LECTURE 9

CATCHMENT CHARACTERISTICS FOR REGIONAL UNIT HYDROGRAPH ANALYSIS

OBJECTIVES

This lecture is intended for explanation and discussion of the parameters representing different aspects of catchment and storm characteristics which are useful for the derivation of the unit hydrograph for ungauged catchments. The participants would also be able to know the procedures involved in the evaluation of these characteristics from available toposheets and climatological data.

9.1 INTRODUCTION

The estimation of runoff, from the watershed is needed for comprehensive water resources planning, flood flow forecast, adequate design of hydraulic structures etc. The climatic and physical characteristics of the watershed are the main factors affecting runoff. The climatic factors include nature of precipitation, evapotranspiration and interception, rainfall, intensity, duration of rainfall, areal and temporal distribution of rainfall and direction of storm movement. The primary physical characteristics of the watershed which influence runoff are its area, length, shape. elevation, slope, orientation, soil type, drainage or channel system, water storage capability and vegetal cover etc.

Unit hydrograph is one of the most popular simple techniques for the computation of runoff from the watershed. It is characteristic for a given watershed and it resresents the integrated effect of various physical features on the routing of the rainfall input through the catchment system The unit hydrograph for gauged catchments can be derived by analysing the available rainfall-runoff data. However, for many small catchments the streamflow data are limited and for ungauged catchments it is not at all available. Therefore, the unit hydrograph for such catchments can only be derived using their physical and storm characteristics. This necessitates the development of suitable regional relationships for unit hydrograph derivation. The procedure used for this purpose involves the derivation of the parameters that describe the unit hydrograph for gauged catchments; and then the development of the regional relationships between the unit hydrograph parameters with pertinent physiographic and storm characteristic of the catchments. The catchments considered for such regional study have to be similar in hydrological and meteorological characteristics.

In this lecture, some pertinent physiographic and storm characteristics, useful for regional unit hydrograph analysis, are described. The procedures involved in the evaluation of the parameters, representing the catchment characteristics, from the available toposheet and climatological data are also discussed.

9.2 PHYSICAL PARAMETER AND VARIOUS LAND USES

9.2.1 Linear Aspects of the Channel System

(a) Length of the main Channel (L) : This is the length along the longest water course from the outflow point of designated sub-basin to the upper limit to the catchment boundary. Schulz (1976) described the following five methods which may be used for length measurement; from topographic maps :

(i) Pair of dividers
(ii) Thread length
(iii) Edge of paper strip
(iv) Opisometer
(v) Analog to digital converter

(i) Pair of dividers : In this method. the stream length can be measured by setting a pair of dividers to a small interval compared to the meander length of the stream. The points of the devider can be 'walked' up the centre line of the stream counting each strip. The stream length is :

stream = (Number of Divider Steps)
× (Length of Divider Step) ×
(Map Scale Factor) (9.1)

(ii) Thread length : In this method, the stream length is measured using the thread. The stream length on the map is carefully pointed with rubber cement. A distinctive coloured thread or thin copper wire is stuck to the adhesive surface over the stream or contour image. The point of a divider can advantageously be used to attach the thread to the map image following all of the twists and bends. The ends of the thread are carefully trimmed with a single edge razor blade or sharp xacto knife blade. The thread is then carefully lifted from the map and stretched along a scale for measurement. The rubber cement can be gently rubbed from the map or areal photo without damage to the map surface.

(iii) Paper strip : In this method, the edge of a sheet of a paper is laid tangent to the stream at the beginning point. The beginning point is indicatad by an arrow on the edge of the paper. Now, hold the position of the edge of the paper with the point of a drawing pencil at the point where the straight edge of the paper begins to deviate from the stream alignment. After this the sheet of paper is rotated until its straight edge is again tangent to the stream. Then the point of pencil is advanced to the edge of the paper where the stream again deviates from the straight edge of the paper and it is to be continued till the end of the stream which is marked with another arrow.

The length of the stream is the distance along the edge of the paper between the start and end arrow measured inches or centimeters (as appropriate) times the scale factor for the map scale ratio. If one sheet of paper has insufficient edge length for the stream length being measured, a second sheet of paper is to be employed. This method has the advantage that the sheet paper provides the length data in a form which can easily be checked again at a later time by some one else.

This method also provides a procedure for obtaining data for constructing a profile of the stream. Whenever the edge of the paper encounters a place on the map where the stream intersects a contour line, indicate this point with a small "tick" mark on the paper and label the tick mark with the contour elevation. The elevation difference between these tick marks divided by ground distance is the average stream slope between the points.

(iv) Opisometer : The opisometer is an instrument having a dial connected by gears to a small roller wheel which is guided over the centre line of the stream. The distance traversed by the roller wheel is indicated on the dial. The units are either in inches or centimeters. It is usually difficult to reset the dial to zero reading at the start of the measurement, therefore, it is customary to read the initial and final readings from the dial. Then the initial dial reading is deducted from the final dial reading to obtain the length of stream.

Because it is difficult to guide the wheel accurately over the stream, it is recommended that the distance be traced at least three or four times and the distance taken as the average of the measurements. Those measurements, which have deviations more than five per cent of the average measurement, should be discarded and replaced with other measurements.

(v) Analog to digital Convertor : Stream lengths and contour lengths can be obtained in an indirect way by tracing the line or stream to be measured in a special machine. This machine is used to record X and Y coordinates of closely spaced points on magnetic tape or punched on paper tape or IBM cards. The required stream length is found by running distances computed from the equation.

$$\text{Distance} = [(\Delta X)^2 + (\Delta Y)^2]^{1/2} \tag{9.2}$$

High speed digital computer is used in the procedure. As a result, the basic map data can be quickly, accurately and inexpensively converted into a form for automatic machine data processing. This method is capable of resolving X and Y distances to the nearest 0.001 inch.

(b) Length of the channel between the outlet and a point nearer to C.G. (L_c) : It is the length of the channel measured from the outlet of the catchment to a point on the stream nearest the centroid of the basin.

The centroid of the basin is derermined using the following steps :

(i) Cut a card board piece in the shape of the catchment.

(ii) Locate the centre of gravity of the catchment shape card piece using standard procedure.

(iii) Superimpose the card board piece marked with centre of gravity over the catchment plan.

(iv) Press a sharp edge pin over the centre of gravity of the card board piece to mark the centre of gravity of catchment.

This length can be measured from the toposheets using one of the methods described in section 9.2.1 (a) after locating the nearest point on the stream from the centroid of the basin.

(*c*) *Total length of channels :* Normally, channel storage varies with stream lengths as a simple power function. Total length of all channels is computed by summing the lengths of all stream reaches.

(*d*) *Wandering Ratio :* The wandering ratio is the ratio of the main stream length and the valley length. It represents the deviations of the mainstream path from the straight line length from the mouth to the tip of the main stream. The wandering ratio is not to be confused with sinuosity or meandering as the wandering ratio represents a more gross deviation of the path of the master stream from a straight line course. It should also be noted that for unusually shaped basins the straight line distance from tip to mouth may not actually follow the valley and the resulting value of the wandering ratio will appear abnormally high.

(*e*) *Basin perimeter :* It is measured along the divides between basins and may be used as an indicator of basin size and shape.

(*f*) *Texture ratio :* The texture of a basin is defined as a ratio between the number of crenulations along the contour line within the basin containing the maximum crenulations to the length of the perimeter of the basin. It provides a measure of the degree of dissection within a drainage basin.

(*g*) *Fineness ratio* : Melton (1957) suggested that the ratio of channel lengths to the length of the basin perimeter is fineness ratio which is a measure of topographic fineness.

(*h*) *Watershed eccentricity* : The watershed eccentricity is given by the expressien :

$$\tau = \frac{\sqrt{\left| (L_c^2 - W_L^2) \right|}}{W_L} \quad (9.3)$$

where τ = watershed eccentricity, a dimensionless factor.

L_C = Length from the watershed mouth to the centre of mass of the watershed, in the same unit as the

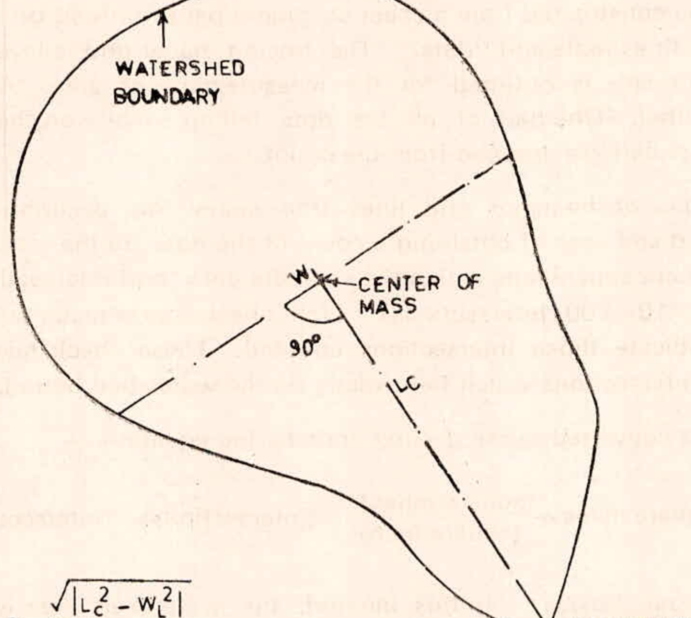
W_L = the width of the watershed at the centre of mass and perpendicular to L_C

The measurements for L_C and W_L are shown diagrammatically in Fig. 9.1. It is to be noted that if $L_C = W_L$, $\tau = 0$, and as either L_C or W_L get large, τ increases. Thus the lower the value of τ, the greater the compactness of the watershed concentrated near the mouth and the higher the flood peak.

9.2.2 Areal Aspects of Drainage basin

(*a*) *Drainage Area* : Schulz (1976) described the following methods for the determination of the area of a drainage basin from the available toposheets of the basin :

- (i) Estimation
- (i i) Polar planimeter
- (iii) Dot grid
- (iv) Strip sub division
- (v) Geometric sub division
- (vi) Analog to digital converter



$$\tau = \frac{\sqrt{|L_c^2 - W_L^2|}}{W_L}$$

Fig. 9.4 Watershed Ecentricity

(*i*) *Estimation* : The area of a watershed can be visually estimated by comparison of the watershed as traced on a topographic map with a square or rectangle of similar size and the known dimensions can be used to easily estimate the area. The method is quick and easy to use but is very subjective.

(*ii*) *Polar planimeter* : It is a widely used analog device which yields a reading from a series of recording dials. The reading is proportional to the area of the figure traced around. The tracer point or optical cursor is set to a beginning point on the periphery of the warershed. An initial reading of the dials is taken (Some planimeters are equipped with a reset lever which allows the dials to be set to zero at the beginning of the tracing operation). The tracer point is then carefully guided around the area in a clockwise direction returning to the starting point. The dial reading after the area has been traced around is proportional to the area enclosed. It is customary to trace around the area three times and taking a reading on the completion of each circuit. The area in map units is taken as the average of these three values. The watershed area is Area in square miles or square kilometre

= (Planimeter units) × (Area per planimeter unit)

The area per planimeter unit may be determined by tracing around a square whose area can be computed in watershed units. For this purpose a map scale line at the bottom of the topographic map can be used.

Some planimeters, which are fitted with an adjustable tracer arm to allow the setting of the instrument, give a direct indication of the area in any units. If the carriege block is in a fixed position on the tracer arm, the instrument will give the area traced in square inches.

(*iii*) *Dot grid* : The area of the watershed can be determined by the use of a dot grid. The dot grid can be constructed from a sheet of graph paper printed on tracing paper. The intersection of the grid lines represent "dots". The trncing paper grid is layed over the map on which the watershed boundary is outlined for the measurement of area. All dots falling within the watershed are counted. One half of all the dots falling excatly on the watershed boundary are counted. The other half are dropped from the count.

The presence of the major grid lines (the heavy line occuring every 10th or 20th line) facilitates the speed and ease of obtaining a count of the dots. In the interior part of the watershed where the entire major square falls within the area, the dots (grid intersections) are quickly counted by inspection ($10 \times 10 = 100$ intersections). Light check marks made with a sharp drawing pencil may be used to indicate those intersections counted. These check marks are particularly useful in counting those intersections which fall exactly on the watershed boundary.

The area is converted to the desired units by the equation :—

$$\text{Area in square miles} = \frac{\text{(square miles)}}{\text{(square inch)}} \times \text{(intersections)} — \text{(intersections per square inch)} \qquad \text{......(9.5)}$$

(*iv*) *Strip sub division* :— In this method, the watershed area is sub divided into narrow strips. The length of each strip falling within the area is scaled. The area in map units is given by :

$$\text{Map area} = \Sigma \text{ (Length of all strips)} \times \text{(Strip width)} \qquad \text{......(9.6)}$$

The watershed area is obtained by :

$$\text{Area in square miles} = \text{(Map area)} \times \text{(square miles per map unit)} \qquad \text{......(9 7)}$$

A sheet of 10×10 per inah or 5×5 per inch. graph paper on a transparent tracing paper can be used to define the strips.

(*v*) *Geometric subdivision* :—The watershed area as outlined on the topographic map can be approximated by a series of simple geometric shapes whose areas can easily be computed. The areas of squares, rectangles and triangles can be easily determined. The area in map units is given by :

$$\text{Map area} = \Sigma \text{ (computed area of simple sub divisions)}$$

The watershed area is obtained by :

$$\text{Area in square miles} = \text{(Map area)} \times \text{(Square Miles per Map Unit)}$$

(*vi*) *Analog to digital converter* :—The basic data, obtained by tracing around the watershed boundaries drawn on the topographic map with the cursor of the analog to digital converter, may be used to compute the watershed area by a computer programme. The analog to digital converter is already described in section 9.2.1 (a) under the discussion dealing with length measurements.

The output from the analog to digital converter consists of a larga number of X and Y coordinates on the periphery of the watershed. The coordinates are recorded on magnetic tape or punched on paper tape or IBM cards. A computer programme uses the basic data to compute the area of watershed converted to square miles, the length of the periphery of the watershed and co-ordinates of the centre of area,

(*b*) *Drainage density* :—Drainage density is defined as the ratio of the total length of channels of all orders in a basin to the area of the basin. Drainage density is a textural measure of a basin which is generally independent of basic size. It is considered to be a function of climate, lithology, and stage of development. Numerically, this ratio expresses the number of miles of channel maintained by a square miles of drainage area.

(*c*) *Constant of channel maintenance* :—Constant of channel maintenance is defined as the ratio between the area of a drainage basin and the total length of all the channels axpressed in square feet per foot or square metre per metre. It is equal to the reciprocal of the drainage density.

The importance of this constant is that it provides a quantitative expression of the minimum limiting area required for the development of a length of channel.

(*d*) *Channel segment frequency* —Channel segment frequency (stream frequency) is defined as the number of streams per unit area in a drainage basin. Horton suggested that the composition of a drainage basin provided a more adequate characterization of a stream than did drainage pattern. His "composition" was completely describad using the two textural measures of drainaga density and stream frequency.

(*e*) *Circularity ratio* :—Basin circularity ratio is defined as the ratio of the basin area to the area of a circle having a circumference equal to the perimeter of the basin. The value of this ratio approaches one as the shape of the basin approaches a circle.

(*f*) *Elongation ratio* : Elongation ratio of a basin is defined as the ratio between the diameter of a circle with the same area as the basin and the basin length. The value of the elongarion ratio approaches one as the shape ot a drainage basin approaches a circle.

(*g*) *Watershed shape factor* : Watershed shape factor is defined as the ratio of the mainstream length to the diameter of a circle having the same area as the Watershed.

(*h*) *Unity shape factor* : Unity shape factor is defined as the ratio of the basin length to the square root of the basin area.

9 2.3 Relief aspects of catchments and channel networks

The elevation difference between two points in a watershed or along a stream is a very significant variable in the hydraulics of the flow of water from the watershed. The slope is related to rate at which the potential energy of the water at high elevation in the headwaters of the catchment is converted to kinetic anergy. Losses in various form occur in the process. Water is held in storage and the travel time in the hydrologic system is in general inversely related to the slope.

Slope data for drawing the stream profile diagram are obtained dividing the measured channel distance between intersections of the channel counterline and successive stream crossing of the contour's map-by the corresponding contour interval. Some of the methods of measurement described in section 9.2.1 (a) regarding distance measurement are adaptable for the measurement of distance of channel between the two successive contours. The "paper strip", "Opisometer" and "Analog to Digital Converter" methods are particularly suited for this purpose.

The parameters involving relief aspect of catchments and channel net works are as follows :

(*a*) *Basin relief* : Relief of a basin is the maximum vertical distance from the stream mouth to the highest point on the divide. The total relief of a basin is a measure of the potential energy available to move water and sediment downslope.

(*b*) *Relief ratio* : The Relief ratio is defined as the ratio between the basin relief and the basin length. In normally shaped basins the relief ratio is a dimensionless height-length ratio equal to the tangent of the angle formed by the intersection at the basin mouth of a horizontal plane with a plane passing through the highest point on the divide. This parameter permits comparision of the relief of the two basins without regard to the scale of the toposheet.

(*c*) *Relative relief* : Relative relief is defined as the ratio of the basin relief, expressed in units of miles, to the length of the perimeter. Relative relief is an indicator of the general steepnes- of a basin from summit to mouth. It has an advantage over the relief ratio in that it is not dependent on the basin length which is a questionable parameter in oddly shaped basins.

(*e*) *Ruggedness number* : The product of drainage density and relief, both in the same units, is called as the ruggedness of a basin. Areas of low relief but high drainage density are thus as ruggedly textured as areas of higher relief having lass dissection.

(*e*) *Taylor and Scharwtz slope* : Taylor and Schwartz (1938) described the slope of the main channel in parts per 10,000. Here the channel was treated as series of lengths (l) of approximately uniform slope (s), whose time of flow was taken as being proportional to ($l/\sqrt{s}$). The slope of the channel (TS) was given by $L/\sqrt{TS} = \Sigma\ (l/\sqrt{s})$ ....(9.10)

here TS is the slope

of a uniform channel of the same length and time of flow as the actual length (Fig. 9.2).

(*f*) *Nash's measure of slope :* Nash (1960) defined another measure of slope, where the profile of the main channel having been plotted from the gauging site to the catchment boundary, a straight line was drawn through the gauging station so as as to form a triangle with the horizontal through the gauging station and the vertical through the highest point of the main channel. Further the slope of the line being so chosen that the area of the triangle was equal to the area contained by the horizontal, the vertical and the channel profile as shown in Fig. 9.2. When the main channel consisted of two branches more or less of equal catchment the channel slopes were taken as the means of the two values calculated separately and weighted with the appropriate catchment area.

(*g*) *Nash's measure of overland slope* : Nash (1960) defined another measure of slope that is known as the overland slope. For this a grid of rectangular mesh is drawn on the $2\frac{1}{2}$ in map of the catchment, the mesh being such that about 100 intersection occured within the catch-

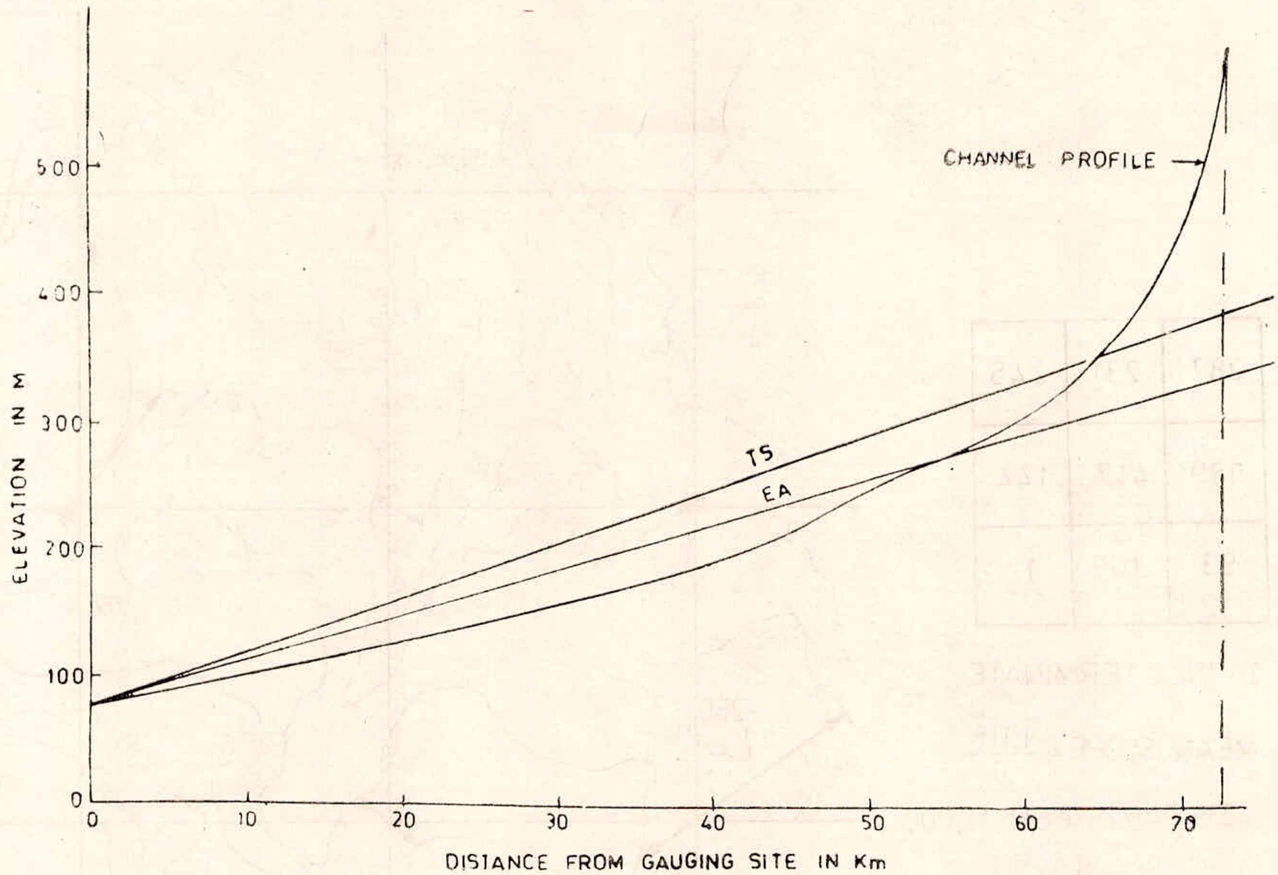


Fig. 9.2 Main Channel Slope

ment boundary. At each intersection the minimum distance between adjacent contours (Fig. 9.3) is measured and the slope at each point is taken as contour interval divided by this distance. This provided a set of slope values, of which the mean is calculated and taken as overland slope When an intersection occurred at a point between two contours of the same value the slope is taken as zero if the point is in valley and as indeterminate if on a hill. The latter is neglected in calculating the mean.

(*h*) *Co-efficient of variation of the square root of the overland slope* : This measure was suggested by Nash (1960). Here the mean and standard deviation of the square roots of the values of the overland slope at the intersections of the grid are calculated and the co-efficient of variation is taken as the standard deviation divided by the mean. This is the measure of the variation of the overland slope of the catchment.

9.2.4 Effects of forests and agricultural land uses on unit hydrograph

It has been recognized for some time that the vegetation cover influences a number of components in the hydrologic cycle. These components include direct interception of a part of precipitation by vegetation, reduction of evaporation from soil, increase of infiltration by

287	231	245
189	417	144
93	309	I

I - INDETERMINATE

MEAN SLOPE = $\frac{1915}{8}$

≈239 PARTS PER 10,000

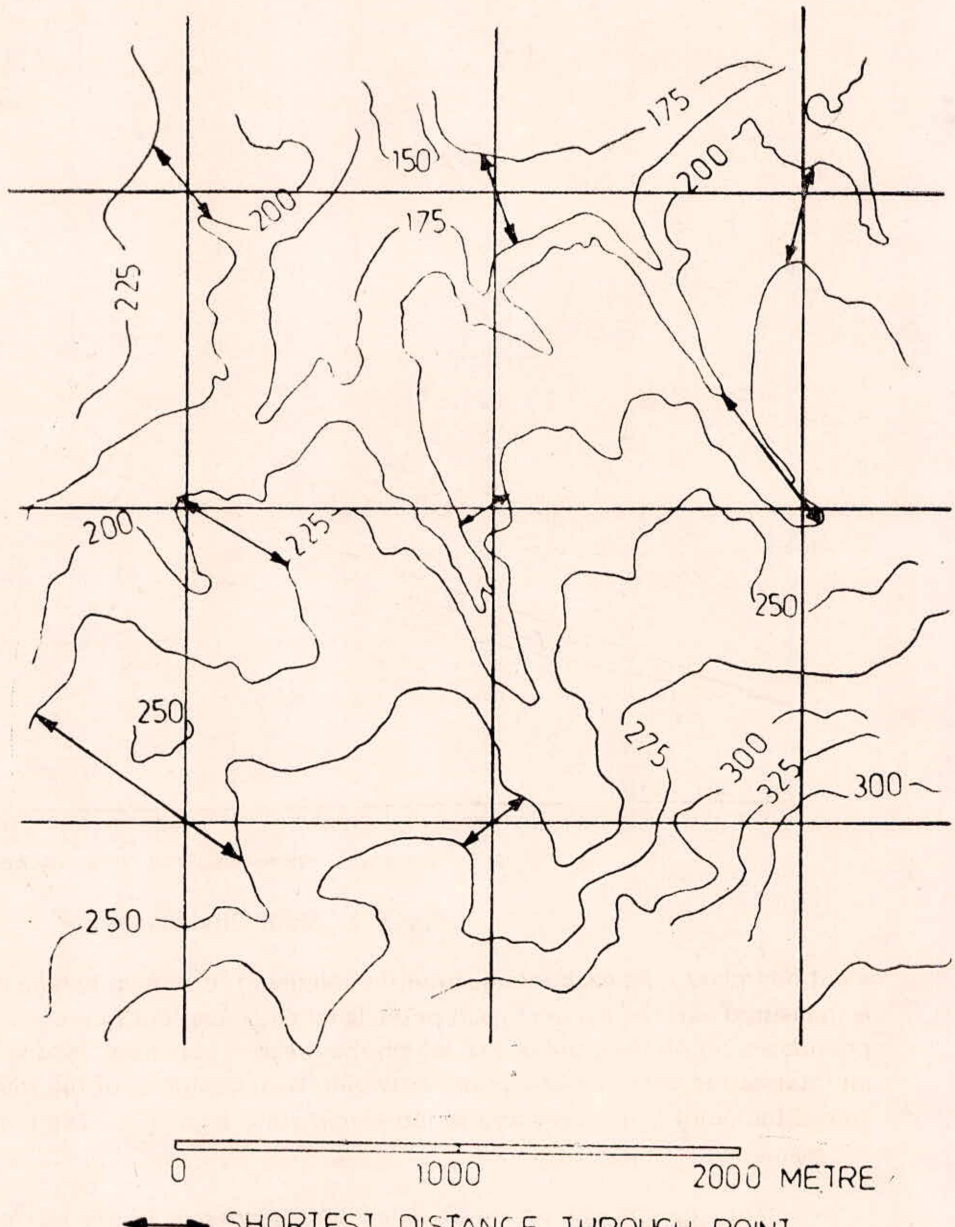


Fig. 9.3 Method of obtaining O.L.S. of Catchment

poening up soil channels through development of roots, depletion of soil moisture by evapotranspiration, trapping and shadding of snow pack, binding the soil against erosion, factors affecting the hydraulic characteristics of overland flow and so forth.

Forested catchments are predominantly covered by deciduous or coniferous trees associated with other small trees shrubby species and grass land. Soils under undisturbed forests have characteristics that are favourable for infiltration, such as porous channels caused by roots and activity by soil organisms, organic matter in the surface layers, and uccumulation of organic debris. Forest vegetation has deep root zone development that increases the amount of detained water in the soil storage. They reduce the overland flow and affect the surface runoff hydrograph resulting from storm rainfall. The removal of forest vegetation affects interception, snowmelt, soil moisture and infiltration rate, and increases the total runoff. The amount of increased surface runoff and peak flow caused by heavy rainstorm of the forested catchments, whose vegetation has been removed, vary according to the rainstorm and catchment characteristics.

Agricultural catchments are mainly covered by small plants, crops and harbaceous vegetation, which have shallow root zone, and intercept lessor amounts of precipitation than forest trees (Chow (1964)). Agricultural areas possess smaller water storage capacities. A larger surface runoff is expected from high intensity rainfall. The runoff from agricultural catchments is regarded sometimes as nonvirgin flow, because it is influenced by man's works, such as land use practices, farm practices, and small water diversions. The study of the effects of vegetation cover and land use practices, especially the use of terraces in conjunction with rotation contour cropping, on peak flows of short return period floods from small agricultural catchments indicates that they decrease the number and the average magnitude of peak flows.

9.2.5 Effect of Urbanization on Unit Hydrograph

The unit hydrograph characteristics and loss rate parameters are to be modified to predict runoff that would occur because of future changes within a watershed such as Urbanization. More peak flow and less lag time are expected in an urbanized catchment due to increase in impervious area causing significant reduction in loss rate.

9.3 CLIMATIC FACTORS

The climatic factors which influence the unit hydrograph are :

(*i*) *Nature of precipitation (rain, snow sheet) :* The effect of a rainfall event is felt immediately but that of snow may be delayed for months. The eventual release of water from snowmelt is usually much more gradual than from a fall of rain, because of the delays in the snowpack and diurnal temperature variations. The snowmelt hydrographs tends to have a lower peak and to extend over a longer period of time.

(*ii*) *Rainfall intensity* : The surface runoff occurs only if the rainfall intensity exceeds the infiltration loss.

(*iii*) *Duration of rainfall* : The rainfall intensity and duration of rainfall are obviously the mosr important climatic factors which effect the catchment response.

(*iv*) *Areal distribution of rainfall* : The areal distribution of a rainfall events affect the shape of the hydrograph. High intensity rain near the outlet lead to a rapidly rising and falling hydrograph with a sharp peak. Rainfall which is mainly concentrated in the upper reaches of the catchment producs a lower peak which occurs later, and a broader hydrograph. If all other conditions remain uniform throughout the catchment, a uniformly distributed rainfall will produce the minimum peak discharge. The more non uniform the rainfall distribution the greater will be the peak discharge. The distribution co-efficient, which is the ratio of the maximum point rainfall to the average rainfall over the catchment is frequently used as an index.

(v) The Distribution of rainfall with time ; The parameter is significant on small catchments. On large catchments, the equalizing effect make the hydrograph insensitive to rainfall distribution with time.

(vi) Direction of storm movement : The direction of storm movement has the greatest effect on elongated catchments. It is obvious that the same amount of rain over the same period produces much greater peak when the storm is moving down the valley. The rainfall from a storm moving up the valley becomes runoff long before the storm reaches the top of the catchment.

9.4 PARAMETERS OF UNIT HYDROGRAPH OR ITS MODEL

9.4.1 Unit Hydrograph parameters

The following parameter are considered by many investigators for describing the shape of the representative unit hydrograph :

(i) t_p = Time from the centre of unit rainfall duration to the peak of the unit hydrograph in hours.

(ii) Q_p = Peak discharge of unit hydrograph in cubic meters per second.

(iii) t_r = Unit rainfall duration adopted in a specific study.

(iv) T_B = Base width of unit hydrograph in hours.

(v) W_{50} = Width of unit hydrograph measured at discharge ordinate equal to 50% of Q_p in hours.

(vi) W_{75} = Width of unit hydrograph measured ar discharge ordinates equal to 75% of Q_p in hours.

(vii) WR_{50}= Width of the rising side of unit hydrograph measured in hours at discharge ordinate equal to 50% of Q_p

(viii) WR_{75}= Width of the rising side of unit hydrograph measured in hours at discharge ordinate equal to 75% of Q_p

A typical unit hydrograph describing the above parameters are shown in Fig. 9.4.

9.4.2 Parameters for Conceptual Models of IUH

(i) Clark Model : Clark (1945) suggested a procedure to derive instantaneous unit hydrograph by routing the time area diagram of the catchment having base length equal to time of concentration of the catchment through a single linear reservoir. Therefore, the method requires knowledge of two quantities, T_c and R in addition to the time area diagram of the catchment. Here, T_c and R are time of concentration and storage co-efficient in hours respectively. The time aree curve can be derived using the topographical characteristics of the catchment. Thus, the two parometers T_c, and R, are required to estimate the instantaneous unit hydrograph by this approach.

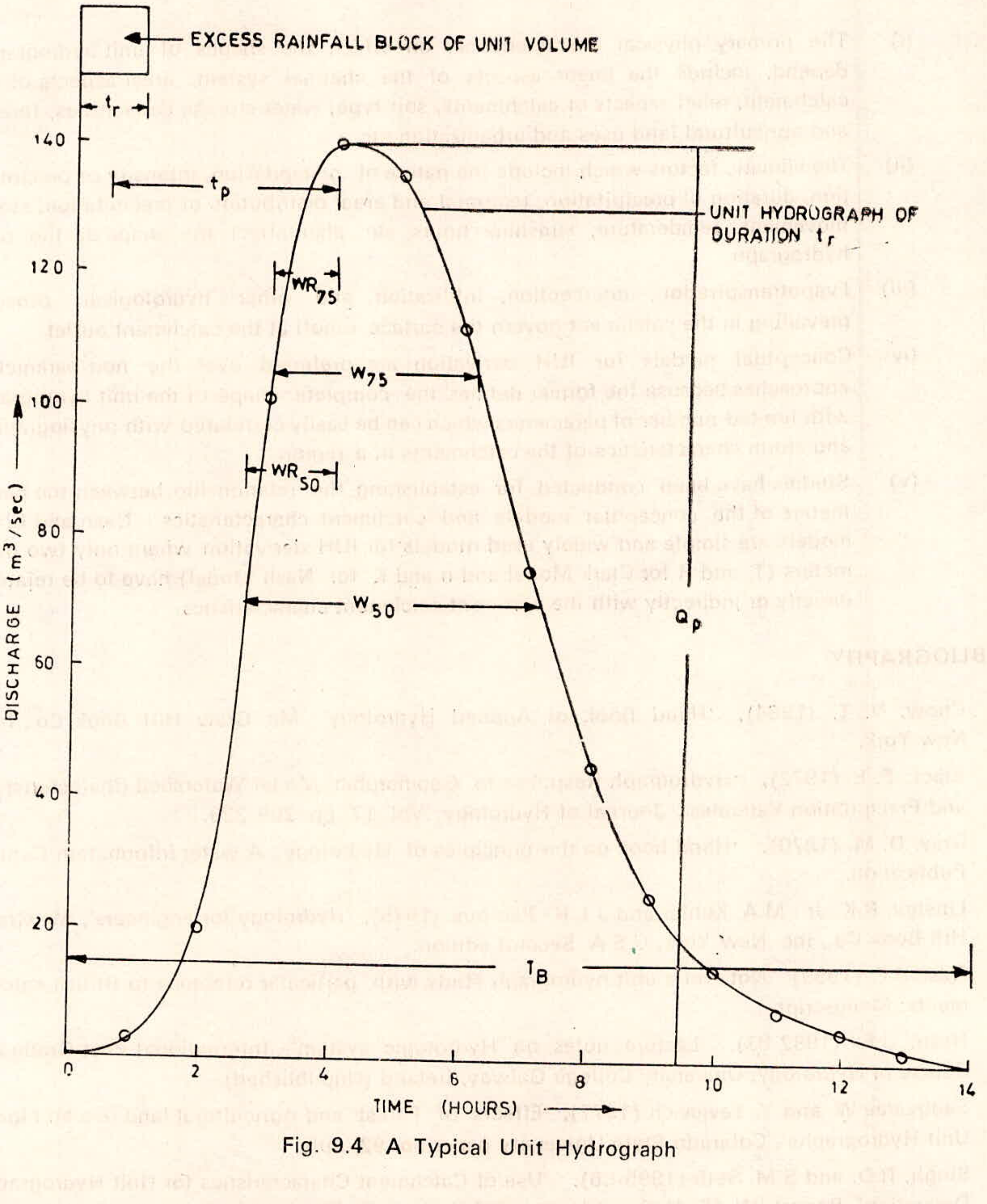


Fig. 9.4 A Typical Unit Hydrograph

(*ii*) *Nash Model* : Nash (1957) derived the IUH by routing the unit impulse input through n linear reservoirs of equal storage co-efficient K. Therefore, the two parameters n and K define the complete shape of IUH.

9.5 SUMMARY

(i) The primary physical characteristics, on which the shapes of unit hydrographs depend, include the lineor aspects of the channel system, areal aspects of the catchment, relief aspects of catchments, soil type, water storage capabilities, forests and agricultural land uses and urbanization etc.

(ii) The climatic factors which include the nature of precipitation, intensity of precipitation, duration of precipitation, temporal and areal distribution of precipitation, storm movement, temperature, sunshine hours etc. also affect the shape of the unit hydrograph.

(iii) Evapotranspiration, interception, infiltration and other hydrological process prevailing in the catchment govern the surface runoff at the catchment outlet.

(iv) Conceptual models for IUH derivation are preferred over the non-parametric approaches because the former defines the complete shape of the unit hydrograph with limited number of paramerers which can be easily correlated with physiographic and storm characteristics of the catchments in a region.

(v) Studies have been conducted for establishing the relationship between the parameters of the conceptual models and catchment characteristics. Nash and Clark models are simple and widely used models for IUH derivation where only two para meters (T_c and R for Clark Model and n and K for Nash Model) have to be related, directly or indirectly with the pertinent catchment characteristics.

BIBLIOGRAPHY

1. Chow, V. T. (1964), 'Hand Book of Applied Hydrology', Mc Graw Hill Book Co., Inc. New York.
2. Black, P. E. (1972), 'Hydrograph Response to Geomorphic Model Watershed Characteristics and Precipitation Variables', Journal of Hydrology, Vol. 17, pp. 309-329.
3. Gray, D. M. (1970), 'Hand book on the principles of Hydrology', A water information Centre Publication.
4. Linsley, R.K. Jr , M.A. Kohler and J.L.H. Paulhus (1975), 'Hydrology for engineers', Mc Graw Hill Book Co., Inc. New York, U.S.A. Second edition.
5, Nash J.E. (1959). 'Note on a unit hydrograph study with particular reference to British catchments; Manuscript.
6. Nash, J.E, (1982-83). 'Lecture notes on Hydrologic system', International Post Graduate Course in Hydrology, University College Galway, Ireland (Unpublished).
7. Sangvaree W. and V. Yevjevich (1977), 'Effects of Forest and Agricultural land use on Flood Unit Hydrographs', Colarado State University paper no. 92, July.
8. Singh, R.D. and S.M. Seth (1995-86), 'Use of Catchment Characteristics for Unit Hydrograph Derivation', Report RN-15, National Institute of Hydrology, Roorkee.
9. Singh, R.D. and S.M. Seth (1985-86). 'Regional Unit Hydrograph', Report RN-17, National Institute of Hydrology, Roorkee (U.P.).