Training Course

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CHAPTER-9

Drainage Basin Characteristics and GIUH Approach for Ungauged Catchments

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9.0 GENERAL

Land phase is one of the main components of the hydrological cycle. This represents the phase of movement of water after it is received on the land and upto when it joins the ocean water. Drainage basin is the medium for this land phase of the hydrological cycle and thus it works like a laboratory for the process of movement of water through it. Also, during this process the moving water leaves permanent imprints on the medium i.e. the drainage basin which are apparent in the form of surficial topography and exhibited in the stream channels themselves by their size, number, and dimensions. All the factors affecting runoff with which rainfall is in contact constitute the surficial environment. These factors include land surface, soil, geology, vegetation, and stream network. The surficial environment should also include climatic factors that indirectly affect soil development and vegetation. An understanding of the clues displayed in a drainage basin is vital to successful prediction of the hydrologic behaviour of that drainage basin.

The problem of transformation of rainfall into runoff has been subject of scientific investigations throughout the evolution of the subject of hydrology. Hydrologists are mainly concerned with evaluation of catchment response for planning, development and operation of various water resources schemes. A number of investigators have tried to relate runoff with the different characteristics which affect it. The conventional techniques of unit hydrograph (UH) derivation require historical rainfall-runoff data. Due to the various reasons, adequate runoff data are not generally available for many of the small and medium size catchments. Indirect inferences through regionalisation are sought for such types of ungauged catchments. A large number of regional relationships have been developed by many investigators relating either the parameters of unit hydrograph (UH) or instantaneous unit hydrograph (IUH) models with physiographic and climatologic characteristics. Geomorphological techniques have recently been advanced for hydrograph synthesis, adding a new dimension to hydrologic simulations. The *Geomorphological Instantaneous Unit Hydrograph* (GIUH) approach has many advantages over the regionalization techniques as it avoids the requirement of flow data and computations for the neighboring gauged catchments in the region as well as updating of the parameters. Another advantage of this approach is the potential of deriving UH using only the information obtainable from topographic maps or remote sensing, possibly linked with GIS and digital elevation model (DEM). Thus, linking of the geomorphologic parameters with the hydrologic characteristics of the basin can provide a simple way to understand the hydrologic behavior of different catchments, particularly the ungauged ones. The methodology for runoff estimation in an ungauged basin using GIS based GIUH approach is presented in the following sub-sections.

9.1 QUANTITATIVE CHARACTERISTICS OF DRAINAGE BASINS

There is deep sense of regularity in many of the geomorphic characteristics of the drainage basins and that this may be utilised for explaining their hydrologic behaviour. This makes it necessary to quantify the physical features of the drainage basins and their channel network. The physical characteristics of the drainage basin include drainage area, basin shape, ground slope, and centroid of the basin. Channel characteristics include channel order, channel length, channel slope, channel profile, and drainage density etc. Nowadays, topographic maps can be digitized and basin characteristics may be conveniently estimated without tedious manual labour.

9.1.1 Basin Order And Channel Order

One of the ways to characterise the drainage basin is by stream ordering and consequently basin order. A casual inspection of the channel network in the drainage basin reveals that the flow from one of the uppermost channels follow a path in which it combines with another channel and then this combined flow joins another channel and so on. As shown in Fig. 2, the first order channels are those parts of the network which do' not have any tributary joining them at any upstream location. These are the streams which drain only the overland flow from the contributing area and there is no channel flow contributed to this stream. When two first order channels combine they make a second order stream. Thus, the flow in a second order stream comprise of the flow of two first order streams, the flow form overland directly contributed to it and the flow of any number of first order streams joining it in its way downstream. As such the flow in a second order stream is more than that in a first order stream. Similarly, when two second order stream joins together they make a third order stream. This third order stream carries the flow of two second order streams, the flow of any number of second order or first order streams joining it in its way and the overland flow from the area adjoining it which directly contributes to it. Thus, a stream of second or higher order has atleast two streams of next lower order and possibly some more streams of other lower orders. The ordering in this manner is done throughout the channel network so as to reach the outlet at the end. A watershed is described as of first, second or higher order depending on the order of the stream at the outlet. That is to say that the order of the drainage basin is the order of the stream of highest order. This scheme of stream ordering is referred to as the Horton-Strahler ordering scheme.

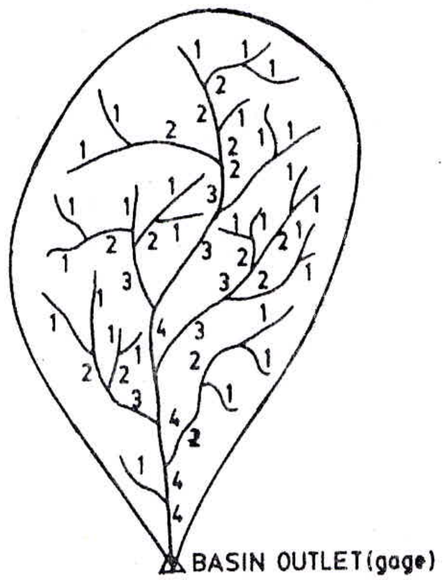

Fig. 2 Channel Network for a typical watershed.

It has been observed that the number of stream channels of each order forms an inverse geometric sequence with order number. This has been shown in Fig. 3. Horton expressed this in the form of law of stream numbers as:

$$N_w = R_b^{W-w} \tag{9.1}$$

or

$$\log N_w = W \log R_b - w \log R_b \quad (9.2)$$

$$= a - b\,w, \qquad \text{where, } a = W \log R_b, \quad b = \log R_b$$

where, N_w is the number of streams of order w, W is the order of the watershed, and R_b is the bifurcation ratio. The value of R_b generally varies between 3 and 5.

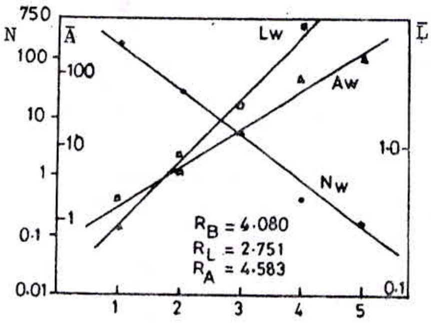

Fig.3 A Typical plot of channel order v/s stream numbers, lengths and areas

9.1.2 Linear Aspects Of The Channel System Length Of The Main Channel (L)

This is the length along the longest watercourse from the outflow point of designated sub-basin to the upper limit to the catchment boundary.

(i) Length Of The Channel Between The Outlet And A Point Nearer To C.G.(Lc)

It is the length of the channel measured from the outlet of the catchment to a point on the stream which is nearest to the centroid of the basin.
The centroid of the basin is determined using the following steps:

- Cut a card board piece in the shape of the catchment.
- Locate the center of gravity of the catchment shape card piece using standard procedure.
- Superimpose the card board piece marked with centre of gravity over the catchment plan.
- Press a sharp edge pin over the center of gravity of the card board piece to mark the center of gravity of catchment.

This length can be measured from the toposheets using one of the methods described above after locating the nearest point on the stream from the centroid of the basin.

(ii) Length Of Channels

This refers to the length of channels of each order. The average length of channels of each order increases as a geometric sequence. Thus, the first-order channels are shorter of all the channels and the length increases geometrically as the order increases. The total length of each stream order is found by summing up the individual lengths of streams of that order. Then the average length of that order is the ratio of this total stream length to the number of streams of that order.

It has been observed that the average length of channels of each higher order increases as a geometric sequence. Thus, the first order channels are the shortest of all the channels and the length increases geometrically as the order increases. This is shown in Fig. 3. This relation is called Horton's law of channel lengths and can be formulated as:

$$\bar{L}_w = \bar{L}_1 R_L^{w-1} \tag{9.3}$$

$$\log \bar{L}_w = \log \bar{L}_1 + (w-1)\log R_L \tag{9.4}$$

$$\log \bar{L}_w = a - bw \tag{9.5}$$

where,

$$a = \log(\bar{L}_1 / R_L), \quad b = -\log R_L, \qquad \bar{L}_w = \frac{\sum_{i=1}^{N_w} L_{wi}}{N_w} = \frac{L_w}{N_w} \tag{9.6}$$

in which L_{wi}, is the length of ith channel of order w, L_w is the total length of all channels of order w, N_w is the number of channels of order w, $\bar{L}_1$; is the mean channel length of order w, $\bar{L}_1$; is the mean length of first-order streams, R_L is the stream length ratio and is generally between 1.5 and 3.5., and is defined as $R_L = \bar{L}_w / \bar{L}_{w-1}$

(iii) Law Of Stream Areas

Hortan (1945) inferred that mean drainage areas of progressively higher orders might form a geometric sequence. This characteristics was formulated as a law of drainage areas by Schumm (1954), who stated that the mean drainage areas of streams of each order tend to approximate a geometric progression as:

$$\bar{A}_w = \bar{A}_1 R_a^{w-1} \tag{9.7}$$

or

$$\log \bar{A}_w = \log \bar{A}_1 + (w-1)\log R_a \tag{9.8}$$

$$\log \bar{A}_w = \log \frac{\bar{A}_1}{R_a} + w \log R_a = a + bw \tag{9.9}$$

$$a = \log \frac{\bar{A}_1}{R_a}, \quad b = w \log R_a \tag{9.10}$$

where $\bar{A}_w$ is the mean area of basins of order w, $\bar{A}_1$ is the mean area of first order basins, and Ra is the stream area ratio defined as $R_a = A_w/A_{w-1}$ and normally varies from 3 to 6. In fact, this relation is valid for basins on uniform soils within a given drainage area.

(iv) Channel Slope

Slope of the channel has a great effect on the velocity of flow in a channel, and consequently, on the flow characteristics of runoff from a drainage basin. The importance of the channel slope is in two areas: determining discharge and velocity using Manning or Chezy equation, and as a variable in multivariate analysis to determine the amount of influence accounted for by channel slope. Since, the slope varies longitudinally, an average value of slope must be determined. There are few methods which are used to express the average slope of the channel. These methods are given here:

Method I
While using Manning or Chezy equation, the channel slope is a local measurement to approximate the energy slope, assuming uniform flow. For this purpose, the channel slope S is the ratio of the fall H with the length L of the reach of interest and evaluated as S = H/L. However, this measurement is a local measurement and cannot hold for other channel reaches in the drainage basin. Cross-sectional area, channel roughness, and cross-sectional shape also affect flow velocity. Therefore, there is not as much difference in the flow velocity between various reaches of the drainage basin as one might think.

Method II
When used in multivariate analysis, the arithmetic slope in S = H/L may be determined in many ways. One common method is to compute the fall from the head of the uppermost first-order channel to the basin outlet and divide this fall by its horizontal length.

Method III
A geometric slope is sometimes used. This slope is determined by locating the median channel profile elevation on the main channel and computing the fall from this point to the outlet. The length

is the horizontal distance between the point of median elevation to the outlet. Slope is then computed using Eq., S = H/L.

Method IV

Benson (1962) found that the "85-10" slope factor was the most satisfactory in his study of floods, in New England. This factor is the slope between 85 % (excluding the upper 15%) and 10% (excluding the lower 10%) of the distance along the stream channel from the basin outlet to the divide. It should be noted that the distance is measured to the divide and not to the end of the defined stream channel. The fall and horizontal length between these two points are computed using Eq., S = H/L.

Method V :

This method is from Johnstone and Cross (1949). The channel can be divided into N number of reaches, each having a uniform slope Si .Then the equivalent uniform slope S_m is :

$$S_m = \left(\frac{\sum_{i=1}^{N} L_i S_i^{1/2}}{\sum_{i=1}^{N} L_i} \right)^2 \qquad (9.11)$$

This is designed to estimate the slope that would result in the same total time of travel as the actual stream if length, roughness, channel cross-section, and any other pertinent factors other than slope were unchanged.

Method VI

This is due to Laurenson (1962). Again the stream is divided into N reaches, each of uniform slope. Further, it is assumed that the effects of the roughness and hydraulic radius on velocity are the same for all reaches. This assumption is questionable but has been used previously (Taylor and Schwarz, 1952). This assumption is also implied in the first method. The velocity U_i of flow through any reach i can be written as,

$$U_i = B \cdot S_i^{0.5} \qquad (9.12)$$

where B is a constant. Then the time of flow t_i is

$$i_i = \frac{L_i}{U_i} \qquad (9.13)$$

Therefore, the total time of travel T_c down the main channel is

$$T_c = \frac{1}{B} \sum_{i=1}^{N} \frac{L_i}{S_i^{0.5}} \qquad (9.14)$$

The mean velocity of flow U_m can be written as

$$U_m = \frac{\sum_{i=1}^{N} L_i}{T_c} = \frac{\sum_{i=1}^{N} L_i}{\frac{1}{B}\sum_{i=1}^{N} \frac{L_i}{S_i^{0.5}}} \qquad (9.15)$$

Further,

$$U_m = B \cdot S_m^{0.5} \qquad (9.16)$$

Hence,

$$S_m = \left(\frac{\sum_{i=1}^{N} L_i}{\sum_{i=1}^{N} \frac{L_i}{S_i^{0.5}}} \right)^2 \qquad (9.17)$$

Method VII

This method is from Gray (1961) and Lane (1975). Gray defined S_c as the slope of a line drawn along the measured profile that has the same area as is under the observed profile. By referring to Fig. 6, the slope is the slope of the hypotenuse of a right-angle triangle with the same A and length Lc as the observed profile. If A is the area under the observed profile, then

$$A = h \; L_c \; / \; 2 \qquad (9.18)$$

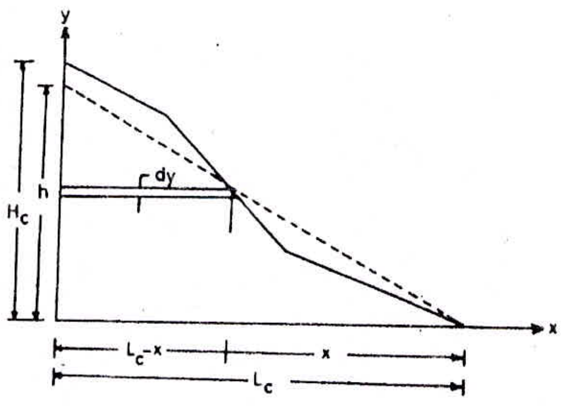

Fig. 6 Illustration for findig the slope (method-VII)

where h is the ordinate of the right-angle triangle. Therefore,

$$S_c = h/L_c \qquad (9.19)$$

or

$$S_c = 2A/ L; \qquad (9.20)$$

However, a more accurate measure of S_c can be obtained as follows. We can express

$$A = \int_0^{H_c} (L_c - x)dy \qquad (9.21)$$

Since the slope S is continuously changing with x,

$$dy = S(x)dx \tag{9.22}$$

Therefore,

$$A = \int_0^{L_c} (L_c - x) S(x) dx \tag{9.23}$$

and thus,

$$S_c = 2\int_0^{L_c} \frac{(Lc - x)}{L_c^2} S(x) dx \tag{9.24}$$

where $(L_c - x)/L_c^2$ can be considered as weighting factor. To illustrate, it is 0 at x = L_c and a maximum at x = 0 (at the outlet). Thus, Gray's method produces a channel slope that is weighted by distance from the head to the outlet.

The quantity h/H_c can be used as an index of concavity. If it is less than 1, which is normally the case, the stream profile is concave. A value of this quantity greater than 1 would correspond to a convex profile. Further, this quantity can be used as an index of how well the natural channel slope is represented by a straight line.

It can be seen from the forgoing methods of determining channel slope that the main channel is used to determine a slope that is presumed to be representative of all other channels in the drainage basin. One might wonder why so many different slopes are necessary. Although slope is recognized to be important in predicting hydrologic response, results of multivariate analysis using slope have produced less than conclusive results. These and other slope values have been developed in an effort to find a value of slope that is consistently important for multivariate hydrologic analyses. No such slope has yet been discovered.

9.2 GIUH DERIVATION USING GEOMORPHOLOGICAL CHARACTERISTICS

Rodriguez-Iturbe and Valdes (1979) first introduced the concept of geomorphologic instantaneous unit hydrograph which led to the renewal of research in hydrogeomorphology. The expression derived by Rodriguez-Iturbe and Valdes (1979) yields full analytical, but complicated, expressions for the instantaneous unit hydrograph. Rodriguez-Iturbe and Valdes (1979) suggested that it is adequate to assume a triangular instantaneous unit hydrograph and only specify the expressions for the time to peak and peak value of the IUH. These expressions are obtained by regression of the peak as well as time to peak of IUH derived from the analytic solutions for a wide range of parameters with that of the geomorphologic characteristics and flow velocities. The expressions are given as:

$$q_p = 1.31\, R_L^{0.43}\, V / L_\Omega \tag{9.25}$$

$$t_p = 0.44 (L_\Omega / V)(R_B / R_A)^{0.55} (R_L)^{-0.38} \tag{9.26}$$

where;

- L_Ω = the length in kilometers of the stream of order Ω
- V = the expected peak velocity, in m/sec.
- q_p = the peak flow, in units of inverse hours
- t_p = the time to peak, in hours
- R_B, R_L, R_A = the bifurcation, length, and area ratios given by the Horton's laws of stream numbers, lengths, and areas, respectively.

Empirical results indicate that for natural basins the values for R_B normally ranges from 3 to 5, for R_L from 1.5 to 3.5 and for R_A from 3 to 6 (Smart, 1972).

On multiplying eq. (9.25) and (9.26) one get a non-dimensional term $q_p * t_p$ as:

$$q_p * t_p = 0.5764\, (R_B / R_A)^{0.55} (R_L)^{0.05} \tag{9.27}$$

This term is independent of the velocity and, thereby, on the storm characteristics and hence is a function of only the catchment characteristics.

9.3 DEVELOPMENT OF RELATIONSHIP BETWEEN INTENSITY OF RAINFALL-EXCESS AND VELOCITY

For the dynamic parameter velocity (V), Rodriguez and Valdes (1979) in their studies assumed that the flow velocity at any given moment during the storm can be taken as constant throughout the basin. The characteristic velocity for the basin as a whole changes throughout the storm duration. For the derivation of GIUH, this can be taken as the velocity at the peak discharge for a given rainfall-runoff event in a basin. However, for ungauged catchments, the peak discharge is not known and, therefore this criterion for estimation of velocity cannot be applied. In such a situation, the velocity may be estimated using the velocity-rainfall excess relationship.

9.4 DATA BASE PREPARATION IN GIS

GIUH based approach and Clark model require some of the important geomorphological parameters from toposheets. Manual derivation of these parameters is tedious and time consuming and often involves certain degree of errors. The procedure is all the more difficult if the toposheets or maps of higher scale e.g. 1:50,000 or 1:25,000 are used for derivation of the geomorphological characteristics. To overcome this difficulty Geographical Information System (GIS) software like ILWIS, ARC/INFO, IDRISI etc. are now a days available for derivation of these characteristics in a less time consuming and simplified manner. Application of the GIS software makes the computation of geomorphological parameters easy, less time consuming, and accurate. On the other hand, the manual methods of the morphometric analysis such as length measurement using thread length, opisometer, rular, digital curvimeter or area measurement by planimeter or dot grid method are very much time consuming and tedious.

9.5 GEOMORPHOLOGICAL DATA BASE PREPARATION

Evaluation of geomorphologic characteristics involves preparation of a drainage map, ordering of the various streams, measurement of basin area, channel length and perimeter etc. and thereafter computing various geomorphological parameters such as bifurcation ratio, length ratio, area ratio, drainage density, drainage frequency, basin configuration and relief aspects etc. The geomorphological parameters viz. bifurcation ratio (R_b), length ratio (R_L), area ratio (R_A), length of the highest order stream ($L_ς$), length of the main stream (L) are required to be evaluated for a catchment for application of the GIUH based model. The methodology adopted for estimation of these geomorphological parameters is described below:

9.5.1 Stream Ordering

Strahler's stream ordering system may be used for stream ordering (u). The principles of Strahler's method of stream ordering are mentioned below.

(i) Channels that originate at a source are defined to be first order streams.

(ii) When two streams of order u join, a stream of order u+1 is created.

(iii) When two streams of different orders join, the channel segment immediately down stream has the higher of the order of the two continuing streams.

(iv) The order of a basin is the order of the highest stream.

This ordering system can be applied through ILWIS over the entire drainage network . In ILWIS, length of each stream is stored in a table. Then, after adding length of each stream for an order, one can get the total stream lengths of each order. The total stream length divided by the number of stream segment (N_u) of that order gives the mean stream length L_u for that order.

9.5.2 Stream Number (N_u)

In ILWIS, the number of streams of each order can be stored in a table and for each order the total number of streams can be computed. Horton's law of stream numbers states that number of stream segments of each order is in inverse geometric sequence with order number i.e. $N_u = R_b^{u-k}$ where, k is the order of trunk segment, u is the stream order, N_u is the number of stream of order u and R_b is a constant called the bifurcation ratio.

9.5.3 Stream Length (L_u)

Length of each stream is stored in a table. Then after adding length of each stream for a given order, the total stream length of each order (L_u) may be computed. The total stream length divided by the number of stream segments (N_u) of that order gives the mean stream length L_u for that order. Length of the main stream from its origin to the gauging site is indicated as (L) while the length of the highest order stream is indicated as L_Ω.

9.5.4 Bifurcation Ratio (R_b)

Horton's law of stream numbers states that number of stream segments of each order is in inverse geometric sequence with order number i.e.

$N_u = R_b^{u-k}$

where, k is the order of trunk segment, u is the stream order, N_u is the number of stream of order u and R_b is a constant called the bifurcation ratio.

Bifurcation ratio (R_b) is defined as the ratio of stream segments of the given order N_u to the number of stream segments of the next higher order N_{u+1} i.e:

$$R_b = N_u \,/\, N_{u+1} \qquad (9.28)$$

9.5.5 Length Ratio (R_l)

Length ratio is one of the important geomorphologic characteristics. Horton (1945) defined length ratio (R_l) as the ratio of mean stream length ($\bar{L}_u$) of segment of order u to mean stream segment length ($\bar{L}_{u-1}$) of the next lower order u-1, i.e.:

$$R_l = \bar{L}_u \,/\, \bar{L}_{u-1} \qquad (9.29)$$

9.5.6 Area Ratio (R_a)

The area of streams of each order can be estimated using the area and length relationship (Strahler, 1964). Horton stated that mean drainage basin areas of progressively higher order streams should increase in a geometric sequence, as do stream lengths. The law of stream areas can be expressed as:

$A_u = A_1 R_a^{u-1}$

Here, A_u is the mean area of basin of order u, A_1 is the mean area of first order basin, and R_a is the area ratio. Areas for different order basins were estimated using the relationship between area of any order and area of highest order as given below:

$$A_u = A_1 \, R_b^{u-1} \, (R_{lb}^{u}-1)/(R_{lb}-1) \qquad (9.30)$$

Where, R_{lb} is the Horten's term for the length ratio to bifurcation ratio. In this relationship the only unknown is A_1 and it can be computed from physical characteristics. The mean areas are computed using the value of A_1.

Area ratio (R_a) is defined as the ratio of area streams (A_u) of order u to the area of streams (A_{u-1}) of the order u-1, i.e.:

$R_a = A_u \,/\, A_{u-1}$

Area ratio is one of the important geomorphologic characteristics.

9.6 DERIVATION OF UNIT HYDROGRAPH

9.6.1 GIUH Based Clark Model Approach

The Clark model concept (Clark, 1945) suggests that the IUH can be derived by routing the unit inflow in the form of time-area diagram, which is prepared from the isochronal map, through a single reservoir. For the derivation of IUH the Clark model uses two parameters, time of concentration (T_c) in hours, which is the base length of the time-area diagram, and storage coefficient (R), in hours, of a single linear reservoir in addition to the time-area diagram. The governing equation of IUH using this model is given as:

$$u_i = C\, I_i + (1-C)\, u_{i-1} \tag{9.31}$$

where;

u_i = ith ordinate of the IUH
C & (1-C) = the routing coefficients.
and C = $\Delta t / (R + 0.5\, \Delta t)$
Δt = computational interval in hours
I_i = ith ordinate of the time-area diagram

A unit hydrograph of the desired duration (D) may be derived using the following equation:

$$U_i = \frac{1}{n}(0.5\, u_{i-n} + u_{i-n} + u_{i-n+1} \ldots\ldots\ldots\ldots + u_{i-1} + 0.5\, u_i) \tag{9.32}$$

where;

U_i = ith ordinate of unit hydrograph of duration D-hour and at computational interval Δt hours,
n = no. of computational intervals in duration D hrs = $D/\Delta t$, and
u_i = ith ordinate of the IUH.

Preparation of time-area diagram

In the GIS and Clark based GIUH model, the time area diagram of a catchment serves as a basic input. The central idea in time-area diagram preparation is a time contour or an isochrone. The time-area diagram illustrates the distribution of travel time of runoff in different parts of a catchment. The application of GIS makes preparation of the time area diagram of a catchment less time consuming and quite easier. Steps for derivation of the time area diagram are described below:

1. Measure the distance from the most upstream point in the basin upto the gauging site along the main stream.
2. It is assumed that the time of travel between any two points is proportional to the distance and inversely proportional to the square root of the slope between these points expressed mathematically,

$$t = KL / \sqrt{S} \tag{9.33}$$

where, t is the time of travel, L is the length of the stream, S is the slope of the stream between two points, and K is the proportionality constant.

3. An initial estimate of time of concentration may be made be derived using Kirpich's formula as:

$$T_c = 0.06628\ L^{0.77}\ H^{-0.385} \quad (9.34)$$

where, T_c is the concentration time in hours, L is the length of stream in kilometers, and H is the average slope of the stream. Substituting the values of L and H in the above equation, the value of T_c can be computed.

4. The value of T_c computed in step 3 may be substituted in equation given in step 2 and then, it may be rearranged as:

$$K = t_c \sqrt{S_A}\ / L \quad (9.34)$$

whetre S_A is mean slope of the main stream

5. By substituting values of T_c, L and S_A in the equation given in step 4, the value of K may be computed.
6. The computed value of constant of proportionality K is used in equation given in step 2 for computing time of travel between the two points of the catchment.
7. Beginning from the gauging site of the catchment progressively, compute the time of travel at various locations in the catchment.
8. Mark all the values of the time of travels for each stream on the map of the catchment. Then, transfer these points in the digital format.
9. Using an interpolation technique, draw a map of time distribution through these points.
10. From the time distribution map values, prepare a map at a desired interval, e.g. 1-hour.

The step by step explanation of the procedure to derive unit hydrograph for a specific duration using the GIUH based Clark model approach is given here under:

(i) Rainfall-excess hyetograph is computed either by uniform loss rate procedure or by SCS curve number method or by any other suitable method.

(ii) For a given storm, the peak velocity V using the highest rainfall-excess is determined from the relationship between velocity and intensity of rainfall-excess.

(iii) Compute the time of concentration (T_c) using the equation :

$$T_c = 0.2778\,L\,/\,V \quad (9.36)$$

where;

L = length of the main channel, and

V = the peak velocity in m/sec.

Considering this T_c as the largest time of travel, find the ordinates of cumulative isochronal areas corresponding to integral multiples of computational time interval with the help of the non-dimensional relation between cumulative isochronal area and the percent time of travel. This describes the ordinates of the time-area diagram at each computational time interval.

(iv) Compute the peak discharge (Q_{pg}) of IUH given by equation (9.25).

(v) Assume two trial values of the storage coefficient of GIUH based Clark model as R_1 and R_2. Compute the ordinates of two instantaneous unit hydrographs by Clark model using time of concentration T_c as obtained in step (iii) and two storage coefficients R_1 and R_2 respectively, with the help of equation (9.25). Compute the IUH ordinates at a very small time interval say 0.1 or 0.05 hrs so that a better estimate of peak value may be obtained.

(vi) Find out the peak discharges Q_{pc1} and Q_{pc2} of the instantaneous unit hydrographs obtained for Clark model for the storage coefficients R_1 and R_2, respectively, at step (v).

(vii) Find out the value of objective function, using the relation:

$$FCN1 = (Q_{pg} - Q_{pc1})^2 \tag{9.36}$$

$$FCN2 = (Q_{pg} - Q_{pc2})^2 \tag{9.37}$$

(viii) Compute the first numerical derivative FPN of the objective function FCN with respect to parameter R as:

$$FPN = \frac{FCN1 - FCN2}{R_1 - R_2} \tag{9.38}$$

(ix) Compute the next trial value of R using the following governing equations of Newton-Raphson's method:

$$\Delta R = \frac{FCN1}{FPN} \tag{9.39}$$

and

$$R_{NEW} = R_1 + \Delta R \tag{9.40}$$

(x) For the next trial, consider $R_1 = R_2$ and $R_2 = R_{NEW}$ and repeat steps (v) and (ix) till one of the following criteria of convergence is achieved.
(a) FCN2 = 0.000001
(b) No. of trials exceeds 200
(c) $ABS(\Delta R)/R_1 = 0.001$

(xi) The final value of storage coefficient (R_2) obtained as above is the required value of the parameter R corresponding to the value of time of concentration (T_c) for the Clark model.

(xii) Compute the instantaneous unit hydrograph (IUH) using the GIUH-based Clark Model with the help of the final value of the storage coefficient (R), time of concentration (T_c) as obtained in step (xi) and time-area diagram.

(xii) Compute the D-hour unit hydrograph (UH) using the relationship between IUH and UH of D-hour.

9.6.2 GIUH Based Nash Model Approach

Nash (1957) proposed a conceptual model in which catchment impulse could be represented as the outflow obtained from routing the unit volume of the instantaneous rainfall-excess input through a series of *n* number of successive linear reservoirs having equal delay time. The equation for the instantaneous unit hydrograph for the Nash model is given as:

$$U(0,t) = \frac{1}{k} \cdot \frac{1}{\Gamma n} e^{-\frac{t}{k}} \cdot \left(\frac{t}{k}\right)^{n-1} \quad (9.41)$$

where, U(0,t) is the ordinate of the instantaneous unit hydrograph, k is the storage coefficient and n is the number of reservoirs.

The complete shape of the GIUH can be obtained by linking q_p and t_p of the GIUH with the scale (k) and shape (n) parameter of the Nash model. Now, by equating the first derivative (with respect to t) of the equation (14) to zero, t becomes the time to peak discharge, t_p. Further, peak discharge q_p and time to peak t_p can be linked as:

$$q_p \cdot t_p = \frac{(n-1)}{\Gamma n} e^{-(n-1)} \cdot (n-1)^{n-1} \quad (9.42)$$

Equating equation (3) with equation (15), one gets

$$\frac{(n-1)}{\Gamma n} \cdot e^{-(n-1)} \cdot (n-1)^{n-1} = 0.5764 \left[\frac{R_B}{R_A}\right]^{0.55} \times R_L^{\ 0.05} \quad (9.43)$$

The parameter n may be substituted in the following equation to determine the Nash Model parameter k for the given velocity V.

$$k = \frac{0.44 L_W}{V} \cdot \left[\frac{R_B}{R_A}\right]^{0.55} \cdot R_L^{\ -0.38} \cdot \frac{1}{(n-1)} \quad (9.44)$$

The derived value of n and k, can be utilised for determination of the complete shape of IUH.

9.7 COMPUTATION OF EFFECTIVE-RAINFALL

9.7.1 Effective Rainfall

Effective rainfall is required for the estimation of direct surface runoff. It can be computed by separating the initial hydrological abstractions from the rainfall hyetographs. When the rainfall occurs over a catchment not all the rain contributes to the direct surface runoff. A part of the rainfall is abstracted as interception, evapotranspiration, surface depression storage and infiltration, which are known as initial abstraction. The remaining part of the rainfall termed as effective rainfall contributes to the direct surface runoff, which by volume is equivalent to rainfall-excess.

A number of techniques are available for the computation of rainfall excess. But the ϕ-index method is one of the simple and quite commonly used technique. Among the other techniques, Soil Conservation Service (SCS) curve number method (SCS, 1956) is also very often used for the estimation of the rainfall excess, particularly when the catchment is ungauged.

9.7.2 Computation of Direct Surface Runoff using the Derived Unit Hydrograph

The direct surface runoff (DSRO) for a storm event whose rainfall-excess values are known at D-hour interval are computed using convolution of the D-hour unit hydrograph. The convoluted hydrograph ordinates can be given as:

$$Q(t) = \Delta t \sum_{i}^{n} [U(D, t - (i-1)\Delta t] * I_i \qquad (9.45)$$

where,

$U(D, t)$ = ordinate of D hour unit hydrograph at time t,
I_i = excess-rainfall intensity at ith interval (i.e., at time = $\Delta t * i$),
n = number of excess-rainfall blocks, and
Δt = computational time interval.

REMARKS

The primary physical characteristics, on which the hydrologic response depend, include linear aspects of the channel network, areal aspect relief aspects of the catchment, soil land use types, etc.. The climatic factors which include the nature, intensity, duration, temporal and areal distribution, direction of movement of precipitation and sunshine duration etc. also affect the hydrologic response of the catchment. In a long term they also change some of the physical drainage basin characteristics. In attempting a hydrologic study based on these governing factors require the basic knowledge about these characteristics which are related to the drainage basin of interest. An outline of these characteristics has therefore been presented here so as to give a preliminary idea about how these characteristics may be evaluated from the information available in different forms. Making use of some of these characteristics may thus be utilised in defining the hydrologic response of the watershed of interest. Further, geomorphological based instantaneous unit hydrographs methodology has been discussed in this lecture. Geomorphological characteristics, which are quite commonly used in geomorphological based instantaneous unit hydrograph, can be evaluated using a GIS package. Manual estimation of the geomorphological parameters is a tedious and cumbersome process and often discourages the field engineers from developing the regional methodologies for solving various hydrological problems of the ungauged basins or in limited data situations.

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