Cooperative Studies
(Reclamation) Section

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U. S. Department of Commerce
Weather Bureau
Office of Hydrologic Director

U. S. War Department
Corps of Engineers
Engineer Department

Hydrometeorolcgical Report No. 20

AN ESTIMATE

OF

MAXIMUM POSSIBLE FLOOD-PRODUCING METEOROLOGICAL CONDITIONS

IN THE

MISSOURI RIVER BASIN ABOVE GARRISON DAMSITE

Prepared by

The Hydrometeorological Section

Office of Hydrologic Director

November 1, 1945

Chapter I

INTRODUCTION

The Assignment

1. The Hydrometeorological Section has been requested by the U. S. Engineer Department, Corps of Engineers, to evaluate the maximum possible flood-producing meteorological conditions over the Missouri River Basin above Garrison damsite (figure 1). The present report contains tentative estimates based on studies completed to date; further study is necessary for additional refinement of results.

2. No study of the Upper Missouri River drainage basin has been undertaken, since the original assignment indicated that Fort Peck Reservoir may be expected to exercise full control over this drainage area. As shown in figure 1, there are only two other tributaries, the Milk and the Yellowstone. The Yellowstone is by far the more important of the two, and all studies to date have been concentrated on its drainage basin.

Aspects of the Problem

3. The Yellowstone River Basin presented a hydrometeorological problem intermediate between the usual flood-producing situation, which is dependent primarily on rainfall of relatively short duration, and the situation encountered in the Columbia Basin, in which the melting of the seasonal accumulation of snow is the primary flood cause.

4. The meteorological analysis of the problem in the Yellowstone Basin was handicapped by the unusual inadequacy of the meteorological data available, but the method of analysis was substantially the same as in previous Hydrometeorological studies.

5. Melting snow is a significant contributor to the annual flood peaks of the Yellowstone and is expected to be equally important in the maximum possible event. The hydrologic data required for thorough analysis of this problem (see paragraph 5, Columbia Basin Report) are, unfortunately, unavailable. Because of this lack, index relations developed by statistical method were used.

6. Approximately two thirds of the streamflow from the Yellowstone River results from melting snow. The maximum possible volume of annual discharge would result from the melting of an extremely heavy, mountain snowpack. The sequence of events leading to the maximum possible rate of discharge is less obvious. That it will be a combination of runoff from melting snow and from heavy rains is definite, but the relative contribution from each source becomes a problem in hydrology beyond the scope of the present report. A qualitative discussion of the considerations is included in chapter IV.

Chapter II

CLIMATOLOGY AND METEOROLOGY

Role of Location and Topography

7. The general climate of the Yellowstone River Basin is determined primarily by its location within the zone of prevailing westerlies, its remoteness from an oceanic moisture source, and its position just east of the Northern and Middle Rocky Mountains. The topography of the basin is responsible for the climatic variations within it.

8. Location within the zone of prevailing westerlies is associated with high frequency of frontal passages, especially in winter. Remoteness from an oceanic moisture source and the sheltering effect of the high mountain barrier west of the basin result in lower precipitation totals than would ordinarily be realized in a region so frequently visited by low-pressure systems. Temperature ranges are very large for the same reasons.

9. The topography of the basin is largely responsible for the variations in annual precipitation. The greatest annual falls occur at the higher elevations of the basin, amounting to about 26 inches at about 8800 feet; at higher elevations the fall is probably greater but there are no actual measurements. The smallest annual falls, about 5 inches, occur in the lower portions of the northern end of the Big Horn Basin. May and June are the wettest months except in the Upper Yellowstone above Livingston, Mont., which lies west of the Absaroka Range. This small area is the only portion of the Yellowstone Basin lying west of the Rocky Mountains; it is therefore most exposed to storms moving in from the Pacific Coast and, like the Pacific Coast, experiences its heaviest rainfall in the winter. January is the peak

month for this part of the Yellowstone Basin. The annual snow ranges from 13-15 inches in the prairies of southeastern Montana to over 150 inches in the rugged mountains of the western part of the basin. January is the month of greatest snowfall throughout the basin.

10. There are orographic barriers on the south and the southeast, which limit the amount of precipitable water entering the basin from these directions. Moisture-bearing air must rise to at least 8000 feet to reach the portion of the Yellowstone Basin west of the Absaroka Range. It must rise almost 7000 feet to enter the Big Horn Basin and about 3500 feet to reach the lower Yellowstone Basin in southeastern Montana.

Storm Types

11. Storms producing heavy precipitation over some portion of the basin can be classified into three general types. Types I and III are more important because they occur more frequently than Type II, and also because they can occur at any time of the year while Type II is restricted to the summer months, when there is no snow-melt problem involved.

12. In the Type I storm the basin is under the influence of relatively high pressure and cool or cold, modified polar maritime or modified polar continental air. The principal source of precipitation is the moisture brought over the basin by a warm current of modified tropical maritime air from the Gulf of Mexico, overrunning the cooler surface air. The direction of the flow, from the south or southeast, depends on the location of the associated Low center, which may be in Nevada, Utah, Colorado, Arizona, or New Mexico. The lift of the warm, moist air due to up-slope motion over orographic

barriers and over the cooler, denser air in the basin is sufficient to release a considerable amount of rain or snow. Because of the height of the Absaroka Range, this flow pattern is not very effective in producing precipitation in the part of the basin west of the range. The storms of September 27-30, 1923, August 24-28, 1933, and June 3-10, 1941 were Type I storms.

13. Strictly speaking, Type II is not a storm but a persistent pressure pattern producing a continuous northward flow of modified tropical maritime air into the basin. The source of the moist air is usually the Gulf, although sometimes the source region is the Pacific side of Mexico. The chief identifying feature of this type is the extensive pressure trough lying in an approximately north-south position between the Rockies and the Pacific. Once established, such a pressure pattern usually persists for about one week, during which warm, moist air is fed almost continuously into the basin. Since tropical maritime air is convectively unstable, the weather over the basin when under its influence is characterized by general showers, thunderstorms, and local cloudbursts. The condition is usually brought to an end by the passage of an active low-pressure system north of the basin, followed by an invasion of polar maritime air into the region. Type II, being restricted to the summer season, need not be considered in combination with snow melt. The sporadic nature of the rainfall renders it less of a flood hazard for large areas than the other types. The storms of July 21-27, 1923, and August 10-20, 1930, are Type II. The storm of July 6-18, 1937, is a combination of Types II and III.

14. Type III is the usual migratory low-pressure system moving into the region from the west, with the Low center generally passing

north of the basin. Since the Pacific is definitely the moisture source, with moisture flow predominantly from the southwest, this storm type is most effective in producing precipitation over the Absaroka Range and over the portion of the basin just west of the range. Heavy precipitation may also be produced over the northeast end of the basin (southeastern Montana) when the storm intensifies east of the Continental Divide and draws in new moisture from the southeast. The heaviest precipitation results when the antecedent meteorological conditions permit a prolonged transport of modified tropical air into the basin. Precipitation is usually limited to small amounts in the Big Horn Basin, since it is well protected from this type of storm by the Absaroka and Wind River Ranges on the west. The storms of June 30-July 4, 1912, June 19-22, 1916, and June 15-20, 1921, belong to Type III, although the 1916 storm became Type I before it ended.

Chapter III

MAXIMUM PRECIPITATION

Maximum Seasonal Accumulation of Snow

15. Preliminary studies have shown that the distribution of mean annual precipitation in northeastern Wyoming is a function of objective topographic parameters, the correlation accounting for about 80% of the variance. At least as close a relation may be expected between these parameters and mean annual snowfall. By use of a statistical regression between mean monthly precipitation and temperature, neglecting station elevations, the water equivalent of mean annual snowfall for precipitation stations in northeastern Wyoming was estimated to be 4.9 inches, or 36% of the mean annual precipitation of 13.7 inches. This method was used because precipitation records fail to distinguish between rain and snow, and snow-survey records fail to indicate total snowfall. By adjustment for station elevation and area-elevation distribution, the estimate of water equivalent of snow may be doubled to about 10 inches. Such an adjustment implies an increase also in the value assigned to mean annual precipitation; furthermore, the basis of such adjustment has not been completely studied nor extended to the basin as a whole. For these reasons, the first estimate of 4.9 inches can be retained for use in computing runoff from snow by index relations. It is a reasonable assumption that a like average ratio of snowfall to total precipitation exists elsewhere in the basin.

16. The estimated upper limits of seasonal accumulation of snow in the Yellowstone Basin, as a function of mean annual precipitation and

size of area, are shown in figure 2. The data of the figure are based on an envelopment of records in and near the project basin (northeastern Wyoming), with some modifications. One modification is the result of a consideration of figure 22 of the Columbia Report, which expresses maximum recorded annual precipitation for state areas as a percentage of the normal annual precipitation for the respective states. Of the states having a climate comparable to the project basin, South Dakota has the highest ratio of maximum to mean annual precipitation - 150% of a mean annual precipitation of 18 inches. This ratio applies to the full year. Actually almost all the snowfall occurs in the winter and spring seasons and a combination of the maximum precipitation amounts recorded in the winter and spring in South Dakota results in a value 184% of normal for the two seasons combined. If the percentage were based on a combination of maximum months it would be even higher. These percentages apply to the whole state area. Consideration of the variation of precipitation intensity with size of area indicates the order of magnitude of the values that must be included in figure 2. For an area of 50,000 square miles and a mean annual precipitation of 15 inches, for example, the estimated maximum possible snow accumulation is estimated at 72% of the mean annual, or 10.8 inches water equivalent. This is purely an index value. It is double the ratio of mean annual snowfall to mean annual precipitation previously obtained for northeastern Wyoming without correction for area-elevation distribution, and 220% of the 4.9 inches for mean annual snowfall.

17. Because of the close correlation between mean annual precipitation and topography, the influence of topography on snowfall is incorporated in figure 2 by the use of mean annual precipitation as a parameter.

The Maximum Possible Snowstorm

18. In addition to the snow accumulation already discussed, consideration must be given to the possible additional accumulation produced by a maximum possible valley snowstorm occurring late in the season. Investigation of snowfall records throughout the country indicates that a record snowstorm can occur in any month in which appreciable snow is possible. At Lander, Wyo., a snowfall of 15.4 inches occurred as late as June 3-4 in 1898. The water equivalent of the maximum possible snowstorm can be estimated from a comparison of the precipitable water that can exist aloft over freezing temperatures at the surface with the precipitable water that has characterized the greatest storms over equal areas. Applying the ratio thus obtained to the enveloping rainfall values results in a maximum possible water equivalent of about two inches (average depth over the Yellowstone Basin) in a late valley snowstorm. Over areas of a few hundred square miles extreme depths of about four inches are possible.

The Maximum Possible Rainstorm

19. In the absence of a dynamic storm model, tested by observations from actual storms, and applicable, with or without modifications, to the range of storm types, the basic method for estimating the maximum possible storm is by adjustment of actual major storms

for possible moisture content. It has been shown in earlier Hydrometeorological Reports that in storm situations values for the actual and for the maximum possible moisture charge can be adequately extrapolated from surface dewpoints, storm-observed or maximum recorded, respectively. Although adjustment by this method assumes extreme dynamic efficiency in the storm so adjusted, the assumption is reasonable if a sufficient number of storms of major character are considered. In the Yellowstone study, however, because the available storm data were too few to make the assumption entirely safe, the technique was modified.

20. In addition to adjustment of actual storms occurring within the area of interest for possible moisture-charge difference, the enveloping values of maximum recorded United States rainfall were also so adjusted. These values are shown in table 1. For the estimate of the moisture charge characterizing the enveloping values, the dewpoints within the storm controlling the particular values were studied.

21. Since not all the months of the critical season from March to October were represented by the rainfall values used for adjustment, a further dynamic factor was introduced. This was a measure of the possible wind variation, the intensity of a storm varying not only with moisture charge but with the intensity of maritime-air flow. The factor was found in the monthly variation of the mean velocities of the winds from the south (southeast and southwest quadrants) at five kilometers over Cheyenne (from the U. S. Airway Meteorological Atlas). It was assumed that the variation of the mean velocity of

winds from this direction (which is also the direction of moisture inflow) was the same as the variation of the maximum possible speed of inflow of maritime air. With the maximum possible storm estimated on a reasonably secure basis for one particular month, it was then possible to use both moisture and dynamic factors to adjust the values thus obtained for occurrence in other months.

22. Depth-duration-area data were available from just two major storms occurring within the basin. Both belong to Type I. Tentative values up to 10,000 square miles are given in table 2 for the storm of May 27-30, 1924, over the Big Horn Basin. The storm of September 27-30, 1923, occurred over northeastern Wyoming, with center at Savageton; its tentative values up to 50,000 square miles are given in table 3. As a further check on possible values within the region and at comparable elevations, the storm of June 15-20, 1921, in eastern Montana (center at Springbrook) was also studied. This study yielded a tentative value of 5.4 inches in 24 hours over 10,000 square miles.

23. The May storm was first adjusted upward for maximum possible moisture charge in May - on the basis of the surface dewpoints, observed in the storm's warm sector and maximum recorded, the ratio used being the ratio of the two values of the precipitable-water (W_p) content of the atmosphere extrapolated from those dewpoints in accordance with figure 1.03 of Hydrometeorological Report No. 2. The extrapolation was to 200 mb. Next, the September storm was adjusted for possible occurrence in May, on the basis of both moisture charge and inflow-wind difference. Finally, the U. S. enveloping values were adjusted downward

by the moisture-charge method. Included in all these moisture adjustments was the factor of elevation - since both the May and the September storms had occurred at elevations above 3500 feet (the elevation of the inflow barrier to the largest portion of the Yellowstone Basin) and the enveloping storms had occurred at about sea level. An additional moisture adjustment resulted from an investigation of the applicability of the W_p extrapolation from surface dewpoint in the region being studied. In figure 1.03 of Hydrometeorological Report No. 2 W_p is computed on the assumption of a pseudo-adiabatic lapse rate of the dewpoint. However, when compared with W_p computed from the mean monthly radiosonde data at Denver (where data were available), the pseudo-adiabatically extrapolated W_p value is too high for the warmer months and too low for the colder months. A W_p correction derived from those data was therefore used in adjusting the September storm to May and also later in the derivation of the maximum storms for other months.

24. The adjustments, as explained above, of the May 1924, September 1923, and U. S. enveloping values, resulted in three sets of values close enough to each other to suggest envelopment of all of them for the best estimate of the maximum possible storm for the middle of May. It is considered on the safe side to place the storm in the middle of the month since the possible moisture charge increases steadily during this month. The final values are given in figure 3 and table 4. They are for areas with inflow barrier of 3,500 feet, in particular the Lower Yellowstone Basin (excluding the Big Horn)

above Sidney and below Billings, an area of 38,320 square miles. The two other portions of the basin must be dealt with separately. The Big Horn Basin, area 19,580 square miles, has an inflow barrier of 7,000 feet; the Upper Yellowstone above Billings, area 11,550 square miles, has an inflow barrier of 8,000 feet. By moisture adjustment of the mid-May maximum storm over the Lower Yellowstone, the mid-May maximum storms over the other two basins were derived. The latter values are given in figures 4 and 5 and tables 5 and 6.

25. From these three mid-May values, it was possible to obtain the variation of the maximum storm from March through October, the season of interest. The adjustment factors used were maximum monthly moisture charge, the monthly W_p correction derived from the Denver mean radiosonde values, and the inflow-wind variation shown at Cheyenne. In terms of percentage of the mid-May maximum storm, the seasonal variation of the maximum possible storm is shown in figure 6, a separate curve for each basin. The percentages may be applied to all areas and durations, the actual range of individually applicable percentages being relatively small. In entering the chart with a predetermined date for the maximum possible rainstorm, it is suggested that the highest percentage within a half month either side of the date be used.

26. The most critical site for centering the maximum possible storm is in the Lower Yellowstone Basin. Since the area of this basin is only 38,320 square miles, a 50,000-square-mile storm would also cover an area of at least 11,680 square miles outside the basin.

The storm would be most effective at Garrison damsite if this excess area were selected so that the drainage would be into the Missouri River between Fort Peck and Garrison. The depth-area curves of figure 3 and the corresponding values of table 4 are for a maximum possible storm assumed to be located in this way. Except for the addition of depths for areas between 38,320 and 50,000 square miles, the curves also apply to the Lower Yellowstone as previously defined, because the inflow barriers would have the same height throughout.

Chapter IV

MAXIMUM FLOODS

Characteristic Yellowstone Floods

27. The floods characterizing the streamflow regime of the Yellowstone Basin can be separated into three classes:

1. An early spring (March) rise resulting from melting of the valley snow, sometimes augmented by ice jams.
2. A June flood resulting from the melting of the mountain snow plus a contribution from rainfall.
3. A late summer flood, primarily from heavy rains (as in July and in September, 1923).

28. It is certain that floods of Class I will never approach the limit of the maximum possible. Because of the possibility of heavier rains associated with Class 3 than with Class 2, only hydrologic trial can determine which will result in the maximum flood. The magnitude of the Class 3 flood may be computed from the maximum possible precipitation; snow melt will contribute no more than a base flow as recession from the June peak of the snow-melt runoff.

29. In Class 2 floods there are several possible sequences of events:

a. A period of heavy snow melt, followed by a heavy valley snow, and succeeded in turn by the maximum possible rainstorm for the time of year.

b. A period of melting reaching the maximum possible peak from snow melt, followed immediately by the maximum possible rainstorm for the time of year.

c. A period of melting reaching the maximum possible snow-melt peak, followed after considerable delay by the maximum possible rainstorm. This sequence is essentially an intermediate classification between the Class 2b and the Class 3 flood.

Factors which will influence the selection of the critical sequences in the Class 2 flood are:

a. Seasonal variation of temperature.

b. Seasonal variation of melting rates.

c. Contributing area for rainfall runoff.

d. Contributing area for snow-melt runoff.

e. Possible magnitude of valley snowstorm.

f. Seasonal variation of maximum possible rainfall.

g. Rate of recession of snow-melt hydrograph.

The definitely meteorological factors are discussed below.

Snow Melting Rates

30. Figure 2, showing the maximum possible accumulation of snow, provides the basic data for the estimate of volume of snow melt. The probable loss from the snowpack to evaporation and infiltration is beyond the scope of this report.

31. The maximum possible melting temperatures can be determined from a synthetic season based on the extremes of record. Figure 7 is a chart showing the monthly mean temperatures as a function of elevation. Figure 8 shows extreme departures of maximum and minimum temperatures from normal for each month for durations of 7 and 30 days. This figure is based on an envelopment of the record and a comparison of similar

estimates for the Columbia Basin (figure 28, Columbia Report). The values are for elevations of approximately 5000 feet. The possible range between extremes of maximum and minimum increases with elevation. A statistical analysis indicates this increase to be about 1°F per 1000 feet of elevation, i.e., at an elevation of 10,000 feet the possible deviations of the extreme maximum from normal are about 2 1/2° greater than indicated by the curves of figure 8. The margin of error in defining figure 8, however, is of the same order of magnitude, so that adjustment for elevation has little significance except as a safety factor.

32. Figures 7 and 8 may be combined to synthesize almost any seasonal progression of temperature. The most critical season presumably would be one in which early season melt is restricted by low temperatures, runoff being concentrated in a short period characterized by abnormally high temperatures.

33. Since no theoretical method for computing maximum melting rates is available, an empirical over-all basin factor has been developed. This factor was derived from the mass curves of figure 9, where accumulated percentages of total snow-melt runoff are plotted against accumulated degree days above 32°F after March 1, for 10 of the highest water years. The steepest segments of these curves, representing maximum degree-day factors, were then combined into one curve, shown in figure 10. The latter curve is thus analagous to an intensity-duration curve, showing maximum snow melt as a function of the magnitude of degree-day accumulation. It can be applied to the synthetic temperature season in order to construct a limiting snow-melt hydrograph. The dashed

portion of the curve indicates the relative insecurity of the data determining the short-period degree-day factors.

34. Although the curve of figure 10 naturally shows a decreasing rate with increasing magnitude of degree-day accumulation, the decreasing rate is not chronologically true. Experience indicates that the period of maximum melt should be restricted to the late spring - between May 15 and July 1. The seasonal increase in incoming solar radiation and the seasonal variation of the contributing area are probably controlling factors. An average rate of degree-day accumulation during the season at Lander, also based on the data of figure 9, is given in figure 11.

35. Since 0.15 inch of melt per degree day is a reasonable degree-day factor for the late valley snow (paragraph 18), a mean temperature of 46°F for 24 hours would be sufficient to melt the snow of 2-inch water content. This rise of temperature must intervene between the end of the subfreezing weather accompanying the snow and the onset of the rain. Some of the snow would therefore begin to melt before the rain, but the process of ripening and the lag between melt and runoff to the stream would delay the runoff from the snow sufficiently to permit the assumption of a melting rate proportional to and synchronized with the mass curve of rainfall for a critical combination.

Contributing Area

36. To deal with the problem of contributing area, the apparent seasonal variation in snow-line elevation has been plotted in figure 12. Only scanty data were available, however, and these were not analyzed for varying station exposure and other factors. In addition, the year-to-year variation of the date of disappearance of the snow line at

particular stations has been as great as one month each side of the mean. In the use of the curve of figure 12 for estimating available contributing area for rainfall runoff, tolerances of plus and minus one month are thus permitted. In the year of maximum snow accumulation it is reasonable to assume that the great volumes of snow would delay the recession of the snow line.

Summary

37. The exact combination of events which will result in the maximum possible flood must be determined by hydrologic trial. The effects of the various factors are summarized as follows:

a. Maximum possible precipitation increases as the season progresses (figure 6).

b. The possible melting temperatures increase as the season progresses (figure 7 and 8).

c. The area contributing to snow melt decreases as the season advances (figure 12).

d. Combining b and c, the maximum possible peak from mountain snow is restricted to the period from May 15 to July 1.

e. A valley snowstorm can occur at any time up to June 15 and contribute to the maximum flood. The cold weather accompanying its occurrence would end the melting of mountain snow, decreasing the contribution from that source. A recession of discharge from the mountain snow for two days would precede the beginning of runoff from the sequence of valley snow and rainfall.

f. A recession of one day in the runoff from the mountain snow would precede the beginning of runoff from the maximum possible rain alone.

g. Subject to the restriction f, the maximum possible rain can coincide with the peak runoff from the mountain snow. However, it may be that a more critical combination can occur later in the season when both rainfall and area contributing to rainfall runoff will be greater.

Table 1

ENVELOPING VALUES OF MAXIMUM RECORDED
U.S. RAINFALL (INCHES)
(Revised October 1945)

Area (sq.mi.)	Duration (hours) 12	24	48	72	96
2,000	19.4	24.4	28.3	29.6	29.9
5,000	14.0	18.3	21.9	23.4	23.8
10,000	10.0	13.7	17.0	18.8	19.5
11,550	9.3	12.9	16.2	18.0	18.8
19,580	7.2	10.2	13.4	15.5	16.4
20,000	7.1	10.1	13.3	15.4	16.3
38,320	5.2	7.8	10.8	12.9	13.8
50,000	4.6	7.0	9.9	12.0	12.9

Table 2

STORM OF MAY 27-30, 1924, BIG HORN BASIN

Area (sq.mi.)	Duration (hours) 12	24	48	72	96
2,000	1.4	2.7	3.9	4.5	4.6
5,000	1.2	2.3	3.3	3.8	3.9
10,000	1.0	1.9	2.7	3.1	3.2

Table 3

STORM OF SEPT. 27-30, 1923, N.E. WYOMING

Area (sq.mi.)	Duration (hours) 12	24	48	72	96
2,000	2.4	4.4	7.2	10.1	12.6
5,000	2.2	3.8	5.9	8.1	10.0
10,000	2.0	3.3	5.0	6.7	8.1
20,000	1.7	2.8	4.4	5.5	6.4
38,320	1.4	2.4	3.8	4.6	5.2
50,000	1.3	2.3	3.6	4.3	4.8

Table 4

MAXIMUM POSSIBLE MID-MAY STORM FOR LOWER YELLOWSTONE (EXCLUDING BIG HORN) BETWEEN BILLINGS AND SIDNEY (INCHES)

Area (sq.mi.)	Duration (hours) 12	24	48	72	96
2,000	7.3	9.3	11.5	12.6	13.0
5,000	5.2	7.0	9.3	10.6	11.0
10,000	3.8	5.2	7.3	8.6	9.0
20,000	2.7	3.8	5.4	6.4	6.9
38,320	2.0	3.0	4.1	4.8	5.4
50,000	1.8	2.7	3.7	4.4	5.0

Table 5

MAXIMUM POSSIBLE MID-MAY STORM FOR BIG HORN BASIN (INCHES)

Area (sq.mi.)	Duration (hours) 12	24	48	72	96
2,000	4.3	5.5	6.9	7.6	7.9
5,000	3.1	4.2	5.6	6.4	6.7
10,000	2.3	3.1	4.4	5.2	5.5
19,580	1.6	2.3	3.2	3.9	4.2

Table 6

MAXIMUM POSSIBLE MID-MAY STORM FOR UPPER YELLOWSTONE BASIN ABOVE BILLINGS (INCHES)

Area (sq.mi.)	Duration (hours) 12	24	48	72	96
2,000	3.5	4.4	5.4	5.9	6.0
5,000	2.5	3.3	4.3	4.9	5.1
10,000	1.8	2.5	3.4	4.0	4.2
11,550	1.7	2.3	3.2	3.8	4.0

U. S. DEPARTMENT OF COMMERCE WEATHER BUREAU HYDROMETEOROLOGICAL SECTION

SCHEMATIC CHART OF MISSOURI RIVER ABOVE GARRISON DAMSITE

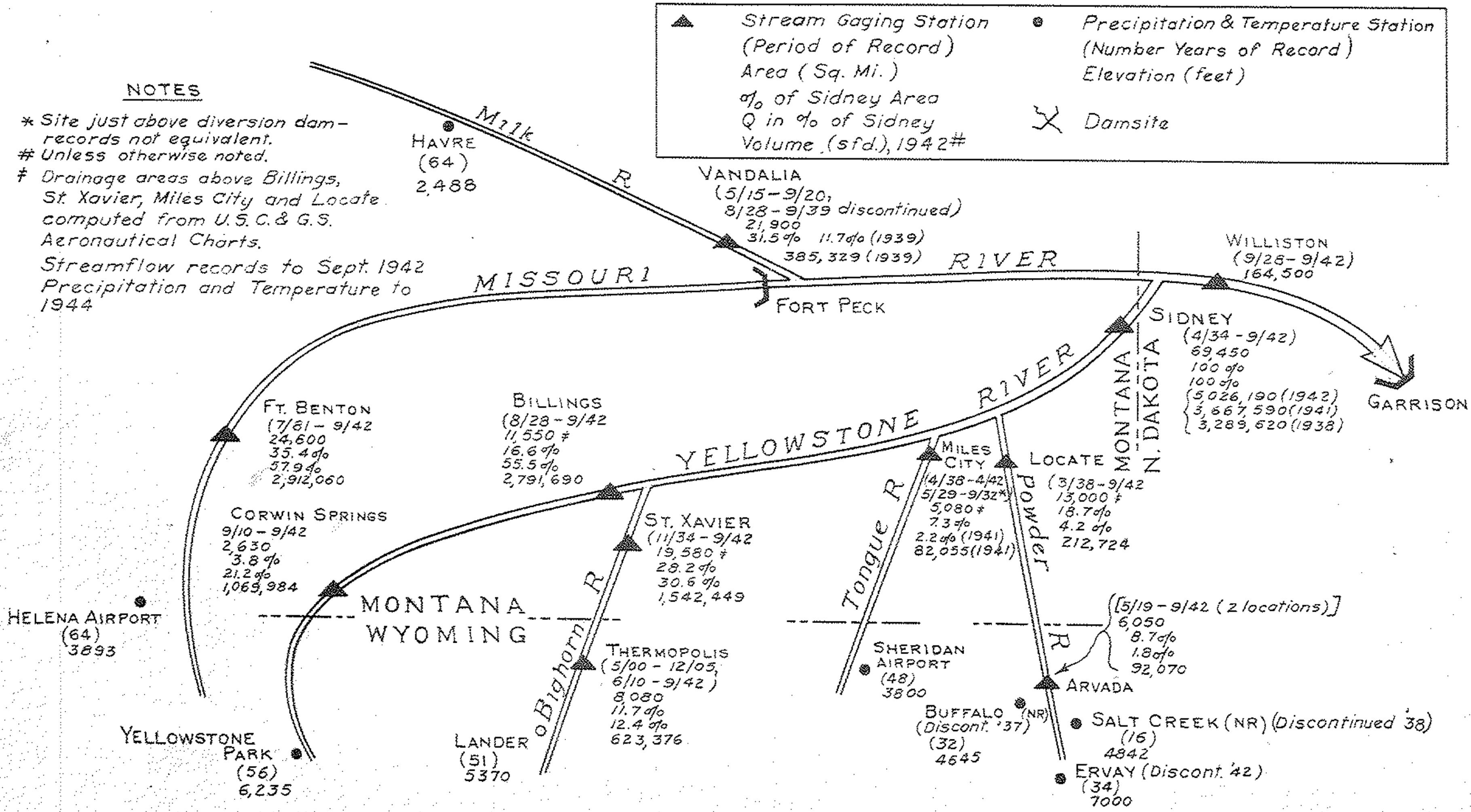
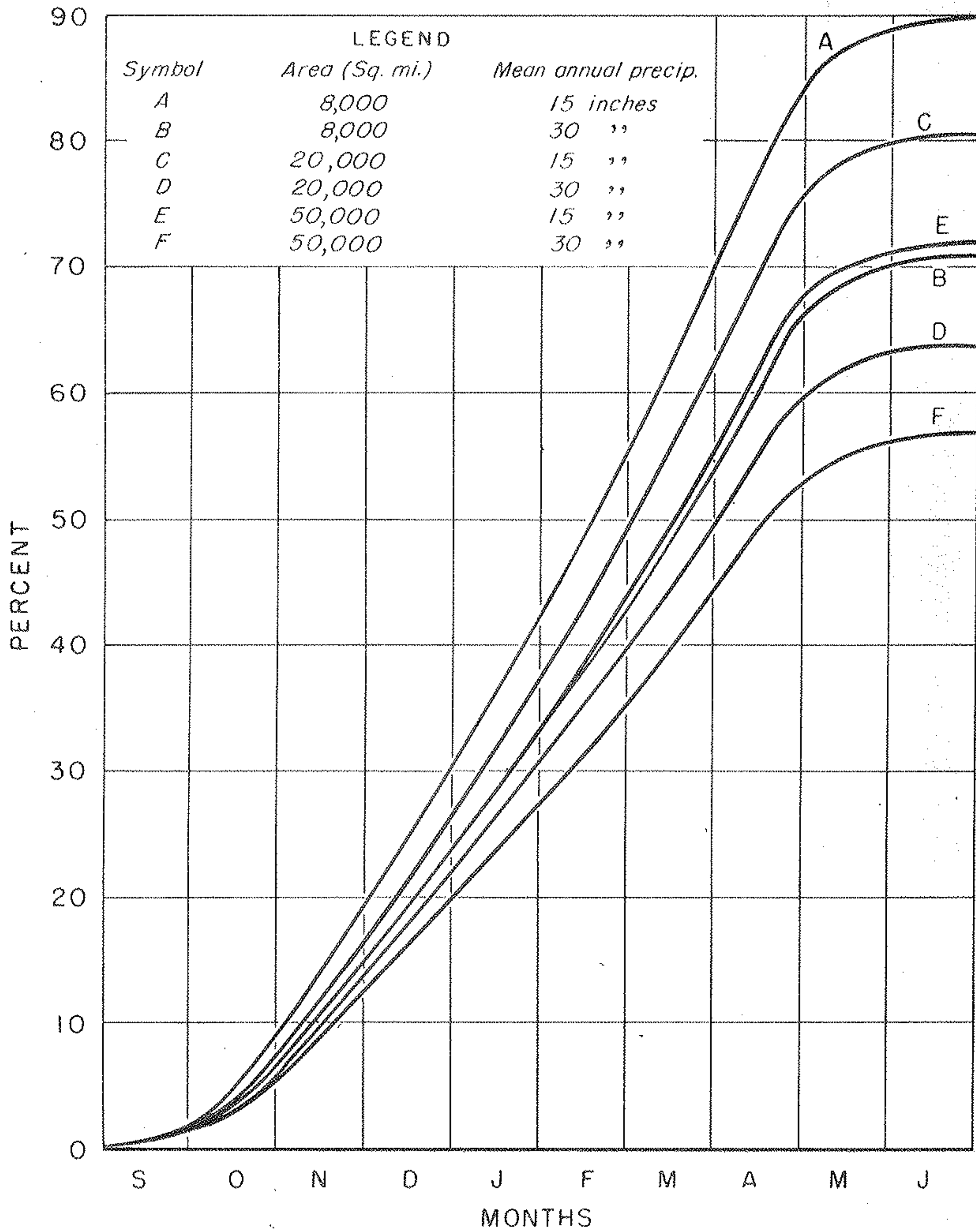


FIGURE 1

FILE 45023

WATER EQUIVALENT OF MAXIMUM POSSIBLE ACCUMULATED SNOW IN PERCENT OF ANNUAL PRECIPITATION MONTANA AND NORTHEAST WYOMING



FILE 45027

FIGURE 2

MAXIMUM POSSIBLE DEPTH-AREA CURVES MID-MAY STORM OVER YELLOWSTONE BASIN (below Billings - excluding Big Horn Basin)

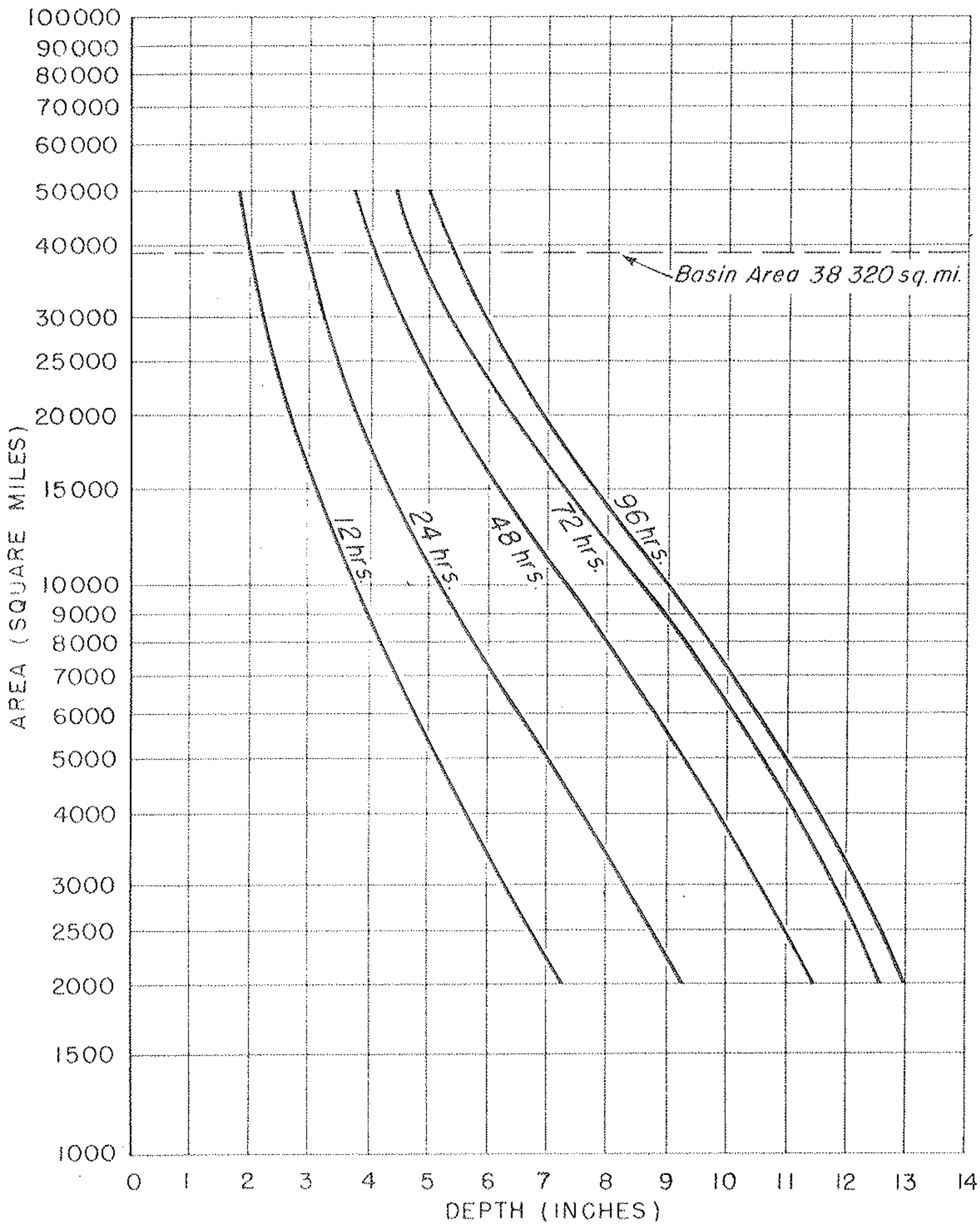


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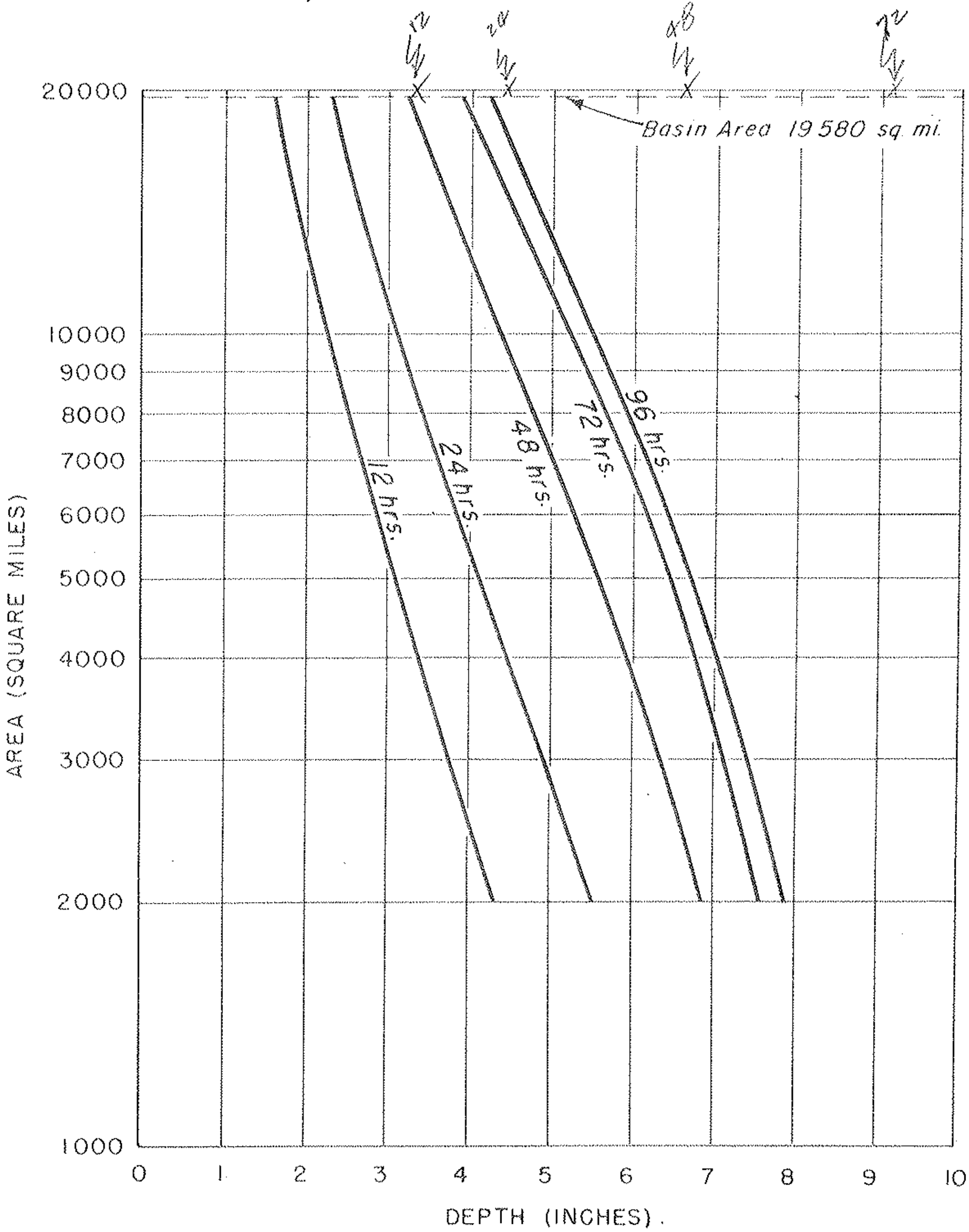
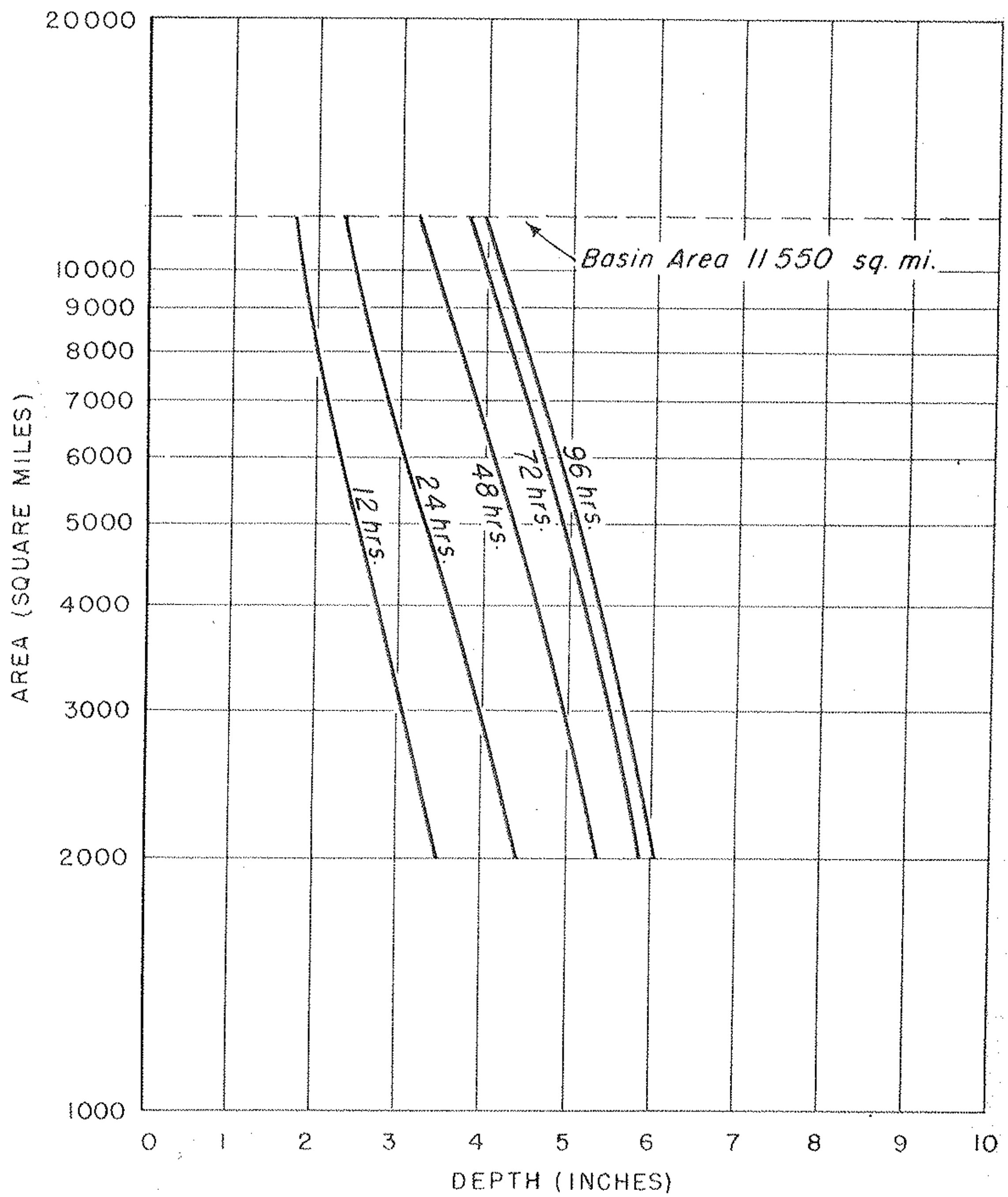
FIGURE 3

MAXIMUM POSSIBLE DEPTH-AREA CURVES
MID-MAY STORM, BIG HORN BASIN ABOVE ST. XAVIER



MAXIMUM POSSIBLE DEPTH-AREA CURVES
MID MAY STORM, YELLOWSTONE BASIN ABOVE BILLINGS



SEASONAL VARIATION OF MAXIMUM POSSIBLE STORM MARCH THROUGH OCTOBER

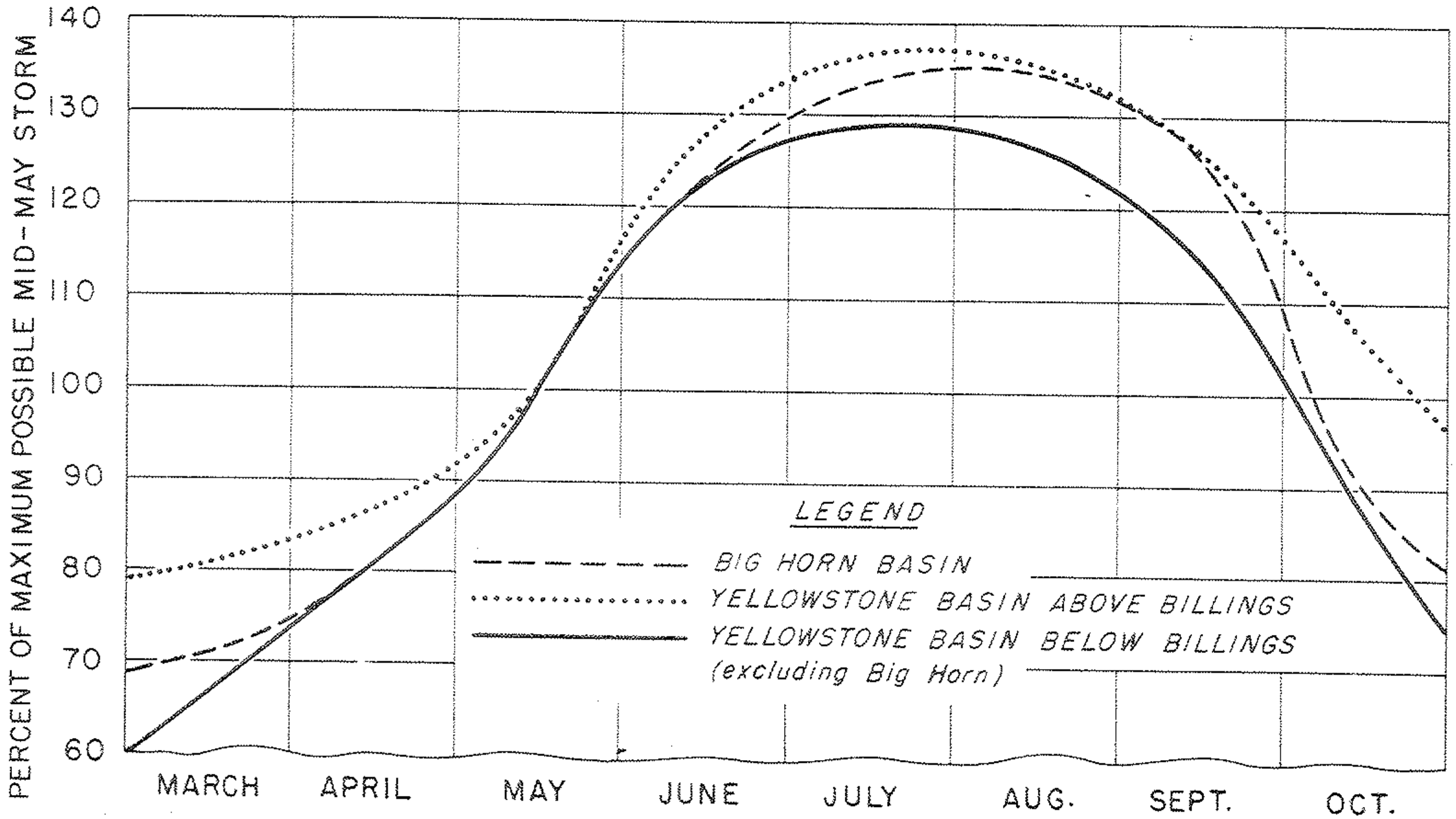


FIGURE 6

FILE 45039

VARIATION OF MEAN MONTHLY SURFACE TEMPERATURES WITH ELEVATION, NORTHEAST WYOMING

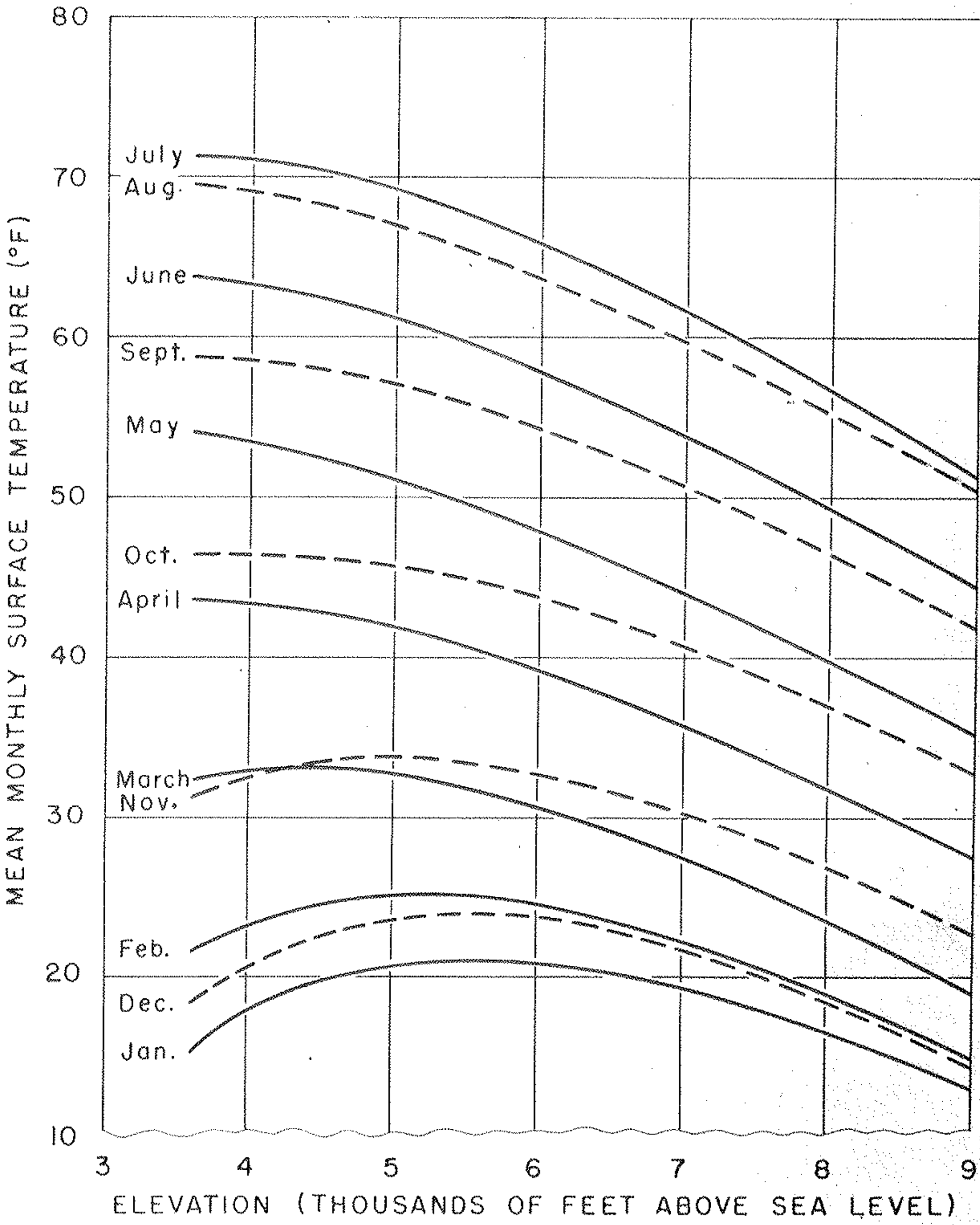


FIGURE 7

EXTREME DEPARTURES OF 7-DAY AND 30-DAY MEAN TEMPERATURES FROM MONTHLY NORMALS, NORTHERN WYOMING

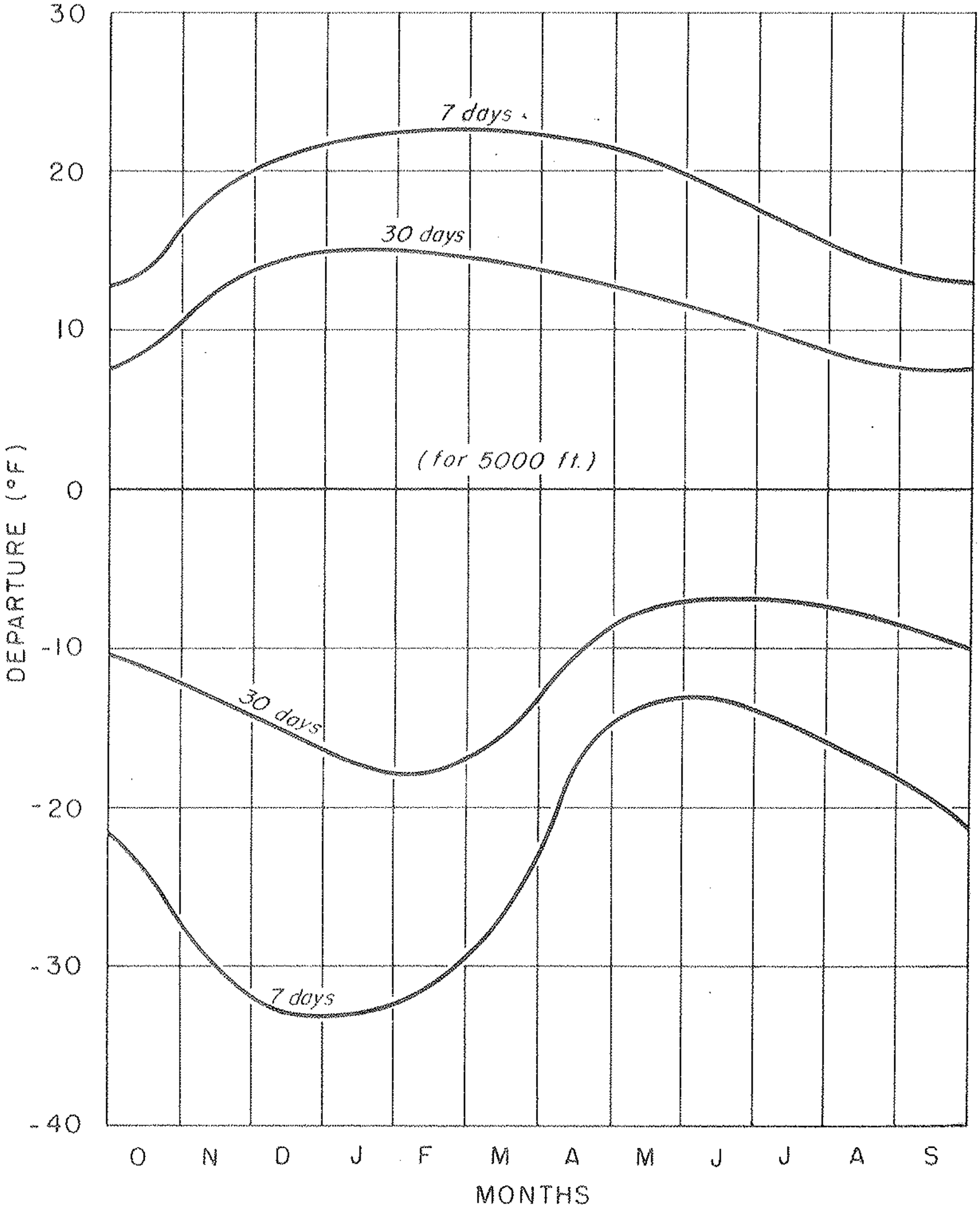


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FIGURE 8

SNOW-MELT RUNOFF VS. DEGREE DAYS
BIG HORN BASIN ABOVE THERMOPOLIS

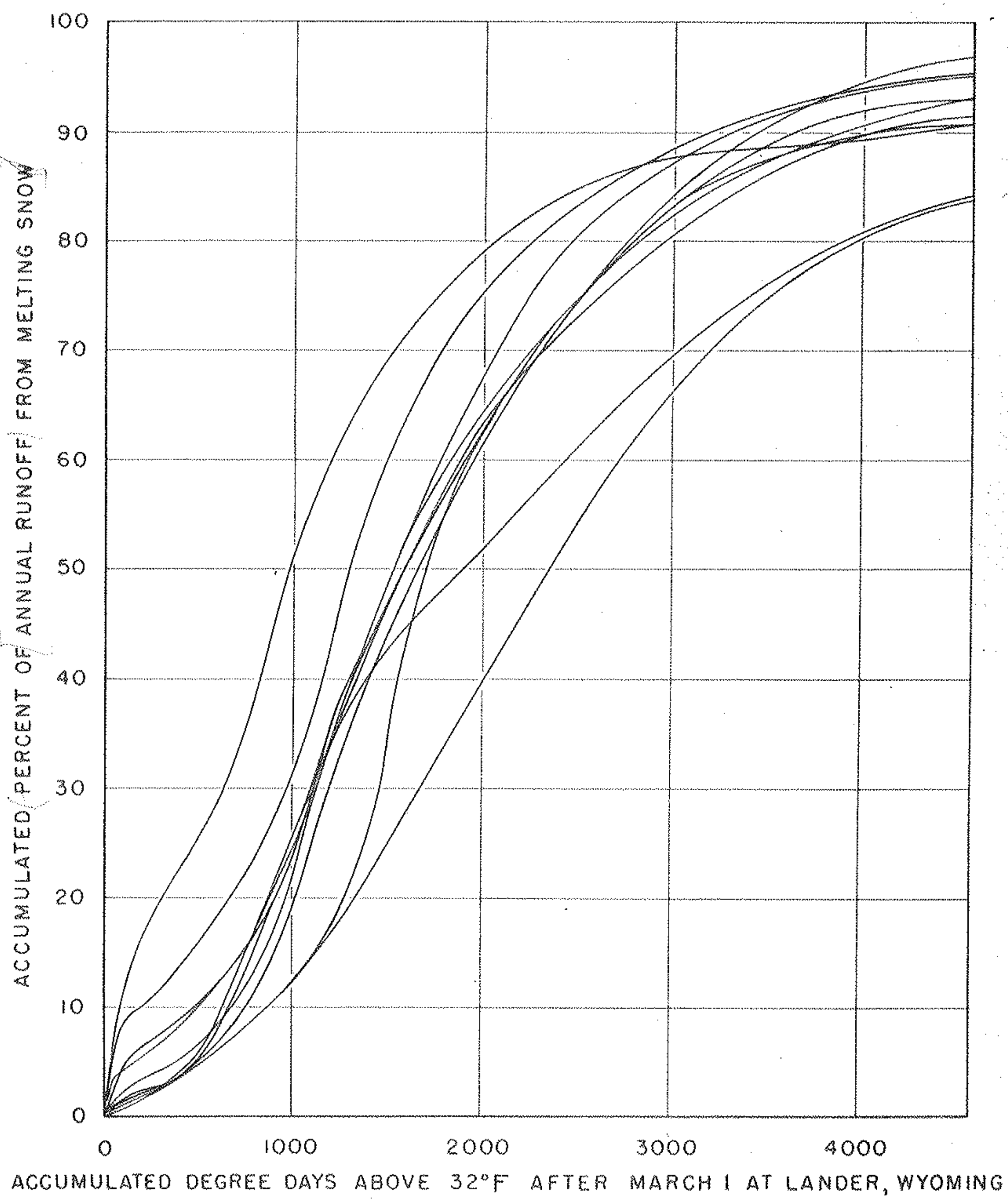

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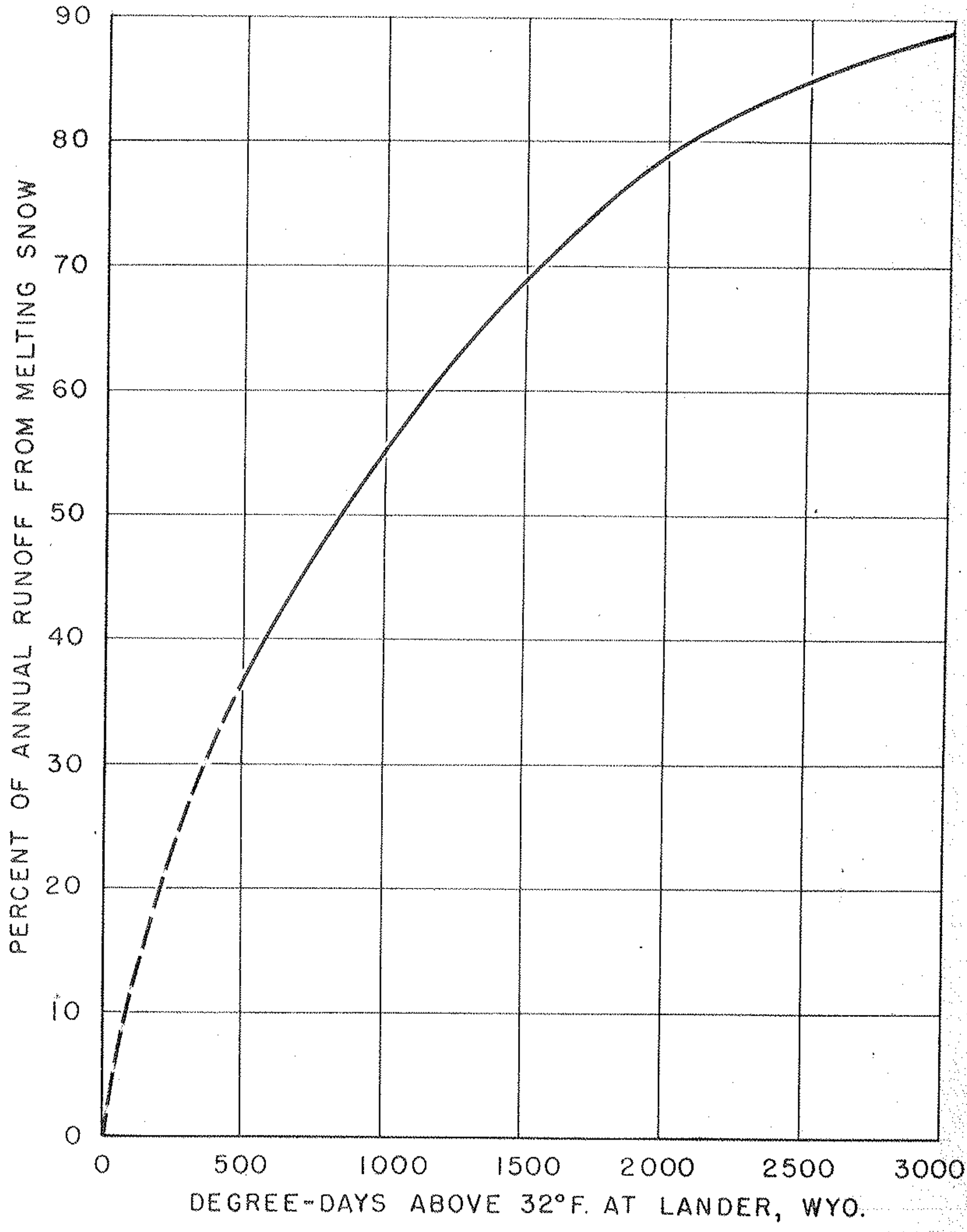
FIGURE 9

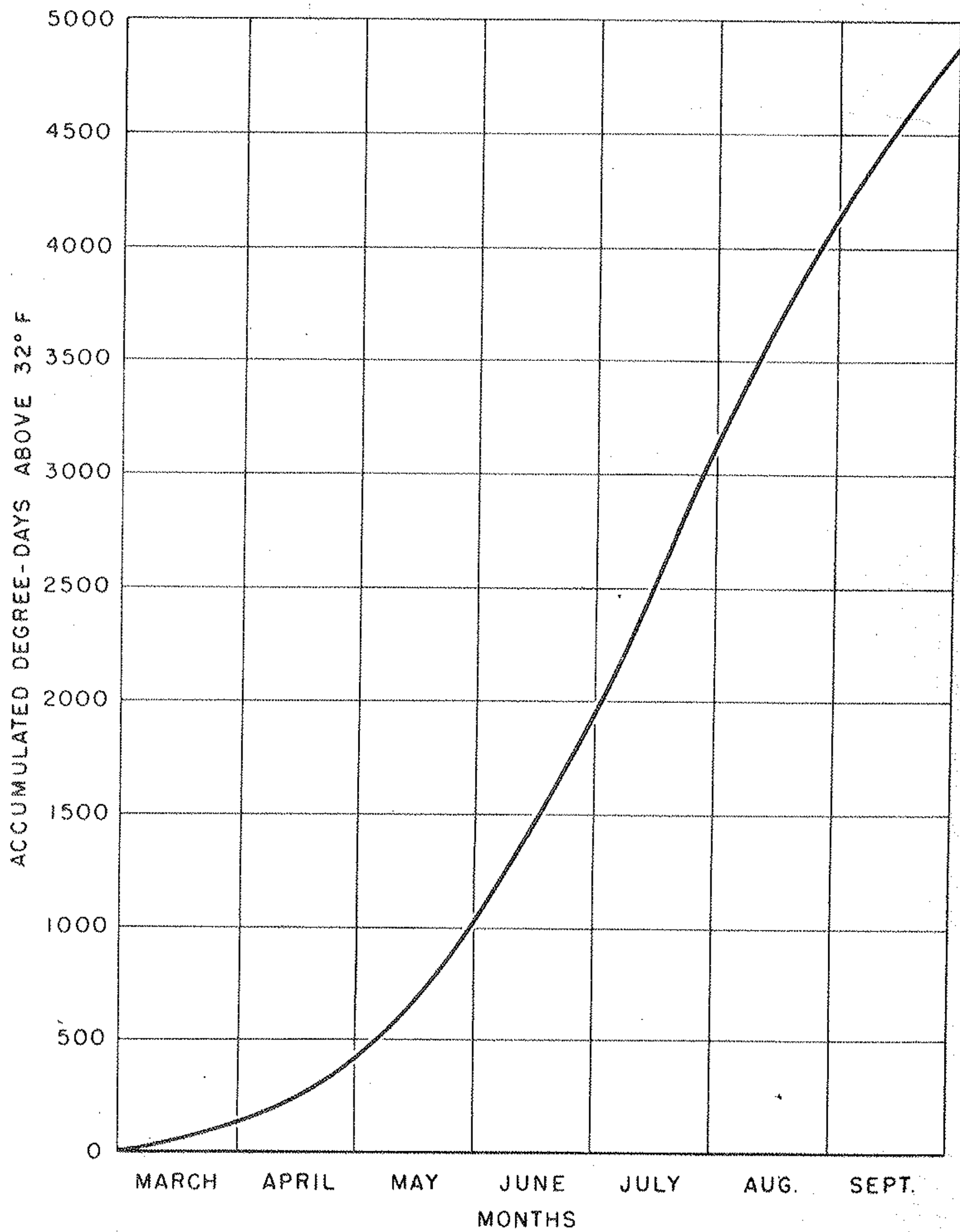
MAXIMUM VALUES OF SNOW-MELT RUNOFF FOR VARIOUS ACCUMULATIONS OF DEGREE-DAYS BIG HORN BASIN ABOVE THERMOPOLIS

(From Figure 9)



AVERAGE DEGREE-DAY ACCUMULATION AT LANDER, WYO. MARCH THROUGH SEPTEMBER

(Based on Fig. 9)



AVERAGE DATE OF DISAPPEARANCE OF SNOW ON GROUND, NORTHEAST WYOMING