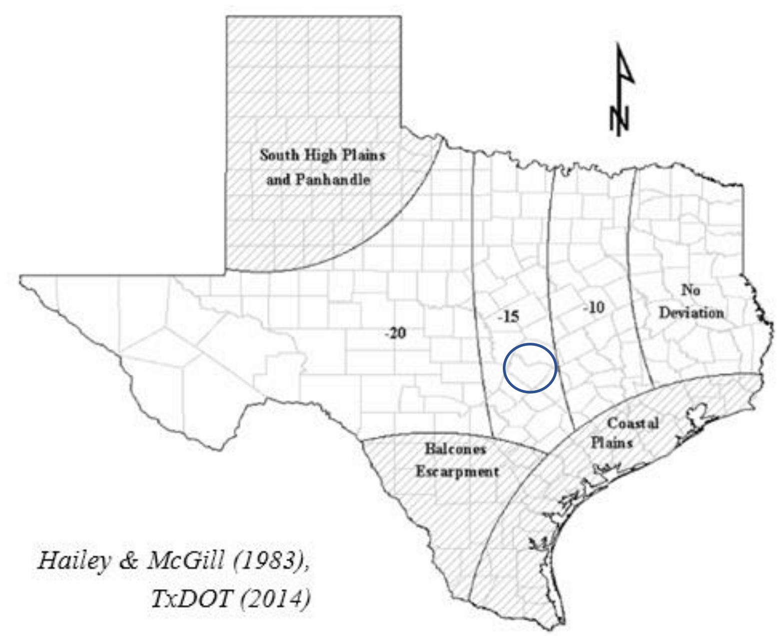
HMS-PrePro
Supplementary Information – Curve Number Reduction Factor

Prepared By: Cynthia V. Castro

CN Reduction Factor

The SCS Curve Number is based on empirical runoff observations. For this reason, HMS-PrePro provides a user-option for incorporating a CN reduction factor. In some regions, historical calibration studies have been performed to test the accuracy of SCS curve number predictions compared with gauge observations. The figure below depicts a Texas Department of Transportation (TxDOT) calibration study where curve number predictions were calibrated to historical rain events. A recommended CN reduction value was proposed for different regions of the state.



TxDOT Curve Number Reduction Calibration Study

The CN reduction factor may be applied to each HMS-PrePro run to reduce the composite curve number values by a specified percentage. For example, Travis County, TX, USA (circled) falls within the -15% reduction region. When HMS-PrePro is run for Travis County, TX, USA, a 0.85 reduction factor may be applied to all subbasins in the watershed. According to comparisons with local models, the curve number reduction factor provides favorable runoff results. The CN reduction factor is optional and may be used as an initial step in model parameterization.

Hailey, J.L. and McGill, H.N. (1983). Runoff curve number based on soil-cover complex and climatic factors, Proceedings 1983 Summer Meeting ASCE, Montana State University, Bozeman, MT, June 26-29, 1983, Paper Number 83-2057.

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

HMS-PrePro
Supplementary Information – Green & Ampt Method

Prepared By: Cynthia V. Castro

Green & Ampt Method

The Green and Ampt method is a simplification of the Richard's equation for describing water flow and infiltration through the soil (USACE, 2010[1]). In watershed modeling, the most sensitive set of values for describing the subbasin are the infiltration parameters (Smemoe et al, 2004[2]). Before the availability of soils data in digital format, the Green and Ampt method was used infrequently due to inherent difficulties in extracting useful soils information for a widespread area (Smemoe et al, 2004). With the advent of digital soils information, the Green and Ampt method has become more popular.

The Green and Ampt infiltration rate may be calculated by:

$$f_t = K + \frac{KS_w(\theta_s - \theta_i)}{F_t}$$

Where:

f_t = infiltration capacity (in/hr)

K = saturated hydraulic conductivity (permeability) (in/hr)

S_w = soil water suction (in)

θ_s = saturated water content

θ_i = initial water content

F_t = total accumulated infiltration (in) (TxDOT, 2014[3])

Soil classifications may be used to derive the hydraulic conductivity (K), soil water suction (S_w), and the volumetric moisture deficit (S_e). The initial water content (θ_i) is estimated according to the relationship between the volumetric moisture deficit (θ_e) and the saturated water content (θ_s), such that:

---

[1] USACE (2010). Hydrologic Modeling System HEC-HMS: User's Manual, Version 3.5. August 2010. US Army Corps of Engineers, Hydrologic Engineering Center.

[2] Smemoe, C.M., Nelson, E.J., and Zhao, B. (2004). Spatial averaging of land use and soil properties to develop the physically-based green and ampt parameters for HEC-1. *Environmental Modelling & Software*. 19(6): 525-535.

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

HMS-PrePro
Supplementary Information – Green & Ampt Method

Prepared By: Cynthia V. Castro

$$\theta_i = S_e(1 - \theta_s)$$

Either the initial water content or the saturated water content is provided by the user. When modeling a specific storm magnitude, regional calibration studies may provide good estimates for the water content ratios. When modeling forecasted rain events, the current in-situ soil water content is useful. Without ongoing and thorough field measurements, an accurate estimation of θ_s and θ_i is problematic. Detailed field measurements for a large watershed are improbable within a short period of time. Given the high sensitivity of loss parameters on the overall hydrograph, rainfall-runoff modeling for forecasted rain events is challenging due to the difficulty in estimating soil water content.

In HMS-PrePro, the Green and Ampt parameters may be estimated from the soils data and a lookup table. At present, HMS-PrePro uses the hydrological soil group (HSG) classification to estimate effective porosity, suction, and hydraulic conductivity according to: http://www.water-research.net/Waterlibrary/Stormwater/greenamp.pdf. The USDA soil texture classifications are related to the HSG, where:

Soil Texture and Hydrological Soil Group

USDA Soil Texture Classification	HSG
Sand	A
Loam	B
Clay Loam	C
Clay	D

In HMS-PrePro, the dominant HSG for each subbasin is determined with *Zonal Statistics*. A lookup table is created that relates the soil parameter estimates to the HSG. Values for the effective porosity (S_e), soil water suction (S_w), and hydraulic conductivity (K) are appended to the subbasin attributes table and used to populate the HEC-HMS output file.

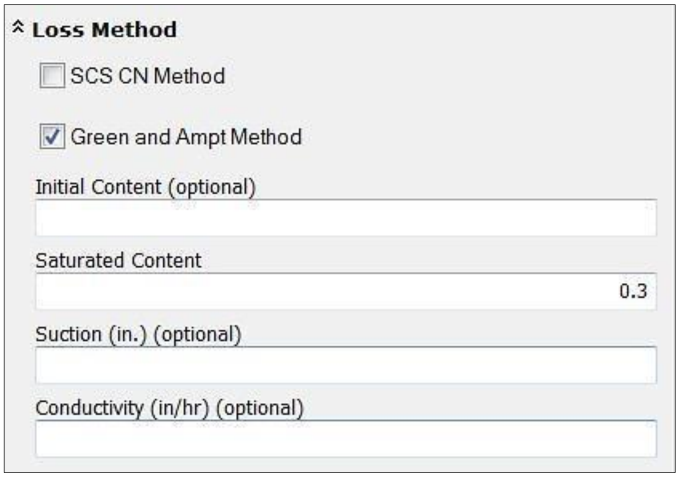
HSG	Porosity_Eff	Suction	Conductivity
A	0.417	1.95	9.276
B	0.436	3.5	0.52
C	0.389	8.22	0.079
D	0.385	12.45	0.024

HMS-PrePro Green & Ampt Lookup Table

HMS-PrePro
Supplementary Information – Green & Ampt Method

Prepared By: Cynthia V. Castro

The user has the option of overriding the SSURGO estimates by specifying regional parameter values within the toolbox interface. In either scenario, the user should choose the saturated content ratio according to best practices from local knowledge and observed data.



Green and Ampt User-Input in HMS-PrePro

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)

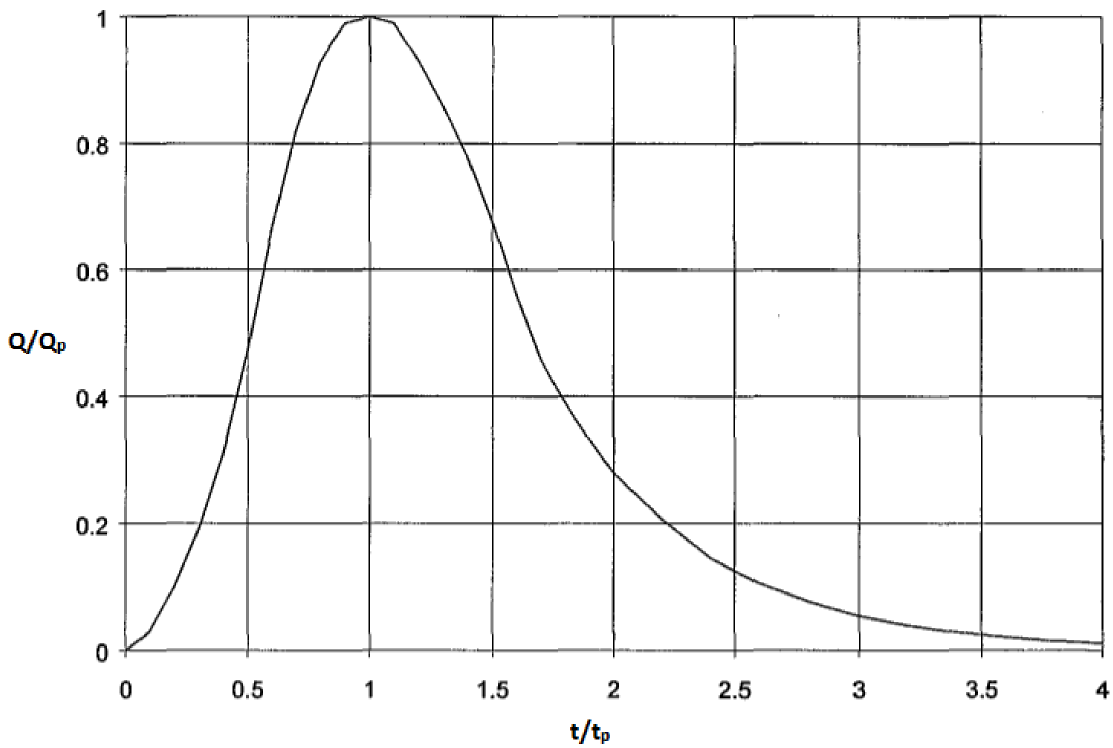
C = conversion constant (484 foot-pound system, 2.08 SI system)

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/

HMS-PrePro
Supplementary Information – Unit Hydrograph Methods

Prepared By: Cynthia V. Castro

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

[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]).

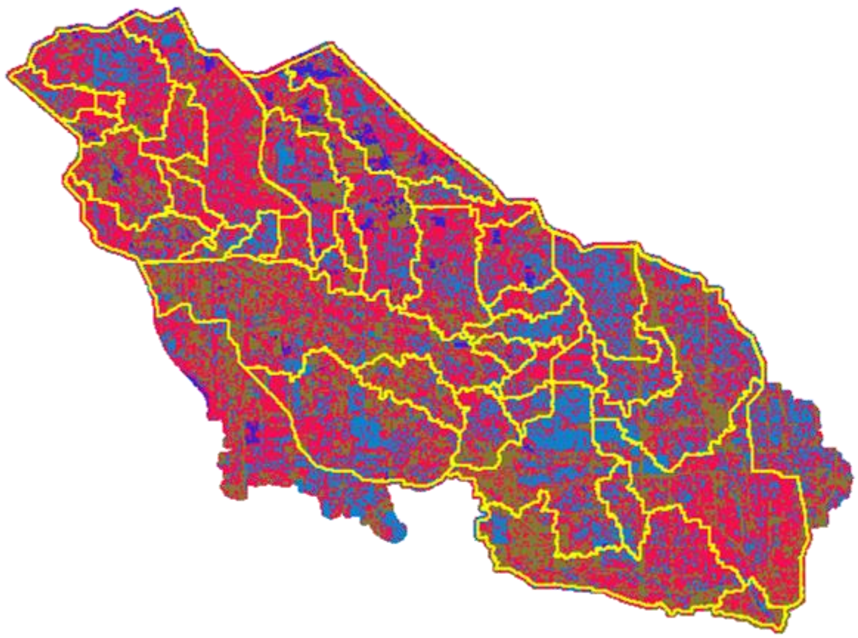
The Harris County Flood Control District (HCFCD) methodology for calculating TC&R was used in HMS-PrePro and is detailed in the HCFCD Hydrology & Hydraulics Guidance Manual, 2009, Section II.3 (HCFCD, 2009[6]). Since the Clark parameters are typically estimated according to local standards and then calibrated 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).

HMS-PrePro
Supplementary Information – Unit Hydrograph Methods

Prepared By: Cynthia V. Castro



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

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 $S_o \le 20$ ft/mi; 3.79 if 20 ft/mi $< S_o \le 40$ 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 %

HMS-PrePro
Supplementary Information – Unit Hydrograph Methods

Prepared By: Cynthia V. Castro

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).

HMS-PrePro
Supplementary Information – Unit Hydrograph Methods

Prepared By: Cynthia V. Castro

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]).

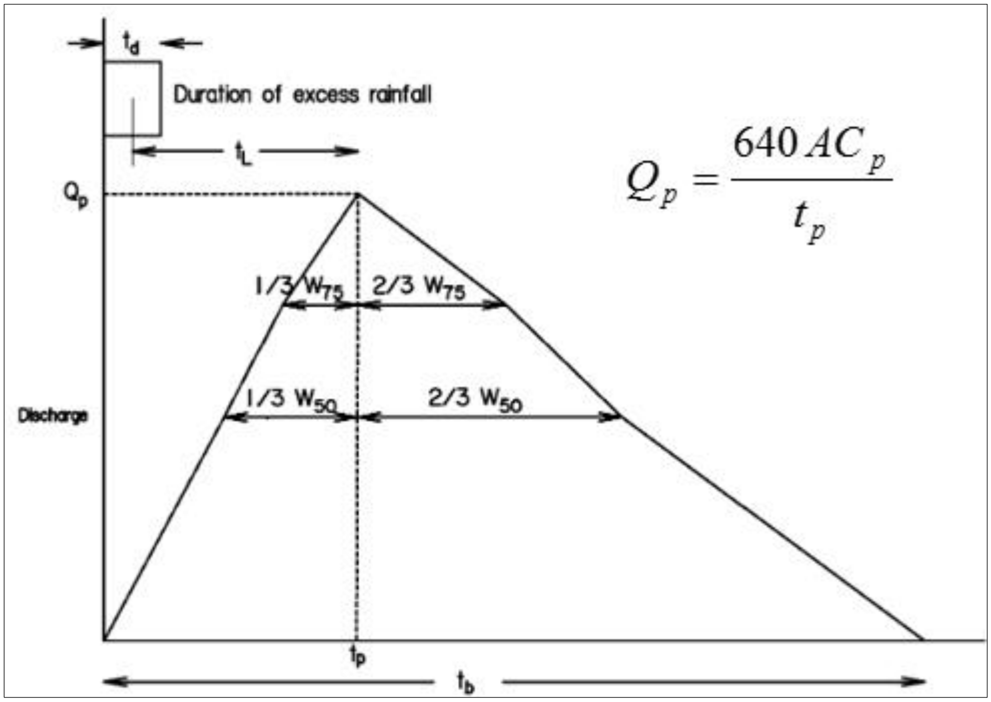
The U.S. Army Corps of Engineers determined that the base time (t_b) may be estimated at 50% and 75% ordinates from the peak time (Meier, 1964). HEC-HMS uses an iterative procedure to derive hydrograph parameters based on the subbasin area (A), lag time (T_p), and peaking coefficient (C_p) (Bedient, 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).

[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>

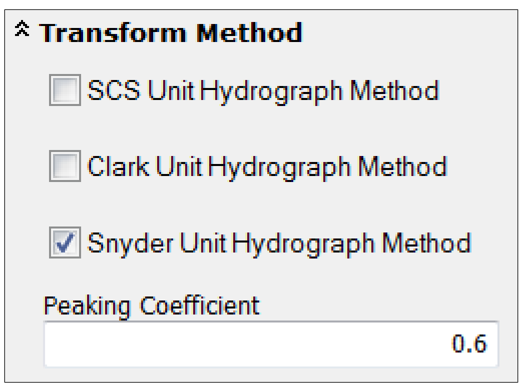
HMS-PrePro
Supplementary Information – Unit Hydrograph Methods

Prepared By: Cynthia V. Castro



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

HMS-PrePro

Supplementary Information – Unit Hydrograph Methods

Prepared By: Cynthia V. Castro

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)

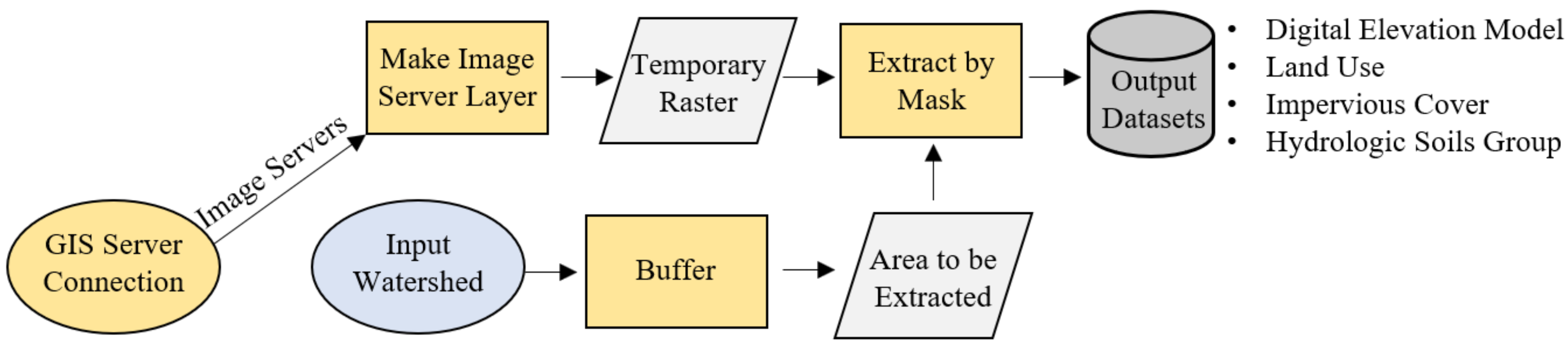
L_c = length of longest flowpath from centroid of subbasin to outlet (miles)

(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). In HMS-PrePro, the default value of C_t is 2.0. The longest flowpath (L) is derived from the flow direction grid from ArcHydro. The centroidal longest flowpath (L_c) is estimated as one-half the basin longest flowpath, which may need to be updated by the user during parameter optimization and calibration.

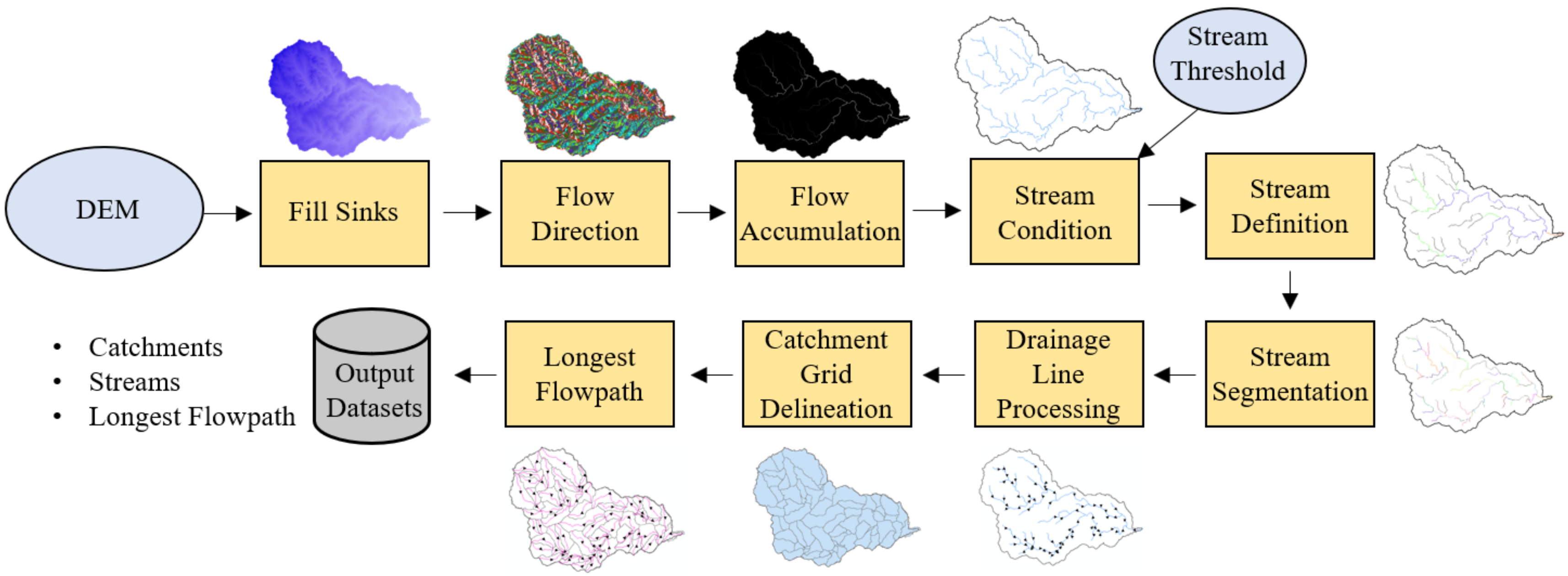
HMS-PrePro
Supplementary Information – Tool Flowcharts
Prepared By: Cynthia V. Castro

Get Data Flowchart



HMS-PrePro
Supplementary Information – Tool Flowcharts
Prepared By: Cynthia V. Castro

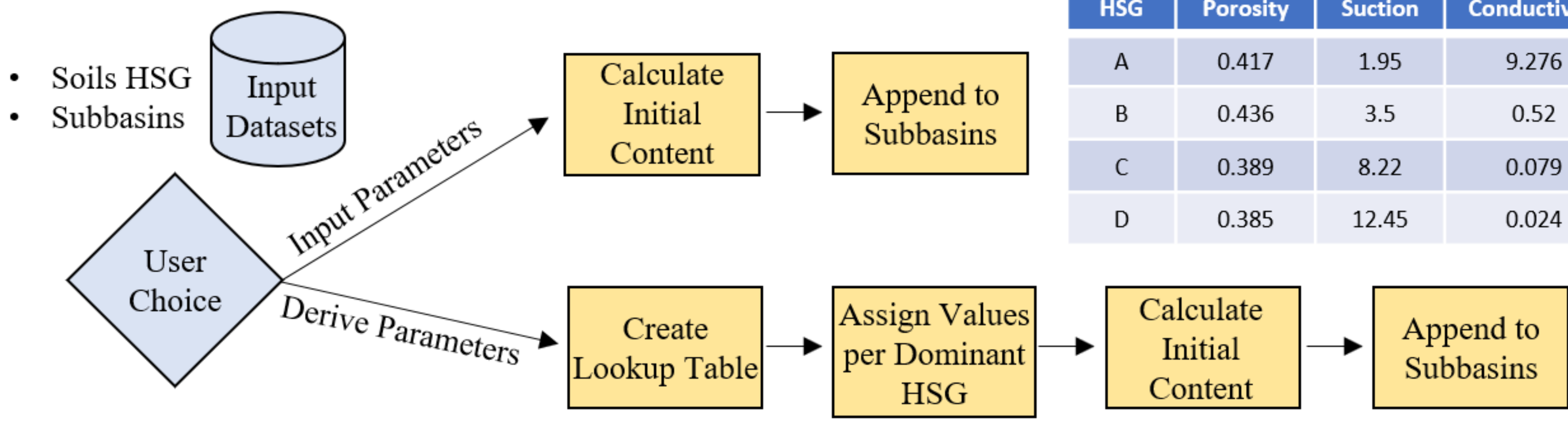
Watershed Delineation Flowchart



HMS-PrePro
Supplementary Information – Tool Flowcharts

Prepared By: Cynthia V. Castro

Green & Ampt Workflow



Lookup Table

HSG	Porosity	Suction	Conductivity
A	0.417	1.95	9.276
B	0.436	3.5	0.52
C	0.389	8.22	0.079
D	0.385	12.45	0.024

HMS-PrePro
Supplementary Information – Tool Flowcharts

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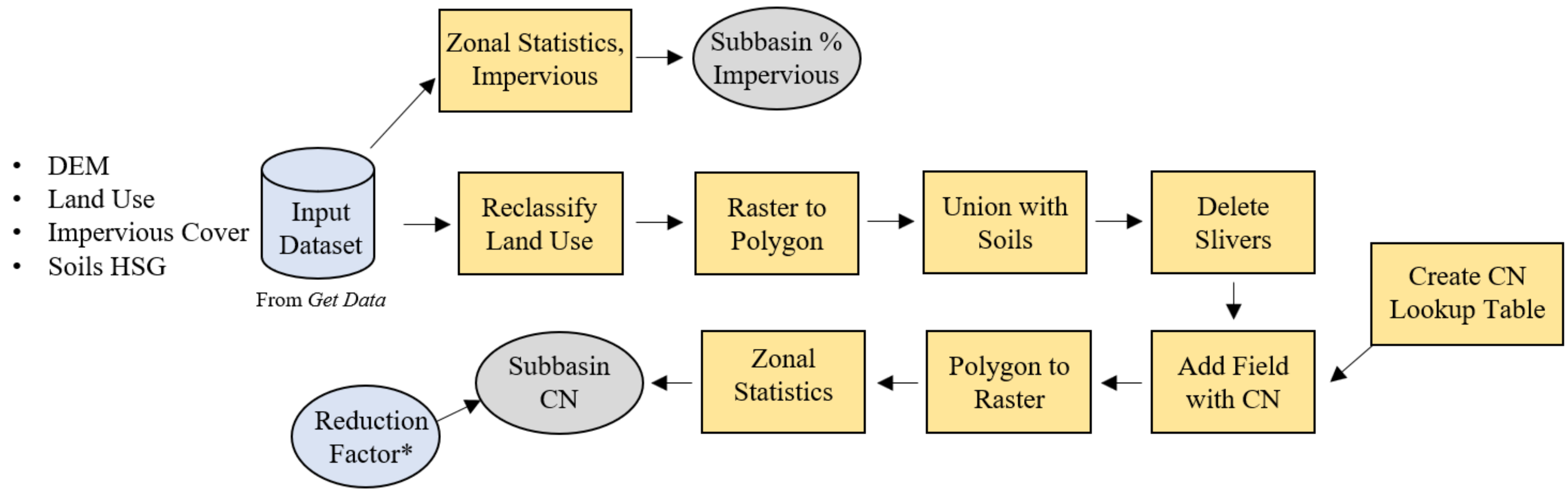
Curve Number Workflow



NLCD Values	NLCD Descriptions	Reclassified Value	Reclassified Description	Hydrologic Soils Group A	B	C	D
11, 12	Open Water, Perennial Ice/Snow	1	Water	98	98	98	98
21	Developed Open Space	2	Developed ROW	68	79	86	89
81, 82	Hay/Pasture, Cultivated Crops	3	Cultivated Pasture	49	69	79	84
41, 42, 43	Deciduous, Evergreen, Mixed Shrub/Scrub	4	Forest	30	55	70	77
22	Developed – Low Intensity	5	Developed – Low Intensity	51	68	79	84
23	Developed – Medium Intensity	6	Developed – Medium Intensity	57	72	81	86
24	Developed – High Intensity, Barren Land	7	Developed – High Intensity	77	85	90	92
90, 95	Emergent Herbaceous Wetlands, Woody Wetlands	8	Wetlands	98	98	98	98
31	Barren Land	9	Barren Land	76	85	90	93
52, 71, 72, 73, 74, 51	Dwarf Scrub, Shrub, Herbaceous, Grassland, Lichen, Moss	10	Grassland	39	61	74	80

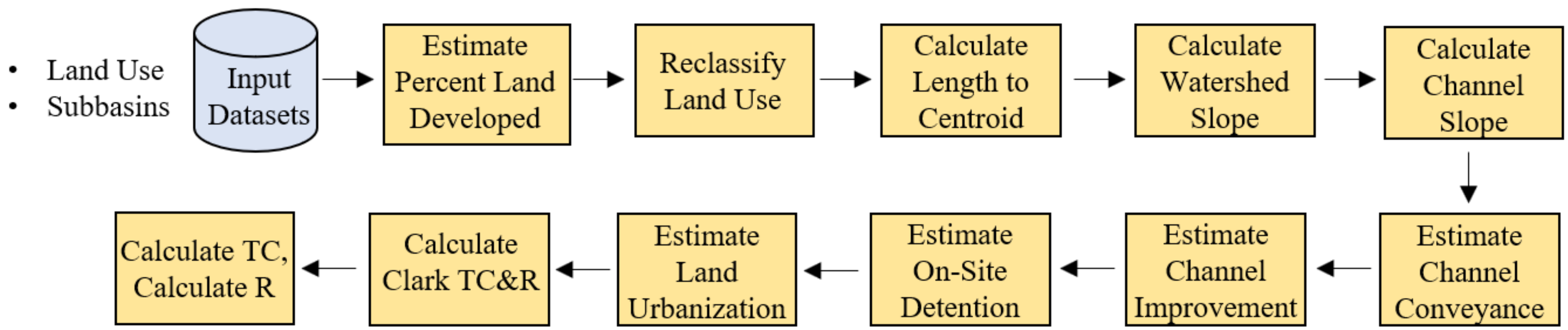
HMS-PrePro
Supplementary Information – Tool Flowcharts

Prepared By: Cynthia V. Castro

Clark Unit Hydrograph Workflow

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

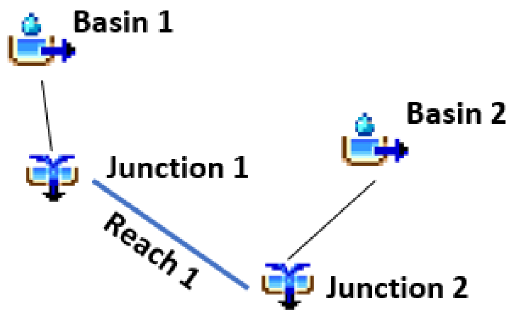
NLCD Classification	Estimated Percent Land Developed (DLU)
Water	100 %
Developed ROW	100 %
Cultivated Pasture	0 %
Forest	0 %
Developed Low Intensity	50 %
Developed Medium Intensity	75 %
Developed High Intensity	100 %
Wetlands	0 %
Barren Land	0 %
Grassland	0 %



HMS-PrePro
Supplementary Information – Topology

Prepared By: Cynthia V. Castro

Topology Schematic and Basin Output Text File



Subbasin: Basin 1
    Canvas X: -4025.974025974026
    Canvas Y: 1839.8268398268397
    Area: 5
    Downstream: Junction 1

    Canopy: None

    Surface: None

    LossRate: SCS
    Percent Impervious Area: 3.0
    Curve Number: 82
    Initial Abstraction: 0

    Transform: SCS
    Unitgraph Type: STANDARD

    Baseflow: None
End:

Junction: Junction 1
    Canvas X: -3405.4834054834055
    Canvas Y: 165.94516594516608
    Downstream: Reach 1
End:

Reach: Reach 1
    Canvas X: 173.16017316017314
    Canvas Y: -1190.4761904761908
    From Canvas X: -3405.4834054834055
    From Canvas Y: 165.94516594516608
    Downstream: Junction 2

    Route: Muskingum
    Muskingum K: 1.14
    Muskingum X: 0.3
    Muskingum Steps: 3
    Channel Loss: None
End:

Subbasin: Basin 2
    Canvas X: -418.47041847041874
    Canvas Y: 1349.2063492063494
    Area: 3.2
    Downstream: Junction 2

    Canopy: None

    Surface: None

    LossRate: SCS
    Percent Impervious Area: 0
    Curve Number: 78
    Initial Abstraction: 0

    Transform: SCS
    Unitgraph Type: STANDARD

    Baseflow: None
End:

Junction: Junction 2
    Canvas X: 173.16017316017314
    Canvas Y: -1190.4761904761908
End: [No Downstream, i.e. Outlet]

HMS-PrePro
Supplementary Information – Topology

Prepared By: Cynthia V. Castro

Topology Code

```
""" Topology """
def nodeID(reach, reachID, basin, basinID, ToNode):
    arcpy.AddField_management(reach, "NodeID", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
    arcpy.AddField_management(basin, "NodeID", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

    tonodes = {}
    with arcpy.da.UpdateCursor(reach, [reachID, ToNode, "NodeID"]) as cursor:
        for row in cursor:
            row[2] = round(row[1],0)
            tonodes.update({row[0]: row[1]})
            cursor.updateRow(row)
    del row, cursor

    with arcpy.da.UpdateCursor(basin, [basinID, "NodeID"]) as cursor:
        for row in cursor:
            if row[0] in reachList:
                row[1] = tonodes[row[0]]
            cursor.updateRow(row)
    del row, cursor

def NextDownID(reach, reachID, FromNode, ToNode):
    fromnode = {}
    fromnodes = []
    with arcpy.da.SearchCursor(reach, [reachID, FromNode]) as cursor:
        for row in cursor:
            fromnode.update({row[1]: row[0]})
            fromnodes.append(row[1])
    del row, cursor

    arcpy.AddField_management(reach, "NextDownID", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

    with arcpy.da.UpdateCursor(reach, [ToNode, "NextDownID"]) as cursor:
        for row in cursor:
            if row[0] in fromnodes:
                row[1]=fromnode[row[0]]
            cursor.updateRow(row)
    del row, cursor
```

```
# Topology Lists
subbasins = []
with arcpy.da.SearchCursor(basin, [basinID]) as cursor:
    for row in cursor:
        subbasins.append(row[0])
del row, cursor

reachList = []
ds_reaches = []
with arcpy.da.SearchCursor(reach, [reachID,
"NextDownID"]) as cursor:
    for row in cursor:
        reachList.append(row[0])
        ds_reaches.append(row[1])

ex_reaches = list(set(reachList) - set(subbasins))

us_subbasins = list(set(reachList) - set(ds_reaches)
- set(ex_reaches))
```