A HYDROMETEOROLOGICAL ANALYSIS OF A MAXIMUM PROBABLE FLOOD FOR THE PORTAGE MOUNTAIN PROJECT PEACE RIVER, BRITISH COLUMBIA [1]

By

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Introduction

The Portage Mountain Project on the Peace River, some 20 miles upstream from Hudson Hope, B. C., in northeastern British Columbia will be one of the largest hydro power projects in North America. The ultimate capacity of the power plant will be about 2,270,000 kw, and the storage capacity of the reservoir behind the 600 foot high earthfill dam will be approximately 60,000,000 acre-feet.

On all counts, Portage Mountain is a major water control project, the failure of which by overtopping of the dam would be catastrophic. The determination of the spillway design flood for a project of such magnitude should be properly based on a rational evaluation of all factors affecting runoff, which can be maximized in accordance with conditions that are "reasonably possible" for the hydrometeorological regime peculiar to the basin. [4] [5] [6]

When the initial estimates of the power potential of the Peace River basin were made in 1959, only three stream-guaging stations and one meterological station were in operation in the entire basin upstream from Husdon Hope. Records for the stream-gauging station on the Peace River at Hudson Hope, approximately 20 miles downstream from the Portage Mountain damsite, were available for summer months from 1916 to 1922, and continuously from 1949 to 1959. Other stations further downstream on the Peace River had records of varying length, -Peace River at Taylor, some 70 miles downstream from Portage Mountain, from 1944 to 1959 excluding 1950; and Peace River at Peace River, Alberta, some 200 miles downstream, from 1915 to 1931. There were no snow-courses in operation within the basin.

Not unnaturally then, the 1959 Report [7] attempted to evaluate the spillway design flood for the Portage Mountain Project by frequency analysis of the actual records of the Peace River at Hudson Hope, extended by correlation with the records of the downstream stations to cover an interrupted 29-year period 1917-1931 and 1945-1958. On this basis the 1000-year flood recommended for design of the spillway had a peak flow of 425,000 cfs and a 60-day volume of about 21.6 MAF.

The 1959 Report contained a strong recommendation that additional stream-guaging and meteorological stations be established in the basin, and that a network of snow survey stations be set up at the earliest possible time.

Between 1960 and 1963 a programme of expansion initiated by International Power and Engineering Consultants Limited, in co-operation with the Federal Water Resources and Meteorological Branches, and the Provincial Water Rights Branch, resulted in the establishment of four additional stream-gauging stations, two meteorological stations, two climatological stations, three partial climatological stations and seventeen snow courses. (See Fig. 2).

The addition of these stations created in the Peace River Basin a basic hydrometeorological network, the data from which it was hoped could be used to estimate the maximum probable flood inflow into the Portage Mountain Reservoir.

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Basin Description

The drainage basin of the Peace River upstream from Portage Mountain Dam is located in north-central British Columbia between latitudes 54°N and 58°N, and has an area of 27,360 square miles. (See Fig. 1). The two major tributaries, the Finlay and Parsnip Rivers, rise in mountainous regions in the north-west and south-east corners of the basin respectively, then flow in the Rocky Mountain Trench to join and form the Peace River near Finlay Forks. The Peace River flows eastward through the Rocky Mountains for about 75 miles to the Portage Mountain damsite, and thence north-eastward through Alberta to join the Slave-Mackenzie River system near Lake Athabasca.

Portage Mountain damsite is at El. 1650 approximately, and the maximum elevation in the basin is 9570' at Mt. Lloyd George in the extreme northeast corner. The mean elevation of the Finlay basin is about 4500 feet, that of the Parsnip basin is about 3500 feet, and the mean for the entire basin is about 4100 feet.

As part of the future flood control programme for the Fraser River, it is proposed to divert the entire flow of one of its tributaries, the McGregor River, whose basin is adjacent to that of the Parsnip River, into the Peace River reservoir through an unrestricted open channel excavated in a natural divide occupied by three small lakes.

The drainage area of the McGregor River at the proposed damsite is about 1840 square miles. The elevation of the McGregor River at the proposed damsite is 2050, and maximum elevations in the headwater regions of the river are between 8000 and 9000 feet.

The Peace and McGregor River basins are generally forested with mature conifers covering most of the areas lying below the 5000 foot level. Because of their higher average levels, the Finlay, Kwadacha, and Omineca River basins have extensive areas which are unforested. The Parsnip and McGregor River basins are mainly forested, and canopy cover is estimated at between 70 and 80 percent. River gradients throughout the Peace River basin range from over 100 feet per mile in the headwater regions to less than 5 feet per mile in the Rocky Mountain Trench; and large natural lakes, with the exception of the Nation Lake chain on the Nation River, are not present.

Climate

The climate of the Peace River basin is characterized by long cold winters and short cool summers. The mean annual temperature at Germansen Landing in the centre of the basin is 33°F, and the means for January and July are 0°F and 57°F respectively. Temperatures at Germansen Landing range between extremes of -53°F and 90°F.

Average annual precipitation at Germansen Landing is approximately 21 inches, about 50% of the total being in the form of snow. Precipitation values increase sharply on the western slopes of the Rocky Mountain particularly south of the Peace River valley where moist Pacific air, having crossed the central Interior plateau regions, meets an abrupt mountain barrier. In 1964, for example Pine Pass recorded a total annual precipitation of 97 inches, and a snowfall of 619 inches, with a water equivalent on May 1 of 68.2 inches, these latter two values being among the highest in the whole of British Columbia.

Summer rainfall is common, and is predominantly of the convectional type so that spotty distribution within the area is characteristic, as are high intensities for short periods.8/

Within the basin, there is a general variation in climate from the relatively cold and dry climate of the upper Finlay basin (at Ware mean annual temperature is 32°F and mean annual precipitation about 19 inches), to the relatively warmer and wetter climate of the upper Parsnip and McGregor basins (at Aleza Lake mean annual temperature is 37°F and mean annual precipitation is about 36 inches). This variation is well brought out by the values of mean annual runoff for the gauged streams in the basin as shown on Fig. 2 - from 22 inches for the Finlay at Ware, to 41 inches for the Parsnip at P.G.E. Bridge, and 67 inches for the McGregor River at Lower Canyon.

Streamflow

The Peace River has a runoff pattern typical of streams in cold snowy climates. In the winter, runoff is derived almost entirely from ground water storage and is relatively low in magnitude. In late April and May, the accumulated winter snowpack begins to melt, and runoff increases rapidly, reaching a peak in late May or early June as solar radiation approaches its seasonal maximum. When the snowpack is depleted, the runoff recedes, but in most years minor rises from rainfall occur during the period from June to October.

The average annual runoff for the Peace River at Portage Mountain Dam has been computed from the extended 46-year period as 26.2 MAF, which is equivalent to a mean discharge of 36,200 cfs or 18.0 inches of runoff from the drainage area of 27,360 square miles. The maximum annual recorded runoff of 38 MAF, and the maximum annual peak discharge of 311,000 cfs both occured in 1964.

Snowmelt Reconstitutions

The first step in the derivation of the maximum probable flood (MPF) by hydrometeorological methods was the definition of the basin hydrologic characteristics, which were derived partly from physical data and partly by trial-and-error reconstitutions of historic streamflow records, using observed records of temperature, snowmelt factors, and rainfall. The reconstitutions which were performed by the computer programme entitled "Streamflow Synthesis and Reservoir Regulation" developed by the U. S. Army Engineers, North Pacific Division,[9] permitted trial evaluation of such co-efficients as those which define basin snowmelt, streamflow routing, snow cover depletion, surface and sub-surface flow separation, channel routing, and lake or reservoir routing characteristics for each component drainage basin, river channel, lake and reservoir in the basin. The co-efficients which yielded the closest agreement between the reconstituted and recorded streamflow hydrographs were chosen for the synthesis of the MPF.

For the reconstitution studies, the drainage basin was subdivided into eight sub-basins as shown in Fig. 3, each area being defined by the location of a gauging station, and each representing a particular hydrologic subdivision.

The periods of reconstitution were limited to the snowmelt periods (April through June in 1963, and May through June in 1964). In both years, most of the snowpack, except for a small amount at high elevations, was melted by the end of June.

For each sub-basin the base flow was determined, and the volume of runoff above the base flow computed from the streamflow hydrographs. Trial reconstitutions of the 1963 flood hydrograph were run. For these reconstitutions, daily snowmelt runoffs in inches/day for each sub-basin were obtained by the computer from the equation:

$$M = \frac{T_{max_1} + T_{max_2}}{2} - T_B \qquad R$$

where T_{max_1}, T_{max_2} = daily maximum temperatures for sub-basin index stations (^oF)

T_B = specified base temperature for sub-basin (^oF)

R = specified melt rate for sub-basin (inches per degree-day)

The daily snowmelt runoff excess amounts were routed through basin storage to produce the streamflow hydrographs.

In succeeding trials, values of R, T_B, and the storage routing times were adjusted to make the synthesized hydrograph fit the observed hydrograph more closely.

Results of the 1963 reconstitutions for three of the gauging stations, showing computed and observed hydrographs, are shown in Fig. 3.

For the 1964 flood, which was the maximum flood of record in the Peace River drainage, the basin routing co-efficients developed for the 1964 flood were used without further adjustment: the only variables being changed were the melt rates and rainfall amounts. The 1964 reconstitutions for the same stations are shown also on Fig. 3. These reconstitutions comprise a verification of the routing co-efficients used in the mathematical model of the basin which was subsequently applied to the routing of the MPF.

Hydrometerorological Conditions for the Maximum Probable Flood

As stated previously, the magnitude of the Portage Mountain Development demanded that the spillway be designed to pass a flood resulting from the most severe combination of meteorologic and hydrologic conditions "reasonably possible" in the basin. Like most basins in the mountainous regions of Western North America, the Peace River basin is subject to spring snowmelt floods, in which the runoff from the melting of six to eight months accumulated snowfall is augmented in some years by May and June rainfall.

It follows then that the maximum probable flood in the Peace River basin must result from the maximum snow accumulation, followed by a period of moderate melt to allow for conditioning of the snowpack and soil, and then by a period of rapid melt at the beginning of June when solar radiation and air temperatures are approaching their annual maximums. A rainstorm of extreme magnitude occurring near the peak of the snowmelt flood would be a critical factor in establishing the volume and shape of the MPF hydrograph.

Critical meterological conditions for maximum inflow to the PMD reservoir have been studied in detail. The report outlining these studies 10/ contains estimates of the probable maximum storm rainfall and maximum snow accumulation based on analyses of historical surface weather maps and 500 mb. charts. It contains estimates of upper limits to the maximum temperature sequences, based on Prince George temperature records from 1942 to 1963, corrected for the elevation difference between Prince George and the basin.

Maximum Snow Accumulation

The basic mean annual snowpack water equivalent has been estimated as 13.0 inches, averaged over the basin, by analysis of snowfall records of meteorological stations within and just outside the basin.10/ This has been confirmed approximately by an analysis of the data from the 17 stations in the snow-course network over the period of record.

Maximum snow accumulation for the Peace River basin has been estimated by maximizing the precipitable water values for the 1963-64 snow storms which produced the greatest flood of record. The maximum basin snow water equivalent thus computed was verified by an alternative method involving composite seasonal totals for meteorological stations within and just outside the basin. This maximum snow water equivalent of 25.2 inches was assumed to be reduced by soil moisture increase, evapotranspiration, and ground water recharge, and the net snow water equivalent pro-rated to each sub-basin in proportion to the snowmelt runoff volume contributed by each area during the 1964 flood.

The variation of maximum snow-pack water equivalent in the sub-basin is shown in the following table.

Area No.	Drainage Area Sq. Mi.	Routed Snowmelt Runoff Volume in Inches
010	4,280	17.3
030	932	17.5
050	1,960	20.8
070	9,428	13.1
090	1,840	41.3
110	1,520	39.4
130	1,600	21.8
150	4,630	16.4
170	3,010	11.4

Critical Snowmelt Sequence

The critical temperature sequence for maximum snowmelt assumes mean temperatures from May 1 to 15, followed by a gradual rise to the maximum possible values on June 2, and a recession to near normal temperature by the end of June. Mean basin temperatures for each day for this sequence were adjusted to account for elevation differences between sub-basins, and also for the difference between the mean elevation of the sub-basin and that of snow-covered area as the snow-line receded.

Since the Finlay River catchment is generally higher and thus less heavily forested than the Parsnip River catchment, the predominant source of snowmelt for sub-basins 010, 030, and 050 is direct solar radiation. A critical sequence of solar insolation which would be consistent with the critical temperature sequence was developed from observed data at Beaverlodge, Alberta (lat. 55° 11' long. 119° 22' El. 2500).

The albedo of the snowpack was assumed to diminish from a value of 0.80 on May 1 to 0.40 on May 31; and dewpoint temperatures for use in computing the convection-condensation component of snowmelt were estimated from laboratory studies in Ref. 1, and from scanty observed data at the Germansen Landing synoptic station.

Probable Maximum Precipitation

The probable maximum precipitation (PMP) estimated by the Meteorological Branch of the Canadian Department of Transport, was derived from an analysis of severe storms of record, and adjusted by maximization factors based on maximum persisting dewpoints at the 1000 mb. level, and also adjusted on a depth-area duration basis. For the total basin area above Portage Mountain Dam the maximized values are 2.8 inches for 24 hours and 3.9 inches for 72 hours. As applied to the basin hydrologic model in combination with the snowmelt component of the maximum probable flood, these basin average values were pro-rated to the sub-basins in proportion to the normal annual runoff.

The following table shows the amount and time distribution of precipitation computed for each sub-basin.

	Total Precipitation in Inches			Total
Area No.	Day 1	Day 2	Day 3	Storm
020	.59	2.75	.49	3.83
040	.64	3.00	.54	4.18
060	.63	2.96	.53	4.12
080	.55	2.55	.46	3.56
100	1.01	4.70	.84	6.55
120	.84	3.92	.70	5.46
140	.59	2.75	.49	3.83
160	.47	2.19	.39	3.05
180	.74	3.45	.62	4.81

The total runoff from the storm precipitation was computed by applying effectiveness factors to each day's precipitation which defined the proportions of rainfall runoff from the snow-covered and snow-free area respectively.

The PMP storm was placed at the point of time when it would be most critical with respect to the flood peak. As shown in Fig. 4, it was placed near the peak of the snowmelt flood in the period June 1 to 3. Snowmelt during the PMP storm was less than that which would have occurred with clear sky conditions.

As shown in Fig. 4 additional rainfall of 2.3 inches, distributed in a pattern similar to the late June rainfall of 1964 flood, was assumed to occur during the last half of June. This rainfall had no effect on the peak of MPF, but added an additional runoff volume during the recession period which is characteristic of the Peace River basin where summer rainfall can be considerable.

Synthesis of Maximum Probable Flood

For this study, snowmelt was evaluated for each sub-basin, from the generalized snowmelt equations described in Refs. 1 and 2. For the partly-forested sub-basins of the Finlay River Catchment, the equations consider heat transfer to the snowpack by short-and long-wave radiation, convection, condensation and rain. For the forested sub-basins of the Parsnip River catchment solar radiation was not considered directly in the snowmelt computations.

The generalized snowmelt equations used were in the following form:

<u>Areas</u> 010, 030, 050, 070 (Partly - Forested)

$$M = k' (1-F),(0.0040\ I) (1-a) + K (0.0084V) (0.22\ T_a' + 0.78\ T_d') + F (0.029\ T_a)$$

<u>Areas</u> 090, 110, 130, 150, 170 (Forested),

$$M = k (0.0084V)\ (0.33\ T_a' + 0.78\ T_d') + (0.029\ T_a')$$

Where
M = snowmelt rate in inches/day
T_a' = difference between air temperature at 10 feet and snow surface temperature °F
T_d' = difference between dewpoint temperature at 10 feet and snow surface temperature °F
V = wind speed at 50 feet above snow, mph.
I_i = observed or estimated insolation, langleys
a = observed or estimated average snow surface albedo
k' = basin shortwave radiation melt factor, which has a value of 1.0 when north and south-facing slopes are balanced.
F = basin average forest canopy cover
k = basin convection - condensation melt factor.

The total daily water excess consists of the total snowmelt, less 0.30 inch/day for loss to deep percolation. This excess is effective over the snow-covered area only, which is depleted by the computer programme in inverse proportion to the total accumulated runoff.

Machine Computations

Water excesses of snowmelt and rainfall were routed through basin storage by the use of computer programme No. 24.J3.H001 9/. The snowmelt and rainfall were computed as separate components for each sub-basin area, and routed flows were summed to obtain each total sub-basin hydrograph. All computations of water excess by periods, snow cover depletion, basin storage routing through surface and sub-surface flow components, base flow computations, channel and reservoir routing, and data processing, were performed internally in the computer under input data and programme control.

A typical output sheet for one sub-area 010, Finlay River at Ware, for the month of June is shown on Fig. 5.

Results

The derived Maximum Probable Flood inflow hydrographs to Portage Mountain Reservoir are shown in Fig. 4. Two cases are shown.

Case I represents the computed maximum probable snowmelt and snowmelt-rain floods for the Peace River basin alone.

Case II represents the computed maximum probable snowmelt and snowmelt-rain floods for the Peace River basin augmented by the McGregor River diversion.

LIST OF FIGURES

REFERENCES

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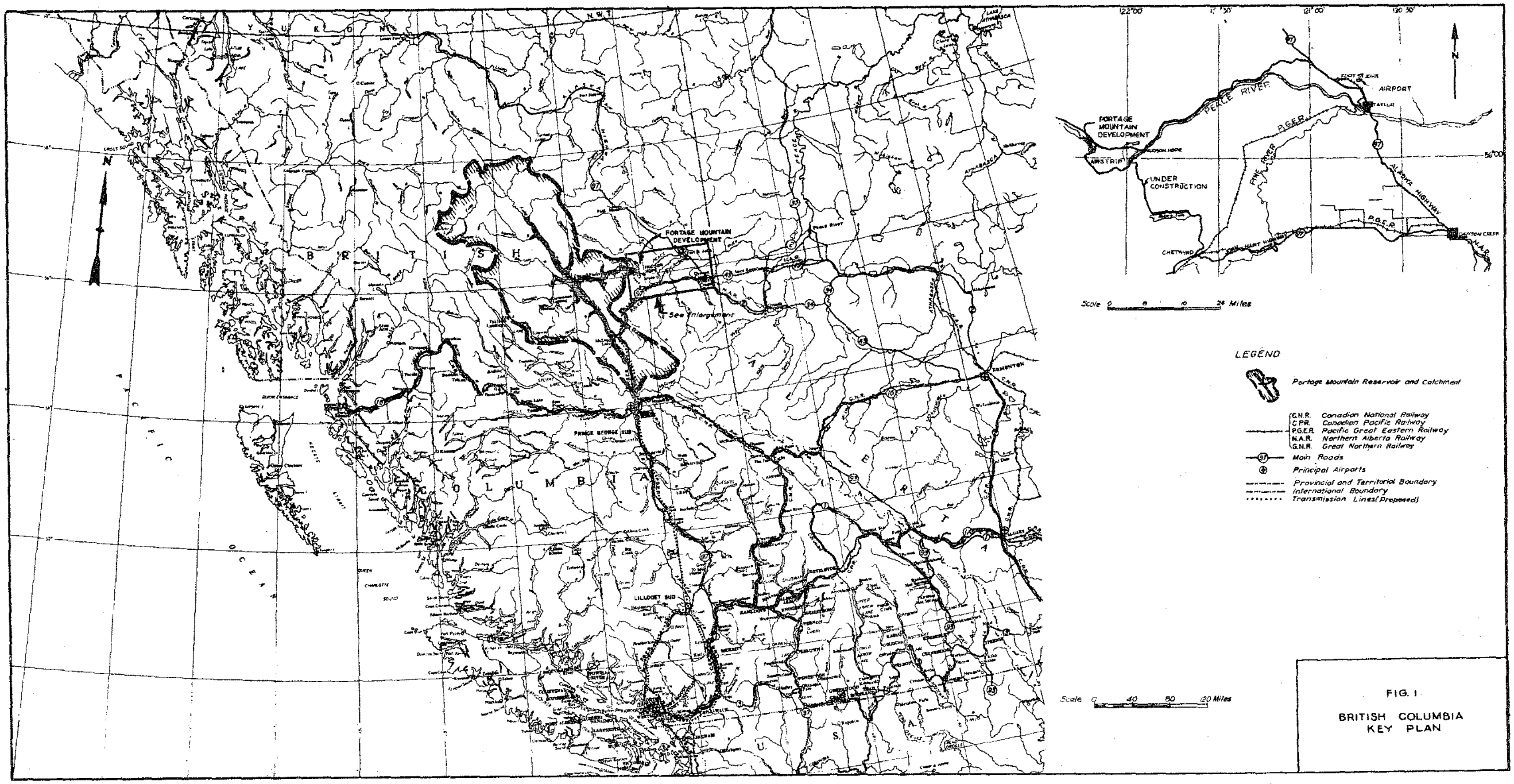
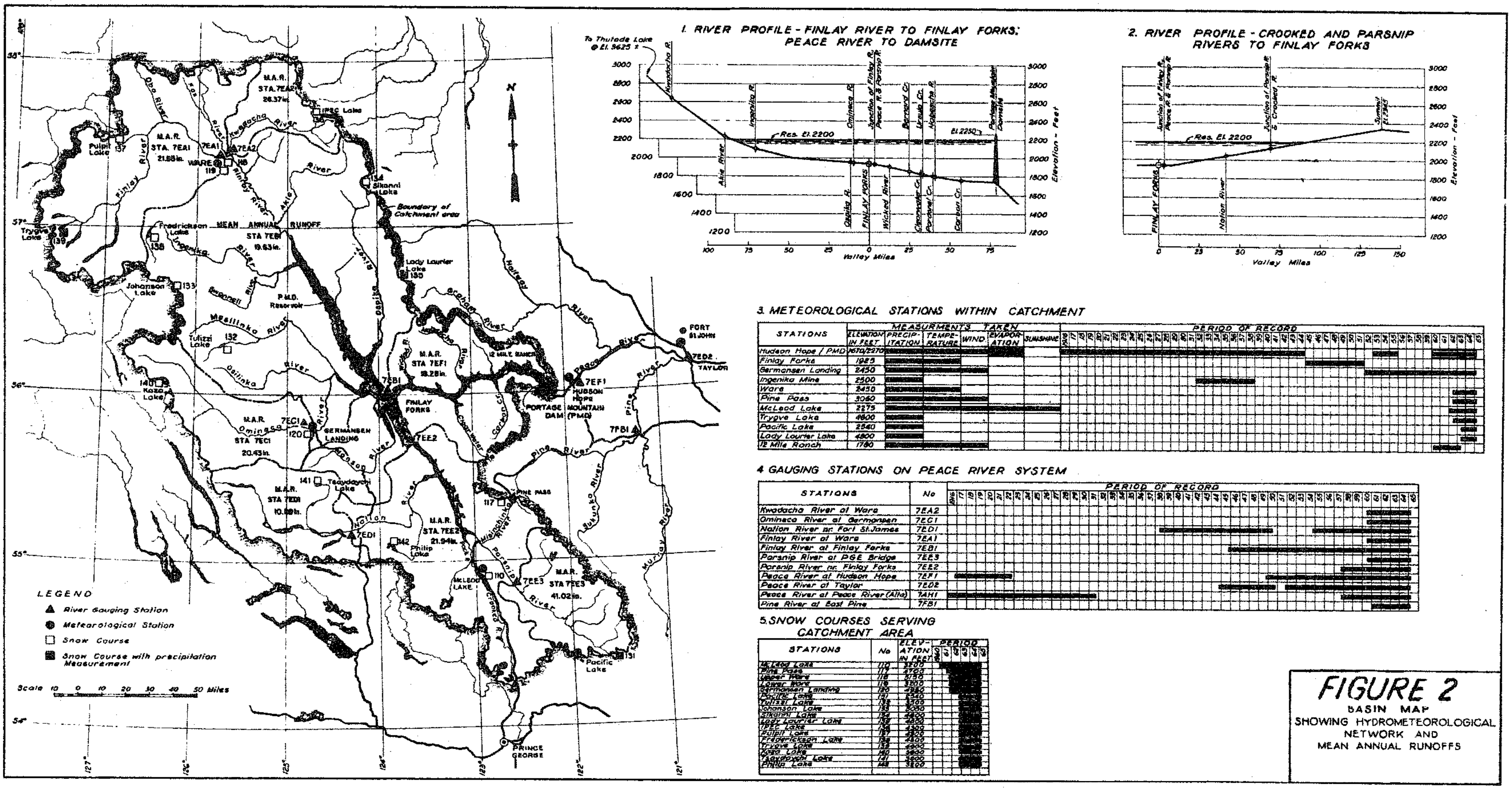


FIG. 1

BRITISH COLUMBIA
KEY PLAN



3. METEOROLOGICAL STATIONS WITHIN CATCHMENT

STATIONS	ELEVATION IN FEET	PRECIP-ITATION	TEMPE-RATURE	WIND	EVAPOR-ATION	SUNSHINE
Hudson Hope / PMD	1670/2270	■	■	■	■	
Finlay Forks	1985	■	■			
Germansen Landing	2450	■	■	■		
Ingenika Mine	2500	■				
Ware	2450	■	■			
Pine Pass	3060	■	■	■		
McLeod Lake	2275	■	■	■	■	■
Trygve Lake	4600	■				
Pacific Lake	2540	■				
Lady Laurier Lake	4800	■				
12 Mile Ranch	1780	■	■	■		

MEASURMENTS TAKEN — PERIOD OF RECORD

4 GAUGING STATIONS ON PEACE RIVER SYSTEM

STATIONS	No
Kwadacha River at Ware	7EA2
Omineca River at Germansen	7EC1
Nation River nr. Fort St.James	7ED1
Finlay River at Ware	7EA1
Finlay River at Finlay Forks	7EB1
Parsnip River at PGE Bridge	7EE3
Parsnip River nr. Finlay Forks	7EE2
Peace River at Hudson Hope	7EF1
Peace River at Taylor	7ED2
Peace River at Peace River (Alta)	7AH1
Pine River at East Pine	7FB1

PERIOD OF RECORD

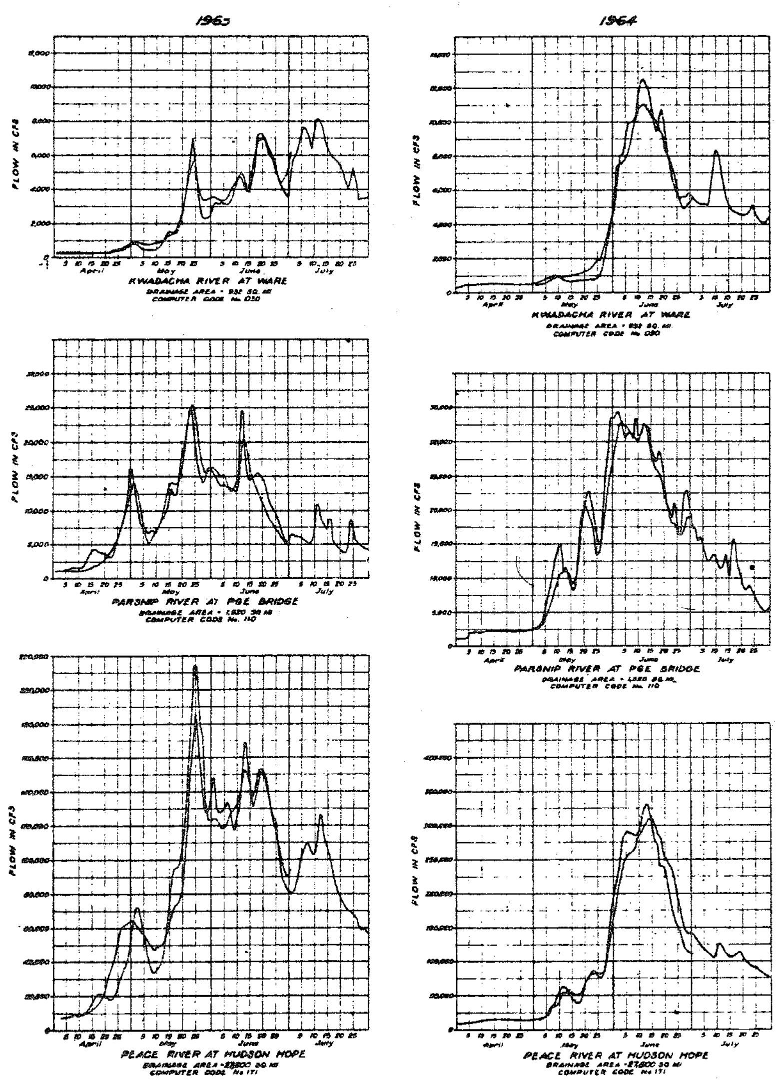
5. SNOW COURSES SERVING CATCHMENT AREA

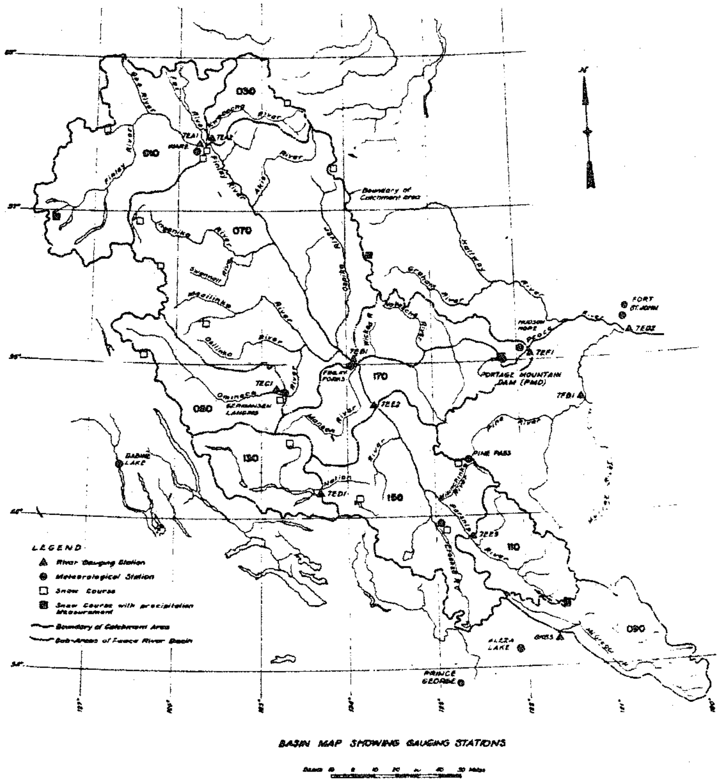
STATIONS	No	ELEV-ATION IN FEET
McLeod Lake	110	3200
Pine Pass	117	4700
Upper Ware	118	5150
Lower Ware	119	3200
Germansen Landing	120	4950
Pacific Lake	131	2540
Tutizzi Lake	132	3500
Johanson Lake	133	5050
Sikanni Lake	134	4600
Lady Laurier Lake	135	4800
IPEC Lake	136	4300
Pulpit Lake	137	4200
Fredrickson Lake	138	4300
Trygve Lake	139	4600
Kazo Lake	140	3600
Tsaydaychi Lake	141	3600
Philip Lake	142	3200

PERIOD

FIGURE 2

BASIN MAP SHOWING HYDROMETEOROLOGICAL NETWORK AND MEAN ANNUAL RUNOFFS



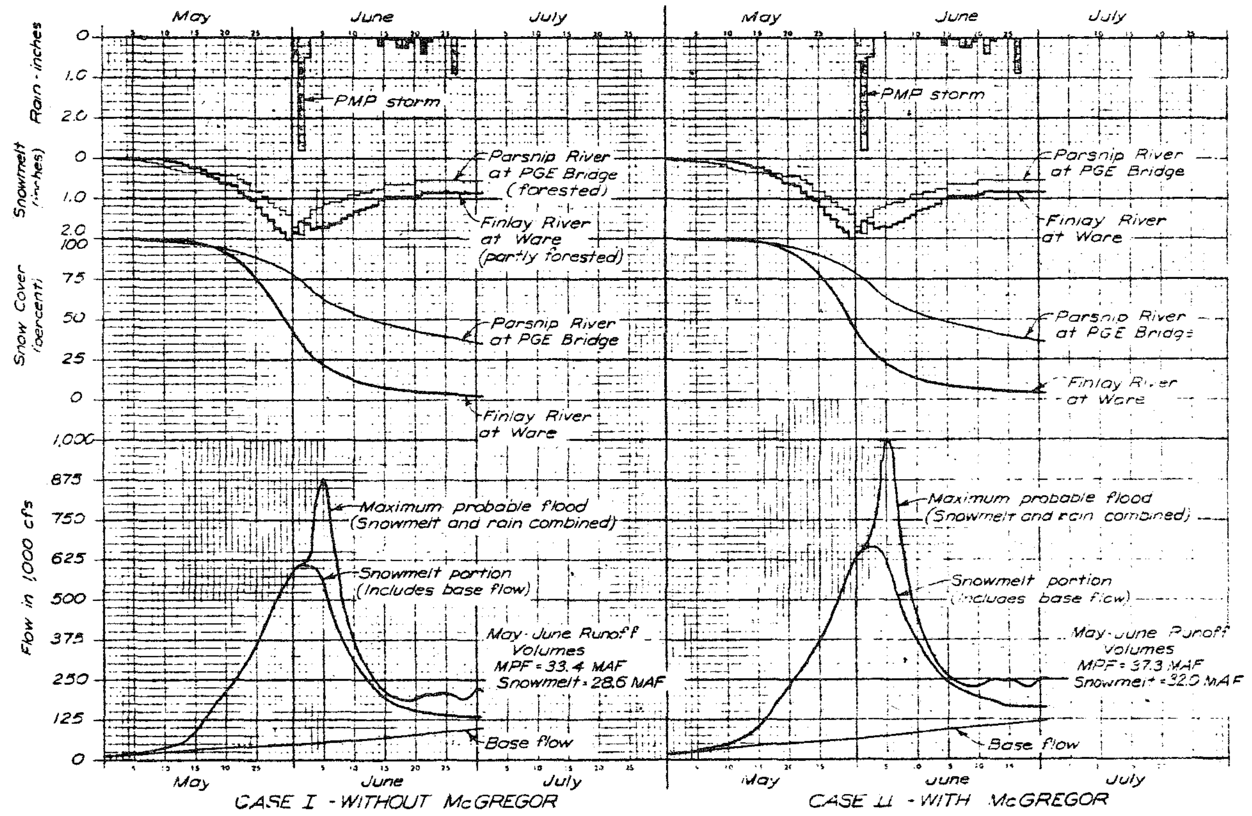


BASIN MAP SHOWING GAUGING STATIONS

NOTES:

1. Flood reconstitutions were made using the computer program 24-J3-K001 entitled "Streamflow Synthesis and Reservoir Regulation", developed in the U.S. Corps of Engineers, North Pacific Division Office.
2. In the flood reconstitution studies, the drainage basin above Hudson Hope was divided into 8 sub-areas. Flood hydrographs were developed for each area, and then routed together downstream to the Hudson Hope gauge.
3. The flood hydrographs shown are for selected key points on the Peace River and its tributaries, and are designated on the above Basin Map.
4. The flood reconstitution studies were made to develop routing coefficients to be used in the derivation of the maximum probable flood.

FIG. 3 FLOOD RECONSTITUTIONS



NOTES

1. The total snowpack water equivalent for the maximum probable flood is an average of 25.2 inches over the Peace River Basin above PMD and this amount has been pro-rated to each sub-basin area
2. The snowpack losses are 3.7 inches
3. The probable maximum precipitation (PMP) storm amounts to 3.9 inches in a 3-day period
4. Assumptions
    - (a) The PMP storm occurred between 1 and 3 June it has been pro-rated to each sub-basin area
    - (b) The post snowmelt rain amounts to 2.3 inches distributed over the basin in a pattern similar to the 1964 late June rain
    - (c) The basin was 100% snow covered on 1 May
    - (d) The base flow values for the MPF were assumed to be 50% greater than those used for the reconstitution studies for the 1964 flood

FIG. 4 MAXIMUM PROBABLE FLOOD— PEACE RIVER AT P.M.D.

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                                              STREAMFLOW ROUTING
                                           PEACE MAX PROB SNOW AND RAIN
   16/05  RUN NO.04 INITIAL TIME AND DATE-1200 01 JUN 99
     DATE           0300    0600    0900    1200    1500    1800    2100    2400    WE1     AR2   PAR3  SC4     BF5

                                 010  FINLAY R AT WARE   S
    01 JUN 99                              114000                               114000  1.850 11.614 67.1  36.5   4180
    02 JUN 99                              113000                               111000  1.580 12.289 71.0  32.0   4550
    03 JUN 99                              107000                               101000  1.610 12.795 74.0  28.6   4920
    04 JUN 99                               95100                                89000  1.750 13.255 76.6  25.5   5280
    05 JUN 99                               83500                                78900  1.740 13.701 79.2  22.5   5650
    06 JUN 99                               75000                                71600  1.740 14.093 81.5  19.9   6020
    07 JUN 99                               68300                                65100  1.640 14.439 83.5  17.7   6380
    08 JUN 99                               61900                                58800  1.620 14.729 85.1  15.8   6750
    09 JUN 99                               55600                                52600  1.520 14.985 86.6  14.2   7120
    10 JUN 99                               49800                                47100  1.410 15.201 87.9  12.8   7480
    11 JUN 99                               44500                                42000  1.320 15.381 88.9  11.6   7850
    12 JUN 99                               39700                                37600  1.300 15.534 89.8  10.7   8220
    13 JUN 99                               35600                                33900  1.200 15.673 90.6   9.8   8580
    14 JUN 99                               32300                                30900  1.190 15.791 91.3   9.1   8950
    15 JUN 99                               29600                                28400  1.110 15.899 91.9   8.4   9320
    16 JUN 99                               27400                                26400   .970 15.992 92.4   7.8   9680
    17 JUN 99                               25500                                24600   .970 16.068 92.9   7.4  10050
    18 JUN 99                               23800                                23100   .970 16.140 93.3   6.9  10420
    19 JUN 99                               22500                                22000   .970 16.207 93.7   6.5  10780
    20 JUN 99                               21600                                21200   .970 16.270 94.0   6.1  11150
    21 JUN 99                               20900                                20600   .950 16.329 94.4   5.8  11520
    22 JUN 99                               20400                                20200   .840 16.384 94.7   5.4  11880
    23 JUN 99                               20000                                19900   .840 16.429 95.0   5.2  12250
    24 JUN 99                               19700                                19500   .840 16.473 95.2   4.9  12620
    25 JUN 99                               19400                                19300   .840 16.514 95.5   4.6  12980
    26 JUN 99                               19200                                19200   .840 16.553 95.7   4.4  13350
    27 JUN 99                               19100                                19100   .840 16.590 95.9   4.2  13710
    28 JUN 99                               19100                                19100   .840 16.625 96.1   4.0  14080
    29 JUN 99                               19100                                19200   .840 16.659 96.3   3.8  14450
    30 JUN 99                               19200                                19200   .840 16.691 96.5   3.6  14810
    01 JUL 99                               19300                                              16.721 96.7   3.4  15000
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1. WE is water equivalent of the snowmelt excess in inches/day.

2. AR is the accummulated runoff from the beginning of the flood in inches over the basin area.

3. PAR is the ratio of the accummulated runoff to the total flood runoff in percent.

4. SC is the proportion of the basin area covered with snow and contributing runoff in percent.

5. BF is the base flow.

Fig. 5