

Runoff Routing Methods

XPSWMM and XPStorm uses seven major types of Hydrograph Generation techniques available in Runoff. This page contains the following topics:

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SWMM Runoff Non-linear Reservoir Method

Subcatchments are modeled as idealized rectangular areas with the slope of the catchment perpendicular to the width. Each subcatchment is classified into 3 or 4 subareas as indicated in the following table.

Subarea	Perviousness	Depression Storage	Snow Cover and Extent	
			Single Event	Continuous
A1	Impervious	Yes	Bare	Normally bare, but may have snow cover on 100% of A1 plus A3
A2	Pervious	Yes	Constant	Snow covered subject to fraction of area areal depletion curve which is snow covered
A3	Impervious	No	Bare	Same as A1
A4	Impervious	Yes	100% covered	Snow covered subject to areal depletion curve

Flow from each sub-area moves directly to a node and does not travel over any other sub-area. The width of the pervious sub-area, A2, is the entire subcatchment width, whereas the width of the impervious sub-areas A1, A3, A4 are in proportion to the ratio of their area to the total impervious area. Subcatchments are analyzed as spatially lumped non-linear reservoirs. The routing is performed separately for each of the four sub-areas (A1-A4) of the catchment.

Kinematic Wave (Runoff)

The kinematic wave method for overland flow applies only the kinematic wave component of the St Venant shallow flow equations for momentum and continuity. Similar to the Runoff procedure the Subcatchments are modelled as idealised rectangular areas with the slope of the catchment perpendicular to the width. The width parameter is used as per the Runoff procedure. Both the Runoff and Kinematic wave procedures only apply either the Horton or Green Ampt loss to the pervious percentage of the subarea, as defined by the % impervious data item. The only loss applied to the impervious component is via the depression storage defined for the impervious area in the infiltration dialog. Additional depression loss (defined with infiltration information) can also be applied to the pervious component. This will be an additional loss to the Horton or Green Ampt loss.

Henderson and Wooding (1964) and Wooding (1965) developed a theory for the overland and stream hydrograph. All flows are assumed to obey the equations of continuity and momentum. The continuity and momentum equations for overland kinematic waves reduce to the following two equations, respectively:

Continuity Equation:

$$\frac{\partial y}{\partial t} + \frac{\partial q}{\partial x} = i - f = ie$$

and

Momentum Equation:

$$q = ay^m = 1.49/N S_o^{1/2} y^{5/3}$$

Where:

$y = y(x,t)$ = depth of overland flow (ft),

$q = q(x,t)$ = rate of overland flow/unit width,

$i-f = i_e$ = net rainfall rate,

a = conveyance factor = $(1/N)S_o^{1/2}$ when obtained from Manning's equation,

$m = 5/3$ when obtained from Manning's equation,

N = effective roughness coefficient,

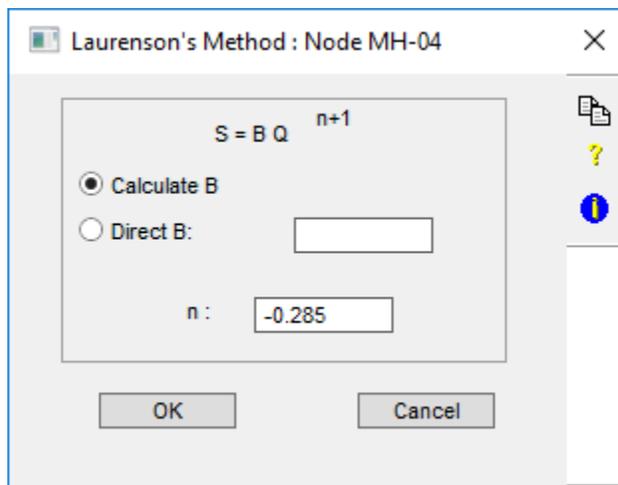
S_o = average overland slope,

Y_o = mean depth of overland flow.

After Bedient and Huber, 1992

The required data for this method is similar to the EPA Runoff method including area (ha or acres), impervious %, subarea width (m or ft) and slope (m/m or ft/ft).

Laurenson



When using Laurenson Hydrology the subcatchment width is by default not used. The catchment roughness utilised when calculating the storage delay parameter "B" is taken from the pervious Manning "n" value for the sub-catchment included with the infiltration information. A second method is available by including the Configuration parameter RAFTS under the [Configuration](#) menu. This allows % imp to be set to 0 and 100 in the first two separate sub areas. This will allow the infiltration equation to be applied to the total subareas. Width is then used as a factor to control the "B" computation by inputting 0.0 and 100.0 respectively for the fully pervious and impervious sub areas. Appropriate infiltration can then be applied to the respective subareas.

The default procedure (without the RAFTS configuration parameter active) only applies either the Horton or Green Ampt loss to the pervious percentage of the subarea, as defined by the % impervious data item. It is encouraged to split the catchment into two subcatchments, with 0 and 100% impervious as the % imperviousness ratio is only applied to the U parameter of the Laurenson's method.

Routing for a particular subcatchment is carried out using the Muskingum procedure. The storage, however, is a non-linear function of the discharge, ie:

$$s = K(q) \times q \quad (\text{equation 3})$$

Where:

s = volume of storage, (hrs \times m³/s)

q = instantaneous rate of runoff, (m^3/s)

$K(q)$ = storage delay time as a function of q (hours).

The storage function is used in the continuity equation in finite difference form thus:

$$(i_1 + i_2) \times t/2 - (q_1 + q_2) \times t/2 = s_2 - s_1 \quad (\text{equation 4})$$

Where:

i_1, i_2 = inflow at beginning and end of routing period (m^3/s)

t = routing interval (hrs)

q_1, q_2 = outflow from the storage at beginning and end of routing period (m^3/s)

s_1, s_2 = storage volume at beginning and end of routing period (hrs \times m^3/s).

Substituting s_2 and s_1 in Equation (4) from Equation (3) gives:

$$q_2 = C_0 i_2 + C_1 i_1 + C_2 q_1 \quad (\text{equation 5})$$

Where:

$$C_0 = C_1 = t/(2K_2 + t) \quad (\text{equation 6})$$

$$C_2 = (2K_1 - t)/(2K_2 + t) \quad (\text{equation 7})$$

An iterative solution to Equation (5) is required due to the interrelation between C_0, C_1, C_2, K_2 and q_2 . K_1, K_2 is defined via Equation (8).

Storage-Discharge Relationship

Each sub-area is treated as a concentrated conceptual storage. Each storage has a storage delay time described thus:

$$K(q) = Bq^n \quad (\text{equation 8})$$

where:

$K(q)$ = subarea storage delay time (hours) as a function of q

q = discharge (m^3/s)

B = storage delay time coefficient

n = storage non-linearity exponent.

Substituting Equation (8) into Equation (3) gives:

$$s = Bq^n + 1 \quad (\text{equation 9})$$

Non-linearity Exponent "n"

The default value for the non-linearity exponent in RAFTS is -.285. RAFTS-XP provides the mechanisms to alter this value, usually in respect to rare events involving significant subcatchment overbank flood routing, by:

- directly entering an amended value of "n". A value of zero (-.001) would indicate linear catchment response and equate with unit hydrograph theory, or
- entering an "n" as a function of Q for each rating curve

It would be expected that the default "n" would prevail up to bank full and then, possibly, progressively drop back towards zero during PMF.

Coefficients B and n

B is either directly input for each subcatchment or estimated from Equation (10) which was derived by Aitken (1975). The value of B for each subarea is assumed to equal the average value of B for the subcatchment.

where:

B = mean value of coefficient B for subcatchment

A = subcatchment area (km^2)

U = fraction of catchment that is urbanised. (Where $U = 1.0$, the catchment is fully urbanised and when $U = 0.0$, the catchment is completely rural)

Sc = main drainage slope of subcatchment (%). (The longest path of the subcatchment, starting at subcatchment outlet running up the main channel then if necessary branching off at the furthest tributary, to the top of the subcatchment.)

This equation was initially derived from six urban catchments in Australia with the following ranges applying:

A varied from 0.8 km² to 56 km²

U varied from 0.0 to 1.00

Sc varied from 0.22% to 2.90%.

However over the last fourteen years a wide range of areas, slopes and urbanisation outside these ranges have been tested with a high degree of success. See Sobinoff et al (1983).

For gauged catchments, deduced B values, evaluated as the average value from recorded rainfall/runoff events, should be used in preference to generalised regression estimates.

As 'U' in certain instances can be rather vague, data input in this respect has been amended to include a % impervious parameter for each subcatchment in place of the 'U' term.

The model interprets U in terms of %I based on the following ratios:

I%	U
0	0
30	0.7
50	1.0
100	2.0*

* This value is extrapolated from the original data based on limited results from fully impervious areas.

B Modification Factors

Where gauged rainfall/runoff data is available for a range of events it should be used in preference to the above regression equation with modifying factors.

PERN. The original regression equation (Equation (10)) does not differentiate between catchments with the same urbanisation but different roughness. An additional empirical parameter has therefore been added to take previous subcatchment roughness into account.

The parameter PERN is input as an Mannings 'n' representation of the average subcatchment roughness. B is then modified in accordance with the following table. If PERN is left blank then B is unchanged.

Mannings "n"	Multiplication Factor
.010	0.4
.015	0.5
.025	1.0
.100	3.0

BX. During calibration of a gauged catchment an additional parameter BX in the header data is included to modify the calculated or input B by a further multiplication factor. The parameter BX will then uniformly modify all subcatchment B values previously computed, or set (Equation (10)). To invoke BX within this program it is necessary to utilise a Configuration Parameter selectable from the Tools menu.

To set a BX to a value of 1.5 for example add the [Configuration Parameter BX=1.5](#).

SCS Hydrology

As an alternative to the non-linear runoff routing method employed by Runoff, hydrographs may optionally be generated by the SCS method described in the SCS National Engineering Handbook - Section 4 (NEH-4).

Pervious Area Curve Number

The runoff [curve number](#) as described in NEH-4 Chapter 9. Typical values vary from 20 for regions with high infiltration and interception capacities to 98 for impervious areas.

It is a dimensionless number depending on hydrologic soil group, cover type, treatment, hydrological condition, and antecedent moisture conditions. This number has a valid range from 0 to 100 with typical values from 60 to 90 and 98 for impervious surfaces.



This curve number is only for the pervious area. Internally, an area weighted composite number is generated using this number for the pervious area and 98 for the impervious area. Essentially, the entire area is subject to infiltration using the composite number. Breaking the catchment to the pervious and impervious parts would allow infiltration to be restricted to the pervious area.

Hydrograph Shape Factor

The shape factor or peak rate factor as defined in NEH-4 Chapter 16. The typical value is 484 for a hydrograph where the volume under the falling side of the triangular unit hydrograph is equal to 1.67 times the volume under the rising limb of the curvilinear unit hydrograph. Actual values may vary from 100 in very flat swampy country to 800 in steep rocky terrain.

The Soil Conservation Service has been determined the hydrograph shape factor to be 484 for most watersheds. This was the result of analyzing many watersheds of various size and geographic location. It is used in the formulation of peak discharge and the peak of the unit hydrograph:

$$Q_p = 484A/t_p$$

in which Q_p is the peak discharge in cfs A is the drainage area mi^2 and t_p is the time to peak in hr. Several other values have been used for shape factor within Florida and other areas of the country for wetlands, sandy soils and steep terrain. Typical values in Florida include 323 or 256 and values as low as 100. Effectively, the hydrograph shape factor will lengthen the time base of the unit hydrograph and lower the peak. If you are using real rainfall data this parameter can be used for calibration. For example the falling limb time base of the hydrograph will be double when using a shape factor of 300 instead of 484.

A curvilinear or triangular shape may be chosen by selecting the appropriate button. Both shapes are supported for the entire range of hydrograph shape factors.

Time of Concentration

The time of concentration as described in NEH-4 Chapter 15 (in mins) is defined in two ways; the time for runoff to travel from the furthestmost point of the watershed to the point in question, and the time from the end of excess rainfall to the point of inflection on the trailing limb of the unit hydrograph. T_c can be estimated from several formula such as Kinematic-wave. For a constant excess rainfall can be described as:

$$T_c = C(n^{0.6} L^{0.6} / i^{0.4} S^{0.3})$$

in which L is the distance from the upper end of the plane to the point of interest (usually the inlet) n is the Manning resistance coefficient, i is the excess rainfall rate, S is the dimensionless slope of the surface, and C is a constant that depends on units of the other variables. For t_c in minutes, i in inches/hr and L in feet C equals 0.938. For t_c in minutes i in mm/hr and L in meters C equals 6.99.

Another formula for determining t_c is the lag equation

$$T_c = L/0.6$$

$$L = I^{0.8}(S+1)^{0.7}/1900Y^{0.5}$$

where:

Tc = time of concentration in hours

L = lag time in hours

I = hydraulic length of the watershed in feet

Y = Average land slope in percent

S = Potential maximum retention in inches

CN = weighted Curve Number

The time of concentration is required as input although internally the time to peak is used in creating the unit hydrograph. $T_p = 2/3 T_c$ for shape factor 484.

Calc: The time of concentration can be calculated using the [Time of Concentration Calculator](#).

Initial Abstraction

The initial abstraction from the precipitation may be represented as an absolute number, that is the total depth of precipitation that is less (in mm or inches) or as a fraction of the amount of precipitation (between 0 to 1).

Initial Abstraction, I_a , contains all the loss terms prior to beginning of runoff. All though it was found to be highly variable for many small agricultural watersheds it was found that

$$I_a = 0.2 \times S$$

Where

$$S = (1000/CN) - 10$$

S is the potential maximum abstraction.

[xp](#) allows the user to use a fraction with .2 being the default or the Initial abstraction can be a depth in inches or mm.

Additional References:

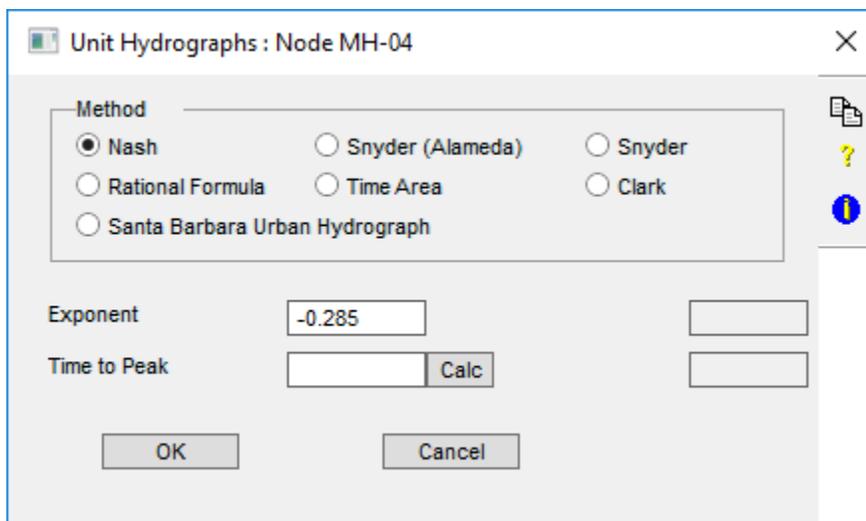
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Unit Hydrographs



The unit hydrograph and quasi unit hydrograph procedures currently available include:

- Nash
- Rational Hydrograph (Triangular Unit Hydrograph)
- Santa Barbara Urban Hydrograph
- Snyder
- Snyder (Alameda modified)
- Time Area
- Clark

When one of the above methods requires a Time to Peak or Time of Concentration this can be calculated using the [Time of Concentration Calculator](#).

Nash Unit Hydrograph Procedure

Nash in 1957 proposed a conceptual catchment model by considering a drainage basin with a series of identical linear reservoirs in series. By routing a unit inflow through the reservoirs, a mathematical equation for instantaneous unit hydrograph can be derived. Two items of data are required to apply this method. These include an Exponent and a Time of concentration. This method requires calibration data to base input data.

Rational Hydrograph

The Rational method as applied by this method uses a unit hydrograph approach applying a deterministic form of the Rational formula $Q = CIA$. The two items of data needed for this procedure are the sub-area runoff coefficient "C" and time of concentration t_c . The method utilizes the rainfall concurrent to the time step being computed. The unit hydrograph incorporates a base length equal to two times the time of concentration.

This method is currently not recommended without calibration data or for models with storage nodes and significant attenuation.

This method is NOT recommended as it requires a new Rainfall event for every T_c in the model and T_c 's must be calculated by hand. If the Rational method is needed then the Rational Formula method should be used.

Santa Barbara Urban Hydrograph Procedure

The SBUH method, like the Soil Conservation Service Urban Hydrograph (SCSUH) method, is based on the curve number (CN) approach, and also uses SCS equations for computing soil absorption and precipitation excess. The SCSUH method works by converting the incremental runoff depths (precipitation excess) for a given basin and design storm hydrographs of equal time base according to basin time of concentration and adds them to form the runoff hydrograph. The SBUH method, on the other hand, converts the incremental runoff depths into instantaneous hydrographs which are then routed through an imaginary reservoir with a time delay equal to the basin time of concentration.

The SBUH method was developed by the Santa Barbara County Flood Control and Water Conservation District, California. The SBUH method directly computes a runoff hydrograph without going through an intermediate process (unit hydrograph) as the SCSUH method does.

The SBUH method uses two steps to synthesize the runoff hydrograph:

Step one – computing the instantaneous hydrograph, and step two – computing the runoff hydrograph.

The instantaneous hydrograph, $I(t)$, in cfs, at each step, dt , is computed as follows:

$$I(t) = 60.5 R(t) A/dt$$

where:

$R(t)$ = total runoff depth (both impervious and pervious runoffs) at time increment dt , in inches (also known as precipitation excess)

A = area in acres

dt = time interval in minutes*



*A maximum time interval of 10 minutes should be used for all design storms of 24-hour duration. A maximum time interval of 60 minutes should be used for the 100-year, 7 day design storm.

The runoff hydrograph, $Q(t)$, is then obtained by routing the instantaneous hydrograph $I(t)$, through an imaginary reservoir with a time delay equal to the time of concentration, T_c , of the drainage basin. The following equation estimates the routed flow, $Q(t)$:

$$Q(t+1) = Q(t) + w[I(t) + I(t+1) - 2Q(t)]$$

where:

$$w = dt/(2T + dt)$$

dt = time interval in minutes

Snyder Unit Hydrograph Procedure

Snyder (1938) was the first to develop a synthetic unit hydrograph based on a study of watersheds in the Appalachian Highlands. In basins ranging from 10 to 10,000 mi^2 . Snyder's relationships are

$$T_p = C_t(LL_c)^{0.3} \quad (\text{equation 1})$$

where

t_p = basin lag

L = length of the main stream from the outlet to the divide,

L_c = Length along the main stream to a point nearest the watershed centroid,

C_t = coefficient usually ranging from 1.8 – 2.2 (C_t has been found to vary from 0.4 in mountainous areas to 8.0 along the Gulf of Mexico),

$$Q_p = 640C_pA/t_p, \quad (\text{equation 2})$$

Where

Q_p = peak discharge of the unit hydrograph

A = drainage area

C_p = storage coefficient ranging from 0.4 to 0.8 where larger values of C_p are associated with smaller values of C_t

$$T_b = 3 + t_p/8 \quad (\text{equation 3})$$

Where:

T_b is the time base of the hydrograph. For small watersheds, Eq 3 should be replaced by multiplying t_p by a value of from 3 to 5 as a better estimate of T_b . Eqns. 1,2 and 3 define points for a unit hydrograph produced by an excess rainfall of duration $D = t_p/5.5$.

For other rainfall excess durations D' , an adjusted formula for t_p becomes:

$$T_p' = t_p + 0.25 (D' - D) \quad (\text{equation 4})$$

Where:

T_p' is the adjusted lag time for duration D' . Once the three quantities t_p , Q_p , and t_b are known, unit hydrograph can be sketched so that the area under the curve represents 1,0 in of direct runoff from the watershed.

In this application the two items of data are:

C_p = Storage coefficient plus

T_p = catchment lag



The percentage of imperviousness is not an input value for the Snyder Runoff method. By design the percentage of imperviousness should be set to 0% for this reason.

Once the percentage is set to 0% it means that the whole catchment will be subject to infiltration. If using the Curve Number method for infiltration, the impervious parts of the catchment can be accounted for by modifying the curve number (CN) that is used for the infiltration accordingly. We recommend a CN value of 98 for the impervious part of the catchment. Users can also check the total infiltration volume in Table R5 of the output file.

Snyder (Alameda) Unit Hydrograph Procedure - old

The Snyder (Alameda) method is the Snyder procedure as applied by Alameda County in California where the individual parameters more suited to Alameda region are computed from catchment characteristics.

This method requires four items of data:

- Stream Length (L) mile
- Centroid Length (L_c) mile
- Stream Slope (S) ft/mile
- Basin "N" (roughness)

where

$$\text{Lag} = K.N ((L + L_c) / S^{1/2})^{0.38}$$

This data allows the other Snyder parameters of t_p , Q_p , and T_b to be computed directly.

Time Area Method

Time-area methods utilise a convolution of the rainfall excess hyetograph with a time-area diagram representing the progressive area contributions within a catchment in set time increments. Separate hydrographs are generated for the impervious and pervious surfaces within the catchment. These are combined to estimate the total flow inputs to individual sub-catchment entries to the underground urban drain network.

The time-area method dates from the research of Ross in 1922. Networked urban drainage adoptions of the procedure however only date back to 1963. This computerised program known as the TRRL Method was developed by the U.K. Transport and Road Research Laboratory, described by Watkins (1963). In the U.S. Terstriep and Stall (1974) further developed the method to include pervious runoff. In South Africa Watson (1981) made a number of additional changes particularly to the way infiltration was estimated. Between 1982 and 1986 O'Loughlin (1988) using Watson's model as a basis carried out extensive changes once again to formulate a computerised package known as ILSAX. Over the intervening years to the present the ILSAX model has had wide usage throughout Australia particularly for routine urban drainage design. The sub-catchment runoff estimating procedure still utilises the basic time-area method to estimate both pervious and impervious portion runoff.

In this application the time/area procedure assumes a linear time area relationship for the subarea and is based on an input time of concentration. It is recommended in urban catchments to define two subarea elements one each to represent the impervious and pervious areas respectively. Values for Impervious% should both be set to 0 (zero) so the input infiltration using either Horton or Green Ampt applies to the full defined area of each. Depression storage loss as defined in the infiltration dialog is currently unused.

The only input necessary for this procedure is the time of concentration for the subarea.

Clark Unit Hydrograph

Enter:

Tc, time of concentration, min for the subcatchment

R, storage coefficient, hr, must be => 0.5 x Runoff time step.

The Clark method (1945) requires three parameters to calculate a unit hydrograph: Tc, the time of concentration for the basin, R, a storage coefficient, and a time-area curve. A time-area curve defines the cumulative area of the watershed contributing runoff to the subcatchment outlet as a function of time (expressed as a proportion of Tc).

xswmm utilizes a dimensionless time area curve:

$A/t =$	$1.414 T^{1.5}$	for $0 \leq T < 0.5$
$1 - A/t =$	$1.414 (1 - T)^{1.5}$	for $0.5 < T < 1$

where:

A/t = cumulative area as a fraction of total subcatchment area and

T = fraction of time of concentration.

The ordinates of the time-area curve are converted to volume of runoff per second for unit excess and interpolated to the given time interval. The resulting translation hydrograph is then routed through a linear reservoir to simulate the storage effects of the basin; and the resulting unit hydrograph for instantaneous excess is averaged to produce the hydrograph for unit excess occurring in the given time interval.

The linear reservoir routing is accomplished using the general equation:

$$Q(2) = CA \times I \times CB \times Q(1)$$

The routing coefficients are calculated from:

$$CA = \Delta T / (R + 0.5 \times \Delta T)$$

$$CB = 1 - CA$$

$$Q_{ungr} = 0.5 [Q(1) + Q(2)]$$

where:

Q(2) = instantaneous flow at end of period,

Q(1) = instantaneous flow at the beginning of period,

I = ordinate of the translation hydrograph,

ΔT = computation time interval in hours (also duration of unit excess),

R = basin storage factor in hours, and

Q_{ungr} = the unit hydrograph ordinate at end of computation interval.

The computation of unit hydrograph ordinates is terminated when its volume exceeds 0.995 inch (mm) or 150 ordinates, whichever occurs first.

Rational Formula Hydrology

Rational Formula Hydrology [Close]

Pervious Runoff C: Runoff Curve Number:

TC Calculation

	Pervious:	Impervious:
TC Method	<input type="text" value="Constant"/>	<input type="text" value="Constant"/>
Additional Travel Time (mins)	<input type="text" value="0.0"/>	<input type="text" value="0.0"/>
Constant (mins)	<input type="text" value="0.0"/>	<input type="text" value="0.0"/>
Flow Path Length (ft, m)	<input type="text" value="0.0"/>	<input type="text" value="0.0"/>
Flow Path Slope (%)	<input type="text" value="0.0"/>	<input type="text" value="0.0"/>
Overland Flow Velocity	<input type="text" value="0.0"/>	<input type="text" value="0.0"/>
Catchment Roughness	<input type="text" value="0.0"/>	<input type="text" value="0.0"/>
Catchment Retardance	<input type="text" value="0.0"/>	<input type="text" value="0.0"/>
Time of Constant Flow (mins)	<input type="text" value="1440"/>	

[OK] [Cancel]

Runoff Coefficient

Pervious Runoff C. The Runoff Coefficient will be required if the Direct or Alameda method for calculating C is selected in the [Rational Formula Global Database](#).

Runoff Curve Number. The Runoff Curve Number will only be required if AR&R 1977 (the Ordon Curve method) is selected in the [Rational Formula Global Database](#).

TC Calculation

Additional Travel Time. Travel time from outlet of subcatchment to the connecting node (minutes). This option allows for defining odd shaped catchments, or catchments whose flow concentrates at points remote to the node itself. This time does NOT represent the gutter time component of a time of concentration, but the additional time beyond the time of concentration. The typical use of this value is to represent a remote catchment connected by a pipe or drain without explicitly modeling the connecting conduit itself. To allow for gutter travel time, an equivalent length of overland path should be added to the overland flow length.

Time of concentration. Time of Concentration, Tc can be input as a constant value (minutes) or calculated using one of the equations listed in the [TC Calculator](#). A minimum Time of Concentration value of 5 minutes is customary and required.

Time of Constant Flow. The program creates a hydrograph from the rational formula. The duration of the rising and recession limbs of the hydrograph are each equal to the time of concentration. The duration of the period of constant flow is entered in this field (in minutes). To simulate constant flow enter a duration equal to or longer than the [Job Control](#) simulation time in this field.



When using the Rational Formula, $Q=kCIA$, where $k=1.008$ for English units and is often omitted from the equation. In SI units, however, $k=0.00278$ and should not be omitted from the equation. It is also critical to enter proper values for C and I.

Time of Concentration Methods

Friend's Equation

$$t_c = \frac{BnL^{0.333}}{S^{0.2}}$$

where;

B = Const (72 US Units, 107 metric)

S = Average catchment slope (Percent, %)

L = Length of overland flow (ft, m)

n = Horton's roughness (similar but not identical to Manning's n)

- Paved 0.015
- Bare Soil .0275
- Poorly Grassed .035
- Average Grass .045
- Dense grass 0.06

Kinematic Wave

$$t_c = 0.93 \left(\frac{L^{0.6} n^{0.6}}{i^{0.4} S^{0.3}} \right)$$

where:

L = Length of overland flow (ft, m)

S = Average catchment slope (ft/ft, m/m)

i = Rainfall Intensity (in/hr, mm/hr)

n = Surface roughness (similar but not identical to Manning's n)

- Concrete or Asphalt 0.010 - 0.013
- Bare Sand 0.010 - 0.016
- Graveled Surface 0.012 - 0.030
- Bare Clay-Loam Soil (eroded) 0.012 - 0.033
- Sparse Vegetation 0.053 - 0.130
- Short Grass Prairie 0.100 - 0.200
- Lawns 0.170 - 0.480

Izzard's Formula

$$t_c = \frac{41KL^{0.333}}{i^{.667}}$$

Where:

$$K = \frac{0.0007i + C_r}{S^{0.333}}$$

L = Length of overland flow (ft, m)

S = Average catchment slope (ft/ft, m/m)

i = Rainfall Intensity (in/hr, mm/hr)

C_r = Retardance Coefficient

- Very smooth asphalt 0.007
- Tar and sand pavement 0.0075
- Concrete 0.012
- Tar and gravel pavement 0.017
- Short grass 0.046
- Dense grass 0.06

Alameda Method

$$t_c = \frac{L}{60V}$$

where;

L = Length of overland flow (ft, m)

V = Overland flow velocity (m/s, ft/s)

Kerby's Equation

$$t_c = 0.83 \left(\frac{Ln}{S^{0.5}} \right)^{0.467}$$

where;

L = Length of overland flow (ft, m)

S = Average catchment slope (ft/ft, m/m)

n = Retardance Roughness

- Smooth pavement 0.02
- Poor grass, bare soil 0.30
- Average grass 0.40
- Dense grass 0.80

Kirpich's Equation

$$t_c = 0.0078 \left(\frac{L^{0.77}}{S^{0.385}} \right)$$

where:

L = Length of overland flow (ft, m)

S = Average catchment slope (ft/ft, m/m)

Bransby Williams Method

$$t_c = 21.3 \frac{L}{5280} \left(\frac{1}{\left(\frac{A}{640} \right)^{0.1} S^{0.2}} \right)$$

where:

L = Length of overland flow (ft)

A = Catchment area (acres)

S = Average catchment slope (ft/ft)



When working in metric units (of meters, hectares, and dimensionless slope m/m), the input is converted automatically to US units for use in this equation. Use meters, hectares and dimensionless slope for a metric unit model.

US Federal Aviation Authority

$$t_c = \frac{1.8(1.1 - C)L^{0.5}}{S^{0.33}}$$

where;

L = Length of overland flow (ft, m)

S = Average catchment slope (ft/ft, m/m)

C = Runoff coefficient

- Business district 0.70 - 0.95
- Single family residential 0.30 - 0.50
- Asphalt/Concrete 0.70 - 0.95
- Sandy soil lawn 0.05 - 0.20
- Heavy soil lawn 0.13 - 0.35
- Brick 0.70 - 0.85

TR-55 Methods

From the Technical Release 55 (TR-55) – Urban Hydrology for Small Watersheds manual – Chapter 3, we have included Sheet Flow, Shallow Concentrated Flow and Channel Flow Time of Concentration calculation options. Additional details and recommendations on these methods and parameters can be reviewed by browsing to the [USDA NRCS TR55 Manual](#).

Sheet Flow

For sheet flow of less than 300 feet, use Manning's kinematic solution (Overtop and Meadows 1976) to compute T_t :

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}} \quad [\text{eq. 3-3}]$$

where:

- T_t = travel time (hr),
- n = Manning's roughness coefficient (table 3-1)
- L = flow length (ft)
- P_2 = 2-year, 24-hour rainfall (in)
- s = slope of hydraulic grade line
(land slope, ft/ft)

This simplified form of the Manning's kinematic solution is based on the following: (1) shallow steady uniform flow, (2) constant intensity of rainfall excess (that part of a rain available for runoff), (3) rainfall duration of 24 hours, and (4) minor effect of infiltration on travel time. Rainfall depth can be obtained from appendix B.

Shallow

Travel time (T_t) is the ratio of flow length to flow velocity:

$$T_t = \frac{L}{3600V} \quad [\text{eq. 3-1}]$$

where:

T_t = travel time (hr)

L = flow length (ft)

V = average velocity (ft/s)

3600 = conversion factor from seconds to hours.

Channel Flow

Manning's equation is:

$$V = \frac{1.49r^{\frac{2}{3}}s^{\frac{1}{2}}}{n} \quad [\text{eq. 3-4}]$$

where:

V = average velocity (ft/s)

r = hydraulic radius (ft) and is equal to a/p_w

a = cross sectional flow area (ft²)

p_w = wetted perimeter (ft)

s = slope of the hydraulic grade line (channel slope, ft/ft)

n = Manning's roughness coefficient for open channel flow.

Manning's n values for open channel flow can be obtained from standard textbooks such as Chow (1959) or Linsley et al. (1982). After average velocity is computed using equation 3-4, T_t for the channel segment can be estimated using equation 3-1.

UK Hydrology

There are five major hydrology methods available within UK Hydrology. The following methods were derived in the UK though may be applicable elsewhere.

The screenshot shows the 'UK Hydrology' software window. The 'Method' dropdown is set to 'Variable PR Method'. Below it are tabs for 'Variable PR', 'Wallingford', 'ReFH', 'FEH', and 'FSR'. The 'Variable PR' tab is active, showing the following parameters and their values:

- Routing Coefficient (KR): 0.0
- Effective Impervious Factor: 0.0
- Maximum Moisture Depth: 200.
- Net Antecedent Precipitation Index (NAPI): 0.0

Below these are the 'WRAP Soil (%)' settings for five soil types, each with a value of 0.0:

Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
0.0	0.0	0.0	0.0	0.0

At the bottom of the dialog are 'OK' and 'Cancel' buttons.

- [Variable PR Method \(Variable PR\)](#)
- [Wallingford Procedure \(Wallingford\)](#)
- [Revitalised FSR/FEH Method \(ReFH\)](#)
- [Flood Estimation Handbook \(FEH\)](#)
- [Flood Studies Report \(FSR\)](#)

The following references are applicable for each method:

- General – The SUDS Manual, CIRIA C697, London, 2007.
- Variable PR – A New Runoff Volume Model. WaPUG User Note No.28, Osborne, M. Version 3, March 2009.
- Wallingford and Variable PR - Design and Analysis of Urban Storm Drainage: The Wallingford Procedure, Volume 1 – Principles, methods and practice. Department of Environment, Wallingford. 1981.
- ReFH – Flood Estimation Handbook Supplementary Report No. 1: The revitalised FSR/FEH rainfall-runoff method, Kjeldsen, Centre for Ecology & Hydrology, 2007.
- FEH – Flood Estimation Handbook, Volume 4, Reed, Faulkner, Houghton-Carr, Robson & Bayliss, Institute for Hydrology, 1999.
- FSR – Flood Studies Report Volumes 1-5, Institute of Hydrology, 1975 and Design of Flood Storage Reservoirs, CIRIA Book 14, 1993.

It is important to note that some data fields may be shared between hydrology methods. These shared data field values may not be the same for all hydrology methods and should be tailored for the specific UK Hydrology method selected.

Variable PR Method (Variable PR)

The Variable PR runoff method, sometimes known as New PR or New UK method, uses the non-linear reservoir routing hydrology method as per the [Wallingford Procedure](#) runoff method. The volume of percentage runoff varies during the rainfall event to take account of changes to the catchment wetness during the storm. The Variable PR method routing equation is shown below:

$$PR = IF * PIMP + (100 - IF * PIMP) * NAPI / PF$$

Routing Coefficient (KR). The Variable PR runoff method routing coefficient (KR) is typically input as a value 0.5 or less when used in rural catchments.

Effective Impervious Factor (IF). The Effective Impervious Factor is used to give an effective contributing impervious area based on the impervious area runoff. Recommended Values for the Effective Impervious Factor (IF) are shown below:

Surface condition	Effective impervious area factor, IF
Poor	0.45
Fair	0.60

Good	0.75
------	------

Maximum Moisture Depth (PF). The Maximum Moisture Depth is typically set at 200mm.

Net Antecedent Precipitation Index (NAPI). The Net Antecedent Precipitation Index (NAPI) is the 30 day antecedent precipitation index, which is directly dependent on the soil type. Starting NAPI and Maximum Soil Moisture are required. The Net Antecedent Precipitation Index is defined by the following equation:

$$NAPI = k^{1/48} NP_{-1} + k^{1/24} NAPI_{-1}$$

Where:

k	Soil Type
0.10	1
0.50	2
0.70	3
0.90	4
0.99	5

t - model timestep (hours)

NP - Rain less unsatisfied DEPSTOG in previous timestep (DEPSTOG – depression storage).

After the depression storage is filled, evaporation will be subtracted from the rainfall and the remaining amount will be routed through the same reservoir than in the Wallingford Method. Qvol is multiplied with AREA to get the outflow volume in cubic meter.

WRAP Soil (%). The WRAP SOIL percentages define the index of the water holding capacity of the soil (0.15 tot 0.5), based on the FSR WRAP parameter obtained from FSR. The formula for calculating the WRAP Soil index is shown below:

$$\text{WRAP SOIL Index} = (\text{Soil 1 \%} * 0.15) + (\text{Soil 2 \%} * 0.3) + (\text{Soil 3 \%} * 0.4) + (\text{Soil 4 \%} * 0.45) + (\text{Soil 5 \%} * 0.5).$$

There are five possible WRAP SOIL percentages which can be input to define the sub-catchment soil conditions. The WRAP SOIL percentages are input as fractions and the sum of which must equal 100% (i.e.: Soil 1 % + Soil 2 %...+ Soil 5 % = 1.0). The W.R.A.P. soil classifications are defined as follows:

Classification	Description
1	<ol style="list-style-type: none"> 1. a. Well drained permeable sandy or loamy soils and shallower analogues over highly permeable limestone, chalk, sandstone or related drifts. b. Earthy peat soils drained by dikes and pumps c. Less permeable loamy over clayey soils on plateaux adjacent to very permeable soils in valleys.
2	<ol style="list-style-type: none"> 1. a. Very permeable soils with shallow ground-water b. Permeable soils over rock or fragipan, commonly on slopes in western Britain associated with smaller areas of less permeable wet soils c. Moderately permeable soils, some with slowly permeable subsoils
3	<ol style="list-style-type: none"> 1. a. Relatively impermeable soils in boulder and sedimentary clays, and in alluvium, especially in eastern England b. Permeable soils with shallow ground-water in low lying areas c. Mixed areas of permeable and impermeable soils, in approximately equal proportions
4	Clayey, or loamy over clayey soils with an impermeable layer at shallow depth
5	<p>Soils of the wet uplands with:</p> <ol style="list-style-type: none"> 1. a. peaty or humose surface horizons and impermeable layers at shallow depth b. deep raw peat associated with gentle upland slopes or basin sites c. bare rock cliffs and screes, and d. shallow, permeable rocky soils on steep slopes

Wallingford Procedure (Wallingford)

The Wallingford Procedure runoff method (Wallingford) is a non-linear reservoir routing method. This method can be simulated with any runoff time step though using the appropriate time step is essential for simulating the correct reservoir routing. The percentage of runoff is fixed throughout the storm. The Wallingford Procedure runoff method routing equation is shown below:

$$PR = 0.829PIMP + 25SOIL + 0.078UCWI - 20.7$$

Routing Coefficient (KR). The Variable PR runoff method routing coefficient (KR) is typically input as a value 0.5 or less when used in rural catchments.

Antecedent Wetness Condition (UCWI). The Antecedent Wetness Condition (Urban Catchment Wetness Index - UCWI), which is a composite of two antecedent wetness parameters and is given by:

$$UCWI = 125 + 8API_5 - SMD$$

Where

API_5 = 5-day antecedent precipitation index (mm)

SMD = soil moisture deficit (mm)

Alternatively, design values are provided by referring to average annual rainfall for a given location.

WRAP SOIL (%). The WRAP SOIL percentages define the index of the water holding capacity of the soil (0.15 to 0.5), based on the FSR WRAP parameter obtained from FSR. The formula for calculating the WRAP Soil index is shown below:

$$WRAP\ SOIL\ Index = (Soil\ 1\ \% * 0.15) + (Soil\ 2\ \% * 0.3) + (Soil\ 3\ \% * 0.4) + (Soil\ 4\ \% * 0.45) + (Soil\ 5\ \% * 0.5).$$

There are five possible WRAP SOIL percentages which can be input to define the sub-catchment soil conditions. The WRAP SOIL percentages are input as fractions and the sum of which must equal 100% (i.e.: Soil 1 % + Soil 2 %...+ Soil 5 % = 1.0). The W.R.A.P. soil classifications are defined as follows:

Classification	Description
1	<ol style="list-style-type: none"> 1. a. <ol style="list-style-type: none"> i. Well drained permeable sandy or loamy soils and shallower analogues over highly permeable limestone, chalk, sandstone or related drifts. ii. Earthy peat soils drained by dikes and pumps iii. Less permeable loamy over clayey soils on plateaux adjacent to very permeable soils in valleys.

2	<ol style="list-style-type: none"> 1. a. <ol style="list-style-type: none"> i. Very permeable soils with shallow ground-water ii. Permeable soils over rock or fragipan, commonly on slopes in western Britain associated with smaller areas of less permeable wet soils iii. Moderately permeable soils, some with slowly permeable subsoils
3	<ol style="list-style-type: none"> 1. a. <ol style="list-style-type: none"> i. Relatively impermeable soils in boulder and sedimentary clays, and in alluvium, especially in eastern England ii. Permeable soils with shallow ground-water in low lying areas iii. Mixed areas of permeable and impermeable soils, in approximately equal proportions
4	Clayey, or loamy over clayey soils with an impermeable layer at shallow depth
5	<p>Soils of the wet uplands with:</p> <ol style="list-style-type: none"> 1. a. <ol style="list-style-type: none"> i. peaty or humose surface horizons and impermeable layers at shallow depth ii. deep raw peat associated with gentle upland slopes or basin sites iii. bare rock cliffs and screes, and iv. shallow, permeable rocky soils on steep slopes

It is noted that while using the Wallingford Procedure runoff method the following sub-catchment slope values are recommended:

1.25% - mild slope

2.75% - medium slope

4.0% - steep slope

Revitalised FSR/FEH Method (ReFH)

The Revitalised FSR/FEH Method is a unit hydrograph method which refines the original FSR/FEH Method. The base flow component is dynamic in this method, it is computed by a routing model of the runoff. The runoff time step has to fulfill the condition $0.02 \cdot TP \leq \text{timestep} \leq 0.2 \cdot TP$. In contrast to the original FSR method this method updates the percentage runoff in each time step. The difference between net and effective rain is infiltration.

Season and Return Period. This input field allows the user to specify in which season the simulation will occur. Recommended seasons are; Winter - November to April, and Summer - May to October. The Return Period represents the number of months in the season. The initial soil moisture and initial baseflow values will vary depending on the season selected.

Mean Drainage Path Slope (DPSBAR). The Mean Drainage Path Slope represents the average sub-catchment drainage path slope.

Extent of Urban and Suburban Land Cover (URBEXT). For the Extent of Urban and Suburban Land Cover either select the 1990 or 2000 values if available or simply enter a user-defined value. Please note that the year 2000 values are only available if using the FEH CD-ROM Version 2. If values for 1990 or 2000 are zero, please check the values as they may not be available from the FEH data.

Proportion of Time when Soil Moisture Deficit was below 6mm (PROPWET). This parameter represents the proportion of time when the soil moisture deficit was below 6mm during the years between 1961-1990, as defined by Met Office Rainfall and Evaporation Calculation System (MORECS).

Mean Drainage Path Length (DPLBAR). The Mean Drainage Path Length represents the average sub-catchment drainage distance.

Average Annual Rainfall (SAAR). This input parameter is the average annual rainfall value from between 1961 to 1990.

Base Flow Index (BFIHOST). The Base Flow Index represents the baseflow index derived from Hydrology of Soil Types (HOST) soils data.

Override Option. The Time to Peak and Baseflow calculations can be specified using the Override option. The user input of these parameters is optional. If they are not specified by the user, the engine will generate its own values based on other input parameters. Note that if a user defined baseflow is used it is a constant baseflow and does not vary with the rainfall.

Loss Model (Rainfall). The Loss Model used to derive Net Rainfall

Net rainfall, p_p , measured in mm, is needed for the convolution of the unit hydrograph. It is derived from the equation below where p_t/P_t represents percentage runoff using P , the design rainfall derived above. Calculate the following parameters:

Calculate Maximum Soil Moisture Capacity, C_{max} (mm):

$$C_{max} = 596.7 BFIHOST^{0.95} PROPWET^{-0.24} \quad \text{Eq.6}$$

$$r^2 = 0.55, \quad fse = 0.161, \quad n = 100$$

Calculate Initial Soil Moisture Capacity, C_{inp} (mm):

If season is *Winter* use:

$$C_{ini, winter} / 0.5C_{max} = 1.20 - 1.70 BFIHOST + 0.82 PROPWET$$

$$r^2 = 0.53, \quad n = 93 \quad \text{Eq.7}$$

If season is *Summer* use:

$$C_{ini, summer} / 0.5C_{max} = 0.90 - 0.82 BFIHOST - 0.43 PROPWET$$

$$r^2 = 0.49, \quad n = 7 \quad \text{Eq.8}$$

If $C_{ini} / 0.5C_{max} < 1$, then $C_{ini} = 0$.

The soil moisture storage C_t (mm) is calculated from:

$$C_t = C_{t-1} + P_t \quad \text{Eq.9}$$

With C_t at time zero equal to $\text{Alpha}_T \times C_{ini}$,

Correction factor, Alpha_T :

$\text{Alpha}_T = 1$ for return periods less than 5 years

If season is *Winter* use:

$$\alpha_T = 1.166T^{-0.073} \quad \text{Eq.10}$$

If season is *Summer* use:

$$\alpha_T = 1.444T^{-0.182} \quad \text{Eq.11}$$

Calculate the net rainfall, p_p :

If $C_t < C_{max}$, use the following equations:

For $t = 1$:

$$\frac{P_t}{P_t} = \alpha_T \left(\frac{C_{ini}}{C_{max}} \right) + \left(\frac{P_t}{2C_{max}} \right) \quad \text{Eq.12}$$

For $t = 2, 3, \dots$

$$\frac{P_t}{P_t} = \left(\frac{C_{t-1}}{C_{max}} \right) + \left(\frac{P_t}{2C_{max}} \right) \quad \text{Eq.13}$$

If soil storage filled during the event, where $C_t = C_{max}$, use:

$$\frac{P_t}{P_t} = 1 - C_{max} \frac{(1 - C_t/C_{max})^2}{2P_t} \quad \text{Eq.14}$$

Clarification for calculation of the first two timesteps:

At time zero, $t = 0$:

$$\alpha_t \times C_{ini} = C_0 \quad \text{Eq.15}$$

First timestep: $t=1$

$$C_1 = C_0 + P_1 \quad \text{Eq.16}$$

using C_0 calculated at $t = 0$, giving:

$$\frac{P_1}{P_1} = \left(\frac{C_0}{C_{max}} \right) + \left(\frac{P_1}{2C_{max}} \right) \quad \text{Eq.17}$$

Second timestep: $t=2$

$$C_2 = C_1 + P_2 \quad \text{Eq.18}$$

using C_1 calculated at $t = 1$, giving:

$$\frac{P_2}{P_2} = \left(\frac{C_1}{C_{max}} \right) + \left(\frac{P_2}{2C_{max}} \right) \quad \text{Eq.19}$$

and so on.

Convert net rainfall values to correct units

Net rainfall values should be divided by 10 to convert them from mm into cm for convolution with the unit hydrograph.

Hydrograph

Instantaneous Unit Hydrograph Calculations:

Calculate Time to Peak, T_p from Eq. 1 above:

$$T_p = 1.563 \text{PROPWET}^{-1.09} \text{DPLBAR}^{0.60} (1 + \text{URBEXT})^{-3.34} \text{DPSBAR}^{-0.28} \quad \text{Eq.1}$$

$$r^2 = 0.81, \quad fse = 1.32, \quad n = 101$$

Calculate other parameters necessary to draw the ReFH Kinked Triangle unit hydrograph.

$$U_k = 0.80 \quad \text{Eq. 20}$$

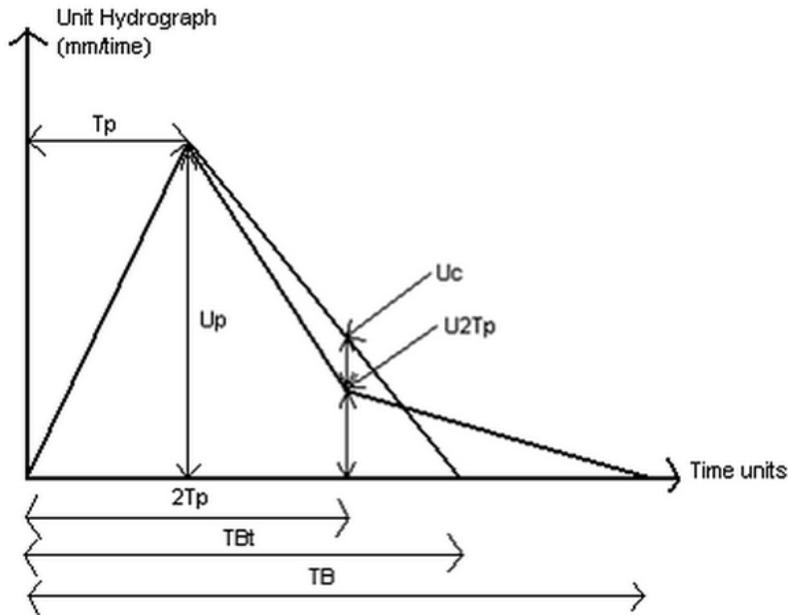
$$U_p = 0.65 \quad \text{Eq. 21}$$

$$TB_t = 2Tp / U_p \quad \text{Eq. 22}$$

$$U_c = U_p (TB_t - 2Tp) / (TB_t - Tp) \quad \text{Eq. 23}$$

$$U_{2Tp} = U_k U_c \quad \text{Eq. 24}$$

$$TB = (1 + 2(1 - U_p) / (U_k U_c)) Tp \quad \text{Eq. 25}$$



Plot the unit hydrograph using points (T_p, U_p) , $(2T_p, U_{2T_p})$, $(TB, 0)$

Finding the unit hydrograph ordinates

If $t < T_p$ use:

$$u_t = \frac{U_p}{T_p} t \quad \text{Eq. 26}$$

If $T_p < t < 2T_p$ use:

$$u_t = \frac{U_{2T_p} - U_p}{T_p} (t - T_p) + U_p \quad \text{Eq. 27}$$

If $2T_p < t < TB$ use:

$$u_t = U_{2T_p} \left(1 + \frac{2T_p - t}{TB - 2T_p} \right) \quad \text{Eq. 28}$$

Converting the IUH to a TUH

To convert the IUH to a TUH (which is the UH for a finite rainfall duration) calculate the area under the graph between timesteps effectively applying an S-Curve to the hydrograph. If the peak and kink of the unit hydrograph do not fall on an exact timestep the area will need to be corrected. These areas should be used for the convolution, for example the area under the graph between timestep 0 and timestep 1 should be used as the unit hydrograph ordinate for timestep 1.

The area under the entire curve should be equal to Tp .

Before convoluting the unit hydrograph, the areas must be multiplied by a factor of $2.78 \cdot AREA / Tp$. This converts the units into $m^3/s/cm$ ready for convolution.

Baseflow Model

Calculate Baseflow Equation.

Calculate Baseflow Recharge Parameter, BR

$$BR = 3.751 BFIHOST^{1.08} PROPWET^{0.36}$$

$$r^2 = 0.34, \quad fse = 2.04, \quad n = 100 \quad \text{Eq. 30}$$

Calculate Baseflow Lag, BL (hours):

$$BL = 25.47 BFIHOST^{0.47} DPLBAR^{0.21} PROPWET^{-0.53} (1 + URBEXT)^{-3.01}$$

$$r^2 = 0.41, \quad fse = 2.03, \quad n = 100 \quad \text{Eq. 31}$$

BL is calculated in hours but should be divided through by 24 to give it in days to be used in the baseflow equation above and in the baseflow constant equations below.

Calculate Initial Baseflow, BF_0 (m^3/s):

The following equation can be used for either season:

$$BF_{0,ALL} = (41.36(C_{ini} - 115.89) + 4.56SAAR)10^{-5} AREA$$

$$n = 1183, \quad r^2 = 0.45 \quad \text{Eq. 32}$$

If season is *Winter* use:

$$BF_{0,WINTER} = (63.79(C_{ini} - 120.79) + 5.54SAAR)10^{-5} AREA$$

$$n = 752, \quad r^2 = 0.47 \quad \text{Eq. 33}$$

If season is *Summer* use:

$$BF_{0,SUMMER} = (33.94(C_{ini} - 85.42) + 3.14SAAR)10^{-5} AREA$$

$$n = 431, \quad r^2 = 0.42 \quad \text{Eq. 34}$$

Baseflow Constant Equations:

$$K_1 = \frac{BR}{1 + BR} \left(\frac{(BL/\Delta)(1 - K_3)}{1 + BR} - K_3 \right) \quad \text{Eq. 35}$$

$$K_2 = \frac{BR}{1 + BR} \left(1 - \frac{(BL/\Delta)(1 - K_3)}{1 + BR} \right) \quad \text{Eq. 36}$$

$$K_3 = \exp\left(-\frac{(1 + BR)\Delta}{BL}\right) \quad \text{Eq. 37}$$

Where Δ is the timestep in days.

Use these parameters to calculate the baseflow profile:

$$BF_t = \frac{1}{1 - K_2} [K_1 q_{t-1} + K_2 q_t + (K_1 + K_3) BF_{t-1}] \quad \text{for } t = 1, 2, 3, \dots$$

Eq. 38

where q_t is direct runoff from the routing model and K_1 , K_2 , and K_3 are constants and functions of the baseflow parameters BR and BL .

Flood Estimation Handbook (FEH)

The Flood Estimate Handbook (FEH) hydrology method is a unit hydrograph method where a constant baseflow is added to the runoff, similar to the Flood Studies Report hydrology method (FSR). The catchment descriptors can be obtained from the FEH CD-ROM which is available from <http://www.hydrosolutions.co.uk>. The runoff time step has to fulfill the condition $0.02 \cdot TP \leq \text{time step} \leq 0.2 \cdot TP$.

Mean Drainage Path Slope (DPSBAR). The Mean Drainage Path Slope represents the average sub-catchment drainage path slope.

Extent of Urban and Suburban Land Cover (URBEXT). For the Extent of Urban and Suburban Land Cover either select the 1990 or 2000 values if available or simply enter a user-defined value. Please note that the year 2000 values are only available if using the FEH CD-ROM Version 2. If values for 1990 or 2000 are zero, please check the values as they may not be available from the FEH data.

Standard Runoff (%) (SPRHOST). The digital FEH data has 29 soil categories while the FSR had only 5.

$$SPR = SPRHOST = SPR_1 \cdot HOST_1 + \dots + SPR_{29} \cdot HOST_{29}$$

SPRHOST is calculated by the FEH CD program and written to the .CSV file.

Where measured flow records are available the SPR may be calculated from the Base Flow Index (BFI) from research published in FSSR 16 and it is not covered here – see also FEH, Volume 4, Chapter 1.

At the moment XP-SWMM only offers direct input for SPR

Proportion of Time when Soil Moisture Deficit was below 6mm (PROPWET). This parameter represents the proportion of time when the soil moisture deficit was below 6mm during the years between 1961-1990, as defined by Met Office Rainfall and Evaporation Calculation System (MORECS).

Mean Drainage Path Length (DPLBAR). The Mean Drainage Path Length represents the average sub-catchment drainage distance.

Average Annual Rainfall (SAAR). This input parameter is the average annual rainfall value from between 1961 to 1990.

Override Option. The Time to Peak, Catchment Wetness Index (CWI) and Baseflow calculations can be specified using the Override option. The user input of these parameters is optional. If they are not specified by the user, the engine will generate its own values based on other input parameters. Note that if a user defined baseflow is used it is a constant baseflow and does not vary with the rainfall.

Computed Variables and Hydrograph

TPO (hrs)

Time to peak is computed based on the following formula:

$$TPO = 4.27 * DPSBAR^{0.35} * PROPWET^{0.5} * DPLBAR^{0.54} * (1+URBEXT)^{-5.77}$$

TPt (hrs)

Time to rise of the unit hydrograph as defined by:

$$TPt = TPO + T/2, T \text{ time step}$$

QP (m³/s 10mm)

The peak flow for the unit hydrograph as calculated by:

$$QP = \left(\frac{220}{TPt} \right) * \left(\frac{AREA}{100} \right)$$

TB (hrs)

Time base of the unit hydrograph as calculated by:

$$TB = 2.52 * TPt$$

Base Flow (m³/s)

Base flow for the unit hydrograph as calculated by:

$$BASEFLOW=AREA [* (33 * (CWI - 125) + 3 * SAAR + 5.5) * 10^{-5}$$

PR (%)

Total percentage run off of the catchment is defined as follows:

$$PR_{total} = PR_{rural} * (1 - 0.615 * URBEXT) + 70 * 0.615 * URBEXT$$

where

$$PR_{rural} = SPR + DPR_{CWI} + DPR_{rain}, \text{ and}$$

$$DPR_{rain} = 0.45 * (P - 40)^{0.7}, \text{ if } P > 40\text{mm and } DPR_{rain} = 0$$

otherwise, P is the rainfall depth.

$$DPR_{CWI} = 0.25 * (CWI - 125)$$

Flood Studies Report (FSR)

UK Hydrology

Method: Flood Studies Report (FSR)

Variable PR | Wallingford | ReFH | FEH | **FSR**

Height at 85% from Catchment Outlet (H85)	0.0
Height at 10% from Catchment Outlet (H10)	0.0
Extent of Urban & Suburban Land Cover	0.0
Standard Runoff (SPR%)	0.0
Length of Main Channel (MSL)	0.0
Average Annual Rainfall (SAAR)	0.0
<input type="checkbox"/> Overrule	
Time to Peak	-1
Catchment Wetness Index	-1
Baseflow	-1

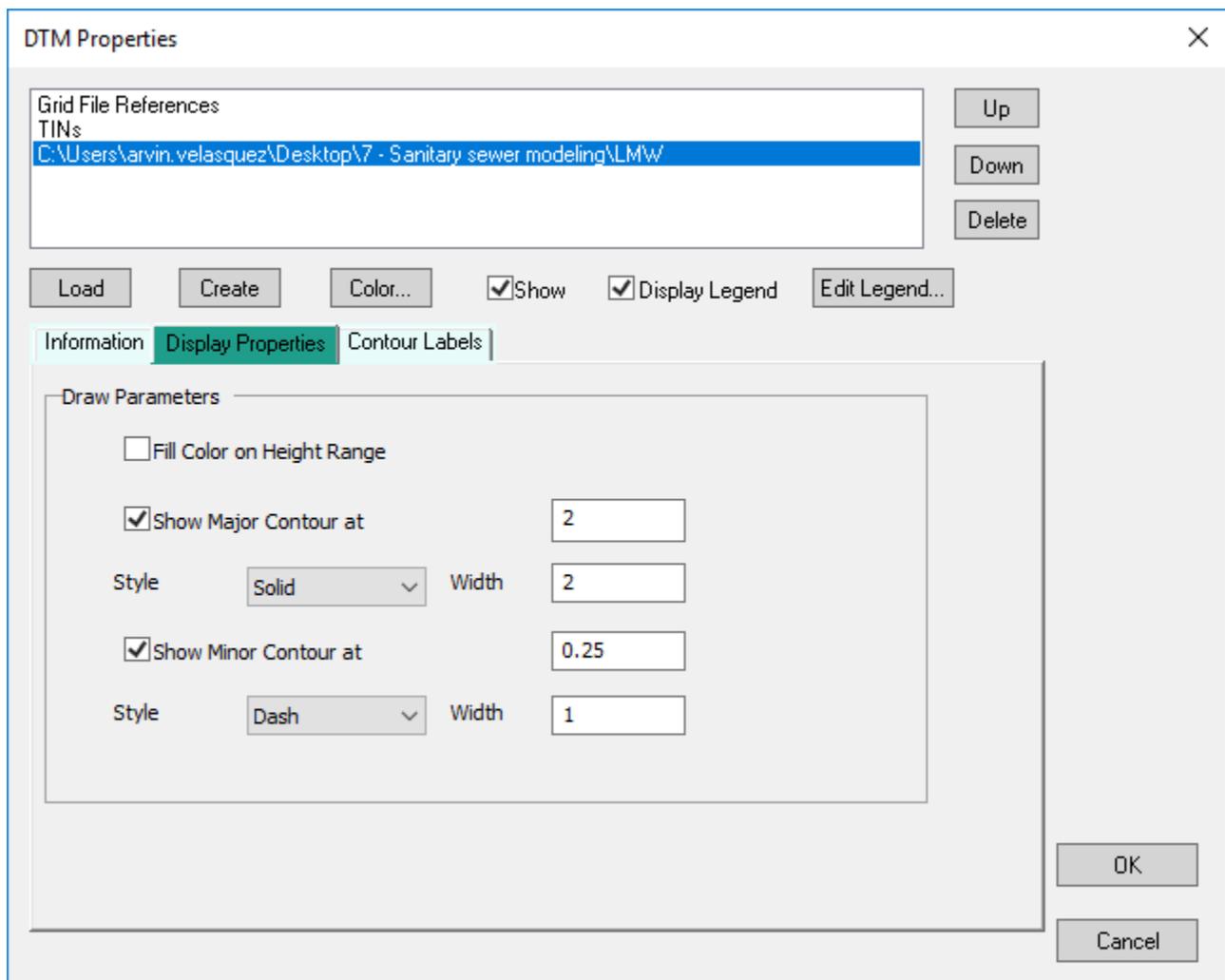
OK Cancel

The Flood Studies Report runoff method (FSR) is a unit hydrograph method where a constant baseflow is added to the runoff. Catchment descriptors should be obtained from measured data. The runoff time step has to fulfill the condition $0.02 \cdot TP \leq \text{time step} \leq 0.2 \cdot TP$.

Height at 85% from Catchment Outlet (H85). This input parameter, in conjunction with the Height at 10% from Catchment Outlet (H10), allows the main channel slope (S1085) to be calculated. The values are the heights at 10% and 85% of the main channel length upstream from the catchment outlet.

Height at 10% from Catchment Outlet (H10). This input parameter, in conjunction with the Height at 85% from Catchment Outlet (H85), allows the main channel slope (S1085) to be calculated. The values are the heights at 10% and 85% of the main channel length upstream from the catchment outlet.

Extent of Urban and Suburban Land Cover



Standard Runoff (%) (SPR%). This value can be calculated from Figure I.4.18 (first revision) (Institute of Hydrology, 1978) which shows the various soil types. The soil classifications are also available from the Wallingford Procedure, Volume 3, Maps, "Winter rain acceptance potential". The equation was first published in FSSR 16, 1985.

$$SPR = 10S1 + 30S2 + 37S3 + 47S4 + 50S5$$

where

S1 – S5 are the proportions of the catchment covered by soil classes 1-5 respectively.

Where measured flow records are available, the SPR may be calculated from the Base Flow Index (BFI) from research published in FSSR 16 and it is not covered here – see also FEH, Volume 4, Chapter 1.

Length of Main Channel (MSL). The Length of the Main Channel or Stream (MSL) measured in metres on a 1:25000 Ordnance Survey Map. It is normally measured in kilometres (and represented in the formulae in km) but it is input in metres to be consistent with other data input.

Average Annual Rainfall (SAAR). This input parameter is the average annual rainfall value from 1941 to 1970 from FSR Figure II.3.1 (Natural Environment Research Council, 1975). The data is also available from the Wallingford Procedure, Volume 3 Maps and the FEH CD.

Override Option. The Time to Peak, Catchment Wetness Index (CWI) and Baseflow calculations can be specified using the Override option. The user input of these parameters is optional. If they are not specified by the user, the engine will generate its own values based on other input parameters. Note that if a user defined baseflow is used it is a constant baseflow and does not vary with the rainfall.

Computed Variables and Hydrograph

TPO (hrs) This is the instantaneous time to peak of the unit hydrograph. Ciria14 uses the equation from FSSR 16 published in 1985. However IH 124 published a more recent equation that outperforms FSSR 16 on small, partly urbanised catchments. The IH equation also performed well on the FSSR 16 data set and therefore it is recommended for general use i.e. on small and large catchments, rural and partly urban. For these reasons the IH 124 formula has been used in the software.

Time to peak when calculated from catchment characteristics is:

$$S1085 = (H85 - H10)/(0.75 * MSL)$$

TPt (hrs). Time to rise of the unit hydrograph as defined by:

$$TPt = TP0 + T/2, T \text{ time step}$$

QP (m³/s 10mm). The peak flow for the unit hydrograph as calculated by:

$$QP = \left(\frac{220}{TPt}\right) * \left(\frac{AREA}{100}\right)$$

TB (hrs). Time base of the unit hydrograph as calculated by:

$$TB = 2.52 * TPt$$

Base Flow (m³/s). Base flow for the unit hydrograph as calculated by:

$$BASEFLOW = AREA * [33 * (CWI - 125) + 3 * SAAR + 5.5] * 10^{-5}$$

PR (%). Total percentage run off of the catchment is defined as follows:

$$PR_{total} = PR_{rural} * (1 - 0.3 * URBAN) + 70 * 0.3 * URBAN$$

where

$$PR_{rural} = SPR + DPR_{CWI} + DPR_{rain}, \text{ and } DPR_{rain} = 0.45 * (P - 40)^{0.7}, \text{ if } P > 40\text{mm and}$$

$$DPR_{rain} = 0$$

otherwise P is the rainfall depth.

$$DPR_{CWI} = 0.25 * (CWI - 125)$$