II.9.1-FFG-RUNOFF FLASH FLOOD GUIDANCE THRESHOLD RUNOFF

Introduction

The amount of runoff needed over an area to initiate flooding is the threshold runoff.

Threshold runoff depends on several characteristics of the watershed and the stream channels. The size of the watershed (area) determines the total volume of water that appears downstream. The slope of the channel and roughness of the steam bed controls the speed of the water as it moves downstream. For example, a steep slope causes higher velocities and a smooth streambed offers less resistance to flow. A rough streambed containing large rocks and trees resists the flow of water and slows the flow. The shape and size of a channel's cross section determines its capacity at a location along the stream. A narrow channel with low banks will hold less water than a wider channel with the same low banks. A wide channel with high banks has even a greater capacity.

Two methods are used to derive threshold runoff depending on the desired type of guidance (gridded and headwater). The methods are described in the following sections.

Gridded Threshold Runoff

In reality there are many more smaller headwaters or sub-basins that are too numerous to gage. In many cases these sub-basins seldom cause flood problems themselves, but the accumulated flows downstream become flood problems. The computation of threshold runoff for these sub-basins is more complex because there are no flood stages, Rating Curves and unit hydrographs available that define characteristics of the sub-basins. It is important hydrologically to maintain physical relationships between threshold runoff and a drainage area. For this reason, threshold runoffs must explicitly represent runoff from actual hydrologic areas to support the interpolation to a grid.

Physical representations of these basins (e.g. stage ratings, slopes, unit hydrographs) are generated that will minimize the subjective factor in deriving threshold runoff. With the increasing use of geographical information systems (GIS) and digital elevation models (DEM), threshold runoff is defined for areas smaller than the RFC's forecast basins. These sub-basins are determined by an algorithm based on size of catchment, drainage network and channel capacity. The threshold runoff software determines geographic locations (sub-basins) on the streams and computes threshold runoffs for these sub-basins as indicated by the dashed lines in Figure 1. Starting upstream, a GIS locates all stream junctions using a sub-basin area of at least 5 KM2. Next the total area is computed upstream of each junction. If the total area upstream of each junction is less than about 775 MI2 (2000 KM2), then the threshold runoff is computed for the location. The threshold runoff is not computed for areas larger than 775 MI2 because uniform distribution of rainfall over the area is less likely and larger areas exhibit fewer characteristics of flash floods.

The methodology requires watershed information for every medium-sized stream (5-10 sq. km.) in the United States. The GRASS routine r.watershed is used to delineate the watershed basin divides. Watershed basins and other hydrologic information is automatically delineated by r.watershed from digital elevation data, which yields results for flat regions. Digital elevation data (90 meter horizontal resolution and 1 meter vertical resolution) is available from the Defense Mapping Agency for the entire United States. This data, with its coarse resolution and poor accuracy, would cause watershed and most other 'pit and lake' watershed delineation algorithms to fail under certain circumstances.

The r.watershed program avoids this problem by treating the digital elevation data 'holistically'. The r.watershed algorithm finds the locations that water would flow off the edge of the digital terrain model. The algorithm works upland from these locations of lower elevations to higher elevations. 'Pits and lakes' in the digital elevation data are processed after the higher elevation regions around them are processed. Thus, the r.watershed program is able to process digital elevation data without modifying 'pit and lakes' elevation values which typically loses local topographic information.

After the watershed basin divides are located, the threshold runoff for the area upstream of each basin is computed using the general equation:

$$R = \frac{Q_p}{q_{pR} A} \qquad \textbf{(1)}$$

where R is the threshold runoff in inches
Q_p is the total flow in CFS
q_{pR} is the unit hydrograph graph peak flow in CFS
A is the drainage area in MI2

The term Q_p in Equation 1 is the flow at bankfull and is determined from Manning's equation using a shape parameter for hydraulic radius:

$$Q_p = \frac{1.486 S^{0.5} B_b}{n} \left(\frac{y_b}{m+1} \right)^{5/3} \qquad \textbf{(2)}$$

where S is the channel slope
B_b is the bankfull width
y_b is the channel depth
n is the Manning's roughness coefficient
m is the shape parameter of cross-section (0 for rectangular, 0.2 for bowl- shaped, 0.5 for parabolic, 1.0 for triangular and 1.5 for triangular with convex-shaped banks)

The Manning roughness coefficient (n) for bankfull flows is computed from the expression:

$$n = \frac{0.39 S_c^{0.38}}{\left(\frac{y_b}{m+1}\right)^{0.16}} \tag{3}$$

subject to $n \geq 0.035$.

The variable S_c in Equation 3 is the stream bottom slope (FT/FT) and the other variables were defined previously.

The variable q_{pR} in Equation 1 is the unit hydrograph peak flow expressed by Snyder as:

$$q_{pR} = \frac{640 c_p}{0.955 C_t \left(\frac{L L_c}{S^{0.5}}\right)^{0.38} + 0.25 t_r} \tag{4}$$

where C_p is the coefficient (range 0.4 to 0.8)
C_t is the coefficient (range 0.3 to 1.2)
L is the length of stream in miles from point of interest to the stream's uppermost end
L_c is the length of stream in miles from point of interest to the centroid of the drainage area above the point
S is the slope of the basin in FT/MI
t_r is the duration of rainfall in hours

When the parameters to compute Q_p in Equation 1 are not available from site observations (i.e., B_b, y_b and m in Equation 4), investigators have found the one- to two-year return period flow, Q_2, as an alternative to computing bankfull flow, Q_p (Riggs, 1990). The return period flow is the flow expected to be equaled or exceeded once during the specified time period. For bankfull flow the return period varies around 1.5 years but the two-year return period more closely approximates when minor flooding begins at slightly over bankfull.

An approach to derive unit hydrographs that avoids the need for 'observed' unit hydrographs for peak flow (q_{pR}) requires geometrical catchment characteristics obtainable from GIS software and digital terrain elevation databases. The approach avoids the need for estimating regionalized coefficients C_t and C_p in Equation 4 for computing q_{pR}. Using kinematic wave analysis and channel geometrical characteristics, i.e. bankfull width (B_b), local channel slope (S_c) and Manning's roughness coefficient (n), the time to peak (t_p) can be expressed as:

$$t_p = C_3 \Pi^{0.4} \tag{5}$$

and the peak value q_{pR}, as:

$$q_{pR} = \frac{C_4}{\Pi^{0.4}} \tag{6}$$

and

$$\Pi = \frac{L^{2.5}}{iAR_L\left(\frac{S_c^{0.5}}{n\ B_b^{2/3}}\right)^{1.5}} \tag{7}$$

where C_3 is the is the coefficient depending on the system of units used (0.576 for English units)
C_4 is the coefficient depending on the system of units used (0.884 for English units)
L is the length (MI) of stream from point of interest to the stream's uppermost end
i is the rainfall intensity (IN/HR)
A is the drainage area (MI2) upstream of point of interest
R_L is the stream length ratio (A property of the stream network relating the mean stream length to Strhaler's stream order (Eagleson (1970) or Bras (1990) review the geomorphological laws in their texts)
S_c is the local channel slope (FT/FT)
n is the Manning's roughness coefficient
B_b is the bankfull width (FT) from a bankfull width vs drainage area regional relationship or local regression equation derived from site observations of B_b and GIS measurement of drainage area and channel slope

This is still an active area of research but the approach is an alternative to the synthetic unit hydrograph method.

The two year return period flow and the geomorphologic unit hydrograph are attractive approaches in computing the threshold runoff. The methodology can be applied to all regions of the country. Initial values for Mannings's roughness coefficient can be computed from Equation 3 and for bankfull width, from bankfull width versus. area relationship or regional regression equations. However, such a method does not negate the need for 'observed' parameters and unit hydrographs. When locally observed information is available, n and B_b in Equation 7 should be optimized within certain limits, i.e., n should be limited to values between 0.02 to 0.09 and B_b should be limited to a range of one half to twice the initial value.

After the threshold runoff has been computed for the sub-basins, the Hydrologic Rainfall Analysis Project (HRAP) grid (Schaake, 1989) is overlaid on the sub-basins (shown in Figure 2) and the threshold runoff values are computed for each grid cell. In the future the gridded threshold runoffs derived from the GIS will be adjusted based on experience in the use of the FFG system and information obtained from site inspections as time allows.

The complete derivation of the above equations appears in Hydro Technical Memorandum 44.

Headwater Threshold Runoff

RFC models are based on geographical drainage areas referred to as RFC forecast basins. Most basins that have a history of flood problems are more likely to be gaged and those flood-prone basins that are headwaters are always gaged.

Describing the method to derive threshold runoff for a headwater is easier because parameters have been defined. As a result threshold runoff is a simple computation. The flood stage has been established and the channel is defined at the cross section by a Rating Curve that relates the depth of the water in feet to the amount of flow in the channel in cubic feet per second (CFS). The flow in CFS at flood stage is determined from the Rating Curve. The slope, roughness of the streambed and area of the watershed are incorporated in the unit hydrograph concept. The unit hydrograph relates stream flow as a function of time for one inch of runoff uniformly distributed over the drainage area for a storm of a specified duration. The peak value of the unit hydrograph is used. Finally, threshold runoff for a headwater is the flow at flood stage divided by the unit hydrograph peak for a specified duration. Only when the flood stage, Rating Curve or unit hydrograph peak is changed does the threshold runoff need to be recomputed.

Figure 1. Some Threshold Runoff Locations in a Single Forecast Basin

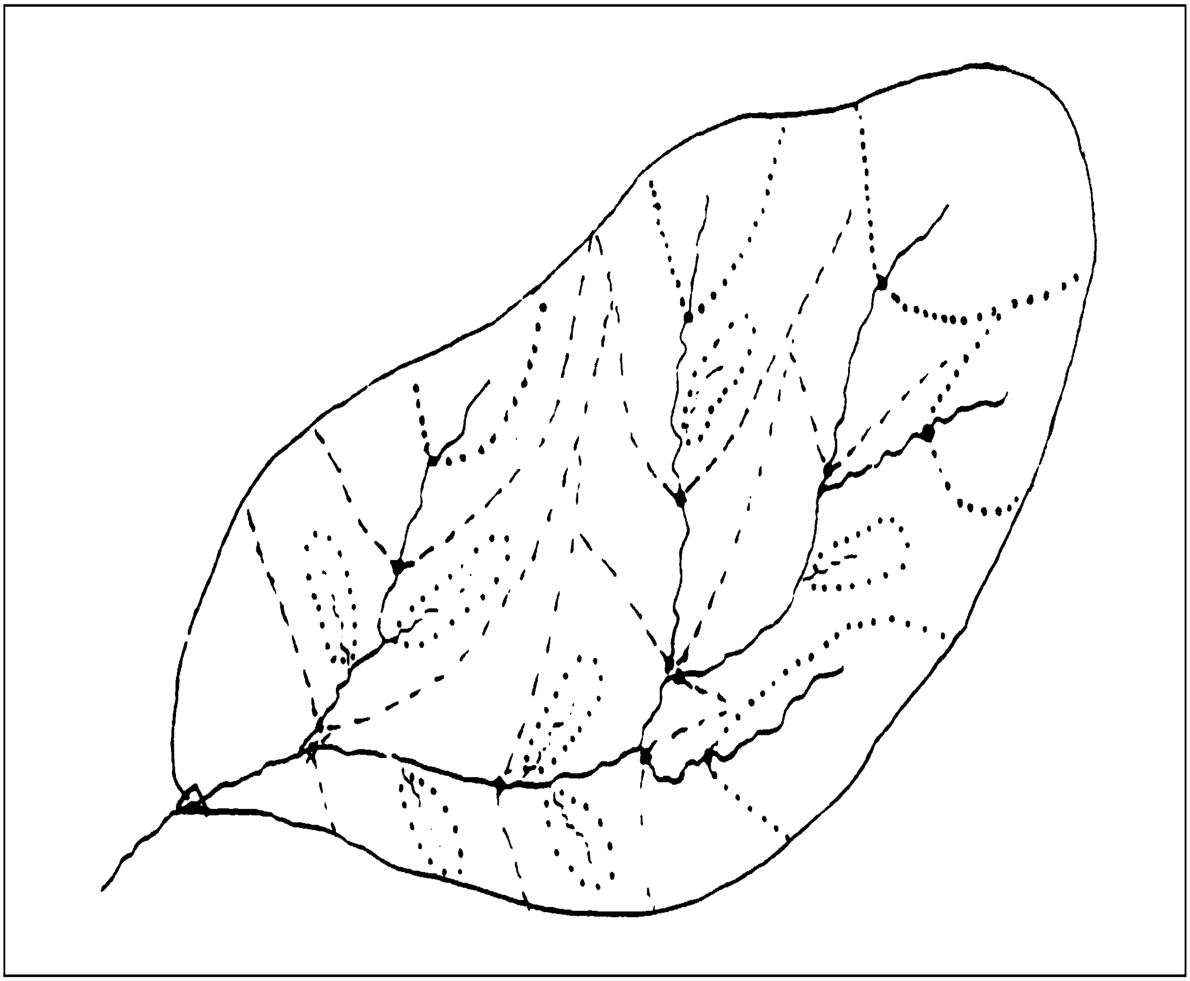

Figure 2. HRAP Grid Superimposed on Threshold Runoff Locations (Sub-basins)