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Development of Synthetic Unit Hydrographs in Small Ungauged Catchments of Pakistan

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DEVELOPMENT OF SYNTHETIC UNIT HYDROGRAPHS IN SMALL UNGAUGED CATCHMENTS OF PAKISTAN

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Preliminary findings of this paper had been presented in the Quarterly journal of Pakistan Engg Congress "Engineering News" Vol XXVIII No. 1, March 1984, When the Author was engaged in post graduate research on the topic under discussion. This paper presents certain modifications and refinments in the method descriped therein to make the study more usefull and worth while.

ABSTRACT

The study present an emperical method of deriving coefficients of Snyder's synthetic Unit hydrograph. Basin lag and peak discharge were related to physical charactiristics of thirteen catchments ranging in are from 56 to 1560 square miles. These are located in Baluchistan Plateau and Potwar Highlangs lands of Himalayan Foothills in the vacinity of Mangla and Tarbela dams.

Equation for the determination of time base and coefficients used by Snyder were not found in line with the hydrological conditions of the catchments that have been studied. The same is the case with equations for the Time Width of Unit hydrograph of 50% and 75% of peak discharge and coefficients used by U.S Army Corps of Engineers. These emperical equations have, therefore, been modified to dervie synthetic unit hydrographs for small catchments in Pakistan.

Synthetic Unit hydrographs derived by the modified snyder's method were compared with that of original snyder's method and U.S Army Corps of Engineers method. Both the available methods have considerable variation in peak discharge time width and time base of unit hydrographs as compared with the modified snyder's method. Both the methods generally underestimate the peak discharge and overestimate the time width and time base of unit hydrographs. However U.S. Army corps of Engineers method have less variation as compared with the original snyder's method.

Validity of the derived coefficients was also tested by comparing the predicted and observed hydrographs. For the purpose of comparison the predicted and observed hydro-

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graphs of the same storm were plotted on the same sheet to see any variation in peak discharge and its time distribution. Comparison of the predicted and observed results was made in all the catchments using modified Snyder's method and original Snyder's method. Results achieved are quite satisfactory and indicate that derived coefficients can effectively be used for hydrologically similar catchments, using modified Snyder's method.

INTRODUCTION

Flood estimation is always a problem in ungaged catchments. Accurate estimation of flood is essential for the design of various hydraulic structures such as bridges, reservoir spillways and other flood control works. The unit hydrograph principle is widely used in flood prediction. This technique is sometimes used to fill in missing discharge records, and to forcast the major hypothetical floods.

STATEMENT OF PROBLEM

Relatively small number of streams are gaged. It is frequently required to synthesize the unit hydrographs for ungaged basins. The approach used is to take the unit hydrographs from various gaged basins to establish relations between basin area, storm and unit hydrograph charactiristics, such as duration of rainfall peak discharge, base length and basin lag. These relationships can be used to synthesize the unit hydrographs for ungauged basins.

Snyder derived the unit hydrograph method for a particuler region. It may not be appropriate to apply this method as such to a region other than for which it was derived. Hence in order to use Snyder method for small basins to Pakistan, It is desirable to derive the coefficients on small gauged catchments. These can then be used for derivation of synthetic unit hydrographs for ungauged catchments.

OBJECTIVES

1. To determine the Coefficients "C_t" and "C_p" of Snyder's equations for various sub catchments of the Indus River Basin using the rainfall and runoff data of gaged streams.
2. To varify the derived paramenters by computing the synthetic hydrographs and comparing them with observed hydrographs.
3. To examine the limitation of base lenth "T" taken three days in Snyder's method.
4. To varify the applicability of method by U.S. Army corps of Engineer's for time lag and time width of unit hydrograph at 50% and 75% peak discharge.

SCOPE OF STUDY

Generally the procedure developed to synthesize unit hydrographs gives reasonable results when applied to catchments in the region for which they are derived. Coefficients involved in the relationships between catchment charactiristics and unit hydrograph parameters vary from region to region because they show the combined effect of all other charactiristics which are not considered in the relationships. These coefficients may affect the unit hydrograph shape. It follows that synthetic unit hydrograph relationships derived for one climatological region may not be applicable to the catchments from a different climatological region. Significant error in predicted results may possibly occur if coefficients derived for some other area situated in a different climatological region are used. Hence for more accurate development of synthetic uni7 hydrographs, the coefficients of Snyder's synthetic hydrographs are determine for small catchments of Pakistan. Equations for time base and time width of unit hydrographs of 50% and 75% of peak discharge are modified to represent the local conition. One additional parameter of time width at 25% of peak discharge is added for the ease of sketching unit hydrograph. Keeping in view the availability of reliable rainfall and runoff record, thirteen catchments are selected for study. Ten catchments are used to derive the coefficients of Snyder's method and these catchments along with the other three catchments are used to varify the reliability of these coefficients.

SECTION OF CATCHMENTS

Primarely the drainage area was taken as he criterion for selection of small basins. The rainfall and runoff record for the selected basins were searched to find out isolated storms of simple structures i.e. single peak floods. Study basins were selected giving due consideration to the following:

1. Basin area not to be more then 2000 square miles.
2. Adequate and reliable rainfall and runoff records available.
3. No peculiar storage charactiristics such as reservoir on any diversion lie with in the basin.
4. Basin equiped with recording rain gages and water stage recorders or at least hourly rainfall and gagehights along with reliable rating curves having reasonable period of rating operations.
5. Topographic maps having scale of 1 inch to 4 miles be available i.e. G.T. Sheets of survey of Pakistan.
6. Basins having insignificant effect of snow melt.

Location map of the study area is shown in Figure 1 Rainfall and runoff data of surface water Hydrology Projects of WAPDA had been used in the study. Thirteen basins satisfying the above conditions were selected for the study. Two catchments are situated in the arid region of Mekram Coast and Kachi Plains of Baluchistan Plateau. The remaining catchments are located in sub-humid to humid region of Murree hills, and hilly part of Hazara and Potwar Plateau in the Northern Pakistan. Various catchment with there phsiographic features are given in table 1.

METHODOLOGY AND DISCUSSIONS

(a) DETERMINATION OF COEFFICIENTS

Observed discharge records from the catchments under study were plotted on the graphs and base flows were separated to find out the direct runoff volume in inches. Ordinates of direct runoff were divided by the runoff volume in inches over the catchment area the resulting hydrograph is unit hydrograph of that catchment. To determine the duration of unit hydrograph, hourly reainfall records were searched out. Storm and unit hydrograph parameters thus obtained such as peak discharge (Q), duration of rainfall excess (t_R) basin lag (t_P) and Base length (T) of unit hydrograph were used to determine the coefficient of Snyder's method. Physical charactiristics of each basin such as catchment area (A), length of main strcum (L) and length of centroid of catchment nearest of main stream from the gaging location (L_c) were determined and used to find out the Snyder's coefficients. The reverse process of Sntder's equations was adopted.

In original equations f Snyder's method, storm of specified duration (t_r) equal to $t_p/5.5$ are used. Where t_p is basin lag in hours. If the observed storm fulfill this condition then C_t can be found by putting the known values of t_p, L and L_c in the following equtions.

$$t_p = C_t (LL_c)^{0.3} \qquad (1)$$

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generally observed storms are not of duration as specified by Snyder. For such a situation the following equation has been used to find t_p.

$$t_{pR} = t_p + \frac{(t_R - t_r)}{4} \qquad (2)$$

Where C_{PR} = basin lag for storm of t_R duratiwn, t_R and t_{PR} are knwwn, t_p car be found by using known values of t_R and t_{PR}. Now this values of t_p can be used ir equation (1) to find out the value of C_t.

The value of C_p can be found with the help of the following equation by using known values of Q, t_{PR} and A.

$$Q = \frac{640\ C_p\ A}{t_{PR}} \qquad (3)$$

Various parameter of observed unit hydrograph of different catchment are given in Table-2 which are used to determine C_t & C_p Values of C_t and C_p obtained by using the proceudre described above are given in Table-3.

Range of average values of C_t and C_p of four catchment i.e. No. 2,3,6 & 7 in the table 2 are very small. This indicate that these are situated in Hydrometeorologically similar areas. These basins can be used as representative basins for nearby ungaged streams.

Some of the basins have wide variability in the range of C_t and C_p values. It indicates that these besins may have different physical and geohydrological conditions.

Some times there are many sub-regions in one hydrological region and they may have significant climatic and geological variation within the region. These changes may affect the coefficients of Snyder's method. The coefficients derived for hydrological region of Baluchistan Plateau are highly variable because two basins studied from Baluchistan Plateau are situated in two different sub-region. Khost River at Chappar Rift is located in semi-arid to subhumid zone of Mekran Coast. Most of the areas have average annual rainfall of less then 10 inches. Barren hills absorb most of the precipitation, which is already less and unevenly distributed. Direct runoff produced varies from less then 1 to 10% of the total valume of precipitation. In such a situation, large variation in derived coefficients, C_t and C_p, is expected.

(b) BASE LENGTH (T)

Snyder (1938) proposed a base length of unit hydrograph in days as given below.

$$T = 3 + \frac{t_p}{8} \qquad (4)$$

This equation suggest minimum base length of three days. This does not truely represent small mountanious catchments with steep slope in general and specifically, for non-perrenial streams in which flow dies out within a couple of hours. This fact is proved by comparing the base length of observed unit hydrographs with that of Snyder's synthetic unit hydrographs.

Base length relationship is modified by correlating the unit hydrographs of different catchments against catchment areas. It gives the following relationship.

$$T = 18.5 \log A - 4 \qquad (5)$$

Where catchment araea (A) is in square miles. Correlation coefficient using least square method was found to be 0.73. This equation gives average values of base length. Observed base length may vary as compared with the computed base length depending upon variations in storm charactiristics and anticident soil moisture conditions of catchments.

This equation is further improved by instroducing the parameter of duration of rainfall excess (t_R). Time to peak is directly proportional to the duration of rainfall excess and it varies one half of the storm duration provided the storm have uniform intensity and distribution. Hence modified base length is as given below.

$$T = 18.5 \log A + o,5\ t_R - 4 \qquad (6)$$

This equation gives an average estimate of base length for natural streams.

Estimate of Base length with the help of modified equation were compared with that of observed hydrographs (Mahboob, 1983). It indicated that modified base length equation underestimate the synthetic graphs only by 2% on the average. This percentage error is within permissible limits. Original Snyder's relationship of base length overestimate the base length by 166% on the average as given in Table 4. This percentage error is significant and beyond the limit of accuracy required for such type of study.

(C) TIME WIDTH OF UNIT HYDROGRAPHS

Correlation equations for time width of unit hydrograph at 50% and 75% of peak discharge developed by U.S. Army corps of Engineers (1959) are given below.

$$W_{50} = 770\ (Q/A)^{-1.08} \qquad (7)$$

$$W_{75} = 440\ (Q/A)^{-1.08} \qquad (8)$$

These equations were used in calculating the time width of synthetic unit hydrographs with the help of original Snyder's method and U.S. Army corps of Engineers method. Comparasion of synthetic hydrographs obtained with these method to the modified method indicate that these equations highly overestimates the W_{50} and W_{75} values for the catchment under study. These equations were modified to represent the requirements of small

catchments of Pakistan. One additional equation representing the width of synthetic hydrograph at 25% of peak discharge was also obtained depending upon the observed data of number of storms from the different catchment given in Table-2. Relationships developed for W_{25}, W_{50} and W_{75} are given below:

$$W_{25} = 90\,(Q/A)^{-0.5} \qquad (9)$$

$$W_{50} = 180\,(Q/A)^{-0.8} \qquad (10)$$

$$W_{75} = 65\,(Q/A)^{-0.7} \qquad (11)$$

These equations give average estimates of time width at 25%, 50% and 75% of peak discharge per square mile of catchment. These equations are extremly helpful in sketching unit hydrographs and were used in testing the reliability of synthetic hydrograph indicated that these equations yield better results for small catchments of Pakistan as compared with the U.S. Army corps of Engineers equations.

(D) COMPARISON OF SYNTHETIC UNIT GRAPHS

Synthetic unit hydrographs from basins under study were prepared with the help of derived coefficients i.e. C_t and C_p given in Table-3. These unit hydrographs were compare with that of original Snyder's method and U.S. Army Corps of Engineers method. Method used to evaluate time lag (t_p) by the U.S. Army Corps of Engineers is different with that of Snyder.s method. Equation used by the U.S. Army Corps of Engineers (Linsley, 1975) is given below.

$$t_p = C_t \left(\frac{LL_c}{S}\right)^{0.38} \qquad (12)$$

in this equation, they introduced slope 9s0 parameter and used a fifferent value of exponant i.e. 0.38 as compared with that of original Snyder's equation No. 1 i.e. 0.30. However corps of Engineers have used different values of C_t depending upon the topography of various drainage areas. They used value of C_t as 1.20 for mountain drainage areas and 0.72 for foot hill drainage areas. Where as Snyder used average value of C_t as 2.0 for all types of catchment.

Great care is used while selecting different values of C_t in the catchments under study. Selection of value of C_t depends upon the judgement and experience. Only helping factor is the slope of catchment. Hilly areas have greater slope as compared with the foot hill areas. Limiting slope for the foot hill and hilly area is assumed to be 150 ft/mile, above

which catchment is supposed to be hilly and below that it is foot hill. G.T. Sheets of the Survey of Pakistan have been used for the determination of slopes of various catchments. These are shown in Table-1. Rest of the procedure is same as that of original snyder's method (Linsley, 1975). Synthetic hydrographs developed with various methods were superimposed on each other to see any variation of peak and shape. Figure 2 to Figure 11 shows the comparative results. Variation in unit hydrograph peak time to peak and base length of various catchments given in Table 4. It indicate that corps of Engineers method and original Snyder's method underestimate the peak discharge by 60% and 366% respectively as compared with the modified Snyder's method. Time to peak and time base are overestimated by 19% and 106% with Corps of Engineers method and this value is 204% and 166% with original Snyder's method respectively.

Such a wide range in percentage error indicates that these methods are not suitable in synthesizing the unit hydrographs for Small catchments of Pakistan as compared with the modified Snyder's method.

(E) APPLICATION OF MODIFIED METHOD TO SIMILAR CATCHMENTS

Three basins were selected for testing the reliability of derived coefficients. These basins were other than thwse which were selected for the determination of Snyder's coefficients. Physical charactiristics of these basins were also given in Table-1 under serial number 11, 12 and 13.

Necessary conditions for the use of Snyder's coefficient for a basin to be tested is that it should have similar hydrological and georgraphical conditions as that of the representative basin. Precipitation, gelogy and topography of catchment areas are the primary indicators of the hydrological response. Hence conditions of the similarity should conform with these factors. The following charactiristic of catchments were compared as a test of similarity.

1. Average slope of main stream.
2. Mean elevation of catchment.
3. Hydrological conditions in terms of mean annual and seasonal precipitation.
4. Geological conditions.
5. Vegetal cover.
6. Ratio of the length of centroid and the main stream.
7. FORM FACTOR. Expressed as ratio of average width to the axial length of catchment. The axial length was measured from the gaging station to the most remote point on the catchment area. Average width was determined by dividing the catchment area by the axial length. Here length of main stream was taken as axial length.

8. COMPACTNESS FACTOR. Defined as the ratio of the catchment perimeter to the circumfrence of circle whose area is equal to the area of catchment.

Three basins to be tested come under the hydrological region of Himalayan foothills and Potwar Plateau. To synthesize the hydrographs of these basins, Snyder's coefficients of nearby study basins having similar conditions are used. Haro River near Khanpur is used as representative basin for Haro River at Sanjwal and Siran River at Thapla, whereas Soan River at Chirah is used as representative basin for the catchment of Ling River near Kahota.

Similar criteria as described in previous paragraphs were adopted for the comparison of observed and synthetic hydrographs of these basins. Comparison of these graphs is shown in Figure 12 to Figure 18.

In this type of hydrological study, there may be many sources of error at any stage, such as:

1. The accuracy of rainfall records and deriving an excess rainfall over the basin.
2. accuracy of River flow measurements and the rating applied to them.
3. The application of the unit hydrograph theory to these real events.
4. The variation in catchment charactiristics from tehse of the representative basins.

Inspite of these possible sources of error, the results are quite comparable. Synthetic hydrographs developed with the help of derived parameters have reasonable match with the observed hydrographs. The method underestimates the peak discharge by 2% and overestimate the time to peak by 14% on the average as compred with theobserved hydrographs peak and time to peak respectively. This percentage of error is within acceptable accuracy limits, keeping in view the quality of data available.

(F) CONCLUSIONS

The following conclusions can be drawn from the results of study.

1. The results indicate that the derived coefficients C_t and C_p, can be used for hydrologically similar ungaged catchments to predict unit hydrographs.
2. comparative study of modifeid Snyder's method with the original Snyder's method and U.S Army Corps of Engineers method indicate that the modified Snyder's method yields more accurete results as compared with the other two methods. However U.S Army Corps of Engineers method may be the second choice in the absence of modified Snyder's method.

3. In order to improve the reliability of the derived results, further study is required to determine optimal values of C_t and C_p in different regions so that the method can be applied under all conditions.

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TABLE 1
PHYSIOGRAPHIC FEATURES OF STUDY BASINS

Sr. No.	STREAM	GAGE LOCATION LATITUDE		LONGITUDE		PHYSICAL FEATURES A Sq.Miles	L Miles	L_c Miles	S Ft/Mile	LL_c S
1.	Bhaishan Dur Khas near missa (tributary to Kanshi River near Missa) – Non-perennial	33°	11'	73°	23'	58	17	7	31.2	21.3
2.	Brandu River near Daggar (tributary to Indus River at Paranjal)	34°	29'	72°	29'	231	17	9	229.6	10.1
3.	Haro River near Khanpur (tributary to Indus River near Ghariala)	33°	48'	72°	54'	300	36	19	195.6	48.9
4.	Kanshi River at Palote (tributary to Jhelum River near Bathar)	33°	14'	73°	26'	429	38	17	36.7	106.6
5.	Ponch River near Kotli (tributary to Jhelum River near Dhangrot)	33°	29'	73°	53'	1250	65	35	203.1	159.6
6.	Sil River near Chahan (Tributary to Soan River near Balawal)	33°	27'	72°	52'	93	19	9	28.1	32.3
7.	Siran River near Phulra (tributary to Indus River near Arbela)	34°	20'	73°	05'	408	44	20	264	54.2
8.	Soan River at Chiran (tributary to Indus River near Pihal)	33°	39'	73°	18'	126	24	13	240	20.1
9.	Khost River at chappar Rift (tributary to Kaman Rud never Shin Tabai) – Non-perennial	30°	20'	67°	30'	510	33	13	120	39.2
10.	Porali River at Sinchi Bent (to Sea near Goth Amun) – Non-perennial	26°	30'	66°	23'	1560	98	46	46.7	660
11.	Haro River at Sanjwal (tributary to Indus River near Gariala)	33°	45'	72°	26'	695	72	43	132	270
12.	Siran River at Thapla (tributary to Indus River near Arbela)	34°	06'	72°	52'	1080	68	22	188.6	108.9
13.	Ling River near Kahota (tributary to Soan River near Sihala)	33°	36'	73°	22'	56	17	9	264	9.4

TABLE 2 SUMMARY OF BASIC DATA

Sr. No.	CATCHMENT	Storm Date	STORM CHARACTERISTICS t_R (Hours)	t_{PR} (Hours)	q_{PR} (ft^3/s)	q_{PR}/A	UNIT HYDROGRAPH CHARACTERISTICS W_{25} (Hrs)	W_{50} (Hrs)	W_{75} (Hrs)	T(Hrs)
1.	Bhishan Dur Khas near Misca Catchment Area = 58 Sq. miles	July 12, 1962	1	2.50	8497	147	5.0	2.5	1.5	34
		July 15, 1964	1	2.50	7589	131	7.0	4.6	2.3	20
		Aug. 7, 1966	2	4.58	7358	127	7.0	4.0	2.0	40
		Feb. 27,1970	1	1.50	9670	167	8.0	2.5	1.8	34
		Aug. 13, 1970	1	0.50	12651	218	6.0	2.0	1.5	27
2.	Brandu River near Dagoar Catchment Area = 231 Sq. Miles	July 17, 1970	1	2.75	37512	162	5.0	3.5	2.0	14
		Aug. 25 & 26, 1970	1	3.50	44769	194	5.0	2.0	1.0	33
		Aug. 31, 1970	2	4.14	26806	116	7.0	5.0	3.5	20
		July 20, 1973	1	2.50	32539	141	6.0	4.0	2.0	19
		Aug. 9, 1973	2	2.70	24970	108	7.0	4.5	2.9	28
3.	Haro River near Khanpur Catchment Area = 300 Sq. Miles	Aug. 21, 1964	2	5.43	34972	117	7.0	4.0	2.0	48
		Aug. 13, 1970	2	3.02	39148	130	6.0	3.8	2.2	48
		Aug. 10, 1979	2	2.80	36501	122	6.0	2.8	1.8	40
		Aug. 19, 1979	1	4.50	42394	141	6.0	2.8	1.4	44
4.	Kanshi River at Palote Catchment Area = 429 Sq. Miles	Sep. 12, 1970	1	7.50	45410	106	7.0	4.0	2.3	44
		Sep. 14, 1970	2	7.33	35679	83	12.0	6.0	4.0	44
		Aug. 23, 1972	1	6.50	45758	107	8.0	4.5	2.5	40
		July 8, 1973	1	6.50	33363	78	11.0	5.5	3.0	42
		Aug. 4, 1973	4	8.00	32641	76	11.0	5.6	2.8	52
		Aug. 6, 1973	4	9.00	24064	56	16.0	9.0	5.5	52
5.	Poonch River near Kotli Catchment Area = 1250 Sq. Miles	Aug. 5, 1963	2	7.50	78419	63	14.0	4.0	2	50
		April, 2 & 3, 1964	6	9.00	124307	99	7.0	4.0	2	46
		Feb, 25 & 26, 1966	4	8.00	119140	95	7.0	4.0	2	58
		March 4, 1966	7	7.00	93665	75	9.0	6.0	3	58
6.	Sil River near Chahan Catchment Area = 93 Sq. Miles	Sep. 1, 1970	2	4.73	13774	148	6.0	3.5	2.0	37
		May 31, 1971	3	3.40	17208	185	9.0	2.8	1.8	30
		March 7 & 8, 1972	3	2.07	12056	130	12.0	4.0	2.5	34
7.	Siran River near Phulra Catchment Area = 408 Sq. Miles	March 18, 1970	2	8.80	31923	78	9.0	6.0	3.0	63
		July 9, 1970	1	4.50	35212	96	9.0	4.0	2.0	51
		Oct. 6, 1970	1	3.50	36473	89	10.0	5.0	2.5	46
		March 30, 1970	5	8.00	26801	66	12.0	9.0	6.0	56
8.	Soan River of Chirah Catchment Area = 126 Sq. Miles.	Agu. 7, 1971	2	2.04	27358	217	4.0	2.0	1.3	34
		July 25, 1974	2	1.40	20809	165	5.5	3.2	1.8	36
		Sep. 6, 1975	1	1.50	22781	181	4.5	2.0	1.2	40
9.	Khost River at Chappar Rift Catchment Area = 510 Sq. Miles.	April 26, 1966	1	8.50	109181	214	8.0	3.0	1.6	17
		July 13, 1966	1	6.50	219244	430	4.0	1.5	1.0	19
		July 24, 1967	1	5.50	104492	205	9.0	2.8	1.5	15
		May 30, 1971	1	2.50	210436	413	5.0	1.5	0.7	11
		Aug. 31, 1975	1	2.50	143055	281	6.0	2.0	1.5	14
10.	Porali River at Sinchi Bent Catchment Area = 1560 Sq. Miles.	July 12, 1962	1	3.50	346115	222	7.0	2.0	1.2	26
		Aug. 14, 1962	1	2.50	239154	153	11.0	3.0	1.8	29
		April 28, 1963	1	5.50	192056	123	15.0	5.0	3.0	27
		April 4, 1965	1	1.50	146523	94	9.0	6.0	3.0	46
		July 19, 1965	1	5.50	289219	185	9.0	4.7	2.3	25

TABLE – 4

COMPARISON OF UNIT HYDROGRAPH PARAMETERS

Sr. No.	Name of Basin.	Peak discharge (ofs)			Time to peak (House)			Time Base (Hours)		
		Modified Method	Corps of Engrs. Method	Original Snyder's Method.	Modified Method	Corps of Engrs. Method	Original Snyder Method	Modified Method	Corps of Engrs. Method	Original Snyder's Method.
1.	Bahishan Nissa.	7784	8592 (+10%)	2727 (–185%)	3	4 (+33%)	10 (+233%)	30	80 (+167%)	98 (+227%)
2.	Brand Daggar	31817	28344(–12%)	10111 (–215%)	3	4 (+33%)	10 (+233%)	41	82 (+100%)	99 (+141%)
3.	Haro Khanpur	37678	21739 (–73%)	8400 (–349%)	5	7 (+40%)	16 (+220%)	43	88 (+105%)	115 (+167%)
4.	Kaushi Palote	35770	37632 (+10%)	12208 (–193%)	8	6 (–25%)	16 (+100%)	46	86 (+87%)	114 (+148%)
5.	Poonch Kotli	115432	59666 (–93%)	24491 (–37%)	8	9 (–13%)	22 (+175%)	54	97 (+80%)	133 (+146%)
6.	Sil Chahan	15284	12078 (–27%)	3943 (–288%)	4	4 (0.0%)	10 (+150%)	33	81 (+145%)	100 (+203)
7.	Siran Phulra	31863	28531 (–12%)	13564 (–135%)	7	7 (0.0%)	14 (+100%)	45	89 (+98%)	108 (+140%)
8.	Soan Chirah	22933	12354 (–86%)	4405 (–421%)	3	5 (+67%)	13 (+333%)	36	84 (+133%)	106 (+194%)
9.	Khost Chappar	142396	62385 (–128%)	15989 (–791%)	6	4 (–33%)	14 (+133%)	47	82 (+74%)	110 (+134%)
10.	Porali Sinchi	198785	68534 (–190%)	24640 (–707%)	6	11 (+83%)	28 (+367%)	57	99 (+74%)	148 (+160%)
AVERAGE			60%	–366		+ 19	+204		+106%	+ 166%

NOTE Duration of unit hydrographs for basins at serial No. 1 to 9 is 2 hours and for serial No. 10, it is 4 hours.

TABLE – 3

SUMMARY OF RESULTS

Sr. No.	Catchment	Storm Date	Derived values of C_p	Derived values of C_t	mean time lag t_p (hours)
1.	Bhishan Dur Khas near Missa Catchment Area = 58 sq. miles	July 12,1962	0.572	0.562	
		July 15,1964	0.511	.562	
		Aug. 7,1966	0.911	1.019	
		Aug. 11,1966	0.391	0.312	
		Feb. 27,1970	0.427	0.290	
		Aug. 13,1970	0.170	0.062	
		Mean	0.497	0.467	1.96
2.	Brandu River near Daggar Catchment Area = 231 Sq. Miles	July 17,1970	0.698	0.579	
		Aug. 25&26 1970	1.060	0.752	
		July 20,1973	0.550	0.522	
		Aug. 9,1973	0.456	0.509	
		Mean	0.703	0.641	2.90
3.	Haro River near Khanpur Catchment Area = 300 Sq. Miles	Aug. 21,1964	0.989	0.729	
		Aug. 13,1970	0.616	0.372	
		Aug. 10,1979	0.532	0.340	
		Aug. 19,1979	0.994	0.628	
		Mean	0.783	0.517	3.66
4.	Kanshi River at Palote. Catchment Area = 429 Sq. Miles	Sep. 12,1970	1.240	1.090	
		Sep. 14,1970	0.953	1.027	
		Aug. 23,1972	1.083	0.940	
		July 8,1973	0.970	0.940	
		Aug. 4,1973	0.951	1.052	
		Aug. 6,1973	0.789	1.203	
		Mean	0.968	1.042	7.26
5.	Poonch River near Kotli Catchment Area = 1250 Sq. Miles	Aug. 5,1963	0.735	0.721	
		April, 2&3, 1964	1.398	0.773	
		Feb. 25&26, 1966	1.191	0.721	
		March 4, 1966	0.820	0.541	
		Mean	1.036	0.689	7.00
6.	Sil River near Chahan Catchment Area = 93 Sq. Miles	Sep. 1,1970	1.095	0.948	
		May 31,1971	0.983	0.594	
		March 7&3, 1972	0.419	0.296	
		Mean	0.832	0.613	2.87
7.	Siran River near Phulra Catchment Area = 408 Sq. Miles	March 18,1970	1,076	1.137	
		July 9,1970	0.607	0.582	
		March 30,1979	0.821	0.925	
		Mean	0.748	0.773	5.91
8.	Soan River of Chiran Catchment Area = 126 Sq. Miles	Aug. 7,1971	0.692	0.288	
		July 25,1974	0.361	0.168	
		Sep. 6,1975	0424	0234	
		Mean	0.492	0230	1.29
9.	Khost River at Chappar Rift Catchment Area = 510 Sq. Miles	April 26,1966	2.843	1.403	
		July 13,1966	4.366	1.063	
		July 24,1967	1.761	0.893	
		May 30,1971	1.612	0.382	
		Aug. 31,1975	1.096	0.382	
		Mean	2.334	0.825	5.08
10.	Porali River at Sinchi Bent Catchment Area = 1560 Sq. Miles	July 12,1962	0.968	0.273	
		Aug. 14,1962	0.599	0.189	
		April 28,1963	1.058	0.441	
		April 4,1965	0.220	0.105	
		July 19,1965	1.593	0.441	
		Mean	0.888	0.290	3.62

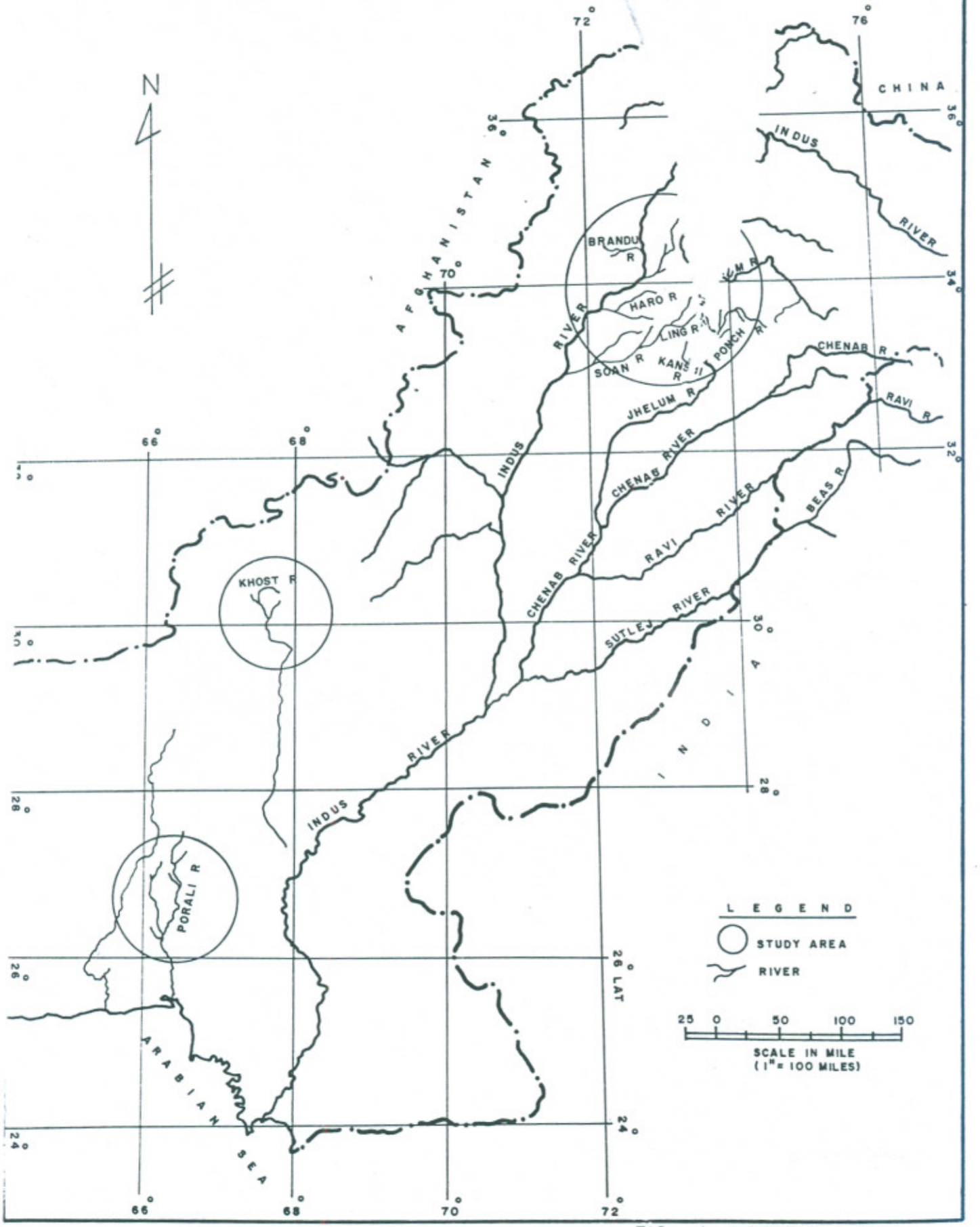


FIG. 1 LOCATION MAP

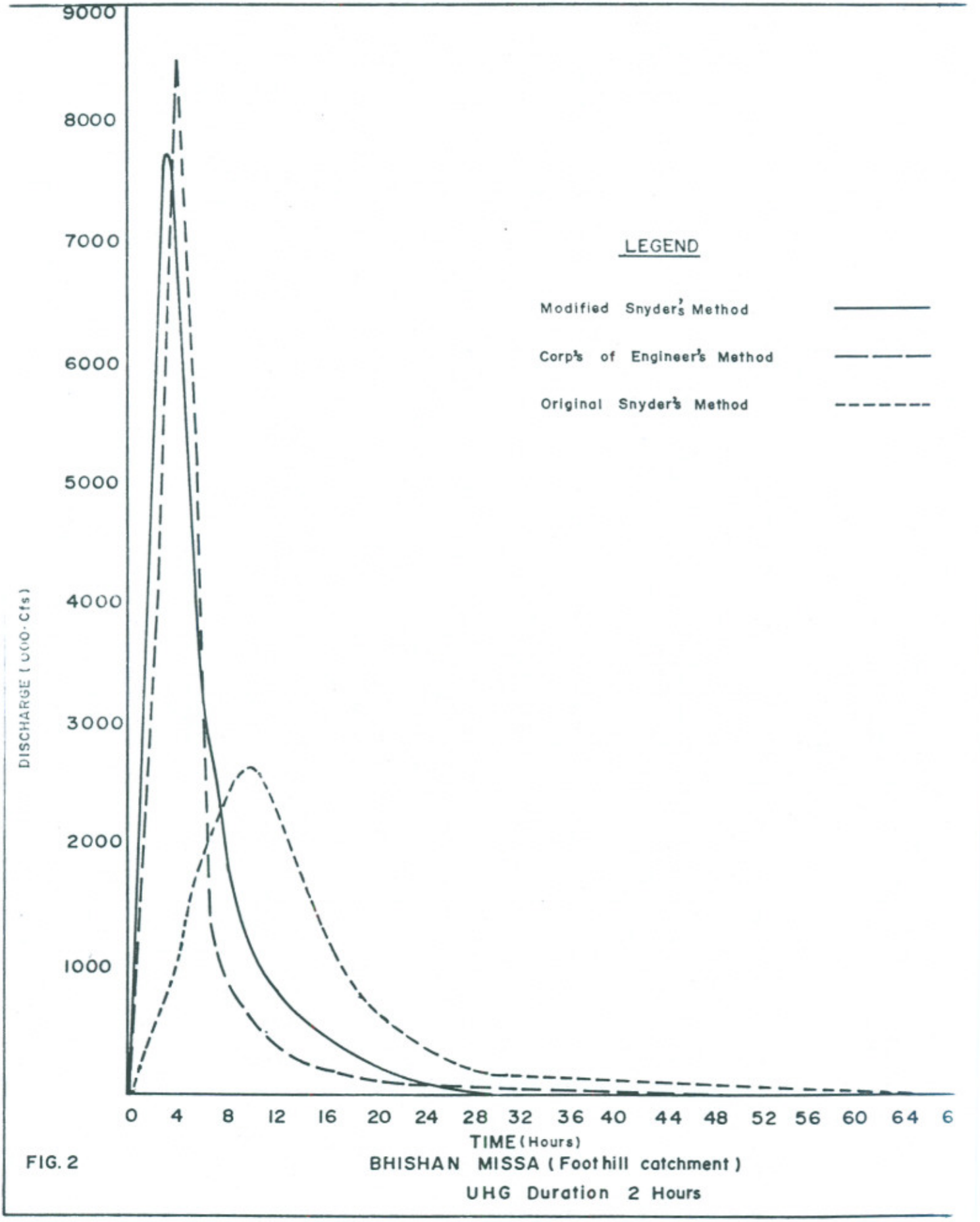


FIG. 2 BHISHAN MISSA (Foothill catchment)

UHG Duration 2 Hours

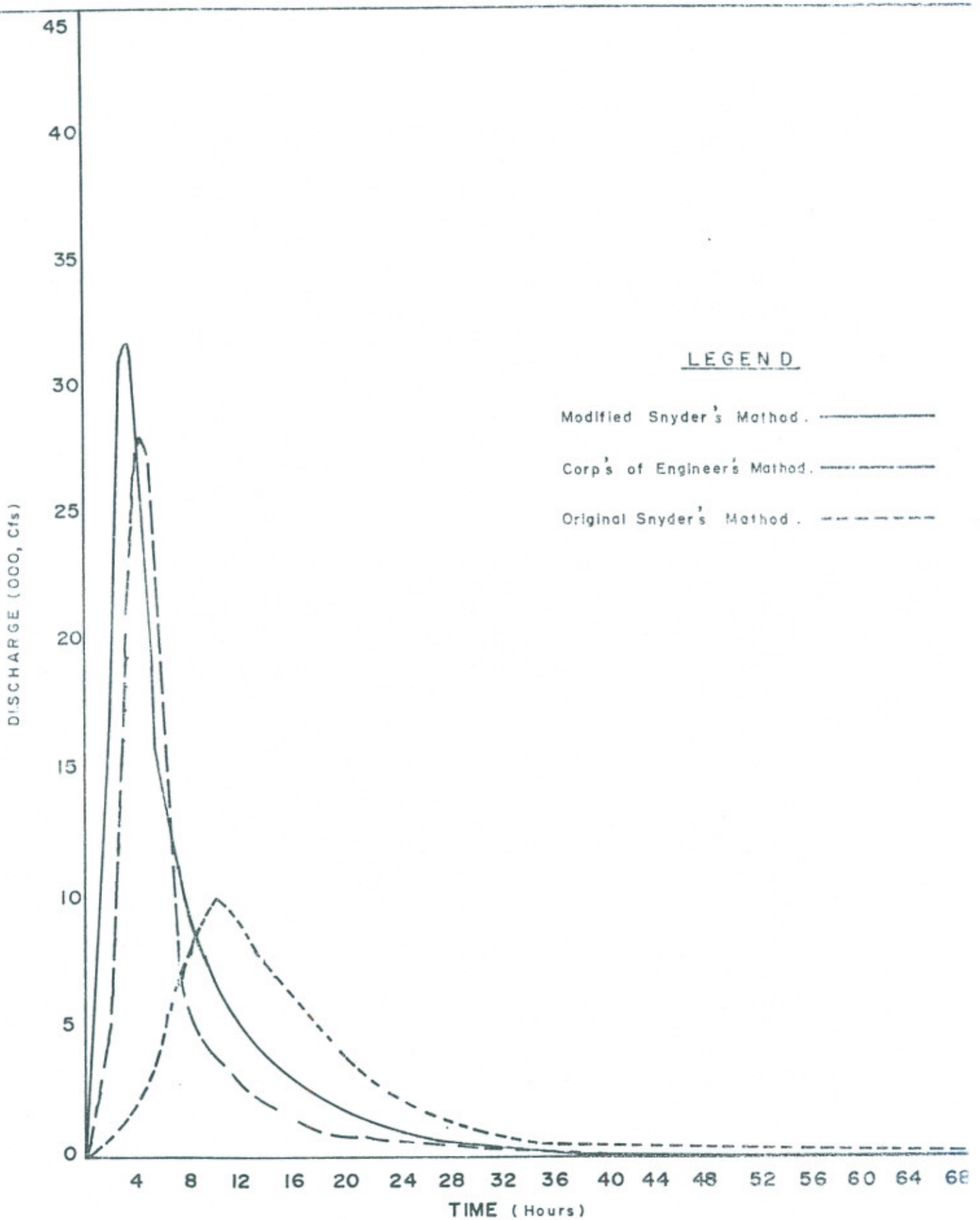


FIG. 3 BRANDU DAGAR (Hilly catchment)
U H G Duration 2 Hours

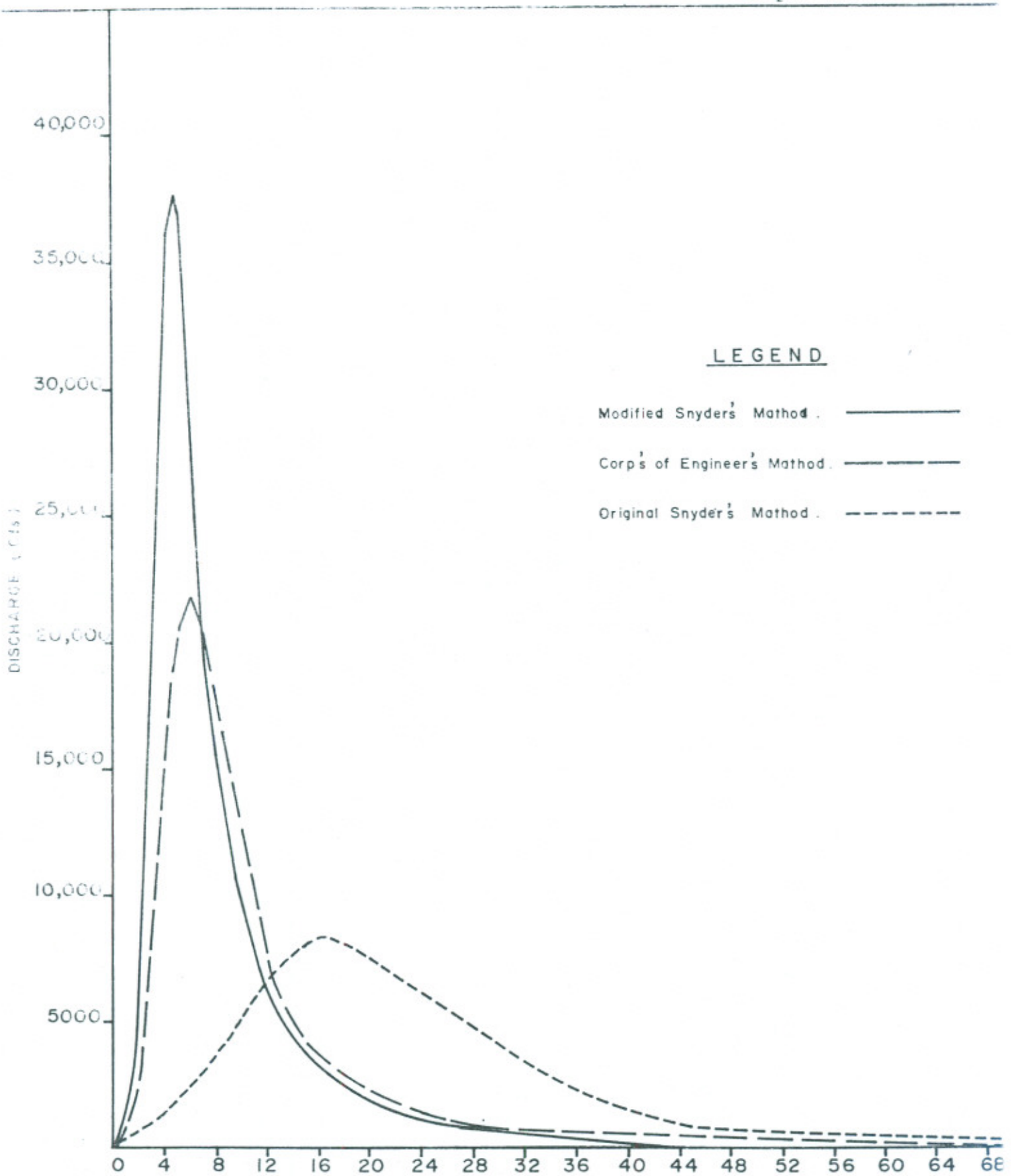


FIG. 4 HARD KHANPUR (Hilly catchment)

UHG Duration 2 Hours

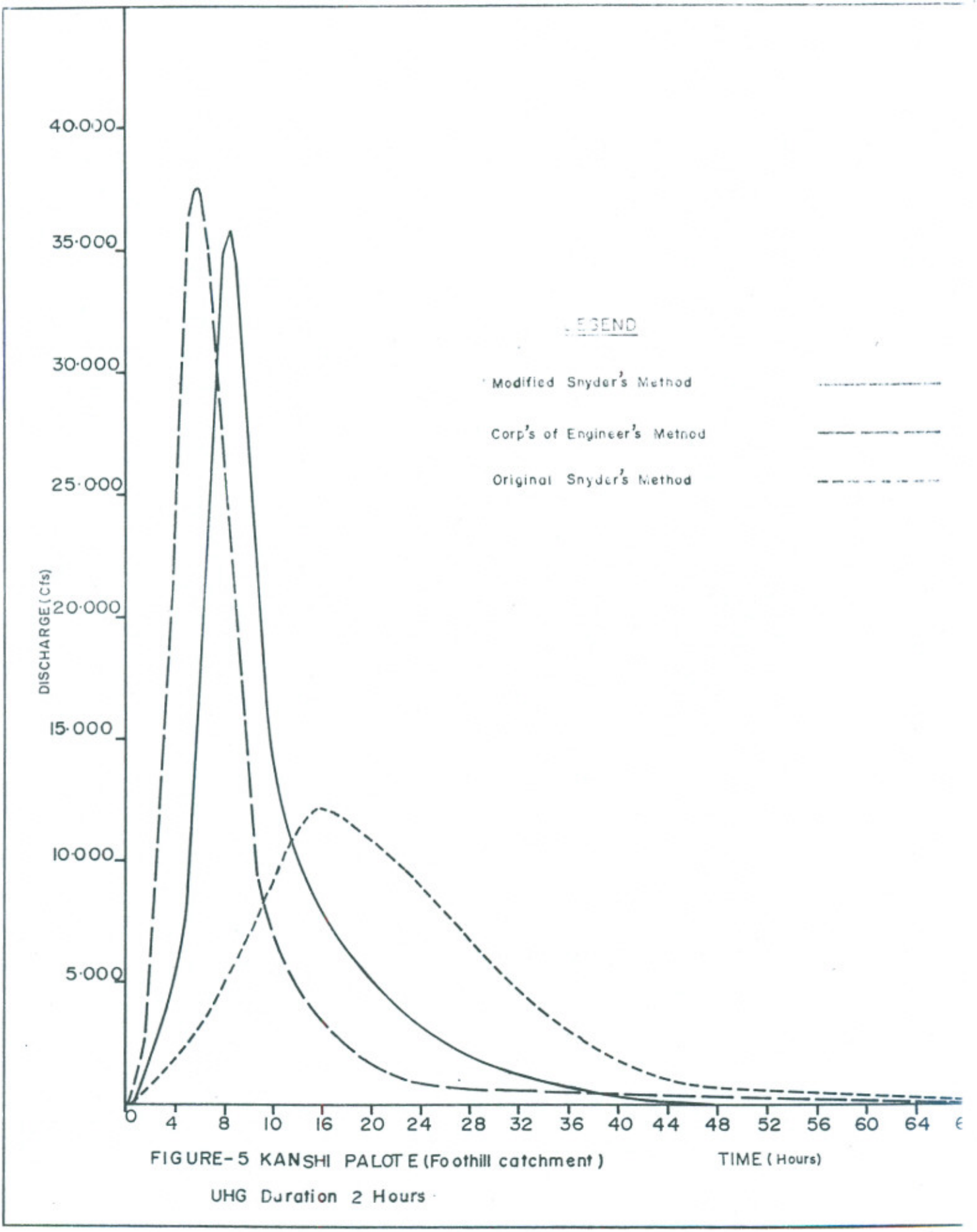


FIGURE-5 KANSHI PALOTE (Foothill catchment)

UHG Duration 2 Hours

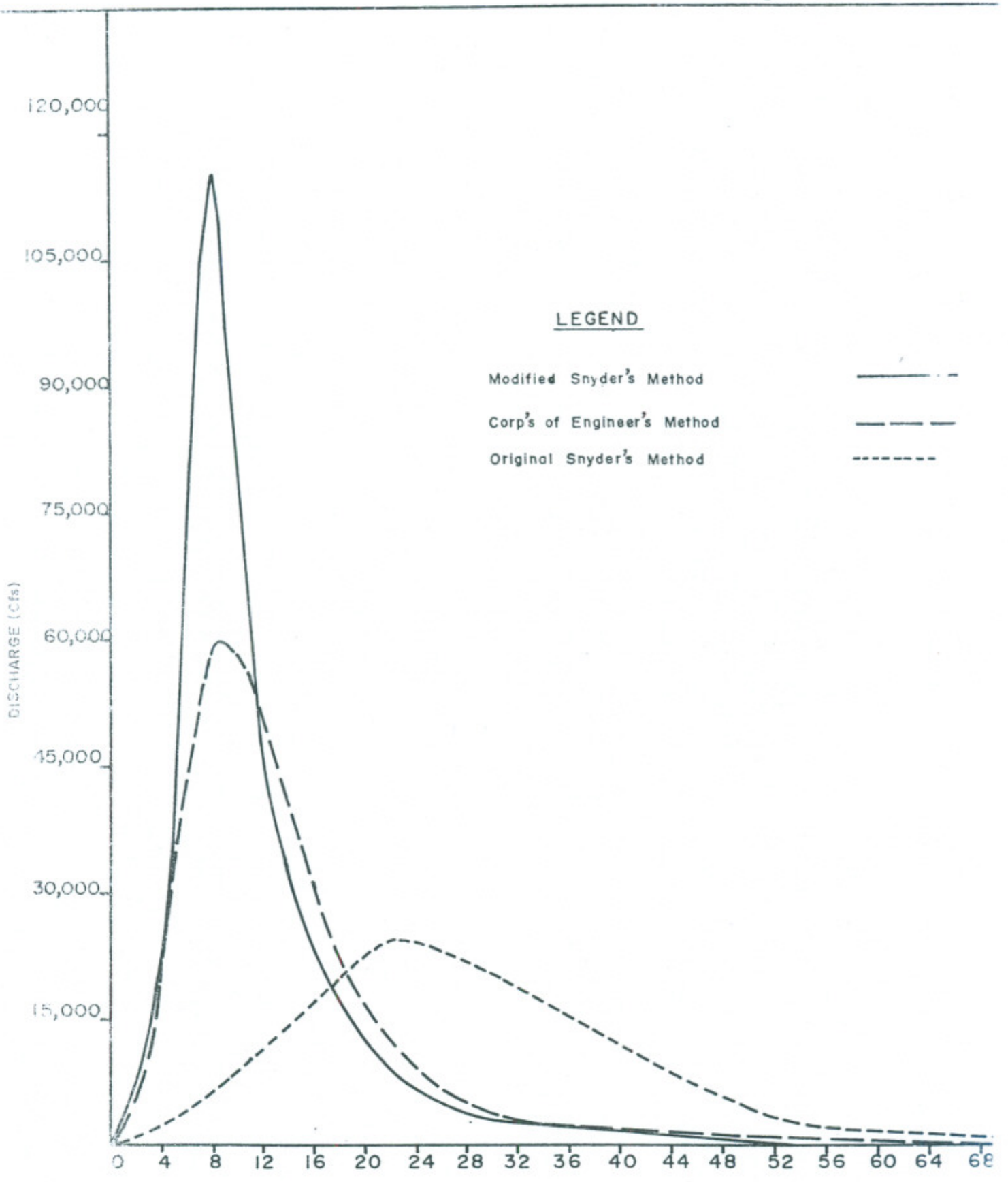


FIG. 6

POONCH KOTLI (Hilly Catchment)

UHG Duration 2 Hours

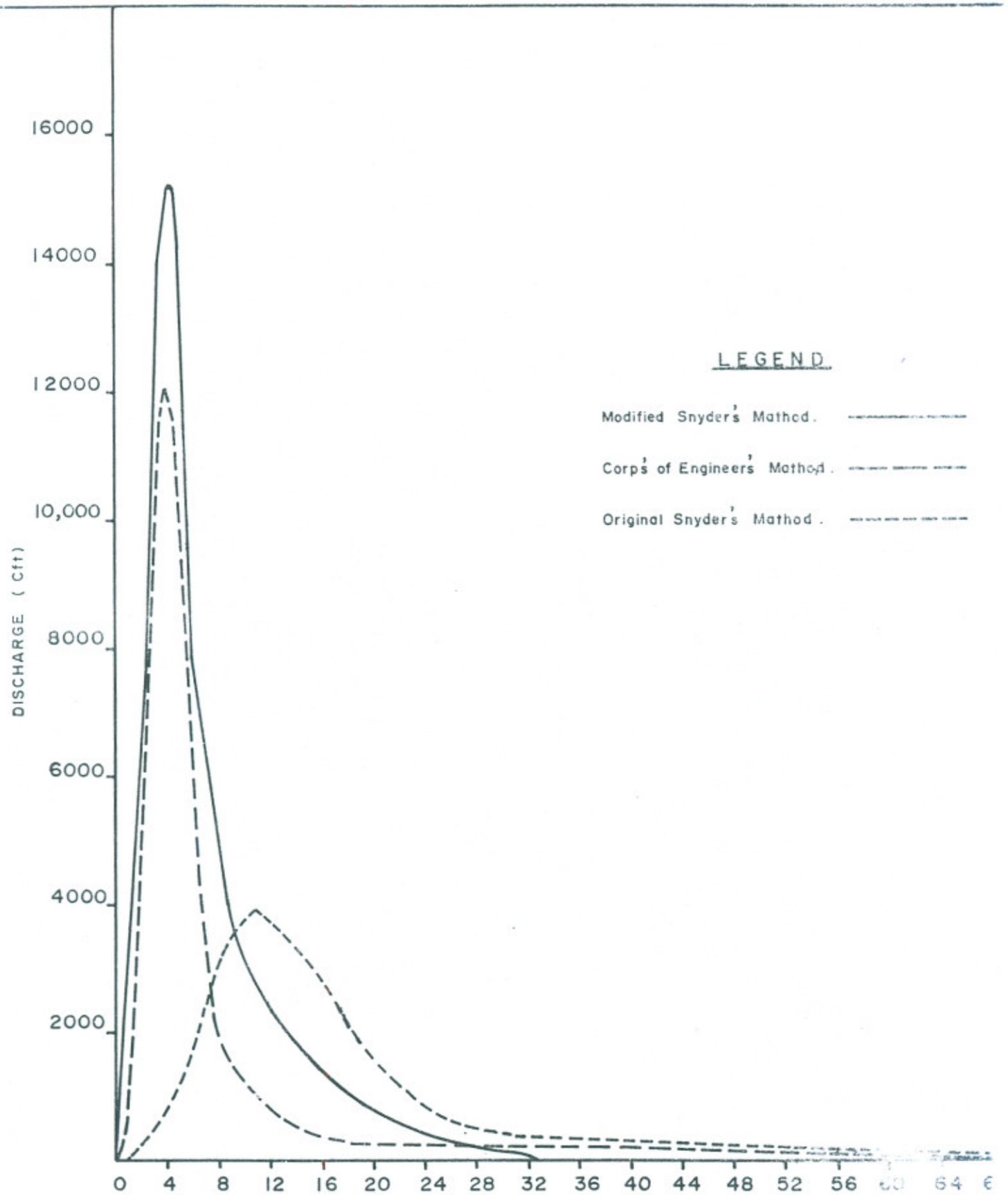


FIG. 7 SIL CHAHAN (Foot hill catchment)
UHG Duration 2 Hours

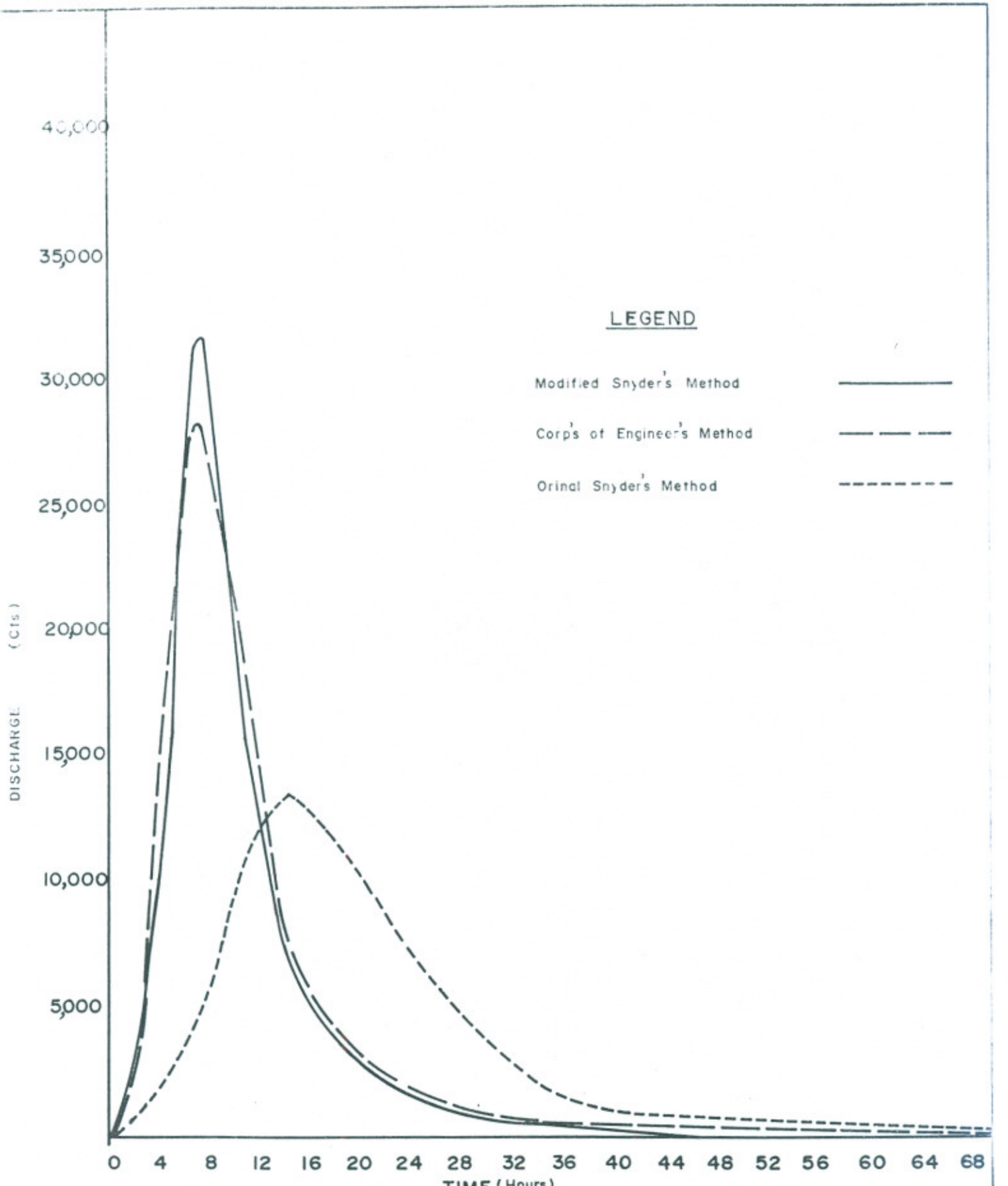


FIG. 8 SIRAN PHULRA (Hilly catchment)
UHG Duration 2 Hours

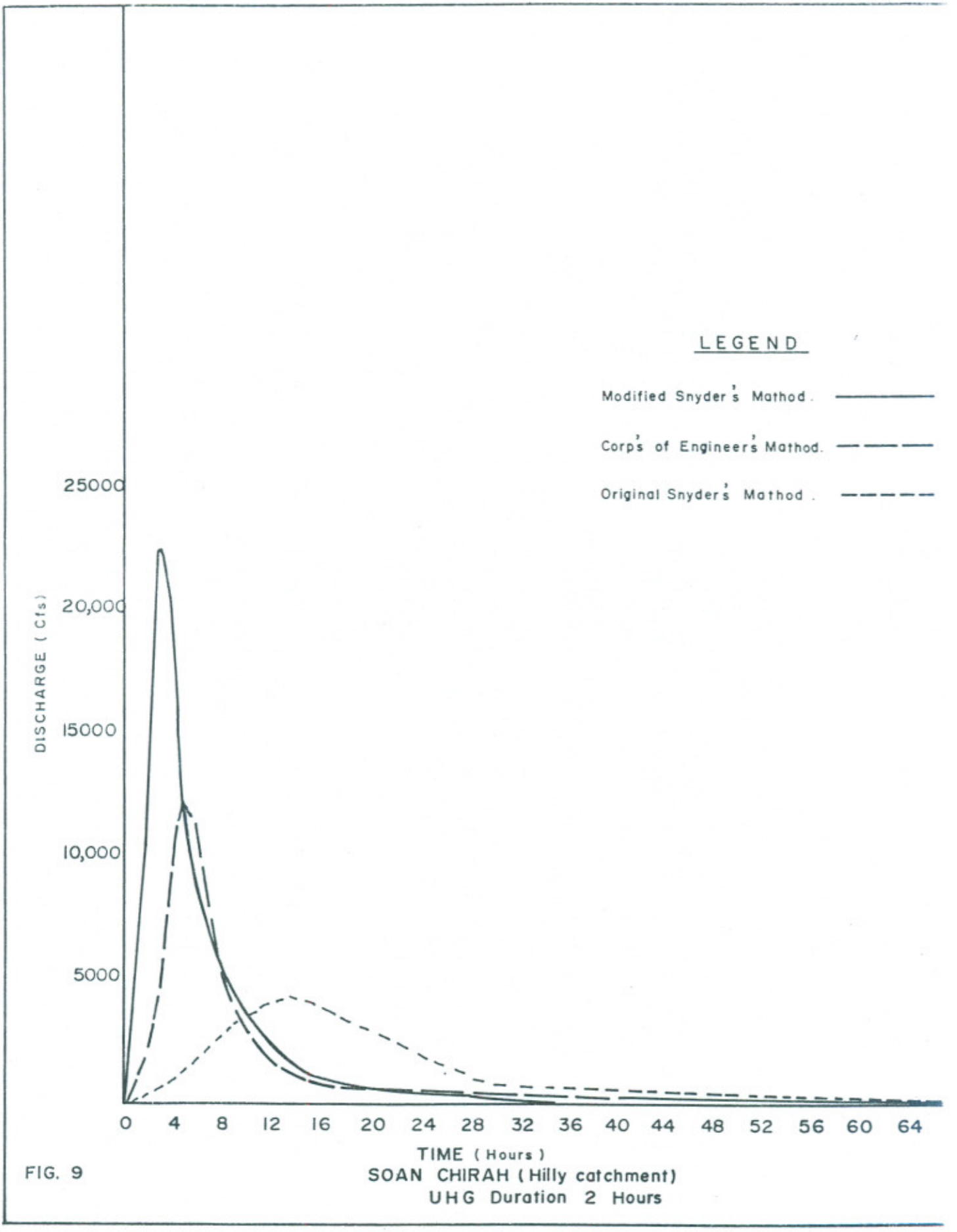


FIG. 9
SOAN CHIRAH (Hilly catchment)
UHG Duration 2 Hours

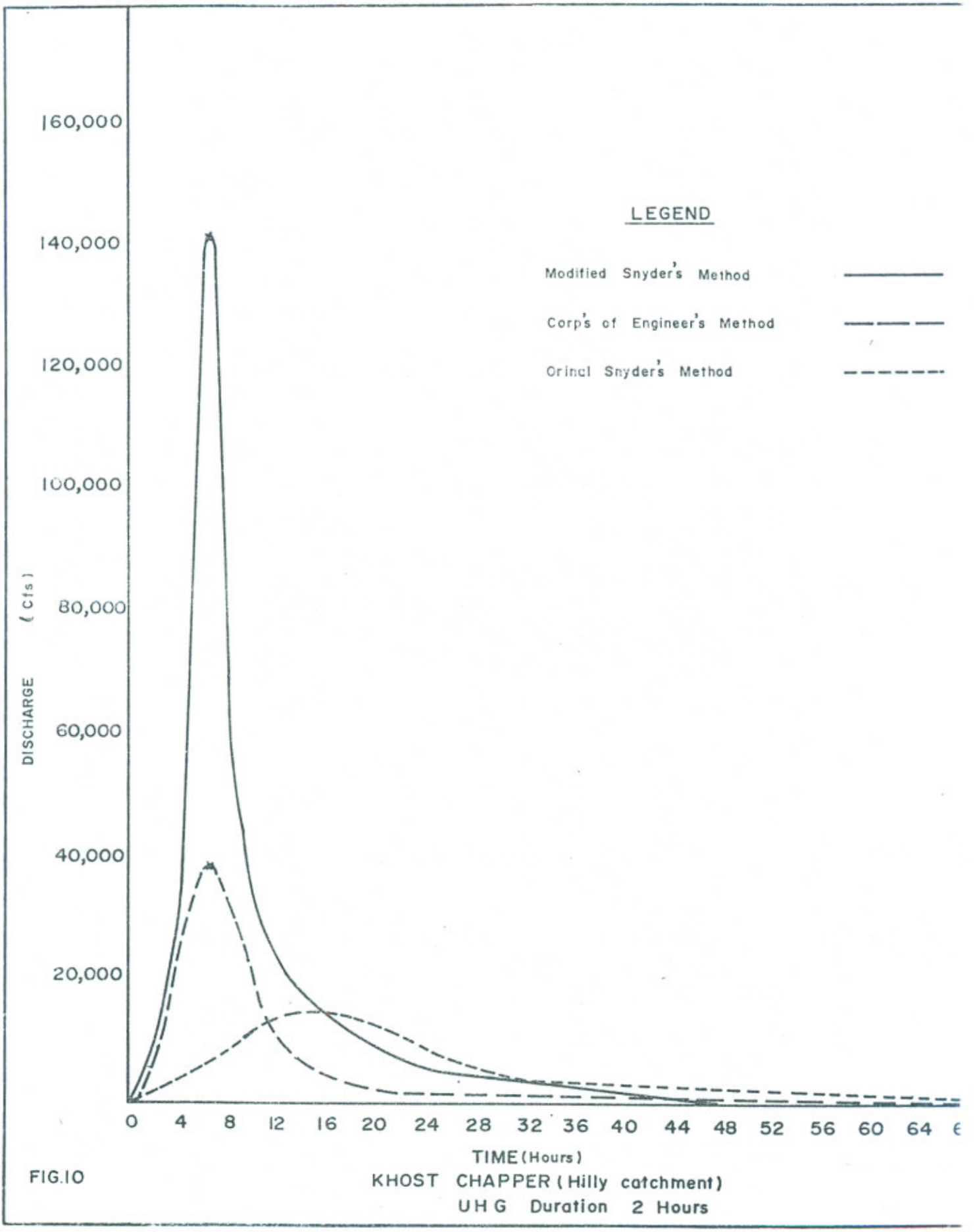


FIG.10

KHOST CHAPPER (Hilly catchment)
UH G Duration 2 Hours

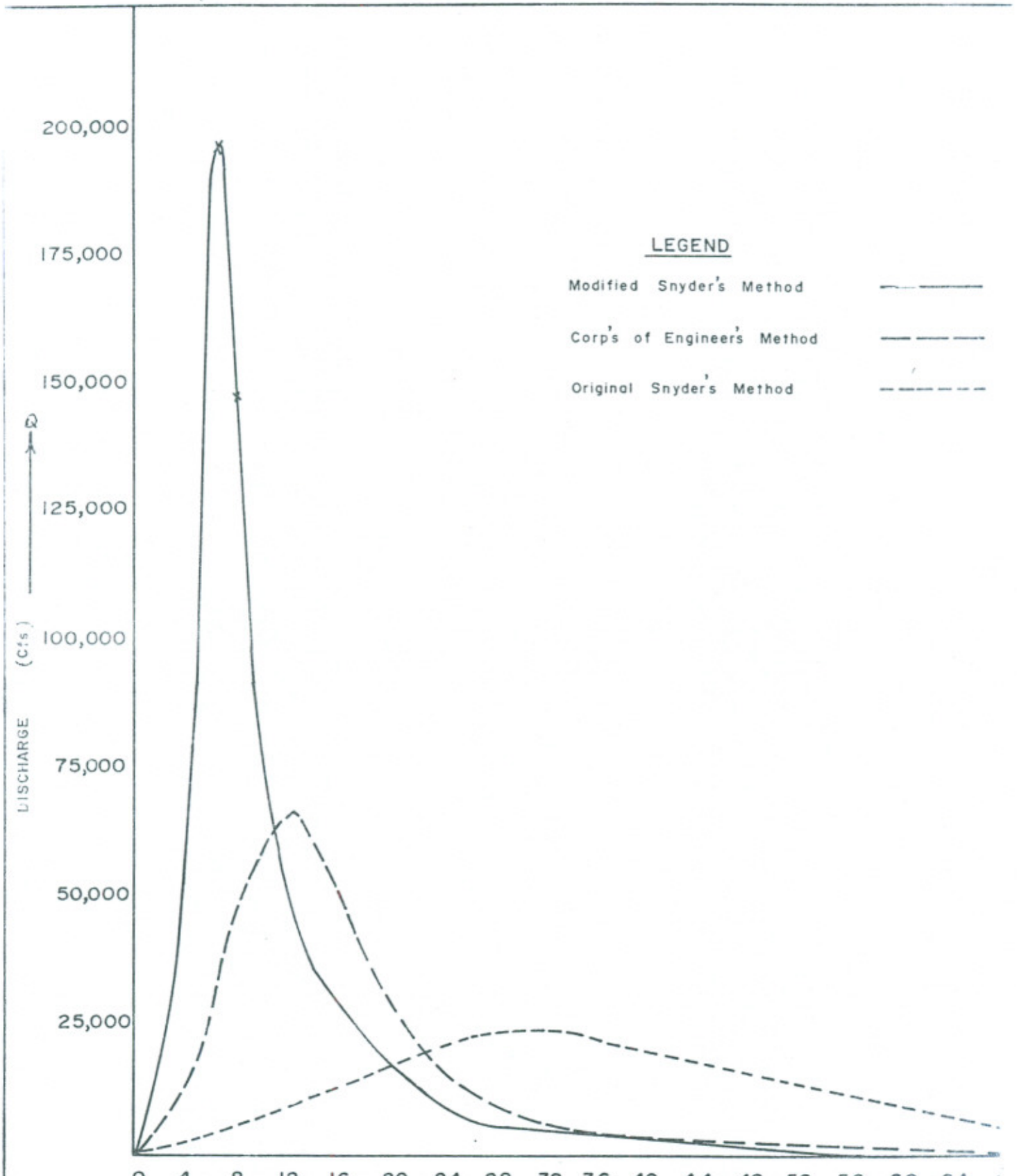


FIG. 11 PORALI SINCHI BENT (Foothill catchment)
UHG Duration 4 Hours

UHG DURATION = 1·0

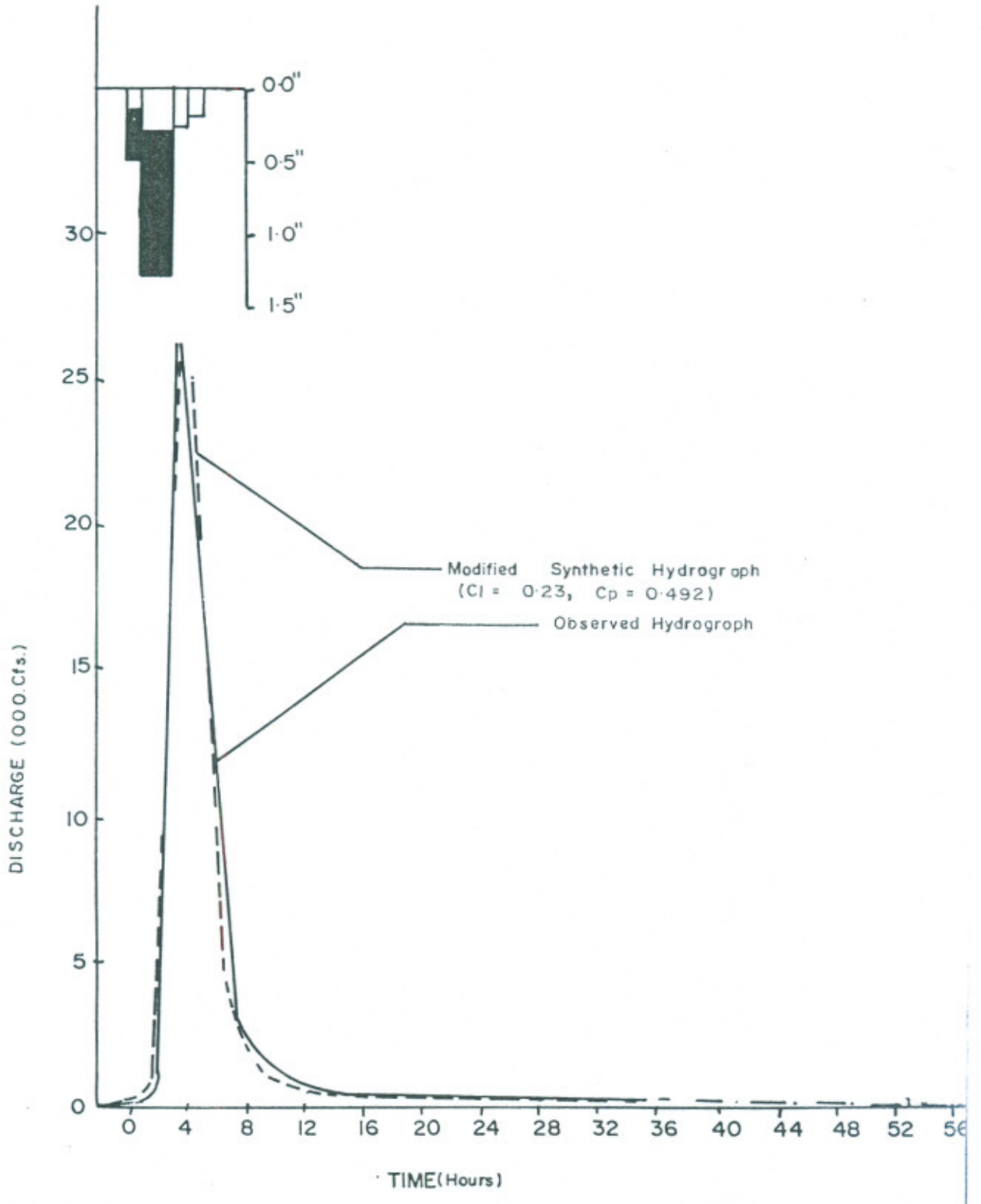


FIG.– 12 SYNTHETIC AND OBSERVED HYDROGRAPHS OF LING RIVER AT KAHOTA (Aug. 13–1970)

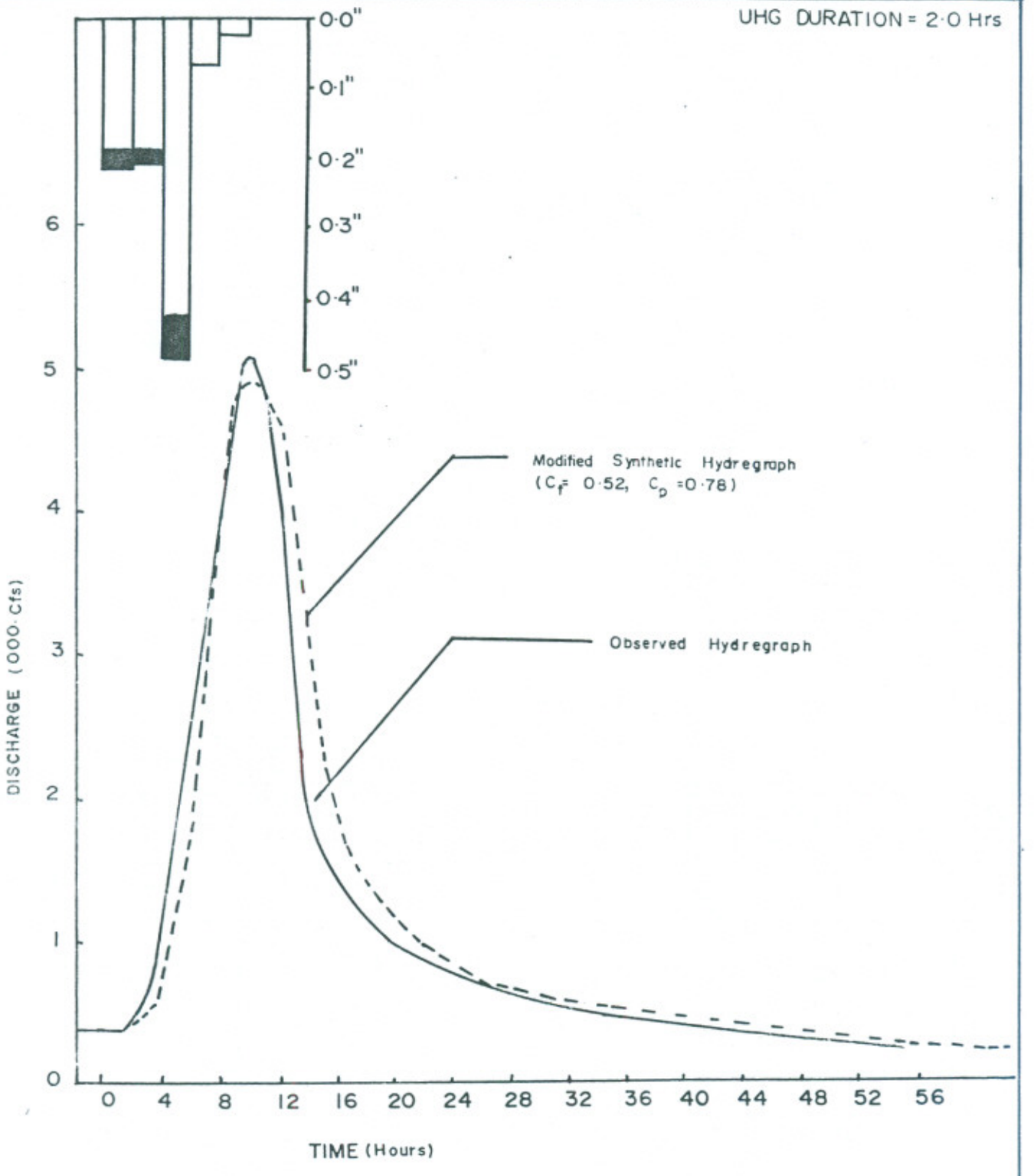


FIG. 14 SYNTHETIC AND OBSERVED HYDROGRAPHS OF HARO RIVER AT SANJWAL

(July 3, 1970)

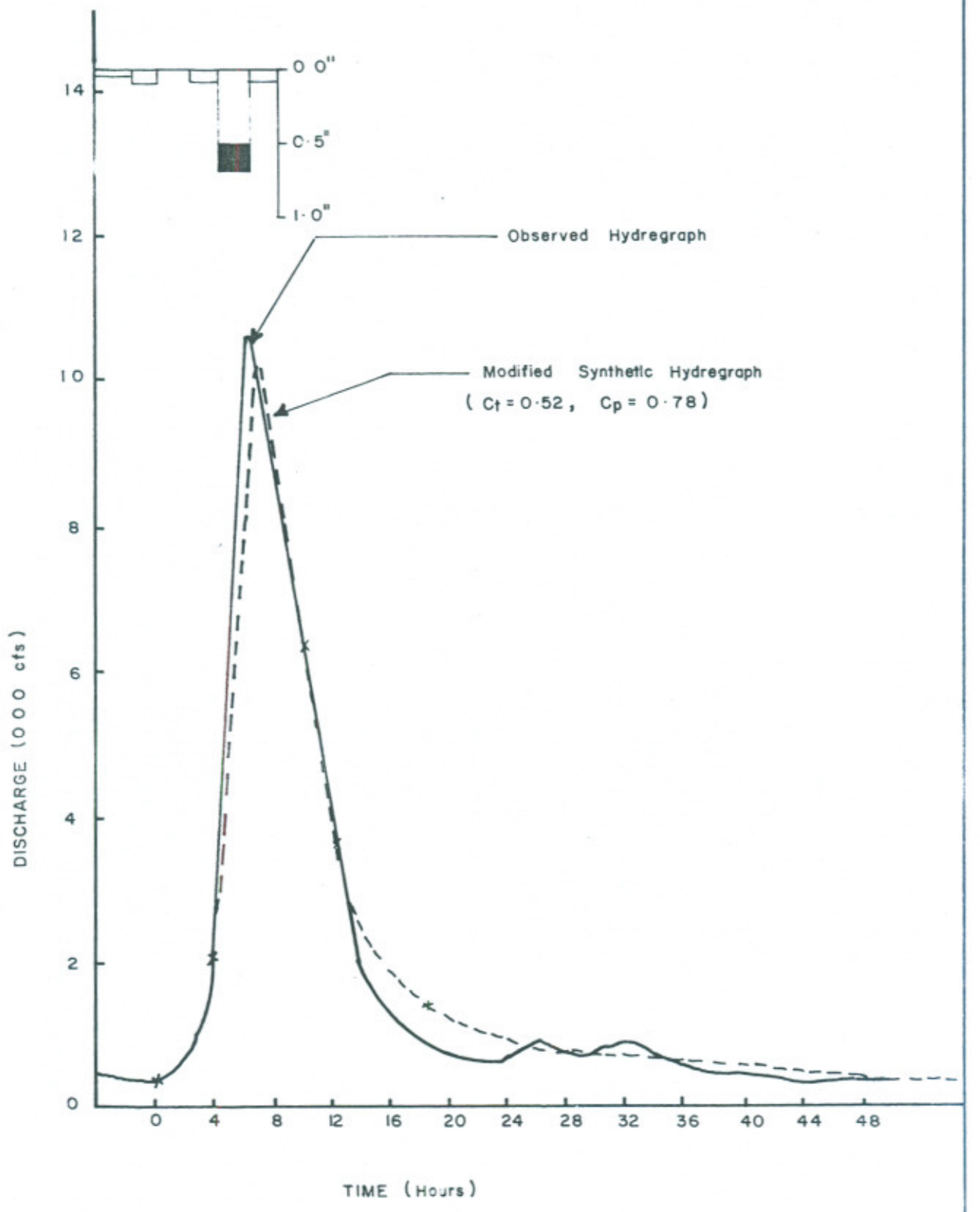


FIG-15 SYNTHETIC AND OBSERVED HYDROGRAPHS OF HARO RIVER AT SANJWAL (AUG. 3, 1970)

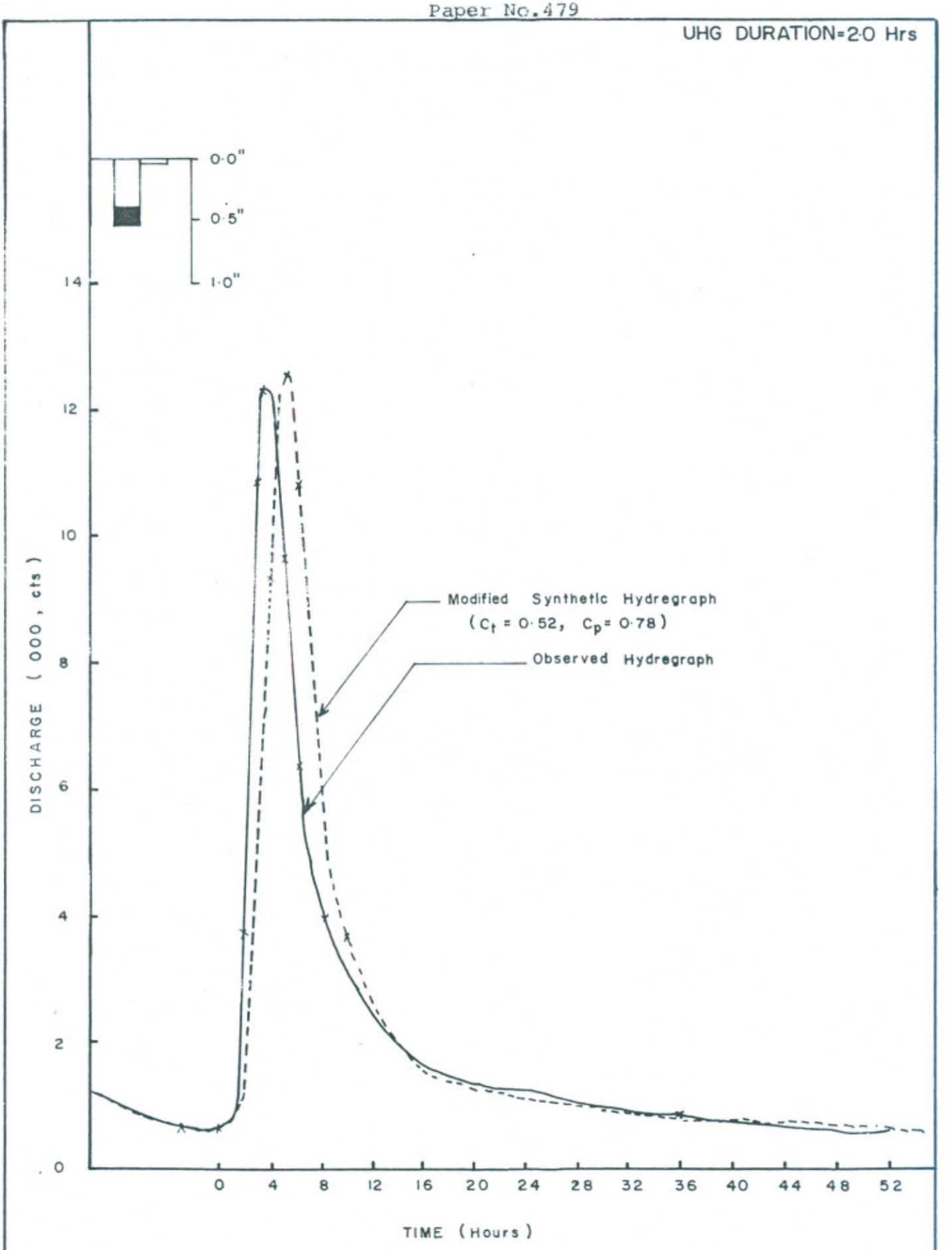
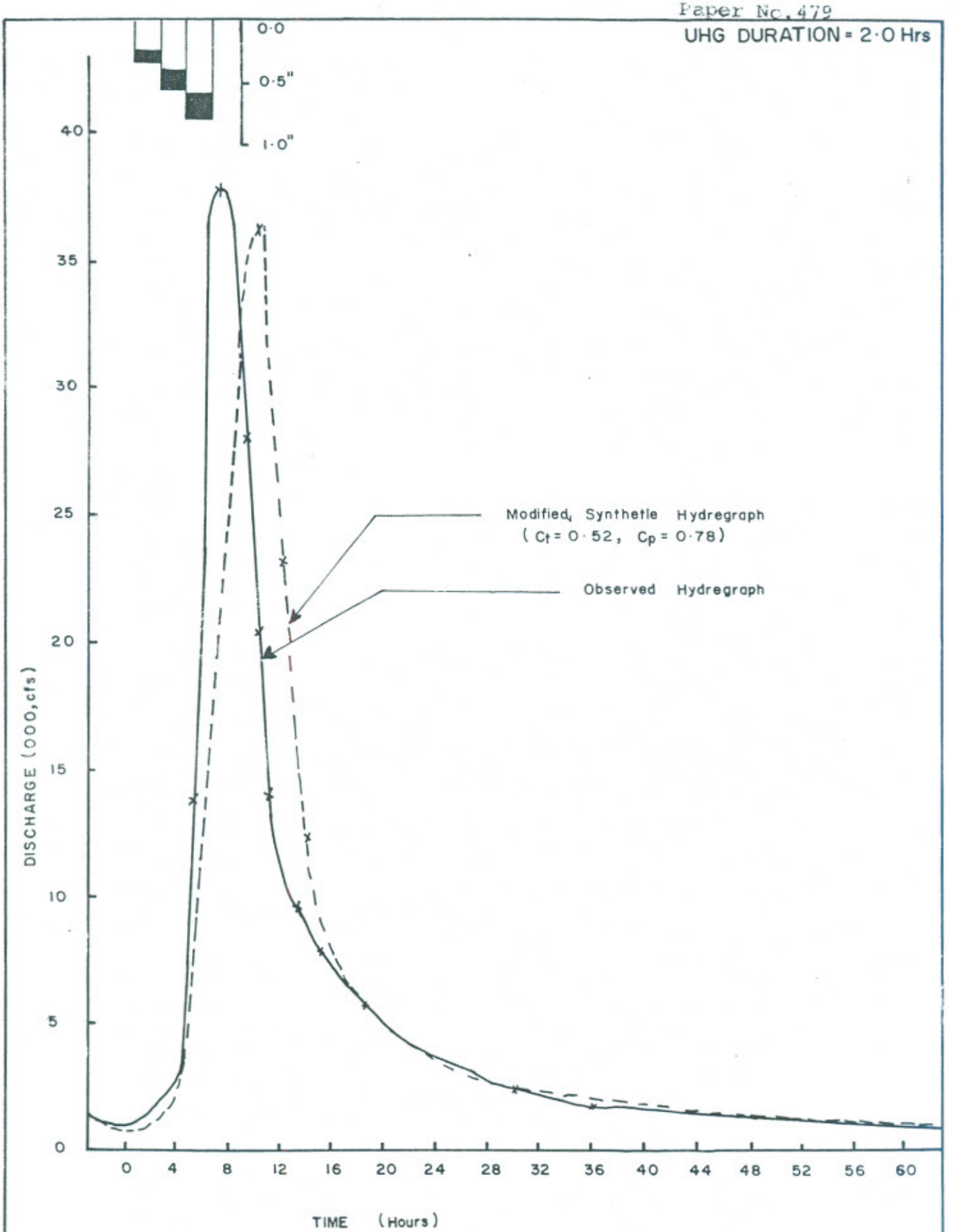


FIG – 16 SYNTHETIC AND OBSERVED HYDROGRAPHS OF SIRAN RIVER AT THAPLA (July 2,1970)



FIG— 17 SYNTHETIC AND OBSERVED HYDROGRAPHS OF SIRAN RIVER AT THAPLA (Aug 1, 1970)

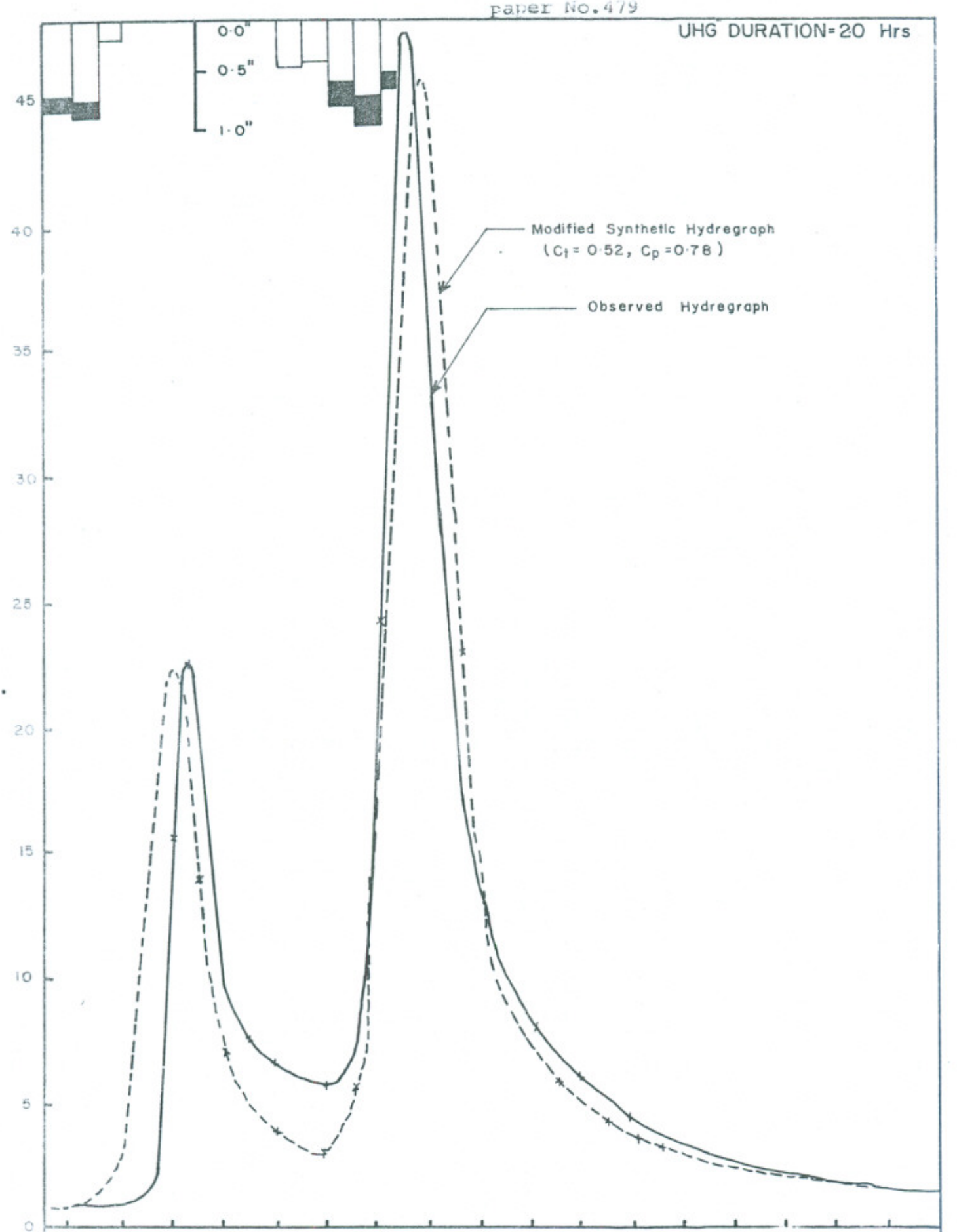


FIG-18 SYNTHETIC AND OBSERVED HYDROGRAPHS OF SIRAN RIVER AT THAPLA
(Aug 31 & Sup 1, 1970)