APPLICATION OF AERIAL SNOW COVER OBSERVATIONS TO FORECASTING FLATHEAD LAKE INFLOWS

By M. E. Thoms 1/

INTRODUCTION

The Columbia River and its tributaries are being developed rapidly for power, flood control, irrigation, navigation and other purposes. With the continued development of the river, conflicts of use may arise. In order that the reservoirs may be operated to the best advantage for all purposes, it is becoming increasingly important to have reliable forecasts of runoff, both seasonal and short term.

In the 1940's, it was realized that too little was known of the Hydrology of snowmelt. As a result to the Corps of Engineers, U. S. Army, the U. S. Weather Bureau, and other federal agencies initiated a cooperative snow investigations program. Many of the findings of this program are presented in the publication entitled "Snow Hydrology" 1/.

This program accomplished much in the way of research. However, basic data are still rather limited for most basins and sub-basins in the Northwest. The basic data most readily available, and most frequently used in seasonal runoff forecasting procedures are precipitation, snow water equivalent and temperature. It was found that data on aerial snow coverage were required, particularly for short term forecasting. Estimates of aerial coverage were made indirectly from snow survey data, but it was felt that direct observations were required to obtain reliable basic data on aerial extent of snow cover, particularly during the ablation season.

SNOW COVER DATA

In 1945 a series of four aerial flights were made over the Flathead Basin above Flathead Lake to obtain data on aerial snow coverage. In 1951 Seattle District of the Corps of Engineers initiated a continuing program of flying over the Kootenai River Basin above Bonner's Ferry, Idaho, to obtain data on aerial snow coverage. In 1954 these flights were extended to include the Flathead Basin. Walla Walla District also began making flights in 1954 and covered the Clearwater, Boise, Payette Basins, and in later years the Snake River above Heise and Henrys Fork. Usually three to four flights were made each year, during the course of the spring snowmelt period.

For several years these data were collected but their use was limited to evaluation of immediate runoff potential. Very little use was made of the data in analytical studies during this period, because it is not practical to use data in any statistical studies unless they are available for several years. The basic data have since been compiled and published by the Corps of Engineers.2/

The primarly purpose of this paper is not to discuss the fact that data have been collected on aerial snow coverage, nor the means used on obtaining such data, but to present an example of the use of these data. This study concerns the determination of potential inflows to Flathead Lake during the snowmelt season.

FLATHEAD LAKE REGULATION

Kerr Dam was constructed by the Montana Power Company on Flathead River below Flathead Lake in 1938. The project location and surrounding area is shown in Figure 1. The authorizing license from the Federal Power Commission permits the company to regulate Flathead Lake between elevations 2883 and 2893 feet. The storage contained between these two levels of Flathead Lake is approximately 1,220,000 acre-feet. With natural and present outlet conditions the lake elevation would exceed 2893 feet in years of unusually high inflows. Kerr Dam was to be operated so that the lake level would not exceed that which would have been reached under natural conditions.

After completion of Hungry Horse Dam, and its operation in the interests of power and flood control, the pattern of inflow to Flathead Lake was considerably altered. The releases made from Hungry Horse during the winter often provided sufficient inflow to the lake to meet power requirements at Kerr. In some winters it was not necessary to draw Flathead Lake down to the minimum elevation of 2883 feet.

During the snowmelt season both Hungry Horse Reservoir and Flathead Lake were storing. Hungry Horse Reservoir was operated in accordance with an operating plan for flood control agreed upon by the Bureau of Reclamation, Bonneville Power Administration, and the Corps of Engineers.

Inasmuch as the operation of Hungry Horse dam reduces the inflows to Flathead Lake during the refill period, and accordingly reduces the likelihood of exceeding elevation 2893 in Flathead Lake, the Montana Power Company in many of the recent years has refilled Flathead Lake sooner than would

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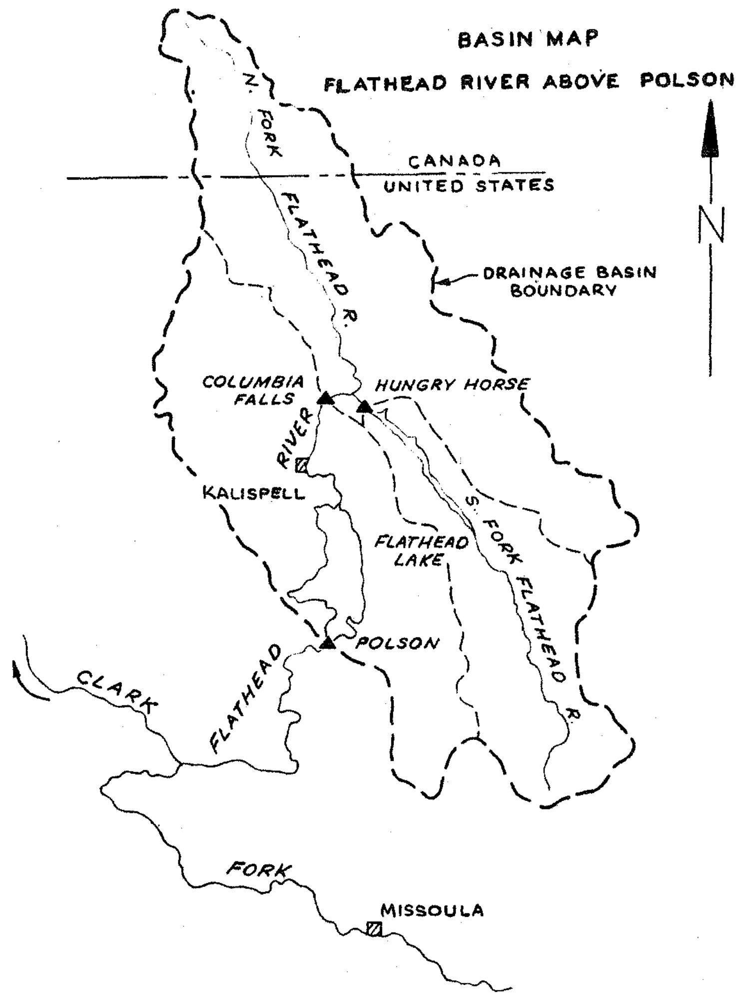
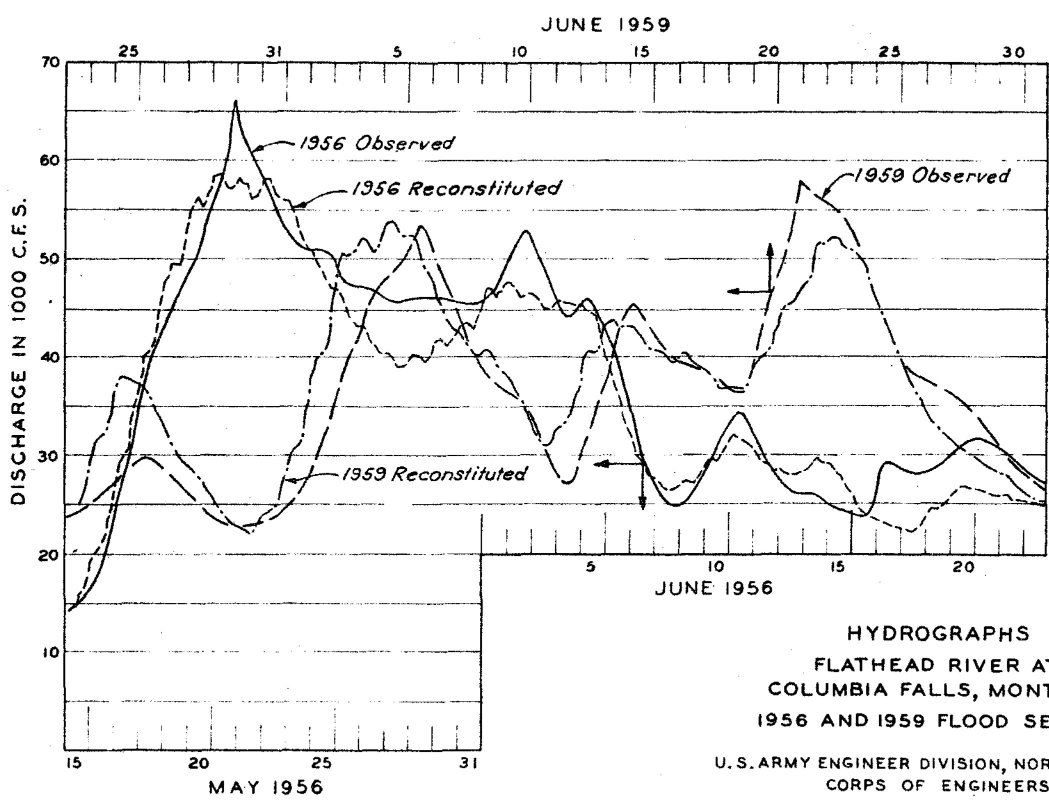




HYDROGRAPHS
FLATHEAD RIVER AT
COLUMBIA FALLS, MONTANA
1956 AND 1959 FLOOD SEASON

U.S. ARMY ENGINEER DIVISION, NORTH PACIFIC
CORPS OF ENGINEERS

have occurred naturally under free-flow conditions. The result of this type of operation has, in some cases, reduced the effect of Hungry Horse storage in reduction of flood flows in the lower Columbia River, in comparison to those which would have been experienced with free-flow conditions at Flathead Lake. This, of course, is undesirable in consideration of expected flood control benefits allocated to Hungry Horse Dam. If, during any moderate to high runoff year, the Montana Power Company allows free-flow conditions to prevail at Flathead Lake outlet and Kerr Dam until such time as the flood potential has passed, full flood control benefits from Hungry Horse Dam will be assured to downstream interests. The objective of the studies presented herein is to show a method of evaluating potential peak inflows to Flathead Lake. These in turn may be used to determine the time to induce filling of Flathead Lake by operation of the gates at Kerr Dam, in the interest of refilling the remaining space for power production during the ensuing low-water period. The derived set of curves can be used to assure the refilling of Flathead Lake without fear of a subsequent peak inflow that would cause the lake stage to exceed elevation 2893 feet.

EVALUATION OF FLATHEAD LAKE INFLOW

The North Pacific Division, Corps of Engineers, has developed a procedure based on streamflow routing by an electronic digital computer, which can be used for reconstituting or forecasting streamflow for many locations in the Columbia River Basin. The data used in this procedure are temperature indexes, estimated snowmelt rates, basin storage routing coefficients and estimated snow covered areas.

This procedure provides objective streamflow forecasts or reconstitutions for periods up to 10 days at one computer run during the snowmelt season in the Columbia River Basin. When this procedure was used for forecasting runoff in the last few years, aerial coverage observations were used when available, and estimates were made for periods between flights and for sub-basins not observed. This procedure is described in ASCE Proceedings Paper 1874, Columbia Basin Streamflow Routing by Computer, by David M. Rockwood.[3]

The routing coefficients used by the Corps were developed for each of the many segments of the Columbia River Basin as a whole. The first step in this study was to ascertain if the coefficients so derived would provide adequate reconstitutions of runoff experienced during the snowmelt season in the Flathead River Basin.

The program developed by the Corps forecasts rates of inflow to Hungry Horse Reservoir and discharges of the Flathead River at Columbia Falls. It provides for a natural runoff for the area above the gage at Columbia Falls, exclusive of the area above Hungry Horse, plus the regulated releases from Hungry Horse. If satisfactory reconstitutions could be developed for Flathead River at Columbia Falls, total inflows to Flathead Lake can be determined with assurance by adding local inflows, generally amounting to about 15 percent of the Columbia Falls natural discharge.

Two years, 1956 and 1959, were selected for this first study. Aerial snow coverage data were obtained by aerial reconaissance flights for two or three dates during the melt season in these years. For intermediate dates snow cover was estimated. Daily temperature indexes were determined as the average of the maximum daily temperatures at Missoula and Kalispell, Montana, above 55 degrees F. Mean Melt rates for the major portion of the snowmelt season were computed to provide roughly the volume of runoff above the assumed base flow and recession of initial flow. Discharges were computed for a period of 40 days during the melt season, using melt rates, snow covered area and temperature index values described above. The resulting reconstitutions of the observed hydrographs at Columbia Falls were found to be satisfactory. (See Figure 2).

After the two reconstitutions were found to be satisfactory, the runoff season of 1960 was studied. Snow covered area and temperature indexes were determined as in the previous studies, but no attempt was made to adjust snow melt rates to yield the observed volume of runoff above the assumed base flow. Melt rates, approximately the mean of those used in the reconstitutions of 1956 and 1959, were selected. A more extended period, 60 days, was studied, and the computed flows were found to reconstitute observed discharges quite satisfactorily for the first 30 days. (See Figure 3). The reconstituted flow for June indicates peaks which are considerably lower than those observed. This is attributable to inadequate evaluations of precipitation or melt rates, snow cover estimates that were low, or a combination of any of these three factors.

In these preliminary studies an attempt was made to estimate runoff resulting from rainfall occurring during the snowmelt season. It was difficult to estimate basin precipitation with any degree of assurance of accuracy because of lack of precipitation stations in the headwater area. It was assumed that essentially only that area which was still snow covered would contribute runoff from rainfall. Most of the estimated rainfall amounts were relatively small, and it was believed that there would be little direct runoff from that which fell on snow-free ground.

SYNTHESIZED RUNOFF POTENTIALS

In synthesizing peak potentials, governing meteorological and melt rate factors were assumed which were approximately maximum of record, or slightly more severe than those indicated in the reconstitution studies. The potential flows derived are those which could be expected under a combination of near maximum or maximum conditions of record, but are not extreme flows which would be associated with maximum probable flood conditions. The various factors considered and assumptions made in the study discussed briefly in the following paragraphs:

(a) Dates Considered. - Examination of data concerning floods of record showed that maximum annual peak flows have occurred at Columbia Falls as early as April 25. Most of the peak discharges have occurred in May, but a few have been observed after mid-June. Usually two to four peaks occur, and the later peaks are usually maximum or near-maximum for the year. It was assumed that the peak should not be considered to have occurred prior to May 15th. Ten-day hydrographs were synthesized for flows with starting dates of May 15, June 1, and June 16.

(b) Area Snow Covered. - Generally speaking, as long as at least 40 percent of the basin above Columbia Falls is snow covered, there is definitely a high flood potential. High flows have been observed when the snow covered about 25 percent of the area. Therefore, three different snow cover conditions, 40, 30, and 20 percent coverage, were assumed to exist at the beginning of the study periods.

(c) Temperature Sequences. - Summaries of daily highest maximum temperatures of record were not available for the two temperature index stations, Kalispell and Missoula. Summaries were available for Helena and Spokane through about 1945. A study of these records indicated that unusually high temperatures had prevailed three to five consecutive days several times in May and June. Maximum observed temperatures for May and June through 1960 at Helena and Spokane are essentially the same as through 1945, so it was assumed that the maximum three to five day sequences would not change much in the last 15 or so years. Maximum temperatures for May and June were available at Kalispell and Missoula, and did not differ greatly from those at Helena. The first five-day temperature sequences adopted for this study were patterned after those at Helena, and modified in accordance with maximums observed at Kalispell and Missoula. The temperature sequence for the last five days were assumed to be the average maximum for the date considered, as computed by the Weather Bureau.

(d) Melt Rate. - In the reconstitution studies the rate of snowmelt was found to vary considerably throught the season. The general trends appeared to be that melt rate increased later in the season, with percentage of snow cover remaining constant, and that melt rate decreased as the percentage of snow cover decreased for a given date. Four trials were made using different schedules of melt rate. The schedule finally adopted for use is shown below:

Date	Melt Rates, Inches per Degree-Day Snow Covered Area 40%	 30%	 20%
May 15	0.050	0.045	0.040
June 1	0.065	0.060	0.055
June 16	0.080	0.075	0.070

The melt rates in the above schedule are equal to, or slightly greater than any used in the reconstitution studies, for comparable dates and snow cover. The melt rates varied for the three periods and for the percentage of area covered.

(e) Basin Routing Coefficients. - Reconstitutions by the method using the digital computer, involve the conversion of snowmelt and rainfall excesses, expressed as inches per 6-hour intervals, to instantaneous streamflows, expressed in cubic feet per second. The computer accomplishes this by performing multi-phase reservoir type storage routing. The routing coefficients determine the amount of time displacement of surface and sub-surface components of runoff. The following lists the storage characterists of the drainage basins:

	Drainage Area Sq. Mi.	Coefficients 1/ Surface K_1, K_2	 Sub-surface K_3, K_4
Hungry Horse Inflow	1,663	12.0	50.0
Columbia Falls Local	2,801	15.0	60.0

Precipitation. - It was difficult to estimate precipitation for reconstitution studies, and it would have been even more difficult to estimate it for the synthesized periods. However, whenever heavy general rains are

1/ See Page 7, ASCE Paper 1874

experienced the temperatures would be expected to be considerably below the maximum or near-maximum values assumed for this study. It is believed that in most instances the runoff resulting from the general rains would not exceed that which would be produced by the higher temperatures and melt rates assumed. It is also assumed that rain falling on snow-free ground would contribute but little to direct and immediate surface runoff. Therefore, the effect of rain has not been included in this study. However, it is possible that sharp, relatively short, peak flows might result from a heavy, general rain, which would exceed the peak flows indicated on the derived curves.

(f) Initial Conditions. - The flow at Columbia Falls at the beginning of the period considered would have some influence on the peak flow that could occur as a result of the conditions assumed. Three initial discharges at Columbia Falls were used, 35,000, 25,000, and 15,000 cubic feet per second. These initial discharges were assumed to include a regulated discharge of 3,000 cubic feet per second from Hungry Horse Reservoir. Three trial routings were made to determine the effect of rising, falling or steady initial trends at Columbia Falls. The differences in peak flows obtained for Columbia Falls were quite small, so in the final study only a rising trend was considered.

Using the several above listed assumptions, resulting runoff was determined by use of the electronic digital computer. The inflows to Hungry Horse Reservoir were computed, and the flows at Columbia Falls, assuming a controlled release of 3,000 cubic feet per second from Hungry Horse Reservoir was inadequate to control releases to 3,000 cubic feet per second, adjustments would have to be made to the values obtained from the curves.

A brief study was made to determine the local inflow between Columbia Falls and Polson. Peak flows at Columbia Falls, assuming releases of 3,000 cubic feet per second from Hungry Horse Reservoir, were plotted against the sum of flows observed at gaging stations plus an estimated flow from ungaged areas. A straight line was drawn enveloping these plotted points. The peak inflows to Flathead Lake were computed by adding values taken from the local inflow curve to the peak flows synthesized for Columbia Falls.

In all, twenty-seven 10-day routings were made in the final trial. The derived synthetic hydrograph for one condition is shown on Figure 4. Peaks determined by the twenty-seven conditions were used to define the potential peak inflow curves shown on Figure 5. The twenty-seven points were defined by three initial dates, three different aerial snow coverages, and three different initial flows at Columbia Falls. The curves for 25 and 35 percent of area covered were interpolated.

1961 RUNOFF SEASON

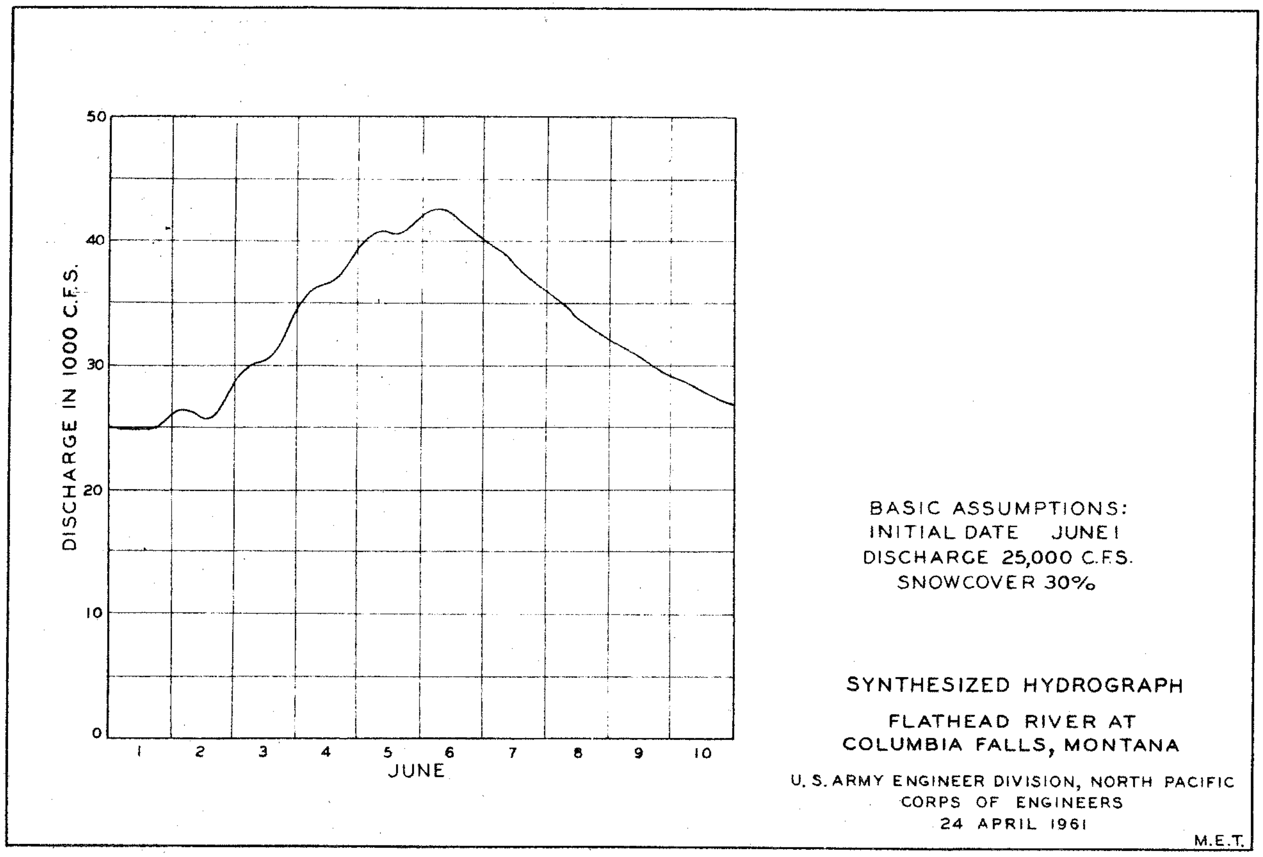
The curves were derived in early April, 1961, and were to be used as a guide to the operation of Flathead Lake during the ensuing snowmelt season. The 1961 snowmelt was retarded by the low temperatures which prevailed until about mid-May. Thereafter the melt and resulting runoff increased rapidly as the temperature rose sharply. The 1961 ratio of peak to volume was unusually high. However, the conditions which occurred during the melt season generally remained within the limits assumed in synthesizing the data for the curves.

SUMMARY AND CONCLUSIONS

This study has demonstrated that it is possible to estimate a potential peak inflow to Flathead Lake, which is related to initial flow at Columbia Falls, the date of forecast and the percentage of area above Columbia Falls which is snow covered. This estimate can be used in operational practices to establish the date when Flathead Lake can be refilled in the interests of power without causing any conflict of interests with flood control operations of Hungry Horse Project. The data on aerial snow cover are the primary variable used in estimating potential flows and are herein shown to be useful in procedures in addition to that of forecasting daily flows during the flood season.

REFERENCES

(1) North Pacific Division, Corps of Engineers, U. S. Army: Snow Hydrology. 30 June 1956.
(2) U. S. Army Engineer Division - North Pacific: Civil Works Investigation - CW-171, Technical Bulletin No. 21, Summary of Aerial Snow-Cover Observations in North Pacific Division, 1945-1960. 12 April 1961.
(3) Rockwood, David M.: Columbia Basin Streamflow Routing by Computer. ASCE Proceedings Paper 1874.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DISCHARGE IN 1000 C.F.S.
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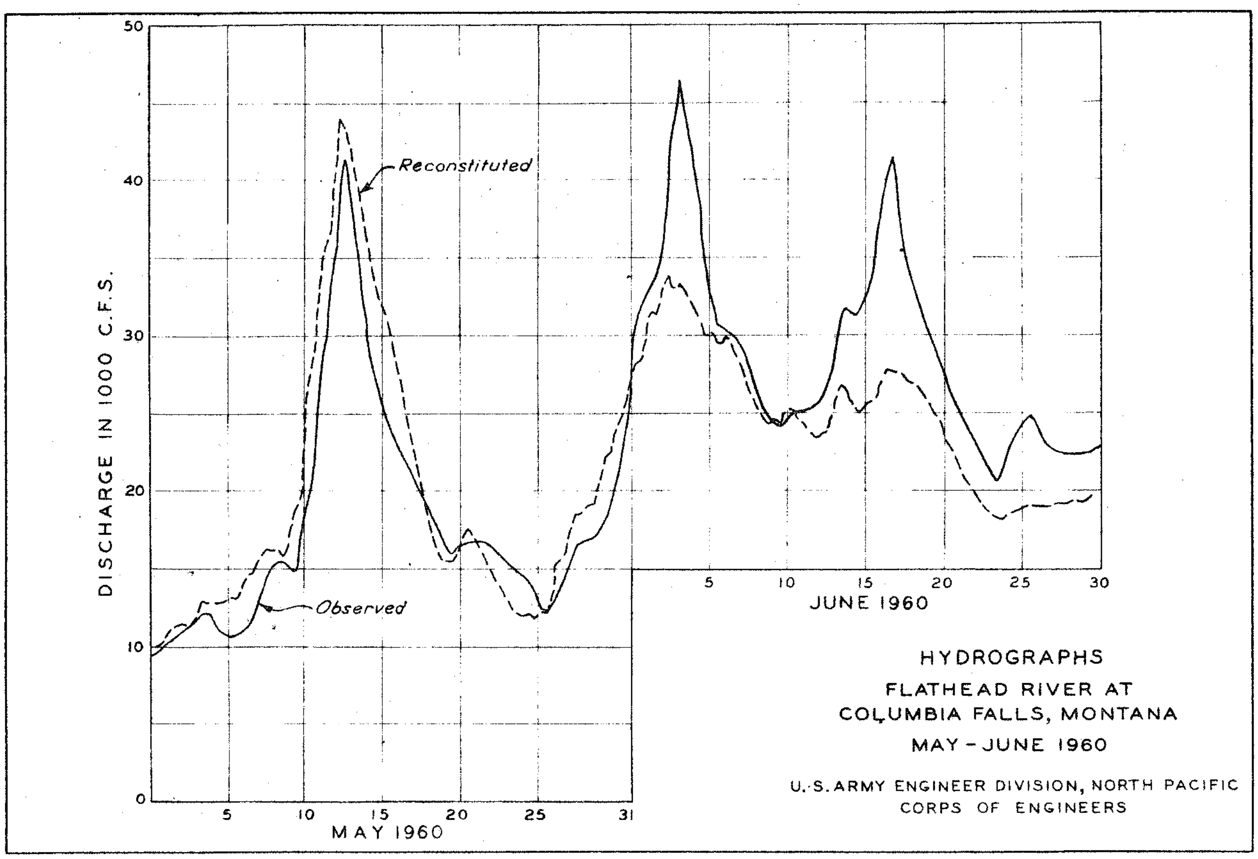
JUNE
BASIC ASSUMPTIONS:
INITIAL DATE JUNE 1
DISCHARGE 25,000 C.F.S.
SNOWCOVER 30%
SYNTHESIZED HYDROGRAPH
FLATHEAD RIVER AT
COLUMBIA FALLS, MONTANA
U. S. ARMY ENGINEER DIVISION, NORTH PACIFIC
CORPS OF ENGINEERS
24 APRIL 1961
M.E.T.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JUNE 1960
HYDROGRAPHS
FLATHEAD RIVER AT
COLUMBIA FALLS, MONTANA
MAY - JUNE 1960
U. S. ARMY ENGINEER DIVISION, NORTH PACIFIC
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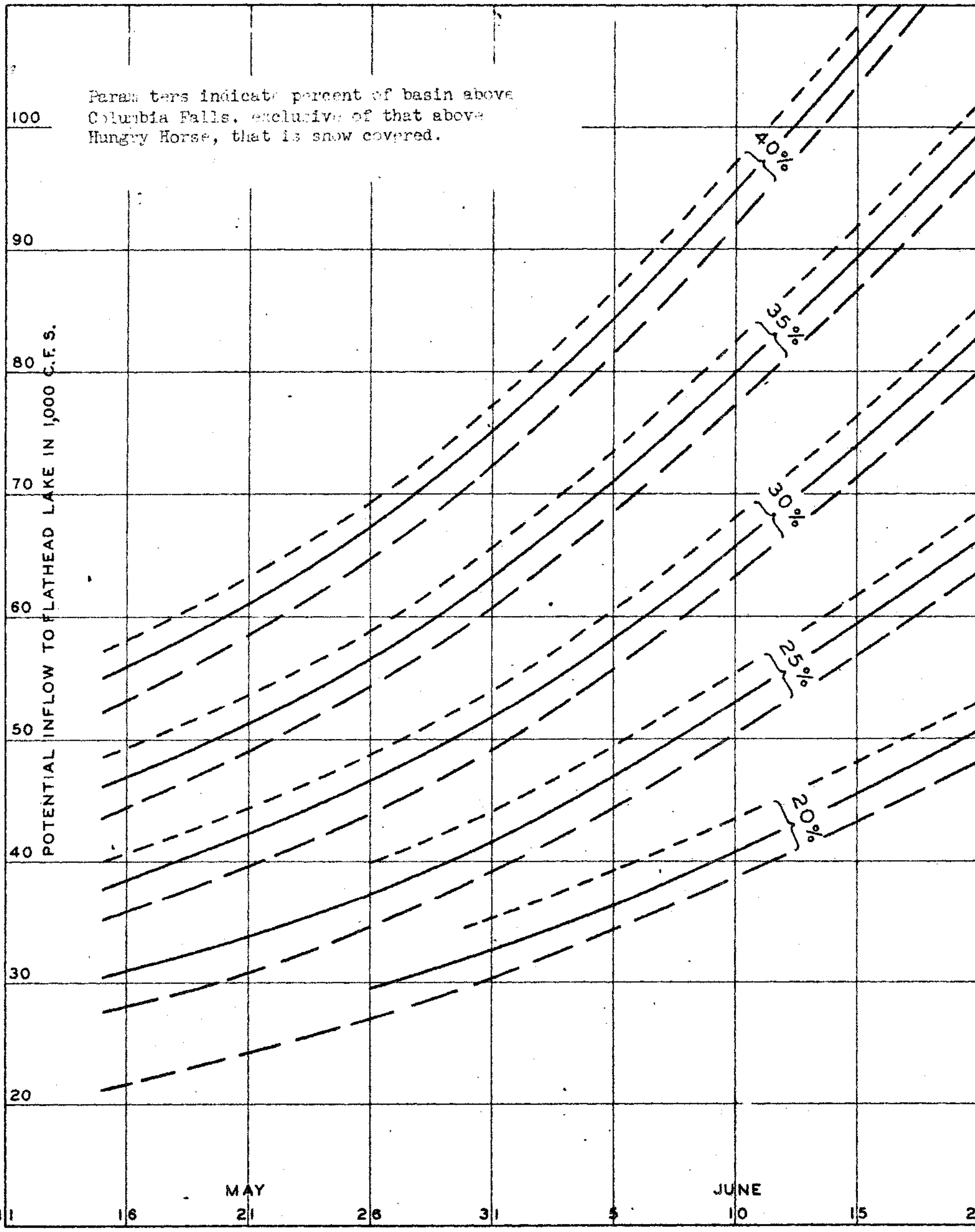

Notes:

1. It should not be assumed that the peak inflow has occurred prior to 15 May.

2. If 40% or more of the area above Columbia Falls, exclusive of that tributary to Hungry Horse Reservoir, is snow covered, the peak inflow, or inflows greater than spillway capacity at Kerr with pool elevation at 2893 feet may occur in the future.

3. If the flow at Columbia Falls exceeds 45,000 cfs, the inflow to Flathead Lake could exceed spillway capacity at full pool, and no voluntary storage should be considered if the elevation of Flathead Lake is approaching 2893 feet.

4. The curves are based on the assumption that there is adequate storage in Hungry Horse Reservoir to control releases to 3,000 cfs. If the storage is inadequate to control releases to 3,000 cfs, adjustments should be made to the values shown on the curves.

5. Curves were defined by synthesizing runoff at Columbia Falls and adding enveloping amounts of local inflow between Columbia Falls and Polson. Enveloping melt rates and temperature sequences were assumed in synthesizing runoff.

6. Curves are for snow melt only. Heavy general rains could cause inflows to exceed those shown on the curves. However, the peak probably would be of short duration.

LEGEND

INITIAL FLOW AT COLUMBIA FALLS

- - - - - - - 35,000 C.F.S.
———————— 25,000 C.F.S.
— — — — 15,000 C.F.S.

CURVES OF REMAINING POTENTIAL FOR PEAK INFLOW TO FLATHEAD LAKE, MONTANA

U.S. ARMY ENGINEER DIVISION, NORTH PACIFIC
CORPS OF ENGINEERS
24 APRIL 1961

M.E.T.

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
Washington

June 22, 1962

In reply, please address
CHIEF, U. S. WEATHER BUREAU
Washington 25, D. C.
And refer to

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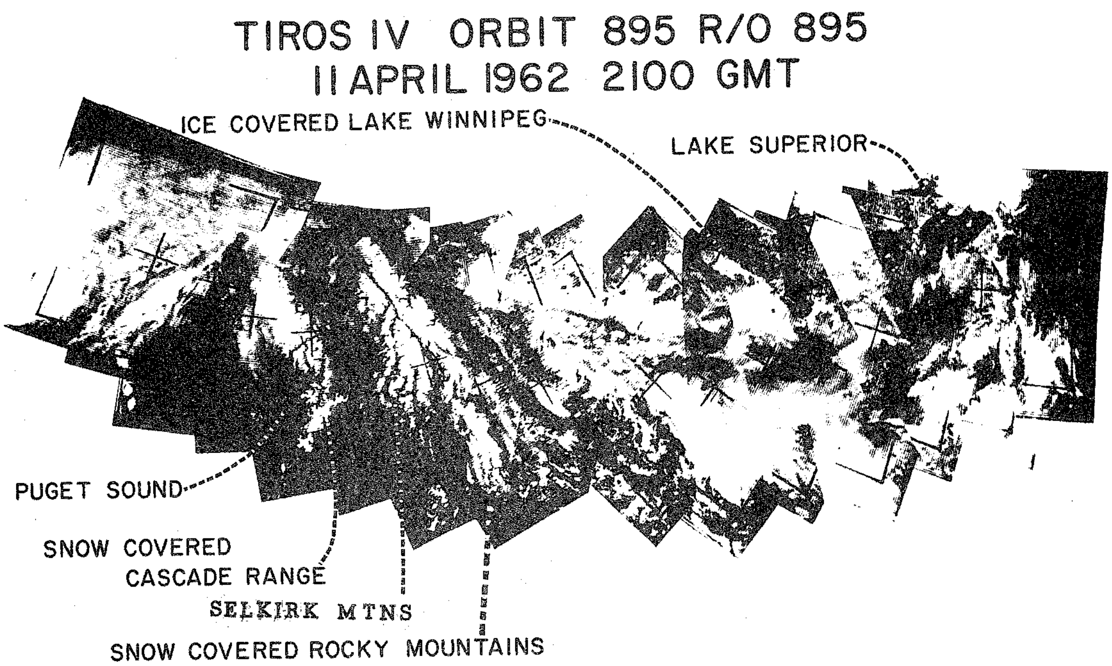

The Tiros IV Weather Satellite launched early in 1962 was able to provide some excellent pictures of the snow cover in the western mountain regions of North America. Fortunately, a print of a picture of the Sierra Nevada range was obtained shortly before the Western Snow Conference convened in Cheyenne. During the course of the discussion of Miss Thoms' paper, "Application of Aerial Snow Cover Observations to Forecasting Flathead Lake Inflow", this picture as well as shots of the Alps, Andes and Himalaya Mountains taken from Tiros I were shown. Though very preliminary in nature, the potential for using satellite pictures operationally for snow cover estimations was clearly indicated.

The U. S. Weather Bureau plans to investigate further the use of satellite pictures in making aerial estimates of snow cover. Current plans are to launch a polar orbiting satellite in the near future. This should allow for more frequent as well as more complete observations of the snow fields particularly during the snowmelt period.

Richard D. Tarble
Hydrologic Services Division
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Weather Bureau
Washington, D. C.