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FINAL REPORT

VOLUME III

HYDROLOGICAL SURVEY OF IRAQ

APPENDIX B - FLOOD POTENTIAL

APPENDIX C - FLOOD-CONTROL OPERATIONS

A REPORT BY

HARZA ENGINEERING COMPANY
CHICAGO

BINNIE & PARTNERS
(FORMERLY BINNIE, DEACON & GOURLEY)
LONDON

IN ASSOCIATION

PREPARED FOR

THE GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

BAGHDAD, IRAQ JULY 1963

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Irrigation Operations

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COPY

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June 15, 1964

Air Mail

Mr. Kenneth F. Vernon
Chief, Public Works and Industry Branch
NASA/Engr. Bureau of Near East and South Asia
Agency for International Development
Department of State
1901 Pennsylvania Avenue
Washington, D. C.

Subject: Hydrological Survey of Iraq - Final Report

Dear Ken:

Some last minute rearranging of Exhibit B and Table 7.4 of Volume I of the subject report resulted in several errors of tabulated data. These do not affect the remainder of the report in any way. Corrections were made in ink to most of the originally distributed reports.

Replacements for these two pages are enclosed for insertion in the copy of the report we sent you on November 1, 1963.

Very truly yours,

HARZA ENGINEERING COMPANY

V. A. Koelzer

Enc: 2 correction sheets

correction sheets inserted 10/13/64
MAR

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Chapter B-1

SUMMARY

1.1 This appendix contains details of the method of computation of the probable maximum flood and of the probabilities of floods of historical magnitude. Such computations have been made for each of the major sub-basins of the Tigris Basin (Exhibit B-4), as well as for the Tigris Basin as a whole.

1.2 Probable maximum floods for various locations in the basin are shown on Exhibit B-1. Flood frequencies are shown on Exhibit B-2.

Definitions

1.3 The probable maximum flood is the estimated flood that would result if all the factors which contribute to the generation of a flood were to reach their most critical value that could occur concurrently. The probable maximum flood is our estimate of the boundary between possible and impossible floods and, as such, has a chance of occurrence of zero or a return period of infinity.

1.4 Probable maximum precipitation, being one of the components of the probable maximum flood, is comparable in probability. It is the amount of precipitation over a given area which, in our best judgment, is the maximum that could occur within a given time period.

Reliability of Probable Maximum Flood Estimates

1.5 The probable maximum flood is an estimate and as such is subject to the same limitations as all estimates, inadequacy of data and

inaccuracies of procedures. The assumption and techniques used in the computation procedures are not new, having been used in previous studies and having gained acceptance after critical review. However, the approximations necessary do reveal certain weaknesses in the study which merit some discussion, as follows:

a. The isohyetal patterns of historical storms were based on fewer precipitation stations than desirable. This could introduce either positive or negative errors. However, since the largest runoff-producing storm was ultimately used, the probability exists that the storm used was one having a positive error, i.e., it was larger than the actual storm and is therefore on the conservative side.

b. The maximization factors are dependent on dewpoint and wind data. These data were rather limited. However, the seasonal curves used in the maximization process were enveloping curves of historical points, and this procedure tends to offset any deficiencies in data.

c. The maximized storms for any one basin might be deficient because of lack of storm experience in the basins. Accordingly, several basins were grouped together and enveloping values used for all basins in each group. This resulted in substantial overenvelopment of many of the maximized points.

d. The data for snowmelt computations were extremely limited, and it was necessary to use some information from comparable areas in the United States. A conservative approach employing envelopes of historical data, critical melting temperatures, etc. was used in this procedure. Since the peak snowmelt contribution represented only six to thirteen percent of the probable maximum flood peak, a sizable error in the snowmelt estimate would introduce only a slight error in the total estimate.

e. Retention loss data were nonexistent. This lack led to use of data from the United States. The losses used

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were near the lowest measured in the entire United States experience (the lowest losses being experienced in areas not comparable to Iraq) and are believed to be somewhat lower than would have been used if fully adequate data had been available.

f. Detailed flood hydrographs were not available for development of reliable unit hydrographs. Synthetic unit hydrographs were developed, but the procedures used are fairly well proven.

1.6 The above inadequacies of data resulted in some possibility that the estimates of the probable maximum flood are too small. However, in the derivation of the probable maximum flood, the limitations in data and procedures in each instance have been considered from the conservative viewpoint, with a tendency to assume more critical values than we believe would be most probable if fully adequate data and procedures had been available. Therefore, it is our opinion that there is a much greater probability that the estimated values are too high, rather than too low.

1.7 The reliability of the flood frequency estimates is discussed in paragraphs 9.17 to 9.23 of this appendix.

General Procedures

1.8 The general procedure followed in estimates of the probable maximum flood is one that has gained wide acceptance in modern practice. A probable maximum storm was developed from a detailed study of historical storm occurrences, with the maximum historical storms being increased to their maximum potential by analysis of meteorological factors. The maximum snowmelt potential was similarly analyzed. The precipitation values of the probable maximum storm were reduced by estimated losses due to infiltration, interception, etc.; the residual values were

applied to unit hydrographs developed for the relevant basin in order to arrive at the probable maximum flood flow from precipitation. To this was added the estimated snowmelt runoff and runoff from a major antecedent flood to determine the probable maximum flood.

1.9 The probabilities of floods of historical magnitude were estimated by a frequency analysis of historical floods in the various sub-basins. Adjustments were made in an attempt to account for possible unique experiences in a particular sub-basin.

Chapter B-2

PROBABLE MAXIMUM PRECIPITATION

General Procedure

2.1 Two general approaches have been used in other areas in the estimation of probable maximum precipitation. The first is by the postulation of a storm model in which all factors influencing precipitation are synthesized. The second is to study precipitation from actual storms that have occurred in the area, increasing the historical storm occurrences to their maximum potential. The second procedure involves estimation of fewer factors and has been used in our analysis.

2.2 The first method, postulation of a storm model, involves estimates of the many factors that influence rainfall rates. These include atmospheric moisture content, rate of net inflow of moisture, convergence, instability and condensation nuclei, as well as many other items. However, these elements cannot be measured accurately, and only a few can be estimated with a reasonable degree of confidence. Wind, which affects rate of inflow, and moisture content are the easiest to measure. Since reasonable estimates of all values could not be obtained for the Tigris River Basin, it was concluded that the storm model approach was not suitable.

2.3 The second method requires that historical storms be increased to their maximum potential by comparison of moisture contents and winds in the historical storm to the maximum believed possible. The fact that these factors are the most easily measured results in the second method's being more applicable to the Tigris River Basin.

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2.4 The general procedure used was (a) to study all historical storms to determine the maximum depths of precipitation that have occurred over areas of various sizes and over various periods of time (maximum depth-area-duration values), (b) to estimate moisture contents and wind speeds of these storms from available related data, (c) to estimate the probable maximum moisture content and wind speed that could occur at any time of the year, and (d) to adjust the historical storm values to their maximum potential by appropriate consideration of the relation between (b) and (c). Enveloping values of all the storms analyzed were considered to be the probable maximum values for the basin. The results are summarized in Table B-1 and are expressed as depth-area-duration curves on Exhibit B-3.

2.5 The extremely specialized nature of the hydrometeorological studies made it desirable that the work be performed by specially trained people. The Hydrological Survey was fortunate to obtain the services of Mr. J. L. H. Paulhus as a special employee, on leave of absence from his regular position as Staff Hydrologist in the office of the Chief, Hydrological Services Division, United States Weather Bureau. Mr. Paulhus's report "Hydrometeorological Criteria for Design Floods in the Tigris River Basin" is abstracted in this appendix (paragraph 2.7 through Chapter 3) but is available in original form in the Hydrological Survey files.

2.6 Units of feet for elevation and degrees Fahrenheit for temperature were used because most literature and references on this subject use those units.

Table B-1

PROBABLE MAXIMUM PRECIPITATION, TIGRIS RIVER BASIN

(in millimeters)

Area Number	Sub-Basin	Total Area (sq. km.)	Duration (hours) 6	12	18	24	36	48	72	96
4	Tigris River above Eski Mosul Damsite	50,200	60	112	142	167	205	236	267	289
3	Greater Zab River above Bekhme Damsite	16,600	150	229	282	312	347	373	407	429
2	Lesser Zab River above Dokan Dam	11,700	170	253	316	346	384	411	439	464
5	Tigris River above Samarra and below Eski Mosul, Bekhme, and Dokan	33,900	43	71	92	108	138	156	174	187
2,3,4,&5	Tigris River above Samarra	112,400	61	96	121	142	172	196	240	277
6	Tigris River above Diyala-Tigris confluence and below Samarra Barrage	22,300	70	113	132	159	192	216	243	264
2,3,4,5,&6	Tigris River above Baghdad	134,700	52	81	104	121	147	169	205	237
1	Diyala River above Derbend-i-Khan Dam	17,800	148	225	278	307	342	369	402	425
7	Diyala River above Diyala Weir and below Derbend-i-Khan Dam	11,900	113	165	192	215	250	275	313	336
1 & 7	Diyala River above Diyala Weir	29,700	114	150	175	190	214	232	264	290
1,2,3,4,5, 6, & 7	Tigris River at Diyala-Tigris confluence	164,400	50	85	106	120	141	162	198	232

Analysis of Historical Precipitation

Precipitation Data

2.7 Precipitation and other climatological records for all stations in the Iraq portion of the Tigris drainage area above Baghdad were obtained from the Climatology Department of the Iraq Directorate of Meteorology. Records from stations in and near the Tigris and Euphrates drainage areas in Turkey were obtained from the Turkish Meteorological Service in Ankara. Very little data were obtainable for the Iranian portion of the basin.

2.8 Records date generally from about the mid-1930's with few stations operating before that time. There has been a moderate increase in stations since 1930. The density of stations with records suitable for this analysis was sparse, with an average of one rain gage per 3500 square kilometers, as compared to one rain gage per 700 square kilometers in the United States. Occasional discrepancies in the records and the fact that most gages were seldom visited by qualified inspectors indicate that portions of the data are of doubtful reliability.

Mean Annual Precipitation

2.9 Preparation of a basin mean annual precipitation map was the first step in the analysis. Relations between elevation and mean annual precipitation were developed by plotting precipitation at stations against elevation in the mountain areas. The relation for those stations with at least five years of record is shown on Exhibit B-8. The following equations were derived:

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$$P = 205 + 0.17\ Z \text{ (southwest exposed)}$$

$$P = 205 + 0.09\ Z \text{ (southwest sheltered)}$$

where P is mean annual precipitation in millimeters and Z is the effective elevation in feet. Effective elevation differs from actual elevation if the site is within eight kilometers of a sheltering mountain or ridge. In this case the first equation applies, but the elevation of the sheltering feature is used for Z. Orographic precipitation has been found to reach its maximum between 6000 feet (1840 meters) and 9000 feet (2760 meters) elevation. The equations were used up to 9000 feet elevation. Above that elevation precipitation was assumed to be constant.

2.10 Mean annual precipitation values were computed for all stations with five or more years of record and plotted on a topographic base map. Mean annual precipitation at the intersection of each quarter degree of latitude and longitude was estimated from the precipitation-elevation relations. Observed precipitation, estimated values, and contours of elevation were used as guides in drawing isohyets of mean annual precipitation. The resulting map of mean annual precipitation is shown on the map of Exhibit B-4.

2.11 It must be kept in mind that with the low density and doubtful reliability of the rain gages, the map has a high possibility of error, especially for small areas. We feel, however, that the estimates of mean sub-basin precipitation presented on Exhibit B-4 are the best that can be made with the available data.

Historical Storms

2.12 Precipitation data for the 42 recorded storms of greatest intensity were summarized and plotted on base maps. Of these storms, 14 were

considered critical and were selected for further study. Precipitation at each station for each storm was expressed as the percentage of that station's mean annual precipitation, and isopercental maps (maps with lines of equal percentage of mean annual precipitation) were drawn for each storm. The isopercental maps were placed over the mean annual precipitation map on a light table. Storm precipitation at any point could then be estimated by multiplying corresponding mean annual precipitation and storm percentage. Storm isohyetal maps were constructed for the 14 critical storms which occurred during the period 1935-1955.

2.13 The depth-area-duration relationships of these storms were then analyzed. Values of greatest precipitation were abstracted from the storm data, for areas ranging from 1000 square kilometers to the entire Tigris Basin above the Diyala confluence and for time periods ranging from six to 96 hours. Time estimates were necessarily crude since the only recording rain gage record was for Baghdad. However, readings obtained two and three times daily at Mosul, Khanaqin, Diyarbakir, and Siirt were of great value.

Moisture Inflow Index

Definitions

2.14 Moisture inflow index is a measure of the flow of potential rain-producing moisture into the area under consideration. Moisture inflow index is defined in these studies as the product of precipitable water in the atmosphere and the 24-hour average southeast or southwest quadrant wind speed. Precipitable water is the maximum amount of moisture that can be retained in a vertical column of air and has been found by reliable

research observations to vary almost directly with surface dewpoint. The wind factor is a measure of the time required to replace with a new moisture supply moisture that has been precipitated from the air.

Analysis of Moisture Inflow Index

2.15 Precipitable water was determined from tables (United States Weather Bureau Technical Paper No. 14) relating surface dewpoint and precipitable water above 3500 feet (1070 meters) elevation (assumed moisture barrier height). It was assumed that moisture was carried into the area by winds in the southeast and southwest quadrants because of the counterclockwise rotation of storms moving east from the Mediterranean Sea.

2.16 The moisture inflow index existing during the storm was computed for each of the 14 storms by multiplying the precipitable water (based on the highest 12-hour persisting dewpoint during the maximum 24-hour precipitation in the storm) by average 24-hour wind speed during that period. Mosul, the most central of the first-order stations, was used as the source of data unless weather maps indicated that Kirkuk or Khanaqin values were more representative of a storm. Moisture inflow indices for each storm and the factors upon which they are based are summarized in Table B-2.

2.17 The maximum moisture inflow index which Mr. Paulhus believes could occur and its variation with seasons of the year were based on the Mosul climatological record. The maximum 12-hour persisting dewpoints for each month of the year were obtained by inspection of the record. A curve drawn through these maximum values, together with a curve of corresponding precipitable water, is shown on Exhibit B-5. Maximum southeast or southwest quadrant 24-hour average wind speeds were also obtained

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Table B-2

STORMS USED IN DERIVING PROBABLE MAXIMUM PRECIPITATION

Storm	Representative Maximum Persisting 12-hour Dewpoint (°F)	Precipitable Water (inches)	Maximum 24-hour Average Windspeed (M.P.H.)	Moisture Inflow Index for Historical Storm	Maximum Moisture Inflow Index	Maximizing Factor
1. Feb. 7-12, 1941	56	0.721	13	9.39	19.1	2.04
2. Nov. 15-24, 1942	60	0.903	13	11.74	19.1	1.63
3. Dec. 28 to Jan. 6, 1946	51	0.538	19	10.22	19.1	1.87
4. Feb. 13-18, 1946	50	0.506	14	7.08	19.1	2.70
5. Mar. 10-15, 1946	53	0.602	12	7.24	19.1	2.64
6. Dec. 22-30, 1949	53	0.602	11	6.62	19.1	2.89
7. Jan. 8-14, 1950	50	0.506	16	8.10	19.1	2.36
8. Mar. 4-10, 1950	53	0.602	16	9.63	19.1	1.98
9. Feb. 17-22, 1951	50	0.506	14	7.08	19.1	2.70
10. Feb. 2-6, 1952	50	0.506	14	7.08	19.1	2.70
11. Feb. 4-11, 1953	48	0.456	19	8.66	19.1	2.21
12. Feb. 17-20, 1953	51	0.538	16	8.61	19.1	2.22
13. Feb. 19-21, 1953	47	0.429	16	6.36	19.1	2.78
14. Mar. 23-27, 1954	59	0.855	10	12.68	19.1	1.40

72.

by inspection, and the resulting curve is shown as (c) on Exhibit B-5. The maximum moisture inflow index for each month was obtained by multiplying maximum precipitable water by maximum (but not necessarily concurrent) 24-hour average wind speed. These values are shown as curve (d) on Exhibit B-5.

2.18 The seasonal variation curve shows two almost equal peaks, one in mid-November and the other about the first of April. Since the flood potential is higher in the spring than in the fall because of more critical snowmelt and soil moisture conditions, the probable maximum precipitation was derived for the first of April. The maximum moisture inflow index for this date on Exhibit B-5 (d) is 19.1.

Reliability of Moisture Inflow Index

2.19 From studies of maximum storms throughout the world, meteorologists are of the opinion that major storms of record in given areas involve optimum or near-optimum moisture conditions. Thus, the precipitable water shown on Exhibit B-5, obtained by enveloping those values which would result from historically observed dewpoints, is believed to be the probable maximum. The degree of dependability of the moisture inflow index, with precipitable water being at its probable maximum value, then depends on the magnitude of the wind speed that could occur with the maximum dewpoint. Some meteorologists believe the wind-speed factor should not be increased above the historical value in the storm under consideration. Mr. Paulhus has been more conservative, assuming it could be equal to the maximum historical.

2.20 In the opinion of Mr. Paulhus, it is not physically possible for both precipitable water and wind speed to be at their physically probable

maximum values at the same time. There is no known way of predicting the probable maximum concurrent values. Mr. Paulhus considered that it would be reasonably conservative to take the individual maximum historic values and to assume these had occurred concurrently (with appropriate recognition for time of year). This procedure obviously yielded a value of moisture inflow index appreciably higher than that from the maximum historical combination of precipitable water and wind speed. In Mr. Paulhus's opinion it was sufficiently in excess of the maximum historical combination to assure it was at least equal to and probably greater than the probable maximum.

Derivation of Probable Maximum Precipitation

Depth-Area-Duration Values

2.21 The probable maximum precipitation for the individual subbasins was computed by adjusting the basin depth-area-duration values of each storm by a maximizing factor. This factor is the ratio of the maximum moisture inflow index (19.1 in Table B-5) to that occurring during the storm. The maximized depth-area-duration points were plotted on semi-logarithmic paper and enveloped by a family of curves, each curve representing a different duration time.

2.22 The storm history available for analysis was relatively short, and it was considered possible that the curves for any particular basin might be too low because of inadequate sampling of precipitation occurrences. Therefore, preliminary depth-area-duration curves for mountainous basins were compared with one another as well as those for the plains basins. Any discrepancy in maximized precipitation for equivalent

area and duration was investigated to see if it was based on meteorological causes. This procedure led to the conclusion that the probable maximum precipitation for the individual sub-basins could be properly depicted by two sets of curves, one for the mountainous basins and one for the plains. In each case the highest values of precipitation for a given area and duration of either group of sub-basins established the value which was applied to that entire group of sub-basins. The resulting maximum depth-area-duration curves are shown on Exhibit B-3. Curves for the Diyala above Derbend-i-Khan are shown separately but are identical to the curves for Dokan, Bekhme, and Eski Mosul.

2.23 Estimates of probable maximum precipitation for the combined basins above Diyala Weir, Samarra, Baghdad, and the Diyala-Tigris confluence were also based on observed storms. Average depth of probable maximum precipitation must decrease with an increase in area, so it was not possible to combine the sub-basin values directly. The storms were reanalyzed without regard to sub-basin boundaries; the new depth-area-duration data were maximized; and preliminary curves of probable maximum precipitation for each of the four combined basins were prepared. These curves were also compared to obtain the final combined basin curves, shown on Exhibit B-3 and summarized in Table B-1.

2.24 Six- and 12-hour curves on Exhibit B-3 frequently over-envelop control points for areas under 10,000 square kilometers by fairly large margins. This over-envelopment was considered advisable because of the inadequate records and low gage density for sampling cloudburst rainfall. The six-hour curves for small areas are based on observed cloudburst rainfall in the United States. Other instances of over-envelopment noted in the depth-area-duration curves are due to smoothing the curves and making curve families consistent.

2.25 Probable maximum precipitation presented for April first can be adapted to any time from October to May by applying the percentages indicated by the curve of seasonal variation of moisture inflow index on Exhibit B-5.

2.26 Inspection of the curves will indicate that some of the values for the entire basin, such as on chart (e) of Exhibit B-3, are larger than values for similar areas in the individual sub-basins. As an example, for a drainage area of 20,000 square kilometers, the 96-hour average precipitation over the entire basin is about 460 millimeters, while on the Diyala, the Zabs, and the Upper Tigris, charts (a) and (b), it is about 410 millimeters. This apparent anomaly is due to the criterion adopted of not allowing transposition of storms. The controlling values for the basin as a whole result from storms which centered on divides between the upstream basins and thus are not represented in any of the individual values for upstream basins. In practical application, this fact becomes unimportant because the depth-area-duration data for individual storms are increased in magnitude to equal critical values on the curves of Exhibit B-3, as described later in paragraphs 7.13 through 7.18.

2.27 The reader is especially cautioned that the curves of Exhibit B-3 should not be used directly for all areas. The curves should be applied by the procedure described in paragraphs 7.13 through 7.18.

Snow in Probable Maximum Storm

2.28 Occurrence of a significant portion of probable maximum precipitation as snow would affect the surface runoff peak considerably. It was therefore necessary to investigate the relative proportions of snow and rain which might be expected. Saturated air conditions would prevail

during the probable maximum storm, making surface temperature equal to surface dewpoint. It can be assumed that precipitation when air temperature is below freezing will be predominantly snow. By adjusting Mosul maximum dewpoint on 1 April (62 1/2°F, 18°C, from Exhibit B-5) by the pseudoadiabatic lapse rate, the freezing level is found to be at 11,000 feet (3360 meters). Area-elevation relations (shown later on Exhibit B-6) indicate that less than one percent of any basin is over 11,000 feet elevation. Therefore the probability of snow's occurring during the probable maximum storm was disregarded.

Time Interval Between Storms

2.29 Estimates of the minimum possible time interval between a maximum storm and a major storm were based on studies of 50 years of Northern Hemisphere weather maps. The minimum time intervals are the number of days between the end of the highest 24-hour precipitation in the first storm and the beginning of the highest 24-hour precipitation in the following storm. The minimum time intervals are estimated to be as follows:

Two major storms	3 days
Major storm followed by probable maximum storm	4 days
Probable maximum storm followed by a major storm	7 days

2.30 Rain or snow might occur during the interval between storms, but it would be of such low intensity that it would be unlikely to cause surface runoff. All probable maximum flood studies were based on the alternative of a major storm followed by a probable maximum storm four days later.

Probable Maximum Precipitation on the Euphrates River Basin

2.31 Rough estimates of probable maximum precipitation on the Euphrates River Basin above Ramadi were made by modifying Tigris Basin results. Depth-area-duration curves were not prepared for the Euphrates Basin because the data essential for such detailed analysis were unavailable or nonexistent.

2.32 Storms used in developing probable maximum precipitation over the Tigris Basin are controlled by the basin topography in a unique way. They cannot be transposed, without modification, to a nearby basin. A rough estimate of the general magnitude of probable maximum precipitation can be obtained, however, by transporting storms directly, or in other words, using depth-area-duration curves prepared for one basin to estimate precipitation on a nearby, similar basin. The resulting accuracy will not approach that obtained by using the curves for the basin for which they were derived, but the results have far more reliability than a pure guess.

2.33 The Euphrates Basin above Ramadi was estimated as 270,000 square kilometers, although there is considerable uncertainty about the location of the drainage divide in the desert areas of western Iraq and eastern Syria. However, the significant precipitation falls in the mountainous Turkish portion of the basin, the area of which is about 80,000 square kilometers. The depth-area-duration curves of observed storms, and hence the probable maximum precipitation, would logically be expected to show rapid decrease of precipitation with increase in area above 80,000 square kilometers.

2.34 Depth-area-duration curves for the Tigris River above Baghdad, Exhibit B-3(d), show a rapid decrease in precipitation above 80,000 square kilometers and, of the curves available, are probably most nearly applicable

to the Euphrates above Ramadi. Depth-area-duration curves in Exhibit B-3(d) and (e) show that the product of precipitation depth and areas above 120,000 square kilometers remains practically constant. In other words, the area covered by the probable maximum storm on the Tigris Basin above Baghdad (134,700 square kilometers) is about 120,000 square kilometers. For larger areas, average precipitation depth is merely that total storm volume divided by the area in question. If this is true, depth-area-duration curves for the Tigris Basin above Baghdad may be simply extrapolated to the area of the Euphrates Basin above Ramadi by the ratio of drainage areas (134,700/270,000).

2.35 Mean annual precipitation data available for the mountainous portion of the Euphrates Basin indicate less precipitation at a given altitude than in the Tigris Basin. Probable maximum precipitation is related to mean annual precipitation, so the extrapolation by the above ratio was reduced to 75 percent, the approximate ratio of Euphrates to Tigris mean annual precipitation. Probable maximum precipitation, roughly estimated as described above, is shown in Table B-3.

Table B-3

ESTIMATED PROBABLE MAXIMUM PRECIPITATION
EUPHRATES RIVER BASIN ABOVE RAMADI
(270,000 SQUARE KILOMETERS)

Duration (hours)	6	12	18	24	36	48	72	96
Probable Maximum Precipitation (mm)	20	31	39	46	56	64	78	90

Chapter B-3

MAXIMUM SNOW ACCUMULATION

Basic Data

3.1 Recorded measurements of snow accumulation and snow water equivalent in the Tigris River Basin were practically nonexistent at the time the hydrometeorological studies were made. Some measurements of depth of snow on the ground at Turkish stations near the Tigris Basin were obtained, but these did little more than establish the fact of snow accumulation at their particular elevations.

3.2 The inadequacy of the available data necessitated the use of additional data from actual snow surveys in a similar area. Of the regions having the required snow survey data, southern California in the United States is considered to have climatological and physiographic characteristics most nearly resembling those of the Tigris Basin. Comparison of upper-air temperatures, humidity, and precipitation regimes of the two areas indicated reasonable agreement. The latitudes and resulting solar radiation of the two areas are also about the same. The Sierras of southern California, like the mountains of the upper Tigris Basin, provide the first substantial barrier or lift to moisture flowing in from its source.

Elevation of Snow Line

3.3 The existing data were used to estimate the mean elevation of the snow line. The data indicated that near 40° latitude the mean snow line was about 4500 feet (1380 meters) on 1 April and about 3800 feet (1160 meters) on 1 March. The stations from which the snow-line elevation was

estimated are all north of the Tigris Basin, so it was necessary to derive a relation between snow line and latitude.

3.4 The north-south temperature gradient for altitude up to 14,000 feet (4280 meters) was determined from radiosonde measurements of upper-air temperature made at Habbaniyah, Iraq and Diyarbakir, Turkey. Mean October-through-March temperatures for various elevations were plotted against their latitudes, and straight isotherms (lines of equal temperature) were drawn, as shown on Exhibit B-7(a). The 1 March and 1 April snow-line elevations of 3800 and 4500 feet were plotted on Exhibit B-7(a) at 40° latitude, and constant-temperature lines were drawn through the points to establish the variation of the snow line with latitude. The apparent inconsistencies in temperature at the snow line on Exhibit B-7(a) result from the use of October-March mean temperatures.

3.5 Snow depth measurements in the Sierras of southern California on 1 March and 1 April were inspected and found to have reasonable agreement with the relation of Exhibit B-7(a). The California data also indicated that for years with unusually heavy snowfall and/or unusually cold temperatures the snow-line elevations may be as much as 1000 feet (306 meters) lower. This 1000-feet departure from the mean was considered to be applicable in the Tigris Basin as well.

3.6 The approximate mean latitude of the higher terrain, above 5000 feet (1530 meters), of each of the four mountainous sub-basins was determined by inspection and plotted as dashed lines on Exhibit B-7(a). It was concluded that snowmelt from areas other than the four mountainous sub-basins would be a negligible factor; thus, this factor was not studied. Mean snow-line elevations obtained for the four basins are summarized in Table B-4, together with the lowest snow-line elevation, estimated by applying the 1000-foot departure from the mean.

Table B-4

ELEVATION OF SNOW LINE

(feet above mean sea level)

Basin	1 March		1 April	
	Mean	Lowest	Mean	Lowest
Tigris above Eski Mosul Damsite	5300	4300	5800	4800
Greater Zab above Bekhme Damsite	5600	4600	6100	5100
Lesser Zab above Dokan Dam	6300	5300	6800	5800
Diyala above Derbend-i-Khan Dam	6900	5900	7400	6400

Maximum Water Equivalent

3.7 Water equivalent of snow is the depth of liquid water which corresponds to a particular depth of snow. The relation of snow depth to its water equivalent is variable. Since the water produced by melting the snow is the item of interest, it is convenient to discuss snow quantities in terms of their water equivalent.

3.8 In the data available, there were no measurements of water equivalent of the accumulated snow on the ground, so it was necessary to use the California snow-survey data. Mean 1 April water equivalents for 15 snow courses were plotted against the corresponding mean precipitations during the October-March snow accumulation period. Each point was labelled with its October-March mean temperature. A family of curves relating mean 1 April water equivalent to mean winter precipitation and mean winter temperature was developed and is shown on Exhibit B-7(b).

3.9 The relation on Exhibit B-7(b) indicates a mean winter temperature of about 45°F (7°C) in California at the 1 April snow line (zero water equivalent) compared with about 36°F (2°C) for Iraq as indicated on Exhibit B-7(a). Possible reasons for the nine-Fahrenheit-degree discrepancy are that factors other than temperature and precipitation affect snow accumulation and that differences in such factors exist between the two regions being compared. The difference in temperatures was accounted for by adding nine Fahrenheit degrees to sub-basin temperatures when obtaining 1 April water equivalent from Exhibit B-7(b).

3.10 The relation between mean October-March precipitation and mean annual precipitation is plotted on Exhibit B-7(c). Mean winter precipitation was determined to be about 78 percent of mean annual precipitation.

3.11 Relations derived to this point allow the estimation of mean water equivalent only. Water equivalent values are not maximized in the same manner as probable maximum precipitations are. Most major snowmelt floods result from unusually critical temperature situations, providing there is sufficient snow cover to sustain the high melting rates over as large an area as possible. Ordinarily, the maximum water equivalent of record with maximum melting rates is sufficient to provide the maximum snowmelt flood peak. The relation expressing maximum 1 April water equivalent as a function of mean 1 April water equivalent, shown on Exhibit B-7(d), is an envelope of maximum recorded 1 April water equivalent for 20 California stations averaging about thirteen years or record.

3.12 The 1 April water equivalent for sub-basins in Iraq was estimated by applying the relations presented on Exhibit B-7(a), (b), (c), and

(d) and Exhibit B-8. Temperature for a given basin and elevation is obtained from Exhibit B-7(a); mean annual precipitation, from Exhibit B-8 (the relation $P = 205 + 0.17 Z$ was used since most snow occurs at high, exposed locations); and mean October-March precipitation, from Exhibit B-7(b). Exhibit B-7(c) is then used to find mean 1 April water equivalent, which is used in the relation of Exhibit B-7(d) to estimate maximum 1 April water equivalent.

3.13 Table B-5 shows an example computation of 1 April water equivalent for various elevations in the Derbend-i-Khan Basin. Lowest snow-line elevation is taken from Table B-4 as 6400 feet. The table shows, step by step, how maximum water equivalent was estimated down to 7600 feet (2330 meters) elevation. The relation of Exhibit B-7(a) is based on the mean snow-line elevation of 7400 feet (2260 meters), so it cannot be used to estimate water equivalents below the mean snow line. The values down to 7600 feet were plotted against elevation and a curve drawn through them to zero-equivalent at 6400 feet (1960 meters). The curve was then used to estimate the maximum water equivalent at 7400 feet (2260 meters) and 7000 feet (2140 meters).

3.14 The probable maximum rain storms were computed for the period 1-4 April, but in order to obtain maximum snowmelt contribution to the storm runoff, snowmelt computations were started in March. Therefore it was necessary to estimate snow accumulation for a date earlier than 1 April. Mean water equivalent on 1 March was related to 1 April mean water equivalent as shown in Exhibit B-7(e). An envelope curve relating mean 1 March water equivalent to maximum 1 March water equivalent, Exhibit B-7(f), was prepared in the same manner as Exhibit B-7(d). Maximum 1 March water equivalent was computed by applying

Table B-5

COMPUTATION OF MAXIMUM 1 APRIL WATER EQUIVALENT,
DIYALA RIVER ABOVE DERBEND-I-KHAN DAM

Elevation (1000 feet)	11.0	10.0	9.0	8.0	7.6	7.4	7.0	6.4
Winter temperature (°F), Exhibit B-7(a)	24	27	30	34	35	36	-	-
Adjusted winter temperature (°F)	33	36	39	43	44	45	-	-
Annual precipitation (mm), Exhibit B-8	1740	1740	1740	1560	1500	1460	-	-
Winter precipitation (mm), Exhibit B-7(c)	1360	1360	1360	1220	1170	1140	-	-
Mean 1 April water equivalent (mm), Exhibit B-7(b)	1280	1150	930	340	160	0	-	-
Maximum 1 April water equivalent (mm), Exhibit B-7(d)	2030	1850	1750	1160	760	(570)	(290)	-

25

the relations of Exhibit B-7(e) and (f) to mean 1 April water equivalent. Values between the mean snow line and the lowest snow line were interpolated from a curve drawn through the computed values to zero at the snow line.

3.15 Maximum 1 March and 1 April water equivalent values for various elevations above the lowest snow line in the four mountainous sub-basins are summarized in Table B-6.

Table B-6

MAXIMUM SNOW WATER EQUIVALENT ABOVE DAMSITES

(millimeters)

Diyala River above Derbend-i-Khan

Elevation (ft. msl)	1 March	1 April
11,000	1650	2030
10,000	1570	1850
9,000	1420	1750
8,000	940	1160
7,500	670	660
6,900	370	230
6,400	160	0
5,900	0	

Lesser Zab River above Dokan

Elevation (ft. msl)	1 March	1 April
11,000	1680	2080
10,000	1630	2010
9,000	1530	1870
8,000	1220	1500
7,000	710	730
6,500	480	380
6,000	260	110
5,800	180	0
5,300	0	

Greater Zab River above Bekhme

Elevation (ft. msl)	1 March	1 April
13,000	1680	2080
12,000	1680	2080
11,000	1680	2080
10,000	1670	2060
9,000	1600	1970
8,000	1420	1750
7,000	1050	1310
6,000	540	420
5,500	310	140
5,100	160	0
4,600	0	

Tigris River above Eski Mosul

Elevation (ft. msl)	1 March	1 April
11,000	1680	2080
10,000	1680	2080
9,000	1630	2010
8,000	1470	1800
7,000	1150	1430
6,000	670	620
5,500	440	310
5,000	220	80
4,800	150	0
4,500	50	
4,300	0	

Chapter B-4

BASIN RETENTION

Definition of Retention

4.1 Runoff from a rainstorm is equal to the volume of rain which falls on a drainage basin less the amount retained in the basin. Of the water retained in the basin, some is lost to streamflow entirely and the balance enters the stream long after the time of peak flows.

4.2 Rain is retained in a basin or lost to storm runoff by wetting of vegetation and soil, by filling undrained depressions ranging from puddles to ponds, by evaporation and transpiration during the storm, by being absorbed and held in snow, and by infiltration into the soil. Retention is high at the beginning of a storm, but as depressions fill and surfaces become thoroughly wetted, the rate of retention diminishes. In a storm of long duration, the retention rate eventually falls to a point where it equals the equilibrium rate of recharge to ground water by infiltration through the soil.

4.3 Retention at the beginning of a storm is very dependent upon the moisture conditions in the basin. Capacity to hold water will be high after a prolonged dry period and low if the rainless interval has been short. It was assumed in all hypothetical flood studies that a major storm preceded the probable maximum storm by the shortest possible rain-free interval, so that retention losses were at the minimum that could be expected at the time of the probable maximum storm.

4.4 For convenience in computations, basin retention is divided into an initial loss and a uniform hourly retention rate. The initial loss is a

fixed quantity of rainfall which satisfies depression storage and the initial soil infiltration capacity. The uniform hourly retention rate satisfies the equilibrium infiltration capacity of the soil and other losses during the storm.

4.5 The estimated retention rates in the various sub-basins of the Tigris River system are shown on Exhibit B-9. These estimates were based on data from similar basins in the United States that have been studied extensively, supplemented by the limited data available from analysis of floods in the Tigris River Basin and field inspections of the Tigris watershed.

Analytical Determination of Retention

4.6 Attempts were made to determine basin retention from actual field data of rainfall and runoff. The general approach in this type of analysis is to assume values of initial loss and retention rate, apply them to storm rainfall, and equate the remaining rainfall excess to the measured runoff volume. The process is repeated with different retention values until the computed rainfall excess is equal to the measured runoff. If consistent results are obtained from several storms, it can be assumed that the derived retention rates are correct.

4.7 The accuracy of derived retention is dependent on the accuracy with which volume, distribution, and timing of rainfall and runoff can be estimated. Rain-gage records available in 1957 were not sufficient in number or detail for estimates of high accuracy. A successful analytical determination of basin retention should be possible within a few years, with more detailed records of rain and runoff for smaller basins. Of special value will be the new rain- and stage-recording gages which simplify the time analysis of hydrologic events.

Retention Estimates

4.8 With the lack of conclusive field retention data, a great deal of judgment was required in the final estimate of basin retention. Discussions with members of our field staff and with hydraulic engineers with long experience in Iraq gave a qualitative basis for differentiation of areas. The conclusions reached from these discussions were as follows:

a. Retention rates in unvegetated desert areas are very low owing to the impervious nature of the soil. However, many blind drainage areas exist in the flatter desert regions.

b. Retention rates are larger in the more humid highlands, owing to plant cover and the more organic nature of the soil.

c. Retention rates in the Ruwanduz and northern Lesser Zab areas are very high because of the prevalence of cavernous limestone with many solution channels, as indicated by the large number of springs. Areas exist in the mountains where all precipitation goes directly into ground water with no surface runoff.

4.9 Results of double-ring infiltrometer tests made in the Khazir and Eski Kelek irrigation investigations were obtained from the Kuljian Corporation. These values were generally much higher than the rates shown on Exhibit B-9. The infiltrometer results were not given much weight in the final estimate because they were not believed to be a representative sampling. Tests were made only on potentially irrigable lands, which are expected to have high infiltration rates because of their soil and slope characteristics. The infiltrometer test is more representative of irrigation water application than of rainfall and is always subject to lateral losses.

4.10 In discussion with experts of United States Government Agencies, suggestions were made, based on Western United States experience, for use of the following retention rates:

a. For the portion of the mountainous areas made up primarily of cavernous limestone, 6-7 mm/hr.

b. For the non-limestone mountainous areas, 3-4 mm/hr.

c. For the heavily eroded foothill areas above Eski Mosul, north of the Tigris River in Turkey, 2-3 mm/hr.

d. In the main Tigris valley above Eski Mosul, on both sides of the river, where the lands are more extensively cultivated, 3-4 mm/hr.

e. In the foothills area below the damsites, 2 mm/hr.

f. On the plains areas (providing non-contributary areas are eliminated), 1 mm/hr.

4.11 In the interests of conservatism, our adopted values shown on Exhibit B-9 are somewhat lower than those listed above. The values are believed to be at the low end of the probable range of values.

4.12 Several studies were made to determine the effect of variations in basin retentions. An increase of 33 percent in retention on the Dokan and Eski Mosul basins caused reductions of about 22 percent in probable maximum flood peaks and about 12 percent in the 20-day probable maximum flood volume.

Retention Losses in Snow-Covered Areas

4.13 A portion of the drainage area would be covered by snow at the time of the maximum storm, with a resultant change in retention characteristics. The water-holding ability of dry snow would greatly increase

the initial loss. On the other hand, the antecedent storm would have reduced the storage capacity of the snow, and the possibility of frozen ground under the snow would reduce infiltration. These factors were assumed to balance. The retention rates were assumed to be the same in snow-covered areas as in non-snow-covered areas, and no adjustment was made in retention for areas of comparable topography and geology.

Chapter B-5

UNIT HYDROGRAPHS

Unit Hydrograph Theory

5.1 Storm precipitation was converted to flood runoff by application of the unit hydrograph principle. The unit hydrograph theory was advanced by L. K. Sherman[1/] in 1932 and has since become a widely accepted hydrologic tool. It is defined as the hydrograph (runoff pattern) that will result from a unit amount of rainfall excess on the basin in a unit time.

5.2 In these studies, the unit hydrographs represent the outflow from the basin caused by a rainfall excess (rain water remaining after retention has been satisfied) over the basin of one centimeter in six hours. The unit hydrograph theory is strictly applicable only to storms of similar duration and areal distribution over the basin. Under this theory, the time bases of the outflow hydrographs are equal and the ordinates of the outflow hydrographs are directly proportional to the volume of rainfall excess. Thus, a storm producing ten centimeters of rainfall excess in six hours would produce a hydrograph whose peak would be twice that produced by a storm with five centimeters of rainfall excess. However, the time required for surface runoff to be completed would be the same in each case.

5.3 Exhibit B-10(c) shows an example of the use of unit hydrographs in determining the flood hydrograph due to a probable maximum storm. Since the unit of rainfall excess is one centimeter, the runoff caused by each six-hour period of rainfall excess is that rainfall excess multiplied by the unit hydrograph ordinates. For example, for a rainfall excess of

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1/ Sherman, L. K. "Streamflow from Rainfall by the Unit-Graph Method," Engineering News-Record, vol. 108, pp. 501-505, 1932.

1.9 centimeters, all ordinates of the unit hydrograph would be multiplied by 1.9. Each resulting hydrograph is then added, in proper time sequence, to obtain the total storm hydrograph, whose volume is equal to the total volume of rainfall excess. The outflow from various sub-basins can be combined by flood routing to obtain the flood flows for very large basins.

Development of Tigris Basin Unit Hydrographs

5.4 Rainfall and river discharge data for the Tigris River system were not in sufficient detail for use in deriving unit hydrographs at each desired point. However, analysis was considered possible for the Lesser Zab River above Dokan, the Khazir River above Manquba, and the Adhaim River above Injana. Our approach was to use these available data for individual sub-basins as a key to analysis of the entire Tigris system. Derivation of the Dokan unit hydrograph will be described as an example.

5.5 Available records of precipitation for all stations in or near the Dokan Basin were obtained. Precipitation was measured daily, usually at nine a.m., and at the time the analyses were made, no recording gages were in operation. Investigations of three-hourly reports from Meteorological Department offices in Mosul, Kirkuk, and Khanaqin gave some information about timing of rainfall. Six-hourly weather maps prepared by the Meteorological Office at Baghdad Airport were also studied to determine the character, distribution, and rate and direction of movement of precipitation areas. Accumulated precipitation was plotted against time to obtain mass curves of rainfall. First, the key stations of Mosul, Kirkuk, and Khanaqin were plotted, and then, with those stations for a guide, the precipitation for the balance of the stations was plotted. The mass curves were used for estimating the time duration and volume of individual rain showers.

5.6 Original discharge and gage-height records for the Lesser Zab River at Dokan Ferry were studied in an effort to find data to allow more detailed plotting of the river hydrograph. In general, however, only daily readings had been made, and smooth curves were interpolated between these points in an attempt to give the best approximation of the actual river flow. Mass curves of rainfall were shown on the hydrograph plot to the same time scale to implement the relating of rain to runoff. Well isolated storms that caused clearly defined hydrograph peaks were selected for further study.

5.7 The storm of 17 February 1953, Exhibit B-10(a), and its corresponding hydrograph peak were selected as well suited for further study. The effective rain shower and the corresponding hydrograph peak for this storm were clearly defined. The small showers preceding the selected storm were apparently insufficient to cause runoff, as can be seen from the hydrograph. Base flow was extrapolated from the pre-storm level to represent typical ground water conditions. Hydrograph inflections caused by subsequent showers were separated by continuing a typical recession curve. The remaining area of the hydrograph represents the volume of runoff produced by the selected storm. Therefore it also represents the volume of rainfall excess.

5.8 Rainfall excess volume over the Dokan Basin from the storm of 17 February 1953 was determined to be 5460 cumec-days or the equivalent of 4.04 centimeters of depth over the drainage area. The rain storm used for analysis was judged to have a time duration of 18 hours. An 18-hour unit hydrograph based on the runoff from this storm has ordinates equal to 1.0 divided by 4.04, multiplied by the ordinates of the historical hydrograph, but has the same time distribution of discharge.

5.9 A unit duration of six hours had been selected for Tigris system unit hydrographs, so it was necessary to develop the six-hour graph from the derived 18-hour graph. The 18-hour unit hydrograph would be the graphical summation of three six-hour unit hydrographs, each of one-third the total volume, added six hours out of phase. A six-hour unit hydrograph that met these qualifications was determined by trial and error, as shown on Exhibit B-10(b). The lag time (mid-point of rain to hydrograph peak) of the adopted six-hour unit hydrograph was reduced from 36 hours to 27 hours to conform with other peaks in the Dokan discharge record.

Synthetic Unit Hydrographs

Tigris Basin Relationships

5.10 Since so little suitable data were available for direct derivation of unit hydrographs,it was necessary to use synthetic methods to develop the unit hydrographs for most of the areas. The Tigris Basin was divided for unit hydrograph purposes into 15 sub-basins. Although it is usually recommended that unit hydrographs be limited to areas less than about 8000 square kilometers, it was considered desirable to allow the use of basins up to 18,000 square kilometers. Further subdivision was not considered to be consistent with the accuracy of the probable maximum storm, since the coverage by rain gages is too sparse to define rainstorm areas closely. In addition, orographic rainfall (rain due to the influence of mountains) tends to repeat the same areal distribution, justifying the use of larger sub-basins in the Tigris River system. One sub-basin, the Central Tigris at Samarra, totals 30,800 square kilometers, but its unit hydrograph is a composite of several unit hydrographs for small basins.

5.11 Curves depicting the relation of unit hydrograph peaks to highland and lowland drainage areas are shown on Exhibit B-11(a). The "highlands" line represents the mountainous areas of the Tigris catchment, and the "lowlands" line represents the foothills and plains. Although unit hydrograph peaks for similar basins increase with increasing area, the unit peaks, in terms of runoff per unit of area (cumecs per square kilometer), will decrease with increasing area. This fact can be represented by a straight line on log-log paper.

5.12 Unit hydrograph data for basins with similar physiography and climate were obtained from United States Corps of Engineers publications. These points were used to establish the slope of the lines. The average results of the Dokan, Khazir, and Adhaim unit hydrograph studies determined the magnitude and relative position of the lines.

Snyder Method

5.13 The method used for development of synthetic unit hydrographs is based on a paper by Snyder[2/]. The Snyder method presents relations for determining the peak, lag time, and shape of unit hydrographs, based on the physical characteristics of the drainage basin. According to Snyder:

$$t_p = C_t (L L_{ca})^{0.3} \qquad q_{pR} = \frac{640\, C_p}{t_{pR}}$$

$$t_r = \frac{t_p}{5.5} \qquad Q_p = q_{pR} A$$

$$t_{pR} = t_p + 0.25 (t_R - t_r) \qquad T = 3 + 3 \frac{(t_p)}{(24)}$$

2/ Franklin F. Snyder, "Synthetic Unit Graphs," Trans. Amer. Geophysical Union, Part 1, 1938, pp. 447-454.

where

t_p	=	Lag time from the midpoint of unit rainfall duration, t_r, to the peak of unit hydrograph in hours.
L	=	River channel length from station to upstream limit of drainage area in miles.
L_{ca}	=	River channel length from station to center of gravity of the drainage area in miles.
t_r	=	Unit rainfall duration.
t_R	=	Selected unit rainfall duration (six hours in Hydrological Survey studies).
t_{pR}	=	Lag time from midpoint of selected unit rainfall duration, t_R, to peak of hydrograph, in hours.
q_{pR}	=	Peak rate of discharge of unit hydrograph for selected unit rainfall duration, t_R, in cubic feet per second per square mile.
Q_p	=	Peak rate of discharge of unit hydrograph in cubic feet per second.
T	=	Time base of unit hydrograph in days.
A	=	Drainage area in square miles.
C_t & C_p	=	Coefficients depending on drainage basin characteristics. Average C_t values based on derived unit hydrographs are 1.8 for highlands and 1.7 for lowlands.

5.14 Snyder also suggested typical unit hydrograph shapes by means of curves showing the time distribution of unit hydrograph volume. His curves are reproduced as Exhibit B-11(c). The curves relate the volume of discharge of each day of the unit hydrograph to the lag time, t_{pR}. Studies of concentration of flow near the peaks of unit hydrographs by the Corps of

Engineers resulted in the graph presented as Exhibit B-11(b), which shows the relation of unit hydrograph peak to width in hours at 75 percent and 50 percent of the peak discharge.

Adopted Unit Hydrographs

5.15 Graphical and tabular summaries of the adopted unit hydrographs for the Tigris sub-basins are presented in Exhibit B-12. The procedure used in developing the unit hydrographs was as follows:

a. The unit peak was obtained from the peak to drainage area relation, Exhibit B-11(a).

b. The lag time, t_{pR}, for a six-hour rainfall interval and the time base, T, were determined from the Snyder equations. Values of C_t of 1.8 for highlands and 1.7 for lowlands (metric units) were obtained by substituting Tigris sub-basin data and actual storm-runoff lag times in Snyder's lag equation.

c. The peak and time base were plotted on graph paper together with the approximate daily distribution of flow taken from Exhibit B-11(a).

d. A trial hydrograph was drawn considering the 75-percent and 50-percent widths from Exhibit B-11(b).

e. The enclosed area was measured by planimeter and compared with the area computed to represent one centimeter of water over the drainage basin.

f. The trial unit hydrograph was adjusted until its area and the computed area were equal.

g. Six-hour ordinates were read off the final unit hydrograph.

Chapter B-6

FLOOD ROUTING

General Procedure

6.1 Flood routing is the process of translating a hydrograph from one station on a river to another station farther downstream. In doing so, adjustments must be made in time and shape due to the hydraulic characteristics of the river reaches. Many methods of flood routing, varying in accuracy and complexity, have been developed to fit various conditions. The Muskingum or coefficient method was selected for use because it is simple to prepare and use, rapid, and sufficiently accurate.

6.2 The Muskingum equations - see Exhibit B-13(c) - contain two constants which relate to the river characteristics. They are "x", a measure of wedge storage, and "K", a measure of prism storage in a river reach. "K" has units of hours and is approximately equal to flood peak travel time. Values of measured peak travel times were obtained from the Directorate General of Irrigation report "Forecasting the Peak Levels for the Tigris," 1955, by Dr. Bakir Kashif Alghita. The value of "x", a dimensionless ratio, may vary from zero to 0.5 and was assumed throughout to be 0.2, a common value for similar rivers.

6.3 To test the adopted values of "K" and "x", the March 1954 flood flows of the Tigris River at Mosul, the Greater Zab at Eski Kelek, and the Lesser Zab at Altun Kupri were routed to Fatha and compared to Fatha recorded discharge as shown on Exhibit B-13(c). The results are shown graphically on Exhibit B-13(a). Since the original hydrographs are poorly defined because of infrequent gage readings and since an unknown amount of local inflow occurs between the upstream points and Fatha, it was considered that the routing procedure is satisfactory.

6.4 Many river reaches in Iraq have cross sections which consist of a well defined channel capable of containing moderate floods and a wide flood plain inundated only during major floods. When the normal channel banks are overtopped, a great increase in valley storage occurs as the water spreads over the flood plain. Values of "K", the prism storage factor, were determined for both in-bank and over-bank flow on the basis of idealized cross sections with total widths of two kilometers and three kilometers. The results obtained from trial routings of the probable maximum floods with these "K" values are shown on Exhibit B-13(b). Since the value of "x" was not determined analytically, "x" values of 0.1 and 0.3 were also tested and are compared on Exhibit B-13(b) with the result obtained when x = 0.2. The results of these comparisons, we feel, justify the simple use of observed travel time for "K" and the selected value of 0.2 for "x".

Derivation of Routing Factors

6.5 After selecting values for "K" and "x", computations are as illustrated on Exhibit B-13(c). Coefficients c_1, c_2, c_3, and c_4 are determined from the Muskingum equations:

$$c_1 = \frac{\Delta t - 2\,Kx}{2\,K\,(1 - x) + \Delta t}$$

$$c_2 = \frac{\Delta t + 2\,Kx}{2\,K\,(1 - x) + \Delta t}$$

$$c_3 = \frac{2\,K\,(1 - x) - \Delta t}{2\,K\,(1 - x) + \Delta t}$$

$$c_4 = c_1\ c_3 + c_2$$

where Δt = the selected time interval (six hours in these studies).

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6.6 These constants are used in the general routing equation:

$$O_n = c_1 I_n + c_2 I_{n-1} = c_3 O_{n-1}$$

where O = outflow from the foot of the reach

I = inflow to the head of the reach

n = the current time interval; n-1, the preceding interval, etc.

In general terms, the outflow from a river reach during a time interval is equal to a proportion of the inflow during that interval, plus a proportion of the inflow during the previous interval, plus a proportion of the outflow during the previous interval.

6.7 The routing equation may also be expressed in terms of inflow alone by a binomial expansion:

$$O_n = c_1 I_n + c_4 I_{n-1} + c_4 c_3 I_{n-2} + c_4 c_3^2 I_{n-3} \ldots\ldots + c_4 c_3^{m-1} I_{n-m}$$

The coefficients in this equation indicate the effect of each preceding inflow interval on the outflow from the reach. The coefficients of earlier periods become small, and in these studies only coefficients greater than 0.005 were considered. This equation furnishes a set of constants by which appropriate inflows are multiplied for determining the outflow of a reach. Constants for longer reaches may be conveniently determined by routing a hydrograph with ordinates of zero, one, zero through the desired number of sub-reaches. An example of this procedure is shown on Exhibit B-13(c). A summary of constants used in flood routing in the Tigris system is also shown on Exhibit B-13(c).

Chapter B-7

MAXIMUM FLOODS AT THE DAMSITES

Summary

7.1 Probable maximum flood hydrographs at Dokan, Derbend-i-Khan, Eski Mosul Damsite, and Bekhme Damsite were computed by combining runoff from a "maximized" rain storm, maximum concurrent snowmelt runoff, runoff from a major antecedent rain storm, and base flow. Six-hour ordinates of the four components were added, with proper orientation in time, to produce a total flood hydrograph for the highest 20-day period between 26 March and 16 April.

7.2 The maximized rain storm was assumed to occur during the period 1-4 April, to correspond with one of the seasonal peaks of atmospheric moisture inflow. Exhibit B-5(d) indicates two peaks of moisture inflow index, about 15 November and 1 April. Since only minor snowmelt contribution is possible in autumn, the November peak was not considered. The relative magnitudes of reduction in maximum rain runoff and increase in maximum snow runoff preclude consideration of any date other than 1 April for the maximized rain storm.

7.3 The runoff from rainfall from the storm of 23-24 March 1954, which contributed to the record 1954 flood, was used for the antecedent storm. Maximum snowmelt runoff was determined by considering optimum temperatures combined with maximum snow accumulation. Base flow values were obtained by inspection of historical hydrographs.

7.4 Floods having peaks of 50 and 75 percent of the probable maximum flood were also estimated. A volume of the maximum 20 days of the flood was determined first, and the 20-day hydrograph was proportioned accordingly.

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Runoff From Maximum Storm

General Procedures

7.5 Flood hydrograph contributions from probable maximum precipitation were derived by determining the quantity of precipitation which would be retained by the soil and applying the balance or "rainfall excess" to the basin unit hydrograph.

7.6 Depth-area-duration curves, shown on Exhibit B-3, indicate the relation between area and average probable maximum precipitation (PMP). If a maximum storm should occur, rainfall over an entire drainage basin would not be uniformly equal to the average indicated by the depth-area-duration curves. Some portions of the basin would have higher precipitation than the indicated average and some would have less. Average rain over any fraction of the basin, however, cannot exceed the depth indicated by the depth-area-duration curves for the fractional area.

7.7 Retention rates, as shown on Exhibit B-9, vary throughout the drainage basins. Different combinations of rainfall intensity and retention rates will produce different rates of runoff, varying from none at all where rainfall is less than retention capacity, to very high rates where high-intensity rain falls on areas of low retention. Since retention capacity is a fixed quantity per unit of area, the concentration of a given volume of rain over the smallest possible area will produce the greatest volume of runoff.

7.8 Use of average PMP over an entire drainage basin would lead to false values of runoff peak and volume, the computed values generally being too low. It was concluded that the most realistic areal distribution of rainfall intensity would be a distribution based on actual occurrences.

Distributions based on recorded storms reflect the orographic effect of mountain barriers, the increase of precipitation with elevation, and the general effects of atmospheric circulation.

7.9 Isohyetal maps of 14 critical storms were prepared in the determination of probable maximum precipitation. These same maps were used as typical rain distributions in determining runoff from probable maximum precipitation. Each storm which applied to a particular basin was maximized, and the rainfall excess and the corresponding flood hydrograph were determined. The highest flood peak produced by any of the storms applied to a basin was adopted as the probable maximum flood for that basin. In each basin several of the peaks were very near the value of the maximum peak. This lends confidence that the adopted value is a close approximation of the critical rainfall distribution.

7.10 Actual rainfall is distributed in time as well as area. The criteria determined in the hydrometeorological studies consider storms of up to 96 hours in duration. A typical time distribution of rainfall was determined as shown on Exhibit B-14, in which the bulk of the rainfall occurs in the first 48 hours. Preliminary analyses showed that rainfall in the last 48 hours of the proposed sequence was always less than retention capacity; therefore, it was only necessary to consider storm durations of 48 hours. Maximum 48-hour precipitation of each recorded storm was increased by a "maximizing factor" to equal the 48-hour PMP.

7.11 Rainfall excess was computed for each specific combination of rainfall intensity and retention rate in the selected storm by subtracting initial losses and equilibrium retention from the six-hour rainfall increments. The individual rainfall excesses were totaled over the basin and converted to streamflow by use of the basin unit hydrograph.

7.12 Some precipitation in the maximized storm would fall as snow on the higher areas. The Mosul dewpoint during the maximum storm must be 62 to 63°F (17°C), as shown in Exhibit B-5, and the freezing level would then be between 11,000 feet (3360 meters) and 12,000 feet (3670 meters). Less than one percent of any catchment area is above that elevation; therefore, precipitation falling as snow was considered negligible.

Maximization of Historical Storms

7.13 Depth-area curves of 48-hour precipitation over the basin were drawn for each historical storm. These curves were based on the highest 48-hour increment of precipitation in the storm and the total storm isohytal map. Exhibit B-15(b) shows the 48-hour depth-area curve of the storm of 2-6 February 1952 over the Bekhme drainage basin. This curve is plotted to the same scale as the Bekhme probable maximum depth-area-duration curves. The storm was maximized by shifting its 48-hour curve to the right until it just contacted the 48-hour probable maximum curve.

7.14 A detailed example, illustrated on Exhibit B-15, will be described. The isohyetal map of the selected storm, as developed in the hydrometeorological analysis, is shown in (a). It was assumed that three levels of rainfall intensity would adequately represent areal rainfall distribution. The basin was divided along isohyetal lines into approximately equal areas of high, medium, and low rainfall. In this case the area of recorded rain higher than 200 millimeters was selected for the high rainfall area; 160 to 200 millimeters, for the medium rainfall area; and below 160 millimeters, for the low rainfall area.

7.15 Average recorded rainfall depth within the high-rain area was determined by dividing the volume of rain by the area. This result was

plotted against the area as the lowest point on the recorded depth-area curve in (b). Average rainfall over the combined medium and high areas was determined and plotted as the middle point on the recorded depth-area curve. Average rainfall over the entire area was plotted as the top point on the curve. In these computations it was possible to use values of rainfall volume and area which had already been determined in the hydrometeorological analyses. The isohyetal lines shown are for the entire recorded storm duration of 102 hours, but values used in plotting the depth-area curve were based on the highest 48-hour rain. This procedure is not inconsistent because the isohyetal lines are used only as a typical distribution.

7.16 The storm was maximized by shifting its depth-area curve to the right to contact the depth-area curve of 48-hour probable maximum precipitation. The ratio by which the observed storm curve had to be multiplied to just contact the probable maximum curve is called the maximizing factor. Precipitation values for the maximized storm were obtained by multiplying recorded storm 48-hour values by the maximizing factor.

7.17 Time distribution of precipitation in the maximized storm was based on the basin PMP curves and Exhibit B-14. The highest six-hour rainfall increment was obtained by multiplying maximized storm 48-hour rainfall by the ratio of six-hour PMP to 48-hour PMP over the basin. The second six-hour increment was determined by the ratio of 12-hour PMP minus six-hour PMP to 48-hour PMP, and so on for succeeding increments.

7.18 The sequence of six-hour precipitation increments follows the typical chronological distribution shown in Exhibit B-14. This arrangement of the increments produced the highest flood peak because the highest

two increments (generally more than half the total precipitation) are adjacent and occur after initial retention losses have been satisfied.

Runoff from Maximized Storm

7.19 Average rainfall over the high, medium, and low precipitation areas of the maximized storm was taken directly from the maximized depth-area computations. The retention map and storm isohyetal map were superimposed to define areas of particular rainfall-retention combinations. Rainfall excess was determined for each combination.

7.20 The eight six-hour rainfall increments for each rainfall-retention combination were tabulated by using the ratios determined above. Equilibrium retention was subtracted from each increment, and the remainders were tabulated. If a rainfall increment was less than equilibrium retention, the remainder was considered to be zero. Remainders were accumulated to satisfy the initial loss. The rainfall which remained after equilibrium retention and initial loss were satisfied is called the rainfall excess and is equal in volume to the storm runoff for that area. The relations between equilibrium retention, initial loss, and rainfall excess are shown in Exhibit B-15(c).

7.21 Areas of each rainfall-retention combination were scaled off the map, and their percentages of the total basin area were determined. Rainfall excesses for each sub-area were weighted by their percentage of total basin area and added to produce total basin rainfall excess. Six-hour increments of rainfall excess were applied to the basin unit hydrograph to produce the hydrograph of maximized storm runoff.

7.22 By definition, the computed total hydrograph ordinates are obtained by adding the products of rainfall excesses and the proper unit

hydrograph ordinates. For example, the fourth six-hour total hydrograph ordinate would be the sum of the following products:

first six-hour rainfall excess unit hydrograph ordinate at 24 hours,

second six-hour rainfall excess unit hydrograph ordinate at 18 hours,

third six-hour rainfall excess unit hydrograph ordinate at 12 hours,

fourth six-hour rainfall excess unit hydrograph ordinate at 6 hours.

This type of calculation can be performed quickly by using an electric calculator capable of cumulative multiplication.

Snowmelt Runoff

7.23 Snowmelt runoff during the probable maximum flood was based on maximum historical snow accumulation and maximum recorded temperatures. The factors contributing to snowmelt runoff were not maximized in the same sense as those leading to maximum rain runoff. It is not unusual to have sufficient snow accumulation to sustain maximum melt for a relatively short period of time, providing the snow-line elevation is as low as possible. Temperature effects were maximized by arranging extreme temperatures of record in an optimum sequence for snowmelt.

Critical Temperature Sequence

7.24 The sequence of temperatures derived in the synthesis of snowmelt contribution to probable maximum floods had two objectives. Temperatures were made as low as possible for the month before the maximized storm to avoid depletion of the snow pack. Shortly before the storm,

temperatures were made as high as possible to promote high snow runoff concurrent with maximized rain runoff.

7.25 Mosul was selected as the temperature index station in these studies because it has a long temperature record and is adjacent to the snow areas. Curves of seasonal temperature limitations at Mosul, shown on Exhibit B-16, were developed from the record as part of the hydrometeorological analyses. Mosul temperatures were adjusted to snow area temperatures by lapse rate and latitude factors described in the following section.

7.26 A critical melting temperature sequence, shown on Exhibit B-17, satisfies the objectives of maximum snow cover and rapid melt, within the limitations of the curves of Exhibit B-16. During the maximized storm period, temperature is limited by probable maximum precipitation criteria to the highest persisting dewpoint as shown in Exhibit B-5(a). At least a day would be required for the build-up of cloudiness before the maximized storm, so the highest one-day mean temperature was scheduled for the second day before the storm. Temperature rise limitations require that the day of highest temperature following the storm be on the second day after the storm. The balance of temperatures in the sequence was obtained by combining the limitations of the highest and lowest 1-, 2-, 5-, 10-, 20-, and 30-day means.

Temperature-Melt Relations

7.27 Snowmelt was computed by use of weighted degree days. A degree day is counted for every ^{o}F by which the daily mean temperature exceeds $32^{o}F$. Degree days for computing snowmelt were related to snowline elevation and Mosul temperature, as shown by the families of curves

on Exhibit B-18. The number of weighted degree days was obtained by entering the curves with the appropriate snow-line elevation and Mosul temperature. Snowmelt volume for the day, expressed as depth of water over the entire drainage basin, was computed by multiplying the weighted degree days by a degree-day factor of three millimeters/degree day.

7.28 Snowmelt per degree day has been found in other areas to vary between one and four millimeters water equivalent per day. Three millimeters per degree day was selected as an appropriate rate by comparing basin conditions of forest cover, slope orientation, and probable ripeness of the snowpack, with the ideal conditions for maximum snowmelt.

7.29 The degree-day curves on Exhibit B-18 are weighted for area of snow cover and variation of temperature with altitude. The percentage of total basin area in each zone between 1000-foot contours was measured, and the difference between mean zone temperature and concurrent Mosul temperature was computed. Radiosonde data indicated a drop of 3.5 Fahrenheit degrees for each 1000 feet of elevation above Mosul, and ground temperature records indicated a drop of two Fahrenheit degrees for each degree of latitude north of Mosul. Degree days in each zone were computed by subtracting 32 degrees from the adjusted Mosul temperature. The zone degree days were then multiplied by the percentage of total basin area in that zone. The weighted degree days from each zone were added and the results plotted to form the basis for the weighted-degree-day curves.

7.30 Snowmelt would continue during the maximized storm, during which saturated atmospheric conditions would prevail. The temperature during the storm would be same as the dewpoint and would vary with altitude according to the pseudoadiabatic lapse rate. Degree-day curves for saturated conditions are also shown on Exhibit B-18.

Snowmelt Computation Example

7.31 The procedure of computing snowmelt runoff is best illustrated by an example. The computations and graphs for determination of snowmelt contribution to the probable maximum flood at Dokan are shown on Exhibit B-19. "Mosul Temperature" is determined directly from the critical temperature sequence on Exhibit B-17.

7.32 The daily change of snow-line elevation was determined by the computations under the heading "Snowline Data." Melting at the snow line was computed by adjusting Mosul temperature to snow-line latitude and elevation, computing degree days above 32°F, and applying the three millimeter per degree day snowmelt factor. Snow-line temperature can be obtained by applying the adjustments to Mosul temperature shown on Table B-7.

7.33 Starting with snow-line elevation of 5300 feet (1620 meters), the adjustment for mean latitude, 36.2°N, is 14.9 Fahrenheit degrees, which, subtracted from the Mosul temperature on 24 March of 47°F, gives a snow-line temperature of 32°F. The snow line is at freezing temperature on 24 and 25 March, so no melt or change in elevation occurs. On 26 March the Mosul temperature of 62°F corresponds to a snow-line temperature of 47°F, giving 15 degree days above 32°F at the snow line. Using the factor of three millimeter water equivalent melt per degree day, the indicated average melt was 45 millimeters. It was assumed that snow would be removed over all areas where the depth was less than 45 millimeters in water equivalent.

7.34 Curves showing the relation of snow depth on 1 March and 1 April to elevation are plotted on Exhibit B-19. It was assumed, in developing the

Table B-7

ADJUSTMENT TO MOSUL TEMPERATURE FOR LATITUDE AND ELEVATION

(Fahrenheit degrees)

Elevation (ft. msl)	Latitude (°N) 34	35	36	37	38	39
1,000	+ 4.5	+ 2.5	+ 0.5	- 1.5	- 3.5	- 5.5
2,000	+ 1.0	- 1.0	- 3.0	- 5.0	- 7.0	- 9.0
3,000	- 2.5	- 4.5	- 6.5	- 8.5	-10.5	-12.5
4,000	- 6.0	- 8.0	-10.0	-12.0	-14.0	-16.0
5,000	- 9.5	-11.5	-13.5	-15.5	-17.5	-19.5
6,000	-13.0	-15.0	-17.0	-19.0	-21.0	-23.0
7,000	-16.5	-18.5	-20.5	-22.5	-24.5	-26.5
8,000	-20.0	-22.0	-24.0	-26.0	-28.0	-30.0
9,000	-23.5	-25.5	-27.5	-29.5	-31.5	-33.5
10,000	-27.0	-29.0	-31.0	-33.0	-35.0	-37.0
11,000	-30.5	-32.5	-34.5	-36.5	-38.5	-40.5
12,000	-34.0	-36.0	-38.0	-40.0	-42.0	-44.0
13,000	-37.5	-39.5	-41.5	-43.5	-45.5	-47.5
14,000	-41.0	-43.0	-45.0	-47.0	-49.0	-51.0

critical temperature sequence, that no melting would occur until late in March, so the 1 March maximum water equivalent curve was used for initial snowmelt late in March. Forty-five millimeters of melt on the 1 March curve indicates a change in elevation of 130 feet, which was added to 5300 feet to obtain a snow-line elevation on 27 March of 5430 feet (1660 meters). Computed melt on 27 March of 66 millimeters was added to previous melt, measured off on the 1 March curve, and the new increment of elevation, 130 feet, was scaled off.

7.35 Computations were continued in the above manner until ten days after the maximized storm, when temperatures fell below freezing as required by the critical temperature sequence. Snow-line temperatures during the maximized storm were determined from the psuedoadiabatic lapse rate on Exhibit B-16 because of saturation conditions during the storm. The shift in total snowmelt on 1 April is an adjustment to allow the use of the 1 April maximum water equivalent curve from that day on.

7.36 After the daily snow-line elevation was determined, computations of total daily snowmelt could be made. The curves of Exhibit B-18 were entered with snow-line elevation and Mosul temperature to determine weighted degree days, which were multiplied by three millimeters to give the melt depth over the total basin. Curves based on saturated air conditions were used for the four days of probable maximum precipitation.

7.37 Snowmelt attributable to rainfall was computed by the formula:

$$M = \frac{R\,(T - 32)}{144}$$

where M is snowmelt due to rainfall, in millimeters, R is rainfall, in millimeters, and T is the temperature of the rain, in degrees Fahrenheit.

7.38 The rain temperature may be considered to be the dewpoint which is equal to the air temperature during the storm. The term (T - 32) is equivalent to the weighted degree days for saturated conditions, already determined. Daily rain for the part of the basin covered by snow was determined directly from the PMP depth-area-duration curves arranged in time sequence according to Exhibit B-14. The quantity of melt caused by rain is small, so more refined computations are not justified.

7.39 Snowmelt in each basin was converted to runoff by use of a "snowmelt unit hydrograph." Studies of the relation between snowmelt and the resulting streamflow have been made recently by interested agencies in the United States. It was determined that for basins of the size considered in this study, about 20 days were required to complete the runoff from one day's snowmelt and that 12 to 15 percent of the volume of one day's melt appears in the streams the first day. On the basis of this, a "snowmelt unit hydrograph" was prepared expressing the percent of one day's melt which runs off each day. The time base of the unit hydrograph was made 20 days. Runoff volume was assumed to be 12 percent of the day's melt on the first day, decreasing by a smooth curve to one percent on the twentieth day. Since the snowmelt hydrograph has a very flat peak, it was not considered necessary to study streamflow timing refinements. The use of the snowmelt hydrograph was identical to that of the rain unit hydrograph except that snowmelt was substituted for rainfall excess. Retention of snowmelt water was considered to be negligible because the soil in snow areas would probably be saturated or frozen.

Runoff From Antecedent Storm

7.40 The most critical condition in the operation of a reservoir system for flood control is the case of a very large flood preceded by a flood of

sufficient magnitude to exhaust or greatly reduce the flood storage capacity of the system. Also, runoff from probable maximum precipitation depends upon the retention capacity of the basins at the time of the maximized storm. Retention capacity at the time of the maximized storm is a function of the rainless interval preceding the storm and increases with the number of rainless days. Accordingly, the minimum time interval between a major storm and a maximum storm was investigated. We concluded that moisture inflow limitations would separate an antecedent major storm and a maximum storm by at least four days. Similarly, the minimum interval between a probable maximum storm followed by a major storm was estimated to be seven days.

7.41 The storm of 23-24 March 1954, which contributed to the record 1954 flood, was selected as the "antecedent storm," and its rain runoff at key points was determined by hydrograph separation. The selected antecedent storm was assumed to occur on 25-26 March, allowing the minimum of four rainless days before the maximized storm. Recorded 1954 hydrographs for the damsites were replotted and the time scale adjusted, as shown on Exhibit B-20. Rain runoff from the selected storm was determined by estimating and separating the portion of the hydrograph representing snow runoff and base flow. The relative magnitude of probable maximum rain runoff and major storm runoff did not justify extremely refined computation of the major storm hydrograph.

7.42 It was not necessary to consider a major storm following the probable maximum storm. While such a storm would influence the flood volume, it would not influence the peak flow. At the damsites, the peak reservoir storage would be reached well in advance of the following major storm, and the reservoir would have been lowered sufficiently by the time

the second storm occurred, so that the new reservoir surcharge would not be higher than that which had occurred from the probable maximum storm. For critical downstream locations (Samarra, Baghdad, and the mouth of the Diyala River), the peaks resulting from routed reservoir outflows also would have passed these points well in advance of the following storm. This fact can be verified by inspection of the typical flood routings on Exhibit B-21. The floods shown on these exhibits were caused by storms which terminated on April 4. It can be seen that seven days later (The estimated minimum interval between the end of the probable maximum storm and the start of a major storm is seven days.) the flood flows at the downstream location were of the order of 35 to 45 percent of the peak flows. Thus a major storm at this time would not affect the peak flood values.

Base Flow

7.43 Base flow from groundwater storage was assumed to be constant at each of the key points. Values of base flow were determined by inspecting historical hydrographs for average minimum summer flows. Base flow during spring flood runoff may be greater than in summer, but since it is negligible in comparison with storm runoff, no attempt at refined computations was made. Base flow was estimated as follows:

Lesser Zab above Dokan Dam	50 cumecs
Greater Zab above Bekhme Damsite	150 cumecs
Tigris above Eski Mosul Damsite	150 cumecs
Diyala above Derbend-i-Khan Dam	100 cumecs

Probable Maximum Flood Hydrograph

7.44 Six-hour runoff ordinates of the four flood components were added with proper time orientation to produce the probable maximum 20-day flood hydrographs at the four damsites. These computations are summarized on Tables B-8 to B-11 inclusive. The 20-day maximum flood hydrographs are shown on Exhibit B-1. The probable maximum flood at the mouth of the Adhaim River is shown in tabular form in Table B-12.

Peak-Volume Relation

7.45 Floods smaller than the probable maximum but greater than historical are usually studied in connection with design of hydraulic structures and development of system flood-operation criteria. Flood volume does not have a fixed relation to flood peak, but it was considered desirable to establish one reasonable and consistent relation to be used in comparative studies.

7.46 A peak-volume relation for use in estimating volumes of floods in the range between historical and probable maximum floods is shown on Exhibit B-22. The curve applies to the four upstream damsites: Eski Mosul, Bekhme, Dokan, and Derbend-i-Khan. The curve was drawn on the basis of historical experience and theoretical limitations.

Derivation of Peak-Volume Relation

7.47 Exhibit B-22 shows historical peaks plotted against their accompanying 20-day volumes in a dimensionless manner, by expressing the peaks and volumes at each site as percentages of that site's probable maximum peak and the maximum 20-day volume of Exhibit B-1. Historical 20-day volumes range up to 63 percent of probable maximum volume, while

Table B-8

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD AT DOKAN

Six-hour ordinates in cumecs

Date	Max. Storm	Max. Snow Melt	Ante-cedent Storm	Base Flow	Prob. Max. Flood	Date	Max. Storm	Max. Snow Melt	Ante-cedent Storm	Base Flow	Prob. Max. Flood
Mar. 26	-	60	20	50	130	Apr. 6	2,170	860	-	50	3,080
	-	140	120	50	310		1,710	880	-	50	2,640
	-	200	260	50	510		1,320	880	-	50	2,250
	-	270	530	50	850		1,050	880	-	50	1,980
27	-	340	1,060	50	1,450	7	790	880	-	50	1,720
	-	400	1,760	50	2,210		230	880	-	50	1,160
	-	450	2,540	50	3,040		-	880	-	50	930
	-	490	2,820	50	3,360		-	880	-	50	930
28	-	540	2,880	50	3,470	8	-	880	-	50	930
	-	590	2,750	50	3,390		-	880	-	50	930
	-	610	2,000	50	2,660		-	870	-	50	920
	-	640	1,560	50	2,250		-	860	-	50	910
29	-	670	1,310	50	2,030	9	-	850	-	50	900
	-	700	1,100	50	1,850		-	840	-	50	890
	-	730	920	50	1,700		-	830	-	50	880
	-	760	780	50	1,590		-	820	-	50	870
30	-	780	680	50	1,510	10	-	810	-	50	860
	-	810	580	50	1,440		-	800	-	50	850
	-	820	500	50	1,370		-	790	-	50	840
	-	830	430	50	1,310		-	780	-	50	830
31	-	850	370	50	1,270	11	-	770	-	50	820
	-	860	320	50	1,230		-	760	-	50	810
	-	850	270	50	1,170		-	750	-	50	800
	-	850	220	50	1,120		-	730	-	50	780
Apr. 1	-	840	180	50	1,070	12	-	720	-	50	770
	-	840	140	50	1,030		-	710	-	50	760
	-	840	110	50	1,000		-	700	-	50	750
	-	850	80	50	980		-	690	-	50	740
2	10	850	50	50	960	13	-	680	-	50	730
	70	850	30	50	1,000		-	670	-	50	720
	570	850	10	50	1,480		-	650	-	50	700
	1,550	840	-	50	2,440		-	630	-	50	680
3	3,170	830	-	50	4,050	14	-	610	-	50	660
	5,940	820	-	50	6,810		-	590	-	50	640
	10,470	810	-	50	11,330		-	570	-	50	620
	15,530	810	-	50	16,390		-	550	-	50	600
4	16,670	800	-	50	17,520	15	-	540	-	50	590
	13,180	800	-	50	14,030		-	520	-	50	570
	9,780	800	-	50	10,630		-	500	-	50	550
	7,560	810	-	50	8,420		-	490	-	50	540
5	5,850	810	-	50	6,710	16	-	470	-	50	520
	4,530	820	-	50	5,400		-	450	-	50	500
	3,490	830	-	50	4,370		-	430	-	50	480
	2,770	850	-	50	3,670		-	410	-	50	460

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Table B-9

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD AT DERBEND-I-KHAN DAM

Six-hour ordinates in cumecs

Date	Max. Storm	Max. Snow Melt	Antecedent Storm	Base Flow	Prob. Max. Flood	Date	Max. Storm	Max. Snow Melt	Antecedent Storm	Base Flow	Prob. Max. Flood
Mar. 26	-	-	50	100	150	Apr. 6	3,980	1,510	-	100	5,590
	-	-	200	100	300		3,330	1,510	-	100	4,940
	-	-	680	100	780		2,720	1,520	-	100	4,340
	-	-	1,550	100	1,650		2,250	1,520	-	100	3,870
27	-	-	3,150	100	3,250	7	1,950	1,530	-	100	3,580
	-	-	4,260	100	4,360		1,600	1,530	-	100	3,230
	-	-	4,360	100	4,460		1,330	1,550	-	100	2,980
	-	-	4,300	100	4,400		1,110	1,570	-	100	2,780
28	-	200	4,120	100	4,420	8	890	1,590	-	100	2,580
	-	290	3,840	100	4,230		680	1,600	-	100	2,380
	-	380	3,480	100	3,960		460	1,600	-	100	2,160
	-	480	3,080	100	3,660		250	1,600	-	100	1,950
29	-	570	2,740	100	3,410	9	50	1,600	-	100	1,750
	-	670	2,430	100	3,200		-	1,600	-	100	1,700
	-	750	2,150	100	3,000		-	1,600	-	100	1,700
	-	840	1,940	100	2,880		-	1,590	-	100	1,690
30	-	920	1,750	100	2,770	10	-	1,580	-	100	1,680
	-	1,000	1,620	100	2,720		-	1,570	-	100	1,670
	-	1,050	1,480	100	2,630		-	1,560	-	100	1,660
	-	1,110	1,350	100	2,560		-	1,550	-	100	1,650
31	-	1,160	1,230	100	2,490	11	-	1,540	-	100	1,640
	-	1,220	1,120	100	2,440		-	1,530	-	100	1,630
	-	1,270	1,020	100	2,390		-	1,520	-	100	1,620
	-	1,330	930	100	2,360		-	1,500	-	100	1,600
Apr. 1	-	1,380	830	100	2,310	12	-	1,480	-	100	1,580
	-	1,430	750	100	2,280		-	1,460	-	100	1,560
	-	1,440	660	100	2,200		-	1,440	-	100	1,540
	-	1,460	580	100	2,140		-	1,420	-	100	1,520
2	-	1,470	500	100	2,070	13	-	1,400	-	100	1,500
	180	1,480	420	100	2,180		-	1,390	-	100	1,490
	1,210	1,480	350	100	3,140		-	1,370	-	100	1,470
	3,120	1,490	270	100	4,980		-	1,340	-	100	1,440
3	6,000	1,490	210	100	7,800	14	-	1,310	-	100	1,410
	10,000	1,500	140	100	11,740		-	1,290	-	100	1,390
	15,190	1,510	80	100	16,880		-	1,250	-	100	1,350
	20,380	1,520	-	100	22,000		-	1,210	-	100	1,310
4	22,930	1,540	-	100	24,570	15	-	1,170	-	100	1,270
	20,630	1,560	-	100	22,290		-	1,130	-	100	1,230
	16,490	1,550	-	100	18,140		-	1,100	-	100	1,200
	12,880	1,540	-	100	14,520		-	1,060	-	100	1,160
5	9,980	1,530	-	100	11,610	16	-	1,030	-	100	1,130
	7,700	1,520	-	100	9,320		-	990	-	100	1,090
	5,940	1,520	-	100	7,560		-	960	-	100	1,060
	4,740	1,520	-	100	6,360		-	920	-	100	1,020

Table B-10

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD AT BEKHME DAMSITE

Six-hour ordinates in cumecs

Date	Max. Storm	Max. Snow Melt	Ante-cedent Storm	Base Flow	Prob. Max. Flood	Date	Max. Storm	Max. Snow Melt	Ante-cedent Storm	Base Flow	Prob. Max. Flood
Mar. 26	-	-	10	150	160	Apr. 6	4,340	2,980	-	150	7,470
	-	-	150	150	300		3,620	3,000	-	150	6,770
	-	-	1,200	150	1,350		3,080	3,030	-	150	6,260
	-	-	6,000	150	6,150		2,680	3,050	-	150	5,880
27	-	-	7,100	150	7,250	7	2,310	3,080	-	150	5,540
	-	-	7,000	150	7,150		1,940	3,100	-	150	5,190
	-	-	6,000	150	6,150		1,570	3,150	-	150	4,870
	-	-	3,300	150	3,450		1,270	3,200	-	150	4,620
28	-	100	1,500	150	1,750	8	1,000	3,250	-	150	4,400
	-	280	1,220	150	1,650		850	3,310	-	150	4,310
	-	400	1,020	150	1,570		690	3,350	-	150	4,190
	-	530	860	150	1,540		510	3,380	-	150	4,040
29	-	660	720	150	1,530	9	390	3,420	-	150	3,960
	-	790	600	150	1,540		300	3,450	-	150	3,900
	-	920	500	150	1,570		200	3,470	-	150	3,820
	-	1,040	400	150	1,590		120	3,490	-	150	3,760
30	-	1,170	270	150	1,590	10	90	3,510	-	150	3,750
	-	1,290	150	150	1,590		30	3,530	-	150	3,710
	-	1,380	60	150	1,590		-	3,530	-	150	3,680
	-	1,470	-	150	1,620		-	3,540	-	150	3,690
31	-	1,560	-	150	1,710	11	-	3,540	-	150	3,690
	-	1,650	-	150	1,800		-	3,550	-	150	3,700
	-	1,750	-	150	1,900		-	3,540	-	150	3,690
	-	1,850	-	150	2,000		-	3,520	-	150	3,670
Apr. 1	-	1,950	-	150	2,100	12	-	3,510	-	150	3,660
	-	2,060	-	150	2,210		-	3,490	-	150	3,640
	-	2,100	-	150	2,250		-	3,480	-	150	3,630
	-	2,130	-	150	2,280		-	3,470	-	150	3,620
2	-	2,170	-	150	2,320	13	-	3,460	-	150	3,610
	20	2,200	-	150	2,370		-	3,440	-	150	3,590
	190	2,250	-	150	2,590		-	3,420	-	150	3,570
	630	2,300	-	150	3,080		-	3,400	-	150	3,550
3	1,570	2,350	-	150	4,070	14	-	3,380	-	150	3,530
	3,200	2,410	-	150	5,760		-	3,370	-	150	3,520
	6,570	2,500	-	150	9,220		-	3,270	-	150	3,420
	13,810	2,600	-	150	16,560		-	3,180	-	150	3,330
4	18,900	2,700	-	150	21,750	15	-	3,080	-	150	3,230
	19,680	2,800	-	150	22,630		-	2,990	-	150	3,140
	17,250	2,820	-	150	20,220		-	2,890	-	150	3,040
	13,140	2,850	-	150	16,140		-	2,800	-	150	2,950
5	9,680	2,870	-	150	12,700	16	-	2,750	-	150	2,900
	7,960	2,900	-	150	10,610		-	2,700	-	150	2,850
	6,160	2,930	-	150	9,240		-	2,650	-	150	2,800
	5,140	2,950	-	150	8,240		-	2,600	-	150	2,750

Table B-11

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD AT ESKI MOSUL DAMSITE

Six-hour ordinates in cumecs

Date	Max. Storm	Max. Snow Melt	Antecedent Storm	Base Flow	Prob. Max. Flood	Date	Max. Storm	Max. Snow Melt	Antecedent Storm	Base Flow	Prob. Max. Flood
Mar. 26	-	-	50	150	200	Apr. 6	12,330	4,360	-	150	16,840
	-	-	150	150	300		10,380	4,380	-	150	14,910
	-	-	380	150	530		8,630	4,400	-	150	13,180
	-	-	900	150	1,050		7,100	4,420	-	150	11,670
27	-	-	1,350	150	1,500	7	5,880	4,440	-	150	10,470
	-	-	1,750	150	1,900		4,650	4,460	-	150	9,260
	-	130	2,150	150	2,430		3,680	4,540	-	150	8,370
	-	270	2,580	150	3,000		2,890	4,620	-	150	7,660
28	-	400	3,050	150	3,600	8	2,200	4,700	-	150	7,050
	-	540	3,400	150	4,090		1,670	4,780	-	150	6,600
	-	750	2,750	150	3,650		1,230	4,810	-	150	6,190
	-	970	2,330	150	3,450		890	4,840	-	150	5,880
29	-	1,190	2,050	150	3,390	9	650	4,870	-	150	5,670
	-	1,410	1,780	150	3,340		480	4,900	-	150	5,530
	-	1,630	1,620	150	3,400		350	4,930	-	150	5,430
	-	1,840	1,450	150	3,440		260	4,960	-	150	5,370
30	-	2,060	1,330	150	3,540	10	190	5,000	-	150	5,340
	-	2,280	1,210	150	3,640		140	5,030	-	150	5,320
	-	2,390	1,090	150	3,630		100	5,000	-	150	5,250
	-	2,510	1,000	150	3,660		80	4,980	-	150	5,210
31	-	2,620	880	150	3,650	11	60	4,950	-	150	5,160
	-	2,740	760	150	3,650		40	4,930	-	150	5,120
	-	2,890	640	150	3,680		30	4,910	-	150	5,090
	-	3,050	550	150	3,750		20	4,890	-	150	5,060
Apr. 1	-	3,200	460	150	3,810	12	20	4,870	-	150	5,040
	-	3,360	390	150	3,900		10	4,850	-	150	5,010
	-	3,390	340	150	3,880		-	4,830	-	150	4,980
	20	3,430	290	150	3,890		-	4,800	-	150	4,950
2	180	3,460	250	150	4,040	13	-	4,780	-	150	4,930
	450	3,500	210	150	4,310		-	4,760	-	150	4,910
	1,090	3,560	180	150	4,980		-	4,730	-	150	4,880
	2,340	3,620	150	150	6,260		-	4,700	-	150	4,850
3	4,440	3,680	120	150	8,390	14	-	4,680	-	150	4,830
	7,620	3,740	90	150	11,600		-	4,650	-	150	4,800
	12,470	3,830	60	150	16,510		-	4,520	-	150	4,670
	18,640	3,920	30	150	22,740		-	4,390	-	150	4,540
4	23,710	4,020	-	150	27,880	15	-	4,260	-	150	4,410
	25,900	4,110	-	150	30,160		-	4,120	-	150	4,270
	25,540	4,160	-	150	29,850		-	4,000	-	150	4,150
	23,700	4,200	-	150	28,050		-	3,880	-	150	4,030
5	21,730	4,250	-	150	26,130	16	-	3,760	-	150	3,910
	19,240	4,290	-	150	23,680		-	2,640	-	150	3,790
	16,780	4,320	-	150	21,250		-	3,540	-	150	3,690
	14,470	4,340	-	150	18,960		-	3,450	-	150	3,600

Table B-12

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD AT ADHAIM MOUTH

Six-hour ordinates in cumecs

Date	Max. Storm	Max. Snow Melt	Antecedent Storm	Base Flow	Prob. Max. Flood	Date	Max. Storm	Max. Snow Melt	Antecedent Storm	Base Flow	Prob. Max. Flood
Mar. 26	-	-	-	-	-	Apr. 6	1,860	-	-	-	1,860
	-	-	20	-	20		1,420	-	-	-	1,420
	-	-	90	-	90		1,070	-	-	-	1,070
	-	-	290	-	290		800	-	-	-	800
27	-	-	970	-	970	7	600	-	-	-	600
	-	-	1,020	-	1,020		430	-	-	-	430
	-	-	870	-	870		280	-	-	-	280
	-	-	740	-	740		170	-	-	-	170
28	-	-	640	-	640	8	90	-	-	-	90
	-	-	550	-	550		20	-	-	-	20
	-	-	480	-	480		10	-	-	-	10
	-	-	400	-	400		-	-	-	-	-
29	-	-	340	-	340	9	-	-	-	-	-
	-	-	300	-	300		-	-	-	-	-
	-	-	250	-	250		-	-	-	-	-
	-	-	210	-	210		-	-	-	-	-
30	-	-	170	-	170	10	-	-	-	-	-
	-	-	140	-	140		-	-	-	-	-
	-	-	110	-	110		-	-	-	-	-
	-	-	90	-	90		-	-	-	-	-
31	-	-	60	-	60	11	-	-	-	-	-
	-	-	40	-	40		-	-	-	-	-
	-	-	20	-	20		-	-	-	-	-
	-	-	-	-	-		-	-	-	-	-
Apr. 1	-	-	-	-	-	12	-	-	-	-	-
	10	-	-	-	10		-	-	-	-	-
	50	-	-	-	50		-	-	-	-	-
	170	-	-	-	170		-	-	-	-	-
2	430	-	-	-	430	13	-	-	-	-	-
	930	-	-	-	930		-	-	-	-	-
	2,020	-	-	-	2,020		-	-	-	-	-
	3,970	-	-	-	3,970		-	-	-	-	-
3	6,740	-	-	-	6,740	14	-	-	-	-	-
	9,700	-	-	-	9,700		-	-	-	-	-
	11,880	-	-	-	11,880		-	-	-	-	-
	12,780	-	-	-	12,780		-	-	-	-	-
4	12,170	-	-	-	12,170	15	-	-	-	-	-
	10,720	-	-	-	10,720		-	-	-	-	-
	8,960	-	-	-	8,960		-	-	-	-	-
	7,200	-	-	-	7,200		-	-	-	-	-
5	5,620	-	-	-	5,620	16	-	-	-	-	-
	4,320	-	-	-	4,320		-	-	-	-	-
	3,290	-	-	-	3,290		-	-	-	-	-
	2,450	-	-	-	2,450		-	-	-	-	-

historical peaks are no higher than 38 percent. This difference is reasonable when it is considered that critical timing is required to produce very high flood peaks even though the "raw material" of snow and rain is present in sufficient volume.

7.48 Peak-volume limitations above the level of historical experience were based on probable maximum flood computations. The 20-day volume of the probable maximum flood peak hydrograph was taken as probable maximum 20-day volume since practically all volume-producing factors were maximized. The volume of runoff due to a subsequent "major storm" is not included, but it would be of about the same magnitude as the antecedent storm, and inspection of Exhibit B-1 indicates that addition of such a flood following the maximum flood would have a negligible effect on the total volume.

7.49 Maximum volumes which could accompany peaks lower than the probable maximum were obtained by modifying maximum flood computations. Rainfall in the maximized storm was reduced by varying percentages, while the volume of base flow and antecedent flood was retained and that portion of snowmelt caused by rain was adjusted. Limitations estimated for each site are shown in Exhibit B-22. The computed limitations appear consistent with historical experience except for one historical flood at Dokan.

7.50 Curves enveloping historical and computed points were drawn. The peak-volume relation for a flood could fall anywhere in the area indicated by these points, but to make computed floods consistent and comparable, it was decided to assume one peak-volume relation line to apply to all four sites. Peaks accompanied by high volumes are critical in flood operations, so the curve was made to favor high volumes.

Application of Peak-Volume Curve

7.51 The peak-volume curves and high-volume-limit lines of Exhibit B-22 were used as guides for computing intermediate flood hydrographs. The 20-day volume to accompany a given peak is obtained directly from the peak-volume curve.

7.52 The shape of the hydrograph combining the specified peak and volume can be obtained by scaling down a known hydrograph with the same peak-volume ratio. The floods which fall on the high-volume-limit lines of Exhibit B-22 are "known" inasmuch as their hydrographs can be readily calculated. Any straight line drawn through the origin of Exhibit B-22 represents the locus of all floods with a particular peak-volume ratio. If a straight line is drawn from the origin through the desired point on the peak-volume curve to intersect with the high-volume limit for that site, the flood represented by the high-volume-limit intersection has the same peak-volume ratio as the desired flood. The high-volume-limit flood hydrograph can be computed and scaled down to match the desired flood peak and volume.

7.53 An example of intermediate-flood hydrograph computation will be described. Assume that it is desired to compute a flood hydrograph for the Lesser Zab at Dokan with a peak of 10,500 cumecs or 60 percent of probable maximum. A straight line is drawn from the origin to intersect the peak volume relation curve at 60 percent of the peak. The curve indicates that the adopted volume for this flood is 73.2 percent of probable maximum 20-day volume. The straight line is extended to intersect the Dokan high-volume-limit line, as it does at 64.5-percent peak and 78.7-percent volume. The ratio 60/73.2 is equal to the ratio 64.5/78.7.

7.54 A flood hydrograph whose peak is 64.5 percent of probable maximum can be computed since its ratio of peak to volume falls on the high-

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volume-limit line. All floods represented by points on the high-volume-limit line include full antecedent storm runoff, base flow, and maximum snowmelt (modified for melt caused by rain). Rain runoff must be determined by trial adjustments of the storm used for probable maximum rain or, as is done in our studies, by interpolating between values computed for establishing the high-volume-limit lines.

7.55 The hydrograph computed with 64.5-percent peak will automatically have the assumed ratio of peak to volume. This hydrograph is then scaled down to 60-percent peak by multiplying all ordinates by the ratio of 60/64.5 to obtain the desired 60-percent peak hydrograph.

Maximum Seasonal Volume

7.56 For purposes of flood routings, it was necessary to make some assumption of the maximum seasonal runoff so that a starting point could be obtained for the storage reached and the flood routings thus initiated during the most important 20-day maximum flood period. Although some estimate of this starting point is necessary, since there can be some build-up in storage prior to the maximum 20-day period, the degree of accuracy in establishing the storage at that time need not be high. Any minor inaccuracies will be largely eliminated during the routing of the 20-day maximum flood, owing to the compensating errors in outflow that will accompany any errors in storage. The probable maximum seasonal flood we have derived, as described in the following paragraphs, cannot be described as highly reliable, but is of sufficient accuracy for the purpose intended.

7.57 The seasonal flood period was taken as January through June. The probable maximum seasonal flood is based on extrapolation of frequency curves of historical floods, by using a straight-line extrapolation

on logarithmic paper. Seasonal flood runoff at Mosul was studied in particular detail, and the relations derived were used as a guide at the other sites.

7.58 Maximum snow accumulations obtained from the hydrometerological studies were assumed to occur over the Eski Mosul Basin. Total snowmelt runoff was computed and adjusted for estimated snow accumulation during the melt season, resulting in a volume of 14 milliards of cubic meters. This value was compared with an estimated volume of 13 milliards, obtained by separation of snowmelt runoff from the 1954 seasonal flood hydrograph at Mosul. It has been stated earlier that snow accumulations used in the probable maximum flood studies are expected to have a frequency of about once in 100 years. The 1954 snow runoff exceeded the next highest recorded occurrence by 60 percent. On this basis, the 1954 snow runoff was assigned a frequency of once in 100 years.

7.59 The total seasonal runoff at Mosul in 1954, including both snowmelt and runoff from precipitation, exhibited a similar relation to the historical record and was assumed to have a recurrence interval of 100 years. The frequency curve of total seasonal volumes at Mosul was extrapolated through the 1954 point at 100 years. The seasonal volume obtained in this manner was 142 percent of the 1954 Mosul seasonal volume.

7.60 The estimated maximum seasonal flood was assumed to be proportional to the 1954 flood, except for the peak 12 to 26 days, which were replaced by the probable maximum flood hydrographs. The proportional increase in 1954 season flow was obtained by subtracting the probable maximum peak flood volume from the derived probable maximum seasonal volume and dividing the result by the 1954 seasonal volume less the replaced days. The proportionality factor for Eski Mosul was found to be 1.25. Similar

computation resulted in factors of 1.22 and 1.18 for the 75-percent and 50-percent seasonal floods.

7.61 Dimensionless seasonal volume frequency curves for the other sites were extrapolated to probable maximum flood frequency using the curve for Mosul and Eski Mosul as a guide. The extrapolations were checked against the factors which would have to be applied to the balance of 1954 flows to obtain maximum seasonal volume. The factors obtained for Samarra were equivalent to the Eski Mosul factors. Those for Bekhme were somewhat lower, but it was concluded that they should be at least as great as those for Samarra and Eski Mosul, so the Bekhme curve was adjusted accordingly. The Dokan curve resulted in factors of 1.46, 1.36, and 1.25 after slight adjustment to conform with the extrapolation for other sites. The factors for Derbend-i-Khan were less than unity, a fact which was considered unsatisfactory; they were arbitrarily increased to 1.10, 1.05, and 1.00.

7.62 Daily discharge hydrographs for the probable maximum, 75-percent, and 50-percent peaks were substituted for the 1954 peak values with a day or two of arbitrary values to furnish a smooth transition from adjusted 1954 flows to derived peaks. Seasonal flood hydrographs were prepared for probable maximum floods at the damsites and for sub-basin inflows making up the probable maximum flood at Samarra. The probable maximum seasonal floods for the damsites are shown in Exhibit B-1.

Chapter B-8

MAXIMUM FLOODS AT SAMARRA, BAGHDAD, AND THE DIYALA CONFLUENCE

General Procedure

8.1 Probable maximum floods at Samarra, Baghdad, and the Tigris-Diyala confluence were synthesized by combining floods from upstream drainage basins. The principle of maximizing historical storms, described for individual basins in the preceding chapter, was used to compute maximum rainfaill runoff from the combined basins. Antecedent storm runoff and base flow were determined for the intermediate basins. It was assumed that there would be no snowmelt runoff produced below the damsites. Discharges from individual basins were combined by the Muskingum method of flood routing. Floods having peaks of 50 and 75 percent of the probable maximum flood were also estimated.

Maximized Storms

8.2 The principle of storm maximization over several drainage basins is identical to that for one basin. Depth-area-duration curves of probable maximum precipitation were prepared for the total drainage areas of the Tigris River at Samarra, at Baghdad, and below the Diyala-Tigris confluence.

8.3 Five recorded storms were considered suitable for combined basin analysis. Depth-area curves of the highest 48-hour precipitation in these storms were prepared and maximized. Runoff from maximized storm rainfall was then determined for individual basins by applying the basin unit hydrographs.

Flood Hydrograph Construction

8.4 Snowmelt runoff, base flow, and antecedent storm runoff from the upper basins (above the damsites) were considered to be the same as those used for the individual basin probable maximum flood. These discharge values were added to maximized storm runoff to produce hydrographs of each basin's contribution to the total basin flood.

8.5 Antecedent storm runoff was computed for the Central Tigris area (Area 5 on Exhibit B-4) and the Middle Diyala area (Area 7). Antecedent storm hydrographs based on the recorded 1954 flood at Eski Mosul, Bekhme, and Dokan were routed to Fatha. The total routed flow was subtracted from the Fatha recorded hydrograph, as shown on Exhibit B-20(d), to obtain the Central Tigris runoff. The area between Fatha and Samarra was assumed to have contributed negligible storm runoff because of large closed basins in the area. Antecedent storm runoff for the Middle Diyala area was obtained by subtracting the routed 1954 rain flood hydrograph of Derbend-i-Khan from the Diyala Weir hydrograph. The area below Diyala Weir was also considered to have contributed negligible storm runoff because of topography. Adhaim flow was taken directly from the Adhaim River record.

8.6 Base flow from the Central Tigris area was estimated to be 50 cumecs. The Adhaim River is usually dry during the summer, so the Adhaim Basin and the similar Middle Diyala Basin were assumed to have negligible base flow. Snowmelt runoff from basins below the damsites was considered to have negligible effect on the combined basin flood hydrographs.

8.7 Computed floods produced at Eski Mosul, Bekhme, and Dokan for the five storms were routed to Samarra and added to the Central Tigris

area outflow to obtain total floods at Samarra. The highest of the five computed floods was considered to be the probable maximum flood at Samarra. The computation of the resulting maximum flood is summarized on Table B-13.

8.8 Total basin storms above Baghdad and the Diyala confluence were used in the same way, with the addition of the Adhaim contribution, to compute the probable maximum flood at Baghdad. The computation is shown on Table B-14. The further addition of Derbend-i-Khan and Middle Diyala flows allowed the computation of the probable maximum flood at the Diyala-Tigris confluence, as shown in Table B-15.

Probable Maximum Floods With Upstream Dams

8.9 When a dam is placed on one of the tributaries, it is likely that the probable maximum flood at a downstream point will then be caused by a different rain distribution. It would be expected that the greatest main stem flood would be produced by rainfall concentrated over the basins of the uncontrolled tributaries.

8.10 The maximized storm for the period 15-24 November 1942, which produced the probable maximum flood at Samarra, was concentrated over the Eski Mosul Basin to the extent that the Eski Mosul contribution was equal to the Eski Mosul probable maximum flood. This arrangement remained critical when Dokan and Bekhme dams were studied for flood control. Critical conditions for flood control at Eski Mosul demanded the maximum contribution from the Bekhme Basin since Dokan Dam is already built. To meet this requirement, a special Samarra flood was developed which included probable maximum contribution from the Bekhme area.

Table B-13

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD AT SAMARRA

Six-hour ordinates in cumecs routed to Samarra

Date	Eski Mosul	Bekhme	Dokan	Cent. Tigris	Prob. Max. Flood	Date	Eski Mosul	Bekhme	Dokan	Cent. Tigris	Prob. Max. Flood
Mar. 26	150	150	50	150	500	Apr. 6	22,880	9,520	2,170	170	34,740
	150	150	50	950	1,300		24,270	9,750	2,080	130	36,230
	150	150	50	1,770	2,120		24,830	9,610	1,960	100	36,500
	150	150	50	2,350	2,700		24,640	9,220	1,810	90	35,760
27	160	150	70	2,580	2,960	7	23,820	8,670	1,660	80	34,230
	170	170	100	2,520	2,960		22,520	8,050	1,520	70	32,160
	210	300	170	2,180	2,860		20,890	7,420	1,400	60	29,770
	290	690	290	1,810	3,080		19,080	6,810	1,300	50	27,240
28	430	1,400	480	1,550	3,860	8	17,230	6,240	1,220	50	24,740
	640	2,300	770	1,260	4,970		15,460	5,730	1,160	50	22,400
	900	3,190	1,160	1,110	6,360		13,820	5,310	1,100	50	20,280
	1,230	3,830	1,590	950	7,600		12,340	4,970	1,050	50	18,410
29	1,600	4,120	2,020	810	8,550	9	11,050	4,700	1,020	50	16,820
	2,030	4,080	2,380	700	9,190		9,940	4,500	990	50	15,480
	2,430	3,820	2,620	570	9,440		8,980	4,330	960	50	14,320
	2,770	3,460	2,710	460	9,400		8,180	4,200	950	50	13,380
30	3,030	3,080	2,690	360	9,160	10	7,510	4,090	930	50	12,580
	3,210	2,730	2,580	290	8,810		6,970	4,000	920	50	11,940
	3,330	2,230	2,420	210	8,190		6,530	3,930	910	50	11,420
	3,400	2,160	2,240	140	7,940		6,190	3,870	900	50	11,010
31	3,440	1,940	2,060	50	7,490	11	5,930	3,830	890	50	10,700
	3,480	1,770	1,890	50	7,190		5,730	3,790	880	50	10,450
	3,510	1,660	1,740	50	6,960		5,580	3,760	870	50	10,260
	3,540	1,600	1,620	50	6,810		5,470	3,740	860	50	10,120
Apr. 1	3,560	1,590	1,520	50	6,720	12	5,390	3,720	850	50	10,010
	3,580	1,610	1,430	50	6,670		5,320	3,710	840	50	9,920
	3,610	1,650	1,360	50	6,670		5,260	3,700	830	50	9,840
	3,630	1,690	1,300	50	6,670		5,220	3,700	820	50	9,790
2	3,660	1,750	1,250	50	6,710	13	5,180	3,690	810	50	9,730
	3,700	1,820	1,190	60	6,770		5,140	3,680	800	50	9,670
	3,730	1,900	1,150	100	6,880		5,100	3,680	790	50	9,620
	3,770	1,980	1,100	190	7,040		5,070	3,670	780	50	9,570
3	3,810	2,050	1,060	310	7,230	14	5,040	3,660	770	50	9,520
	3,860	2,120	1,030	440	7,450		5,010	3,640	760	50	9,460
	3,970	2,200	1,010	560	7,740		4,980	3,630	740	50	9,400
	4,200	2,300	1,000	640	8,140		4,960	3,620	730	50	9,360
4	4,630	2,470	1,030	680	8,810	15	4,930	3,600	720	50	9,300
	5,430	2,740	1,100	690	9,960		4,900	3,590	700	50	9,240
	6,780	3,200	1,240	670	11,870		4,870	3,570	680	50	9,170
	8,820	3,970	1,460	620	14,870		4,830	3,540	660	50	9,080
5	11,540	5,100	1,730	550	18,920	16	4,770	3,500	650	50	8,970
	14,680	6,450	1,970	440	23,540		4,690	3,450	630	50	8,820
	17,870	7,790	2,140	320	28,120		4,600	3,380	600	50	8,630
	20,700	8,860	2,200	230	31,990		4,510	3,310	590	50	8,460

Table B-14

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD AT BAGHDAD

Six-hour ordinates in cumecs routed to Baghdad

Date	Samarra	Adhaim Mouth	Probable Maximum Flood	Date	Samarra	Adhaim Mouth	Probable Maximum Flood
Mar. 26	400	-	400	Apr. 6	20,200	70	20,270
	400	-	400		23,930	60	23,990
	460	10	470		27,420	50	27,470
	700	40	740		30,360	40	30,400
27	1,120	140	1,260	7	32,490	30	32,520
	1,610	470	2,080		33,720	20	33,740
	2,050	690	2,740		34,060	20	34,080
	2,390	770	3,160		33,580	10	33,590
28	2,600	760	3,360	8	32,430	10	32,440
	2,810	710	3,520		30,780	10	30,790
	3,160	650	3,810		28,790	10	28,800
	3,740	580	4,320		26,630	10	26,640
29	4,560	510	5,070	9	24,460	-	24,460
	5,520	440	5,960		22,360	-	22,360
	6,520	390	6,910		20,420	-	20,420
	7,420	330	7,750		18,660	-	18,660
30	8,140	280	8,420	10	17,100	-	17,100
	8,630	230	8,860		15,750	-	15,750
	8,880	200	9,080		14,590	-	14,590
	8,930	160	9,090		13,610	-	13,610
31	8,810	130	8,940	11	12,800	-	12,800
	8,560	100	8,660		12,140	-	12,140
	8,240	80	8,320		11,600	-	11,600
	7,890	50	7,940		11,170	-	11,170
Apr. 1	7,580	30	7,610	12	10,830	-	10,830
	7,300	20	7,320		10,560	-	10,560
	7,090	10	7,100		10,350	-	10,350
	6,930	10	6,940		10,190	-	10,190
2	6,820	-	6,820	13	10,060	-	10,060
	6,760	-	6,760		9,960	-	9,960
	6,730	-	6,730		9,870	-	9,870
	6,730	-	6,730		9,800	-	9,800
3	6,770	-	6,770	14	9,730	-	9,730
	6,850	10	6,860		9,670	-	9,670
	6,970	20	6,990		9,620	-	9,620
	7,120	40	7,160		9,560	-	9,560
4	7,320	70	7,390	15	9,510	-	9,510
	7,580	90	7,670		9,460	-	9,460
	7,970	120	8,090		9,410	-	9,410
	8,600	130	8,730		9,360	-	9,360
5	9,620	130	9,750	16	9,300	-	9,300
	11,250	120	11,370		9,220	-	9,220
	13,600	110	13,710		9,140	-	9,140
	16,650	90	16,740		9,030	-	9,030

Table B-15

FLOOD COMPUTATIONS

PROBABLE MAXIMUM FLOOD BELOW DIYALA-TIGRIS CONFLUENCE

Six-hour ordinates in cumecs routed to confluence

Date	Baghdad	Derbend-i-Khan	Lower Diyala	Probable Maximum Flood	Date	Baghdad	Derbend-i-Khan	Lower Diyala	Probable Maximum Flood
Mar. 26	400	110	10	520	Apr. 6	17,400	1,790	-	19,190
	400	220	120	740		20,130	1,760	-	21,890
	420	520	420	1,360		24,550	1,730	-	26,280
	540	880	760	2,180		27,890	1,710	-	29,600
27	860	1,160	970	2,990	7	30,650	1,690	-	32,340
	1,440	1,420	1,050	3,910		32,600	1,680	-	34,280
	2,180	1,790	1,040	5,010		33,680	1,660	-	35,340
	2,780	2,360	1,000	6,140		33,880	1,660	-	35,540
28	3,160	3,050	940	7,150	8	33,300	1,660	-	34,960
	3,380	3,680	860	7,920		32,090	1,660	-	33,750
	3,580	4,150	780	8,510		30,410	1,660	-	32,070
	3,920	4,430	670	9,020		28,410	1,670	-	30,080
29	4,480	4,530	550	9,560	9	26,270	1,680	-	27,950
	5,240	4,470	420	10,130		24,120	1,690	-	25,810
	6,130	4,280	280	10,690		22,050	1,700	-	23,750
	7,040	4,030	160	11,230		20,150	1,700	-	21,850
30	7,840	3,770	80	11,690	10	18,430	1,700	-	20,130
	8,460	3,520	40	12,020		16,910	1,700	-	18,610
	8,870	3,310	10	12,190		15,580	1,700	-	17,280
	9,050	3,130	-	12,180		14,450	1,690	-	16,140
31	9,040	2,990	-	12,030	11	13,500	1,690	-	15,190
	8,870	2,870	-	11,740		12,710	1,680	-	14,390
	8,590	2,760	-	11,350		12,070	1,670	-	13,740
	8,250	2,670	-	10,920		11,540	1,660	-	13,200
Apr. 1	7,890	2,600	-	10,490	12	11,130	1,650	-	12,780
	7,570	2,530	-	10,100		10,790	1,640	-	12,430
	7,300	2,470	-	9,770		10,530	1,630	-	12,160
	7,080	2,420	-	9,500		10,330	1,620	-	11,950
2	6,930	2,370	-	9,300	13	10,170	1,600	-	11,770
	6,820	2,320	-	9,140		10,050	1,580	-	11,630
	6,760	2,260	-	9,020		9,950	1,560	-	11,510
	6,730	2,210	-	8,940		9,860	1,540	-	11,400
3	6,740	2,150	-	8,890	14	9,790	1,530	-	11,320
	6,790	2,090	-	8,880		9,720	1,510	-	11,230
	6,890	2,030	-	8,920		9,660	1,490	-	11,150
	7,020	1,980	-	9,000		9,610	1,460	-	11,070
4	7,210	1,950	-	9,160	15	9,550	1,440	-	10,990
	7,440	1,930	-	9,370		9,500	1,410	-	10,910
	7,760	1,920	-	9,680		9,450	1,380	-	10,830
	8,230	1,910	-	10,140		9,400	1,350	-	10,750
5	8,950	1,900	-	10,850	16	9,350	1,310	-	10,660
	10,100	1,880	-	11,980		9,280	1,280	-	10,560
	11,860	1,860	-	13,720		9,210	1,240	-	10,450
	14,310	1,830	-	16,140		9,120	1,210	-	10,330

8.11 The storm of 2-6 February 1952 was modified to give the maximum Bekhme contribution. Total rainfall volume computed for the Bekhme probable maximum flood was subtracted from the Samarra 48-hour PMP volume. The maximizing factor for the other three basins above Samarra was determined as the ratio of remaining Samarra PMP volume to the 1952 storm 48-hour rain volume over the three basins. Flood contributions for the three basins were computed, routed to Samarra, and added to the routed Bekhme probable maximum flood.

8.12 Many combinations of sub-basin flows can produce a given peak at a downstream point, but the above method of combination was used for all comparative flood-control studies, as described in Appendix C, because it is consistent and does not unnaturally favor or penalize any one flood-protection system.

Floods Less Than the Probable Maximum

8.13 Intermediate-sized floods, producing peaks at Samarra equal to 50 percent and 75 percent of the probable maximum flood peak at Samarra, were also computed. These floods were not based on individual storms, as were the probable maximum floods, but constructed in such a way that each sub-basin would be producing the same proportion of its probable maximum flood peak. This was accomplished by first computing a trial flood at Samarra, made of simultaneous probable maximum floods on each sub-basin, and determining the ratio of the desired flood peak at Samarra to the trial flood peak. Individual sub-basin floods were then computed by applying that ratio to the probable maximum floods for the sub-basins. The hydrograph at Samarra was computed by routing the sub-basin floods to Samarra and combining the flows.

8.14 An intermediate-sized flood, producing 68, 72, and 80 percent, respectively, of the probable maximum flood peak at Samarra, Baghdad, and downstream of the Diyala-Tigris confluence, was also computed by the same method as described above.

Chapter B-9

FLOOD FREQUENCIES

Summary

9.1 Engineers concerned with the design of structures on or near rivers and those concerned with river control are interested in the probability of floods of various sizes. This need to arrive at decisions on the degree of flood protection to be provided arises in the planning of reservoirs. The information is also required for such design considerations as diversion of rivers during construction of a control structure, highway drainage structures, canal cross-drainage facilities, etc.

9.2 Our estimates of flood frequencies have been limited to estimates of recurrence intervals up to 100 years. Due to limitations in data, estimates of longer recurrence intervals, and hence of frequency of greater floods, are not practicable. "Recurrence interval" is defined as the average interval in years between the occurrence of a flood of specified magnitude and an equal or larger flood. The recurrence interval does not in any way imply a future sequence of floods, nor does it imply that floods will occur at regular intervals. Frequency is defined as the mathematical chance of a flood of specified magnitude or larger occurring in any year. The chance of a flood's occurring in any year is unaffected by events of preceding years. If a flood with a frequency of 0.05 (one chance in twenty) occurs this year, there is still one chance in twenty that it will occur next year. Frequency is the reciprocal of recurrence interval but is usually expressed in percent by moving the decimal point two places to the right.

9.3 The frequency curves derived for various locations in the Tigris River Basin are shown on Exhibit B-2(c). Since those curves have been

limited to only a slight extension beyond the period of record, they are not affected to a very large degree by the variation in methods of analysis that are possible. The basic data for the curves were estimated by correlations between the damsites and the points of observations of stream flows. The curves are based primarily on estimates for each individual damsite, analyzed by the Hazen procedure. However, adjustments have been made on the basis of regional parameters to take into account the widest possible range of unusual occurrences that may have happened by chance in one basin but not in another.

Statistical Parameters

9.4 Statistical parameters in the Hazen formula include the coefficient of variation, coefficient of skew, and mean annual flood. Coefficient of variation is the ratio of the standard deviation of a series to the mean of the series, and coefficient of skew expresses the relation of the most probable value or mode of a series to the mean of a series. The values of coefficient of variation, coefficient of skew, and mean flood, developed for seven gaging stations in the Tigris River Basin, are shown on Table B-16. The values for Baghdad were derived from the recorded flows at the Serai gaging station, without any allowance for the substantial flows from breaches that by-passed the station in times of high flood; the values are not therefore representative and are included for interest only.

9.5 The coefficient of skew (C_s) in the Hazen equation is generally believed to be indicative of the variability in the general climatic regime of the drainage basin. Since the general variability throughout the Tigris River Basin is believed to be about the same, we have assumed that C_s will be an average of the computed C_s for five tributary stations in the

Table B-16

STATISTICAL PARAMETERS BASED ON ANNUAL FLOOD PEAKS

Item No.	River	Drainage Area (sq. km.)	Period of Record (years)	Mean Flood (cumecs)	Coefficient of Variation (C_v)	Coefficient of Skew (C_s)	$n(C_s)$
1.	Tigris at Mosul	54,900	40	3,300	0.374	-0.058	-2.3
2.	Greater Zab at Eski Kelek	20,500	28	2,850	0.530	1.99	55.7
3.	Khazir at Manquba	2,900	15	574	0.746	1.81	27.2
4.	Lesser Zab at Altun Kupri	15,600	33	1,750	0.407	1.34	44.2
5.	Diyala at Discharge Site (Diyala Weir)	29,700	38	1,360	0.579	0.715	27.2
6.	Tigris at Fatha	107,600	28	6,470	0.411	0.155	-
7.	Tigris at Baghdad*	123,100	49	5,100	0.300	-0.026	-
	Totals (Items No. 1-5 only)		154				151.9
	Average (Items No. 1-5 only)						0.99

*Parameters not representative; see text.

Station	Mean Annual Flood (cumecs)			Coefficient of Variation		
	From Record	From Curve	Average Used	From Record	From Curve	Average Used
Fatha	6,470	5,600	6,040	0.411	0.360	0.39
Mosul	3,300	3,550	3,420	0.374	0.420	0.40
Eski Kelek	2,850	1,800	2,320	0.530	0.510	0.52
Altun Kupri	1,750	1,500	1,620	0.407	0.535	0.47
Diyala Weir	1,360	2,320	1,840	0.579	0.475	0.53

$$C_v^2 = \frac{\sum\left(\frac{Q}{m} - 1\right)^2}{(n - 1)} \qquad C_s = \frac{\sum\left(\frac{Q}{m} - 1\right)^3}{(n - 1)\, C_v^3}$$

where: C_v = coefficient of variation
C_s = coefficient of skew
Q = individual annual flood peak
m = mean annual flood peak
n = years of record
C_s = (adjusted for length of record) = $C_s\left(1 + \frac{8.5}{n}\right)$

basin having relatively long periods of record. The Fatha station was not included since it is an integration of upstream locations and therefore considered to be a duplication. We have used an average value, weighted according to the period of record of the gaging stations, as shown on Table B-16. An average value of 0.99 was obtained for the basin.

9.6 To check the weighted average value of C_s, we have computed values of C_s for rivers in the western United States which we considered to be generally comparable in their climatic regime. Values of C_s were computed for 12 stations having records of 17 to 42 years, with a total of 412 station-years of record. The weighted average value of C_s obtained from the western United States stations was 1.05, which compares favorably with the values derived for the Tigris Basin stations.

9.7 The values of the mean flood and the coefficient of variation C_v are more dependent on local topography, drainage pattern, and other conditions peculiar to the basin. At the same time, we feel that these factors also have a variability related to basin-wide characteristics. Accordingly, data were plotted relating these values to drainage areas, and mean curves were drawn, as shown on Exhibit B-2(a). The values of mean flood and C_v used in our analysis were the average of the individually computed values and the values indicated by the curves. The average values so determined are shown on Table B-16.

Relation Between Flows at Gaging Stations and at Damsites

9.8 The statistical parameters were computed for gaging stations located some distance downstream from the sites of Bekhme, Dokan, and Derbend-i-Khan dams. The flow at Eski Mosul Damsite can be assumed to be the same as that at Mosul, and the flow at Samarra can be assumed

to be the same as that at Fatha. Correlations, based on the available concurrent record, were developed between Bekhme and Eski Kelek, Dokan and Altun Kupri, and Derbend-i-Khan and Diyala Discharge Site.

9.9 The plotting of flood peaks at the gaging stations and the damsites is shown on Exhibit B-2(b). The values used represent the maximum observed gage heights at the two points during individual rises and are not necessarily for the same day. Since gage readings are generally taken only once daily, they are not necessarily the peak values of the flood. However, the use of an average curve is believed to eliminate practically any errors that may arise from this cause.

9.10 The relationships on Exhibit B-2(b) are based on the following data:

Damsite Station	Downstream Station	Period of Concurrent Record	Number of Flood Peaks
Bekhme (Dor Teswe)	Eski Kelek	1940-54	36
Derbend-i-Khan	Discharge Site	1954-57	14
Dokan	Altun Kupri	1953-57	20

9.11 The three correlation curves were compared by plotting them in dimensionless form, as shown in the lower portion of Exhibit B-2(b). The curves could be expected to coincide if the relationships between area at the damsite to the area at the gaging stations were equal, providing the runoff characteristics above and below the damsites were equivalent in all three cases. The relative runoff characteristics above and below the damsites are believed to be about the same for the three streams; however, the area proportions are different. Since the historical relationship did not appear consistent with the area relationship, adjustments were made in the

dimensionless curves to make them consistent, as shown on the lower graph of Exhibit B-2(b). These adjustments were then made to the correlation curves for the individual stations, shown in the upper graphs of Exhibit B-2(b).

9.12 It will be noted from the curves on Exhibit B-2(b) that peak flows at the damsites are substantially larger throughout the high-flow range than the peaks downstream, even through substantial increases in drainage area exist for the downstream stations. This is not unexpected, as the drainage areas above the damsites have high precipitation and steep slopes, contributing to high runoff; below the damsites the streams begin to emerge onto the plains, where slopes are smaller and precipitation is less, resulting in minor contribution to flooding. Thus, the flood peak can be expected to reduce as it proceeds downstream, owing to the effect of valley storage.

Frequency Curves

9.13 The first step in the computation of flood frequency was the plotting of historic floods at the gaging stations. These were plotted, as shown on Exhibit B-2(c), by the Hazen procedure. In this procedure the plotting position is determined by the formula:

$$p = \frac{2m-1}{2n}$$

where: p = percent of time given annual flow has been exceeded;

m = order number of the occurrence when all occurrences are arranged in order of magnitude;

n = years of record.

9.14 Frequency curves were computed for each gaging station by using the weighted average basin value of C_s and values of C_v and mean

flood as taken from Exhibit B-2(a). The resulting frequency curves are shown on Exhibit B-2(c). For Mosul and Samarra, these curves represented the adopted frequency curves at the damsites. For Bekhme, Dokan, and Derbend-i-Khan, where the curves as computed were for the gaging stations, adjustment to the damsite was necessary.

9.15 Adjustments of the Eski Kelek, Altun Kupri, and Discharge Site frequency curves to the damsite first was made by direct use of the correlation curves of Exhibit B-2(b). It was noted that, at the lower frequencies, the discharges were appreciably lower than shown by the historical values. It was concluded that this effect resulted from use of average basin values and was unrealistic in that range of flows. Accordingly the curves were used as computed by the basin parameters for the upper range of the frequency curve, but adjustments to nearly the historical values were made for the lower 20 to 40 percent of the range. The adopted frequency curves are shown as solid lines on Exhibit B-2(c).

9.16 We do not consider that the available data enable realistic estimates to be made of probable recurrence intervals of more than 100 years for floods on the Tigris. However, it can be said that, from the historical records of all basins studied, the 50-percent values of probable maximum flood peaks appear to have an average recurrence interval of substantially more than 100 years, while the 50-percent values of probable maximum 20-day volumes have very much shorter recurrence intervals of approximately 50 years.

Reliability of Flood Frequency Estimates

9.17 In discussing the reliability of flood frequency estimates, it is pertinent to examine the underlying assumptions made in computing a

frequency curve and to assess the value of the result. The basic assumptions are:

a. That each flood occurrence on the river under study is independent; that each occurrence is a random event having no connection with other events in the series;

b. That all the flood occurrences are homogeneous and members of one family;

c. That the recorded floods are representative of future floods.

9.18 The first assumption is subject to conflicting opinions. Hurst has presented data which indicate that annual precipitation, tree rings, clay varves, etc., tend to occur in groupings of high and low values. He also shows this trend for annual riverflow volumes. There is wide acceptance, although far from universal agreement, that annual volumes exhibit this tendency. On the other hand, there is a great deal of data throughout the world which tends to indicate that individual large storm occurrences are random events, not related to annual volumes. The annual flood peaks of mountain rivers in Iraq are practically always due to individual storms superimposed on a snowmelt base. While there is some variability in the snowmelt base, the greatest factor in the magnitude of the peak flow is the size of the rain-flood component. Therefore, we have concluded that peak values for Iraq rivers can reasonably be assumed to be random events.

9.19 Our conclusions on the second basic assumption are related to the first. Since the variability from year to year in peak discharges on the Tigris and its tributaries can be attributed primarily to the storm component, we consider it not unreasonable to assume that all such occurrences are members of one family. However, Hazen has suggested

that very great and rare flood peaks have a special character outside a river's normal family of flood occurrences.

9.20 The third basic assumption (that the historical records are representative of the future) introduces some doubt. Even when events are random, groupings of high and low values do occur. It can be shown mathematically that if 10,000 years of record were available, the "100-year flood" would have a probable distribution as follows:

37	centuries would have no "100-year flood"	
37	centuries would have one "100-year flood"	= 37 such floods
18	centuries would have two "100-year floods"	= 36 such floods
6	centuries would have three "100-year floods"	= 18 such floods
1.5	centuries would have four "100-year floods"	= 6 such floods
0.5	centuries would have six "100-year floods"	= 3 such floods
100	centuries would have	100 such floods

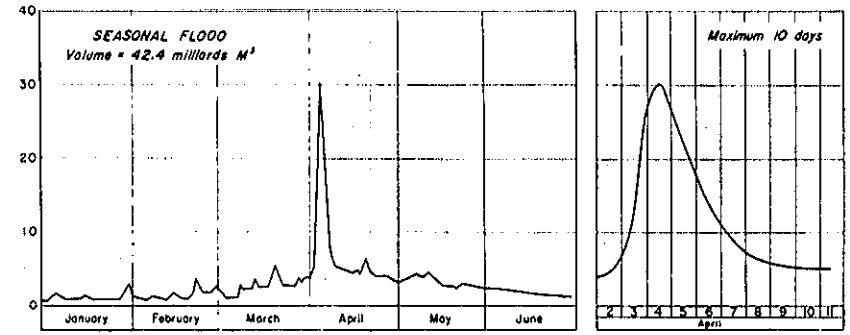
9.21 Thus, there is an appreciable chance that the period of record we have considered is not representative of the future. As a means of effectively lengthening the period of record (and thereby reducing the chances of the period's being unrepresentative) we have used the Hazen concept of taking together the floods on all streams in the basin for developing the factors to determine the frequency curves. This procedure cannot be considered as increasing the effective length of record to the total of the lengths of the individual records, since there must exist some general correlation between flood occurrences in the individual basins. However, the effective length of record does become somewhat longer than the longest individual record, to an extent represented by the amounts that individual occurrences in separate basins do not follow a perfect correlation. Therefore, we believe we have taken the best precautions to eliminate the possibility of the

period's being unrepresentative; at the same time this possibility must still be distinctly recognized.

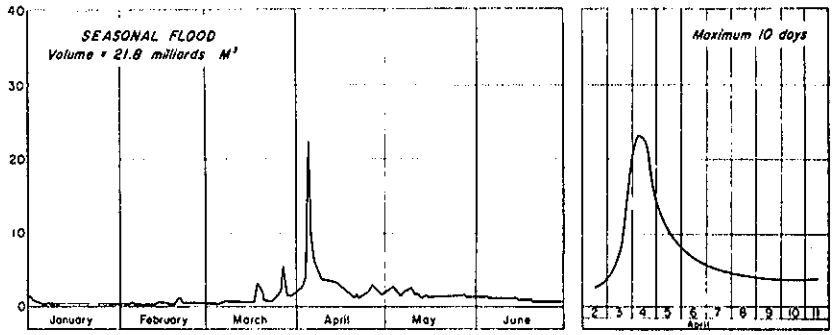
9.22 The necessity of introducing correlations between flows at gaging stations and flows at the damsites, as required for Bekhme, Dokan, and Derbend-i-Khan, inevitably introduces some error. The periods of concurrent record at the gaging stations and the damsites are relatively short for development of the correlations. However, while individual points show great deviations for the lower peaks, the values exceeding the mean annual flood are fairly consistent. Also, there is a general consistency between basins when the correlation curves are shown on a dimensionless basis, as is indicated on Exhibit 12. The deviation from complete consistency between basins has been partially adjusted, as indicated. It can be further stated that in a probability analysis deviation of individual points is not highly significant as long as the general relationship is valid. We believe that possible errors in the frequency curve due to the necessity of converting flows from the gaging station to the damsite are not large.

9.23 To summarize, we believe that the probability curves shown on Exhibit B-2 are the best that can be made with the available data and that they are a reasonable representation of the frequencies of occurrence to be expected. The possibility exists, however, that the three basic assumptions mentioned in paragraph 9.17 are not entirely valid, and this fact must be considered in any use to which our estimates of flood frequency are put.

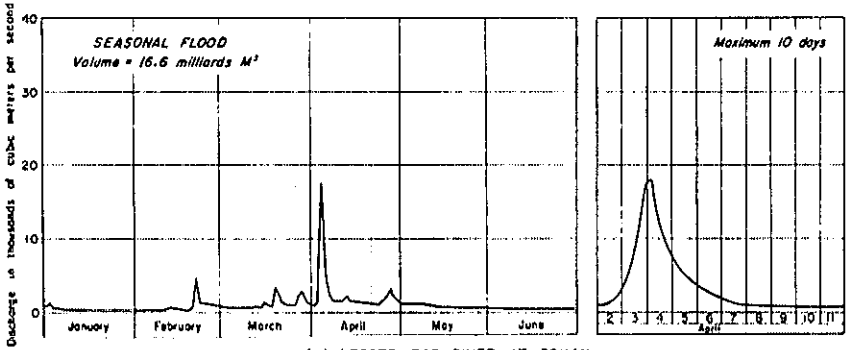
EXHIBIT B-1



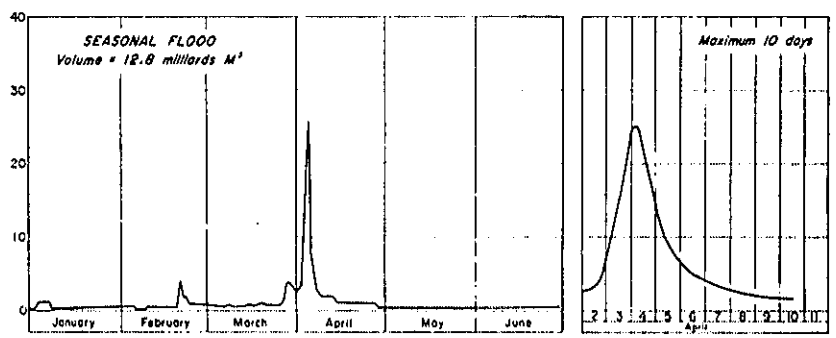
(a) TIGRIS RIVER AT ESKI MOSUL



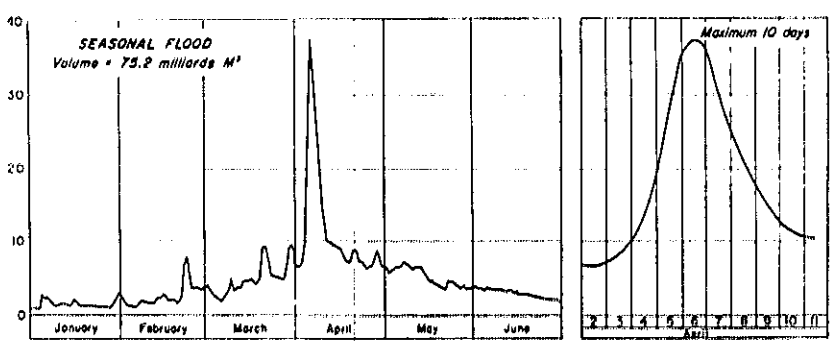
(b) GREATER ZAB RIVER AT BEKHME



(c) LESSER ZAB RIVER AT DOKAN



(d) DIYALA RIVER AT DERBEND-I-KHAN



(e) TIGRIS RIVER AT SAMARRA

NOTES:

1 - Hydrographs shown represent natural, uncontrolled floods

2 - Additional probable maximum floods, for which hydrographs are not shown, have been developed, as follows:

Basin	Flood Peaks (cubic meters per second)
Central Tigris River, between Eski Mosul, Bekhme, Dokan and Samarra damsites	11,000
Adhaim River at its mouth	13,000
Lower Diyala River, between Derbend-i-Khan Dam and mouth of Diyala	11,000
Tigris River at Baghdad	34,000
Tigris River below mouth of Diyala River	38,000

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

PROBABLE MAXIMUM FLOODS
TIGRIS RIVER BASIN

HARZA ENGINEERING CO. CHICAGO — BINNIE, DEACON & GOURLEY LONDON
IN ASSOCIATION
BAGHDAD, IRAQ — DATE 3 Aug 1965 — DWG NO 627-14

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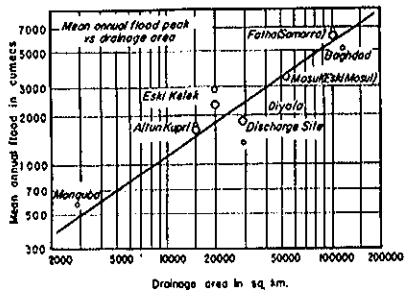
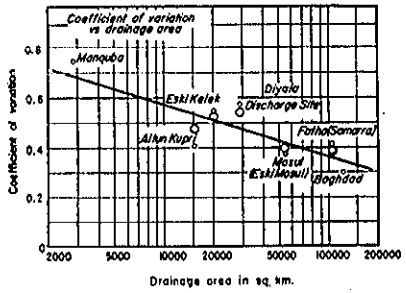
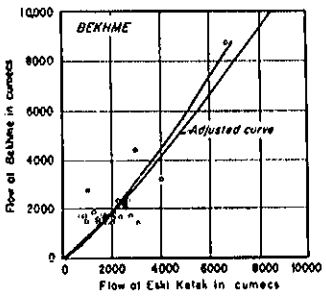
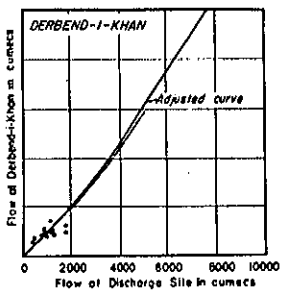


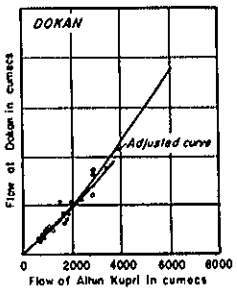


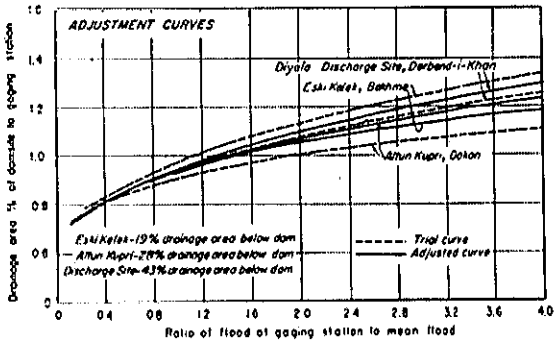
(a) STATISTICAL PARAMETERS

LEGEND
- ● Values of cv and mean flood computation for gaging station record
- ○ Partial adjustment to agree with basin curve, as used in frequency computations



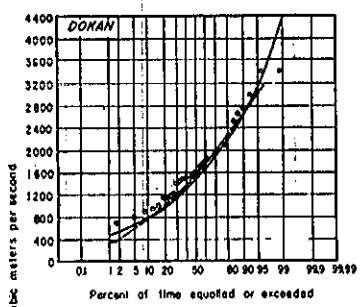


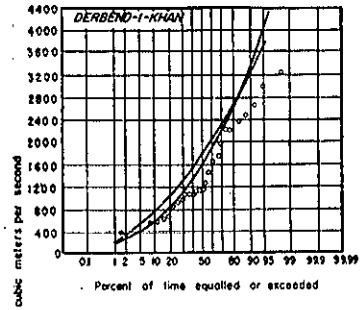


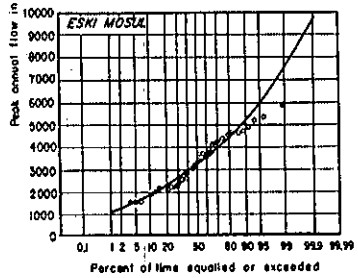


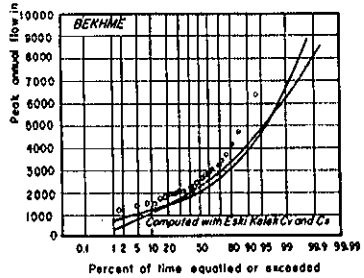
(b) DAM SITE TO GAGING STATION CORRELATIONS

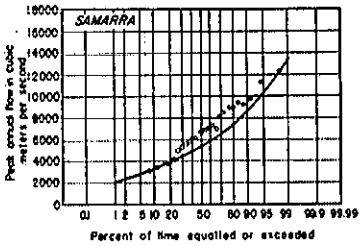
NOTE. Adjustment curves represent changes to make flow contributions between damsites and gaging stations consistent with contributing areas below damsites.











(c) FREQUENCY CURVES

LEGEND
- ● Historic flood at gaging station.
- ----- Frequency curve for gaging station computed on basis of weighted average C_s for basin, and values of C_v and mean flood from Fig.(a).
- ——— Adopted curve for damsite on basis of correlation between damsite and gaging station. (For Eski Mosul and Samarra curve is same as -----).

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

PEAK FREQUENCY CURVE DERIVATION

HANZA ENGINEERING CO CHICAGO IN ASSOCIATION DINNIC, DEACON & GOURLEY LONDON

BAGHDAD, IRAQ DATE 23 Feb 59 DWG NO 627-25

-89

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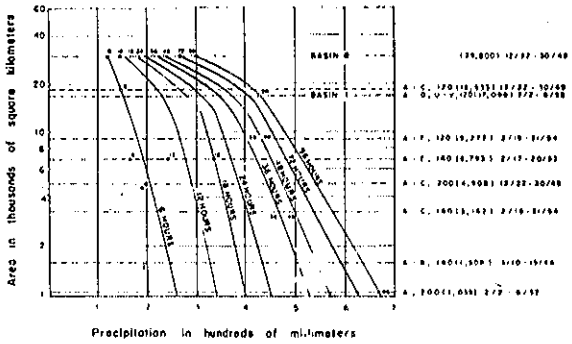
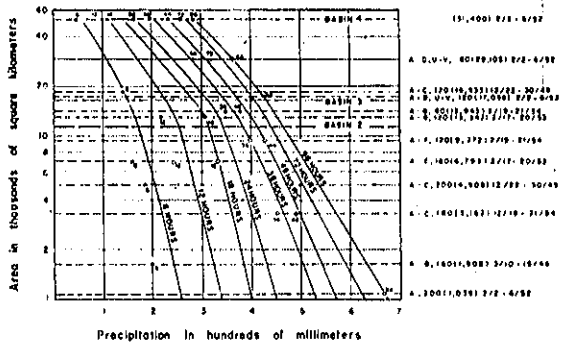


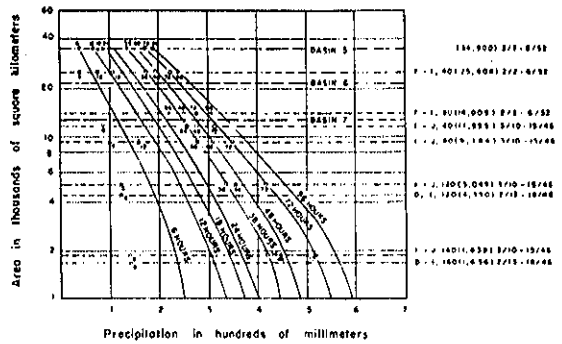
(a)

1. DIYALA RIVER ABOVE DERBEND-I-KHAN DAM
8. DIYALA RIVER ABOVE DIYALA WEIR



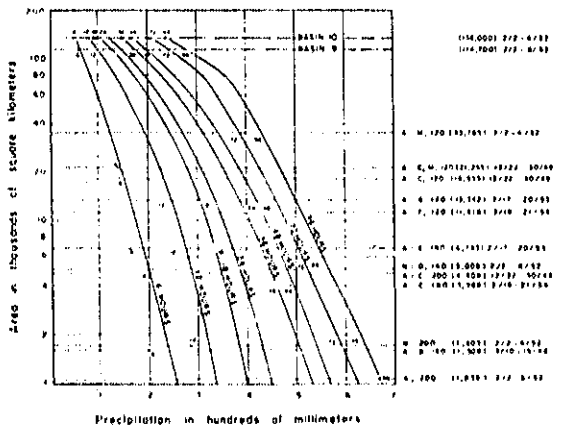
(b)

2. LESSER ZAB RIVER ABOVE DOKAN DAM
3. GREATER ZAB RIVER ABOVE BEKHME DAM SITE
4. TIGRIS RIVER ABOVE ESKI MOSUL DAM SITE



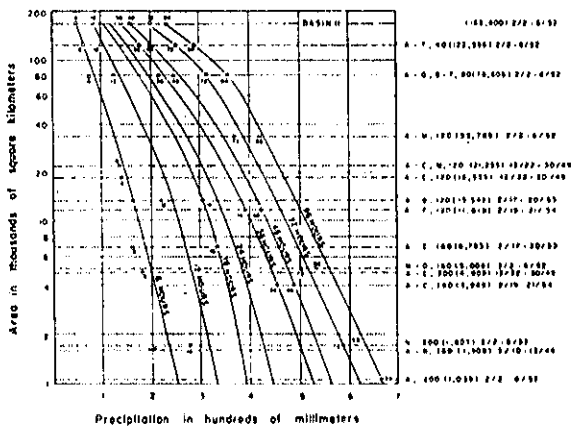
(c)

7. DIYALA R. BETWEEN DERBEND-I-KHAN DAM AND DIYALA WEIR
6. ADHAIM RIVER AT ITS MOUTH
5. CENTRAL TIGRIS (BELOW ESKI MOSUL, DOKAN, AND BEKHME BUT ABOVE SAMARRA)



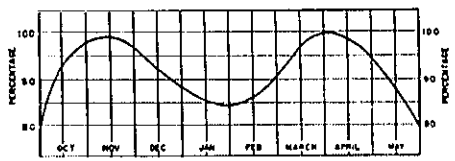
(d)

9. TIGRIS RIVER ABOVE SAMARRA
10. TIGRIS RIVER ABOVE BAGHDAD



(e)

11. TIGRIS RIVER ABOVE AND INCLUDING DIYALA RIVER



SEASONAL VARIATION OF PROBABLE MAXIMUM PRECIPITATION

NOTE

1 Notations to right of grids identify maximized historical storm from which plotted points were obtained
Following example gives the key for second from top horizontal dashed line of grid (e).

2/2-6/52	Date (Feb 2-6, 1952) of maximized historical storm
6,* 12,* etc	Maximized precipitation for 6, 12 etc hours durations of storm
A-T	Storm center designations used to determine precipitation
40	Lowest isohyet (in mm) included
122,595	Area encompassed by lowest isohyet (in sq km)

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

PROBABLE MAXIMUM PRECIPITATION
TIGRIS RIVER BASIN

HARZA ENGINEERING CO. CHICAGO — IN ASSOCIATION — DIPPEL, DEACON & COURTEY LONDON

BAGHDAD, IRAQ — DATE 6 JAN 1958 — DWG NO 627-11

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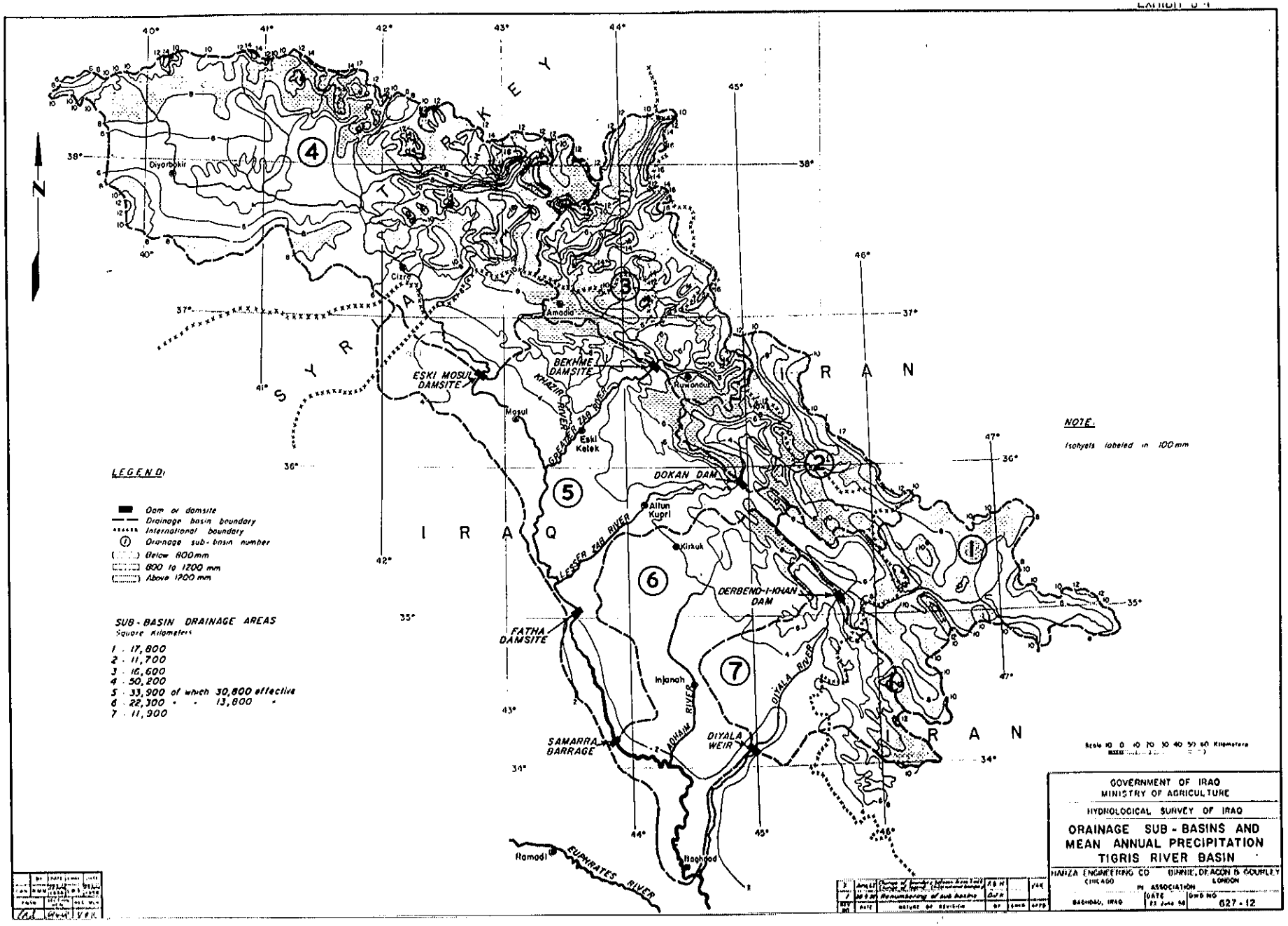

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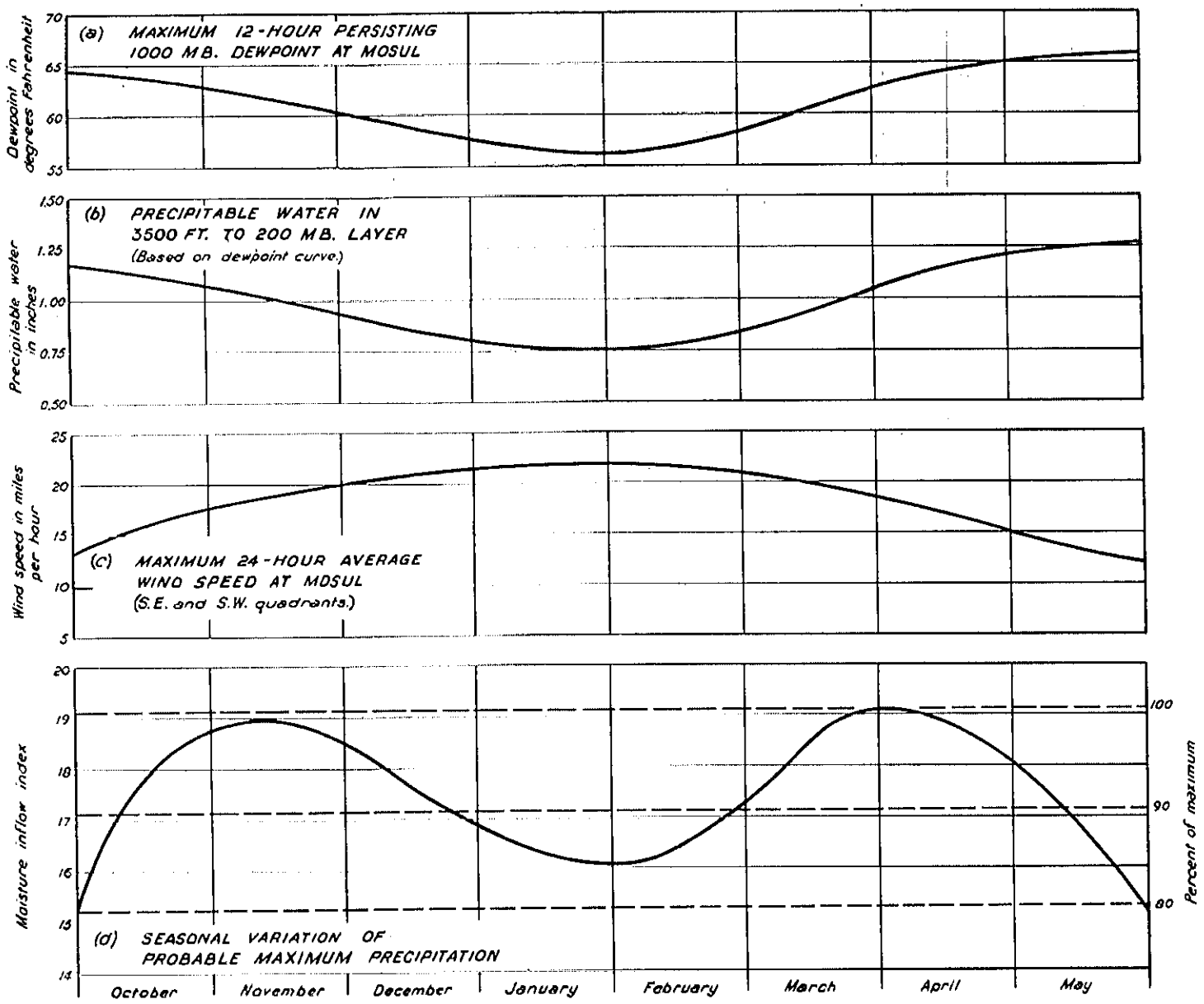

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

SEASONAL VARIATION MAXIMUM PRECIPITATION

HARZA ENGINEERING CO CHICAGO — DINNIE, DEACON & GOURLEY LONDON — IN ASSOCIATION

BAGHDAD, IRAQ — DATE 18 JAN. 57 — DWG NO. 627-30

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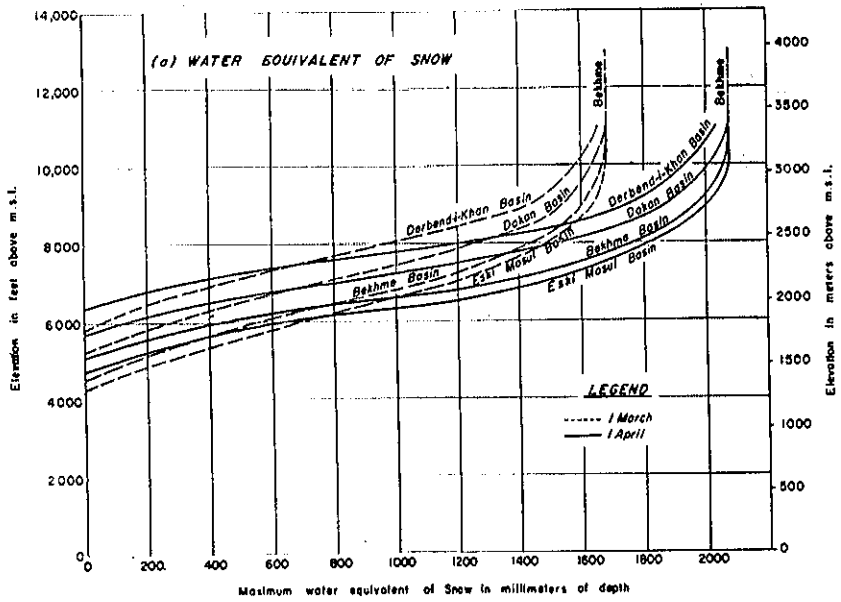

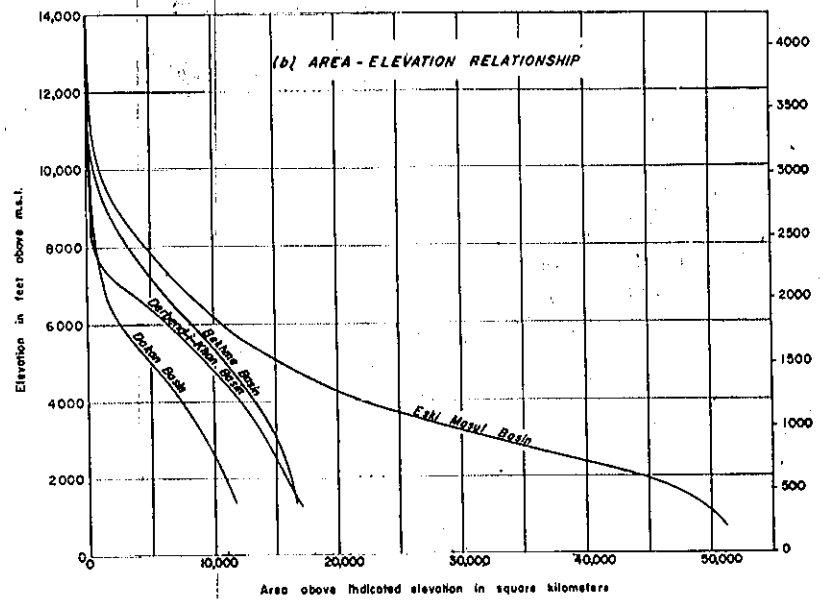

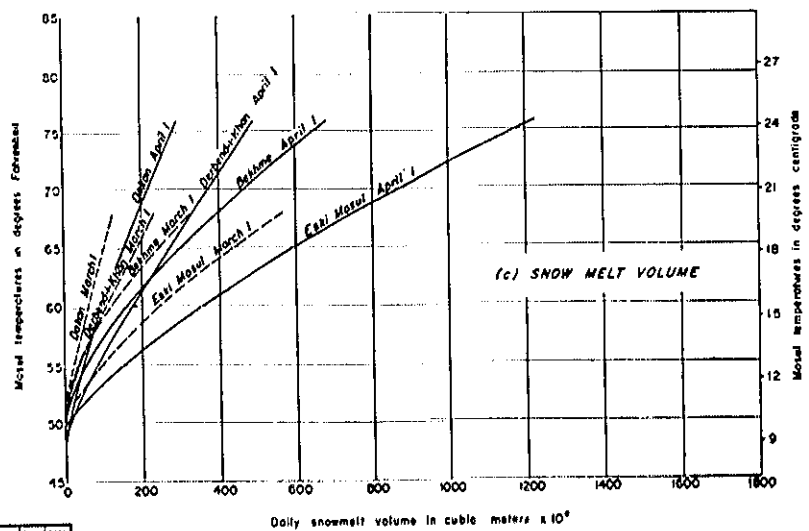

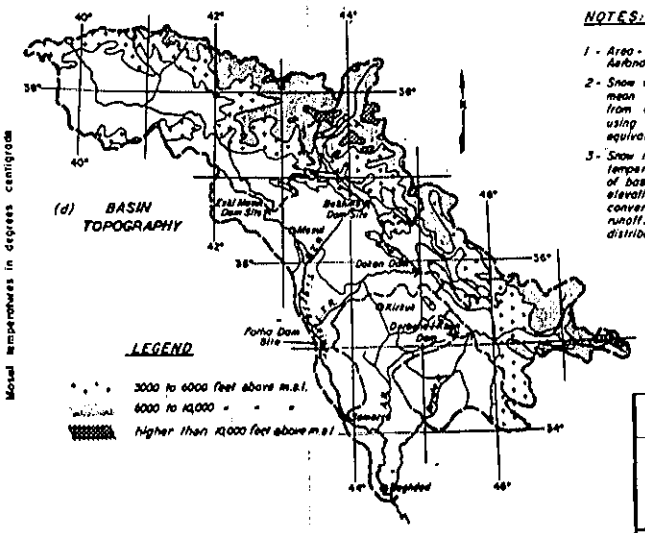

NOTES:

1 - Area - elevation curves and topographic data from World Aeronautical Charts, Scale 1:1,000,000.

2 - Snow water equivalent curves computed from observed mean winter precipitation for basin, using correlations from California (U.S.) snow surveys, and maximized using relation between mean and maximum water equivalent from California snow surveys.

3 - Snow melt curves based on relation between Mosul temperature and melt factor of 3mm. per degree-day of basin melting temperature, assuming minimum snow elevation shown on graph (a). Values represent volume converted to water in one day, rather than a rate of runoff. Runoff from one days melt assumed to be distributed over 20 days.

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

SNOW DATA, AREA-ELEVATION CURVES, AND BASIN TOPOGRAPHY

HARZA ENGINEERING CO. CHICAGO — IN ASSOCIATION — DINNIE, OLCACON & GOURLEY LONDON

BAGHDAD, IRAQ — DATE 27 July 1956 — DWG. NO. 625-3

NO.	DATE	NATURE OF REVISION	BY	CHKD	APPD

-93-

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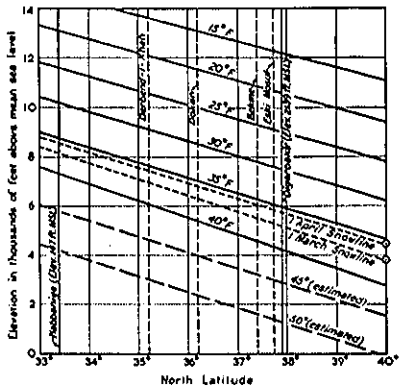
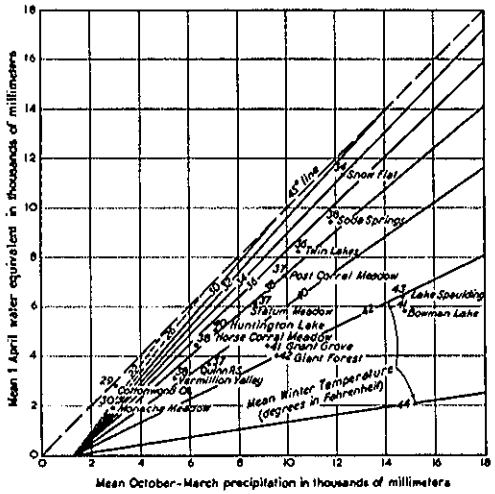
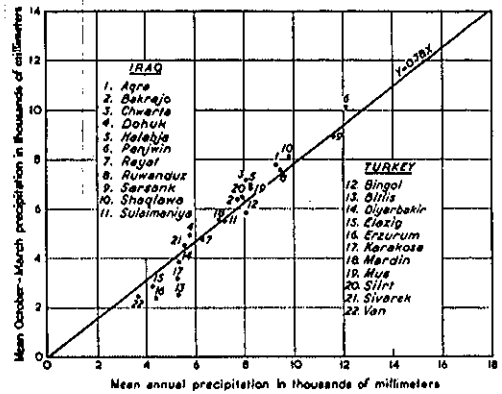


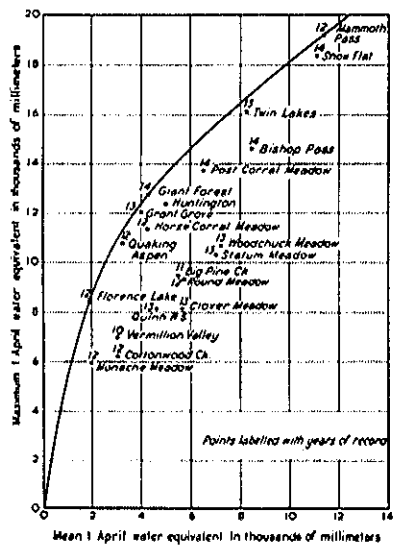
(a) MEAN WINTER UPPER AIR TEMPERATURES



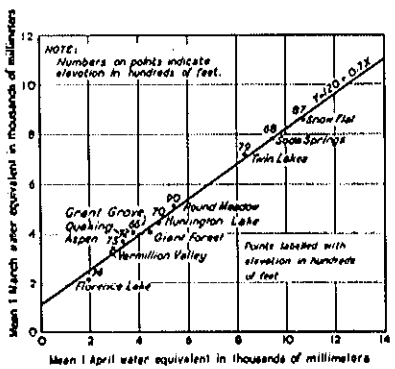
(b) WINTER PRECIPITATION VS. WATER EQUIVALENT ON 1 APRIL



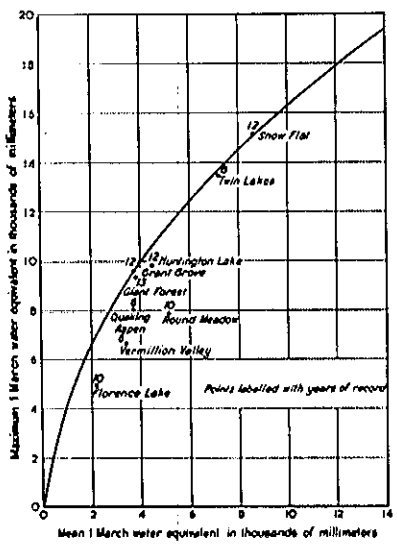
(c) MEAN ANNUAL VS. OCTOBER-MARCH PRECIPITATION



(d) MEAN VS. MAXIMUM WATER EQUIVALENT ON 1 APRIL



(e) 1 APRIL WATER EQUIVALENT VS. 1 MARCH EQUIVALENT



(f) MEAN VS. MAXIMUM WATER EQUIVALENT ON 1 MARCH

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

WATER EQUIVALENT OF SNOW

HANZA ENGINEERING CO. CHICAGO IN ASSOCIATION DINNIE, DEACON & GOURLEY LONDON

BAGHDAD, IRAQ DATE JAN 1957 DWG NO 627-32

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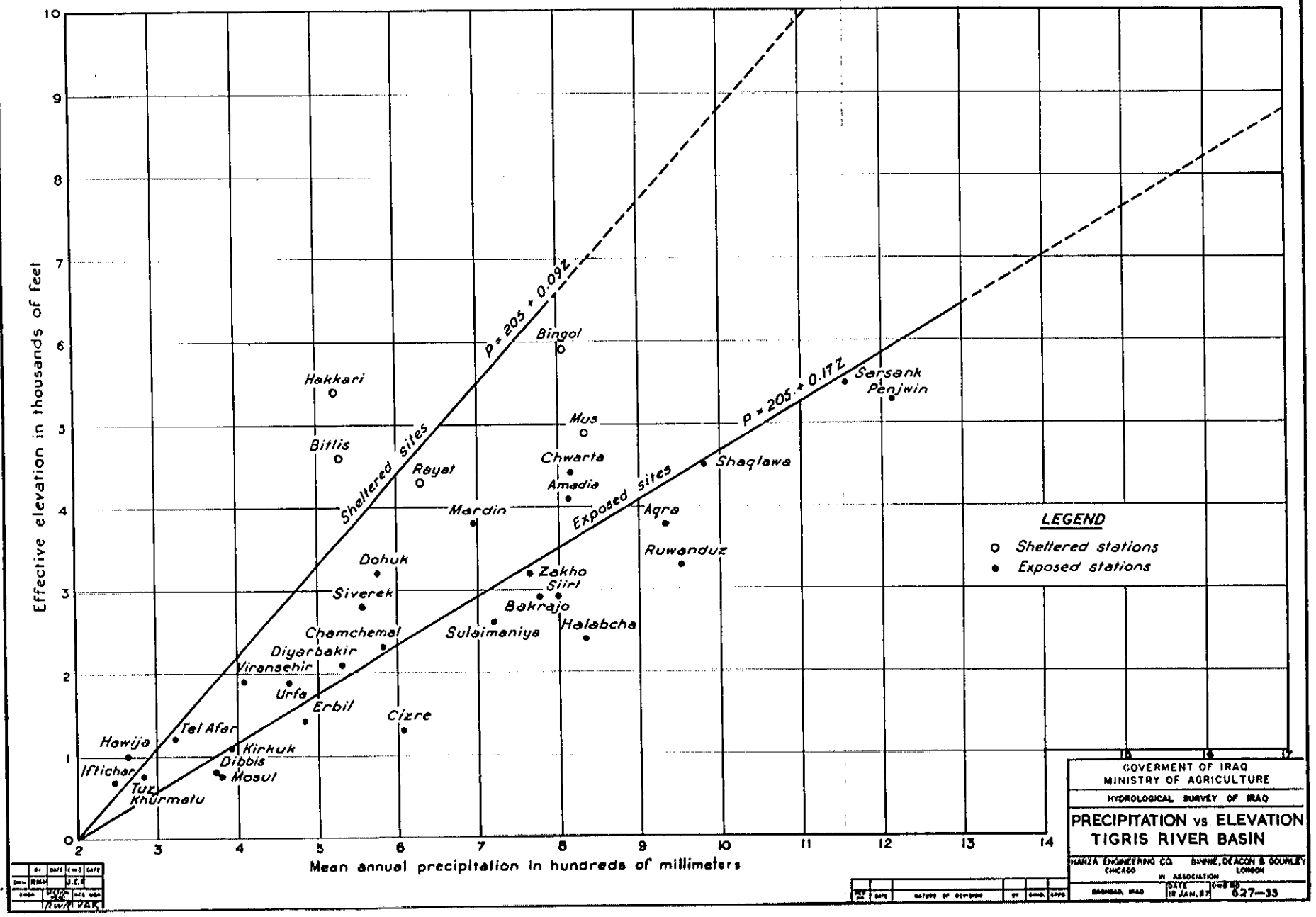

95.

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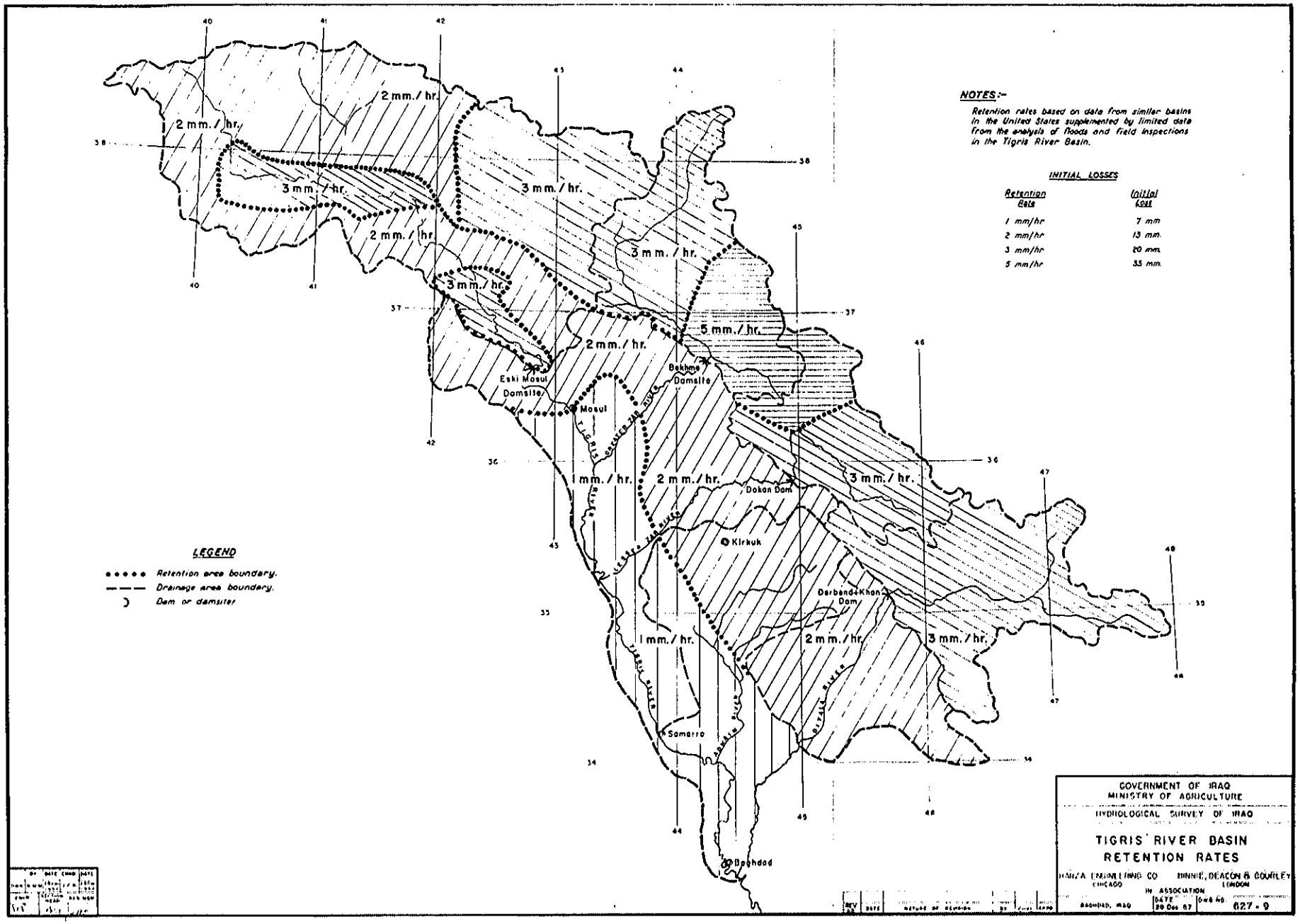

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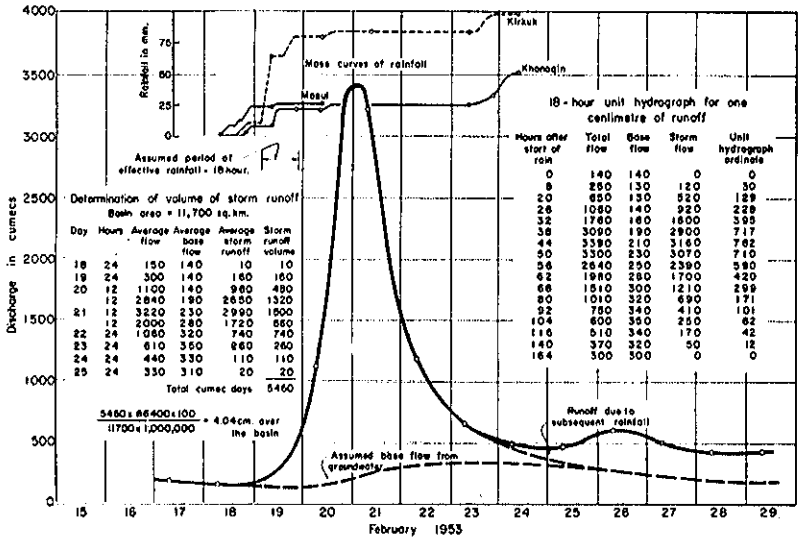


Determination of volume of storm runoff
Basin area = 11,700 sq. km.

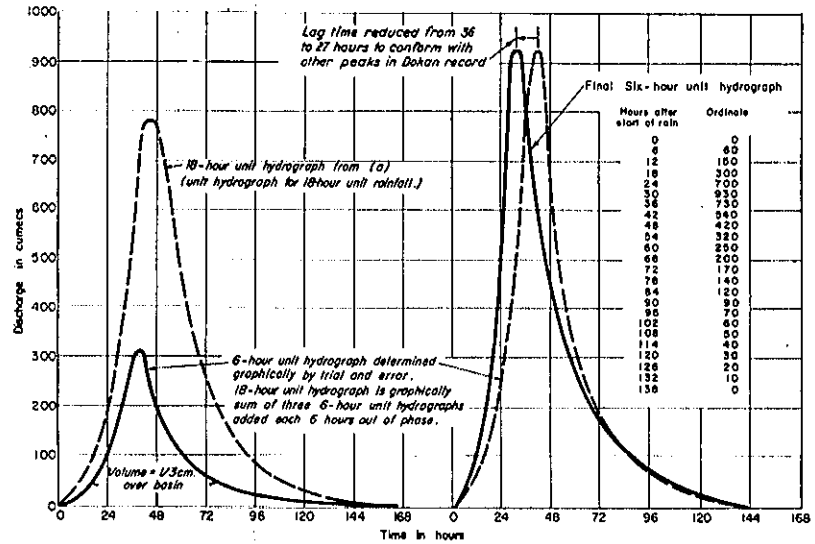
Day	Hours	Average flow	Average base flow	Average storm runoff	Storm runoff volume
18	24	150	140	10	10
19	24	300	140	160	160
20	12	1100	140	960	490
	12	2840	190	2650	1320
21	12	3220	230	2990	1500
	12	2000	280	1720	860
22	24	1080	320	760	760
23	24	610	350	260	260
24	24	440	330	110	110
25	24	330	310	20	20
			Total cumec days		5460

$\frac{5460 \times 86400 \times 100}{11700 \times 1{,}000{,}000} = 4.04$ cm. over the basin

18-hour unit hydrograph for one centimetre of runoff

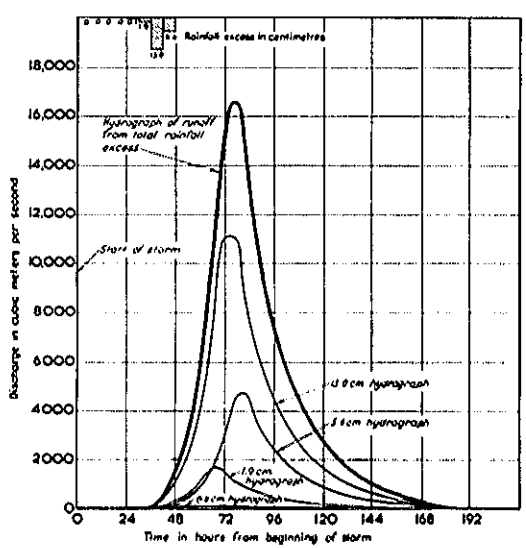
Hours after start of rain	Total flow	Base flow	Storm flow	Unit hydrograph ordinate
0	140	140	0	0
8	250	130	120	50
20	650	130	520	129
28	1080	140	920	229
32	1780	180	1600	395
38	3090	190	2900	717
44	3390	210	3160	782
50	3300	230	3070	710
56	2640	250	2390	590
62	1980	280	1700	420
68	1510	300	1210	299
80	1010	320	690	171
92	750	340	410	101
104	600	350	250	62
116	510	340	170	42
140	370	320	50	12
164	300	300	0	0

(a) HISTORICAL PEAK ANALYSIS LESSER ZAB RIVER AT DOKAN FERRY



Hours after start of rain	Ordinate
0	0
6	60
12	150
18	300
24	700
30	930
36	730
42	540
48	420
54	320
60	250
66	200
72	170
78	140
84	120
90	90
96	70
102	60
108	50
114	40
120	30
126	20
132	10
138	0

(b) DEVELOPMENT OF SIX-HOUR UNIT HYDROGRAPH



(c) APPLICATION OF DOKAN UNIT HYDROGRAPH

BY	DATE	CHKD	DATE
J.C.R.		J.C.R.	

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD	APPD

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

DOKAN UNIT HYDROGRAPH DERIVATION

HAZZA ENGINEERING CO CHICAGO — IN ASSOCIATION — BINNIE, DEACON & GOURLEY LONDON

BAGHDAD, IRAQ — DATE FEB. 1959 — DWG NO. 627-31

-97-

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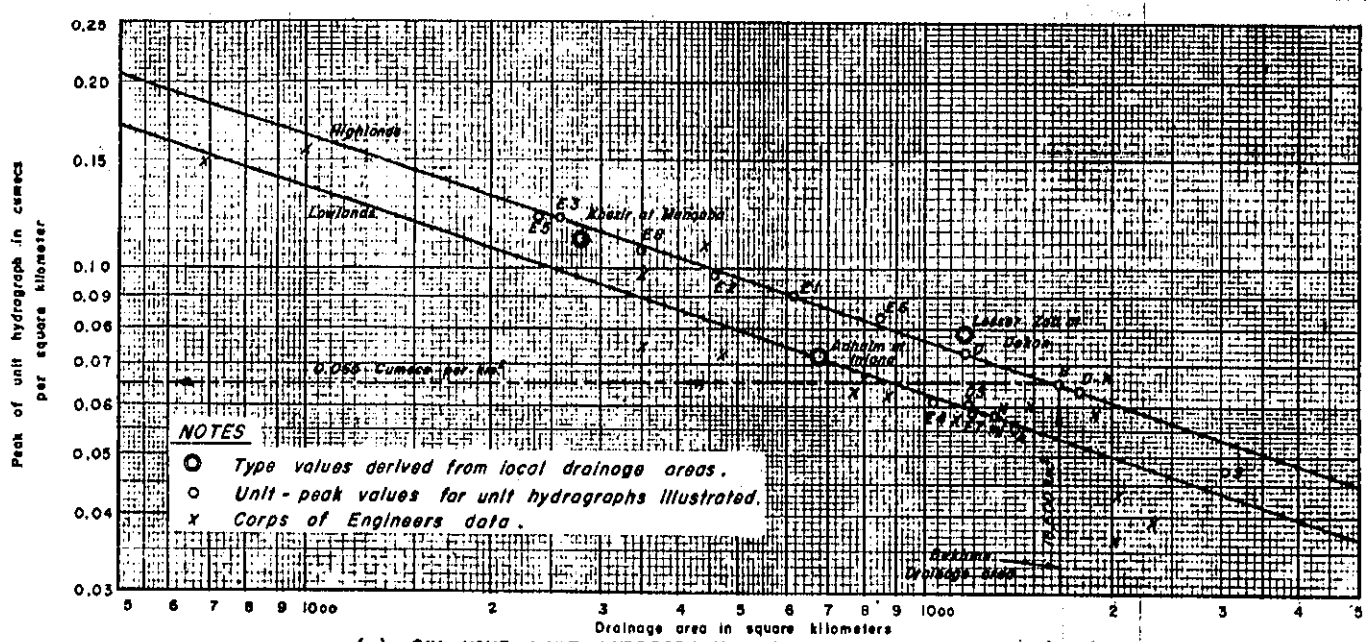
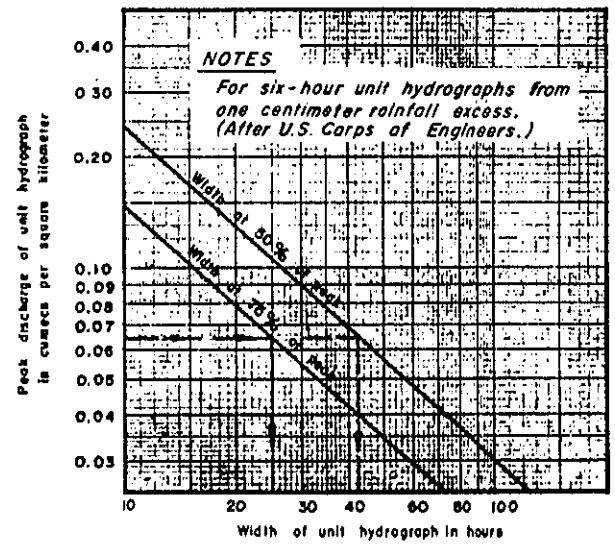
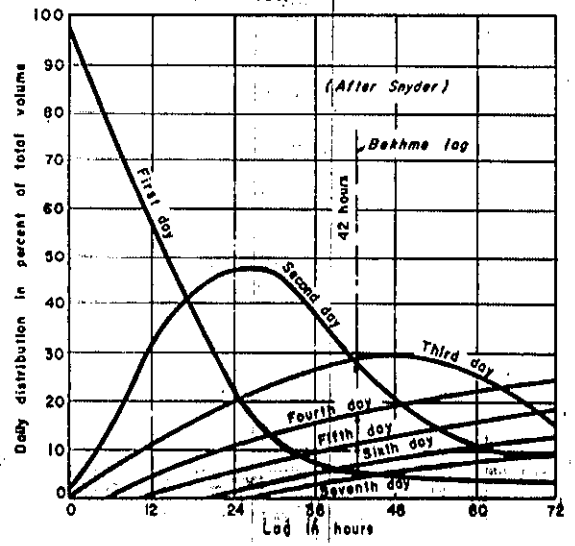


(a) SIX-HOUR UNIT HYDROGRAPH PEAK-DRAINAGE AREA RELATION



(b) UNIT HYDROGRAPH WIDTHS



(c) UNIT HYDROGRAPH VOLUME DISTRIBUTION

(d) SAMPLE DERIVATION

Bekhme unit hydrograph
Drainage area = 16,600 Sq km.

(From a)

Unit peak = 0065 cumecs/Sq.km.
Unit peak = 1080 cumecs

(From b)

Width at 75% peak = 25 hours
Width at 50% peak = 42 hours

(From c)

Runoff distribution for 42 hours lag time

Day	Percent
1	5
2	28
3	28
4	17
5	12
6	6
7	4

NOTE:

Lag time = $C_t (L L_{ca})^{0.3}$

L = river channel length from station to upstream limit of drainage area in kilometers

L_{ca} = river channel length from station to center of gravity of drainage area.

C_t = constant (1.8 for highlands and 1.7 for lowlands)

GOVERMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

SYNTHETIC UNIT HYDROGRAPH RELATIONS

HARZA ENGINEERING CO CHICAGO — BINNIE, DEACON & GOURLEY LONDON — IN ASSOCIATION

BAGHDAD IRAQ — DATE 15 Nov. 58 — DWG NO 627-18

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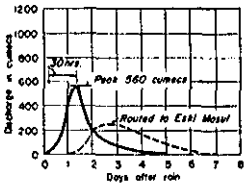
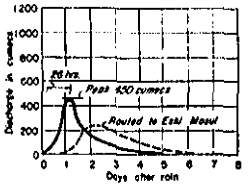
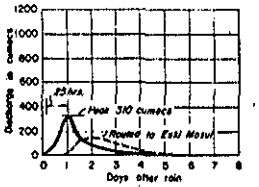


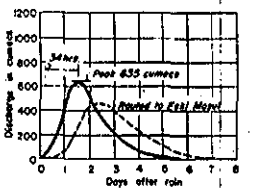
ESKI MOSUL SUB-BASIN E 1
Tigris River at Diyarbakir
Drainage area 6,200 Sq.km.



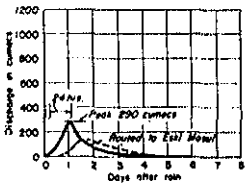
ESKI MOSUL SUB-BASIN E 2
Batman River at Sinan
Drainage area 4,600 Sq.km.



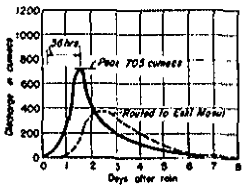
ESKI MOSUL SUB-BASIN E 3
Garzan River at Besiri
Drainage area 2,600 Sq.km.



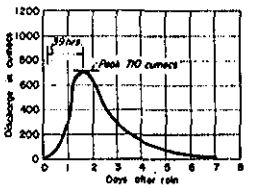
ESKI MOSUL SUB-BASIN E 4
Tigris River, Diyarbakir to Semsi
Drainage area 10,300 Sq.km.



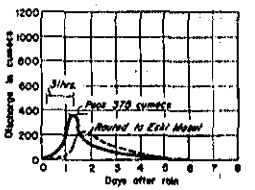
ESKI MOSUL SUB-BASIN E 5
Bozar River at confluence with Botan River
Drainage area 2,400 Sq.km.



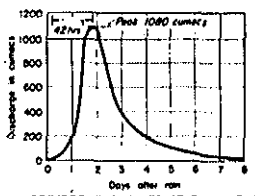
ESKI MOSUL SUB-BASIN E 6
Botan River at Bitloris
Drainage area 8,500 Sq.km.



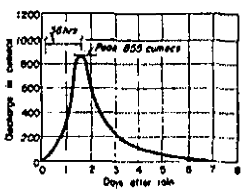
ESKI MOSUL SUB-BASIN E 7
Tigris River, Semsi to Eski Mosul
Drainage area 12,100 Sq.km.



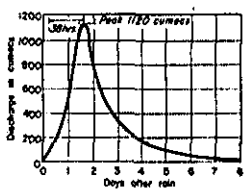
ESKI MOSUL SUB-BASIN E 8
Khabur River at Zakho
Drainage area 3,500 Sq.km.



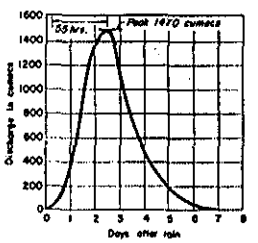
GREATER ZAB RIVER AT BEKHME, B
Drainage area 16,600 Sq km



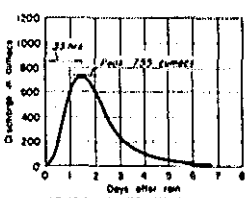
LESSER ZAB RIVER AT DOKAN, D
Drainage area 11,700 Sq km.



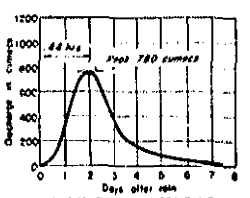
DIYALA RIVER AT DERBEND-I-KHAN, DK
Drainage area 17,800 Sq.km.



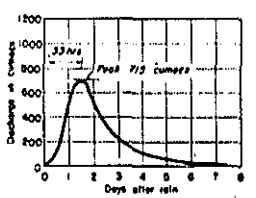
CENTRAL TIGRIS DRAINAGE AT SAMARRA, S
Composite Unit Hydrograph
Effective drainage area 30,800 Sq.km.



ADHAIM RIVER AT INJANA, INJ
Drainage area 13,000 Sq km



ADHAIM RIVER AT CONFLUENCE WITH TIGRIS RIVER, A
Effective drainage area 13,800 Sq.km.



DIYALA RIVER, DERBEND-I-KHAN TO DISCHARGE SITE, D.S.
Drainage area 11,900 Sq.km.

(a) SUB-BASIN UNIT HYDROGRAPHS
FOR ONE CENTIMETER RAINFALL EXCESS

SIX-HOUR UNIT HYDROGRAPH ORDINATES

Cumecs for one centimeter rainfall excess

Sub-basins

Hours from beginning of rain	E1	E2	E3	E4	E5	E6	E7	E8	B	D	DK	S	INJ	A	DS
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	20	35	20	40	25	20	20	10	10	30	60	20	45	30	60
12	70	95	60	115	70	50	55	25	35	80	150	70	190	70	120
18	165	205	138	240	150	110	120	55	90	160	290	190	340	135	230
24	420	450	310	400	290	195	250	180	175	300	480	370	340	250	420
30	580	620	440	580	600	500	540	375	350	550	740	590	690	440	620
36	430	540	530	635	530	705	705	595	650	840	1000	835	755	610	715
42	270	175	100	603	100	610	710	150	1070	840	1120	1105	700	730	850
48	200	140	80	523	75	430	645	110	1070	590	930	1320	820	780	835
54	160	110	65	435	60	335	530	90	900	450	730	1450	810	710	485
60	120	85	50	350	40	275	440	70	630	350	570	1470	410	615	540
66	95	65	35	275	30	230	365	60	480	270	440	1350	315	485	470
72	70	50	30	220	20	200	305	50	383	210	340	1145	245	385	410
78	55	35	20	175	15	170	250	35	315	160	260	930	185	275	370
84	40	20	10	135	5	140	210	30	263	130	210	755	135	210	140
90	30	15	10	100	0	120	175	25	223	100	180	590	105	160	180
96	20	5	5	70		100	140	20	183	80	150	445	80	125	100
102	10	0	0	45		80	110	15	150	60	120	345	60	100	80
108	5			30		70	85	10	140	50	100	265	45	80	70
114	0			20		50	65	5	120	40	90	195	35	65	60
120				10		40	50	0	100	30	70	145	25	50	50
126				10		30	40	0	80	20	60	95	15	40	40
132				5		20	30		65	10	50	70	10	30	30
138				0		5	15		50	5	40	45	5	20	25
144						0	10		45	0	30	30		15	20
150							5		35		20	20		10	15
156							0		25		10	15		5	10
162									20		0	10		0	5
168									15			0			
174									10						
180									5						
186									5						
192									0						

Routed to Eski Mosul

	E1	E2	E3	E4	E5	E6	E8
0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
12	0	0	0	5	5	5	5
18	0	5	5	20	15	10	10
24	5	15	15	65	35	30	20
30	10	55	45	135	110	45	55
36	45	135	105	250	140	145	145
42	115	205	140	350	140	300	220
48	185	250	145	423	130	395	195
54	230	225	135	460	120	415	170
60	252	210	125	460	105	400	140
66	250	190	110	440	90	370	115
72	240	165	90	400	75	335	95
78	225	145	75	355	60	305	80
84	200	120	65	315	50	270	65
90	180	100	55	270	40	240	50
96	155	80	45	230	30	210	40
102	130	65	35	190	20	180	35
108	110	52	25	155	15	155	30
114	90	40	20	120	10	135	25
120	75	30	15	95	10	115	15
126	60	20	10	75	5	95	10
132	45	15	10	60	5	80	5
138	35	10	5	45		65	5
144	30	10	5	35		50	
150	20	5	5	25		35	
156	15			20		25	
162	10			15		20	
168	10			10		15	
174	5			5		10	
180						10	
186						5	

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

TIGRIS RIVER BASIN
UNIT HYDROGRAPHS

HANZA ENGINEERING CO CHICAGO — IN ASSOCIATION — BONNIE, DEACON & GOURLEY LONDON

BAGHDAD, IRAQ — DATE 30 Jan 58 — DWG NO 627-21

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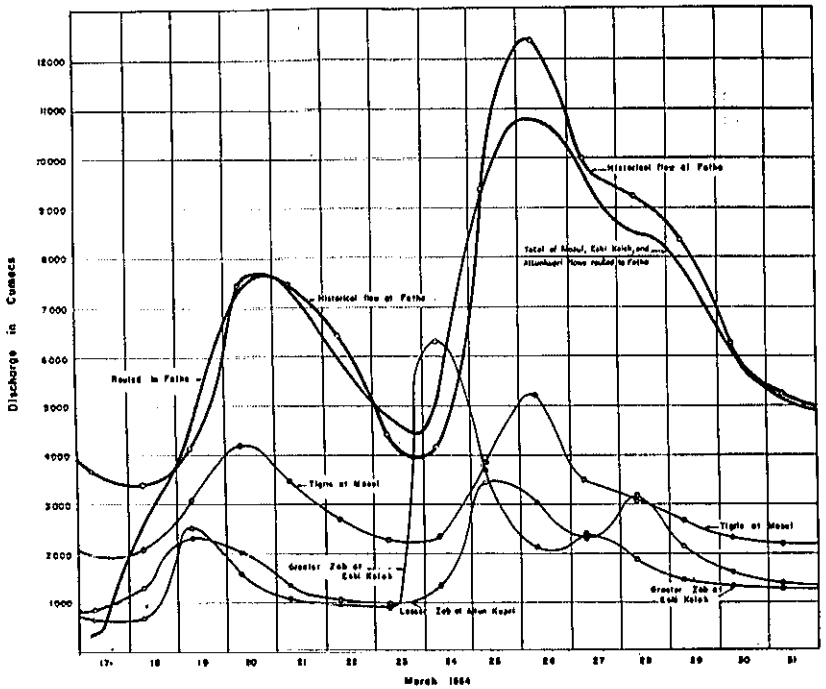
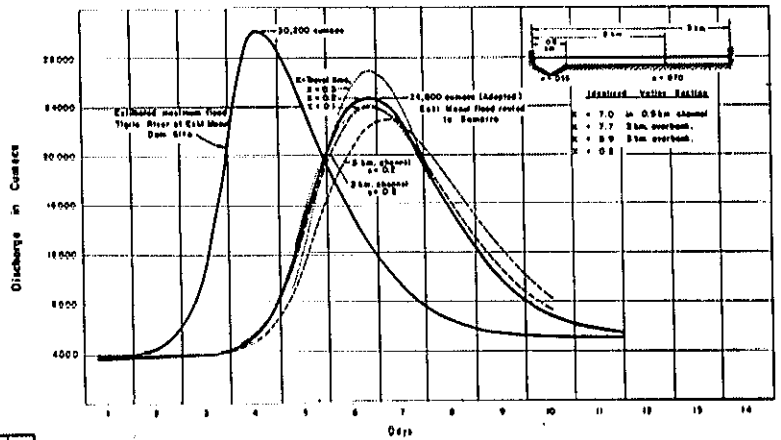


(a) FLOOD ROUTING TEST



(b) COMPARISON OF ROUTING CONSTANTS

(c) MUSKINGUM FLOOD ROUTING RELATIONS

CONSTANTS

K = peak travel time in hours
x = 0.2 (assumed value)
Δt = time interval in hours (6 hours)

I = inflow to head of reach
O = outflow from foot of reach
n = time interval for which outflow is being determined

COEFFICIENTS

$$c_1 = \frac{\Delta t - 2Kx}{2K(1-x) + \Delta t}$$

$$c_2 = \frac{\Delta t + 2Kx}{2K(1-x) + \Delta t}$$

$$c_3 = \frac{2K(1-x) - \Delta t}{2K(1-x) + \Delta t}$$

$$c_4 = c_1 c_3 + c_2$$

Inflow	Factor
I_n	c_1
I_{n-1}	c_4
I_{n-2}	$c_4 c_3$
I_{n-3}	$c_4 c_3^2$
I_{n-4}	$c_4 c_3^3$
I_{n-m}	$c_4 c_3^{m-1}$

EQUATIONS

$$O_n = c_1 I_n + c_2 I_{n-1} + c_3 O_{n-1}$$

$$O_n = c_1 I_n + c_4 I_{n-1} + c_4 c_3 I_{n-2} + c_4 (c_3)^2 I_{n-3} + \ldots\ldots$$

EXAMPLE

Flow of Tigris at Eski Mosul dam site to Samarra

Travel time = 81 hours – use four reaches K = 12.75, x = 0.2, Δt = 6

c_1 = 0.034
c_2 = 0.420
c_3 = 0.546
c_4 = 0.439

	For one reach	Unit inflow at Eski Mosul Interval n	Routed to Reach 2	Routed to Reach 3	Routed to Reach 4	Routed to Samarra
I_n	= 0.034	1	0.034	0.001	0.000	0.000
I_{n-1}	= 0.439		0.439	0.030	0.001	0.000
I_{n-2}	= 0.240		0.240	0.209	0.021	0.000
I_{n-3}	= 0.131		0.131	0.196	0.106	0.014
I_{n-4}	= 0.071		0.071	0.177	0.146	0.062
I_{n-5}	= 0.039		0.039	0.126	0.159	0.106
I_{n-6}	= 0.021		0.021	0.087	0.143	0.135
I_{n-7}	= 0.011		0.011	0.057	0.117	0.143
I_{n-8}	= 0.006		0.006	0.035	0.089	0.134
I_{n-9}				0.022	0.064	0.117
I_{n-10}				0.010	0.044	0.094
I_{n-11}				0.005	0.028	0.073
I_{n-12}					0.016	0.052
I_{n-13}					0.008	0.036
I_{n-14}						0.023
I_{n-15}						0.011
						1.000

ROUTING FACTORS

6-hour Interval	Dokan to Samarra 48 hours	Bakhme to Samarra 52 hours	Eski Mosul to Samarra 81 hours	Derbend-i-Khan to Tigris 32 hours	Samarra to Baghdad 24 hours	Adhaim to Baghdad 15 hours	Diyala Weir to Tigris 17 hours	Baghdad to Diyala 6 hours
I_n	-	-	-	-	-	-	.018	.286
I_{n-1}	-	-	-	.008	.043	.402	.143	.612
I_{n-2}	.005	-	-	.056	.230	.241	.339	.088
I_{n-3}	.029	.011	.014	.166	.230	.145	.241	.012
I_{n-4}	.068	.054	.062	.200	.177	.087	.137	.002
I_{n-5}	.136	.100	.106	.180	.124	.053	.069	
I_{n-6}	.158	.135	.135	.139	.082	.031	.033	
I_{n-7}	.150	.141	.143	.098	.060	.018	.015	
I_{n-8}	.128	.132	.134	.065	.030	.011	.006	
I_{n-9}	.101	.113	.117	.041	.016	.007		
I_{n-10}	.076	.093	.094	.024	.011	.004		
I_{n-11}	.054	.072	.073	.014	.006			
I_{n-12}	.036	.054	.052	.008				
I_{n-13}	.022	.039	.036	.005				
I_{n-14}	.010	.025	.023					
I_{n-15}	.006	.017	.011					
I_{n-16}		.011						
I_{n-17}								

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

FLOOD ROUTING

HAMZA ENGINEERING CO CHICAGO — DUNNIE, DEACON & COURLEY LONDON IN ASSOCIATION

BAGHDAD, IRAQ — DATE 18 Feb 1956 — DWG NO 612-7

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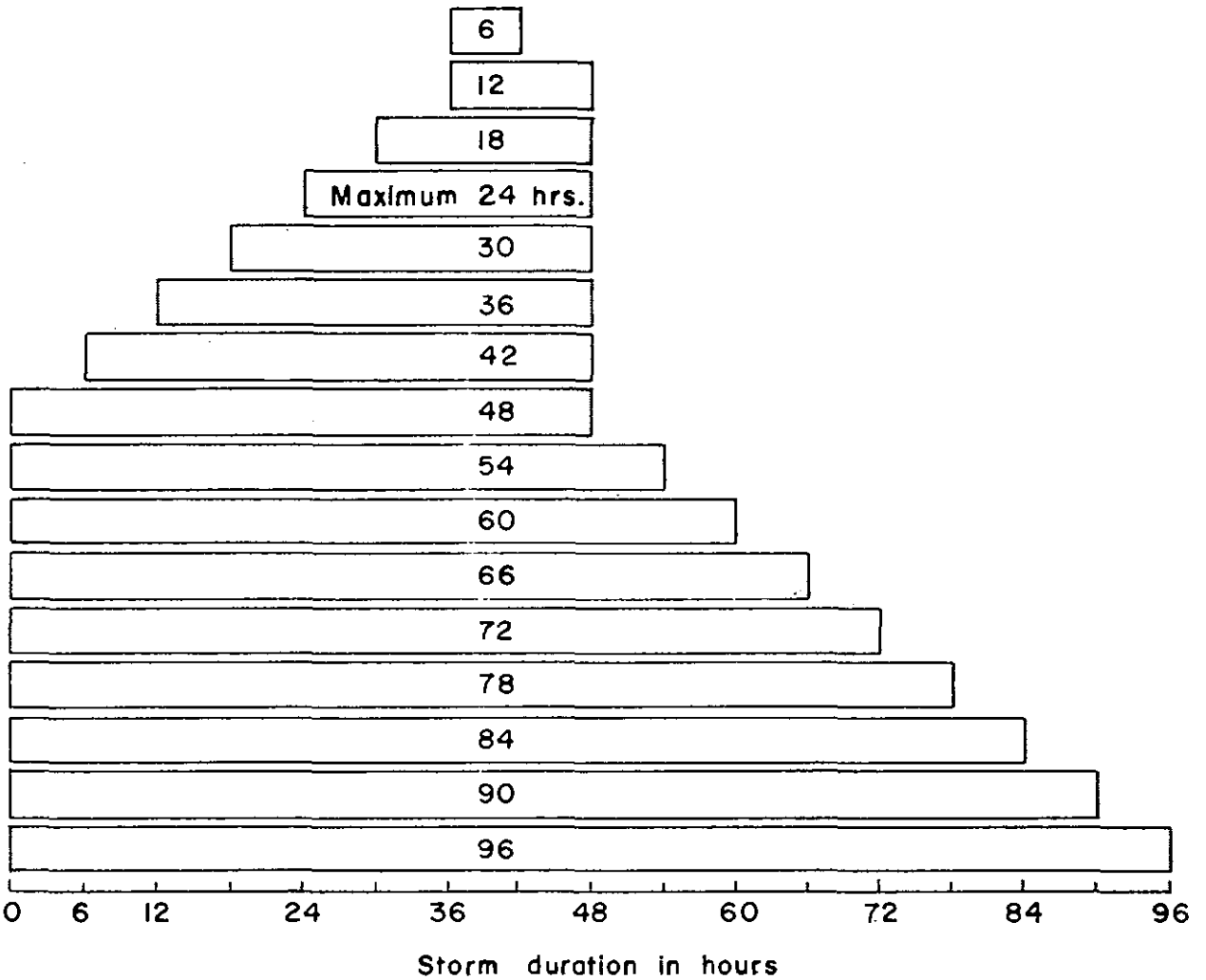


CHRONOLOGICAL DISTRIBUTION OF MAXIMUM INTENSITIES

8	7	6	5	4	3	1	2	9	10	11	12	13	14	15	16

SEQUENCE OF 6-HOUR

INCREMENTS NUMBERED IN DESCENDING ORDER OF MAGNITUDE

NOTE:

Typical time distribution was developed from study of 14 storms in the Tigris River Basin.

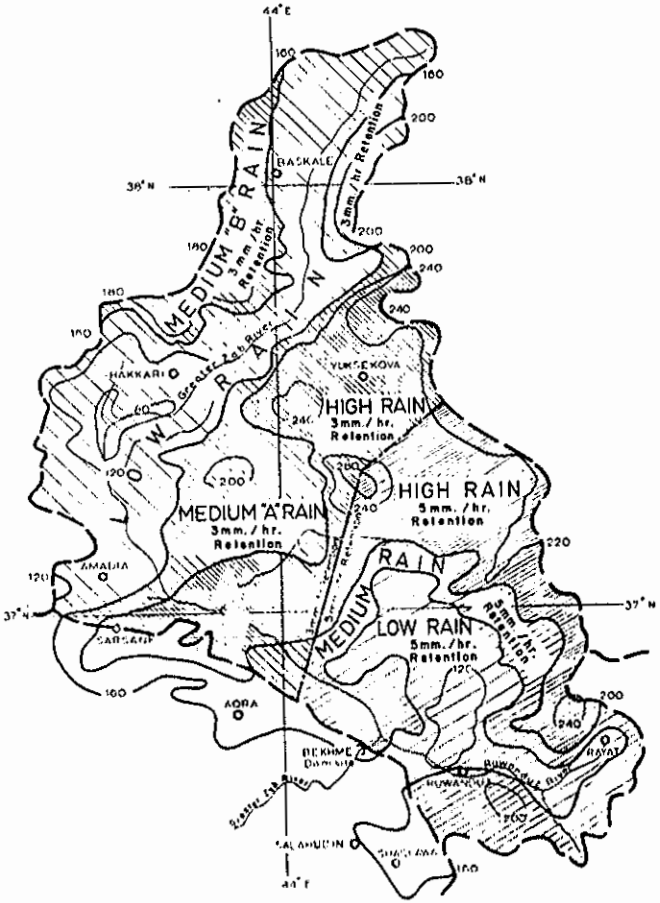
GOVERMENT OF IRAQ
MINISTRY OF AGRICUTURE

HYDROLOGICAL SURVEY OF IRAQ

TIME DISTRIBUTION OF MAXIMIZED PRECIPITATION

HARZA ENGINEERING CO CHICAGO — IN ASSOCIATION — BINNIE, DEACON & GOURLEY LONDON

BAGHDAD, IRAQ | DATE 29 Jan.59 | DWG NO 627-22

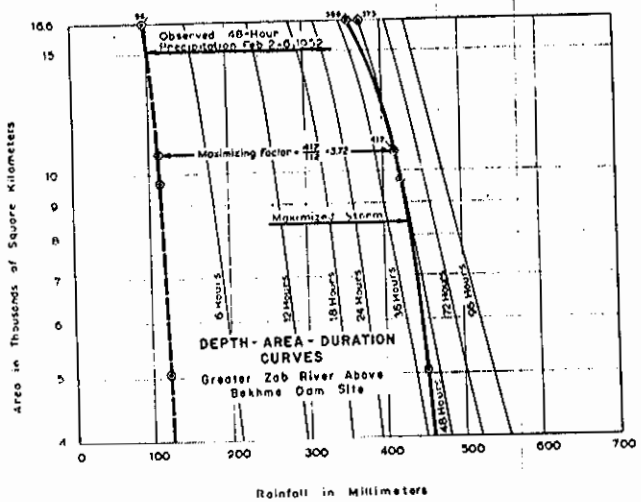


DRAINAGE AREA OF GREATER ZAB RIVER AT BEKHME
16.600 Sq.Km.

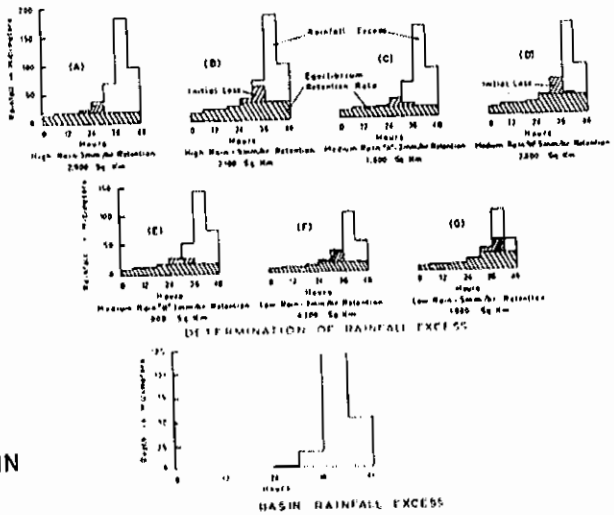
(a) RAINFALL DISTRIBUTION BEKHME DRAINAGE BASIN

Storm of February 2-6.1952

o Precipitation Station



(b) STORM ADJUSTMENT



(c) COMPUTATION OF RUNOFF

(d) EXAMPLE STORM ANALYSIS COMPUTATIONS

Storm Adjustment

Max. 48 hr. precip. / Obs. 48 hr. precip. = 417/112 = 3.72 = Maximizing Factor

Class	Area	Observed 48 hr. Precip.	Maximized 48 hr. Precip.	Area Summation	Depth-Area Relation
High Rain	5000 Sq Km.	122 mm.	454 mm.	5000 Sq Km.	454 mm.
Medium A	4600	104	387	9600	422
Medium B	900	98	365	10500	417
Low	6100	69	257	16600	358

Rainfall Increments

6 hr Period	Fraction of 48 hr. Precip.	High Rain (454 mm.)	Medium "A" (387 mm.)	Medium "B" (365 mm.)	Low (257 mm.)
1	.03	14 mm	12 mm.	11 mm	8 mm.
2	.04	18	16	15	10
3	.04	18	16	15	10
4	.05	23	19	18	13
5	.08	36	31	29	21
6	.15	68	58	55	39
7	.40	182	155	146	102
8	.21	95	81	76	54

Depth of Rainfall Excess

6 hour Period	(A) High 3mm/hr	(B) High 5mm/hr	(C) Medium "A" 3mm/hr.	(D) Medium "A" 5mm/hr	(E) Medium "B" 3mm/hr	(F) Low 3mm/hr	(G) Low 5mm/hr.
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	3 mm	-	-	-	-	-	-
6	60	11 mm	54 mm	-	28 mm	4 mm.	-
7	164	158	137	121 mm	128	84	48 mm
8	77	65	63	51	58	36	24

Basin Rainfall Excess

6 hour Period	(A) 2900 km 17.5%	(B) 2100 km 12.5%	(C) 1800 km 11%	(D) 2800 km 17%	(E) 900 km 5.5%	(F) 4200 km 25%	(G) 1900 km 11.5%	Basin Total
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	5 mm	-	-	-	-	-	-	1 mm
6	9.8	14 mm	38 mm	-	15 mm	10 mm	-	17
7	28.7	19.0	15.1	20.6 mm	7.0	21.0	5.5 mm	117
8	13.5	8.1	6.9	8.7	3.2	9.0	2.8	52

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

RAIN
STORM ANALYSIS

HARZA ENGINEERING CO CHICAGO
IN ASSOCIATION
BINNIE DEACON & GOURLEY LONDON
BAGHDAD, IRAQ
DATE 25 Oct 1957
DWG NO. 627-7

102

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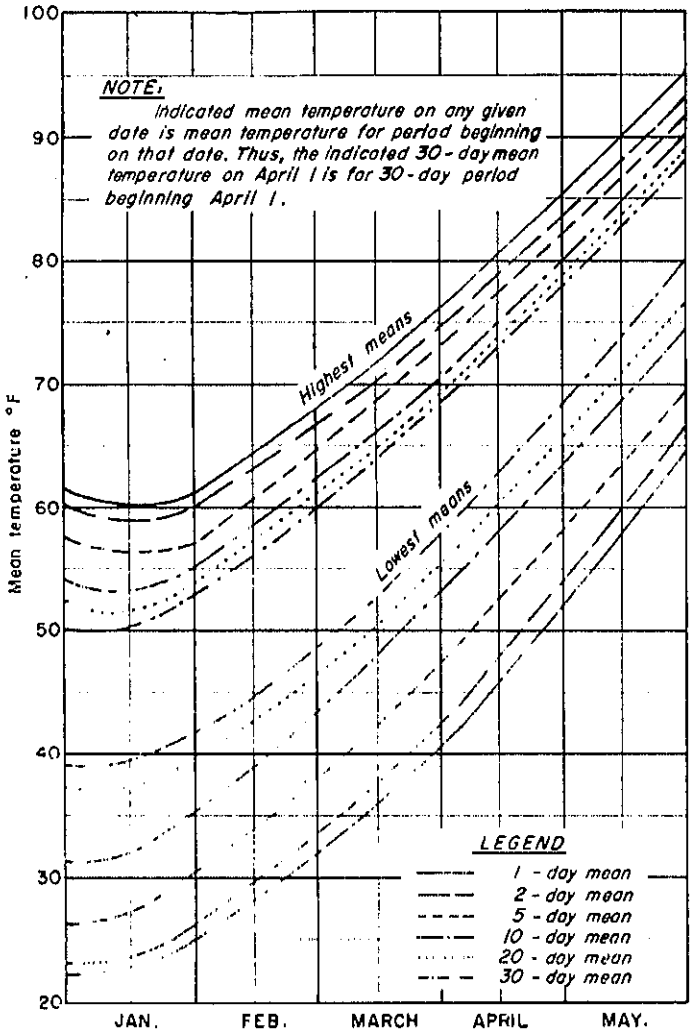
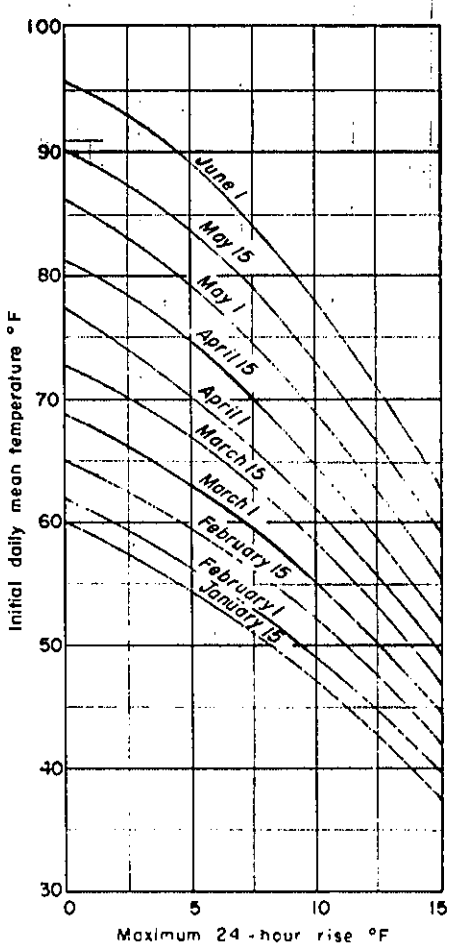
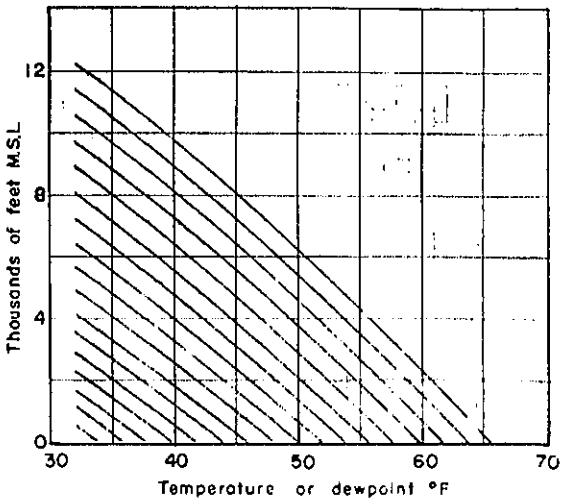


(a) EXTREME MEAN TEMPERATURES
Mosul elevation 730 feet



(b) MAXIMUM 24-HOUR RISES OF DAILY MEAN TEMPERATURE
Mosul



(c) TEMPERATURE CHANGE WITH ELEVATION IN SATURATED AIR
Pseudoadiabatic lapse rate

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

TEMPERATURE LIMITATIONS
TIGRIS RIVER BASIN

TAHZA ENGINEERING CO. CHICAGO — IN ASSOCIATION — DENNIS, DE ACON & COMPANY LONDON

BAGHDAD, IRAQ — DATE 10 Feb 59 — DWG NO 62: 2

103

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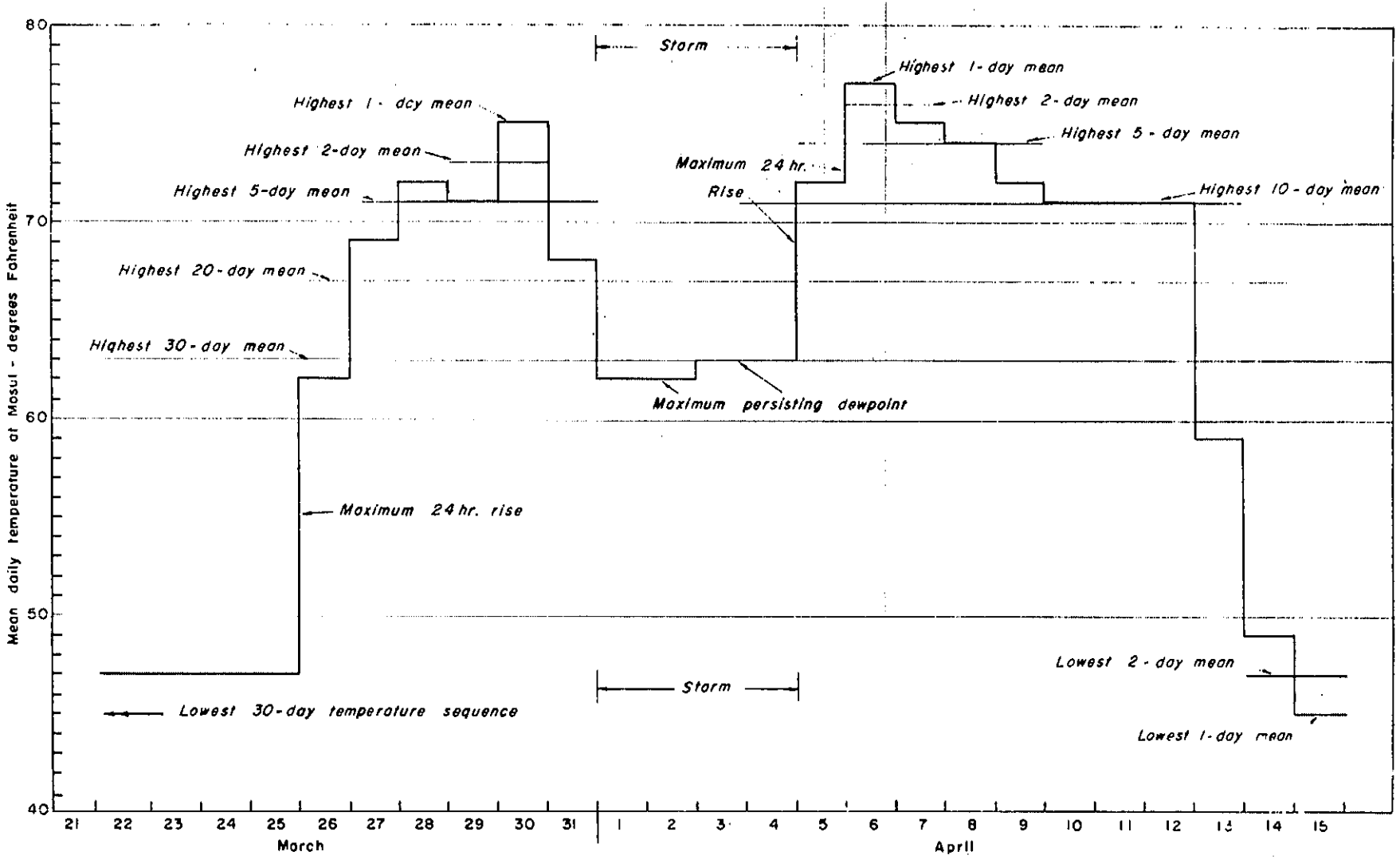

NOTE:

Critical melting temperature sequence derived from temperature limitation based on Mosul record, Exhibit object is to maintain maximum snow cover until six days before maximized storm and then to have snowmelt take place as quickly as possible.

GOVERMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

CRITICAL MELTING TEMPERATURE SEQUENCE AT MOSUL

HARZA ENGINEERING CO. CHICAGO — IN ASSOCIATION — WINNIE, DEACON & COUNSLEY LONDON

BAGHDAD, IRAQ — DATE 7-1-68 — DWG NO 627-10

JCR

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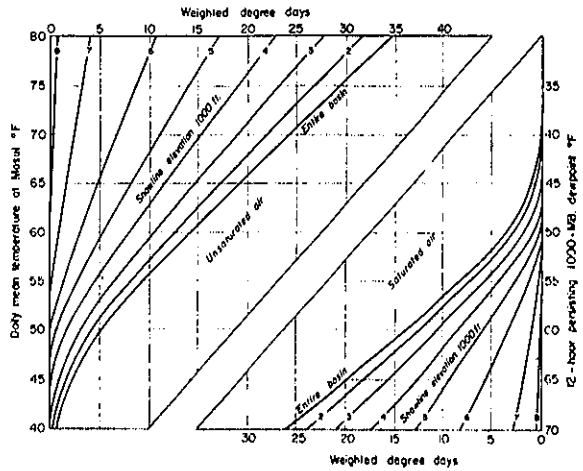
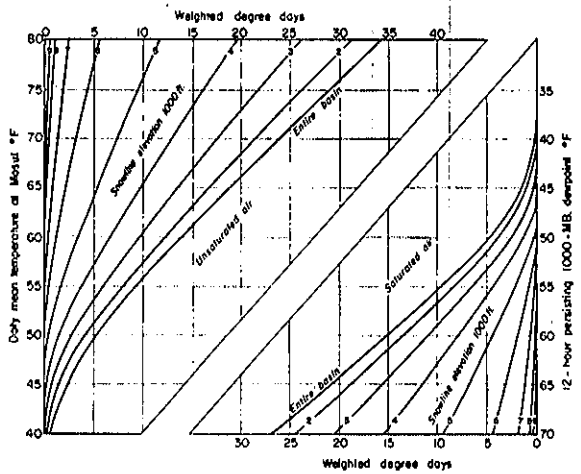
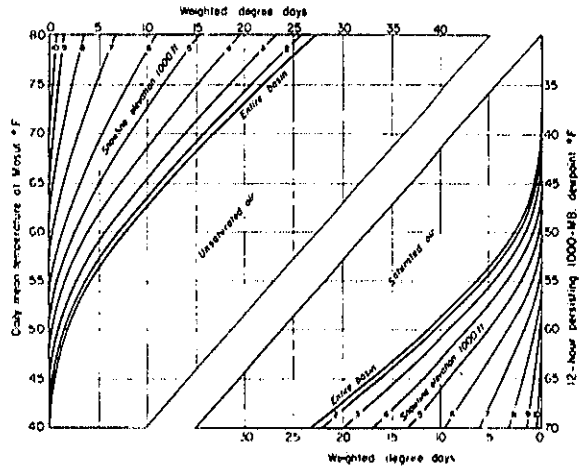


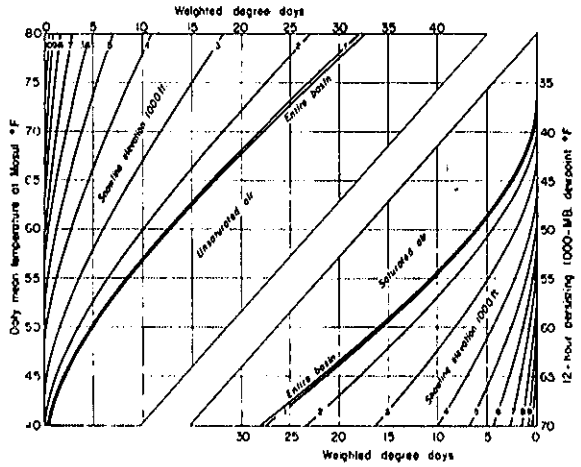
(a) DIYALA RIVER ABOVE DERBEND-I-KHAN DAM



(b) LESSER ZAB RIVER ABOVE DOKAN DAM



(c) GREATER ZAB RIVER ABOVE BEKHME DAM SITE



(d) TIGRIS RIVER ABOVE ESKI-MOSUL DAM SITE

NOTE

Curves are labeled with elevation of snowline in thousands of feet above mean sea level.

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

WEIGHTED DEGREE DAYS

HAMZA ENGINEERING CO. CHICAGO — BIRNIE, DEACON & COURLEY LONDON — IN ASSOCIATION — BAGHDAD, IRAQ — DATE 2 March 59 — DWG NO 627-27

705.

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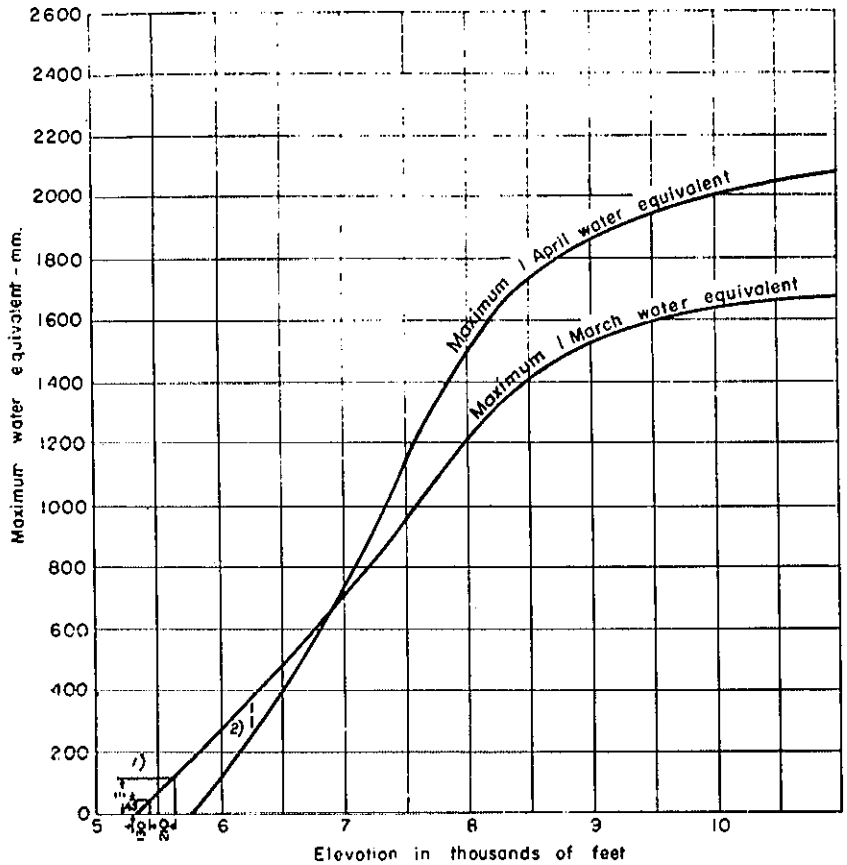

DOKAN BASIN SNOW WATER EQUIVALENT
AVERAGE LATITUDE 36.2°N

MAXIMUM SNOWMELT RUNOFF

	Date	Mosul temp.	Snowline data: Snowline temp.	Deg days	Av. melt	Total melt	Elev. Incr.	Snowline elev.	Weighted Degree days	Daily Ave. melt	Daily rainfall	Melt from rain	Total Ave melt
	24	47	32	0	0	0	0	5300	0	0			0
March	25	47	32	0	0	0	0	5300	0	0			0
	26	62	47	15	45	45	130 1)	5300	3	9			9
	27	69	54	22	66	111	210 1)	5430	6	18			18
	28	72	56	24	72	183	180	5620	5	15			15
	29	71	54	22	66	249	170	5800	4	12			12
	30	75	58	26	78	327	180	5970	4	12			12
	31	68	50	18	54	381/250 2)	130	6150	3	9			9
	1	62	(46)	14	42	292	70	6280	1	3	75	0.5	4
	2	62	(46)	14	42	334	70	6350	1	3	420	3	6
	3	63	(47)	15	45	379	80	6420	1	3	40	0	3
	4	63	(47)	15	45	424	60	6500	1	3	40	0	3
April	5	72	53	21	63	487	100	6560	2	6			6
	6	77	57	25	75	562	110	6660	3	9			9
	7	75	55	23	69	631	100	6770	2	6			6
	8	74	54	22	66	697	100	6870	2	6			6
	9	72	51	19	57	754	60	6970	1	3			3
	10	71	50	18	54	800	80	7030	1	3			3
	11	71	50	18	54	862	60	7110	1	3			3
	12	71	50	18	54	916	70	7170	1	3			3
	13	59	37	5	15	931	20	7240	1	3			3
	14	49	32	0	0	931	0	7260	0	0			0
	15	45	28	0	0	931	0	7260					

NOTE:

Temperatures in degrees Fahrenheit. Elevations in feet.
Snowmelt and rainfall in millimeters
Mosul temperature from critical temperature sequence.
Snowline Temp. = Temperature at snowline corresponding to Mosul temperature. ( ) by psuedoadiabatic lapse rate.
Temp. = snowline temperature during maximum storm.
Melt. = 3mm. water equivalent per degree day.
Elevation increment from graph of variation of water equivalent with altitude.
Weighted degree days from basin temperature - area - elevation - degree day relations.
Melt from rain = rain in mm. times (temp. °F - 32) divided by 144.
1.) See increments measured at low end of 1 March curve.
2.) Adjustment for change from 1 March curve to 1 April curve.

GOVERMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

SNOWMELT COMPUTATION
DOKAN BASIN

HAUZA ENGINEERING CO CHICAGO — IN ASSOCIATION — BINNIE, DEACON & GOURLEY LONDON
BAGHDAD, IRAQ — DATE 10 Feb. 59 — DWG NO 627-24

REV NO	DATE	NATURE OF REVISION	BY	CHKD	APPD

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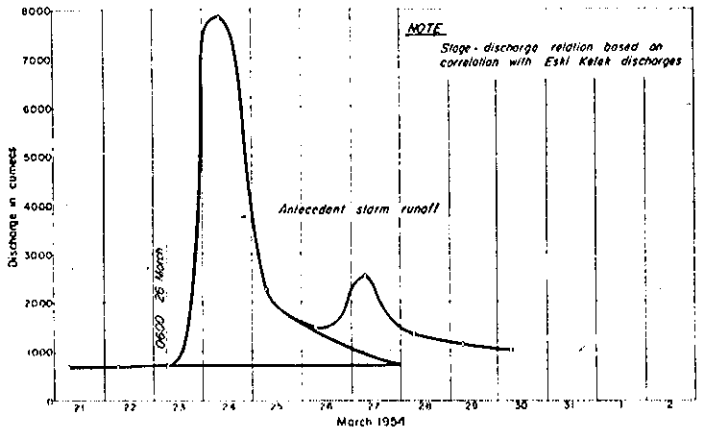
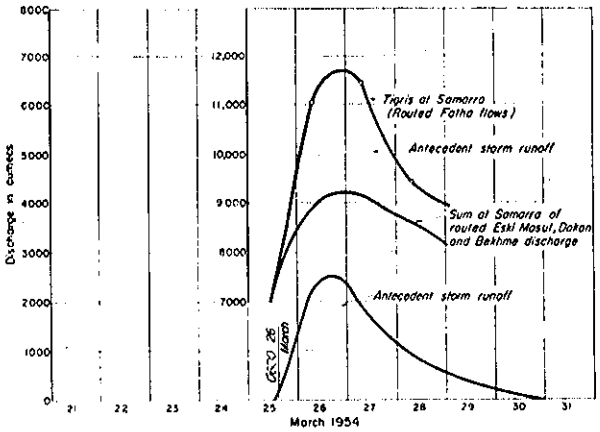
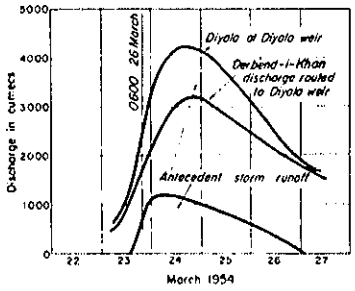


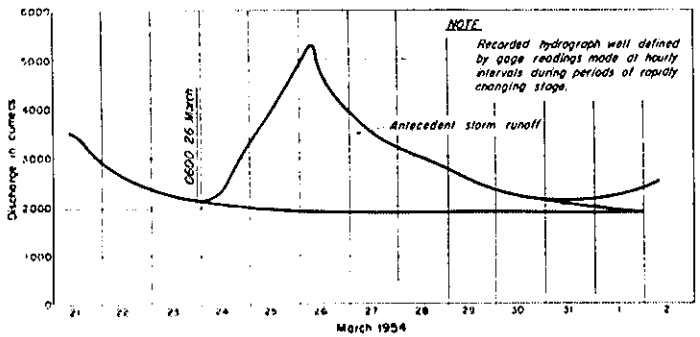
(a) GREATER ZAB AT BEKHME DAM SITE
Dar Teswe gage



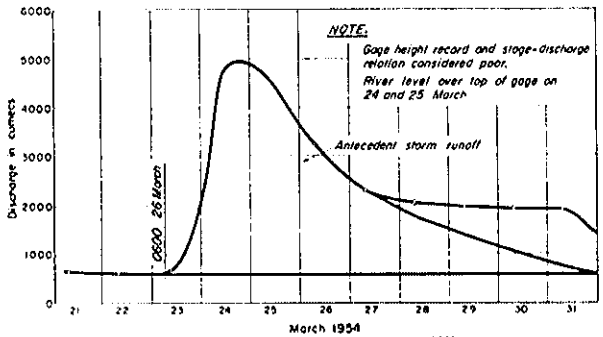
(d) CENTRAL TIGRIS AREA CONTRIBUTION



(g) DIYALA BELOW DERBEND-I-KHAN DAM



(b) TIGRIS AT ESKI MOSUL DAM SITE
Mosul gage

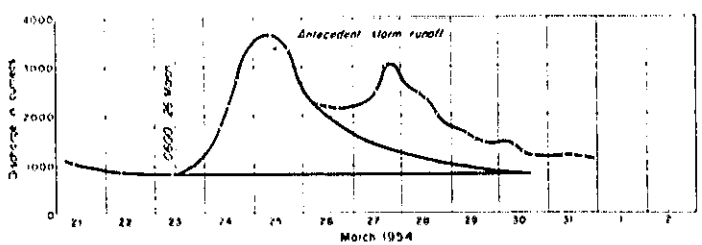


(e) DIYALA AT DERBEND-I-KHAN

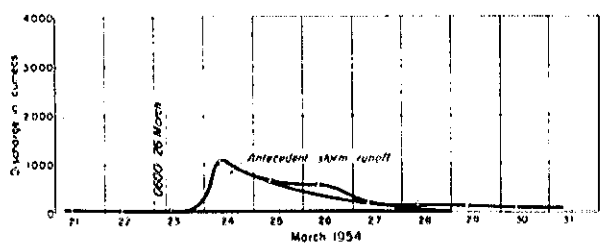
NOTES:

Storm of 23-24 March 1954 selected as antecedent storm.

Notation "0600 26 March" indicates timing used in probable maximum flood studies.



(c) LESSER ZAB AT DOKAN DAM



(f) ADHAIM AT ITS MOUTH

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE

HYDROLOGICAL SURVEY OF IRAQ

RUNOFF FROM ANTECEDENT STORM

HARZA ENGINEERING CO. CHICAGO — IN ASSOCIATION — DIRKIE, DEACON & COURTLEY LONDON

BAGHDAD, IRAQ — DATE 16 FEB 59 — DWG NO 627-23

REV NO	DATE	NATURE OF REVISION	BY	CHK	APPD

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Existing system plus High Eski Mosul (overflow spillway)

50% probable maximum flood over entire Tigris drainage area

Date	Dokan Reservoir: Inflow	Stor. incr.	Storage ½ cu. days	Storage M	Rule Curve	Outflow	Eski Mosul Reservoir: Inflow	Stor. incr.	Storage ½ cu. days	Storage M	Rule Curve	Outflow	Routed to Samarra: Dokan	Bakhme	Eski Mosul	Gem. Tigris	Samarra: Inflow	Diversion	Outflow	Adhaim	Adhaim plus Samarra	Baghdad	Derbend-i-Khan Reservoir: Inflow	Stor. incr.	Storage ½ cu. days	Storage M	Rule Curve	Outflow	Diyala Weir: Routed D.K.	Middle Diyala	Total	Below Diyala Confluence: Tigris	Diyala at Tigris	Total	Date
March 26	890	+ 230	269190	5.82		660	2600	- 160	466640	10.12		2760	730	1060	2780	70	4620	630	3990	10	4000	4000	480	0	115740	2.50		480	490	200	690	4000	560	4560	March 26
	890	+ 230	269420	5.83	5.83	660	2570	- 190	466450	10.12	8.15	2760	710	1090	2780	430	5010	1020	3990	10	4000	4000	460	0	115740	2.50	2.50	460	480	300	780	4000	590	4590	
	980	+ 230	269650	5.83		750	2530	- 210	466240	10.11		2760	700	1150	2780	770	5400	1630	3970	30	4000	4000	440	0	115740	2.50		440	470	550	1020	4000	650	4650	
	1140	+ 230	269880	5.83		1010	2530	- 220	466020	10.11		2750	690	1210	2780	1070	5750	1870	3880	120	4000	4000	430	0	115740	2.50		430	470	550	1020	4000	740	4740	
27	1400	+ 230	270110	5.83		1170	2510	- 240	467780	10.10		2750	690	1280	2780	1080	5830	2210	3620	380	4000	4000	440	0	115740	2.50		440	460	520	980	4000	860	4860	27
	2140	+ 380	270490	5.84	5.84	1760	2500	- 240	467540	10.10	8.15	2740	690	1550	2780	1150	5970	2470	3500	500	4000	4000	880	0	115740	2.50	2.50	880	470	460	930	4000	930	4930	
	2930	+1160	271650	5.87		1770	2490	- 250	467290	10.09		2740	680	1680	2770	990	5900	2380	3520	480	4000	4000	1470	0	115740	2.50		1470	460	440	1000	4000	960	4960	
	3240	+1650	273100	5.90		1790	2500	- 250	467060	10.09		2730	690	1700	2770	820	5980	2440	3540	460	4000	4000	2180	0	115740	2.50		2180	890	400	1250	4000	970	4970	
28	3350	+1540	274640	5.93		1810	2980	+ 250	467310	10.09		2730	740	2100	2770	700	6310	2980	3330	420	3750	4000	2910	+ 310	116050	2.51		2600	1310	370	1680	4000	1050	5050	28
	3260	+1420	276060	5.96	5.86	1840	3380	+ 640	467950	10.11	8.15	2740	890	2630	2760	600	6840	3900	2940	380	3320	3990	3150	+ 900	116550	2.52	2.50	2850	1050	330	2160	4000	1190	5190	
	2970	+ 710	276770	5.98		1860	3020	+ 270	468220	10.11		2750	1010	3150	2760	500	7400	4900	2500	340	2840	3910	3170	+ 500	117050	2.53		2670	2240	270	2510	3970	1480	5450	
	2170	+ 300	277070	5.98		1870	2860	+ 110	468330	10.12		2750	1200	3460	2750	430	7840	5640	2200	290	2490	3740	3140	+ 440	117490	2.54		2750	2470	200	2670	3850	1850	5660	
29	1960	+ 90	277160	5.99		1870	2810	+ 50	468380	10.12		2760	1360	3530	2750	370	8010	5930	2080	250	2350	3470	3110	+ 310	117800	2.54		2800	2600	150	2750	3680	2170	5850	29
	1790	- 80	277080	5.98	5.88	1870	2760	0	468300	10.12	8.15	2760	1300	3390	2750	320	7960	5920	2040	210	2250	3160	3050	+ 180	117980	2.55	2.50	2850	2690	70	2760	3400	2430	5830	
	1640	- 230	276850	5.98		1870	2810	+ 50	468430	10.12		2760	1610	3100	2740	260	7710	5650	2060	180	2260	2880	2920	- 10	117970	2.55		2930	2760	10	2770	3110	2590	5700	
	1530	- 350	276520	5.97		1860	2850	+ 90	468520	10.12		2760	1700	2760	2740	210	7410	5320	2090	140	2230	2660	2880	- 170	117800	2.54		2990	2830	0	2830	2850	2690	5540	
30	1460	- 390	276150	5.96		1850	2930	+ 170	468690	10.12		2760	1760	2420	2740	160	7080	5030	2050	120	2170	2500	2710	- 290	117510	2.54		3000	2890	0	2890	2640	2750	5390	30
	1390	- 450	275680	5.95	5.89	1840	3010	+ 250	468920	10.13	8.15	2780	1810	2120	2740	130	6500	4790	2010	100	2110	2300	2600	- 400	117110	2.53	2.30	3000	2950	0	2950	2480	2800	5280	
	1320	- 520	275160	5.94		1840	3090	+ 310	469230	10.14		2780	1840	1890	2750	100	6340	4500	1960	90	2050	2300	2530	- 470	116640	2.52		3000	2980	0	2980	2370	2850	5120	
	1270	- 570	274590	5.93		1840	3030	+ 240	469470	10.14		2780	1850	1660	2750	60	6320	4370	1950	70	2020	2230	2470	- 530	116110	2.51		3000	2990	0	2990	2290	2900	5190	
31	1220	- 610	273980	5.92		1830	3020	+ 250	469720	10.15		2790	1860	1480	2750	50	6140	4190	1950	60	2010	2160	2460	- 370	115740	2.50		2770	2990	0	2990	2220	2940	5160	31
	1190	- 570	273640	5.91	5.91	1560	3020	+ 220	469920	10.15	8.15	2800	1860	1350	2760	50	6020	4060	1960	50	2010	2110	2360	0	115740	2.50	2.50	2360	2940	0	2940	2150	2960	5110	
	1130	+ 230		5.91		900	3050	+ 250	470170	10.16		2000	1850	1270	2760	50	5930	3910	2020	40	2060	2070	2320	0	115740	2.50		2320	2780	0	2780	2110	2970	5080	
	1080	+ 250		5.92		850	3100	+ 290	470460	10.16		2810	1850	1250	2770	50	5900	3710	2190	50	2220	2050	2300	0	115740	2.50		2300	2560	0	2560	2070	2930	5000	
April 1	1030	+ 230		5.92		800	3160	+ 340	470800	10.17		2820	1830	1220	2770	50	5870	3440	2430	10	2440	2050	2280	+ 90	115830	2.50		2190	2420	0	2420	2050	2830	4880	April 1
	990	+ 230		5.93	5.93	760	3220	+ 400	471200	10.18	8.15	2820	1790	1240	2780	50	5860	3280	2580	0	2580	2100	2250	+ 100	115930	2.50	2.51	2150	2330	0	2330	2060	2690	4750	
	960	+ 230		5.93		730	3210	+ 370	471570	10.19		2840	1690	1260	2780	50	5780	3150	2650	20	2670	2200	2210	+ 90	116020	2.51		2120	2250	10	2260	2120	2530	4670	
	940	+ 230		5.94		710	3210	+ 560	471930	10.19		2850	1540	1300	2790	50	5680	3020	2660	80	2740	2310	2130	+ 100	116120	2.51		2050	2190	20	2210	2220	2440	4660	
2	920	+ 230		5.94		690	3220	+ 360	472290	10.20		2860	1300	1340	2790	60	5570	2980	2590	200	2790	2430	2110	+ 90	116210	2.51		2020	2130	50	2180	2330	2340	4670	2
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	4080	+1780	303520	6.56		2500	13150	+8940	527570	11.40		4130	1350	2770	2990	4730	11840	9000	2840	3280	6120	5410	7220	- 150	148530	3.21		7370	5900	1780	7680	5070	5270	10340	
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	1200	+ 230	288880	6.24		970	4540	- 460	576780	12.46		5000	1990	2540	5000	50	9590	5750	3830	70	3900	3900	1220	+ 90	121950	2.63		1130	1110	0	1110	3890	1090	4980	

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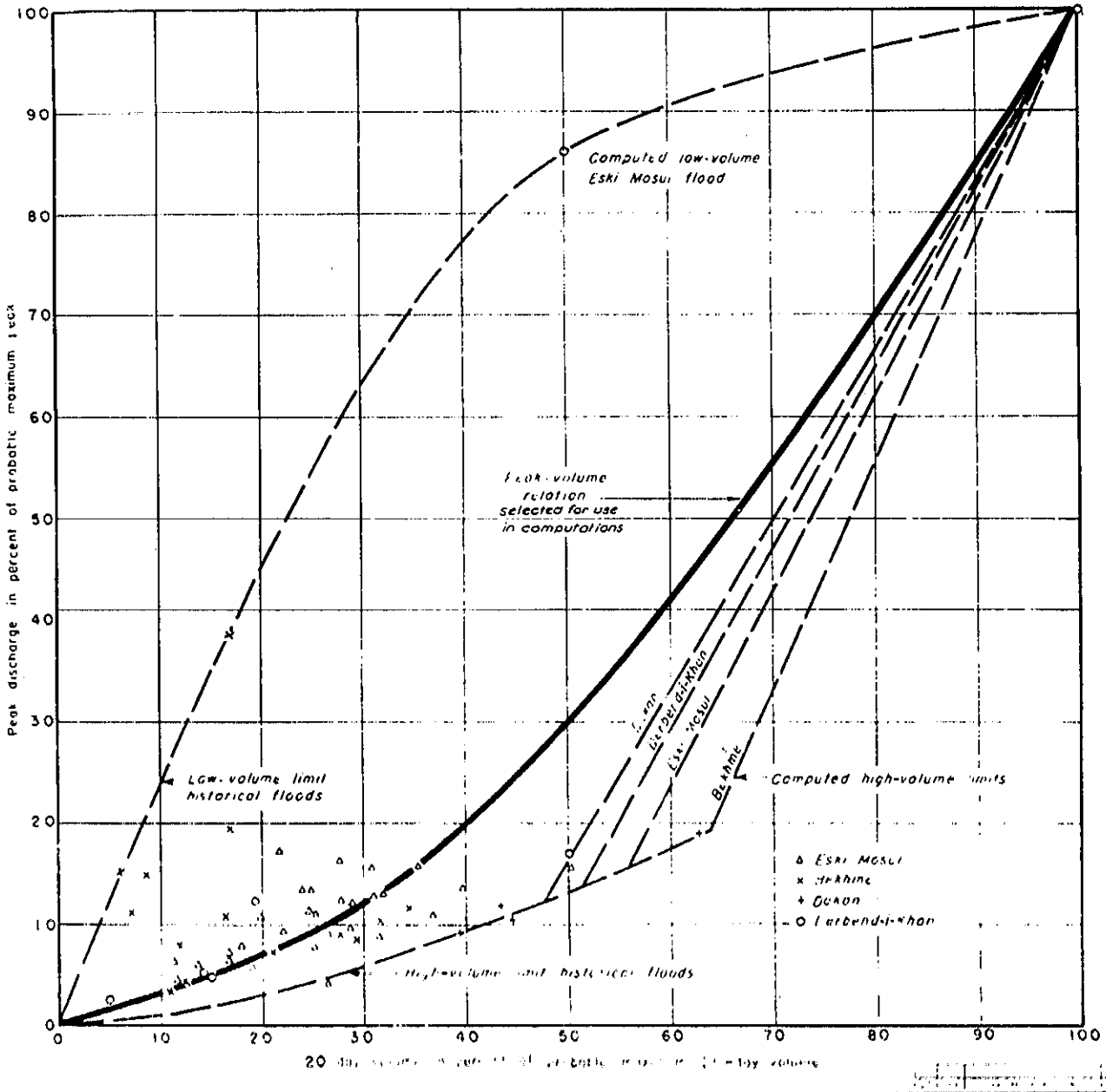

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

TIGRIS FLOOD
PEAK - VOLUME RELATION

HARZA ENGINEERING CO CHICAGO
BINNIE DEACON & GOURLAY LONDON
IN ASSOCIATION
BAGHDAD IRAQ
24 Feb 55
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Chapter C-1

INTRODUCTION

1.1 The primary objective in system flood-control operations was to limit the discharge of the Tigris River at Baghdad to 4000 cumecs and to limit the discharge below the confluence of the Diyala and Tigris rivers to 5000 cumecs. Corollary objectives were to limit the discharge above Samarra to 13,000 cumecs and to limit the discharge at the Diyala Weir to 3000 cumecs. A secondary objective was to limit flooding below dams on controlled tributaries.

1.2 . Operation studies were made in a manner believed to be representative of realistic methods of flood-control operation. It was assumed that flows at Samarra would be known 12 hours in advance because a minimum of 12 hours elapses before changes in flows at the gaging stations at Mosul on the Tigris, Eski Kelek on the Greater Zab, and Dokan on the Lesser Zab affect the flow at Samarra. No other foreknowledge was assumed.

1.3 Rapid and reliable communication through a central operating center was assumed between Samarra and Mosul (or Eski Mosul), Eski Kelek (or Bekhme), Dokan, Adhaim River at the Narrows (or Injana), and the Diyala Weir. Good communications were also assumed between Derbend-i-Khan and the Diyala Weir.

1.4 The flood-control criteria provide for protection against moderate floods with reserve protection against extreme floods The two-stage protection is obtained by operating to limit the discharge above Samarra to 10,000 cumecs when the upstream reservoirs are in the lower half of their

flood-control allocation. After reservoirs reach the normal maximum operating level, they are required to discharge all inflow, as limited by spillway capacity, except in the case of Eski Mosul and Fatha, which were allowed to store water voluntarily above that water level.

1.5 The term "existing system," as used in this appendix, includes the Dokan Dam, Derbend-i-Khan Dam, and Samarra Barrage and the diversion channel, all of which are completed or nearing completion.

Chapter C-2

BASIC DATA

Discharge Data

2.1 Flood-control operation studies were performed with flows recorded during the flood of March-April 1954 and the flood flows computed in the probable maximum flood studies.

2.2 Mean daily discharges presented in our report "Discharges for Selected Stations in Iraq 1930-1956" were used for operations to study control of the 1954 flood. Much of these data must be considered of a questionable nature because of infrequent reading of gage heights, extrapolation of rating curves, and overtopping of gages. The daily time interval did not allow refinement in the flood operation studies. The 1954 flood was not considered to be critical since if it recurred at the present time it could be safely handled by the existing flood-control facilities.

2.3 The probable maximum flood studies are described in Appendix B. The studies resulted in probable maximum flood estimates on each tributary and in estimates at Samarra, Baghdad, and the Diyala confluence. For the latter estimates, different floods, centered over uncontrolled areas, produced maximum floods at the downstream points when variations in the reservoirs were introduced.

2.4 Flood hydrographs were also developed in Appendix B for floods having peaks of 50 and 75 percent of the probable maximum flood at the damsites and at Samarra. Another flood, representing 68, 72, and 80 percent, respectively, of the probable maximum flood at Samarra, Baghdad, and the Diyala confluence, was developed for demonstration purposes.

2.5 The computation of these floods is described in Chapters 7 and 8 of Appendix B. Hydrographs of probable maximum floods are shown on Exhibit B-1, in Appendix B.

Dam and Reservoir Characteristics

2.6 Reservoir volume-elevation relations, discharge capabilities, and other physical details of dams and reservoirs were based on information in other consultants' planning reports, except for Fatha Reservoir, where the discharge capability was estimated by the Hydrological Survey.

2.7 For those reservoirs in the proposed stage, alternative heights of dam, storage allocation, and physical characteristics were assumed. Characteristics of each dam and reservoir are discussed in the following paragraphs. Table C-1 shows certain discharge and storage capacity values for the various dams and reservoirs studied. Most of these values are also shown graphically on Exhibit C-1.

Derbend-i-Khan Dam and Reservoir

2.8 This is a rock fill dam now nearing completion, with gated overflow spillway and low-level irrigation outlets. Discharge capacities and reservoir volume-elevation relations were taken from the contract drawings by the Harza Engineering Company. The capacity of the irrigation outlets was assumed to be usable in the flood-control operation range.

Dokan Dam and Reservoir

2.9 This is a completed concrete arch dam with gated overflow spillway, ungated bellmouth spillway, and low-level irrigation outlets. The discharge capacities and reservoir volume-elevation relationships were

Table C-1

DAM AND RESERVOIR CHARACTERISTICS

Elevation in meters m.s.l., Storage Capacity in milliards of cubic meters, and Discharge Capacity in cubic meters per second

Dam and Reservoir	Normal Maximum Operating Levels		Lowest Rule Curve Storage	Flood Control Storage Allocation	Surcharge Storage	Outlet Capacity	Combined Discharge Capacity of Outlets and Spillway		
	Elevation	Storage					Lowest Rule Curve Elevation	Normal Maximum Operating Elevation	Crest of Dam
Derbend-i-Khan	485	3.00	2.50	0.50	0.80	400	3,400	6,200	10,800
Dokan	511	6.82	5.34	1.50	1.50	300 1/	1,300	2,500	4,800
Bekhme	500	2.97	0.97	2.00	0.35	510-800	510	11,600	16,800
Bekhme	550	8.30	6.30	2.00	0.60	800	800	10,700	15,600
Eski Mosul, overflow spillway	320	7.65	4.88	2.77	2.60	500	1,620	6,500	12,500
Eski Mosul, overflow spillway	328	10.26	6.38	3.88	2.90	500	970	6,500	12,500
Eski Mosul, overflow spillway	335	13.15	8.15	5.00	3.40	500	730	6,500	12,500
Fatha	165	11.80	6.80	5.00	4.40	1,000	2,200	13,000	20,000
Fatha	172.5	18.00	12.00	6.00	4.40	1,000	2,000	13,000	20,000
Fatha	178	24.00	17.00	7.00	2.50	1,000	1,700	13,000	15,000

1/ Including power penstock

Interim Flood-Control Capacities That Could Be Provided Pending Development of Full Irrigation Requirements

Eski Mosul	328	10.26	4.88	5.4
	335	13.15	6.38	6.8
Fatha	177	18.00	6.80	11.2
	182	24.00	12.00	12.0

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taken from the project planning report of Binnie, Deacon and Gourley. The discharge capacity of the two irrigation outlets and one power penstock was assumed to be available in the flood-operation range.

Bekhme Dam and Reservoir

2.10 This is a proposed massive buttress dam with overflow spillway and low-level irrigation outlets. The discharge capacities and volume-elevation relationship were taken from the project planning report of the Harza Engineering Company. The capacity of the irrigation outlets was considered usable for flood control. Two heights of dam were considered.

Eski Mosul Dam and Reservoir

2.11 This is a proposed earth fill dam with gated overflow spillway capable of controlling discharges at levels above the normal maximum operating level and with low-level irrigation outlets. Three heights of dam were studied for the basic design. The discharge capability and volume-elevation relationships were based on a preliminary draft of the project planning report by the Harza Engineering Company and on informal discussion with that consultant.

Fatha Dam and Reservoir

2.12 There were no designs available on this dam although the possibility of such a dam was discussed in the Haigh Commission Report. Three heights of dam were considered. Discharge capacities were assumed by the Hydrological Survey. Area-elevation relationships were based on data in the Haigh Commission Report.

Samarra Diversion Works

2.13 This is a concrete and earth-bank barrage across the Tigris River, together with a concrete regulator, which controls diversion of water into the natural Wadi Tharthar depression through a channel formed by an earth embankment and cut. The diversion channel capacity was assumed to be 9000 cumecs, although it has been variously estimated as being from 6000 to 9000 cumecs. The regulator capacity is accepted as 9000 cumecs. NEDECO, consultants on the project, have indicated that only minor works are needed to give an equal diversion channel capacity. The discharge capacity of Samarra Barrage to the Tigris River has been assumed to be 10,000 cumecs.

Chapter C-3

RULE CURVES

General Description

3.1 Reservoir operating rule curves define the storage allocations for various functions of a reservoir. In the Tigris River Basin, where runoff follows a fairly definite seasonal pattern from year to year, such allocations will vary according to the time of the year. As used in these studies, the rule curve specifies the reservoir storage capacity which must not be exceeded at a given time of the year unless necessary in the interest of flood-control operations.

3.2 Early in the flood season, a high amount of storage capacity must be left unused to provide space for flood-control storage unless the flood-control operations dictate that such capacity be used. During this period it will not be necessary to maintain a full reservoir for purposes of irrigation water supply since, if the rule curve is properly designed, assurance of filling during the latter portion of the flood season will be provided. The rule curve level early in the flood season is therefore set at that unfilled storage that can later be assuredly filled by late season floods.

3.3 As the flood season progresses in its later stages, the potential for floods decreases and at the same time the ability for assured filling decreases correspondingly. Thus, the rule curve level late in the flood season is progressively raised. At the end of the flood season, when the potential for floods and for subsequent filling of the reservoir are both negligible, the rule curve is at its highest elevation. This elevation is referred to as the normal maximum operating level.

3.4 The above procedure results in joint use of a portion of the reservoir storage capacity. During the early flood season it is used for flood-control storage; later it is used for irrigation storage purposes. At the Eski Mosul and Fatha reservoirs, the rule curve extends above the normal maximum operating level, with certain inviolate storage capacity that would be used for regulation purposes only in the interest of flood control.

Rule Curves for Specific Reservoirs

3.5 Flood-control rule curves were established for each on-stream storage reservoir and are shown graphically on Exhibit C-1. The Dokan and Derbend-i-Khan rule curves were taken from the consultants' project planning reports. Rule curves for Eski Mosul, Bekhme, and Fatha were established by the Hydrological Survey and were based primarily on reservoir refilling capacity. Interim rule curves were prepared for Eski Mosul, Bekhme, and Fatha. These rules could be used for operational purposes after the completion of the dam, prior to development of full irrigation requirements, to provide temporary additional flood-control storage capacity.

3.6 All rule curves, except for Dokan Reservoir, require full flood allocation during the months of January, February, and March. Flood-control space is then decreased uniformly until reaching normal maximum operating level on the first of June. The rule curve for Dokan requires full flood allocation of 1.5 milliards for the period of November through February; this decreases uniformly to 0.25 milliards on the first of May and then uniformly to zero on the first of June. Table C-1 summarizes the full flood allocation values in these studies.

Chapter C-4

OPERATION PROCEDURE

General Procedure

4.1 The reservoir operating procedure is dependent on two criteria, (a) the rule curves, described in Chapter C-3, and (b) reservoir operating rules. The reservoir operating rules are restrictions on releases for downstream and local protection and are guiding within the limits established by the rule curves. A summary of the reservoir operating rules used in the flood routing studies is given in Table C-2. The rules are discussed in the following paragraphs.

Upstream Reservoirs

4.2 The upstream reservoirs (Dokan, Bekhme, and Eski Mosul) were all operated in a similar manner. Reservoir elevations were kept to rule curve level, within the limits of discharge capacity, until routed releases and routed tributary contributions indicated that Samarra inflow would exceed 10,000 cumecs 12 hours in the future. All inflows were then stored until the routed contributions to Samarra indicated a flow of less than 10,000 cumecs 12 hours hence, except when the reservoir level reached a storage capacity midway between rule curve level and normal maximum operating level. When a reservoir reached the mid-storage point and inflows to Samarra continued in the 10,000-to-13,000 range, reservoir inflows were discharged within the limits of discharge capacity.

4.3 When routed contributions to Samarra indicated an inflow of 13,000 cumecs or more 12 hours hence, the reservoirs were required to

Table C-2

RESERVOIR OPERATING RULES USED IN FLOOD ROUTING STUDIES

Reservoirs	Reservoir Release Limitations: A. For Local Protection — Reservoir Level	Allowable Release	B. For Downstream Protection — Indicated Flow at Samarra 12 Hours Hence	Reservoir Level	Operation
1. Eski Mosul					
(a) Overflow Spillway	Rule Curve (normal maximum)	5,000 cumecs			
	Normal maximum - 2.0m. surcharge	5,000 cumecs	~~10,000 cumecs~~	All levels	Release to limits in (A)
	2.0m. surcharge - 4.0m. surcharge	6,000 cumecs	10,000-13,000 cumecs	Lower half joint use capacity	Store all inflows
	4.0m. surcharge - 5.0m. surcharge	8,000 cumecs			
	Above 5.0m. surcharge	Full spillway capacity	10,000-13,000 cumecs	Upper half joint use capacity and above	Release to limits in (A)
(b) Low Level Spillway	All levels	Full spillway capacity			
2. Bekhme	Rule Curve (normal maximum)	4,000 cumecs	13,000 cumecs	Below normal maximum	Store all inflows
	Above normal maximum	Full spillway capacity			
3. Dokan	All levels	Full spillway capacity	13,000 cumecs	Above normal maximum	Release to limits in (A)
4. Fatha					
(a) High Dam	Rule Curve (normal maximum)	10,000 cumecs			
	Normal maximum - 0.5m. surcharge	10,000 cumecs			
	0.5m. surcharge - 0.7m. surcharge	13,000 cumecs			
	Above 0.7m. surcharge	Full spillway capacity			
(b) Intermediate Dam	Rule Curve (normal maximum)	10,000 cumecs			
	Normal maximum - 2.0m. surcharge	10,000 cumecs			
	2.0m. surcharge - 3.0m. surcharge	13,000 cumecs		Not Applicable	
	3.0m. surcharge - 3.5m. surcharge	15,000 cumecs			
	Above 3.5m. surcharge	Full spillway capacity			
(c) Low Dam	Rule Curve (normal maximum)	10,000 cumecs			
	Normal maximum - 2.25m. surcharge	10,000 cumecs			
	2.25m. surcharge - 4.0m. surcharge	13,000 cumecs			
	4.0m. surcharge - 4.5m. surcharge	15,000 cumecs			
	Above 4.5m. surcharge	Full spillway capacity			
5. Derbend-i-Khan	Rule Curve (normal maximum)	3,000 cumecs less average flow contribution over previous six hours from Middle Diyala Area (above Diyala Weir and below Derbend-i-Khan)		Not Applicable	
	Above normal maximum	Full spillway capacity			

store all inflow. All inflows were stored until an inflow to Samarra of less than 13,000 cumecs was indicated or until the reservoir reached normal maximum operating level. When a reservoir reached normal maximum operating level, with inflows to Samarra continuing in excess of 13,000 cumecs, reservoir inflows were discharged to the limit of spillway capacity, except in the case of Eski Mosul and Fatha reservoirs. Eski Mosul is discussed in paragraph 4.7; for Fatha operation under various possible development schemes, see Table C-2.

4.4 Stored flood water was released from the reservoir in the reverse manner to which it was stored, with additional individual requirements described below. Water stored in the upper half of the flood-control allocation was discharged when the indicated inflow to Samarra fell below 13,000 cumecs. All stored flood water was discharged when indicated inflow to Samarra fell below 10,000 cumecs. Specific outflow limitations on individual reservoirs are described in the following paragraphs.

Dokan

4.5 All releases from flood storage were made at spillway capacity, which would not cause destructive flooding on the Lesser Zab River.

Bekhme

4.6 Releases were limited to 4000 cumecs while the reservoir was below normal maximum operating level. Above normal maximum water level, releases were made at total discharge capacity.

Eski Mosul

4.7 Releases were not allowed to exceed 5000 cumecs until two meters of surcharge was reached, with 5000 cumecs always being discharged

while the reservoir was between normal maximum operating level and two meters of surcharge. Between two and four meters of surcharge, the release was held at 6000 cumecs; and between four and five meters, at 8000 cumecs. Above five meters of surcharge, full spillway capacity was used.

Derbend-i-Khan Reservoir

4.8 Derbend-i-Khan Reservoir was operated solely to limit the flow at the Diyala Weir to 3000 cumecs until normal maximum operating level was reached. At that time inflows were released up to discharge capacity. It was considered undesirable to try to operate Derbend-i-Khan in conjunction with other reservoirs because of the complicated operation required and because Derbend-i-Khan will be hard pressed to meet the flood-control requirements on the Diyala River. Derbend-i-Khan releases during periods of high inflow were made equal to 3000 cumecs less the previous six hours' contribution from the Middle Diyala area (below Derbend-i-Khan and above Diyala Weir). Stored flood water was released in the same manner.

Samarra Diversion Works

4.9 For purposes of flood operation, the outflow to the Tigris River from Samarra Barrage and the flow of the Adhaim River at Injana were combined for routing to Baghdad. This combination is reasonable because both Samarra and Injana are about equidistant from Baghdad; it allows Samarra operation to be coordinated with uncontrolled Adhaim River floods to reduce flood peaks at Baghdad. The same procedure was used in computing the flows immediately upstream of the Diyala-Tigris confluence. In this case the drainage below Injana and Samarra was considered non-contributory to flood discharge.

4.10 Releases from Samarra Barrage to the Tigris River were governed by the desired flow limit of 5000 cumecs below the Diyala-Tigris confluence, the limit at Baghdad of 4000 cumecs, uncontrolled flows of the Adhaim River, and the Wadi Tharthar diversion channel capacity. The combined discharge of the Adhaim and the Tigris below Samarra was held to 4000 cumecs unless the discharge at Diyala Weir exceeded 1000 cumecs, at which time it was made equal to 5000 cumecs less the previous six hours' flow at Diyala Weir. The excess flow of the Tigris above Samarra was diverted to Wadi Tharthar, but diversion was limited to 9000 cumecs regardless of downstream conditions.

Chapter C-5

FLOOD OPERATION EXAMPLE

5.1 A step-by-step description of a typical flood operation study is presented in this chapter. The system described consists of the existing system of Dokan, Derbend-i-Khan, and Samarra, with the addition of a high Eski Mosul Reservoir with 6000 cumec capacity (at normal operating level) in the overflow spillway and 500 cumec outlet capacity. Computations are tabulated in Exhibit B-21 and are shown graphically on Exhibit C-2.

5.2 The operation at each reservoir is summarized in Exhibit B-21 by tabulating for each reservoir the inflow, storage increment, total water in storage, rule curve limitation, and outflow. Six-hour increments were used in the routing operations. Inflow and outflow are expressed as the average flow in cumecs, and the storage increment and first storage column are in units of cumec-quarter-days, which can be defined as the volume equivalent to a flow of one cumec for six hours. The second storage column and rule curve are in units of milliards (10^9) of cubic meters. The discussion of storage and storage increments in the following paragraphs is in terms of cumec-quarter-days, except where otherwise noted.

5.3 The example on Exhibit B-21 is for a flood which produced discharges at Samarra, Baghdad, and the mouth of the Diyala equivalent to 68, 72, and 80 percent, respectively, of the probable maximum floods at those locations. The method of computing inflow to damsites and the contribution of uncontrolled areas is described in Chapter B-8, Appendix B. Rule curve values and spillway capacities were obtained from tables prepared from the curves shown on Exhibit C-1.

5.4 The basic storage equation was used; thus, the change in storage is equal to the inflow minus the outflow. If the outflow is greater than the inflow, the storage increment is negative. Storage is equal to the algebraic sum of storage increment and storage in the preceding time interval. Storage in milliards is obtained by dividing storage in cumec-quarter-days by 46,300.

5.5 The first two main sections of Exhibit B-21 show the storage operations at Dokan and Eski Mosul reservoirs. The main section, headed "Routed to Samarra," gives the outflows from Dokan and Eski Mosul and the natural flows at Bekhme translated to Samarra by flood routing. Since Bekhme Reservoir was not included in this study, the Bekhme flows are unregulated. The flood routing procedure is described in Chapter B-6, Appendix B. Runoff from the area above Samarra but below the damsites is shown under "Central Tigris" and is not routed, as are the damsite flows, because this runoff gives the contribution of this area at Samarra directly. The inflow in the main section, headed "Samarra," is the sum of the four preceding columns. "Diversion" is the flow diverted to the Wadi Tharthar Depression, and "Outflow" is the release from Samarra Barrage to the Tigris River. "Outflow" is equal to "Inflow" minus "Diversion."

5.6 Adhaim River flow is added to Samarra outflow to obtain the value in the column headed "Samarra." This sum is then routed to obtain the flow at Baghdad in the following column. To simplify the operation it was assumed that Adhaim flows could be routed as if they originated at Samarra because the travel times from Samarra to Baghdad and from the Adhaim gage at Injana to Baghdad are practically equal.

5.7 Diyala River flows are carried through Derbend-i-Khan Reservoir as described above for other reservoirs. The outflow is then routed to Diyala Weir. Inflow from the Middle Diyala area (above Diyala Weir but below Derbend-i-Khan) is added to routed Derbend-i-Khan flows to obtain "Diyala Weir Total" flow. No contribution to Diyala flows below Diyala Weir was assumed, so "Total" flow is routed directly to the mouth of the Diyala as shown in the column "Diyala at Tigris."

5.8 Flows at Baghdad are routed to the mouth of the Diyala and added to Diyala flows to obtain the total flow of the Tigris River below the Diyala-Tigris confluence.

5.9 Six-hour operation studies were begun on 26 March and carried through 16 April. Each reservoir was operated on a daily or five-day basis from 1 January, using 80 percent of the seasonal flood inflows, to determine reservoir level at the beginning of the peak flood period. In this example, Dokan Reservoir was at rule curve level at 2400 hours on 25 March, but Eski Mosul storage was at 10.12 milliards, or in other words, 1.97 milliards over the rule curve level of 8.15.

5.10 The rule curve at Dokan requires the storage to be increased 230 cumec-quarter-days each six hours during March; therefore, during each of the first five periods, the storage increment is 230. This operation is called "following the rule curve." In the second period of 27 March, inflow is 2140, which exceeds spillway capacity at that reservoir level by 380 cumecs. The excess inflow must be stored, so that the storage increment is 380. Inflow continues to exceed spillway capacity through the first period of 29 March, and the reservoir level is forced to continue its rise above rule curve level. In the next period, inflow is less than spillway capacity, and since the reservoir is above rule curve level, water is

discharged at full spillway capacity. Discharge of excess water continues through the third period of 31 March, at which time the reservoir has returned to rule curve level and again begins to follow the rule curve.

5.11 Eski Mosul Reservoir is above rule curve level at the start of operations; therefore, water is discharged at full spillway capacity in an attempt to return to rule curve level. In the first period of 28 March, inflow exceeds spillway capacity so that excess water must be stored. This condition continues until April 5.

5.12 Samarra inflow will become greater than 10,000 cumecs in the second period of 4 April. The flood operation criteria are that all inflow to reservoirs above Samarra must be stored when Samarra inflow exceeds 10,000 cumecs, if the reservoir is in the lower half of its flood-control allocation. As explained earlier, a 12-hour forecast of flows at Samarra was permitted. Therefore, the flow at Samarra in the second period of 4 April corresponds to Dokan and Eski Mosul flows in the last period of 3 April. Or in other words, the operator of the system will know, during the last period of 3 April, that the flow at Samarra during the second period of 4 April will exceed 10,000 cumecs unless additional water is stored upstream.

5.13 Dokan Reservoir is at 6.17 milliards at 2400 on 3 April. This is less than 6.40, the storage midway between rule curve storage of 5.98 and normal maximum operating storage of 6.82. Therefore, the entire inflow in the first period of 4 April, 7960 cumecs, is stored and the outflow is zero. Only 5290 cumecs of the 6510 inflow during the next period can be stored before the lower half of the flood-control allocation is filled; thus the balance of 1250 cumecs is discharged. (This is an approximation made to simplify the computations.) Inflow continues to exceed spillway

capacity, so the reservoir continues discharging at full spillway capacity and is forced to store more water than the rule curve and other operating criteria demand.

5.14 At the time that it is known that Samarra inflow can exceed 10,000 cumecs, Eski Mosul Reservoir has already filled above the lower half of its flood allocation. Therefore, it continues to discharge at full spillway capacity.

5.15 During the first period of 5 April, it is determined that Samarra inflow will exceed 13,000 cumecs in the third period of 5 April unless further storage of inflows is made upstream. The operating criteria are that when inflows to Samarra exceed 13,000 cumecs, reservoirs above Samarra will store all inflow until they reach normal maximum operating level. Both Dokan and Eski Mosul reservoirs are below normal maximum operating level (6.82 and 13.15 milliards, respectively); therefore, starting with the second period of 5 April, all inflow is stored and outflow becomes zero.

5.16 During the first period of 6 April, it is determined that the inflow to Samarra will fall below 13,000 cumecs in the third period of 6 April. Both reservoirs cease storing all inflow and begin to discharge at full allowable capacity in an attempt to remove water stored in the upper half of the flood-control allocation. Dokan discharges at full spillway capacity, which is greater than inflow, so the reservoir level is lowered. Eski Mosul is limited by the operating criteria to a discharge of 5000 cumecs and is required to store water until inflow drops below 5000 cumecs.

5.17 Dokan completes the removal of water from the upper half of its flood allocation during the first period of 10 April, and reservoir level is now at a point midway between rule curve level and top water level. The

mid-storage point rises at a rate one half that of the rule curve rise, so one half of the storage required to follow the rule curve must be stored. Half of 230 is 115, but since computations are carried to the nearest ten cumecs, the storage increment alternates between 110 and 120 to avoid a cumulative error.

5.18 During the last period of 10 April, it is determined that the inflow to Samarra will fall below 10,000 cumecs in the second period of 11 April. Dokan discharge is then increased to spillway capacity, to remove the water stored in the lower half of the flood-control allocation. This water is completely removed in the last period of 15 April, and the reservoir returns to following the rule curve.

5.19 The Diyala River is treated as an independent system for the operation of Derbend-i-Khan Reservoir. The basic objective of operation is to limit the flow at Diyala Weir to 3000 cumecs. Derbend-i-Khan Reservoir operation is represented by computations similar to those used for Dokan and Eski Mosul, but its outflows are limited to 3000 cumecs minus the previous period's contribution from the Middle Diyala area.

5.20 Derbend-i-Khan starts operation on 26 March with the reservoir at rule curve level and follows the rule curve through the last period of 27 March. Inflow in the first period of 28 March is 2910 cumecs; however, 3000 less the previous period's Middle Diyala flow (400 cumecs) is 2600 cumecs, so the storage increment is thus 2910 plus 400 minus 3000 or 310. Water is stored in this manner through the second period of 29 March, at which time inflow becomes smaller than 3000 minus Middle Diyala flow. Water is removed from storage thereafter by the same procedure.

5.21 All water above rule curve level is removed in the first period of 31 March, and the reservoir resumes following the rule curve. Rule

curve level is constant through the end of March so that no water is stored. Rule curve level starts to rise on 1 April at a rate which requires the storage of 95 cumecs. The storage increment is made 90 and 100 alternately to avoid a cumulative error.

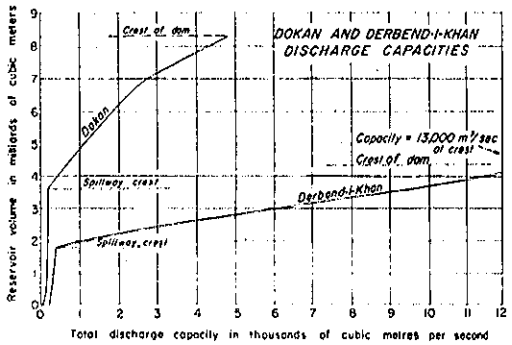
5.22 Derbend-i-Khan is again required to store flood water in the last period of 2 April, and it continues using the procedure described above until the last period of 3 April, at which time the reservoir reaches normal maximum operating level, 3.00 milliards. Outflow is made equal to full spillway capacity, so it is necessary to store water in surcharge until the first period of 6 April, when the reservoir returns to normal maximum water level. The reservoir is held at 3.00 milliards until 3000 cumecs minus Middle Diyala flow becomes less than inflow, at which time water stored in the flood allocation is discharged.

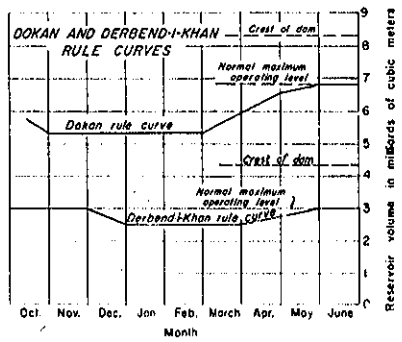
5.23 Samarra Diversion works are operated to limit the flow at Baghdad to 4000 cumecs and to limit the flow below the Diyala-Tigris confluence to 5000 cumecs. Flows from the Adhaim River are treated as originating at Samarra except, of course, that no control can be exercised over them. When flows at Diyala Weir are greater than 1000 cumecs, "Adhaim plus Samarra" is made equal to 5000 minus the previous period's flow at Diyala Weir.

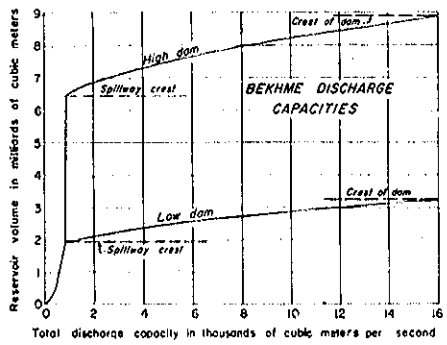
5.24 The flows of the Adhaim plus releases from Samarra are made to equal 4000 cumecs through the last period of 27 March, with surplus flows in the Tigris being directed to Wadi Tharthar. The flow at Diyala Weir on 27 March reaches 1250 cumecs, so Adhaim plus Samarra is controlled to 5000 minus 1250 or 3750 cumecs. The Adhaim flow becomes greater than 5000 minus Diyala Weir in the first period of 3 April, so all inflow to Samarra is diverted to the Tharthar Depression. At that time the flows at Baghdad

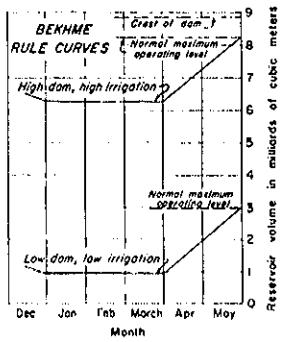
and the mouth of the Diyala must exceed 4000 and 5000 cumecs, respectively, because of lack of control on the Adhaim. Inflow to Samarra exceeds 9000 cumecs, the assumed maximum diversion capacity, in the first period of 4 April, and the excess above 9000 must be discharged down the Tigris River, causing further increases above the desired flows at Baghdad and the mouth of the Diyala. In the second period of 7 April, inflow to Samarra decreases sufficiently so that outflow from Samarra plus Adhaim flow can be made equal to 5000 minus Diyala Weir flow for the preceding period, and this type of operation is continued until the end of the study.

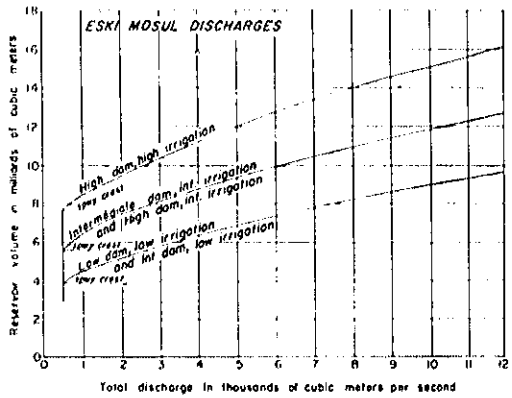
5.25 Flows at Baghdad and downstream of the Diyala-Tigris confluence are computed without the need for further operation decisions.

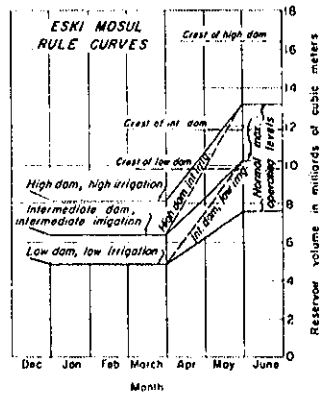


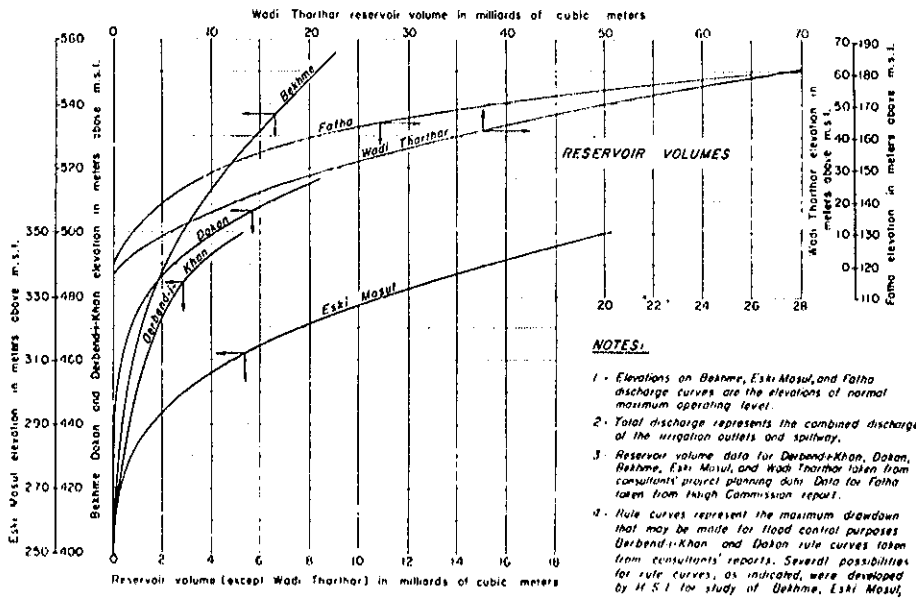


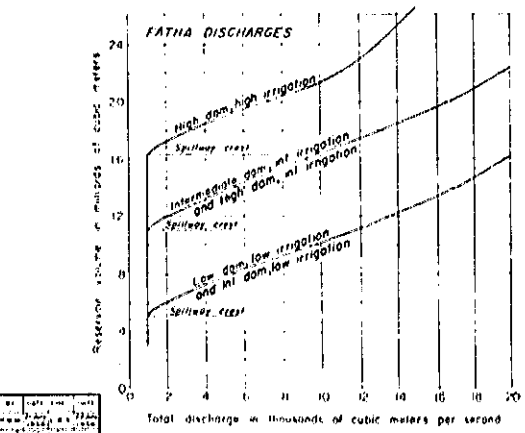


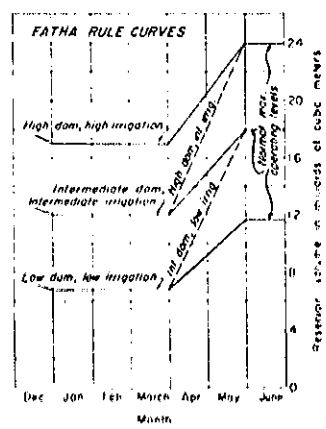












NOTES:

1. Elevations on Bekhme, Eski Mosul, and Fatha discharge curves are the elevations of normal maximum operating level.
2. Total discharge represents the combined discharge of the irrigation outlets and spillway.
3. Reservoir volume data for Derbend-i-Khan, Dokan, Bekhme, Eski Mosul, and Wadi Thorthar taken from consultants' project planning data. Data for Fatha taken from Irrigation Commission report.
4. Rule curves represent the maximum drawdown that may be made for flood control purposes. Derbend-i-Khan and Dokan rule curves taken from consultants' reports. Several possibilities for rule curves, as indicated, were developed by H.S.I. for study of Bekhme, Eski Mosul, and Fatha. High, intermediate, and low irrigation refers to relative allocation of inactive storage for irrigation.
5. All volumes shown are total reservoir volumes.

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

RESERVOIR VOLUMES DISCHARGE CAPACITIES AND RULE CURVES

HARZA ENGINEERING CO. CHICAGO — IN ASSOCIATION — BINNIE, DEACON & GOURLEY LONDON

BAGHDAD, IRAQ — DATE 28 Sept 1958 — DWG NO 627-17

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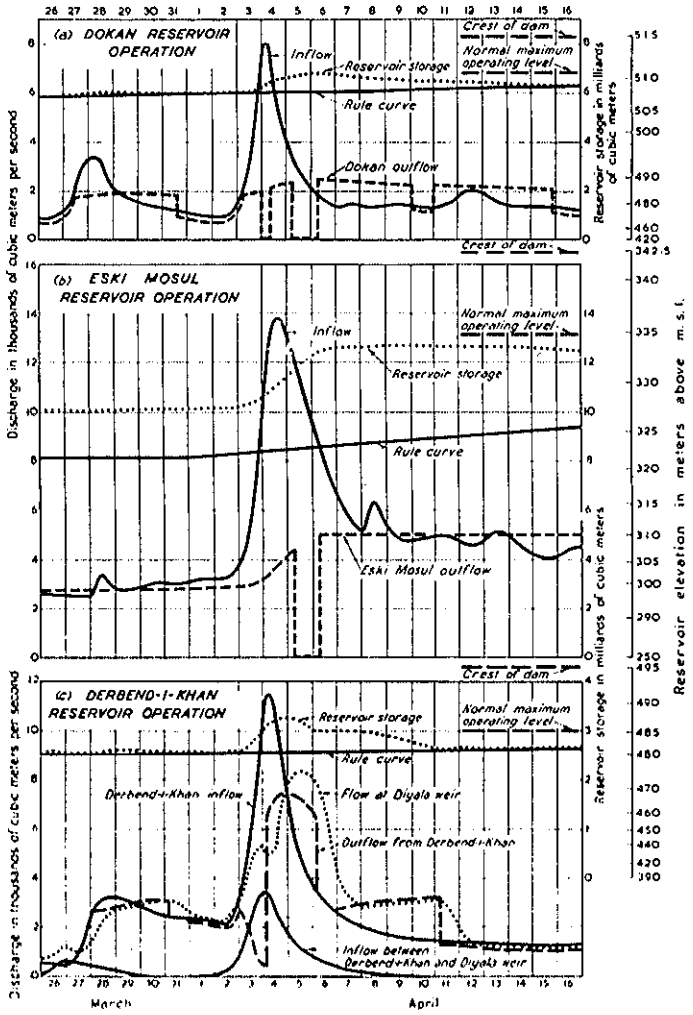

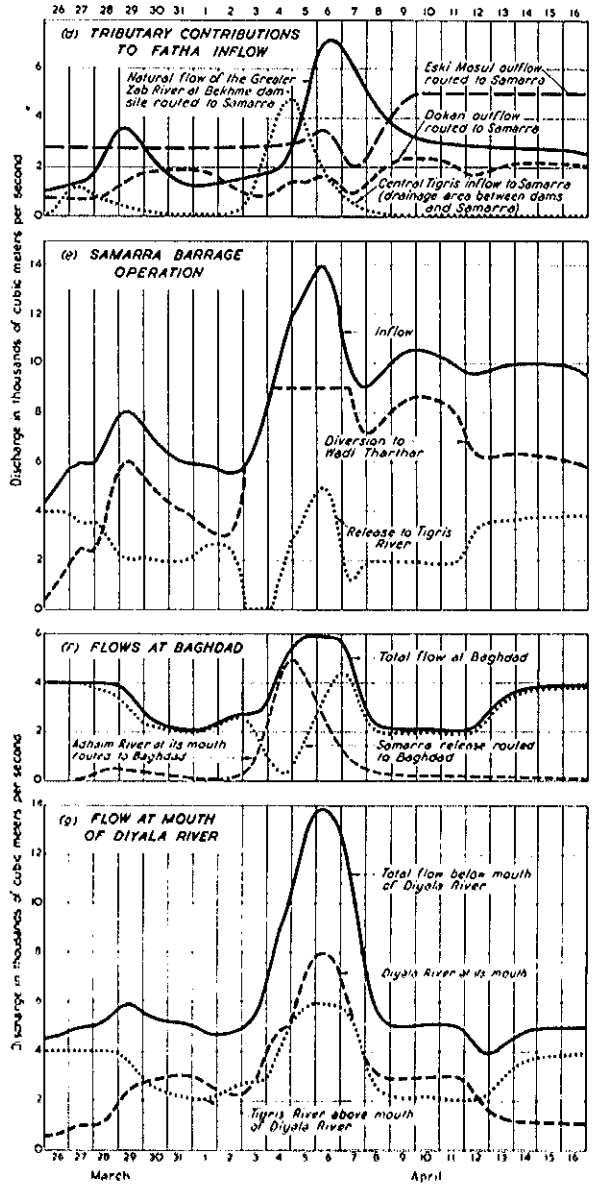

NOTES:

1 - This operation is for a system consisting of Dokan Reservoir, high Eski Mosul Reservoir, the existing Samarra diversion facilities, and Derbend-i-Khan Reservoir.

2 - Operation is for a flood having an unregulated peak flow below the mouth of the Diyala River of 28,700 cubic meters per second (80% of the probable maximum flood).

3 - Sub-basin inflows are assumed to be proportional to the individual sub-basin's probable maximum flood peak. Sub-basin probable maximum peaks must be multiplied by 0.435 to give 80% probable maximum peak below mouth of Diyala.

4 - Rule curves and discharge capabilities shown on Exhibit 21 are used.

5 - Dokan and Eski Mosul Reservoirs are operated to limit Samarra inflow to 10,000 cumecs when the reservoirs are in the lower half of joint use allocation. The reservoirs are operated to limit Samarra inflow to 15,000 cumecs when in the upper half of joint use allocation. Reservoirs discharge inflows when at normal maximum operating level. Water in storage in joint use allocation is released in a similar manner.

6 - Samarra Barrage is operated to limit Baghdad flows to 4000 cumecs, or to limit flows below the mouth of the Diyala River to 5000 cumecs whenever possible. Capacity of diversion assumed to be 9000 cumecs.

7 - Derbend-i-Khan Reservoir is operated to limit flows at Diyala Weir to 3000 cumecs while reservoir is below normal maximum operating level.

GOVERNMENT OF IRAQ
MINISTRY OF AGRICULTURE
HYDROLOGICAL SURVEY OF IRAQ

FLOOD-CONTROL OPERATION
EXISTING SYSTEM
PLUS HIGH ESKI MOSUL

HANZA ENGINEERING CO. CHICAGO — DINNIE, DEACON & GOURLEY LONDON
IN ASSOCIATION
BAGHDAD, IRAQ — DATE 27 MAY 1959 — DWG NO. 612-12

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