

<i>D</i>rainage	<i>Chapter</i> HYDROLOGY
	<i>Subject</i> Fundamentals

DR 401-1 GENERAL INFORMATION

One of the first steps in the analysis and design of a drainage system is to determine discharges for a range of storms used to analyze the system. These storms range from a channel-forming storm to a maximum probable storm.

A conservative design approach would be to build all structures to withstand an infrequent event, such as the 100 year storm or the 500 year storm. However, this type of approach may not be economical when compared to the benefits that are obtained.

It must be realized that any hydrologic analysis is only an approximation. The relationship between the amount of precipitation on a drainage basin and the amount of runoff from the basin is complex. There is not enough data available on the factors influencing the rainfall–runoff relationship to expect exact solutions. Compounding this problem is the significant variation in the amount of runoff from different surfaces. On some surfaces, such as paved areas, nearly all of the rainfall will translate to surface runoff. However on other surfaces such as forested areas, much of the rainfall will be absorbed, and a small percentage will be translated into runoff.

This document deals with the reasonable engineering estimation of peak runoff and runoff hydrographs. Numerous empirical formulas have been developed to simplify this complex process of determining design discharges. Because each method requires user-supplied parameters, they give the designer great latitude in developing a drainage model, and therefore, the potential for varying results from different design engineers exists.

Available analytical methods can be grouped into the two broad categories of deterministic and statistical methods. Deterministic methods (rational formula, NRCS Unit Hydrograph) strive to model the physical aspects of the rainfall-runoff process while statistical methods (USGS Regional Methods) utilize measured data to fit functions that represent the process.

Hydrologic methods other than those detailed in this manual may be used if circumstances warrant their use. In the event that other methods are used, they must be justified and documented in the Drainage Folders (See DR 300).

DR 401-2 HYDROLOGY

Hydrology is the science dealing with the occurrence and movement of water upon and beneath the land areas of the earth. It overlaps and includes portions of other sciences such as meteorology and geology. The sequence of events, called the "hydrologic cycle," describes the various movements of water as it relates to the earth. These processes of water movements are:

- Precipitation
- Infiltration
- Evaporation, transpiration, interception
- Surface runoff
- Subsurface runoff and storage

The drainage engineer is concerned with surface runoff and relationships of rainfall to surface runoff. Total losses constitute the difference between total rainfall and the surface runoff available from that rainfall. Precipitation minus infiltration, evaporation, transpiration, interception, and groundwater storage equals surface runoff. Typically only total loss is considered in drainage investigations. In general, no attempt is made to evaluate separate losses. Surface runoff is sometimes called "excess rainfall."

DR 401-3 SURFACE RUNOFF

Runoff comprises the movement of water overland or through channels. Runoff is affected by variations in precipitation. These variations may be characterized by:

- Seasonal fluctuations
- Long-term variations as cycles of droughts and floods over periods of many years

Runoff rate is influenced by:

- Topographic features
- Geological formations
- Soil
- Vegetal cover
- Land usage

Runoff from small drainage areas (less than ten square miles) is affected by factors of physiography usually differing from those used for river basins.

Factors affecting runoff from small drainage areas are:

- Topography
- Soil type and depth
- Shape and slope of area
- Land usage
- Vegetal cover
- Condition and season of crops
- Method of tillage
- Antecedent soil moisture

- Stream patterns
- Pondage

Factors influencing runoff in river basins are:

- Topography, geology, and soil provinces
- Size and shape of basin
- Size and shape of tributary watershed
- General vegetal cover
- Infiltration losses
- Depression storage
- Channel storage

The foregoing factors may have greater influence on runoff rates and volumes than rainfall intensity alone. Frequency of peak runoff is not always the same as recurrence of like rainfall intensities in an area. Peak rate of runoff produced by rainfall of given amounts, distribution, and intensities cannot be expected to occur as often as such rainfall recurrence.

When physiographic factors remain the same in any one drainage area, then high-intensity, short-duration rainfall generates a high rate of runoff. Low-intensity, long-duration rainfall generates a low rate of runoff, but the total volume of runoff may be higher than indicated by high-intensity, short-duration rainfall. Runoff rates (quantity of flow per unit of time) and runoff peaks should be based on actual runoff measurement records (whenever possible) rather than rainfall relationships.

DR 401-4 PEAK FLOW VS. HYDROGRAPH METHOD

A consideration of peak flow rates for design is generally adequate for conveyance systems (e.g., storm drains or open channels). However, if the design must include flood routing (e.g. detention basins or complex conveyance networks), a flood hydrograph is usually required. Development of runoff hydrographs is usually accomplished using computer programs or tabular methods. Where storage is a significant factor and the drainage basin can be divided into homogeneous sub basins, hydrograph methods should provide better flow estimates.

DR 401-5 PEAK FLOW METHODS

There are two methods recommended by the cabinet to determine peak flows:

- Rational Method ($Q = CIA$)
(Use Kinematic Wave Time of Concentration)
Refer to Section DR 403
- Regional Method (Refer to USGS Water-Resources Investigations Report 03-4180, "Estimating the Magnitude of Peak Flows for Streams in Kentucky for Selected Recurrence Intervals," published 2003)
Refer to Section DR 404

DR 401-6 HYDROGRAPH METHODS

When performing hydrographic calculations, the Natural Resources Conservation Service (NRCS) Unit Hydrograph Method is recommended for use on KYTC projects. This method is discussed in DR 405.

DR 401-7 KARST CONSIDERATIONS

Kentucky is unique from a geologic standpoint because about 55% of Kentucky is underlain by rocks that have the potential for karst development. Approximately 38% of the state has at least some karst development recognized, and 25% of the state is known to have well developed karst features (Kentucky Geological Survey Information Circular 4). Well-developed karst terrain is typically characterized by sinkholes, sinking streams, subterranean drainage, caves, and springs.

The amount of runoff reaching a highway structure in a karst area may be reduced by water being intercepted by a karst feature. Due to the uncertainty and inaccuracy in determining existing and future hydraulic capabilities of karst features, drainage areas are generally not reduced in the runoff calculations due to the presence of karst topography. Refer to DR 202 for additional discussion.

DR 401-8 FLOOD INSURANCE STUDIES

Flood Insurance Studies (FIS) are a valuable resource for hydrologic calculations. In order to meet National Flood Insurance Program (NFIP) requirements, Flood Insurance Study flows shall be used when assessing flooding impacts in detailed FEMA study areas (See DR 204). If the FIS hydrologic methods are outdated or invalid, revised flows may be used for design purposes. If revised flows are used, the decision will need to be made if it is appropriate to recommend a revision to the flood insurance study. This will have to be coordinated with the Division of Water and the local floodplain coordinator. Refer to Chapter 2 for additional guidance on flood insurance studies.

DR 401-9 LOCAL METHODS

Some local jurisdictions may have preferred peak runoff and/or hydrograph calculation techniques. When requested by these jurisdictions, the project team and the central office drainage engineer may agree to use these methods if it is deemed feasible.

DR 401-10 FULLY DEVELOPED WATERSHED CONDITIONS

The possibility of future development can be considered in hydrologic calculations if the project team determines it is appropriate to do so or at the request of a local jurisdiction. This can be accomplished by assuming urbanized conditions (more impervious surfaces) in areas of the watershed that have the potential for future development. This potential can be based on zoning information or other data available from local city or county governments.

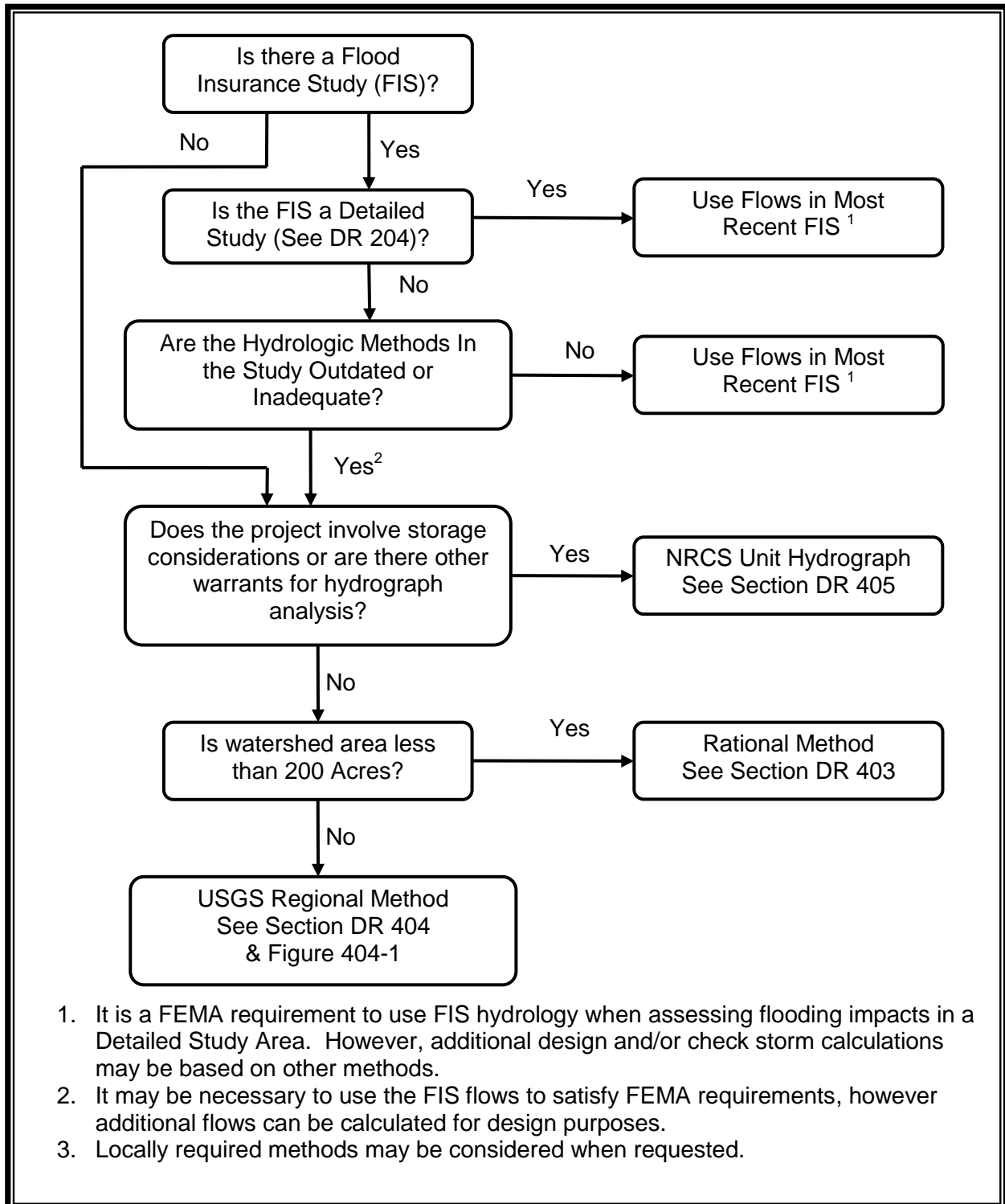


Figure 401-1 Hydrologic Methods Flowchart

DR 401-11 PRECIPITATION FREQUENCY DATA

In 2004, the National Oceanic and Atmospheric Administration released “NOAA Atlas 14 Volume 2 for the Ohio Valley Region.” The document provides documentation behind the Precipitation Frequency Data Server available on NOAA website at: http://hdsc.nws.noaa.gov/hdsc/pfds/orb/ky_pfds.html.

The Data Server allows the user to generate intensity values and rainfall depths for individual locations. The user can input the Latitude and Longitude of a location in Kentucky, and the interface will create unique rainfall intensity and depth data based on the site’s geographic location.

The rainfall intensities used in the Rational Method (DR 403) and the rainfall depths required for the NRCS Unit Hydrograph Method (DR 405) shall be obtained from this server, unless locally required information is available, or as noted elsewhere in this manual.

Although each project will require the acquisition of this data, it can be used for all calculations on the project. The designer will need to determine the latitude and longitude for a representative location on the project. The data will be extracted for this location. The location should be based near the geographic center of the project.

The information needed to obtain the required rainfall data is selected from pull downs or entered into fields on the Precipitation Frequency Data Server website. The data entry section of the website is shown in Figure 401-2. The site contains a pull down that allows the user to select a data type of “precipitation depth” or “precipitation intensity”. Ensure that “partial duration” is selected for time series type and English units are selected when acquiring this data. The latitude and longitude will be entered into the field in section 2.2.

Once the above data are entered, the user hits “Submit Location” button to retrieve the data. The resulting pop up window will contain a report for the point precipitation data. The contents of this report are required documentation in the drainage folder for the project.

1. DATA DESCRIPTION:
Data type:
Units:
Time series type:

2. SELECT LOCATION:
Choose one of the following options:

2.1 Select site from list:

2.2 Enter location:
Latitude (decimal degrees):
Longitude (decimal degrees):

2.3 Click on map to select location information:
Latitude:
Longitude:

Figure 401-2
Data Entry Section of Precipitation Frequency Data Server



Drainage	<i>Chapter</i> HYDROLOGY
	<i>Subject</i> Return Interval

DR 402-1 GENERAL INFORMATION

Because it is not economically feasible to design a structure for the maximum runoff a watershed is capable of producing, KYTC has attempted to balance the costs of designing and constructing drainage facilities with the benefits and risks associated with the drainage structure. This is accomplished by analyzing drainage structures by using storm discharges that vary according to the risk involved.

Table 402-1 reflects the results of evaluating these issues and lists the various storms used to analyze drainage systems for the Cabinet.

The discharges used to analyze drainage systems are based on storms that are anticipated to recur within a specified return interval (also called recurrence interval, return period or flood frequency). The return interval is the average time interval between occurrences of a hydrologic event of a given or greater magnitude, usually expressed in years. The return interval is based on the average statistical time between storm events. Therefore a 50 year storm is expected to occur on average every 50 years.

The probability of a flood event being exceeded in a given time period (usually one year) is termed the exceedance probability. The exceedance probability (based on a one year period) is related to the return interval by the following equation: $\text{Return Interval} = 1 / \text{Exceedance Probability}$. Thus a storm with a 50-year return interval has a 1/50, or 2%, chance of recurring in any particular year.

Drainage facilities are analyzed using multiple storms of differing return intervals. The reason for this is that each analysis involving these various return intervals have different purposes and risks associated with them. The two primary types of storms used to analyze drainage systems are the Design Storm and the Check Storm. The return intervals used for these storms are based on the traffic volume, potential flood hazard to property, expected level of service, and the risk associated with damages from larger flood events.

DESIGN STORM

The “design storm” or “design discharge” is primarily used to evaluate the level of protection that the drainage facility provides for the roadway. As can be seen

from Table 402-1, the return intervals used to determine the design discharge are different for each type of drainage facility and the size of the road facility.

The design discharge values are used to evaluate the drainage facilities ability to meet certain design criteria. These criteria differ according to the type of drainage facility and the intended purpose of each drainage facility. These criteria are discussed in the applicable chapters in this manual for the type of facility being analyzed (culvert, bridge, storm sewer, etc).

CHECK STORM

The “Check Storm” is used to determine the off-site impacts to surrounding property and to evaluate the facilities performance under more severe flooding conditions. The 100 year storm (1%) is the standard most used to determine the impacts to surrounding properties. The National Flood Insurance Program (NFIP) specifies the use of the 100 year storm (1%) for this purpose. More information on the NFIP requirements for drainage facilities is presented in DR 200. The NFIP requirements generally apply to watersheds larger than one square mile and are based primarily on damage to insurable buildings.

Refer to the appropriate chapter for the drainage facility in question to determine how to apply the check storms.

DOMINANT DISCHARGE (CHANNEL FORMING STORM)

For drainage systems involving natural channels, the channel forming storm should also be considered. This discharge is also referred to as the dominant discharge or the bank full discharge. Although there are a multitude of definitions for this storm, it is commonly taken to be the two year (50%) storm. As the name implies, the channel forming storm is the flow primarily responsible for shaping the channel section. As such, modifications to the flow regime for this storm can lead to channel instability. The channel forming storm also has environmental significance and is used to determine the ordinary high water mark when quantifying stream impacts.

DR 402-2 APPLICATION

The following table shows appropriate return intervals for each indicated situation. Design storm return intervals are indicated by a “D”. Check storms are denoted by a “C”. Other storms that are required to meet a specific purpose are indicated by an “X”. See the appropriate chapter for the type of drainage facility being designed for discussion on how these storms are used to analyze the facility.

Table 402-1, Return Intervals for Drainage Analysis								
Situation		Return Interval (years)						
Structure	ADT Limits	2	5	10	25	50	100	500
Bridge Size Structure (Span ≥ 20')	ADT < 400			D			C	
	400 < ADT < 2,000				D		C	
	2,000 < ADT					D	C	
	Interstate					D	C	
Culvert or Lateral Storm Sewer in a Sag	ADT < 400			D			C	
	400 < ADT < 2,000				D		C	
	2,000 < ADT				D		C	
	Interstate					D	C	
Bridge Scour Analysis							D ⁽¹⁾	C
Storm Sewer				D ⁽²⁾			X	
Inlet Spread				D ⁽³⁾				
Channel Change		X		D			C	
Roadway Ditch capacity / Ditch Lining shear				D			X	
Drop Inlet				D			X	
Detention or Retention Basin		D		D			D, X	
Risk Analysis		X	X	X	X	X	X	
No Impact Certification							X	
Letter of Map Revision (FEMA)				X		X	X	X

- (1) If the overtopping storm is less than the 100 year storm (1%), it should be used as the design storm to calculate scour.
- (2) Storm sewer pipes which drain at sag points where runoff can only be removed through the storm system should be designed for a 25-year storm (4%). Storm Sewers on interstates should be checked to ensure that the hydraulic grade line resulting from the 50 year storm (2%) does not surcharge into the roadway.
- (3) Pavement inlet spacing spread calculations shall be based on four (4) in/hr Rainfall intensity.



<h1>Drainage</h1>	<small>Chapter</small> HYDROLOGY
	<small>Subject</small> Rational Method

DR 403-1 INTRODUCTION

KYTC's standard practice is to use the Rational Method for determining peak flow from drainage areas less than 200 acres. Although the 200 acre limitation is a widely used standard upper limit for the Rational Method, engineering judgment should be used to determine if a watershed smaller than 200 acres requires other methods. The Rational Method formula estimates discharge according to the equation below. The accuracy of this formula is highly dependent upon the user's ability to select an appropriate runoff coefficient and to calculate the time of concentration.

**EQUATION 403-1
RATIONAL FORMULA**

$$Q = C \times I \times A$$

Where:

- Q = Peak runoff discharge (ft³/s)
- C = Runoff Coefficient for the drainage area
- I = Average Rainfall intensity (inch/hr) for a duration equal to the time of concentration, T_c
- A = Drainage area (acres)

DR 403-2 RATIONAL METHOD ASSUMPTIONS

It is useful for the designer to understand the assumptions behind the Rational Method.

- Peak discharge is assumed to occur when the entire watershed is contributing to the flow.
- Rainfall Intensity is assumed to be uniform across the entire drainage area and for a duration equal to the time of concentration (T_c).
- The return interval for the peak flow rate is the same as that of the average rainfall intensity for a given time of concentration (i.e., the 10 year rainfall intensity produces the 10 year peak runoff).
- The fraction of rainfall that becomes runoff, also known as the runoff coefficient (C), is assumed to be independent of rainfall intensity, volume, or

antecedent moisture conditions. It is also assumed to be constant over the course of the entire rainfall duration.

DR 403-3 RUNOFF COEFFICIENT (C)

Only a portion of the total storm water falling on an area will reach the drainage structure. Many factors govern the percent of runoff, including rate of evaporation, rate of transpiration, volume of infiltrated water, and volume of ponded water. The runoff coefficient attempts to condense all of these factors into one value. Table 403-1 lists typical C values for various land coverage types:

Table 403-1. Runoff Coefficients for Rational Formula	
Type of Drainage Area	Runoff Coefficient, C
Business:	
Downtown areas	0.70 - 0.95
Neighborhood areas	0.50 - 0.70
Residential:	
Single-family areas	0.30 - 0.50
Multi-units, detached	0.40 - 0.60
Multi-units, attached	0.60 - 0.75
Suburban	0.25 - 0.40
Apartment dwelling areas	0.50 - 0.70
Industrial:	
Light areas	0.50 - 0.80
Heavy areas	0.60 - 0.90
Parks, cemeteries	
Parks, cemeteries	0.10 - 0.25
Playgrounds	0.20 - 0.40
Railroad yard areas	0.20 - 0.40
Unimproved areas	0.10 - 0.30
Lawns:	
Sandy soil, flat, 2%	0.05 - 0.10
Sandy soil, average, 2 - 7%	0.10 - 0.15
Sandy soil, steep, 7%	0.15 - 0.20
Heavy soil, flat, 2%	0.13 - 0.17
Heavy soil, average, 2 - 7%	0.18 - 0.22
Heavy soil, steep, 7%	0.25 - 0.35
Streets:	
Asphaltic	0.70 - 0.95
Concrete	0.80 - 0.95
Brick	0.70 - 0.85
Drives and walks	0.75 - 0.85
Roofs	0.75 - 0.95

The C-factor of a complex area is determined by calculating a weighted C value using the appropriate C-factor for each subarea. The following table shows an example of determining a weighted C-factor for a composite area.

Table 403-2, EXAMPLE: Weighted C-Factor			
Surface	C-Factor	Area (%)	Product
Watertight roof surfaces	0.75	10	0.08
Traffic-bound pavement	0.90	15	0.14
Concrete pavement	0.80	25	0.2
Slightly pervious soil, with turf	0.25	50	0.13
Weighted C-Factor Result		100	0.55

DR 403-4 TIME OF CONCENTRATION (T_c)

The time of concentration (T_c) is the time (usually in minutes) for excess runoff to travel from the most hydraulically distant point of the watershed to the outlet/design point. In order to estimate the average design rainfall Intensity (I) in the Rational Method, the duration of the storm is assumed to be equal to the time of concentration for the watershed. Once the time of concentration is determined, the intensity is selected from an Intensity-Duration-Frequency relationship for the computed storm duration (equal to the time of concentration). High T_c values result in lower intensities, while lower T_c values result in higher intensities. It recommended using a minimum value of eight (8) minutes for T_c in order to avoid extremely high storm-intensity values.

Time of concentration is composed of three components: overland flow, shallow concentrated flow, and channel flow. The Cabinet's practice has been to incorporate shallow concentrated flow into the channel flow component thereby reducing the calculations to overland and channel flow. However, it is permissible to include all three types of flow. The equation for time of concentration is:

**EQUATION 403-2
TIME OF CONCENTRATION**

$$T_c = T_o + T_s + T_{ch}$$

Where:

- T_c= Total time of concentration (minutes)
- T_o= Overland flow travel time (minutes)
- T_s= Shallow concentrated flow travel time (minutes)
- T_{ch}= Channel flow travel time (minutes)

OVERLAND FLOW TRAVEL TIME

Overland flow, or sheet flow, is the shallow flow of runoff on plane surfaces. These flows typically occur at the head of a watershed or subbasin where the runoff has not accumulated enough mass to form a definable swale or channel. Typical depth ranges from less than an inch to two (2) inches. Impacting this flow is a friction value expressed as an effective roughness coefficient. It includes many factors that are difficult to observe or measure such as raindrop impact, drag over the plane surface, and resistance by obstacles such as litter, crop ridges, and rocks. Representative values of surface roughness for various

surfaces are listed in Table 403-3. The Cabinet uses a version of the kinematic wave equation to estimate overland flow times. The formula for the overland flow component is:

**EQUATION 403-3
OVERLAND FLOW TRAVEL TIME**

$$T_o = \frac{0.933}{I^{0.4}} \times \left(\frac{N \times L}{\sqrt{S}} \right)^{0.6}$$

Where:

- T_o = Overland flow travel time (minutes)
- I = Rainfall Intensity (inches per hour)
- N = Manning's Roughness Coefficient for Overland Sheet flow (Table 403-3)
- L = Overland flow length (feet)
- S = Slope of Overland flow length (feet per foot)

As can be seen from equation 403-3, the overland flow travel time equation has the intensity as a dependant variable. However, the intensity is a function of the time of concentration. This makes determining time of concentration an iterative process. Fortunately most software design packages perform this process for the user.

In order to avoid necessity to solve for T_c iteratively, the Natural Resources Conservation Service (Formerly SCS) developed the following variation of the kinematic wave equation which is also acceptable:

**EQUATION 403-4
NRCS OVERLAND FLOW TRAVEL TIME**

$$T_o = \frac{0.42}{P_2^{0.5}} \times \left(\frac{N \times L}{\sqrt{S}} \right)^{0.8}$$

Where:

- T_o = Overland flow travel time (minutes)
- P₂ = 2-Year, 24-Hour rainfall depth (inches), can be obtained from the Precipitation Data Frequency Server, See DR 201
- N = Manning's Roughness Coefficient for Overland Sheet flow (Table 403-3)
- L = Overland flow length (feet)
- S = Slope of Overland flow length (feet per foot)

Representative values for overland flow length are difficult to determine. Generally, 300 feet is considered to be a maximum length for overland flow and, therefore, it should be the maximum value on KYTC projects. Selecting a longer value as opposed to a shorter value for this length does not ensure a more conservative hydraulic design. In fact selecting shorter overland flow lengths is a more conservative hydraulic practice because storm intensity is inversely proportional to overland flow length. The FHWA publications "Hydraulic

Engineering Circular 22” (HEC-22) and “Highway Hydrology” (HDS-2) both offer some guidance on overland flow distances. HEC-22 states that sheet flow “usually occurs at the headwater of streams over relatively short distances, rarely more than 90m [300 ft] and possibly less than 25m [80 ft].” Similarly HDS-2 makes the following statement, “Such flow occurs over relatively short distances, rarely more than about 100m [328 ft] but most likely less than 25m [80 ft].” Engineering judgment should be used when selecting overland flow lengths.

Table 403-3 Manning’s Roughness (N) for Overland Flow	
Surface	Value
Paved Surfaces	
Smooth surfaces (concrete, asphalt, gravel or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Fields	
Residue cover ≤ 20 percent	0.06
Residue cover > 20 percent	0.17
Range (natural)	0.13
Grass	
Short grass prairie	0.15
Dense grasses	0.24
Bermuda grass	0.41
Woods	
Light underbrush	0.40
Dense underbrush	0.80

SHALLOW CONCENTRATED FLOW TIME

After short distances, sheet flow tends to concentrate in rills and gullies of increasing proportions and begins moving at a much faster rate. Such flow is referred to as shallow concentrated flow. The velocity of such flow can be estimated using an empirical relationship between the velocity and slope.

**EQUATION 403-5
SHALLOW CONCENTRATED FLOW**

$$V_s = k \times S^{0.50}$$

Where:

V_s = Average shallow concentrated velocity (feet per second)

k = intercept coefficient (Table 403-6)

S = Shallow Concentrated Slope, (feet per foot)

Table 403-4, Intercept Coefficients for Velocity vs. Slope	
K¹	Land cover/ flow regime
0.249	Forest with heavy ground litter, hay meadow
0.499	Trash fallow or minimum tillage cultivation; contour or strip cropped; woodland
0.699	Short grass pasture
0.899	Cultivated straight row
1.000	Nearly bare and untilled; alluvial fans in western mountain regions
1.499	Grassed waterway
1.610	Unpaved
2.030	Paved area; small upland gullies

1. Values derived from Table 2.2 in HDS 2. Values are valid for English units only.

CHANNEL AND PIPE TRAVEL TIME

Overland and/or shallow concentrated flow empties into channels or pipes where it is conveyed to the outlet point. The transition between shallow concentrated flow and channel flow is assumed to occur where either the blue line stream is visible on USGS quadrangle sheets or when the channel is visible on aerial photographs or field inspections. The Manning's equation is often used to estimate average flow velocity in the channel or pipe. A channel section typical of the entire channel length should be used to estimate channel velocity. Alternately, the channel flow can be divided up into multiple sections to determine the total channel travel time.

EQUATION 403-6
MANNING'S EQUATION

$$V = \frac{1.486}{n} \times R^{0.67} \times S^{0.50}$$

Where:

V = Average channel velocity (feet per second)

n = Manning's roughness coefficient

R = Hydraulic radius [A/P] (feet)

S = Slope (feet per foot)

In areas where it is difficult to determine the hydraulic radius, such as swale ditches and indeterminate flow paths, it is permissible to assume values of R = 0.20 feet for paved surfaces and R = 0.40 feet for unpaved surfaces.

EQUATION 403-7
CHANNEL TRAVEL TIME

$$T_t = \frac{L}{(60 \times V)}$$

Where:

V = Average velocity for channel segment

L = Segment flow length

T_t = Travel time per channel segment

DR 403-5 STORM INTENSITY (I)

The rainfall intensity (I) is the average rainfall rate (in/h) for a duration equal to the time of concentration for a selected return interval. Once a particular return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from Rainfall-Intensity-Duration curves.

The storm intensity for a particular return interval and duration of storm varies across the state. Statistical methods have been used to determine these storm intensities. These methods analyze past records of storm intensity–duration relationships for various return periods to produce storm intensity–duration frequency (IDF) relationships in the form of tables or curves. These IDF relationships shall be obtained from the NOAA Precipitation Frequency Data Server described in DR 401.

IDF curves are often plotted as storm intensity (iph) versus storm duration (min). The designer should become familiar with the IDF curves and their relationships. General relationships should be observed:

- The actual reoccurrence interval for any storm is not accurately predictable. A 100-year storm has a 1% chance of occurring in any particular year while a 25-year storm has a 4% chance of occurring in any particular year.
- Short duration storms usually produce the highest storm intensities while longer duration storms usually produce lower storm intensities.
- Intensity is a direct function of maximum travel time or time of concentration (T_c). Longer travel times produce lower intensities while shorter travel times produce higher intensities.



<i>D</i> rainage	<i>Chapter</i> HYDROLOGY
	<i>Subject</i> Regional Method

DR 404-1 INTRODUCTION

For watersheds larger than 200 acres the United States Geological Survey (USGS) Regression Equation Methodology has been adopted by the Cabinet to calculate peak flows. The method is described in USGS Water Resources Investigations Report 03-4180 (2003) titled "Estimating the Magnitude of Peak Flows for Streams in Kentucky for Selected Recurrence Intervals". The method divides the state into seven regions. Regression equations have been developed for each region based on stream gage station data and other parameters that are applicable to the watersheds that were analyzed.

The Regression Equation Methodology is modified for urban areas in a set of Nationwide Urban Equations. This methodology is detailed in USGS Survey Water-Supply Paper 2207 (1983) titled "Flood Characteristics of Urban Watersheds in the United States". This method applies to all areas of Kentucky outside of Jefferson County. In Jefferson County there is a more localized methodology developed to determine peak flows. This method is outlined in the Water Resources Investigations Report 97-4219 (1997) titled, "Estimation of Peak-Discharge Frequency of Urban Streams in Jefferson County Kentucky."

These methods are detailed in the succeeding sections of this chapter. The choice of the proper regression method is dependant on several factors. Please refer to the flowchart on in Figure 404-1 as a guide in the selection of these methods. Before discussing the regional method, some definitions should be presented:

Site at a gage station - For a site to be considered at a gage, the drainage area of the site must be within +/- 3 percent of the drainage area at the USGS stream flow gage station in question and on the same stream as the gage. The regression equation maps in the "Rural Regression Equations" section shows locations of stream gages.

Regulated - The drainage basin above the site contains more than 4.5 million ft³ of usable reservoir storage per mi² (usable reservoir storage is the volume of water normally available for release from a reservoir, between the minimum and maximum controllable elevations) or peaks have changed significantly following the addition of a reservoir(s) to a drainage basin.

Site near a gage station – For a site to be considered near a gage, the drainage area of the site ranges from 50 to 200 percent of the drainage area of a USGS gage station (excluding the plus or minus 3 percent considered “at a gage station”) and on the same stream.

Urbanized - more than 15 percent of the drainage-basin area above the site is covered by some type of commercial, industrial, or residential development.

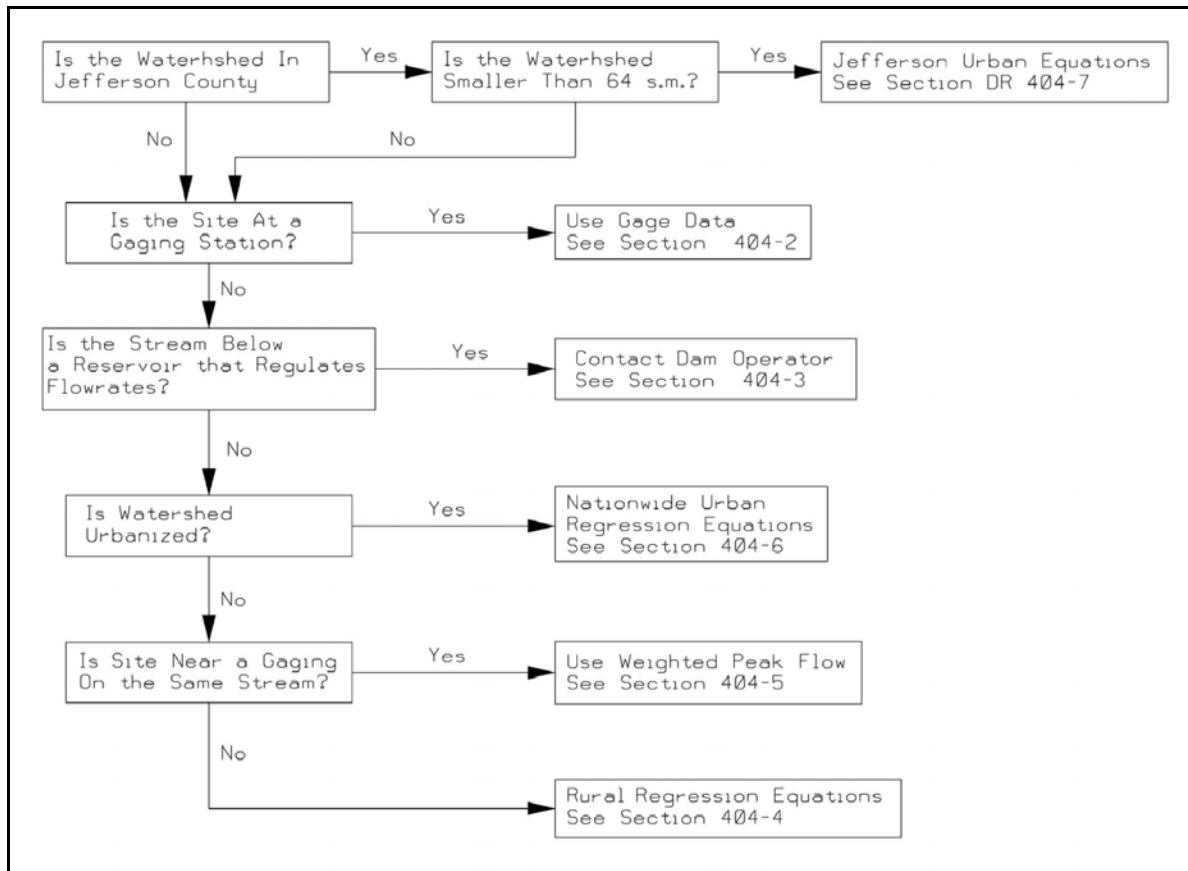


Figure 404-1 USGS Regional Method Flowchart

DR 404-2 SITE LOCATED AT A GAGING STATION

If a site is located “at a gaging station” as defined in the previous section, a weighted average between the gage flow and the flow resulting from the appropriate regression equation is used.

The USGS report Water Resources Investigations Report 03-4180 has an extensive listing of gage data for 222 stations located in Kentucky. The data in Table 404-1 shows a portion of the gage data listed in the report. The report can be found on the drainage website. It contains the gage flows, the estimated peak flow computed from regression equations (discussed later), and a weighted average of these two. The following abbreviations are used in the table.

- G = estimate computed from analysis of the observed annual peak flows at the gage stations
- R = estimate computed from regression equation
- W = estimate computed as a weighted average of the gage estimate and the regression estimate

The weighted average flow is the value recommended by the USGS and should be used for KYTC projects when available. There are cases where gages do not have weighted entries. In such a case the stream is either regulated or the basin characteristics were outside of the range for the regression equations (See Table 404-3). In these instances use the observed gage flows (denoted by G). In all other cases use the weighted average values (denoted by W) as recommended by USGS Report 03-4180.

Station Number	Code	Drainage Area (Sq. mi.)	Peak Flow (Cubic Feet per Second) for Given Recurrence Interval							
			2 years	5 years	10 years	25 years	50 years	100 years	200 years	500 years
3207965	G	6.20	696	1,090	1,360	1,700	1,940	2,190	2,430	2,740
	R		574	891	1,120	1,430	1,680	1,930	2,190	2,540
	W		678	1,050	1,290	1,610	1,840	2,080	2,320	2,650
3208000	G	392	1,500	1,500	1,500	NC	1,500	1,890	NC	NC
3209300	G	554	19,800	29,100	37,600	NC	56,700	66,500	78,200	96,800
3209500	G	1,232	21,600	27,400	32,700	NC	51,100	60,900	71,600	88,000
3209575	G	3.17	282	426	538	698	833	982	1,150	1,390
	R		352	549	694	891	1,050	1,210	1,370	1,600
	W		295	458	589	776	928	1,090	1,260	1,500
3209800	G	1,702	24,600	31,200	37,000	NC	60,600	74,400	90,000	115,000
3210000	G	56.3	2,630	4,100	5,050	6,220	7,050	7,850	8,620	9,610
	R		2,860	4,370	5,430	6,850	7,920	9,000	10,100	11,600
	W		2,640	4,120	5,090	6,290	7,170	8,030	8,870	9,970
^P 3211500	G	206	2,900	3,350	3,580	3,820	3,970	NC	NC	NC
3212000	G	103	5,200	8,920	11,500	14,900	17,500	20,000	22,500	25,800

DR 404-3 SITE LOCATED ON A REGULATED STREAM

Flow rates on some streams in Kentucky are “regulated” by large reservoirs or dams. If a stream fits the definition of a regulated stream, as defined in DR-404-1, and the site is not close enough to be considered “at a gage”, the operator of the reservoir should be contacted to obtain the flow rate information.

Another option would be to perform hydrologic routing calculations through the reservoir itself. The following agencies should be contacted in regard to regulated flows on the following streams:

Table 404-2, REGULATED STREAMS IN KENTUCKY	
Stream Name	Agency to Contact for Flood Magnitude and Frequency
Levisa Fork below Fishtrap Lake Near Millard, Ky.	U. S. Corps of Engineers Huntington, W. Va.
Russell Fork downstream from Virginia-Kentucky State Line	U. S. Corps of Engineers Huntington, W. Va.
Johns Creek below Dewey Lake Near Van Lear, Ky.	U. S. Corps of Engineers Huntington, W. Va.
Big Sandy River downstream from Louisa, Ky.	U. S. Corps of Engineers Huntington, W. Va.
Little Sandy River below Grayson Lake near Leon, Ky.	U. S. Corps of Engineers Huntington, W. Va.
Licking River below Cave Run Lake Near Farmers, Ky.	U. S. Corps of Engineers Louisville, Ky.
Middle Fork Kentucky River below Buckhorn Lake at Buckhorn, Ky.	U. S. Corps of Engineers Louisville, Ky.
North Fork Kentucky River below Middle Fork Kentucky River	U. S. Corps of Engineers Louisville, Ky.
Dix River below Herrington Lake near Burgin, Ky.	U. S. Corps of Engineers Louisville, Ky.
Green River below Green River Lake Near Campbellsville, Ky.	U. S. Corps of Engineers Louisville, Ky.
Nolin River below Barren River Lake Near Jamestown, Ky.	U. S. Corps of Engineers Louisville, Ky.
Barren River below Barren River Lake near Finney, Ky.	U. S. Corps of Engineers Louisville, Ky.
Rough River below Rough River Lake Near Falls of Rough, Ky.	U. S. Corps of Engineers Louisville, Ky.
Cumberland River below Cumberland Lake near Jamestown, Ky.	U. S. Corps of Engineers Nashville, Tenn.
Cumberland River below Lake Barkley Near Grand Rivers, Ky.	U. S. Corps of Engineers Nashville, Tenn.
Tennessee River below Kentucky Lake at Gilbertsville, Ky.	Tennessee Valley Authority Knoxville, Tenn.
Ohio River below mouth of Cumberland River	U. S. Corps of Engineers Louisville, Ky.

The designer should contact the Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, to obtain discharge information about smaller impoundments.

DR 404-4 RURAL REGRESSION EQUATIONS

The Rural Regression Equations apply to rural watersheds, on unregulated streams that are not near or at a gage. Regression equations were developed to determine the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year flood discharges for each

region. The state of Kentucky is divided into seven regions as depicted in Tables 404-4 through 404-10. In five of the seven regions, the only variable in the equation is drainage area. Two of the regions have a second variable, main channel slope. The general form of the regional regression equation for peak flow is as follows:

**EQUATION 404-1
RURAL REGIONAL FLOW**

$$Q_R = K \times A^b \times S^c$$

Where:

- Q_R = Design flow (ft³/s) for specified return periods (years)
- K = Empirical coefficient for region in question
- A = Total drainage area (square miles)
- b = Empirical coefficient for region in question
- S = Main channel slope (feet/mile). Computed as the difference in elevation between points at the 10 and 85 percent of the main channel length from the gage divided by the stream length between the two points.

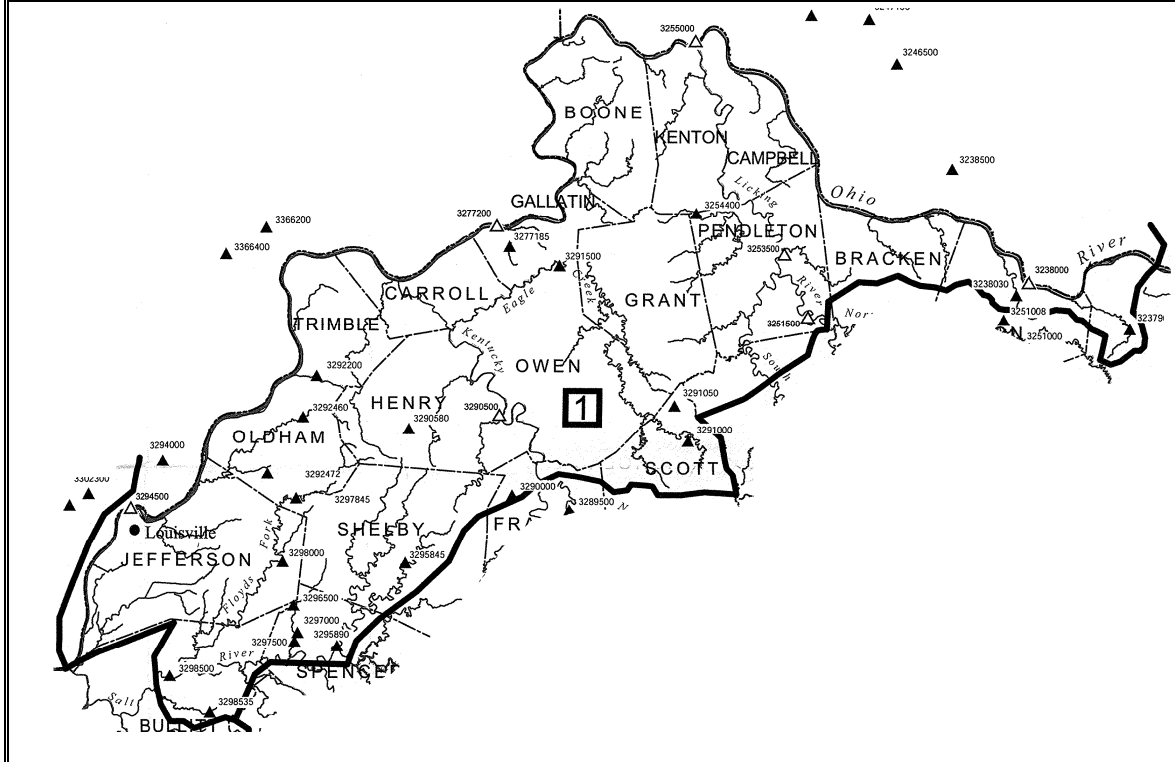
The variables used in the above regression equation are subject to the limits in the table 404-3.

Table 404-3, Regression Equation Variable Limits		
Region	Total Drainage Area (square miles)	Main-Channel Slope (feet / mile)
1	0.16 – 1,197	3.49 – 206
2	0.09 – 1,232	-
3	0.59 – 722	-
4	0.26 – 960	3.60 – 343
5	0.24 – 1,299	-
6	0.22 – 757	-
7	0.10 – 706	-

The regional coefficients are summarized in Table 404-4 though 404-10. Each table has a map showing the limits of each region.

Table 404-4, Region 1 (North) - Regression Equation Variables

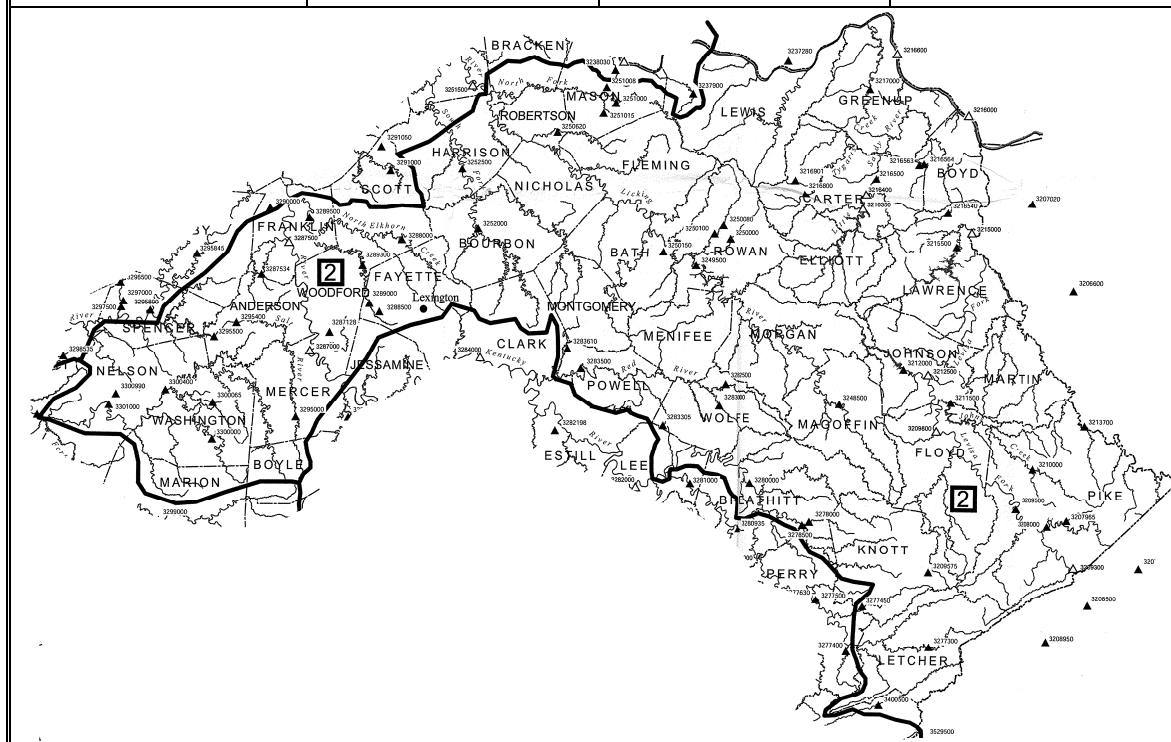
Return Period (years)	K	b	c
2	312	0.673	0
5	493	0.651	0
10	91.5	0.843	0.451
25	81.2	0.872	0.535
50	75.8	0.890	0.587
100	71.4	0.907	0.632
200	67.8	0.922	0.673
500	63.6	0.941	0.722



- ▲ Denotes a stream gage station used in the development of the regional regression equations
- △ Denotes a stream gage stations that were not used in the development of the regional regression equations

The USGS Station number is also shown to the right of each gage station

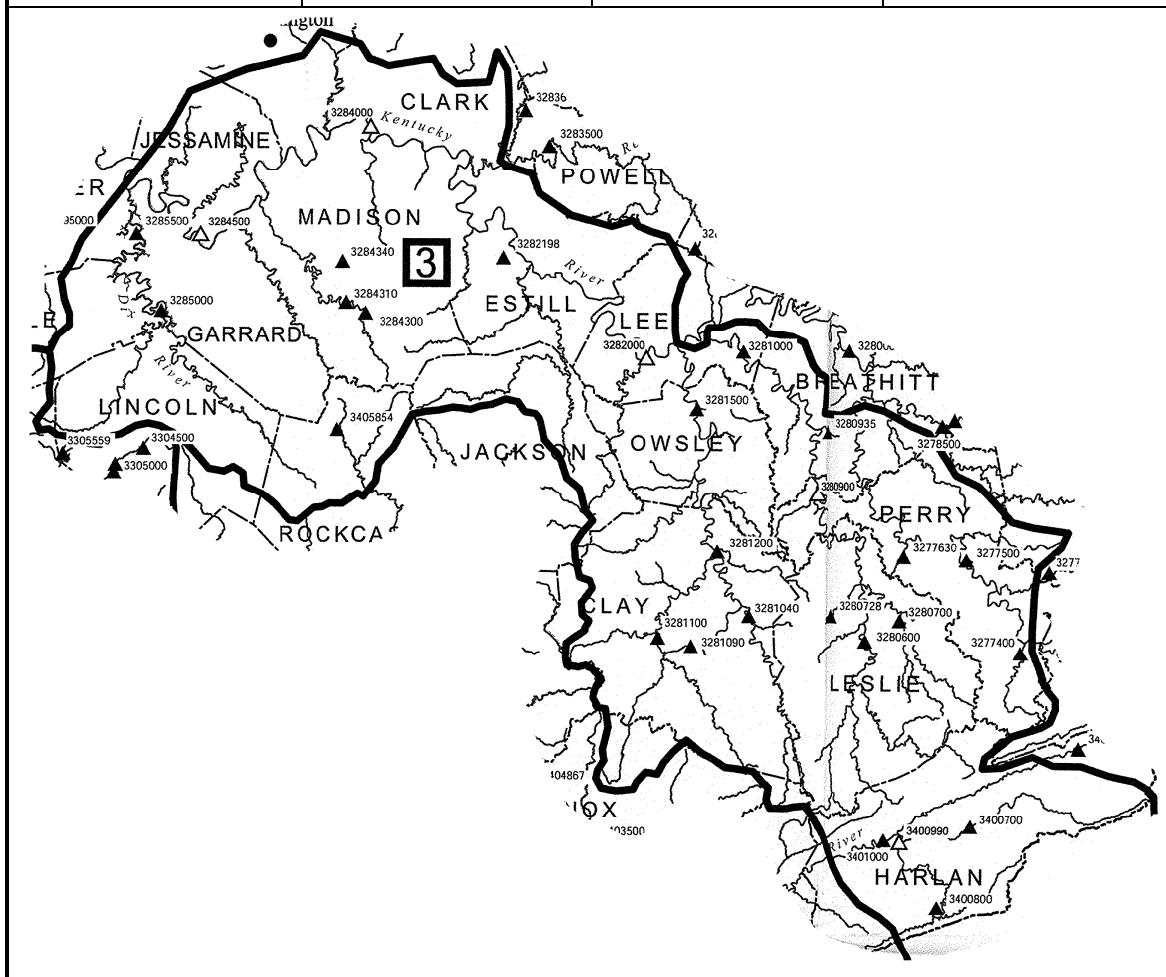
Table 404-5, Region 2 (Upper East) - Regression Equation Variables			
Return Period (years)	K	b	c
2	152	0.728	0
5	239	0.721	0
10	304	0.715	0
25	393	0.709	0
50	464	0.704	0
100	538	0.699	0
200	615	0.695	0
500	721	0.690	0



- ▲ Denotes a stream gage station used in the development of the regional regression equations
- △ Denotes a stream gage stations that were not used in the development of the regional regression equations

The USGS Station number is also shown to the right of each gage station

Table 404-6, Region 3 (Lower East) - Regression Equation Variables			
Return Period (years)	K	b	c
2	187	0.748	0
5	355	0.712	0
10	498	0.692	0
25	714	0.670	0
50	897	0.656	0
100	1100	0.643	0
200	1320	0.632	0
500	1640	0.620	0

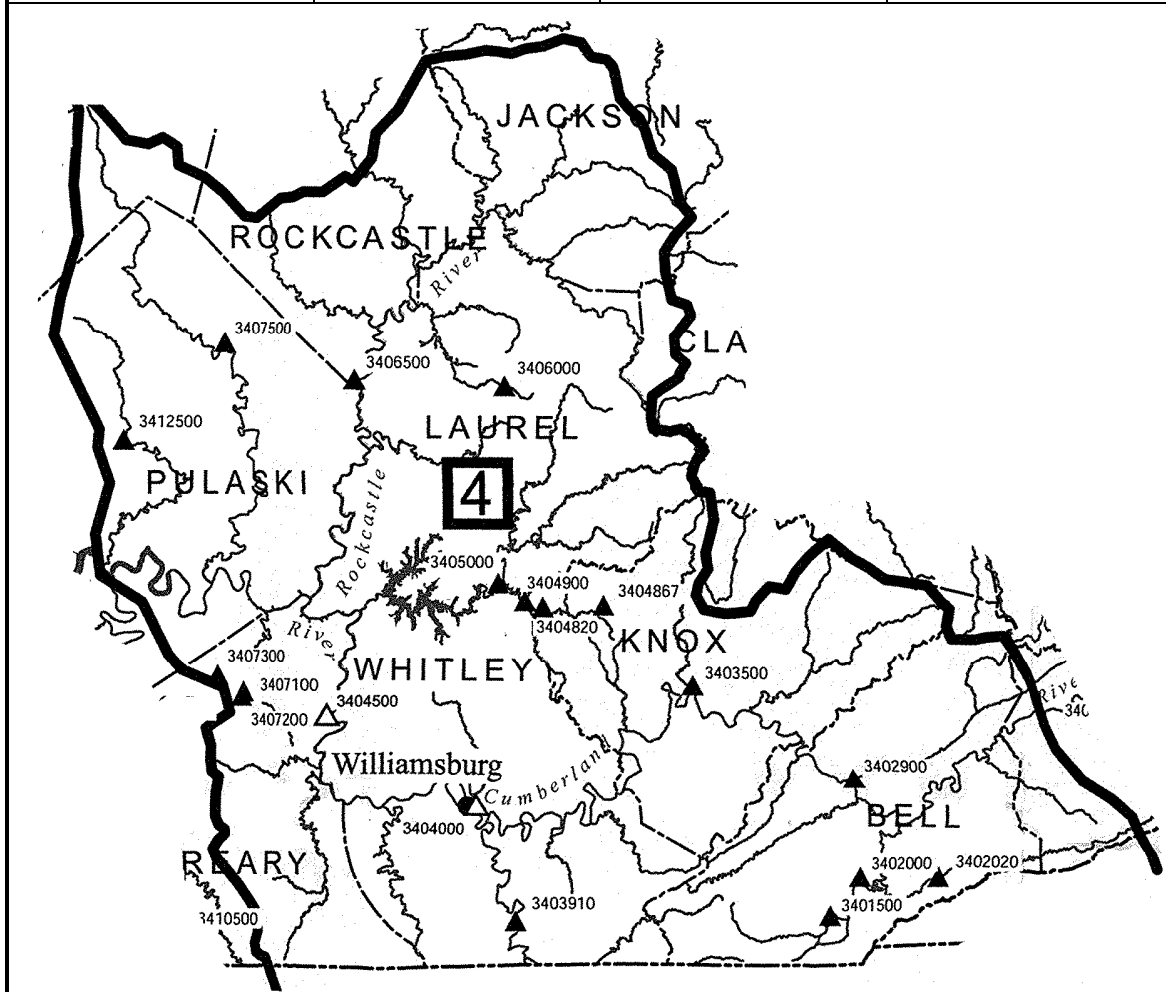


- ▲ Denotes a stream gage station used in the development of the regional regression equations
- △ Denotes a stream gage stations that were not used in the development of the regional regression equations

The USGS Station number is also shown to the right of each gage station

Table 404-7, Region 4 (Southeast) - Regression Equation Variables

Return Period (years)	K	b	c
2	39.0	0.923	0.204
5	69.8	0.894	0.186
10	92.7	0.882	0.178
25	121	0.873	0.173
50	140	0.870	0.173
100	392	0.780	0
200	441	0.778	0
500	510	0.776	0

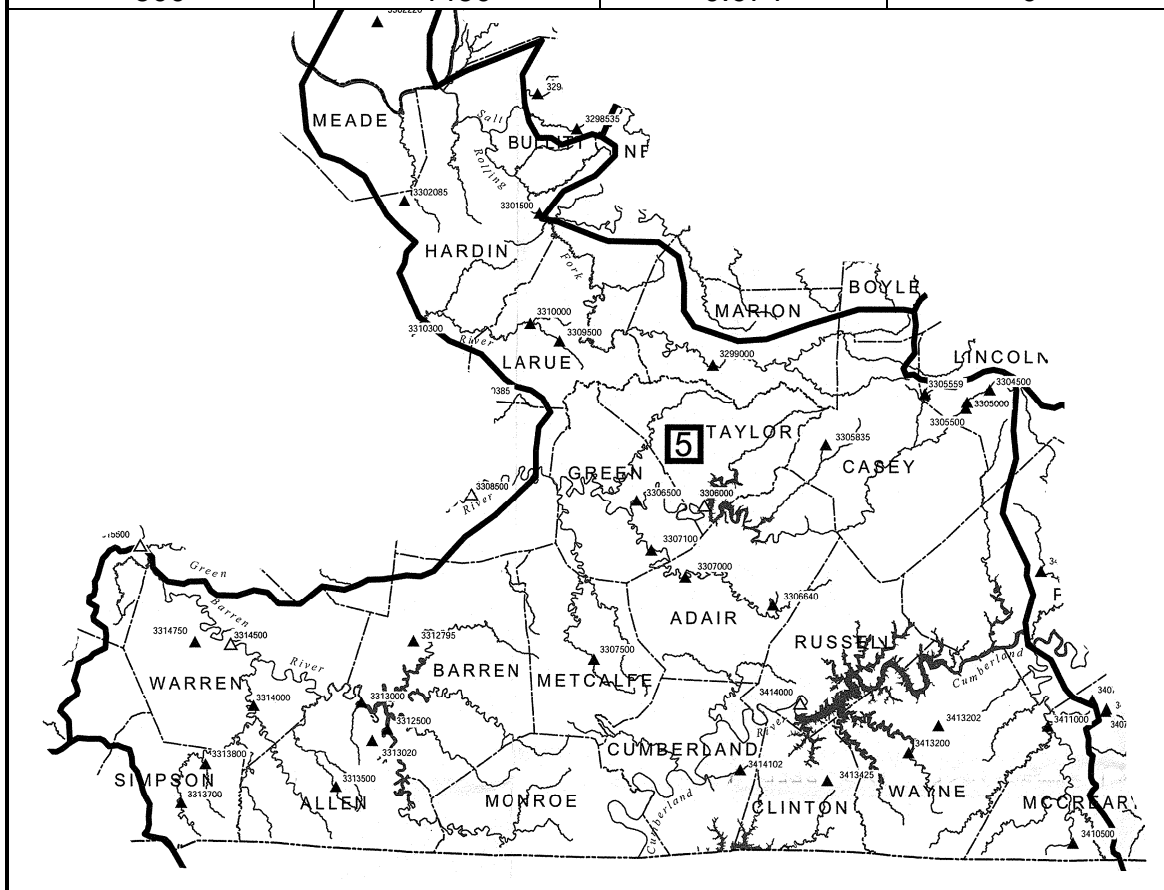


▲ Denotes a stream gage station used in the development of the regional regression equations

△ Denotes a stream gage stations that were not used in the development of the regional regression equations

The USGS Station number is also shown to the right of each gage station

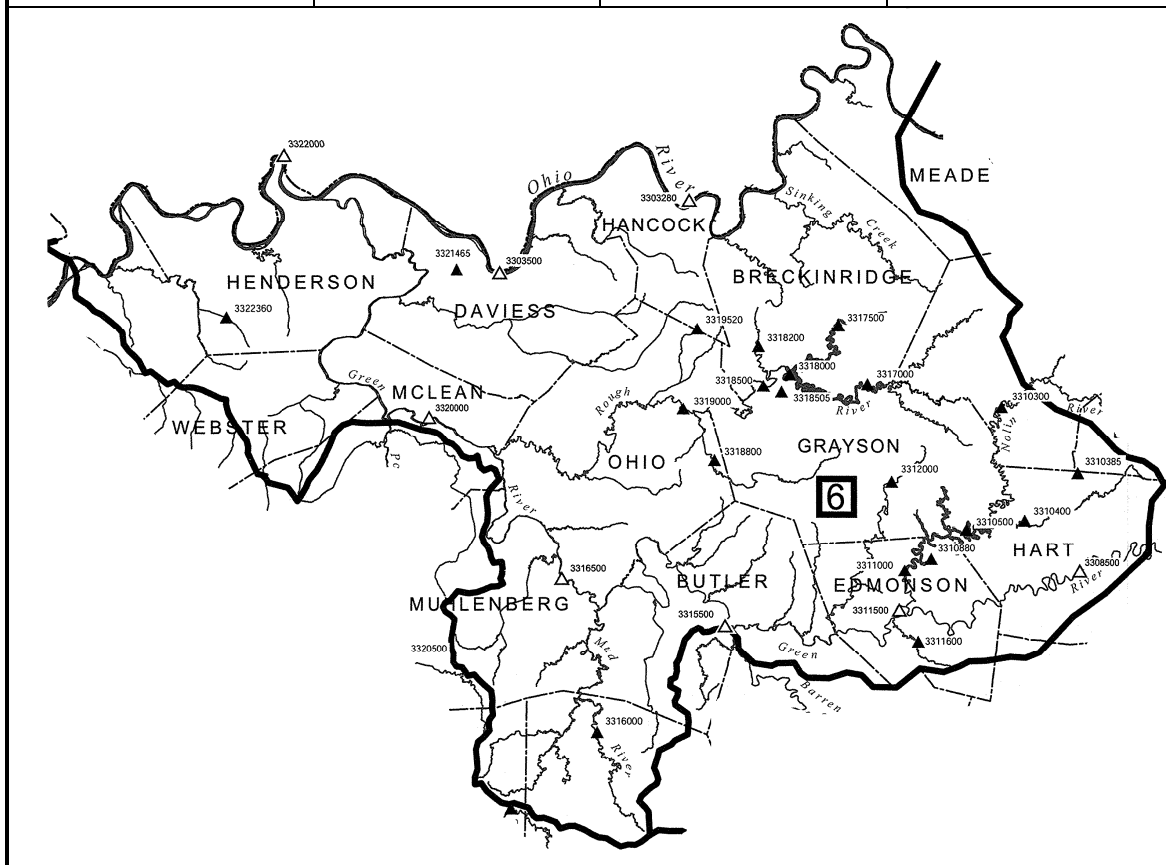
Table 404-8, Region 5 (East Central) - Regression Equation Variables			
Return Period (years)	K	b	c
2	260	0.704	0
5	437	0.692	0
10	571	0.686	0
25	754	0.682	0
50	901	0.679	0
100	1060	0.677	0
200	1220	0.676	0
500	1450	0.674	0



- ▲ Denotes a stream gage station used in the development of the regional regression equations
- △ Denotes a stream gage stations that were not used in the development of the regional regression equations

The USGS Station number is also shown to the right of each gage station

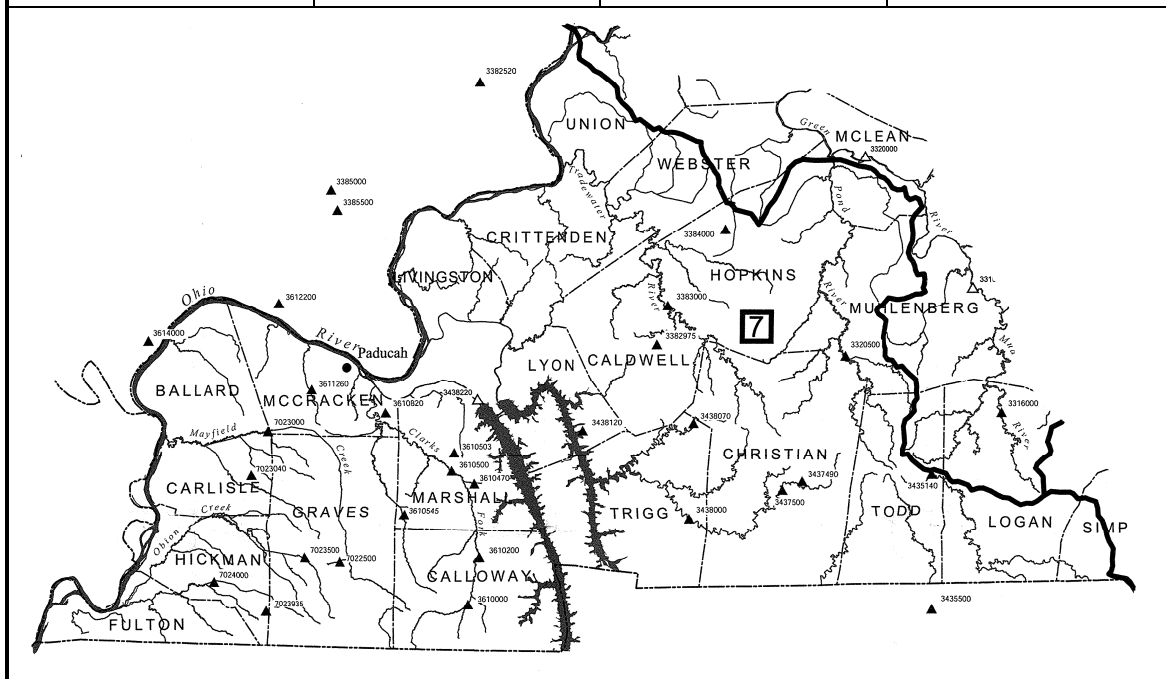
Table 404-9, Region 6 (West Central) - Regression Equation Variables			
Return Period (years)	K	b	c
2	256	0.600	0
5	397	0.586	0
10	499	0.578	0
25	636	0.569	0
50	740	0.564	0
100	846	0.559	0
200	953	0.555	0
500	1100	0.551	0



- ▲ Denotes a stream gage station used in the development of the regional regression equations
- △ Denotes a stream gage stations that were not used in the development of the regional regression equations

The USGS Station number is also shown to the right of each gage station

Table 404-10, Region 7 (West) - Regression Equation Variables			
Return Period (years)	K	b	c
2	293	0.623	0
5	476	0.616	0
10	614	0.613	0
25	804	0.610	0
50	956	0.610	0
100	1110	0.609	0
200	1280	0.610	0
500	1510	0.610	0



- ▲ Denotes a stream gage station used in the development of the regional regression equations
- △ Denotes a stream gage stations that were not used in the development of the regional regression equations

The USGS Station number is also shown to the right of each gage station

DR 404-5 SITES NEAR A GAGE STATION

This section applies to sites that are: in rural locations, on unregulated streams, and are considered “near a gage” as defined in DR 404-1. Flows at these sites are determined by applying a weighted peak flow technique using the gage data and the Rural Regression Equation for the area in question. It is subject to the same limits set in Table 404-3 for the watershed variables. The weighted peak flows in these areas are to be calculated as follows:

**EQUATION 404-2
WEIGHTED PEAK FLOW (GAGE DATA & REGRESSION EQUATION)**

$$Q_{UF} = Q_R \times W_R + Q_U \times (1 - W_R)$$

Where:

- W_R = Weighting factor = $(A_U/A_G) - 1$ for $A_U > A_G$ or $(A_G/A_U) - 1$ for $A_U < A_G$
- Q_U = $Q_W \times (A_U/A_G)^B$
- Q_W = Weighted peak flow for the applicable return period from Table 404-1, Estimated Peak Flows in Kentucky (code W in Table 404-1 and in Table 1 of Water Report 03-4180)
- A_U = Total drainage area at the unaged site
- A_G = Total drainage area at the gage site
- B = Exponent from Table 404-11 (Table 5 of Water Report 03-4180)

For those sites with basin variables outside the limits shown in Table 404-3, the final weighted flow shall be calculated with gage data only as follows:

**EQUATION 404-3
WEIGHTED PEAK FLOW (GAGE DATA ONLY)**

$$Q_U = Q_W \times (A_U/A_G)^B$$

Where:

- Q_U = Final weighted peak flow (ft³/s)
- Q_W = Weighted peak flow for the applicable return period from Table 404-1 “Estimated Peak Flows at Selected Gages in Kentucky (Code W)”
- A_U = Total drainage area at the unaged site
- A_G = Total drainage area at the gage site
- B = Exponent from Table 404-11

If the site is located between two gage stations, and considered near both gages, then the log base-10 interpolated peak-flow estimate may be calculated using equation 404-4.

**EQUATION 404-4
FLOW BETWEEN TWO GAGE STATIONS**

$$\text{LOG}(Q_{U1}) = \text{LOG}(Q_{W1}) + \frac{(\text{LOG}(Q_{W2}) - \text{LOG}(Q_{W1})) \times (\text{LOG}(A_U) - \text{LOG}(A_{G1}))}{\text{LOG}(A_{G2}) - \text{LOG}(A_{G1})}$$

The final flow can then be transformed from the log base 10 values ($Q_U = 10^{\text{LOG}(Q_U)}$) where:

Where:

- Q_{U1} = interpolated peak flow for a given return interval
- Q_{W1} & Q_{W2} = Weighted-average peak flows at the upstream and downstream gages, respectively for a return interval from Table 404-1 "Estimated Peak Flows at Selected Gages in Kentucky" (Code W).
- A_U = Total drainage area for the ungaged site
- A_{G1}, A_{G2} = Total drainage area at the upstream and downstream gage stations, respectively

Table 404-11, Coefficient B for gage weighting equations							
Recurrence Interval (yrs)	Region						
	1	2	3	4	5	6	7
2	0.673	0.728	0.748	0.824	0.704	0.600	0.623
5	0.651	0.721	0.712	0.803	0.692	0.586	0.616
10	0.642	0.715	0.692	0.794	0.686	0.578	0.613
25	0.634	0.709	0.670	0.786	0.682	0.569	0.610
50	0.629	0.704	0.656	0.783	0.679	0.564	0.610
100	0.625	0.699	0.643	0.780	0.677	0.559	0.609
200	0.622	0.695	0.632	0.778	0.676	0.555	0.610
500	0.618	0.690	0.620	0.776	0.674	0.551	0.610

DR 404-6 NATIONWIDE URBAN REGRESSION EQUATIONS

The Nationwide Urban Regression Equations are used to adjust the regional flow values if the drainage basin has at least 15 percent development. There are two versions of the Nationwide Urban Equations, the seven parameter and the three parameter. Both methods are discussed in the aforementioned USGS Survey Water-Supply Paper 2207 (Sauer 1983) titled "Flood Characteristics of Urban Watersheds in the United States." Although the three parameter equations are easier to apply, they are not contained in most off the shelf software packages such as the NSS program developed by the USGS to compute Regional flows. Also, it is the recommendation of USGS Water Report 03- 4180 to use the seven parameter equations in Kentucky. KYTC has developed a spreadsheet application that will calculate and compare the results for both equations. Either

method is acceptable on KYTC projects. The 7 Parameter USGS Nationwide Regression equations are shown in Equation 404-5 below.

**EQUATION 404-5
USGS 7 PARAMETER NATIONWIDE URBAN REGRESSION EQUATION**

$$UQR = K \times (A^M) \times (S^N) \times ((RI2 + 3)^O \times (ST + 8)^P \times (13 - BDF)^Q \times (IA^R) \times (RQ^S)$$

Where:

- UQR = Regression discharge adjusted for urbanization (ft³/s)
- A = Contributing drainage area (square miles)
- S = Main channel slope in ft/mile, measured between points that are 10% and 85% of the main channel length upstream from the study site (for sites where S is greater than 70 ft/mile, 70 ft is used in the equations)
- ST = Basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, swamps and wetlands (channel storage of a temporary nature, from detention ponds or roadway embankment, is not included)
- BDF = Basin development factor
- IA = Percentage of the drainage basin occupied by impervious surfaces (e.g. houses, buildings, streets, parking lots)
- RQ = Rural regression regional peak flow from equation 404-1) Other variables are constants from Table 404-12.
- RI2 = Rainfall depth, in inches, for the two-hour, two-year occurrence. See Table 404-14

K, M, N, O, P, Q, R, S are constants from table 404-12

Table 404-12, Constants for the USGS 7 Parameter Urbanization Regression Equations								
Return Interval	K	M	N	O	P	Q	R	S
2	2.35	0.41	0.17	2.04	-0.65	-0.32	0.15	0.47
5	2.70	0.35	0.16	1.86	-0.59	-0.31	0.11	0.54
10	2.99	0.32	0.15	1.75	-0.57	-0.30	0.09	0.58
25	2.78	0.31	0.15	1.76	-0.55	-0.29	0.07	0.60
50	2.67	0.29	0.15	1.74	-0.53	-0.28	0.06	0.62
100	2.50	0.29	0.15	1.76	-0.52	-0.28	0.06	0.63
500	2.27	0.29	0.16	1.86	-0.54	-0.27	0.05	0.63

The 3 Parameter USGS Nationwide Regressions equation is shown in Equation 404-6. The three variables for this equation are included in the 7 parameter equations. The constants for the 3 variable equations are shown in Table 404-13.

EQUATION 404-6
USGS 3 PARAMETER NATIONWIDE URBAN REGRESSION EQUATION

$$UQR = C \times (A^D) \times (RQ^E) \times (13 - BDF)^F$$

Where:

- UQR = Regression discharge adjusted for urbanization (ft³/s)
- A = Contributing drainage area (square miles)
- RQ = Rural regression regional peak flow from equation 404-1
- BDF = Basin development factor

Other variables are constants from Table 404-13

Table 404-13, Constants for the USGS 3 Parameter Urbanization Regression Equation				
Return Interval (years)	C	D	E	F
2	13.20	0.21	0.73	0.43
5	10.60	0.17	0.78	0.39
10	9.51	0.16	0.79	0.36
25	8.68	0.15	0.80	0.34
50	8.04	0.15	0.81	0.32
100	7.70	0.15	0.82	0.32
500	7.47	0.16	0.82	0.30

The most significant index of urbanization in the urban regression equations is the basin development factor (BDF), which provides a measure of the efficiency of the drainage system. This factor is used in both the three (3) parameter and seven (7) parameter equations. This parameter has proven to be highly significant in the regression equations and can be easily determined from drainage maps and field inspections of the drainage basin.

The BDF for the watershed basin is determined by dividing the drainage basin into three sub areas (upper, middle, and lower). Divisions are located so that each third of the basin contains approximately one-third of the total contributing drainage area. Each area should be sized on the basis of time of concentration. The outlet of the basin is included in the lower third of the basin.

Travel time of flow is considered in locating the divisions. Therefore, distances along main streams and tributaries should be marked to help determine the boundaries of each basin. This does not mean that all three (3) basins have equal travel distances but that within each third the travel distances of two (2) or more streams are about equal. Precise division of each basin is not considered

necessary. Complex basin shapes and drainage patterns are sometimes encountered, and these conditions require more judgment when subdividing. After subdivision of the basin into thirds, four (4) aspects of the each sub area are evaluated and each assigned a code as follows:

Aspects

- A. Channel Improvements** - If at least 50 percent of the main drainage channels and principal tributaries have been straightened, enlarged, deepened, or cleared, code 1 is assigned; otherwise, code 0 is assigned.
- B. Channel Linings**—if at least 50 percent of the length of the main drainage channels and principal tributaries has an impervious liner such as concrete, code 1 is assigned; otherwise, code 0 is assigned. The presence of channel linings would obviously indicate the presence of channel improvements as well. Therefore, this is an added factor and indicates a more highly developed drainage system.
- C. Storm Drains, Storm Sewer**—Storm drains are enclosed drainage structures (usually pipes) frequently used on the secondary tributaries where the drainage is received directly from streets or parking lots. Many of these drains empty into open channels; however, in some basins they empty into channels enclosed as box or pipe culverts. If more than 50 percent of the secondary tributaries consist of storm drains, code 1 is assigned; otherwise, code 0 is assigned. It should be noted that if 50 percent or more of the main drainage channels and principal tributaries are enclosed, code 1 is assigned; otherwise, code 0 is assigned in both "A" and "B" above. It should also be noted that if 50 percent or more of the main drainage channels and principal tributaries are enclosed, then the aspects of channel improvements and channel linings would also be assigned code 1.
- D. Curb and Gutter Streets**—if more than 50 percent of an area is covered by residential, commercial, and/or industrial development and if more than 50 percent of the streets and highways are constructed with curbs and gutters, code 1 is assigned; otherwise, code 0 is assigned. Drainage from curb-and-gutter streets frequently empties into storm drains.

The preceding guidelines for determining the various drainage system codes are not intended to be precise measurements. A certain amount of subjectivity will necessarily be involved. Field checking should be performed to obtain the best estimate. The basin development factor (BDF) is the sum of the assigned codes. Therefore, with 3 subareas per basin and 4 drainage aspects to which codes are assigned in each subarea, the maximum value for a fully developed drainage basin would be 12. Conversely, if the drainage system is totally undeveloped, then a BDF of 0 would result. Such a condition does not necessarily mean that the basin is unaffected by urbanization. In fact, a basin could be partially urbanized, have some impervious areas, and have some improvement of secondary tributaries but still have an assigned BDF of 0.

The BDF is a fairly easy index to estimate for an existing urban basin. The 50 percent guideline will usually not be difficult to evaluate because many urban areas tend to use the same design criteria and therefore have similar drainage aspects throughout. Also, the BDF is convenient for projecting future

development. Projections of full development or intermediate stages of development can usually be obtained from city engineers, design engineers and others.

In terms of the other variables in the equations: main channel slope, basin storage (the percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands), and the percentage of the drainage area occupied by impervious surfaces can be estimated from measurement off an aerial map or via GIS applications.

The variable RI2, the rainfall intensity, in inches, for the two-hour, two-year occurrence can be taken from Table 404-14. The table was derived from "Engineering Memorandum No. 2" which was published by the Kentucky Department for Natural Resources in 1971, and revised in 1979. Since the Urban Regression equations were developed using these precipitation values, the updated values found in the Precipitation Frequency Data Server should not be used.

The worksheet shown in Figure 404-2 may be used to compute the urbanized regional flows.

Figure 404-2 Urbanization Worksheet

Kentucky Transportation Cabinet Division of Highway Design 1-05	URBANIZATION TECHNIQUE	Page 1 of 2
County: Breckinridge	Route: US 421	Item No.: 4 -125.0
UPN: SSP 045 231 002-003 045D	FPN: FD52 011	Station: 1254+33

Urbanization Equation:

$$UQR = K (A^M) (SL^N) (RI2+3)^O (ST+8)^P (13 - BDF)^Q (IA^R) (RQ^S)$$

- UQR = regression discharge adjusted for urbanization (cfs)
- A = contributing drainage area (square miles)
- SL = main channel slope in ft/mi, measured between points that are 10% and 85% of the main channel length upstream from the study site (for sites where SL is greater than 70 ft/mi, 70ft/mi is used in equations)
- RI2 = rainfall intensity, **in inches**, for the two-hour, two-year occurrence
- ST = basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands (channel storage of a temporary nature, resulting from detention ponds or roadway embankment, is not included in the computation of ST)
- BDF = basin development factor
- IA = percentage of the drainage basin occupied by impervious surfaces (e.g. houses, buildings, streets, parking lots)
- RQ = regression estimate of discharge (weighted or unweighted as applicable) (cfs)
- K, M, N, O, P, Q, R, S = constants from the following table

To determine Regional Urbanized flows, enter **B**asin **D**evelopment **F**actors for the upper, middle and lower thirds of the drainage basin and unadjusted regional flows in the following cells. Using the cursor, drag-select an area to include the shaded areas and press F9 to perform the calculations.

BASIN DEVELOPMENT FACTOR COMPUTATION

Portion of Drainage Area	Channel Improvement	Channel Lining	Storm Sewers	Curb & Gutter Streets
Upper Third	0	0	1	0
Middle Third	1	0	0	0
Lower Third	0	1	1	1
Σ =	1	1	2	1
BDF =	5			

Drainage Area (sq. mi.) = 100

Return Period	Regional Flow (cfs)	Regional Urbanized Flow (cfs)
2	10	76.3
5	20	106.6
10	30	138.0
25	40	163.3
50	50	196.1
100	60	226.8
500	70	272.5

Table 404-14 2YR (50%), 2 Hour duration Peak Rainfall Totals (Inches)					
COUNTY	RI-2	COUNTY	RI-2	COUNTY	RI-2
ADAIR	1.8	GRANT	1.7	MASON	1.6
ALLEN	1.8	GRAVES	1.9	MEADE	1.8
ANDERSON	1.7	GRAYSON	1.8	MENIFEE	1.7
BALLARD	1.9	GREEN	1.8	MERCER	1.7
BARREN	1.8	GREENUP	1.6	METCALFE	1.8
BATH	1.8	HANCOCK	1.8	MONROE	1.8
BELL	1.7	HARDIN	1.8	MONTGOMERY	1.7
BOONE	1.7	HARLAN	1.7	MORGAN	1.6
BOURBON	1.7	HARRISON	1.7	MUHLENBERG	1.9
BOYD	1.6	HART	1.8	NELSON	1.8
BOYLE	1.7	HENDERSON	1.8	NICHOLAS	1.6
BRACKEN	1.6	HENRY	1.7	OHIO	1.8
BREATHITT	1.7	HICKMAN	1.9	OLDHAM	1.7
BRECKINRIDGE	1.8	HOPKINS	1.9	OWEN	1.7
BULLITT	1.8	JACKSON	1.7	OWSLEY	1.7
BUTLER	1.8	JEFFERSON	1.7	PENDLETON	1.7
CALDWELL	1.9	JESSAMINE	1.7	PERRY	1.7
CALLOWAY	1.9	JOHNSON	1.6	PIKE	1.7
CAMPBELL	1.6	KENTON	1.6	POWELL	1.7
CARLISLE	1.9	KNOTT	1.7	PULASKI	1.7
CARROLL	1.7	KNOX	1.7	ROBERTSON	1.6
CARTER	1.6	LARUE	1.8	ROCKCASTLE	1.7
CASEY	1.7	LAUREL	1.7	ROWAN	1.6
CHRISTIAN	1.9	LAWRENCE	1.6	RUSSELL	1.7
CLARK	1.7	LEE	1.7	SCOTT	1.7
CLAY	1.7	LESLIE	1.7	SHELBY	1.7
CLINTON	1.8	LETCHER	1.7	SIMPSON	1.8
CRITTENDEN	1.9	LEWIS	1.6	SPENCER	1.7
CUMBERLAND	1.8	LINCOLN	1.7	TAYLOR	1.8
DAVISS	1.8	LIVINSTON	1.9	TODD	1.8
EDMONSON	1.8	LOGAN	1.8	TRIGG	1.9
ELLIOTT	1.6	LYON	1.9	TRIMBLE	1.7
ESTILL	1.7	MCCRACKEN	1.9	UNION	1.9
FAYETTE	1.7	MCCREARY	1.8	WARREN	1.8
FLEMING	1.6	MCLEAN	1.8	WASHINGTON	1.7
FLOYD	1.6	MADISON	1.7	WAYNE	1.8
FRANKLIN	1.7	MAGOFFIN	1.7	WEBSTER	1.9
FULTON	1.9	MARION	1.7	WHITLEY	1.8
GALLATIN	1.7	MARSHALL	1.9	WOLFE	1.7
GARRARD	1.7	MARTIN	1.6	WOODFORD	1.7

DR 404-7 JEFFERSON COUNTY REGRESSION EQUATIONS

The aforementioned USGS publication “Estimation of Peak-Discharge Frequency of Urban Streams in Jefferson County, Kentucky”, 1997 was prepared in cooperation with Louisville and Jefferson county Metropolitan Sewer District. The purpose of the study was to obtain hydrologic information needed for water resources management using discharge data and rainfall-runoff data collected from 13 urban basins inside Jefferson County and 4 rural basins in hydrologically similar areas of neighboring counties. The nationwide 3 parameter and 7 parameter urban regression equations were found in the study to produce biased (high) estimates for the local urban basins studied. As such, local regional equations were developed to more closely fit the Jefferson county data and are presented Table 404-15 for use inside Jefferson county limits. The limitations of these equations as given in the report are: drainage areas limited between 1.36 to 64.0 square miles, channel slopes between 11.7 to 75.1 feet/mile, and BDF between 0 to 7. Outside of this range, the standard USGS equations presented in the preceding sections will have to be used.

Table 404-15 Jefferson County Regression Equations	
Return Interval (Years)	Jefferson County Urban Peak-discharge estimating equations
2	$UQ2 = 442(A^{0.635})(SL^{0.128})(13 - BDF)^{-0.337}$
5	$UQ5 = 517(A^{0.589})(SL^{0.208})(13 - BDF)^{-0.268}$
10	$UQ10 = 561(A^{0.574})(SL^{0.243})(13 - BDF)^{-0.235}$
25	$UQ25 = 647(A^{0.556})(SL^{0.276})(13 - BDF)^{-0.209}$
50	$UQ50 = 703(A^{0.547})(SL^{0.295})(13 - BDF)^{-0.189}$
100	$UQ100 = 780(A^{0.538})(SL^{0.310})(13 - BDF)^{-0.181}$

DR 404-8 WATERSHEDS SPANNING MULTIPLE REGIONS

If the watershed being analyzed spans more than one region, the appropriate equations for computing the regional peak flows as describe in this section shall be used assuming that the entire basin is in one of the hydraulic regions. The peak flows are then recomputed with the assumption that the basin is in the other hydraulic region or regions. Final peak flow is computed as a weighted average of the peak flows based upon the fraction of the basin area within each basin. Peak flow estimates for zones adjacent to Kentucky may be obtained from similar USGS publications.



<i>D</i> rainage	<i>Chapter</i> HYDROLOGY
	<i>Subject</i> NRCS Unit Hydrograph

DR 405-1 INTRODUCTION

A hydrograph is a graph of the time distribution of runoff from a particular point in a watershed. Hydrograph design is only necessary in certain cases when timing of the runoff becomes important. Detention basin design is the most common type of drainage analysis that requires hydrograph calculations. However, complex storm sewer designs or watershed analysis may necessitate the use of hydrographs. As a general rule, peak flow design will suffice for most highway drainage designs. KYTC has adopted the Natural Resources Conservation Service (NRCS) Unit Hydrograph Method for these types of analyses. The NRCS was formerly known as the Soil Conservation Service (SCS). Some publications still refer to this method as the SCS method, however both acronyms refer to the same method.

The techniques developed by NRCS for calculating rates of runoff require the same basic data as the Rational Method, drainage area, a runoff factor, time of concentration, and rainfall depths. However, the NRCS approach considers additional factors such as the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. With the NRCS method, the direct runoff can be calculated for any storm, either real or fabricated, by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess.

DR 405-2 RAINFALL

The NRCS method is based on a 24-hour storm event. For Kentucky this rainfall distributed base on a Type II time distribution. The storm distributions are "typical" time distributions which the NRCS has prepared from rainfall records for various regions of the country. Table 405-1 illustrates the Type II distribution. To use one of these distributions, it is necessary for the user to obtain the 24-hour rainfall depth for the frequency of the design storm desired from the Precipitation Frequency Data Server described in DR 401. The NRCS distributions are programmed into most hydrologic software applications, and usually the only input required is the storm depth.

TABLE 405-1 NRCS 24-Hour Type II Rainfall Distributions			
Time, t (h)	Fraction of 24-h Rainfall	Time, t (h)	Fraction of 24-h Rainfall
0	0	11	0.235
2	0.022	11.5	0.283
4	0.048	11.75	0.393
6	0.080	12	0.663
7	0.098	12.5	0.735
8	0.120	13	0.772
8.5	0.133	13.5	0.799
9	0.147	14	0.820
9.5	0.163	16	0.880
9.75	0.172	20	0.952
10	0.181	24	1
10.5	0.204		

DR 405-3 HYDROLOGIC SOIL GROUPS

Soil properties influence the relationship between runoff and rainfall because soils have differing rates of infiltration. Infiltration is the movement of water through the soil surface into the soil. Based on infiltration rates, NRCS has divided soils into four hydrologic soil groups as follows:

- Group A Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.
- Group B Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.
- Group C Soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.
- Group D Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious parent material.

The NRCS soil group can be identified at a site using either soil characteristics or county soil surveys. The soil characteristics associated with each group are listed above and provide one means of identifying the SCS soil group. County soil surveys, which are made available by Soil Conservation Districts, give detailed descriptions of the soils at locations within a county; these surveys are usually

the better means of identifying the soil group. Many of the more recent reports actually categorize the soils into these four groups. The NRCS also has a web application called the "Web Soil Survey" that contains much soil information through a GIS based web browser. As of the publication date of this section, the website address for this application is located at the following address: <http://websoilsurvey.nrcs.usda.gov/app/>.

DR 405-4 CURVE NUMBER

In hydrograph applications, runoff is often referred to as rainfall excess or effective rainfall, all defined as the amount by which rainfall exceeds the capability of the land to infiltrate or otherwise retain the rainwater. The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types and land slope.

Land use is the watershed cover, and it includes both agricultural and nonagricultural uses. Items such as type of vegetation, water surfaces, roads and roofs are all part of the land use. Land treatment applies mainly to agricultural land use, and it includes mechanical practices (e.g., contouring, terracing) and management practices (e.g., rotation of crops).

NRCS uses a combination of soil conditions and land use (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area when the soil is not frozen. The higher the CN, the higher the runoff potential.

Tables 405-2 and 405-3 presents the NRCS curve number values for the different land uses, treatments and hydrologic conditions; separate values are given for each soil group. For example, the CN for a wooded area with good cover and soil group B is 55; for soil group C, the CN would increase to 70. If the cover (on soil group B) is poor, the CN will be 66. These tables are based on an average antecedent moisture condition; i.e., soils that are neither very wet nor very dry when the design storm begins. Curve numbers should be selected only after a field inspection of the watershed and a review of zoning and soil maps. For areas with differing curve numbers, a weighted curve number can be calculated by the same methods described for weighted C-factors in DR 403.

Table 405-3 uses Hydrologic Condition to determine the appropriate Curve Numbers. Hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year-round cover; (c) amount of grass or close-seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness.

Tables 405-2 & 405-3 have been simplified from most published versions of the curve number tables. Credit is given to certain agricultural conservation

practices such as conservation tillage, land contouring and land terracing. Also more cover types are included in other published curve number tables. If the designer feels a more detailed determination of the curve number values are warranted, more information can be obtained from Hydraulic Design Series No. 2 (HDS-2) "Highway Hydrology" published by the Federal Highway Administration and Chapter 9 of "The National Engineering Handbook, Part 630," published by the NRCS.

* Table 405-2 NRCS Curve Numbers For Urban Areas					
Cover Type		Curve Numbers For Hydrologic Soil Group			
		A	B	C	D
Fully developed urban areas ^a (vegetation established)					
Lawns, open spaces, parks, golf courses, cemeteries, etc.					
Good condition; grass cover on 75% or more of the area		39	61	74	80
Fair condition; grass cover on 50% to 75% of the area		49	69	79	84
Poor condition; grass cover on 50% or less of the area		68	79	86	89
Paved parking lots, roofs, driveways, etc. (excl. right-of-way)		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers (excl. right-of-way)		98	98	98	98
Gravel (incl. right-of-way)		76	85	89	91
Dirt (incl. right-of-way)		72	82	87	89
Paved with open ditches (incl. right-of-way)		83	89	92	93
Cover Type	Average % impervious	Curve Numbers For Hydrologic Soil Group			
		A	B	C	D
Commercial and business areas	85	89	92	94	95
Industrial districts	72	81	88	91	93
Row houses, town houses, and residential with lots sizes 0.05 ha or less (0.12 acres or less)	65	77	85	90	92
Residential: average lot size					
0.1 ha (0.25 acres)	38	61	75	83	87
0.135 ha (0.33 acres)	30	57	72	81	86
0.2 ha (0.5 acres)	25	54	70	80	85
0.4 ha (1.0 acres)	20	51	68	79	84
0.8 ha (2.0 acres)	12	46	65	77	82

*This table is abbreviated from its original form in HDS-2

Table 405-3 NRCS Curve Numbers For Agricultural & Forested Areas					
Cover Type	Hydrologic Condition	Curve Numbers for Hydrologic Soil Group			
		A	B	C	D
Row crops	Poor	72	81	88	91
	Good	67	78	85	89
Small grain	Poor	65	76	84	88
	Good	63	75	83	87
Pasture or range	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow - continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77

*This table is abbreviated from its original form in HDS-2

DR 405-5 RAINFALL-RUNOFF RELATIONSHIP

A relationship between accumulated rainfall and accumulated runoff was derived by NRCS from experimental plots for numerous soils and vegetative cover conditions. Data for land-treatment measures (e.g., contouring, terracing) from experimental watersheds were included. The equation was developed mainly for small watersheds for which only daily rainfall and watershed data are ordinarily available. It was developed from recorded storm data that included the total amount of rainfall in a calendar day but not its distribution with respect to time. The NRCS runoff equation is therefore a method of estimating direct runoff from a 24-hour or 1-day storm rainfall. The equation is:

Equation 405-1 Direct Runoff

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

Where:

- Q = accumulated direct runoff, inches
- P = accumulated rainfall (potential maximum runoff), inches
- I_a = initial abstraction including surface storage, interception and infiltration prior to runoff, inches
- S = potential maximum retention, inches

It is worthwhile noting that Q in the NRCS runoff equation is a depth of runoff and not a flow rate as with most other hydrologic calculations. While Q and P have units of depth, they reflect volumes and are often referred to as volumes because it is usually assumed that the same depths occurred over the entire watershed area.

The relationship between I_a and S was developed from experimental watershed data. It removes the necessity for estimating I_a for common usage. The empirical relationship used to estimate the initial abstraction is shown in Equation 405-2.

Equation 405-2 Initial Abstraction

$$I_a = 0.2S$$

Substituting $0.2S$ for I_a in Equation 405-1, the NRCS rainfall-runoff equation becomes:

Equation 405-3 Direct Runoff

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Equation 405-3 represents the basic equation for computing the accumulated runoff depth, Q , for a given accumulated rainfall depth, P .

Additional empirical analyses were made to estimate the value of S . The studies found that S was related to soil type, land cover, and the hydrologic condition of the watershed. These are represented by the runoff curve number (CN), which is used to estimate S by:

Equation 405-4 Maximum Potential Retention

$$S = \frac{1000}{CN} - 10$$

where:

- S = potential maximum retention, inches
- CN = index that represents the combination of a hydrologic soil group and a land use and treatment class

DR 405-6 NRCS DIMENSIONLESS UNIT HYDROGRAPH

Two types of unit hydrographs are used in the NRCS procedure to develop the direct runoff hydrograph that will be used in the design of the drainage facility. These are unit hydrographs and the dimensionless unit hydrograph.

A unit hydrograph (UH) represents the time distribution of flow resulting from a unit of precipitation (usually 1 inch) of direct runoff occurring over a watershed in a specified time. A dimensionless unit hydrograph represents the composite of many unit hydrographs. The dimensionless unit hydrograph is plotted in non-dimensional units of time versus time to peak and discharge at any time versus peak discharge.

In the development of the NRCS Unit Hydrograph Method, unit hydrographs were evaluated for a large number of actual watersheds and then made dimensionless by dividing all discharge ordinates by the peak discharge and the

time ordinates by the time to peak. An average of these dimensionless unit hydrographs was computed. The time base of the dimensionless unit hydrograph was approximately 5 times the time to peak, and approximately 3/8 of the total volume occurred before the time to peak; the inflection point on the recession limb occurs at approximately 1.7 times the time to peak, and the UH has a curvilinear shape. The NRCS dimensionless unit hydrograph is shown in Figure 405-1 and the discharge ratios for selected values of the time ratios are given in Table 405-4.

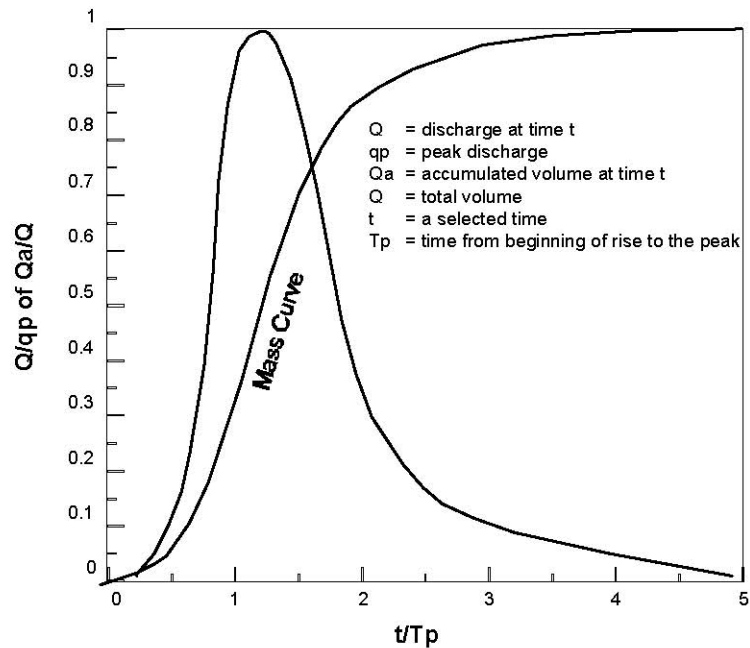


Figure 405-1 NRCS Dimensionless Unit Hydrograph

DR 405-7 WATERSHED LAG & TIME OF CONCENTRATION

There is a delay in time, after a rain event, before the runoff reaches its maximum peak. This delay is a watershed characteristic called lag. The lag is defined as the time from the center of mass of excess rainfall to the time to peak of the hydrograph. Steep slopes, compact shape and an efficient drainage network tend to make lag time short and peaks high; flat slopes, elongated shape and an inefficient drainage network tend to make lag time long and peaks low.

Lag is related to the time of concentration and may be estimated from it. In hydrograph analysis, time of concentration (T_c) is defined in two ways:

- The time for runoff to travel from the hydraulically most distant point in the watershed to outlet or point in question. This is the same definition offered in DR 403.
- The time from the end of excess rainfall to the point of inflection on the receding limb of the unit hydrograph.

The first definition is used to calculate the time of concentration. The NRCS derived the following empirical relationship between lag and time of concentration:

Equation 405-5 Lag Time

$$L = 0.6 T_c$$

Where:

- L = watershed lag in minutes
- T_c = Time of Concentration (See DR 403)

Table 405-4 Ratios for Dimensionless Unit Hydrograph and Mass Curve		
Time Ratios t/T_p	Discharge Ratios q/q_p	Mass Curve Ratios Q_a/Q
0	0.000	0.000
0.1	0.030	0.001
0.2	0.100	0.006
0.3	0.190	0.012
0.4	0.310	0.035
0.5	0.470	0.065
0.6	0.660	0.107
0.7	0.820	0.163
0.8	0.930	0.228
0.9	0.990	0.300
1.0	1.000	0.375
1.1	0.990	0.450
1.2	0.930	0.522
1.3	0.860	0.589
1.4	0.780	0.650
1.5	0.680	0.700
1.6	0.560	0.751
1.7	0.460	0.790
1.8	0.390	0.822
1.9	0.330	0.849
2.0	0.280	0.871
2.2	0.207	0.908
2.4	0.147	0.934
2.6	0.107	0.953
2.8	0.077	0.967
3.0	0.055	0.977
3.2	0.040	0.984
3.4	0.029	0.989
3.6	0.021	0.993
3.8	0.015	0.995
4.0	0.011	0.997
4.5	0.005	0.999
5.0	0.000	1.000

DR 405-8 NRCS UNIT HYDROGRAPH PEAK DISCHARGE

For purposes of comparison, the curvilinear dimensionless unit hydrograph (UH) can be approximated by a triangular dimensionless UH that has similar characteristics; Figure 405-2 shows a comparison of the two dimensionless unit hydrographs.

It is important to recognize that the triangular dimensionless UH is not a substitute for the curvilinear dimensionless UH. The curvilinear UH is always used in hydrologic computations. The triangular dimensionless UH is only used to develop an expression for computing the peak discharge of the curvilinear UH.

The dimensionless unit hydrograph is used to develop a unit hydrograph for the watershed being analyzed. In order to convert the dimensionless UH to a UH for the watershed being analyzed it is necessary to determine the peak flow and time to peak. Using the relationships shown in Figure 405-2, NRCS developed an equation for the peak discharge of the unit hydrograph:

Equation 405-6 Unit Hydrograph Peak Flow

$$q_p = \frac{K_p \times A \times Q}{T_p}$$

Where:

- q_p = unit hydrograph peak discharge (cfs)
- K_p = peak rate factor equal to 484 (dimensionless)
- A = drainage area (mi^2)
- Q = direct runoff, (inches)
- T_p = time to peak (hours)

By definition the unit hydrograph represents the time distribution of flow resulting from a unit of precipitation. Therefore, when using English units, Q in the above will be equal to 1 inch.

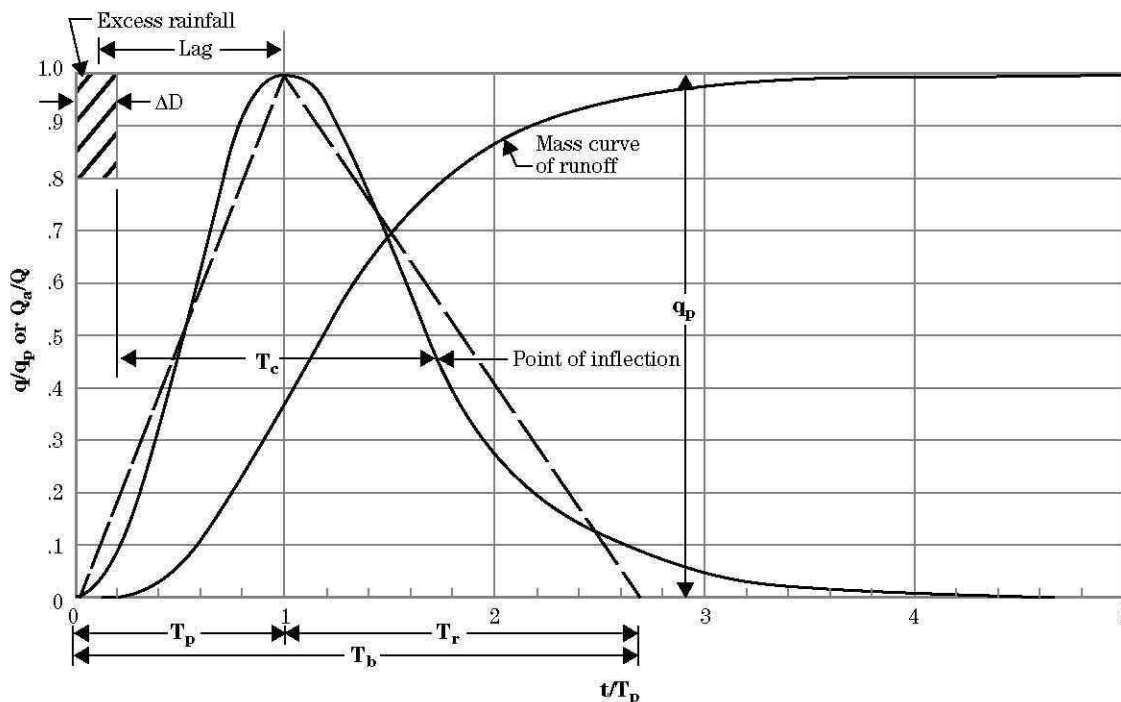


Figure 405-2
NRCS Dimensionless Curvilinear Unit Hydrograph and Equivalent Triangular Hydrograph

Referring to figure 405-2, the time to peak in equation 405-6 can be expressed by the following relationship:

Equation 405-7 Time to Peak

$$T_p = \frac{\Delta D}{2} + L$$

Where:

- ΔD = duration of unit excess rainfall (hours)
- L = Lag time (hours)

Unit hydrograph analysis involves dividing up precipitation events into smaller unit storms (more specifically into smaller durations of excess precipitation). The duration of these unit storms is ΔD . The unit hydrograph developed for a watershed is often referred to as a ΔD -hour unit hydrograph. Substituting equation 405-5 into equation 405-7, the time to peak can be expressed as:

Equation 405-8 Time to Peak

$$T_p = \frac{\Delta D}{2} + 0.6T_c$$

As mentioned earlier, the inflection point on the recession limb of the NRCS dimensionless UH occurs at approximately 1.7 times the time to peak. Again

referring to Figure 405-2, a relationship between the time to peak and time of concentration can now be established:

Equation 405-9

$$T_c + \Delta D = 1.7T_p$$

Using equations 405-8 & 405-9 a relationship between ΔD and T_c can be established:

Equation 405-10

$$\Delta D = .133T_c$$

DR 405-9 CONVOLUTION

The general procedure involves using the NRCS dimensionless unit hydrograph to develop a unit hydrograph specific to the watershed being analyzed. This unit hydrograph is used in conjunction with the design storm discussed in DR 405-2 and the rainfall-runoff relationships discussed in section 405-5 to develop the direct runoff hydrograph that will be used to design the drainage facility.

The process by which the design storm rainfall event is combined with the unit hydrograph to produce the direct runoff hydrograph is called convolution. Conceptually, it is a process of multiplication, translation with time, and addition. The rainfall event is divided up into small bursts of excess rainfall with a duration of ΔD . The first burst of rainfall excess of duration ΔD is multiplied by the ordinates of the unit hydrograph, the UH is then translated a time length of ΔD , and the next ΔD -hour burst of rainfall excess is multiplied by the UH. After the UH has been translated for all ΔD -hour bursts of rainfall excess, the results of the multiplications are summed for each time interval. This process of multiplication, translation, and addition is the means of deriving a design runoff hydrograph from the rainfall excess and the UH.

For more information on this process consult Hydraulic Design Series No. 2 (HDS-2 "Highway Hydrology") published by the Federal Highway Administration. "The National Engineering Handbook (NEH), Part 630" published by the NRCS is the primary reference for the NRCS methods. Chapter 16 of NEH, Part 630 provides a comprehensive example done with manual calculations.

DR 405-10 APPLICATION AND LIMITATIONS

Applying the NRCS Unit Hydrograph methodology to develop design hydrographs requires a significant amount of tedious calculations if performed by hand. However the advent of computer technology has made this method easy to apply. Most off the shelf hydrology programs that do hydrograph analysis have the NRCS unit hydrograph elements programmed into them. As noted earlier, the input required for the NRCS UH method include the drainage area, a runoff factor, time of concentration, and rainfall depths.

Many variables are integrated into the shape of a unit hydrograph. Since a dimensionless unit hydrograph is used and the only parameters readily available from field data are drainage area and time of concentration, consideration should be given to dividing the watershed into hydrologic units of uniformly shaped

areas. These subareas, if at all possible, should have a homogeneous drainage pattern, homogeneous land use and be approximately the same size. To assure that all contributing subareas are adequately represented, it is suggested that no subarea exceed 20 square miles in area and that the ratio of the largest to the smallest drainage area not exceed 10.

