HMS-PrePro
Supplementary Information – Unit Hydrograph Methods

Prepared By: Cynthia V. Castro

SCS Unit Hydrograph

The Soil Conservation Service (SCS) analyzed historical rainfall frequencies and determined four dimensionless rainfall distributions for the country. Each distribution is expressed as a mass curve for a 24-hour rainfall duration. The SCS Unit Hydrograph method, also known as the NRCS dimensionless unit hydrograph method, is based upon average unit hydrographs from geographic rainfall distributions. In HEC-HMS, the SCS Unit Hydrograph may be approximated for each lumped subbasin according to the lag time. The unit hydrograph peak time is related to the lag time by:

$$t_p = \frac{\Delta t}{2} + t_L$$

Where:

t_p = time to peak for unit hydrograph (min.)

t_L = basin lag time (min.)

Δt = unit hydrograph time interval (min.);

computational time interval in HEC-HMS

Then, the unit hydrograph peak flow may be represented by:

$$Q_p = \frac{CA}{t_p}$$

Where:

Q_p = peak discharge (cfs)

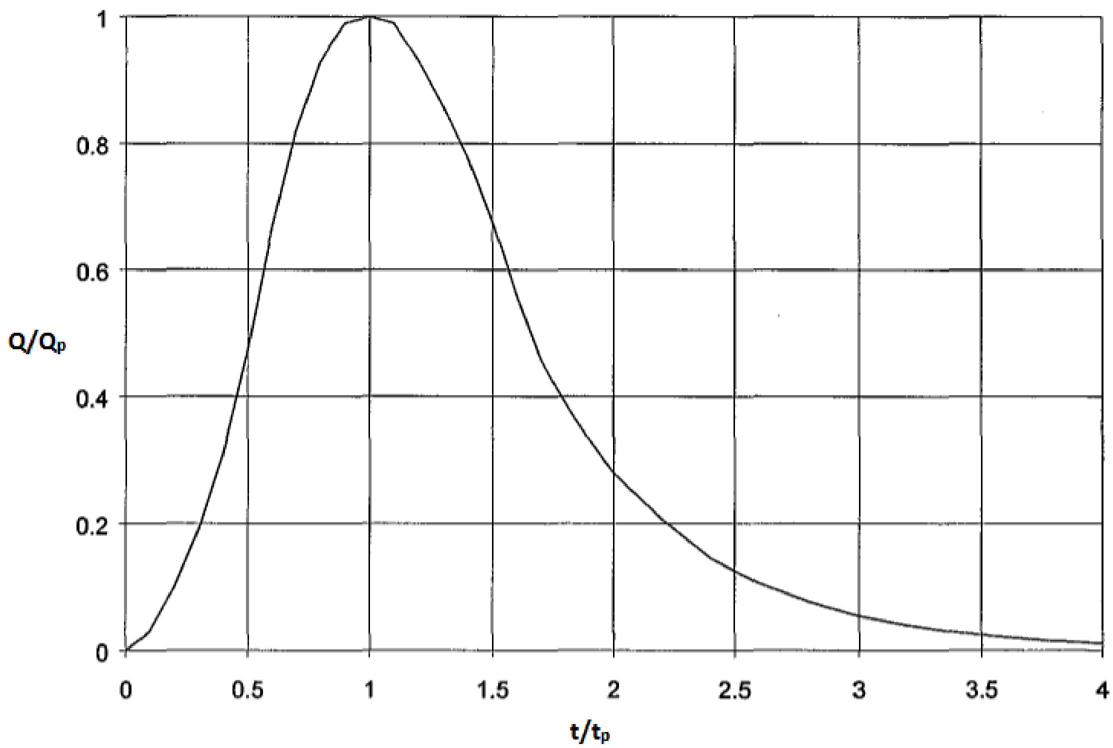
C = conversion constant (484 foot-pound system, 2.08 SI system)

A = basin drainage area (mi^2)

t_p = time to peak (hr.) (TxDOT, 2015)[1]

[1] TxDOT (2014). Hydraulic Design Manual. *Texas Department of Transportation*.

In HEC-HMS, the lag time is specified, and the SCS parameters are solved internally to determine the dimensionless unit hydrograph. When the user selects the SCS method for subbasin transformation, HMS-PrePro populates the .BASIN file with the lag time value for each subbasin.



SCS Unit Hydrograph[2]

[2] https://swmm5.org/2017/11/06/rules-for-using-the-nrcs-scs-dimensionless-unit-hydrograph-method-in-infoswmm-and-infoswmm-sa/

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SCS Lag Time

The lag time represents the interval between the moment rainfall-runoff begins until the peak of the hydrograph is reached (USDA, 2010[3]). When creating hydrologic models, the lag time (t_L) is generally estimated from the time of concentration (t_c), where:

$$t_L = 0.6 * \ t_c$$

The time of concentration represents the time required for water to travel along the longest flowpath from the hydraulically most remote point in the watershed to the basin outlet. The longest flowpath depends on physical characteristics such as slope, land use, and soil type. A common approach is to divide the watershed into smaller subbasins and estimate each time of concentration. Two methods for calculating the lag time are the Curve Number Lag method and the TR-55 method. These methods are described in the National Engineering Handbook and are commonly applied in standard hydrologic modeling (USDA, 2010[3]).

Curve Number Lag Method

The Curve Number Lag method, also known as the SCS Lag method or the Watershed Lag method, is based on average watershed characteristics such as slope and runoff potential. The CN Lag method, developed by Mockus (1961[4]), may be applied to a broad set of conditions ranging from steep forests to shallow meadows. The CN Lag equation may be expressed as:

$$t_L = \frac{l^{0.8}(\frac{1000}{CN} - 9)^{0.7}}{1900\ Y^{0.5}}$$

Where:

t_L = lag time (hr)
l = longest flow length in subbasin (ft)
Y = average watershed land slope (%)
CN = curve number

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[3] USDA. "National Engineering Handbook – Part 630 – Chapter 15 Time of Concentration." *United States Department of Agriculture, Natural Resources Conservation Service* (2010).

[4] Mockus, V., 1961. Watershed Lag, ES-1015. Unpublished Original Computations by Victor Mockus Showing Derivation of Lag Equation and Data Used.

This method aggregates land data over the drainage subbasin. Parameters for the CN Lag method may be determined using geospatial analysis tools. In HMS-PrePro, the longest flowpath is determined from the flow direction grid. The basin slope is determined using the Spatial Analyst *Slope* tool and then averaged over each subbasin area using the Spatial Analyst *Zonal Statistics* tool. A minimum slope of 0.005 is applied to very flat areas.

Clark (TC&R) Unit Hydrograph

The Clark unit hydrograph method was used to optimize the HMS-PrePro model by comparing simulated results with published hydrographs in Houston, Texas. The Clark watershed parameters include the unit hydrograph time of concentration (TC) and the storage coefficient (R). The Clark loss model derives a unit hydrograph by combining a translation hydrograph and a linear reservoir. In HEC-HMS, the translation hydrograph is represented by a synthetic time-area curve and the time of concentration (TC) for each subbasin. The linear reservoir is represented by the storage coefficient (R) to describe the storage effects in the subbasin (Scharffenberg et al, 2003[5]).

The Harris County Flood Control District (HCFCD) methodology for calculating TC&R was used in HMS-PrePro and is detailed in the HCFCD Hydrology & Hydraulics Guidance Manual, 2009, Section II.3 (HCFCD, 2009[6]). Since the Clark parameters are typically estimated according to local standards and then calibrated to historical gage flows, the GIS method presented in this paper should only be used as a guideline for initial estimates.

[5] Scharffenberg, W.A., Fleming, M.J., and Feldman, A.D. “The hydrologic modeling system (HEC-HMS): Toward a complete framework for hydrologic engineering.” *World Water & Environmental Resources Congress. 1-8.* (2003).

[6] HCFCD “Hydrology & Hydraulics Manual.” *Harris County Flood Control District.* (2009).

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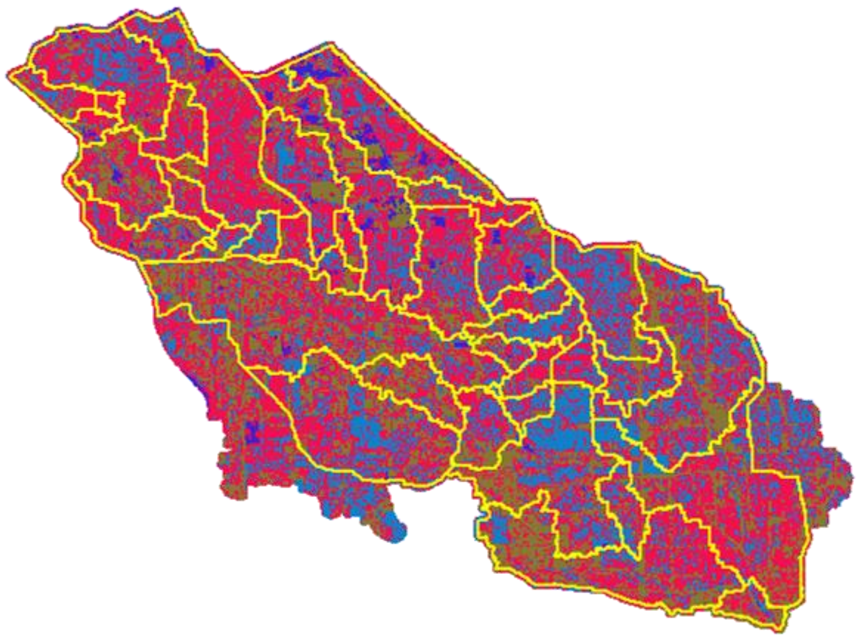

HMS-PrePro Spatial Analysis for Clark Method

According to the HCFCD (2009) drainage manual, TC&R may be estimated from the following relationships:

IF…	THEN…
$DLU - DET > DLU_{minimum}$	• $DLU_{detention} = DLU - DET$ • $TC = D[1 - (0.0062)(0.7\,DCI + 0.3\,DLU_{detention})](L_{CA}/\sqrt{S})^{1.06}$ • $TC{+}R = 4295(DLU_{detention})^{-0.678}(DCC)^{-0.967}(L/\sqrt{S})^{0.706}$
$DLU > DLU_{minimum}$ AND $DLU\text{-}DET < DLU_{minimum}$	• $DLU_{detention} = DLU_{minimum}$ • $TC = D[1 - (0.0062)(0.7\,DCI + 0.3\,DLU_{minimum})](L_{CA}/\sqrt{S})^{1.06}$ • $TC{+}R = 4295(DLU_{minimum})^{-0.678}(DCC)^{-0.967}(L/\sqrt{S})^{0.706}$
$DLU < DLU_{minimum}$	• $DLU_{detention} = DLU$ • $TC = D[1 - (0.0062)(0.7\,DCI + 0.3\,DLU)](L_{CA}/\sqrt{S})^{1.06}$ • $TC{+}R = 7.25(L/\sqrt{S})^{0.706}$

TC&R Calculations (HCFCD, 2009)

Where:

DLU = percent urban development (%)

DET = percent on-site detention (%)

DCI = percent channel improvement (%)

DCC = percent channel conveyance (%)

$DLU_{minimum} = 1344\ (DCC)^{-1.4049}$

D = watershed slope factor (2.46 if $S_o \leq 20$ ft/mi; 3.79 if 20 ft/mi < $S_o \leq 40$ ft/mi, 5.12 if $S_o > 40$ ft/mi), S_o = watershed slope

L = length flowpath (miles)

L_{CA} = length to centroid (miles)

S = channel slope (ft/mi)

Many of these parameters, such as the channel percentages within each subbasin, are unlikely to be obtained through GIS spatial analysis. Assumptions may be applied for deriving initial parameter estimates and later adjusted to reflect observed conditions. In HMS-PrePro, the NLCD land use raster is used to estimate the percent land developed (DLU) for each subbasin through a *Zonal Statistics* analysis. The land use data is reclassified according to the estimated development within each NLCD classification, as summarized in the table below:

NLCD Land Use to DLU Reclassification Values

NLCD Classification	Estimated Percent Land Developed (DLU)
Water	100 %
Developed ROW	100 %
Cultivated Pasture	0 %
Forest	0 %
Developed Low Intensity	50 %
Developed Medium Intensity	75 %
Developed High Intensity	100 %
Wetlands	0 %
Barren Land	0 %
Grassland	0 %

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These values correspond to Table 4 in the HCFCD (2009) manual, describing the relationship between land use type, percent impervious, and percent development. The percent DLU is rounded to the nearest whole number and appended to the *Subbasins* layer. The DLU is then used to estimate the DET, DCI, and DCC values according to the assumption that development causes an increase in channel improvements and a decrease in local detention and channel conveyance. The table below was created to define initial estimates of DET, DCI, and DCC according to the DLU. This table is based on the author's assumptions from comparing TC&R results with local models.

Clark Classification Table (DLU, DET, DCI, DCC)

DLU	**DET**	**DCI**	**DCC**
% Urban Development	*% On-site Detention*	*% Channel Improvement*	*% Channel Conveyance*
≤ 40	10	0	100
40 < DLU ≤ 60	3	50	100
60 < DLU ≤ 70	0	100	90
70 < DLU ≤ 80	0	100	80
80 < DLU ≤ 90	0	100	70
90 < DLU ≤ 100	0	100	60

In urban areas, channels are often structurally improved, and local on-site detention may be minimized due to the lack of grassy areas. The channel conveyance is often reduced as urbanization increases because capacity may be met and exceeded. As such, the channel conveyance percentage (DCC) may be used as a measurement tool for determining areas where channel improvements have not kept pace with local development (HCFCD, 2009). In HMS-PrePro, all ponding (DPP) is assumed to be equal to zero. The watershed length (L), centroid length (L_{CA}), channel slope (S), and watershed slope (S_o) are all spatial parameters that may be measured using GIS tools. TC and R is then estimated according to the relationships described in HCFCD (2009).

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Snyder Unit Hydrograph

The Snyder method was developed to predict stormwater hydrographs in ungauged watersheds. This method defines a unit hydrograph by the base time (t_b), peak discharge (Q_p), and Snyder's lag time (T_p). The peak flow is estimated as a function of the drainage area, lag time, and a dimensionless coefficient (C_p) (Meier, 1964[7]).

The U.S. Army Corps of Engineers determined that the base time (t_b) may be estimated at 50% and 75% ordinates from the peak time (Meier, 1964). HEC-HMS uses an iterative procedure to derive hydrograph parameters based on the subbasin area (A), lag time (T_p), and peaking coefficient (C_p) (Bedient, 2003[8]). When the Snyder unit hydrograph method is specified for a geographic region, locally-developed C_p values are recommended. Otherwise, the user may estimate the peaking coefficient according to previous studies and the physical properties of the watershed. Lower C_p values cause the hydrograph to rise more quickly, and higher values suggest a greater storage capacity in the watershed (TxDOT, 2014).

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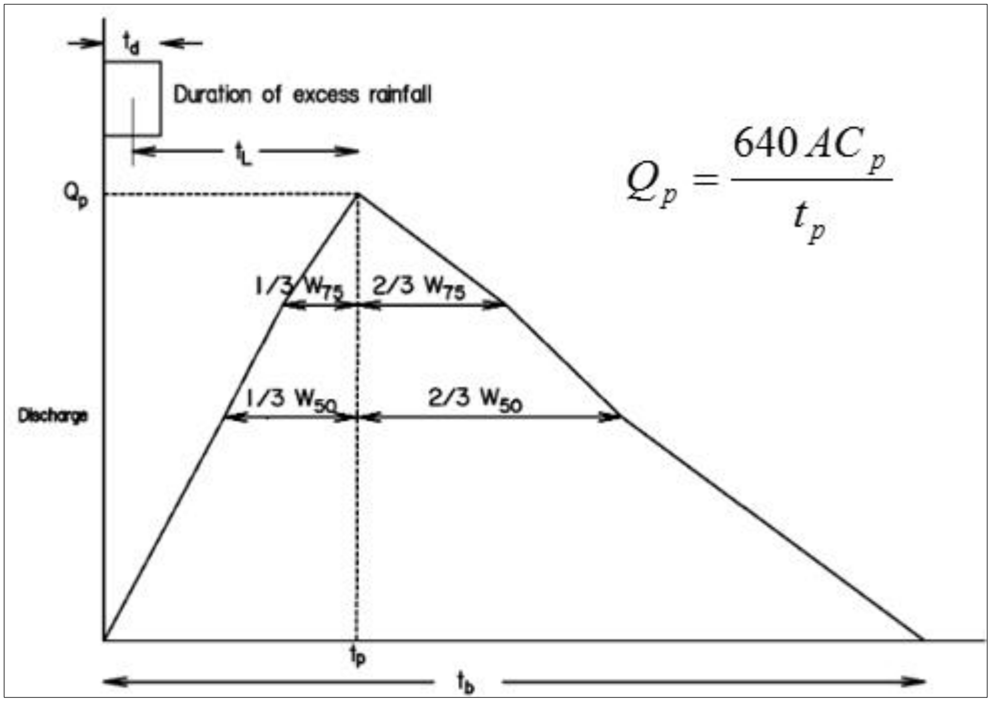
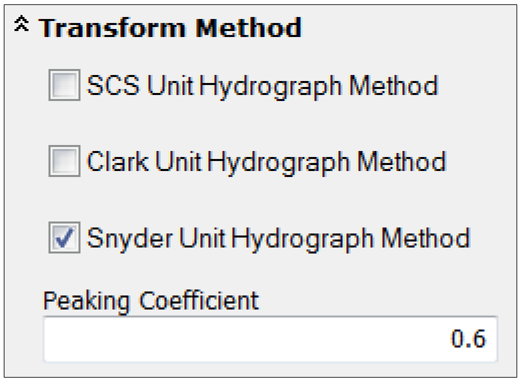
[7] Meier, W.L. (1964). Analysis of unit hydrographs for small watersheds in Texas. Texas Water Commission Bulletin 6414. Texas Water Development Board.

[8] Bedient, P. (2003). "HEC-HMS and Hydrologic Modeling Tutorial". Feb. 2003. Web. Mar. 5, 2016. < http://sspeed.rice.edu/bedient/Handouts/ HMS%20Tutorial%202003.doc>



Snyder Unit Hydrograph (TxDOT, 2014)

Typical values for C_p range from 0.4 to 0.8. In HMS-PrePro, the default value of C_p is 0.6. The user may modify the peaking coefficient according to local standards, observations, or calibration studies.



Snyder Unit Hydrograph Peaking Coefficient

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In order to estimate the Snyder lag time, the following relationship is used:

$$T_p = C_t(LL_c)^{0.3}$$

Where:

T_p = Snyder's peak lag time (hours)

C_t = steepness/storage coefficient based on local watersheds

L = length of longest flowpath for each subbasin (miles)

L_c = length of longest flowpath from centroid of subbasin to outlet (miles)

(Chow et. al. 1988)

The C_t coefficient typically ranges from 1.8 to 2.2 but has been found to be higher or lower depending on local drainage characteristics (Meier, 1964). The longest flowpath (L) may be estimated from the flow direction grid from ArcHydro or the NHDPlusV2.1 datasets. The centroidal longest flowpath (L_c) is computed with HEC-GeoHMS tools.

Advanced hydrological knowledge about local drainage characteristics are required for correctly applying the unit hydrograph methods. These transform methods were developed by the author to compare the HMS-PrePro results with local HEC-HMS models and should only be used to initialize a basin model prior to parameter optimization and calibration.