SPILLWAY DESIGN FLOOD FOR THE PROPOSED RAMPART CANYON DAM

By

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Introduction

The reservoir behind the Rampart Canyon Dam will be enormous in size, containing 1,265,000,000 acre-feet of water. This is about 7½ times greater than the largest reservoir in the world, Owens Falls in Uganda, Africa, which has a capacity of 169,500,000 acre-feet. The volume of water to be stored behind Rampart Canyon Dam is enough to inundate the entire state of Texas to a depth of 7 feet. The reservoir water surface area will be about 10,500 square miles which is roughly the size of the state of Maryland or Lake Erie.

A spillway is required even though the mean annual runoff of 81,000,000 acre-feet can be stored in the top 15 feet of the reservoir. Design safety criteria adopted by the Corps of Engineers requires that all dams be designed to resist failure in the event of occurrence of the most severe flood that could be considered reasonably possible from the watershed area above the dam. In order to derive the maximum probable flood to be used for spillway design, assistance was obtained from the Hydrometeorological Section of the U. S. Weather Bureau, Washington, D. C. This agency developed the probable maximum precipitation (PMP) and the maximum winter snow accumulation to be used in the flood derivation. In addition, flood reconstitution studies were made to determine the basin routing constants. These constants, along with the quantity of snowmelt and precipitation developed using the Weather Bureau's data were placed on IBM cards and processed by the IBM 1920 electronic computer using computer program 24.J3.H001. This program, entitled "Stream-flow Synthesis and Reservoir Regulation" was developed by the North Pacific Division of the Corps of Engineers. Several runs were made on the computer by varying the placement of the PMP. This program was necessary to determine the most critical sequence of climatological conditions which would give the highest peak discharge. The derived maximum probable flood (MPF) was found to have a peak discharge of 3,160,000 cfs and a four-month volume of 217,000,000 acre-feet. The most critical item controlling design of the Rampart Spillway is the volume of the MPF. The reason for this is the great regulating effect provided by surcharge storage in a reservoir of this size. The details of development of the maximum probable flood are presented in the following paragraphs.

Flood Reconstitution Studies

One of the first steps in the development of the maximum probable flood was to reconstitute some of the past floods. This was done to determine the flood-wave travel time between various points on the Yukon River and to develop basin coefficients to be used in derivation of the MPF. After an examination of the available streamflow records, the 1957 and 1959 floods were chosen for study. The 200,000 square mile basin above the damsite was then divided into 21 sub-areas by using existing stream-gaging stations as much as possible for control points. Figure 1 shows the Yukon River Basin above the damsite and the 21 sub-areas. Next, it was necessary to determine the volume of runoff from each of the sub-areas during the flood season. This was done by utilizing 14 Canadian streamgaging stations and two Alaskan gages. A reasonable base flow was then assumed for each gaged area and the flow in excess of the assumed base occurring during the three-month period of May through July was considered to be runoff from the accumulated winter snowpack and precipitation during the period. A study of precipitation records was made in order to determine what portion of the runoff should be attributed to rain and what portion of the runoff should be attributed to snowmelt. With these values determined for the gaging stations, values were calculated for the ungaged areas on a proportional basis and varied according to the mean basin elevation. This procedure was used to derive the volume of runoff, in inches, from snowmelt and precipitation for each sub-area.

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There are 14 climatological stations located in or close to the drainage area above Rampart. The next step was to decide which two of the 14 climatological stations could be used as base temperature stations to best represent that specific sub-area. The maximum daily recorded temperatures for the 14 stations were punched on cards and fed into the computer. An estimate of a base temperature, or estimated maximum temperature that could occur without the snow melting in the sub-area, was made for each sub-area. The computer assembled the maximum daily temperatures for the two stations and averaged them. After deducting the base temperature, the computer derived the daily amount of snowmelt by using the degree-day method and by taking into account the amount of snow-cover in that sub-area.

With the above-described basic data and assumptions punched on IBM cards, the 1957 flood was reconstituted using the IBM 1920 electronic computer and the North Pacific Division streamflow routing program. It required approximately 10 computer runs of 10 to 30 minutes duration each to reach a point where the computed 1957 flood hydrograph was reasonably similar to the recorded discharge hydrograph at the 16 control points.

The 1957 flood was used to develop the basin characteristics and flood-wave travel time. With these values, the 1959 flood was reconstituted by modifying only the snowmelt rates as a check on the assumed routing coefficients used in the 1957 flood. The actual flood and reconstituted flood hydrographs at key points on Yukon River for the 1957 and 1959 floods are shown on Figure 2.

Snowmelt Computations

The next step in the development of the MPF was to compute the daily snowmelt rates using data from the report by the Hydrometeorological Section of the U. S. Weather Bureau. Average daily temperatures and wind speeds were computed for four different elevation bands, with the PMP storm at three different times. The following elevation bands were used: 500 to 2500 feet, 2500 to 3500 feet, 3500 to 4500 feet and 4500 to 5500 feet. The PMP storm was assumed to occur during the period from 26 to 31 May for the first study, from 1 to 6 June for the second, and from 7 to 12 June for the third.

Upon computation of average daily temperature and wind speeds, these values were then used to compute the daily snowmelt. The snowmelt equation used was developed by research studies of the Cooperative Snow Investigation Program sponsored by the Corps of Engineers and U. S. Weather Bureau. The snowmelt equation is for a partially forested area and is as follows:

$$M = k' (1-F) (.0040 I_i) (1-a) + k(.0084v) (0.22T'_a + 0.78T'_d) + F(0.029T'_a)$$

Where: M is the snowmelt rate in inches per day.

T'_a is the difference between the air temperature measured at 10 feet and the snow surface temperatures, in ^oF.

T'_d is the difference between the dewpoint temperature measured at 10 feet and the snow surface temperature, in ^oF.

v is the wind speed at 50 feet above the snow, in miles per hour.

I_i is the estimated solar radiation on a horizontal surface, in langleys.

a is the estimated average snow surface albedo.

k' is the basin short wave radiation factor.

F is an estimated average basin forest canopy cover.

k is the basin convection - condensation melt factor.

Daily values for T'_a, T'_d, v, and I_i were developed by computations using data presented in the report from the Hydrometeorological Section. The value for basin short

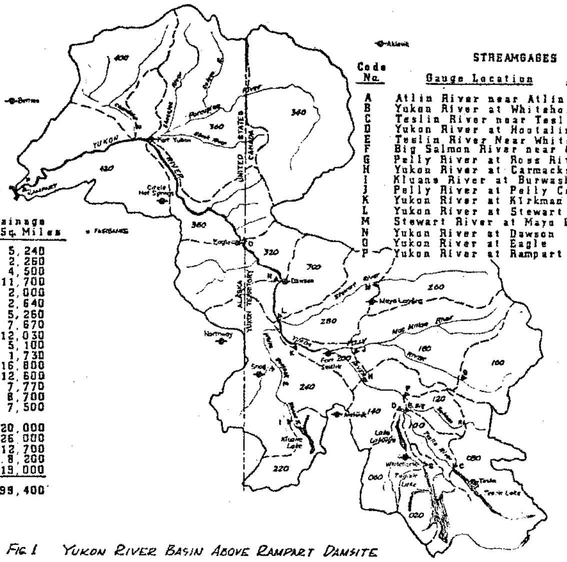


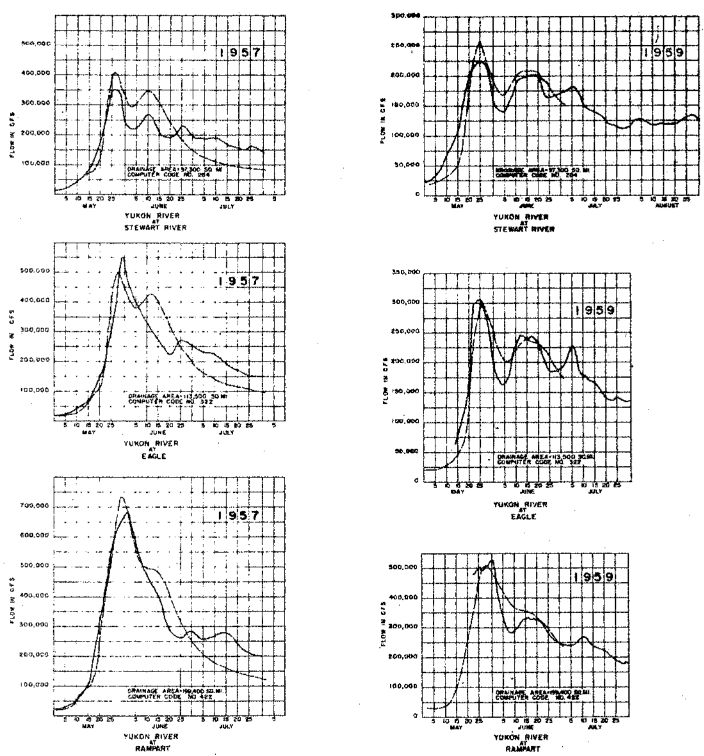
Fig. 1 Yukon River Basin Above Rampart Damsite

SUB AREA

Code No.	Sub Area	Drainage Area Sq. Miles
020	Tagish Lake Inflow	5,240
040	Atlin Lake Inflow	2,260
060	Hootalinqua Local Inflow	4,500
080	Teslin Lake Inflow	11,700
100	Teslin River Local Area	2,000
120	Big Salmon River	2,640
140	Carmacks Local Area	5,260
160	Pelly River at Ross River	7,670
180	Pelly River Local Area	12,030
200	Kirkman Local Area	5,100
220	Kluane Lake Inflow	1,730
240	White River Local Area	16,800
260	Stewart River at Mayo Landing	12,600
280	Stewart River Local Area	7,770
300	Dawson Local Area	8,700
320	Eagle Local Area	7,500
340	Porcupine River at Canadian Border	20,000
360	Porcupine River Local Area	26,000
380	Fort Yukon Local Area	12,700
400	Chandalar River	8,200
420	Rampart Local Area	19,000
	TOTAL	199,400

STREAMGAGES

Code No.	Gauge Location	Drainage Area Sq. Miles
A	Atlin River near Atlin	2,260
B	Yukon River at Whitehorse	7,500
C	Teslin River near Teslin	11,700
D	Yukon River at Hootalinqua	12,000
E	Teslin River Near Whitehorse	13,700
F	Big Salmon River near Carmacks	2,640
G	Pelly River at Ross River Post	7,670
H	Yukon River at Carmacks	33,600
I	Kluane River at Burwash Landing	1,730
J	Pelly River at Pelly Crossing	19,700
K	Yukon River at Kirkman Creek	58,400
L	Yukon River at Stewart River	97,300
M	Stewart River at Mayo Landing	12,600
N	Yukon River at Dawson	106,300
O	Yukon River at Eagle	113,500
P	Yukon River at Rampart	199,400



NOTES

1. FLOOD RECONSTITUTIONS were made using "The Computer Program 24-J3 HOOI" entitled "Streamflow Synthesis and Reservoir Regulation," developed in the North Pacific Division Office.

2. In the FLOOD RECONSTITUTION STUDIES, the Drainage Basin above Rampart was divided into 21 sub-areas. Flood Hydrographs were developed for each area and then routed together downstream to the Rampart Gage.

3. The FLOOD HYDROGRAPHS shown are for selected key points on the Yukon River and its tributaries and are designated on FIGURE 1.

4. The FLOOD RECONSTITUTION STUDIES were made to develop routing coefficients to be used in the derivation of the Maximum Probable Flood.

LEGEND

——— Recorded Flow
– – – Reconstituted Flow

FIG. 2 FLOOD RECONSTITUTIONS

wave radiation factor (k') was assumed to be 1.0 which indicates that the north and south slopes are assumed to be areally balanced. The effective forest canopy cover (F) was estimated to be 0.3 based on a general knowledge of the area above Rampart. This factor represents an estimate of the forest characteristics, considering density and spacing of forest stands and the amount of forested area. The reduction of wind speed in forested portions of the basin was accounted for in the selection of the basin convection - condensation melt coefficient, k. For the Yukon basin the value for k was assumed to be 0.7 since a great deal of the area is not forested. The snow surface albedo a, which is an estimate of the reflectivity of the snow surface, was assumed to be 0.4 throughout the snowmelt period. Using the mean basin elevation as basic criteria, the daily snowmelt values and the total snowpack valueswere developed for each sub-area. The variation of the amount of total snow-pack relative to elevation is given in the report from the Hydrometeorological Section and is summarized below:

Elevation Band Feet-MSL	Snowpack Water Equivalent Inches
1000 to 2000	14.3
2000 to 3000	15.4
3000 to 4000	17.1
4000 to 5000	20.3
5000 to 6000	25.5
6000 to 7000	32.3

For example, if a sub-area had an average basin elevation of 4300 feet, a total snowpack water equivalent of 20.3 inches was assumed to exist at the start of the snowmelt season. The daily melt values from the snow-covered area for the 3500 to 4500 foot elevation band would then be assumed to occur in that sub-area. In the Rampart analysis, all the sub-areas were assumed to be 100 percent snow-covered at the start of the MPF. Losses were deducted from the total assumed snowpack prior to machine computations of snowmelt runoff. It was estimated that two inches of snow-melt were required to satisfy the soil moisture deficiency. This was based on the types of soil and vegetation in the basin above the damsite. The loss rate to ground water recharge was assumed to be 0.2 inches per day over the snow-covered area. Assuming that the basin snow-covered area averaged 50 percent for a duration of 30 days, the loss to ground water recharge would be 3.0 inches. The losses due to evaporation and transpiration on the snow-covered area were estimated to be 1.0 inch. The total of all these losses is 6.0 inches, which was deducted from the total accumulated winter's snowpack.

Probable Maximum Precipitation

The probable maximum precipitation (PMP) storm was taken from the report of the Hydrometeorological Section of the U. S. Weather Bureau. The basic 3-day PMP storm was developed as the main contribution of direct rainfall to the snowmelt-season flood hydrograph. The 3-day PMP storm was assumed to occur first over the upper half of the basin (above Eagle, Alaska), followed by a repetition of the storm over the lower half of the basin. The 72-hour probable maximum precipitation storm beginning 26 May for the Yukon River Basin above Rampart based on an area of about 100,000 square miles is shown in the tabulation below:

PMP FOR 72 HOURS

Time	Rain- Inches
1st Day	0.30"
2nd Day	1,60"
3rd Day	0.50"

No losses were taken from the PMP storm as it was assumed that the losses were accounted for in the deduction of 6 inches of water equivalent from the accumulated winter snowpack. The assumption was based on the fact that the Yukon River Basin above Rampart is located in a permafrost zone, and indications are that the ground would not have thawed any appreciable amount by 26 May. The storms were arranged in a critical sequence with the largest amount occurring on the second day.

Post-snowmelt rain of sufficiently rare magnitude was required for completing the maximum probable flood hydrograph. This was the estimated long-duration rain that could be expected to occur during the summer of the MPF. It was assumed that the post-melt rain would begin after the PMP storm, and there would be very little, if any, rain prior to that time. The following tabulation presents the monthly values of precipitation used for post-melt rain:

CALENDAR MONTH PRECIPITATION

Month	Precipitation	Loss	Runoff
June	3.10"	1.24"	1.86"
July	4.10"	1.64"	2.46"
August	3.80"	1.52"	2.28"

The amount of loss from each rain storm was assumed to be 40 percent after the probable maximum precipitation storm. This was based on studies of the relationship of the amount of rainfall to the volume of runoff. These studies indicated that about 60 percent of the rain recorded at precipitation stations appeared as runoff at stream-gaging stations.

Base flow for the maximum probable flood was assumed to be about 25 percent higher than that estimated for the 1957 flood. The computer program makes a straight-line interpolation of the base flow from the first of the month to the last. The base flows were assumed to be as follows:

Date	Base Flow
1 May	30,000 cfs
1 June	70,000 cfs
1 July	110,000 cfs
1 August	85,000 cfs
1 September	50,000 cfs

This amounts to 18,000,000 acre-feet during the four-month period from 1 May to 1 September and is equivalent to 1.7 inches of runoff from the entire area.

Machine Computations

Program Used. - Water excesses of snowmelt and rainfall were routed through the basin storage by the method of successive increments of reservoir storage. Computer program 24.J3.H001 solves the storage equation in successive finite time and storage increments, whereby the time delay to runoff from basin input to outflow at a gaging station or control point can be established. The necessary routing coefficients for use by the computer in synthesizing streamflow in the Yukon River Basin were determined from generalized unit peak and lag data, and from the flood reconstitution studies. General concepts of this type of storage routing by the computer are contained in the 1961 Transactions of the American Society of Civil Engineers.

Runoff Characteristics in the Computer Program. - Computer program 24.J3.H001 has the ability to compute proportional components of the daily water excesses considered to contribute to surface and subsurface components of flow. Coefficients are stored by the computer as part of runoff characteristic data for each basin, whereby the proportional part of the total water excess contributing to surface runoff is a function of the inflow rate. The function is non-linear and allows a relatively larger portion of the water excess to be routed through surface component storage as inflow rates increase. Coefficients used for sub-basins in the Yukon River result in the separation of water excess inputs between surface and sub-surface components, as illustrated in the following tabulation:

Water Excess Input Rate, Inches Per day	Component Input in Inches Per Day		Surface Component Input in Percent of Total
	Surface	Subsurface	
0.50	.09	.41	18
1.00	.27	.73	27
1.50	.52	.98	35
2.00	.87	1.13	43
2.50	1.30	1.20	52

The input for each daily component is converted to an equivalent equilibrium flow rate in cfs for the specified dranage area of each sub-basin. The surface and sub-surface components are routed separately through differing amounts of storage time, as specified for the sub-basin.

The hydrograph from snowmelt is calculated by the computer, using a typical snow cover depletion curve. The computer depletes the snowpack by calculating the amount of flow from snowmelt that would occur if the basin was 100 percent snow-covered; this figure is then multiplied by the percentage of the basin that actually is snow-covered. Each increment of depletion of the snowpack, calculated as snowmelt, was decuted from the remaining snowpack; in turn this reduced the area of the basin estimated to be snow-covered as depicted by the depletion curve. Typical computer output for one sub-area, Pelly River at Ross River, is shown on Table 1. This table represents the hydrographs developed from snowmelt including base flow, the PMP storm and post-melt rain, and the resulting combination of the two hydrographs.

Computer Results. - Using these concepts, and the basic data and assumptions presented in the preceding paragraphs, the maximum probable flood for the Yukon River at Rampart was derived. The IBM 1920 electronic computer located in the North Pacific Division Office was used in the derivation. It took approximately 30 minutes of computer machine time to derive the flood and to route the hydrographs to Rampart by computing daily discharges for 109 locations on Yukon River and its tributaries for a 4-month period. For each of the 21 sub-areas, two hydrographs were developed by the computer, one for the snowmelt and base flow and one for the precipitation. This was done for two purposes--the first to show the flood that could be developed from snowmelt alone and the second to show what effect the moving of the PMP storm would have on the maximum probable flood. The derived maximum probable flood with the portions from snowmelt and PMP and post-melt rain is shown on Figure 3. The MPF for Rampart has a peak discharge of 3,160,000 cfs and a volume of 217,000,000 acre-feet. This hydrograph was used in designing the spillway for the dam. In order to determine the reasonableness of this flood, a study was made of peak to volume ratios of past floods in the Yukon River. While the period of record is short, the indications are that the peak to volume ratio of the MPF is close to the peak to volume ratios of past floods.

The routing effect on the maximum probable flood as it passes through the reservoir is also shown on Figure 3. This is based on the preliminary design of the spillway. In order to safely pass the flood, 14 feet of surcharge storage and a spillway capable of passing 603,000 cfs is required. In effect, the Rampart Canyon Reservoir will reduce the maximum probable flood from 3,160,000 cfs to at least 703,000 cfs below the reservoir. This will, for all practical purposes, eliminate all flooding below the dam except that possibly caused by ice jams.

Acknowledgment

The development of the maximum probable flood was conducted by the Planning and

TABLE 1

STREAMFLOW ROUTING
FINAL MPF RAIN 26'31 MAY

27/02 RUN NO.01 INITIAL TIME AND DATE-0900 01 MAY 99

CORPS OF ENGINEERS US ARMY, NPD

DATE	0300	0600	0900	1200	1500	1800	2100	2400	WE	AR	PAR	SC	BF	STORAGE	ELEV
150 SNOW PELLY R AT ROSS															
15 MAY 99			4490						.720			100.0	4490		
16 MAY 99			5510						.800	.720	6.5	96.4	4700		
17 MAY 99			10100						.930	1.491	13.4	91.6	4900		
18 MAY 99			21100						1.040	2.343	21.1	85.5	5110		
19 MAY 99			38200						1.260	3.232	29.1	78.2	5320		
20 MAY 99			59000						1.500	4.217	38.0	69.3	5520		
21 MAY 99			81900						1.730	5.257	47.4	59.2	5730		
22 MAY 99			107000						1.550	6.281	56.6	48.8	5930		
23 MAY 99			131000						1.430	7.037	63.4	40.9	6140		
24 MAY 99			151000						1.370	7.622	68.7	34.7	6350		
25 MAY 99			162000						1.430	8.097	72.9	29.7	6550		
26 MAY 99			163000						1.050	8.522	76.8	25.3	6760		
27 MAY 99			157000						1.340	8.788	79.2	22.5	6970		
28 MAY 99			148000						.940	9.090	81.9	19.5	7170		
29 MAY 99			137000						1.540	9.273	83.5	17.6	7380		
30 MAY 99			125000						2.300	9.544	86.0	14.9	7590		
31 MAY 99			114000						1.090	9.887	89.1	11.5	7790		
01 JUN 99			105000							10.012	90.2	10.2	8000		
02 JUN 99			97100						1.650	10.193	91.8	8.5	8030		
160 RAIN PELLY R AT ROSS															
24 MAY 99												100.0			
25 MAY 99												100.0			
26 MAY 99									.300			100.0			
27 MAY 99			250						1.600	.300	4.9	100.0			
28 MAY 99			4070						.500	1.900	31.0	100.0			
29 MAY 99			17800							2.400	39.2	100.0			
30 MAY 99			39300							2.400	39.2	100.0			
31 MAY 99			55100							2.400	39.2	100.0			
01 JUN 99			58100							2.400	39.2	100.0			
02 JUN 99			53800							2.400	39.2	100.0			
161 PELLY R AT ROSS R															
15 MAY 99			4490												
16 MAY 99			5510												
17 MAY 99			10100												
18 MAY 99			21100												
19 MAY 99			38200												
20 MAY 99			59000												
21 MAY 99			81900												
22 MAY 99			107000												
23 MAY 99			131000												
24 MAY 99			151000												
25 MAY 99			162000												
26 MAY 99			163000												
27 MAY 99			158000												
28 MAY 99			152000												
29 MAY 99			155000												
30 MAY 99			164000												
31 MAY 99			169000												
01 JUN 99			163000												
02 JUN 99			151000												

WE Is water equivalent of either snow or rain runoff with losses already taken into account.

AR Is the accumulated runoff from the beginning of the flood.

PAR Is the per cent of the accumulated runoff of the total amount of runoff that occurs during the flood.

SC Is the per cent of the basin that is snow covered and contributing runoff in the snowmelt computations. In the rain computations it is the per cent of the basin that is contributing runoff.

BF Is the base flow which is a straight line interpolation.

* Excerpts from computer output.

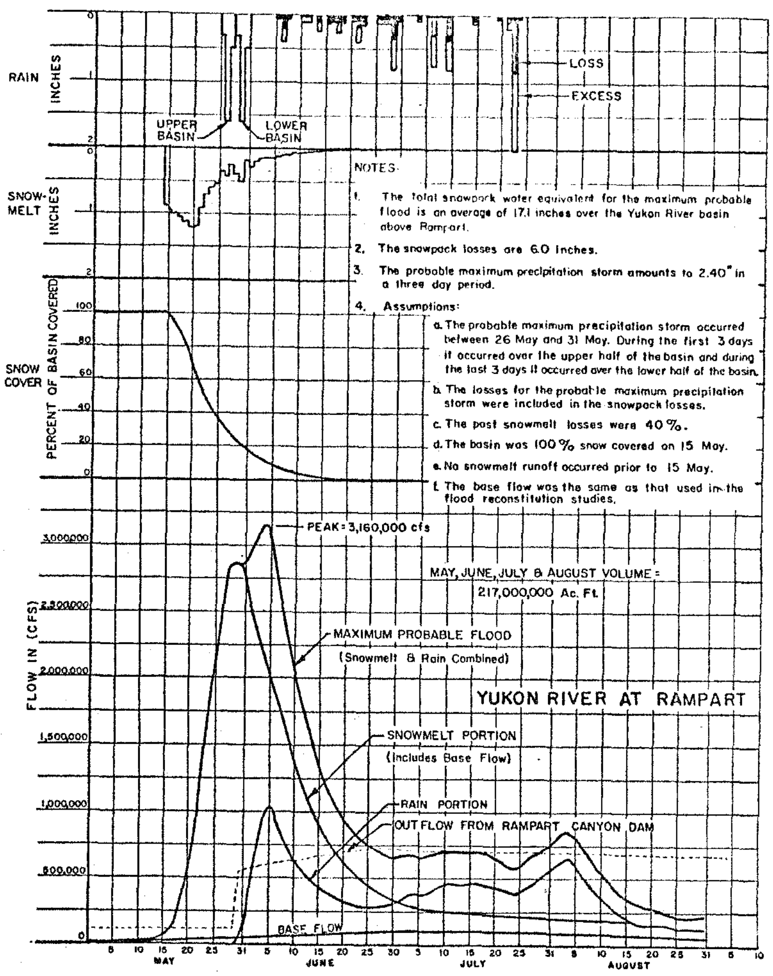


FIGURE 3

MAXIMUM PROBABLE FLOOD

Reports Branch of the Alaska District, Corps of Engineers. Technical assistance was provided by Curtis G. Green, Jr., and Donald E. Wilbur of the Alaska District and By David M. Rockwood, North Pacific Division, Corps of Engineers.

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