Morphology of the First-Order Streams in a Semi-arid Watershed: Wadi Shueib Basin, Jordan.

★ Hassan Ramadan Salameh

★ Ph.D. in Geography, University of California, Los Angeles 1974
Professor, Department of Geography, Faculty of Arts, University of Jordan.

Abstract

Wadi Shueib Watershed drains into the Jordan river, and is dominated by a semi-arid climate and limestone lithology. Its drainge network consists of 666 streams, out of which 78.34% of total stream numbers and 62.47% of total stream lengths belong to the first-order. The first-order streams practised backward wearing, lateral planation and micro-piracy, leading to the shifting of drainge divides and, with a bifurcation ratio of 4.53, form streams of higher orders, supplying them with water and sediment discharges. Their morphology is mainly affected by lithology and location. The study reveals that streams which are closer to the mouth of the study basin and the trunk stream, particularly if they run on a nodular thick bedded limestone, are generally steeper and shorter than others. Faulting, which led to the lowering of the mouth area, caused during the pluvials of the pleistocene deep incision and meandering of the main stream. However, accelerated erosion which coincided with a steady slope retreat contributed to lowering of slopes in faulted country rocks.

The first-order streams are not isolated from other streams. Close interrelation - ships are revealed between different stream orders, mainly between water and sediment discharges, slope, length and erosional activities. Such streams contributed to the formation of an alluvial fan below the mouth area. The construction of a reservoir in 1970 escaped the fan from its sediment supply, which was, accordingly, trapped behind the dam where a small delta seems to be developed.

Introduction

Watershed channel networks have become of an increasing concern to geomorphogists as well as to other researchers (Morgan, 1972; Gregory, 1973; Abrahams, 1984). Their morphology sheds light on the interaction existing between environmental factors, such as geology, climate, vegetation and human activities, and, also, contributes to watershed geomorphology. Stream order, as defined by strahler (1955) is considered an important variable applied to distinguish between channels supposidly differ in other parameters, including discharges. It, also, explains possible micro-piracy between neighbouring channels and shifting of drainage divides by the processes of backwearing and lateral planation.

The geomorphology of Wadi Shueib Basin, as in others, is much affected by the behavior of its channel networks. However, its first order streams, neighbouring to others of adjacent basins, i.e. Zarqa and Kafrein, seem to cause considerable geomorphological changes, as affected by location on the western slopes of Balqa Highlands, and along the Jordan graben and other faults, under past and prevailing environmental conditions.

It is the purpose of this research to analyze the morphology of the first-order streams in Wadi Shueib Basin, and to extrapolate their role in the geomorphological development of the basin. Thus, their morphometric variables are measured, including; stream number, stream length, slope, relevant location to mouth area, and also their areal distribution in the watershed itself. Other stream orders are, also, studied to explain possible drainage network interrelationships that may be developed in the basin. The main measurements were derived from topographic maps of 1:50000 scale (Salt, Suweilih, Amman and El Karama plates), while aerial photographs of 60 000 altitude were used for comparison with map data. Fieldwork was excecuted to study cerain representative first-order streams in the basin.

The subjects which are, accordingly, covered in this research are: the physical environment of Wadi Shueib Basin, a geomorphological analysis of the main morphological characteristics of first - order streams, the morphology of other stream orders as related to the first, and finally the conclusions.

1. The physical environment of W. Shueib Basin:

Wadi Sueib Basin is located between 35° $\overline{38}$ - and 35° $\overline{48}$ - East and 31° $\overline{53}$ and 32° $\overline{05}$ North, extending for a 23.35 km. length and an average width of 8.9 km, covering an area of 165.4 sq. km. (measured by a digital planimeter). Approximately, 51% of the basin is located above 600m height, whereas 18.11% is below the sea - level (Fig. No. 1). Thus, the study basin exhibits climatic and vegetational differences.

Three of the koppen's climatic regions are established in the basin: Csa region, which covers the area above the town of Salt (900m). Bsh below Salt, and Bwk at the mouth area. The average annual rainfall is 393 mm (70.8 MCM) but it may decrease to 294 mm (52.3 MCM) in dry years or increase to 502 mm (89.4 MCM) in wet years (N.W.A. and F.R. Germany, 1977). The rainy season extends between October and May, with increasing rainfall amounts between December and March. Most of the rainfall is either evaporated or infiltrated as is indicated by the low percentage of stream discharge to rainfall (11%).

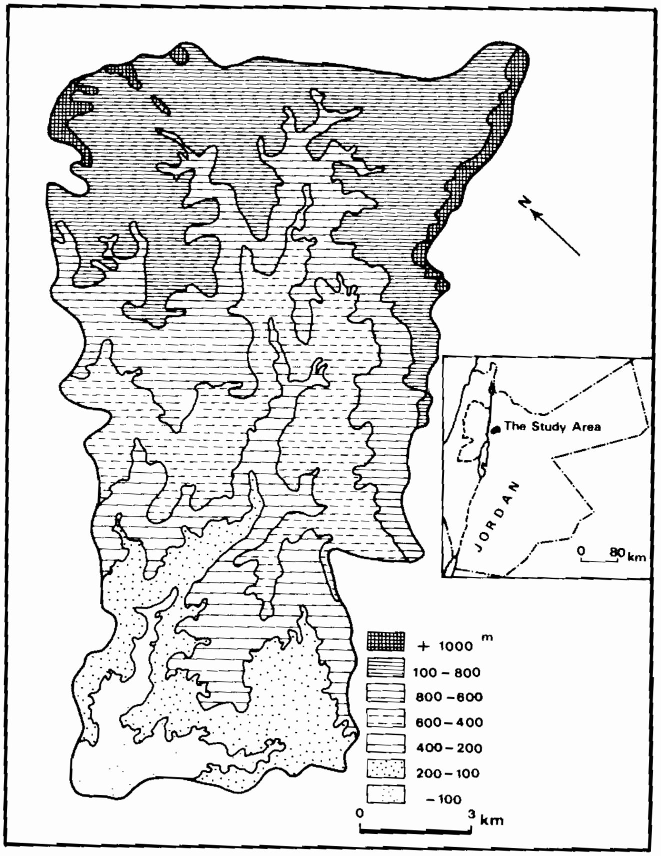

Fig.1 Releif Map of Wadi Shu'eib Basin

Evaporation rates are 788 mm in wet seasons and 1854 mm in dry seasons (measured by a class -A- pan method). This is due to high temperatures dominating summer seasons and day times. In Shuneh South[1] August registered the highest maximum monthly temperatures (+ 38°C), whereas Jubeiha's highest maximum temperature was in July (28.9°C). As for the lowest minimum in the two stations were both in January of 1964 (8.0°C, and 0.7°C, respectively). The mean monthly temperatures for the periods studied were 23.35°C, thus Jubeihas' mean is only 64.23% of the other's. The months of June through September are considered the warmest in the basin (+ 20°C in Jubeiha and + 30°C in Shuneh South), (Table No. 1).

Oak and pine forests cover the area around Salt, while brush steppe and desert vegetation grow in lower elevations. Such vegetation has been subjected to over - grazing, resulting in the shrinkage of vegetated areas, and, above all, leading to heavy soil erosion.

Soils in the basin are Red Mediterranean, with increasing depth and zonation in the lower areas, below Salt. Yellow regosols are developed in the mouth area.

The geology of W. Shueib Basin reflects structural instability as is

Table No -1-
Mean monthly temperatures in Jubeiha and Shuna South

	Jubeiha (1961-1975)	**Shuna South (1964-1967)**
January	6.0	14.3
February	6.2	15.5
March	10.1	18.5
April	16.1	22.4
May	17.4	26.3
June	20.7	30.8
July	22.8	31.5
August	21.9	32.3
September	21.0	30.1
October	18.0	27.3
November	13.2	22.8
December	6.7	18.4
Mean	15.0	23.35

represented by a part of the Jordan graben faults which passes across the middle part of the basin. Also, lateral movement faults run in the lower area of the basin forming a drift valley for the main stream. Such faults brought displacements in strata, and segmentation in slopes. Their geomorphic effects are analyzed later.

In terms of lithology, the following formations (2) are considered widespread (Fig. No. 2):

1. Fluviatile deposits-Ouaternary
2. Thick bedded limestones and dolomites, limy marls-Turnian.
3. Chalky limestones, marls, chert, dolomitic limestones-Santonion-Turonian.
4. Nodular limestones, clays and marls gypsum, thick bedded limestones, locally dolomites - Cenomanian.
5. Argillaceous sandstones, sandy dolomites, sandy limestones, massive white sandstones - Lower Cenomanian - Lower Cretaceous.
6. Calcareous sandstones, sandstones, limestones, shales - Jurassic.

Under such physical environmental conditions, Wadi Shueib Basin could host 666 streams, measuring 437.6 km. and developing a drainage density of 4.02 km/sq. km, and stream frequency of 2.64 streams/sq. km. (Fig. No .3) 78.22% of the total stream numbers and 62.47% of their lengths are of the first- order. Although, they were developed under more humid and pluvial periods prevailed in the past, they are still considered active erosional agents, particularly when the basin receives high amounts of rainfall. Weak lithology and topography contribute effectively to such processes. The main stream, which belongs to the fifth-order, practised downcutting through limestone strata, facilitated erosional activities by lower stream orders. In fact, some of these streams were developed to hanging valleys. As a result, the basin gradually shifted its drainage divides as is explained by their clavity and circularity ratio (14.20%). Micro-piracy or overtopping of low order streams had been active, too. The overall slopes became lower. and much of the sediment yield was deposited in the Jordan valley, building an alluvial fan. However. the basin is generally considered at the first stage of the Davisian cycle of erosion, as its hypsometric integral is not below 82.54% (Fig. No. 4) Such an integral is sustained by relatively high elongation ratio (62.13%). Climatic changes are held responsible for this development.

II. First - order streams:

A total of 521 of first-order streams (F.O.S.) forming 78.34% of the total stream numbers, are distinguished in Wadi Shueib Basin. These streams vary in location, length, slope and geomorphological behavior.

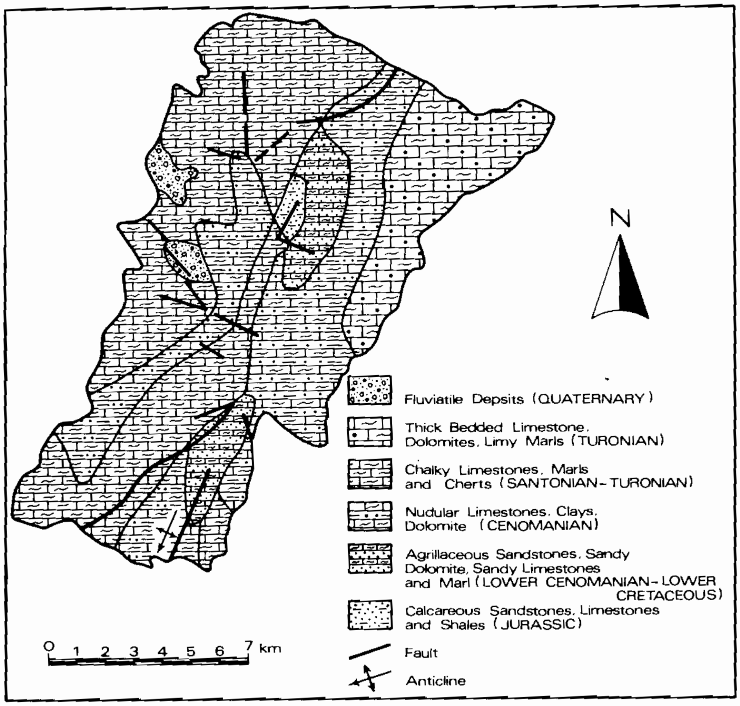

Fig. 2 Geological Map of Wadi Shu'eib Basin

Location of F.O.S: The morphology of F.O.S. is influenced by their areal distribution. Two locations in this respect are noticed: (a) the source areas and (b) below the source area.

(a) The source area first-order streams: These streams are considered responsible for the development of higher stream orders located usually in lower elevations (Doornkamp and King. 1971). None of the higher order streams might be developed without F.O.S. Also, they subjected interfluvial areas and drainage divides to major changes caused by their erosional activities. They are usually formed below the belt of no erosion suggested by Horton (Horton, 1945). These streams, which represent 34.35% of the total number of F.O.S. mostly link with each other to form second order streams (50.83%). or join them afterwards (25.69%) (Table No. 2). They also maintain relatively short lengths ($\bar{X}$=0.556 km.) and only 8.77% of the total exceeds 1.00 km. In terms of gradient, most of these streams (41.89%) develop moderately steep slopes (10°-18°), whereas very few streams maintain slopes less than 5°. or more than 30° ($\bar{X}$=13° 18).

Such streams also vary in distance to drainage divides, trunk stream and the mouth of the basin. Such differences explain variable rates of backward

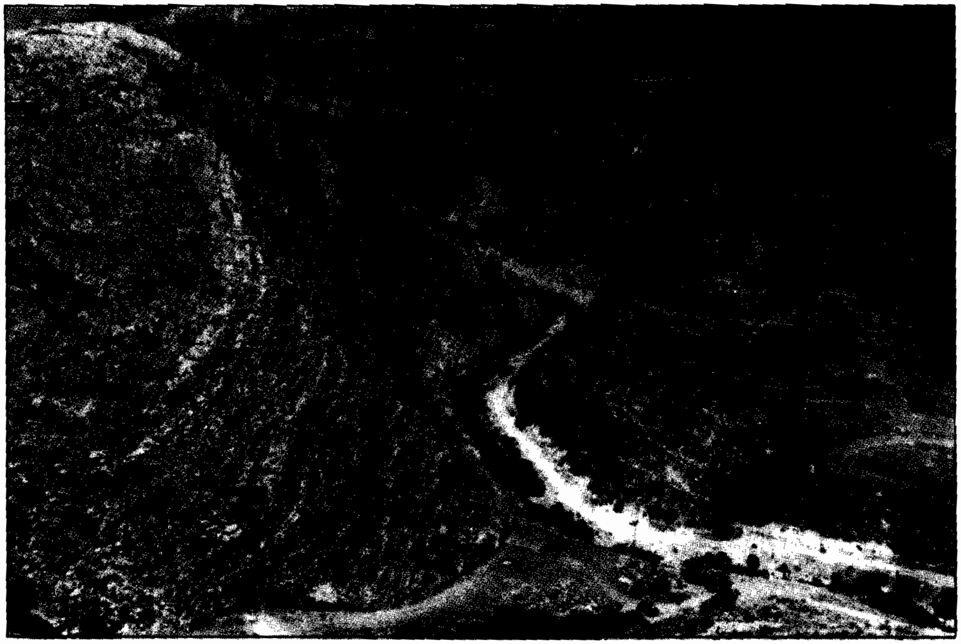

Plate No. 1: A linkage point between two fourth-order streams separated by a hogback.

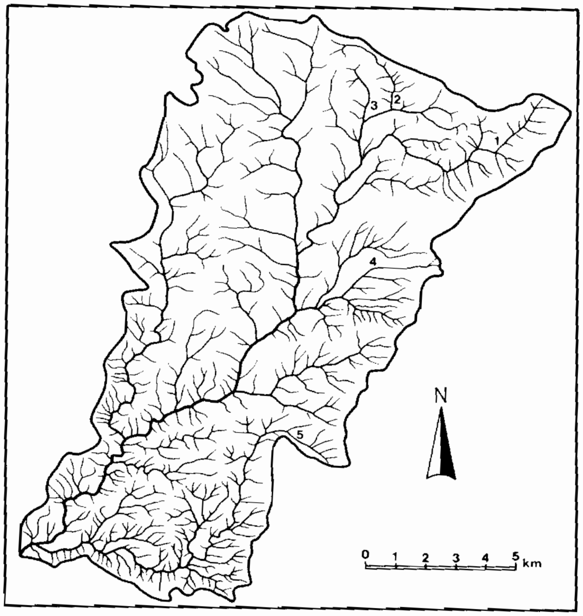

Fig. 3 Drainage Network in Wadi Shu'eib Basin

Plate No. 2: First and second-order streams developed on the southern bank of Wadi Shueib of limestone and marl formations.

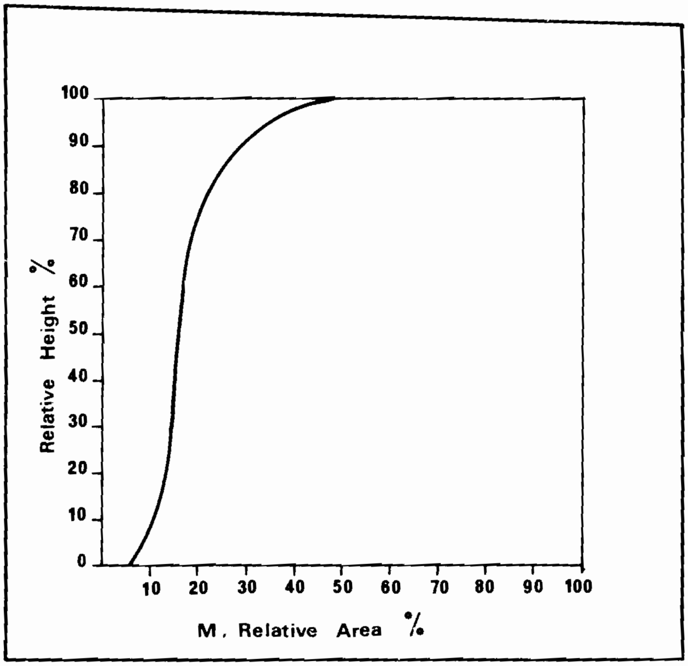

Fig. 4 Hypsometric Integral of Wadi Shu'eib Basin (82,54%)

Table No. (2)
Length, slope and order of source area first - order streams ★

Length, km.	%	Slope (0)	%	order of mouth area streams ★★	%
less than).25	6.70	Less than2	0.00	1	50.83
0.25-0.50	40.78	2-5	5.58	2	25.69
0.50-0.75	26.25	5-10	30.72	3	8.93
0.75-1.00	17.87	10-18	41.89	4	11.17
More than 1.00	8.37	18-30	18.43	5	3.35
		30-45	2.79		
		More than 45	0.55		
Total	99.97		99.96		99.97

★ Measured by author.

★★ These orders designate the main streams into which tributaries (F.O.S.) drain water.

wearing they conduct. Any stream may accelerate degradational activties as the trunk stream becomes closer to its course, and the distance to the mouth area decreases. This is mainly due to slope changes imposed when streams of different slopes link.

The mean distance of F.O.S. in the source areas to the drainage divides of the basin is 329.60m, but 51.38% of such streams are only 250 m far from the drainage divides, whereas 5.58% of them have arrived the drainage divides, subjecting them to backwearing. However, the F.O.S. that are closer to the drainage divides are not necessarily the steepest or the longest ones. They maintain, in fact, comparatively shorter and steeper course than the average streams in the same location. This is mainly due to the low gradient that generally characterizes the source area along the drainage divides, and, also, to changing orders that such streams undergo when they become subject to increase in slope and length. (Table No. 3).

Distance to the main stream may impose an increase in erosional processes due to existing differences is slopes, discharges and channel forms. When a channel of a lower slope and discharge links with another of a steeper slope and a higher discharge, the first is likely become under backwearing and down-cutting. As a result, the F.O.S. suffer an increase in gradient as they become closer to the main stream. In other words, linkage of F.O.S. to higher stream orders leads to increasing gradient. (Table No. 4).

Distance to the mouth of the basin has also a similar effect upon stream gradient (3) The Jordan graben contributed to increasing slopes of F.O.S. Both the mouth area and the trunk stream which experienced lowering, either caused by faulting or by downcutting, imposed slope increase and segmentation as local base levels went down.

Variations in stream slopes and lengths are also noticed according to rock types. It is found that streams which develop on rock formation No. 4 are the steepest ($\bar{X}$=16°18) and shortest ($\bar{X}$=0.487 km.) whereas those which run on more than one lithology developed lower slopes and longer courses ($\bar{X}$=7°43, and 0.670 km.) (Table No. 5).

Table No. (3)
First - order streams in source areas:
means of slopes and lengths according to distance from drainage divides

Distance between upper ends of streams and drainage divides, km.	Length,km $\bar{X}$	Slope ($\bar{X}$) (0)	(/)	Frequency %
Zero	0.585	14	5	5.58
0.025 — 0.050	0.620	14	21	2.79
0.050 — 0.250	0.530	13	18	42.45
0.250 — 0.500	0.604	12	33	26.25
0.500 — 0.750	0.545	14	27	12.84
0.750 — 1.000	0.622	9	3	6.14
1.000 +	0.542	13	27	3.91

Table No. (4)
First-order streams in source areas:
Slopes and lengths according to distance to main stream

Distance to main stream km.	Frequency %	Length,km $\bar{X}$	Slope, ($\bar{X}$) (0)	(/)
- 1	13-63	0.556	18°	15
1 - 2	7.38	0.546	15	54
2 - 3	12.50	0.759	13	17
3 - 4	19.31	0.470	12	20
4 - 5	14.77	0.571	11	6
5 +	32.38	0.553	10	—
Total	99.97			

Table No. (5)
Slope and lengths of first-order streams in major lithologies in source areas

Rock formation	Frequency of stream No.%	Slope $\bar{X}$ 0 /	length, $\bar{X}$ km.
2	22.34	11 19	0.593
3	41.34	13 9	0.591
4	26.25	16 18	0.487
others	10.02	7 43	0.670

(b) Below the source area F.O.S: A total of 342 F.O.S. are located on the topographic maps studied, below the source area "belt". They coincide with other stream order belts. Such streams are considered erosional agents contributing to the denudation of land surface in the watershed. They practise mainly lateral erosion against interfluves but tend to maintain relatively steeper slopes ($\bar{X}$=19° 55) and shorter lengths ($\bar{X}$=0.508 km) than the F.O.S. in source areas. Such streams seem to cluster between 10° 18° and 0.250 - 0.500 km (45.32% and 51.75% of the total number of streams, respectively). Thus they become comparable to the F.O.S. in the source areas. (Table No. 6).

Interfluvial areas are commonly formed of micro and local landforms, such as ridges, anticlines, hogbacks. hills. etc, Many of those streams run across limestones of relatively thick bedded strata and are developed into hanging valleys. This is particularly obvious when they link with streams of higher orders. Their large number mainly in the lower part of the basin indicates tendency to higher rates of channel erosion than the F.O.S. in the source areas. This is attributed to downfaulting and increasing stream discharges towards the mouth area of the study basin.

Table No. (6)
First - order streams below source areas

Stream Slope(O)	Frequency %	Stream length, k.m.	Frequency %	order of mouth area streams	Frequency %
- 2	Zero	-0.250	4.97	1	46.49
2-5	2.04	0.250-0.500	51.75	2	19.88
5-10	19.29	0.500-0.750	30.11	3	12.86
10-18	45-32	0.750-1.000	8.77	4	10.81
18-30	28.94	1.000 +	4.38	5	9.94
30-45	4.38				
45 +	Zero				

When examining faulting effects upon F.O.S. slopes and lengths, it is found that F.O.S in faulted areas are longer ($\overline{X} = 0.573$ Km.), but are not necessarily always steeper ($\overline{X} = 14^\circ\ 13'$) than other F.O.S. in the basin. However, location and direction of faults with relevace to F.O.S. contribute largely to slope variations. As is shown in table No. (7), streams running along the faults seem to be steeper than others which run across such faults ($\overline{X} = 14^\circ\ 33'$and $14^\circ\ 9'$, respectively). Also, the faults which occupy the source areas of F.O.S. lead to developing steeper streams than those existing in either the mouth or the middle areas ($\overline{X} = 15^\circ\ 30'$ and $12^\circ\ 52'$, respectively). When faults cause an uplifting in the source areas, or initiate the formation of a stream, they usually expose the strata to vertical erosion, increasing and segmenting stream slopes.

Micro-piracy between F.O.S: micro-piracy "is a consequence of the over-topping and breaking down of ridges that initially separate adjacent rills" "or" the robbing of small channels, drainage systems by lower channels "(Leopold and others, 1964, P.41), whereas river capture" is the name given to change in river pattern when a stream which is capturing down rapidly extends headwards into the catchment of a stream which is cutting down only slowly (Ollier, 1981, p. 165) Thus, the later applies to main tributaries or streams, Whereas the first term indicates small channels and rills. Such a process depends on stream characteristics, including stream length, slope, order. elevation, drainage area, discharge, etc. These variables put adjacent streams in a crosstopping process. Lithology, also, contributes to such a process. Those streams which run in a weak country rock usually achieve high rates of back and lateral wearing, approaching other streams in hard lithologies and capturing their drainage areas.

Possible micro-piracy in W. Shueib Basin: Table No. (8) shows 15 selected cases of possible micropiracy among 38 F.O.S. This process is considered possible when two streams or more compete to capture other's drainage area under certain conditions. Most of the streams that prove tendency to capturing others enjoy steeper slopes, longer courses. and are closer to the mouth area of the study basin. If the streams are of Comparable slopes and lengths, then either the order of the streams they link with, or the distance to the mouth area becomes a determining factor. In other words, the stream that links with a higher order one tends to capture the other of lower stream linkage. Also, the streams which are closer to the mouth area tend to capture others of farther distances, as is illustrated by streams number: 15,18,26,39 and 47 (Fig, No.5). It is found, too, that streams which follow the overall slope of the basin, i.e. slope towards the mouth area, are more capable for capturing others which run in an opposite direction through incised valleys. as is examplified by the stream number (15), which extends backward to capture the drainage area of the stream numbers 13 and 14.

Table No. (7)
Slope and length of faulted first-order stream in Wadi shueib Basin

stream No.★ Fault	location★★	Fault direction	Slope, O	O /	length. km.
20	S	A	18	39	0.50
21	D	A	14	15	0.65
27	D	A	5	27	2.10
28	M	L	10	28	0.55
34	S	L	10	37	0.65
35	D	A	12	37	0.55
46	M	A	11	31	0.30
47	S	A	8	56	0.90
48	D	A	6	53	0.15
49	S	A	11	31	0.30
50	S	A	13	52	0.75
51	S	A	9	35	0.60
56	S	A	20	28	0.40
57	S	A	23	34	0.30
60	M	A	13	52	0.50
61	D	A	10	28	0.55
62	D	A	20	49	0.45
63	M	A	12	36	1.10
64	S	A	12	36	0.55
70	S	A	23	34	0.40
71	S	A	16	15	0.50
72	D	A	15	00	0.85
73	M	A	20	03	0.35
74	M	A	11	31	0.30
80	S	A	8	12	0.70
83	L	L	9	52	0.35
86	L	L	26	22	0.45
88	L	L	15	27	0.25
90	M	A	18	39	0.25
91	D	A	13	12	0.50
95	M	A	8	37	0.40
96	M	A	13	12	0.35
97	D	A	16	36	0.35

★ = See Fig. No.5 for stream locations.
★★A= Streams which run across the faults.
L = Streams which run along the faults.
M = Faults which occupy the mouth area.
S = Faults which occupy the source area.
D = Faults which occupy the middle areas of streams.

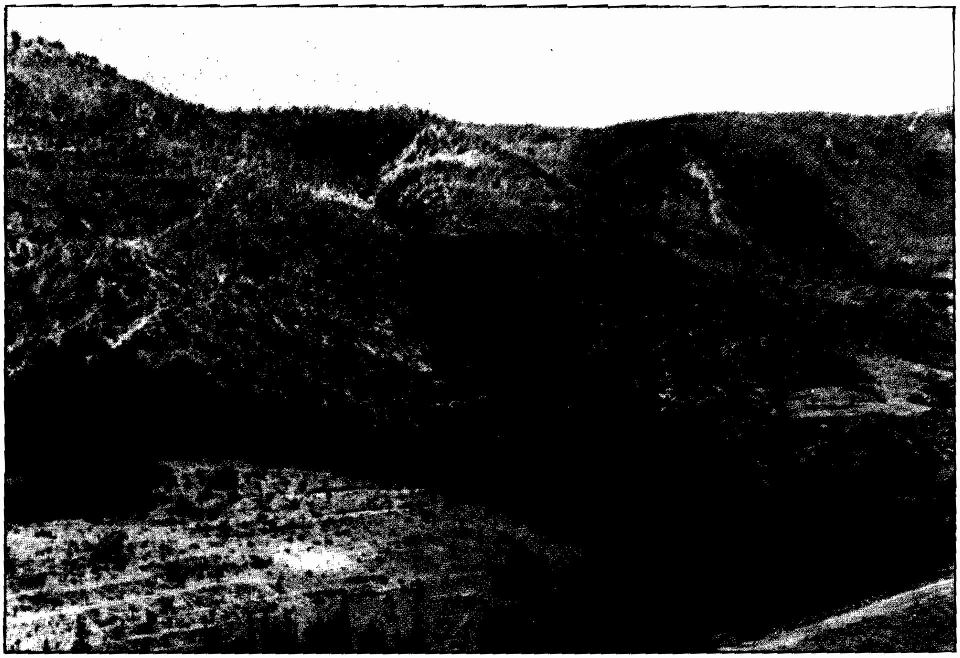

Plate No. 3: Two first-order streams: the left runs in a local syncline; the right runs in a landslide area.

Plate No. 4: Dissection and slope retreat of thick-bedded limestone strata by two neighbouring first-order streams, developed to hanging valleys.

Table No. (8)
Piracy variables of some first-order streams in Wadi Shueib Basin

Case No.	Stream No.★	Slope (O /)	Length, km.	distance to basin mouth, km.	order of mouth stream	lithology
1	9	8 21	0.55	20.75	2	2
	10	10 28	0.55	19.90	1	2
	11	4 34	0.50	20.25	1	2
2	12	11 31	0.30	20.00	1	2
	13	6 53	0.50	19.30	1	2
	14	7 39	0.60	19.30	1	2
	15	11 36	0.85	19.35	3	2
3	18	5 43	1.20	19.10	3	2
	19	9 35	0.60	18.10	1	2
4	25	5 43	0.40	19.40	1	3
	26	7 39	0.45	18.85	1	3
5	27	5 27	2.10	16.90	1	3
	29	7 39	0.30	15.75	1	3
	30	7 03	0.65	15.75	1	3
6	31	9 52	0.35	15.75	2	3
	32	8 56	0.90	15.85	1	3
7	39	10 28	1.65	13.40	3	3
	40	4 14	1.35	14.10	1	3
8	55	14 54	0.70	8.00	4	3
	58	21 30	0.60	7.70	3	3
	59	14 22	1.45	6.85	1	3
9	65	21 55	0.75	4.20	5	4
	66	20 16	0.75	3.40	1	4
10	68	19 28	0.45	2.35	5	3
	69	10 14	1.35	0.75	1	3
11	74	11 31	0.30	4.50	1	3
	78	23 34	0.30	4.40	1	3
12	79	16 04	0.65	5.85	1	4
	84	18 39	0.25	5.50	1	4
	85	18 07	0.45	5.50	1	4
13	87	20 49	0.45	3.60	2	3
	103	16 15	0.50	7.00	1	3
14	92	14 08	0.45	4.60	2	4
	93	16 36	0.35	4.70	4	4
	100	15 27	0.45	5.05	4	4
15	89	14 44	0.55	4.40	1	4
	101	17 27	0.20	4.65	1	4
	102	23 34	0.15	5.05	1	4

★ See Fig. No. 5 for stream locations.

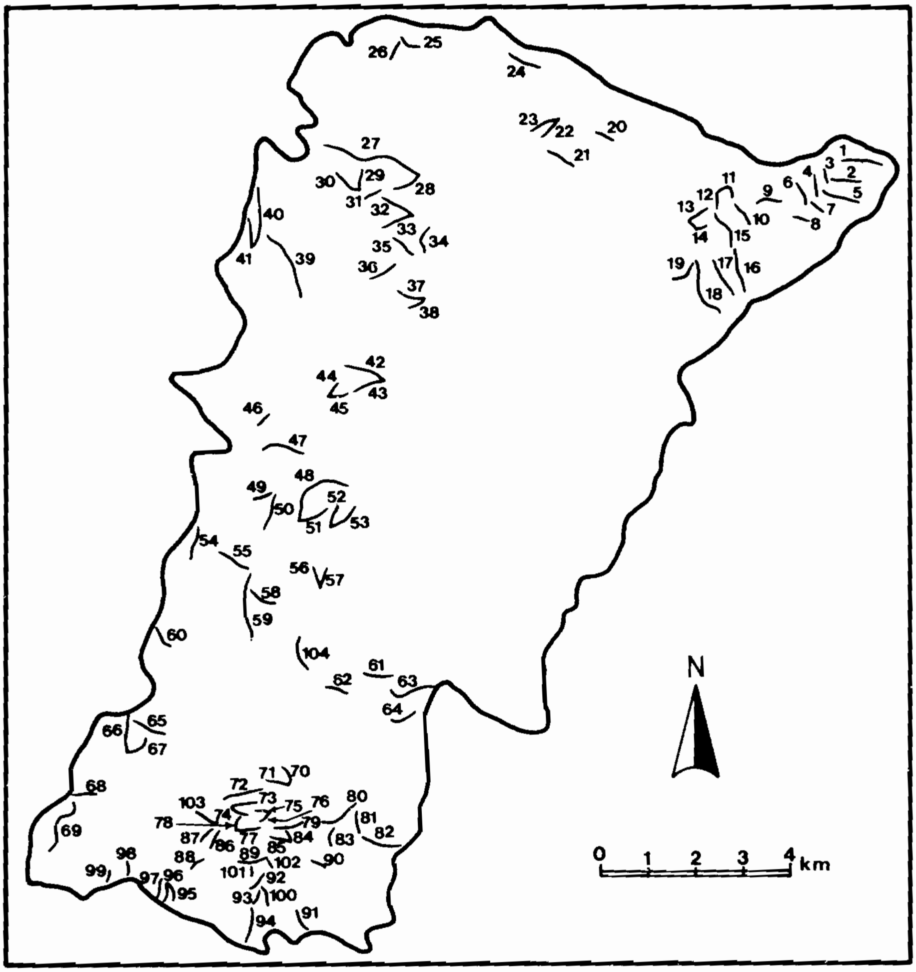

Fig. 5 Some First Order Streams Studied in Wadi Shu'eib Basin

First-order stream pattern: Most of F.O.S. develop parallel courses. separated by interfluves, mainly when they link with higher stream orders. Some of them drain into the same streams but from opposite directions and with a horizontal displacement as is the case in streams number 2.3,4,5 and 6 or without any displacemet as illustrated by the streams number 81.82,93,98, and 99. Some of these streams run parallel to the drainage divides of the basin. In this case, they practise lateral planation against the drainage divides. However, inclavities by streams of adjacent watersheds may develop if they run vertically towards their drainage divides.

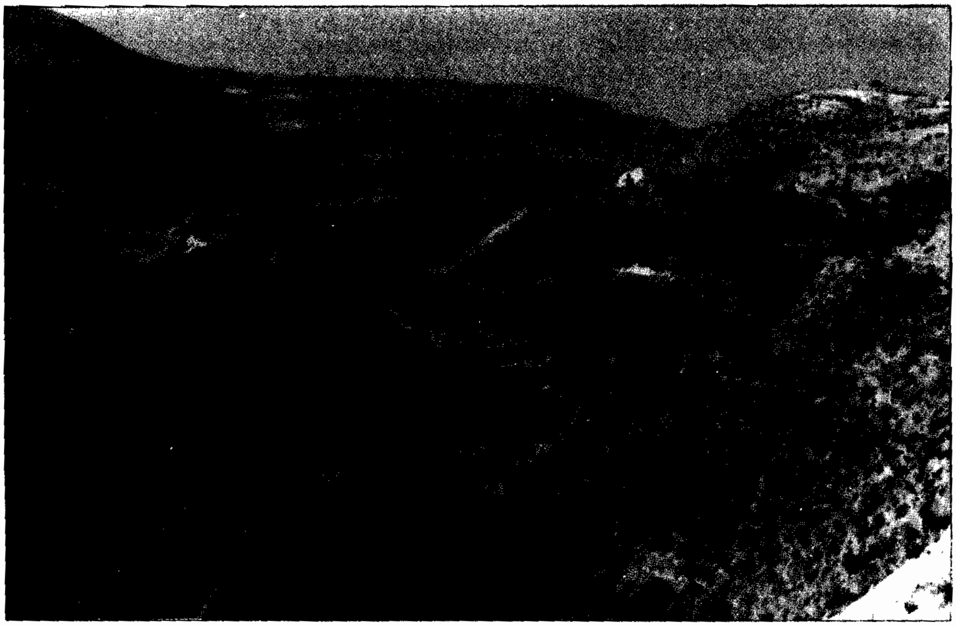

Plate No. 5: The middle part of Wadi Shueib with faulted thick-bedded strata in the northern bank subjected to rock falls and dissection by a first-order stream.

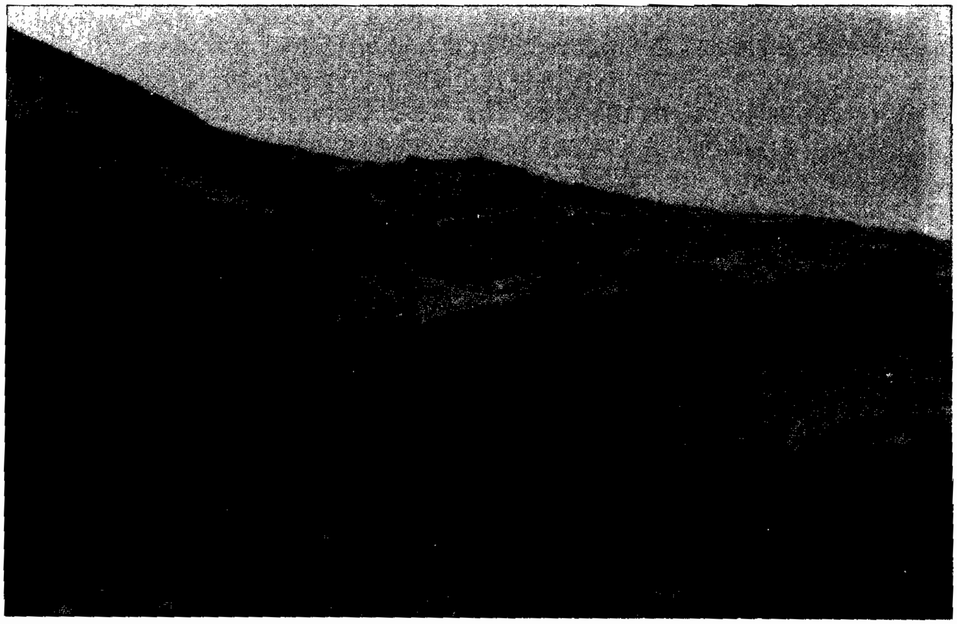

Plate No. 6:A close-up photo of the above first-order stream developed on faulted strata.

A radial stream pattern may develop when two F.O.S. are linked and, at the same time, neighbour others of opposite directions, as examplified by the streams number 34. 44. 45. 51.52. 53. 73. 74. 75. 76. 77, and 78. Also, such a pattern is noticed where two F.O.S. are linked in a "V" shape, and surrounded by another in their source areas as in streams number 65.66 and 67.

The "V" pattern characterizes those streams of the first-order which join each other in their mouth areas at the same elevation. Their source areas are not necessarily located in the same heights. Neither their lengths nor their slopes are always equal. They may vary in orientation, too, although the angle of less than 45° is mostly formed at the linkage points.

Some F.O.S. are distributed very far from each other throughout the basin with no pattern to adopt. This covers the F.O.S. which link with higher orders, on which are controlled by rock flextures and joints, Meanwhile, all the F.O.S. maintain a straight to a very low ratio of sinuosity or meandering (F=1-1 $^1/_2$) (4) as a result of their short lengths. None of the study streams is, however, braided.

III Second-order streams (S.O.S.)

A total of 116 second-order streams (S.O.S.) are distinguished in the study basin, representing 17.26% of all streams hosted in the basin, and 22% of the total number of F.O.S. or 18.80% of the total stream length in the basin and 30.10% of total F.O.S. length only. The S.O.S. vary, also, in slopes, lengths and orders of mouth area streams. With means of 12°9 and 0.718 k.m. of slopes and lengths, the majority of such streams (44.82%) develop slopes of 10° - 18° whereas 26.72% of them are 0.25 - 0.50 km. long, and 45.68% of them, too, link with streams of the same order, developing third-order streams (Table No. 9).

The S.O.S. are distributed throughout the basin, and, accordingly, classified into two main groups: (a) The second order streams that are formed by the linkage of the first-order streams located in source areas, and, thus, represent their future development. Such streams occupy a high belt extending just below the source areas. They are referred to here as H.S.O.

(b) Other second - order streams, located in lower areas, and are distributed throughout the basin. These streams are referred to here as L.S.O.

The high second order streams (H.S.O.): These streams which represent 63.46% of the total number of S.O.S. are lower ($\overline{X} = 11° 24$) and longer ($\overline{X} =$

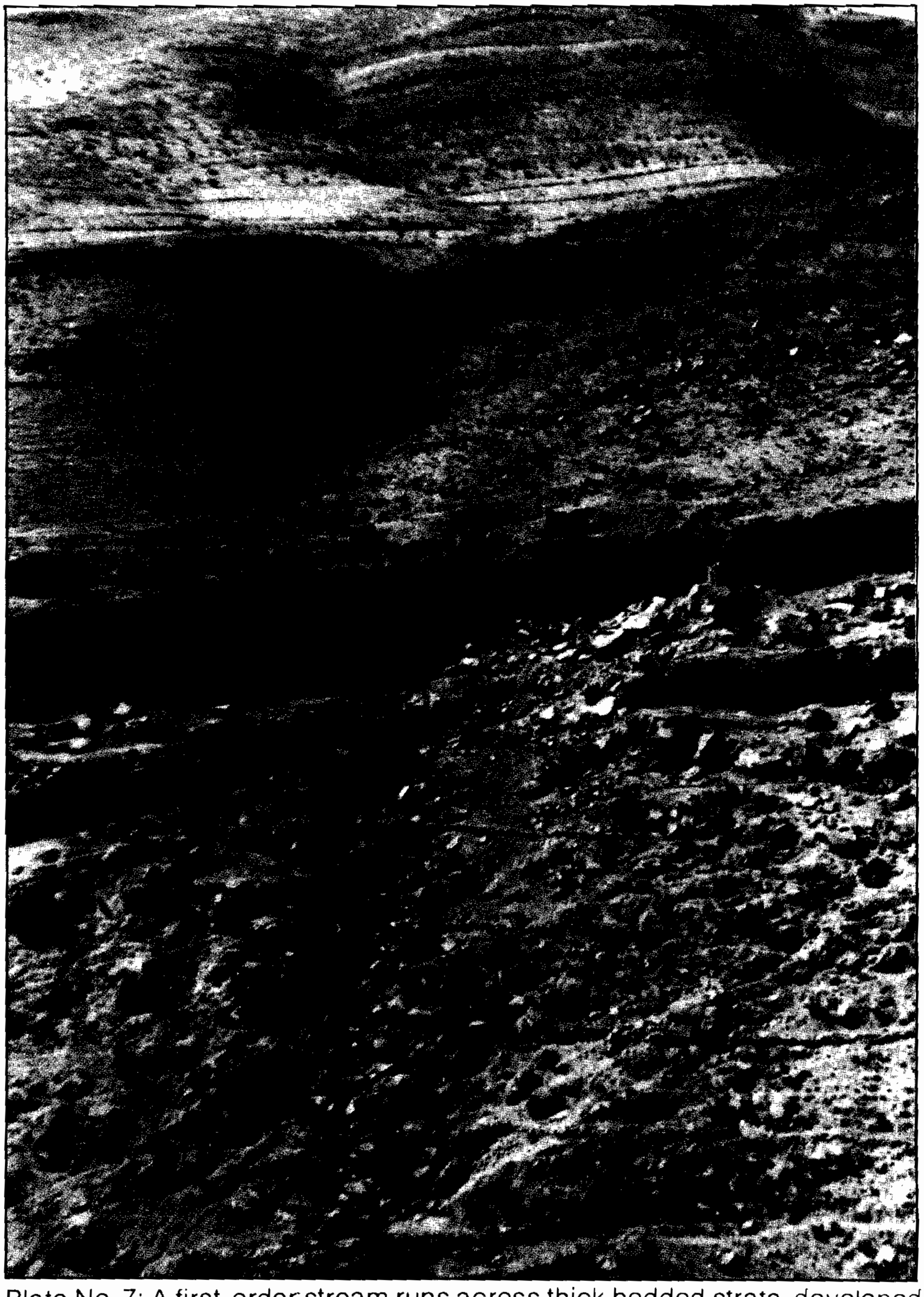

Plate No. 7: A first-order stream runs across thick bedded strata, developed to a hanging valley.

Plate No. 8: A first-order stream runs across limestone strata except in its lower part where it runs deeply in a marly formation.

0.759 km.) than the average second-order stream in the basin studied. They also tend to cluster around the same slope and length values. However, their slopes and lengths decrease as they become closer to the main stream and the mouth area, establishing a negative relation between their slopes and length.[5]

The low second order streams (L.S.O.): These streams are generally shorter and steeper than the average S'O'S or the H.S.O. in the study basin. Although they occupy the lower areas of the basin, they are developed where a high relief prevails, driving them to down cutting activities through retreating thick strata. Their relative location to the main stream, the mouth area and faults adds to relief variations, activating their erosional processes.

Table No. (9)
Second-order streams in Wadi Shueib Basin: slope, length and order of mouth stream frequency distributions

	A					B			C		
Slope (o)	Slope %	Length,km.	%	Order of mouth stream	Order of mouth stream %	Slope %	Length %	Order of mouth stream %	Slope %	Length %	Order of mouth stream %
- 2	Zero	- 0.25	18 96	2	45.68	Zero	17.80	41.09	Zero	20.93	51.16
2-5	5.17	0.25-0.50	26 72	3	33 62	5.47	30.13	39.72	4.65	20.93	23.25
5-10	36.20	0.50-0.75	18.96	4	13.79	38.35	16.43	15.06	32.55	23.25	11.62
10-18	44.82	0.75-1 00	15 51	5	6.89	45 20	12 32	4 10	44.18	20 93	13.95
18-30	12.06	1 00 +	19 82			9.58	23.28		16.27	13.95	
30-45	1 72					1 36			2.32		
45 +	Zero										
X = 12° 9		0 724				11°.24	0.759		13°.22	0.663	
Total	99.97		99.97		99.98	99.96	99.96	99.97	99.97	99.99	99.98

A: Wadi Shueib Basin as a whole.
B: High 2nd - order streams.
C: Low 2nd - order streams.

Contrary to F.O.S., the second order streams are more adjusted to back wearing than overtopping or micropiracy. This is, mainly, attributed to their limited numbers and scattering. However, they are separated from the drainage divides of the study basin by the belt of the first-order streams of source areas, and can only subject the drainage divides to backwearing after converting these first-order streams into a second-order, increasing their lengths and inclaving into adjacent basins, e.g. streams number 1,4 and 5 (Fig. No. 3). Micropiracy, in turn, is practised by a limited number of second-order streams wherever adjacent streams become capable of doing so, as is the case in streams number 2 and 3 (Fig. No. 3).

Faults have a similar effect on S.O.S. as on F.O.S. The faulted second-order streams are lower ($\overline{X} = 10° 33'$) and longer ($\overline{X} = 1.16$ km.) than others. They certainly progressed in the cycle of erosion at higher rates, lengthening and lowering their slopes.

IV. Other stream orders:

Wadi Shueib Basin hosts 23 third-order streams, six fourth-order streams and only one fifth-order stream which is considered as the main or trunk stream of the basin.

The average stream length of the third-order streams is 1.83 km., and that of slope is 6°34' (Table No. 10). They mostly link with each other to form fourth-order streams. 65.2% of them occupy the higher elevations just below the high second order stream belt (H.S.O.). The rest of such streams run in lower elevation, and maintain shorter and steeper courses. These streams, themselves, are considered local base levels for 60 first-order streams and 39 second-order streams, draining their water and sediments, and resulting in a considerable increase in third-order stream discharges.

Table No. (10)
Third-order streams: frequencies of length and slope★

Stream length km.	A Frequency %	B Frequency %	C Frequency %	Stream slope (o)	A Frequency %	B Frequency %	C Frequency %
- .50	12.5	13,33	12.50	- 2	Zero	40.00	12.50
.50-1.0	37 5	20.00	37.50	2-5	30.43	60.00	62.50
1.0-1.50	Zero	20.00	Zero	5-10	60.86	—	25.00
1.50-2.00	25.0	6.66	25.00	10-18	6.69	—	—
2.00-2.50	25.0	Zero	25.00	18-30	—	—	—
2.50 +	Zero	40.00	Zero	30-45	—	—	—
Total	100.0	99.99	100.00	45 +	99.98	100.00	100.00

★A = All 3rd. order streams in the basin.
B = High 3rd. order streams in the basin.
C = Low 3rd. order streams in the basin.

The six fourth-order streams developed in the basin belong to two slope classes: 2°-5° and 5°-10°, but their lengths vary between 0.500 - 7.000 km. Four of these streams drain into the main stream, while the other two are linked to form the trunk stream of the basin. Their average length is 4.11 km and that of slope is 4°24′. These streams, also, represent local base levels for 57 first-order streams, 39 second-order streams. and three streams of the third order, totaling 102 streams.

Finally, the fifth-order stream of the basin is 15.00 km long and 2°17 slope. It is, therefore, considered the longest and the lowest stream in Wadi Shueib Basin. It actually occupies 64.23% of the total basin length. That is 35.77% of the basin, located at higher elevations, has not yet been under backward wearing imposed by this stream. 57 streams drain directly into it: 40 streams of the first-order, 8 from the second, 5 from the third, and 4 from the fourth-order . The other streams in the basin are indirectly drained into it through linkages with each other. Such a drainage net forms a major source of water and sediment discharges that the trunk stream transport to the mouth area, building its alluvial fan. Being subjected to down faulting, this stream developed higher rates of wearing which led to more incision in the valley, (Fig. No. 6).

Other interrelationships among stream orders: None of the stream orders developed in the study watershed is considered of less importance than the others. Actually, as was stated earlier, each of the stream orders represents a transitional step to forming a higher stream order. The high order streams are the only means to transport both water and sediment discharges of the lower order streams. The first, thus, forms local base-levels for the later. Changes in the morphological characteristics in any order should lead to subsequent changes in other orders.

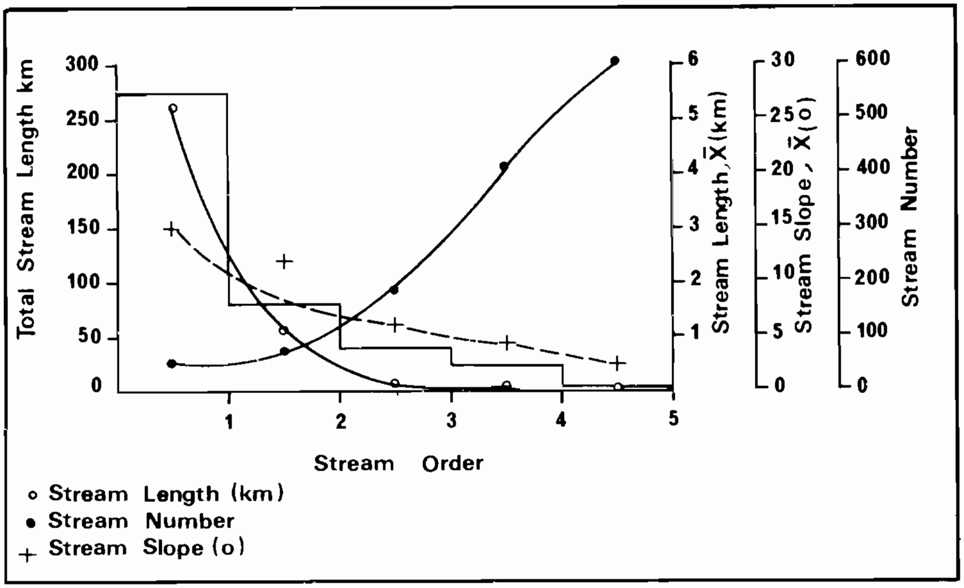

Fig. 6 Stream Length, Number, Slope & Order in Wadi Shu'eib Basin

Bifurcation ratio[6] compares between numbers of streams of different orders, and indicates the actual number of streams in any order needed to develop a stream of a higher order. In the study, it was found that six streams of the fourth order were needed to develop the only fifth order stream in the basin, whereas 4.53 streams of the first-orders form one stream of the second, five of the second to form one of the third, and 3.83 streams of the third were needed to develop one stream of the fourth order (Fig. No 7).

Clavity between different stream order belts also illustrates other interrelationships among stream orders. Each of the stream order belts (Fig. No. 8) is delimited to areas where two streams of higher elevations link firstly to form a higher stream order mostly at lower heights. Stream orders developed in lower elevations, and within areas of others' belts are excluded. Such "drainage belts" develop certain degree of clavity between their boundary lines. This is mainly attributed to differential backwearing processes which lead to varying stream lengths, slopes and orders, while progressing in the cycle of erosion, stream order belts tend to "promote" their orders to higher ones, i,e. one becomes two, and two changes to three, and so on.

As far as the first-order streams belt is concerned, it constantly shifts its bourders to higher elevations on the account of the drainage areas of abjacent basins. Also, stream order belts maybe overlapped, turning parts of them into inclaves and exclaves. An inclave of any stream belt in a lower one represents a leading step in backwearing towards higher elevations or the source areas. In contrary, an exclave of another stream order belt in a higher one reflects erosional remnants or the slowing down of backwearing processes. Table No (11) illustrates some properties of the stream order belts identified. The fourth order belts are the largest, whereas the third order belt, being a transitional, seems the smallest. The first order stream belt hosts the shortest and steepest streams in the basin, and, also, maintains high drainage density and stream frequency. Drainage density tends to decrease with stream order as a result of another decrease in stream numbers and lengths in larger areas.

V. Conclusions:

When comparing between streams of different orders in Wadi Shueib Basin, it becomes very clear that the first-order streams are dominant in the drainage network in numbers, lengths, and slopes. They are developed by backward erosion, causing drainage divides to clavity and shifting, and, also, by micropiracy through leteral planation. They are evolved, accordingly, into higher stream orders, leading to the denudation of the basin. The first-order

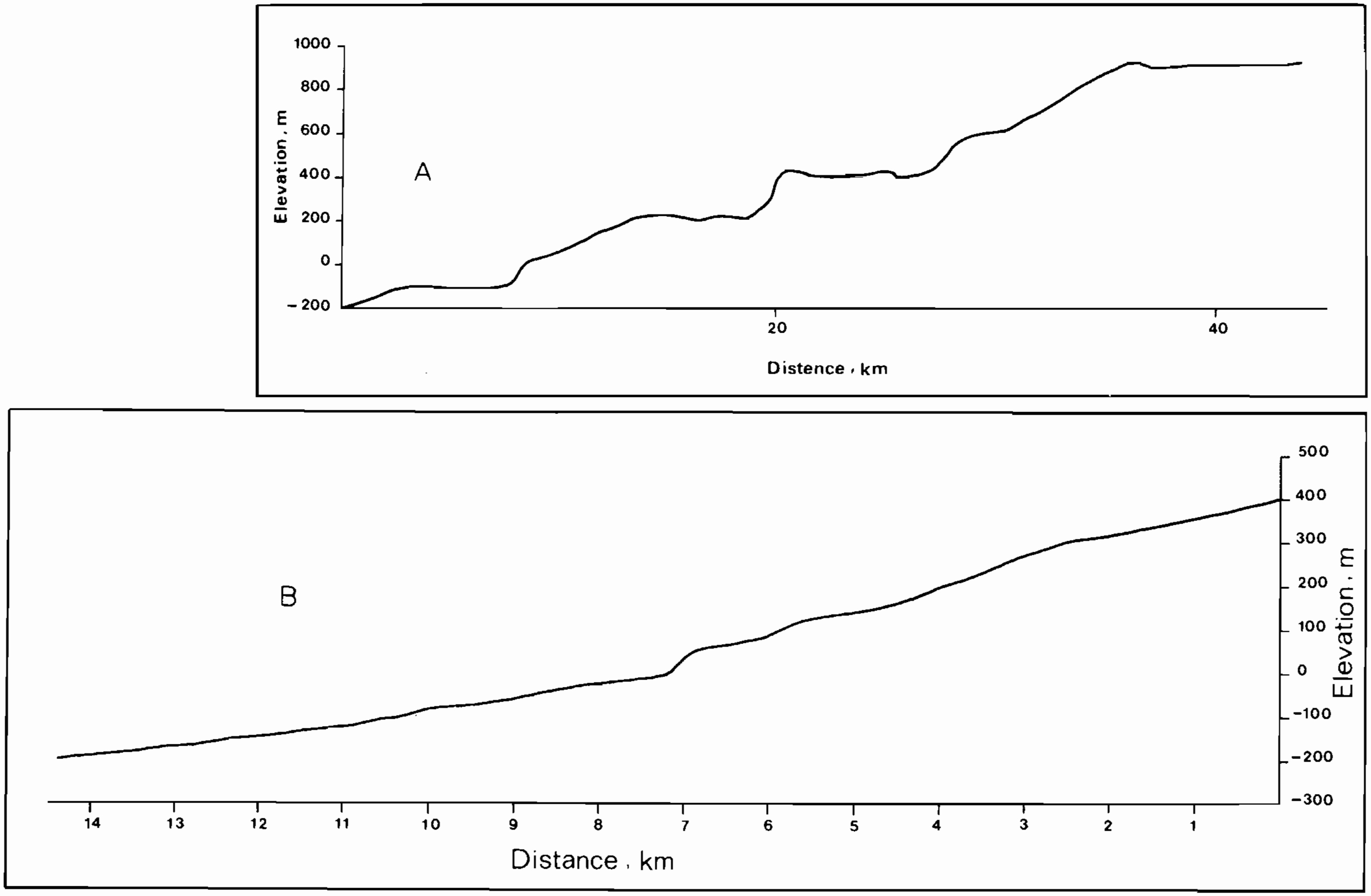

Fig 7 Longitudinal Profiles of: A-Wadi Shueib Basin B - The Main Stream in Wadi Shueib Basin (Fifth - Order)

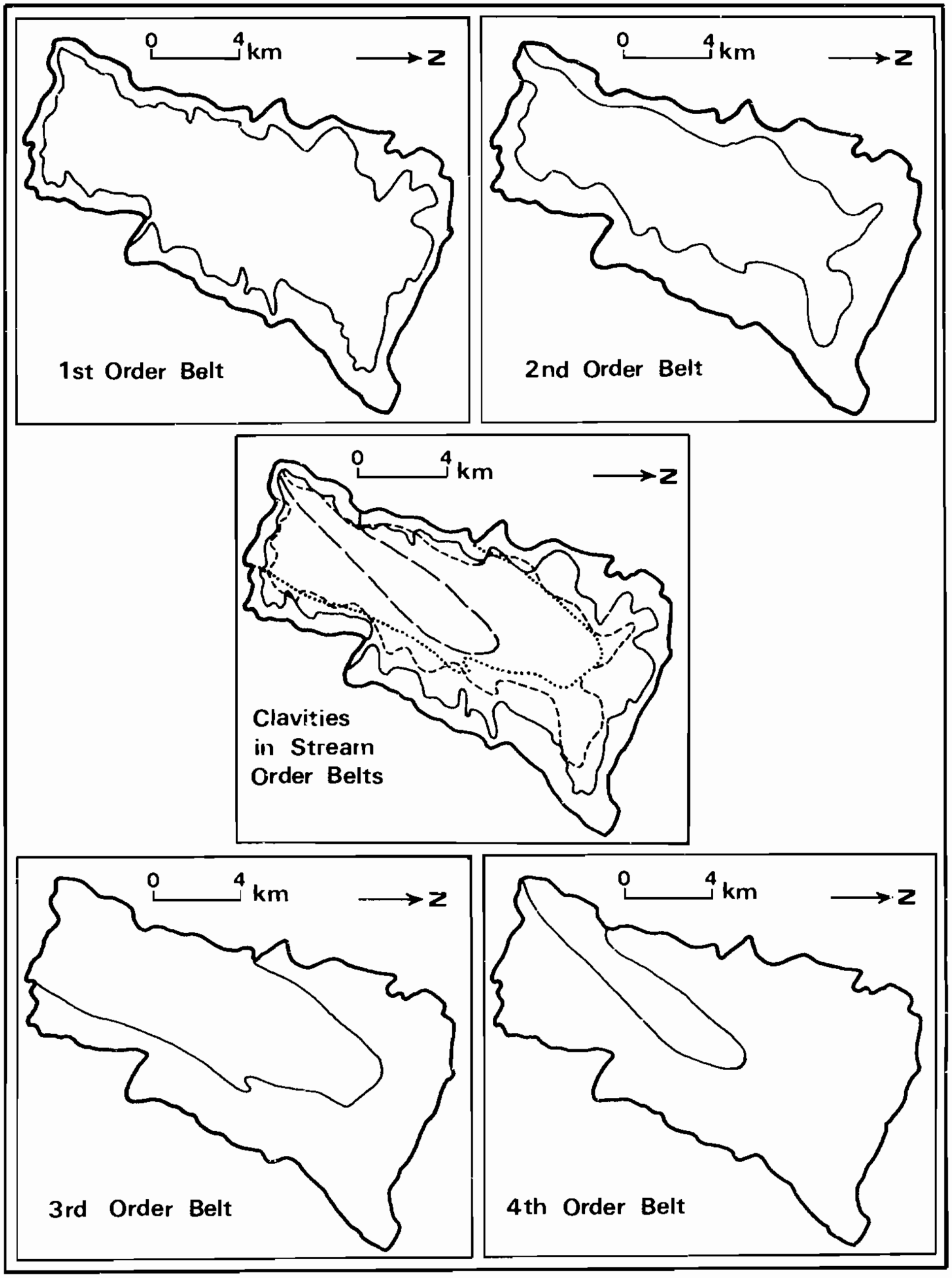

Fig. 8 Stream Order Belts in Wadi Shu'eib Basin

Table No. (11)
stream - order belts: area, drainage density, stream frequency, means of stream slope and length.★

1	2	3	4	5	6	7	8	9
1	48.20	48.20	29.14	21.14	2.06	3.71	13° 18	0.556
2	35.60	83.80	21.52	50.66	1.55	2.05	11 24	0.759
3	14.02	97.82	8.47	59.13	2.26	1.06	6 23	2.120
4	44.90	142.72	27.14	86.27	0.55	0.13	4 24	4.110
5	22.67	165.40	13.71	99.98	0.66	0.04	2 17	15.000
Total	165.39		99.98					

★ All figures apply only to streams delineating the stream order belts.
Horizontally arranged figures:
1 = Stream order belts.
2 = Area of each belt, Sq. km.
3 = Cummulative areas of successive belts, Sq. km.
4 = Area of each belt, % of total basin area.
5 = Cummulative areas of successive belts, %.
6 = Drainage density in each belt, km/Sq. km.
7 = Stream frequency in each belt, stream / Sq. km.
8 = Stream slope (o) in each belt, $\overline{x}$.
9 = Stream length (km) in each belt, $\overline{x}$.

streams provide higher stream orders with both water and sediment discharges, too. Down faulting in the mouth area certainly enabled the trunk stream to transport most of the sediment yield, forming an alluvial fan on the lacustrine deposits of the Jordan Valley.

Lithology under the past pluvials was very susceptible to erosion, although it became almost resistant under prevailing arid conditions except when high intensity rainfall occurs. The basin is, thus, yielding sediments which, lately, accumulated behind Wadi shueib Reservoir. With an annual siltation of one meter, the reservior has lost about 60 per cent of its original capacity (2.3 MCM) since it became into use in 1970. Aside from sediment yield, stream erosion in the basin studied led to the development of hanging valleys, strath terraces, incised meanders, and ex-bow cut offs, with no major depositional land forms, e.g. flood plain, to be formed behind the mouth area.

Plate No. 9: Wadi Shueib Reservoir in Summer, 1986. A delta is exposed due to excessive evaporation and shortage of the stream discharge, changing to a grazing land.

Notes

1. Due to the absence of weather stations and shortage of climatological data in the study basin, Shuneh South, located just below the basin's mouth at - 230 m, and Jubeiha, located at about 2 km east to the basin's eastern extension at 980m or 18 km. to the east of Salt, to represent temperature changes in the basin. Data for Jubeiha were taken from: Arab league, Agroclimatological study in the Arab countries, Data Bank, Jordan, Khartaum, 1976, Several pages. The data for Shuneh South were taken from: Meteorological Department, climatological data, volumes of 1964-1967, Amman, several pages.
2. These formations are referred to later as numbers one through six, successively.
3. The correlation coefficient (r) of stream slope and distance to main stream is (-0.26), and between stream slope and the distance to the mouth area is (-0.33).
4. F value (Sinuosity) = Actual length of a stream / its horizontal length.
5. The (r) value between distance to main stream and slope is (-0.32) and between distance to mouth area and slope is (-0.15), and between stream length and slope is (-0.54).
6. Bifurcation ratio = the number of streams of any order (N) to the number of streams in the next order (N +1).

Bibliography

Abrahams, A.D., "Factor analysis of drainage basin properties: evidence for stream abstraction accompanying the degradation of relief" **Water Resour Res.** (1972:8), 624-633.

Abrahamas, A.D., "Channel networks: a geomorphological perspective". **Water Resour Res.,** (1984:20), 161-168.

Bender, F., **Geology of Jordan,** Berlin , Stuttgart: Gebruder Borntraeger, 1974.

Burden D., **Handbook of the geology of Jordan,** Amman, Government of H.K. Jordan, 1959.

Coates, D. and J.D. Vitek, **Thresholds in geomorphology,** London....: George Allen Unwin, 1980.

Cook, R. and J.D. Doornkamp. **Geomorphology In Environmental Management,** London: Oxford University Press, 1974.

Daniel, J.R.K., "Drainage density as an index of climatic geomorphology". **J.Hydrol.,** (1981:50), 147-154.

Doornkamp J. and C.A. King, **Numerical analysis in geomorphology,** London: Edward Arnold, 1971.

Dunkerley, D.L., "Frequency distributions of stream link lengths and the development of channel networks" **J. Geol.,** (1977:85), pp. 459 - 470.

Chosh,A.K. and A.E. Scheidegger, "Dependence of stream link length and drainage areas on stream order" **Water Resour. Res.,** (1970:6), 336 - 340.

Goudie,A. and Others, **Geomorphological Techniques,** London: George Aller Unwin, 1981.

Gregory K. J. **Drainage basin form and process,** London: Edward Arnold, 1973

Horton,R.E., "Erosional development of streams and their drainage basins" **Geol. Soc. Am., Bull.,** (1945:56) 275 - 370.

Leopold, L. and Others **Fluvial processes in geomorphology,** San Francisco W.H. Freeman Co., 1964.

Marcus, A. "First-order drainage basin morphology - definition and distribution" **Earth Surf. proc.,** (1980:5), 389-398.

Marisawa. M., ed.. **Fluvial geomorphology,** London: George Allen Unwin, 1973

Morgan. P. "Observation on factors affecting the behavior of a first-order streams. "**Inst. Brit. Geohr.,** (1972:56). 71-185

N.W.A.and F.R. Germany **National Water Master plan of Jordan.** Amman, 1977.

Ollier, C.D. **Tectonics and landforms,** London and New York. Longman, 198?.

Shreve. R.L. "Variation of main stream length with basin area in river networks" **Water Resour. Res.,** (1974:10), 1167-1177.

Smith. I. and P. Stopp. **The river basin: an introduction to the study of hydrology,** Cambridge...: Cambridge University press, 1978.

Strahler. A.N. "Statistical analysis in geomorphic research". **J.Geol.,** (1954:62), 1-25.

Strahler A.N., "Quantitative analysis of watershed geomorphology," **Trans. Am. Geophys. Union,** (1955:38). 913-920