Unit Hydrograph

Method of Analysis

There have been some improvements to the FSR method published since Ciria 14 and these have been included in the software. Some of the units have been altered to coincide with units used for urban drainage e.g. area measured in hectares instead of square kilometres.

Those familiar with the manual calculation will know that a critical storm duration is needed. However this duration may not be critical for the sewered part of the catchment and it may not be critical either for the combination of sewered and rural elements. The program runs all the storm durations listed in the wizard. The critical durations are then listed on the summary in the usual way. Also the duration does not have to be an odd multiple of the time interval because this is only done to make manual calculations easier.

Construction of the Unit Hydrograph & Total Runoff Hydrograph

The construction of the Unit Hydrograph and the Runoff Hydrographs are discussed in Ciria 14, Chapter 3, FEH Volume 4, Chapters 1 to 4 and Revitalisation of the FSR/FEH rainfall runoff method (R&D Technical Report FD1913/TR). This is recommended reading as we have only summarised the methods here.

The Unit Hydrograph represents the flow generated on the site for every unit of net rainfall. The units used by the program are m³ of runoff for every mm of net rainfall. So if 1mm of rainfall fell in one time interval then the runoff hydrograph would be the same as the Unit Hydrograph.

If Xmm of net rain fell in one time interval it would be necessary to multiply the UH by X. If Y mm of net rainfall fell in the next interval it would be necessary to multiply the UH by Y and add the two flows together staggered by one time interval, and so on.

This process is known as the convolution of the Unit Hydrograph and the Net Rainfall Hyetograph. This convolution is shown on the Unit Hydrograph tab in the program.

By net rainfall we mean the proportion of rainfall that runs off and it is derived from the rainfall profile and the percentage runoff. The total runoff hydrograph also includes the base flow which is added after the convolution. The baseflow is expressed as a constant for the FSR/FEH method but is calculated using the baseflow model of the ReFH method (this is based on the linear reservoir concept - see the Revitalisation of the FSR/FEH rainfall runoff method reference for a full discussion on this model).

The Unit Hydrograph itself is triangular in shape for the FSR/FEH methods. The length of the base, the height of the apex, and the distance the apex is from the start are given by the outputs TB, QP and TPt respectively.

However using the ReFH method the unit hydrograph is based on a kinked triangle. The length of the base, the height of the apex, the distance the apex is from the start and the kink point are given by the outputs TB, QP, Tp and Uc respectively.

The formulae to determine the time to peak TP and the percentage runoff PR vary between the FSR, FEH and ReFH methods. A discussion of the variables required for the different methods now follows.

The formulae for both FSR and FEH are also detailed and discussed in FEH volume 4, Appendix B, whilst the ReFH formulae are discussed in Revitalisation of the FSR/FEH rainfall runoff method (R&D Technical Report FD1913/TR).

Discussion of the Unit Hydrograph Construction

The following figures illustrate the similarities between Unit Hydrographs, Time-Area, and the Rational Methods. A Unit Hydrograph has units of "Area /Time" while a Time-Area table has units of "Area". Therefore to convert the Unit Hydrograph ordinates to Flow it must be multiplied by a rainfall depth (p, cm). The Time-Area ordinates are multiplied by a rainfall rate (i, mm/hr) to convert them to "Flow". The constant 2.78 converts (mm/hr * ha) to (l/s) in the rational and time-area methods – a more accurate conversion is (1.0/0.36). Note also that the normal units used in the Unit Hydrograph method are m³/s for flow, km² for catchment area, cm for rain, hours for
time, and the conversion constant for this set of units is also 2.78. Therefore either set of units may be used with the equations that follow.

It can be seen from these diagrams and calculations that a Time-Area table may be converted to a unit hydrograph by multiplying its ordinates by 2.78 so that the integration of the unit hydrograph is always 2.78*Area (for either set of units discussed above).

Even the Rational Method can be shown to be to a rectangular unit hydrograph equal to 2.78 Area. FSSR 8 incorrectly suggested that the unit hydrograph and rational methods reduce to similar equations. They in fact reduce to identical equations.
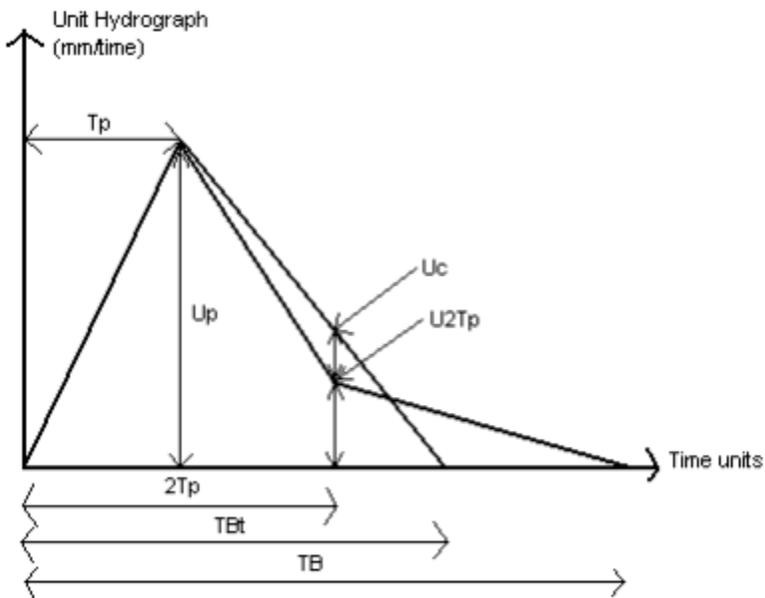
Convolution of Unit Hydrograph and Net Rainfall

Unit Hydrograph (FSR/FEH Method)

Qp=2.2Area/Tp

Tp

TB = 2.52 Tp
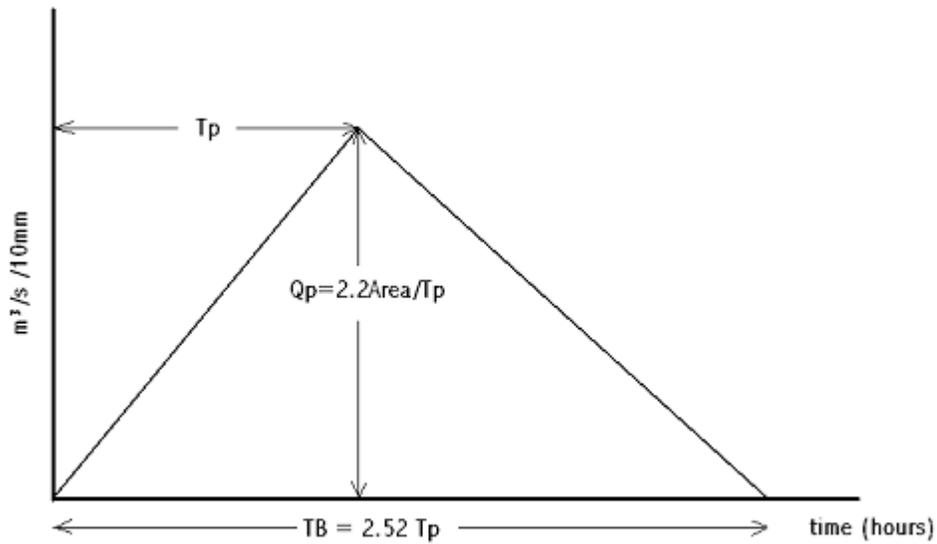
$Q = 2.78$ Area * Rainfall where 2.78 is the units conversion & the area under the Unit Hydrograph. Therefore the convolution of the UH is equivalent to a Time/Area convolution.

Unit Hydrograph (ReFH Method)

q1= p1 u1

q2 = p2 u1 + p1 u2

q3 = p3 u1 + p2 u2 + p1 u3

q4 = p4 u1 + p3 u2 + p2 u3 + p1 u4

q5 = ……...

Where p1, p2, p3 etc is the net rainfall depth (cm) in time intervals 1, 2, 3 etc.
and u1, u2 etc are the values obtained from the unit hydrograph for the same intervals.

Convolution of Time / Area and Net Rainfall
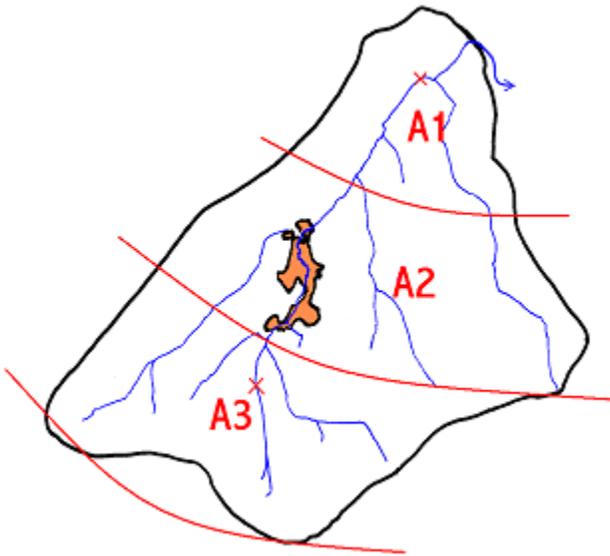
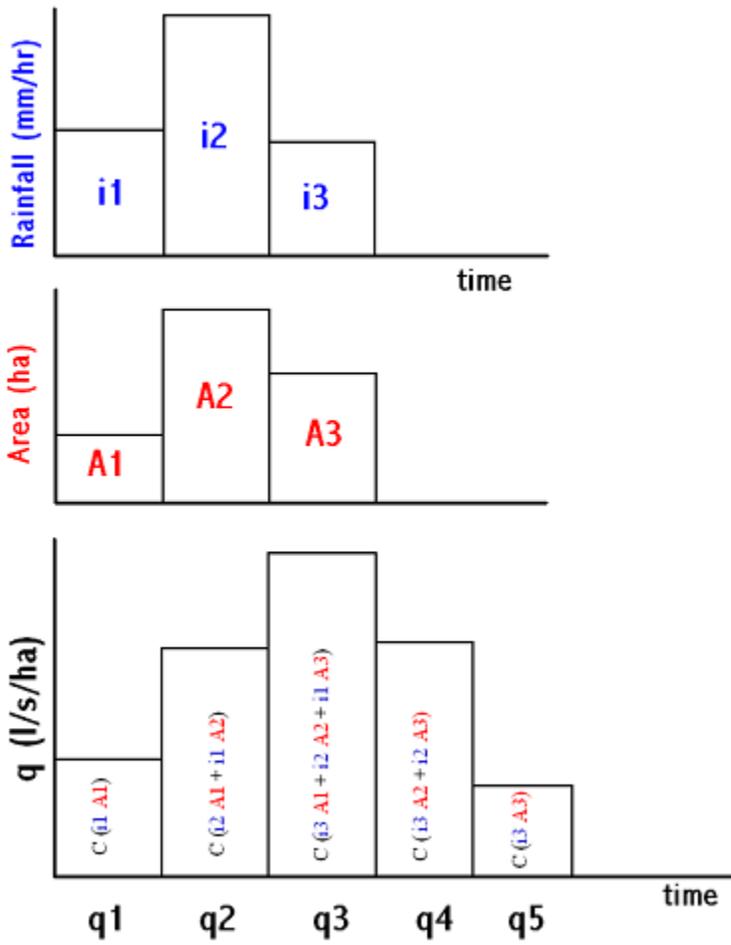
$q_1 = 2.78 * (i_1 A_1)$

$q_2 = 2.78 * (i_2 A_1 + i_1 A_2)$

$q_3 = 2.78 * (i_3 A_1 + i_2 A_2 + i_1 A_3)$
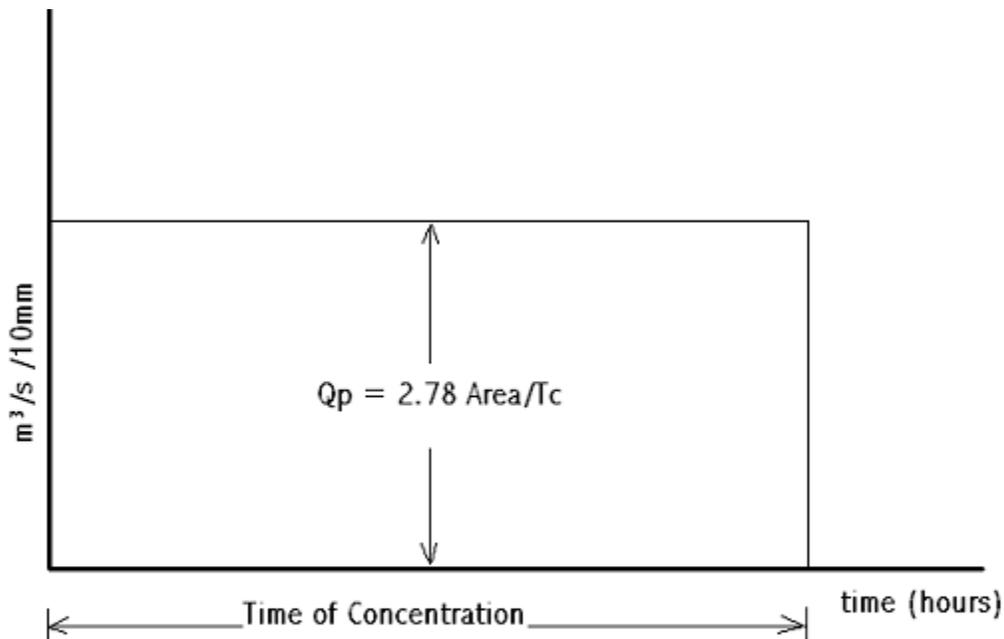
$q_4 = 2.78 * (i_4 A_1 + i_3 A_2 + i_2 A_3 + i_1 A_4)$

$q_5 = 2.78 * (i_5 A_1 + i_4 A_2 + i_3 A_3 + i_2 A_4 + i_1 A_5)$

Where i_1, i_2, i_3 etc are the net rainfall rate (mm/hr) in time intervals 1, 2, 3 etc. and A_1, A_2 etc are the values obtained from the Time Area graph for the same intervals.

The Rational Method expressed as a rectangular unit hydrograph

$Qp = 2.78\ Area/Tc$

y-axis: m³/s /10mm

x-axis: Time of Concentration — time (hours)

$Q = 2.78\ Area * Rainfall$ where 2.78 is the units conversion and the area under the Unit Hydrograph. The above diagram is the Rational Method expressed as a rectangular unit hydrograph which illustrates the close relationship between all rainfall runoff methods.

Example

If Tc = 3 hours and the calculation interval dT = 1 hour then:

q1= p1 * 2.78 A/3

q2 = p1 * 2.78 A/3 + p2 * 2.78 A/3

q3 = p1 * 2.78 A/3 * p2 * 2.78 A/3 + p3 * 2.78 A/3

q4 = p2 * 2.78 A/3 + p3 * 2.78 A/3

q5 = p3 * 2.78 A/3

For the Rational Method the rainfall is assumed to be constant over Tc and the rainfall rate per hour is the same as the rainfall depth for a 1 hour dT therefore:

i = p1 = p2 = p3

Max flow q3 = 2.78 i A   .. the Rational Formula   QED

The equivalence is true for any Tc and dT.

Unit Hydrograph (ReFH2 Method)

Please note that in order to generate a ReFH2 unit hydrograph, the ReFH2 software (version 2.1.5827.39730 or above) must be installed on the same machine as InfoDrainage.

Please contact the Centre for Ecology & Hydrology (CEH) for more details regarding this method and Wallingford Hydrosolutions (WHS) for more details on the use of the Revitalised Flood Hydrograph 2 (ReFH2) model software.