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METEOROLOGICAL BRANCH

Technical Memoranda

CRITICAL METEOROLOGICAL CONDITIONS FOR MAXIMUM INFLOW, CHURCHILL FALLS POWER DEVELOPMENT, NEWFOUNDLAND

BY
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CRITICAL METEOROLOGICAL CONDITIONS FOR MAXIMUM INFLOW CHURCHILL FALLS POWER DEVELOPMENT, NEWFOUNDLAND

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ABSTRACT

Estimates are made of the physical upper limits to winter season snow accumulation in the Churchill River basin of Labrador by two methods. Estimates of critical melt season conditions are presented including maximum melt season temperature sequences and maximum spring time rainfall depth-area-duration values.

CONDITIONS METEOROLOGIQUES CRITIQUES POUR LE DEBIT ENTRANT MAXIMAL AMENAGEMENT USINIER DES CHUTES CHURCHILL (TERRE-NEUVE)*

par

D. M. Sparrow

La'auteur effectue des estimés des limites physiques superieures pour l'accumulation de neige durant la saison d'hiver dans le la rivière Churchill, au Labrador, selon deux méthodes. Il présente des estimés de conditions critiques de la suasib de fonte, y compris des séquences de température maximale de la saison de fonte et des valeurs de "hauteur-surface-durée" de chute de chute de pluie printannière maximale.

* Cette étude a été préparée à la demande de la compagnie H. G. Acres Ltd., ingenieurs-conseils, en vue d'aider aux etudes de crues dans le bassin de la riviere Churchill.

CRITICAL METEOROLOGICAL CONDITIONS FOR MAXIMUM INFLOW, CHURCHILL FALLS POWER DEVELOPMENT, NEWFOUNDLAND*

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D. M. Sparrow

(Manuscript received March 28, 1968)

1. Introduction

This study was undertaken to determine the critical meteorological conditions for maximum floods in the Churchill River drainage basin of Labrador in order to assist in assessing criteria for the spillway design of a proposed dam at the Churchill Falls power site. The study includes investigations of the physical upper limits to winter season snowfall in the basin, the upper limits to maximum temperature sequences during the melt season, and maximized depth-area-duration relationships for spring rainstorms. These results may be used by the engineer as meteorological input to a computerized basin model, with a view to ascertaining by hydrologic trial, the combination of events most critical in producing a design flood. For the purposes of this study, the basin was considered to be the enlarged drainage area while will be realized when various dams and dykes have been constructed, increasing the present drainage area (13,289 sq. mi.) above Churchill Falls by some 12,700 sq. mi. (Figure 1).

2. Maximum Snow Accumulations

Estimates of the maximum seasonal snow accumulation in the Churchill River drainage basin were made by two independent methods, the partial season method, and the snow storm maximization method (1).

Partial season method

A machine analysis was made to compute the maximum running sums of snowfall for 4, 8 and 16 day periods for all years of record for five Labrador and northern Quebec stations in or close

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* This study was prepared at the request of H. G. Acres and Co. Ltd., Consulting Engineers, to assist in flood studies in the Churchill River Basin.

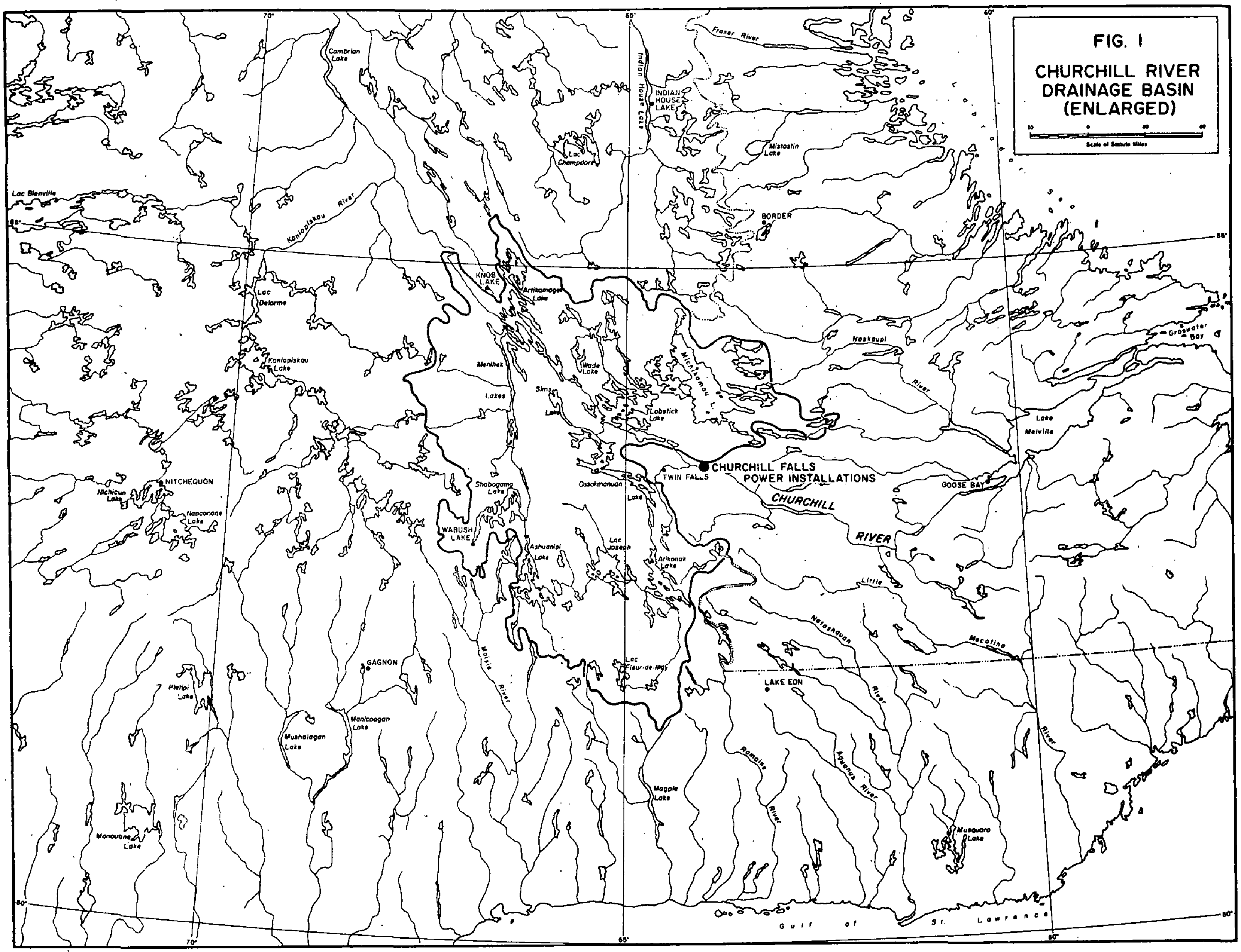


FIG. 1

CHURCHILL RIVER DRAINAGE BASIN (ENLARGED) to, the drainage basin. There is no particular reason for choosing these three periods of days for computing running sums of snowfall, except that well defined winter snow storms in this area are not likely to recur at intervals more frequent than four days on the average nor at intervals less frequent than sixteen days on the average. Table I lists the stations examined and the length of record available on punched cards.

TABLE I

STATIONS USED, LENGTH OF RECORD EXAMINED

Station	Lat. (°')		Long. (°')		Elevation (Ft.)	Period of Record	Missing Data
Indian House Lake	56	14	64	44	970	1947-64	Mar. 1949
Knob Lake	54	48	66	49	1681	1948-65	-
Lake Eon	51	51	63	17	1840	1955-65	-
Twin Falls	53	30	64	30	1585	1960-65	Dec. '61, Oct. '62, Jan., Feb., May, Dec. '63, Feb., Apr., May, Nov. '64
Wabush Lake	52	56	66	53	1807	1960-65	-

Goose Bay was not used in this part of the investigation because its low elevation (144 feet), and its location well east of the proposed basin, tended to make its meteorological observations unrepresentative of the project basin.

The period October 23, to June 3, inclusive was examined for maximum running sums of snowfall for each station for the periods of record noted. For example, for Knob Lake, the snowfall for each four day period of October 23-26 inclusive for each October from 1948 to 1965 was determined, and the largest of these values was printed on the tabulation. Then the snowfall for each four day period of October 24-27 inclusive was examined for each October from 1948 to 1965, and again the largest value was printed. This examination of consecutive four day periods, shifting one day at a time, was continued to June 3. The tabulation then showed the greatest four day sums for all the years of record each ending on 224 consecutive days. Similarly, this procedure was used for each station for eight and sixteen day periods.

The machine tabulations were further analyzed clerically. There are four ways that the four-day interval snowfall totals can be combined to give a composite extreme seasonal snowfall total. For example, the largest four day total for all the years of record ending on October 26, is added to the largest four day total for all the years of record ending on November 3, etc., through the entire season. This process is done again starting with the largest four-day total ending on October 27, and so on. When this has been done four times there will be four totals of "synthetic" seasons of maximum snow accumulation for that station. Similarly there are eight ways that the eight day interval snowfall amounts can be combined. The result is 4, 8 and 16 totals of composite season snowfall for each station.

Before proceeding further with these totals, the Thiessen polygon method was used to determine weighting factors for the data from each station (2). In determining weighting factors for each station, it was not possible to assign a percentage of the basin to Indian House Lake at first because of its location outside the basin to the north. However, this was a station with a relatively lengthy record of good quality while Twin Falls had a relatively short record with numerous periods of missing data. If Twin Falls was omitted from the map it was possible to assign a small percentage of the basin to Indian House Lake. Accordingly, two sets of weighting factors were determined and basin snowfall estimates were obtained using both sets. The weighting factors are shown in Table II.

TABLE II

STATION WEIGHTING FACTORS

Station	Weighting Factor	Station	Weighting Factor
Knob Lake	41	Knob Lake	24
Wabush Lake	40	Wabush Lake	25
Lake Eon	18	Lake Eon	9
Indian House Lake	1	Twin Falls	42
	100		100

The basin snowfall using these weighting factors was determined for each of the 4 starting days of the 4 day series and for each of the 8 starting days of the eight day series, etc. For each of the combination intervals of 4, 8 and 16 days and for annual snowfall, the basin snowfall came to a higher value using weighting factors which included Indian House Lake and excluded Twin Falls. It was decided that the higher value be accepted as a better estimate partly for reasons of safety in design, and partly because of the doubtful quality of the Twin Falls data. The largest value for each combination interval was converted to a percentage of average annual snowfall and the resulting "synthetic" season snowfall curve by the partial season method is indicated in Figure 2.

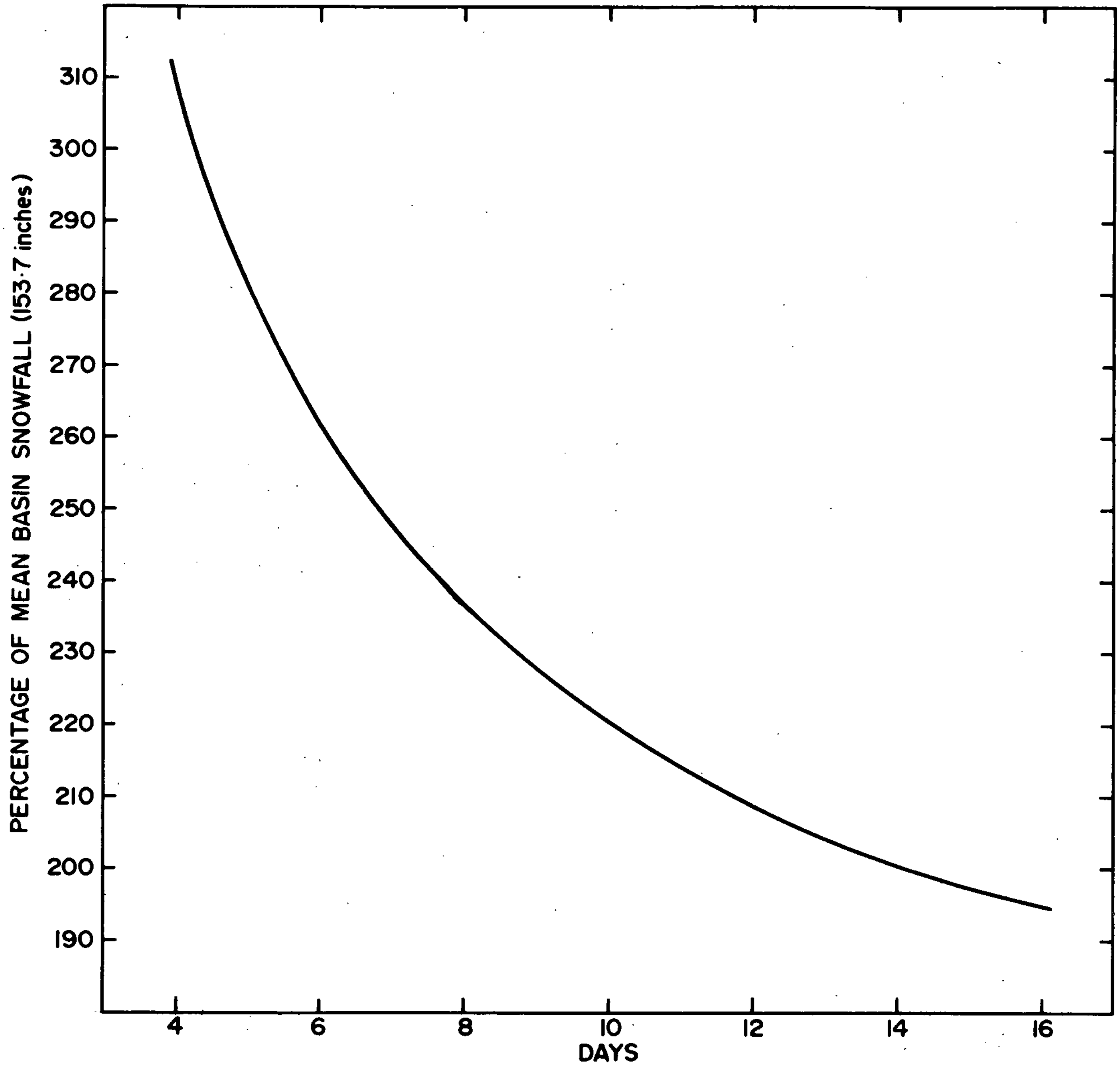
The question now arises as to which combination interval ought to be used to select a point on the curve which would indicate the physical upper limit to basin snowfall. This point is discussed at the end of the section on the snow storm maximization method. (See section below).

Snow storm maximization method

The second technique for determining the physical upper limit to seasonal snowfall has been described in earlier studies by Bruce (1, 3). In brief, it involves analyzing each of the snow storms of a winter season and maximizing the actual snowfall of each storm by using a factor which is a ratio of the maximum air mass moisture content of record for that particular time of year at a location near the storm, and the actual moisture content of the snow producing air mass at the same location. Total snowfall was listed for each year from 1948 to 1965 for those stations noted in Table I, plus Goose Bay and Nitchequon, and on the basis of these figures, the winters of 1963-64 and 1964-65 were selected for individual snow storm analysis. The greater actual and maximized snowfall was obtained for the 1964-65 season. The dates of these storms and the maximization factors are listed in Table III. Basin snowfall for each storm was determined by planimetering the isopleths of snowfall on maps for each storm.

From the data in Table III, the total maximized storm snowfall (298.6 inches) divided by total observed storm snowfall (156.3 inches) gives an average maximization factor of 1.91. Applying this maximization factor to the total accumulated snowfall for the 1964-65 season of 193.3 inches gives a maximized total of 369.3 inches or 240% of the average basin snowfall of 153.7 inches. This corresponds to a combination interval of about 7.7 days on the curve indicated in Figure 2.

FIG. 2 ESTIMATED MAXIMUM SEASONAL SNOW ACCUMULATION CHURCHILL RIVER BASIN PARTIAL SEASON METHOD



An examination of the frequency of storms in the winter of greatest snowfall of those studied for the storm maximization method gives an average combination frequency of 8.3 days or about 234% of average basin snowfall. This is in reasonable agreement with the previous figure of 240% and would suggest that a figure of about 240% of average basin snowfall may be considered as the physical upper limit to winter snow accumulation in the extended drainage area above Churchill Falls. According to a study by Potter (4), the mean water equivalent of new snow in the project basin is about 0.09 of the snow depth rather than 0.1 as usually assumed. This would give an estimate of 33.2 inches as the water equivalent of the probable maximum snowpack.

3. Estimates of Maximum Melt Season Temperature Sequences

In order to establish a relationship between basin monthly mean maximum temperatures in the melt season and some key station in or near the basin, monthly maps were prepared of mean maximum temperatures for the northeastern Quebec and Labrador region for April through July for 1962 through 1966. From each of these maps, a temperature value near the geographical centre of the basin was determined by interpolation. These values were tabulated along with the corresponding mean monthly maximum temperatures for Knob Lake and Wabush Lake, the two stations whose data were considered most likely to be highly correlated with the mean basin temperatures. A plot of station vs. "basin" temperatures for all the months together (April through July) showed good linear relationships.

Correlation analyses were carried out to relate mean maximum monthly temperatures of:

(1) Knob Lake and the basin.

(2) Wabush Lake and the basin.

(3) Both stations and the basin (multiple correlation).

The equstions resulting from this analysis are as follows:

y = basin temperature X_1 = Knot Lake temperature X_2 = Wabush Lake temperature

Table III

Churchill River Basin Snow Storms of Winter 1964-65

Storm	Basin Snowfall (inches)	Maximization Factor	Maximized Basin Snowfall
Oct. 10-12	8.4	1.42	11.9
Oct. 19-21	7.5	1.94	14.6
Oct. 30-31	3.0	2.20	6.6
Nov. 7-12	7.0	2.50	17.5
Nov. 13-16	11.0	1.95	21.5
Nov. 17-20	11.7	1.66	19.4
Nov. 25-27	6.2	1.19	7.4
Nov. 29-Dec. 2	13.8	1.76	24.3
Dec. 12-14	5.8	1.67	9.7
Dec. 17-20	1.6	2.07	3.3
Dec. 22-24	1.6	1.05	1.7
Dec. 30-Jan. 5	11.8	2.46	29.0
Jan. 12-15	4.4	2.39	10.5
Jan. 27-31	12.2	2.34	28.5
Feb. 19-23	5.5	2.15	12.8
Feb. 6-8	3.2	1.40	6.9
Feb. 9-13	8.6	2.32	12.0
Feb. 26-28	7.5	1.21	9.1
Mar. 11-20	7.5	1.74	13.1
Mar. 27-31	1.6	1.64	2.6
Apr. 9-10	2.1	2.47	5.2
Apr. 15-20	5.4	1.71	9.2
Apr. 22-23	1.4	2.27	3.2
Apr. 28-30	1.5	1.54	2.3
May 1-5	6.0	2.72	16.3
Total	156.3		298.6

(temperatures in $^{\circ}F$)

$$y = 3.8 + 0.9546 X_1 \qquad (1)$$

standard error of estimate = $\pm$ 1.053

correlation coefficient = 0.9966

coefficient of determination = 0.9934

$$y = -3.1 + 1.034 X_2 \qquad (2)$$

standard error of estimate = $\pm$ 0.9849

correlation coefficient = 0.9971

coefficient of determination = 0.9942

$$y = 0.454 X_1 + 0.545 X_2 \qquad (3)$$

standard error of estimate = $\pm$ 0.7560

correlation coefficient = 0.9984

coefficient of determination = 0.9966

Taking the standard errors of estimate and the coefficients to four significant figures, it is seen that the Wabush Lake temperatures have a slightly closer relationship to basin temperatures than do Knob Lake temperatures, and that by using both stations' temperature data, a further slight improvement is noted. It is somewhat unreasonable to take these coefficients to four decimal points, but by doing so, it is possible to determine minor improvements with each succeeding equation.

However, it was decided that equation (1) should be used because of the much greater length of high quality record available for Knob Lake and, hence, a greater likelihood that the machine tabulation would show record high values, and the fact that the coefficients of correlation and determination were not significantly smaller than for those equations using Wabush Lake and the two stations together.

Machine tabulations of the maximum running sums of maximum daily temperatures for four, eight and sixteen day periods were prepared in exactly the same way as for maximum snowfall, with the greatest sum for all the years of record ending on a particular day being printed for each of the stations in Table I. The season considered for temperatures was March 27 to July 16.

The running sums of daily maximum temperatures for each of the four, eight, and sixteen day intervals for Knob Lake were plotted on calendar graph paper and enveloping curves drawn through the highest points. Sums corresponding to every 10 days were selected from these curves, converted to daily temperature values, substituted into equation (1) and the resulting basin temperatures plotted on calendar graph paper at the last date of the series. For example, the eight day sum of maximum temperatures ending on May 10 (397 degrees) was converted to a daily value by dividing by 8, giving 49.6 degrees. This was substituted into equation (1) to give 51.1 degrees F as a basin temperature which was plotted for May 10. The resulting curves of the upper limits of maximum temperatures are indicated in Figure 3. The application of these curves to basin snowmelt studies has been outlined in a paper by Bruce (1).

A check of snow cover data at Knob Lake was made to determine whether or not some of the higher running sums of maximum temperatures which the machine had selected were actually achieved over a snow surface. It was determined that up to the 26th of May the greatest sums were achieved over a snow surface and the highest values attained, thereafter, occurred with bare ground present at the Knob Lake site. While the observing site at Knob Lake was reporting no snow on the ground after this date, it is likely that some snow remained in the bush and at higher elevations for several weeks thereafter. Thus, four, eight, and sixteen day running sums for which the summing process began before May 26 would contain at least some maximum temperatures which occurred over a snow surface.

4. Estimation of Maximum Spring Storm Rainfall

In order to estimate the maximum depth-area-duration relationships of spring rains over the basin, a survey was made of all the major rainstorms, in the season March through June, from 1948 to 1966. No examination of earlier storms was made because of the lack of stations in the area prior to 1948. Major storms which occurred over the basin or which were considered transposable to it were selected for study and are listed in Table IV.

FIG. 3 ESTIMATES OF MAXIMUM TEMPERATURES FOR CONSECUTIVE DAYS IN THE CHURCHILL RIVER BASIN

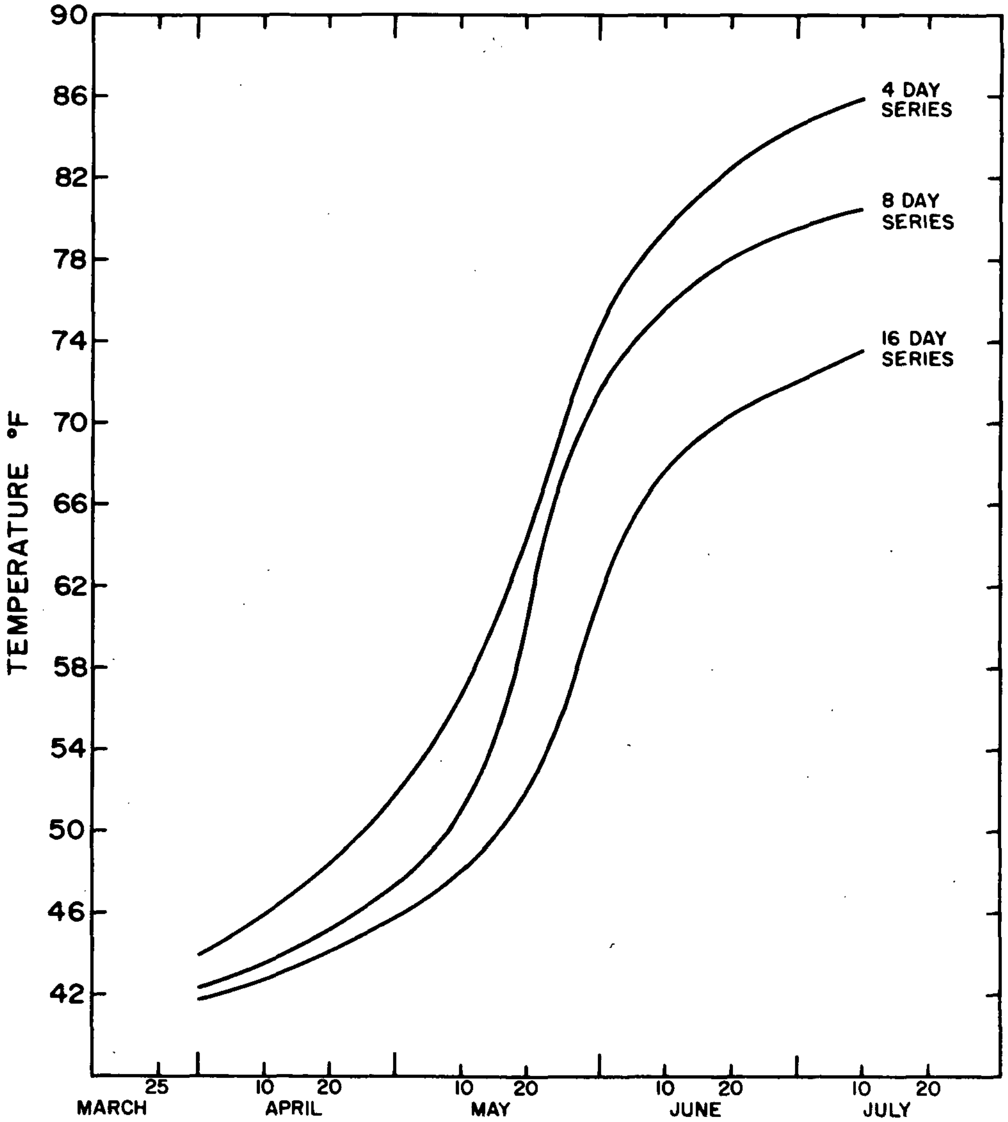


TABLE IV

SPRING RAIN STORMS

Date	Storm Centre	Max. Observed Point Rainfall	Period of Total Storm	Maximization Factor
June 13-15, 1958	Knob Lake	2.36 in.	60 hr.	2.20
May 25-27, 1961	Lake Eon	3.19	66	1.96
June 24-25, 1962	Twin Falls	2.09	42	1.98
May 26-29, 1963	Nitchequon	3.22	42	1.97
May 24-25, 1964	Wabush Lake	3.41	48	1.43

Maximization factors were applied to the observed depth-area relationships for the 24 hour, 48 hour, and total storm durations. The greatest depth values for a given area were selected and plotted on semi-logarithmic graph paper. The resulting curves are shown in Figure 4.

In order to assist in postulating a maximum temperature sequence which might be expected to occur over the basin during major spring rain storms, hourly temperature data were examined for Knob Lake, Wabush Lake and Lake Eon for each of the storms of Table IV. The most critical of these temperature sequences is given in Figure 5. In estimating a design flood from the report, the assumption of a major rainstorm during the snowmelt period would mean that maximum temperature sequences in Figure 3 would have to be restricted to somewhat lower values of the order of those indicated in Figure 5 for the period of the assumed storm.

5. Assessment of Validity of Results

The number of meteorological observation stations and their periods of record were much smaller and shorter than is desirable for studies of this kind. This inevitably makes the results less reliable than they would be in an area where observational data are more plentiful.

FIG. 4 MAXIMIZED SPRING RAINSTORM DEPTH-AREA-DURATION VALUES CHURCHILL RIVER DRAINAGE BASIN (MARCH THROUGH JUNE)

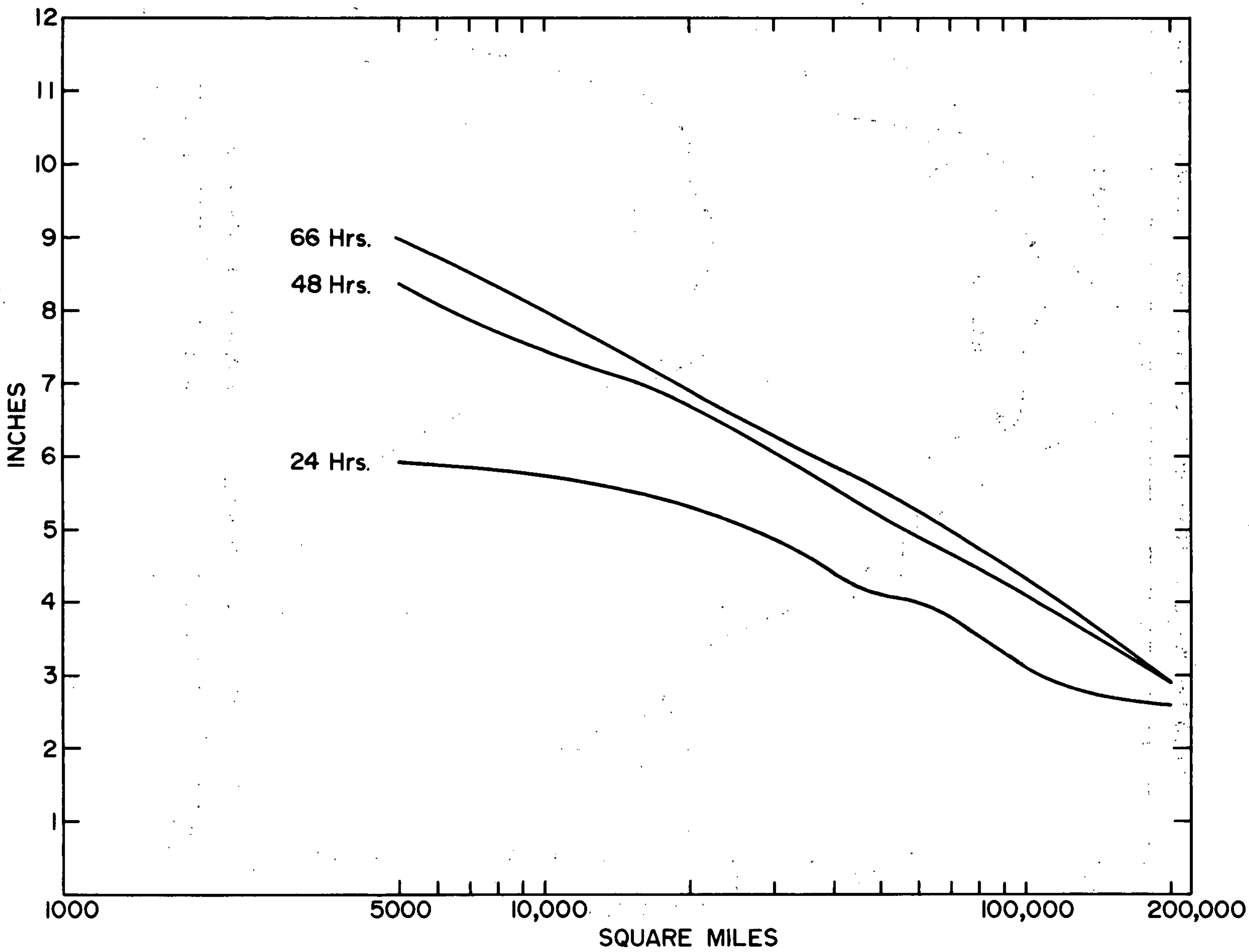
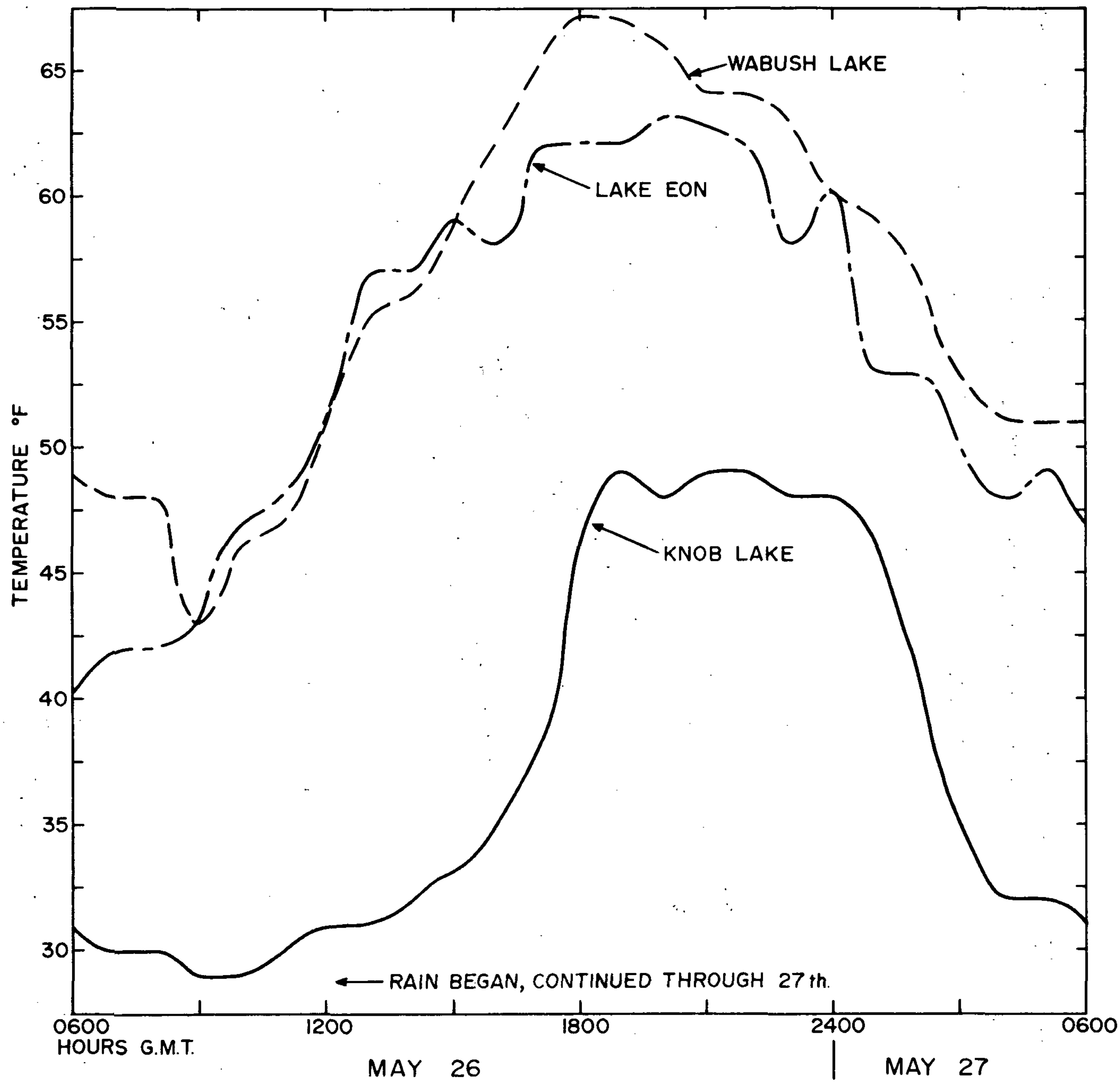


FIG. 5 SEQUENCE OF TEMPERATURES FOR STORM OF 26 and 27 OF MAY 1963



In order to partially compensate for the short length of record, the assumption made in attempting to set physical upper limits to the Meteorological factors were on the conservative side, i. e. where a choice existed, the assumption which would yield higher values was taken. For example, in the snowstorm maximization method, (para 2. 2) it would be more realistic to use a lesser maximization ratio for the residual snowfall amount (the small amounts of snow which fell during the season, but not as identifiable parts of migrating storms) than an average maximization ratio determined by examinations of individual storms. However, since there is no known way of determining how much less this residual ratio should be, and in the interests of making the most conservative assumption, it was decided to use, as a maximization factor for the residual amount, the average of the storm maximization factors.

Since the records of streamflow in the basin are also very short in duration, it is desirable to exploit to the full both the meteorological and the hydrometric data in order to make the best decision on a design flood. Thus, while the results from this study are not as reliable as they would be if more data had been available, they do represent best estimates, making maximum use of available data of upper limits to meteorological factors affecting flood flows in the basin.

6. Acknowledgements

The author wishes to acknowledge the guidance and advice of Mr. J. P. Bruce, under whose supervision this study was done. Thanks are also due to Miss M. E. Schurter and to Mr. D. A. F. Carr for the compiling of data, plotting of charts and graphs, and preparing diagrams. The author is grateful to the Machine Data Processing Section which did the computing of running sums, and to Messrs. T. L. Richards, H. L. Ferguson, G. A. McKay, and B. F. Findlay who reviewed and provided helpful comments on text and diagrams.

APPROVED,

J. R. H. Noble,
Director,
Meteorological Branch.

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