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HYDROGEOMORPHOLOGICAL STUDY OF BAIRA NALLA SUB-CATCHMENT (H.P.)

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WESTERN HIMALAYAN REGIONAL CENTRE
NATIONAL INSTITUTE OF HYDROLOGY
BELICHARANA, SATWARI
JAMMU CANTT - 180 003

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PREFACE

Defining run - off response i.e. relative concentration and timing of run - off in watersheds in quantitative expressions has been the concern of hydrologists. In the prevailing situation that in most of the basins and sub - basins few precipitation measurement stations and even fewer discharge sites exist, the relationships describing run - off process remain mostly as the guess work or crude empirical statements. Various investigators considered and showed that measurable basinal properties or geomorphological characteristics of a basin describing its linear, areal and relief aspects can reflect the hydrological properties also. This has helped many to simulate flow, synthesize hydrograph and regionalise model parameters for an ungauged catchment from the results of gauged catchments. Derivation of Geomorphologic Instantaneous Unit Hydrograph has helped renewed research in hydrogeomorphology. Though many successful uses of these basin characteristics in hydrologic analysis have been documented, substitution of these results for more traditional tool is open to view as yet.

While reviewing the various works and elements about application of quantitative gecmorphology in hydrology, the report attempts to quantify some of the important hydrogeomorphological parameters of Baira nalla sub-basin within Western Himalayan Region, as component part of its long term representative studies taken up by the regional centre, NIH, Jammu since 1991-92. In absence of existing net work of hydrometeorological observation and sufficeent informations for hydrologic research, these estimated basin descriptors should be helpful to synthesise some system parameters.

The report has been prepared by **B C PATWARY**, Scientist E & **Kamal Kumar**, SRA and assisted by Puran Singh, RA.

(S M SETH)
DIRECTOR

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Geomorphology is the science of evolution of land forms in terms of its lithology, structure, basin geometry and other morphometric factors. Of interest to hydrology, the measurable geomorphological descriptors of basinal properties grouped under linear aspect of channel network, areal aspect of basin and relief aspect of channel system and basin form are regarded to have potential to describe hydrological properties of the basin. Therefore, faced with the common problem of non availability of hydrometeorological data for hydrologic simulation of run - off process, specially in ungauged catchment, various investigators have used these basin parameters to synthesize flow hydrographs. The relationships developed between characteristics of quantitative geomorphology of drainage basin and parameters of an instantaneous unit hydrograph have encouraged the hydrologists to look more and more into such physical and geomorphological properties of drainage basins. Introduction of Geomorphological Instantaneous Unit Hydrograph has since led to the renewal of research in hydrogeomorphology.

While reviewing the various application of hydrogeomorphologic parameters in hydrologic studies it has been attempted to estimate the geomorphological characteristics of Baira Nalla sub - basin in this report. The Baira Nalla, a Western Himalayan river of Indus system and a tributary of Ravi, has vast potential of water resources development and calls for comprehensive hydrologic studies. In view of paucity of data the geomorphological parameters estimated in the report extend scope to carry out further studies and reagionalise the results.

1.0 INTRODUCTION:

Drainage basins are created, shaped and structured by nature in some orderly manner and it exhibits interdependence of hydrogeoclimatic factors and soil vegetation complexes. Hydrologists and earth scientists in their effort to understand and synthesize hydrologic response of such basins have started looking into its morphologic or topographic features and establish connection of fluvial geomorphology to hydrology. Geomorphology, the science of evolution of land forms in terms of lithology, structure , climate & other climatic factors , had been mostly qualitative in its initial stage. Now geomorphologic efforts have come out of past trend and with the rational relation between the" ensemble" average response of a basin with given geomorphologic properties established, greater need for quantitative information is felt for. To evaluate or predict the run-off response of a river basin hydrologists are faced with the vexed problem of non availability of flow- precipitation data. Therefore, measurable basinal features of drainage network which have been considered and shown to have potential to describe some of the hydrograph parameters of the ungauged system have encouraged hydrologists for hydrologic simulation and applying relationships developed for gauged basins at ungauged basins through hydrograph synthesis.

The geomorphological characteristics which relate to hydrology, as suggested by many investigators, consist of linear aspect of channel system dealing with one dimensional overland flow lengths & length of streams etc, aereal aspect of catchment relating to basin shape, drainage, texture etc. and relief aspect of channel network/catchment describing elevation difference etc. The first two categories of measurement are planimetric (i.e.treat properties projected upon a hydrological datum plane) and the third category treats the vertical inequalities of the drainage basin form. Some typical catchment characteristics have also been identified which will be useful to derive unit hydrograph for the catchment. Some of the studies where quantitative geomorphological characteristics have been applied to describe hydrologic properties such as run- off response or flow hydrograph etc. are as follows:

- Development of empirical formula using geomorphological parameters.
- Regional Unit Hydrograph Studies
- Regional Flood Frequency Analysis
- Development of Geomorphological Instantaneous Unit Hydrograph
- Hydrologic modeling studies.

The report attempts to estimate the various geomorphological characteristics of Baira river sub basin within Western Himalayan Region with the help of established laws and procedures and using survey of India map of scale 1:50,000. In absence of existing network of hydrologic observation sites in the area, the geomorphological parameters derived for the basin may be used for further hydrologic studies. Regional Centre, NIH, Jammu, in consultation with the Govt of H.P., has also since taken up long term representative studies at Baira Nalla Sub-basin.

2.0 REVIEW:

To understand the laws of run off processes in a watershed hydrologists have been faced with many problems specially in respect of ungauged catchments where hydrological data are rarely available. Many approximate formulae, usually crude empirical statements, have been developed to relate precipitation with flow. For ungauged basins it has been the endeavor to quantify geomorphological parameters of naturally shaped river basins to its hydrologic response characteristics.

Horton (1932,1945) pioneered the hydromorphometric analysis of drainage basin and provided a rational and systematic base, rather a framework of outline of geomorphological characteristics to relate them to various hydrological properties of the system. His works were pursued by many investigators like Langbein et al. (1947), Strahler (1952, 1056, 1957, 1964), Melton (1957), Schumm (1956) , Chorley(1957), Miller (1953) and so on. These works have brought forward many laws of fluvial geomorphology connected to hydrology and study of geomorphological characteristics of river basins has become a major area of scientific research for hydrologists throughout the globe.

Hydromorphometric studies in quantitative terms are very few in Himalayan Region where the present study area is situated. Shukla and Verma (1975) studied morphometry in relation to slope development in sub Himalayan Siwalik ranges of Dehradun valley and similar study followed at Western part of it by Prasad and

Verma (1975) . Mithal et al. (1974, 1982) carried out hydromorphometric studies in Garhwal Himalayas and morphometric elements like stream length, length ratio, basin area, basin relief etc. were related to rock types. Roohani and Gupta (1988) studied some relationships between hydromorphometric parameters like stream order vs number, stream order vs mean stream length, stream order vs mean drainage area, stream order vs channel slope etc. and inferred that the channel network lacked morphometric similarity or steady state for which the hydromorphometric relations exhibited deviations from the widely established and accepted norms. Patwary and Kumar (1993) carried out hydrogeomorphological Study for Tawi Basin and estimated various parameters of linear, aerial and relief aspects with a view to develop Geomorphological Instantaneous Unit Hydrograph (GIUH) for the basin. Some of the works carried out by National Institute of Hydrology, Roorkee India have been described at the end of this section.

Geomorphological characteristics and their use in various hydrologic studies, presently of interest to scientists and water resources managers are described briefly below:

2.1 Empirical Relationships Based on Basin Characteristics:

In the absence of precipitation and flow data empirical relationships based on basin characteristics have been used in many parts of the world since nineteenth century to estimate flow expectations from different drainage networks. Some of such relationships are discussed in para 2.7.1. These statements are very simple but crude and have many limitations in their applicability. This calls for in depth knowledge of hydrological process and physical characteristics of the basin where they were developed so that the results can be transformed elsewhere.

2.2 Geomorphological parameters for Unit Hydrograph Studies:

Unit hydrograph studies have been very useful for flood estimation. For ungauged catchments, peak flow and run off hydrograph can be synthesized with the help of unit hydrograph of a gauged catchment and its known basin characteristics. Effect of drainage basin characteristics upon unit hydrograph lag and peak flow has been reported by Taylor & Schwartz (1949) using the data of 20 basins ranging area from 20 to 1600 sq. miles and located in North and Middle Atlantic states. Drainage area, length of the main stream , mainstream length to the centroid of catchment and equivalent main stream slope were regarded as the most significant variables(4)

In India, the Central Water Commission conducted studies to develop regional unit hydrograph in 26 hydrometeorological sub zones covering whole of India. All the major storms for the gauged stations were analyzed and derived unit hydrograph parameters were related to physical characteristics of the basin so that regional unit hydrographs can be developed for each sub zone.

2.3 Regional Flood Frequency Analysis:

To estimate design flood of certain frequency historical flood records are often not available at site .For the ungauged site regional flood frequency analysis may be done using only the regional information in the form of regional frequency curve together with an estimate of mean annual flood obtained from the appropriate relationship established between the mean annual flood and geomorphological characteristics for the hydrological homogeneous regions . Mean annual flood may be influenced by catchment area, stream flow, land slope, stream density and relief aspects of the basin.

U.S. Geological survey carried out such study and published a manual under Geological Survey Water Supply paper. 1543-A by T. Dalrymple (1960) . Nash (1966) analysed discharge records of 57 catchments of Great Britain and parameters of the frequency distribution of annual maximum flood peaks were correlated with the catchment area, slope and mean annual rain fall of the catchment (24).

2.4 Geomorphological Instantaneous Unit Hydrograph (GIUH):

Rodriguez and Valdes (1979) first introduced GIUH which led to the renewal of research in hydrogeomorphology. The concept was restated by Gupta et al. (1980) (2) . For GIUH fully analytical and complicated expressions for complete shape of IUH were derived. Hence they suggested that it is adequate to assume a triangular IUH specifying peak time and peak flow.

In summary the IUH is a function of the probability that a drop , initially falls in an area that drains to channel of given order , the transition probabilities from a stream of one order to another that are functions of the basin's geomorphologic characteristics Ra & Rb , and travel time distribution in streams of a given order. Initial and transition probabilities provide a probabilistic description of the drainage network and a link between quantitative geomorphology and hydrology (2) :

For the simplified triangular IUH:

$$QP = \frac{1.31}{LW} Rl^{0.43} * V \qquad (2.1)$$

$$TP = \frac{0.44\ LW\ Rb^{0.55}}{V.Ra^{0.55}} Rl^{-0.38} \qquad (2.2)$$

Where :

QP = Peak, given in units of inverse hours

TP = Peak time in hours.

LW = Length in km of highest order stream

V = Expected peak velocity in m/sec.

Ra = Area ratio

Rb = Bifurcation ratio

Rl = Length ratio

Fig. 1 & Fig. 2 show how the geomorphologic instantaneous unit hydrograph changes with parameters . Clearly there is wide variation of shapes of GIUH.

2.5 Geomorpho-Climatic IUH:

Due to difficulty that GIUH is dependent on peak velocity 'V' Rodriguez - Iturbe et al. (1982) rationalized that V must be a function of the effective rainfall intensity and duration and proceeded to eliminate 'V' from the results .Two important restatement of QP and TP were given as below :

$$QP = 2.42 \frac{Ir.Aw.Tr}{II_i^{0.4}} \left(1 - \frac{0.218\ Tr}{II_i^{0.4}} \right) \qquad (2.3)$$

$$tp = 0.585\ II_i^{0.4} + 0.75\ Tr \qquad (2.4)$$

Where

AW = Basin area of order W

Ir = Mean effective rainfall intensity

Tr = Duration of time

$$II_i = \frac{LW^{2.5}}{Ir.Aw.Rl.Lw^{1.5}} \qquad (2.5)$$

$$LW = \frac{1}{n.bw^{2/3}} SW^{1/2} \qquad (2.6)$$

bw = Mean width of main stream

sw = Mean slope of main stream

n = Manning's roughness co-efficient

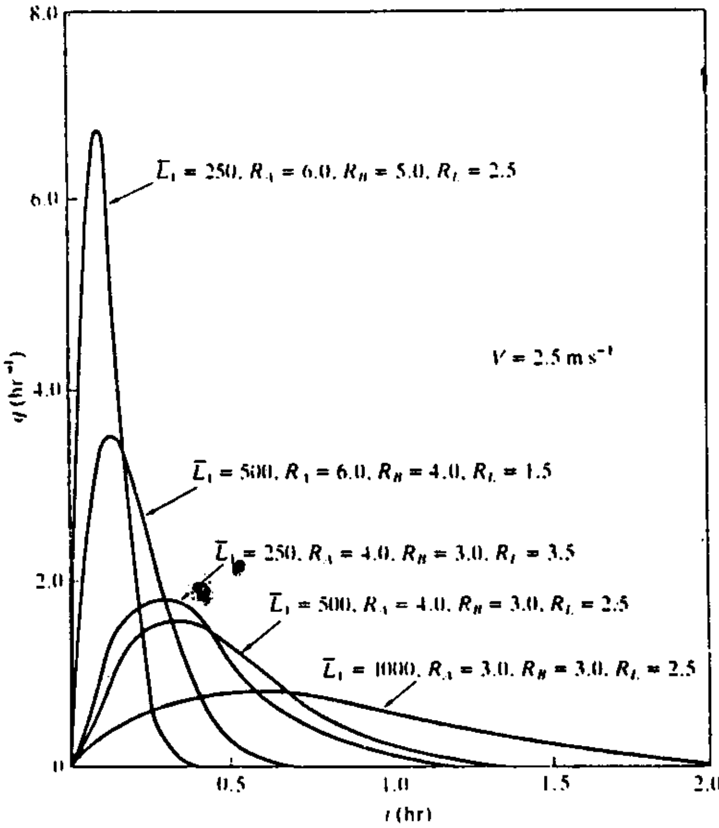


FIGURE 1. Changes in the geomorphologic instantaneous unit hydrograph when the velocity is kept constant and geomorphologic properties vary. Source: I. Rodriguez-Iturbe and J. B. Valdes, "The Geomorphologic Structure of Hydrologic Response," *Water Resources Res.* 15(6):1409–1420, 1979.

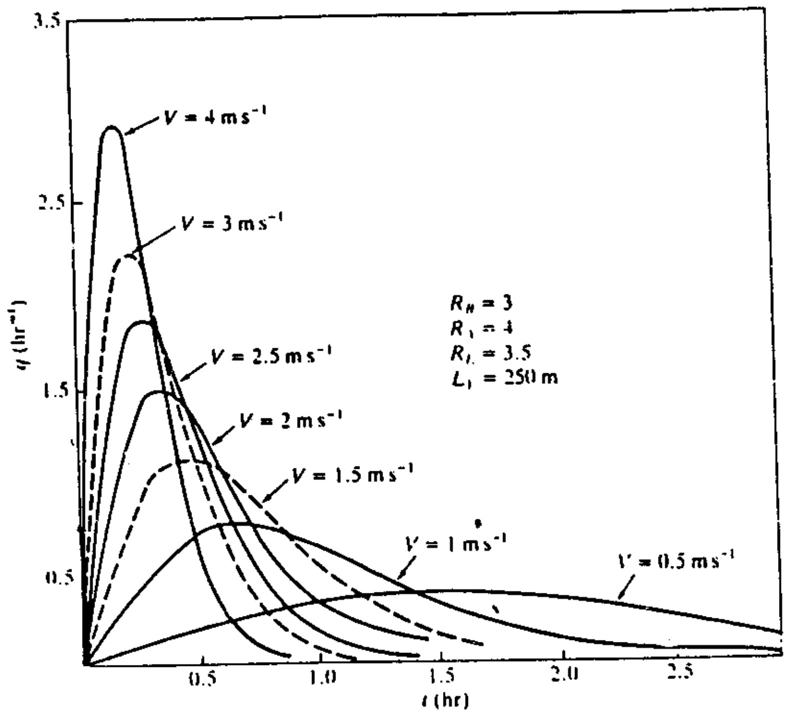


FIGURE 2. Changes in the geomorphologic instantaneous unit hydrograph when the geomorphologic characteristics are kept constant and the velocity varies. Source: I. Rodriguez-Iturbe and J. B. Valdes, "The Geomorphologic Structure of Hydrologic Response," *Water Resources Res.* 15(6):1409–1420, 1979.

The above two equations imply a rainfall - run-off relationship that is not dependent on calibration with input output data and is theoretically only dependent on geomorphologic and climatic data, hence the name geomorphoclimatic instantaneous unit hydrograph (2).

2.6 Derivation of Nash Model Parameters from QP & tp of GIUH:

For the derivation of the complete shape of GIUH, the scale (k) and shape (n) parameters have been linked with qp and tp of GIUH. Nash(1957) had proposed a conceptual model in which catchment impulse response (IUH) can be represented as the outflow from routing the unit volume of instantaneous excess rainfall input through a series of 'n' number of successive linear reservoirs having equal delay time or storage co-efficient. The equation of IUH for Nash's model is given as:

$$U(O,t) = \frac{1}{K}\,\frac{1}{Z\,n}\,.\,e^{-t/k}\,.\,(t/k)^{n-1} \qquad (2.7)$$

Where,

$U(O,t) = t^{th}$ ordinate of IUH (of duration O)

Z = Gamma function.

K = Storage co-efficient

n = no. of Linear reservoirs

Equating first derivative w.r.t. time 't' to zero then t become peak time tp and we get:

$$t = t_p = (n-1).k \tag{2.8}$$

Substituting $t = t_p$ in eq. (2.7) we get,

$$U(0,t)_{peak} = Qp = \frac{1}{k}\frac{1}{Z n} . e^{-(n-1)} .(n-1)^{n-1} \tag{2.9}$$

From eqns. 2.8 & 2.9

$$Qp.tp = \frac{(n-1)}{Z n} . e^{-(n-1)} .(n-1)^{(n-1)} \tag{2.10}$$

This eqn. is function of Nash Model parameter 'n' only.

Again multiplying eqns. 2.1 & 2.2 we get:

$$Qp.tp = 0.5764 \left(\frac{Rb}{Ra}\right)^{0.55} . Rl^{0.05} \tag{2.11}$$

Equating 2.10 & 2.11,

$$\frac{n-1}{Z n} . e^{-(n-1)} .(n-1)^{(n-1)} = 0.5764\left(\frac{Rb}{Ra}\right)^{0.55} Rl^{0.05} \tag{2.12}$$

In eqn. (2.12) all terms on R.H.S. are known. The Nash Model Parameter n is obtained by solving the eqn. 2.12 using Newton Raphson method of non linear optimization. The parameter 'n' when substituted in the following equation for a given velocity 'v' the value of k(inversely proportional to 'v') can be obtained.

$$k = \frac{0.44\ LW}{v} . \left(\frac{Rb}{RA}\right)^{0.55} .Rl^{-0.38} .\frac{1}{(n-1)} \tag{2.13}$$

Now with 'k' and n evaluated complete shape of IUH can be derived from eqn. (2.7) (14) .

Rosso (1984) found the following empirical relations between the Nash Model and the GIUH

$$n = 3.29(Rb/Ra)^{0.78} \, Rl^{0.07} \quad (2.14)$$

$$k = 0.70\,(Ra/(Rb.\,Rl))^{0.48} .V^{-1} .L \quad (2.15)$$

Where L is the length of highest order stream and V is the average cross sectional velocity at the out let during peak flow(15).

2.7 Hydrogeomorphological Parameters:

Keeping in view of the above specialised application of geomorphological characteristics to hydrology, the report attempts to derive some of the important morphometric parameters of the study area. The parameters considered for analysis in the report and various findings & applications related to them have been discussed and reviewed in chapter 5. Some more such other parameters reported by various investigators are reviewed below:

2.7.1 Length Area Relationship:

P.S. Eagleson (1970) developed relationship between mainstream length (L) and Basin Area 'A' (Fig.3) as

$$L + 1.40.\,A^{0.568} \quad (2.16)$$

The ratio A/L^2 is not constant for all basins which implies that geometrical similarity is not fully preserved for the basins. The fig.3 gives geometrically similar fit as:

$$L = 1.73.A^{0.5} \quad \text{or} \quad \frac{A}{L^2} = \frac{1}{3} \quad (2.17)$$

One of the possible explanations may be larger basins are more elongated than smaller basins since the ratio $A/(L)^2$ falls as area increases.

2.7.2 Width Function, N (x) :

Surkan (1968), Calver et al. (1972), Kirkby (1976) Gupta et al. (1986), Troutman & Kartinger (1986) showed that the width function N (x) which measures the number of links at a given distance x from outlet, has significant effects on hydrograph shape and peak. Assuming a basin as in Fig. 4 with behaviour that travel time of water is same for each link, if 19 drops of water (like balls) are released at heads of 19 links, the number of drops reaching the outlet at each time interval is given by width function. In this, It is the IUH, which is nothing but the distribution of travel time of water to the outlet when unit amount of water is applied uniformly over the basin instantaneously. the length x may be geometric or straight line distance between nodes, the actual or topologic length.

However, in practice travel time in each link of different lengths cannot be the same and IUH is derived relating travel time with geomorphologic characteristics.

2.7.3 Link Concentration Function, N (h):

Mesa (1986) and Gupta et al. (1986) used this function to see if there is any relation between run-off sediment yield and basin elevation. Analogous to width function. link concentration

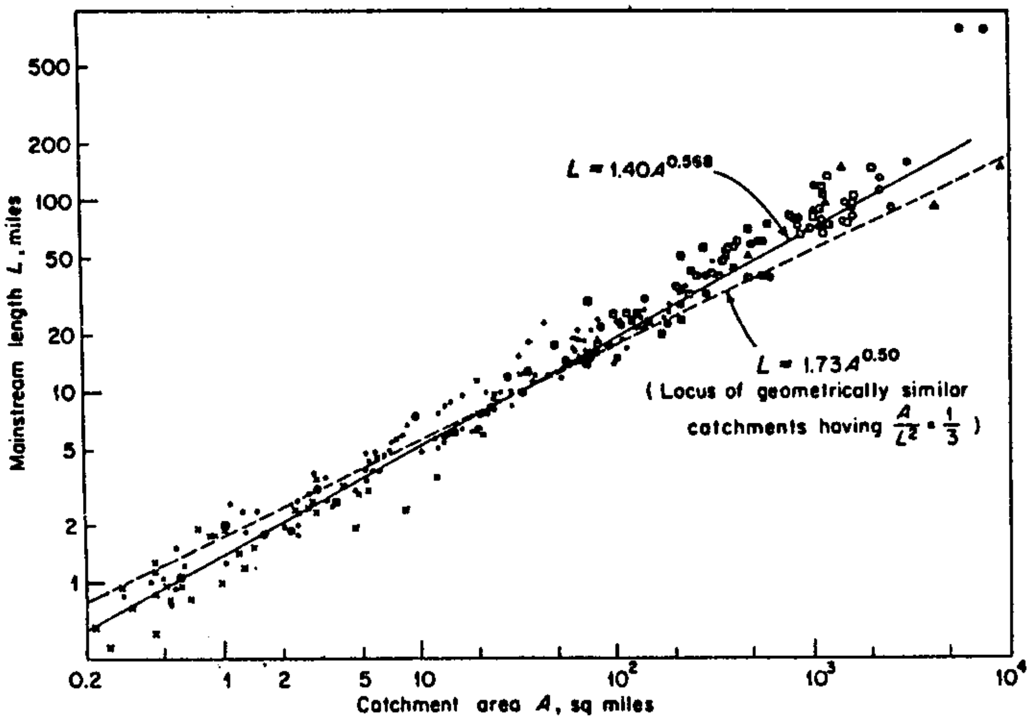


FIGURE 3 Relationship between catchment area and catchment length. Source: P. S. Eagleson, *Dynamic Hydrology*, McGraw-Hill, 1970.

function N (h) for O<h<H, measures the number of links in the network at elevation h i.e. the number of links cut by a particular contour line. Fig.5 shows N(h) for a basin . Like hypsometric curve (discussed later) which describes elevation relative to area, the link concentration function describes elevation relative to channel net work (2).

2.7.4 Relief Ratio and Sediment Yield:

Schumm found that sediment loss per unit area is closely correlated with relief ratio as experimented in small drainage basins in six localities of the Colorado Plateau Province with resistant rock like conglomerate & sand stone and weak rocks like friable sand stone & shale. The significant regression with small scatter suggests that relief ratio may prove useful in estimating sediment yield if the appropriate parameters for a given climatic province are established (4)

2.7.5 Law of stream slope & slope Ratio (Rs):

It is clear that the average slope of channel segments of a given order will be less than that of next lower order but will be higher than that of next higher order. Horton (1945) expressed this relationship in a law of stream slopes, an inverse - geometric series law, which is analogous to the law of stream numbers.

$$\bar{S_u} = \bar{S_1} \, R_s^{(k-u)} \qquad (2.18)$$

Where

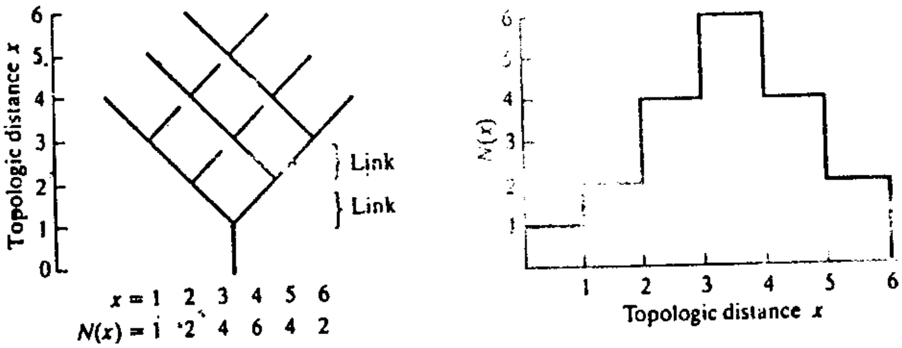


FIGURE 4 Width function defined in terms of topologic length.

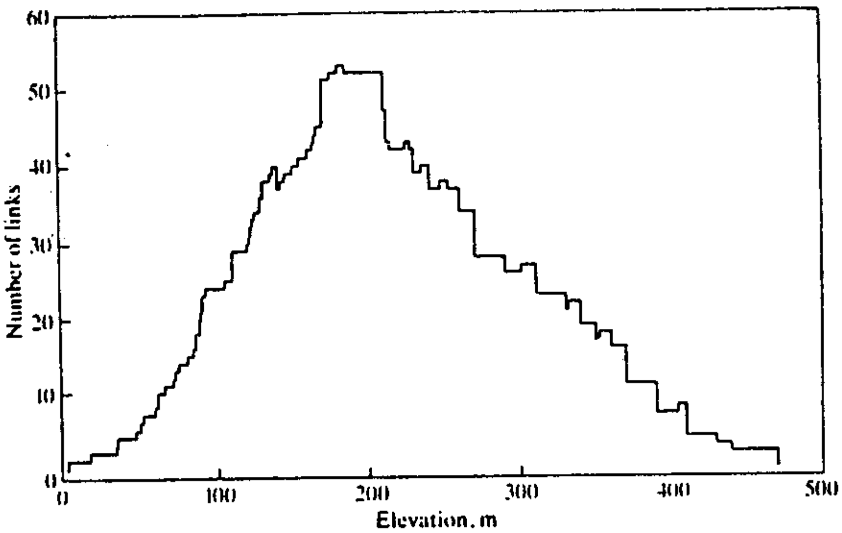


Fig. 5 Link concentration function for the Agua Fria Basin in Venezuela. Source: V. K. Gupta and O. J. Mesa, "Runoff Generation and Hydrologic Response via Channel Network Geomorphology: Recent Progress and Open Problems." *J. Hydrol.* 102(1-4):3–28, 1988.

Su = Average slope of segments of order u.

$\bar{S}1$ = Average slope of stream of order 1

K = Order of highest order segment

Rs = Slope ratio analogous to bifurcation ratio, Rb

The law of stream slopes brings elevation and hence energy in to the description of the river basin.

2.7.6 Division Ratio (Rd):

It has been shown by Scheidegger (1966) that in a Horton's net work Rb is constant only if streams of order u received streams of orders u-1. Thus if the lost segments are removed and the ratio of Nu-1 and Nu is computed according to Horton , then this ratio is the division ratio, which is analogous to Rb. Coffman and Melhorn (1970) examined the consistency of both Rb and Rd within and between six fourth order basins located on glacial hill within a single drainage system in India. They reported a wide and erratic variation in Rb for the test watershed but Rb was almost equal to 3 with one exception. The concepts of Rd may be very useful in estimating parameters of rain fall run-off models (24).

2.7.7 Nash's Measure of Slope (EA):

To define measure of slope Nash (1960) plotted the profile of main channel from the gauging site to the basin divide (boundry) and a straight line was drawn through the gauging

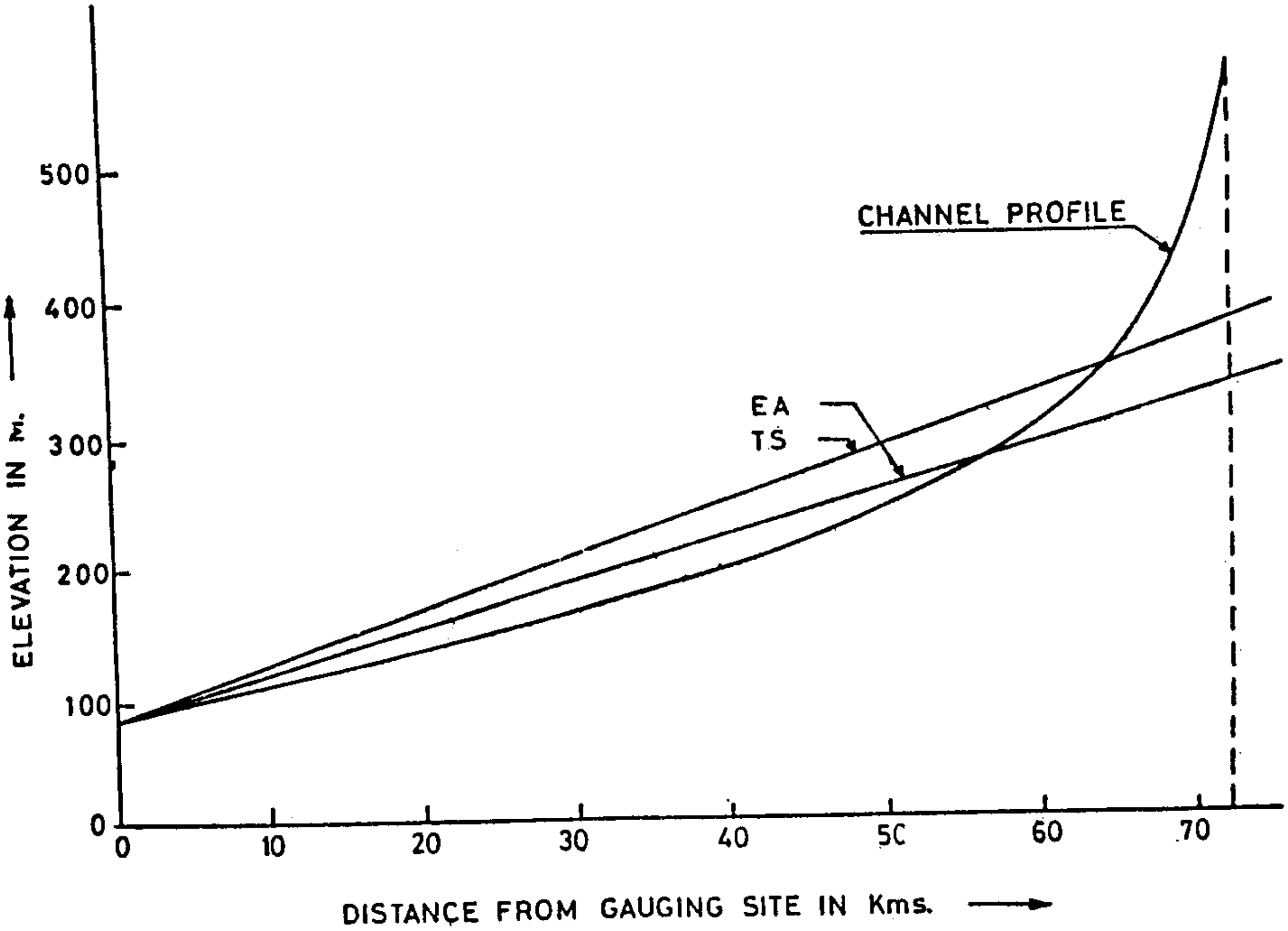


Fig. 6 MAIN CHANNEL SLOPES

287	231	245
189	417	144
93	309	I

I – INDETERMINATE

Mean Slope $= \frac{1915}{8}$

$= 239$ parts per 10,000

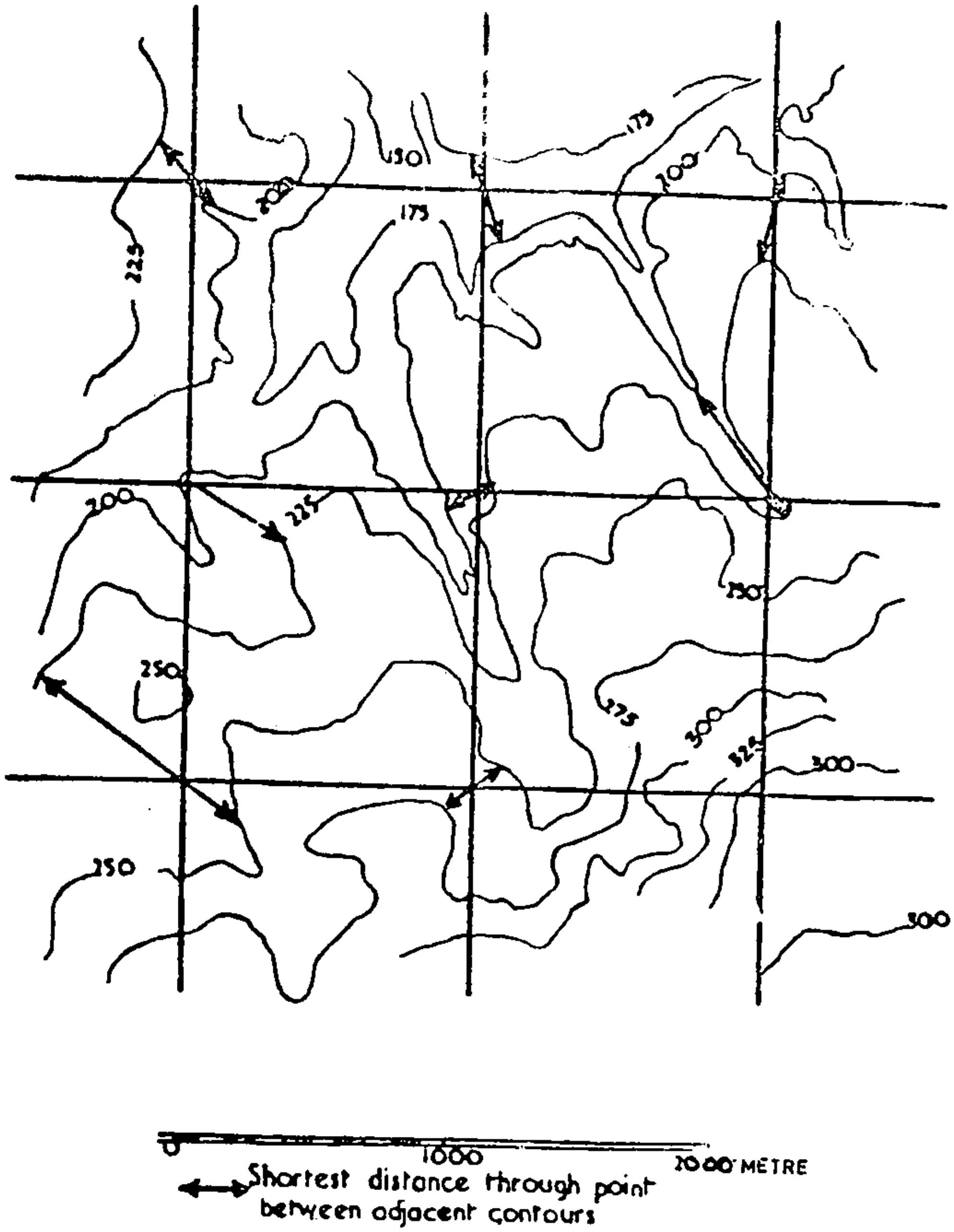


Fig.7 METHOD OF OBTAINING O.L.S OF CATCHMENT

station so as to form a triangle with the horizontal (through gauging station) and the vertical (through the highest point of the main channel). The slope of the line was so aligned that the area of the triangle be equal to the area contained by the horizontal, the vertical and the channel profile as shown in Fig.6.

2.7.8 Nash's Measure of Over land Slope (OLS):

Another measure of overland slope was suggested by Nash (1960) in which a grid of rectangular mesh was drawn on the 2.5" in map of the catchment, the mesh being such that about 100 intersections occurred within the catchment boundary. At each intersection the minimum distance between adjacent contours is measured and the slope at each point is taken as contour interval divided by this distance (Fig.7) . This provided a set of slope values of which the mean is calculated and taken as over land 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 later is neglected in calculating the mean.

2.7.9 Hypsometric Curve (Area-Altitude Analysis):

Langbein et al. (1947) introduced the non dimensional hypsometric curve to study the topography of watershed. The curve plots the percent area (area divided by total basin area) of the basin found above a given percent elevation contour. The percent elevation is defined as a given elevation divided by the maximum basin relief (H). This is shown in Fig. 8 and Fig. 8(c) shows several possible shapes of the curve. Davis (1899) suggested that basins evolved after some sudden tectonic uplifting and ensuing erosion & degradation. Such a model led to the identification of curve A with a young basin, curve B with a mature basin and curve C with an old basin. Scheidegger (1987) rebuts this classification by arguing that uplifting is continuous process and that throughout the basin history there is a tendency to balance the opposing forces of tectonic build up and degradation by erosion and other mechanisims. He then attributes the various shapes of the hypsometric curve to the levels of activity of the antagonistic processes. Curve A corresponds to high activity, curve B to medium and curve c to low activity. A third interpretation is that the shape of the hypsometric curve is a measure of relative equilibrium, in terms of tectonic uplift and erosional activity. This may or may not be measure of basin age. Curve A shows inequilibrium between opposing processes. The mature curve B corresponds to dynamic equilibrium, of agradation and degradation. Erosion continues during equilibrium phase, leading to a general reduction in relief but maintaining the same relative elevation area distribution. The Monadnock phase (distorted hypsometric curve) may arise when rock outcrops, resistant to erosion, are exposed, leading to fairly large contrast between the elevations of erodable and non erodable parts of the basin (2).

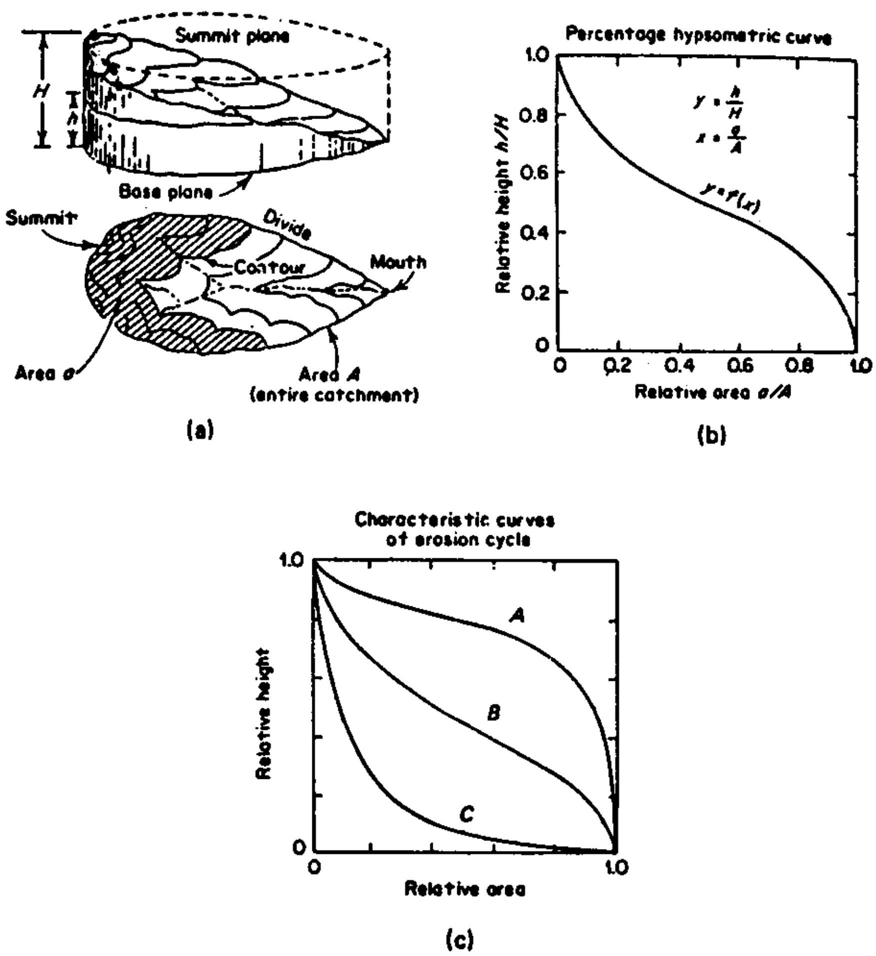


FIGURE 8 Construction of the hypsometric curve. Source: After A. N. Strahler, "Quantitative Analysis of Watershed Geomorphology," *Trans. Am. Geophys. Union* 63:1117–1142, 1957.

The hypsometric curve which describes the overall relief of a catchment is used when a hydrologic variable such as precipitation, Vegetative cover or snow fall shows a marked tendency to very with altitude. In such cases the hypsometric curve provides the quantitative means to evaluate the effect of altitude (18).

2.7.10 Area Elevation Relation:

Distribution of areas between contours in a drainage basin is of interest for comparing drainage basins and to understand the storage and flow characteristics of the basin. For the purpose an area distribution curve can be obtained by planimetering the areas between adjacent contours or by using a square grid and forming a ratio of the number of squares contained within the drainage boundary. The mean elevation is determined as the weighted average of elevations between adjacent contours. The median elevation can be determined from the area elevation curves as the elevation at which the percent area is 50% This is shown in Fig.9 (30)

2.7.11 'T' Factor:

Potter defined T factor as the ratio between length of highest order stream to the sq root of average main stream slope from head to mouth. He determined empirically a regression of peak discharge upon factors of topography, basin area and rainfall for 51 basins in the Appalachian Plateau. The T factor

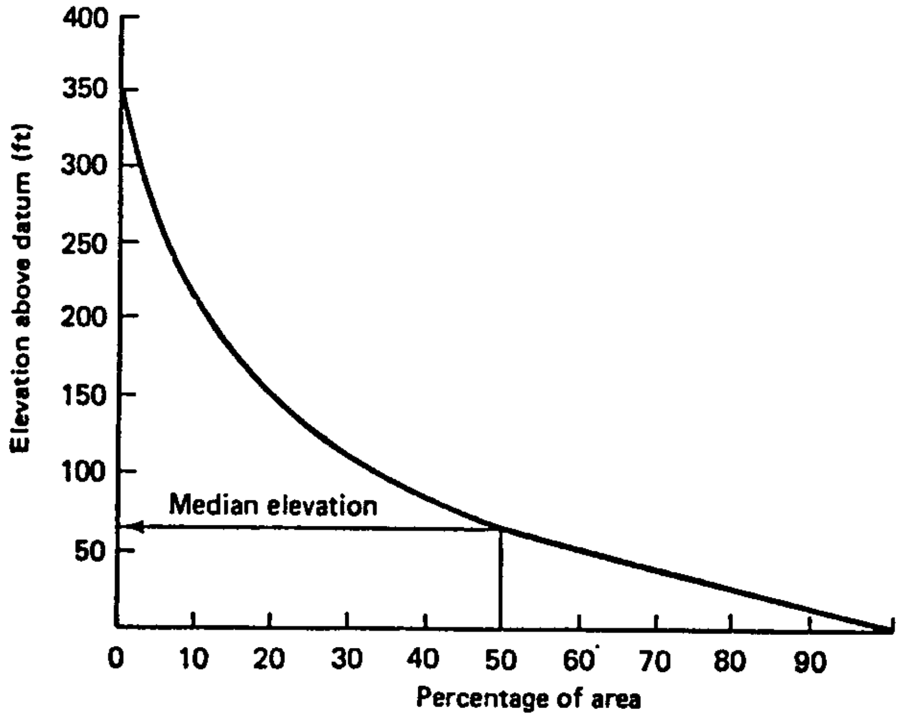


Figure 9 An area-elevation distribution curve.

was regarded to be significant in multiple regression with basin area and measures of rainfall intensity & frequency (4).

2.7.12 Peak Discharge & Basin Geometry:

Maxwell (1960) related stream discharge characteristics to several elements of basin geometry in the San Dimas Experimental Foreśt of Southern California. Correlations between peak flow & storm rainfall cover density , antecedent rainfall, and nine geomorphic properties taken five at a time. The geomorphic variables taken were 5th order area & diameter, means of 2nd order area, diameter , relief , drainage density , channel frequency and relief ratio and watershed, drainage density, channel frequency and relief ratio and watershed bifurcation length, diameter and area ratios. It was concluded that 5th and 2nd order areas or diameters, together with 2nd order drainage density and relief ratio, provide a good estimate of the variability of peak discharge which can be explained by geomorphic variation between watersheds.

2.8 Geomorphological studies by NIH:

The National Institute of Hydrology a premier Institute of the country in the field of hydrology and allied research has since taken up geomorphological studies of river basins through its regional centres spread over the entire country. Faced with the vexed problem of non availability or inadequacy of data for the river basins, particularly in mountainous areas the geomorphological studies have been taken up with the following objectives:

- Estimation of geomorphological parameters covering Linear aspects of channel network, Areal aspects and Relief aspects of drainage basins.

- To study the relationships of drainage characteristics with stream with stream flow.

- Synthesizing flow parameters with the help of morphometric parameters

- To regionalise hydrological models of run-off process.

The National Institute of Hydrology and its regional centres have since completed studies on estimation of geomorphological characteristics for the following river basins:

1. Varna basin upto Samdoti
2. Krishna basin upto Karad (Western Ghats)
3. Krishna Basin upto Arjunabad (Do)
4. Ghataprapha basin upto Daddi (Do)
5. Malaprabha basin upto Khanpur (Do)
6. Kolar Sub - basin
7. Hemavathy basin in Karnataka
8. Sabarmati basin in Gujrat
9. Tawi basin up to Jammu (J & K)

3.0 PROBLEM DEFINITION:

Hydrological studies in drainage basins and sub basins often suffer setbacks due to lack of various long term data. Then there is the need to extrapolate the results of few small sub systems (where only data are available) to other hydrologically similar regions which mostly remain ungauged for want of enormous resource and time involved in instrumentation & monitoring them. The measurable geomorphological parameters which have since been considered and shown to have potential to describe network provide simple means for hydrologic simulation, hydrograph synthesise and for development of empirical relationships to quantify some elements of flow processes. In context of hydrology, geomorphological parameters provide reasonable scope to compare basins and transform the results of gauged basins to ungauged areas for its regionalization.

The network of hydrometeorological observation in Baira Nalla Sub-basin is not existing and data are not available for systematic hydrologic studies. Moreover, the channel network of the basin is very complicated with most of the first , second and third order streams flowing on steep slope. Even many of the major streams remain dry during winter and experience flash flood during rainy days. There is no gauge discharge sites on these streams. Therefore, geomorphological parameters of the basin may provide an alternative to establish relationships describing flow process of the network.

With the long term representative basin studies taken up by NIH at Baira Nalla Sub-basin, estimation of its geomorphological parameters has been felt necessary for further study to follow. These parameters consisting of linear, areal and relief aspects of Baira sub-basin, as quantified in the report, may be used to develop hydrological model and regionalize the model parameters.

4.0 THE STUDY AREA:

The study area of Baira Nalla sub catchment at Tissa in the district of Chamba, Himachal Pradesh, India has been selected as one of the areas within the Western Himalayan region for representative basin studies. It is located between latitude 32^{o} - 45'N to 33^{o} - O'N and longitude 76^{o} - O' E to 76^{o} - 30' E (Fig.10). The area exhibits some of the prominent features of the western Himalayan region.

The sub - catchment of Baira Nalla above Tissa is about 585 sq. km (covered under survey of India Maps; 52 D / 1, 52 D / 5, 52 C / 4, and 43 P / 13 of scale 1:50,000) with its elevation varying from 1600 m to 4400 m above m.s.l.and basin slope from North to South (Fig.11). The sub - catchment is within Tissa block (area 996 sq.km) in the district of Chamba in Himachal Pradesh.

Baira sub catchment have steep slopes with 'V' shaped valleys. Area reconnaissance reveals that there are two types of soil. The upland soil is derived from quartzite parent material and is sandy with moderately high infiltration rates. At lower elevations old river terraces contain more clay and have a lower infiltration rate. Soil depths on the upper slopes are shallow, approximately 18-24 inches (9).

Geologically, the Baira Nalla sub-catchment lies within Lesser Himalayas. Lesser Himalayas are separated from Siwalik rocks by main boundary thrust. The main rock types occurring in the area are dollomite, limestone, philates, Mica, Schist, Quartz(gray) etc dipping towards southwest at the of 30-50 degree bearing three phases of folding. The lesser himalayas are separated from **Higher Himalayas** by main central thrust diping towards North-East.

There is unconformity in depositions of different layers. Rocks are highly fractured and planes are developing probably due to instability. Because of the presence of dollomite, Limestone etc. the area is very prone to erosion by process of chemical weathering when they come in contact with water. In phillates (low gravity metamorphic rock) and quartzites in the barren slopes water percolates along the fractures and erosion is caused due to biological weathering.

The river Baira Nalla has a total catchment of 585 sq km of which some areas at higher elevation are under permanent snow cover. The basin is partially snow covered during winter from December to March with maximum snow cover of 70.22% and minimum of 52.40% in February and March as interpretated from Landsat imageries of five years (Feb. 1984, Feb. 85, Feb. 89, March 90 and March 1992). Rain occurs mostly during July to August.

The annual flow at Baira is of the order of 160 cumecs. The flood discharge with a return period of 100 years was estimated to be 2379 cumecs(31). At basin mouth the stream bed width varies from 25 m to 40 m and its general slope is 1 in 40 with high velocities causing a significant transport of suspended sediments and also bed loads consisting even man size boulders.

5.0 METHODOLOGY:

Procedures for estimation of various geomorphological parameters of the river basin, in requirement of many hydrological studies, is described in this section. For the purpose, a large scale basin map 1:50000 of Baira nalla sub basin upto Tissa was prepared from Survey of India topo sheets. Field verification of the map was made to some extent and before finalising it, the delineation of drainage divide was also compared with land sat imageries. The geomorphological parameters that are used in hydrological models and having potential to describe basin characteristics are broadly grouped under three categories:

I Linear Aspect of the Channels system

II Areal Aspect of the Catchment

III Relief Aspect of the Basin

Based on the methodology and works done by many earlier investigators like Horton (1945), Strehler (1953,1956,1964,1968), Chroley (1957), Miller (1953), Schumm (1954) , Bernard (1935), Snyder (1938), Linsey (1943), Jetter (1944), Lucas (1944) , Taylor(1952), Eaton (1954), Yonezol (1956), Muckus (1975), Nash (1960), Gray (1961). CWC (1980), Gundlach (1975) etc., the parameters under these three aspects are studied and quantified as described below:

5.1 Linear Aspect of the Channel System:

Linear aspect of basin characteristics includes overland flow lengths of channels of all orders. Usefulness of ordering channel system lies on the hypothesis that basin size, channel dimension and stream flows are proportional to the stream orders provided investigation is made for quite large number of watersheds. Two basins having different Linear measures can be compared with respect to corresponding points in their geometry through use of dimensionless order number . However, such comparisons should be made at locations in the two systems that have similar geometry, that is, second order stream third order streams and so forth.

5.1.1 Stream Orders:

Horton (1945) pioneered quantitative study of channel net-works by classifying the channels by order in United States. This was slightly modified by Strahler (1952) . Melton (1959) explained the mathematical concepts involved. As per Strahler's scheme of ordering in a channel network map showing the intermittent and permanent flowlines located in clearly defined valleys the smallest unbranched (finger tip) tributaries are designated as order one(Fig.12). The point at which two first order streams join a channel segment of order 2 is formed. Where two steams of 2nd order join, a segment of order 3 is formed and so on . The main or trunk channel carrying the entire discharge of the drainage basin upstream of basin outlet is obviously the segment of highest order. Parameters under linear aspect of channel system and their estimations are described below:

5.1.2 Length of Main Channel , (L):

This is the length of the longest water course when projected on a horizontal plane, (i.e. in a map) from the basin outlet to the farthest point on the basin boundary. To measure this length there are several conventional methods like pair of dividers, thread length, edge of paper strip, opisometer and so on. This can also very well be done by Analog to Digital Converter by tracing along the main channel with the cursor which records the x and y co-ordinates of closely spaced points. The digitized co-ordinates of the main channel points are stored in computer and distance between two points is calculated from

$$\text{Distance} = \left((x)^2 + (y)^2 \right)^{1/2}$$

Length of the channel is the summation of all segmental distances. For the purpose a subroutine 'LENGTH' is already available at NIH (24). Similarly length of all streams of all orders can be found out.

However, in absence of facility lengths of the main channel and other channels have been measured manually with the help of opisometer on the basin map. Bernard (1935), Snyder (1938), Linsley (1943), Jetter (1944), Lucas (1944), Taylor (1952) Eaton (1954), Yonezol (1956), Mockus (1957), Nash (1960) , Gray (1961), CWC (1980) and Gundlech (1975) considered the stream length as one of the catchment characteristics in establishing the relationship for synthetic unit hydrograph (23).

5.1.3. Length of the Channel between the Outlet and Point nearest to C.G.., (LC):

It is the length of the channel measured from the outlet of the catchment to a point on the stream nearest to the centroid of the basin (C.G.of the plane area of the drainage basin). The centroid is found out by cutting a card board piece in the shape of the catchment and then balancing it on a horizontal plane with a pivot. Linear measurement of the parameters is same as described in 5.1.2 This measure have been used in the studies of basin lag i.e. time between the centres of mass of effective storm input and the resulting output (30).

5.1.4 Total length of Channels:

This is the total length of channel segments of all orders within the basin. Total length of channels gives an idea of overland flow and channel flow in the watershed. Procedure to estimate this parameter is described in para 5.1.2.

5.1.5 Wandering Ratio:

This is the ratio between main stream length along the course to the straight line distance between the two extremes outlet and farthest point in basin boundary. While this factor broadly indicates the amount of deviation of main stream from straight line path, it does not necessarily explain the meandering of the main stream.

5.1.6 Bifurcation Ratio (Rb):

The ratio of number of stream segments of a given order Nu to the number of segments of the higher order Nu+1 is termed as bifurcation ratio, Rb.

$$Rb = Nu/(Nu+1) \qquad (5.1)$$

Calculation of an average value of Rb for a given channel network can be made by determining the slope of the fitted regression of logarithm of numbers (ordinate) on order (abscissa). This means a plot of the Log Nu vs u will approximately yield a straight line with negative slope. The magnitude of the slope is the logarithm of Rb (identical to the regression co-efficient b). If the Rb is estimated to be 3.52, this means that on the average, there are 3 1/2 times as many channel segments of any given order as of the next higher order. Taking precipitation and other factors uniform, an elongated basin (high Rb) would give rise to a hydrograph of low but extended flow peak where as a round basin (low Rb) would produce a sharp peak (22).For a basin with a dipping rock strata where narrow valleys are confined between high ridges the Rb may be abnormally high. Strahler concludes that Rb characteristically ranges between 3.0 and 5.0 for watersheds in which the geologic structures do not distort the drainage pattern. The theoretical minimum possible value of 2.0 is rarely approached under natural conditions. The bifurcation ratio is however, not the same from one to the next order but will tend to be constant throughout the series. This is the basis of Horton's law of stream numbers.

5.1.7 Stream Number (Nu) :

Horton's (1945) law of stream Numbers states that the number of streams of a given order follows an inverse geometric relationship with stream number :

$$Nu = (Rb)^{k-u} \qquad (5.2)$$

Where k = Order of trunk segment i.e. the highest order of the stream in the drainage basin.

u = Order of interest

From eqn. 5.2 it follows

$$\log Nu = (k-u) \log Rb \qquad (5.3)$$

or

$$\text{Log } Nu = a-bu \qquad (5.4)$$

Where, $a = k \log Rb$
$b = \log Rb$

Or, $Rb = \log (b)^{-1}$

For computing log Rb a sub - routine "REG" based on least square approach is available. The value of Rb can be used to compute the total number of streams (N) of all orders from the eqn.:

$$N = \sum_{u=1}^{k} Nu = (Rb^{k} - 1) / (Rb - 1) \qquad (5.5)$$

These results have been confirmed many times using Strahler's ordering system (2).

5.1.8 Average stream length (Lu):

Mean length Lu of a channel segment of order u is a dimensional property revealing characteristic size of components of a drainage network and its contributing basin surfaces (22).

Law of stream length (Horton, 1945) states that the average length of streams of each of the different orders tend to approximate a direct geometric series (In which the first term is average length of first order stream) with the relation:

$$\bar{L}u = \bar{L}1 \quad R1^{(u-1)} \qquad (5.6)$$

Where $\bar{L}1$ = average length of streams of first order

$\bar{L}u$ = Average length of streams of order u

R1 = A constant called length Ratio discussed later

The validity of law of stream length relating R1 when Strahler ordering is used has been studied by several authors Maxwell (1960) & Melton (1957) indicated considerable variation in segment length data from a geometric series. If it is assumed that the Horton's law of stream length is valid then the Length Ratio R1 of eqn. (5.6) is obtained for the watershed as the antilogarithm of regression co-efficient of a line fitted by inspection or by least square method to the plot of logarithm of stream length on order (23) . Broscue (1959) found that substituting cumulative mean length for average length and cumulative R1 in equation (5.6) the geometric series was indeed obtained. Of interest in the estimation of channel storage capacity for an entire watershed, is Horton,s observation that the laws of stream numbers and lengths can be combined as product to yield an equation for the total length of channels of a given order 'u' knowing only the Rb and R1, the mean length L1 of the first order segments and the order of the trunk segment (22).

Thus:

$$\sum_{i=1}^{N} Lui = \bar{L}1 \quad Rb^{k-u} \quad R1^{u-1} \qquad (5.8)$$

In the report $\bar{L}u$ is calculated from the linear measurement of channel segments i.e. total length of each order is divided by the number of segments of that order such that:

$$\bar{L}u \quad + \quad (\sum_{i=1}^{N} Lu)/Nu \qquad (5.9)$$

5.1.9 Stream Length Ratio, (R1):

This is the ratio of mean length $\bar{L}u$ of segments of order u to mean length of segments of the next lower order Lu-1:

$$R1 = \bar{L}u \ / \ \bar{L}u\text{-}1 \qquad (5.10)$$

Horton stipulated that R1 tends to be constant throughout the successive orders of a watershed. Its value is normally between 1.5 and 3.5 in natural drainage networks. It is useful in synthesizing hydrograph characteristics.

Horton gave another method for computing R1 (or also to estimate total length of channels of all orders of a watershed of order k) by introducing the term R1b (=R1/Rb)which is found from:

$$\sum_{u=1}^{k} \sum_{i=1}^{Nu} Lui = \bar{L}1.Rb^{k-1} \quad (R1b^{k}-1)/(R1b-1) \qquad (5.11)$$

Nu= Total number of streams of order u

Here RHS i.e. total stream length of all orders, L1 and Rb are known and R1b can be calculated. Then R1 is calculated from:

$$R1 = Rb/R1b \qquad (5.12)$$

Since the from of the equation (5.11) is non linear, solution of R1b can be obtained by technique based on Newton-Raphson non linear optimisation. For the purpose a separate sub routine, NEWTON has been developed at NIH(24).

5.1.10 Basin Perimeter (P):

Basin perimeter is the total length of the basin boundary or the length measured along the divide between basins and may be used as an indicator of basin size and shape. It was emphasized by Smith (1950) in his derivation of Texture ratio.

5.1.11 Fineness Ratio:

The ratio of the channel length to the lengths of the basin perimeter is termed by Melton (1957) as the fineness ratio which indicates fineness of the topography.

5.1.12 Watershed Eccentricity (T):

Black (1972) gave the express for T as :

$$T = \frac{\left(Lc^2 - WI^2 \right)^{1/2}}{W1} \qquad (5.13)$$

Where Lc = Length from the watershed mouth (outlet) to the centre of mass of watershed.

W1 = the width of the watershed at the centre of mass and perpendicular to Lc.

When Lc = W1, eccentricity become zero. Greater is the value of (W1-Lc) or (Lc-W1) more will be the eccentricity, lesser will be the compactness of watershed near the mouth and lower willbe the flood peak.

5.1.13 Length of Overland Flow, (lo):

Horton (1945) defined Lo as the length of flow path, projected to the horizontal of non channel flow from a point on the drainage divide (basin boundary) to a point on the adjacent stream channel (22). It is the length of overland flow of water before it joins a channel. The average length of overland flow Lo is approximately half the average distance between stream channels and is therefore approximately equal to half the reciprocal of drainage density (discussed in Areal Aspects in clause 5.2.3) such that (22):

$$\bar{Lo} = 1/2D \qquad (5.15)$$

Horton noted that " length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basins (7).

5.2 Areal Aspect of Watershed :

Areal measure of a drainage basin net works relates to many of its hydrologic characteristics. Some of these characteristics and methodology of estimation adopted by various investigators are described below:

The basin area is the plane area within the perimeter along the drainage divide. It is one of the most important characteristics of the basin reflecting the run-off process. The area of the basin of a given order u is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and including all tributaries of lower order. Thus Schumm (1956) stated that the area of basin of fourth order A4 would cumulate the area of all first, second and third order basin plus all additional surface elements, Known as INTER BASIN AREAS, contributing directly to a channel of order higher than first (27) .Estimation by comparison of watershed tracing with square of rectangle of known dimension, polar planimeter, Dotgrid, strip sub division , geometric sub division, Analog to digital converter are some methods to measure basin area(9).

5.2.2 Law of Stream Areas: Area Ratio, (Ra):

The concept of law of stream area is same as the law of stream lengths and stream numbers. Horton (1945) stated that mean basin areas ($\bar{A}$) of progressively higher orders should increase in a geometric sequence as do stream lengths . Schumm (1954) expressed this relationship in a law of stream areas which states that " mean basin areas of the stream of each order tend closely to approximate a direct geometric sequence in which the first term is the mean area of the first order (27) Mathematically:

$$\bar{A}u = \bar{A}1 \quad (Ra)^{u-1} \qquad (5.15)$$

Where $\bar{A}u$ = mean area of basin of order u.

$\bar{A}1$ = mean area of basin of order

RA = an area ratio analogous to R1

which follows:

$$R_a = \bar{A}_u / (\bar{A}_{u-1}) \qquad (5.16)$$

Smart (1972) concludes that for natural basins value of R_a normally ranges from 3 to 6.

5.2.3 Drainage Density,(D):

Horton (1945) defined drainage density as the ratio of total channel segment lengths of all orders within a basin to the area of the drainage basin projected to horizontal and expressed as the number of miles of channels per square mile of basin area.

$$D = \frac{\sum_{u=1}^{k} \sum_{i=1}^{N_u} L_{ui}}{A} \qquad (5.17)$$

Dimensionally this ratio reduces to inverse of length (L^{-1}) and hence is a quantity dependent on the level of resolution of the map from which lengths are measured. Horton relates drainage density to the Horton numbers (2) as :

$$D = \frac{\bar{L}_1 . R_b^{k-1} . R_{1b}^{k} - 1}{R_{1b} - 1} \qquad (5.18)$$

Drainage density characterises textural measure independent of basin size and considered to be function of climate, Lithology, stage of development etc. In fact the drainage density is constant everywhere in the basin and the average length of contributing hill slope is approximately half the average distance between stream channels as expressed in equation (5.14).

5.2.4 Constant of Channel Maintenance, (C):

Schumm (1956) used this term as the inverse of drainage density i.e.

$$C = \frac{1}{D} \qquad (5.19)$$

With its unit as sq. ft per foot (on a horizontal plane) the term indicate the square feet of watershed surface required to sustain one linear foot of channel.

5.2.5 Stream Channel Frequency, (F):

Stream Frequency or channel frequency was defined by Horton (1945) as the numbers of stream segment per unit area or:

$$F = \frac{N}{A} \qquad (5.20)$$

Where N = Total stream segments of all orders

A = Drainage area of the basin

Relationship between drainage density (D) and stream frequency both of which measure the drainage texture (but each treating a distinct aspect) was studied by Mellon (1958) . Although both the terms measure different properties , Melton found a dimensionally correct equation as:

$$F = 0.694\ D^2 \qquad (5.21)$$

This implies that the dimensionless ratio F/D^2 approaches a constant value of 0.694 independently of scale.

5.2.6 Circularity Ratio, (RC):

Miller (1953) introduced a dimensionless circularity ratio which is defined as the ratio of the basin area to the area of a circle having circumference equal to the perimeter of the basin.

The value of this ratio approaches one as the shape of the basin approaches a circle. Miller found the value consistently in the range of 0.6 to 0.7 for first and second order basins in homogeneous shales and dolomites, indicating the tendency of small drainage basins in homogeneous geologic materials to preserve geometrical similarity. By contrast first and second order basins situated on the flanks of moderately dipping quartzite strata of clinch Mountain, Virginia, were strongly elongated and had values of Rc between 0.4 to 0.5.

5.2.7 Elongation Ratio (Re):

Schumm (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Obviously for a circular basin the value tends to unity. This ratio runs between 0.6 to 1.0 over a wide variety of climatic and geologic types. Values near to 1.0 are typical of regions of very low relief, where as value in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes.

5.2.8 Form Factor (Rf):

Horton (1932) used this dimensionless quantity which he defined as the ratio of basin area (A) to the square of the basin length (L), measured along the longest water course.

$$Rf = A/L^2 \qquad (5.22)$$

This is a quantitative expression of basin shape (outline form). In its inverted form, L^2 / A, this ratio was used in unit hydrograph applications by the U.S. Army crops or Engineers (4)

5.2.9 Compactness Ratio (RK) :

Basin shape has been defined by an alternate descriptor based on perimeter rather than area. The compactness ratio is the ratio of the catchment perimeter to that of the equivalent circle having area as that of the basin. This leads to (18):

$$Rk = \frac{0.282\ P}{A^{1/2}} \qquad (5.23)$$

5.2.10 Watershed Shape Factor (Rs) :

This was defined by Wu et al (1964) as the ratio of main stream length L to the diameter D of a equivalent circle having same area as the basin.

$$Rs = \frac{L}{D} \qquad (5.24)$$

5.2.11 Unity Shape Factor (Ru):

Smart & Surkan (1967) used the unity shape factor to be defined as the ratio of the basin length L to the square root of the basin area (A).

$$Ru = \frac{L}{A^{1/2}} \qquad (5.25)$$

5.3 Basin Relief Aspect:

Relief morphometry of river basin describes variation of elevations between the highest and the lowest point. This is significant to study the flow phenomena in the watershed .The potential energy of flowing water from high altitude gets converted to kinetic energy which is related to slope. Various losses of water like storage, infiltration, evaporation etc. and travel time are inversely related to slope. The parameters relating to relief aspect of the drainage network are as follows:

5.3.1 Basin Relief (H):

Relief is the elevation difference between two reference points. Maximum basin relief (H) is the elevation difference between the highest point in the catchment divide and the catchment outlet. Methods of measurement of basin relief adopted by various investigators are different . Schumm measured basin relief along the Longest dimension of the basin parallel to the principal drainage line. Basin relief may also be obtained by determining the mean height of the entire basin perimeter above the mouth , thus minimising the spurious effects of sharply pointed summits (4).

5.3.2 Relief Ratio (Rh):

"Relief ratio is the ratio of the maximum basin relief (H) to the catchment's longest horizontal straight distance measured in a direction parallel to that of the principal water course

(18)". Schumm (1956) explained that taking vertical and horizontal distances as legs of a right-angled triangle , relief ratio is equal to the tangent of the lower acute angle and is identical with the tangent of the angle of slope of the hypotenuse with respect to the horizontal .The relief ratio thus measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on slopes of the basin.

5.3.3 Relative relief (Rhp):

Melton (1957) used the term relative relief which is basically the ratio of the basin relief to the perimeter and expressed in percent as:

$$Rhp = \frac{100\ H}{5280\ P} \qquad (5.26)$$

Where,

H = Maximum basin relief in ft.
P = Basin perimeter in miles

5.3.4 Ruggedness Number (Rn):

To take into account of both slope, steepness and length , a dimensionless ruggedness number has been used by Melton (1957) and Strahler (1958). It is defined as the product of relief H and drainage density D (both in same unite) i.e.

$$Rn = H \times D \qquad (5.27)$$

Observed values of the ruggedness number range from as low as 0.06 in the subdued relief of the Louisiana coastal plain to over 1.0 in coast ranges of California or in badlands on weak clays (4).

5.3.5 Law of Basin relief:

The law postulated by Maxwell (1960) states that the mean relief of basins tends to closely approximate a geometric series and is expressed as:

$$\bar{H}u = \bar{H}1 \; Rh^{u-1} \qquad (5.28)$$

Where,

$\bar{H}u$ = Mean relief of a watershed of order u.

$\bar{H}1$ = Mean relief of a watershed of order 1

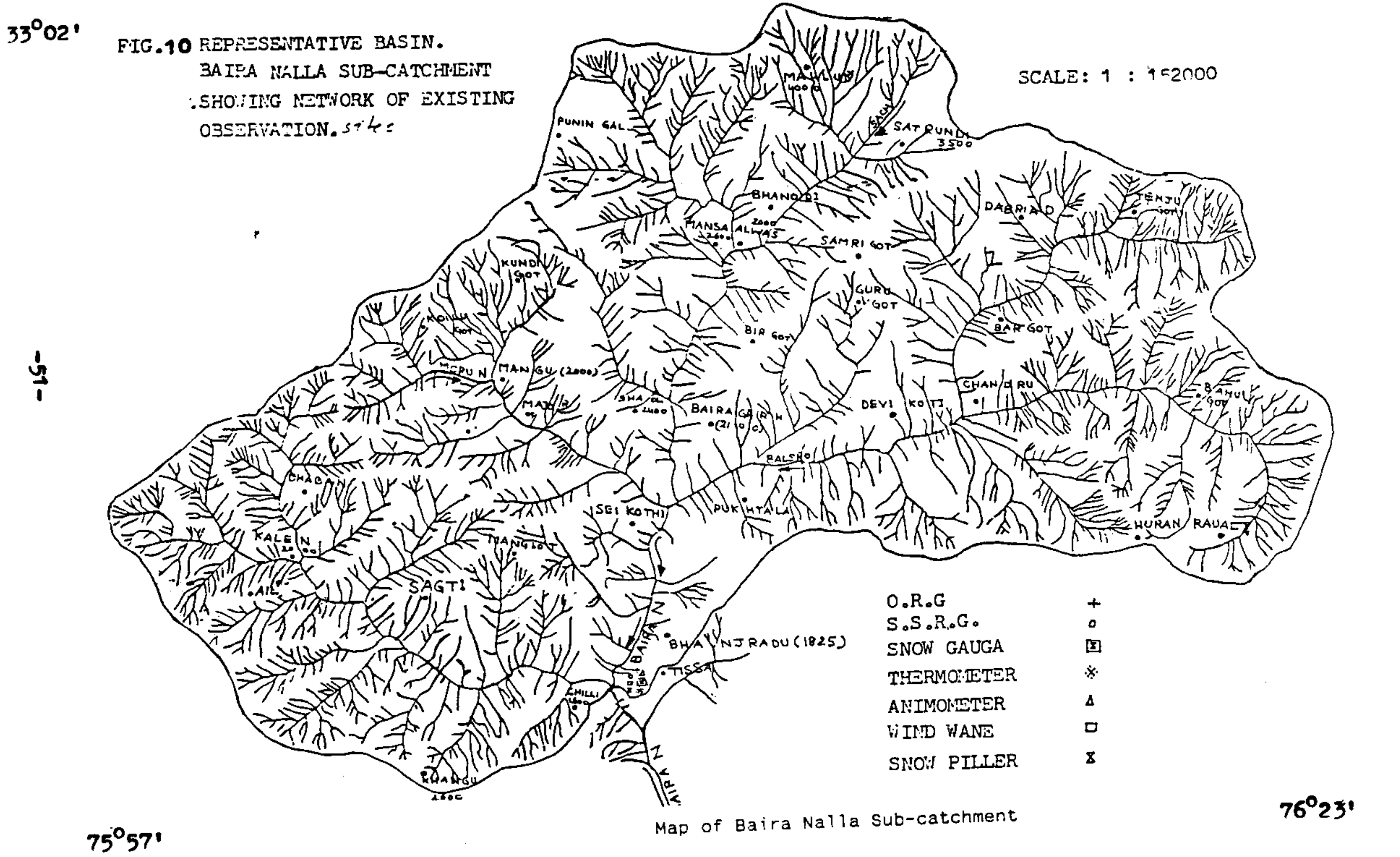
Rh = Relief Ratio.

6.0 ANALYSIS AND DISCUSSION OF RESULTS:

To estimate the hydromorphologic parameters of Baira sub basin the topographic map delineating the basin divide and other topographic features was prepared from Survey of India toposheets Nos.52 D/1, 52 D/5, 52 C/4 & 43 P/13 in the scale 1:50,000(Fig.10). The stream net work has been ordered using Strahler's ordering procedure (Fig.12). It is principally a six order network having 1701 first order, 378 second order, 88 third order, 17 fourth order and 4 fifth order streams contained in the drainage area under investigation of 585 sq km up to Tissa. Ranging from 1600 m to about 4400 m the average basin elevation is about 3500 m .

From the map the basic linear parameters like basin perimeter, lengths of streams , basin length etc. were measured manually with the help of opsiometer. The basic parameters of areal aspects like basin area, areas of different order streams etc. were measured from the map with a planimeter and other derived parameters were estimated with the relationships discussed in chapter 5. To study the relief aspects of the basin a contour map of the whole basin was prepared with contour interval of 200 m (Fig.11). The numbers, lengths and areas of different channel segments are furnished in Table.1.

FIG.10 REPRESENTATIVE BASIN.
BAIRA NALLA SUB-CATCHMENT
SHOWING NETWORK OF EXISTING
OBSERVATION.



Map of Baira Nalla Sub-catchment

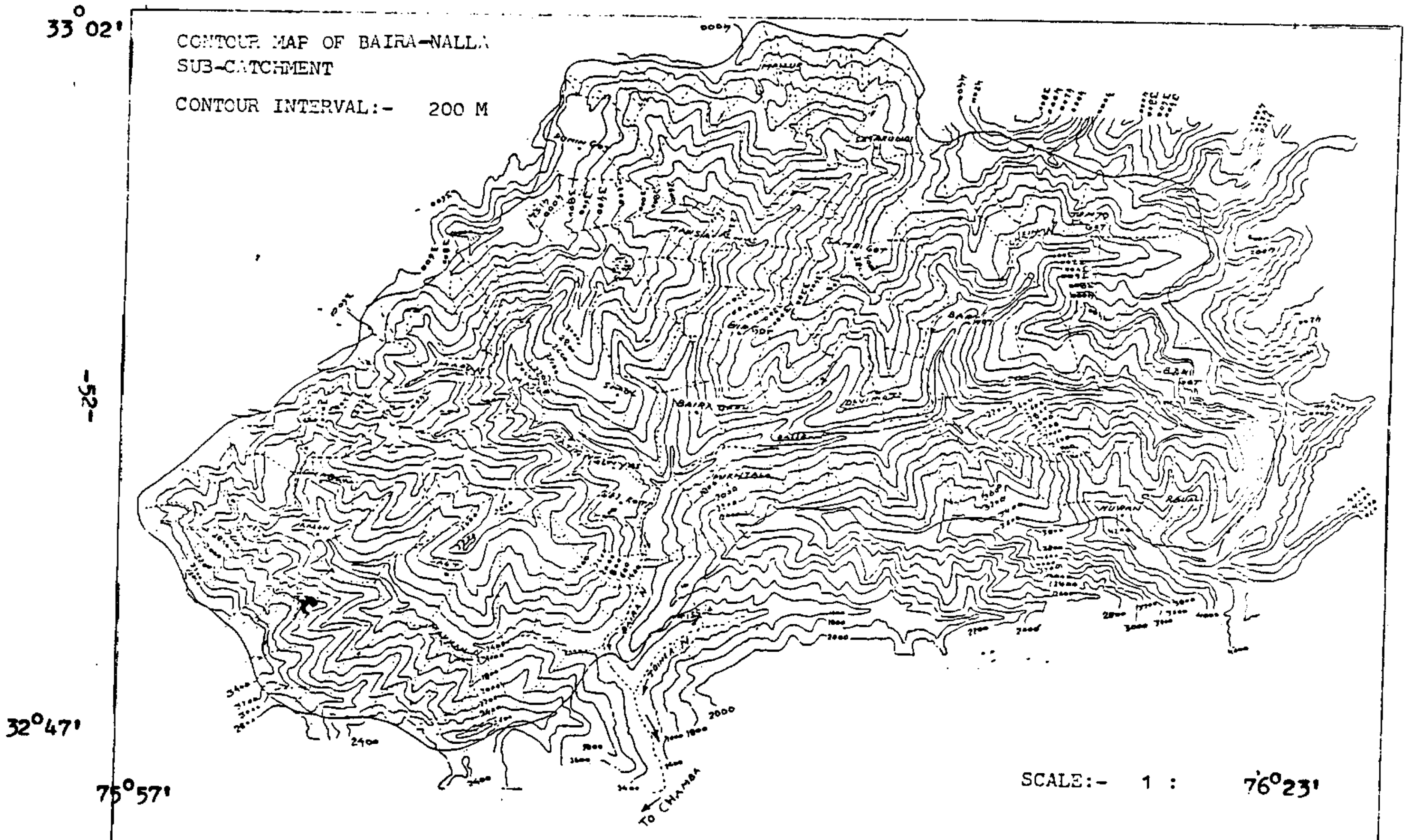


Fig 11 Contour Map of Baira Nalla Sub-catchment.

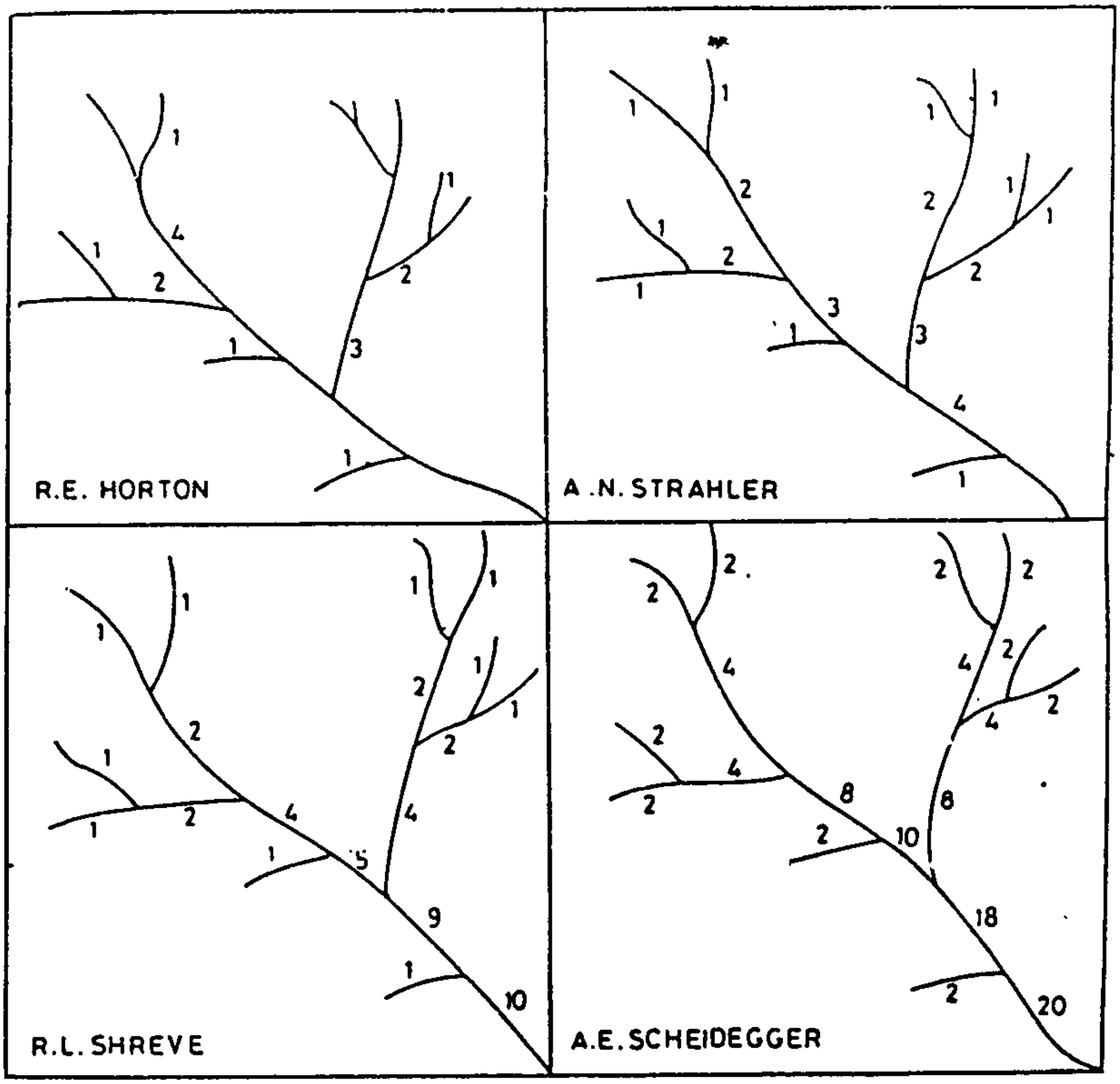


Fig. 12 METHODS OF STREAM AND SEGMENT ORDERINGS

Table.1

Stream Order	Stream No.	Stream Length L,	Average Length Km	Area, A Sq. Km	Mean Area, A Sq. Km
1.	1701	1118.5	0.65	344.175	0.202
2.	378	316.5	0.83	114.4	0.302
3.	88	147.5	1.67	56.87	0.646
4.	17	61.5	3.61	31.57	1.857
5.	4	52.0	13.0	31.0	7.75
6.	1	7.0	7.0	5.6	5.6

The results of the study in respect of linear, areal and relief aspects are discussed below:

6.1 Linear Aspects of Baira nalla Sub Basin:

The parameters studied under this aspect and their quantitative measures are furnished in Table.2 below:

Table.2

1.	Length of main channel, L	33.5	Km
2.	Length up to centroid, Lc	11.95	Km
3.	Length of Basin / Valley length, Lv	15.00	Km
4.	Total length of Channels, Lt	1703.00	Km
5.	Length of Overland flow, Lo	0.171	Km
6.	Basin Perimeter, P	113.00	Km
7.	Watershed eccentricity, Ew	0.83	Km

contd.

contd.

8.	Length ratio, Rl	1.5
9.	Wandering ratio, Rw	2.23
10.	Fineness ratio, Rf	0.2964
11.	Bifurcation ratio, Rb	4.57

It can be seen from the Table.1 that the average length (total length divided by the number of stream) increases with increasing order. Nnumber of streams rapidly decreases with increasing order which is probably due to hilly sub-catchment. The non dimensional parameters (i.e. bifurcation ratio and length ratio estimated), should reflect to peak time characteristics of the Baira sub basin and may only be confirmed after hydrological modeling . The measure of length upto centroid may be useful in the regional unit hydrograph studies . The other linear measures shown in Table.2 for the Baira sub basin will also be useful to describe the various hydrologic properties of the net work as discussed in Chapter 5. Fig.13 shows the variation of stream number with stream order on semi-log plot. The negative slope of the line confirms the law of stream numbers indicating reduction of number from lower to higher orders. Fig.14 shows a semi log plot of the quantities of stream order vs average stream length. The plot shows the increasing trend in average length with increasing order following Horton's Law of stream length .

6.2 Areal Aspect of Baira sub basin:

The basin characteristics of the Baira drainage network in

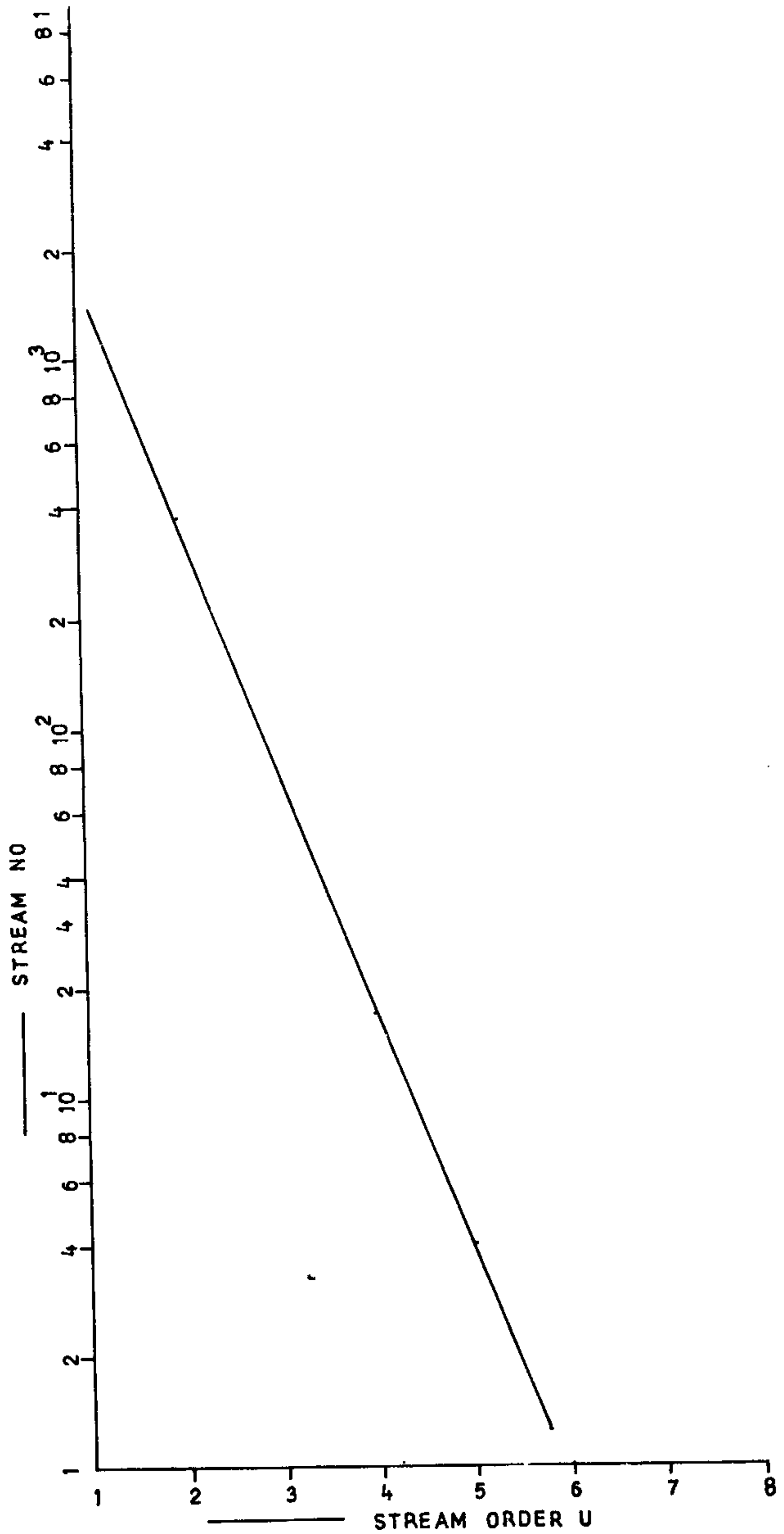


FIG. 13 VARIATION OF STREAM NO WITH ORDER

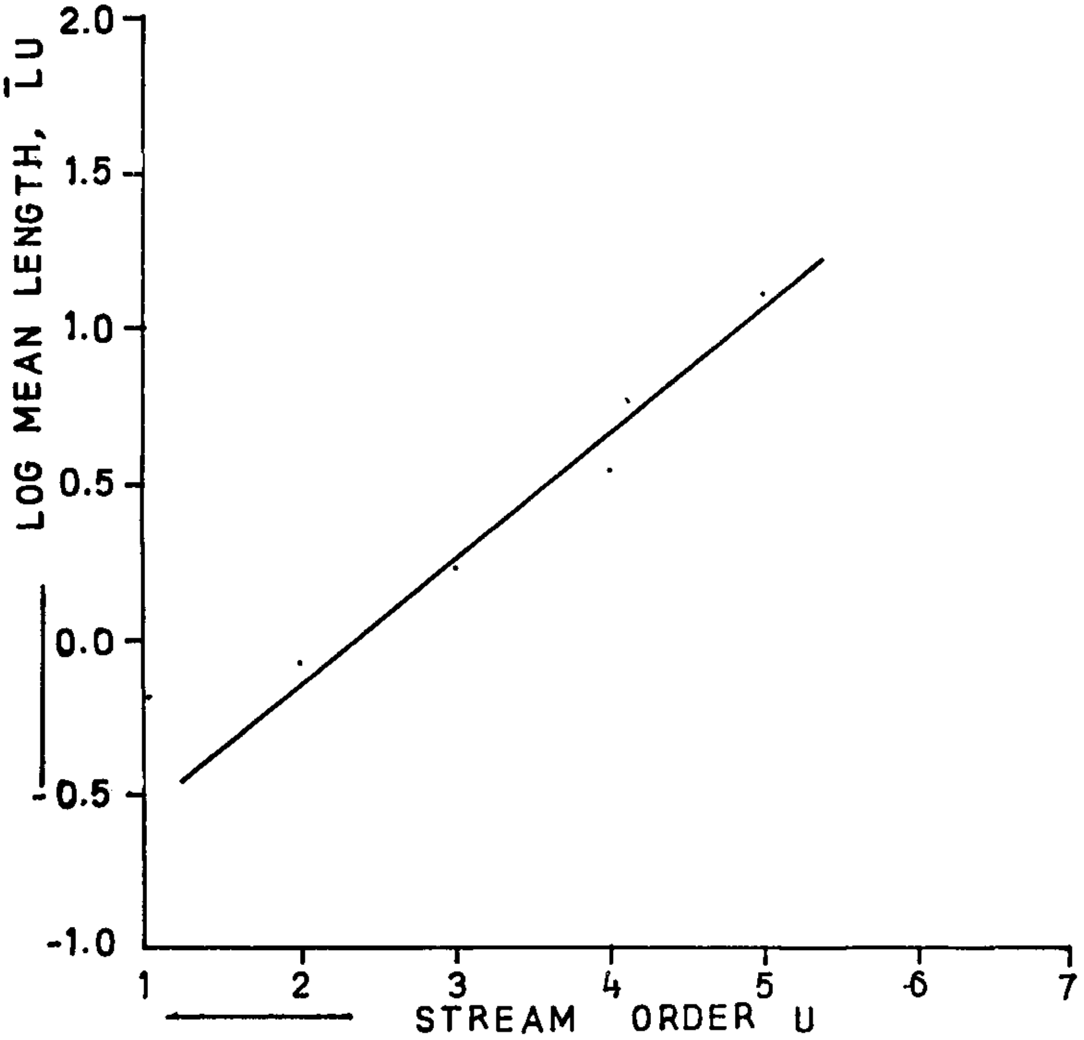


FIG. 14 VARIATION OF MEANSTREAM LENGTH WITH ORDER

terms of areal measures as described in clause 5.2 has been studied and the parameters of areal aspects are estimated as presented in Table.3 below:

Table.3

1.	Drainage Area, A	584.875	Sq.Km
2.	Drainage Density, D	2.91	Km/ Sq.Km
3.	Constant of Channel Maintenance, C	0.3434	Sq.Km/ Km
4.	Channel Segment Frequency, F	3.742 /	Sq.Km
5.	Circularity Ratio, Rc	0.5753	
6.	Elongation Ratio, Re	1.81	
7.	Watershed Shape Factor, Rk	1.228	
8.	Unity Shape Factor, Ru	0.6202	
9.	Form Factor, Rf	2.59	
10.	Compactness Ratio, R	1.307	

From Table.2 & Table.3 it is observed that there is an increasing trend in the mean areas of different order streams with increasing order which confirms the Schumm's Law of stream areas as discussed in para 5.2.2. A semi log plot to this effect between mean areas and orders is shown in Fig.15. The other areal measures furnished in the Table above are regarded to have effect on peak and shape of the basin hydrograph and may be used in modeling the hydrological response of the basin when flow records are not available

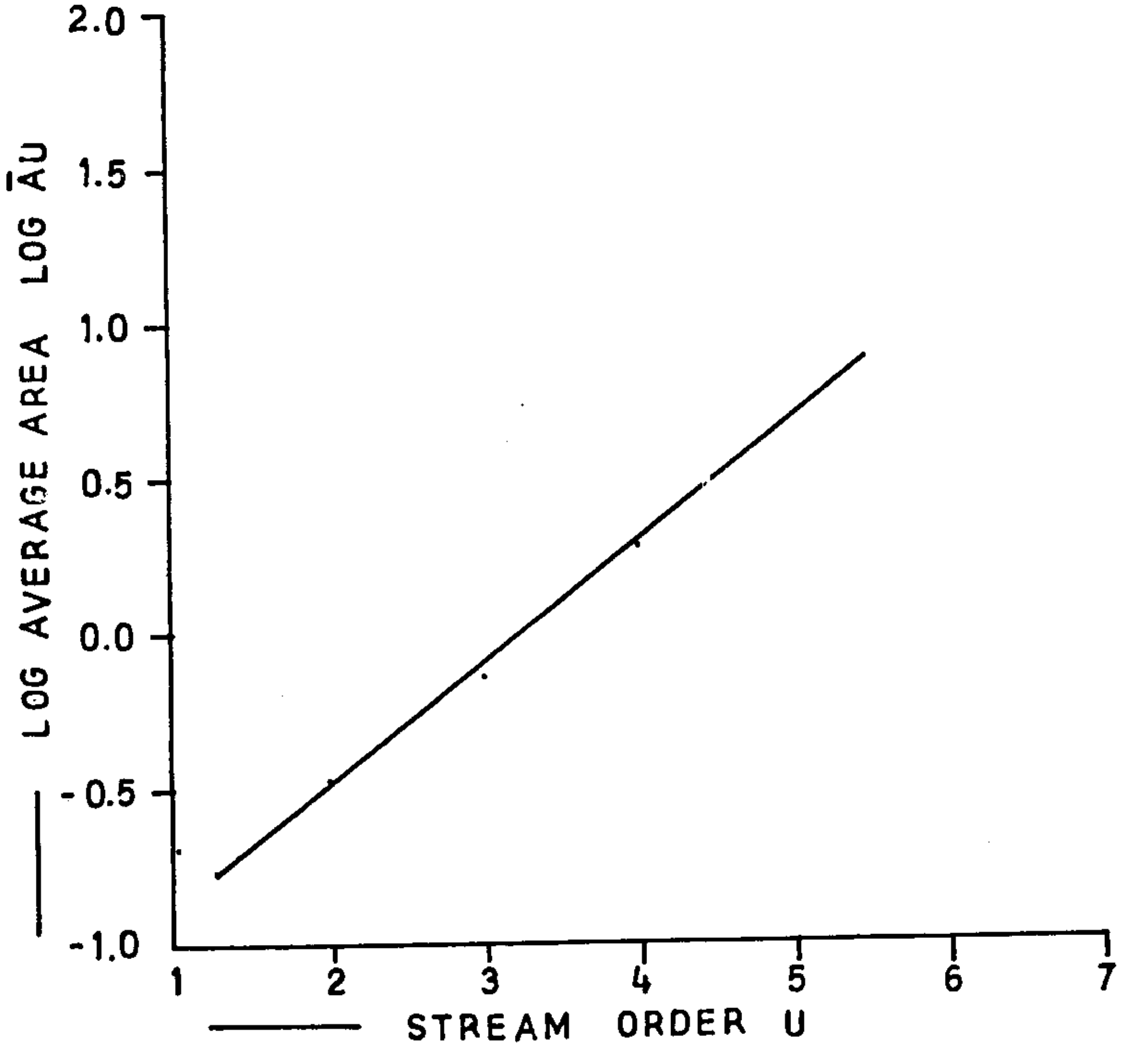


FIG. 15 MEAN AREA Vs STREAM ORDER

6.3 Relief Aspects of Baira Nalla Sub Basin:

The geomorphological parameters, of interest to hydrology, under this aspect has been described in section 5.3 and accordingly these are estimated for Baira nalla sub basin. The results are furnished in Table.4. The relief aspect parameters of the basin which are mostly non dimensional have significant effect on overland flow governing the flow processes.

As discussed in earlier chapter these areal descriptors are of great importance specially for a mountainous catchment like that of Baira nalla to understand the storage and flow characteristics, intensity of erosion processes operating on slope, comparison of basins for hydrograph synthesis etc.

Table.4

1.	Basin Relief, H	3.92 Km
2.	Relief Ratio, Rh	0.26
3.	Relative Relief, Rhp	0.0346
4.	Ruggedness Number, Rn	0.224

7.0 CONCLUDING REMARKS:

In the light of review and discussion on various elements on basin geomorphology, of interest to hydrology in the previous chapters, it is seen that , in absence of adequate data specially in ungauged basins, the measurable geomorphological properties can be applied to synthesize the run off response of the basin. However, in India, not enough successful applications of geomorphological characteristics to specific hydrologic studies in a basin and then transforming the results to other basins have yet been documented .There are, therefore, Many limitations in substituting the results of such applications for more traditional tools of hydrologic methods.

The hydrogeomorphological parameters as suggested by many investigators have been estimated for Baira sub basin from a toposheet manually which is very tedious , time consuming and prone to human error. It is felt that use of a digitiser where basic map data can be quickly, accurately and inexpensively converted into a form of automatic machine a data processing would have been more helpful.

The estimated geomorphological parameters of Baira sub basin covering linear areal and relief aspects as presented in the report , will be helpful in estimating and modeling flow processes of the basin.

In the Baira nalla sub basin there is no existing network of hydrometeorological observations. Now with the estimated geomorphological parameters of the basin it may be possible to develop synthetic Geomorphological Instantaneous Unit Hydrograph or evaluate important hydrologic model parameters like that of Nash Model (Nash,1960).

The geomorphological characteristics of Baira nalla sub basin will provide a simple means to compare it with other basin to regionalise the experimental results.

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DIRECTOR : S M SETH

COORDINATOR : K S RAMASASTRI

STUDY GROUP

B C PATWARY

KAMAL KUMAR

Assisted By : Puran Singh