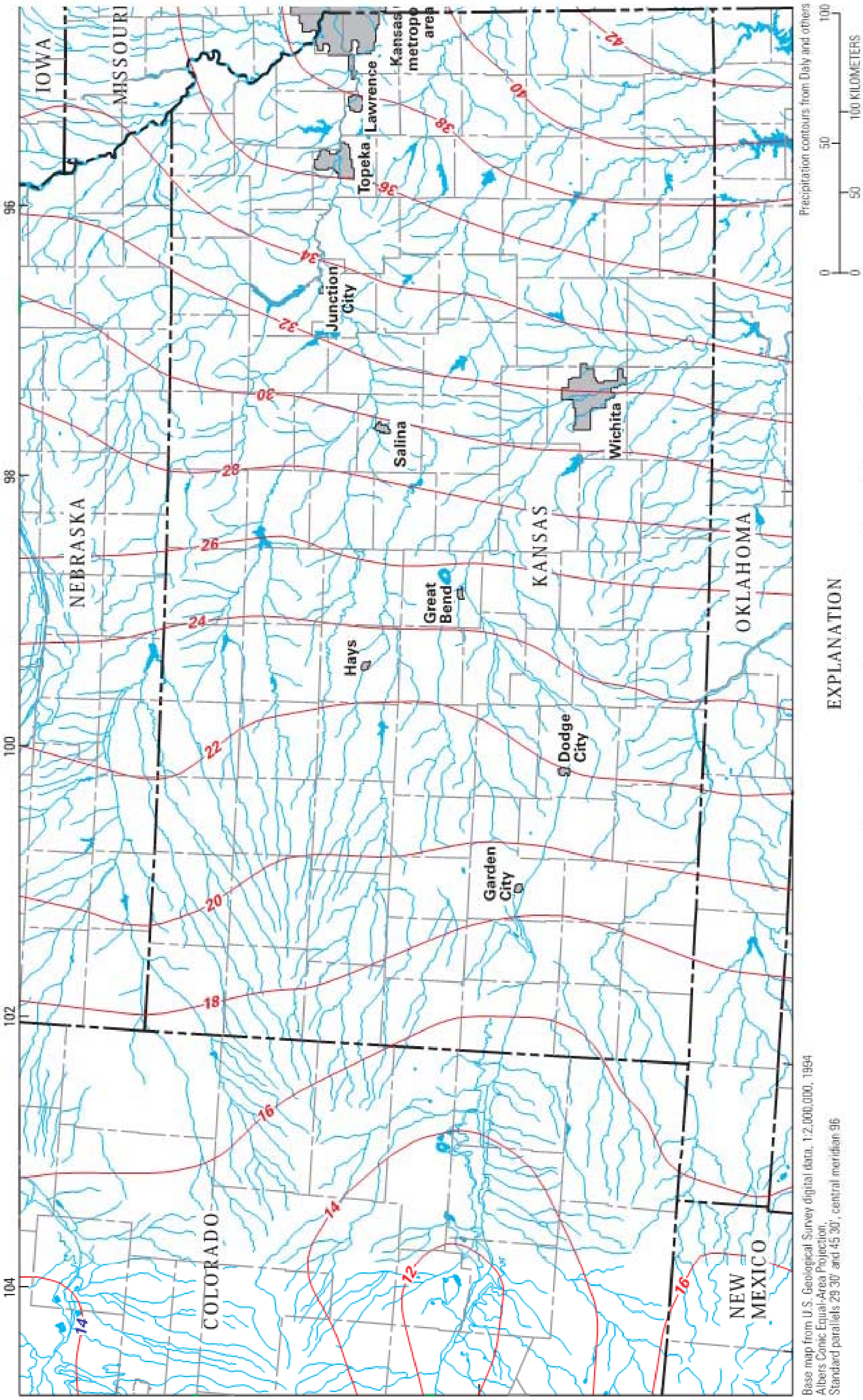
CDA = contributing drainage area (mi^2)

P = mean annual precipitation over the watershed (in.)

The mean annual precipitation is obtained from Figure 3.4.1-1. Estimate the mean annual precipitation at the centroid of the watershed by interpolation between the contour lines. Note:

Figure 3.4.1-1 should be used to obtain the mean annual precipitation, P, for use with USGS Regression Equations.

Figure 3.4.1-1 Mean Annual Precipitation (P) using the USGS Regression Method



3.4.2 Regression Equations for CDA greater than or equal to 30 square miles

The regression equations in this section are applicable to unregulated rural streams in Kansas with contributing drainage areas from 30 mi^2 to 9100 mi^2.

$$Q_2 = 0.00001477\ (CDA)^{0.646}\ (P)^{4.307}\ (Sl)^{0.527}\ (S)^{-0.174} \quad (3\text{-}19)$$

$$Q_5 = 0.001336\ (CDA)^{0.590}\ (P)^{3.373}\ (Sl)^{0.424}\ (S)^{-0.223} \quad (3\text{-}20)$$

$$Q_{10} = 0.01085\ (CDA)^{0.568}\ (P)^{2.945}\ (Sl)^{0.374}\ (S)^{-0.248} \quad (3\text{-}21)$$

$$Q_{25} = 0.0829\ (CDA)^{0.549}\ (P)^{2.532}\ (Sl)^{0.326}\ (S)^{-0.275} \quad (3\text{-}22)$$

$$Q_{50} = 0.283\ (CDA)^{0.539}\ (P)^{2.283}\ (Sl)^{0.298}\ (S)^{-0.293} \quad (3\text{-}23)$$

$$Q_{100} = 0.810\ (CDA)^{0.532}\ (P)^{2.070}\ (Sl)^{0.272}\ (S)^{-0.309} \quad (3\text{-}24)$$

$$Q_{200} = 2.050\ (CDA)^{0.526}\ (P)^{1.882}\ (Sl)^{0.250}\ (S)^{-0.324} \quad (3\text{-}25)$$

where: Q_T = discharge with recurrence interval of T years (cfs)

CDA = contributing drainage area (mi^2)

P = mean annual precipitation over the watershed (in.)

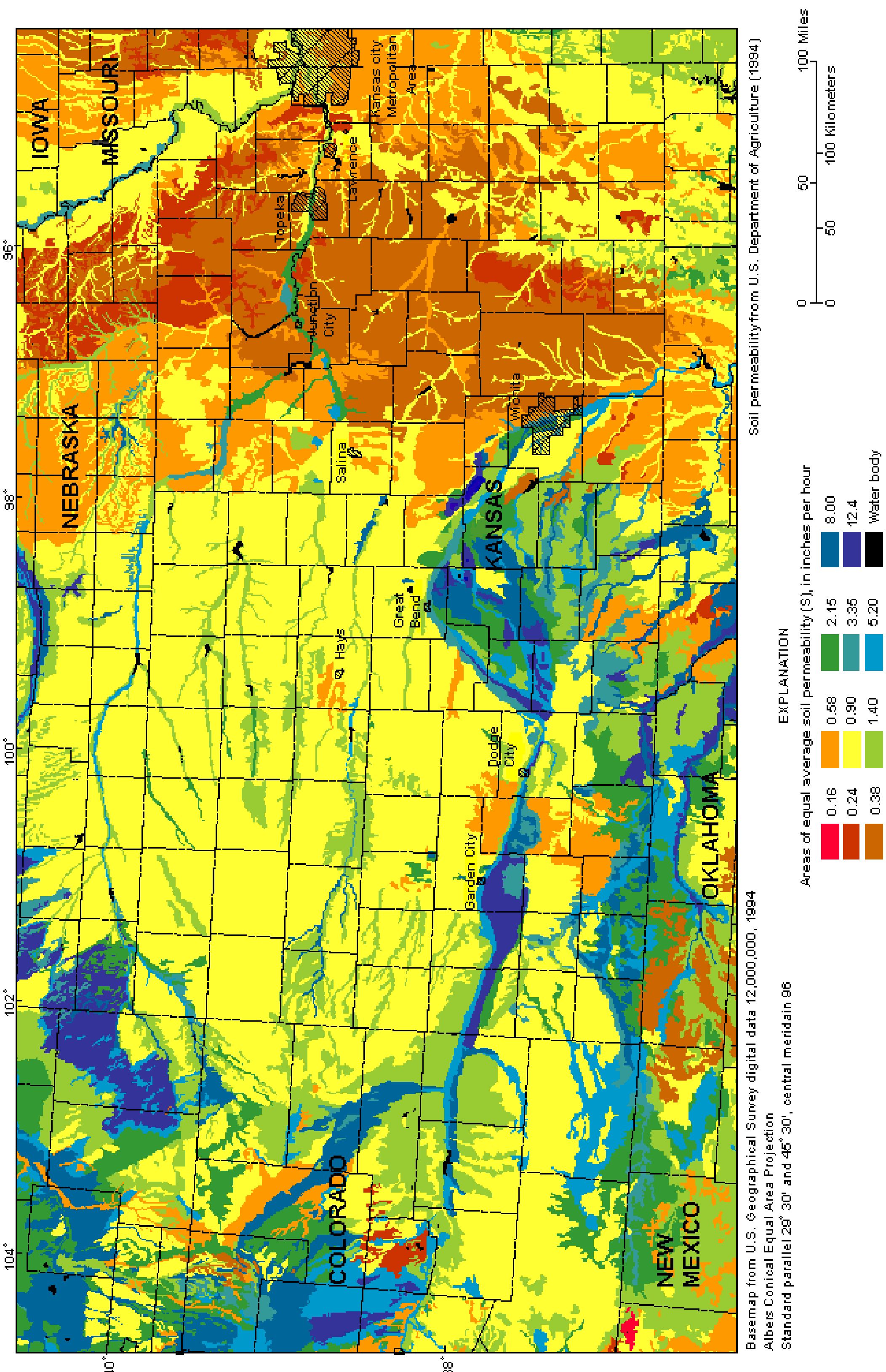
Sl = average slope of the main channel (ft/mi)

S = average soil permeability for the watershed (in./hr)

The mean annual precipitation over the watershed, P, is obtained from Figure 3.4.1-1. The average soil permeability for the watershed, S, is obtained from Figure 3.4.2-1. Note: Figure 3.4.1-1 should be used to obtain the mean annual precipitation, P, for use with USGS Regression Equations.

To determine the average slope of the main channel, Sl, identify the main channel on a topographic map and extend it up-gradient to the watershed boundary. Measure the total length of the extended channel. Locate two points on the main channel at 10% and 85% of the channel length, measured from the design point. The average slope of the main channel is defined as the elevation difference between the two points, divided by the length of channel between the points (75% of the total channel length).

Figure 3.4.2-1 Generalized Soil Permeability



3.4.3 Examples: Design Flows from USGS Regression Equations

Problem 1:

Compute the 25-year discharge for a stream crossing in northwestern Thomas County. The stream is unregulated and the watershed is rural. The contributing drainage area is 1.33 mi^2.

Solution:

The contributing drainage area (CDA) is smaller than 30 mi^2, so Equation 3-15 is applicable.

Obtain the mean annual precipitation, P, from Figure 3.4.1-1.

$$P = 19.0 \text{ in.}$$

Compute the 25-year discharge with Equation 3-15.

$$Q_{25} = 4.673\ (CDA)^{0.622}\ (P)^{1.572} = 4.673\ (1.33)^{0.622}\ (19.0)^{1.572} = 571 \text{ cfs}$$

Problem 2:

Estimate the 100-year discharge for a stream crossing in western Elk County. The stream is unregulated and the watershed is rural. The contributing drainage area is 47.5 mi^2. The average slope of the main channel, as defined in Section 3.4.2, is 14.3 ft/mi. The centroid of watershed is located near the southeast corner of Butler County.

Solution:

The contributing drainage area is larger than 30 mi^2, so Equation 3-24 is applicable.

Obtain the mean annual precipitation, P, from Figure 3.4.1-1 by interpolation.

$$P = 35.6 \text{ in.}$$

Obtain the generalized soil permeability, S, from Figure 3.4.2-1.

$$S = 0.38 \text{ in./hr}$$

Compute the 100-year discharge, Q_{100}, with Equation 3-24.

$$Q_{100} = 0.810\,(CDA)^{0.532}\,(P)^{2.070}\,(Sl)^{0.272}\,(S)^{-0.309}$$

$$= 0.810\,(47.5)^{0.532}\,(35.6)^{2.070}\,(14.3)^{0.272}\,(0.38)^{-0.309}$$

$$= 28{,}600 \text{ cfs}$$

3.5 FLOOD HYDROGRAPH SIMULATION METHOD

3.5.1 Overview

Flood hydrograph simulation should be used for detention storage analysis of culverts and bridges. It may also be used in situations where the peak flow at a culvert or bridge would be affected significantly by a permanent lake or detention structure upstream.

If the watershed does not contain any significant lakes or detention structures, it can usually be modeled as a single unit. Watersheds that contain significant storage elements should be modeled with multiple subbasins. The watershed can also be subdivided to account for major differences in hydrologic characteristics (e.g., land use, soils or topography). If the watershed is subdivided, a hydrograph is computed for each subbasin. Subbasin hydrographs are routed downstream through channel reaches and storage elements and are combined at junctions.

3.5.2 Computer Programs

Flood hydrograph simulation should be performed with the HEC-HMS computer program or the HEC-1 computer program of the U. S. Army Corps of Engineers. Both of these computer programs are in the public domain.

3.5.3 Design Storms

Design storms for flood hydrograph simulation should be frequency-based hypothetical storms of the type generated by HEC-1 and HEC-HMS. The appropriate duration of the design storm depends on the recurrence interval and the location. Table 3.5.3-1 shows the recommended storm durations. Figure 3.5.3-1 defines the eastern and western hydrologic regions of Kansas. The rainfall depth-duration-frequency data required by HEC-1 and HEC-HMS should be obtained from KDOT's *Precipitation Frequency Tables for Counties in Kansas*(2014).

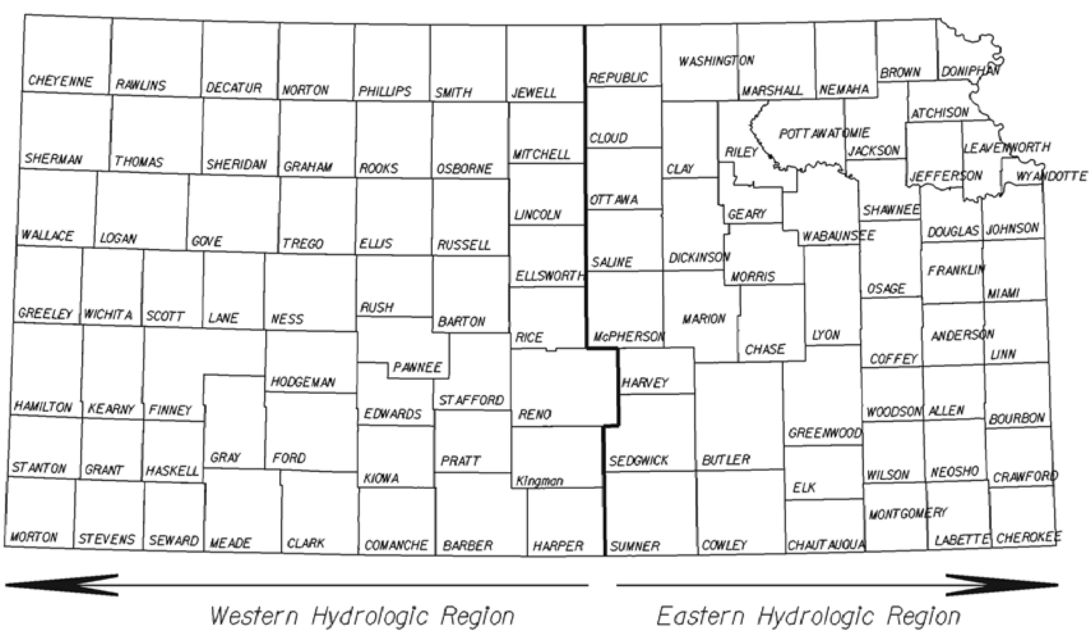
Table 3.5.3-1 Storm Duration and Antecedent Moisture Condition (AMC) for Flood Hydrograph Simulation

Recurrence Interval (years)	Eastern Region*		Western Region*	
	Storm Duration (hours)	AMC	Storm Duration (hours)	AMC
2	6	2	3	2
5	6	2	3	2
10	12	2	3	2
25	24	2	6	2
50	24	$2^{1}/_{4}$	6	2
100	24	$2^{3}/_{4}$	12	2

*See Fig. 3.5.3-1

Source: KDOT Report No. K-TRAN: KU-02-04

Figure 3.5.3-1 Eastern and Western Hydrologic Regions of Kansas



3.5.4 Rainfall-Runoff Model

The runoff generated by the design storm should be computed by the NRCS curve-number method. The runoff curve number, CN, depends on three factors: the Hydrologic Soil Group (HSG), the cover type, and the Antecedent Moisture Condition (AMC).

The Hydrologic Soil Group (A, B, C or D) is an indicator of the rate at which water can move downward through the soil profile. Group A soils have the lowest runoff potential, and Group D soils have the highest runoff potential. NRCS Technical Release 55, *Urban Hydrology for Small Watersheds,* provides a complete listing of HSG classifications for various NRCS soil types in the United States. Soil types are mapped in the NRCS county soil survey reports. Some county soil survey reports also list HSG classifications.

Soils that have been disturbed significantly by construction or urban development can have a higher runoff potential than undisturbed soils. 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 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).

In the NRCS curve-number method, the antecedent moisture condition (AMC) is represented by a number that can range from 1 (very dry) to 3 (very wet). Table 3.5.3-1 lists the appropriate antecedent moisture conditions for design applications in Kansas.

Table 3.5.4-1 provides guidance for the estimation of runoff curve numbers for AMC 2. Table 3.5.4-2 gives the equivalent runoff curve numbers for AMC 2¼, AMC 2½, AMC 2¾ and AMC 3. The watershed or subbasin should be assigned a curve number equal to the area-weighted average of the curve numbers for the included land uses and soil types. The example in Section 3.5.4.1 illustrates the procedure.

Table 3.5.4-1 NRCS Runoff Curve Numbers for AMC 2

Fully Developed Urban Areas (vegetation established)					
Cover Description		**Curve Numbers for hydrologic soil group**			
		A	**B**	**C**	**D**
Open space (lawns, parks, golf courses, cemeteries, etc)	Poor condition (grass cover <50%)	68	79	86	89
	Fair condition (grass cover 50 to 75%)	49	69	79	84
	Good Condition (grass cover >75%)	39	61	74	80
Impervious areas	Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	98	98	98	98
Streets and roads	Paved, curbs and storm sewers (excluding right-of-way)	98	98	98	98
	Paved, open ditches (including right-of-way)	83	89	92	93
	Gravel (including right-of-way)	76	85	89	91
	Dirt (including right-of-way)	72	82	87	89
Western desert urban areas	Natural desert landscaping (pervious area only)	63	77	85	88
	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand gravel mulch and basin borders)	96	96	96	96
Urban districts	Commercial and business (85% imp.)	89	92	94	95
	Industrial (72% imp.)	81	88	91	93
Residential districts by average lot size	1/8 acre or less (town houses) (65% imp.)	77	85	90	92
	1/4 acre (38% imp.)	61	75	83	87
	1/3 acre (30% imp.)	57	72	81	86
	1/2 acre (25% imp.)	54	70	80	85
	1 acre (20% imp.)	51	68	79	84
	2 acre (12% imp.)	46	65	77	82

Developing urban areas				
Cover Description	**Curve Numbers for hydrologic soil group**			
	A	**B**	**C**	**D**
Newly graded areas (pervious area only, no vegetation)	77	86	91	94

Cultivated agricultural lands						
Cover Description			**Curve Numbers for hydro-logic soil group**			
Cover type	**Treatment [A]**	**Hydrologic condition**	**A**	**B**	**C**	**D**
Fallow	Bare soil	----	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR+ CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + R	Poor	65	73	79	81
		Good	61	70	77	80

Cultivated agricultural lands (continued)						
Cover Description			Curve Numbers for hydrologic soil group			
Cover type	Treatment [A]	Hydrologic condition	A	B	C	D
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + R	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[A] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

Other agricultural lands					
Cover Description		**Curve Numbers for hydrologic soil group**			
Cover type	**Hydrologic condition**	**A**	**B**	**C**	**D**
Pasture, grassland, or range - continuous forage for grazing. [A]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow - continuous grass, protected from grazing and generally mowed by hay.	-----	30	58	71	78
Brush - brush-weed-grass mixture with brush the major element. [B]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[C]	48	65	73
Woods - grass combination (orchard or tree farm). [D]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [E]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads - buildings, lanes, driveways, and surrounding lots.	-----	59	74	82	86

[A] Poor: <50% ground cover or heavily grazed with no mulch; Fair: 50-75% ground cover and not heavily grazed; Good > 75% ground cover and light or only occasional grazed.

[B] Poor:<50% ground cover; Fair: 50-75% ground cover; Good >75% ground cover.

[C] Actual curve number is less than 30; use CN=30 for runoff computation.

[D] CN’s shown were computed for areas with 50% wood and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN’s for woods and pasture.

[E] Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning; Fair: Woods are grazed but not burned, and some forest litter covers the soil; Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

<table>
<tr><th colspan="6">Arid and semiarid rangelands</th></tr>
<tr><th colspan="2">Cover Description</th><th colspan="4">Curve Numbers for hydrologic soil group</th></tr>
<tr><th>Cover type</th><th>Hydrologic condition</th><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td rowspan="3">Herbaceuous - mixture of grass, weeds, and low-growing brush, with brush the minor element</td><td>Poor</td><td>----</td><td>80</td><td>87</td><td>93</td></tr>
<tr><td>Fair</td><td>----</td><td>71</td><td>81</td><td>89</td></tr>
<tr><td>Good</td><td>----</td><td>62</td><td>74</td><td>85</td></tr>
<tr><td rowspan="3">Oak-aspen-mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush</td><td>Poor</td><td>---</td><td>66</td><td>74</td><td>79</td></tr>
<tr><td>Fair</td><td>----</td><td>48</td><td>57</td><td>63</td></tr>
<tr><td>Good</td><td>----</td><td>30</td><td>41</td><td>48</td></tr>
<tr><td rowspan="3">Pinyon-juniper-pinyon, juniper, or both, grass understory</td><td>Poor</td><td>----</td><td>75</td><td>85</td><td>89</td></tr>
<tr><td>Fair</td><td>----</td><td>58</td><td>73</td><td>80</td></tr>
<tr><td>Good</td><td>----</td><td>41</td><td>61</td><td>71</td></tr>
<tr><td rowspan="3">Stagebrush with grass understory</td><td>Poor</td><td>----</td><td>67</td><td>80</td><td>85</td></tr>
<tr><td>Fair</td><td>----</td><td>51</td><td>63</td><td>70</td></tr>
<tr><td>Good</td><td>----</td><td>35</td><td>47</td><td>55</td></tr>
<tr><td rowspan="3">Desert shrub-major plants include saltbrush, greasewood, creosotebrush, blackbrush, bursage, palo verde, mesquite, and catus.</td><td>Poor</td><td>63</td><td>77</td><td>85</td><td>88</td></tr>
<tr><td>Fair</td><td>55</td><td>72</td><td>81</td><td>86</td></tr>
<tr><td>Good</td><td>49</td><td>68</td><td>79</td><td>84</td></tr>
<tr><td colspan="6">[A] Poor:<30% ground cover (litter, grass, and brush overstory); Fair: 30 to 70% ground cover; Good >70% ground cover.</td></tr>
<tr><td colspan="6">[B] Curve number for group A have been developed only for desert shrub.</td></tr>
</table>

Sources: NRCS Technical Release No.55 and NRCS *National Engineering Handbook, Section 4, Chapter 9*

Table 3.5.4-2 Equivalent Runoff Curve Numbers for AMC 2¼, 2½, 2¾ and 3

CN for AMC 2	Equivalent CN for				CN for AMC 2	Equivalent CN for			
	AMC 2¼	AMC 2½	AMC 2¾	AMC 3		AMC 2¼	AMC 2½	AMC 2¾	AMC 3
100	100	100	100	100	62	66	71	75	79
99	99	100	100	100	61	65	70	74	78
98	99	99	100	100	60	65	69	74	78
97	98	98	99	99	59	64	68	73	77
96	97	98	98	99	58	63	67	72	76
95	96	97	97	98	57	62	66	71	75
94	95	96	97	98	56	61	66	70	75
93	94	96	97	98	55	60	65	69	74
92	93	95	96	97	54	59	64	68	73
91	93	94	96	97	53	58	63	67	72
90	92	93	95	96	52	57	62	66	71
89	91	93	94	96	51	56	61	65	70
88	90	92	93	95	50	55	60	64	69
87	89	91	93	95	49	54	59	63	68
86	88	90	92	94	48	53	58	62	67
85	87	90	92	94	47	52	57	61	66
84	86	89	91	93	46	51	56	60	65
83	86	88	91	93	45	50	55	59	64
82	85	87	90	92	44	49	54	58	63
81	84	87	89	92	43	48	53	57	62
80	83	86	88	91	42	47	52	56	61
79	82	85	88	91	41	46	51	55	60
78	81	84	87	90	40	45	50	54	59
77	80	83	86	89	39	44	49	53	58
76	79	83	86	89	38	43	48	52	57

Table 3.5.4-2 Equivalent Runoff Curve Numbers for AMC 2¼, 2½, 2¾ and 3

CN for AMC 2	Equivalent CN for				CN for AMC 2	Equivalent CN for			
	AMC 2¼	AMC 2½	AMC 2¾	AMC 3		AMC 2¼	AMC 2½	AMC 2¾	AMC 3
75	78	82	85	88	37	42	47	51	56
74	78	81	85	88	36	41	46	50	55
73	77	80	84	87	35	40	45	49	54
72	76	79	83	86	34	39	44	48	53
71	75	79	82	86	33	38	43	47	52
70	74	78	81	85	32	37	42	46	51
69	73	77	80	84	31	36	41	45	50
68	72	76	80	84	30	33	37	40	43
67	71	75	79	83	25	28	31	34	37
66	70	74	78	82	20	23	25	28	30
65	69	74	78	82	15	17	19	20	22
64	68	73	77	81	5	7	9	11	13
63	67	72	76	80					

Source: NRCS National Engineering Handbook, Section 4, Chapter 10

3.5.4.1 Example: Runoff Curve Number for Design Event

Problem:

A culvert to be designed for detention storage is located in the eastern region of Kansas. The recurrence interval is 100 years. The 101-ac watershed includes 21 ac of woods in good hydrologic condition with group B soil, 50 ac of pasture in fair hydrologic condition with group C soil, and 30 ac of contoured row crops in good hydrologic condition with group B soil. Determine the weighted curve number for the design event.

Solution:

Obtain the CN for the average antecedent moisture condition, AMC 2, for each combination of land use and Hydrologic Soil Group (HSG) from Table 3.5.4-1.

Land cover	HSG	CN for AMC 2	Area A (ac)	A · CN
Row crops, contoured, good condition	B	75	30	2250
Pasture, fair condition	C	79	50	3950
Woods, good condition	B	55	21	1155
			101	7355

$$\text{Weighted CN for AMC 2} = \frac{\sum A \cdot CN}{\sum A} = \frac{7355}{101} = 72.8 \text{ (round to CN = 73)}$$

For a 100-year recurrence interval in eastern Kansas, use AMC 2¾ (Table 3.5.3-1).

Obtain the equivalent CN for AMC 2¾ from Table 3.5.4-2.

CN = 84

3.5.5 Streamflow Hydrographs

Streamflow hydrographs should be computed by the NRCS dimensionless unit hydrograph procedure. Basin lag times should be computed with Equation 3-26 or Equation 3-27. If no more than 3% of the drainage area is impervious, use Equation 3-26. If the impervious percentage is greater than 3%, use Equation 3-27.

$$T_{lag} = 0.0221 \left[\frac{L}{\sqrt{Sl}}\right]^{0.66} \quad \text{for } R_i \leq 0.03 \qquad *(3\text{-}26)$$

$$T_{lag} = 0.0112 \left[\frac{L(1-0.75R_c)}{\sqrt{S}}\right]^{0.87} [W(1+2.0R_i)]^{-0.26} \quad \text{for } R_i > 0.03 \text{ or } R_c > 0.03 \qquad (3\text{-}27)$$

where: T_{lag} = basin lag time (minutes)

A = drainage area (acres)

L = length of the longest flow path (ft), measured from a point on the drainage divide to the watershed outlet or design point.

S = slope of longest flow path (ft/ft), defined as the total fall in elevation divided by the flow-path length

Sl = average slope of the longest flow path (ft/ft), defined as the elevation difference between two points on the drainage path, located at 10% and 85% of the path length (measured from the design point), divided by the path length between the points (0.75 L).

W = average width of the watershed (ft), defined as A/L

R_c = channel development ratio (dimensionless), defined as the fraction of the longest flow path with low frictional resistance (e.g., pavements, gutters, enclosed conduits, and channels with paved bottoms)

R_i = impervious area ratio (dimensionless), defined as the fraction of the drainage area covered by impervious surfaces = (impervious area) / (total drainage area)

*Equation 11-26, is applicable to watersheds in Kansas with $L/Sl^{0.5} < 1.6 \times 10^6$ ft.

3.5.6 Channel Routing

Channel routing accounts for travel time and storage effects as a flood wave passes through a reach of channel. Channel routing should be performed by the Muskingum Cunge method (U. S. Army Corps of Engineers, 2000). The required inputs are the length and average slope of the channel reach, a typical channel cross section that includes the overbank regions, and Manning's roughness coefficients for the main channel and the left and right overbank regions. Table 3.5.6-1 provides guidance for estimation of Manning's roughness coefficients for channels and floodplains.

Table 3.5.6-1 Manning's Roughness Coefficients for Minor Streams and Floodplains

Type of Channel and Description	Minimum	Normal	Maximum
Minor Streams (top width at flood stage < 100 feet)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravel, cobbles, and a few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070

Note: Table continued on next page

Table 3.5.6-1 Manning's Roughness Coefficients for Minor Streams and Floodplains

Type of Channel and Description		Minimum	Normal	Maximum
Floodplains				
a.	Pasture, no brush			
	1. Short grass	0.025	0.030	0.035
	2. High grass	0.030	0.035	0.050
b.	Cultivated areas			
	1. No crop	0.020	0.030	0.040
	2. Mature row crops	0.025	0.035	0.045
	3. Mature field crop	0.030	0.040	0.050
c.	Brush			
	1. Scattered brush, heavy weeds	0.035	0.050	0.070
	2. Light brush and trees, in winter	0.035	0.050	0.060
	3. Light brush and trees, in summer	0.040	0.060	0.080
	4. Medium to dense brush, in winter	0.045	0.070	0.110
	5. Medium to dense brush, in summer	0.070	0.100	0.160
d.	Trees			
	1. Dense willows, summer, straight	0.110	0.150	0.200
	2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
	3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
	4. Heavy stand of timber, a few down trees, little under-growth, flood stage below branches	0.080	0.100	0.120
	5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160

Source: Chow, *Open-Channel Hydraulics* (1959)

3.5.7 Reservoir Routing

Reservoir routing accounts for the effect of storage attenuation on the hydrograph as the flood wave passes through a lake or detention storage site. Reservoir routing should be performed by the standard level-pool method incorporated in HEC-HMS and HEC-1. The required inputs are a stage-discharge (outflow) relationship and a stage-storage or stage-area relationship. Stage-discharge relationships for culverts should be developed by the procedures in Section 6.5. An example of reservoir routing for detention storage design is presented in Section 6.5.

3.6 REFERENCES

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