CHAPTER IV

D R A I N A G E

GENERAL FEATURES

MORPHOMETRIC STUDY OF THE DRAINAGE

DRAINAGE CHARACTERISTICS

GENERAL FEATURES

Lower Narmada River System

The drainage network of the study area that comprises a part of the Lower Narmada Valley is of great significance towards an understanding of the area's geomorphic evolution. The drainage is delineated in the north by the divide (watershed) between the rivers Heran and Unch, while to the south, the divide between the rivers Narmada, Kim and Tapi marks the limit. The eastern divides (watersheds) of the rivers Heran and Devganga mark the eastern limit, and the coastline forms the western limit. All the rivers except Kim, meet Narmada. Kim falls directly into the sea.

The drainage of the area has played vital role in the formation of the various topographical features and has imparted a fascinating diversity to the landscape. This 8090 sq.km hilly to flat terrain is dissected by 52340 streams that fall within 12 river systems. On this 180 km wide and 80 km broad terrain, the Narmada flowing WSW from Hanfeshwar to Hansot forms the principal river, has a 210 km long consequent stream and provides the backbone of the drainage system, comprising 11 main rivers, 25 tributaries and about 95 sub-tributaries. It divides the drainage into two parts, each quite distinct in its nature from the other (Fig. IV 1) :-

i. the drainage to the north of Narmada :

Rivers Heran, Aswan (Ashiwini), Men and Ruwel.

ii. the drainage to the south of Narmada :

Rivers Devganga, Terav, Karjan, Kim, Amaravati, Kaveri and Madhumati. (Fig. IV 1).

The river Narmada enters in Gujarat from the eastern hills, which are the offshoots of Vindhyas and Satpudas, the source of the river is located 800 km away in the Amarkantak hill (1067 m above M.S.L.) in M.P. This course of Narmada lies between the Vindhya ranges on the right and the Satpuda hills on the left, and throughout this distance, the valley of the Narmada is narrow, flanked by mountain ranges on either side, with an average distance of 30 to 45 km and which are nowhere more than 65 km. apart. The last stage of the river which lies within the plains of Gujarat, forms the main drainage of the study area. This part of the river has been designated as the 'Lower Narmada System' which is divisible further in following three parts : (Fig. IV2 i, ii & iii).

i. Hanfeshwar to Garudeshwar : A narrow Valley course of hilly track of about 60 km an almost straight ENE-WSW course made up of a zone of an 'en echolon' faults conspicuous gorge from Hanfeshwar to Surpan within the trappean hilly terrain.

Plate IV 1 A panoramic view of a Narmada meander curve with alluvial terrace (Locality : Tilakwada).

ii. <u>Garudeshwar to Bharuch and Ankleshwar</u> : A 116 km long swinging and meandering course with wide flood plains marked by three conspicuous meander curves and depositional features. (Plate IVI).

iii. <u>Bharuch to Alia bet (Sea)</u> : A 34 km stretch of Narmada showing a funnel shaped mouth, essentially estuarine, marked by the islands of Govali, Kabirvad, Aliabet and others, the braided river course also characterised by sand bars, clay/mud f flats along the mouth and along the coast (Hansot). The Aliabet island, right at the mouth of the river, is about 15 km long and about 20 km broad. Almost oval or boat shaped, all the three islands are of Quaternary age made up of alluvial deposits comprising sand and silt.

The meandering course from Garudeshwar to Bharuch, is characterised by floodplains along the southern bank. These floodplains are 13-15 km wide and their east-west extent is about 75-80 km. These floodplains are surrounded by trappean hills in the east and SE while to the E and SW, these plains abut against the Tertiary sedimentary hills and uplands and the coastal plains respectively. Towards the north i.e. beyond the river Narmada, North eastern rocky to alluvial undulating terrain surrounds the floodplains.

Within the study area the river touches six talukas (Chhotaudeipur, Naswadi, Tilakwada, Sinor, Dabhoi and Karjan) of the Vadodara district on the right bank and five talukas (Nandod, Jhagadia, Bharuch, Ankleshwar and Hansot) of the Bharuch district on the left bank.

The drainage properties of the rivers and their basin components are tabulated in the table IV-1 which gives basic information of the rivers.

Main rivers of Lower Narmada River System

North of Narmada River

The rivers Heran, Aswan, Men and Ruwel which are the northern tributaries of the river Narmada drain the eastern and south-eastern rugged hilly terrain and the western alluvial plains. In general, these follow westerly course, coming down from the altitudes of the order 600 to 700 m to as low as 40 to 50 m to meet Narmada.

Heran River - The northernmost river Heran which is a tributary of Orsang river is the biggest. This 98 km long river has formed an elongated rectangular basin of 1424.7 sq.km area, with a basin length of 84 km and width of 29 km. The basin contains two tributaries viz. Kara and Rami nadis. The trunk stream Heran and the tributaries Kara and Rami, originate in the Panwad - Phulmal, Kawant - Bakhatgrah, Ambadungar and Karipani hills of the east and southeast; other supporting streams are seen to emerge from the isolated hills of Naswadi, Phenai Mata and other hills. In all, the Heran river system has 6929 streams. The river Orsang to which the Heran meets in turn, joins Narmada near Chandod (Fig. IV - 3). Plate IV 3.

Aswan River - The next river to the south is Ashwan. It originates in the Ambadungar and Karipani hills. The 64 km long river has formed 45.08 km wide and 10.95 km broad rectangular basin with an area of about 427.7 sq.km. The east-west oriented basin of Aswan shows an altitude variation from 319 m in the east to 46 m in the west. The river drains the eastern hills of Amba dungar, Karipani, and crosses the Naswadi hills while flowing across the western alluvial plains. The main Aswan stream is about 64 km long and has 4 small sub-tributaries which are in turn supported by 1795 smaller streams (Fig. IV - 4).

Men River - Next to Aswan southward comes the river Men. This 68 km long river has its origin in the Kawant hills, the streams from Amba dungar, Karipani, Kajalmata dungar and Vadgam hills also add their waters to this river. It has a 46 km long and 9.00 km wide basin with an area of about 333.2 sq.km. The basin comprises 2368 streams and this east-west elongated rectangular basin has an altitude range from 414 m in the east to 46 m in the west. The Men river is 4 km longer than the river Aswan and has a smaller basin area, but as the rugged hilly terrain part is larger than the Aswan, the Men river basin has a large number of streams (Fig. IV - 5). Plate IV 2.

Ruwel River - Ruwel river a small tributary of river Narmada, is the fourth river. This east-west coursed river is 29 km long, originating from the Kajalmata Dungar. It is also fed by the streams from Vadgam - Limdi hills, Naswadi hills and other isolated hills. In all, 1419 component streams make up this rectangular basin, which is 28 km wide and 9 km broad and holds an area of about 192.7 sq.km with 565 m maximum and 43 m minimum altitudes from east to west (Fig. IV - 6).

South of Narmada River

The rivers to the south of Narmada constitute two different categories of river basins viz. (i) the rivers and their basins of the eastern hilly terrain and (ii) the rivers and their basins draining the uplands and coastal plains. The rivers Devganga, Terav and Karjan belong to the former category. While the rivers Kim, Amaravati, Kaveri and Madhuvati fall within the latter category.

Devganga river - The Devganga is the easternmost river. It marks the boundary of Gujarat with Maharashtra and the eastern divide of its basin also marks the eastern limit of the study area. The Mal - Samot plateau and its surrounding hills initiate the streams to feed this 36 km long north flowing river. The river has formed a 25.16 km wide and 20.61 km broad oblong/square-shaped basin, holding an area of about 345.6 sq.km with an altitude range of 810 m to 36 m from south to north. The basin consists of 5942 streams; and the prominent sub-tributaries that meet the main stream are Devkhadi (from the south i.e. Mal-Samot and Saribari hills), Som khadi, Kanji khadi and Bhanumati khadi (from the eastern hilly terrain). Geomorphically the Devganga river basin comprises basaltic ridges and hills with intermonst valleys, and a criss-cross drainage network dissecting the terrain to a considerable ruggedness (Fig. IV - 7).

Terav river - Terav, a tributary of Karjan represents a river which drains the eastern and south-eastern hilly terrain of the study area. In the east, Mal-Samot hills, the hills of Dhamanmal Dungar, and Dumkhal-Piplod provide the initial streamlets which combine to form the river Terav proper that flows westward, dissects the trappean ridges and hills by its 65 km long course. This river has formed a 40 km wide and 28 km broad square shaped basin spread over 680 sq.km area of the hilly terrain, the altitude range varies from 688 m to 76 m. The basin is characterised by a very rugged relief, a criss-cross dissection pattern has been developed on account of 9785 streams which support the sub-tributaries like Bogla Khadi, Sankali Khadi, Kaludi Khadi,Panch Khadi and Dhaman Khadi. These streams and Khadis are flowing over the basaltic terrain, and are seen to follow zigzag courses, resembling 'meanders'. But this feature is due to the flow of water

Plate IV 2   River Men : A relatively smaller river but with wide channel and alluvial cliffy banks.

Plate IV 3 The river Heran : Rocky bed and alluvial cliffy banks.

Plate IV 4 River Karjan, flowing within the trappean hilly terrain : The rocky channel shows sharp bends or "Meander" controlled by intersecting joints (Locality : Juna Raj).

along the joints and fractures. The overall drainage network of the basin shows, therefore a rectangular pattern (Fig. IV - 8).

Karjan River - The river Karjan, a subsequent tributary of Narmada has its origin in the Mangrol - Mandvi hills (Wankal Dungar) of Surat district (Southern part of the area). Within the study region, it is one of the biggest rivers (next to Kim river), flowing over the trappean uplands and the alluvial flood plains. A large part of it, is however, restricted to the hilly terrain of the east including high altitude areas of the Mosda-Sagbara hills and the Dediapada uplands. This 105 km long northward flowing river has formed 63.50 km wide and 32.20 km broad basin of 842.9 sq.km area with the altitude range of 300 m i.e. from 345 to 45 m. Mohan khadi, Kanjai khadi and Kukardad khadi are the smaller tributaries that meet the river Karjan. The Karjan basin has 8785 streams which drain the hilly and undulating upland terrain. (Fig. IV - 9). Plate IV 4.

Kim River - The river Kim the longest stream (Other than Narmada, of course) of the study area drains the south-eastern part, and is the only river that does not meet the river Narmada, and flows independently into the Gulf of Khambhat and Motiya, Rajwadi and Wankal dungars of the Netrang uplands provide the source from where the streamlets are generated that initiate the course of the river Kim.

This westward flowing river, supported by about 3030 streams of various orders drains the Netrang uplands and the coastal plains along its 142 km long course. It has formed a basin which is 86 km wide, 27 km broad (in the east) and holds the 1022.5 sq.km area. This narrow elongated rectangular basin has an altitude range from 290 m to M.S.L. As the river flows on a very gently sloping terrain, it is quite sluggish and has carved distinct entrenched meanders on the almost flat terrain of the Tertiary uplands and the alluvial coastal plains. (Fig. IV - 10).

Amaravati river - The Amaravati stream is a tributary of Narmada, to the north of the river Kim and west of the river Karjan. It originates in the Netrang uplands and in the southern part of the Western basaltic hilly terrain and in its Westward journey, it drains the hilly terrain, uplands and the coastal plains in turn, till it meets the river Narmada near Ankleshwar. The Amaravati river basin is 45 km wide, 21 km broad and comprises an area of 396.5 sq.km. The terrain of the basin shows a gradual decrease westward from an altitude of 348 m. to almost 10 m. The total number of streams of the basin is 2686. Crossing the undulating uplands and gently rolling coastal terrain, 85 km long river course is quite zig zag due to meanders which show entrenchment of 3 to 8 m. (Fig. IV - 11).

Kaveri river - Kaveri perhaps the smallest river of the study area, is a tributary of the river Narmada, has its origin in the Asnavi and Vadkhuta dungars and drains the Kadvali uplands before meeting Narmada near Jhagadia. The river is 34 km long and its drainage network consists of 739 streams within a basin area of about 164.1 sq.km. The basin itself is 27 km long and 7.33 km broad. The highest altitude of 288 m is in the east and the lowest altitude is 15 m in the west. It is seen to flow for the most part over an almost flat low gradient terrain, this causing it to follow a very sluggish zig zag and entrenched course (Fig. IV - 12).

Madhuvati river - River Madhuvati another tributary of Narmada, originating from the western hills, flows westward through Kadvali uplands and the coastal plains. Its basin has an areal extent of 167.86 sq.km with the length and width being 24 km and 8 km respectively. The river has 42.38 km long course and its rectangle shaped basin consists of 2016 streams and shows an altitude decrease from 274 m in the east (in the western hills) to 14 km in the west. Again on account of the low gradient of the flat terrain that it drains, the river course is zig zag with entrenchment on the uplands and on the coastal plains. (Fig. IV - 13).

General Characters of the Drainage

The existing drainage exhibits a wide diversity caused by varied combinations of topographic features, geological factors (rocks, faults, joints, eustasy and neotectonism) and geomorphic factors (slope condition, erosion and deposition etc.). In a general way, it can be stated that most of the major streams are tributaries or sub-tributaries of the river Narmada. The regional flow trend is from east to west, and is essentially slope controlled. Originating in the hilly trappean terrains of the east, the streams of different dimensions flow slopeward i.e. either due NW or due West. Once these emerge out of the hills, and start draining the uplands and the coastal plains, they shown an abrupt drop in the velocity. It is so significant to observe that on account of this phenomenon, the headward portions of the streams flow rapidly while their courses over gradientless uplands, are sluggish. The flow direction is also dependent on the occurrence of the linear E-W ridges and an anticlinal uplifts, which guide the direction of stream courses.

The entire drainage is characterised by an interesting combination of structural control and lack of slope, due to which, most of the streams are seen to show significant meandering. The study has shown that the abundance of curves and loops along the stream courses is controlled by the following two entirely unrelated factors :

1. In the upper reaches of the streams, where they flow within traps, their courses tend to become 'zig zag' because they flow along numerous joint sets oriented in different directions. This resembles meandering. (Plate IV

2. In the uplands and the coastal plains, the streams flow over a surface which has very low gradient, and the surface rocks are soft. The lack of gradient is responsible for meandering, while the neotectonic uplifts/ sea-level changes, have caused vertical incision of the meandering courses.

The various river systems provide a variety of drainage patterns. Even an individual river, on emerging from the eastern hills and flowing over the western plains, typically show marked variation in the pattern because of the diverse conditions of slope, structure and lithology prevailing in the different parts of the stream course. The radial, parallel and rectangular drainage patterns are normally observed on the ridges, hills, plateaus and uplands. The trellis and modified trellis patterns are seen developed from the parallel and rectangular drainage and are most common on the foothills, uplands and plains. Towards west, the floodplains and alluvial plains show trellis and dendritic drainages. In general, these are modified from rectangular pattern. So normally, radial, parallel, rectangular and parallel rectangle drainage patterns characterise the elevated rugged terrain while low altitude undulating flat terrain show a modified rectangular, trellis and dendritic drainage patterns.

Longitudinal Profiles

The longitudinal profile of a stream is a graph showing 'Distance versus Elevation', and is a function of the following variables :

1. Discharge.
2. Load (delivered to the channel).
3. Size of debris.
4. Flow resistance.
5. Velocity.
6. Width.
7. Depth.
8. Slope.

The control exercised by these variables is reflected in the relation between the fall in elevation and the distance along the channel. The gradient of the longitudinal profile also shows the control of structure and lithology.

From 1 : 50,000 scale maps, elevation and distance of the channels of 12 rivers and 10 tributaries were measured. The profiles were drawn on the basis of the relative relief and horizontal extent of the river channels. Longitudinal profiles (vertical scale 1 cm = 50 m, horizontal scale 1 cm = 5 km). The various profiles are shown in (Fig. IV - 14, 15 i, ii, iii).

From the profiles, relief ratio and the gradients for each stream were computed and tabulated (Table V - 2). Considering the data from the 22 longitudinal profiles, the following gradient data has been obtained :-

Gradient range	-	0°-13' to 1°-90'
Average gradient	-	0°-64'
High gradient	-	above 1°-00'
Low gradient	-	below 0°-50'

The longitudinal profiles have been examined in the light of the following basic laws expressed by Hang (1907) as given by Fairbridge (1968).

Law 1. "The deepening process of a river by the flow of water takes place from its mouth upstream leaving a fixed point at the base of the slope, which is base level. Its movement is thus regressive" (i.e. erosion is headward and downward, but there is no erosion at base level, the principle of headwards regression).

Law 2. "The Longitudinal profile leaves base level in a regular curve. This curve is concave towards the top and tangential to the horizontal in its lower section, and upstream it trends sharply upward so that it becomes tangential to the vertical.

Both the above laws are fully substantiated by the profiles of the study area. Obviously, the erosion in the head water area is more vigorous than it is downstream and the erosive channels are concave towards the top.

The profiles were also examined in terms of slope conditions, nature of the curves and the confluences of the tributaries and the main river Narmada. In general the 'L' profile curves of the streams are concave towards the top and horizontal (very gentle) towards the base (ground). The curves of the different streams and rivers indicate the following :

1. The curves point to low to average gradients. The rivers have initially concave curves and downwards they become horizontal, pointing to alluvial channels in the stage of deposition. The rivers Heran, Ashwan, Men, Karjan, Kim, Amaravati, Kaveri and Narmada fall into this category.

2. The curves have a tendency to show an overall high gradient and also have a tendency to, concave almost to vertical towards the top (sky), but show tangential curves towards the base. This tendency is observed in profile curves for the rivers Devganga, Terav, Ruwel, Madhuvati and in many tributaries (of the river Heran, Terav and Karjan). This is indicative of more vigorous erosion in the headwater areas as compared to the downstream portions; the entire length however comprise erosive channels. Such vertically steep concave curve channels are characteristically seen to rise from high altitudes (between 500 m and 800 m) and impinge upon uplands within a short distance.

An interesting feature of the most of the river profiles is the nature of the confluence of their tributaries. Except Kim, all the other rivers meet Narmada, and their various tributaries rise from the altitudes higher than those of the main rivers starting points. Whereas the Kim that

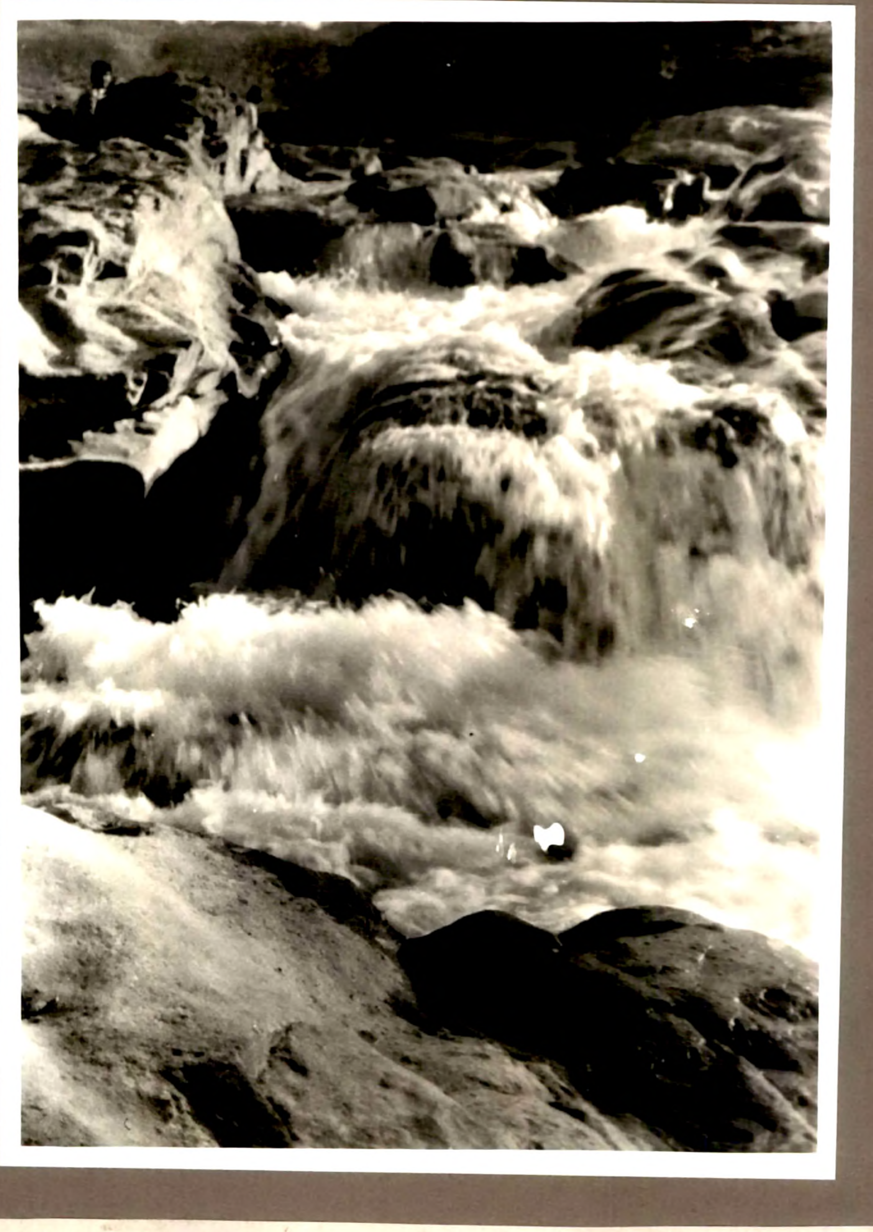


Plate IV 5 A typical waterfall in Dhaman khadi a tributary of Terav, showing a drop of 5-7 m (Locality : near village Ghantoli).

meets the sea directly is characterised by tributaries rising from altitudes lower than that of the Kim river.

The breaks in the profile are a common phenomenon in the curves of the rivers Heran, Kara, Men, Terav, Karjan, Kim, Amaravati, Madhuvati and Narmada. Even the tributaries of the rivers Devganga (Som khadi, Kanji khadi), Terav and Karjan also show the breaks in the curves (profiles). Obviously these breaks in profiles mark the abrupt change in slope and in levels. These breaks, or drop in the stream profiles are of the order 3 to 5 m or 8 to 12 m and are mostly confined to the upstream parts, usually observed in the terrain above 300 m altitudes. These breaks, normally forming waterfalls in the trappean terrain are due to the joints and fractures across the stream paths. Plate IV 5

MORPHOMETRIC STUDY

The overall drainage characteristics and pattern of stream network reflect the surface and subsurface conditions of the terrain. An analysis of drainage thus provides important clues towards visualisation and reconstruction of the geomorphic history of the region. The drainage analysis of the study area has thus not only helped in understanding the stages of the fluvial cycle through analysis which the rivers are passing. The main purpose of the drainage analysis however is to establish the correlations between the drainage characteristics and those of the slope of a landscape which shows the control of lithology, structure and slope.

Appropriate morphometric methods have been used to analyse the drainage systems, patterns and basins; and the various parameters and drainage characteristics of twelve basin have been analysed.

The present author has followed Horton (1945) and Strahler (1952), in his morphometric analysis. It was Horton (1945, p.280) who demonstracted that enough hydrological measurements were available to quantify the description and theories of developing river networks and drainage basin and its stream - channel system required measurements of linear aspects of the drainage network, areal aspects of the drainage basin, and relief (gradient) aspects of channel network and contributing ground slopes.

The available channels network on the map including all intermittent and permanent flow lines located in clearly defined valleys are taken into consideration. The smallest fingertip tributaries have been designated as order 1; where two first order channels join, a channel segment of order 2 is formed; where two of order 2 join, a segment of order 3 is formed and so forth. The trunk stream through which all discharge of water and sediment passes, is the stream segment of highest order. The drainage network of the study area has been mapped and analysed from the Survey of India Topographic sheets of scale 1" = 1 mile or 1 : 50,000. In all streams of twelve basins have been organised orderwise and the relevant geometric measurements carried out and analysed as per the Horton's Laws.

The author, for the purposes of drainage analysis, following measurements were carried out :-

1. Stream components in the basin - Number of streams of different orders.

2. Measurement of stream - length of different orders.

3. Measurement of basin area of all the streams of different orders.

4. Measurement of slopes of stream channels of different orders.

Horton's(1945) proposed Laws of drainage composition listed below assume an orderly development of the geometrical qualities of the drainage system :

1. The law of stream numbers, is stated as follows : "The numbers of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and the ratio is the bifurcation ratio.

2. The second law concerns stream lengths : "The average lengths of each of the different orders in a drainage basin tend closely to approximate a direct geometric series in which the first term is the average length of streams of the first order."

3. Horton's third law states : "There is a fairly definite relationship between slope of the streams and

order, which can be expressed by an inverse geometric series law."

4. A fourth law of drainage composition formulated by Horton as : "The mean drainage basin areas of streams of each order tend to approximate closely a direct geometric series in which the first term is the mean area of the first order basins. It could be assumed that such a relationship would exist if there were any connection between the length of a stream and the size of its drainage basin.

The morphometric analysis of the drainage of the study area, has taken into account with the above laws.

Following parameters and variables have been taken into consideration :-

1. Total number of streams of all orders N_u (N_u).
2. Total length of streams in the basin - L in km mean length ratio R_L in km.
3. The ratio of number of streams (segments) of a given order N_u to the number of streams of the higher order $N_u + 1$ termed as the bifurcation ratio $R_b = N_u \div N_u + 1$.
4. Basin length (maximum length parallel to main river) in km L_b and basin width in km Br.
5. Basin area in sq. km A_u.

6. Basin perimeter in km P.

7. Basin outline form ratio (Schumm 1956), can be made through a form factor which is the dimensionless ratio of basin $R_f = A_u \div L_b^2$.

8. A dimensionless circularity ratio (Miller, 1953), p.8 defined as basin area to the area of a circle having the same perimeter as the basin $R_e = A_u \div P$.

9. An elongation ratio (Schumm 1956), p.612 defined as the ratio of the diameter of a circle of the same area as the basin, to the maximum basin length $R_e = P \div L_b$.

No. 5 to 9 show and explain the shape of the basin).

10. Drainage density $D = L \div A_u$ km length in unit sq. km.

11. Stream frequency $F = S_u \div L$ number of streams in unit km.

12. Texture ratio, (Horton 1945), A related texture measure is the length of overland flow, the distance over which runoff will flow before concentrating into permanent drainage channels. The length of overland flow equals the reciprocal of twice the drainage density texture ratio $T_u = N_u \div P$.

13. Constant channel maintenance (Horton 1945), the ratio represent in sq. km the area required to

maintain 1 km of drainage channel.

(C = 1 $\div$ D (Sq. km per km)

14. Relief ratio (Schumm 1956) p.612 , measures the overall steepness of a drainage basin (and is an indicator of the intensity of erosion processes operating on slopes of the basin) - maximum basin relief (H = maximum height - minimum height) to maximum length of the basin.

$R_h = H_{(m)} \div L_b$

15. Ruggedness number (Horton, 1945, Schumm, 1954). Slope steepness and length, this dimensionless number is the product of relief and the drainage density,

$R_n = D \times H \div 1000$

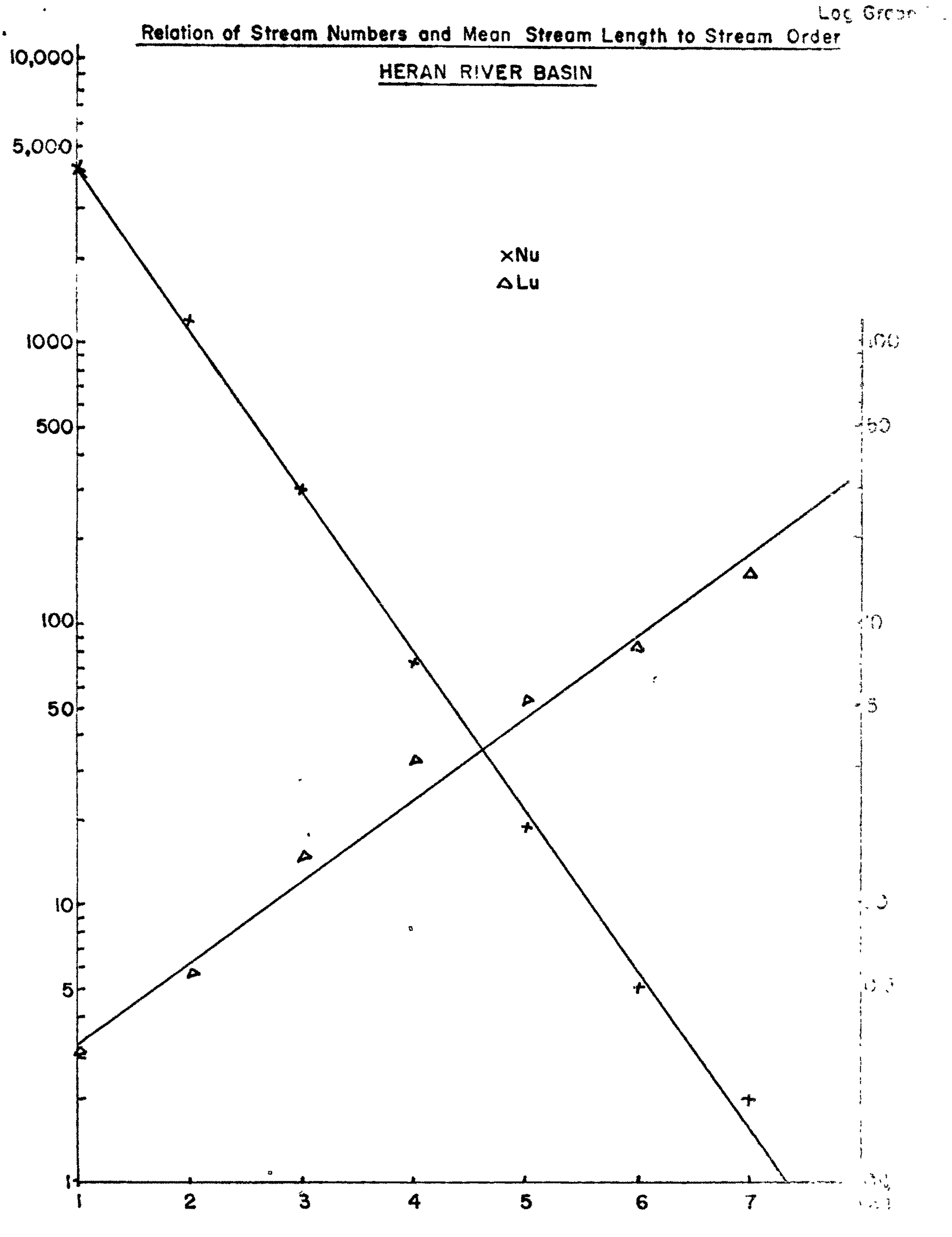
The above 15 parameters of each basin were obtained which are given in the Table (IV.1) and (IV.3).

From the table, the various morphometric parameters like Number of streams (orderwise), Mean stream length, stream basin area, and stream (Channel) slope, are used to show the correlation among the following two relationships :

i. Relation of stream Numbers and Mean stream Length to stream Order.

ii. Relation of stream slope and stream Area to Stream Order.

Twenty two log-graphs are prepared to show these correlations (Log graph IV 1 to 11 a.b).


Log Graph
Relation of Stream Numbers and Mean Stream Length to Stream Order
HERAN RIVER BASIN
×Nu
△Lu
10,000
5,000
1000
500
100
50
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1
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4
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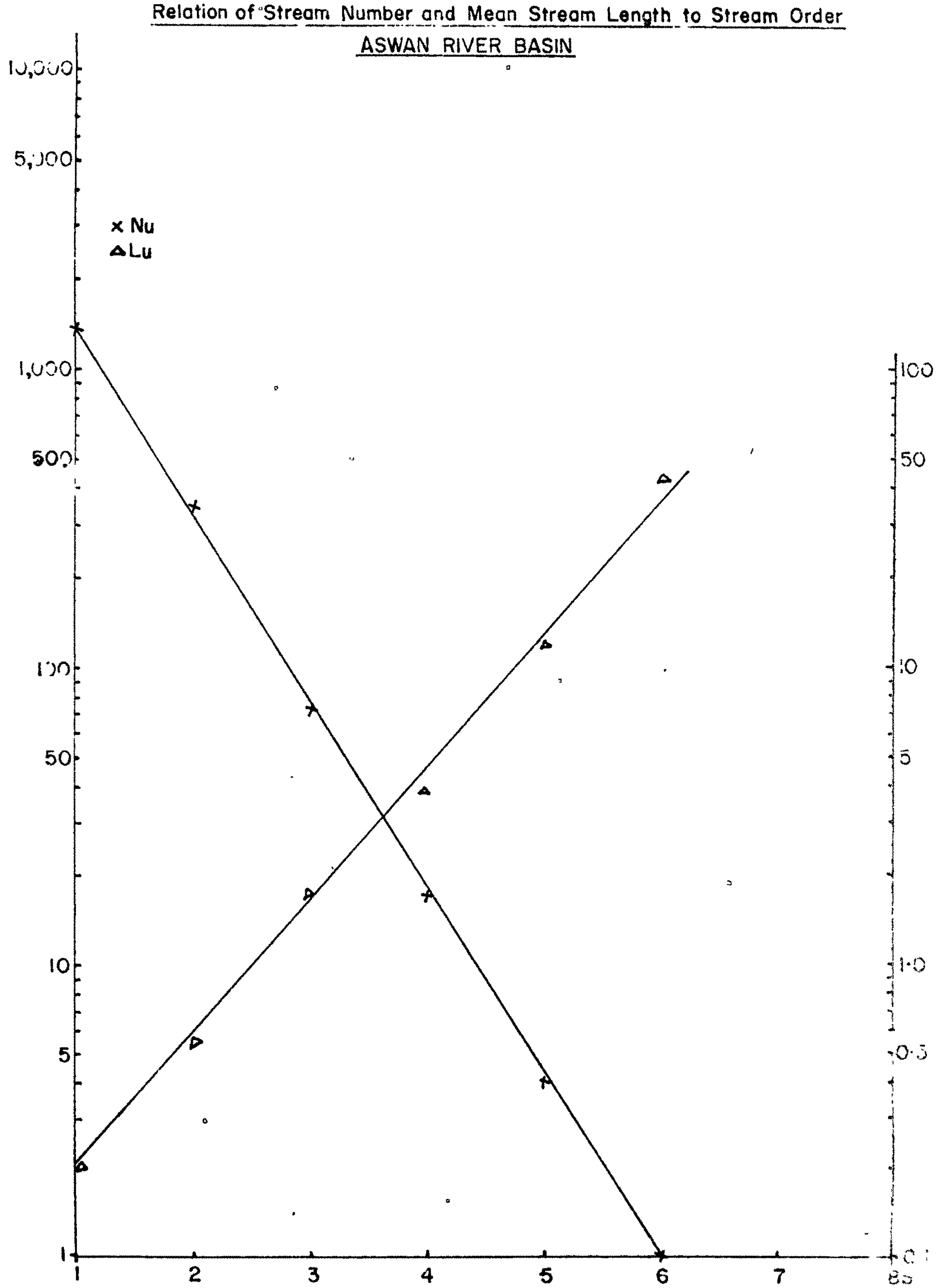
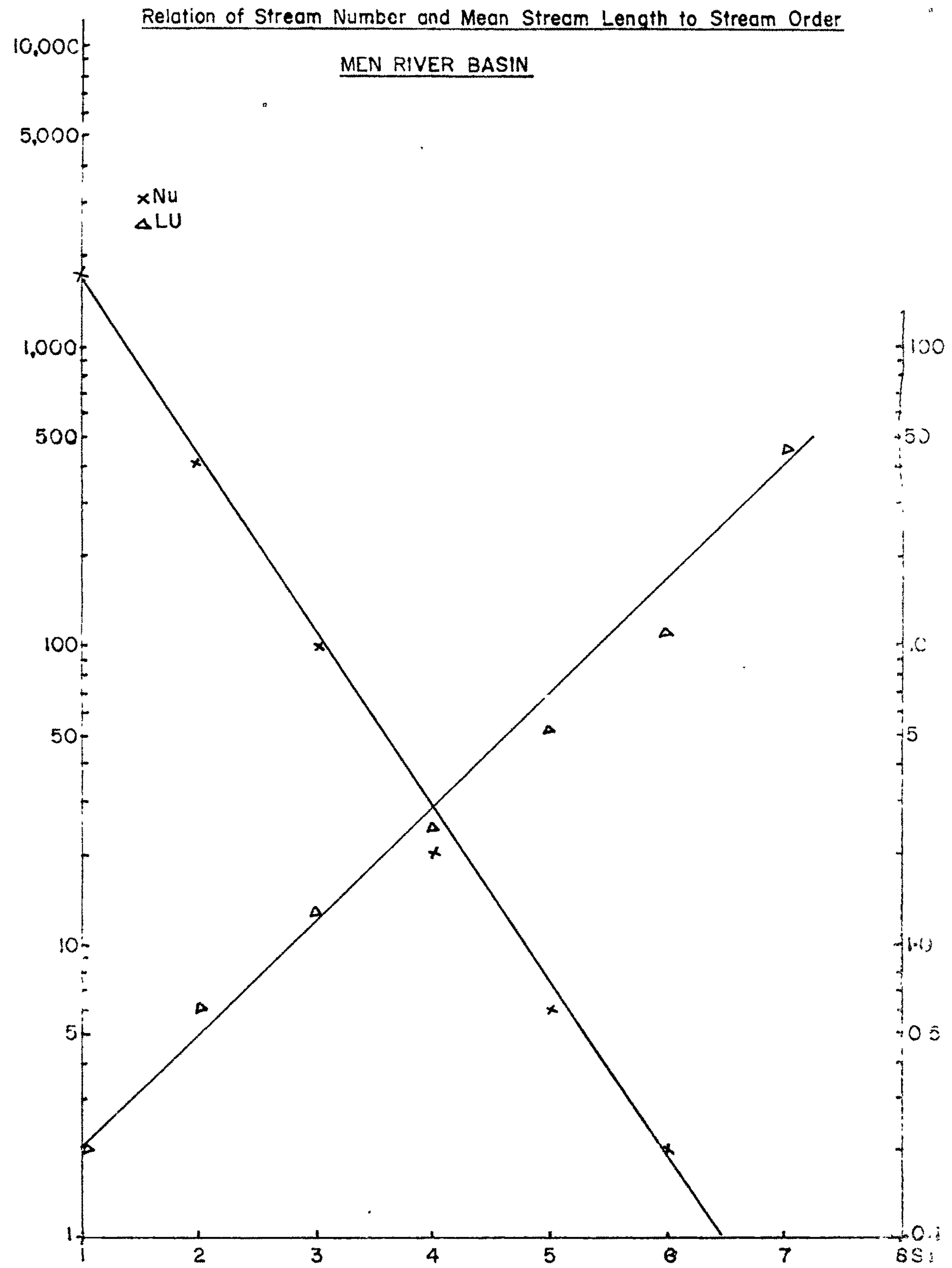
6
7
100
50
10
5
1.0
0.5

Log Graph III 2




Relation of Stream Number and Mean Stream Length to Stream Order
MEN RIVER BASIN
×Nu
△LU
10,000
5,000
1,000
500
100
50
10
5
1
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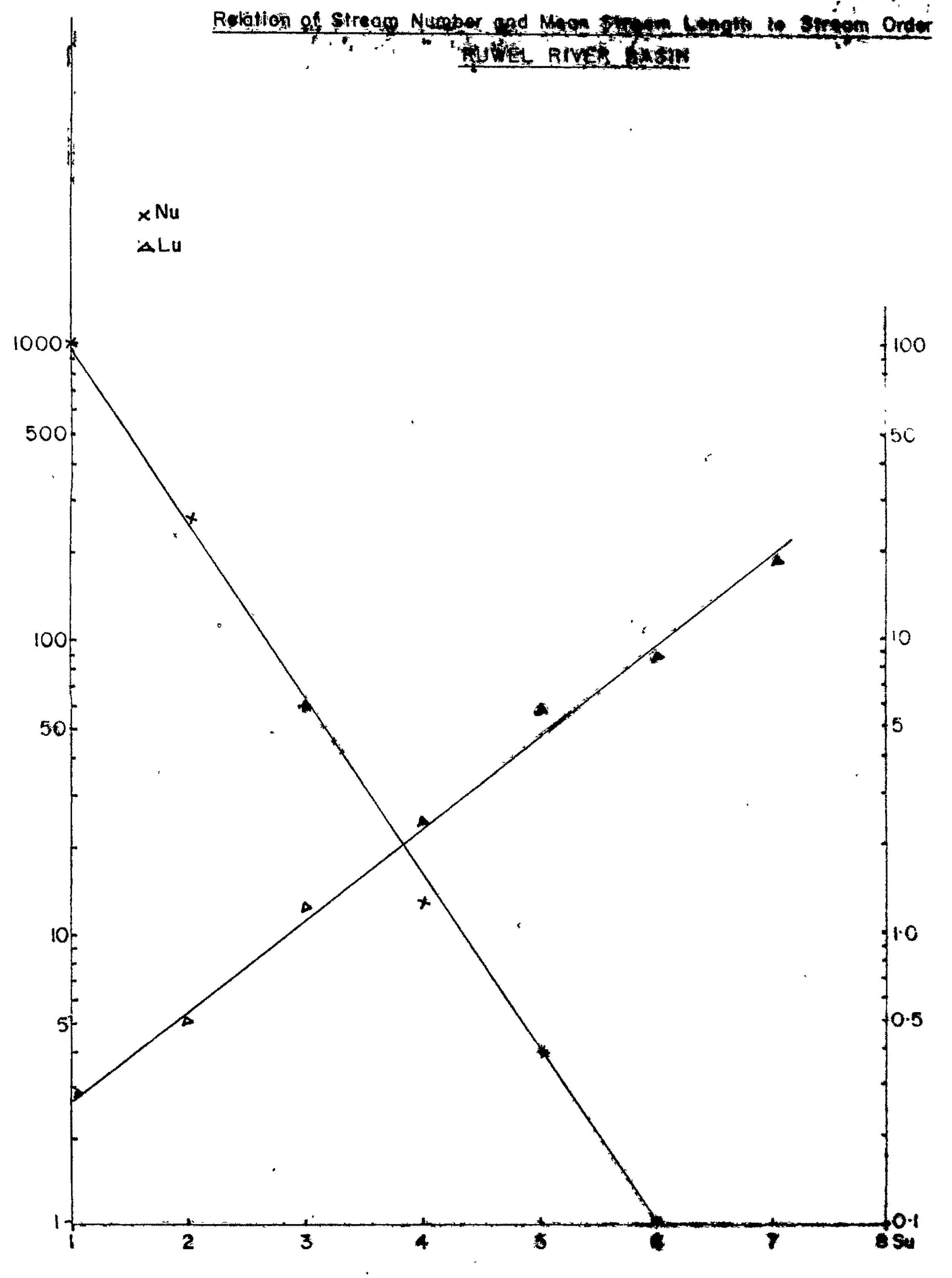
6
7
8

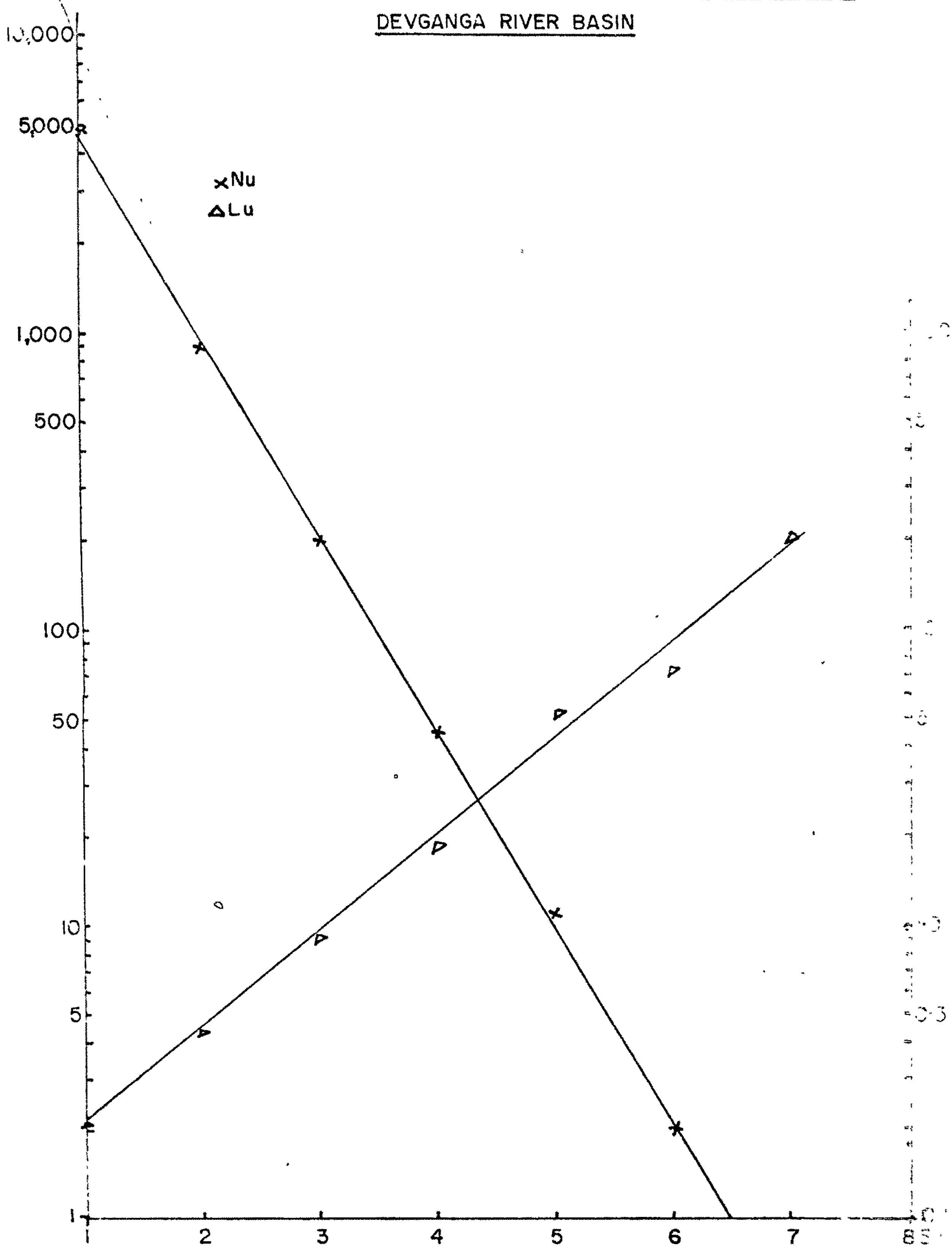
Log Graph IV 4 (a)



Log Graph

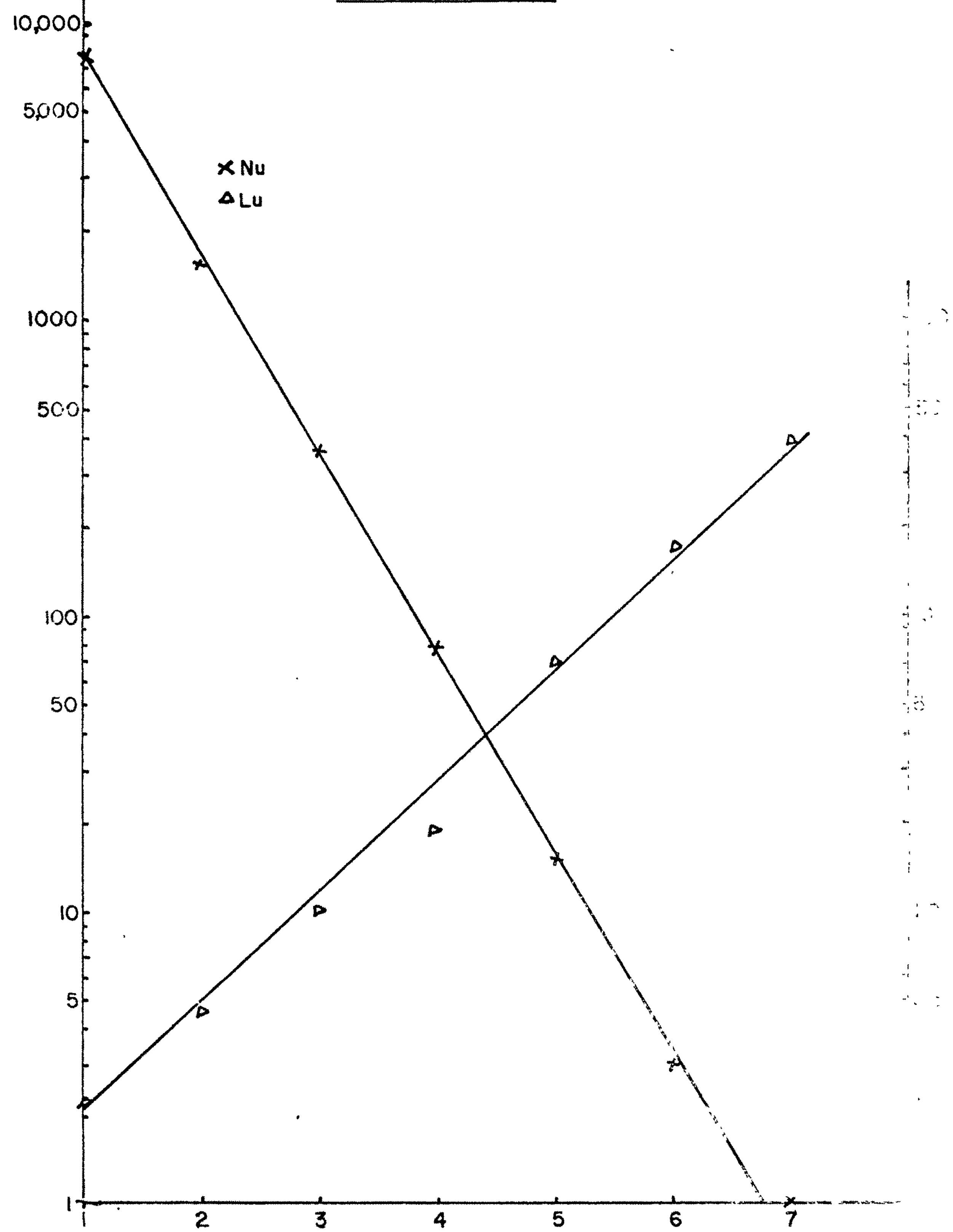
Relation of Stream Number and Mean Stream Length to Stream Order

DEVGANGA RIVER BASIN



Relation of Stream Number & Mean Stream Length to Stream Order

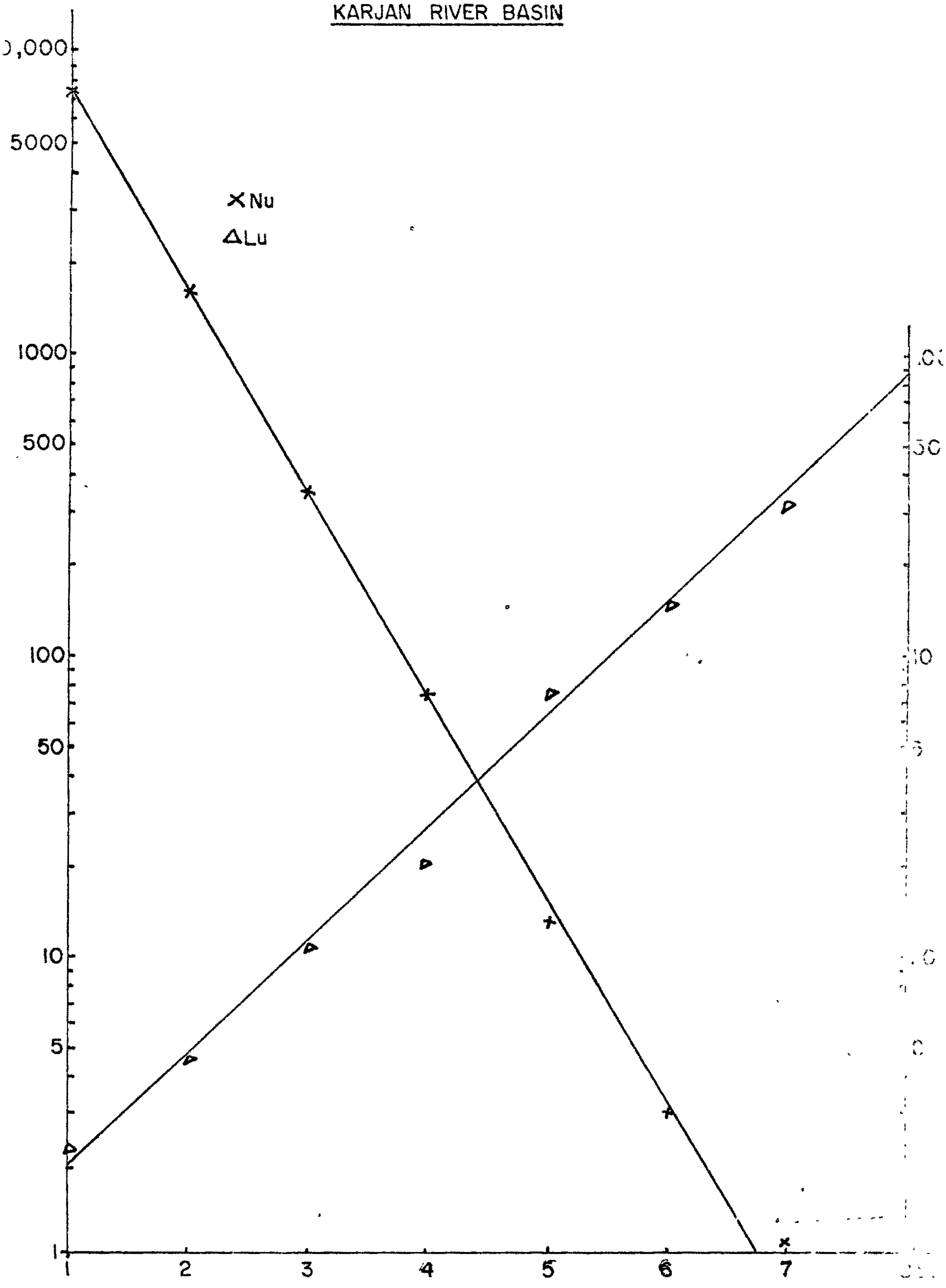
TERAV RIVER BASIN



Log Graph

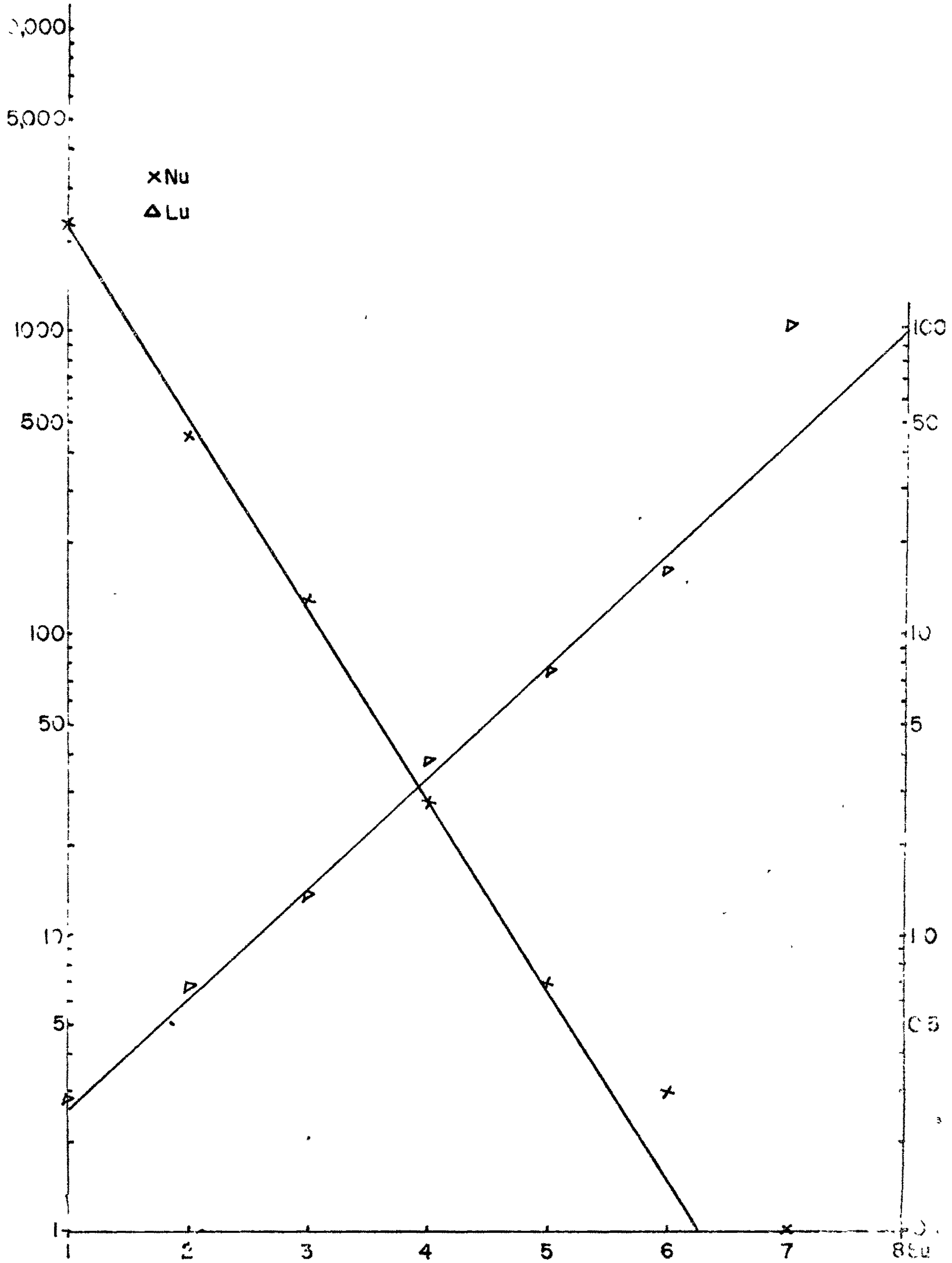
Relation of Stream Number & Mean Stream Length to Stream Order

KARJAN RIVER BASIN



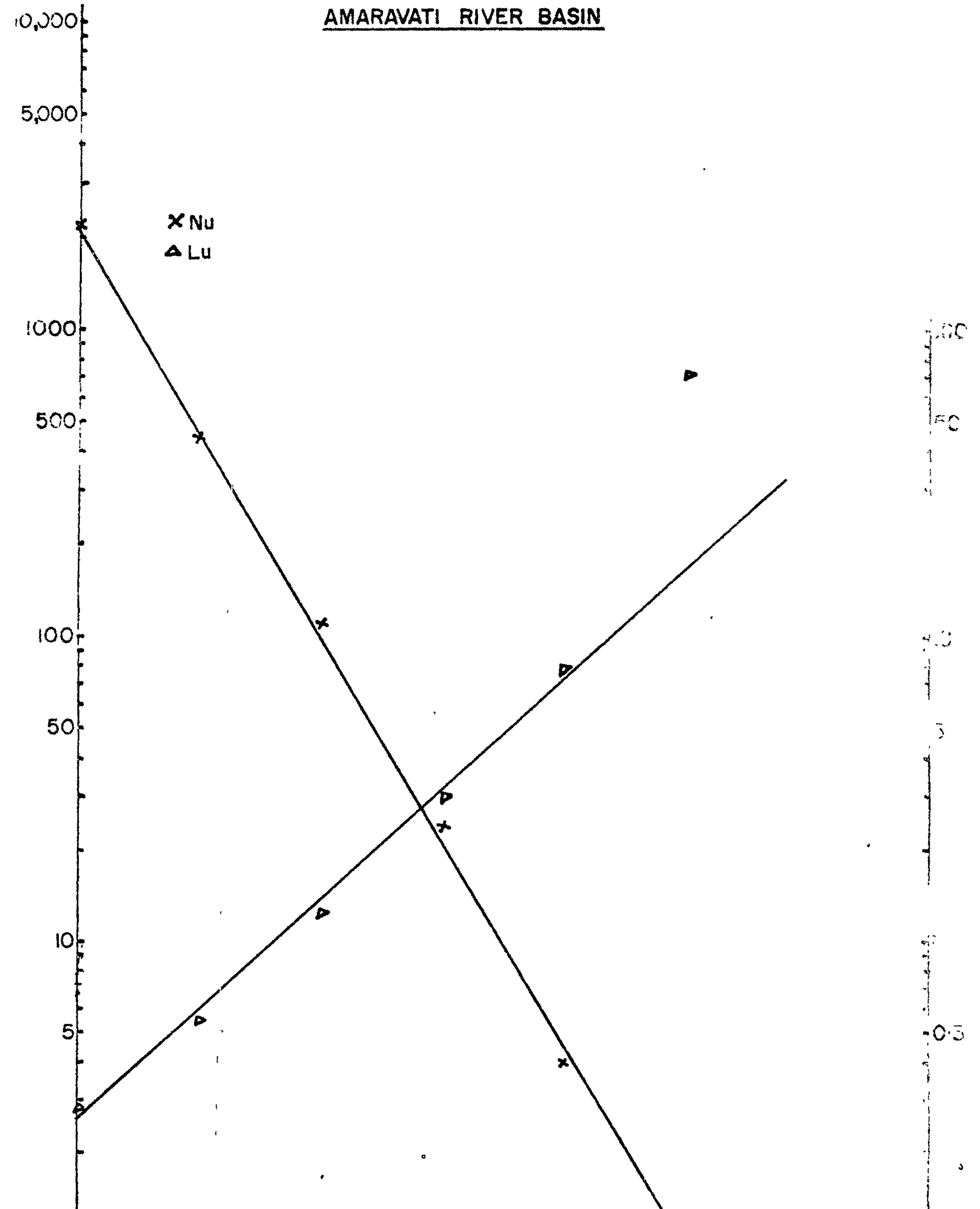
Relation of Stream Number & Mean Stream Length to Stream Order

KIM RIVER BASIN

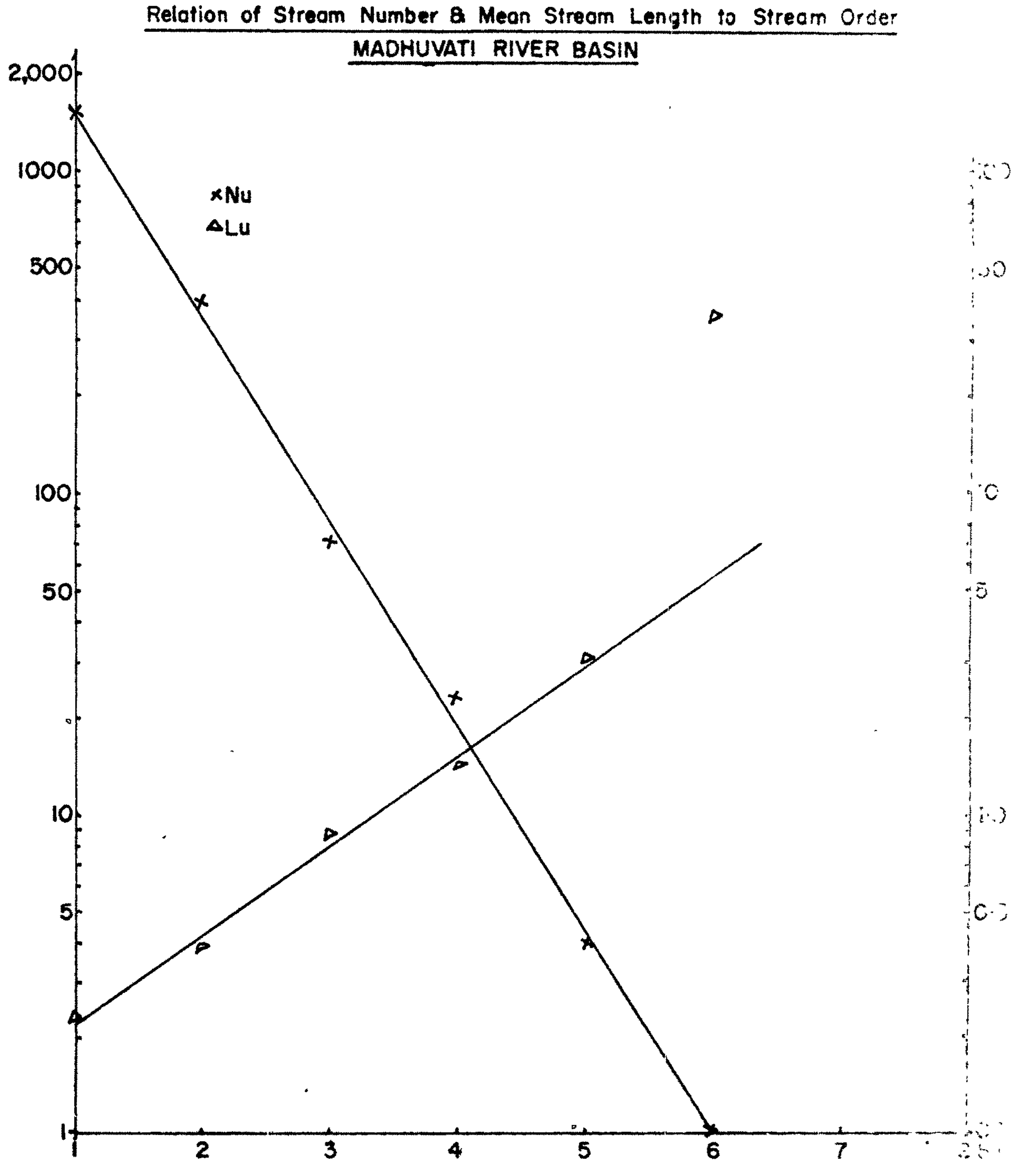


Relation of Stream Number & Mean Stream Length to Stream Order

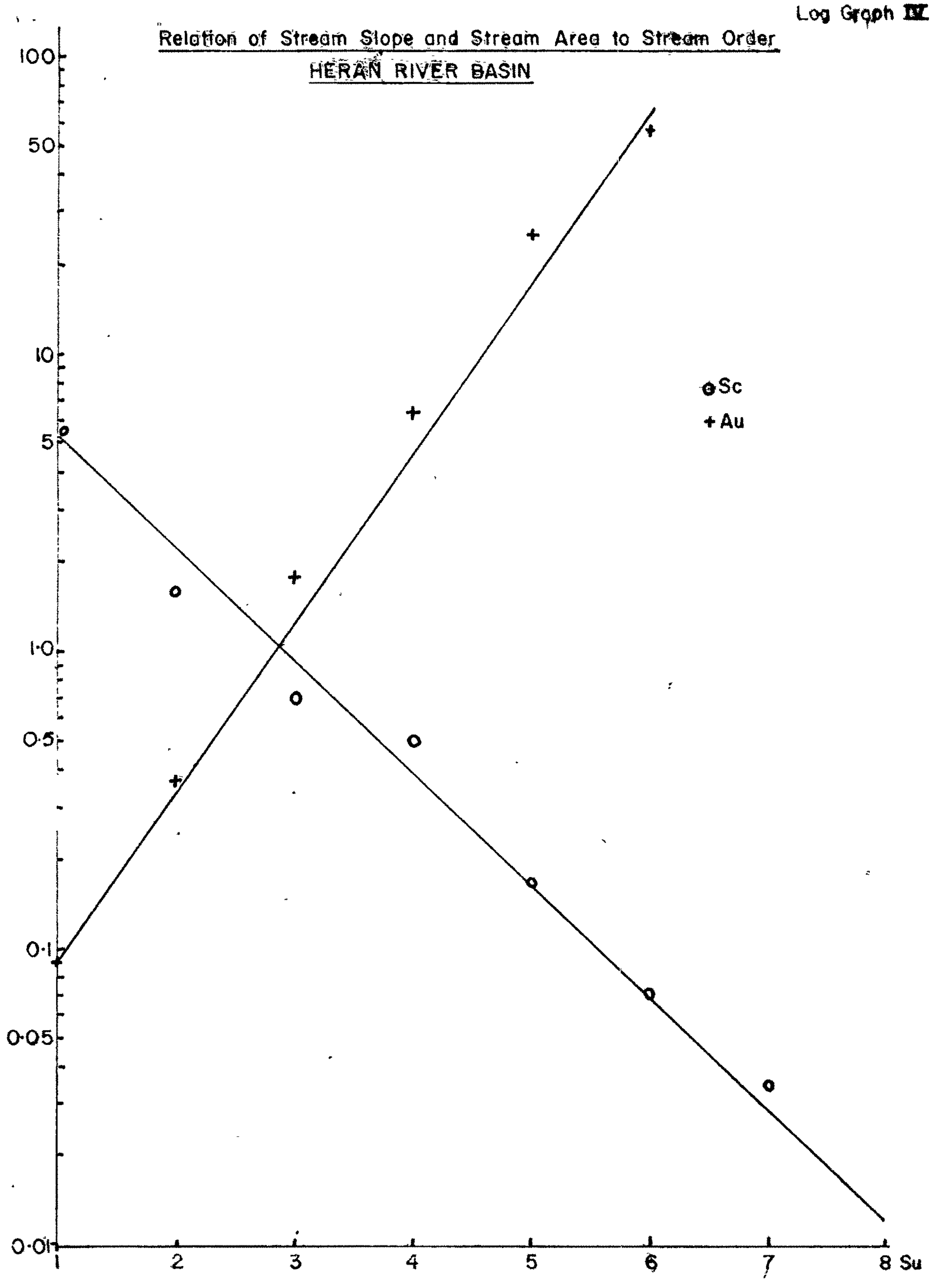
AMARAVATI RIVER BASIN



Log Graph IV (c)

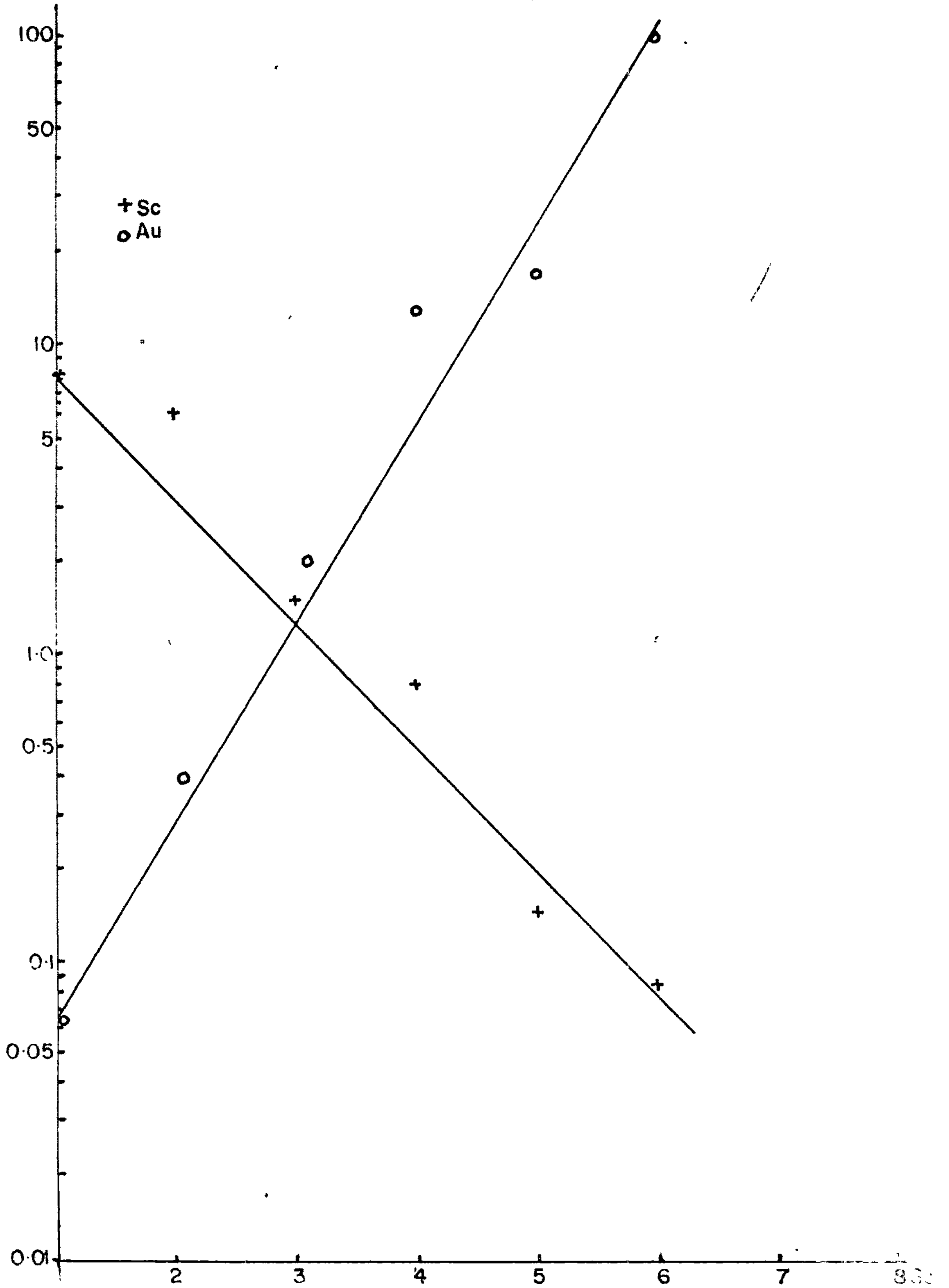


Log Graph IX (b)



Log Graph

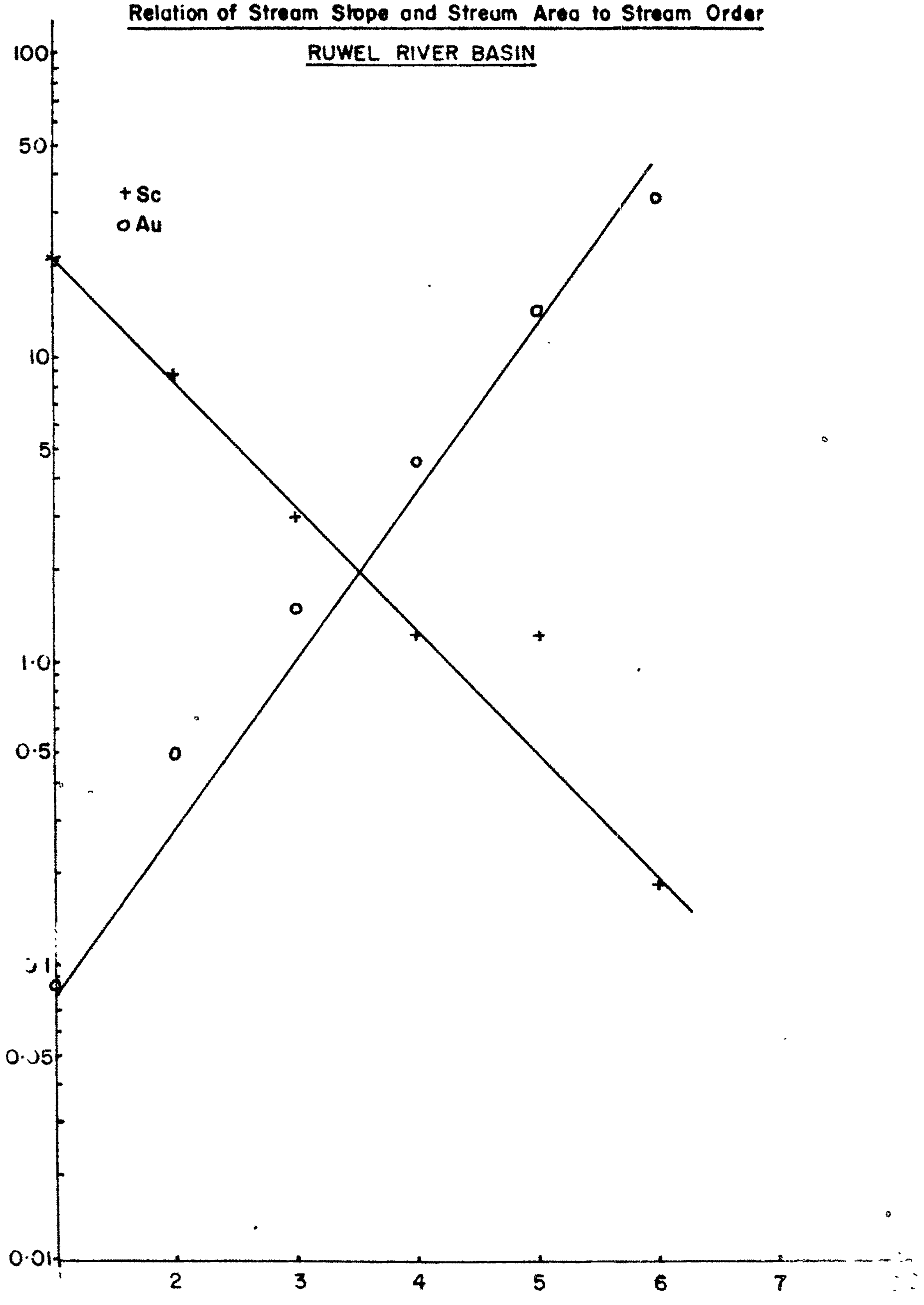
Relation of Stream Slope and Stream Area to Stream Order
ASWAN RIVER BASIN



Log. Graph IV.4(-)

Relation of Stream Slope and Stream Area to Stream Order

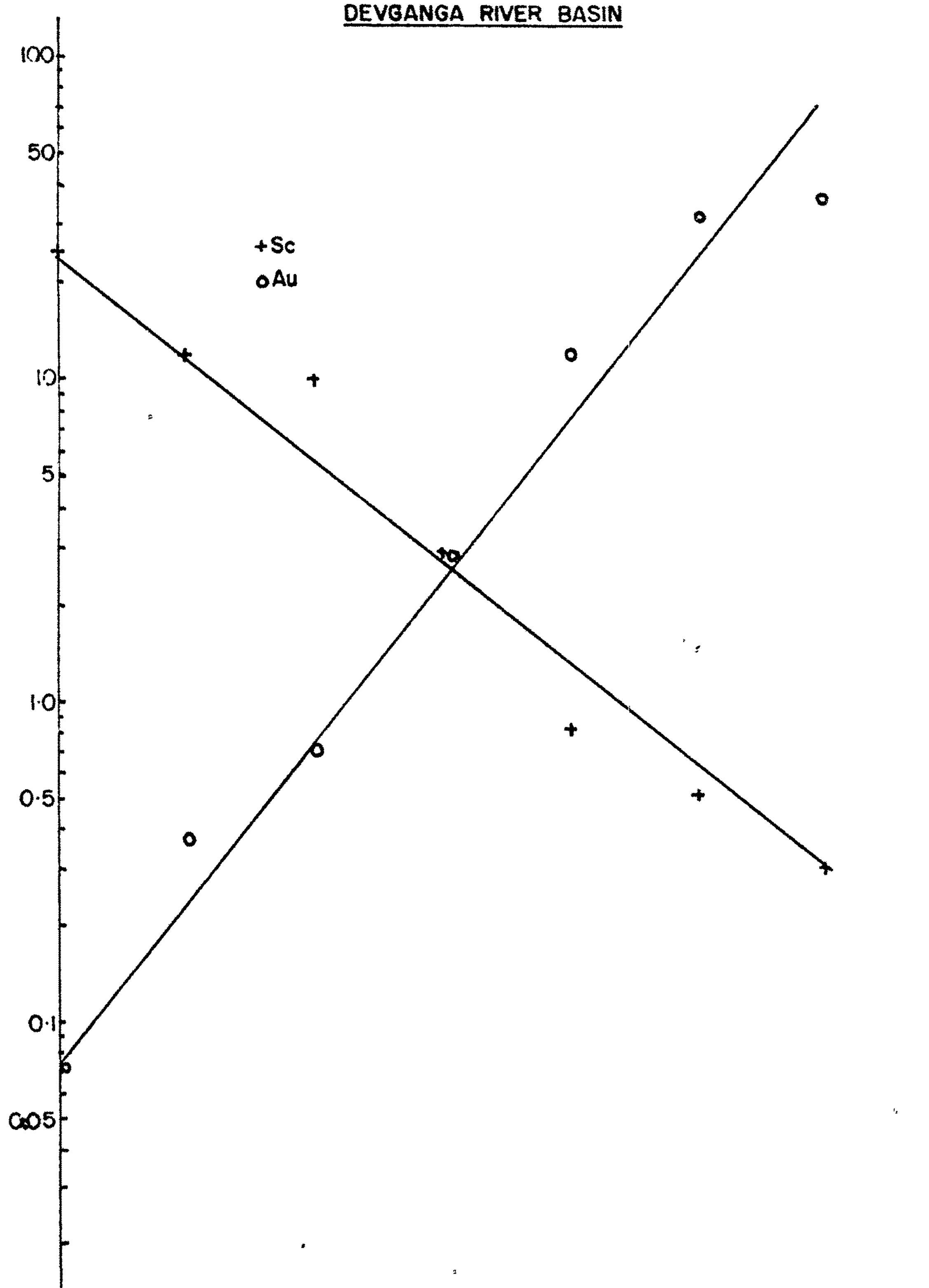
RUWEL RIVER BASIN



Log Graph IV 5 (b)

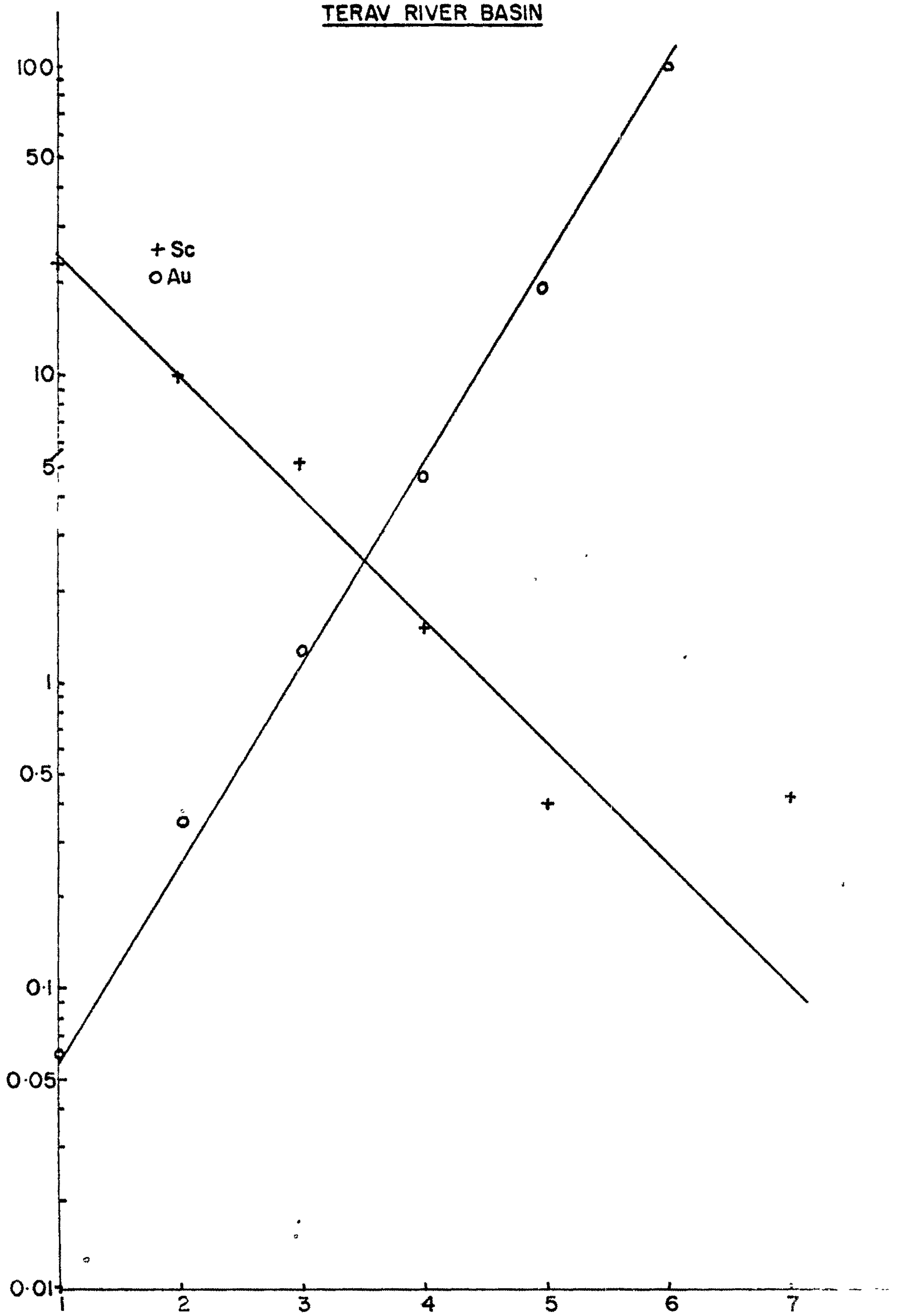
<u>Relation of Stream Slope and Stream Area to Stream Order</u>

<u>DEVGANGA RIVER BASIN</u>

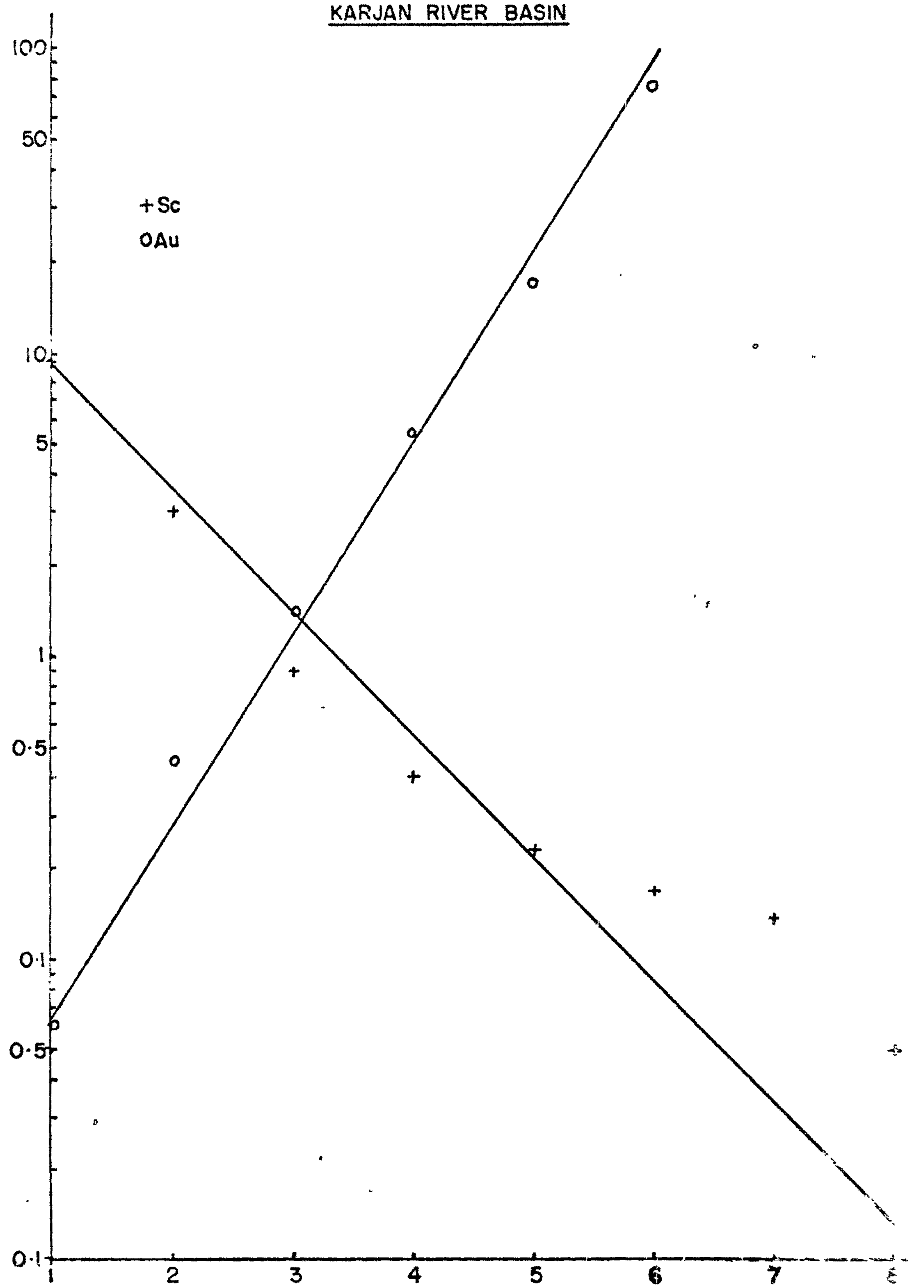


Relation of Stream Slope & Stream Area to Stream Order

TERAV RIVER BASIN



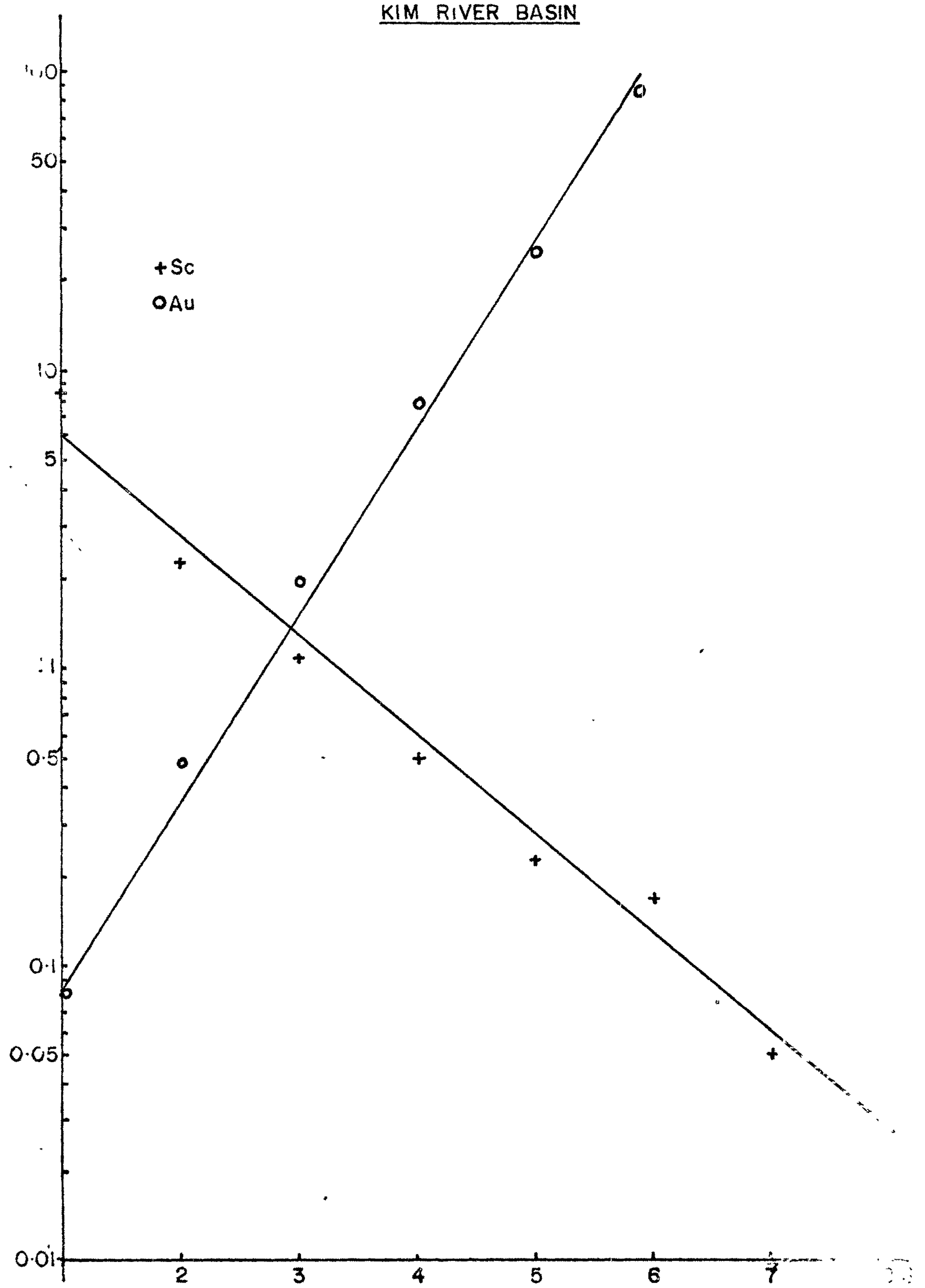
Relation of Stream Slope & Stream Area to Stream Order
KARJAN RIVER BASIN



Log Graph IV 8 (b)

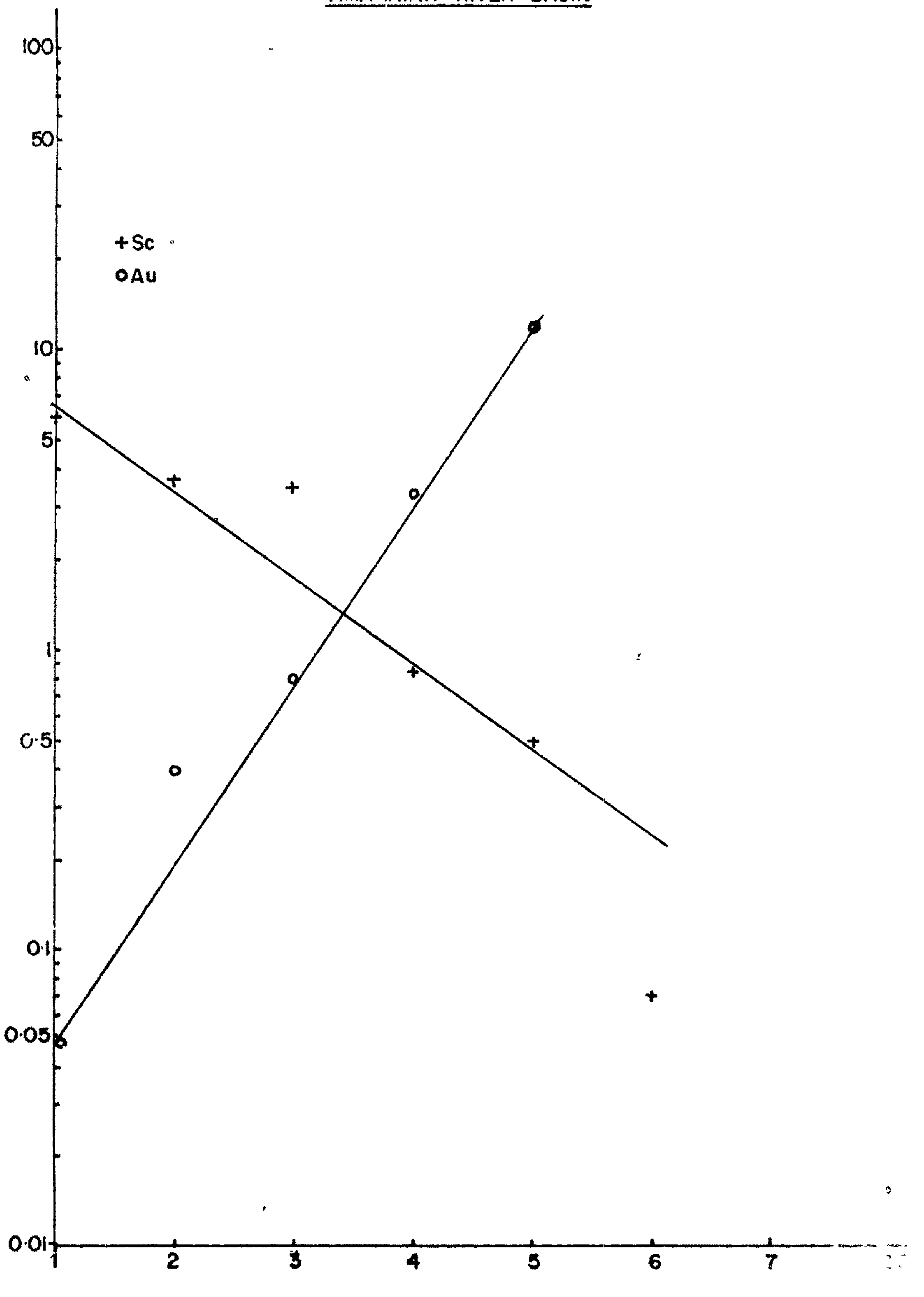
<u>Relation of Stream Slope & Stream Area to Stream Order</u>

<u>KIM RIVER BASIN</u>



Log Graph

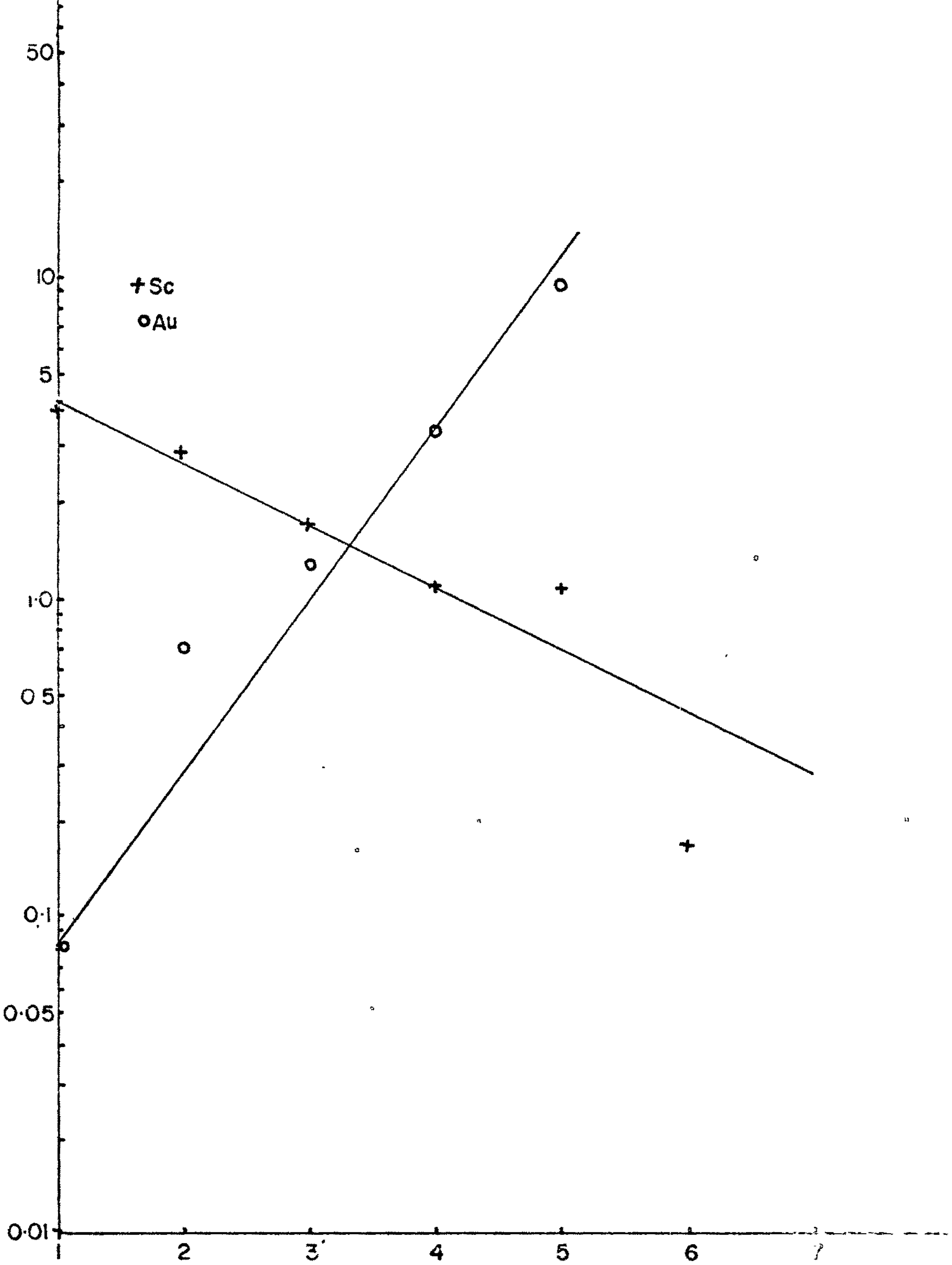
Relation of Stream Slope & Stream Area to Stream Order
AMARAVATI RIVER BASIN



Log Graph

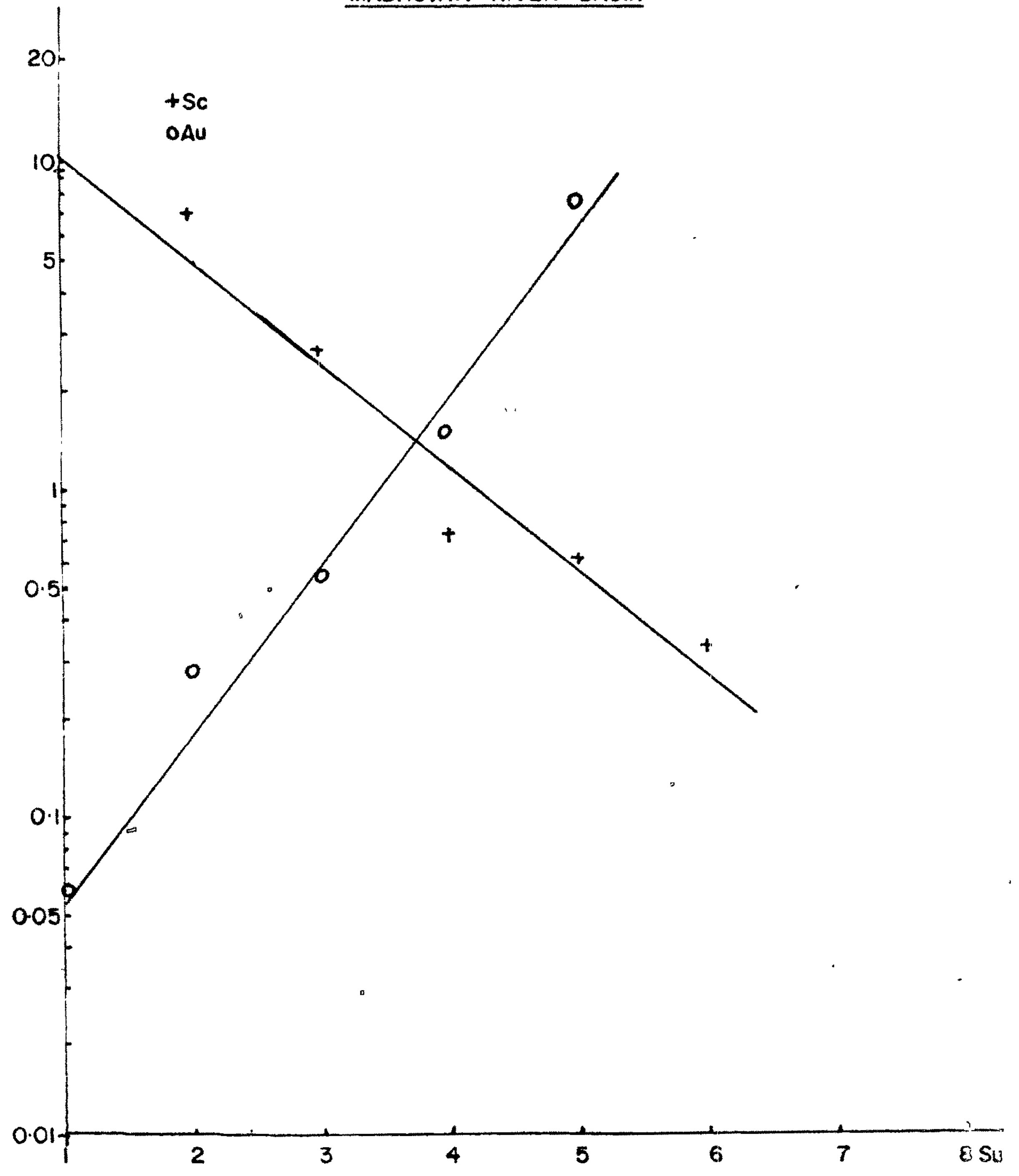
Relation of Stream Slope & Stream Area to Stream Order

KAVERI RIVER BASIN



Log Graph IV II (b)

Relation of Stream Slope & Stream Area to Stream Order
MADHUVATI RIVER BASIN



The above 15 parameters of each basin were obtained which are given in the accompanying Tables(IV 1 and 3). The tables give a fairly comprehensive and comparative picture of the basins, their drainage system and patterns. An analysis of the data helps in deciphering the drainage characteristics vis-a-vis landscape evolution.

Comparative Morphometric Analysis of the River Basins :

The rivers and their drainage systems have dissected an area of 8090 sq.km. that constitutes the four main physiographic divisions and have given rise to eleven basins, mainly of the tributary streams that meet the river Narmada. These basins show some similaries on one hand, while are marked by significant morphometric diversities. The basins, streams, drainage systems and patterns are chief components which are analysed and compared significantly on the basis of the physiographic diversities. This terrain configuration is dissected by a drainage network of 52340 streams of various orders. The drainage to the north of Narmada includes the northern basins i.e. the basins of the rivers Heran, Aswan, Men and Ruwel. The drainage to the south of Narmada and west of the Karjan has been included under the western basins i.e. the basins of the rivers Kim, Amaravati Kaveri and Madhuvati. The observed variations in the parameters amply reflect the nature of the evolution of the stream components of the basins.

The eastern basins like Devganga (345.60 sq.km), Terav (680.00 sq.km) and Karjan are comparatively smaller, than those of the Heran and Kim. The former basins have a large number of lower order stream especially the 1st order streams (Devganga - 4788, Terav - 7493 and Karjan 6749) and this makes the bifurcation ratios for them very high varying between 4.5 and 5.5. But these streams are smaller in length; Devganga 240 m, Terav 220 m and Karjan 230 m. The length ratios range between 1.83 and 3.89. In all these basins the 1st order stream slopes are steep Devganga : 24°-42', Terav : 23°-14' and Karjan : 9°-82' while the slope ratio changes from 0.30 to 0.86. Also the individual 1st order streams of these basins hold small areas e.g. a 1st order stream of Devganga would hold 0.07 sq.km are while those of the Terav and Karjan hold 0.06 sq.km areas each.

On the other hand, basins like Heran (1424.7 sq.km) and Kim (1022.5 sq.km) are big in size, their 1st order stream numbers are 5311 and 2342 and the stream bifurcation ratio is 4.00 to 4.86. These streams are longer than the streams of the eastern basins. The mean length of the 1st order streams is 280 m and the length ratio varies from 1.86 to 3.89. Further, the streams of Heran and Kim hold larger areas as compared to the streams of the eastern basins i.e. Heran 0.09 sq.km (area of the single 1st order stream) and Kim 0.08 sq.km. Comparatively the 1st order streams of Heran and Kim are less steeper than the comparable eastern basin streams - the 1st order stream slope for Heran 13°-64' and for Kim is 8°-53'.

The western river basins of the Kaveri (164.1 sq.km) and Madhuvati (167.9 sq.km) are the smallest. These basins have 564 and 1524 1st order streams respectively with the mean lengths of 420 m and 230 m, and the 1st order streams hold areas of 0.08 sq.km (Kaveri) and 0.06 sq.km (Madhuvati) with the slope variation for Kaveri : 4°-00' and for Madhuvati : 9°-38'.

The 'stream numbers', 'drainage density and drainage frequency' and the 'stream area' (or basin area) are the parameters which reveal the dissection patterns. The dissection patterns are, largely controlled by the lithology, neotectonism and structure. The eastern basins i.e. those of Devganga, Terav and Karjan ideally exhibit the control exercised by the basaltic lithology and the joint pattern. Though these basins are smaller as compared to those of Heran and Kim rivers, these show high values for 'drainage density (Devganga - 5.49, Terav - 4.31 and Karjan - 7.49) and 'drainage frequency' (Devganga - 17.19, Terav - 13.95 and Karjan - 10.42). The total number of streams in each basin is also very large (Devganga - 5942, Terav- 9487 and Karjan - 8783). On the other hand, the Heran and Kim river basins are the two largest in the study area (Heran 1424.70 sq.km and Kim 1022.50 sq.km) but show relatively low drainage density (Heran 2.12 and Kim 1.47) low drainage frequency (Heran 4.86

and Kim 2.96) and the stream numbers too (Heran 6929 and and Kim 3030) are comparatively smaller. These big size basins with the low drainage density, low drainage frequency and relatively small number of streams point to terrain conditions, quite distinct from those of the basaltic hills. The Heran a 98 km long river and its drainage network that comprise a basin with an altitude range - 40 to 600 ÷ 700 m, shows interesting variation in its different parts. It originates in the trappean hills in the east, but flows for a major part of its length over a low relief terrain of the western alluvial plains, dotted with scattered basaltic and Bagh bed hills. The Kim marks the longest river unlike others, it is an independent river rising from the low altitude trappean hills and after flowing through the trappean and Tertiary uplands of Netrang and the Quaternary alluvial coastal plains, meets the Gulf of Khambhat directly. These two basins (Heran and Kim) do show some control of neotectonism and of joints and fractures. It is observed that within the basins of these two rivers themselves, the stream numbers, stream frequencies and stream densities are different in the higher altitude portions. These values are quite high in the neighbourhood of their sources, but for the rest of their courses the various parameters show low values.

The stream length varies among the various basins of the study area, and the variation in the mean stream length has been found to show the following ranges :

i.	the northern basins	- 410 m to 450 m.
ii.	the eastern basins	- 310 m to 350 m.
iii.	the western basins	- 320 m to 580 m.

Normally the stream length is seen increasing towards the W, NW or SW. This trend of increase in length significantly is related with slope, gradient, relief ratio and the area of the stream basin. It is observed that higher the stream density, smaller the streams; small streams show steep slopes, high gradients and high relief ratios. The smaller streams of the eastern basins have steep slopes (1st order stream slope - Devganga 24°-42', Terav 23°-14' and Karjan 9°-82'), high gradient (Devganga 1°-18', Terav 0°-54' and Karjan 0°-16') and also show the high altitude relief (300 m to 882 m). While the biggest or largest river basins Heran and Kim have low density of streams, the 1st order streams of these rivers show an overall higher values of stream length; and average length of 435 m which is higher than that for the streams of the eastern basins. Though the Kaveri basin is the smallest, its constituent low order streams show high values for average length. Interestingly, the stream length values for the Heran and Kim river basins, though higher than those of the eastern hills, are lower than that of the Kaveri basin. This phenomenon of higher stream length value is related to the gentler slopes, low gradient and low relief ratio.

The various parameters like stream length with inter-related stream density, gradient, slope and relief ratio all these collectively comprise the reflection of the physiographic diversity of the terrain, which in turn reflects the difference of the lithological structural and geomorphic characteristics.

DRAINAGE CHARACTERISTICS

The drainage network of the Rajpipla hills and the neighbouring coastal plains presents anunique picture of the controls exercised by a number of geological factors operating over a considerable span of time. The prevailing diversity of the landscape as revealed by the drainage characteristics, which has been in turn reflecting the geological diversity, is manifested in the forms of radial, parallel and linear streams, having evolved as closed systems in eleven basins and one open system, i.e. Lower Narmada river basin. These systems have given rise to diagnostic drainage patterns, having developed over a terrain that comprises rocks of different ages : Pre-cambrian, Cretaceous, Tertiary and Quarternary. The rocks of successive geological periods are each characterised by their own lithology and structure, which have considerably influenced the drainage development within them.

From the genetic point of view, the twelve main streams have been classified as under :-

Consequent	:	Narmada and Kim.
Subsequent	:	Devganga and Karjan.
Resequent	:	Heran, Aswan, Men, Ruwel, Terav, Amravati, Kaveri and Madhuvati.

Of the two consequent streams, Narmada though following the general slope of the terrain, is also flowing along a major geofracture zone. The Kim river however is exclusively controlled by the regional slope. The Devganga and Karjan, especially the latter, flow along the secondary slope related to the Narmada valley, but in their upper portions, a strong structural control is also observed. The remaining streams of resequent category, though essentially following the general slope of the ground, finally meet Narmada, but before they do so, they flow across the hilly terrain, undulating uplands and the gently undulating alluvial plains. This diversity of the terrain drained by these resequent streams is reflected in the zig-zag nature of their channels.

By way of a summary, it can be stated the areas drainage consists of numerous streams of various orders - ranging from 1st order to as much as 8th or 9th order. The smaller lower order streams (1st, 2nd and 3rd) are mostly restricted to the rugged hilly terrain as well as the ridges and hills of the uplands. The 3rd and 4th order streams are the common features of the foot-hill portions, flat portions of the plateaux, uplands and part of the alluvial plains. By and large, the 4th and 5th order drainage lines comprise most of the trunk-streams; these in turn, either change over to or by way of confluences, become 5th or 6th order, while some of the 6th order and most of the 7th/8th order streams are either the main tributaries of Narmada, or are independent rivers. These high order streams, while flowing over uplands and plains, have carved very conspicuous valleys and gullies. The joints and fractures of the basalts control the lower order streams which are normally straight with steep sloped channels, and form small streams restricted to the high altitude hills and ridges. The tendency of higher order streams viz. 4th, 5th and 6th to flow straight in elongated channels along joints and fractures has given rise to zig zag courses with small but straight bends or loops which resemble meanders.

A step-like topography of the hilly area typically characterised by numberous plateaux at successively decreasing heights, points to erosion of horizontally piled lava flows of different weathering properties. The vast network of criss-cross streams has been mainly responsible for carving out such a topography. Broadly speaking, the various streams that flow down the plateaux towards the uplands, are seen to form 4th and 5th order channels which have been referred to as 'Khadis'. These typically comprise rocky narrow channels, sometimes fairly deep. The velley

Plate IV 6 A stream showing joint controlled zig-zag course and a waterfall/rapid. (Locality : Som khadi - near village Kokam).

Plate IV 7 A small stream showing entrenched meander, on the uplands (Locality : Near Rajpardi).

Plate IV 8 Dissected alluvial terrain, characterising a bad land topography, (N. of Narmada).

plains with alluvium and finally drown into the Gulf of Khambhat. The total drainage provides a variety of patterns. The rather straight coursed streams, radiating as well as parallel with their criss-cross network, form rectangular or sub-rectangular drainage patterns which are significantly associated with the trappean terrain of the eastern ridges and hills. Devganga, Terav and Karjan provide good example of such rectangular pattern. While the northern basins have rectangular pattern in their rugged eastern parts, westward these comprise E-W parallel linear elongated streams.

Trellis, sub-trellis, sub-dendritic are other patterns evolved on the low altitude trappean, and Bagh bed hills, these are well formed over the undulating uplands and on the alluvial formed flood plains and coastal plains. Almost all basins show these trellis, sub-trellis and sub-dendritic patterns which are modification of either parallel linear streams or rectangular drainage patterns of the higher altitudes. The northern and western basins have wide areas covered by these type of patterns.
(Plate IV8).