ABU ALI RIVER
FLOODS AND THEIR CONTROL IN
TRIPOLI, LEBANON

by

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THIS PROJECT IS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF CIVIL ENGINEERING

ACKNOWLEDGEMENTS

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FOREWORD

This is a study of Abu Ali River floods and their control in the town of Tripoli, Lebanon.

The Abu Ali River watershed is 500 square kilometers in area and has elevations variyng from sea level to about 2400 meters above sea level. The eastern part of the watershed is covered with snow in the winter season. While the longest water course in the watershed belongs to the Abu Ali River proper, the Rashieen tributary is reported to have quite a high flood discharge.

Studies of the flood control for the town of Tripoli were prompted by the high losses inflicted by the recent flood of December 17th, 1955. This particular flood resulted in the loss of 160 lives and 2000 homeless.

Other organizations studying this problem are thee Service Hydraulique of the Republic of Lebanon, in conjunction with the Lebanese Reconstruction Board, and the Engineering Department of the United States Operations Mission to Lebanon.

The Lebanese government is at the moment studying a different proposal than that mentioned later on in this report.

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SYNOPSIS.

The data available was meager and insufficient for a rational determination of the design storm and its runoff hydrograph. An approximate solution which is believed to give quite accurate results was resorted to and use was made of an empirical relationship to obtain the design storm runoff hydrographs.

A paper study of the economics of various possible solutions then followed, resulting in the choice of a rectangular artificial channel 20 meters wide in its upper reaches and 17 meters wide in its lower reaches. A constant width could have been used to simplify the design. The high cost of expropriations for the extra three meters of land, however, justifies a more complicated study involving a junction. The structural design presented is not intended to be final but is made with a view to its economical aspect.

Following the determination of a channel as the most economical solution, its hydraulic considerations were studied and various recommendations made.

The writer believes that, to make this study complete, model tests on the proposed solution are necessary.

CHAPTER I

COMPUTATION OF A DESIGN STORM
FOR THE ABU ALI DRAINAGE BASIN

INTRODUCTION:

As the term implies, a "design storm" is the storm estimate that would result in the critical runoff hydrograph for the project involved.

The procedure followed in determining design storms is dependant on the available data. It can have a rational basis if the right data is available or it can have an approximate basis if the data is meager.

Included in the required data are the following:

1. Complete records of major storms that have occurred in the basin under study and its neighbourhood for a sufficient number of years.
2. Continuous rainfall records covering a long period.
3. Stream gauge records at a number of critical points along the stream in question.
4. Relative humidity, temperature, and wind records.
5. Snow depths and snow water content where snow is to be considered.

The rational method of analysis can be rigorously defended on statistical and mathematical grounds and involves a long period of study of the various factors affecting the design. This rational approach may be made along two different basic lines:

1. The statistical - based on a statistical analysis of available records.
2. The "Maximum Possible Storm" - based on a meteorological study of weather conditions.

The first approach is based on statistics and necessitates a thorough analysis of the records. The second approach is becoming increasingly popular in recent years and is used extensively in areas where failure of the protecting structure may lead to very serious consequences. By this approach the designer estimates the physical limit of rainfall over a drainage area by studying meteorological conditions.

Approximate design storm estimates are used when the available data is meager. Current practice follows one or more of the three methods outlined below:

1. Computation of a maximum rainfall depth-duration relationship for the size of the drainage area involved. This is based on rainfall data for a large number of storms that are considered possible of occurring in the given region, and

may involve the development of a hystograph[x] or mass curve to represent the critical sequance of rainfall quantities corresponding to the adopted depth-duration curve.

2. The transposition of the isohyetal pattern of an actual storm to a critical position over the given drainage basin, without any major changes in pattern or chronology of rainfall increments.
3. A modified transposition method in which it is assumed that the direction and/or rate of translation of rainfall zones during the record storms might have differed in such a manner as to have resulted in a more critical sequence and concentration of rainfall increments over an area comparable to the basin under study, the modifications assumed being based and predicted on meteorological studies. This method is mostly applied to drainage areas of over 10,000 square miles.

AVAILABLE DATA:

Data available to the writer for the purposes of the present study may be divided under the following

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[x] A histogram type of rainfall (intensity / depth) -duration curve.

categories:

1. 24 hr. rainfall records for the Abu Ali, Becharre, Tripoli, and Sir-ed-Danieh rainfall stations in Lebanon, as shown in Fig. 1
2. A report on the storm which occurred over Tripoli on 17th December, 1955.
3. Isohyetal maps of the major storms that occurred over the Litani Basin.
4. The result of a study performed by the I.C.A. on the A.U.B. rainfall records.

1. The 24 hr. rainfall records were obtained from the Lebanese Ministry of Public Works Weather Bulletin available at the A.U.B. Observatory. The rainfall gauging stations (as shown in Fig. 1) in the Abu Ali River basin and the neighbouring region were plotted and a Theissen Net drawn to determine the rainfall gauging stations whose records have a bearing on the Abu Ali River basin, namely those at the Abu Ali and Becharre Power Plants, at Tripoli, and at Sir-ed-Danieh. The records are shown in tabular form in plates 1, 2, 3 and 4. Except for the North East sector where records are a little scant, the stations provide satisfactory coverage of the basin in question. The distance between stations varies between 15 and 20 Kms. The first three of the stations mentioned are within the basin proper but the last one falls just outside.

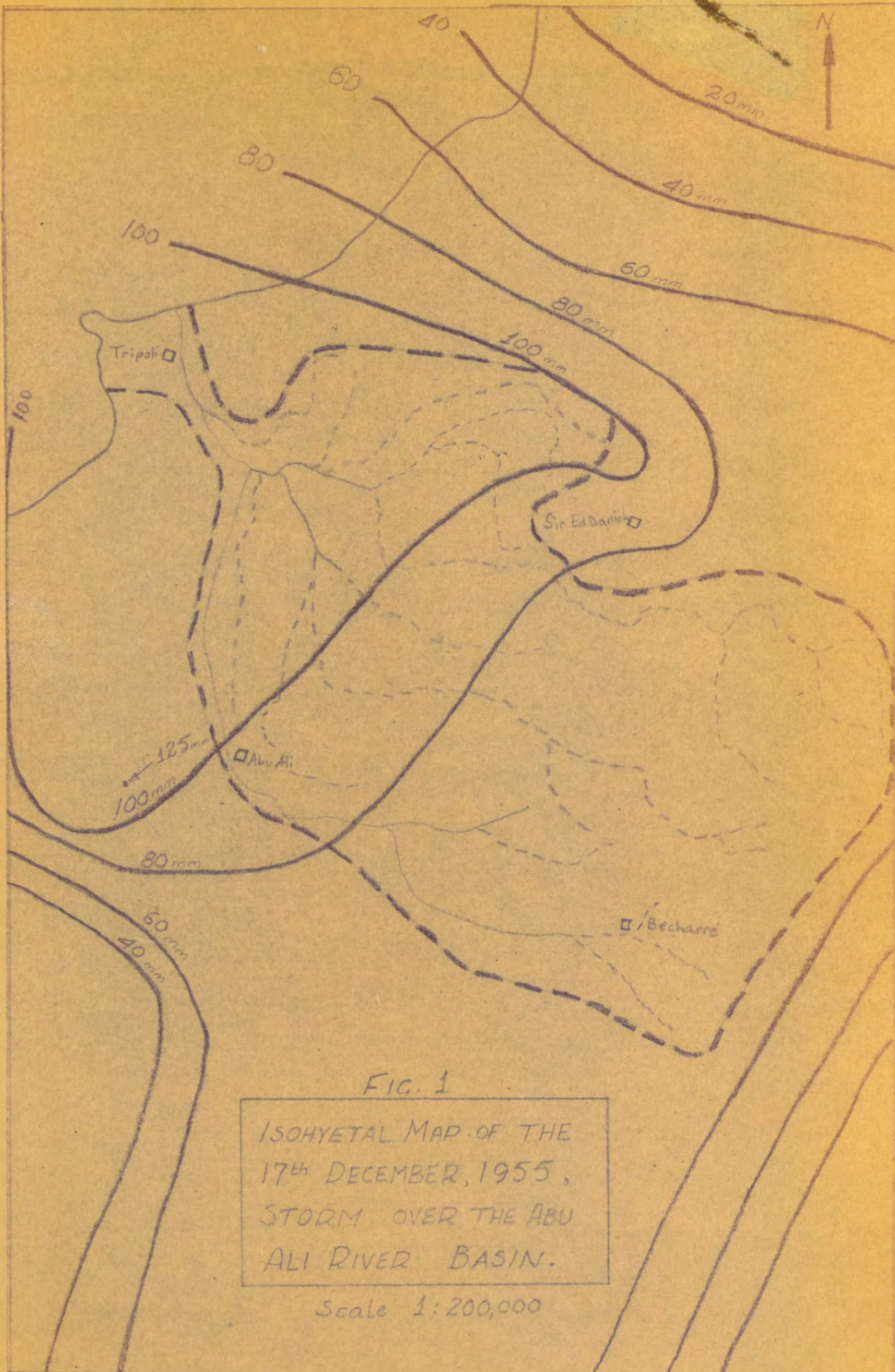


FIG. 1

ISOHYETAL MAP OF THE 17th DECEMBER, 1955, STORM OVER THE ABU ALI RIVER BASIN.

Scale 1:200,000

The records studied covered the period of April 1938, through May 1956, for all four stations except Tripoli which was discontinued in April 1949. The readings recorded were those taken at 08:00 hours every morning.

2. A supplement to the monthly Weather Bulletin previously mentioned came out in January 1956, describing the storm of 17th December, 1955, that caused the disastrous flood of that date at Tripoli in North Lebanon. The report gives hearsay approximate times for the beginning and the end of the storm, the storm having started at 16:50, becoming torrential from 17:15 - 18:30, and petering out at 19:15. Also given are the times the river is said to have begun its rise, reached its peak value, and receded, the times being 19:00, 20:30, and 22:45 hours. The cause of the storm is given as the meeting of warm, moist Mediterranean winds with cold winds moving South from Turkey. Included in the report are a number of water marks within Tripoli and an invaluable isohyetal map of the storm.

An account also appeared in the December, 1955, issue of La Revue du Liban, describing a similar flood that took place in Tripoli on 12th December, 1843.

3. The hydrology volume of the "Development Plan for the Litani River, Republic of Lebanon" prepared by the I.C.A. contains isohyetal maps of some long duration storms that occurred over the Litani Basin.

STORM	DURATION	MAXIMUM CUMULATIVE RAINFALL (mm)
JAN., 1940	JAN. 29 - 31	335
MAY, 1946	MAY 8 - 10	275
JAN. - FEB. 1947	JAN. 30 - FEB. 1	225

4. The above mentioned study also presents a 5 day, 10,000 yr. storm of 400 mm. total rainfall for Beirut, arrived at after a study of rainfall records A.U.B.

DATA ANALYSES:

1 - 24 hr. Rainfall Records:

In the use of rainfall data to determine the maximum values, the frequency of recurrence of these maxima is as important as their values. Such frequency is defined as the number of times within a selected period of years that any particular amount of rainfall has occurred. The average length of time (in years) during which some particular rainfall amount may be expected to recur may be obtained by dividing the total number of years in the available period of record by the number of times that that particular rainfall was exceeded or equalled. It is not a regular interval of occurrence that is implied but an average one. This is known as the Station-Year Method.

Some criticism has been directed by various hydrologists against this method with regard to its reliability. For the sake of example, if a rainfall studied over a 10 year period occurs once and is not exceeded, its frequency would be 10 years. If the 11th year is ~~not~~ to be included and it has a rainfall that equals or exeeds the previously mentioned rainfall, its frequency becomes 5 years. This effect is not so pronounced on storms of less intensity.

Inspite of this weakness the Station Year Method is used extensively due to the great ease and facility with which it can be employed. There have also been some tests devised to check its reliability.

The writer has used this method in analysing the 24 hr rainfall data collected. Records indicating storms greater than 50 mm. were taken as the lower limit and values for 1, 2, 3, 4, 5, and 6 day storms were obtained. Any daily records of 50 mm. or above were taken as one day storms irrespective of whether they were isolated or not; but for the two, three, four, five and six-day storms only isolated values were used. To obtain the frequency for a particular storm, the number of occurrences of greater or equal intensity were counted and the total period of record of all the stations used was divided by this number of occurrences. The results are shown in Table 1.

The values given in Table 1 were plotted according to the duration of the storm. Plots were made in Figs. 2(a)

TABLE 1

FREQUENCY (IN YEARS) CORRESPONDING TO THE INDICATED RAINFALL FOR THE ABU ALI RIVER BASIN.

(OBTAINED BY THE STATION-YEAR METHOD FOR A RECORDED PERIOD OF 62 YEARS)

RAINFALL (mm)	STORM DURATION (DAYS)					
	1	2	3	4	5	6
245						60
235						
225					30	
215						
205						20
195			30			15
185						12
175			20	60	12	
165			15	20	10	10
155				10	7.5	8.7
145		60		7.5	5.5	6.8
135		30	7	7.0	3.6	5.0
125		20	6	5.5	2.6	3.6
115	30	10	3.6	4.0	2.5	3.4
105		7.5	2.5	2.5	2.0	2.8
95	8.5	4.4	2.0	2.1	1.5	2.2
85	3.0	3.2	1.6	1.7	1.2	2.0
75	1.4	2.2	1.1	1.3	1.1	1.8
65	0.7	1.5	0.9	1.0	1.0	1.7
55	0.35	1.0	0.7	0.8	0.5	1.5

and 2(b), and an attempt made to fit them to different exponential curves. These attempts failed inspite of the shape of the curves which seemed to indicate an exponential function. The curves through the plotted points do not pass through the origin but have a finite positive frequency for values of zero rainfall. This frequency increases with the duration of the storms studied. This is to be expected as a given frequency for zero rainfall indicates that during the period of record there must have been a number of instances when there was no rainfall and the time of each instance was equal to the storm duration. For the same given number of years it is also reasonable to have a fewer number of these instances for longer storm durations, hence the larger frequency values corresponding to the zero rainfall of greater storm durations.

Another plot of the frequencies was made on semi-logarithmic graph paper (Fig. 3(a) and 3(b)) and the points appeared to be represented by a straight line function, again not passing through the origin and again having greater frequencies for the larger duration storms. The straight line function was not consistent throughout but tended to become exponential for some parameters. The straight line equations derived by the method of least squares gave frequency values that were too low for high total rainfall and values that were too high where the total rainfall was low. This type of fit was therefore discarded.

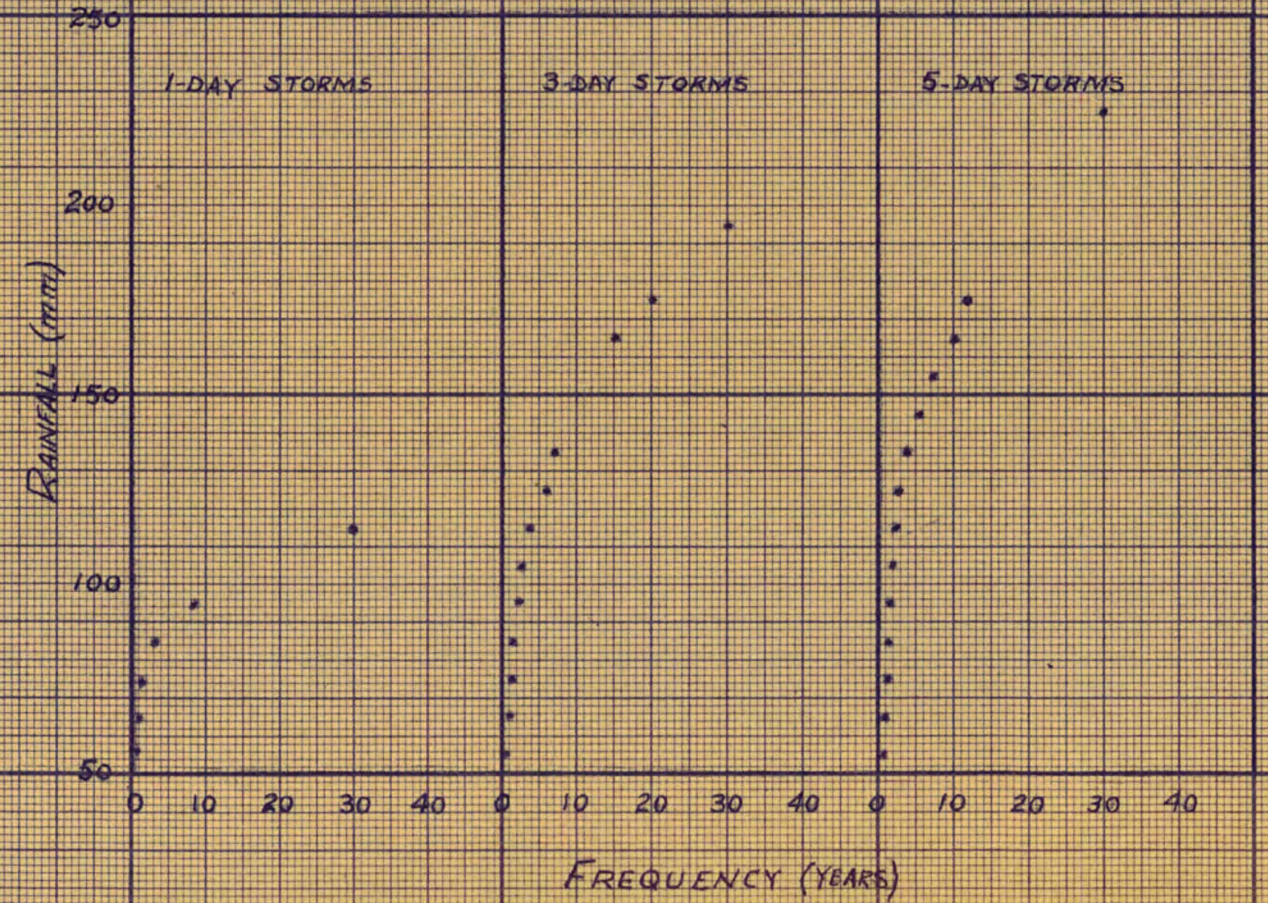


FIG. 2(a) RAINFALL-FREQUENCY CURVES

FOR THE ABU ALI RIVER BASIN
(obtained by the STATION-YEAR METHOD as shown in TABLE 1)

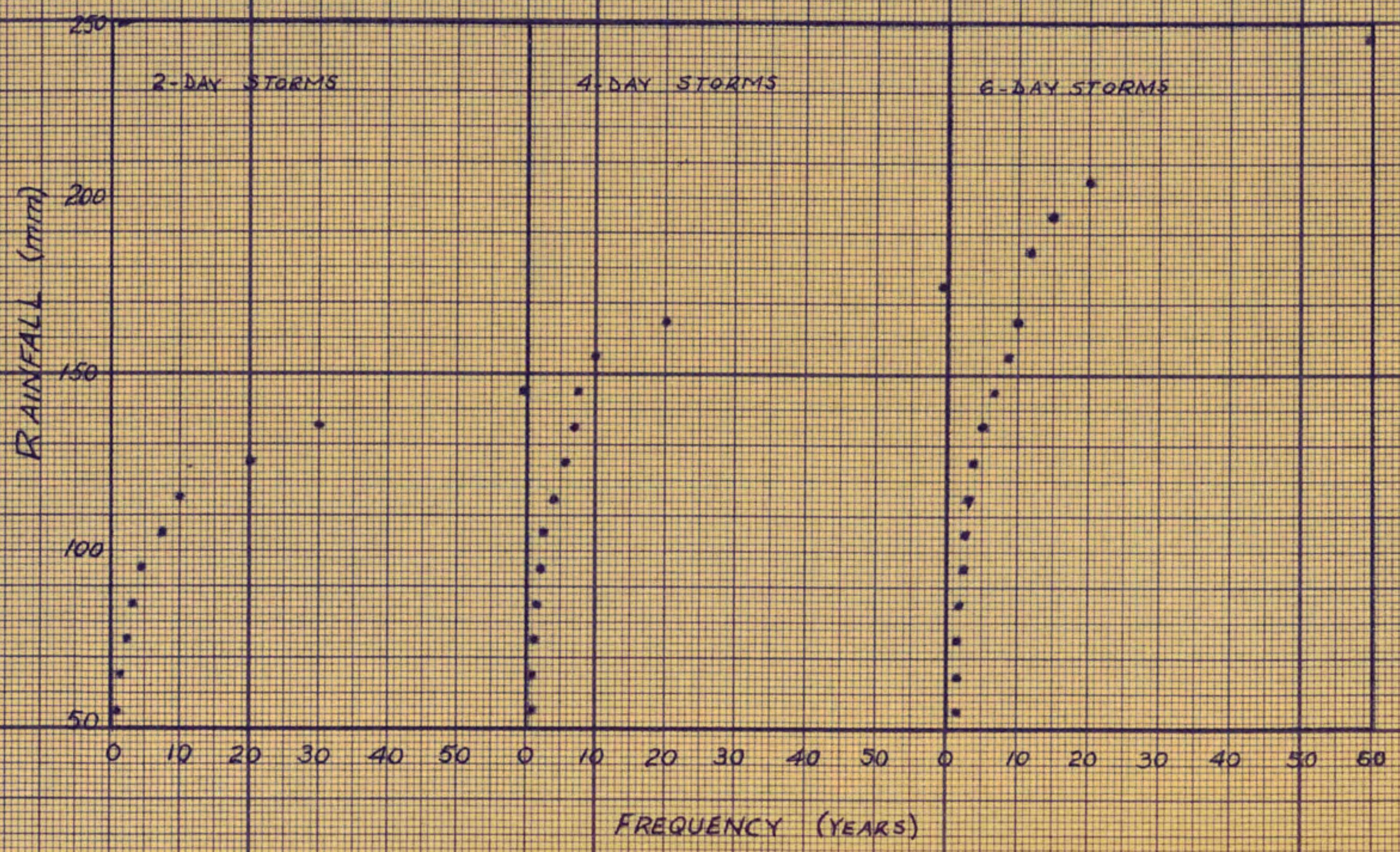


FIG. 2 (b) RAINFALL-FREQUENCY CURVES

FOR THE ABU ALI RIVER BASIN
(obtained by the STATION-YEAR METHOD as shown in TABLE 1)

22/b

Plots on logarithmic graph paper were then made (Figs. 3c and 3d) and a definite parabolic function was observed, the function becoming more pronounced with increasing storm duration.

The general equation of the parabola may be written in the form:

$$y = ax^2 + bx + c$$

Where x and y are the logarithms of the rainfall (X) and the frequencies (Y) respectively.

By applying the Method of Least Squares to the above equation, and using the data given in Table 1, the following six equations will result:

1-day storms : $y = -1.4040x^2 + 12.4108x - 18.0000$

2-day storms : $y = +2.0594x^2 - 1.0000x - 5.2941$

3-day storms : $y = +0.3402x^2 + 1.9759x - 4.8293$

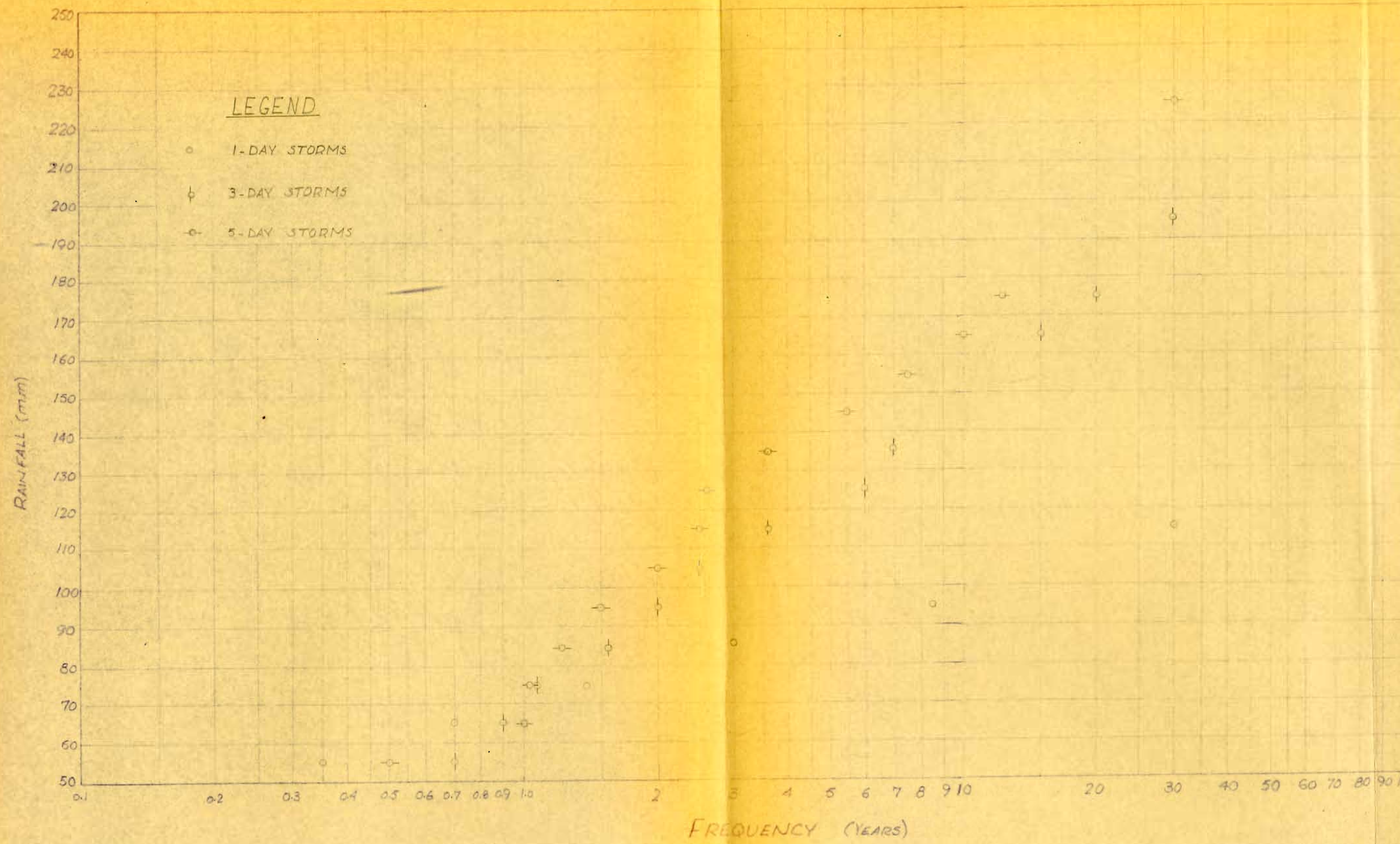
4-day storms : $y = 0.9169x^2 - 0.0884x - 2.9875$

5-day storms : $y = 0.0560x^2 - 2.7999x - 5.5050$

6-day storms : $y = 0.9279x^2 - 1.1783x - 0.9423$

A mistake was made in the derivation of the above formulae. The (X) values used were 5 mms. too small. For substitution in the formulae the (X) values should be reduced by 5 mms.

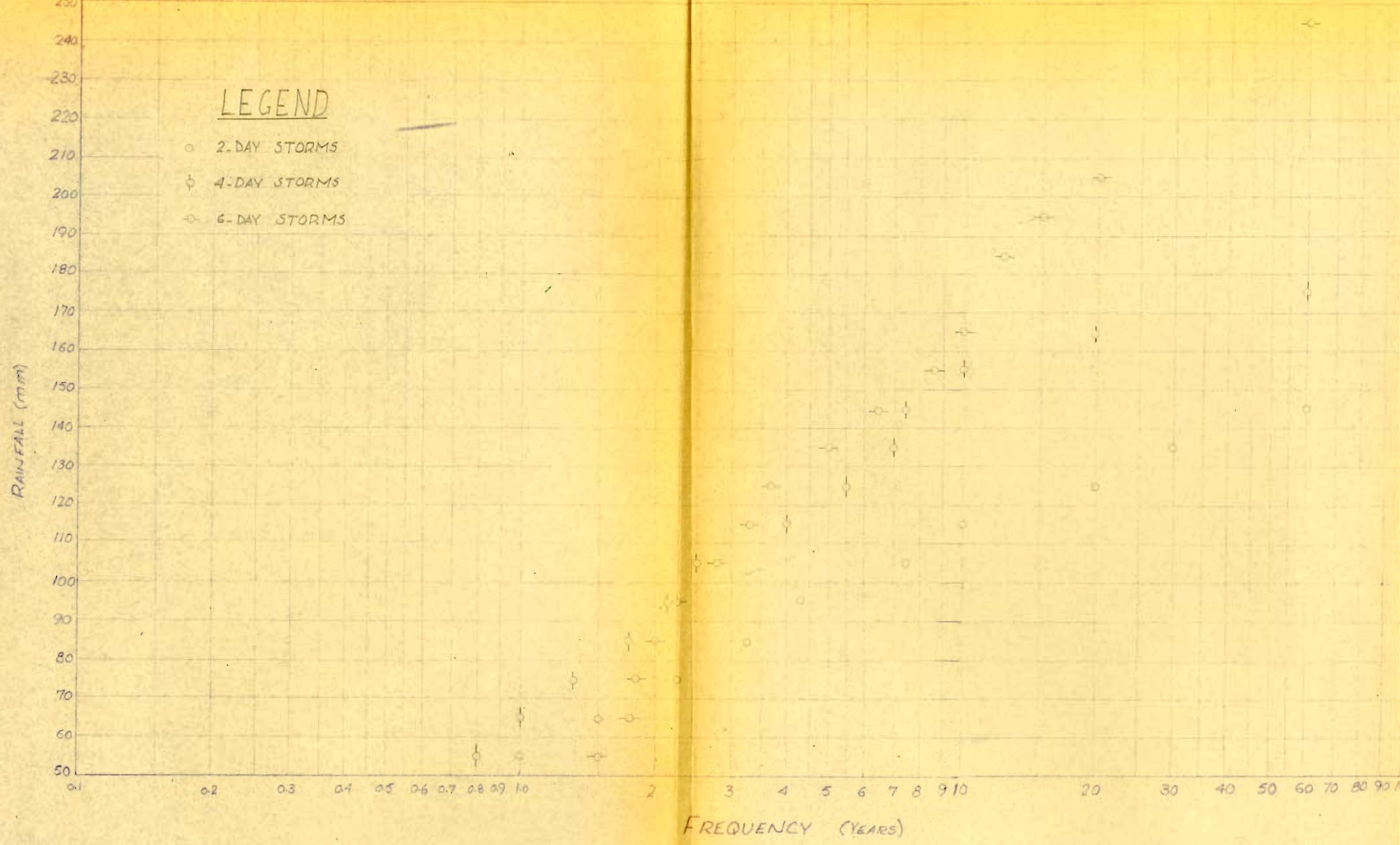
The values of rainfall computed from the formulae are shown in Table 2 and are plotted in Figs. 4 and 5.



(FOR DURATIONS INDICATED BY THE PARAMETERS)

FIG. 3(a) RAINFALL-FREQUENCY CURVES FOR THE ABU ALI RIVER BASIN

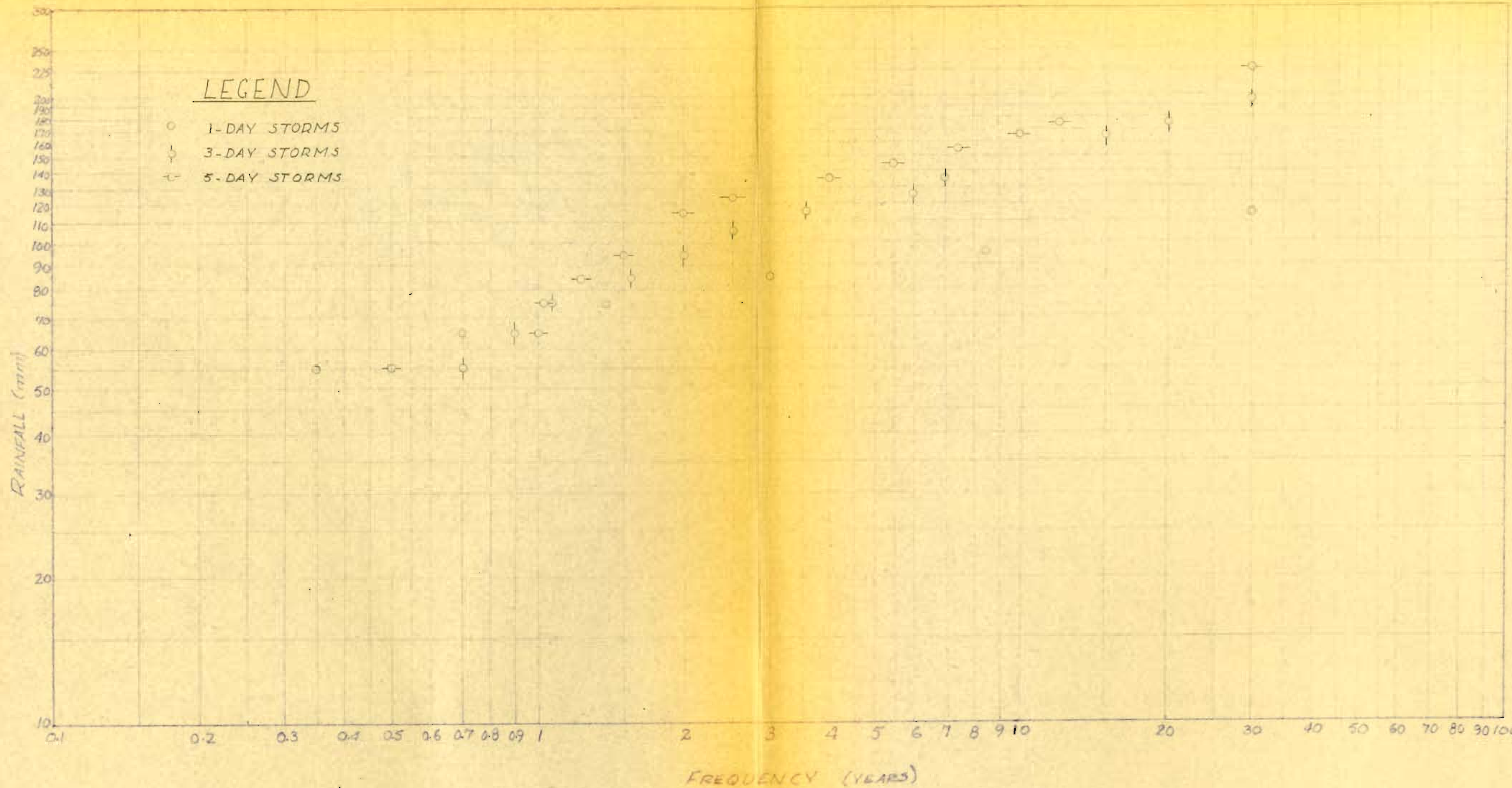
(AS OBTAINED BY THE STATION-YEAR METHOD AS SHOWN IN TABLE 1)



(FOR DURATIONS INDICATED BY THE PARAMETERS)

FIG. 3 (b) RAINFALL - FREQUENCY CURVES FOR THE ABU ALI RIVER BASIN

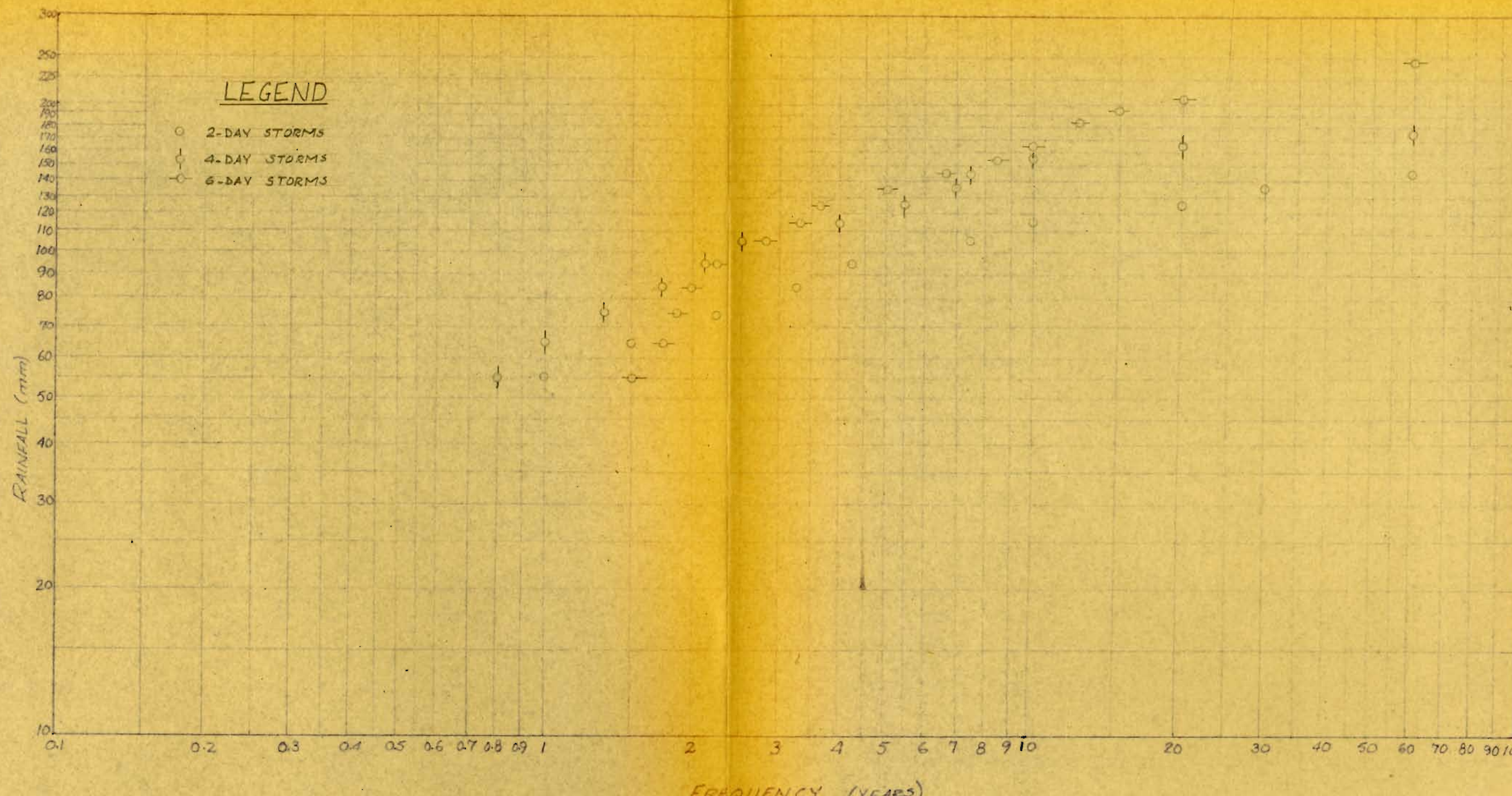
(AS OBTAINED BY THE STATION - YEAR METHOD AS SHOWN IN TABLE 1)



(FOR DURATIONS INDICATED BY THE PARAMETERS)

FIG. 3 (c) RAINFALL-FREQUENCY CURVES FOR THE ABU ALI RIVER BASIN

(AS OBTAINED BY THE STATION-YEAR METHOD)
(AS SHOWN IN TABLE 1)



(FOR DURATIONS INDICATED BY THE PARAMETERS)

FIG. 3(d) RAINFALL-FREQUENCY CURVES FOR THE ABU ALI RIVER BASIN

(AS OBTAINED BY THE STATION-YEAR METHOD)
(AS SHOWN IN TABLE 1)

A study of Figs. 4 and 5 shows a serious discrepency in the results. Had the values been correct all the points of the same parameter would have fallen on one smooth curve in Fig. 5. They do not. Fig. 4 shows the curves unevenly spaced and even staggered. The writer attributes this to the fact that in the results of Table 1 of the Station Year Method two readings of similar magnitude occurred in the higher frequencies in the 1, 3, and 5 day storm records whereas only one high rainfall was observed for the 2, 4, and 6 day storms, indicating that the period of record analysed was insufficient.

Furthermore, the range over which the values of frequency were obtained (62 years) is too small to justify any extrapolation beyond that for a 100 yr. frequency. Thus if the 5 day storm value corresponding to a 10,000 yr. frequency were to be extrapolated, the ridiculous value of 1020 mms. would be obtained whereas studies of A.U.B. records give the more reasonable value of 400 mms.

A further defect is to be found in the records themselves. The only durations that are recorded are multiples of 24 hours.

All the preceding points indicate that there is insufficient data for a strictly statistical procedure in determining the design storm or storms.

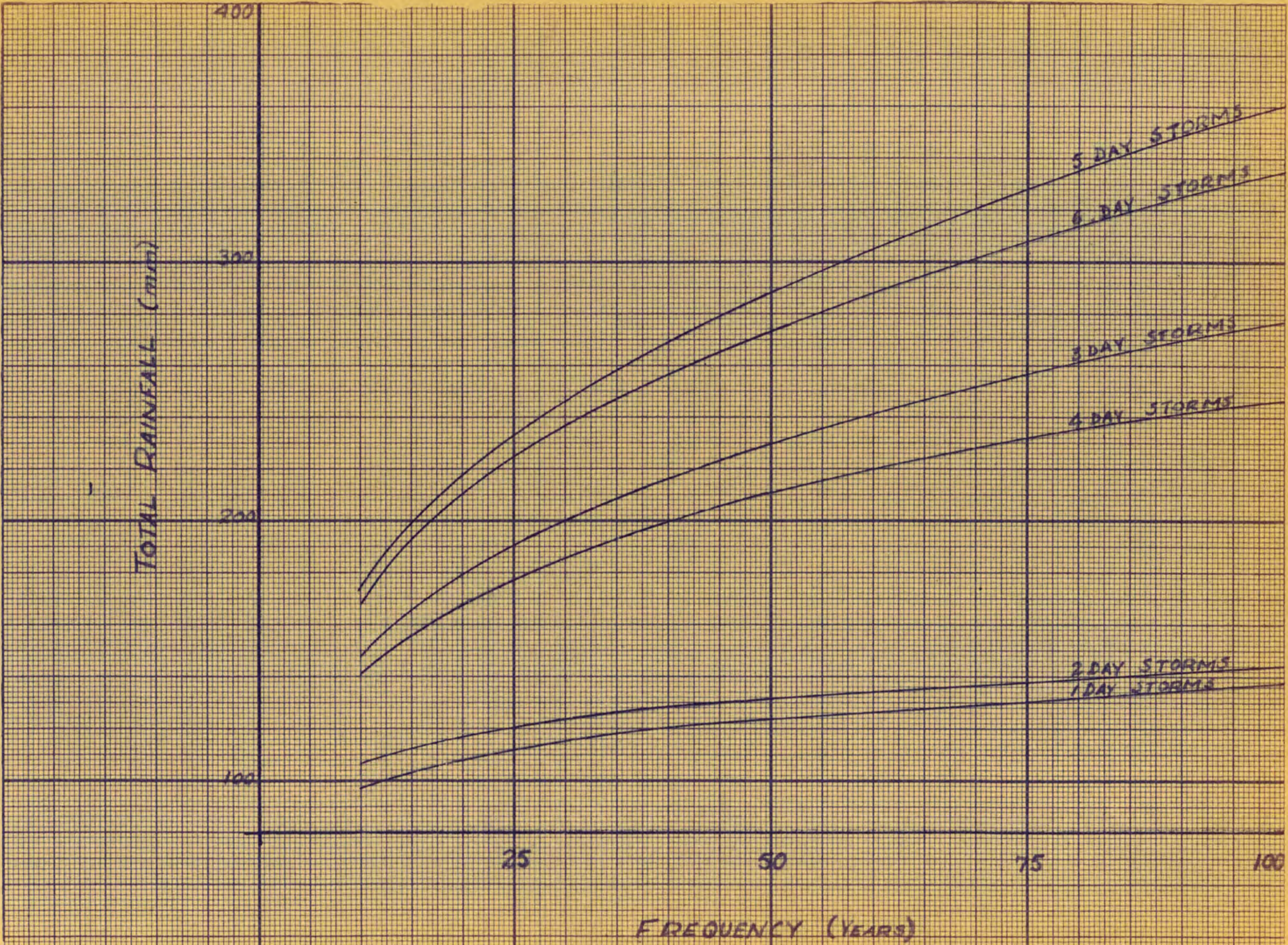


FIG.4. COMPUTED RAINFALL-FREQUENCY CURVES
FOR THE ABU ALI RIVER BASIN
(obtained by LEAST SQUARES for the Data of Table 3)

29a

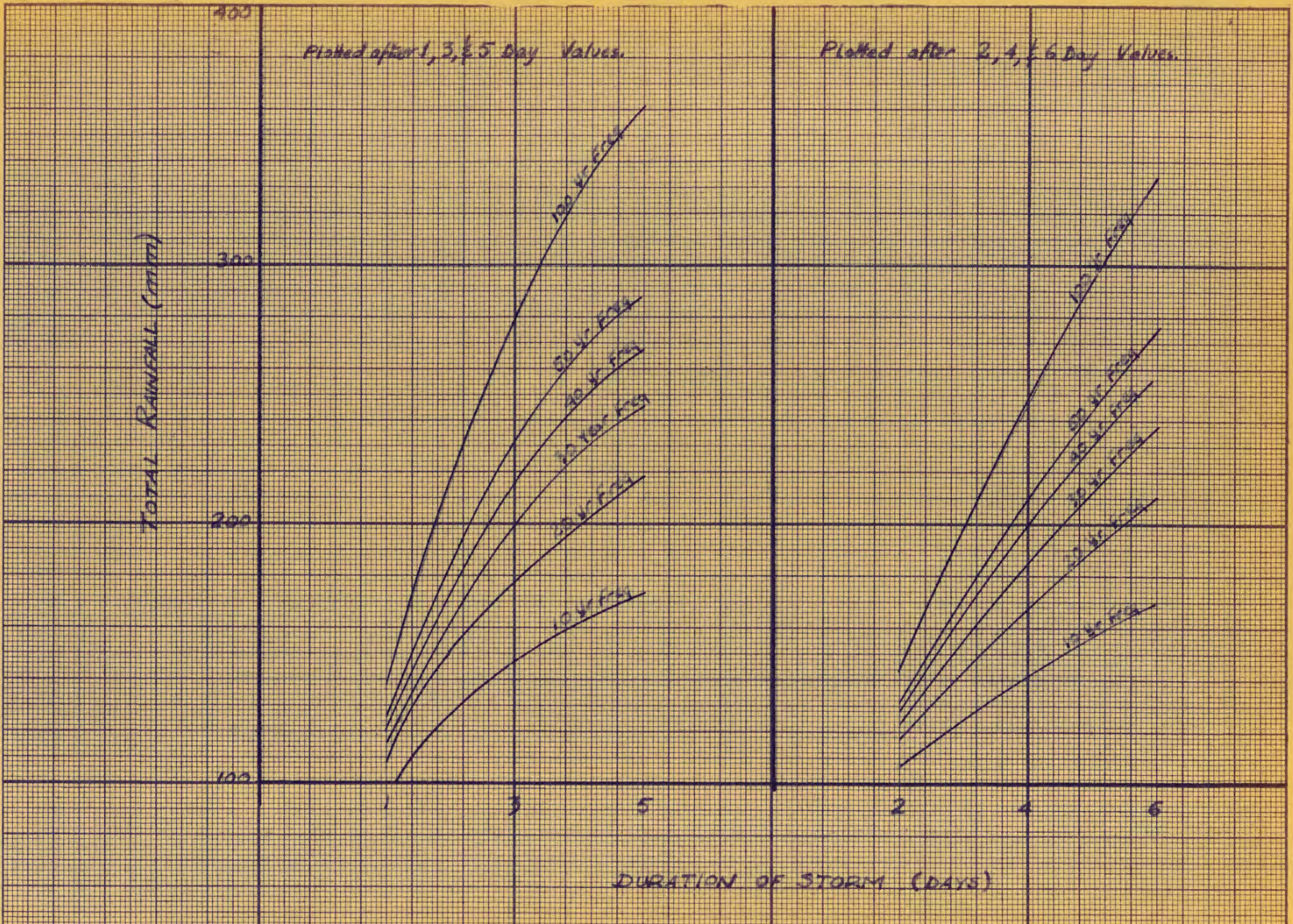


FIG. 5. COMPUTED RAINFALL-DURATION CURVES
FOR THE ABU ALI RIVER BASIN
(obtained by LEAST SQUARES for the Data of TABLE 2)

TABLE 2

CALCULATED RAINFALL (IN MMS.) FOR THE INDICATED FREQUENCIES FOR THE ABU ALI RIVER BASIN

(AS OBTAINED BY LEAST SQUARES FOR A 62 YEAR PERIOD)

FREQUENCY (YEARS)	STORM DURATION (DAYS)					
	1	2	3	4	5	6
10	97	107	147	141	173	169
20	108	117	179	168	217	211
30	115	123	200	185	246	237
40	120	127	216	200	268	256
50	123	131	230	210	289	274
100	137	143	277	246	361	335

2. Storm over Tripoli on 17th December, 1955.

Study of the isohyetal map for the storm that was included in the supplement to the January issue of the "Lebanese Ministry of Public Works Weather Bulletins", reveals that the rainfall over the basin is equivalent to an 85 mms. rainfall over the whole basin. The conversion from an isohyetal map to an average equivalent value will not appreciably affect the hydrograph except for the time lag between the center of mass of the rainfall and the crest of the flood wave as it reaches Tripoli. The peak value would be relatively unchanged and the total flood hydrograph time base will be reduced almost in the same proportion as the time lag.

THE DESIGN STORM:

In determining design storms applicable to all types or a variety of types of flood control structures, the writer has considered two types of storms:

1. A short duration storm which will produce a relatively high peak and thus be the major, if not only, factor in determining the dimensions of a flood protection structure, and,
2. a long duration storm which would be the major factor in determining the height of a control dam and its reservoir capacity due to the high volume of runoff produced.

If a combination of elemental flood control structures is to be considered (and economic consideration would seem to justify that), both types of storms will have to be considered in their resultant effect on the combination.

SHORT DURATION STORM:

The available rainfall data has 24 hours for its lower time limit and is thus useless for any attempt to obtain rainfall values for a shorter duration storm.[x]

This approach was therefore discarded and the approximate methods outlined in the introduction of this chapter were resorted to, the second in particular.

The isohyetal map of the storm of 17th December, 1955, was used and the contours rearranged over the basin to give maximum rainfall over the Abu Ali River Basin. This resulted in the equivalent of 109 mms. of rainfall over the whole basin. This will be taken as the short duration design storm.

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[x]Professors Salem Khamis and Des Raj of the Mathematics Department at the American University of Beirut were consulted on the matter and they concurred on the futility of such an attempt. They required data on shorter duration storms and only one such storm was available, namely that of 17th December, 1955.

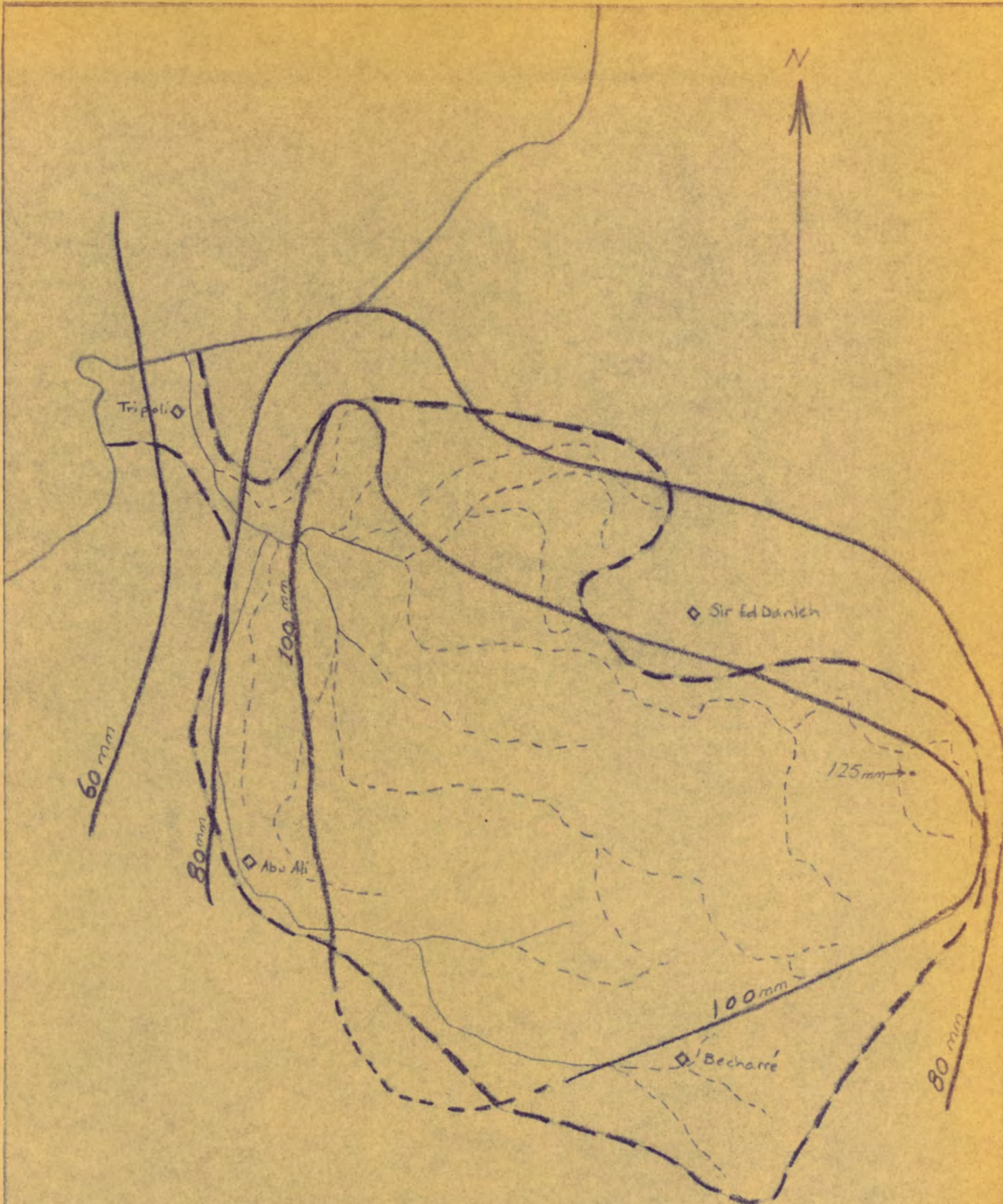

Fig. 6

Adopted Short Duration Design Storm for the Abu Ali River Basin Based on Fig. 1

Scale 1:200,000

No records are available to hint at the amount of rainfall in the 12th December, 1843, storm, but its wave appears to be quite similar to that of the 17th December, 1955, storm and a very rough estimate for the frequency for this design storm would thus be about 100 years. It should be pointed out that this is the frequency of the storm - not the flood; since the center of the storm may or may not be located over the basin, and so the frequency of the flood may be much higher than that of the storm.

LONG DURATION STORM:

The determination of the long duration design storm was more accurate in nature as a statistically correct storm for another station was used. The 10,000 year 5 day storm of 400 mms. as determined in the Hydrology volume of the Litani report previously mentioned based on the A.U.B. observatory records was superimposed on the Abu Ali River basin. It was assumed to cover the whole basin since the area is relatively small, in as far as drainage basins go, it being only 500 square kilometers (about 200 square miles).

PROBABILITY OF RECURRENCE:

If the average recurrence interval of a storm is (i_r), then the chance of having this storm occur once in any one year is

$$P = \frac{1}{i_r}$$

and the possibility of its not occurring in one year is therefore

$$(1 - P)$$

The probability of the storm not occurring in N years is $(1 - P)^N$. It follows that the probability of the storm being equalled or exceeded in N years is

$$1 - (1 - P)^N.$$

The following table was prepared by applying the method just outlined.

TABLE 3

Probability of Recurrence of Design Storms in N Years.

Design Storm & Frequency / N Yrs.	1	10	20	50	100	1,000	10,000
Short Duration (100 yrs)	0.0100	0.0956	0.1921	0.3950	0.6340	0.9999	1.0000
Long Duration (10,000 yrs)	0.0001	0.0010	0.0020	0.0049	0.0098	0.0933	0.6280

CHAPTER II

CALCULATION OF THE DESIGN FLOOD

INTRODUCTION:

Before a start can be made on the design of flood protection works, a fairly good idea should be had as to the way in which the river is expected to behave under critical conditions.

River behavior studies can follow one of two approaches, the statistical or the unit hydrograph approach.

1. Statistical:

In this approach the river stage fluctuations are analyzed. This can be done for one or more rivers in the same region and under similar weather conditions, the results being applicable to the one or more rivers. The formulae derived employ a number of parameters, the two most frequently used being the area of the drainage basin and the average stream flow. Some formulae have made no provision for the intensity of rainfall. The reader is referred to Barrows' "Water Power Engineering" for a thorough discussion on the different approaches.

2. Unit Hydrograph:

The graphical presentation of stream flow data is known as a hydrograph. The runoff characteristics that can be determined from a hydrograph are the distribution of runoff with respect to time, the quantity and the relative amounts of the different sources of runoff.

Rouse in "Engineering Hydraulics" defines a unit hydrograph as "the hydrograph of one inch of surface or storm runoff from a given drainage area for a typical or specified rainfall distribution of some unit time duration ....its principal characteristics are the time lag and the peak rate of discharge". The unit hydrograph concept is based on the phenomenon that, if two identical storms occurred under identical conditions, the runoff hydrographs would be the same.

The derivation of the unit hydrograph for a given area requires a thorough study of the records of river stage, distribution and duration of rainfall, the paths followed by the storms, and the seasons they occur in.

The major influences on the hydrograph are the rainfall distribution and the basin characteristics, such as area, slopes, length of river, shape of area, etc..

The basic assumptions of a unit hydrograph are not rigorous but this method has been found to give results sufficiently accurate for most practical problems.

INTERPRETATION OF AVAILABLE DATA:

1. Stream Flow Records:

Only two sets of stream flow records seem to be available, those taken at Kousba and those of Tourza, both being in the upper reaches of the Abu Ali River. The Tourza records are monthly or bimonthly measurements of the flow diverted to the Abu Ali Power Station and hence do not give any measure of total stream flow except in dry seasons. The Kousba river stage gauge was operated between 1949 and mid 1953, when a rock avalanche destroyed it. The writer discarded the Tourza records in favour of those of Kousba but again the period of record at Kousba is insufficient for any statistical analysis and the area drained by the Abu Ali River at Kousba amounts to only 2/5 of the whole watershed. One thing of value can be obtained from the Kousba records, however, and that is the ground water flow, its being about 3 cubic meters per sec. A proportional extrapolation to the whole watershed would give a value of about 7.5 cubic meters per second. This value may be assumed to represent the ground water flow arriving at Tripoli.

2. Infiltration:

No infiltration data of any kind was available. At the suggestion of Selim Maksoud[x], the infiltration curve

[x] Associate Professor, School of Agriculture, American University of Beirut.

shown in Fig.7 was adopted for the Abu Ali Basin.

3. Long Duration Design Storm:

The cumulative rainfall diagram for the long duration design storm (obtained from the I.C.A. Litani Report as discussed in Chapter 1) is shown in Fig.8.

4. Flood Hydrograph at Tripoli for the Storm of 17 Dec., 1955.

From the government report on the flood the writer obtained an estimate of the time lag (difference in time between the center of mass of the rainfall excess and the flood peak) for the peak of the flood wave, and, using the unit hydrograph to obtain the peak, the flood hydrograph for the storm of the 17th December, 1955, at Tripoli was constructed as shown in Fig.9. (i.e. Since the rainfall excess was 82 mms., the peak value was taken to be 82/10 of the unit hydrograph peak.)

5. Capacity of the Abu Ali River Channel Through Tripoli.

The capacity of the channel was obtained by referring to the government report on the flood to get the time at which the river overflowed its banks. Using this time in the flood hydrograph of Fig.9 results in the discharge at the moment of overflooding, namely 400 cubic meters per second. This, of course, is not to be related to steady flow conditions but for flood conditions similar to those shown in Fig.9.

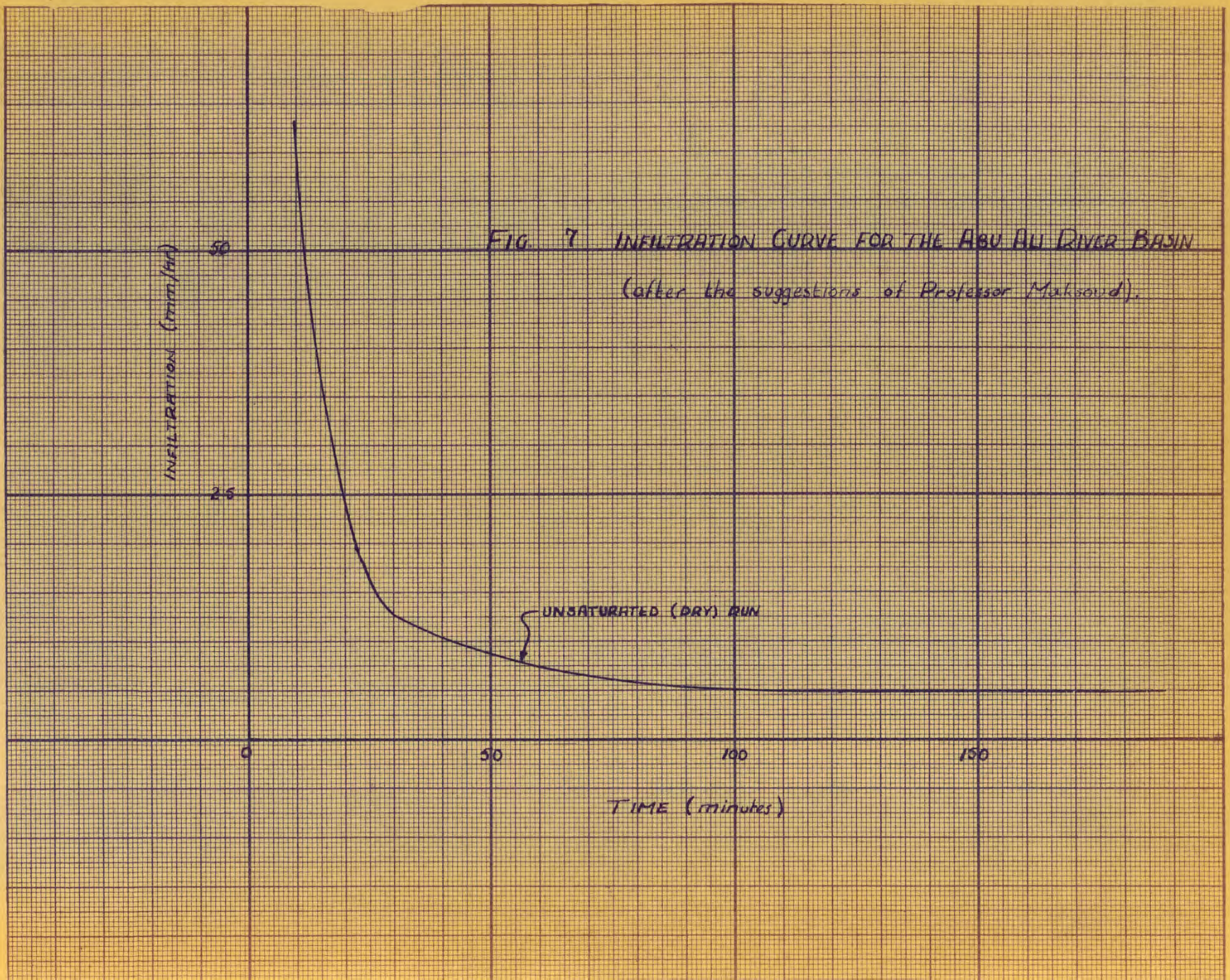

FIG. 7 INFILTRATION CURVE FOR THE ABU ALI RIVER BASIN

(after the suggestions of Professor Maksoud).

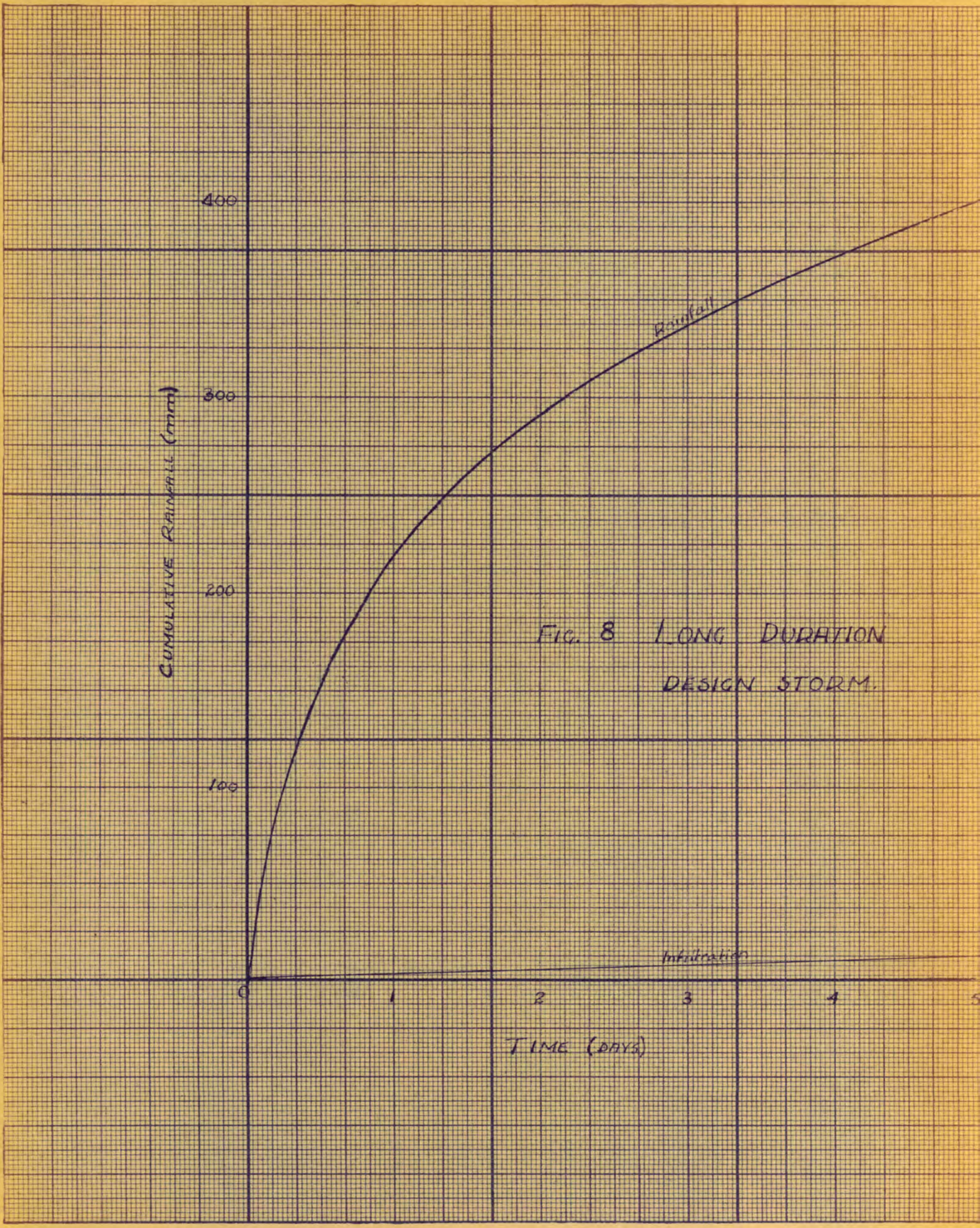

FIG. 8 LONG DURATION DESIGN STORM.

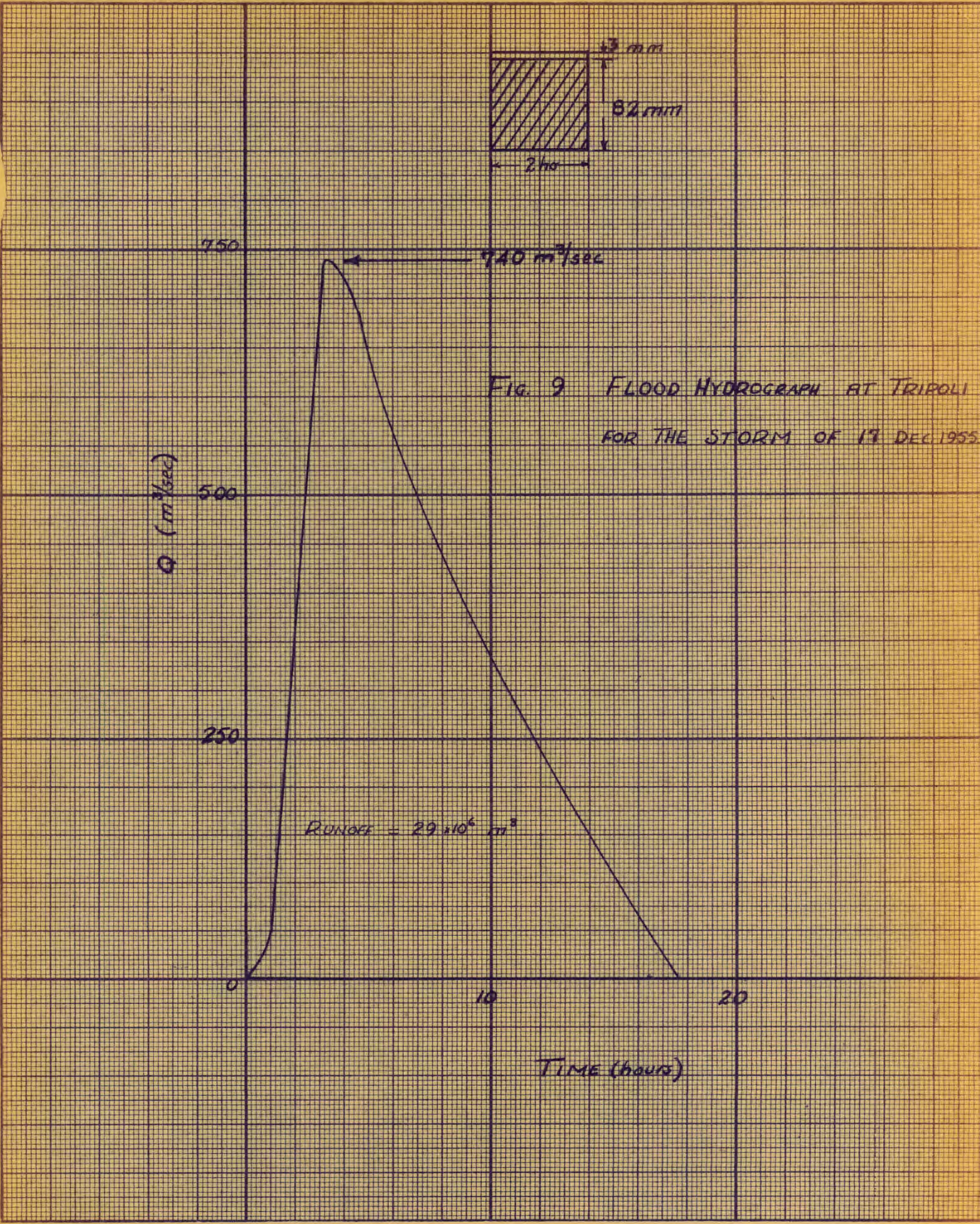

Fig. 9 Flood Hydrograph at Tripoli for the storm of 17 Dec 1955.

DERIVATION OF THE UNIT HYDROGRAPH:

As the data required for the statistical approach was meager, the writer decided upon the use of unit hydrographs inspite of the fact that insufficient data was available for their proper construction.

The writer used an article[x] which discusses the construction of synthetic unit hydrographs. The requirements are the total length (L) of the longest watercourse measured to the basin boundary, the distance (L_{ca}) along the main drainage channel from the point of interest to the center of gravity of the basin measured along the main stream, and the equivalent slope (S_{st}) of a uniform channel having the same length as the longest watercourse and an equal travel time. The first two can easily be found by measurement. The equivalent slope may be determined by the following method:

The watercourse is divided into a number of equal lengths (n) and the average slope of each length is determined. The slopes thus determined are substituted in the following formula which is derived on the basis of

---

x "Unit Hydrograph Lag and Peak Flow Related to Basin Characteristics" by Taylor and Schwarz, American Geophysical Union, April, 1952.

the previously mentioned conditions and Manning's open channel formula:

$$S_{st} = \left[\frac{n}{\sum 1/S^{\frac{1}{2}}} \right]^2$$

LL_{ca} and S_{st} are then located in the nomograph which is reproduced in Fig.10 to determine the time lag (in hours) and the peak (in cfs/sq. mile). The total time base (T) of the unit hydrograph can then be found by the application of the following empirical formula:

$$T = 5 \left(t_{PR} + \frac{t_r}{2}\right)$$

Where t_{PR} is the time lag and t_r is the duration of rainfall excess.

To obtain more points on the unit hydrograph another publication was resorted to [x]. It gave values for time widths of the unit hydrographs for discharges whose magnitude is 75% and 50% of the peak discharge.

The computations for S_{st}, the peak, time lags, time bases, and 75% and 50% values are presented in Tables 4 and 5. The unit hydrographs for a 2 hr, 4hr, 6 hr, 12 hr, and 24 hr rainfall excesses of 10 mms. are shown in Figs. 11, 12, 13, 14, and 15.

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[x] Flood Hydrograph Analyses and Computations, Corps of Engineers, 1948, Plate IX.

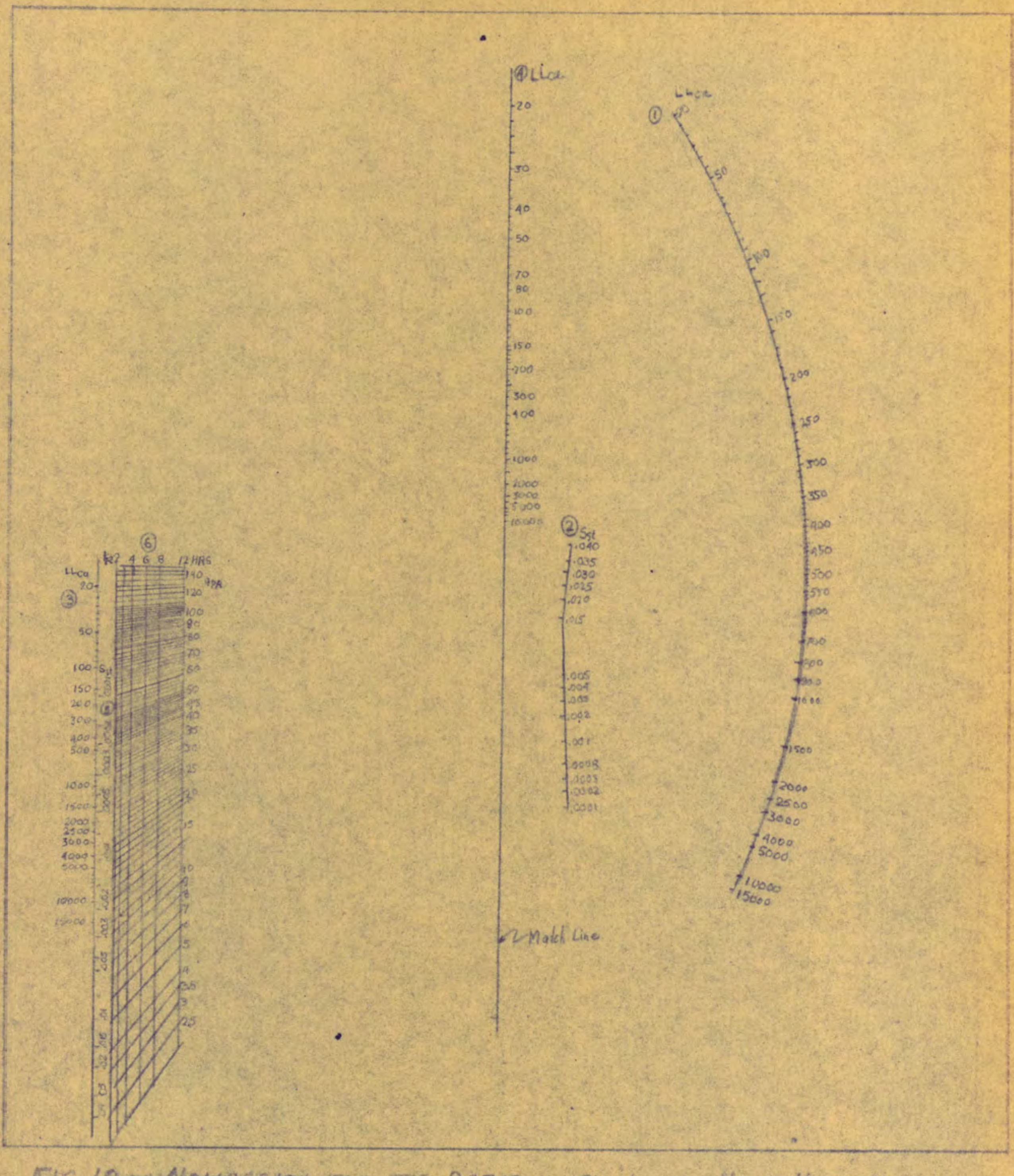


FIG. 10 — NOMOGRAPH FOR THE DETERMINATION OF UNIT HYDROGRAPH PEAKS AND TIME LAGS FROM BASIN CHARACTERISTICS.

(FROM "UNIT HYDROGRAPH LAG AND PEAK FLOW RELATED TO BASIN CHARACTERISTICS" BY TAYLOR AND SCHWARZ, A.G.U. TRANSACTIONS, APRIL, 1952.)

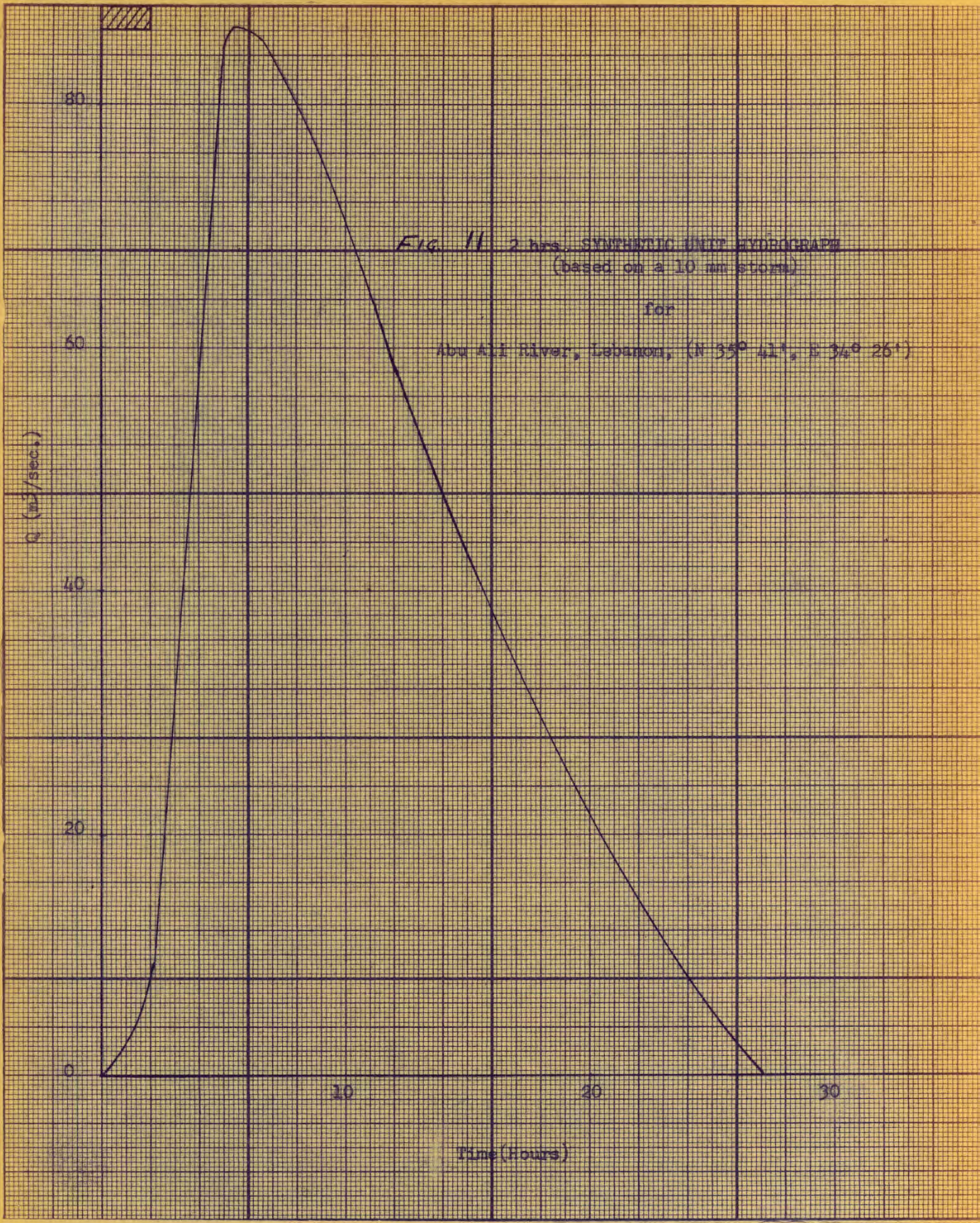


Fig. 11 2 hrs. SYNTHETIC UNIT HYDROGRAPH
(based on a 10 mm storm)
for
Abu Ali River, Lebanon, (N 35° 41', E 34° 26')
Q (m3/sec.)
80
60
40
20
0
10
20
30
Time(Hours)

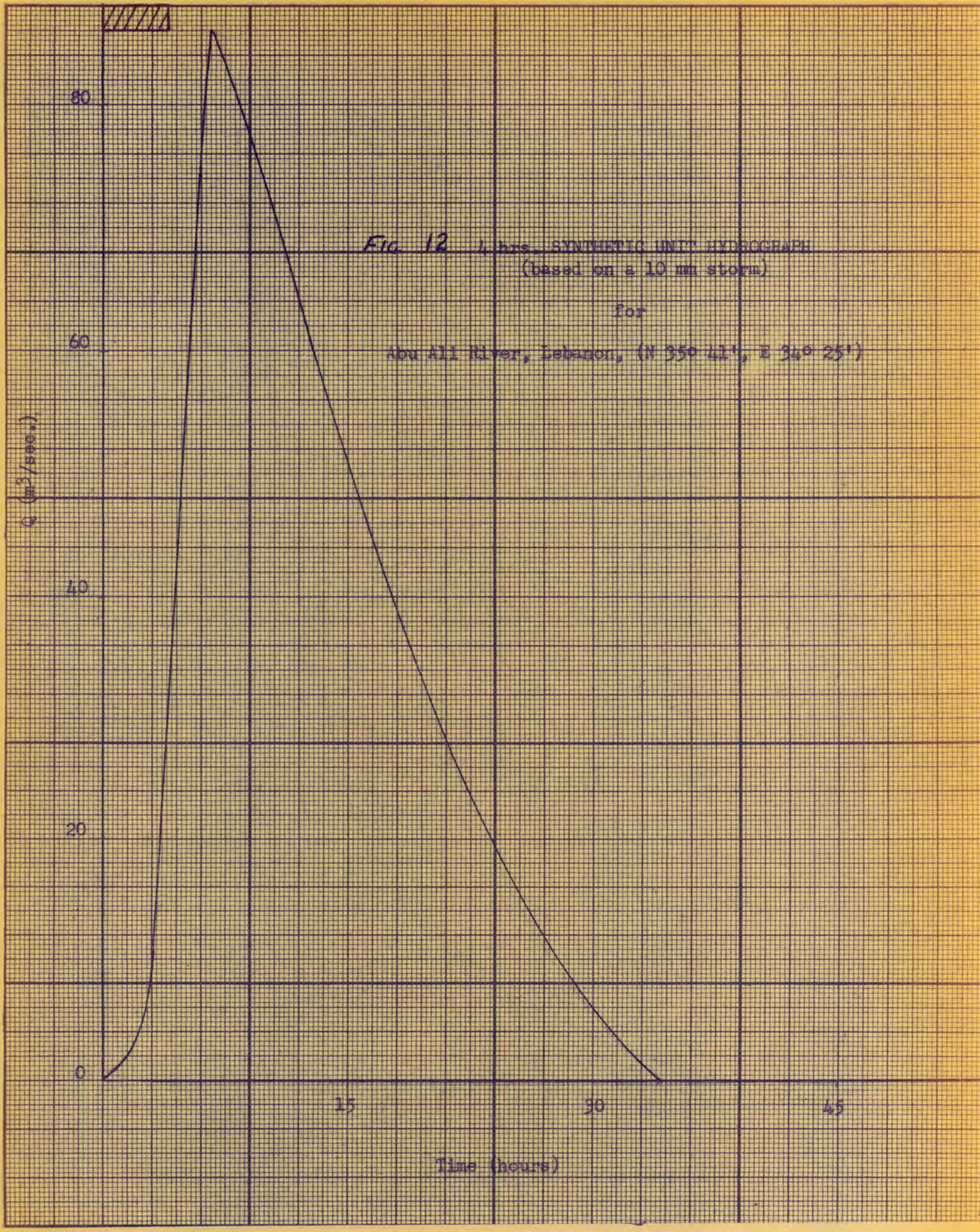


Fig. 12 4 hrs. SYNTHETIC UNIT HYDROGRAPH
(based on a 10 mm storm)
for
Abu Ali River, Lebanon, (N 35° 41', E 34° 25')

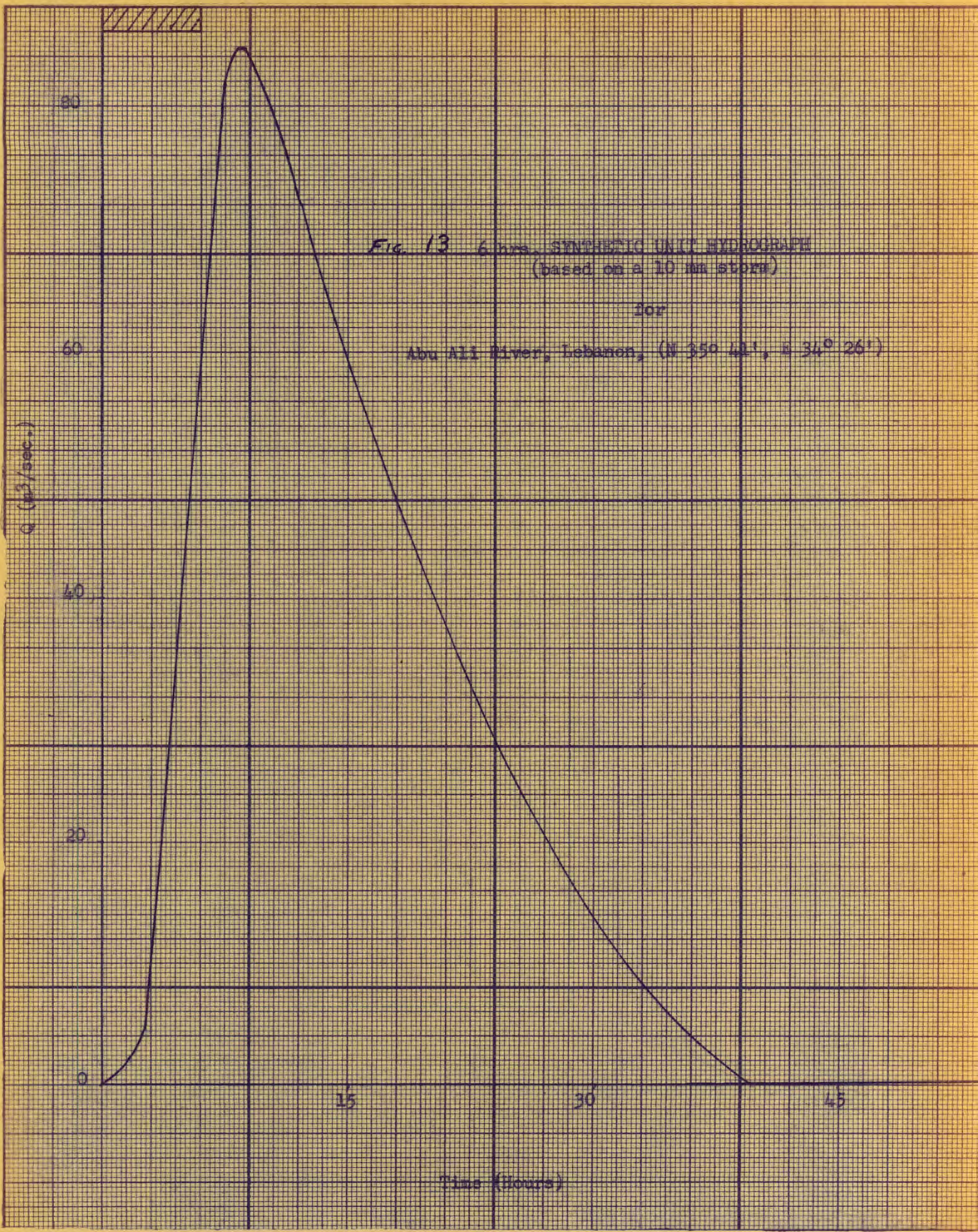


Fig. 13 6 hrs. SYNTHETIC UNIT HYDROGRAPH
(based on a 10 mm storm)

for

Abu Ali River, Lebanon, (N 35° 41', E 34° 26')

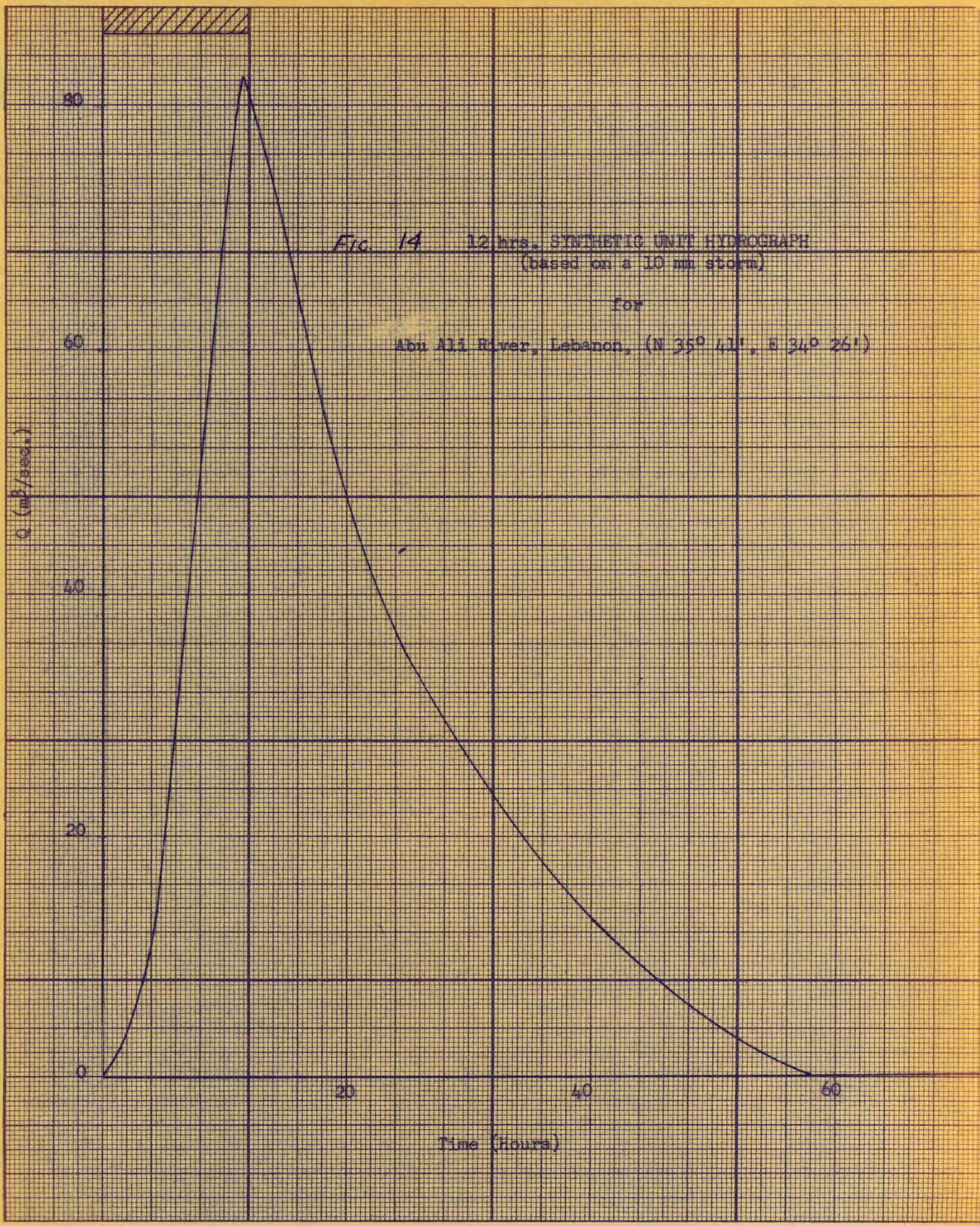


FIG. 14 12 hrs. SYNTHETIC UNIT HYDROGRAPH
(based on a 10 mm storm)
for
Abu Ali River, Lebanon, (N 35° 41', E 34° 26')
Q (m³/sec.)
80
60
40
20
0
20
40
60
Time (Hours)

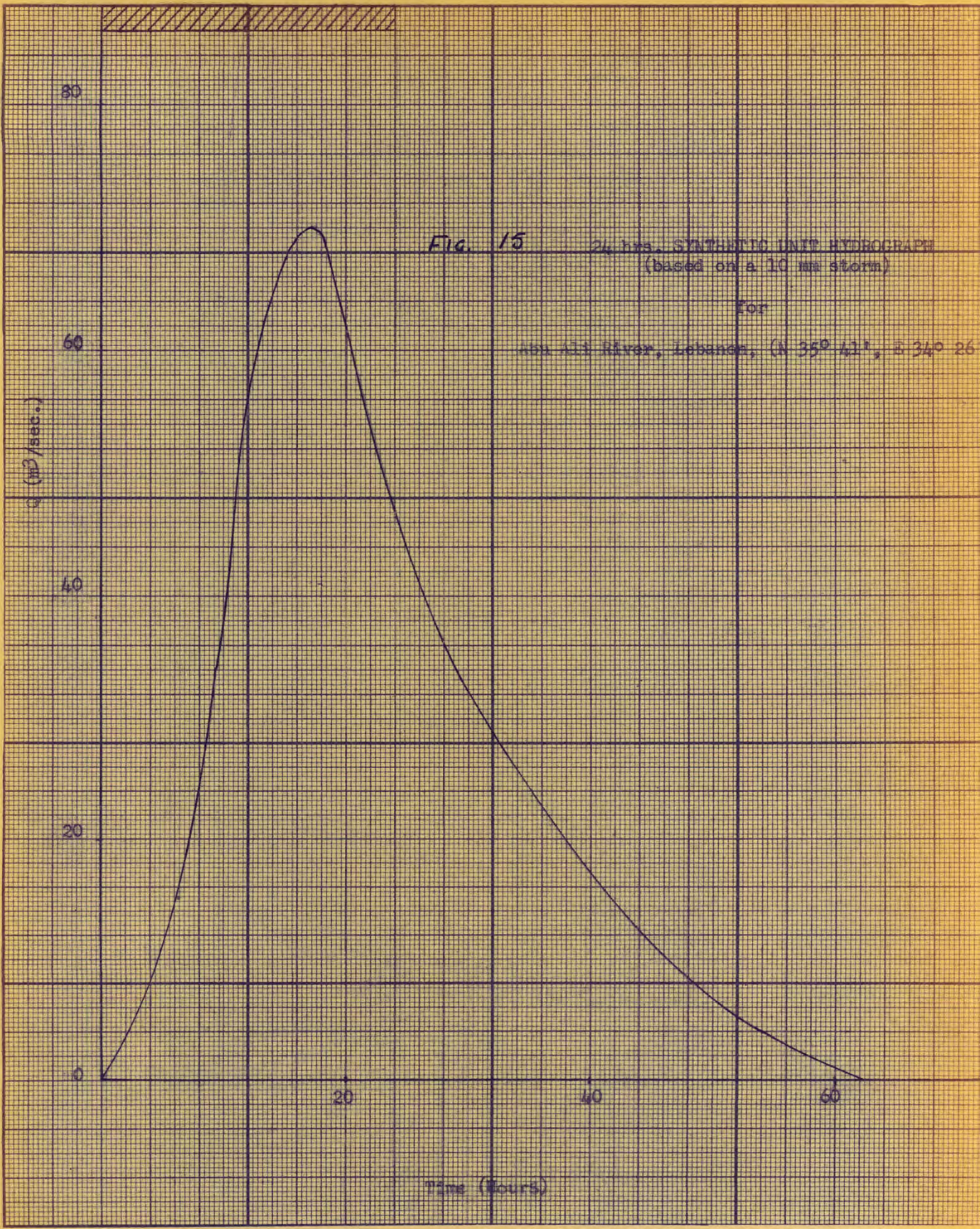


Fig. 15 24 hrs. SYNTHETIC UNIT HYDROGRAPH
(based on a 10 mm storm)
for
Abu Ali River, Lebanon, (N 35° 41', E 34° 26

TABLE 4

DETERMINATION OF THE EQUIVALENT MAIN STREAM SLOPE

DIFFERENCE OF ELEVATION (m)	LENGTH (m)	AVERAGE SLOPE (S_i)	$\sqrt{S_i}$	$1/\sqrt{S_i}$
800	4000	0.200	0.446	2.24
500	4000	0.125	0.354	2.80
250	4000	0.0625	0.250	4.00
200	4000	0.050	0.224	4.46
200	4000	0.050	0.224	4.46
110	4000	0.026	0.161	6.20
70	4000	0.018	0.132	7.60
40	4000	0.010	0.100	10.00
30	4000	0.0075	0.086	11.60
20	4000	0.0050	0.071	14.10

$L = 25\,miles$ $\quad L_{CA} = 20\,miles$ $\quad LL_{CA} = 500$

$$S_{st} = \left[\frac{n}{\Sigma\left(1/\sqrt{S_i}\right)}\right]^2 = \left(\frac{10}{67.46}\right)^2 = 0.022$$

TABLE 5

SYNTHETIC UNIT HYDROGRAPH CHARACTERISTICS

(based on a 10mm storm)

RAINFALL EXCESS DURATION (hrs)	PEAK DISCHARGE (m^3/sec)	TIME LAG (hours)	TIME BASE (hours)	WIDTH AT 75% OF PEAK (hours)	WIDTH AT 50% OF PEAK (hours)
2	87	4.4	27	7.0	14.0
4	86	4.7	34	7.2	14.5
6	85	4.9	40	7.4	14.8
12	82	5.5	58	7.7	15.1

The 24 hr unit hydrograph was derived by superimposing two 12 hr unit hydrographs, staggering the second by 12 hours.

DESIGN FLOOD HYDROGRAPHS:

Assumptions:

In constructing the design flood hydrographs, the writer made the assumptions:

1. That the design storms are isolated and occur only when river flow is made up of ground water flow. This assumption is justified by the low probability of having the design storms precede or follow another high intensity storm.

2. That the snow melt is neglected. Two reasons justify this assumption. The first is that any snow melt percolates into the soil due to its low magnitude and so is of no consequence in stream flow. The second reason is the lack of data such as snow depths, snow water content, temperatures, etc., which would be necessary for accurate evaluations.

3. That the soil has had a previous wetting and so allows a minimum of percolation. The values of 3 mms. and 10 mms. were deducted from the rainfall of the 2 hr and 5-day design storms respectively to represent percolation losses.

4. That the ground water flow of 7.5 cubic meters per second can safely be neglected in the hydrograph construction due to its low magnitude.

HYDROGRAPH CONSTRUCTION AND CORRELATION:

The unit hydrograph in Fig.11 was used to construct the flood hydrograph for the short duration design storm as shown in Fig.16 (i.e. The ordinates of the flood hydrograph are 106/10 times those of the unit hydrograph).

An envelope curve of flood peaks used in the design of Litani Basin dams was drawn and the design peak of the Abu Ali River check favourably as indicated in Fig.17.

A discrepency arises, however, when one considers the time lag, the observed lag being less than that obtained in the hydrograph. This can be explained by the fact that the heavy rainfall was concentrated in the neighbourhood of Tripoli while the design hydrograph is based on the assumption of a uniform rainfall distribution over all the basin.

No hydrograph is presented for the 5-day design storm as it would give a lower peak than that of the 2-hr flood hydrograph and would be of interest in storage problems only.

S-Curve Hydrographs:

An S-Curve hydrograph is a graphical representation

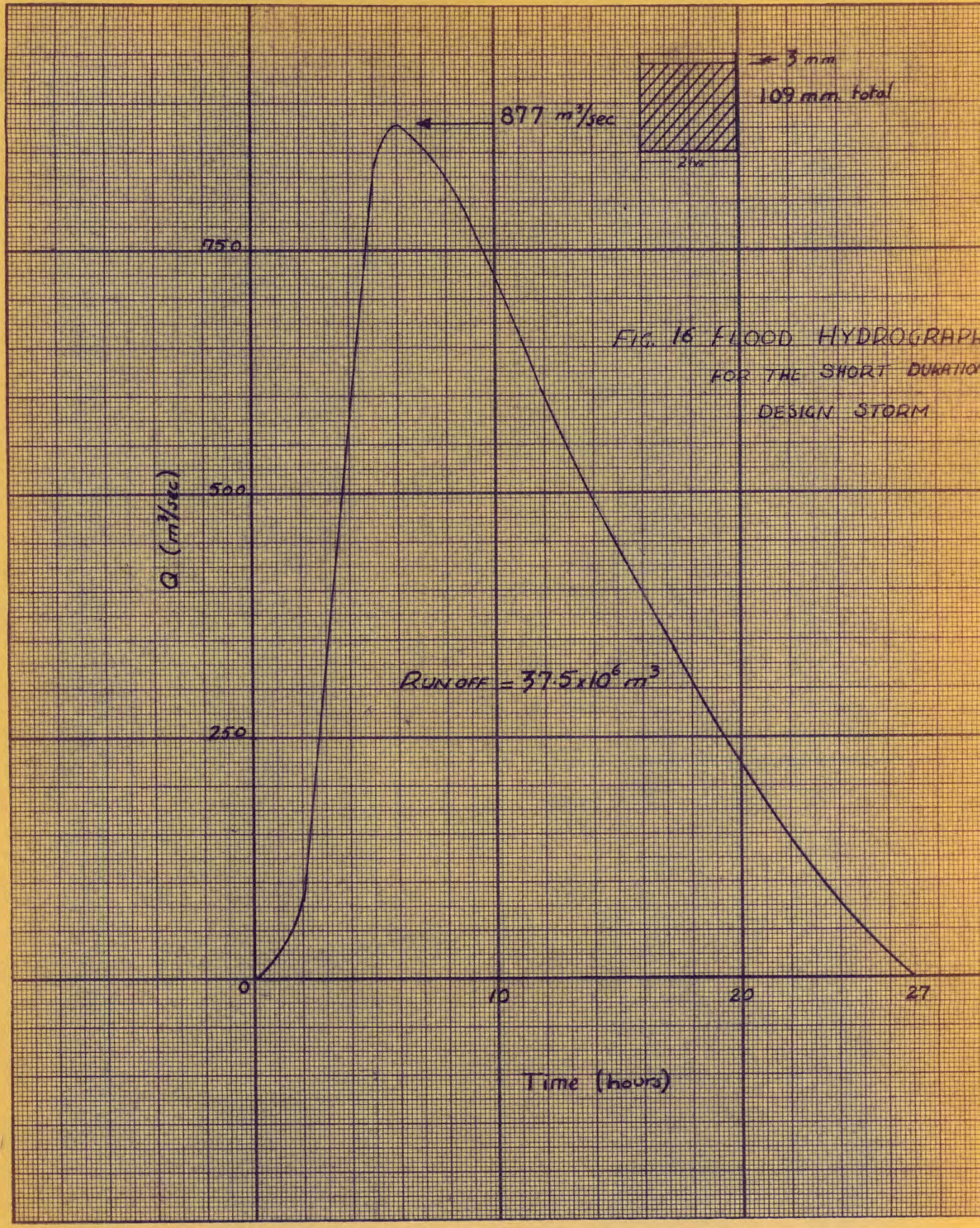


FIG. 16 FLOOD HYDROGRAPH FOR THE SHORT DURATION DESIGN STORM

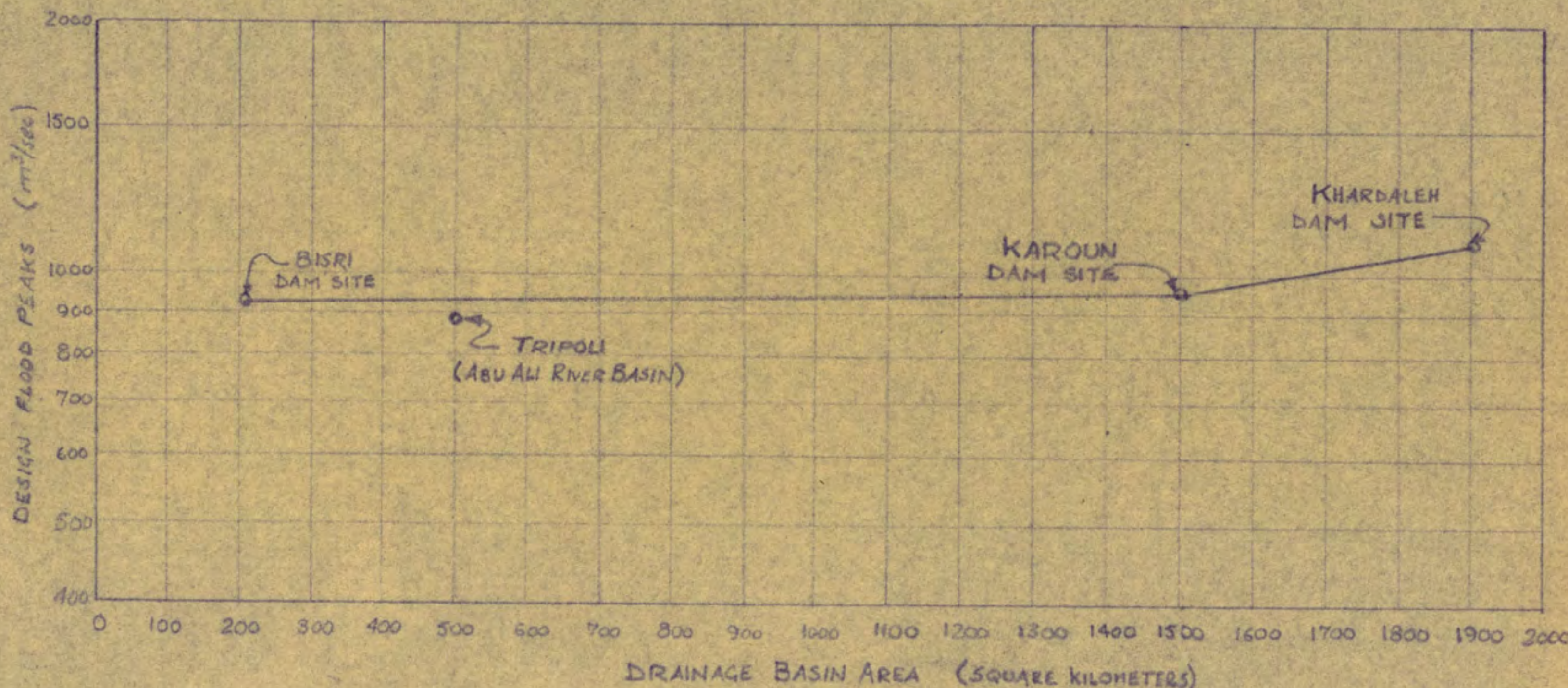


FIG. 17 ENVELOPE CURVE OF DESIGN FLOOD PEAKS FOR THE LITANI RIVER BASIN, LEBANON.
(after the ICA HYDROLOGY REPORT ON THE LITANI).

of cumulative runoff with time. It is useful in studies entailing volume.

The S-Curve presented for both the short and long duration design floods were prepared on the basis of their respective flood hydrographs. They are shown in Figs. 18 and 19.

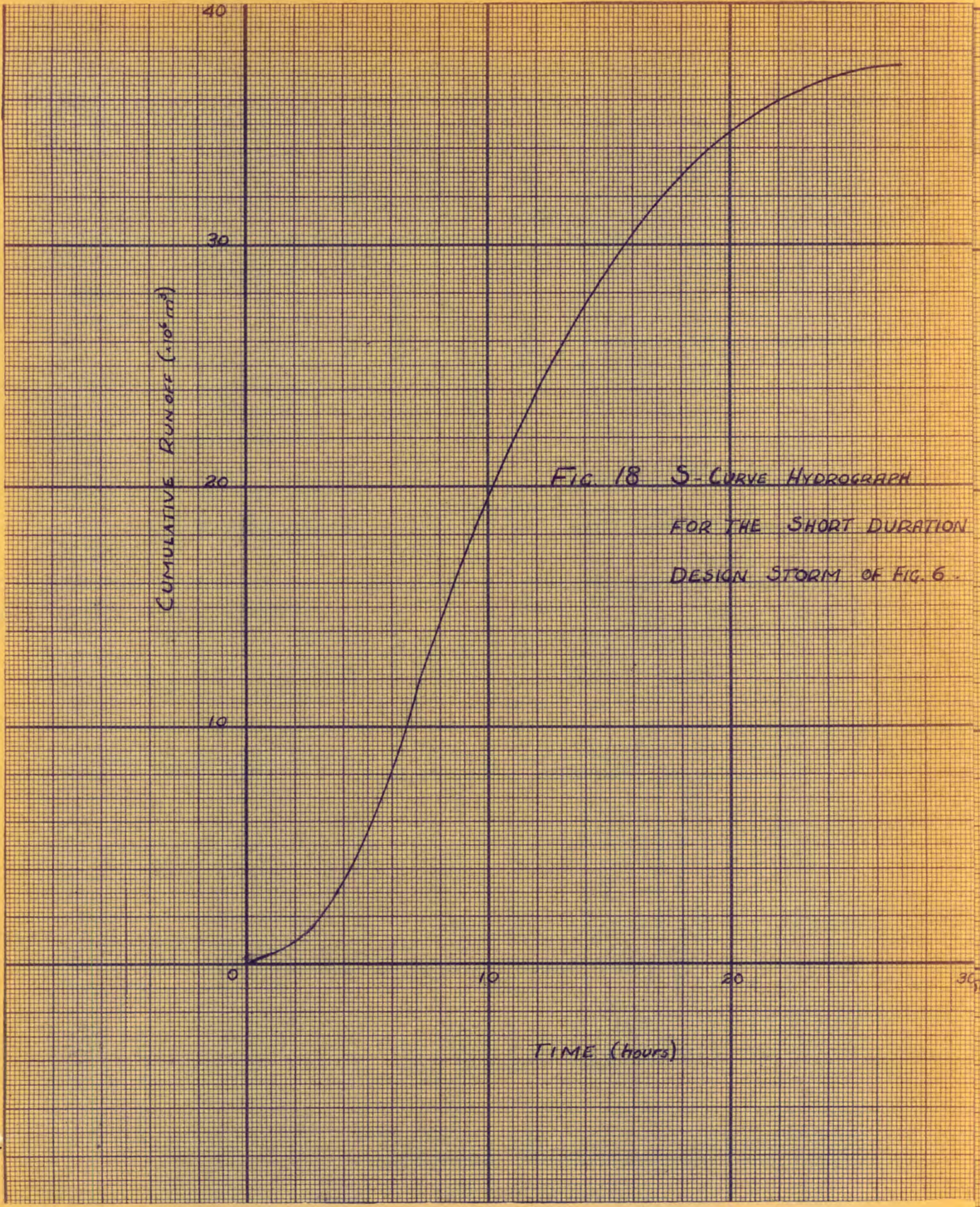
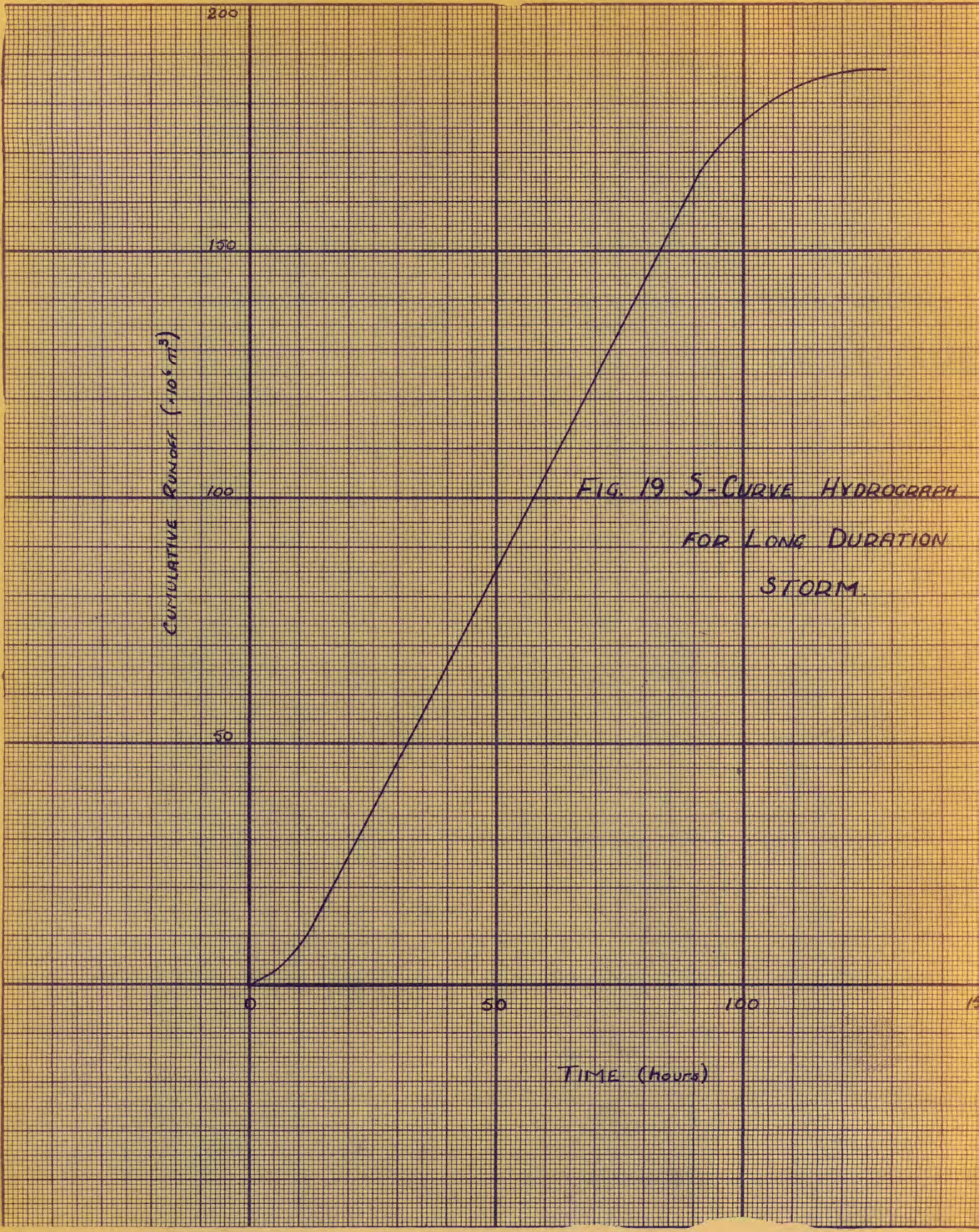


FIG. 18 S-CURVE HYDROGRAPH FOR THE SHORT DURATION DESIGN STORM OF FIG. 6.



200
150
100
50
0
50
100
CUMULATIVE RUNOFF ($\times 10^6 m^3$)
TIME (hours)
FIG. 19 S-CURVE HYDROGRAPH FOR LONG DURATION STORM.

CHAPTER III

PROPOSED SOLUTION OF FLOOD CONTROL PROBLEM.

INTRODUCTION:

Of the possible types of flood control structures six are applicable in this particular case:

1. Reservoirs.
2. Channel Improvement.
3. Levees and Flood walls.
4. Flood ways.
5. Town Planning and Land Management.
6. Bypasses.

1. The function of a flood control resevoir is to store a portion of the flood flow in such a way as to minimize the flood peak at the point to be protected. The ideal location for a resevoir is directly upstream of the point to be protected. This location would deprive the designer of any downstream valley storages which would be available otherwise. The high degree of control over the stream flow offsets this disadvantage, however, and specially where the valley storage is small. Reservoirs are of two types: The storage type where flood forecasting plays an important role, and the retarding type whose only purpose is to reduce and delay the flood peak.

2. Channel improvement includes straightening of the original river channel, lining it, widening it, etc., all of which tend to increase the river channel capacity by increasing the velocity of flow.

3. Levees and flood walls may also be constructed along the river banks to restrict the flood waters within the stream bed. The increase in depth thus provided usually increases the velocity and thus provides more than a proportionate increase in discharge capacities.

4. Floodways are large depressions where the flood waters may be stored temporarily. These serve two purposes: (a) They create large and shallow reservoirs which store a portion of the floodwaters and hence decrease the flow in the main channel below that point. (b) They provide an additional outlet and hence lower the river stage upstream from that point.

5. Town Planning or Land Management involves control over the use to which the flooded land will be put. Parks or pasture lands are some of the uses that can be allowed. This necessitates an efficient warning system.

6. Bypasses are artificial channels provided to skirt the point to be protected. They need not be longer than the original river length but, as in the case of river bends, they may even be shorter.

ANALYSES OF DIFFERENT SOLUTIONS:

I. General:

General considerations may eliminate some of the possible flood control structures without any further detailed study being necessary.

1. The valley immediately upstream from Abu Samra in the town of Tripoli is a narrow gorge developing into a wide valley further upstream. This indicates the feasibility of a resevoir. The writer did not have enough time to study the possibility of a multipurpose resevoir but he was given to understand that such a possibility is being studied by the Engineering Department of the United States Operations Mission to Lebanon. A factor against the use of multipurpose reservoirs is the small size of the watershed which would make flood forecasting practically impossible. On the other hand a retarding resevoir would allow the use of the irrigated lands in the valley as they would only rarely be inundated.

2. Channel improvement and alinement is another possible solution. The channel flood capacity has been found to be 400 cubic meters per second while the peak of the design flood is 880 cubic meters per second. It will be very hard to increase the discharge capacity so much by channel improvement alone. It would seem, therefore, that channel improvement will have to be coupled to some other type of control and act in conjunction with it.

3. Levees are out of the question because of the large area of land that will be taken up by them. Flood walls would be feasible were it not for the three bridges that cross the Abu Ali River in the town of Tripoli. These bridges may be elevated. This would entail elevating all the approaches, too. If they are not to be elevated they would require special gates for closing the gap they create in the walls. Flood walls may be used, however, in the upper reaches of the channel through the town of Tripoli as no bridges are envisaged there.

4. The topography of the region makes the use of floodways impossible due to the total absence of large depressions which could be used for this purpose.

5. The area in Tripoli that is most likely to be flooded is Bab el Tabbanneh and the neighbouring quarters along the banks of the river. They constitute the market and central business district of Tripoli and it would be prohibitively expenssive to remove them.

6. There are two possible bypasses:

a) Bypass of the Town of Tripoli: Any bypass of the town will be longer than the present path followed by the river. It would also pass through populated areas which would introduce high expropriation costs. Moreover, the total width of path will have to be bought.

b) Bypass of the Bab el Tabbanneh river Bend:
The normal flow and low flood flows could be passed along the present river bed while a fuse plug gate would be installed at the head of a canal cutting across the bend. This gate would automatically open up when a certain flow is passing through the river channel and thus relieve the bend of some of its load. The problems involved in this solution are too difficult to solve on a mathematical basis. A model study is recommended.

The damages caused by the flood will determine whether or not the cost of the contemplated project is justified. It would be ridiculous to construct flood protection works at a cost of LL 50 million while the design flood of 100 years frequency would cause damages worth only LL 2 million for example. The lack of time and the lack of data or the means of collecting the required data prevented the writer from determining the flood stage beyond which the extra benefits gained are less than the extra cost required to provide the necessary protection.

From the previous discussion it would be obvious that the only feasible solution would be retarding reservoirs, channel improvements and channel widths, or a combination of the two. They will be discussed in detail in the rest of this chapter.

II RESERVOIRS:

Dam Sites:

The topography of the reach of stream just above Tripoli was examined and four possible dam sites were chosen (location shown in Plate 5). The first is at Abu Samra, the most upstream quarter of the Town of Tripoli. Its location offers ideal control of flood flows. The storage capacity for low dam heights is very small, however. The second location is a few hundred meters further upstream where the tributary gorge could be used for storage and its flow would also be controlled. The storage capacity available here is larger than that of the first site for the same dam heights. For the third dam site, a location just upstream from the second was chosen. Its advantages over the second would be its shorter dam crest lengths but it would not have any control over the small tributary that both the first and the second dam sites controlled. The fourth site was chosen for the sole reason that it would provide more storage capacity than any of the other sites for the same dam heights. Its crest lengths are also the longest. A section of the valley at each of the sites is shown in Fig. 20.

The whole reach of river between the town of Tripoli and Zghorta apparently does not have any good foundation

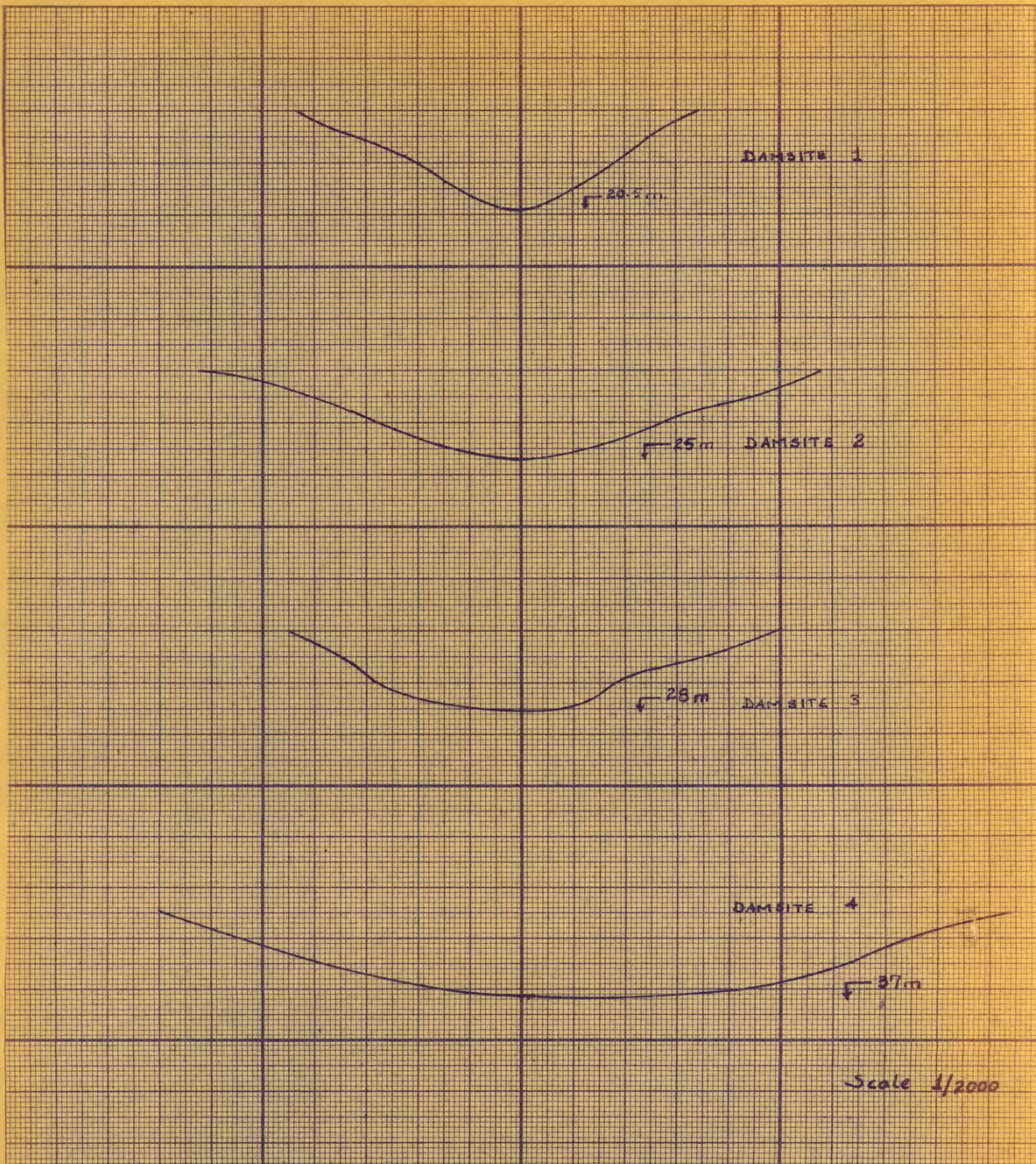


FIG. 20 CROSS SECTIONS AT DIFFERENT DAM SITES.

conditions.[x]

The storage capacities against dam heights at each of the four sites are shown in Fig. 21.

Inquiries from a few inhabitants of Tripoli resulted in prices for the land along the river banks between the town of Tripoli and Zghorta being LL. 5/sq.m. adjacent to the banks of the river and LL. 2/sq.m. at a height of 30 - 40 meters above the stream bed.

Dams:

Two types of dams were considered: The masonry gravity type and the earth fill with a concrete core type.

1. Masonry Gravity Type:

The section given in "Water Power Engineering" by Barrows was used for approximating concrete volumes in the dams, the resulting volume being:

$$V = 0.4\ h^2$$

Where V is the volume in cubic meters per meter length of crest and h is the dam height in meters. The reproduced section is shown in Fig. 22.

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[x] Associate Professor Burke and Mr. Minassian of the School of Engineering at A.U.B. concurred on this although the Engineering Department of the USOM/Lebanon think otherwise for a site just downstream from Zghorta.

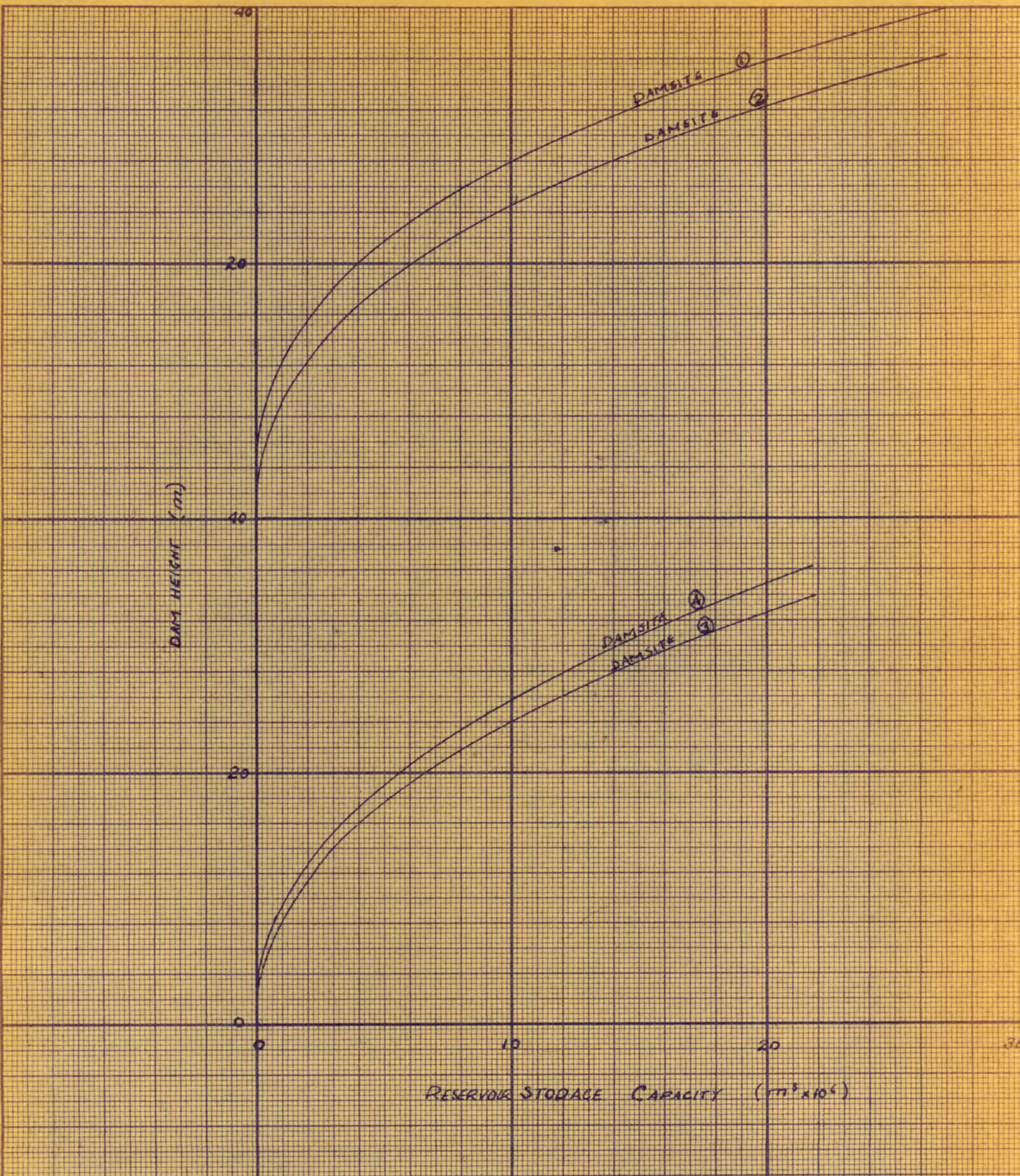

FIG. 21 RESERVOIR STORAGE CAPACITIES.

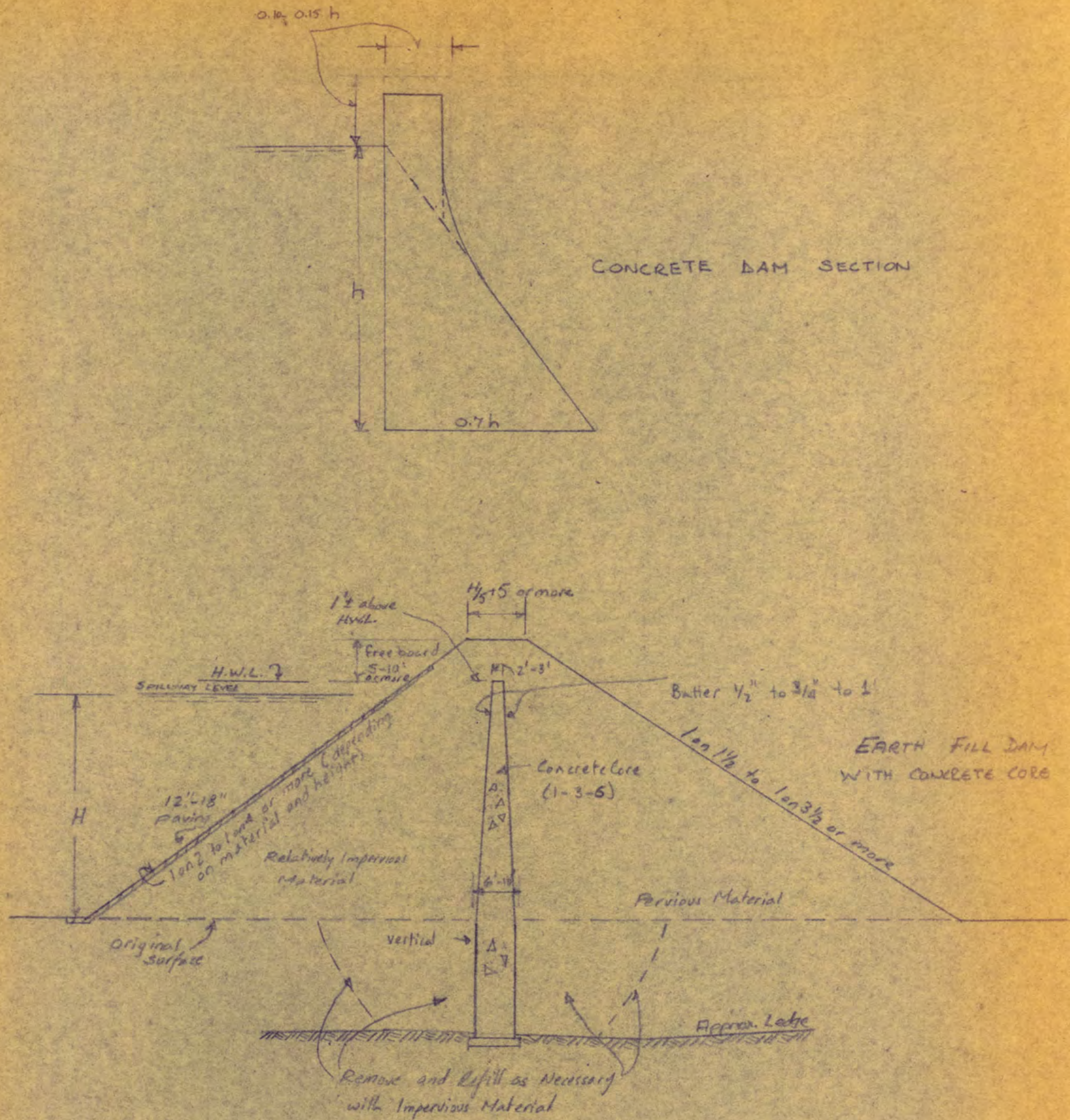

FIG 22. CONCRETE & EARTH FILL DAM SECTIONS

(after Barrows, "Water Power Engineering")

A life expectancy of 100 years was assumed for the dam structure.[x]

Unit prices for cyclopean concrete in the dam and the earth excavations for the dam were obtained by the following analyses.[xx]

Cyclopean Concrete:

Cement (5 bags/m^3)	= LL 16.00
60% Debesh, sand and gravel	= LL 6.00
Labour	= LL 15.00
Cost of cubic meter	LL 37.00

Earth excavation:

LL 4.50/m^3 up to a depth of 4 meters. Cost to include disposal of earth.

2. Earth Fill with Concrete Core Type:

The section of an earth fill with a concrete core type of dam given in "Water Power Engineering" by Barrows was used in approximating the volume of earth that will be used in constructing the dam, the resulting volume being:

$$V = 3.5h^2$$

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[x] Upon the recommendation of Abdul Aziz Kashef, Associate Professor of the School of Engineering at A.U.B.

[xx] Upon the recommendation of Khozrof Yeramian, Associate Professor of the School of Engineering at A.U.B.

where V is the volume of earth fill in cubic meters per meter length of crest and h is the dam height in meters. The reproduced section is shown in Fig.22. A life expectancy of 60 years was assumed for the earth fill dam.[x]

The unit price for providing the earth which is available on the road to Chekka, a distance of about 15 kms. away from the town of Tripoli, is LL 6.00/m^3. This price includes the placing and compaction of the earth.[xx]

Cost Curves and Tables:

The costs for reservoirs were studied along two lines of approach: Initial and annual costs.

In the initial cost study (presented in Table 6) the costs of concrete, excavation, and buying up the land that may be inundated by the reservoir were included.

The annual cost study, however, included the depreciation of the dam structure, and average interest of 3% for the whole initial cost of the works, an operational maintenance cost of 10%, and an indemnity payment

[x] Upon the recommendation of Selim Maksoud, Associate Professor of the School of Agriculture at A.U.B.

[xx] Upon the recommendation of Khozrof Yeramian, Associate Professor of the School of Engineering at A.U.B.

TABLE 6

INITIAL COST OF FLOOD PROTECTION DAMS.

	DAMSITE 1				DAMSITE 2				DAMSITE 3				DAMSITE 4			
DAM HEIGHT (m)	10	20	30	40	5	15	25	35	2	12	22	32	3	13	23	33
CREST LENGTH (m)	45	78	115	155	50	110	170	240	40	90	140	190	120	200	260	330
COST OF LAND (LL)	670,000	2700,000	4,000,000	5,400,000	430,000	2,600,000	4,300,000	6,200,000	185,000	2,080,000	3,500,000	4,700,000	440,000	1,700,000	3,300,000	4,300,000
COST OF EARTH FOR EARTH DAM (LL)	40,000	260,000	900,000	2,000,000	8000	180,000	800,000	2,100,000	1400	100,000	520,000	1,400,000	1500	240,000	1,080,000	2,640,000
COST OF CONCRETE FOR MASONRY DAM LL	40,000	200,000	540,000	1,330,000	25,000	204,000	850,000	4,800,000	700	122,000	1,000,000	2,200,000	5000	196,000	1,000,000	3,070,000
COST OF EXCAVATION FOR MASONRY DAM (LL)	4500	15,000	34,000	60,000	6000	30,000	70,000	130,000	6000	30,000	80,000	110,000	15,000	115,000	200,000	700,000
TOTAL INITIAL COST OF EARTH DAM (LL)	710,000	2,960,000	4,900,000	7,400,000	438,000	2,780,000	5,100,000	8,300,000	186,400	2180,000	4,020,000	6,100,000	441,500	1,940,000	4,380,000	6,940,000
TOTAL INITIAL COST OF MASONRY DAM (LL)	714,500	2,905,000	4,674,000	6,790,000	461,000	2,834,000	5,220,000	11,130,000	191,700	2,232,000	4,580,000	7,030,000	460,000	2,011,000	4,500,000	8,070,000

for the proprietors of the land that will be temporarily inundated. This payment will be LL 10 per 1000 sq. meters per year at the river banks and in irrigated lands, and LL 3 per 1000 sq. meters per year for higher lands.[x] The results of this study are shown in Table 7.

The initial and annual cost studies were also prepared in a graphical form and are presented in Figs.23 and 24.

The minima costs of Figs.23 and 24 were combined to show the site at which the costs (both annual and initial) are a minimum for a specified reservoir storage capacity. The results are shown in Figs.25 and 26.

III CHANNELS AND THEIR IMPROVEMENT:

Channel Improvement:

The Abu Ali River, in passing through the town of Tripoli, follows a straight line up to the vicinity of Bab-el-Tabbane where it bends to the left.

The profile of the river bed (~~Plate 6~~) shows a slope of -1.13% just up-stream from the Bab-el-Tabbane quarter and an average slope of -0.7% in the first 460 meters of river through the town of Tripoli was estimated. This profile

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x Upon the recommendation of Selim Maksoud, Associate Professor of the School of Agriculture at A.U.B.

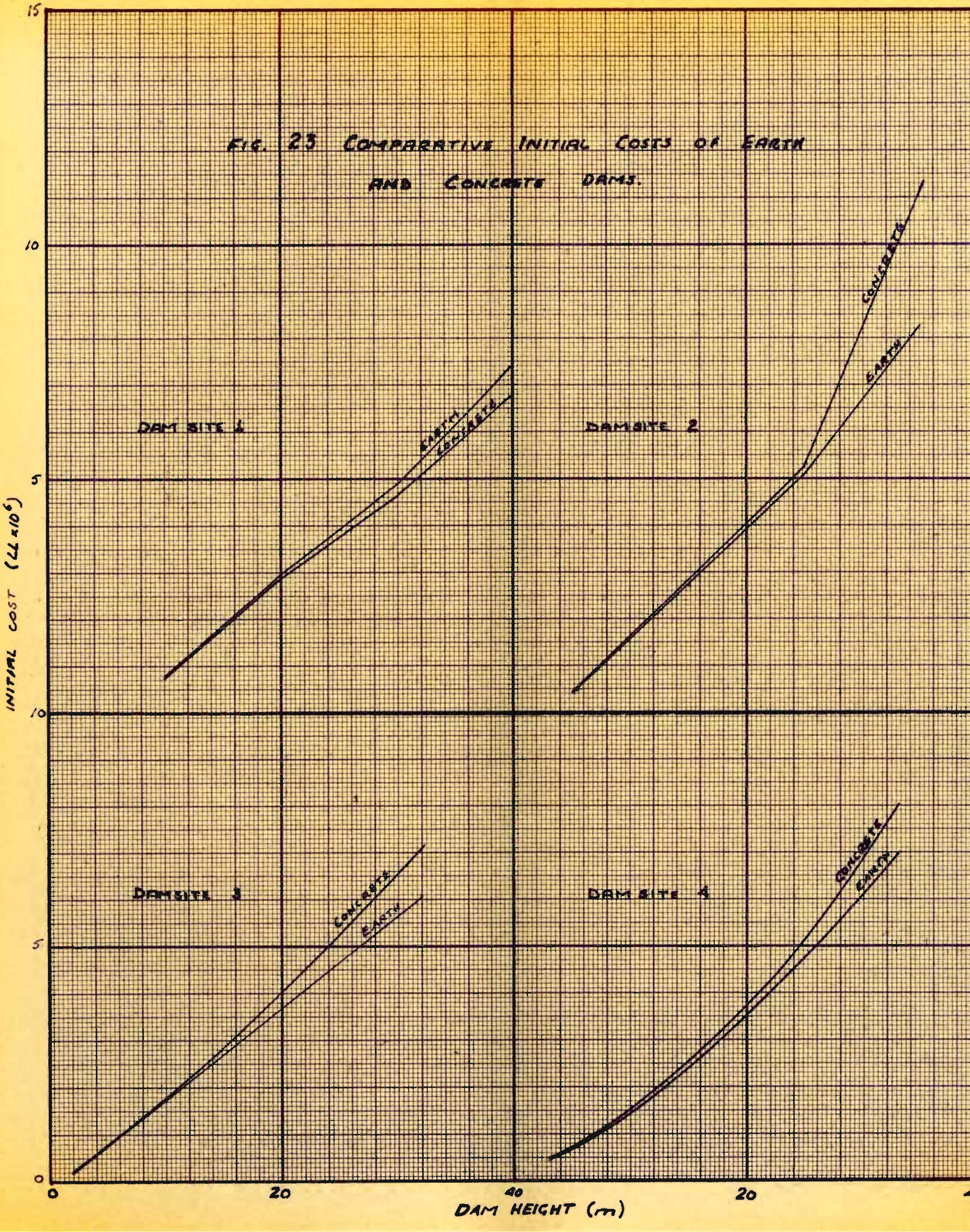

FIG. 23 COMPARATIVE INITIAL COSTS OF EARTH
AND CONCRETE DAMS.
DAM SITE 1
EARTH
CONCRETE
DAMSITE 2
CONCRETE
EARTH
DAMSITE 3
CONCRETE
EARTH
DAM SITE 4
CONCRETE
EARTH
INITIAL COST (LL x10^6)
15
10
5
0
10
5
0
0
20
40
20
DAM HEIGHT (m)

68

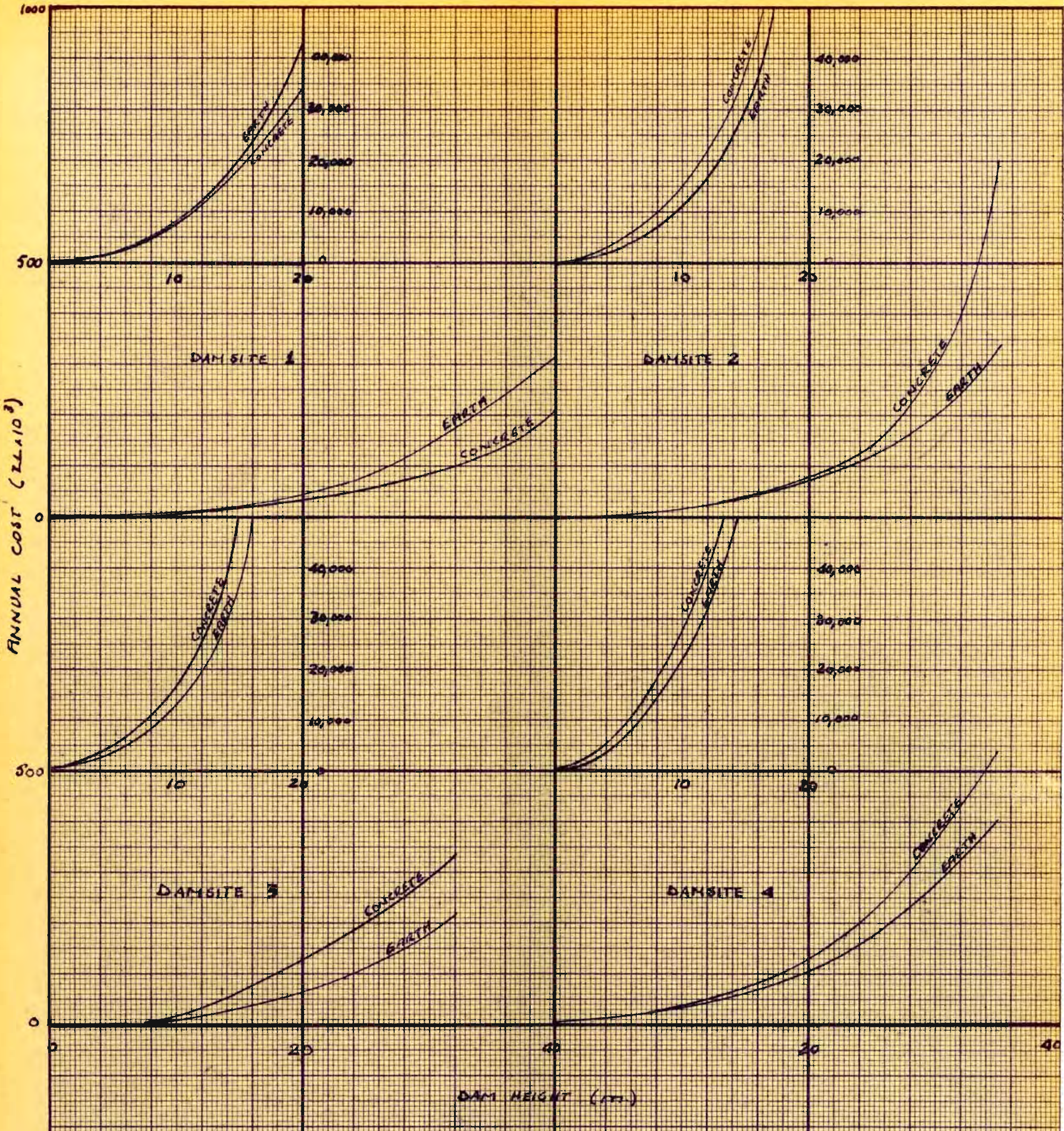

FIG. 24 COMPARATIVE ANNUAL COSTS OF CONCRETE & EARTH DAMS.

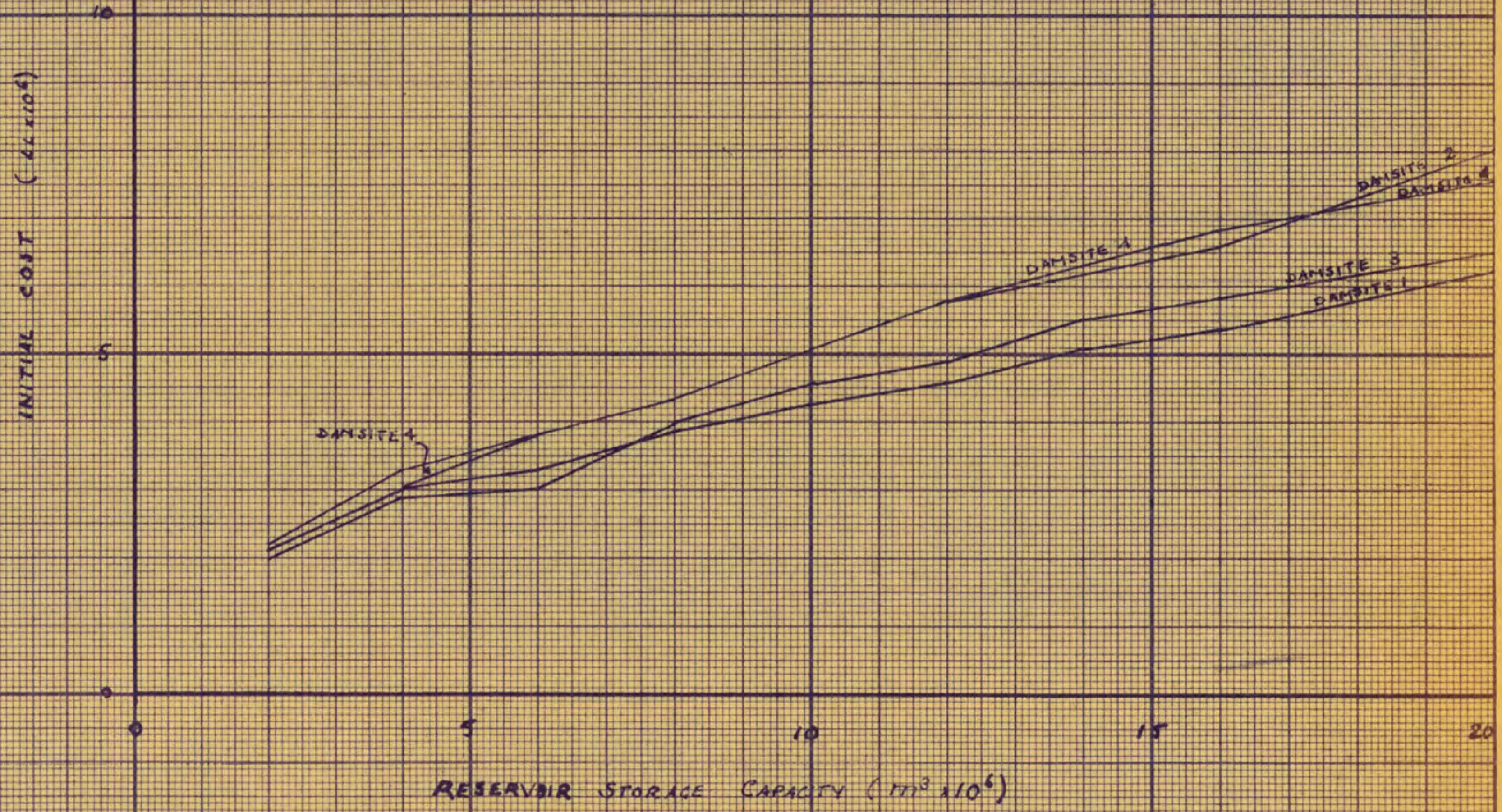

Fig. 25 COMPARATIVE INITIAL COSTS OF LEAST EXPENSIVE DAMS AT THE DIFFERENT DAM SITES

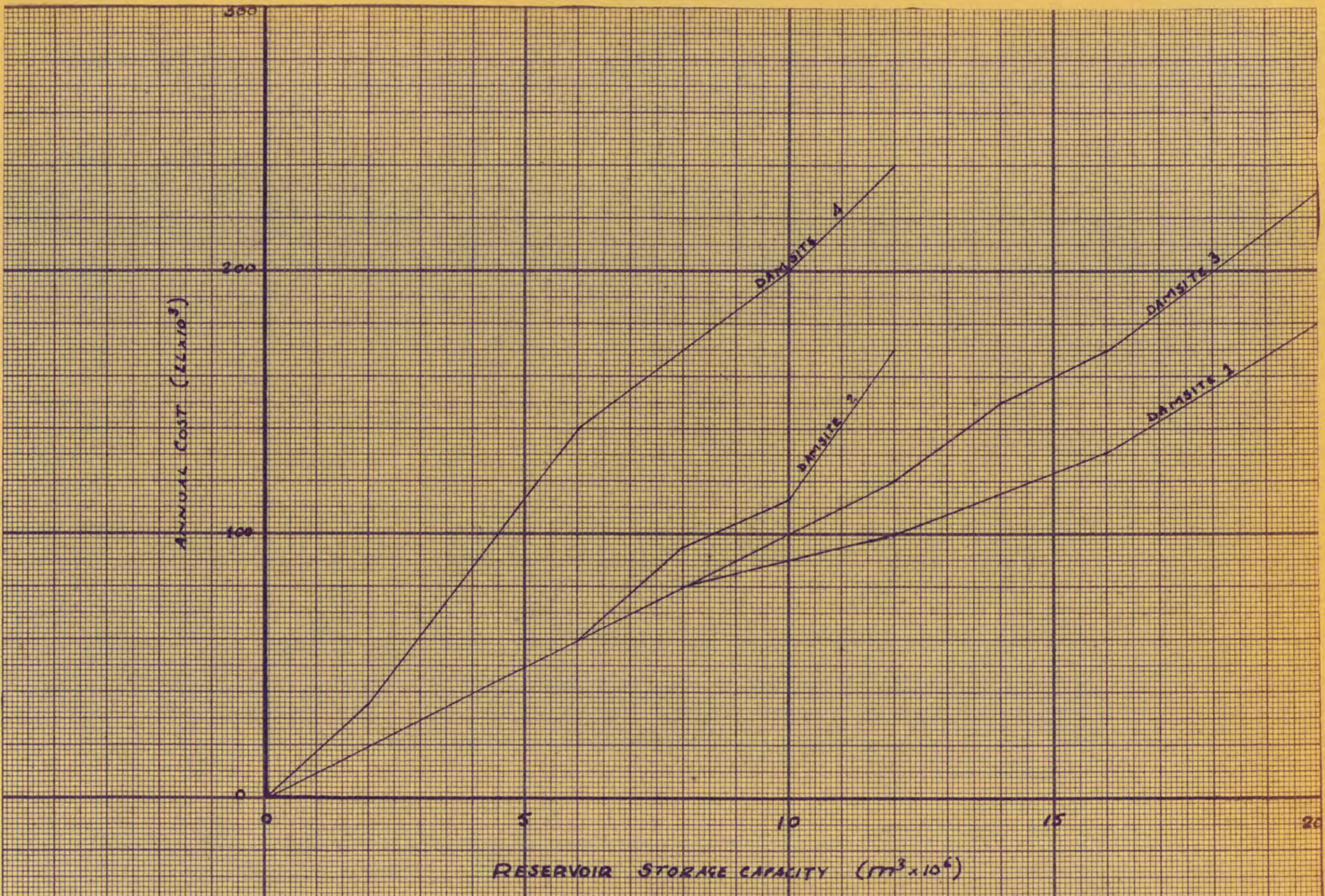

FIG. 26 COMPARATIVE ANNUAL COSTS OF LEAST EXPENSIVE DAMS AT THE DIFFERENT DAM SITES.

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TABLE 7

ANNUAL COST OF FLOOD PROTECTION DAMS.

		DAMSITE 1				DAMSITE 2				DAMSITE 3				DAMSITE 4			
	Reservoir Capacity $10^6 m^3$	0.5	4.0	12.2	27.0	0.2	3.1	10.4	26.6	—	2.2	8.1	18.2	—	2.5	9.0	18.0
	Dam Height (m)	10	20	30	40	5	15	25	35	2	12	22	32	3	13	23	33
MASONRY DAMS	Annual Depreciation (LL)	450	2150	5750	13,900	310	2340	9200	49,300	67	1820	10,800	23,300	200	3110	12,000	37,700
	Annual Land Rental (LL)	1350	3200	6000	9,700	860	4160	6350	9800	370	4150	6000	8800	890	3340	5300	7800
	Interest 3% (LL)	1350	6450	17,250	41,700	930	7020	27,600	147,900	200	4560	32,400	69,900	600	9330	36,000	113,100
	Operational Maintainance (LL)	4500	21,500	57,500	139,000	3100	23,400	92,000	493,000	670	15,200	108,000	233,000	2000	31,100	120,000	377,000
	Total Annual Cost (LL)	7650	33,300	86,500	204,300	5,200	36,920	185,150	700,000	1300	25,430	157,200	335,000	3700	46,900	178,300	535,000
EARTH DAMS	Annual Depreciation (LL)	800	5200	18,000	40,000	200	4000	16,000	42,000	30	2000	5600	28,000	30	4800	21,600	53,000
	Annual Land Rental (LL)	1350	3200	6000	9700	860	4160	6350	9800	370	4150	6000	8800	890	3340	5300	7800
	Interest 3% (LL)	1200	8000	26,000	60,000	270	5000	24,000	66,000	40	3000	17,000	42,000	40	7200	36,400	80,000
	Operational Maintainance (LL)	4000	26,000	90,000	200,000	800	20,000	80,000	216,000	150	10,000	52,000	140,000	150	24,000	108,000	264,000
	Total Annual Cost (LL)	7350	42,400	140,000	309,700	2100	31,160	126,350	334,000	600	19,150	80,600	218,800	1100	39,300	172,000	405,000

also indicates a river bank height of 6 meters in the high slope stretch and another varying between 2 and 4 meters in the low slope stretch.

One improvement that immediately comes to mind is the straightening of the above mentioned bend by cutting through the Bab-el-Tabbane quarter with an artificial channel. The cut required to provide a continuous river bed is 6 meters deep.

A flood passing through the town of Tripoli would posses very high velocities and would have high erosive powers. Lining the channel would be necessary, and the high order of velocity would seem to indicate a concrete lining. The effects of this lining would not be confined to protection against erosion - higher velocities will be induced, and hence greater discharge, for the same section. This is due to the low friction factor of the concrete lining.

Types of Retaining Walls:

In the design of possible retaining walls, sand was chosen as the fill material behind the retaining wall. A load of the H-20 type as specified by the AASHO was used at a distance of 2 meters from the wall to allow for a side-walk 2 meters wide.

Reinforced concrete allowable stresses are taken as

60 kg/cm^2 for flexural compression and 1300 kg/cm^2 for its steel reinforcement. Plum concrete is allowed 15 kg/cm^2 in vertical compression and 4 kg/cm^2 for temporary tension.

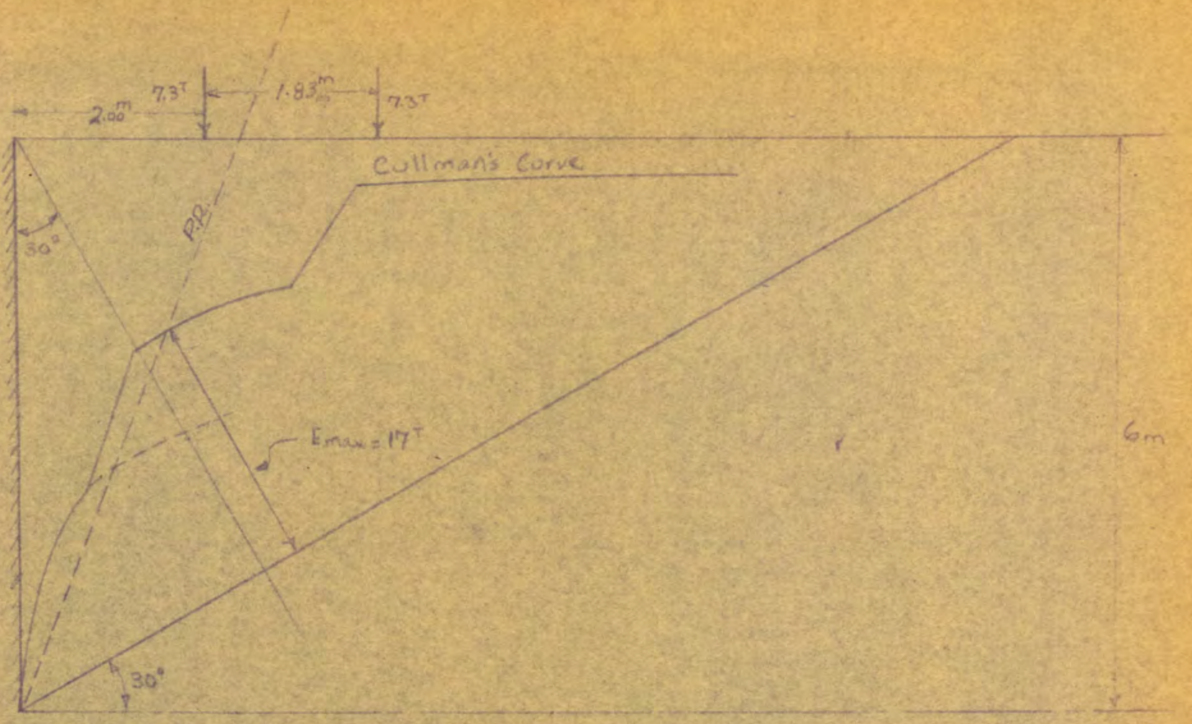
The life expectancy of the concrete channel is assumed to be 60 years.[x]

The total earth pressure acting on the retaining wall was obtained by Coulomb's theory of earth pressure and the graphical procedure was followed as is shown in Fig.27a, b, and c. The sand fill has an angle of internal friction of 30° and the angle of friction between the wall and the soil was assumed to be zero. This assumption gives results on the safe side. The point of application of the resultant earth pressure was also obtained by an approximate graphical method.[xx]

In choosing the types of retaining walls that will be investigated the writer had to consider the high land and expropriations costs in addition to concrete and excavation costs. Two gravity types were considered, one with the water contact surface inclined and the other with that surface vertical. A reinforced concrete cantilever

[x] Upon the recommendation of Selim Maksoud, Associate Professor of the School of Agriculture at A.U.B.

[xx] "Soil Mechanics in Engineering Practice" by Terzaghi and Peck.



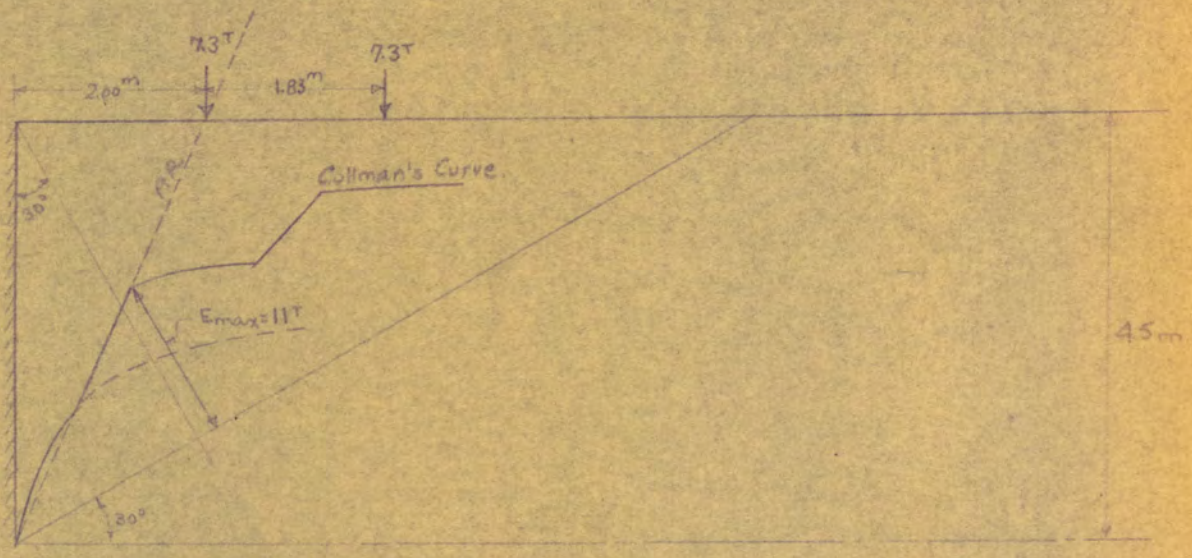


FIG. 27(a) EARTH PRESSURE DIAGRAM

(for Vertical Face)

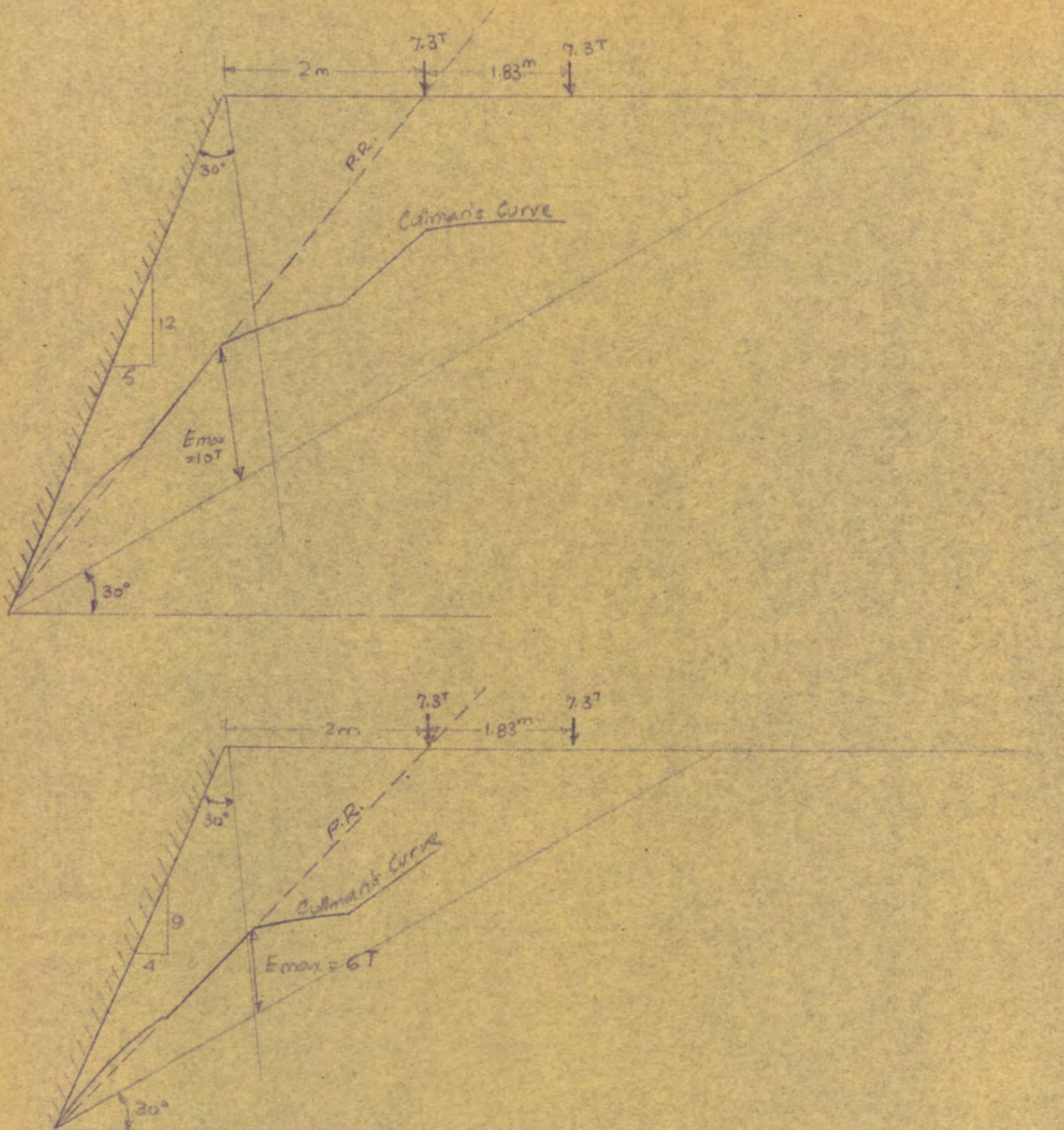
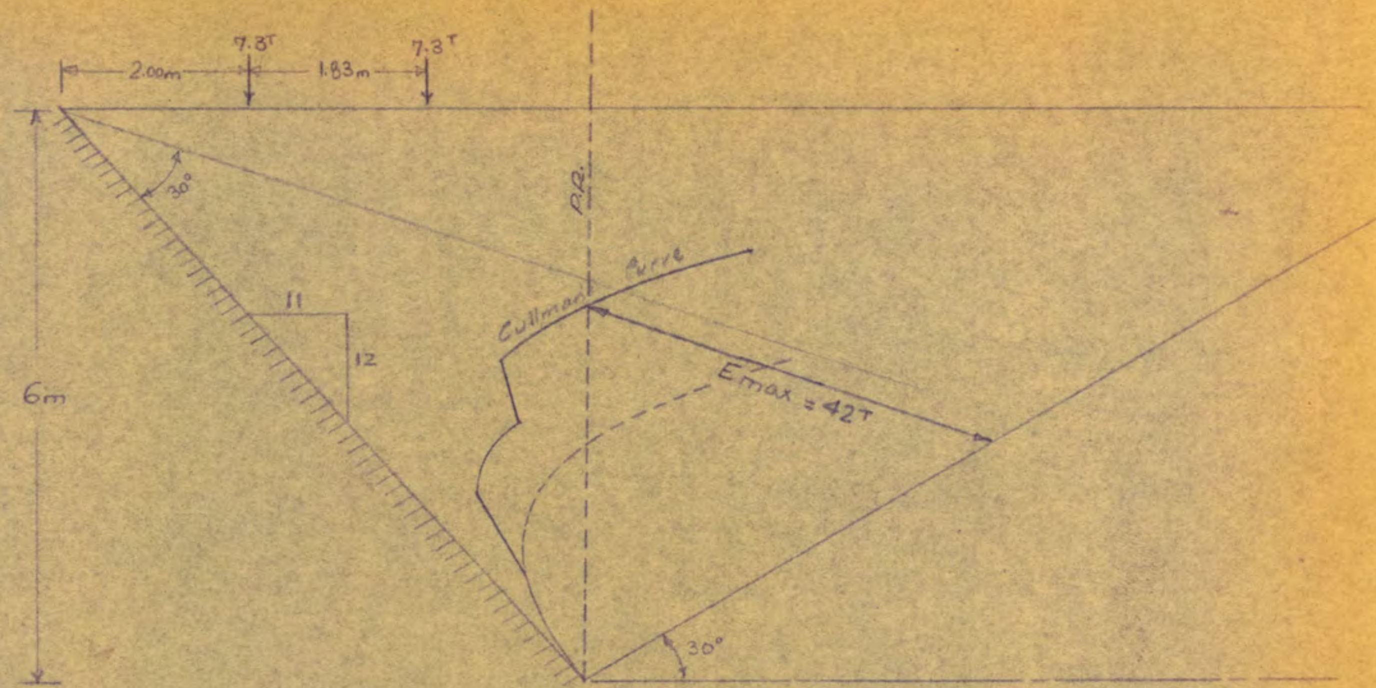


FIG. 27(b) EARTH PRESSURE DIAGRAM

(for Face Inclined Backwards)



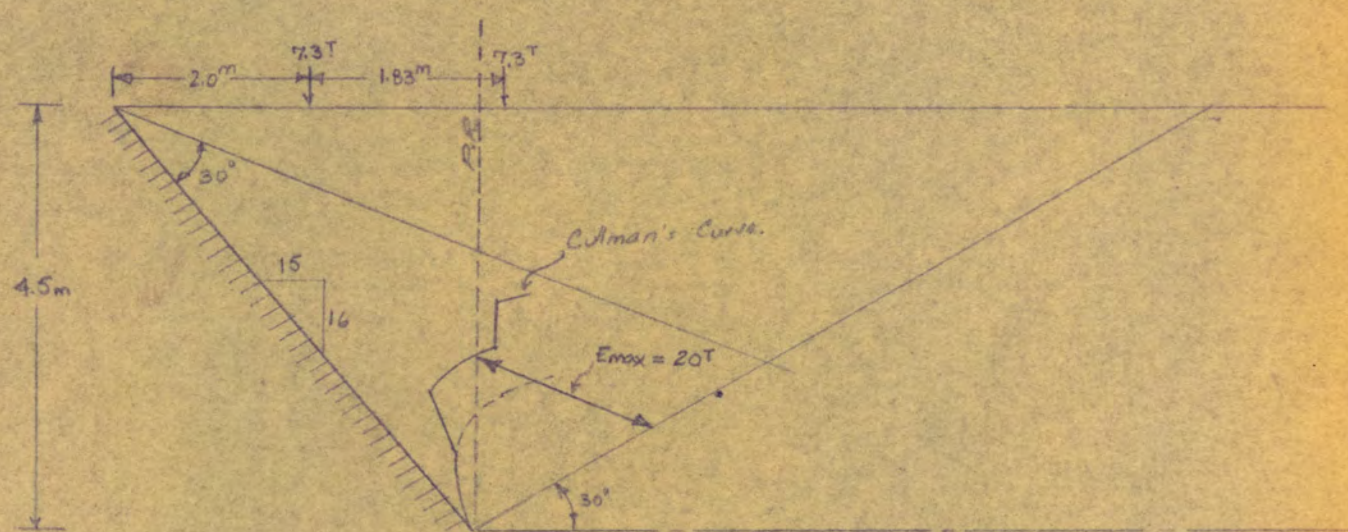


FIG. 27(c) EARTH PRESSURE DIAGRAM

(for Face Inclined Forward)

section is another possibility. The fourth possibility investigated is that of an extended lining on an inclined earth surface.

The design of the four types are shown in Figs.28a, b, c, and d.

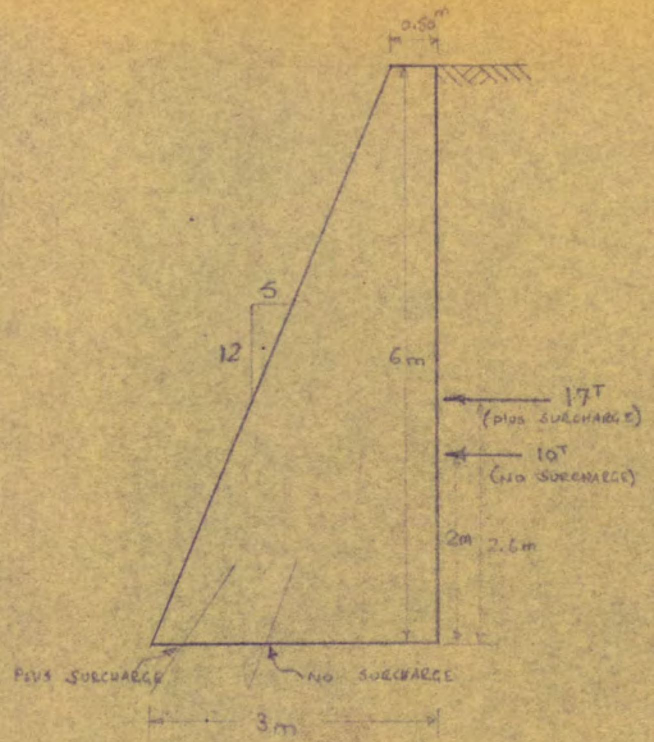
Channel Capacities for Steady Flow Conditions:

Steady flow conditions were assumed. All channel sizes smaller than that which can discharge the short duration design flood peak will be considered in conjunction with retarding reservoirs. The reservoirs will be assumed to have manually operated gates to control channel flow.

The depth of water in the -1.13% slope section of the channel was taken as 4 meters, thus leaving a clearance of 2 meters for the three bridges in that stretch of river. The depth was kept the same for the -0.7% slope river stretch. A 50 cm freeboard was assumed, thus resulting in a retaining wall 4.5 meters high. It will not be acting as a retaining wall along all its length but as a flood wall where the topography is such as to make the natural stream channel shallower than 4.5 meters deep. No bridges are envisaged in this section so there is no need for any allowance for girder depth as in the -1.13% slope river stretch.

Manning's formula

$$V = \frac{1.486}{n} \cdot R^{2/3} \cdot S^{\frac{1}{2}}$$



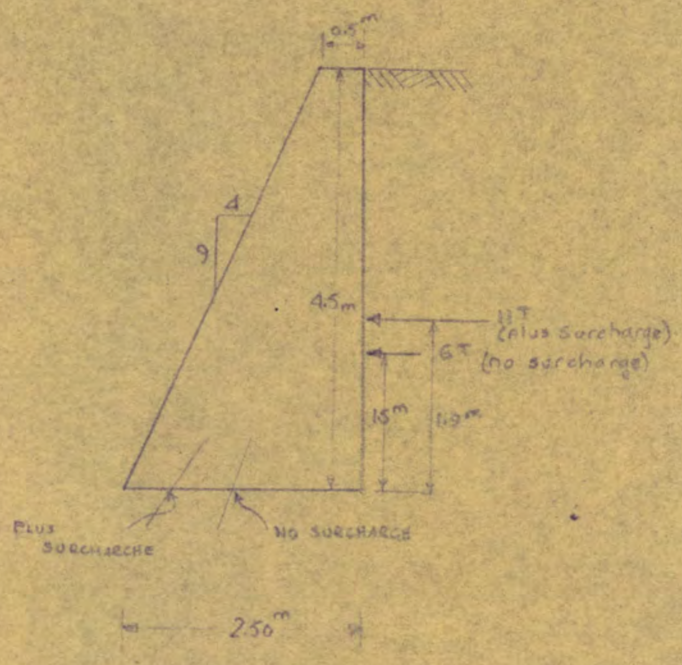
$\frac{P}{A} = 8.7\ T/m^2$

$\frac{Mc}{I} = 10.3\ T/m^2$

MAX. COMPRESSION = 1.9 kg/cm²

MAX. TENSION (TEMPORARY) = 1.0 kg/cm²

CONCRETE = 10.5 m³/m.r.



$\frac{P}{A} = 6.8\ T/m^2$

$\frac{Mc}{I} = 12.3\ T/m^2$

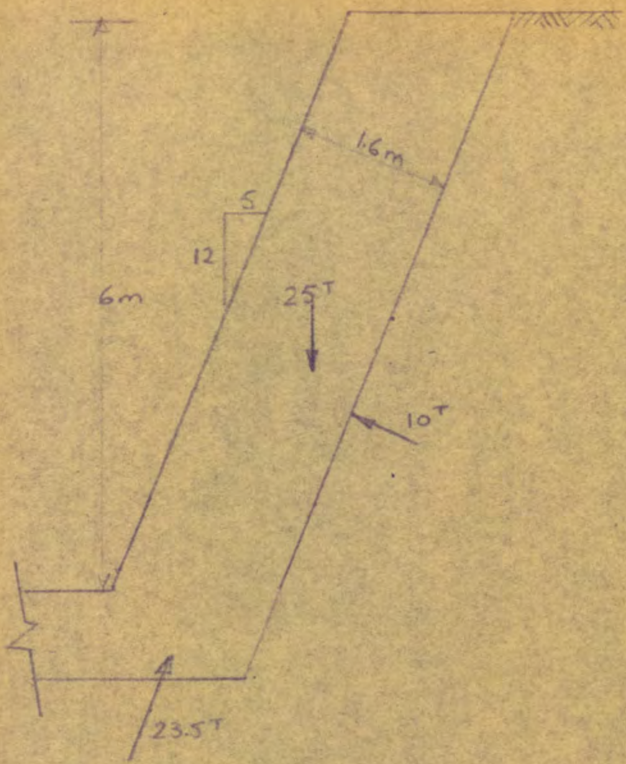
MAX. COMPRESSION = 1.9 kg/cm²

MAX. TENSION (TEMPORARY) = 0.6 kg/cm²

CONCRETE = 6.75 m³/m.r.

FIG. 28(a) RETAINING WALL DESIGN

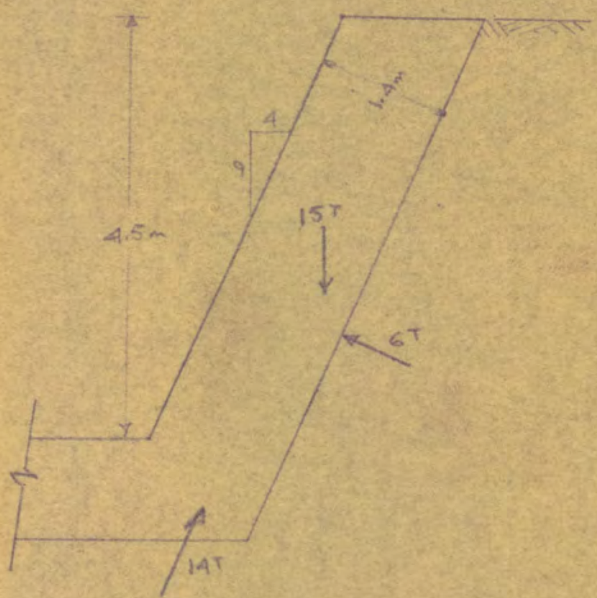
GRAVITY TYPE 1 – water on Inclined Face.



MAX. COMPRESSION = 1.5 kg/cm²

MAX. SHEAR = 0.65 kg/cm²

CONCRETE = 10.5 m³/mr



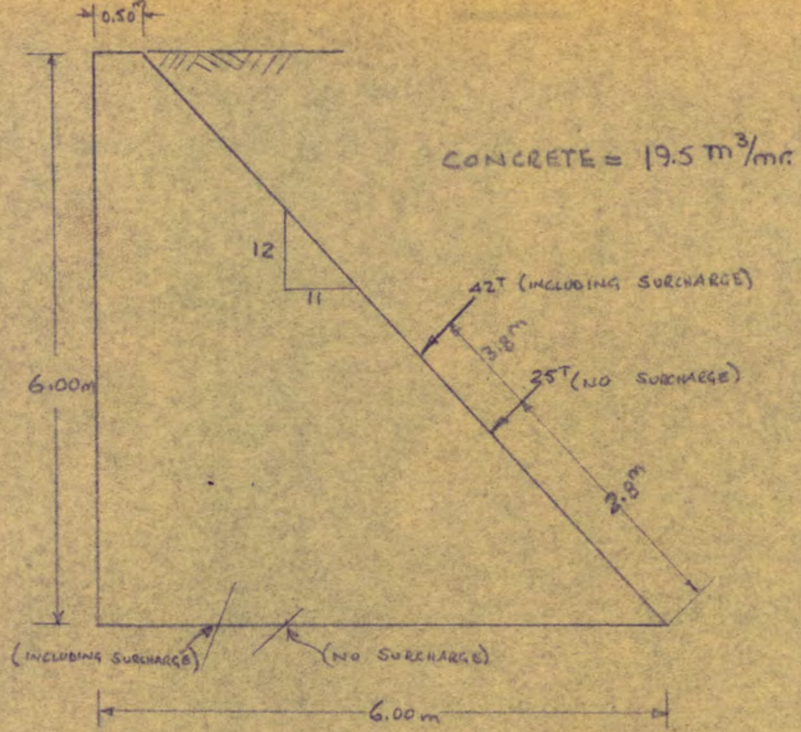
MAX. COMPRESSION = 1.0 kg/cm²

MAX. SHEAR = 0.45 kg/cm²

CONCRETE = 7 m³/mr

FIG. 28(a) RETAINING WALL DESIGN

EXTENDED CANAL LINING.



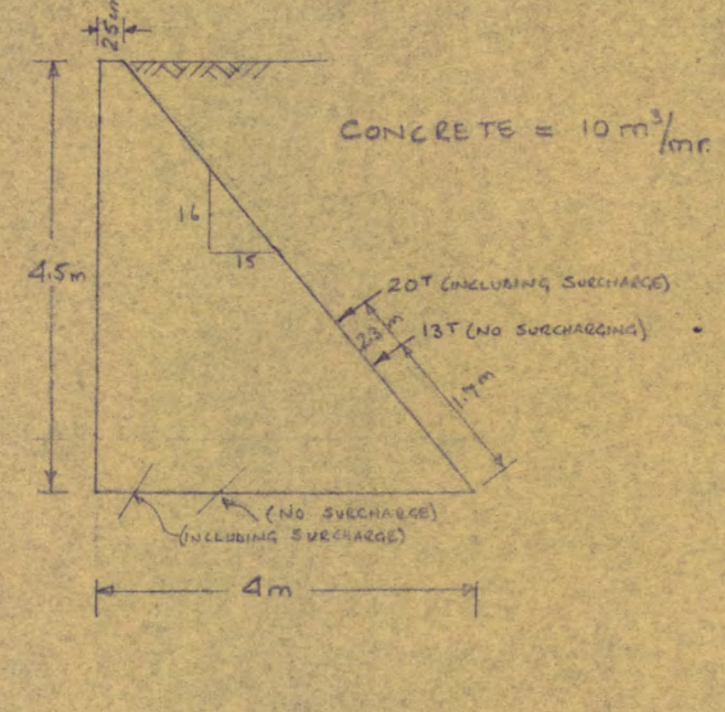
$\frac{P}{A} = 12.5\ T/m^2$

$\frac{Mc}{I} = 21.3\ T/m^2$

MAX. COMPRESSION = $3.4\ kg/cm^2$

MAX. TENSION (TEMPORARY)

$= 0.9\ kg/cm^2$



$\frac{P}{A} = 7.5\ T/m^2$

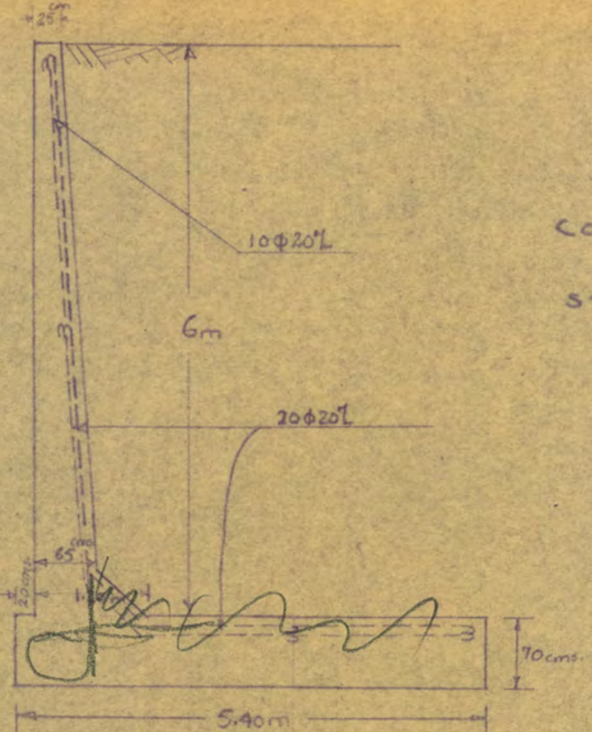
$\frac{Mc}{I} = 18.0\ T/m^2$

MAX. COMPRESSION = $2.6\ kg/cm^2$

MAX. TENSION (TEMPORARY) = $1.0\ kg/cm^2$

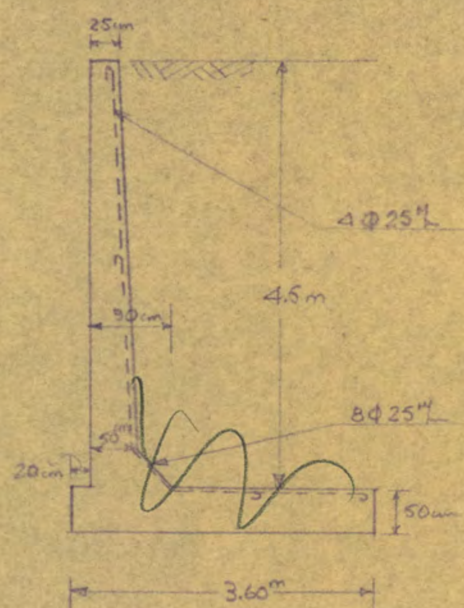
FIG. 28(c) RETAINING WALL DESIGN

GRAVITY TYPE 2 - water on Vertical Face.



CONCRETE = 6.5 m³/mr.

STEEL = 600 kg/mr



CONCRETE = 3.3 m³/mr.

STEEL = 200 kg/mr.

FIG. 28(d) RETAINING WALL DESIGN

REINFORCED CONCRETE - CANTILEVER SECTION.

was used for different widths of the rectangular section with n equal to 0.015. The results are shown in Fig.29.

The two side slopes of the trapzoidal channel, as determined in the retaining wall design were used. The results obtained by using the same formula and the same n are shown in Fig.30.

Choice of Retaining Wall:

A 70 meters wide belt going through the Bab-el-Tabbane quarter was estimated by the Reconstruction Board of Lebanon to cost LL 4 millions in expropriations only. The land cost there is LL 40/m^2 and it decreases to LL 25/m^2 along the river banks of the small slope river reach.

The reinforced concrete unit cost for a 7 bag mix was taken as LL 65/m^3. This does not include the cost of steel which is LL 500/ton.Cyclopean concrete, as previously analyzed, costs LL 37/m^3.

The above mentioned prices were used in determining the most economical retaining wall section. The comparison is made in Table 8, and the most economical type chosen is the reinforced concrete cantilever wall type.

Channel Cost Curves and Tables:

The Channel reach of -1.13% slope passing through the Bab-el-Tabbane quarter is 600 meters long and that of -0.7% slope in the town of Tripoli is 460 meters long.

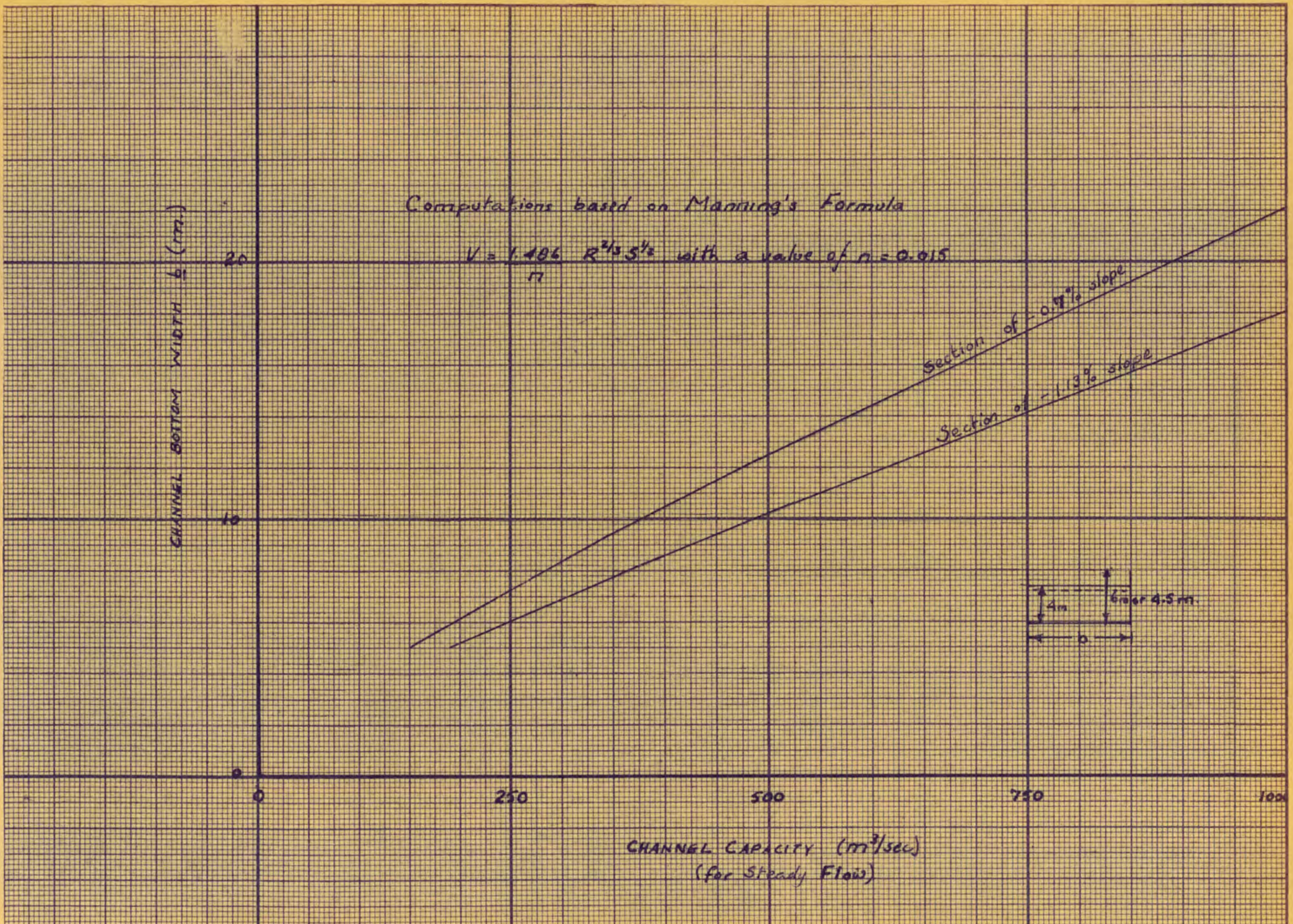


FIG. 29 CHANNEL CAPACITIES VS. CHANNEL WIDTHS FOR RECTANGULAR CROSS SECTIONS.

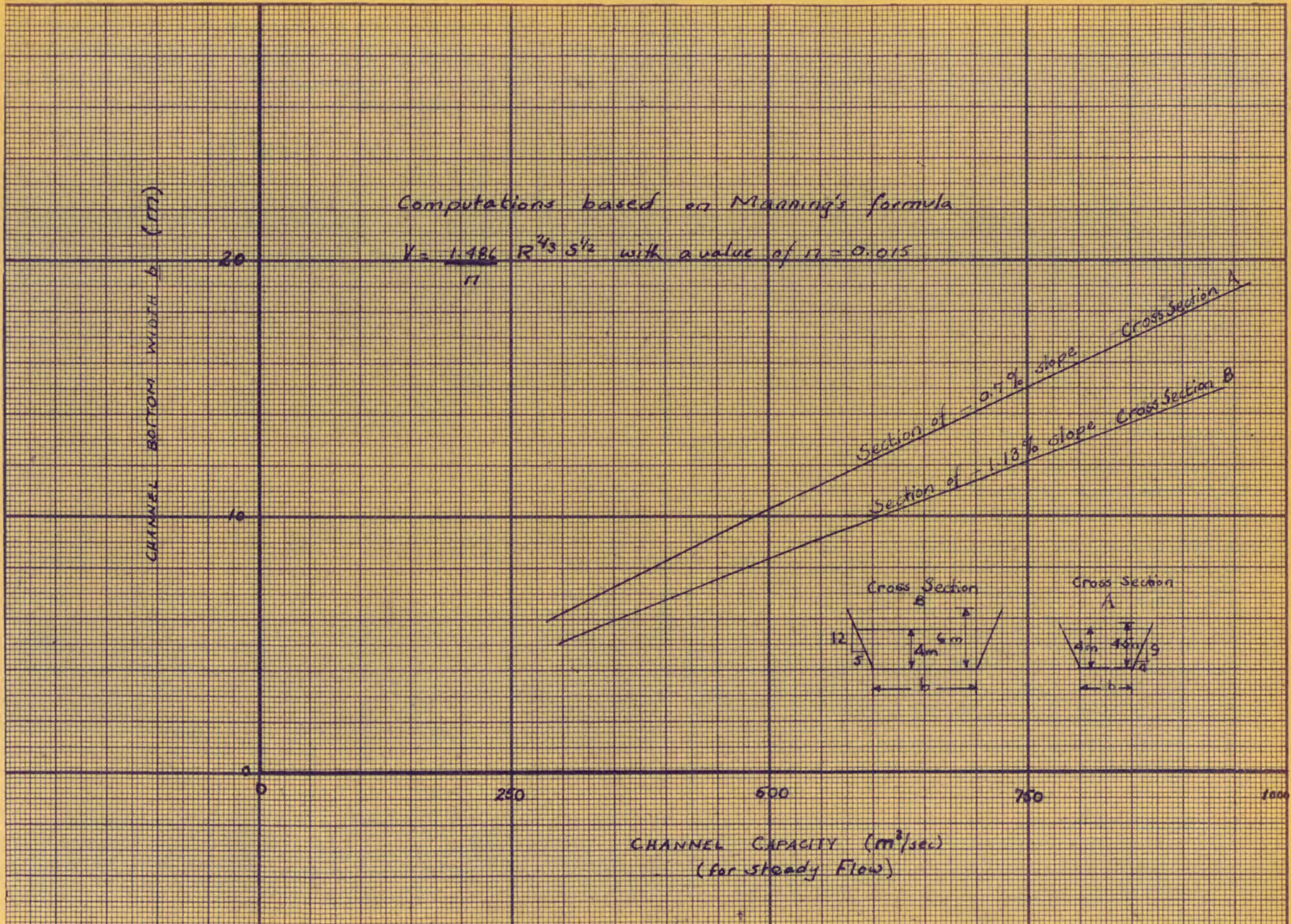
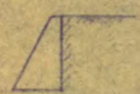
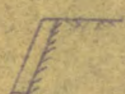
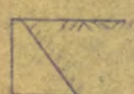
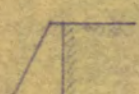


FIG. 30 CHANNEL CAPACITIES VS. CHANNEL WIDTHS FOR TRAPEZOIDAL CROSS SECTIONS.

TABLE 8

DETERMINATION OF THE MOST ECONOMICAL TYPE OF RETAINING WALL.

Retaining Wall Type	WALL HEIGHT (m)	Cost of Cyclopean Concrete (LL)	Cost of Reinforced Concrete (LL)	Extra Cost of Land (LL)	Extra Cost of Excavation (LL)	Comparative COST (LL)	COMMENTS.
 (A)	6	390	-	-	-	390	Type A is to be preferred over type B for both heights.
	4.5	250	-	-	-	250	
 (B)	6	390	-	-	-	390	
	4.5	260	-	-	-	260	
 (C)	6	720	-	-	-	720	Type D is to be preferred over type C for both heights
	4.5	370	-	-	-	370	
 (D)	6	-	720	-	-	720	
	4.5	-	315	-	-	315	
 (A)	6	400	-	400	50	850	Type D is to be preferred of all the types for both heights
	4.5	250	-	200	15	465	
 (D)	6	-	750	-	50	800	
	4.5	-	325	-	15	340	

Channels of different widths and capacities were considered. Any land which the road covers was excluded from the cost of flood protection. For the determination of annual cost for different channel widths the following were assumed: Maintenance costs 5% of the concrete cost; depreciation of the concrete, and an average rate of interest of 3% of the total cost. Initial cost, however, included the cost of concrete, expropriations, and excavations. The results are shown in Table 9 and Figs.31 and 32.

IV. RESERVOIR AND CHANNEL COMBINATIONS.

Channel Capacities vs Reservoir Storage Capacities:

A certain amount of storage capacity, to be effective in controlling the flood, would entail a definite minimum discharge. As it is a combination of reservoirs and channel, it is reasonable to assume steady discharge from manually operated gates in the dam structure which would allow the full use of the channel without its overflowing for a maximum period of time. The S-Curves of Figs.18 and 19 were used. Straight lines of different slopes were drawn tangent to the curves to represent different constant discharges. The maximum ordinate to each of these straight lines would represent the amount of storage capacity that requires the discharge. As this process involves subtraction from S-Curves as described above it is expected that the results would have an S-Curve shape. This is

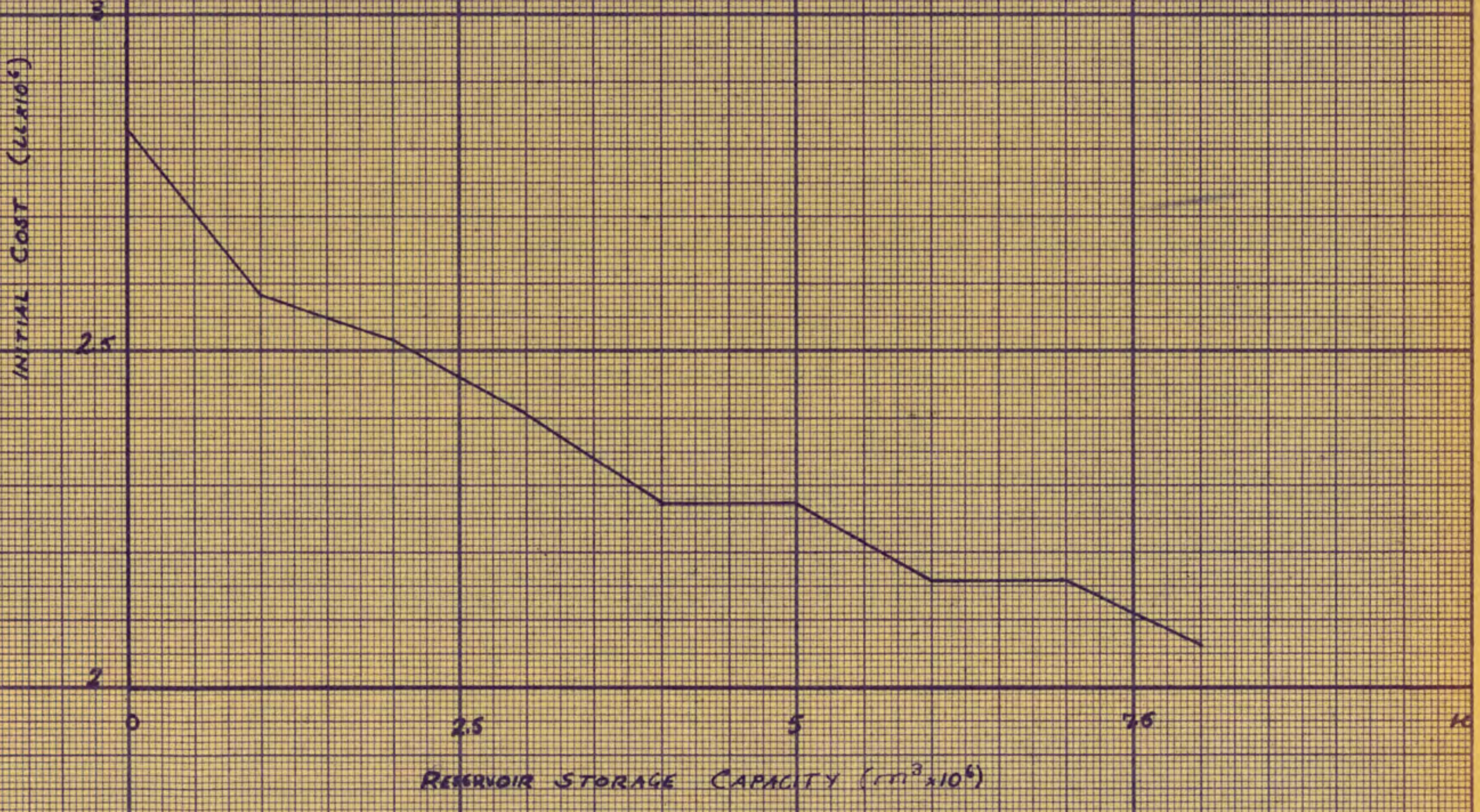


Fig. 31 Initial Costs of Artificial Channel for Different Reservoir Storage Capacities

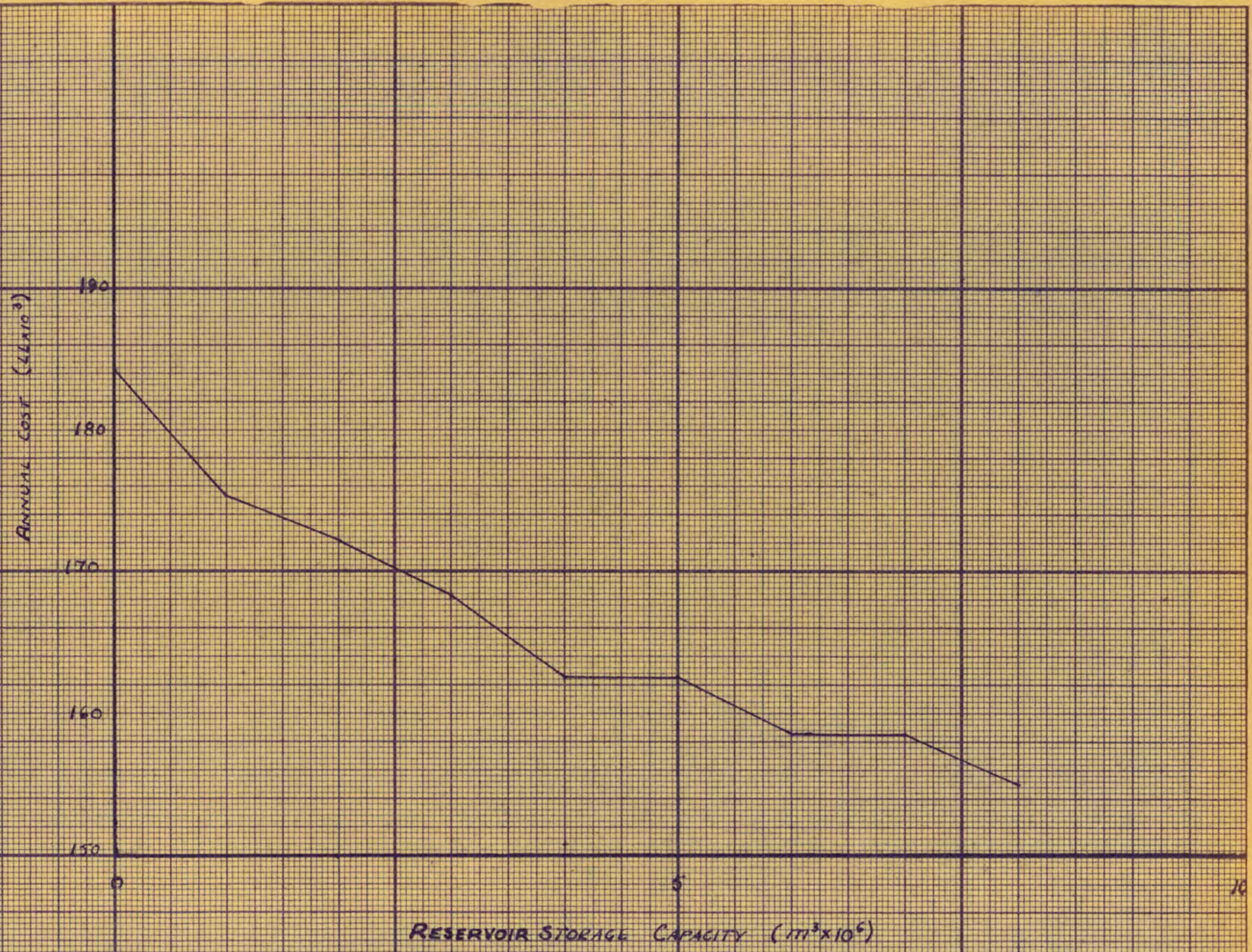


FIG. 32 ANNUAL COSTS OF ARTIFICIAL CHANNEL FOR DIFFERENT RESERVOIR STORAGE CAPACITIES.

TABLE 9

COST OF CHANNELS AT DIFFERENT CAPACITIES.

STEADY-FLOW OF CHANNEL (m^3/sec)	CHANNEL TOP WIDTH (m)		COST OF CONCRETE (LL)	COST OF EXCAVATION (LL)	COST OF EXPROPRIATION (LL)	TOTAL INITIAL COST (LL)	DEPRECIATION (ON A 60-yr LIFE BASIS) (LL)	INTEREST 3% (LL)	MAINTAINANCE 5%	TOTAL ANNUAL COST (LL)
	Slope of -1.13%	Slope of -0.7%								
890	17	20	1,503,000	120,000	1,205,000	2,827,000	25,000	84,800	75,100	184,900
770	15	17	1,467,000	105,000	1,010,000	2,582,000	24,500	77,500	73,400	175,400
720	14	17	1,458,000	100,000	960,000	2,518,000	24,300	75,500	72,900	172,700
680	13	16	1,443,000	91,000	875,000	2,409,000	24,000	72,200	72,200	168,400
610	12	14	1,422,000	84,000	765,000	2,271,000	23,700	68,100	71,100	162,900
465	12	14	1,422,000	84,000	765,000	2,271,000	23,700	68,100	71,100	162,900
460	11	13	1,407,000	77,000	675,000	2,159,000	23,400	64,800	70,400	158,600
460	11	13	1,407,000	77,000	675,000	2,159,000	23,400	64,800	70,400	158,600
450	10	12	1,392,000	70,000	600,000	2,062,000	23,200	62,000	69,600	154,800

apparent in Fig.33

Combined Cost Curves:

The reservoir storage capacity was used as the common base for channel and reservoir costs. The cost curves of Figs.25, 26, 31, and 32 are combined to give those of Figs.34 and 35. They show the annual and initial cost curves for a complete flood control system made up of a retarding reservoir and a channel.

Cheapest Combination:

The obvious result in both the initial and annual cost studies shows that a channel is the most economical of all the possible combinations of channel and reservoirs.

The dimensions of the required channel is 17 meters wide, 6 meters deep in the -1.13% slope reach and 20 meters wide, 4.5 meters deep in the -0.70% slope reach. The channel cross section would be rectangular with a 30cm thick concrete bed and reinforced concrete cantilever retaining walls as shown in Fig. 28(d).

The initial cost of this channel would be LL2,827,000 while the annual cost would be LL185,000.

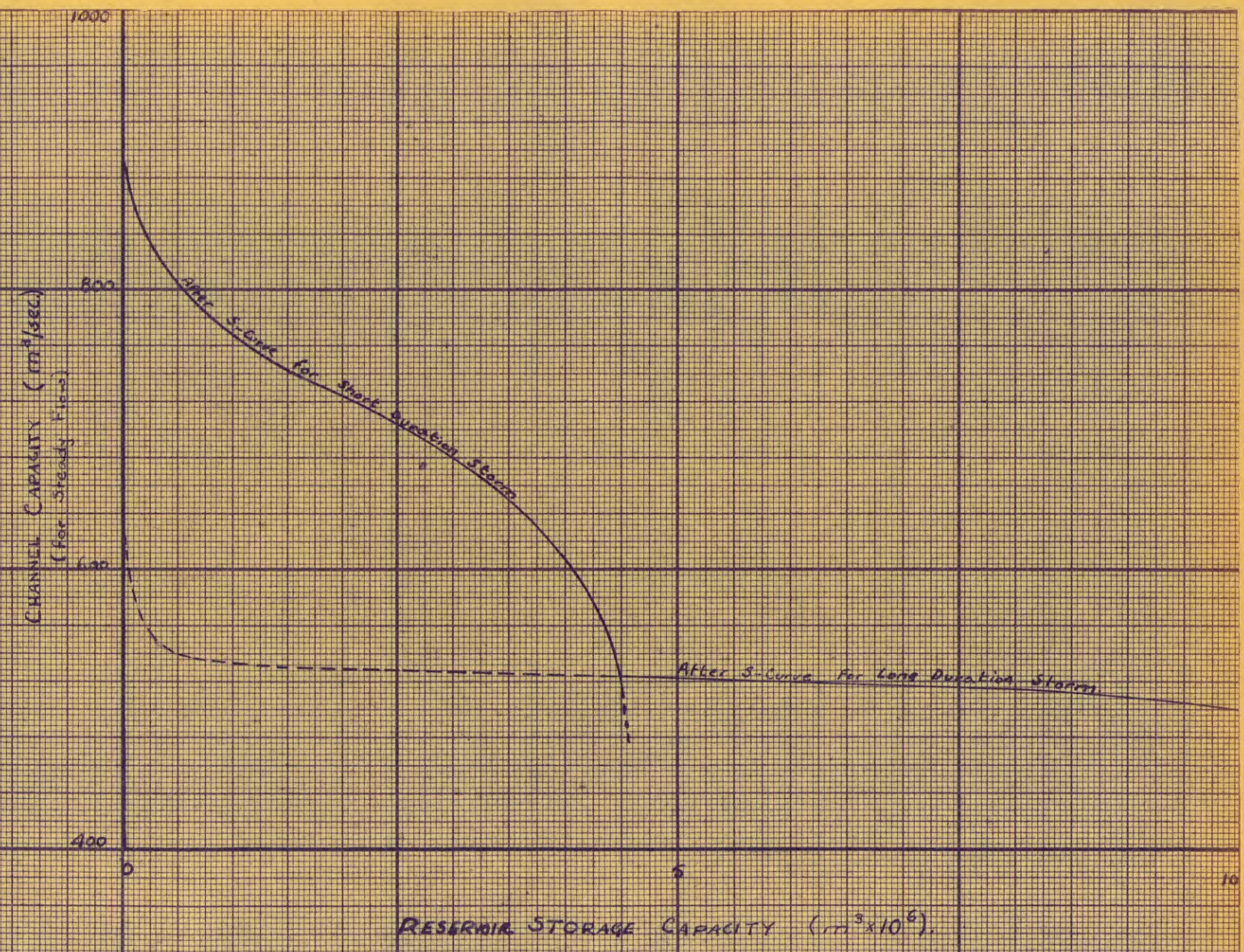


Fig. 33. Reservoir Storage vs. Channel Capacities for Steady Flow Conditions

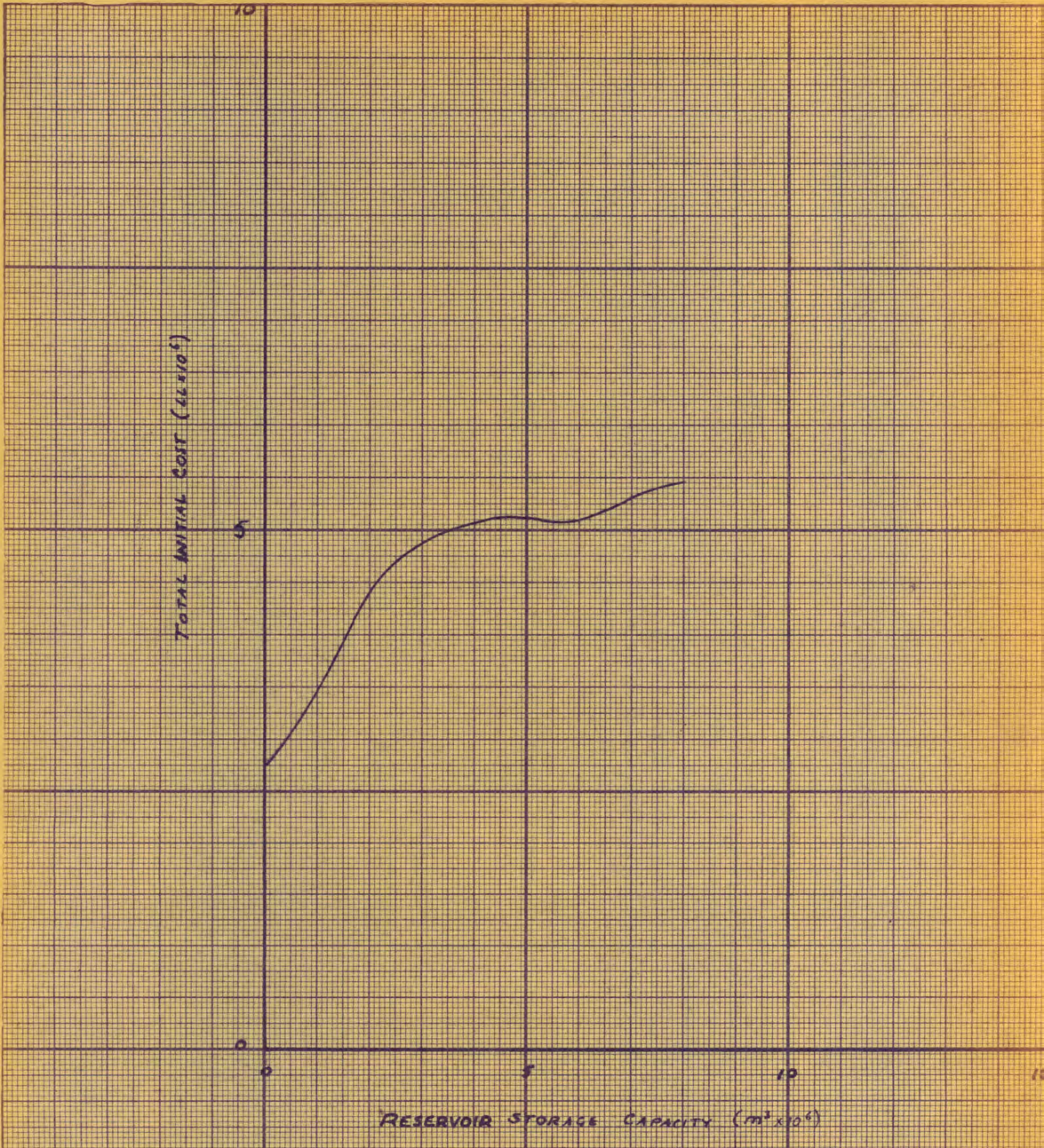


FIG. 34. COMBINED INITIAL COSTS OF A FLOOD PROTECTION DAM SUPPLEMENTED BY ARTIFICIAL CHANNELS.

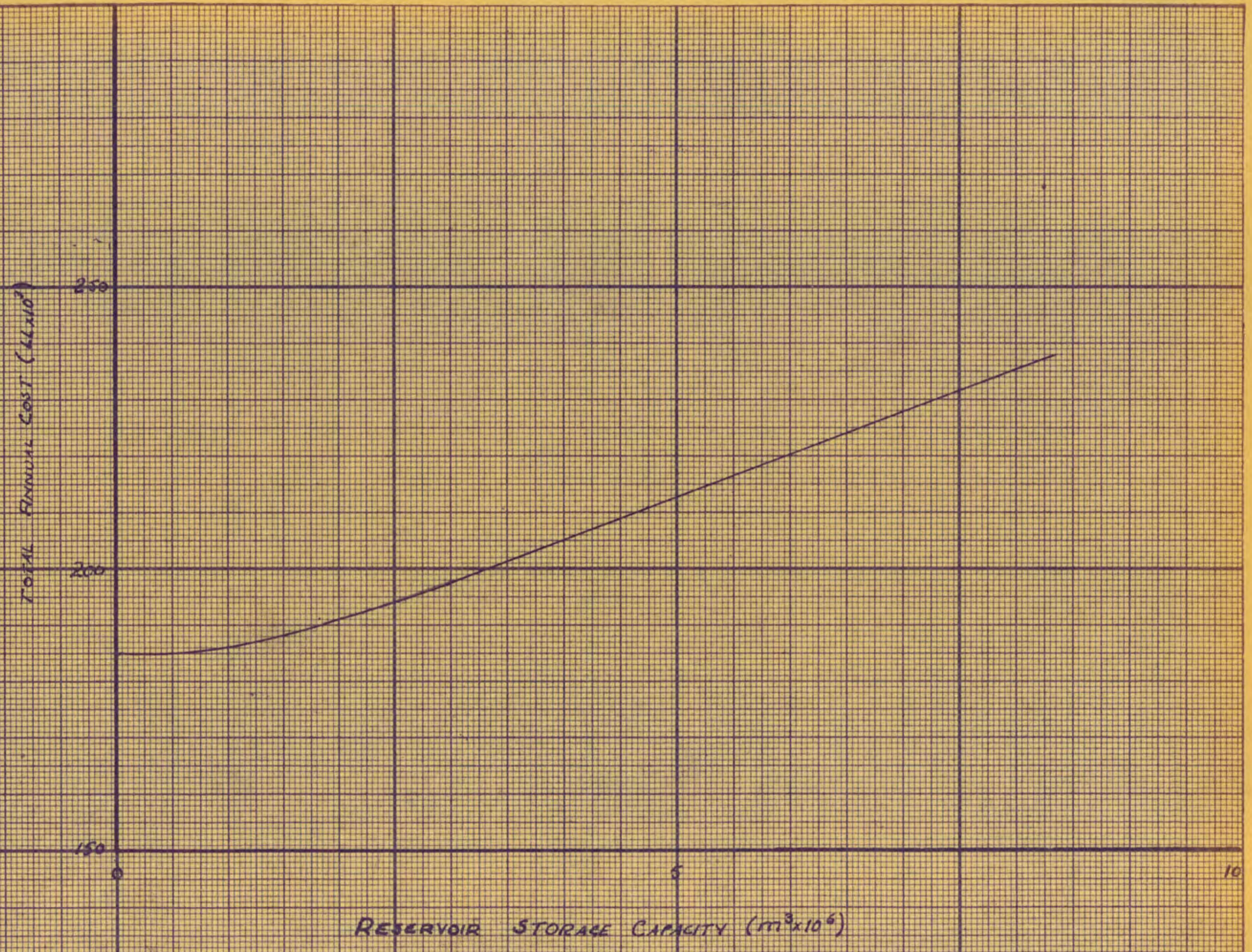


FIG. 35 COMBINED ANNUAL COSTS OF A FLOOD PROTECTION DAM SUPPLEMENTED BY ARTIFICIAL CHANNELS.

CHAPTER IV

HYDRAULIC CONSIDERATIONS.

Synopsis :

In the following section some of the hydrodynamics of flow in the artificial flood channel are considered and briefly discussed. Unfortunately, the unavailability of any predetermined control points and the nearly complete lack of data have necessitated an approximate approach, although the inaccuracies introduced may not be serious.

The main lines of attack are outlined and some of the possible problems mentioned. At certain control points, the essential differences in design between subcritical and supercritical flow conditions are carefully brought out and solutions recommended.

Uniform Flow Computations :

As mentioned in the previous chapter, the artificial flood canals are made up of two sections : the first (20 meters in width) starting at a bend below Abu-Samra and extending for a distance of 460 meters at a slope of 0.7%, and the second (17 meters in width) running for a further 600 meters at a slope of 1.13% and ending at the Bab-el-Tabbane bridge at an elevation of about 10 meters above sea level.

The discharge of the channels for conditions of uniform flow is computed on the basis of the Manning formula

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \qquad \text{IV.1}$$

where V = average velocity of flow in the channel = Q/by

R = hydraulic raduis = Area $\div$ wetted perimeter

S = slope of the energy gradient.

The value chosen for the coefficient of surface roughness "n" was 0.015 - this value being described as suitable for a " concrete with smooth sides bat roughly troweled or shot bottom " X channel.

Table 10 gives values of the normal depth (y_0) and the critical depth (y_c) at different discharges for both channels. The values of (y_c) were obtained by the well-known relationship

$$y_c = \sqrt[3]{Q^2/b^2g} = \sqrt[3]{q^2/g} \quad \text{where } q = Q/b \qquad \text{IV.2}$$

It will be noted that the channels have been designed to give identical values of (y_0) at a given discharge i.e. the effect of the additional slope in channel II is nullified by the decrease in width.

It is apparent from an examination of Table 10 that both channels have slopes which are capable of sustaining uniform flow at supercritical speeds i.e. steep slopes.

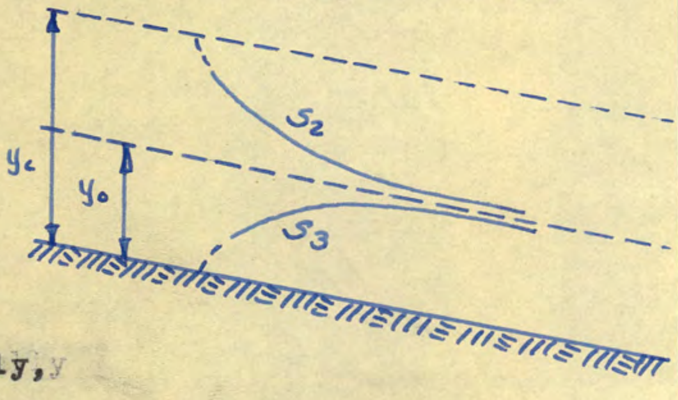
X "Engineering Hydraulics" by H. Rouse. Chapter IX.

DISCHARGE		CHANNEL I S = 0.7% b = 20m 4m				CHANNEL II b = 17m 6m S = 1.13%			
Q m^3/sec	Q c.f.s.	$q = Q/b$ $m^3/sec/m$	$q^2/9.81$ m^3	y_o m	y_{cr} m.	$q = Q/b$ $m^3/sec/m$	$q^2/9.81$ m^3	y_o m	y_{cr} m
400	14,100	20.0	40.8	2.32	3.44	23.5	56.0	2.32	3.82
500	17,650	25.0	63.7	2.68	4.00	29.4	87.5	2.68	4.44
600	21,200	30.0	91.7	3.03	4.50	35.3	127.0	3.03	5.02
700	24,700	35.0	124.5	3.37	5.00	41.2	173.0	3.37	5.56
750	26,500	37.5	142.5	3.52	5.22	44.1	199.0	3.52	5.84
800	28,200	40.0	163.0	3.68	5.42	47.0	225.0	3.68	6.08
850	30,000	42.5	184.0	3.84	5.69	50.0	255.0	3.84	6.34
900	31,750	45.0	207.0	4.00	5.91	53.0	285.0	4.00	6.58
950	33,500	47.5	229.0	4.15	6.10	55.9	319.0	4.15	6.82
1000	35,300	50.0	255.0	4.30	6.34	58.9	352.5	4.30	7.06

TABLE 10.

DEPTH DISCHARGE RELATION FOR UNIFORM FLOW IN THE ARTIFICIAL FLOOD CHANNELS.

Under certain conditions, this could be an advantage. Thus, for example, if flow is inherently stable, water surface profiles would follow the standard S_2 or S_3 curves. Both of these, unlike practically all other types, approach uniform flow conditions asymptoticly,



starting off with high rates of curvature. Furthermore, under supercritical flow conditions, it is not possible for any disturbance to travel upstream ; and hence the danger section in a uniform channel will be limited to its upstream end.

Due to excessively high speeds the situation presently under discussion is not so simple, and certain aspects of the problem necessitate special attention.

Varied Flow Computations :

Based on Bernouilli's Equation a general differential equation for gradually varied in a rectangular channel under steady conditions may be written in the form

$$dy/dx = \frac{S_o - S}{1 - \frac{v^2}{gy}} \qquad \text{IV.3}$$

where S_o = the bed slope

S = the slope of the energy gradient (defined by equation IV.1 for any given point).

x = horizontal distance.

Computation of the shape of a backwater curve may be made by means of the "step" method - also based on the Bernouilli Equation and written in the form

$$\Delta x = \frac{y_1 - y_2 + \dfrac{V_1^2 - V_2^2}{2g}}{S - S_o} \qquad \text{IV.4}$$

where increments of the horizontal distance (Δx) are obtained by slightly differing values of y_1 and y_2.

Based on Eq. IV.4 and the assumption that all flows enter the artificial flood channel at its maximum depth (the worst condition), three water surface profiles are plotted in Fig. 38. It should be pointed out that these would have applied only in the case of no interference from special wave formations (which does not apply to the present situation), but their deviation from the actual condition need not be too large.

Supercritical Flow :

Unlike flow conditions for tranquil flow, small changes in channel geometry can not produce any effect on the flow upstream in supercritical flow; and are characterised instead by surface disturbances which are propagated downstream in an interweaving standing wave pattern.

Channel cross-sections which are so affected are therefore bound to be quite different from the constant-velocity-steady-surface-elevation on which the analysis in the preceding two sections was based. Furthermore, channels which are made to deliver uniform rates of flow at velocities well in excess of the critical have been known to fail in fulfilling their purpose because of a phenomenon known as slug flow or roll waves. This and other pertinent aspects are discussed below with specific reference to certain sections of the channel. The relevent variables referred to are found in Figs. 36 and 37 and Tables 11(a) and 11(b).

(1) Curvature :

In tranquil flow in artificial channels a curved portion between two straight sections is designed as a simple circular arc of constant radius. The flow then adjusts itself by adopting a surface which slopes towards the center of curvature at an angle which may be approximated by the expression v^2/gr_c (r_c= central radius of curvature).

In rapid flow at shallow depths the whole body of fluid may leave the actual bottom and flow, partly or completely, on the outer side of the channel. In supercritical flow at appreciable depths the onset of a curved section will set up two wave formations - one at each of the inner and outer ends of the channel. It is the combination of these positive and negative disturbances which leads to unsatisfactory conditions in plain circular curves. Suffice it to mention that experimental investigation has ascertained that, as a first approximation, the superelevation at the outer wall above the surface of the approaching flow may be taken as twice that for tranquil flow

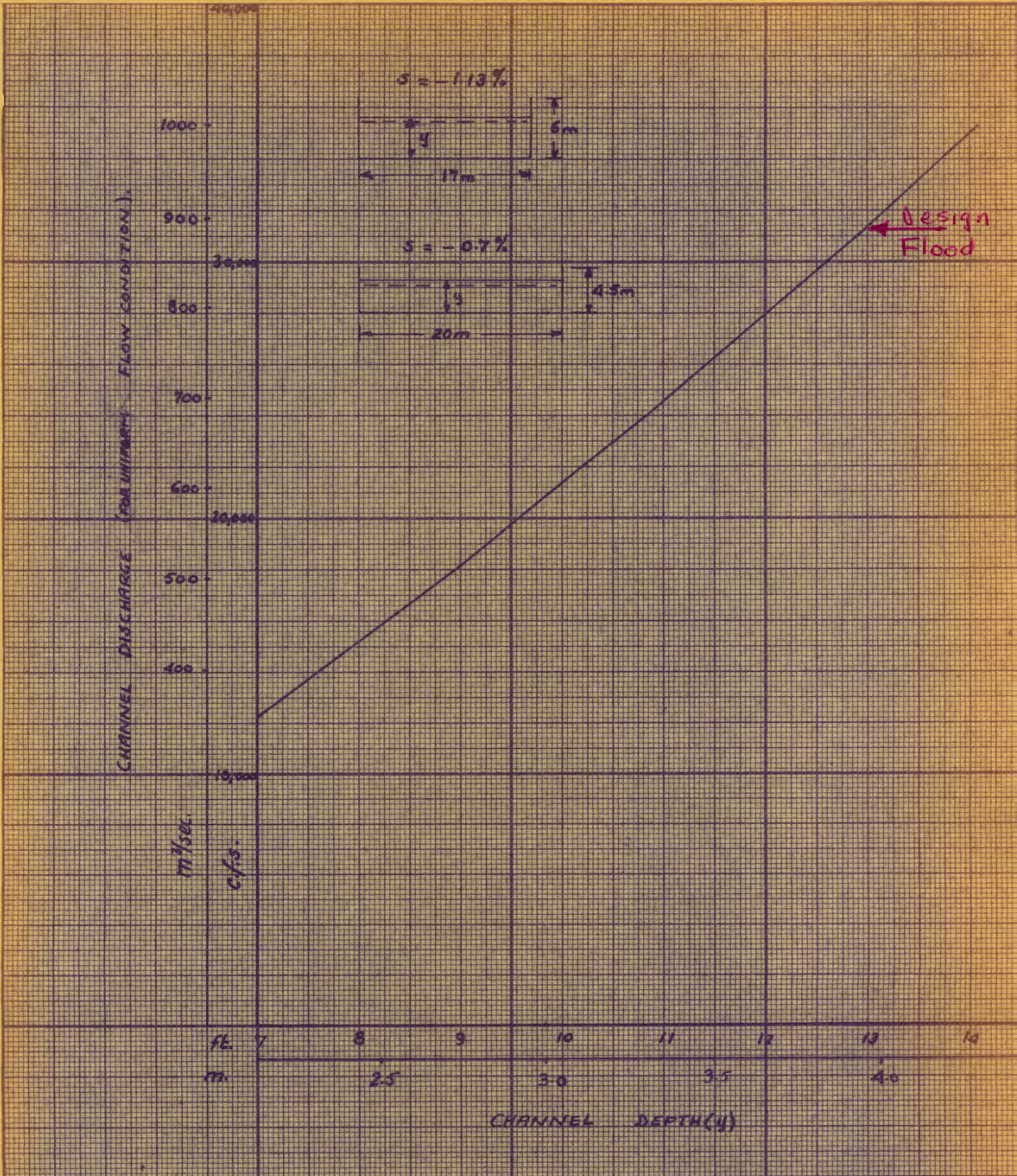


FIG. 36. CHANNEL DEPTH AGAINST UNIFORM FLOW CHANNEL DISCHARGES

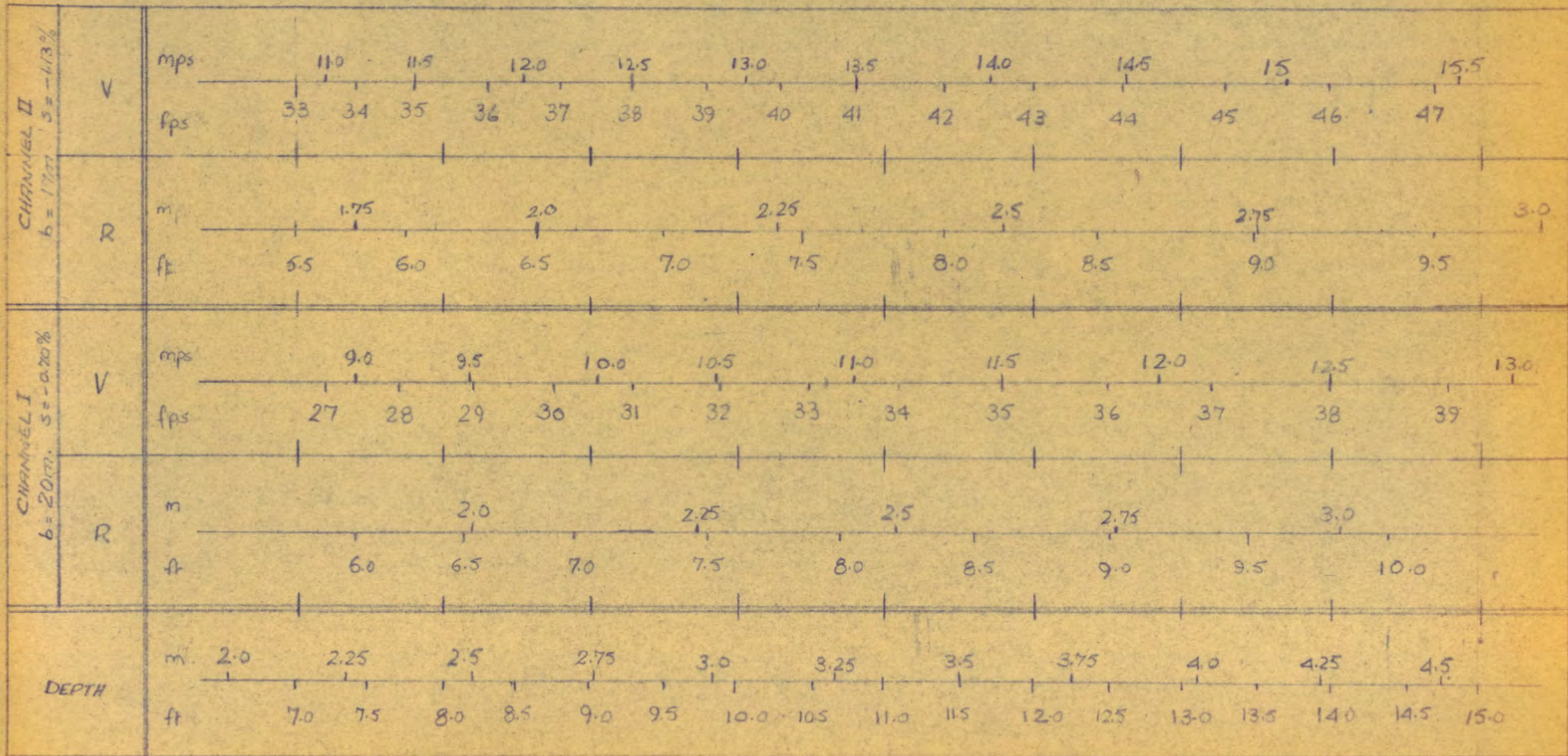
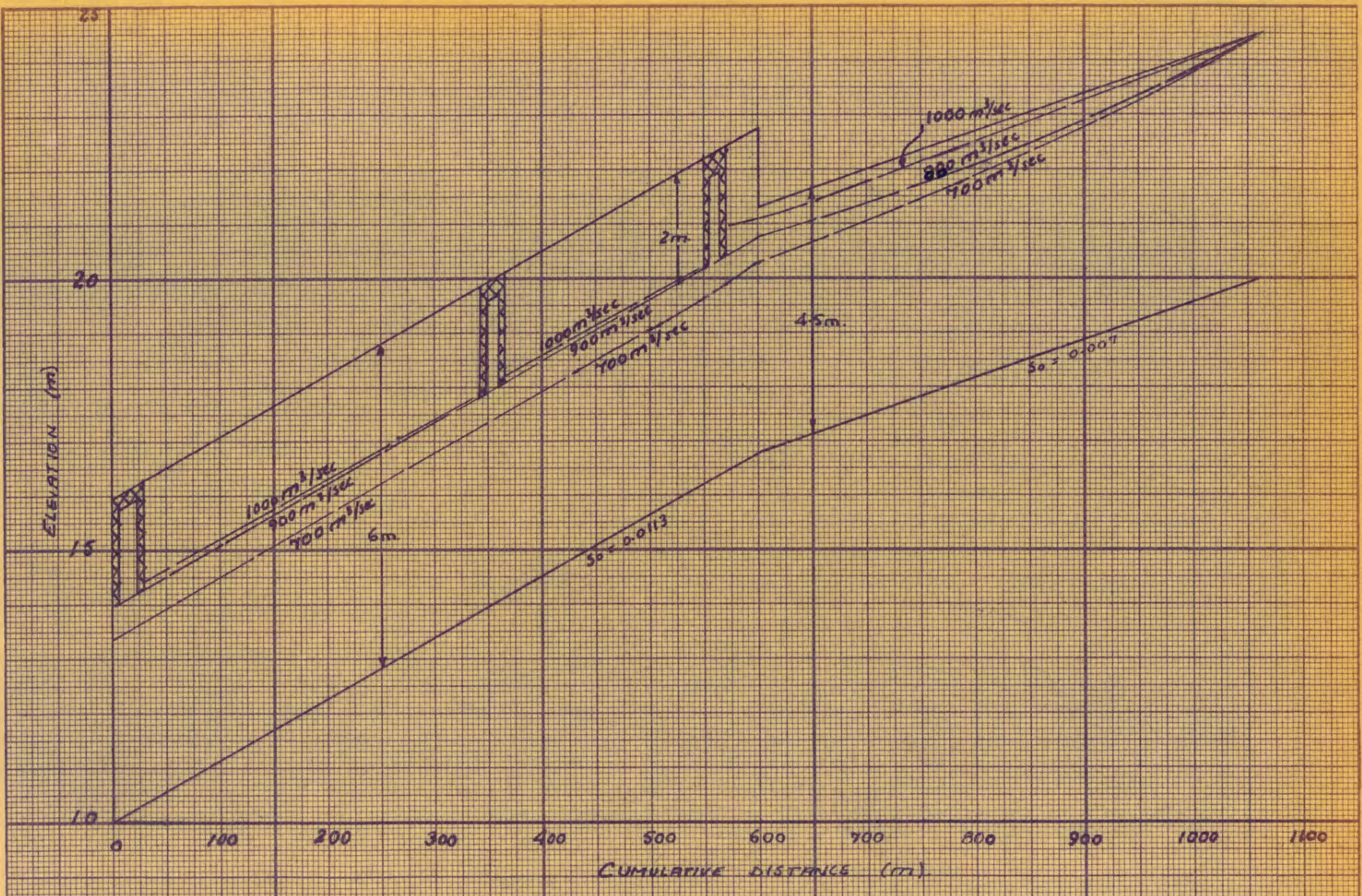


FIG. 37. ARTIFICIAL CHANNEL CHARACTERISTICS FOR UNIFORM FLOW.



F I G. 38. WATER SURFACE PROFILES.

CHANNEL I

$b = 65.6$ ft $s = -0.7\%$

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Q cfs	y_0 ft	gy_0 ft²/sec²	V^2 ft²/sec²	$\frac{V^2}{2g}$ ft	$R^{2/3}$	$\frac{1.49}{n} R^{2/3}$	$\left[\frac{1.49}{n} R^{2/3}\right]^2$	$F^2 = \frac{V^2}{gy_0}$	$F = \frac{V}{\sqrt{gy_0}}$	$S_{cr} = gy_0 / \left[\frac{1.49}{n} R^{2/3}\right]^2$
							$(7)^2$	(4) ÷ (3)	$\sqrt{(9)}$	(3) ÷ (8)
14,100	7.60	245	890	13.9	3.36	333	111,000	3.64	1.90	0.00220
17,650	8.80	284	1030	16.0	3.65	361	130,000	3.64	1.90	0.00219
21,200	9.95	320	1190	18.5	3.85	382	146,000	3.73	1.94	0.00219
24,700	11.05	355	1320	20.6	4.06	403	162,000	3.73	1.94	0.00219
26,500	11.52	371	1400	21.75	4.15	411	169,000	3.78	1.95	0.00219
28,200	12.10	390	1460	22.8	4.25	421	177,500	3.75	1.94	0.00219
30,000	12.60	405	1525	23.8	4.35	431	186,000	3.78	1.95	0.00219
Design Flood 31,750	13.10	422	1590	24.75	4.42	439	192,000	3.78	1.95	0.00219
33,500	13.60	438	1645	25.6	4.51	448	200,000	3.72	1.93	0.00219
35,300	14.10	454	1700	26.5	4.59	455	207,000	3.75	1.94	0.00219

TABLE II(a) HYDRAULIC CHARACTERISTICS OF ARTIFICIAL CHANNEL

CHANNEL II								b = 54 ft.		s = −1.13 %
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Q cfs	y_0 ft	$g y_0$ ft²/sec²	V^2 ft²/sec²	$\frac{V^2}{2g}$ ft	$R^{2/3}$	$\frac{1.49\,R^{2/3}}{n}$	$\left[\frac{1.49\,R^{2/3}}{n}\right]^2$	$F^2 = \frac{V^2}{g y_0}$	$F = \frac{V}{\sqrt{g y_0}}$	$S_{cr} = g y_0 / \left[\frac{1.49 R^{2/3}}{n}\right]^2$
							$(7)^2$	(4) ÷ (3)	$\sqrt{(9)}$	(3) ÷ (8)
14,100	7.60	245	1180	18.4	3.27	324	105,000	4.82	2.19	0.00233
17,650	8.80	284	1370	21.4	3.52	348	121,000	4.82	2.19	0.00233
21,200	9.95	320	1550	24.2	3.75	371	137,500	4.85	2.20	0.00233
24,700	11.05	355	1700	26.5	3.94	390	152,000	4.80	2.19	0.00233
26,500	11.52	371	1775	27.7	4.01	397	157,500	4.80	2.19	0.00234
28,200	12.10	390	1860	29.0	4.12	408	166,500	4.78	2.18	0.00234
30,000	12.60	405	1925	30.0	4.20	416	173,000	4.75	2.18	0.00234
Design Flood → 31,750	13.10	422	2000	31.2	4.26	422	178,000	4.75	2.18	0.00237
33,500	13.60	438	2050	32.0	4.34	430	185,000	4.69	2.16	0.00237
35,300	14.10	454	2125	33.1	4.40	435	189,000	4.69	2.16	0.00240

TABLE II (b). HYDRAULIC CHARACTERISTICS OF ARTIFICIAL CHANNEL i.e. $\frac{v^2 b}{g r_c}$ (where b = channel width).

According to the plan prepared by the Tripoli Office of the National Bureau of Reconstruction (identical with Plate 6 except for a constant channel width of 30 meters) three bends are shown : one at the inlet (r_c = 115 meters), and two in the center of the town (r_c = 400 and 500 meters respectively).

It may be concluded, therefore, that apart from all other disturbances, a minimum superelevation of about 2.5 meters should be expected at the channel inlet due to curvature; while superelevations of about 90cms. above normal depth will be encountered along the course of the channel. This is indeed a serious situation, not so much due to the magnitude of the superelevation itself, but to the excessive disturbances which will be transmitted downstream.

The complete elimination of the inlet curve is, therefore, a more or less absolute necessity. Not only that, but it would probably be advisable to create a type of basin at inlet through which the channel will be fed. Furthermore, a serious attempt should be made to make an absolutely straight channel through the town center - which with the proposed widths of 20 and 17 meters (as opposed to the 30 meters width proposed by the Tripoli Office of the National Bureau of Reconstruction) should not prove difficult. If this is not possible, then banking of the channel bed would probably prove an effective means of reducing wave disturbance. Otherwise, it should be remembered that adequate freeboard must be provided along the whole length of channel sides falling below the curve.

(2) Slug Flow or Roll Waves:

Owing to small initial differences in celerity, disturbances entering a steep channel could overtake, absorb others, and increase in size until, at a considerable distance from the inlet, the water surface acquires the form of a series of intermittent surges (known as Roll Waves) very similar to breakers in shape.[x] A detailed treatment of this phenomenon is beyond the scope of this work, but some analytical and experimental results are worth mentioning.

Based on the usual differential equation for gradually varied flow (Eq. IV.4), it is possible to evaluate the limiting flow conditions below which surges of this nature will not form. The result gives:

$$S_o \le \frac{4gy_o}{\left(\frac{1.49}{n} R^{2/3}\right)^2} \le 4S_{cr} \quad \& \quad F = \frac{V}{\sqrt{gy_o}} \le 2 \qquad \text{IV.5}$$

where S_{cr} = critical slope (i.e. one maintaining flow at critical depth).

F = Froude Number,

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[x] Thomas, Harold: The Propagation of Waves in Steep Prismatic Conduits, Proc. of Hyd. Conf., Univ. of Iowa Studies in Eng., Bulletin 20, 1940.

It is evident from a comparison of the results obtained in Tables 11(a) and 11(b) with Eq. IV.5, that for all discharges above 400 cu./sec. the flow in channel II is inherently unstable, since the channel bed slopes at more than 4-times the critical slopes and the Froude Numbers are greater than 2. Channel I on the other hand is just within the safe limits.

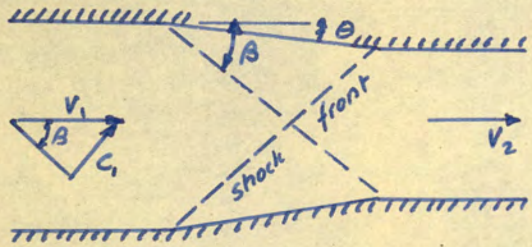
It will be seen from an examination of the surface profiles in Fig.38 that the three bridges which cross Channel II will probably be slightly submerged at the higher flows. In view of the quiescent effect which this will have on the water surface, and the sensitivity of one of the criteria to the value of the channel roughness factor 'n', and since the danger limits are only slightly exceeded, the writer does not believe that it will be necessary to modify the design of Channel II.

(3) Channel Contraction:

In the design of a channel contraction for super-critical flow attention must be given both to the magnitude of the initial disturbance produced and the wave pattern transmitted downstream, as well as the protection of the contraction from choking due to the formation of a hydraulic jump.[x] Since this will

[x] In the present instance a hydraulic jump (at design flood) would have a total water depth of about 10 meters.

necessitate the selection of as small an angle of deflection as possible, it can be shown that transition curves for the side walls are all eliminated in favour of a straight line connection - which is diametrical opposite of the principles of streamlining for subcritical flow.



It can be seen from the definition sketch that the angle 'β', which the wave front makes with the initial direction of flow, is the result of a vectorial sum of 'V_1' (the approach channel velocity) and 'C_1', (the wave celerity at the given depth of flow). Since C_1 may be approximated by $\sqrt{gy_o}$, then

$$\sin \beta = \frac{C_1}{V_1} = \frac{\sqrt{gy_o}}{V_1} = \frac{1}{F_1} \qquad \text{IV.6}$$

Based on Eq. IV.6, it will be found that β is about 26^o, θ about 2^o, and the transition distance around 40 m.

Subject to further study, beyond the scope of the present work, it is recommended that the 20 m. section be extended at the higher slope of 1.13% until the first bridge where a 40 to 50 m. transition section would direct the flow into Channel II.

DE - 9

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PLATES

1938

Day of Month	April A	April B	April T	April S	August A	August B	August T	August S	September A	September B	September T	September S
1												
2												
3												
4												
5												
6			3									
7		3	2									
8												
9												
10												
11												
12												
13			15									
14			16									
15												
16		7	1									
17			10								5	
18		28	20								19	
19												
20											8	
21												
22												
23									2			
24											1	
25						12			2			
26											60	
27											6	
28									4	1		
29									13	24		
30												
31												

Day of Month	October A	October B	October T	October S	November A	November B	November T	November S	December A	December B	December T	December S
1						2						
2												
3						8	5					
4					3		5					
5					21	13	18	25			5	
6					14	13	10	18		5	17	11
7					15	22	72	43	19	5	5	1
8					59	54	32	73		3	14	
9					38	20	44	13		1		
10					20	32		35			9	
11									18	7		
12												
13											10	
14												6
15									15	16		6
16											1	
17												
18									6		1	5
19									3	3		
20	5											
21	6	2	12									
22											3	
23	6								1	8	4	
24												
25												
26							7					
27					19						18	
28									3	12	12	23
29									15	25	6	40
30									24	31		
31											19	26

1939

Day of Month	January A	January B	January T	January S	February A	February B	February T	February S	March A	March B	March T	March S	April A	April B	April T	April S
1	18	27	46	30			19	31	3	9	19					
2	30	12	15	47	17	21	9	19	3	3			3			
3	27			16	18	8	5	18		2	23	46				
4					13	4				4	50	59				
5										20	5					
6			2						9	16	3				42	16
7		25	14						1	8	2		68	78	5	35
8						8	2			12	3	2	13	24		
9						1				1				2		
10				6												
11		9	10													
12	17	5				1	4	1						2		
13					2											
14																
15							4				3					
16				5			29	8		15	6	27				
17					14	15	21	30	15	2	16	15				
18					19	20	9	30	35	25	3	22				
19					15	13				10		3				
20									6	2		5				
21			5				13	20								
22			27	18	7	25	15	20		10	11	4				
23	22	24	7		25	9	22	15	21	12	20					10
24			3	31	26	29	13	22	10	17	2	20				3
25	3	25	25		34	12	3	9	10	3					1	
26	30		34	40		4		4							4	
27	24	8	2	10									3	13	2	
28	4	10												2		
29																
30											4					
31																

110

110

110

1939																							1940																			
…UARY			FEBRUARY				MARCH				APRIL				NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				OCTOBER			
B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S
7	46	30			19	31	3	9	19						12	28		4			7	14																				
2	15	47	17	21	9	19	3	3			3				2	12				13	3	14	45	36		47	23	32		40						4						
		16	18	8	5	18		2	23	46										3			6					1						17	18	7		3				
			13	4				4	50	59													15	34		22			7		6	10		13	8	2		10				
								20	5															4			3	2			11	4		2	4	2		1				
	2						9	16	3				42	16																	3	2			3	6		6				
5	14						1	8	2		68	78	5	35																												
				8	2			12	3	2	13	24														7																
				1				1				2									25		22	8		20			26					3								
		6													5	11		2		1	20	8	27	18		44		2	14	6	4	3		35						9		
	10															3		5	22	5	14	12	13	11			7	8	6	7	15	12		8					2			
				1	4	1						2			17	12		5	18	11	14	6					25	35	2	21	2	6		2								
			2													1			4	5	38	4					4	4	1							10					8	
																		17	22	9	10	40	3	5		3													8	7	20	
					4				3										7	7	2	2		6															9	11		
		5			29	8		15	6	27										4	1	1		7					15										2	3	12	
			14	15	21	30	15	2	16	15											12								3	1									4	4		
			19	20	9	30	35	25	3	22											17	7				7		5	10	8									8	6		
			15	13				10		3					6	11		17	4	14	7	10					11		11					5							1	
							6	2		5					48	20		32	8	6		1					11	4	10	6	7	15		34							8	
5					13	20										30					43			1			6	17	24	11	31	27		22					15	2		
27	18		7	25	15	20		10	11	4									28	20	17	61					8	2	2		1	8		1				5				
7			25	9	22	15	21	12	20					10					56	42	6	55				25	13	15		15	10	3		47		2					1	
3	31		26	29	13	22	10	17	2	20				3					19	15		19	13	12					2	10	38	33		19					2	7	1	
25			34	12	3	9	10	3					1					9									6			5		16			4	4						
34	40			4		4							4		10	5		21								3	7	4			5	4		1				4	16		4	
2	10										3	13	2		31	18		43					14	18		16		1														
												2				42		10					11	4		24																
																22							21	35		44																
									4													3	72	54		94															26	
																					9	3	18	31		23																

1941

OCTOBER				NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				OCTOBER				NOVEMBER				DECEMBER				JANUARY				FEBRUARY	
A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B
						11	30	19	27		3	7	9	6	8	30			8	1		11	5													5		24	19		1
				36	22		41			48	60		3			2	5			9	16	32	26											36		60		7			
				12	12	10	11	22	12	25	42									27	29		1									46	29	15	46	16				6	1
						11		34	50	15										6		16	2										2			2				4	4
					1		7	7	8											1	22		1										19								1
				12	6					25	2									1												7	5	58	7					6	6
								42	26	2							1					1										29	30		29						
								4	4		1																						3								
						25								3				34	4												1	4	2		3						
	9					21	14				4		2	14	4	25	14	10	25	2	6												1								
2				12	1	1			4	5		13	5	1		6	11	3	12													62	61	32	90	36					
				4	7	6		6	4				3	5		11	4					1											16			8					
		8		3	1	18	5					26	24	9	55					6	2													12		11					
8	7	20		2								42	42																			3		26							
9	11			10	8					21	25		3									19	19	12	14		31						2	15							
2	3	12			1			18	7	7										9	30	1	66	19	20								1	1							
4	4							12	13											30	40																	4	35		1
8	6													17	10							3			6		13									19			16		
		1										25	18		47					2		1						3	5		28					7	8	12			
		8								24	53	5	12	4	11					2								17								2	1	6	8		4
15	2							24	8	17	46	7	24							2				4	13		15		1					30	50	22	9	23	21	81	27
								33	41	5			13									9			5							26	30	8	40	18	18	13	20	25	8
		1						6	28											9	8											20	24	9	38	30	22		31	23	17
2	7	1						3	3																							14	10	3	20	16	13	18	20		10
						4								8	8					1												29	14		55	14	12	25	31		
16		4				1						12	15	3	8																	29	48	4	18	12	15		2		
				5	8	55	16				9	2	5	1																		4	2		26	11	15		15		
				17	7	28	23			1	12		1	1														29	16		34	17	25	12	23		3				
				17	32	36	42	4	6	24	59	16	19	1	14														1					19		22	32		35		
		26		14	15		27	48	17	62	25	1															5					12	2	37	60		1	18			
								34	10	8				15	20				1						3							37	40	4	30						

110

110

1942

ARY		FEBRUARY				MARCH				OCTOBER				NOVEMBER				DECEMBER			
T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S
24	19		1	2											1						
7							2								2	2	10				
		6	1	27	12									8							
		4	4	5	2			6			2		10							21	
			1	5			2	2	7	11	14							10	5	2	4
		6	6	2		8	15		6		3							2	1	1	12
						4	14									6	5		2		
														5	10	18		5	1		
														2	4		9				
																		24	27		25
									7										3		
						5	9	16													
					13		4														
												9				27	3				
										6	1	40		14	4	25	9				
4	35									14	16	43	26	17	8	36	10		6		
	16						1	9	10	31	17	9		6	12						
12				3		9	7	14	40	6	9		2			17	10				
6	8		4	39	24	45	47	3	26		2			8	6	31	61				
23	21	81	27	20	70	5	4	4	13					76	54	27	45				
13	20	25	8	6	42	30	36	63	65					25	26	9	13				
	31	23	17	12	20	58		3	34					11	15	9	12				
18	20		10			3		44	4					6	13						
25	31																				
	2										3	2	11			3					
	15			2		7	9		3	25	6	32	40						2		
					2					2	1		9						1		
	35									2	2		2						2		10
18											2	27	10		4		13	6	7	10	
											1		1					7	3	9	15

A - ABU ALI GAGING STATION.

B - BECHARRE " "

T - TRIPOLI " "

S - SIR-ED-DANIEH " "

24-hr. RAINFALL IN mm. FOR THE INDICATED GAGING STATIONS (1938 - 1942)		
SCALE : -	DATE: 29-3-1957	PLATE No. 1
COLLECTED BY : SUWAYDAN, MUBADDA		
APPROVED BY :		
FACULTY OF ENGINEERING AMERICAN UNIVERSITY OF BEIRUT		

DAY of MONTH	1943 JANUARY A	B	T	S	FEBRUARY A	B	T	S	MARCH A	B	T	S	APRIL A	B	T	S
1	8	10		2	15	33										
2		1					11	8			8					
3		8		4	20	19		22			8					
4	2	11	3	3		16	10				8					
5			24	7		1	8	10	11	6	28	21			14	
6	15	2		2	4	2			42		8	19	9	10	55	32
7							12		20	21			34	6	7	
8			1	8	16			28		4	1	8	5	14		
9		1	35	2		12										
10	15	24	64	57												
11	62	25	2	54		1									70	49
12		30		1			1						35	17	4	5
13		4	15			13	10	13				4	12	15	13	17
14	12	9	10	17	14	12	12	17	6	7	4	4	6	8	2	7
15	7	9		5		6		3		2	3	9	5	5	29	6
16		2	43					4	16	6		1	4	2		5
17	20	3	20	35		2			8	1	1	3				14
18	6	17	6							5		8	6	6	1	4
19	4	3	34	21			1	2	5		1		4	1		12
20	34	4	3	47	13	1		5	8	8	6	2	6	4		
21	18			9	2	7			8	11	3	21				
22		28					10	4	19	12	1	7				
23					6	1			19	66	25	17				
24					1				12	12	50	21				
25						1	4	2	32	7	13	77		3		6
26							20	10	31		6	14				
27			25	1	17		12	16	9	18						
28	21	8	33	53	12	42		6								
29	35		43	57										3		
30	39	18	30	33												
31	37	25	4	33												

DAY of MONTH	1943 OCTOBER A	B	T	S	NOVEMBER A	B	T	S	1944 JANUARY A	B	T	S	FEBRUARY A	B	T	S
1										9				16	1	3
2										3	4					
3							29	10								
4					33	11	5	14		6	15	39				
5					6		6	20	51	60		73				
6						3	16	2	3	13		3			8	
7													2		5	2
8											50	4			27	
9									36	30	1	65	18	6	3	32
10										14			4	14		
11		1									4				9	
12											4			1		
13		9									11					
14							7		42	32	27	96				
15					10	6		7	57			19				
16										16						
17										23					28	5
18											3		12	22	82	70
19		4							3		24	18	54	38	1	38
20			6						19	12	25	39		6		
21									20	17	20	33			1	
22									26	27		9			14	16
23	1		5							18			19	11	8	17
24	2	4											20	8	5	23
25	9	3		32						3				13		6
26			1						4	2	1	4		15		
27			36	28			6									
28		3														
29		9									69	6				
30									54		58	61				
31		2							38	26		37				

DAY of MONTH	1944 MARCH A	B	T	S	APRIL A	B	T	S
1								
2							5	16
3			14	19		3	1	2
4	14	18	2			4		
5		4				2		
6							2	
7					3		26	20
8						20		15
9						6		
10								
11		1						
12							5	5
13					8	2	3	
14			5	3		5		
15	5	5				3		11
16				8			21	24
17			3	8	21	8		
18	8	6				6		
19								
20								
21								
22								
23								
24								
25								
26								
27			30	71				
28	7	8	32	63		2		
29	80	14	19	57				
30	40	10	1					
31	13	7						

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	1944																								1945																	
	FEBRUARY				MARCH				APRIL				OCTOBER				NOVEMBER				DECEMBER				JANUARY				FEBRUARY				NOVEMBER				DECEMBER				JANU	
S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B
		16	1	3																					5	1	11	6	38		17	27						9	25	18	17	25
											5	16													5	4	7	9	35		5						35	16	7	12	7	9
							14	19		3	1	2													4	12			6	23								3				
39					14	18	2			4																	25	36		26												
73						4				2									40	11			4	2	1	4	30	24											12	4		
3			8								2						44	44	18	41	2				32	38									2			5	19	7		
	2		5	2					3		26	20						34	36	11		2															7		15			
4			27							20		15					10	20	32	20											3											
65	18	6	3	32						6							20	8	8	14							26	10											13		44	31
	4	14															4								8	6				2							10	5	6	24		5
			9			1																									1	2	1	2			9	10				2
		1									5	5			8		4	8	7				22	10			8	34	6	3	3	2										
									8	2	3		12								4	4			23	19	1				9	3							3			
96							5	3		5											8	4			6	12		3		1	2						8	5	2	17		
19					5	5				3		11														2	12	14										9	27			
								8			21	24			2								12		4	9	10	13							5		16	17	4	22		2
			28	5			3	8	21	8				2	1					8		14	7	27	13	18	4	13		2		15		4		5		7				
	12	22	82	70	8	5				6				2					30	55	37	16		4	4	5	4	33		4	10	27	4		9	26						
18	54	38	1	38													38	28	34	46		4		5	22	16	17	64		6	8	10	3	12	22	44					10	12
39		6													2		22	44				2	6	2	39	50	30	14	23	13	2		58	82		3						
33			1																		9	20	30	17		37	13	13				6	18	6								
9			14	16									3	2	29						30	20	2	35	25	17			12		38	43										
	19	11	8	17									10	6						4		4	6				18	68	25	3	15	27									6	11
	20	8	5	23															19	20	6	6	3	5	30				31		1											
		13		6													19	18	34	25	3	2	12	4	1	19				34	13	8										
4		15															46	37	7		10	4	4	5					9	10	10	8										
							30	71									1	1				1	9	6						2	8	21			19							
					7	8	32	63		2											3		29	12					24	23	2											
6					80	14	19	57													32	14	3	15											4							
51					40	10	1																44	49									2	6	25			2	2	4		
37					13	7															55	75	5	6			46										7	13	25	17	6	5

1946

CEMBER			JANUARY				FEBRUARY				MARCH				APRIL				MAY				OCTOBER				NOVEMBER				DECEMBER				JANUARY				FEBRUARY			
B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S
9	25	18	17	25	4	35		3								15																			6	14	13	9	6	24		14
6	7	12	7	9					13	7																									1	3	6	2		5		
3					1		11	9		7											6										2							7				
							1	4	4										2	4	7	3										2	19		26	23	45	26	1			
	12	4					1	3					1						7	12												2			17	20	41	27				
5	19	7									11	6	20	17							1														16	24	17	29				
	15								30	3	14	13		7		3			2	4	20	27									2			6		1		2	32	14	7	9
					39	14	30	15	18	70									41	54	35	110									3	2	2	6	4	9	11	11				
	13		44	31	1	36	34	43		22									30	44							4	12					3	2	21	6	26	28				
5	6	24		5									1			1		11														2			8	5	1					
0				2							1	9																							1			10				
													2			6									13										6	12	22	15				
	3								17	50			7		2		1	1															3		24	14	27	20	3		4	
5	2	17					19	20	18	6	3	3	1			2				1			30	22	22						25		5	5	3	1	10		28	3	23	9
9	27				1		10	5	38	39	3	8		10									67		10	78					1	12			1	2	11		1	1	3	8
7	4	22		2			63		30	55															11							3										8
7							12		4				8												1						15		27	29					24	23	19	37
					6	7		41	19		38	17	23																		36	17	19	25	2		6		11	26	5	27
			10	12			22	13	20	51	26	27	5	32			2						20	6	13	7					9	37	3	34	5	3	30	12		2		
								21	1	22	4	3	1	27	9	4		10					3	1	4	8	1					20			38	44	45	95				
							6	1				1	3	5												10						1			21	17	22	16	5	2	3	3
					4	10					1	1		1				2																	24	12	7	43		4	1	
			6	11					3				4	1	4				2	1		3													26	18	18	54				
							9	6	40	42	12	4		9						1		3													24	24		23				
							32	29	8	35		6		17																			8			1						
							10	11		6																																
							7	2																			4				7		5			20	7	23				
																						4										1	12		25	29	12	36				
													9	12																					5	4	1	3				
2	2	4			1	5					15	3	15				1										8	13	3	7					31	16	36	47				
3	25	17	6	5							10	6	1	29																					80	31	49	43				

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1947

JANUARY		FEBRUARY				MARCH				APRIL				NOVEMBER				DECEMBER			
T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S	A	B	T	S
13	9	6	24		14																
6	2		15																		
	7																			1	
45	26	1						5								3		3	1		
41	27					4	7	3						5		20					
17	29					15		34						9		4		1		10	
	2	32	14	7	9	1	18							2	2						
11	11					1			31					26	19	38					
26	28													10	14	25					
1						3	8		9					24	18	11					
	10					1	5	6	4												
22	15							6													
27	20	3		4						4	2	3	5				31				
10		28	3	23	9					22	15	3	25				20	1	15	1	
11		1	1	3	8					6	10		10				33	7	12	8	80
					8		1	2		8	6	7	12							3	
		24	23	19	37						1									5	
6		11	26	5	27									6	2	3	14				
30	12		2														7	1	2	5	50
45	95																				
22	16	5	2	3	3								12				5				
7	43		4	1										8	1	9				1	
18	54														1	8	23	17	43	14	56
	23													2	5	13			3		
											3	3									
7	23																				
12	36																				
1	3																				
36	47																	8	6	76	3
49	43																	1	2		2

A – ABU ALI GAGING STATION.
B – BECHARRE " "
T – TRIPOLI " "
S – SIR ED-DANIEH " "

24-hr. RAINFALL IN mm. FOR THE INDICATED GAGING STATIONS (1943 - 1947)

SCALE: –	DATE: 29-3-1957	PLATE No. 2
COLLECTED BY: SUWAYDAN, MUBADDA		
APPROVED BY:		

FACULTY OF ENGINEERING
AMERICAN UNIVERSITY OF BEIRUT

111

111

1948

DAY OF MONTH	JANUARY A	JANUARY B	JANUARY T	JANUARY S	FEBRUARY A	FEBRUARY B	FEBRUARY T	FEBRUARY S	MARCH A	MARCH B	MARCH T	MARCH S	APRIL A	APRIL B	APRIL T	APRIL S
1																
2		2	1	2	4		9	6		1						
3	26	43	22	33		1										
4	39		34	52					1	4	5		12	16	13	
5	7		3	3				5	4		3					
6						3		2	1			50				18
7					11	4	10	20	25	4	5	62				
8					21	18	24	27	6	2	10	3				
9					28	30	9	31	1	2	5				2	
10					3	15	10		1	2			19	16	27	28
11						1								1		
12					18	6	29	9		1		8				
13					22	18	25	26	18	17	29	36				
14					4	1	17	30	32		21	59	2	3	4	
15					10	13	21	7	19	18	3		6	2		9
16					56	30	79	80	1	2				3		
17					19	14		19	7	7	28	50				
18					6	6	13	15	28	39	23	31				
19					2	2		3		1			16	13	13	26
20								3					2	9	5	12
21														2		
22	1	8	8	10						1				2	7	10
23	50	48	59	63					4	3	12			13		
24	1		7	2												
25	5				4	1					15	11				
26									2	2					2	
27	1		1	8	45		14						41	12	7	40
28				3	13		4						38	21	58	45
29		1				37			11		6	27	22	45	8	43
30	11			2					20	27	2	44	2	1		
31																

DAY OF MONTH	NOVEMBER A	NOVEMBER B	NOVEMBER T	NOVEMBER S	DECEMBER A	DECEMBER B	DECEMBER T	DECEMBER S
1							2	
2					12	3	45	
3					1	1		
4					1		23	
5					1	1		
6	4	5	7					
7		2						
8							7	
9					13	2	7	
10					6	2	30	
11					9	3	20	
12	2				14	16	25	30
13	23	14	26		6	20	13	21
14	52	21	15			2		
15						3		
16						9	8	
17					20	9	23	20
18					8	15	4	
19								
20								
21								
22		1					10	
23	7	9	7		22		17	30
24	6	4	5		22	3	7	
25	30	31	52	30	3	2	9	23
26	51	34	25	33	40	34	56	
27	37	30	20	80	36	45	22	31
28	13	3	29	49	4	4	5	51
29	2	2		31				
30								
31								

1949

DAY OF MONTH	JANUARY A	JANUARY B	JANUARY T	JANUARY S	FEBRUARY A	FEBRUARY B	FEBRUARY T	FEBRUARY S	MARCH A	MARCH B	MARCH T	MARCH S	APRIL A	APRIL B	APRIL T	APRIL S
1					21	21	34	65					5	5	9	
2					21	20	23	55		7				1	5	
3													11	17	23	
4							11						1	9	4	19
5					9	30	15		5	1	17		6	5	11	
6					37		28				2		5	7	7	
7					44	57	33						1	8	1	
8					13	16	4		15	17	22	20				
9						1			32	26	18	31				
10						4	7		10	21	8	40				
11							2	30	6	8	1	10	28	5	5	
12					12	11	18		28	29	9	31	10	18	55	
13			20		6	2	7	10					31	22	6	23
14	10	7	11	20	7	9	27	41					10	14	4	20
15	10	9	28	26	35	21	6	50					17	24	7	
16	32	30	41	18						2						
17	34	46	47	22	1	3	6		1	1						
18	8	11	27	16									2	5		
19	24	11	37	20									28	16	37	21
20	10	13	1	21									17	4	6	40
21		14														
22	3								12	14	6					
23					1	1	2		2	13	1					
24			1		10	5	9		2	3	2					
25			1		8	20	7		4	8	11					
26	5	8	9	14	18	25	6	23			1					
27		1			24	22	11	25		9	1	10				
28	2	5	1					9	2	2						
29	16	14	38	14					14	6	8	36		2		
30	31	11	37						1						1	
31	1	1	1	13					2	2	5					

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1949											1950																														
MARCH				APRIL				DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER			JANUARY			FEBRUARY			M.
A	B	T	S	A	B	T	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A
				5	5	9								28	39	52							9	7																	
	7				1	5					33	16	30	2	3	25								3																	
				11	17	23		1	1		19	7	45	16	22		1							1													9				9
				1	9	4	19	1	2		3	1	16	15	30	30	16	14		1	1	10		2								4	3	49				7	17	18	
5	1	17		6	5	11		1	3		44	14	25	2	25		13	6	12				25	9								1	1	31			10	7	17	9	
		2		5	7	7			4	47	2		5	8	10		3	3	10				1	3											26	20	20	2	7		
				1	8	1		15	10	6	6						12	24	35							45	22	20								11					
15	17	22	20					6	6	15	5	3	5				1	10	10	1				6		45															
32	26	18	31						2	30							7	7	17	11	8																				
10	21	8	40						5	30	1	3		2	1		7	1	20		7	13				5			2	12											
6	8	1	10	28	5	5					23	20	34	2	2					20	25	30	9	9																	1
28	29	9	31	10	18	55					28	22	40											3																	
				31	22	6	23				12	12	37	2	1								15	6																	
				10	14	4	20						4										10	2					3	9											
				17	24	7		3			1						2	8																	6	2					
	2																												19	12	14				8	4		6	22		
1	1								3	25																			1	2								1	11	17	
				2	5			10	17	32																												25	48	40	
				28	16	37	21	1	2																	2	6					4	5		6	8		14	21		
				17	4	6	40		3		15	25	36													11									20	3	20	6	13	8	
								2	14		47	45	80	19	21											45	26	50							9	3	31	7	5	6	
12	14	6						4	7	10	15	14															2								41	44	60				
2	13	1						4	3		23	15	21																			14	12								
2	3	2						8	2	10	2		25																			8	15	10							20
4	8	11						8	11	10				8	14		12	7																10							10
		1						30	1	40	9	6		8	4		7	1			9								12	15											1
	9	1	10					42	53	31			23						31		1																				11
2	2									20			27				50	43	31	1	28	4							2	1	11	3	8	11							13
14	6	8	36		2				7	20							4	8			3								7	9	12	57	44	50							
1						1														8		5							15	1	3	52	38	30							
2	2	5										4	3																			22	5	70							

1951																				1952																				
UARY		FEBRUARY			MARCH			APRIL			OCTOBER			NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL			OCTOBER			NOVEMBER			DECEMBER		
B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S
																10							5	14	6	4	7	14												
																	2	2					58	28	59	22	41	27												
	9				9	10											8	4		3	2		46	52	60	1	15	2							19	7	21			
		7	17	18									6				4	4	7				42	25	50											3				
	10	7	17	9													2								4															
20	20	2	7																	7	5	10																		
11											18	10		21	18	5				3	6	7													1	11	7			
											7	6								10	6		8	8		9	8	15												
											19	10								31	15	20	19	18	25	10	18	23												
																			10	7	18	20	2	2	6	26	28	46										6	6	10
					1	4	14										7	6	6	13	2	3	34			22	31	46							20	20		4	2	
																				14	19	17	2	10		15	12	24	3	4						3		10	12	10
											21	9	10				57	31	76								1	45										24	20	30
											1						32	36	75																					
2																	41	26	49	6	13	18																		
4		6	22														6	12	25							2	5													
		1	11	17						5				10	1		25	25	40							8	13	17												
		25	48	40				23	26	21				15	10	14	58	42	56							3	4													
8		14	21					3	22	10							10	57	29												8									1
3	20	6	13	8													8	1					7				2	21			10									
3	31	7	5	6													9	1	10							15	8													
44	60										15	8					9	8	19			4	7	4	9													2	1	
								1	5		1	1	9						2	6	2	17						7							1	6	16			
					20	19	14	37	22	76							5	5					3	1	8										23	34	16			
					10	11	11	20	37							10																			12	34	13			10
					1	1							5	2	3										1											1		24	44	30
					11	4	10											1							1										2	13		9	8	
					13	4														5	16															1	2		1	20
											28	19				24							13	13	18				7	7	8									
											1	2																	11	8	14	8	9							
																				1	3											35	6							

1952

MBER		JANUARY			FEBRUARY			MARCH			APRIL			OCTOBER			NOVEMBER			DECEMBER		
B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S
					5	14	6	4	7	14												
2					58	28	59	22	41	27												
4		3	2		46	52	60	1	15	2							19	7	21			
4	7				42	25	50											3				
							4															
		7	5	10																		
		3	6	7													1	11	7			
		10	6		8	8		9	8	15												
		31	15	20	19	18	25	10	18	23												
	10	7	18	20	2	2	6	26	28	46										6	6	10
6	6	13	2	3	34			22	31	46							20	20		4	2	
		14	19	17	2	10		15	12	24	3	4						3		10	12	10
31	76								1	45										24	20	30
36	75																					
26	49	6	13	8																		
12	25							2	5													
25	40							8	13	17												
42	56							3	4													
57	29												8									1
1					7				2	21			10									
1	10							15	8													
8	19			4	7	4	9													2	1	
	2	6	2	17						7							1	6	16			
5					3	1	8										23	34	16			
																	12	34	13			10
							1											1		24	44	30
1							1										2	13		9	8	
		5	16															1	2		1	20
					13	13	18				7	7	8									
											11	8	14	8	9							
		1	3											35	6							

A - ABU ALI GAGING STATION.

B - BECHARRE " "

T - TRIPOLI " "

S - SIR-ED. DANIEH " "

24-hr RAINFALL IN mm. FOR THE INDICATED GAGING STATIONS (1948 - 1952)		
SCALE : –	DATE : 29-3-1957	PLATE No. 3
COLLECTED BY : SUWAYDAN , MUBADDA		
APPROVED BY :		
FACULTY OF ENGINEERING AMERICAN UNIVERSITY OF BEIRUT		

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DAY OF THE MONTH	1953																					1954														
	JANUARY			FEBRUARY			MARCH			APRIL			OCTOBER			NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL			SEPTEMBER			OCTOBER		
	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S
1							30	41	62	15	13	23										2	2								66	66	75						
2							25	29	20													43	56									2	8						
3							3	5		8	1					1	17					6	12	115	16	11	22												
4							9	2		4												12	20	31	8	10	20				5		8						
5		1		42	32	55	4	2			4											8	2	44							25	29	40						
6				2	13		21	22	50	2												1	6																
7	4	2					37	48			6											9	2		9	14		3			4	12	4						
8	9	9	16	2	2																	39	14	14	13	5	32	4											
9	2		1	63	69	14																			47	27	50	2											
10	53	46	60	34	30	80																64	42	66	28	26	41	1			15	37	30						
11	5	38	36	4	12	66	24	7														9	46	55	4	2	23												
12	28	20	20				14	45									3						28	14			1												
13																						16	1					1			7	9							
14							10	28	80																3	8	5												
15	6	4	8				2	6	30																5	4													
16	14	17	18																1		13													9	4				
17					5		5	15						20		49	33	59	34	20	51							28		30									
18				20	33	58		1	14							64	58	73	15	17	20				2	5	2	2											
19	19	2		39	32	55	33	26								21	43	38	10	24	2	26	4		14	6	4												
20				3	11		19	18	74							8	29		4	5	18	2	29	18	8	8	8												
21	24	8	30				25	8	20								1		1		19	7	5	23	4	5	10												
22	14	5	14				29	14	15									31	1	5		1	21	7				1									8		
23	30	22		12	24		17	33	15							16	21	54	8	3		5		15	5	12	8	4											
24	25	13			9		1	3								40	57	70	16	24		5	1		15	16	21	2											
25	6	6	30													34	29	4	1	2		3	4	55	24	24	24											10	
26				11	2												6					22	10		8	29	3										16	1	
27				23	7	42											1			1		3	18																
28				19	12	35																																	
29																						17	9	14															
30																			6	20	13	10	24	17															
31							1	8											18	38	14							26		47							6	6	

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1954																		
RY	MARCH			APRIL			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER		
S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S
				66	66	75							2	2				
					2	8							27					
22													1	1		2	3	15
20				5		8												10
				25	29	40										8	10	30
																1	2	10
	3			4	12	4												
32	4												4					
50	2												23	2				
41	1			15	37	30												
23																		
1																		
	1			7	9													
5																		
							9	4						1				
	28		30										28	24		8		5
2	2												19	15				
4														2				
8													30	21		17	14	81
10													2	1		5	10	
	1									8			5	3		6	5	
8	4												20	14		2		
21	2												7	10		15	18	13
24											10			1				
3										16	1		4	5				
-													4	1		11	2	10
																3	1	22
													12	15				
													6	6		9	12	20
	26		47							6	6							

1955																							
JANUARY			FEBRUARY			MARCH			APRIL			MAY			OCTOBER			NOVEMBER			DECEMBER		
A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S
																			3				
												11	5	8								1	
												5	13	6									
			24	8	8	2	1					5	5	1									30
			7	5	18	10	17	25	4	3											5	8	11
			10	20	23	9	10	5	7	18	19							16	6		32	40	40
			1						11	4													
									21	31	3		1					8	8				
				3					5	26	3											2	
3	2		13		50				4	11								6	7		1	1	
	1	4				22	8	20										1	5		2	2	
23	8					5	42	6											1		8	13	1
3	9						5														16	14	20
1	5			9	10	17	24														6	7	10
						34	26	50													9	6	1
						21	16	30															
						19	15	42													98	70	81
						5	10	50														1	
													6										
					25								9						5				
					32								2					1	6				
			10	20														61	79				
4	10	10																14	48			5	
8	10	16																4	12		2	1	1
7	12																	4			1	1	
						8																	
						10	9	13	11	8					1	3		11	1		3	2	10
															10	12		13	10		17	23	11
																8		20	22		5	8	
12		40													3	3		4	3		1	1	
															12	3							

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1956

NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL			MAY		
A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S	A	B	S
	3								6	10		4	11	10				1		
				1								8	14	31		12		1	4	
							1	1				3	1		26	16	20	4	1	
					30	19	37	10				2			2	7	1	30	37	
			5	8	11	20	10	31										4	4	
16	6		32	40	40	9	5	10	33	20	81							7	2	
									55	62	61	11	9	21				7	2	
8	8						2	10	3	16										
				2		16	52	20	15	26	20									
6	7		1	1			4		1	8		4								
.1	5		2	2								12	9	21						
	1		8	13	1							2								
			16	14	20			10												
			6	7	10							7	19	20	4	1				
			9	6	1	1	1		3	1		16	21	40						
												18	4	10		9				
			98	70	81	4	4	10												
				1		1	12													
												22	13	11						
	5								5	12										
1	6																			
61	79											8	7	10						
14	48			5					10	10										
4	12		2	1	1															
4			1	1																
									2	13										
11	1		3	2	10	22	25	20	6	25	20							1		
13	10		17	23	11	38	28	40	23	58	61	25	14	20						
20	22		5	8		58	52	110	10	10		25	13	10						
4	3		1	1				20				6		10						
						5	6	30												

A - ABU ALI GAGING STATION

B - BECHARRE " "

T - TRIPOLI " "

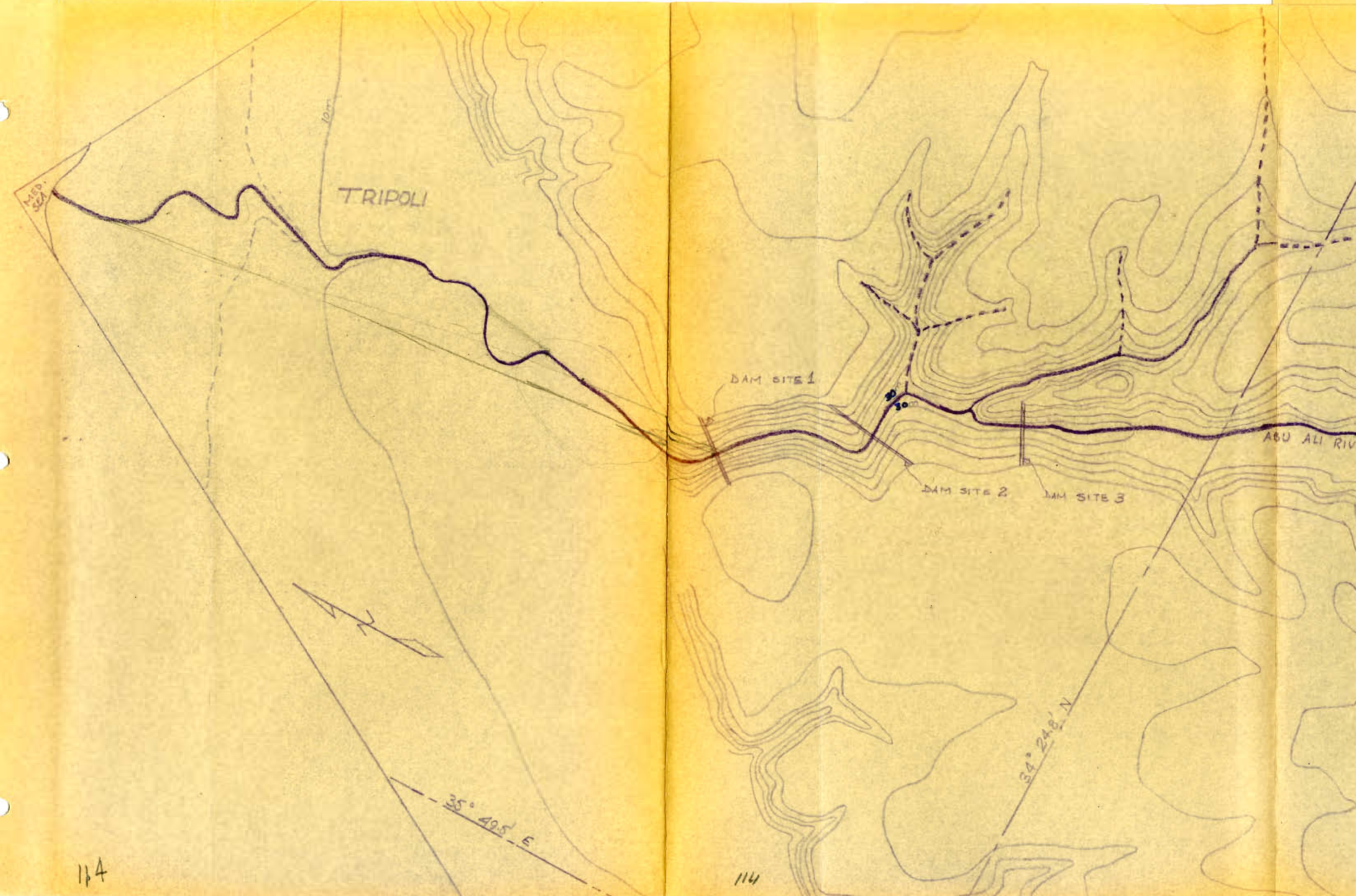
S - SIR-ED-DANIEH " "

24-hr. RAINFALL IN mm. FOR THE INDICATED GAGING STATIONS (1953 - 1956)

SCALE : —	DATE: 29-3-1957	PLATE No.
COLLECTED BY: SUWAYDAN, MUBADDA		4
APPROVED BY:		

FACULTY OF ENGINEERING

AMERICAN UNIVERSITY OF BEIRUT



MED. SEA
TRIPOLI
10m
DAM SITE 1
30
30m
DAM SITE 2
DAM SITE 3
ABU ALI RIVER
34° 24.8' N
35° 49.5' E

114

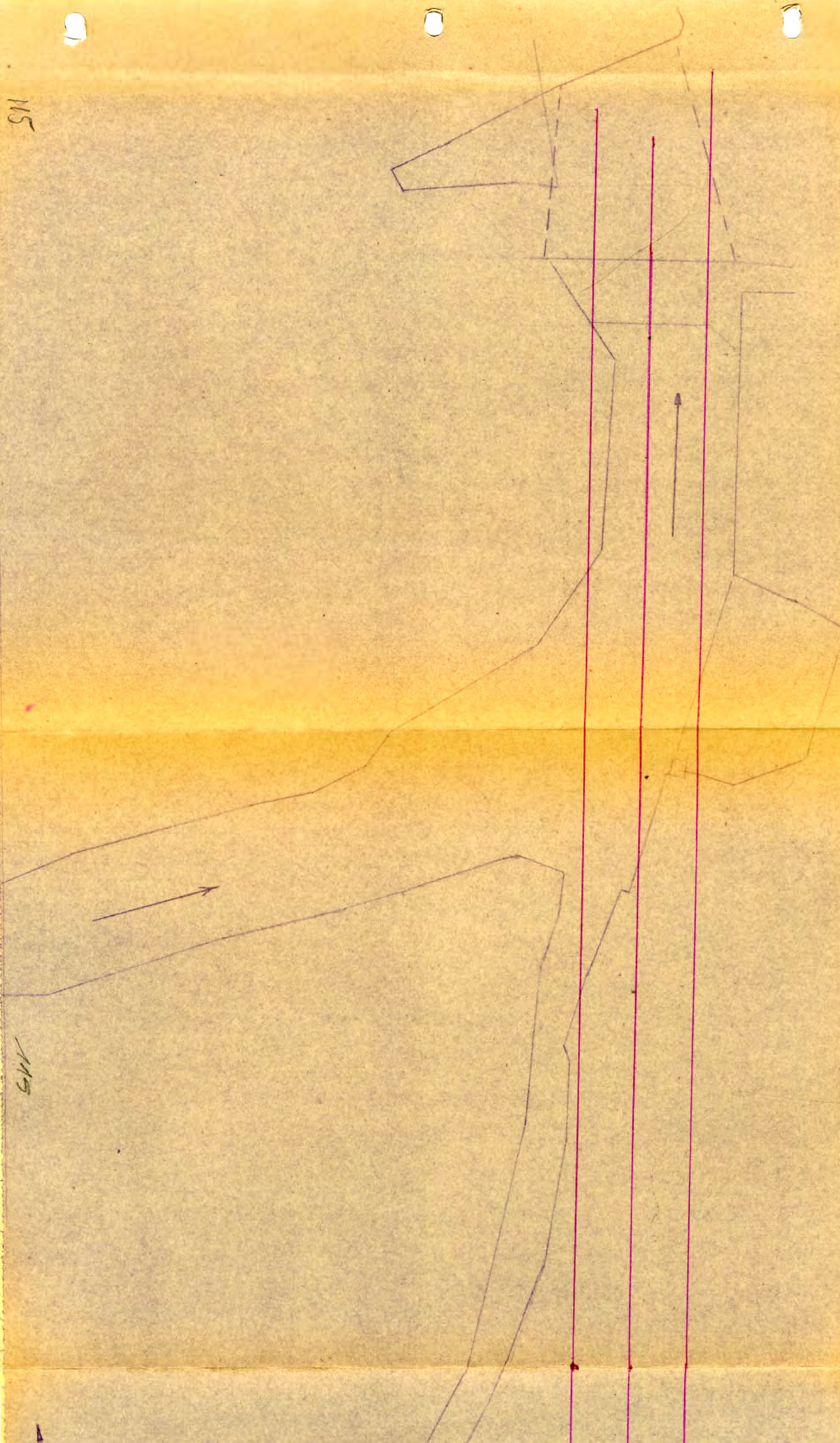
114

Scale 1
DRAWN, BY
APPROVED BY
AME

KEY PLAN		
Scale 1:12,500	Date: 29-3-1957	PLATE No. 5
DRAWN BY: SUWAYDAN, MUBADDI		
APPROVED BY:		
FACULTY OF ENGINEERING AMERICAN UNIVERSITY OF BEIRUT		

114

115



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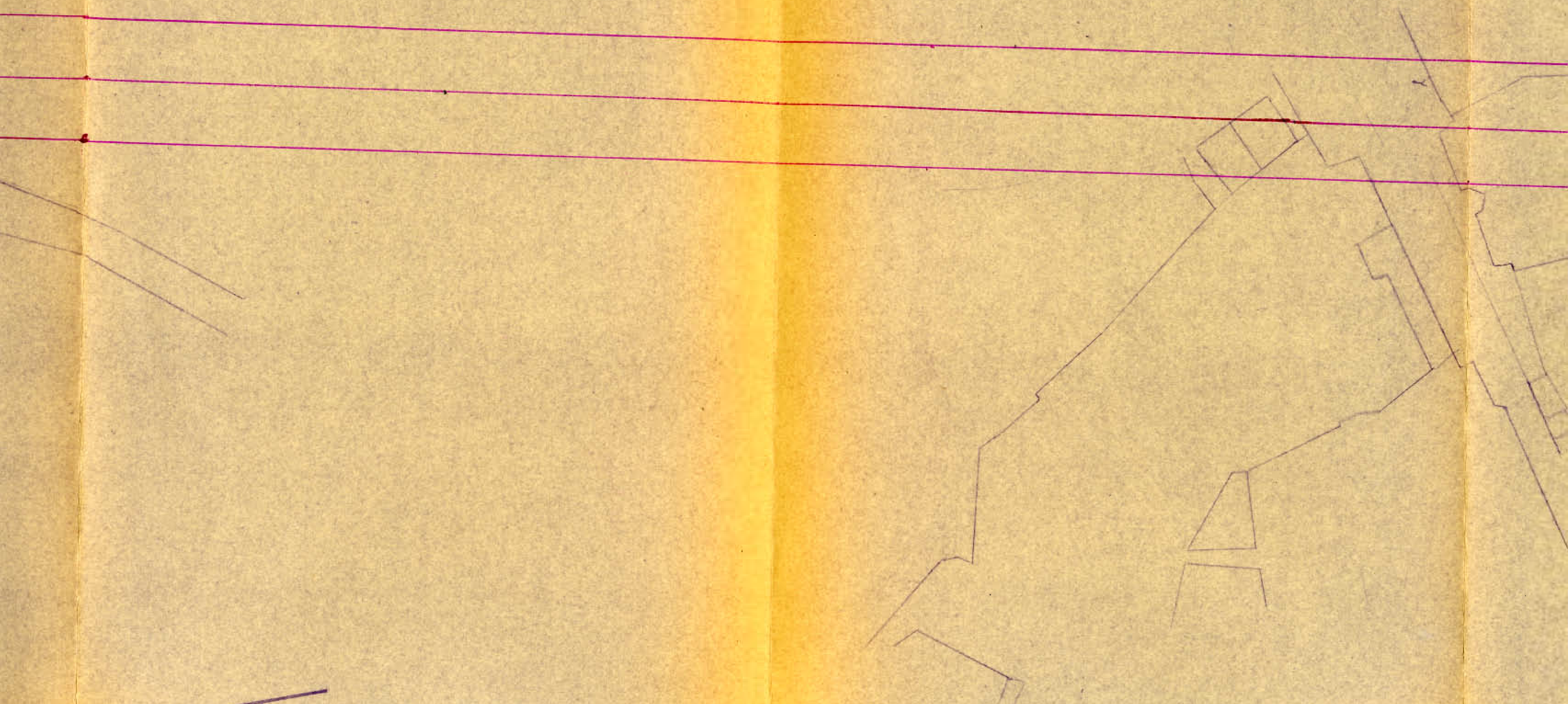

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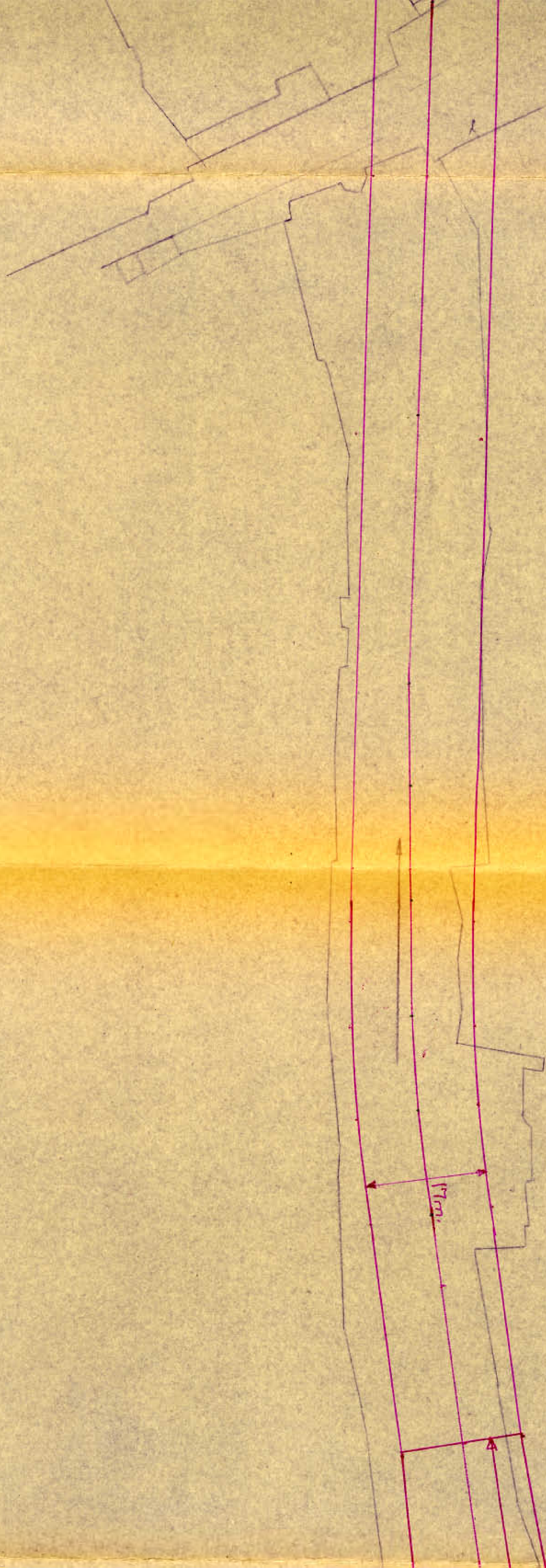

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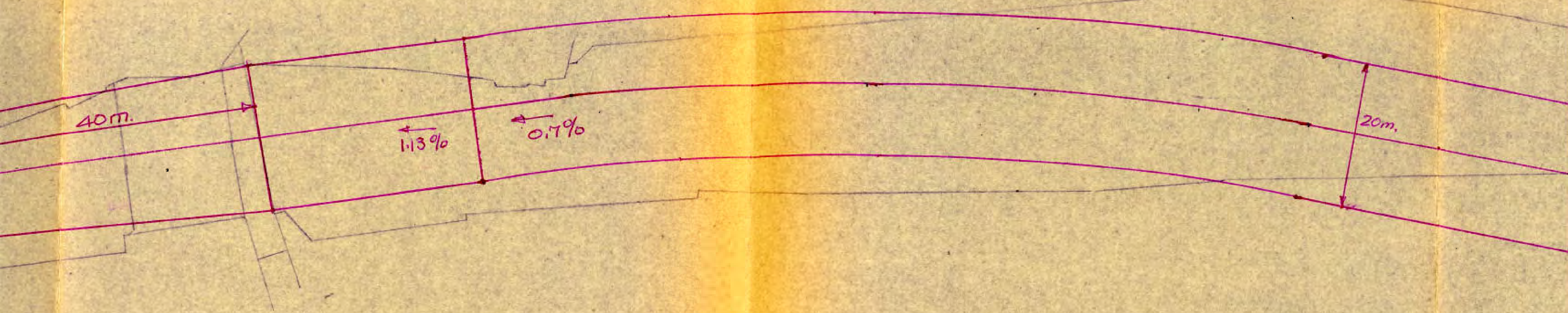


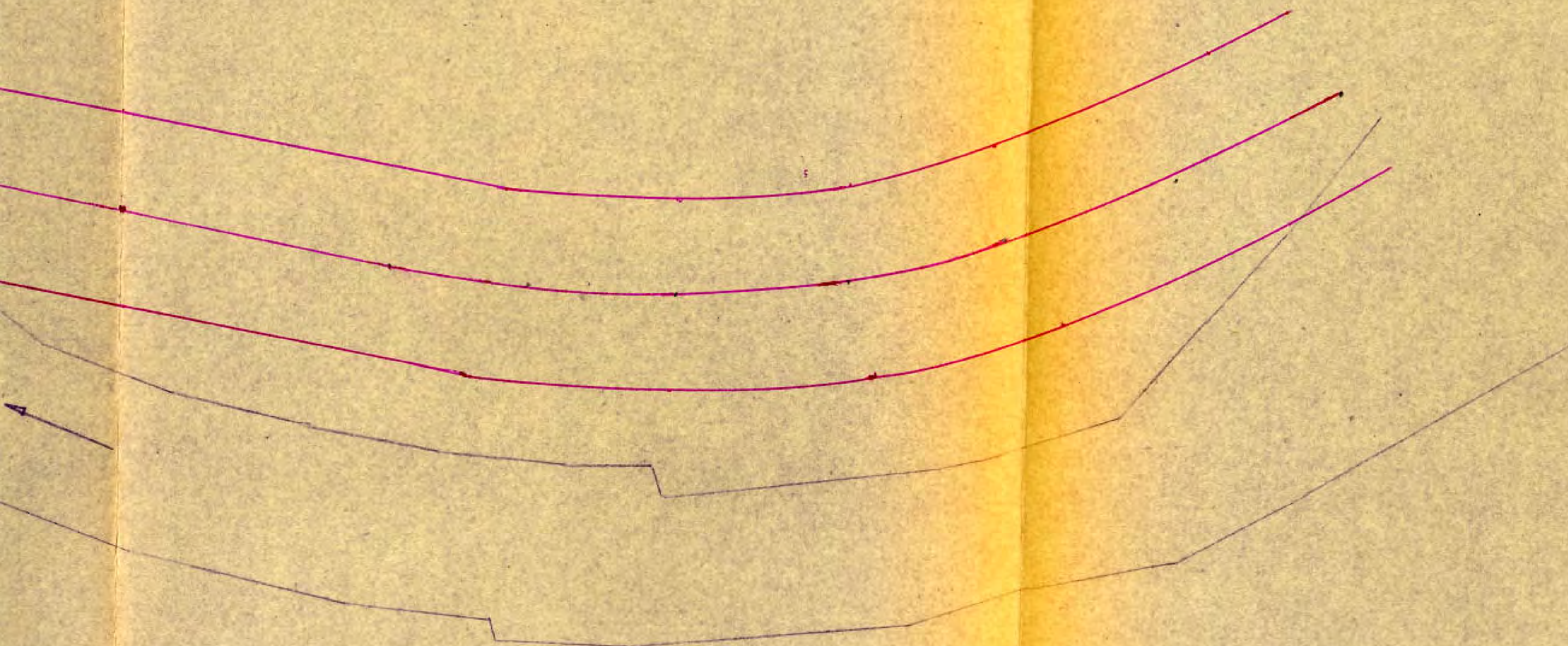
115

115

115

115

Scale 1:500



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PLAN OF ARTIFICIAL CHANNEL THROUGH THE TOWN OF TRIPOLI		
Scale 1:500	Date: 29-3-1957	PLATE No. 6
PROJECT BY: SUWAYSAH, MUBADDA		
APPROVED BY:		
FACULTY OF ENGINEERING · AMERICAN UNIVERSITY OF BEIRUT		

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