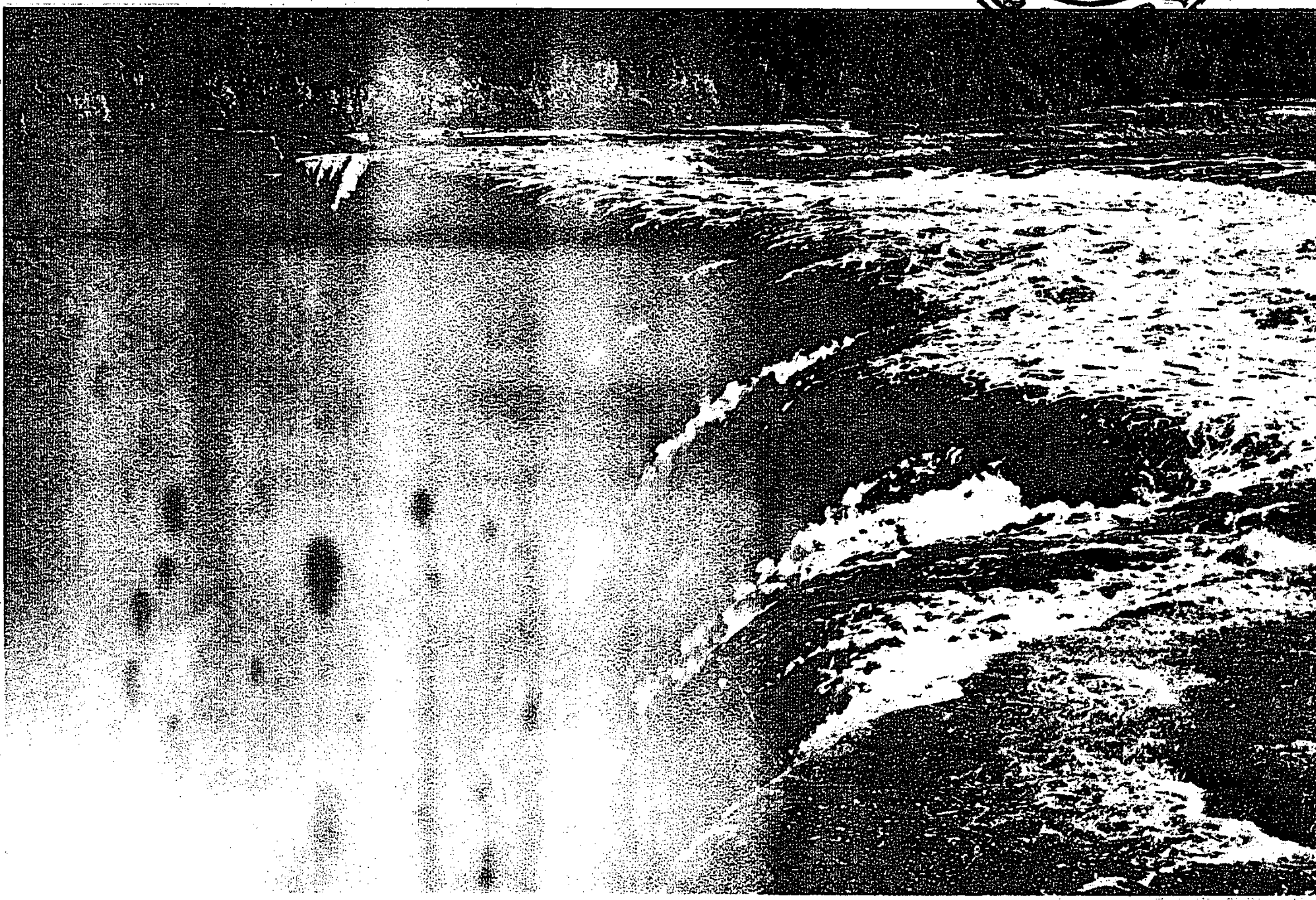
Flood of June 1971 Fort Nelson and Muskwa Rivers

A. G. Smith



TECHNICAL BULLETIN NO. 85
Résumé en français

INLAND WATERS DIRECTORATE (PACIFIC REGION)
WATER RESOURCES BRANCH
VANCOUVER, BRITISH COLUMBIA, [illegible]

Environment Canada Environnement Canada

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／# Abstract

On June 16, 1971, runoff from heavy precipitation, combined with river channels already bankfull from snowmelt runoff, produced floods in the Muskwa River and Fort Nelson River Valleys of northern British Columbia. The instantaneous maximum flow of the Fort Nelson River near the Town of Fort Nelson has been estimated at 234,000 cfs, the largest flow since records began in 1961. The instantaneous maximum flow of the Muskwa River near Fort Nelson has been estimated at 165,000 cfs, the largest flow since records began in 1944.

Résumé

Le 16 juin 1971, les écoulements dus aux fortes précipitations en plus des canaux fluviaux dont les rives débordaient déjà à cause des écoulements de la neige fondue ont provoqué les crues dans les vallées de la rivière Muskoua et de la rivière Fort Nelson, dans le nord de la Colombie-Britannique. On a évalué à 234,000 pi ^{3}/s l'écoulement maximal et instantané de la rivière Fort Nelson près du Fort Nelson, le plus important enregistré depuis 1961. Le débit maximal et instantané de la rivière Muskoua près du Fort Nelson a été évalué à 165,000 pi ^{3}/s, le plus fort enregistré depuis 1944.

Introduction

The Fort Nelson River is the largest river system rising in the eastern slopes of the Rocky Mountains in northeastern British Columbia. The drainage area, measured at a point just below its confluence with the Muskwa River, and including the drainage area of Muskwa, is 17,200 square miles. Figure 1, a key map of British Columbia, shows the location of the two basins.

There is little history of floods in the Basin which is mainly due to the sparse settlement of the area. Damage is usually confined to washouts on the Alaska Highway and more recently to the British Columbia Railway.

This report has been written to improve the understanding of the causes of floods in this region and to present an analysis of the basic data. It provides a general description of the topography, climate and geology of the area. The events leading up to the flood, the extent of flooding and the flood damage are described in some detail. The quality of the data is examined and a method of extending rating curves is described. The frequency characteristics are presented to indicate the probability of the occurrence of the flood event of June 16, 1971.

TOPOGRAPHY OF THE RIVER BASIN

The Basin consists of three main physiographic subdivisions:

The Front ranges of the Rocky Mountains extend from the divide east to the Foothills. The gradient is steep, the rivers dropping from 9800 feet to 2500 feet for a distance of 40 miles. The whole area contains many high and rugged peaks. Within it are many icefields and alpine glaciers, none more than a few miles in length.

The Foothills belt is composed mainly of rounded hills and low-lying swampy terrain. Within the area are outlying mountain ridges nearly as high and rough as the main mountain area to the west. The gradient changes drastically, the rivers dropping from 2500 feet to 1500 feet for a distance of 30 miles.

The Plains region is characterized by high buttes and mesas. The gradient is very flat, the rivers dropping less than 1.5 feet per mile.

The drainage pattern consists of parallel stream systems flowing easterly and transecting the regional physiographic trends. Glaciation has affected even the highest hills and has modified the major river valleys. Toward the west, till deposits are 300 feet thick in the river valleys, but decrease to 15 feet or less in the east.

CLIMATE

The climate of the Basin is dominated by continental climatic influences. For periods during the winter, continental arctic air masses move down from the Mackenzie Valley. These cold anticyclone air masses create conditions unfavourable to precipitation. The Basin is characterized by semi-arid conditions in the Interior Plains and by heavier precipitation in the mountains.

The lines of the various pressure systems are not fixed; they vary considerably throughout the year. In the winter many depressions enter British Columbia from the ocean and continue their eastern course over the western mountains into the Plains. In the spring as the land warms, the frontal zones shift to the north. Thus any depressions travelling across British Columbia are less affected by the cold arctic air masses.

Precipitation

The annual precipitation on the Interior Plains averages around 15 inches. The Foothills range from 15-20 inches with the mountainous areas reaching double this amount.

The summer (June to August) receives 50 percent of the annual mean precipitation.

Snowfall

The mean annual snowfall in the area ranges from 60 inches in the Plains to over 140 inches on the highest mountain ranges. December and January usually have the most snowfall and after a pronounced drop in February, the total rises in March to a secondary maximum, before decreasing finally toward summer.

Temperature

Temperatures rise with remarkable rapidity from winter to summer and decrease as fast to winter. The highest temperature on record is 98° (July) at Fort Nelson which has a 34-year record.

A year may be divided into five winter months, five summer months and spring and autumn each with one month. The mean monthly temperature is below 32° in all of the five months from November to March and the monthly mean is above 50° from May to September. In April, spring has a mean between 30° and 50°. Autumn occurs in October.

GEOLOGY

The Rocky Mountains, in the area west of Fort Nelson, for the most part consist of massive Palaeozoic limestone and quartzite. The quartzite, with its resistance to erosion, has given the mountains a rocky, rugged character. The mountains generally consist of ridges which form a north-westerly alignment parallel with that of the entire Rocky Mountain Range. The ridges are separated by valleys cut deeply by erosion along zones weakened by folds, fractures and the presence of relatively soft strata. The soft strata are formed mainly of Palaeozoic sediments.

The Foothills are entirely of sedimentary origin, underlain chiefly by Cretaceous shales. The western half of the Foothills is a typical valley and ridge province. Most of the Plains area is underlain with shales and sandstone.

Vegetal Cover

The tree-line extends to the 4700-foot contour in the eastern Foothills and to the 5000-foot contour in the west. The slopes and valleys are heavily wooded and covered in some areas with thick bush or deep moss. The forest cover consists of firs, spruce, lodgepole pine, cottonwood, birch and aspen. Most of the evergreens are located at the higher elevations.

Soil Types

In the Mountain region, most of the soils are of glacial origin. Glacial-fluvial and glacial-lacustrine are thin on the higher elevations but thick over the lower areas and very thick in the large stream valleys.

The main soil type in the Plains region is of organic origin, degrading black, gley, muck and peat. In the Foothills the main type is grey wooded, intermingled glacial-lacustrine and till deposits.

FORT NELSON RIVER BASIN

Fort Nelson River

The Fort Nelson River, formed by the confluence of the Sikanni Chief and Fontas Rivers, follows a meandering

Table 1. Mean Annual and Maximum Runoff for Selected Basins

Basin	Drainage area (sq mi)	Mean annual flow (cfs)	Mean annual runoff (cfs per sq mi)	Maximum daily flow (cfs)	Maximum runoff (cfs per sq mi)
Beatton River Station 07FC001	6,200	1,730	0.3	53,400	8.6
Halfway River Station 07FA001	3,630	2,690	0.7	70,000	19.3
Sikanni Chief River Station 10CB001	800	879	1.1	16,900	21.0
Fort Nelson River Station 10CC001	17,200	10,900	0.6	185,000	10.8
Muskwa River Station 10CD001	7,600	6,950	0.9	141,000	18.6
Toad River Station 10BE004	993	1,570	1.6	17,500	17.6
Kwadacha River Station 07EA002	932	1,730	1.9	11,500	12.3

Table 2. Basin Characteristics

Basin	Drainage area (sq mi)	Mean basin elevation (ft)	Average slope	Forest (%)	Swamp (%)	Glacier (%)
Fort Nelson	17,200	2,980	2.4	72.0	14.0	0
Muskwa	7,600	3,680	3.5	69.0	5.0	1.0
Sikanni Chief	800	4,630	3.5	67.0	0	0
Toad	993	5,210	5.4	27.0	0	1.0
Kwadacha	932	5,070	5.8	57.0	0	4.0

course for nearly 80 miles to the Town of Fort Nelson. A few miles above the town, the Fort Nelson River is joined by the Muskwa River, its main tributary, and from this point flows northwest 125 miles to the Liard River. From the point at which it is formed to its junction with the Liard River, the Fort Nelson River has a very flat gradient, dropping less than 350 feet in over 200 miles (Fig. 2). The annual runoff contributed by the Plains region to the Fort Nelson River is about 4 inches. Table 1 indicates the mean annual and maximum runoff values for selected basins in the area.

Sikanni Chief River

From its source in the eastern slopes of the Rocky Mountains, the Sikanni Chief River flows for a distance of 220 miles to its confluence with the Fontas River. The major portion of its drainage area is in the Plains region and the average runoff above Station 10CB001 (Sikanni Chief River near Fort Nelson), located near the Alaska Highway, is approximately 15 inches.

Fontas River

The entire basin of the Fontas River is within the Plains region and the highest elevation in the basin is just over 3000 feet. The average runoff is about 5 inches.

Muskwa River

The Muskwa River is 250 miles long and drains 7600 square miles of the total drainage area of the Fort Nelson River at Fort Nelson. It rises in the Rocky Mountains and flows east through the Foothills to join the Fort Nelson River at Fort Nelson. For the last 50 miles of its course the Muskwa traverses the flat Interior Plateau. The average annual runoff above Station 10CD001 (Muskwa River near Fort Nelson) is 12 inches. Figure 2 shows the profile of the Muskwa River system.

The Muskwa River's major tributary, the Prophet River, rises in the Rocky Mountains. Although it flows through the same physiographic subdivisions as the Muskwa, most of its drainage area is in the Foothills and Plains. Basin characteristics for selected basins are listed in Table 2.

Description of Flood

Flood conditions of any appreciable magnitude are related primarily to monthly and seasonal amounts of precipitation. High water on all river systems flowing in the Rocky Mountains occurs during summer when flows are swollen by melting snow and ice.

In the Fort Nelson Basin, spring runoff normally commences during the latter half of April and peak snowmelt flows are reached in late May or early June. Secondary peaks often occur later in June and July, as a result of fairly heavy rains falling on the snowmelt saturated Basin. These secondary peaks are usually greater than the first. As there is little natural storage in the Basin, streamflow recession is fairly rapid and by November discharge in the River is low. Figures 3 and 4 show the streamflow hydrographs of the Fort Nelson and Muskwa Rivers, respectively.

Very few flood peaks in the past have been caused by snowmelt alone. Generally the snowmelt peaks are not significant. The very high flows are the result of summer rains that follow a bankfull situation caused by the earlier snowmelt runoff. Generally saturated ground conditions also exist at this time.

RAINSTORM OF JUNE 13-16, 1971

The flood of June 16, 1971, was caused by heavy rainfall which covered the entire Fort Nelson River Basin. The distribution was uneven, as the greater portion of precipitation fell in the southeastern part of the Basin. Table 3 lists temperatures and precipitation for June 1-30, 1971, for selected stations.

At the time of the storm there was no snow at any of the snow course stations in the surrounding basins. Table 4 lists the snow course data April 1 to June 1, 1971, and the locations of the stations are shown in Figure 5.

Meteorological Description of the Rainstorm of June 13-16, 1971, over the Fort Nelson River Basin

A chronological description of the meteorological occurrences, prepared by the Scientific Support Unit of the Atmospheric Environmental Service (AES), Vancouver, B.C., follows:

1. Prior to the onset of the rainfall, a ridge of high pressure dominated the Prairies and a deep cold low was tracking down the Pacific coast toward Vancouver Island.
2. Subsequently a cold vortex split off the coastal low and moved inland across southern B.C. into central Alberta. The residual portion of the original low recurved north of Vancouver Island and weakened (Figs. 6 & 7).
3. The dynamics of the changing upper-air regime caused significant surface pressure falls east of the Rockies ahead of the moving cold low. A surface cyclonic centre was generated over western Alberta. Moist, cool and unstable air covered the region as the cold low approached. Rain began on the afternoon of June 13th (about 140000Z) in the Peace River area. As the surface low deepened, a more intense northeasterly circulation spread over the Fort Nelson River Basin. Rain began at Fort Nelson in the early hours of June 14th (Figs. 8, 9 & 10).
4. Several thunderstorms in western Alberta and unstable cloud forms in northeastern B.C. were reported. The mass curves of rainfall for selected stations presented in Figure 11 show an uneven accumulation with periods of lull followed by periods of heavier precipitation. This is more evident to the southeast of the Basin and it is likely that pure orographic lifting was more of a factor in the northern parts of the Basin.
5. As the remnant cold low off the coast weakened the Alberta low became dominant and moved slowly eastward. Winds over the Fort Nelson River Basin became more northerly and the air began to dry. The rain stopped first in the northwest (just before noon on June 15th at Fort Nelson) and finally in the Grande Prairie area during the evening of June 16th (Figs. 12, 13 & 14). Hydrographs showing the effect of the rainstorm on gauged basins in the vicinity of the Fort Nelson River are shown in Figures 15 to 18.

Table 3. Temperature and Precipitation Data, June 1-30, 1971

Day	Arras (2 yr)			Dawson Creek A (13 yr)			Fort St. John A (30 yr)			Fort Nelson A (34 yr)			Fort Nelson Churchill Mine (3 yr)		
	Max.	Min.	Prec.	Max.	Min.	Prec.	Max.	Min.	Prec.	Max.	Min.	Prec.	Max.	Min.	Prec.
1	76	36		77	37		76	43		81	43		64	40	
2	80	36		82	44		81	53		76	50		62	44	
3	75	39		76	53		75	53		74	49		58	36	
4	78	37	.20	77	40	.06	77	46	T	60	47	.02	48	36	.02
5	54	50	.82	56	52	.59	57	47	1.02	53	48	.78	44	34	.03
6	55	46	.05	57	48	.03	53	45	.44	56	45	.39	50	30	.02
7	55	48	.01	54	50	.02	55	47	.04	56	48	.08	49	32	
8	58	48	.04	58	48	.11	58	48	T	70	49	T	60	34	
9	70	50		71	51		70	48		73	46	T	58	39	.02
10	69	47	.25	71	50	.12	72	55		76	49	.41	58	40	.04
11	65	48		67	48		65	49		69	50	.07	48	32	.01
12	68	30	T	69	41	.05	68	44		67	49	T	44	33	T
13	70	45	1.30	68	47	1.10	68	48	.62	71	46	T	55	33	
14	55	47	1.42	53	50	1.30	53	49	1.14	61	52	.65	43	35	1.00
15	56	46	.51	57	48	.34	54	48	.52	65	52	.61	48	35	.70
16	65	46	.49	66	48	.25	69	50	.13	76	55		60	37	
17	69	42		70	47		69	50	T	77	44		65	40	
18	71	39		71	44		72	48		81	48		68	40	
19	74	37		76	42		75	49		82	49		70	48	
20	76	40		75	46	.03	76	51		81	51		67	46	.30
21	77	42		77	51		75	53		77	52		63	44	
22	74	41	.80	75	47	.84	75	48		79	50		53	44	1.20
23	63	50	.29	60	52	.45	64	51	.91	72	55	.06	44	36	.40
24	67	33	.26	66	42	.45	66	44	T	58	52	.33	44	37	.30
25	53	45	.80	51	47	.78	56	45	.75	64	47	.26	50	31	
26	60	42	.05	60	44	.19	61	44	.44	67	48	T	52	33	.30
27	65	42	T	63	41	.02	62	46	.09	67	43	.17	49	39	
28	69	42		70	47	T	69	47	T	61	49	.01	50	38	.10
29	74	36		69	45		68	46		66	47	.10	50	35	.04
30	67	45	T	67	41	.08	67	45		69	45		47	33	
Mean temperature	66.9	42.5		67.0	46.4		66.9	48.0		69.5	48.5		54.0	37.1	
Total precipitation			7.29			6.81			6.10			3.94			4.48
Average for period of record			5.40			2.60			2.53			2.56			3.74

Isohyetal Chart

There are only two meteorological observation stations located within the Fort Nelson River Basin. Thus it is not possible to draw accurate isohyets for the Basin. The map presented is a rough estimate of possible precipitation amounts over the area based on air flow and amounts measured in parts of western Alberta. On that basis, amounts of around 3-4 inches appear likely. Although no definitive answer can be given, the location of the hypothetical maximum could perhaps be shifted westward to lie along the east slopes of the Rockies rather than at the divide between the Fort Nelson and Beatton River systems. The isohyetal chart, prepared by the Scientific Support Unit of the Atmospheric Environment Service, Vancouver, B.C., for the climatological days of June 13-16, 1971, is shown in Figure 19. The daily rainfall during June 1-30, 1971, for the precipitation Stations at Fort Nelson Airport and Fort Nelson Churchill Mine is indicated in Figures 20a and 21a. Figures 20b and 21b show the streamflow hydrographs for June 1-30, 1971, of the Fort Nelson and Muskwa Rivers, Stations 10CC001 and 10CD001.

Data available for the isohyetal map included numerous Alberta Forest Service lookouts and Ranger Stations, a number of AES first order stations and several AES volunteer climatological stations. All reported to the AES and the data were obtained from the *Monthly Record Meteorological Observations in Canada.* Precipitation reports were totalled for the four-day period June 13-16, 1971, which spanned the entire storm event. A list of the meteorological stations and the amounts of precipitation is given in Table 5.

Table 4. Snow Course Data for Selected Stations

Course number	Snow course	Elevation (ft)	Date (1971)	Snow depth (in.)	Water equivalent (in.)
134	Sikanni Lake	4,600	Apr 1	36.4	8.8
			May 1	26.8	7.3
136	Ipec Lake	4,300	Apr 1	39.1	10.7
			May 1	26.9	7.2
145	Summit Lake	4,200	Apr 1	22.4	5.0
			May 1	0.0	0.0
146	Pink Mountain	3,850	Apr 1	21.6	3.9
			May 1	0.0	0.0
209	Mount Roosevelt	4,360	Apr 1	22.4	5.1
			May 1	7.0	2.7
			May 15	8.0	1.0
			Jun 1	0.0	0.0

Table 5. Rainfall Totals at Meteorological Stations, June 13-16, 1971

Station name	Precipitation (in.)	Station name	Precipitation (in.)
British Columbia-Yukon		Elmworth CDA EPF	3.28
Arras	3.72	Eureka River	0.88
Beldonnel	2.10	Fairview	1.59
Cecil Lake CDA	1.86	Fontas LO	3.04
Chetwynd BCFS	1.94	Footner Lake LO	1.53
Dawson Creek A *	2.99	Goodfare CDA EPF	3.76
Fort Nelson A *	1.26	Grande Prairie A *	2.99
Fort Nelson Churchill Mine	1.70	Hawk Hills LO	2.19
Fort St. John A	2.41	Hines Creek RS	1.83
Germansen Landing *	1.75	Hotchkiss LO	1.51
Hudson Hope BCHPA Dam *	Missing	Keg River	1.76
Lower Post	0.00	Keg River RS	2.47
Mackenzie A	2.39	Keg LO	2.95
Muncho Lake	0.05	Naylor Hills LO	2.39
Rolla	2.87	Notikewin East	1.57
Watson Lake A *	0.00	Notikewin LO	2.68
		Peace River A *	1.01
Alberta		Puskwaskau LO	3.23
Adair LO	0.74	Rycroft	3.03
Amber LO	0.76	Spirit River RS	2.86
Basset LO	3.61	Steen LO	0.03
Battle River LO	1.82	Valleyview RS	1.69
Beaverlodge CDA	2.98	Wanham CDA EPF	2.47
Blueberry Mtn. CDA	2.29	Watino *	1.91
Clear Hills LO	0.82	Watt Mtn. LO	2.55
Codesa LO	2.46	White Mtn. LO	4.64
Deadwood LO	2.36	Whitemud LO	1.84
Demmitt CDA EPF	4.75	Worsley RS	2.75
Doig LO	2.40	Zama LO	2.75

* Stations with recording rain gauges (tipping-bucket type)

Analysis of Flood Data

FORT NELSON RIVER AT FORT NELSON —STATION 10CC001

The highest measured flow prior to June 1971 was 34,900 cfs at a gauge height (local elevation) of 13.92 feet. The maximum mean daily gauge height observed at this station prior to the flood was 27.72 feet on July 20, 1962, which corresponds to an estimated discharge of 121,000 cfs. A new rating curve has been developed since the flood of June 16, 1971.

A discharge of 174,000 cfs was measured by the 0.2 method on June 16, 1971, at a gauge height (local elevation) of 32.77 feet. The maximum mean daily gauge height observed on June 16, 1971, was 32.92 feet corresponding to an estimated discharge of 185,000 cfs.

Mean daily gauge heights are obtained generally by readings taken once a day and cannot be expected to reflect the instantaneous peak, as the Fort Nelson River rises and falls very rapidly.

An instantaneous gauge height of 38.42 feet was obtained at approximately 1800 MST on June 16, 1971. This corresponds to an instantaneous estimated flow of 234,000 cfs obtained from the extended rating curve.

MUSKWA RIVER NEAR FORT NELSON —STATION 10CD001

The highest measured flow prior to June 1971 was 51,000 cfs at a gauge height (local elevation) of 12.23 feet. The maximum mean daily gauge height observed at this station prior to the flood was 30.84 feet on July 14, 1956, which corresponds to an estimated discharge of 140,000 cfs. A new rating curve has been developed since the flood of June 16, 1971.

A discharge of 96,000 cfs was measured by the 0.2 method on June 15, 1971, at a gauge height (local elevation) of 23.01 feet. The maximum mean daily gauge height observed on June 15, 1971, was 31.74 feet corresponding to an estimated discharge of 141,000 cfs.

The maximum instantaneous gauge height (local elevation) of 34.45 feet was observed on June 16, 1971, corresponding to an estimated discharge of 165,000 cfs.

The gauge is located on the Alaska Highway Bridge and it has been suggested that the station is affected by backwater at certain high stages of the Fort Nelson River.

The data review of this station in 1960 indicates that until the rating curves are better defined, the records should be considered poor and used with discretion.

CORRELATIONS

Some correlations were attempted with the streamflow record of both the Fort Nelson and Muskwa Rivers. The investigations covered serial correlation — the relationship between the mean annual flow in one year and the mean annual flow of the previous year. The relationship between the annual peak and the annual volume as ratios to the mean annual peak was also investigated. There were no apparent relationships in either of these two correlations.

EXTENT OF FLOODING

The extent of flooding of the Fort Nelson and Muskwa Rivers, in the vicinity of the Village of Fort Nelson, is shown on Figures 22 and 23. Flooding of the left bank of the Fort Nelson River has occurred in 1955 and in 1933, at gauge heights of 44 feet and 44 feet +, respectively (local elevation). This information has been obtained from long-time residents and substantiated by evidence found on trees and bushes. The local residents may have been one year out in their estimate of time, as the streamflow records on the Muskwa River show that high water occurred on July 14, 1956.

There was very little flood damage done at the Old Town of Fort Nelson, although some buildings and some local roads were underwater. In the Village, several water test wells were silted-in and the water pumping unit was damaged.

The Bailey bridge across the Fort Nelson River collapsed because of the pressure of driftwood.

Numerous bridge approaches and culverts were washed out along the Alaska Highway. At this time no overall monetary value can be placed on the damage done by the flood.

The following is a newspaper report of the flood published in the June 23, 1971 issue of the *Fort Nelson News:*

Then The Rains Came

After an extremely dry, hot spring the tables suddenly turned and rain poured down upon us for a steady week. River, creeks and mud puddles began to swell and several smaller bridges along the highway washed out and the highway was closed to all traffic for awhile. On the 16th of June, the height of the flood, the Muskwa was reported rising at 1/2 ft. per hour. George Streeper and the TRUDY JEAN kept a constant eye on the old Muskwa bridge and probably saved its existence from the raging muddy river. Old Fort residents moved out of their homes and higher up the bank while the barges on the other side of the river floated to the top of the high sandy bank. Finally on the evening of June 16, the Sikanni bridge, which had been holding back nearly a mile of driftwood, gave way with a terrific boom and the jam of logs careened off down the river. Most of Fort Nelson was down at the rivers at one time or another to survey the flood and perhaps consider the possibility of building an arc.

There are various versions of the Highway being out but as it may have delayed a few vehicles for brief times it was not in effect out. Had the Muskwa bridge – which was feared for a time – given way, then the whole thing could be out of commission and they could cancel their paving programs. . . . or at least talks.

The daily press reported the following item:

Washouts Close Alaska Highway

Washouts caused by heavy rain forced closure Tuesday of a 250-mile section of the Alaska Highway.

The Department of Public Works report five washouts between Fort St. John and Fort Nelson. A department spokesman said culverts were overflowing and at least one bridge – the Adsett Creek overpass at Mile 234 – was out.

The spokesman warned motorists to stay off the gravelled highway because of the danger of being trapped between washouts. More than three inches of rain has fallen in the area since Sunday.

Photographs of the flood are shown in Figures 24 to 31.

Frequency Characteristics of the Flood

A frequency curve is a graphic representation of the average occurrence of events, derived from past experience. Its intended use is to estimate how often, on the average, certain events will occur in the future.

The plotting position for each flow is calculated from the Weibull formula $T = \frac{n+1}{m}$. Peak annual flows for the Fort Nelson and Muskwa Rivers are listed in Tables 6 and 7, respectively.

The Hydrology Committee of the Water Resources Council of the United States federal government has recommended that the log-Pearson Type III distribution be used in the analysis of floods. This decision was based on the need for a uniform method of establishing flood frequencies for general use where many agencies are involved in flood plain management. This allows an equable analysis of flood frequencies and a consistent approach to the estimation of the average annual value of flood losses.

The maximum mean daily flows for the Fort Nelson and Muskwa Rivers have been plotted on Gumbel extremal probability paper. The log-Pearson Type III distribution has been fitted to the flows by the method of moments. This distribution appears to fit the data very well and indicates a trend which can be extrapolated to cover a larger range. The frequency curves are shown on Figures 32 and 33 for the Fort Nelson and Muskwa Rivers, respectively.

INTERPRETATION OF FREQUENCY CURVES

Assuming that the curve is a good representation of the population distribution, the following interpretations can be made. For the Fort Nelson River (Fig. 32) the annual maximum mean daily flood may exceed the flood of June 16, 1971, at intervals averaging 35 years in length, or the probability of the annual maximum mean daily flood exceeding the flood of June 16th in any one year is 1 in 35.

The annual maximum mean daily flood may exceed the flood of June 16, 1971, on the Muskwa River (Fig. 33), at intervals averaging 23 years in length.

The flood frequency curve can be readily converted into terms of stage. One must be careful, however, that the flood at a particular stage does not constitute overbank flow.

Table 6. Maximum Daily Mean Flows, Fort Nelson River at Fort Nelson, Station 10CC001

Date	Maximum daily flow (cfs)	Rank	Recurrence interval (yr)	Maximum daily flow (cfs)	Year
Jun 30, 1961	97,000	1	13.0	185,000	1971
Jul 20, 1962	121,000	2	6.5	121,000	1962
May 1, 1963	92,100	3	4.33	97,000	1961
Aug 3, 1964	63,200	4	3.25	92,100	1963
Jun 29, 1965	65,900	5	2.60	79,500	1966
Jul 12, 1966	79,500	6	2.17	68,400	1972
May 16, 1967	36,200	7	1.86	65,900	1965
Jun 13, 1968	65,100	8	1.62	65,100	1968
May 4, 1969	42,300	9	1.44	64,800	1970
May 9, 1970	64,800	10	1.30	63,200	1964
Jun 16, 1971	185,000	11	1.182	42,300	1969
Jun 23, 1972	68,400	12	1.083	36,200	1967

Mean annual flood: 81,700 cfs; drainage area: 17,200 sq mi ; standard deviation: 39,900 cfs

Table 7. Maximum Daily Mean Flows, Muskwa River Near Fort Nelson, Station 10CD001

Date	Maximum daily flow (cfs)	Rank	Recurrence interval (yr)	Maximum daily flow (cfs)	Year
Jun 10, 1945	19,200	1	28.0	141,000	1971
Jul 13, 1946	65,700	2	14.0	140,000	1956
Jun 9, 1947	17,100	3	9.3	117,000	1949
May 26, 1948	66,400	4	7.0	96,300	1954
Jul 17, 1949	117,000	5	5.6	92,400	1962
May 6, 1950	24,800	6	4.67	87,700	1957
Jun 28, 1952	29,400	7	4.00	85,100	1953
Jul 25, 1953	85,100	8	3.50	80,800	1961
Jun 19, 1954	96,300	9	3.11	78,800	1955
Jul 3, 1955	78,800	10	2.80	74,300	1966
Jul 14, 1956	140,000	11	2.55	70,000	1963
Jun 30, 1957	87,700	12	2.33	68,800	1965
Jul 17, 1958	20,300	13	2.15	66,400	1948
Aug 24, 1959	53,400	14	2.00	65,700	1946
Aug 14, 1960	43,400	15	1.87	61,700	1972
Jun 30, 1961	80,800	16	1.75	53,400	1959
Aug 15, 1962	92,400	17	1.65	50,700	1970
Jul 11, 1963	70,000	18	1.56	50,200	1968
Aug 1, 1964	46,400	19	1.47	46,400	1964
Jun 29, 1965	68,800	20	1.40	43,400	1960
Jul 12, 1966	74,300	21	1.33	29,400	1952
May 16, 1967	26,700	22	1.27	26,700	1967
Jun 13, 1968	50,200	23	1.22	24,800	1950
May 5, 1969	20,200	24	1.167	20,300	1958
Jun 11, 1970	50,700	25	1.120	20,200	1969
Jun 16, 1971	141,000	26	1.077	19,200	1945
Jun 23, 1972	61,700	27	1.037	17,100	1947

Mean annual flood: 64,000 cfs; drainage area: 7,600 sq mi ; standard deviation: 34,800 cfs

Conclusions and Recommendations

CAUSES OF THE FLOOD

The flooding of the Fort Nelson and Muskwa Rivers was due to several factors:

1. *antecedent conditions* — the streamflow preceding the rainstorm was already high due to snowmelt runoff and earlier precipitation,
2. *heavy precipitation* — rainfall from the storm was concentrated over the Basin, and
3. *timing* — the peak flow from the Muskwa and Fort Nelson Rivers coincided at the confluence of the two Rivers.

PEAK FLOWS

Since the maximum instantaneous rates of flow are the direct cause of most flood damage, greater effort should be expended to measure these flows when they occur.

Great difficulty was experienced in obtaining streamflow measurements by boat during the flood. Slope stakes were set on the left bank of the Muskwa River to mark the peak stage of the flood. An attempt was made, at the time of the writing of this report, to locate the slope stakes and carry out a survey. The river bank on which the stakes were set, however, was subject to considerable sliding due to seepage. Only one stake could be located and it had obviously shifted since being placed.

It is recommended that an indirect measurement site be established to record floods in the future. Readings taken once a day are not very useful in recording peak flows of rivers that rise and fall as quickly as the Fort Nelson and the Muskwa.

It is also recommended that a small representative basin should be gauged along the Alaska Highway in the Fort Nelson River Basin to obtain realistic values of potential floods.

In future studies consideration of rainfall intensities in determining the magnitude and frequency of floods will be of greater practical importance than snowmelt potentialities. Before this type of study can be done, however, a denser network of rain gauges is required.

ACKNOWLEDGEMENTS

The author would like to acknowledge the contributions of Mr. D. Garry Schaefer, from the Scientific Support Unit of the Atmospheric Environment Service, for his analysis and description of the storm event of June 13-16, 1971, and the field staff of the Water Survey of Canada, from the sub-offices of Prince George and Whitehorse, which supplied information and photographs of the flood.

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Illustrations

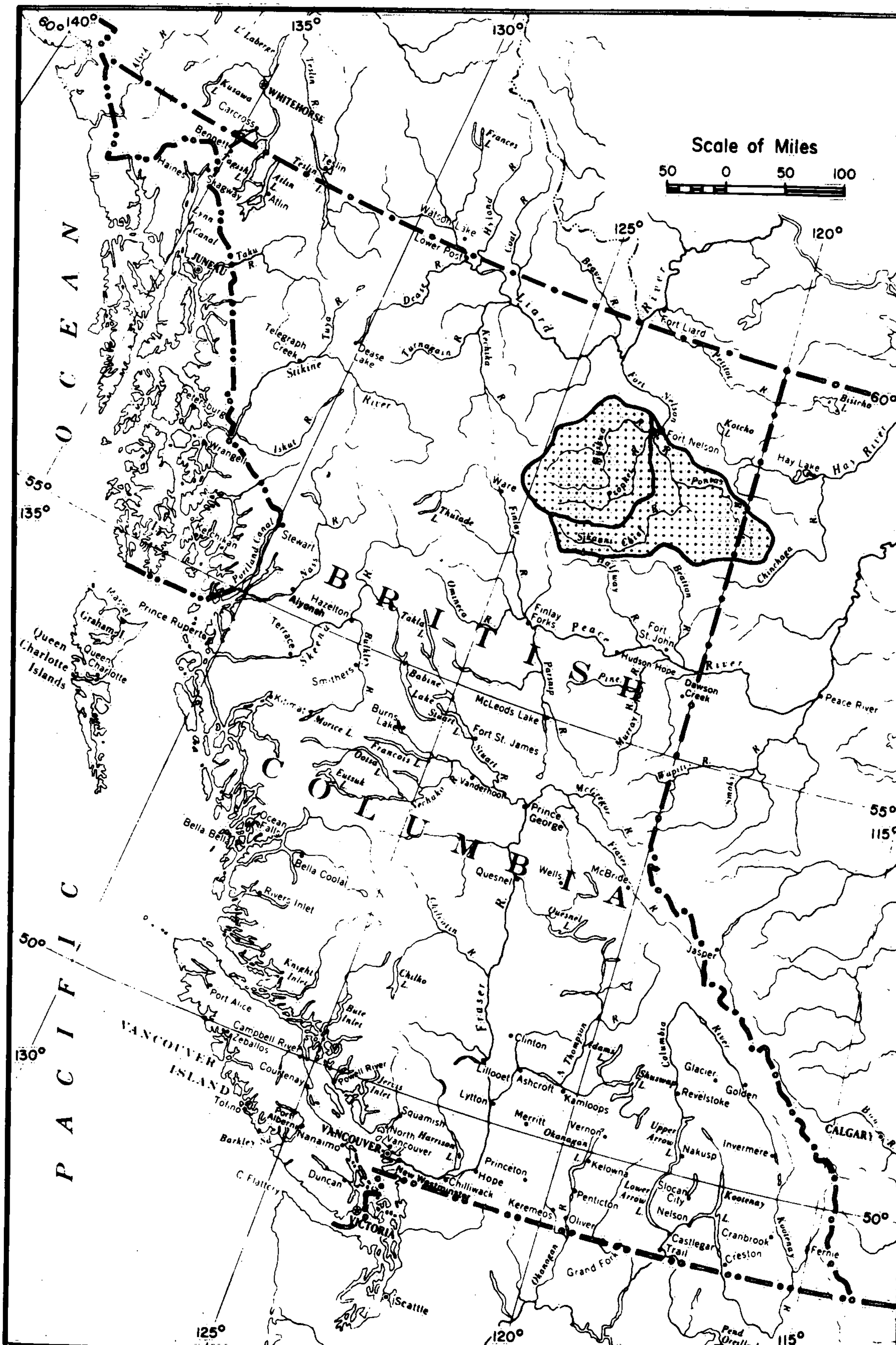
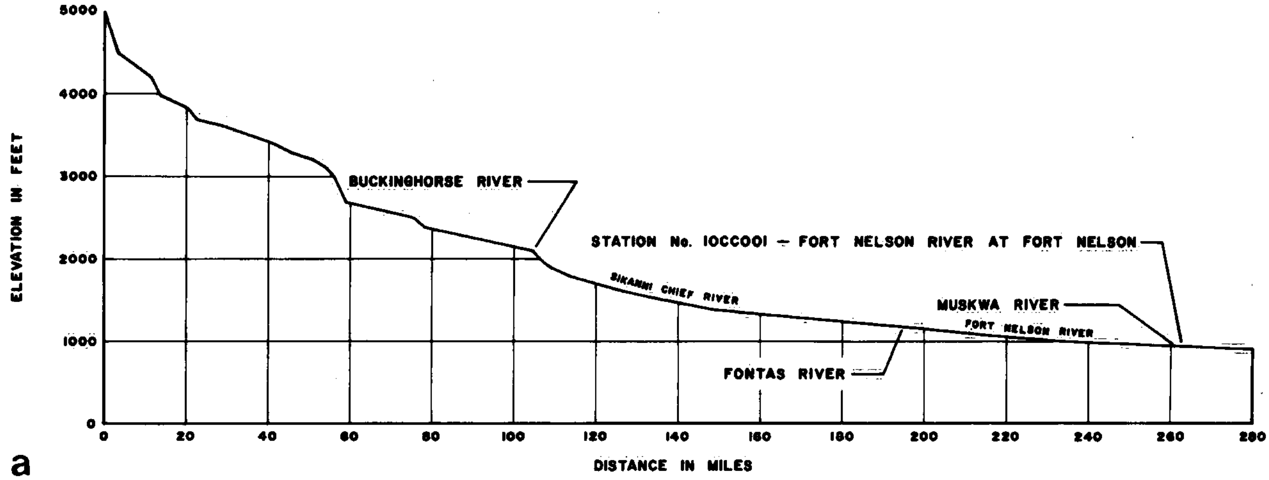
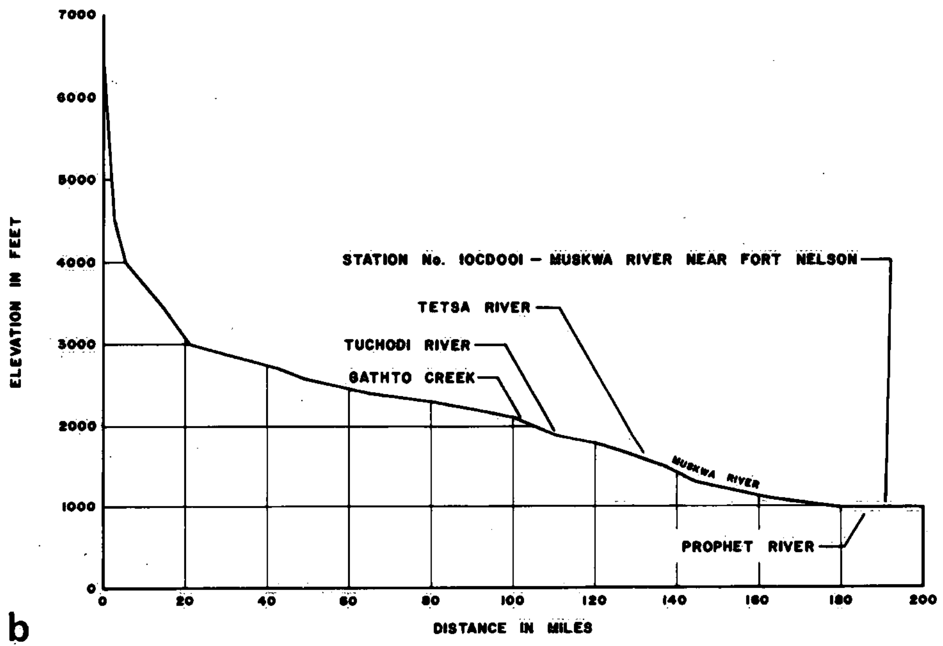


Figure 1. Key map of British Columbia.



a



b

Figure 2. Profiles of (a) Fort Nelson River and (b) Muskwa River.

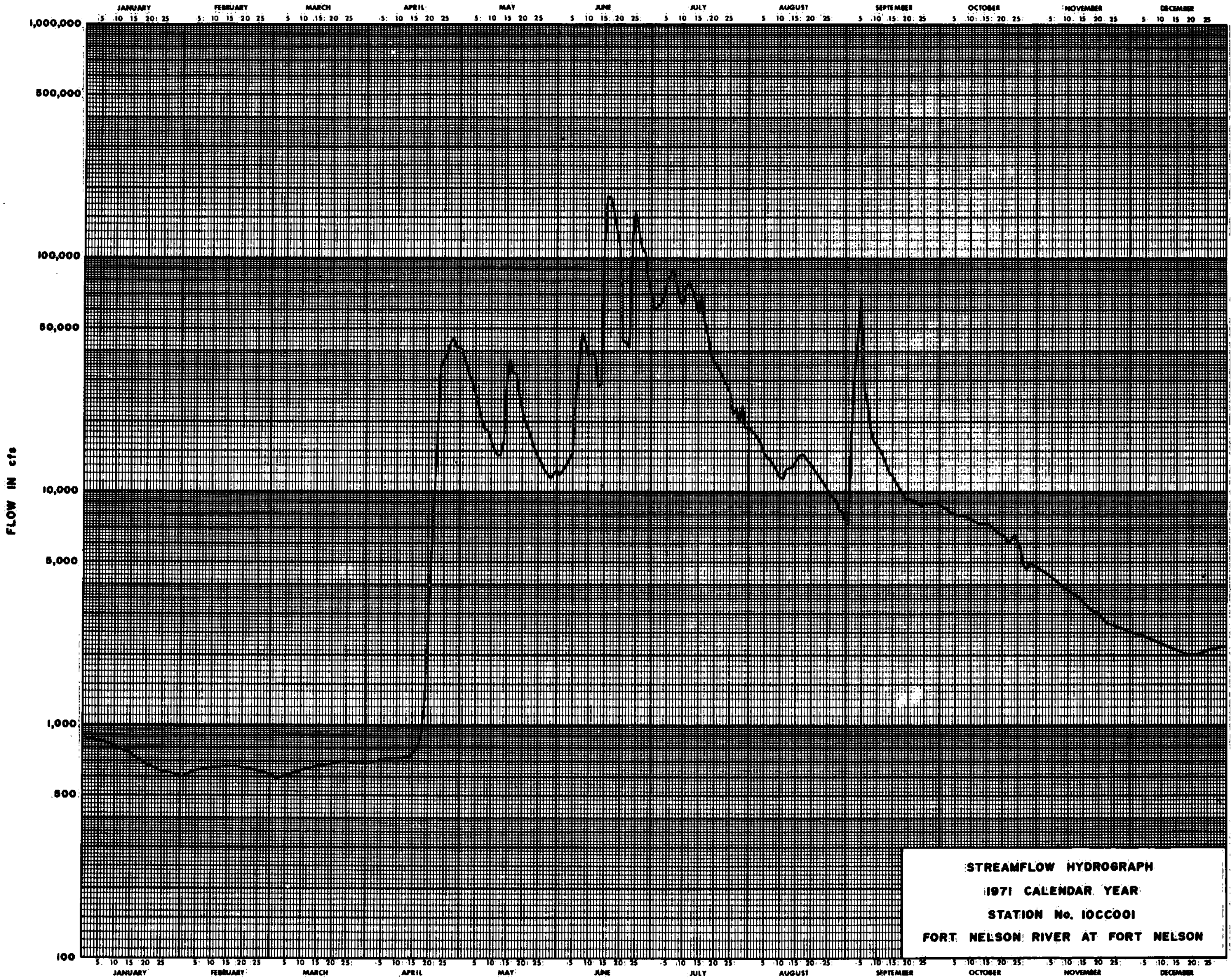


Figure 3. Streamflow hydrograph, Fort Nelson River at Fort Nelson, 1971.

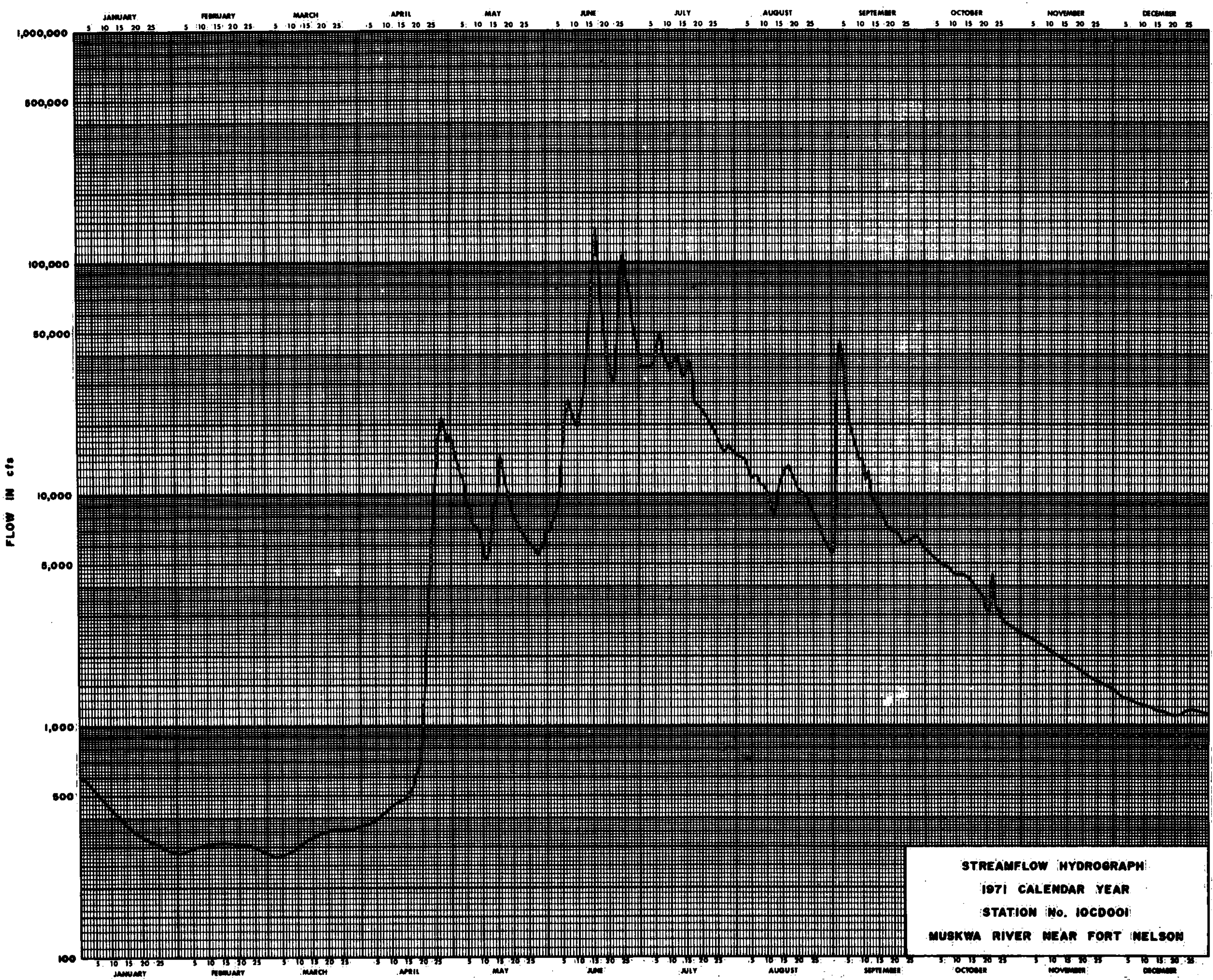


Figure 4. Streamflow hydrograph, Muskwa River near Fort Nelson, 1971.

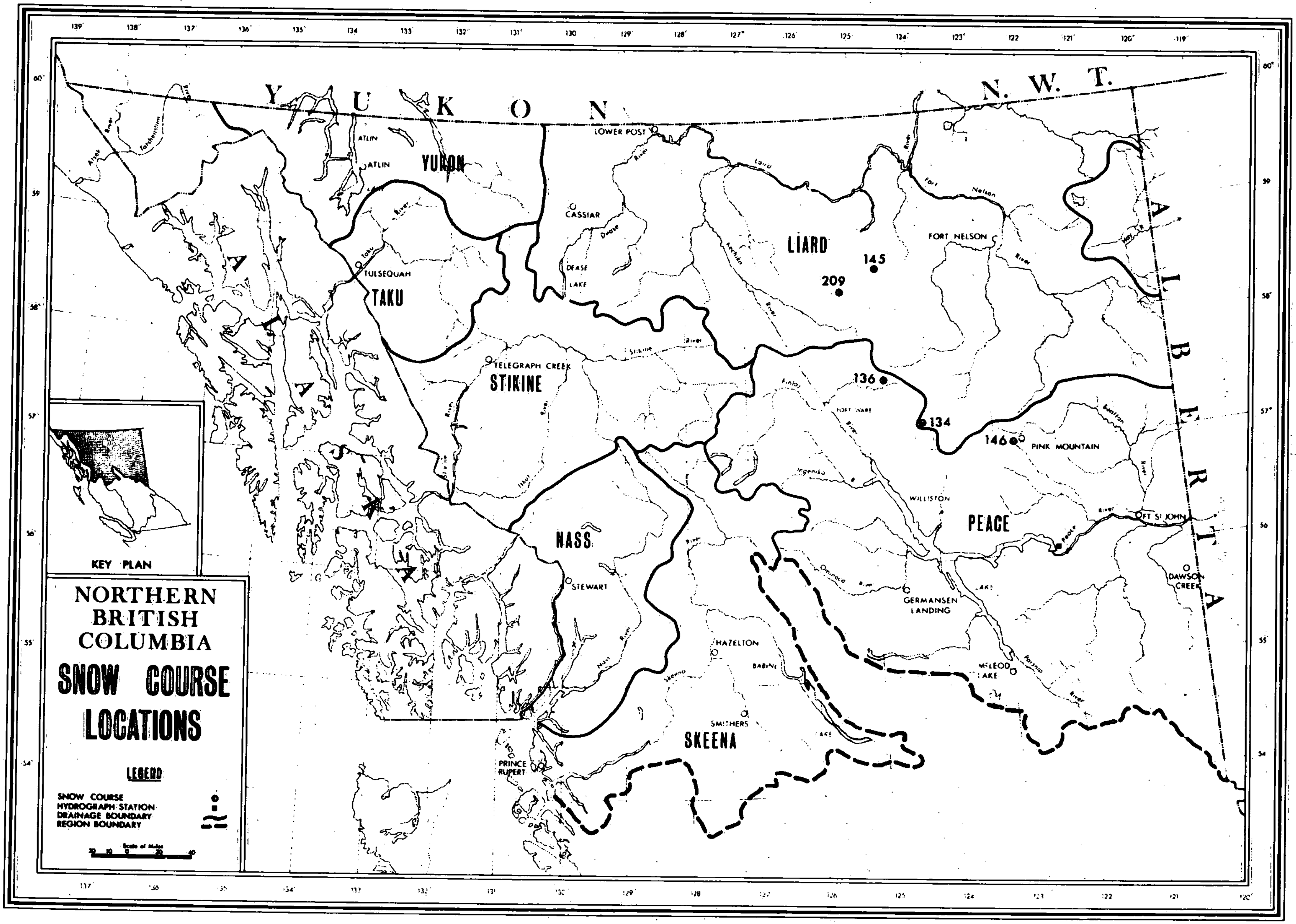


Figure 5. Snow course stations.

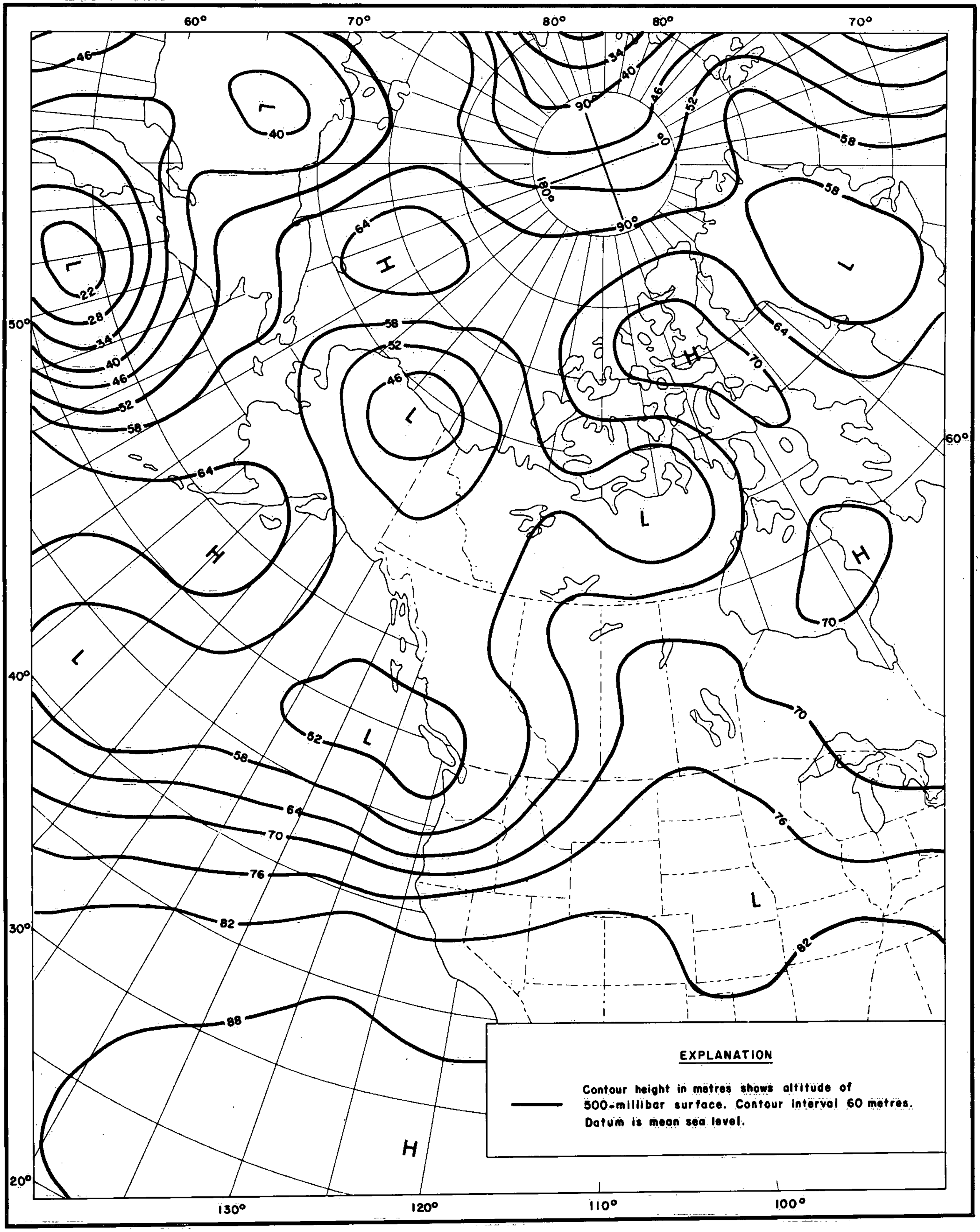


Figure 6. 500-millibar chart, June 14, 1971 – HR0000Z.

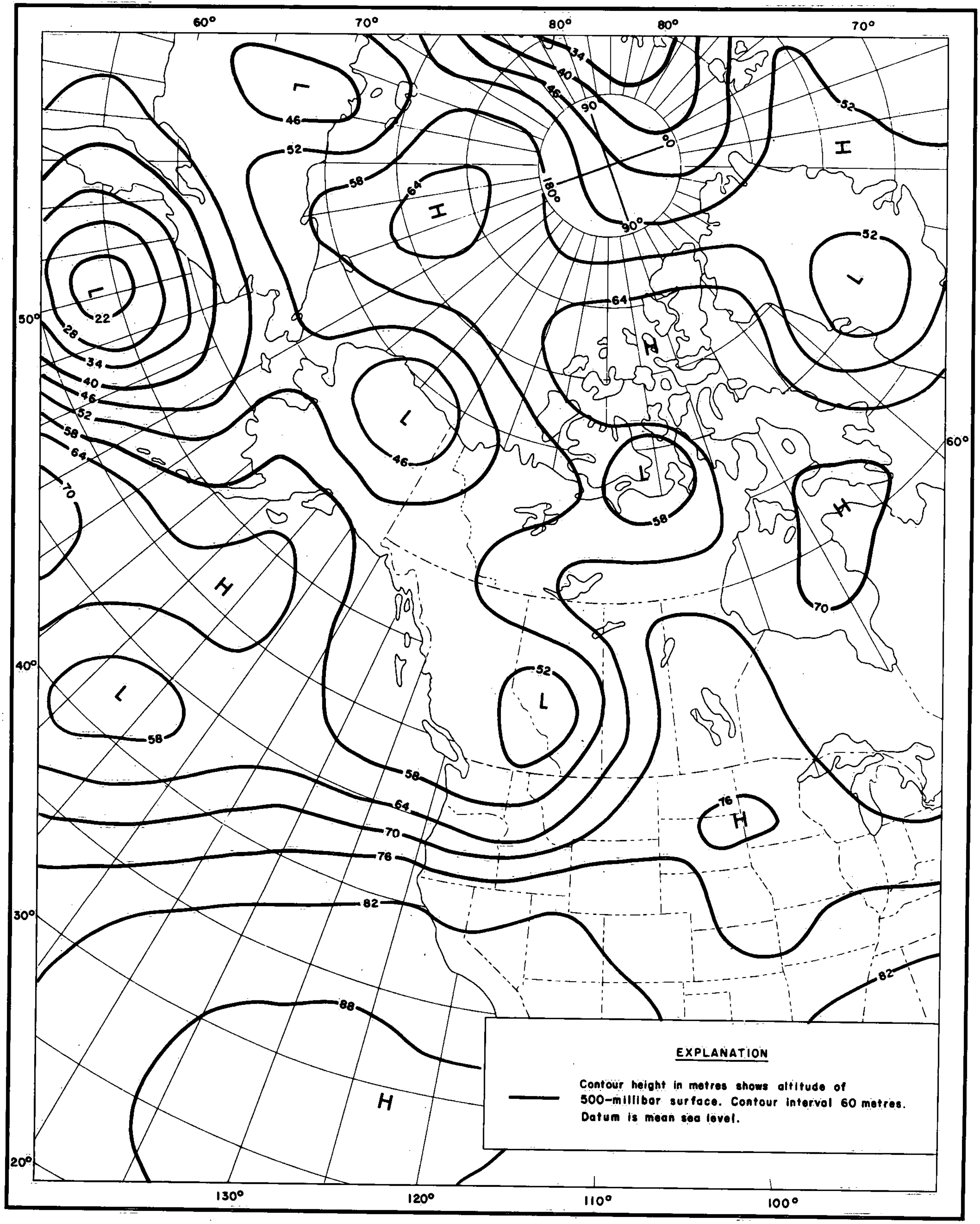


Figure 7. 500-millibar chart, June 14, 1971 – HR1200Z.

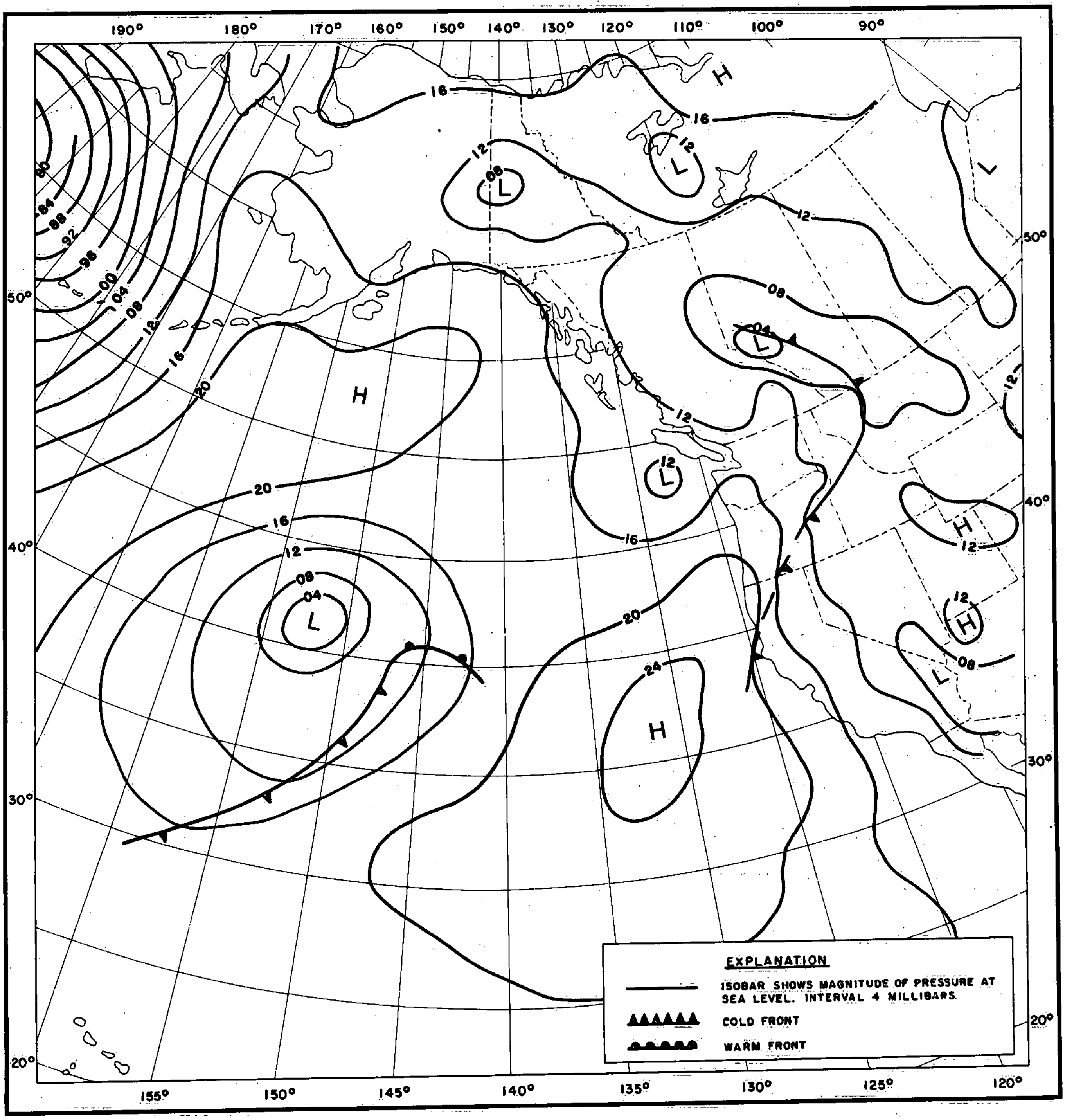


Figure 8. Surface chart, June 14, 1971 – HR0000Z.

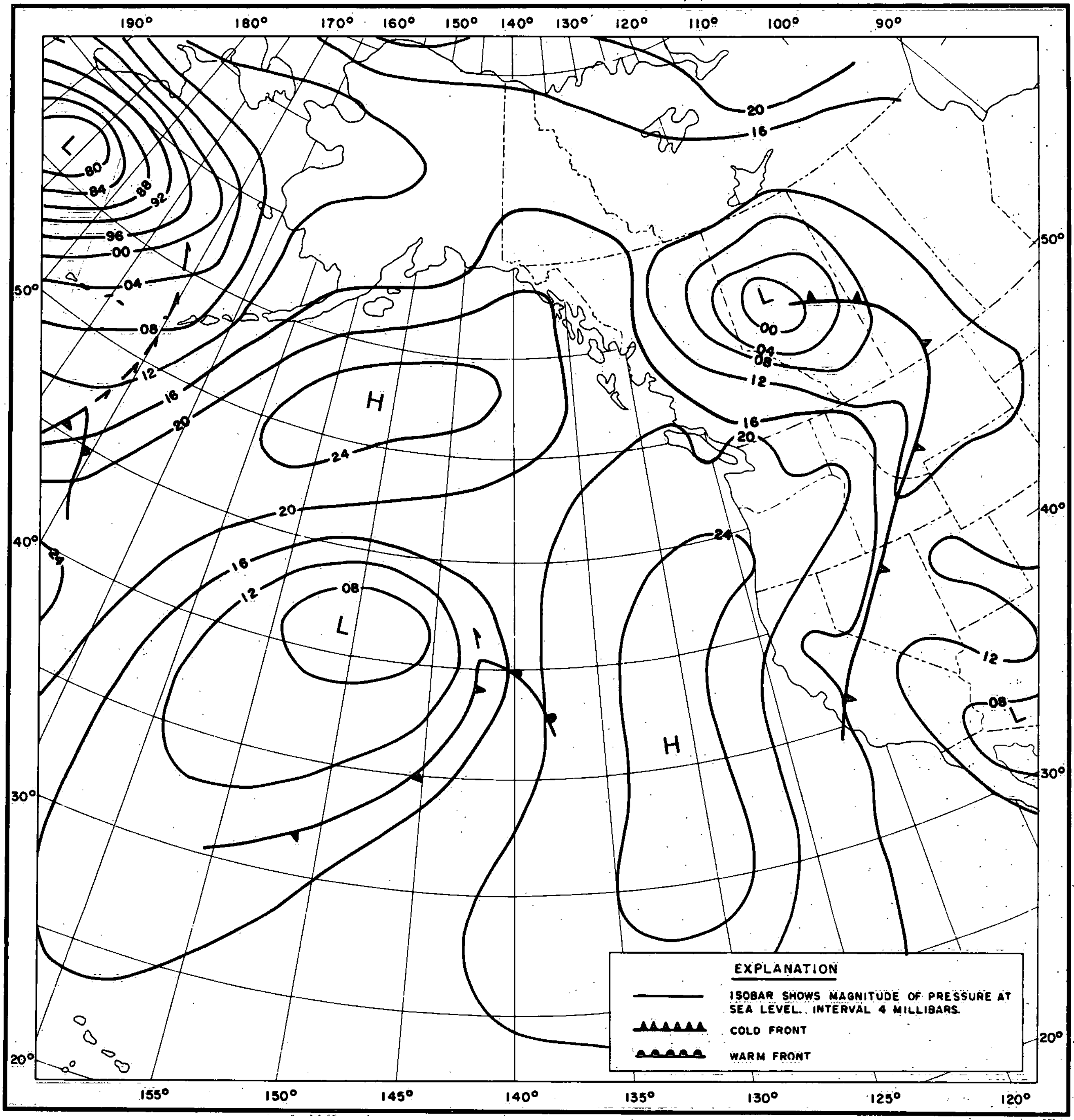


Figure 9. Surface chart, June 14, 1971 – HR1200Z.

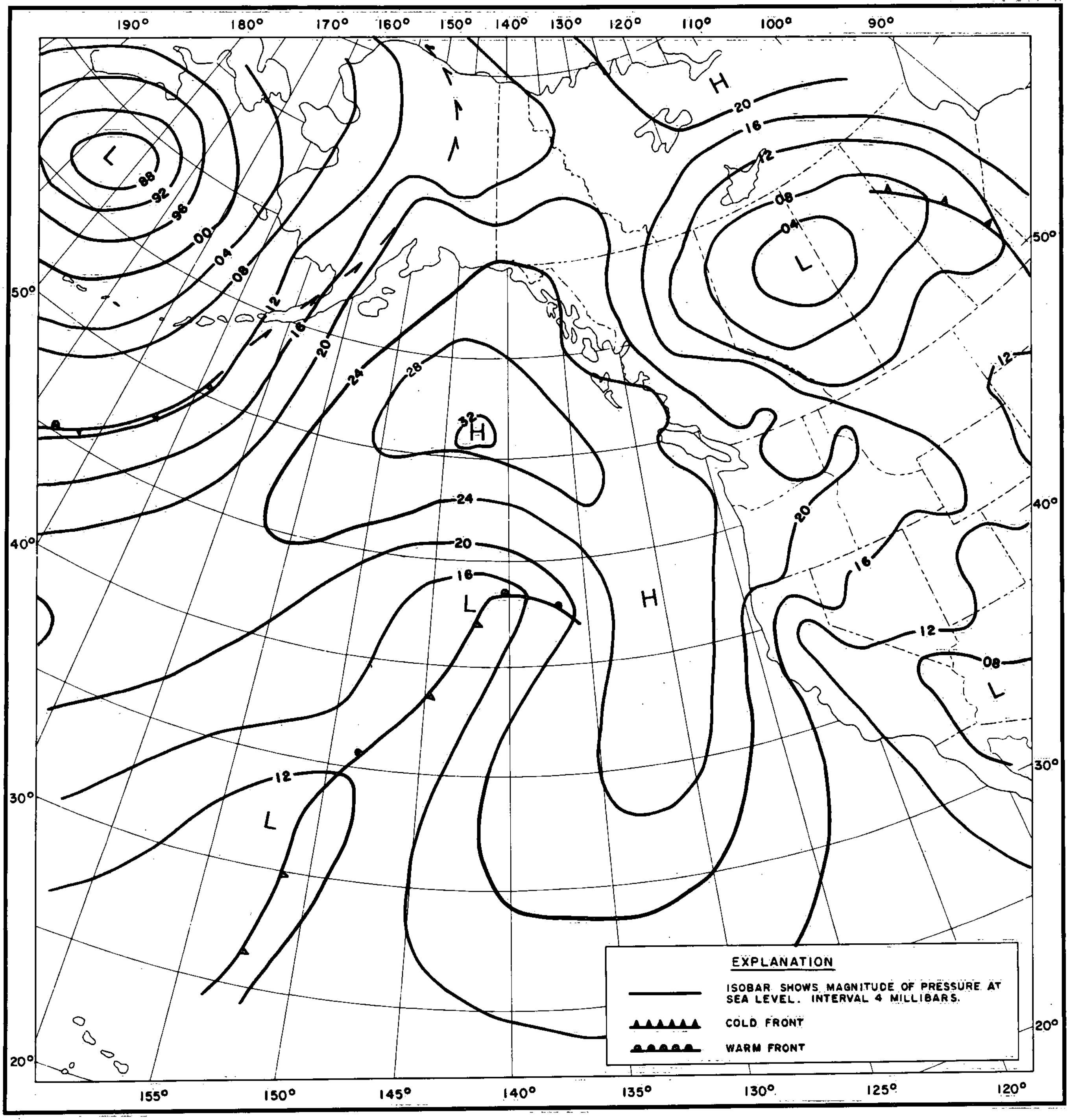


Figure 10. Surface chart, June 15, 1971 – HR1200Z.

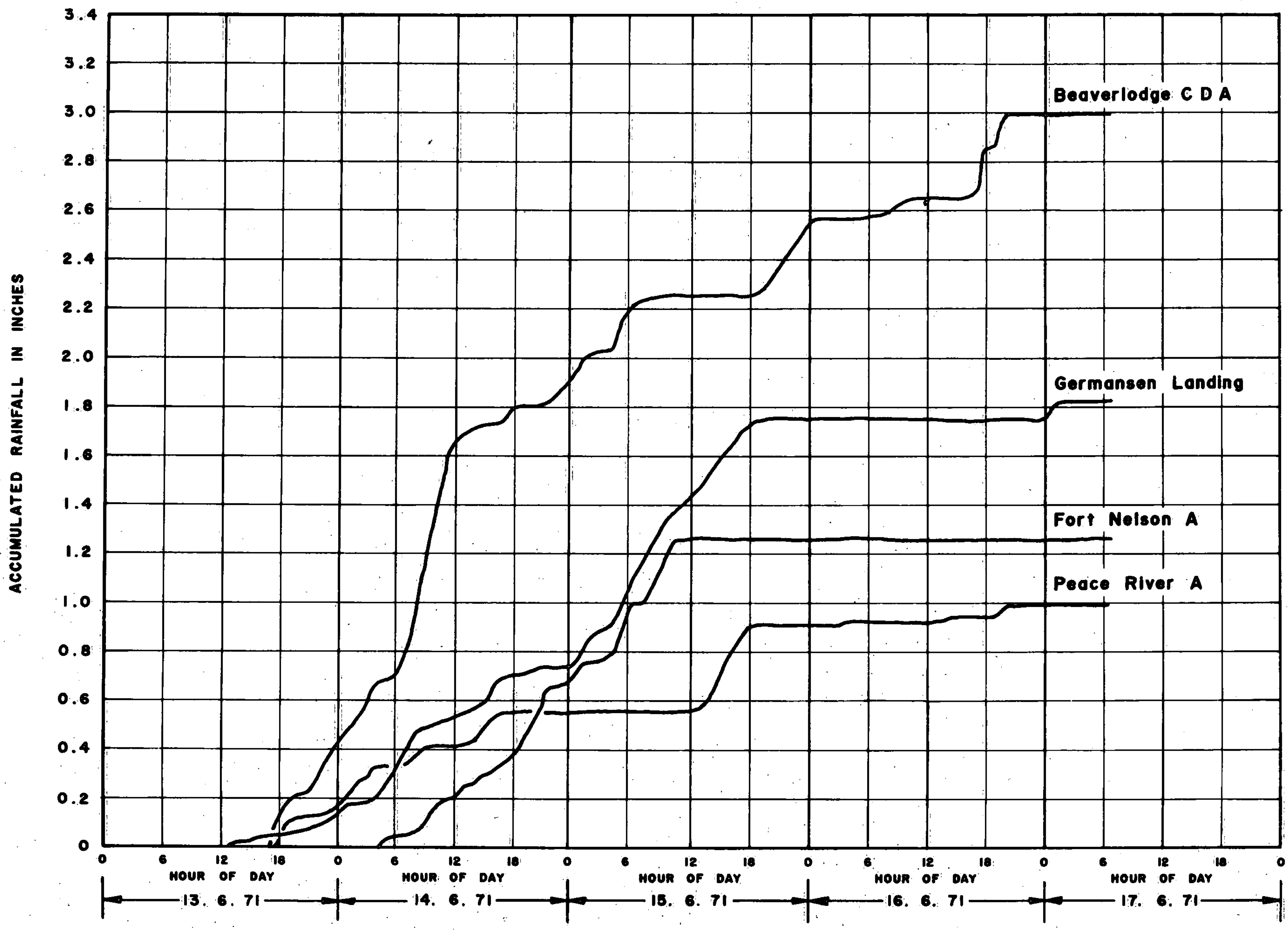


Figure 11. Mass curves of rainfall for storm June 13-16, 1971.

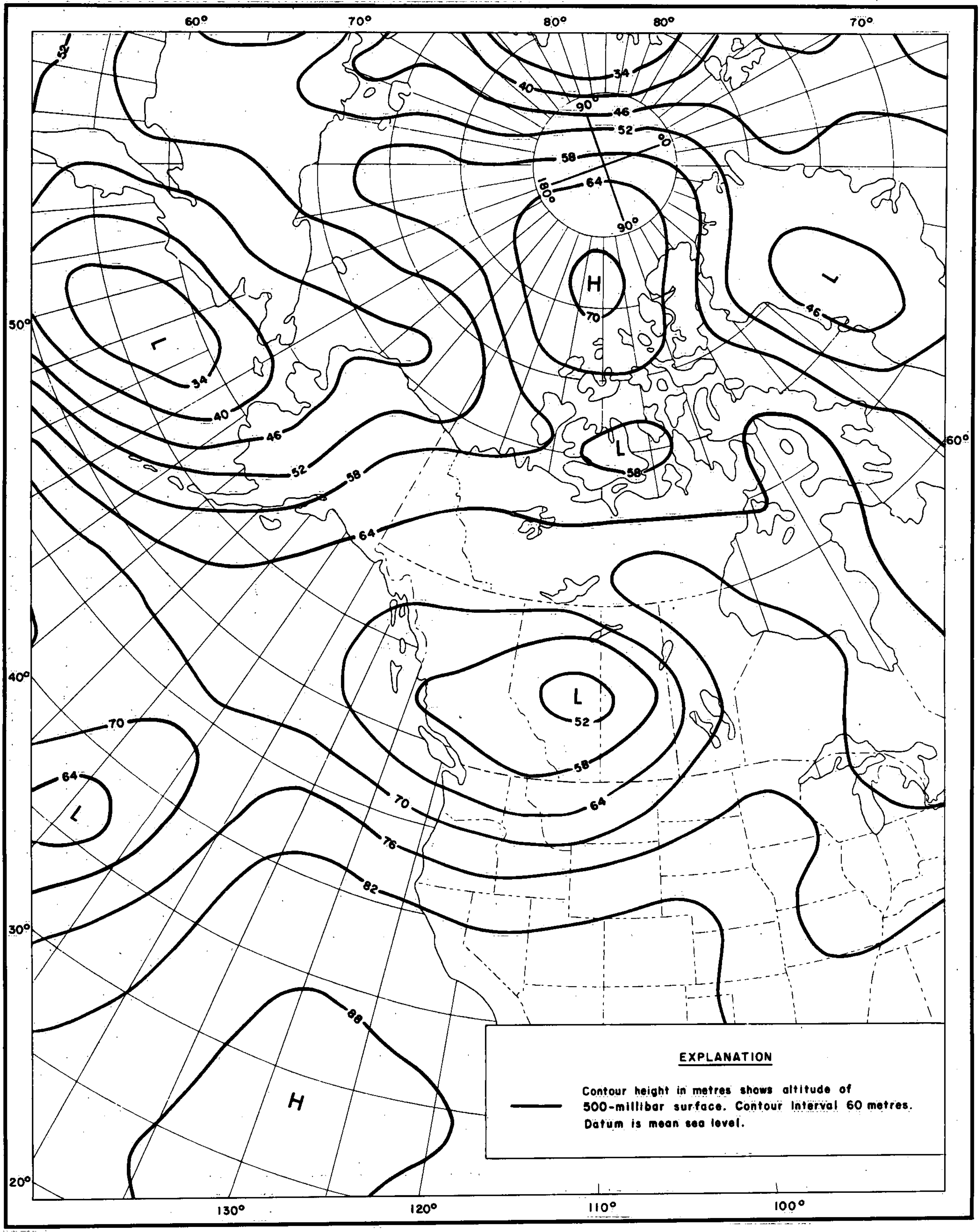


Figure 12. 500-millibar chart, June 15, 1971 – HR1200Z.

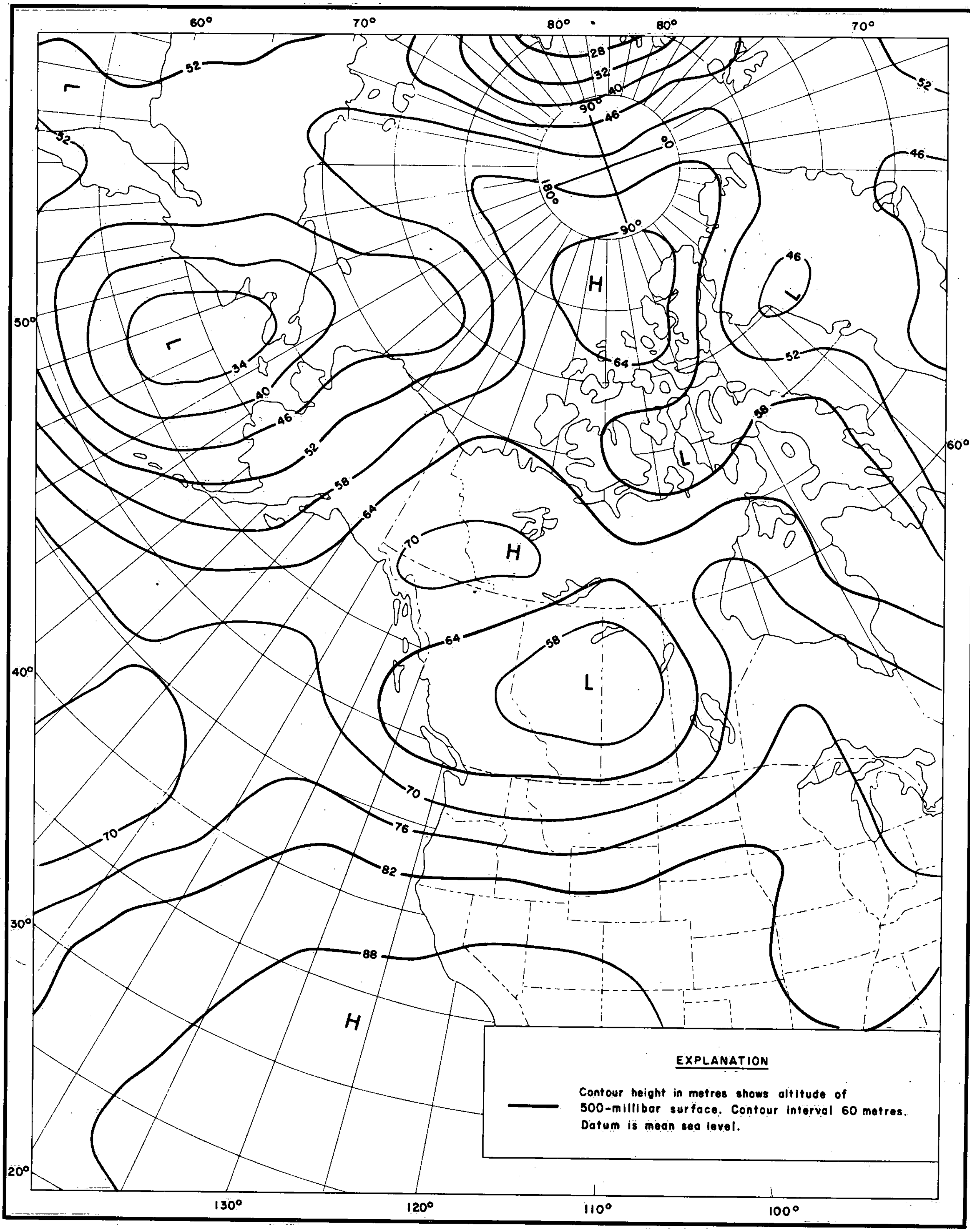


Figure 13. 500-millibar chart, June 16, 1971 – HR0000Z.

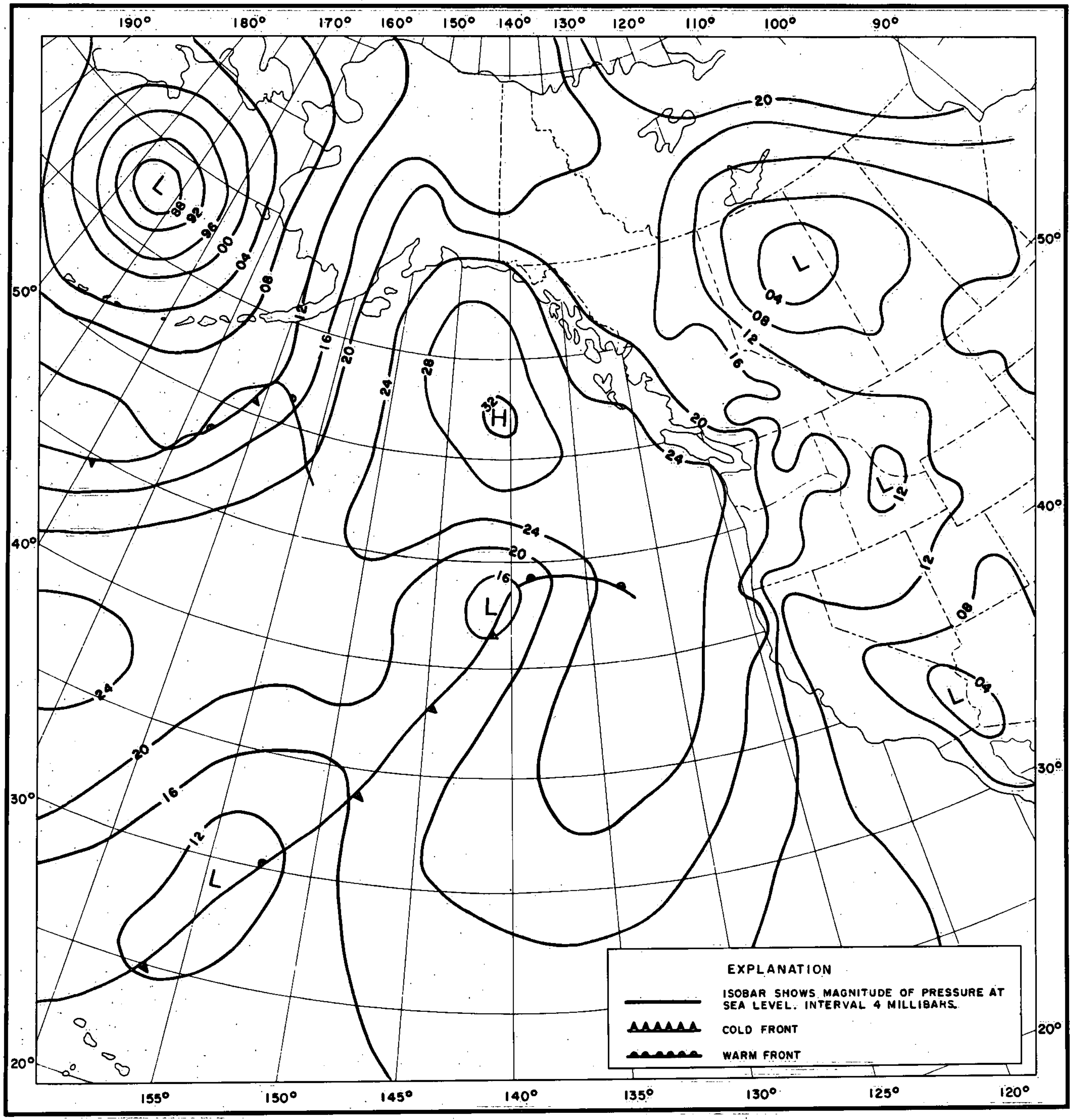


Figure 14. Surface chart, June 16, 1971 – HR0000Z.

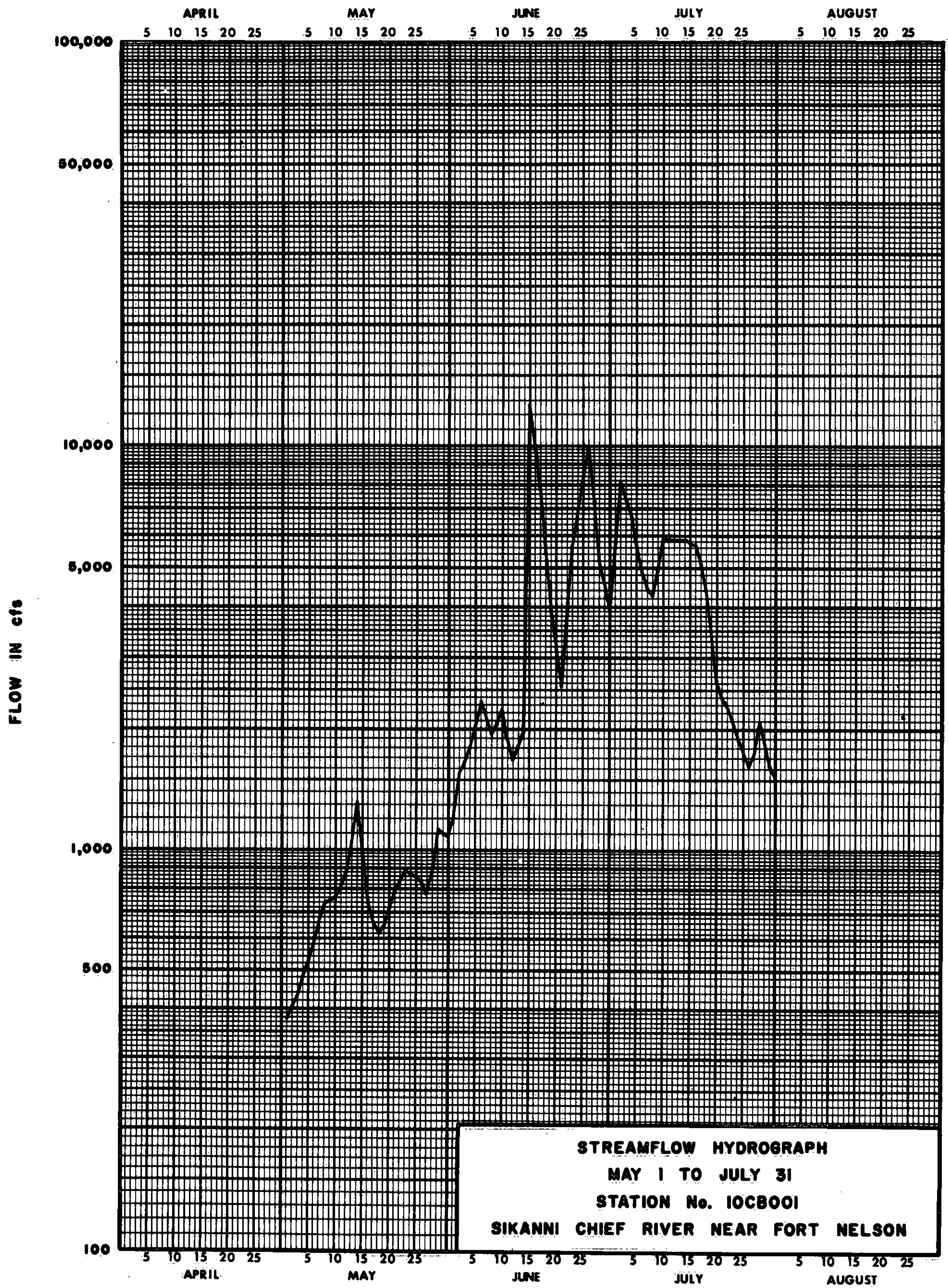


Figure 15. Streamflow hydrograph, Sikanni Chief River near Fort Nelson, May 1 to July 31, 1971.

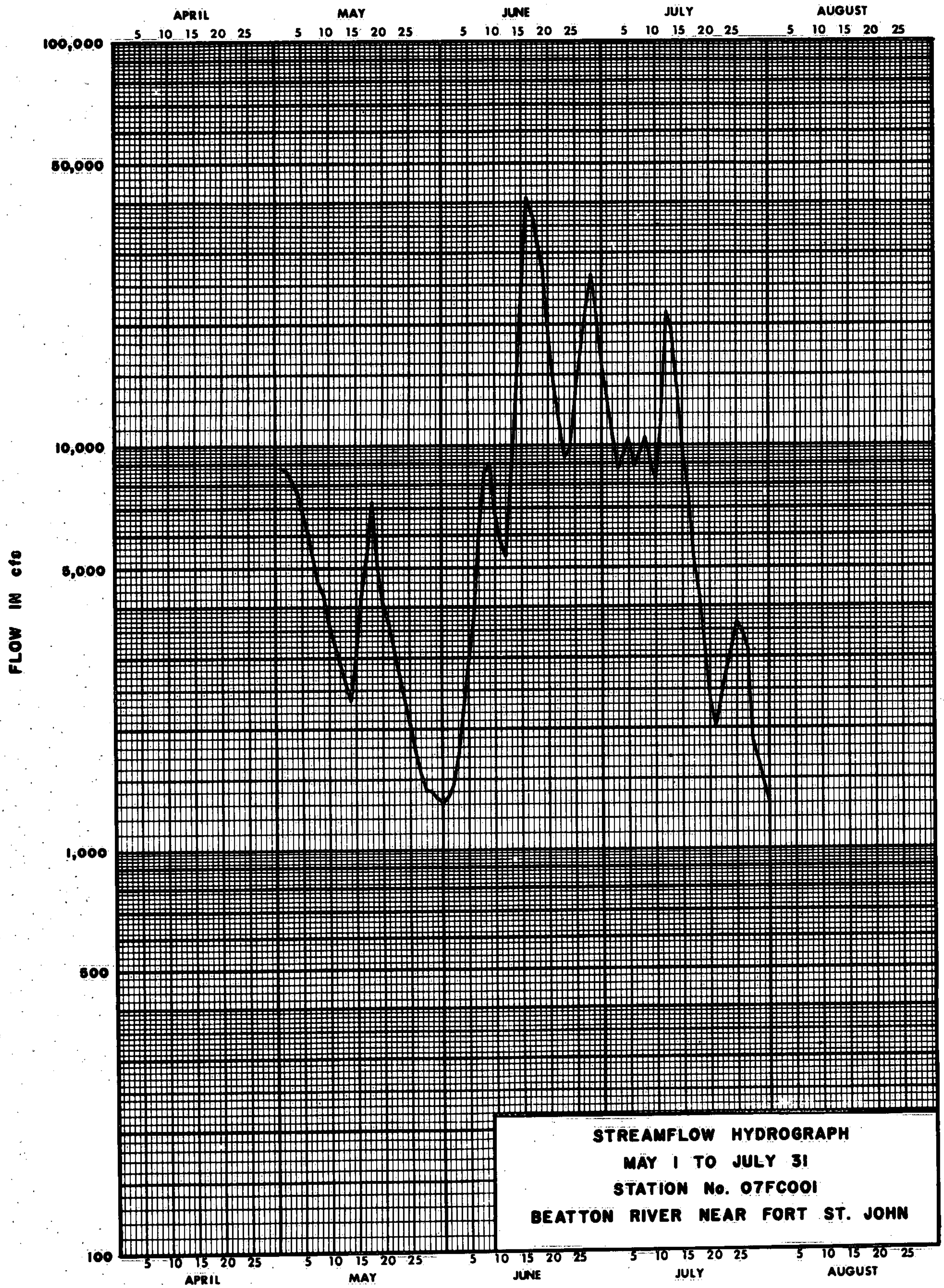


Figure 16. Streamflow hydrograph, Beatton River near Fort St. John, May 1 to July 31, 1971.

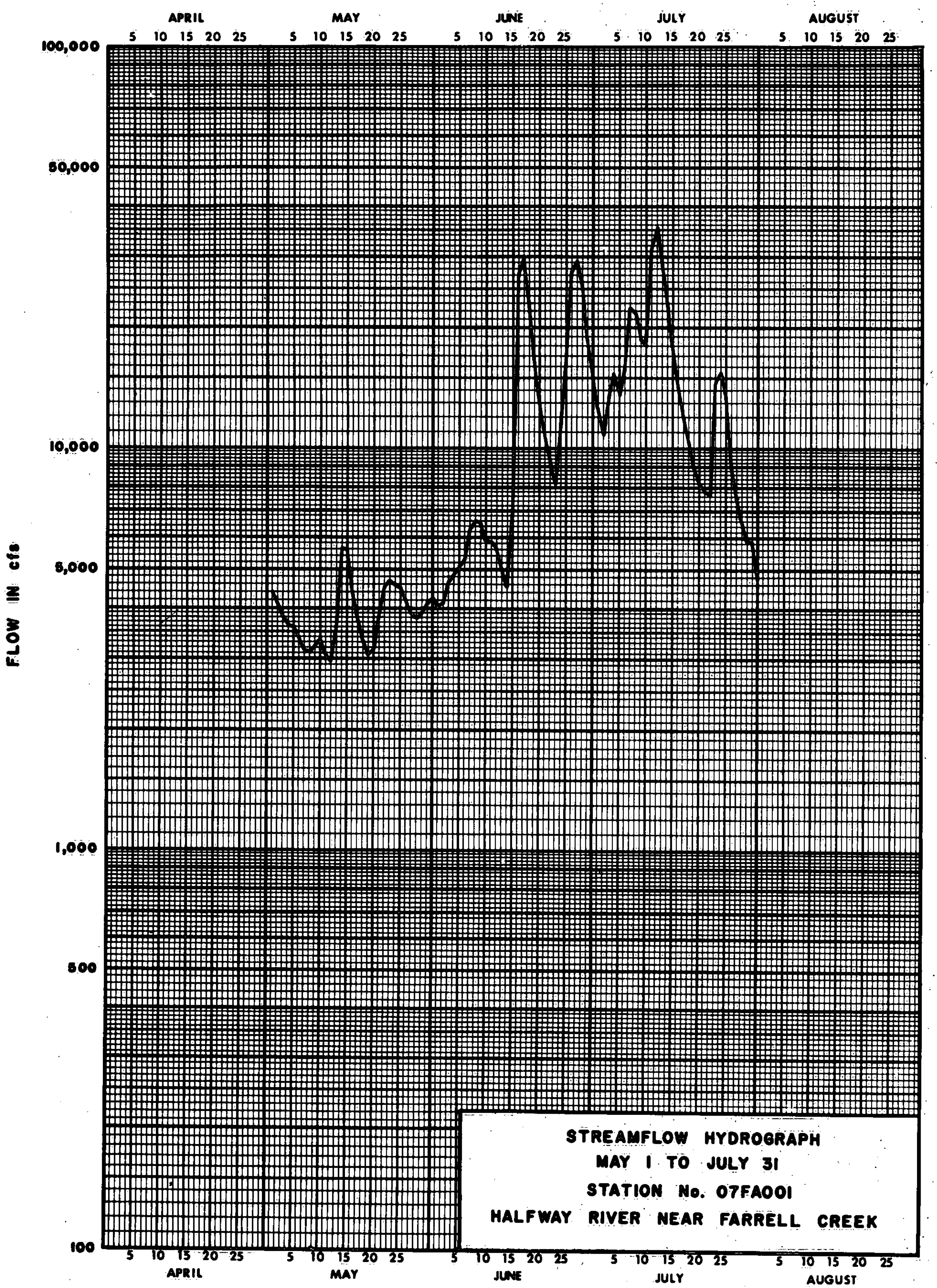


Figure 17. Streamflow hydrograph, Halfway River near Farrell Creek, May 1 to July 31, 1971.

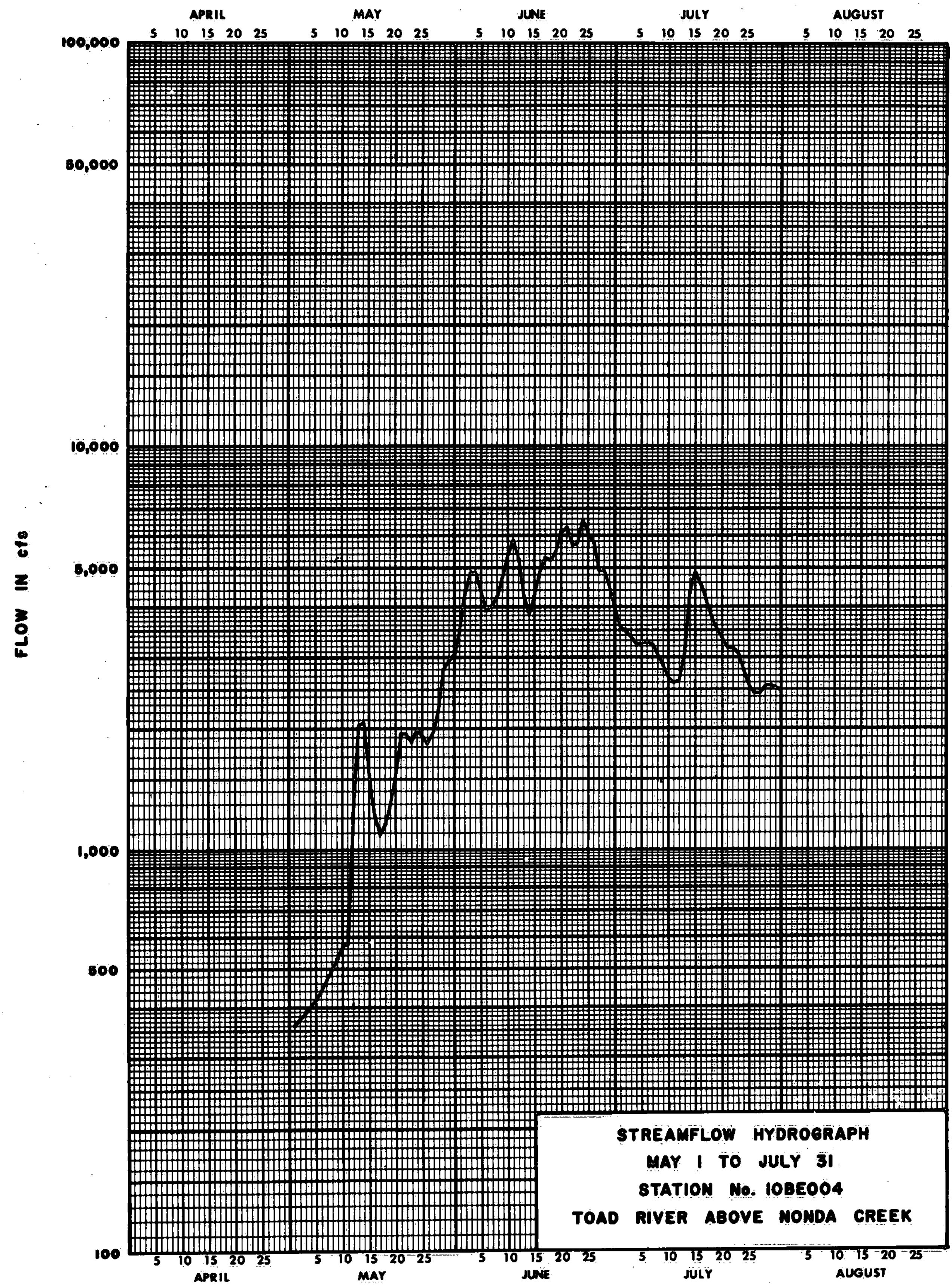


Figure 18. Streamflow hydrograph, Toad River above Nonda Creek, May 1 to July 31, 1971.

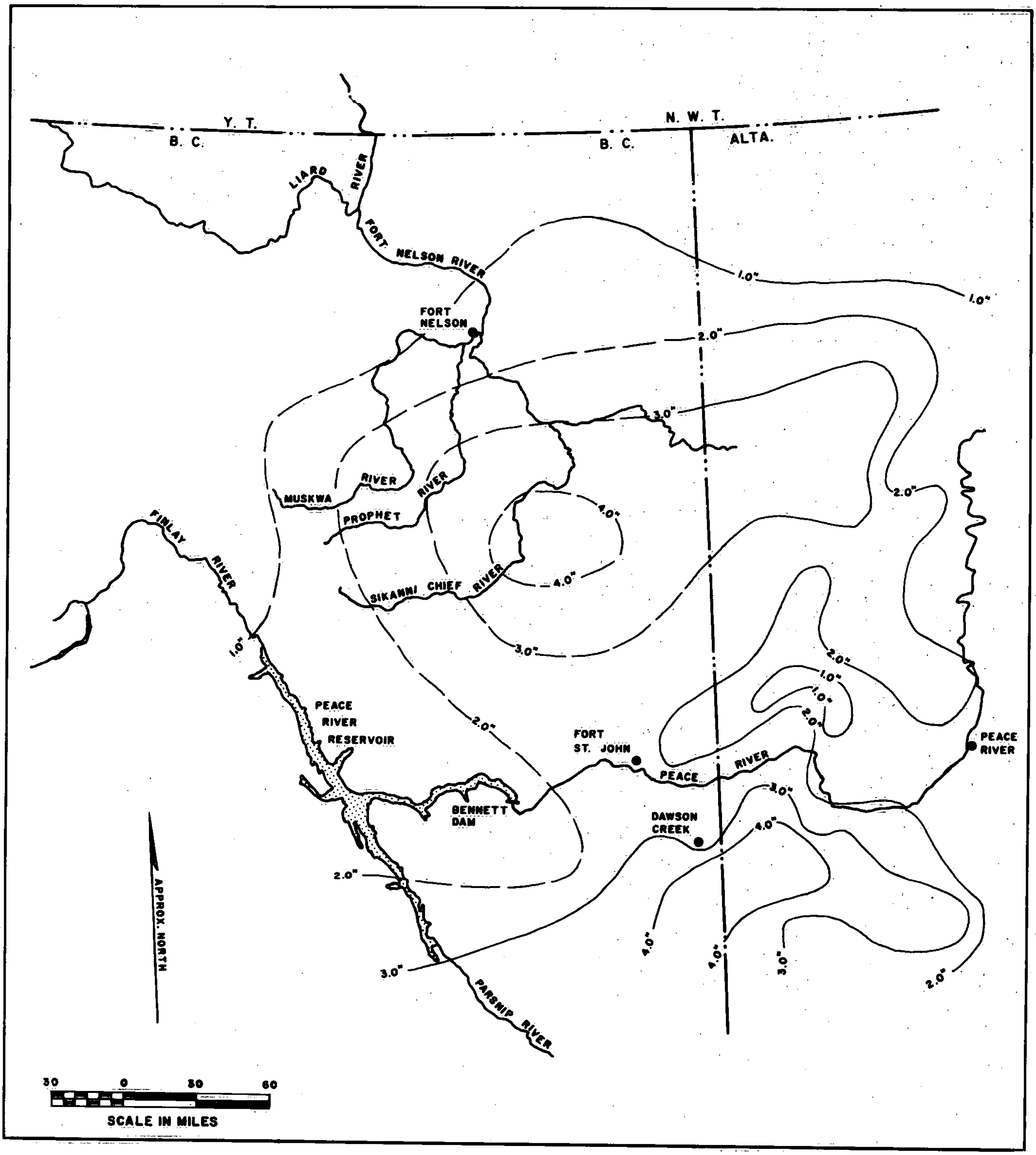


Figure 19. Isohyetal chart, Fort Nelson River Basin, June 13-16, 1971.

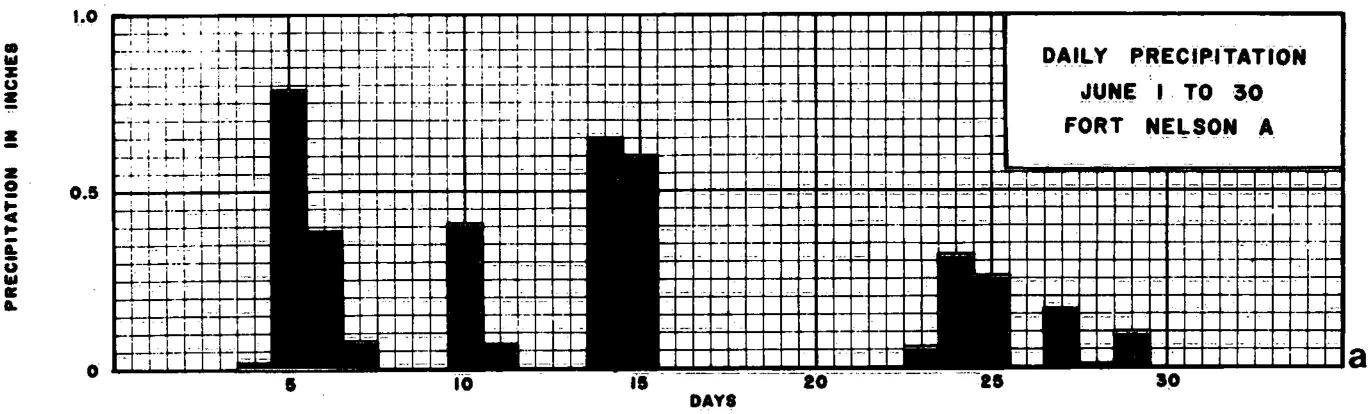


Figure 20a. Daily precipitation chart, Fort Nelson Airport, June 1-30, 1971.

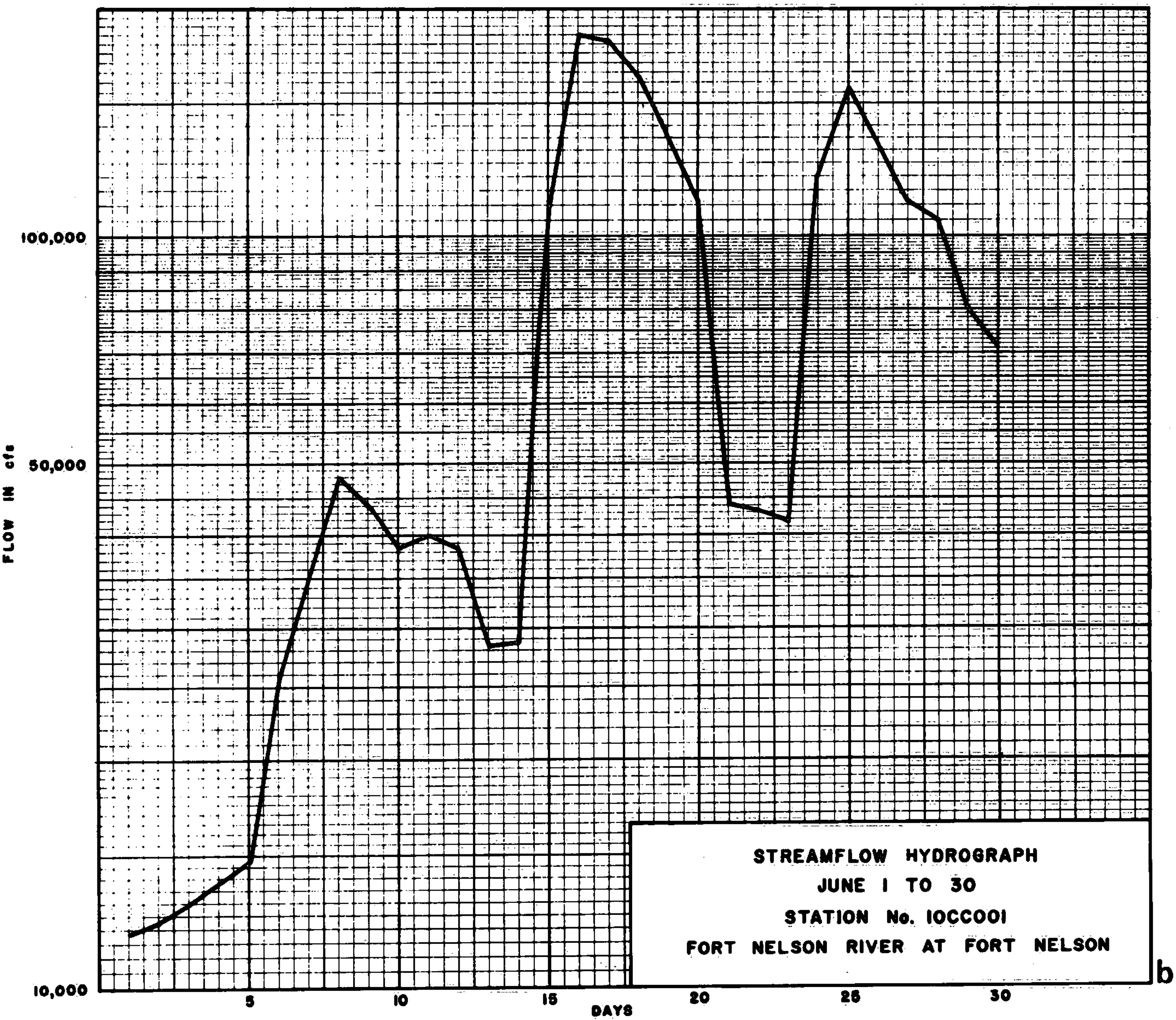


Figure 20b. Streamflow hydrograph, Fort Nelson River at Fort Nelson, June 1-30, 1971.

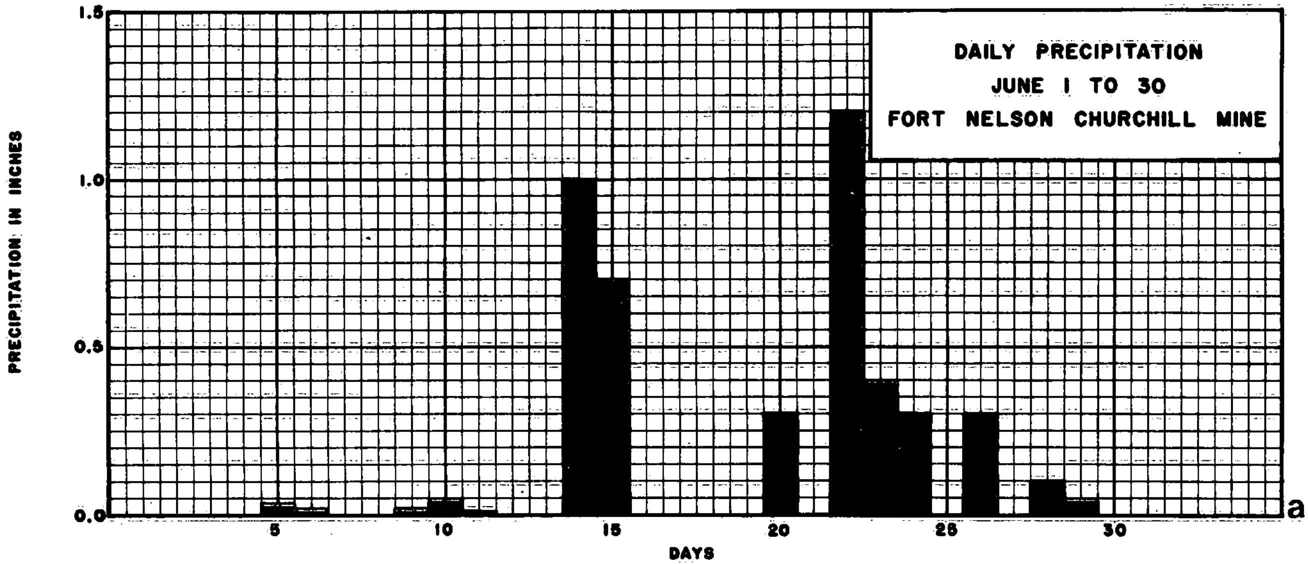


Figure 21a. Daily precipitation chart, Fort Nelson Churchill Mine, June 1-30, 1971.

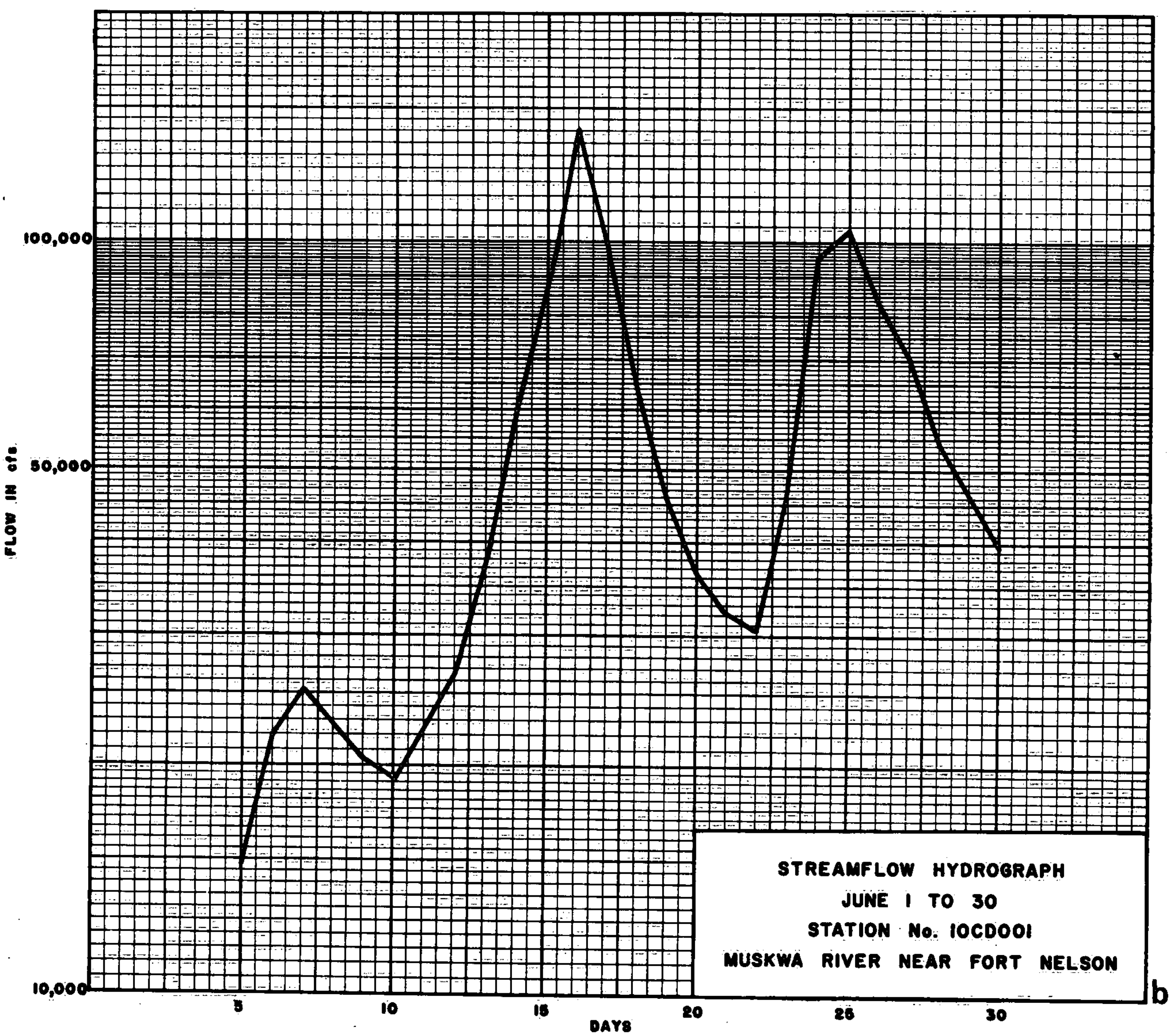


Figure 21b. Streamflow hydrograph, Muskwa River near Fort Nelson, June 1-30, 1971.

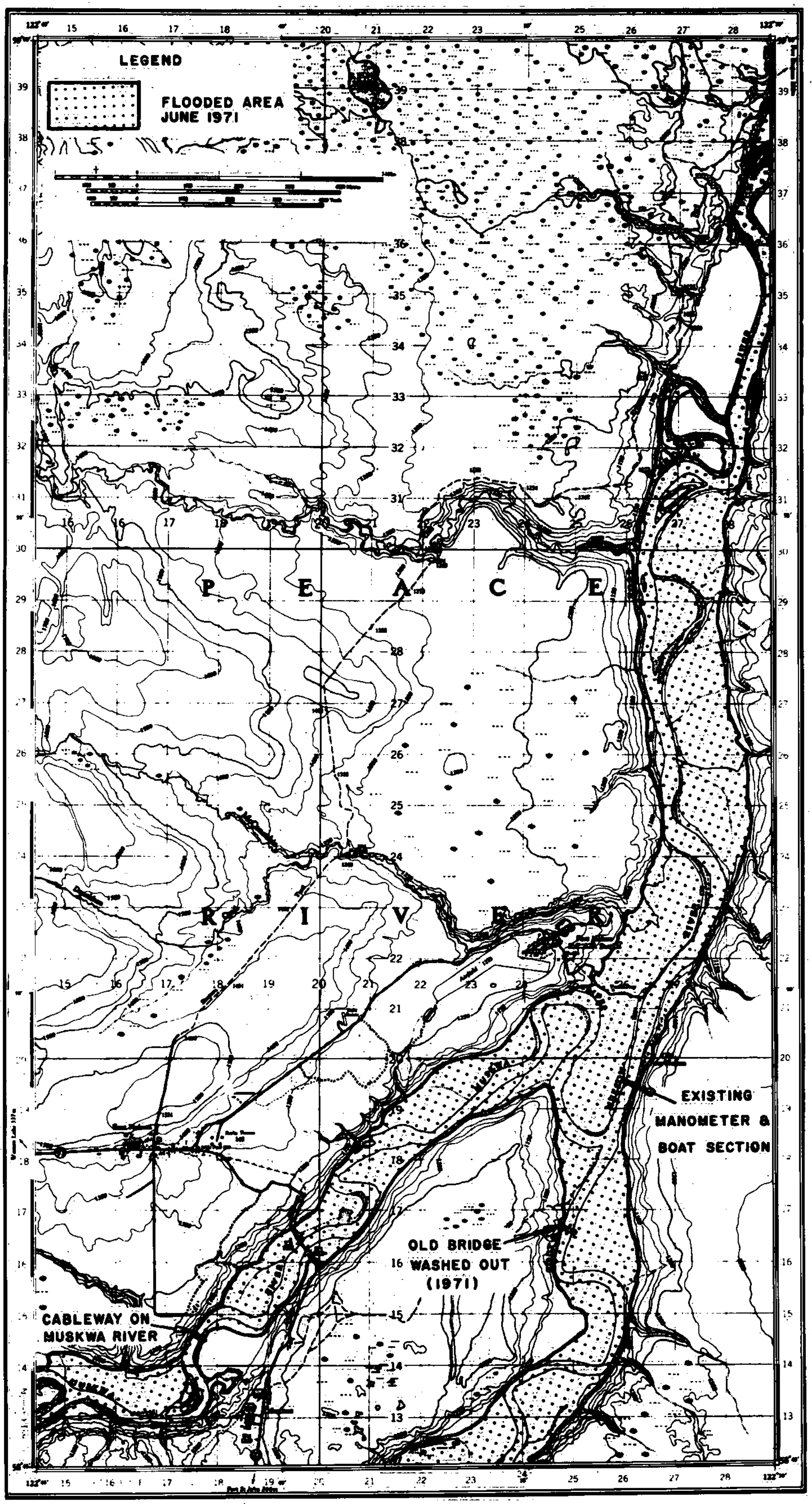


Figure 22. Extent of flooding–Fort Nelson.

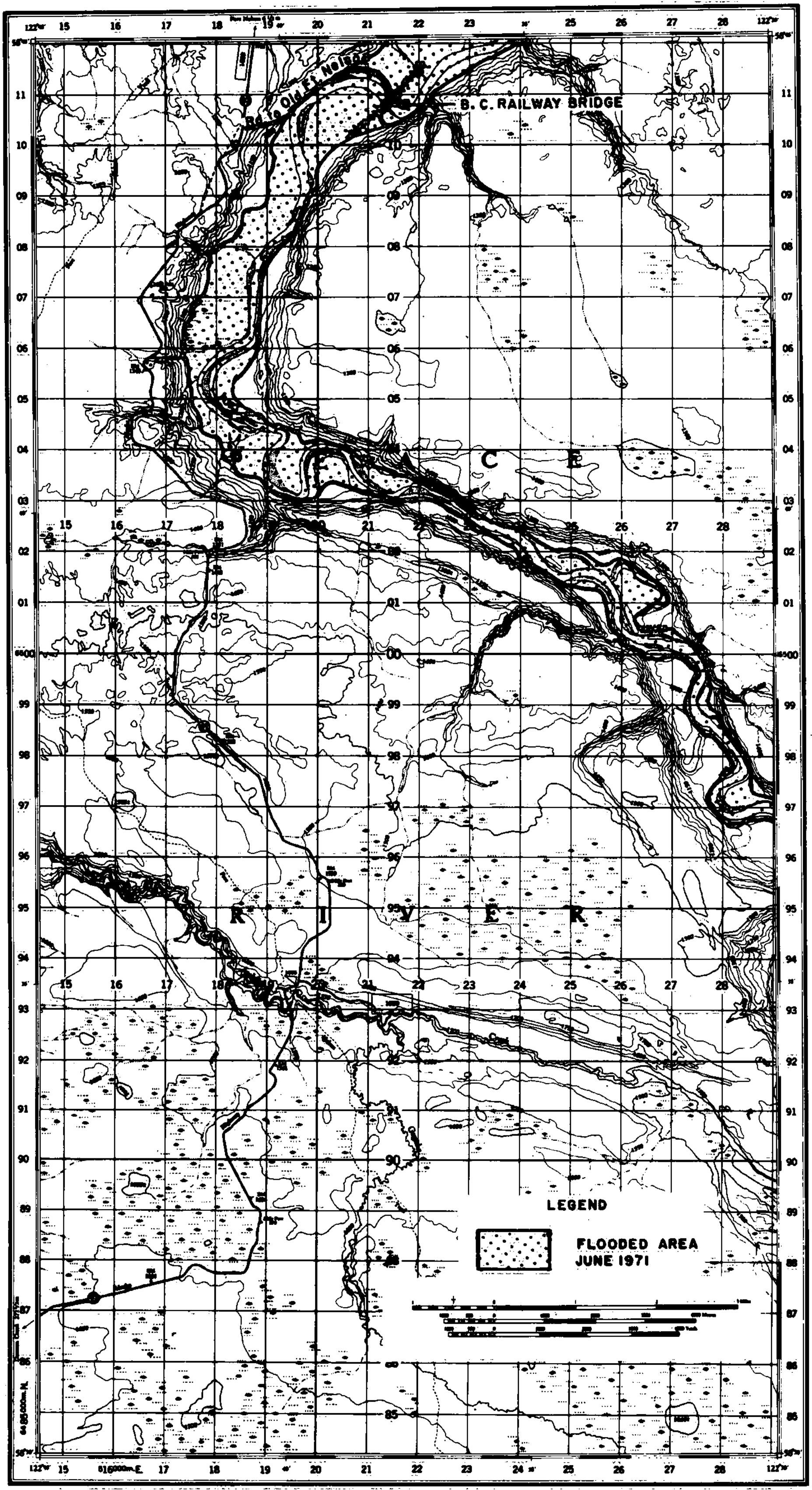


Figure 23. Extent of flooding–Jackfish Creek.

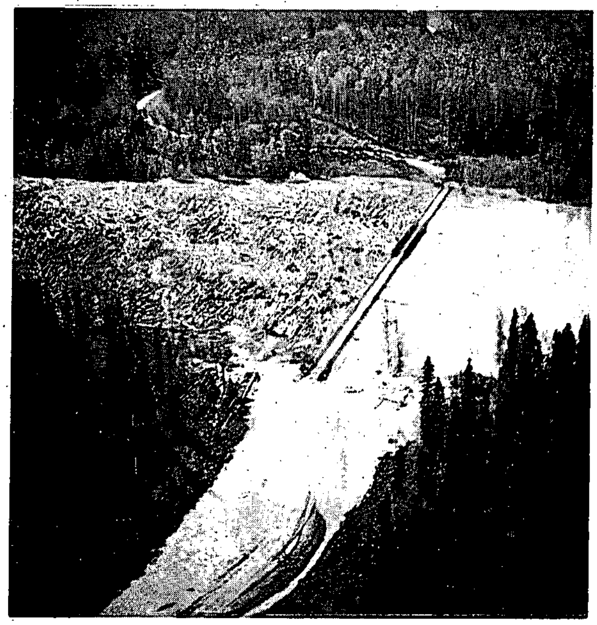


Figure 24. Bailey bridge across Fort Nelson River, June 16th, 1400 MST.

Figure 25. Debris behind Bailey bridge, June 16th, 1400 MST.

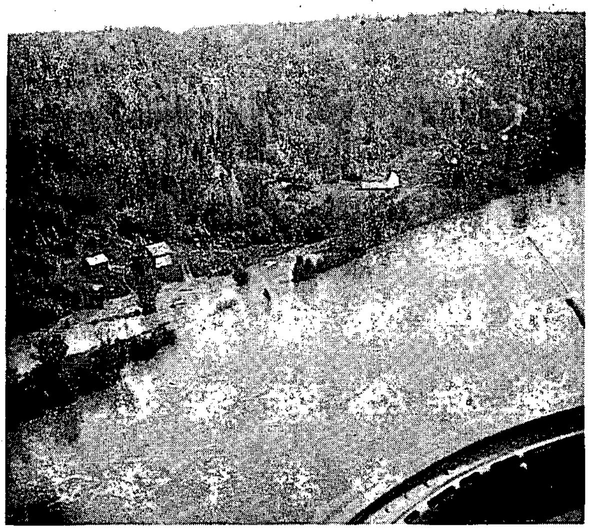


Figure 26. Old Town of Fort Nelson on right bank of Fort Nelson River, June 16th, 1600 MST.

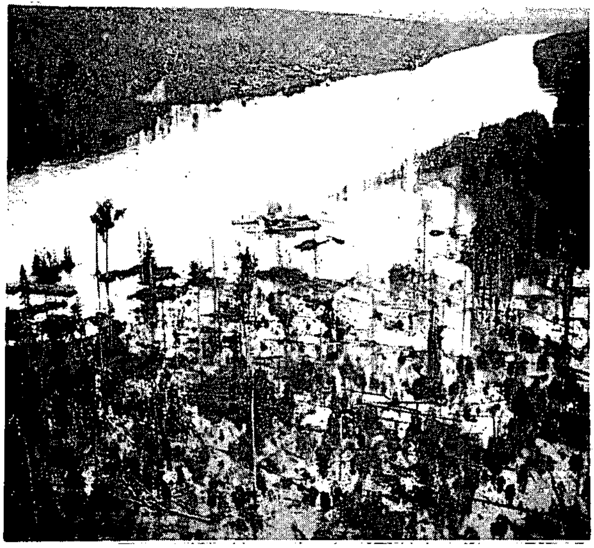


Figure 27. Freight barge landing on left bank of Fort Nelson River, June 16th, 1630 MST.

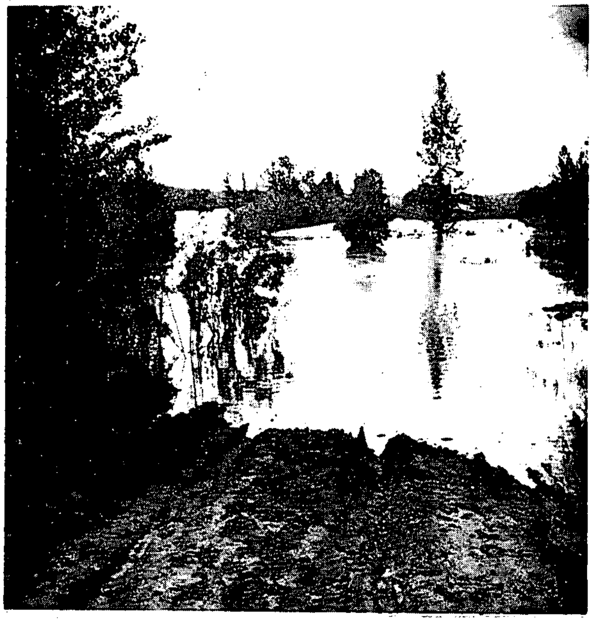


Figure 28. Road through Old Town of Fort Nelson, June 16th, 1600 MST.

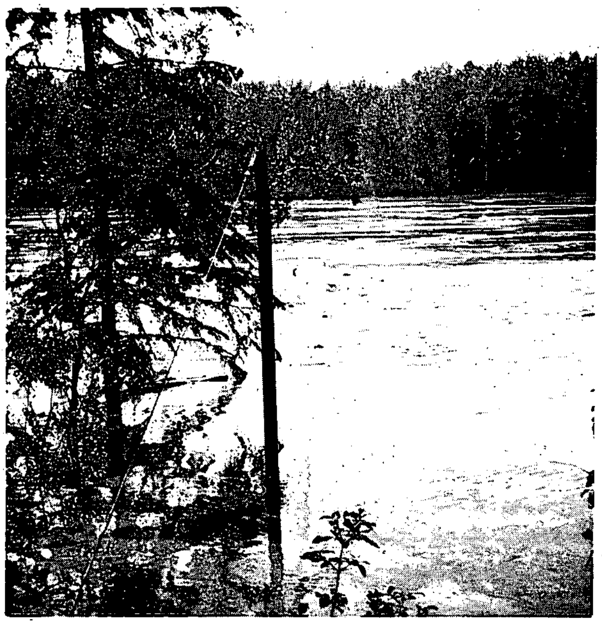


Figure 29. Remains of boom gauge, Fort Nelson River, June 16th, 1600 MST.

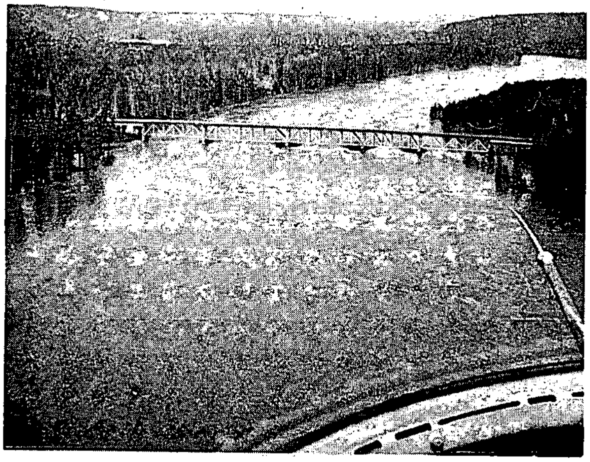


Figure 30. Alaska Highway Bridge across Muskwa River, June 16th, 1600 MST.

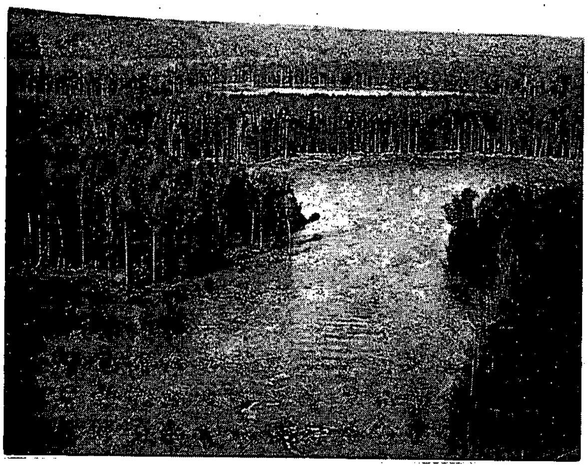


Figure 31. High-water channel near mouth of Muskwa River, June 16th, 1630 MST.

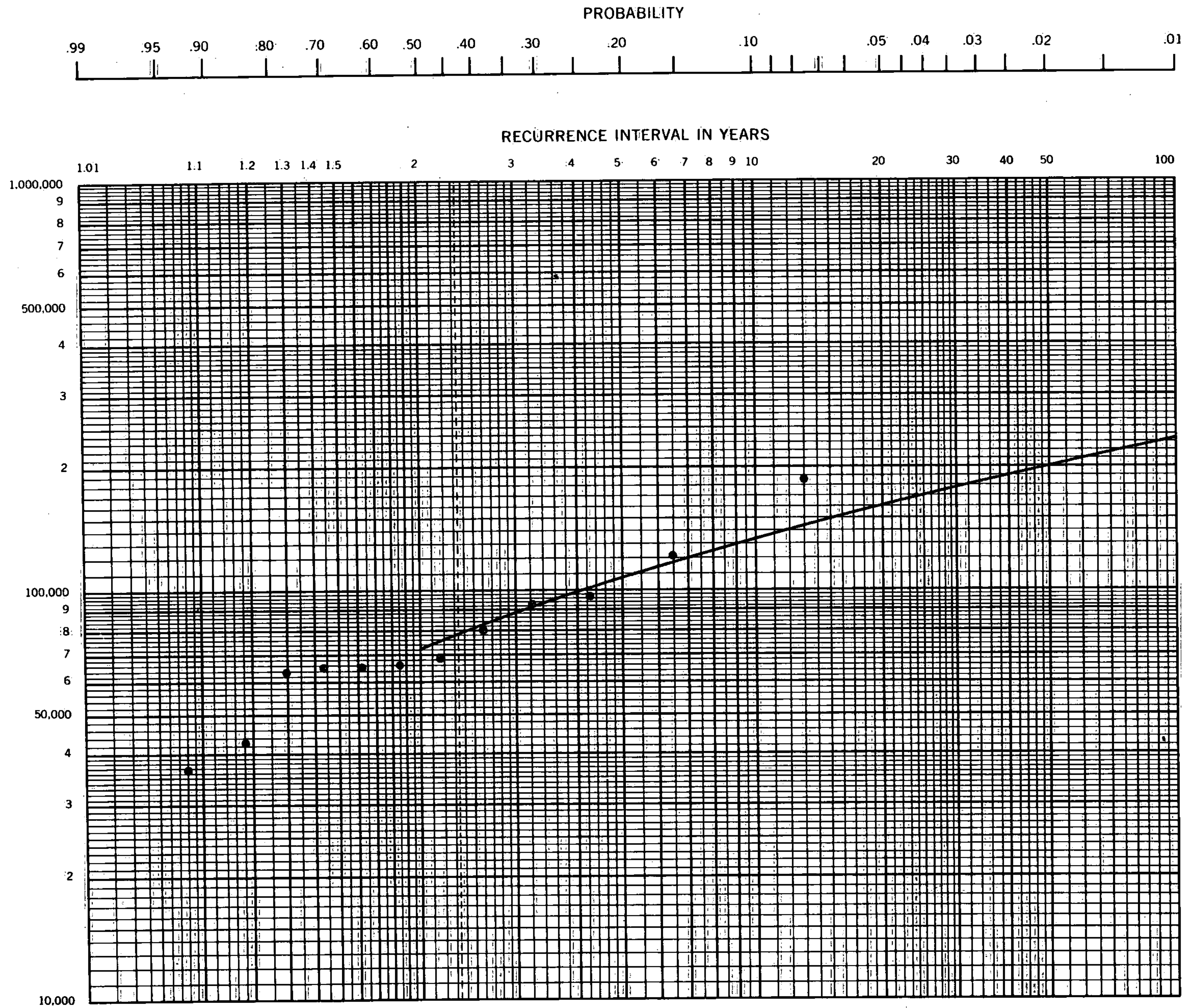


Figure 32. Frequency curve, Fort Nelson River at Fort Nelson, Station 10CC001.

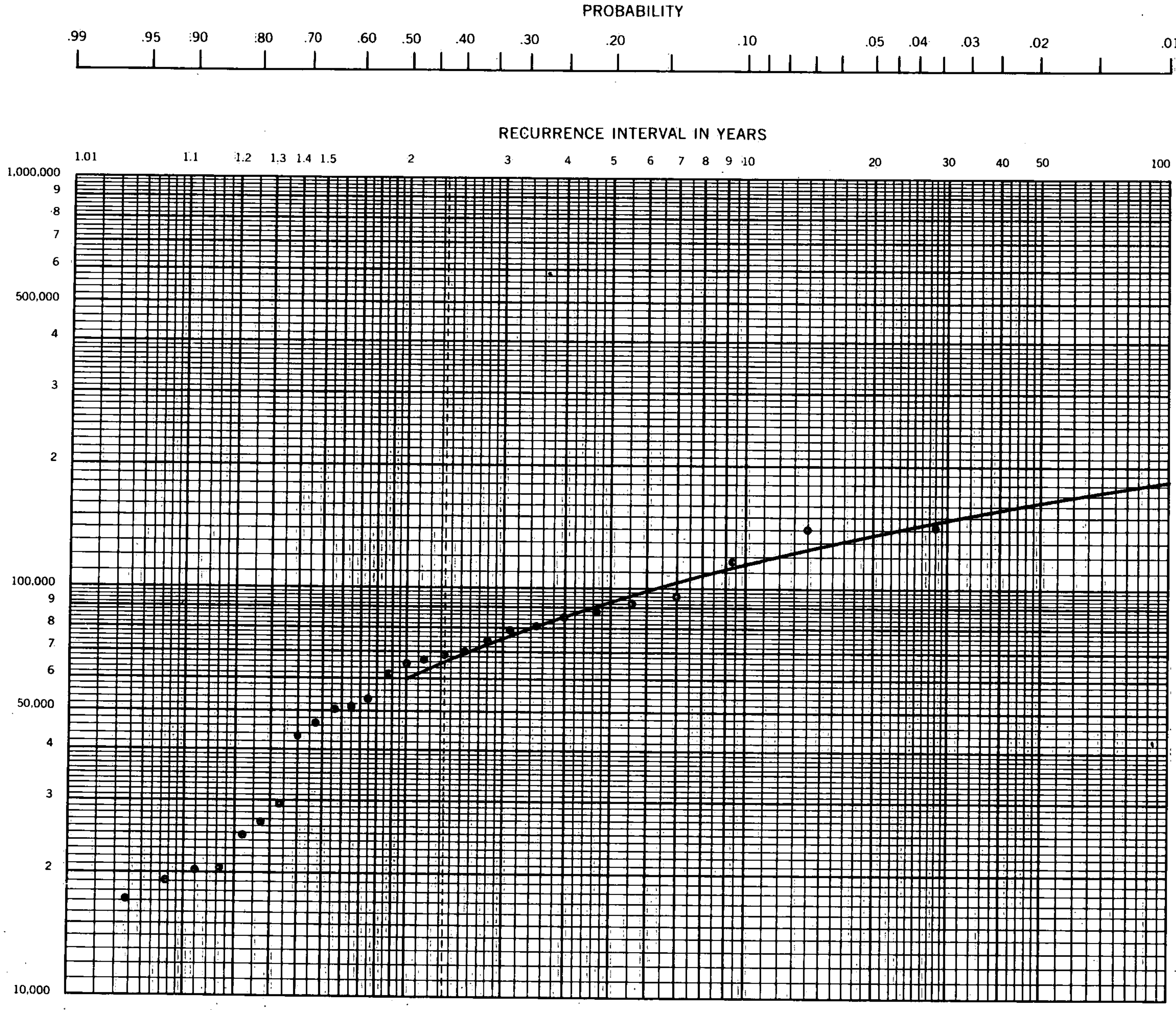


Figure 33. Frequency curve, Muskwa River near Fort Nelson, Station 10CD001.

Appendix

Definition of Rating Curves by Conveyance Method

FORT NELSON RIVER AT FORT NELSON – STATION 10CC001

It was considered desirable to shape the rating curve above the highest current-meter measurement to the maximum recorded gauge height as a check against the "eyeball" method.

The discharge for any stage is equal to the conveyance multiplied by the square root of the energy slope, $Q = KS^{1/2}$, where K is determined from Manning's formula as $K = 1.486 R^{2/3} A$. All factors that determine the conveyance can be obtained from field measurements, with the exception of the roughness coefficient *n*. This coefficient can be estimated from tables or photographs with reasonable accuracy.

The conveyances for a number of elevations are computed and plotted to define a curve of gauge height vs conveyance as shown on Figure A1. The cross section should be the average for the stream. The data obtained during the boat measurements were used to compute the cross-sectional area.

The energy slope for stages at which discharge measurements have been made is computed. These results are plotted to define a curve of gauge height vs energy slope. The curve is shown on Figure A1. This curve can be extended to the desired gauge height because the slope for flood stages tends to approach a constant, so that extension can be made accurately. For very high floods it is likely that the slope will approximate the general slope of the stream bed and thus may be determined from a low water profile or from a topographic map.

The rating curve as defined by this method plots to the left of the eyeball curve or gives a lower value for the same gauge height. The comparison of rating curves is shown on Figure A2. The instantaneous flow for the flood stage gauge height of 38.42 feet would be 227,000 cfs. This is approximately 3 percent less than that obtained from the eyeball extended rating curve. No allowance has been made for overbank flow, which could account for approximately 5-10 percent of the total flow at this section.

A more accurate assessment requires a cross-sectional survey covering the overbank flow section and summing the flow for two or more trapezoidal sections.

MUSKWA RIVER NEAR FORT NELSON – STATION 10CD001

The rating curve was extended by the conveyance-slope method using ten measurements taken over the last two years. Figure A3 shows the curve of gauge height vs conveyance and gauge height vs energy slope. The comparison of rating curves is shown on Figure A4.

A more reliable definition was obtained for this station because all of the measurements used were taken from the cableway. The top end of the conveyance extension of the rating curve plots to the right of the eyeball curve. Verification of the extension should be made by an indirect slope-area measurement.

The instantaneous flow for the flood stage gauge height of 34.45 feet would be 175,000 cfs. This is approximately 6 percent more than that obtained from the eyeball extended rating curve.

As with the Fort Nelson River, no allowance has been made for overbank flow. It could amount to approximately 3 percent of the total flow at this section.

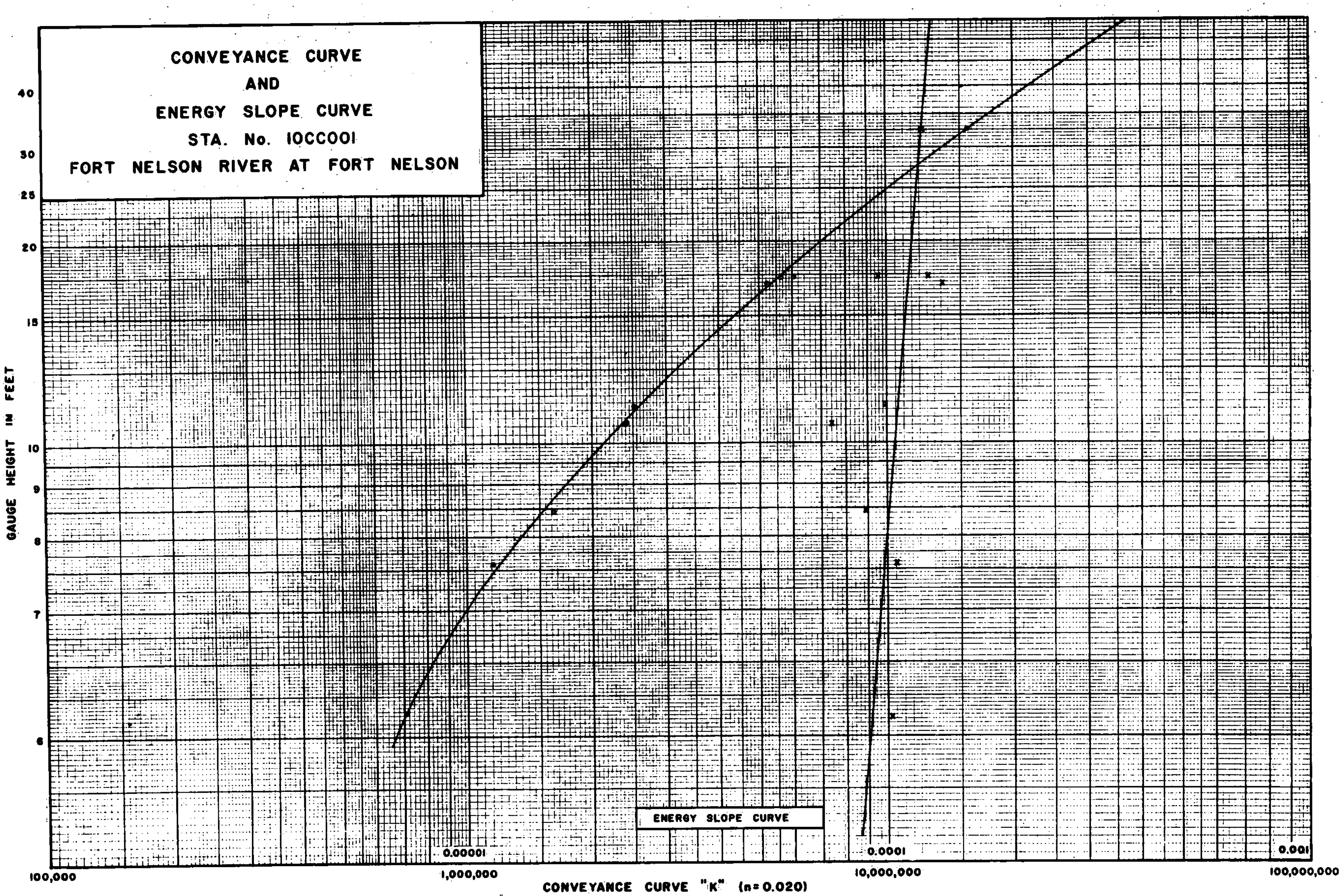


Figure A1. Conveyance curve and energy slope curve, Fort Nelson River at Fort Nelson, Station 10CC001.

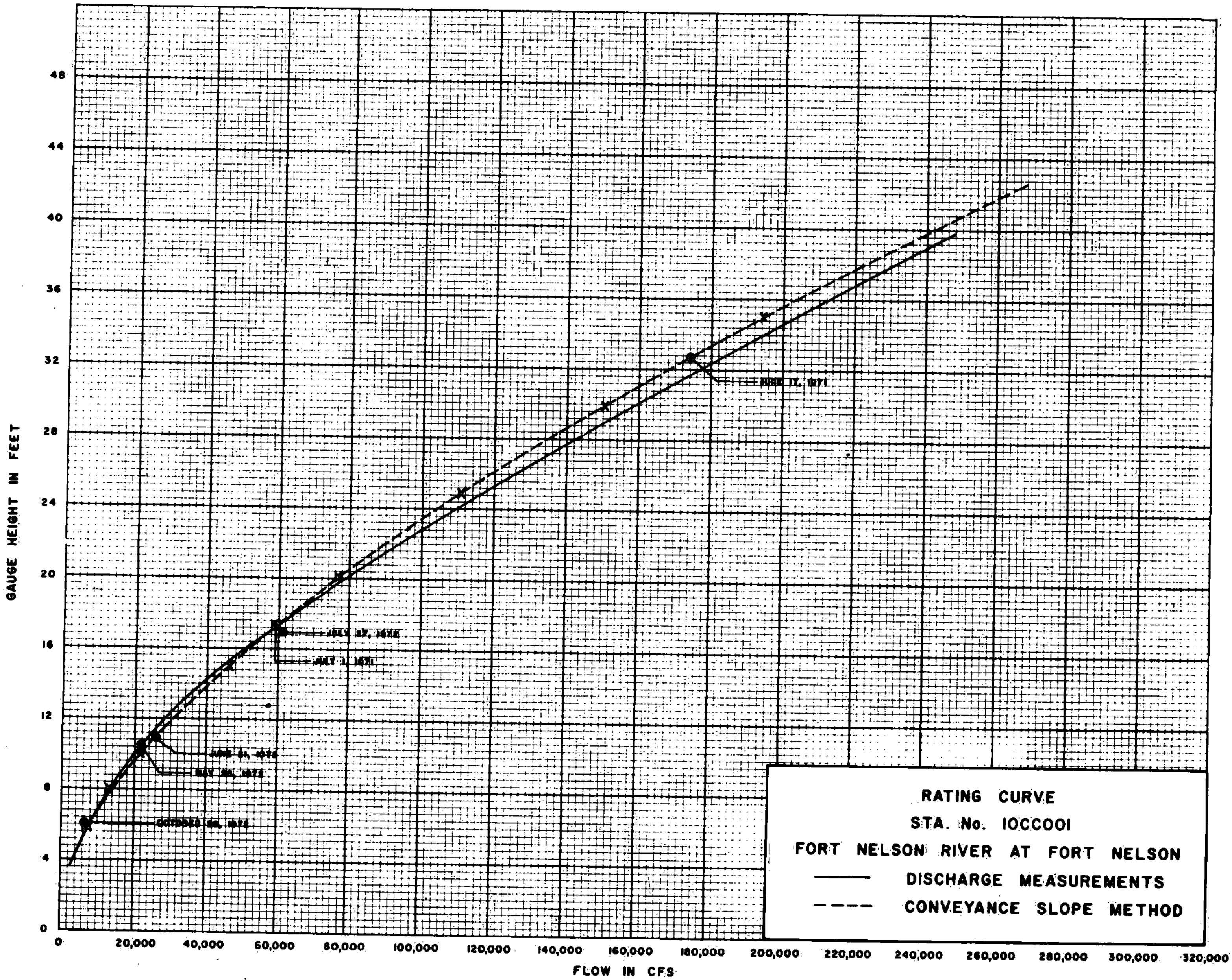


Figure A2. Rating curve, Fort Nelson River at Fort Nelson, Station 10CC001.

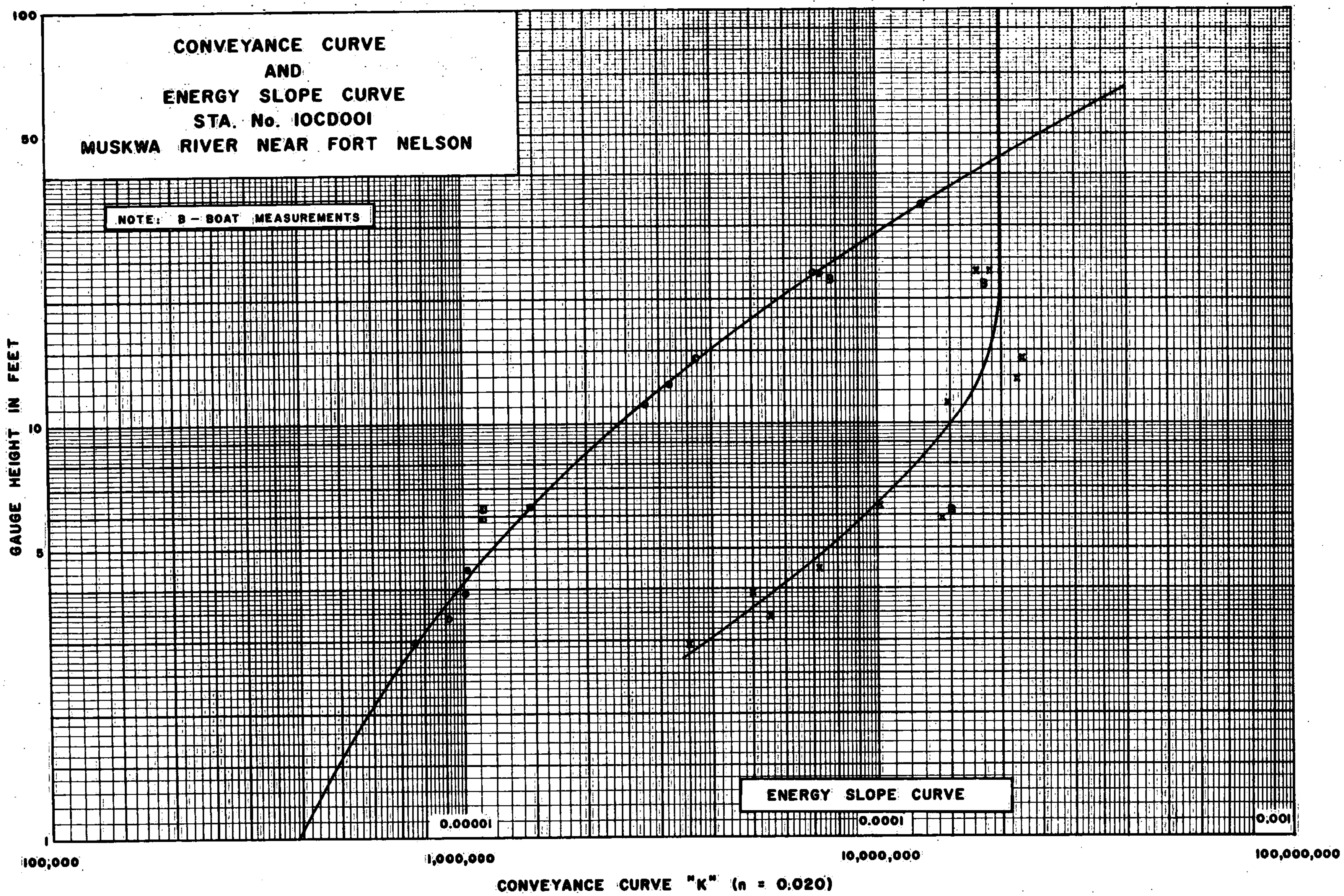


Figure A3. Conveyance curve and energy slope curve, Muskwa River near Fort Nelson, Station 10CD001.

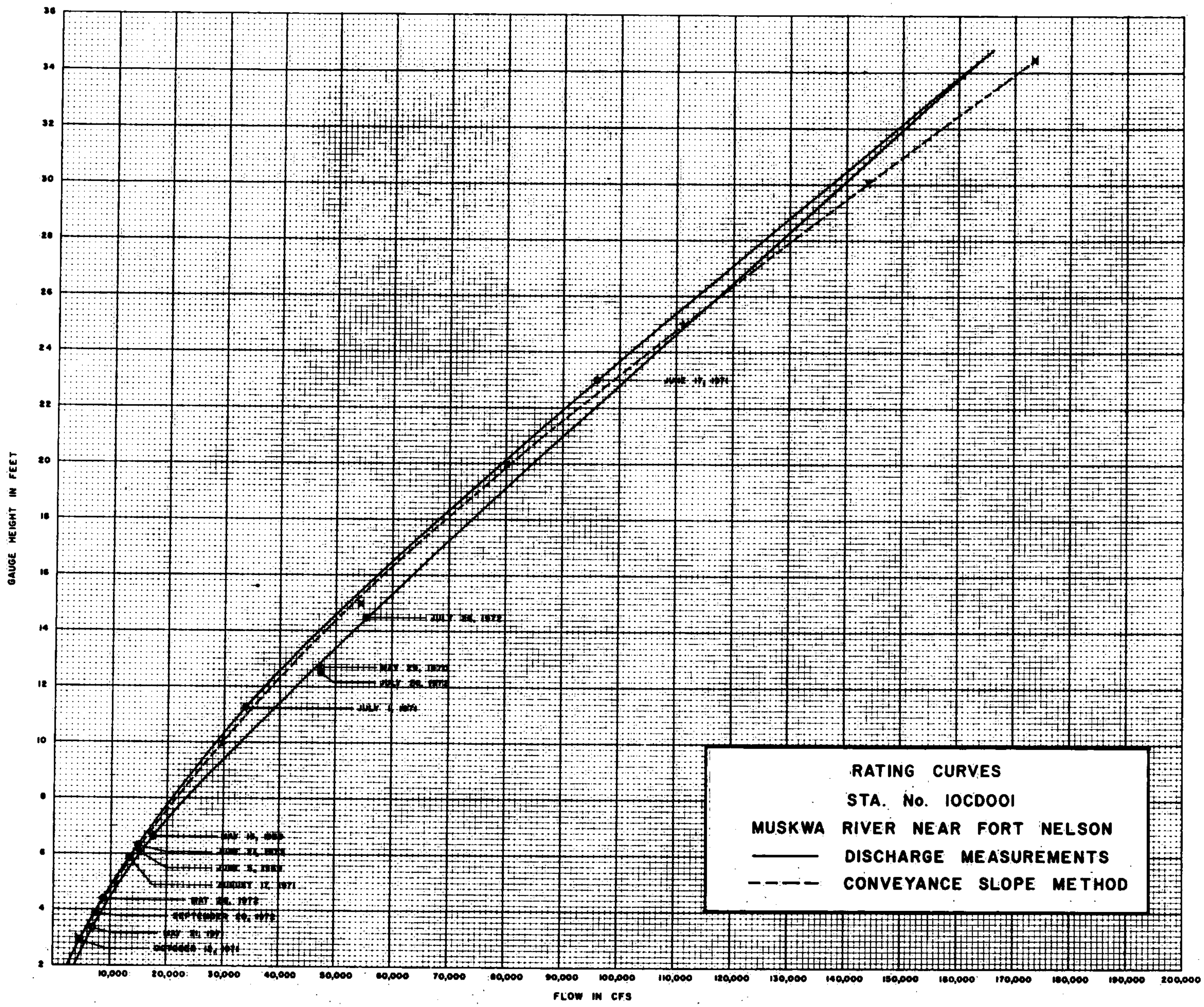


Figure A4. Rating curves, Muskwa River near Fort Nelson, Station 10CD001.