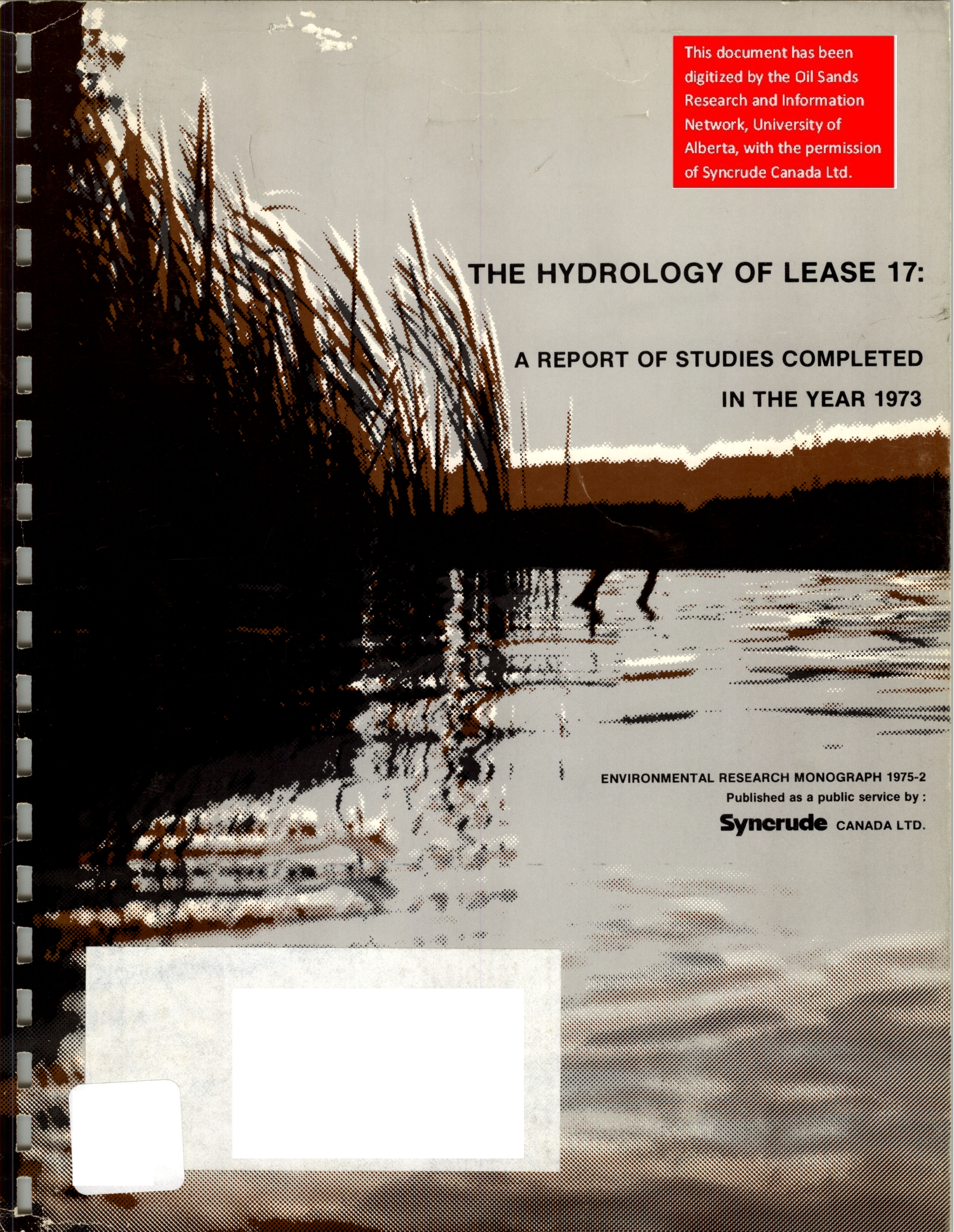

THE HYDROLOGY OF LEASE 17:

A REPORT OF STUDIES COMPLETED IN THE YEAR 1973

ENVIRONMENTAL RESEARCH MONOGRAPH 1975-2

Published as a public service by :

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THE HYDROLOGY OF LEASE 17:

A REPORT ON STUDIES COMPLETED IN THE YEAR 1973

SYNCRUDE CANADA LTD.

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Through a comprehensive program of surveillance of the effects of our technology and careful application of that technology, we aim to prevent accidental damage to the environment. Total effects will be examined by professional ecologists and study results provided to public representatives.

FOREWORD

The usual conflict that exists between mining activities and environmental protection (and that makes environmental research a necessary constituent of modern mining technology) is absent from hydrological studies. Sound hydrological management is essential to both efficient mining and protection of the environment. The hydrological studies reported in this monograph have been abstracted from a preliminary investigation, undertaken in 1973 on behalf of Syncrude Canada Ltd. Although the investigation was intended principally for the use of mining and civil engineers to provide information for proposed changes to the drainage of Crown Lease No. 17, this preliminary work was considered suitable for inclusion in the Syncrude monograph series because the work, of necesssity, involved study of the many ecological variables that contribute to the science of hydrology. The investigation culminated in the prediction of flood frequencies for streams of the area, and these findings are reported here. It is emphasized however, that the purpose of publishing this work is not to provide reliable values of predicted flood frequencies for Lease No. 17 but to show how a preliminary investigation, starting from very limited meteorological and run-off data, may be performed.

Hydrology is one of the most ubiquitous of ecological disciplines, involving an understanding of geology, topography, existing drainage, vegetation, and meteorology. The monograph therefore includes a review of these topics which, it is hoped, will make it a useful source of reference when each of the topics is itself under separate investigation.

The Syncrude project is a pioneering enterprise in the large-scale mining of tar sand and has been initiated at a time when the consuming public, while aware of the urgent need to find new sources of oil, is concerned that this very urgency may lead to serious ecological damage in the tar sands region. Fortunately the relatively new environmental sciences make possible the industrial development of the tar sands in an ecologically-organized fashion. With this in mind, Syncrude's mining and industrial work is supported by ecological studies undertaken both by Syncrude's own environmental scientists and by outside consultants. To provide maximum benefit these research findings are issued as Syncrude environmental monographs intended for the scientific community at large and for interested members of the public.

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ABSTRACT

Flood frequency prediction for Syncrude Lease 17 is necessary for both mining activities and environmental protection. Due to a scarcity of local data, flood frequency curves could not be prepared directly. It is demonstrated that flood frequency curves can be derived from limited data following an indirect method in which one year's local data is generalized by reference to precipitation and runoff records from similar terrain. The study involved a stream-gauging program (undertaken in 1973), and the preparation of a regional flood-frequency curve and flood frequencies for individual streams on the lease. These, in their turn, have required the study of precipitation, geology, topography and vegetation for the area.

The result is:

(a) a general review of the hydrologically-significant features of the lease, and

(b) a set of flood-frequency curves adjusted by reference to the stream gauging program of 1973.

1. INTRODUCTION

To provide design criteria for an effective drainage scheme for the Syncrude mine at the Athabasca tar sands, it is necessary that the behaviour of surface water in the area be understood.

Water management for the Syncrude project is complicated by the need to divert the surface runoff currently carried through the lease to the Athabasca River via Beaver Creek. The creek will be dammed at the southern boundary of the lease and the water re-routed via a canal into Ruth Lake. A canal on the outlet side of Ruth Lake will lead water into Poplar Creek, with the confluence controlled by a dam and spillway. Hydrological studies are called for: to assess the efficacy of the proposed new drainage scheme; to project its effect on the currently-established natural drainage; and to help in deciding how to monitor changes that will occur throughout the mining process.

While the immediate need for a hydrological study arose from mining considerations, the study simultaneously provided useful ecological information about the area.

In assessing the overall water balance, the following program was pursued:

a) An inventory was taken of the "hydrological budget", i.e. water entering the area as precipitation, and water leaving the area by means of evaporation, sublimation, and surface drainage.
b) The existing areas of soil and vegetation types were planimetered, and the geology and topography of the lease reviewed.
c) Flood frequency curves* were constructed from available data and adjusted by the application of runoff measurements made in the study area in 1973.

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*See Glossary

The study focused on the Beaver Creek region since this was to be the most affected area.

2. LOCATION OF THE STUDY AREA

The area for which hydrological data were collected during the summer of 1973 is shown in Fig. 1. Lease No. 17, located approximately 25 miles north of Fort McMurray, includes portions of the MacKay River and Beaver Creek drainage basins. Since mining will initially be restricted to the Beaver Creek basin, and a flow diversion into the adjoining Poplar basin is being planned, the study has concentrated on these two basins. Fig. 1 shows the location of the Beaver and Poplar basins, together with basin outlines for those Beaver tributaries which were gauged as part of this study.

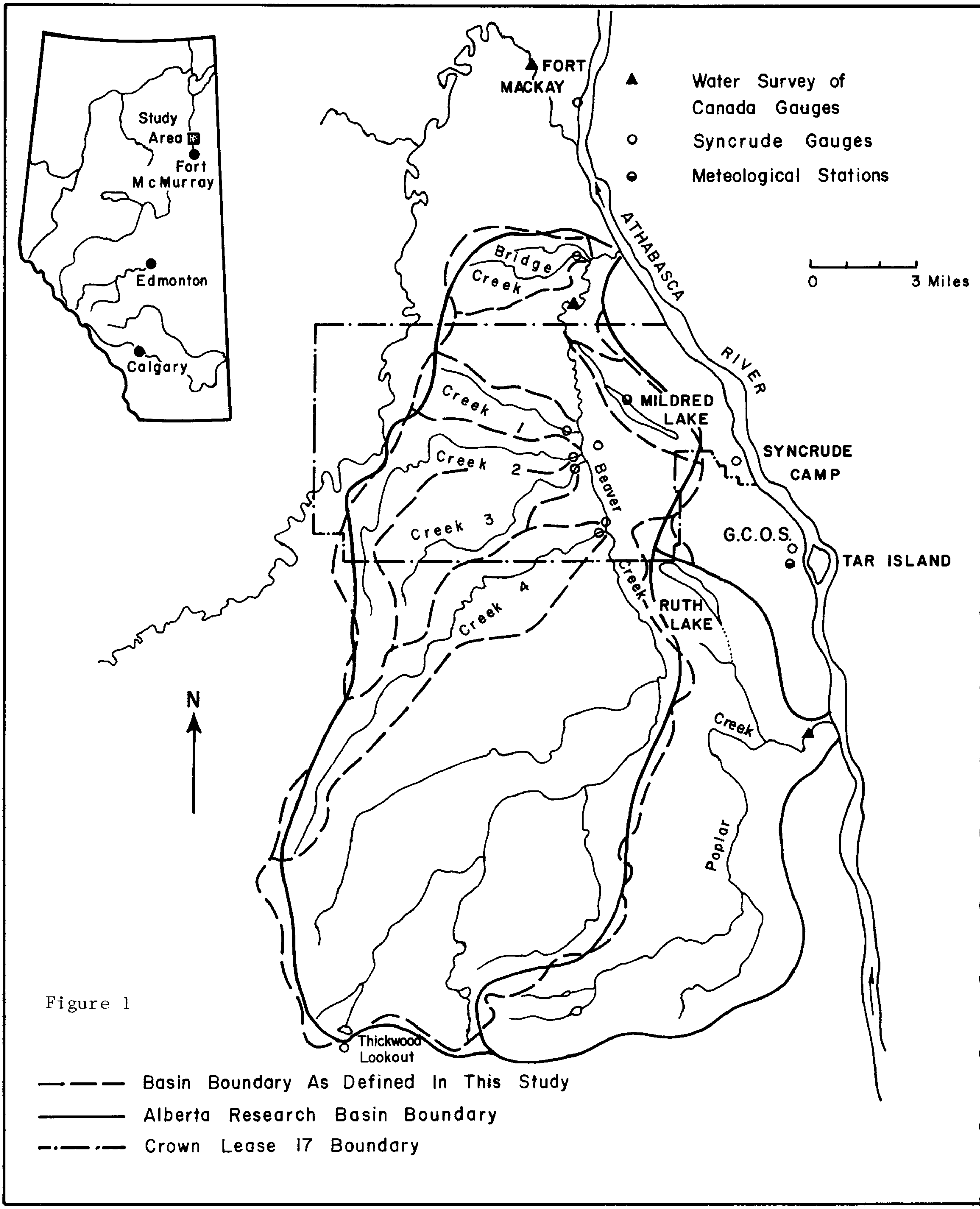

Study Area
Fort McMurray
Edmonton
Calgary
FORT MACKAY
Water Survey of Canada Gauges
Syncrude Gauges
Meteological Stations
ATHABASCA RIVER
0 3 Miles
Bridge Creek
Creek 1
Creek 2
Creek 3
Creek 4
Beaver Creek
MILDRED LAKE
SYNCRUDE CAMP
G.C.O.S.
TAR ISLAND
RUTH LAKE
Creek
Poplar
N
Thickwood Lookout
Basin Boundary As Defined In This Study
Alberta Research Basin Boundary
Crown Lease 17 Boundary

Figure 1

3. INGRESS OF WATER INTO THE AREA BY PRECIPITATION

3.1 Regional Climate

According to climatic data recorded at Fort McMurray airport over the past 27 years, the region has a cold, snowy, forest climate (Köppen classification Dfc) with a large annual range of temperatures. The summer is short and relatively cool. Although summer cyclonic storms bring occasional heavy precipitation, summer precipitation is generally light. Nevertheless, low evaporation resulting from low temperatures keeps the climate moist. Winter precipitation is also light but the low temperatures allow a considerable accumulation of snow for between 5 and 7 months.

The study area encompasses the Beaver and Poplar Creeks. To assist in deciding how climate in the headwaters affects these little-studied creeks, an analogy may be drawn between Birch Hills (for which climatic data exist) and the Thickwood Hills of the Beaver and Poplar Creek headwaters. It has been pointed out in *An Environmental Study of the Athabasca Tar Sands* (Intercontinental Engineering of Alberta, Ltd., 1973) that due to elevation, the Birch Hills area is up to 10°F warmer in winter, and 10°F cooler in summer than the surrounding lowlands. Accordingly, the Thickwood Hills may be expected to have a similarly modified climate, with the effect that summer evaporation would be lower than in the lowlands, and winter snowfall higher, but with increased snow losses due to sublimation.

Of the 143 meteorological stations in northern Alberta, 122 were active in 1970 -- the date of the latest collected report (Department of Transport, 1970). Many of these stations are fire lookouts which report maximum and minimum temperatures and 24 hour precipitation in the summer months only (usually less than 5 months per year). However, the data from the fire lookouts are more useful than may appear from their seasonal nature because it has been established that the largest floods in northern Alberta result from rainfall rather than snowmelt. The period of record is short for the majority of the 143 stations, usually from 3 to 10 years, but a few cover more than 50 years. The locations of hydrometric sites and meteorological stations in the north of the province are shown in Fig. 2.

3.2 Mean Precipitation

Table 1 indicates that the distribution of mean precipitation across northern Alberta is relatively uniform, ranging from 14 to 17 inches. Although for Crown Lease No. 17 the *Atlas of Alberta* (1969) indicates a mean annual precipitation of 18 inches, Table 1 suggests 17 inches as a better estimate -- at least for the lower regions. Because mean precipitation for the months of May to August is 17% larger at the Thickwood Hills Lookout (10.74 inches) than at the lower-lying Fort McMurray Airport (9.14 inches), mean annual precipitation over the Beaver Creek basin may be assumed to vary, depending on elevation, from 17 to 19 inches.

Given that for 68% of all years, mean annual precipitation is within ± 23% of the long term mean (i.e. coefficient of variation is 23%) (Thomas, 1964), an approximate frequency curve for mean annual precipitation can be drawn. It is shown as Fig. 3.

3.3 Maximum Rainfall Rates

The most recent detailed study of high intensity rainfall in the province of Alberta was published as far back as

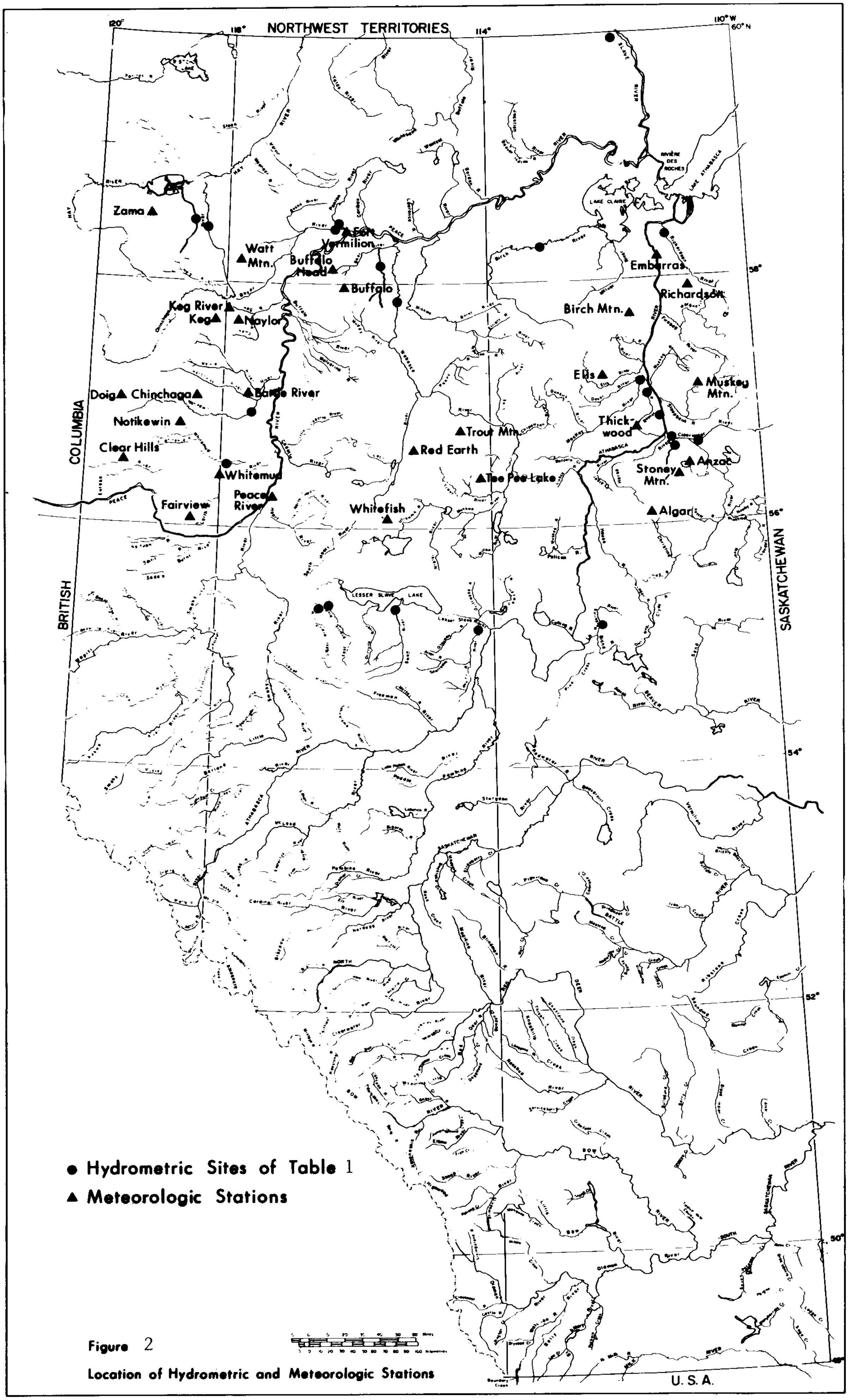


Figure 2

Location of Hydrometric and Meteorologic Stations

Table 1: SUMMARY OF PRECIPITATION DATA, 1941-1970

Station[1]		Number of Years of Record	Max. 24-Hour Precipitation (inches)	Mean Annual Rainfall (inches)	Mean Annual Precipitation (inches)
Alberta, North of 56° Lat.					
Algar	Lo	14	3.21		
Battle River	Lo	15	3.86		
Birch Mountain	Lo	11	2.37		
Buffalo Head		27	2.53	9.93	14.71
Buffalo	Lo	12	3.28		
Chinchaga	Lo	13	3.05		
Clear Hills	Lo	16	3.25		
Deadwood	Lo	10	3.66		
Doig	Lo	12	2.91		
Ells	Lo	10	1.67		
Embarras		20	3.22	10.47	15.71
Fairview		30	2.50	10.12	16.63
Fort McMurray	A	27	2.38 [2]	11.99	17.14
Fort Vermillion		30	2.36	8.94	14.18
Keg River		30	2.36	10.44	15.87
Keg	Lo	11	3.63		
Muskeg	Lo	12	3.23		
Naylor Hills	Lo	16	3.67		
Notikewin	Lo	13	4.01		
Peace River	A	18	1.89	8.88	13.81
Red Earth	Lo	12	2.01		
Richardson	Lo	11	1.66		
Stoney Mountain	Lo	17	3.11		
Teepee	Lo	11	2.33		
Thickwood	Lo	14	2.37		
Trout Mountain	Lo	10	2.18		
Watt Mountain	Lo	14	3.13		
Whitefish	Lo	13	3.04		
Whitemud	Lo	17	3.79		
Zama	Lo	10	2.29		
Saskatchewan, North of 56° Lat., West of 105° Long.					
Stony Rapids		10	2.75	9.60	15.13
Uranium		13	1.84	8.00	13.94

1) Lo - Lookout
A - Airport
2) A maximum of 3.34 has been observed before 1941.

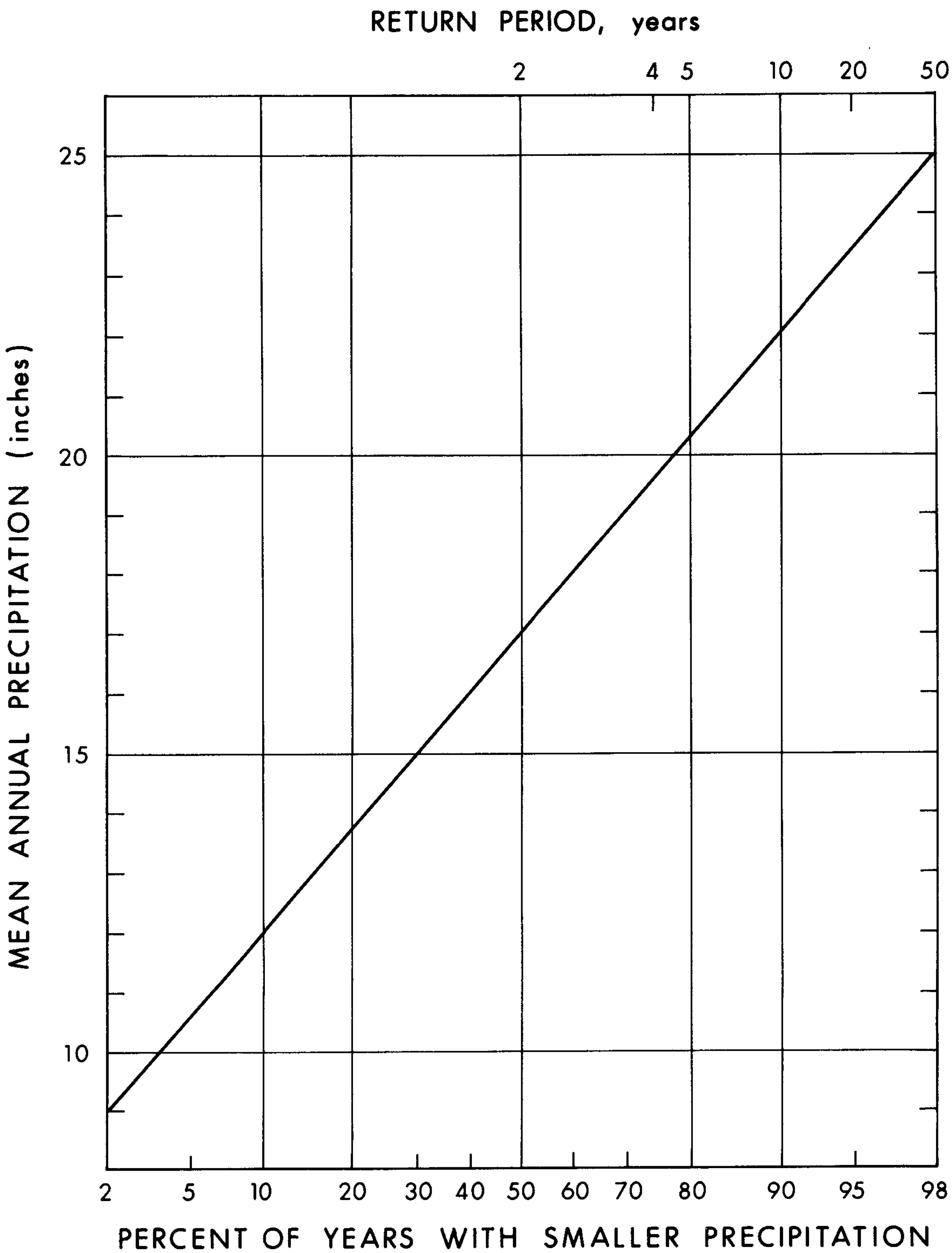


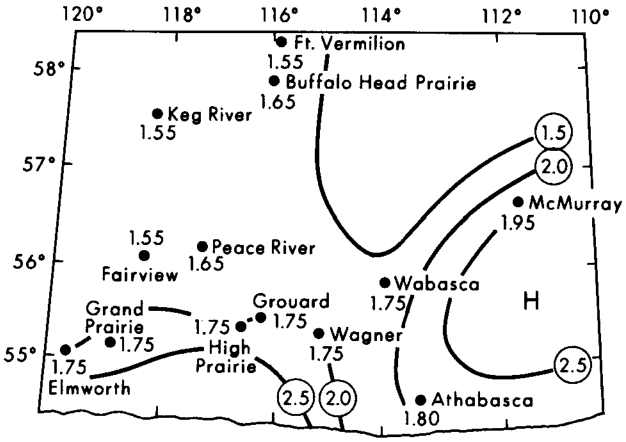
Figure 3 Approximate Distribution of Mean Annual Precipitation over Lower Beaver Basin

1963 (Storr, 1963), and deals with data collected between 1916 and 1960. The northern portions of Storr's maps for three return periods are reproduced as Fig. 4. The variation of 24 hour maxima across northern Alberta is seen to be small, with the gradient decreasing to the north and west of the province. Any orographic effect in the Thickwood Hills and Birch Hills escapes detection due to lack of data. Storr's study suffers from two drawbacks: first, during this period, the data coverage for northern Alberta as a whole was sparse; and secondly, readings were for artifically-fixed 24 hour periods rather than for 24 hour periods of natural maximum rainfall. Natural rainfall maxima have been found to be about 13% higher than fixed maxima.

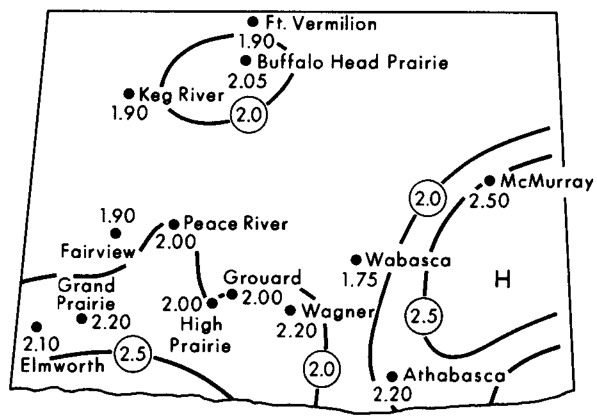
Later but less specific maps of rainfall intensity for the whole of Canada have been prepared by Bruce (1968). He has investigated rainfall for various durations ranging from 5 minutes to 72 hours, and applied a 13% adjustment to convert values from artificial to natural maxima. Data analysed by these two authors have been used to prepare approximate frequency curves for Crown Lease No. 17 (Fig. 5). All values include the 13% correction factor.

To check whether Fig. 5 is in keeping with recent, more extensive data, Table 1, assembled from the latest published summary of meteorological data (Atmospheric Environment Service, 1970) may be referred to. All the stations in the publication that are located north of 56° in Saskatchewan are listed (Fig. 2). Thirty-two stations are involved, including new fire lookouts at the higher elevations. From Fig. 5 one would expect maximum 24 hour precipitation in the lower Beaver basin to lie between 2.3 inches for the 10 year return period*, and 3.2 inches for the 30 years return period. This range of values is found more or less in the precipitation records listed in Table 1.

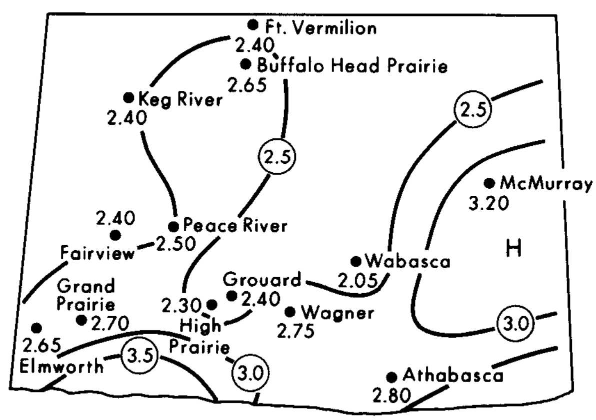
*See Glossary



5 YEAR RETURN PERIOD



10 YEAR RETURN PERIOD



25 YEAR RETURN PERIOD

Figure 4   24-Hour Rainfall Intensities for Northern Alberta

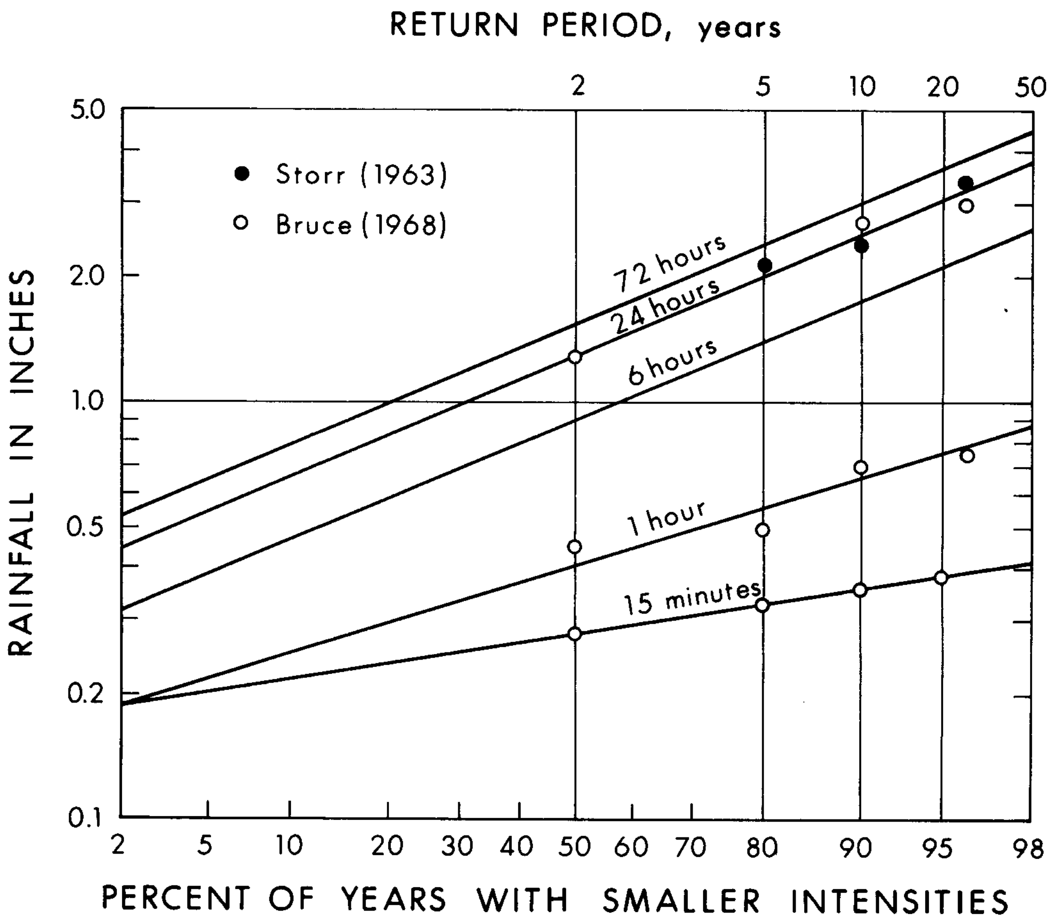


Figure 5 Rainfall Intensities in the Lower Beaver River Basin

3.4 Storm Analysis

The frequency curves of Fig. 5 do not give any information as to the areal extent of high intensity rainfall. To evaluate this, isohyetal maps* of many individual storms must be plotted. The Atmospheric Environment Service has done this for most major storms since about 1960, and, since 1970, on a continuous basis for all storms producing more than 3 inches of rain. These isohyetal maps are publicly available but no detailed analysis has been undertaken to date. However, a preliminary analysis (Buckler and Pollock, 1972) based on 55 storms, has produced the rainfall area-frequency relation shown in Table 2. The results are not directly comparable with readings for the Beaver basin (Fig. 5) because the frequencies in the table are for storms occurring "somewhere in Alberta". Clearly, the return periods for any one fixed location would be far longer.

Examination of some of the isohyetal maps shows that the 24 hour and 72 hour intensities for the Beaver basin (Fig. 5) are applicable to areas up to 100 square miles without reduction. The intensities for shorter periods are not to be relied upon because intense, highly localized storms of short duration (e.g. thunderstorms) would introduce anomolies. The Fort McMurray station is particularly vulnerable to this effect, being subject to approximately 50 hours' of thunderstorms per year.

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*See Glossary

Table 2: INTENSITY - AREA - FREQUENCY RELATIONS FOR ALBERTA (from Bucker and Pollock, 1972)

Rainfalls expected to be exceeded somewhere in Alberta, on the average once in:

<u>100 Years</u>

Duration (Hours)	Area (square miles) 100	300	1000	
6	5.0	4.2	3.3	(inches)
12	7.0	6.2	5.1	
24	9.0	8.3	7.0	
48	10.3	9.5	8.8	
72	10.4	9.8	9.1	

<u>10 Years</u>

Duration (Hours)	Area (square miles) 100	300	1000	
6	3.2	2.8	2.2	(inches)
12	4.7	4.2	3.6	
24	6.3	5.8	5.1	
48	7.6	7.1	6.6	
72	8.2	7.7	7.2	

4. FACTORS AFFECTING EGRESS OF WATER FROM THE AREA

Hydrology is concerned less with precipitation itself than with the progress of precipitation on reaching the ground. An investigation into the relationship between precipitation and runoff is here prefaced by a review of the relevant geography of the study area.

4.1 Bedrock Geology and Bedrock Topography

The bedrock geology of the Fort McMurray area has been mapped by the Alberta Research Council (Carrigy and Collins, 1959), and the appropriate information used to prepare a geological map of the study area (Fig. 6). Most of the bedrock underlying the area belongs to the shales and sandstones of the Cretateous Clearwater formation. Being impermeable, this material affects the hydrology of the area. In headwater regions of the Thickwood Hills there is a small area of the porous and permeable Grand Rapids sandstone, and where this abuts with the impermeable Clearwater formation, springs emerge. In lower reaches of the Beaver and Poplar basins, tar sand of the McMurray formation provides the upper surface of the bedrock.

Information on bedrock topography is available only for the southern half of the study area (Carlson, 1971). Preliminary mapping indicates that the drift thickness varies from 100 feet of till in the Thickwood Hills to 20 feet or less of glaciofluvial deposits in the lower reaches of both the Beaver and Poplar basins.

4.2 Surficial Geology

Surficial geology, mapped for the study area in Fig. 7 (derived from Bayrock, 1971) affects water retention and hence rate of runoff. Planimetering of the various surficial deposits gave values for area and composition listed in Table 3.

For the Beaver basin as a whole, almost 75% of the surface is composed of glaciolacustrine deposits of silt, clay, and sand (generally overlaying glacial till). Principal surficial components of particular localities within the study area are as follows:

Beaver Creek, headwaters	glacial till
Beaver Creek, lower reaches	glaciofluvial sands and gravels
Creeks 1, 2, 3, and 4	glaciolacustrine deposits
Bridge Creek, lower reaches	some glaciofluvial material
Poplar Basin	predominantly glaciolacustrine, but with some glaciofluvial deposits
Mildred Lake Basin	glaciofluvial material alone or overlain by aolean sands. This anomalous regime results from Mildred Lake's occupying a glacial meltwater channel.

4.3 Surface Topography

The elevation of the area ranges from less than 800 feet along the Athabasca River to over 1700 feet in the Thickwood Hills. The general slope is upwards to the northeast,

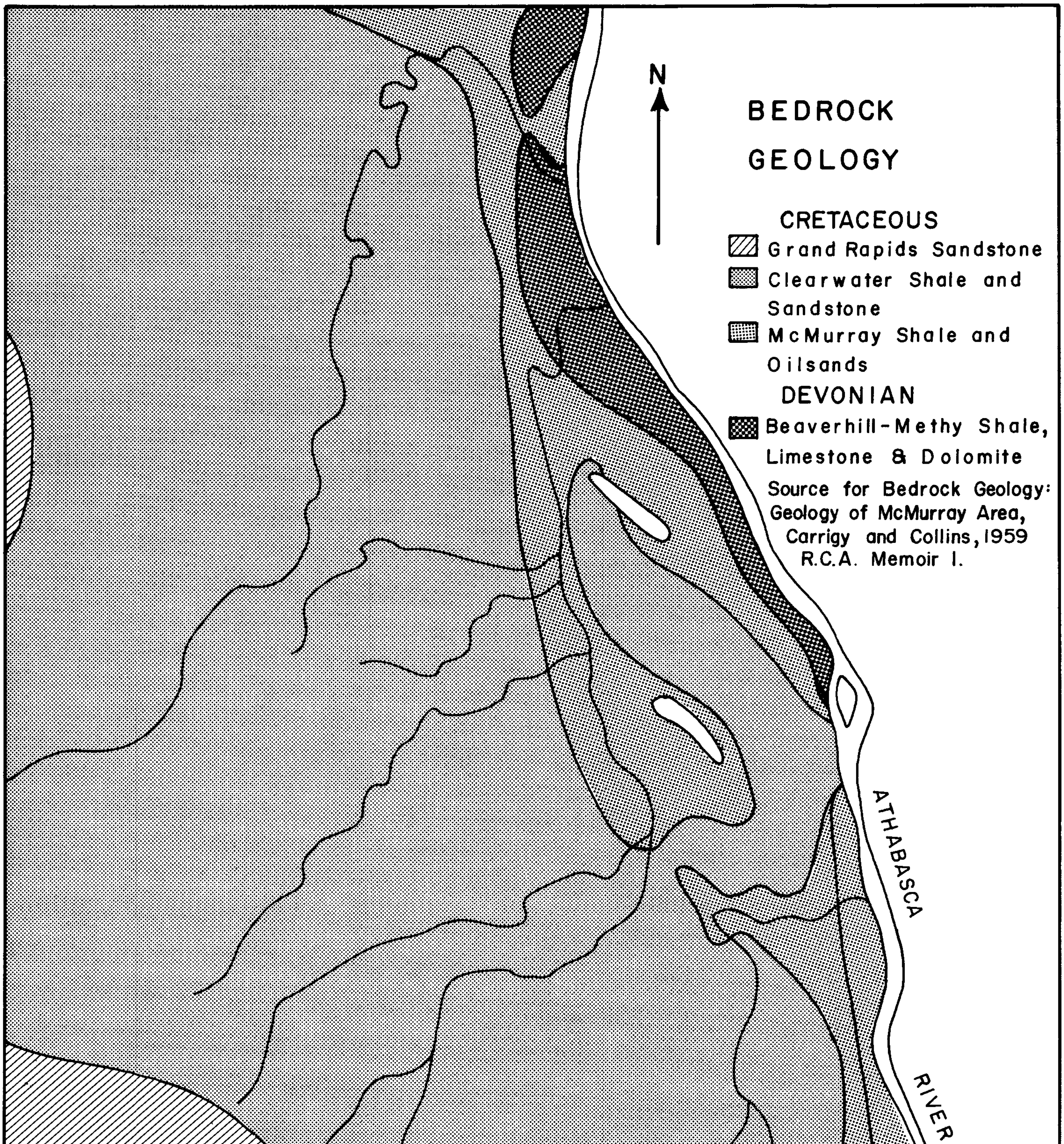

Figure 6 -- Bedrock Geology of the Study Area

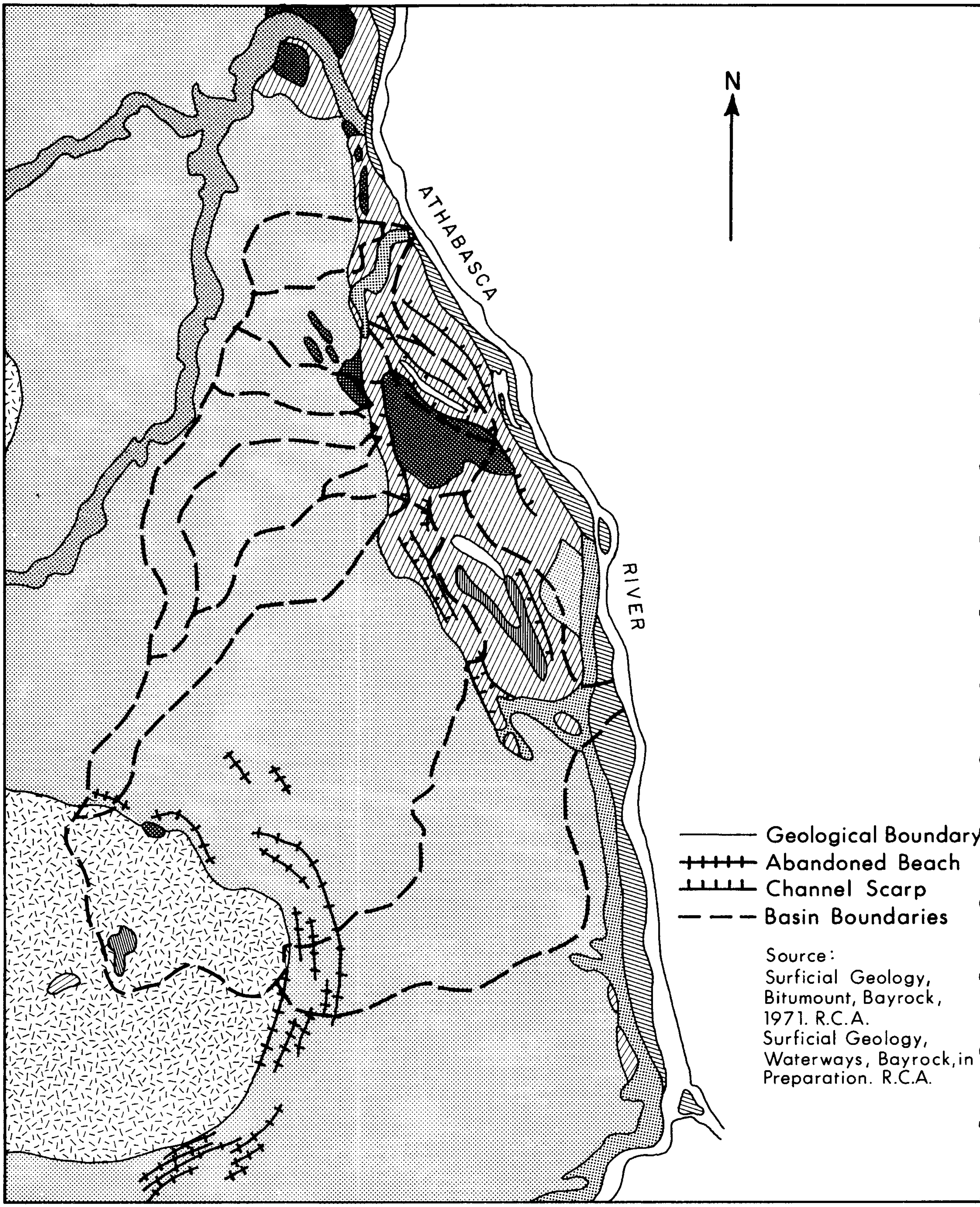

Figure 7 -- Surficial Geology of the Study Area

LEGEND FOR SURFICIAL GEOLOGY

EROSIONAL FEATURES

Gully, stream valley: thin colluvial cover on valley slopes, thin alluvium along streams.

ORGANIC DEPOSITS

Muskeg, sedge bog: thick organic materials.

ALLUVIAL DEPOSITS

Stream alluvium: mainly sand along Athabasca River; silt, clay and sand along other streams.

AEOLIAN DEPOSITS

Aeolian sand, dunes: medium-grained sand in sheet and dune form; thick in dunes; 2-10 feet in sheet form.

GLACIOLACUSTRINE DEPOSITS

Mixed: bedded silt, clay and sand; with some pebbles and till-like layers; overlying till or outwash sand.

GLACIOFLUVIAL DEPOSITS

Outwash sand and gravel: sand and gravel forming outwash plains; generally thick; surface level to undulating.

Outwash sand: outwash sand plain; medium to coarse sand; variable thickness; surface level to undulating.

Meltwater channel sediment: sand and gravel; generally thin.

GLACIAL DEPOSITS

Ground and hummocky moraine: till; variable in composition, variable in thickness; topography gently undulating to rolling.

Legend to Figure 7

TABLE 3 - PLANIMETRY OF SURFICIAL GEOLOGY FOR BEAVER CREEK AND POPLAR CREEK BASINS

STREAM BASIN	AREA	TAKES		TILL		GLACIOFLUVIAL		LACUSTRINE		AEOLIAN		ALLUVIUM		THICK ORGANIC		GULLY ETC.	
	mi^2	mi^2	%	mi^2	%	mi^2	%	mi^2	%	mi^2	%	mi^2	%	mi^2	%	mi^2	%
Creek #1	5.9					1)	1)	5.4	93	0.4	0.7						
Creek #2	14.0					0.01	0.1	13.99	99.9								
Creek #3	13.3					0.01	0.1	13.29	99.9								
Creek #4	18.8			0.3	1.6	0.15	0.8	18.3	97.6								
Mildred	4.9	0.5	10.2			3.2	65.3			1.2	24.5						
Bridge	7.0					0.8	11.4	6.2	88.6								
Beaver U/S Creek #4	101.2			21.4	21.2	4.9	4.9	73.5	72.8	0.3	0.3			0.9	0.9		
Remainder of Beaver Basin						8.3	32.9	8.4	33.3	6.6	26.2	0.1	0.4			1.8	7.1
Total Beaver Creek	187.8	0.5		21.7	11.4	17.4	9.2	139.1	73.4	8.5	4.5	0.1	0.1	0.9	0.5	1.8	0.9
Beaver Creek at Gauge	177.3																
Total Poplar	54.9	0.8	0.2	0.15	0.3	10.9	19.9	35.2	64.1	1.1	2.0	1.1	2.0	2.5	4.6	3.1	5.6

1) Very Small

but Ruth Lake and Mildred Lake (set in north-south trending glacial meltwater channels) slope gently upward to the north. The glaciolacustrine and glaciofluvial deposits which cover most of the study area have a surface that is level to slightly undulating. Topography in the moraine area of the Thickwood Hills is more variable, ranging from undulating to rolling. As is usual for areas with topography such as this, deciding upon the natural boundaries of a drainage basin is difficult. The basin boundaries selected for this study seem to be called into question by forest cover maps showing several small streams crossing the selected boundaries. However, since such maps are prepared from air photographs, which are notoriously poor at exposing the exact location of small streams, they do not furnish a reason why the selected boundaries should be revised.

4.4 Soils and Vegetation

Only preliminary soil mapping is available for the area (Lindsay *et. al.*, 1958, 1963). As expected, the soil types reflect the parent materials, and are also closely related to vegetation. In till and lacustrine areas, the soils are generally grey wooded and with clay-loam texture in well drained areas; and generally gleysolic in poorly drained depressions. Vegetation is mainly white spruce with some aspen, but with black spruce and muskeg found in the poorly drained locations. The soils of glaciofluvial parent material are mainly podzols of sandy texture in well drained areas, and gleysolic soils and peat in areas of poor drainage. Vegetation on the podzol soils is divided into jackpine (well drained, sandy areas) or mixed aspen and white spruce (more heavily textured soils). Again, black spruce and muskeg predominate in poorly drained locations.

Quantitative assessment of vegetation for any drainage basin can be useful to the hydrologist because the extent of individual species reveals the extents and types of soils present. Maps of the Beaver and Poplar basins prepared by Alberta Forest Service, depicting vegetation by species have been simplified by the Highway and River Engineering Division of Alberta Research to show selected vegetation associated with particular hydrological regimes. Table 4 lists the areal extent of these selected types as measured by planimetry for the Beaver and Poplar basins in general (reproduced from Alberta Research) and Mildred Creek, Bridge Creek, and Creeks 1, 2, 3, and 4 in particular.

The combination of white spruce and deciduous vegetation (of which the deciduous is mainly aspen) is high for all the separate basins studied (68% to 90%) indicating a preponderance of well drained soils. Combined values for black spruce, treed muskeg, and muskeg (indicating water retentive soils) are much smaller, falling between 15% and 25% for all individual basins except that of Creek #1. The small areas of Mildred, 1, 2, and 3 that have been cleared may be ignored as hydrologically insignificant.

TABLE 4 - PLANIMETRY OF VEGETATION TYPES[1)]

Stream Basin	Percentage of Vegetation Type						
	White Spruce and Deciduous	Black Spruce	Pine	Treed Muskeg	Muskeg	Lakes[2)]	Clearings
	%	%	%	%	%	%	%
Poplar Ck.	52.4	29.8	1.3	14.5	0.5	1.0	0.5
Mildred	67.8	15.0	1.5	4.3	.2	8.6	2.6
Bridge	76.9	3.1	4.3	15.2	-	-	-
#1	89.4	1.3	4.2	2.1	-	.2	3.8
#2	79.1	6.7	.3	11.1	1.6	.6	.5
#3	82.7	13.7	-	1.8	1.3	.2	.1
#4	71.9	17.4	-	8.4	1.1	.6	-

1) This table is based on the Beaver and Poplar Basin outlines adopted by Alberta Research.

2) This column includes several small lakes omitted in Table 3.

5. INTERPRETATION OF PUBLISHED RUNOFF DATA

The immediate, pragmatic aim of a hydrological study associated with a mining project, is to ensure that the mine and civil engineering structures (highways, dams, bridges, etc.) are protected from flooding. The critical time occurs when surface runoff is at a maximum. Since the necessary runoff data for the Beaver Creek basin was not available, and the collecting of such data would have to be done over many years, an indirect approach was followed, using available data from documented basins similar to that of the Beaver Creek. The procedure was:

a) To select documented basins similar to the Beaver Creek and prepare a regional flood frequency curve therefrom.
b) To establish a relationship between area and mean flood discharge for streams covered by the regional flood frequency curve.
c) To measure (by planimetry) the area of drainage for individual streams of the study area.
d) To construct flood frequency curves for the streams of the study area.
e) To make direct measurements of runoff occurring in the streams of the study area (this was done in 1973), and adjust the flood frequency curves using the fresh data of 1973, but with the proviso that the typicality of 1973 be checked by reference to average annual precipitation, and the usual state of wetness or dryness of the receiving basins.

5.1 Regional Flood Frequency Curve

To be suitable for use in the indirect method, substitute basins had to be:

i) within the boreal forest zone of the northern great plains;
ii) sufficiently distant from the Rocky Mountain foothills to be free from orographic influence;
iii) essentially undisturbed by human activity;
iv) well documented with respect to surface runoff.

The Water Survey of Canada's *Surface Water Data, Reference Index, 1972* describes 12 basins fulfilling these requirements reasonably well (Table 5). Deficiencies exist in the completeness of the data (condition (iv) above) because whereas 10 years' recording is commonly regarded as the minimum basis for flood frequency curves, basins with records as short as 5 years have had to be accepted for this study.

Spence (1971) has shown that on the Canadian great plains, log-normal distribution gives straight-line frequency for annual stream peaks. Arithmetic mean flood, Q_m, is derived by summing flood readings, and dividing by the number of readings used. Individual flood peaks, Q, are then "normalized" by dividing by Q_m. Hence, "normalized" flood peak = Q/Q_m

$$\text{where } Q_m = \frac{\text{Sum of several flood readings}}{\text{Number of readings}}$$

Fig. 8 shows normalized discharge *vs* frequency for the streams listed in Table 5. Because the normalization procedure is inadequate to encompass all the factors affecting the runoff behaviour of any basin, there is some scatter in the plots graphed in Fig. 8. Nevertheless, the several lines have slopes sufficiently close together for an average value to represent them all with reasonable accuracy. As expected, the widest departures from the average curve are shown by the Boyer River whose runoff and water yield

TABLE 5 - SUMMARY OF STREAMFLOW RECORDS FOR POTENTIALLY COMPARABLE BASINS

Major basin and stream 1	Hydrometric station name 2	Drainage area (sq.mi.) 3	Observed peak: Discharge [1] (cfs) 4	Observed peak: (cfs/ sq.mi.) 5	Observed peak: Date 6	Observed peak: No. of years [3] 7	Observed mean: Discharge (cfs) 8	Observed mean: Yield (in) 9	Observed mean: No. of years 10
SLAVE R.									
Birch R.	below Alice Ck.	3,860	12,600 D	3.26	13/5/72	5	882	3.10	5
PEACE R.									
Notikewin R.	at Manning	1,810	17,800 D	9.84	23/5/64	11 (6R+5S)	532	3.99	10
Boyer R.	near Fort Vermilion	2,420	4,120 D	1.70	3/5/63	10 (OR+10S)	142 [2]	0.535	10
Ponton R.	above Boyer R.	984	5,850 I	5.95	23/5/67	10 (4R+6S)	520 [2]	4.82	10
Wabasca R.	at Wadlin Lk. Road	13,800	32,900 D	2.35	2/5/72	6 (1R+5S)	2,300	2.23	5
ATHABASCA R.									
West Prairie R.	near High Prairie	430	6,480 D	15.1	5/7/71	15 (9R+6S)	215 [2]	4.55	13
East Prairie R.	near Enilda	500	11,600 I	23.2	4/7/71	16 (SR+8S)	305 [2]	5.56	13
Swan R.	near Kinuso	742	12,400 I	16.7	1/7/61	10 (6R+4S)	593 [2]	7.28	8
Saulteaux R.	near Spurfield	1,030	6,210 I	6.03	10/7/71	7 (4R+3S)	625 [2]	5.62	3
Clearwater R.	at Draper	11,800	23,700 R	2.18	3/7/70	15 (6R+9S)	4,490	5.16	15
Hangingstone R.	at Fort McMurray	344	4,760 D	13.85	2/7/70	9 (5R+4S)	169	6.67	3
Richardson R.	near the mouth	1,140	1,350 I	1.18	7/5/72	2	521	6.21	2
Poplar Ck.	near Fort McMurray	54.9	237 D	4.31	2/5/72	2			
Beaver Ck.	near Fort McMurray	177	1,670 D	8.56	2/5/72	1	60 (est)	4.61	2

1) I = instantaneous peak, D = mean daily peak.

2) For period April 1 to October 30.

3) Total number and number of rainfloods, R, and number of snowmelt floods, S.

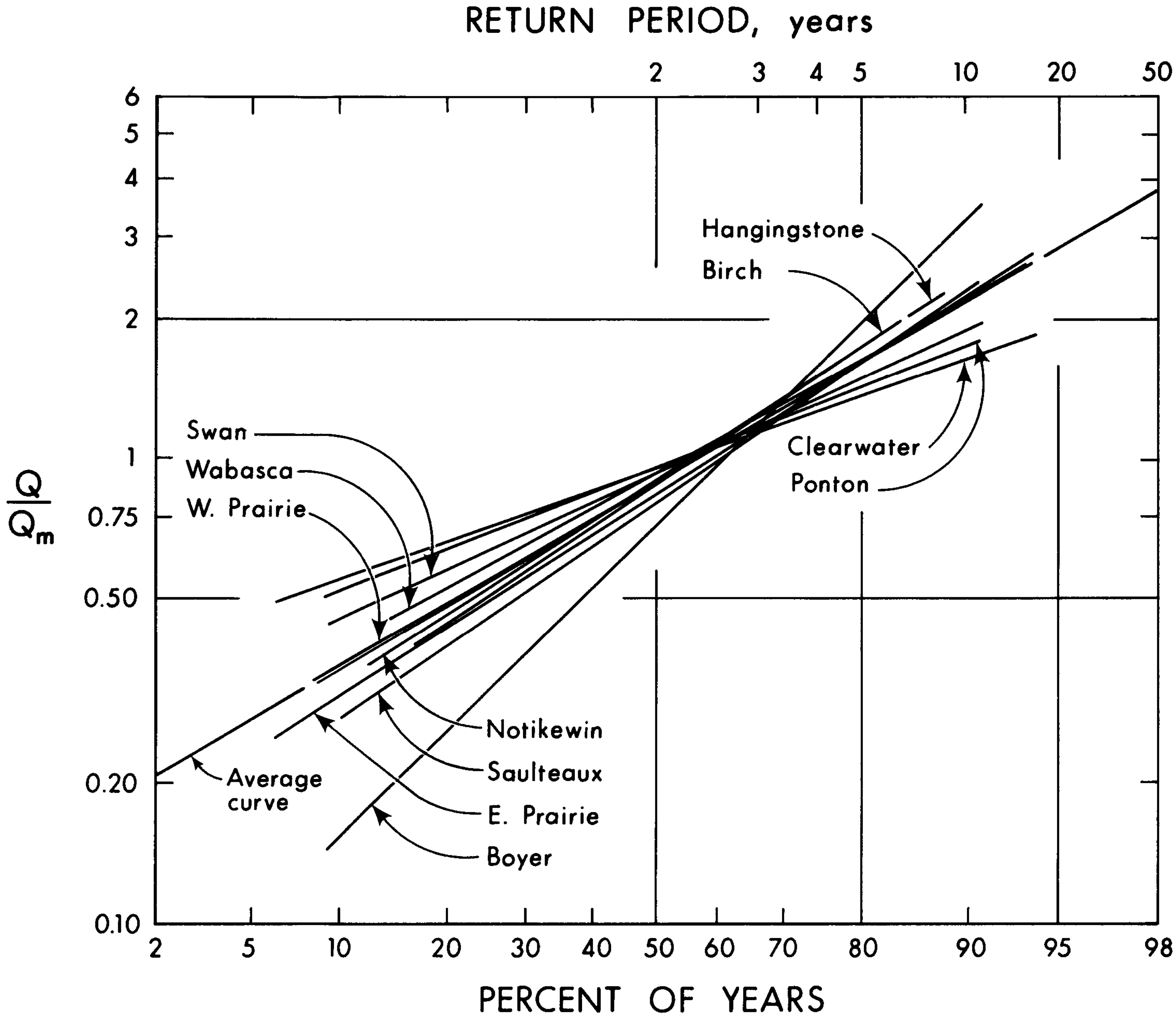

Figure 8 Flood Frequency Curves for Streams in Northern Alberta

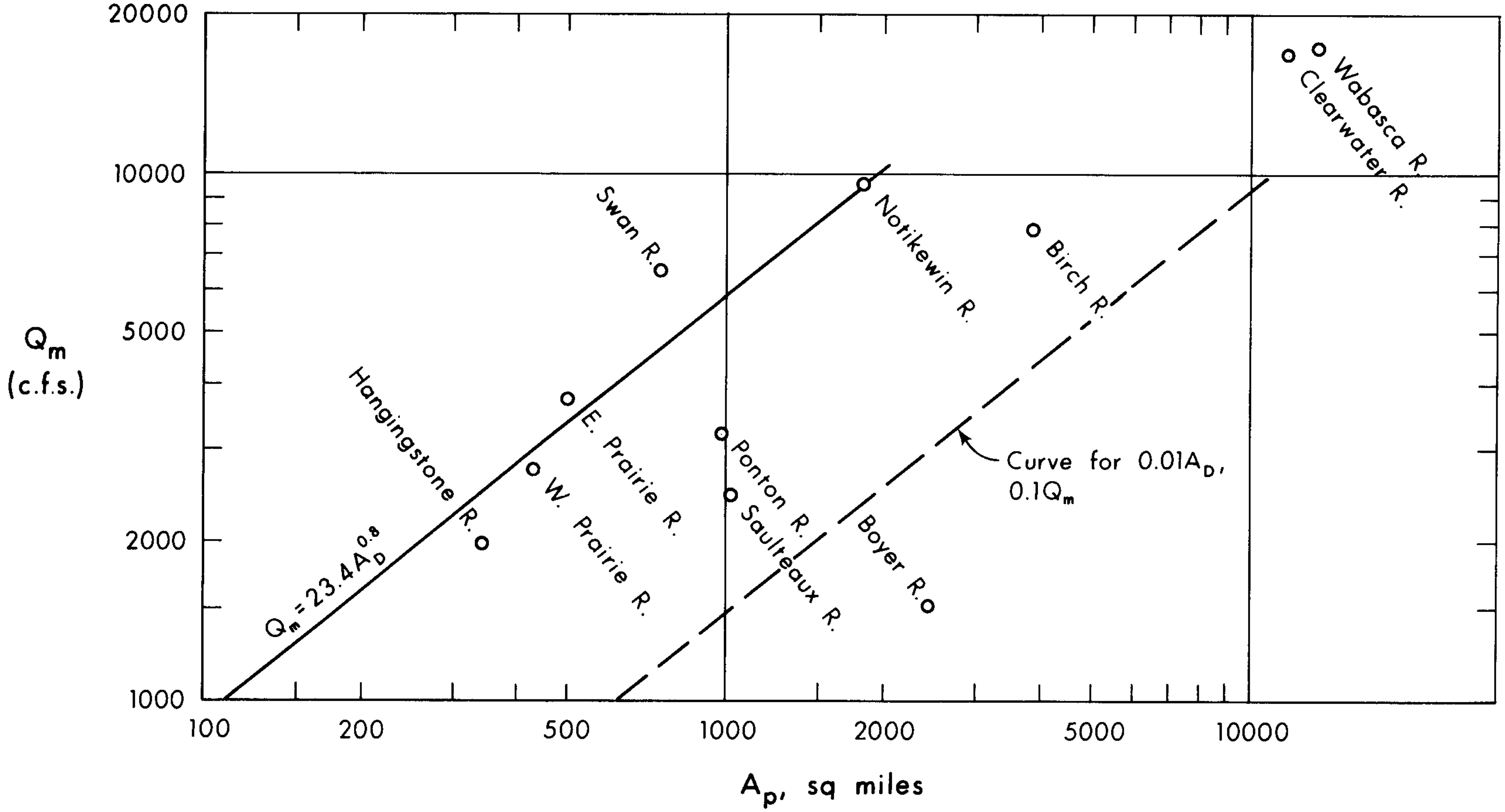

Figure 9 "Envelope" Curve Relating Mean Annual Flood, Q_m, and Drainage Basin Area, A_D

are unusually low (see Table 5), probably because it originates in an extensive area of poorly drained lowlands; and the Clearwater and Ponton Rivers, where the small range in normalized flood values can be attributed to the extensive lake storage in these basins.

5.2 Mean Flood as a Function of Drainage Area

In order to apply the regional curve to a particular stream, a relationship between the mean flood, Q_m, and some parameter of the drainage basin is needed. Other studies similar to the present one have related Q_m to such factors as percentage of the drainage area covered by lakes and swamps; parameters describing surficial geology; parameters describing vegetation and land use; and parameters describing slope and relief. The most important variable however, and one to which all the rest are ancillary, is area of drainage basin, A_D, and this has been selected for use here, although knowledge of the other factors can be of help in explaining anomalies. Data points for the selected streams are plotted in Fig. 9 as $\log_{10}$ mean flood (Q_m) in c.f.s. *vs* $\log_{10}$ drainage basin area (A_D) in square miles. It is usual to express the relationship between Q_m and A_D as a curve of the form,

$$Q_m = a.A_D^{\ n},$$

and by using logarithms of the data this can be drawn as a straight line. The best average fit for the available data can be computed and values of a and n obtained. However, since maximum runoff is a more critical measure of surface water behaviour than average runoff, an "envelope" line has been drawn in Fig. 9 to cover most flood contingencies. In this case,

$$a = 23.4 \text{ and } n = 0.8$$

Only the Swan and East Prairie Rivers are outside the range of this line (the latter only slightly so) but this is justified by their basins having different forest cover and steeper topography than the tar sands region (see *Atlas of Alberta*).

5.3 Flood Frequency Curves for Streams of the Study Area

From the measured areas of drainage basins of the various streams of the study region it is possible to estimate maximum discharge by means of the "envelope" curve of Fig. 9. Then, using the average regional slope of Fig. 8, curves for peak discharge *vs* frequency can be constructed for the various streams. This is done in Fig. 10 in which the slope of the different curves is given by Fig. 8 and their vertical position by Fig. 9.

Because 1972 and 1973 are believed not to have been hydrologically-unusual years, the points for these years might be expected to fall close to the 50% frequency line for all streams. In most cases Fig. 10 does not show this to be the case -- the flood values recorded for Poplar Creek and Creeks 1, 2, and 4 in these years falling within the 20% of dryest years. This is probably caused by the predominance of lacustrine surficial deposits over till and the absence of swamps and muskeg in these basins. It would therefore seem that relating flood runoff to area of basin alone is deficient, and that more detailed work on the relationship between Q_m and A_D (as outlined below) might justify a lowering of the curves.

In the absence of more extensive data, this contribution could not be measured. It would be possible however to make one useful modification to Fig. 9 using existing data. The floods on which the regional frequency curve is based are approximately evenly divided between rain and snowmelt floods, but inspection of Table 5 reveals that the largest floods are almost always rain floods, suggesting that rain flooding alone would be a better basis for a regional flood frequency curve. The expected result would be a lowering and steepening of the frequency curves of Fig. 10.

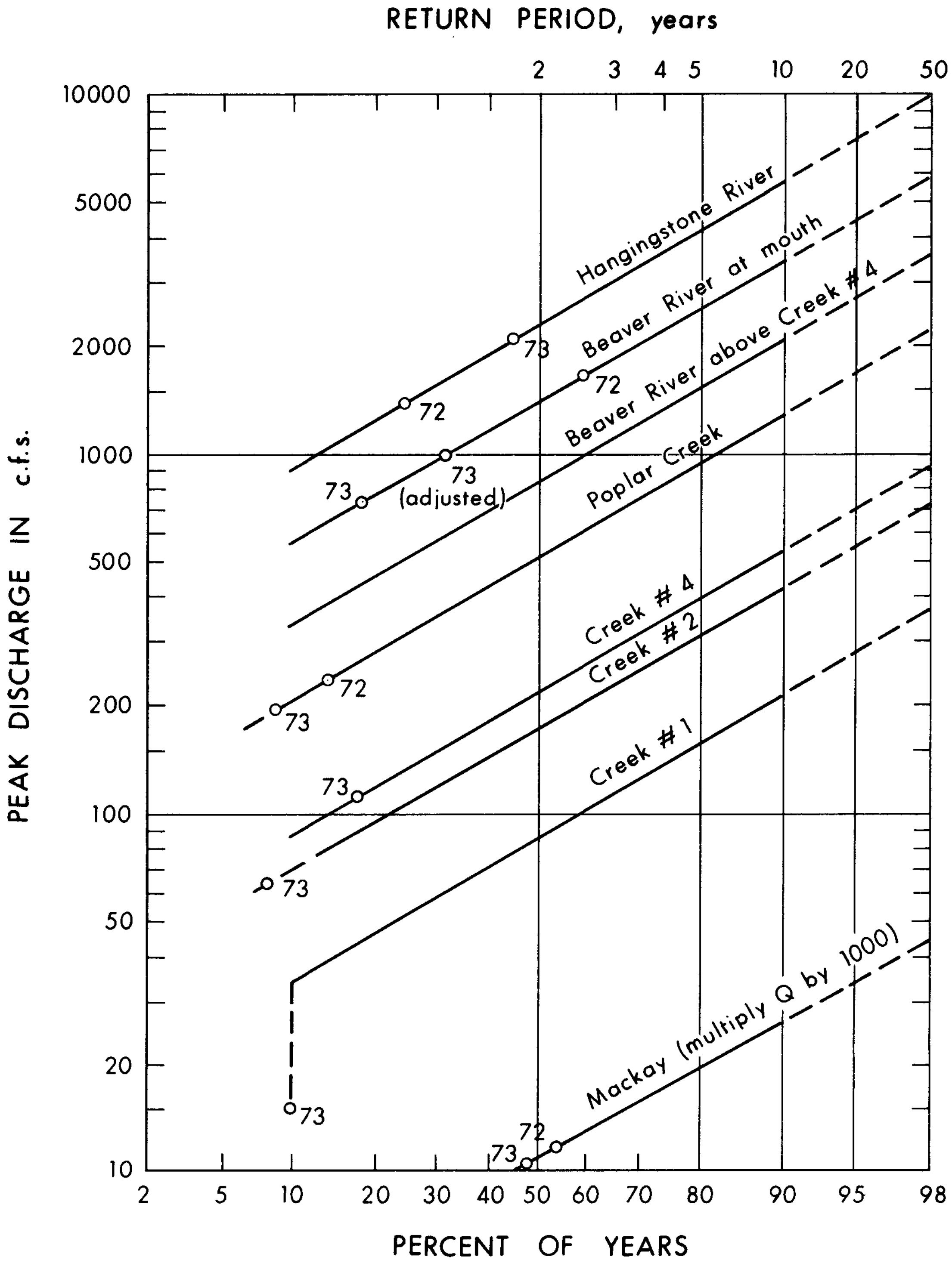

Figure 10 Some Preliminary Flood Frequency Curves
(based on the regional analysis)

5.4 Water Yield

Areas comparable with Crown Lease No. 17 have water yields ranging from the 2.23 inches per year of the Wabasca River to the 7.28 inches per year of the Swan River (see Table 5). Reference to maps of mean annual precipitation indicates that the Swan, East Prairie (Central Swan Hills) and Hangingstone basins are likely to have somewhat higher runoff than the area of Crown Lease No. 17, while the tributaries to the Hay, Slave, and Peace Rivers should be on the low side. The Wabasca basin must be discounted since it is found to have an unusually low yield, probably arising from one or more of the following: poorly drained, flat terrain; extensive areas with internal drainage; and large areas of deep muskeg or swamp. Hence, the long term mean yield of Crown Lease No. 17 may be expected to be best represented by the Saulteaux, West Prairie, Clearwater, and Richardson Rivers, and will probably fall into the range of 4 to 5 inches per year, but subject to large local variations depending mainly on vegetation and surficial geology. The upper, till-covered basins are likely to have the highest yield.

Since Syncrude's water supply will be independent of local water sources, the variation of water yield between years has not been examined: but as a rough indication of the probable distribution of runoff on Crown Lease 17, Fig. 11 shows the variation of runoff in the East Prairie River. The runoff values used in the plot are based on the period March 1 to October 31 only.

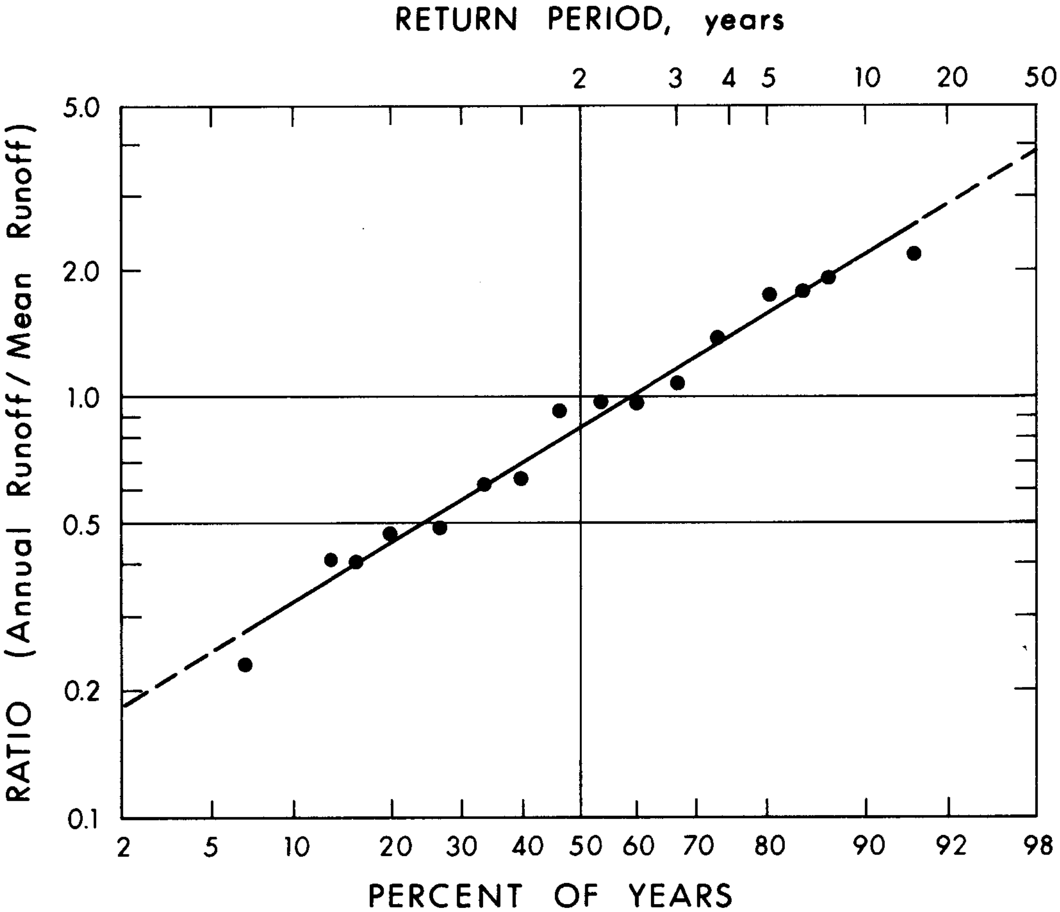

Figure 11 Probable Distribution of Runoff
(Based on East Prairie River)

6. REFINEMENT OF THE FLOOD FREQUENCY CURVES THROUGH APPLICATION OF 1973 STREAM GAUGING DATA

6.1 1973 Stream Gauging Program

Because such factors as relief and surficial geology influence runoff and hence the relationship between Q_m and A_D in a way that is imperfectly understood, the flood frequency curves of Fig. 10 cannot be accepted without further examination. In particular, to make the flood frequency curves more accurate, it is necessary that they be adjusted by reference to actual runoff measurements in the study area. Accordingly, in the summer of 1973, seven staff gauges* were installed, located as shown in Fig. 1. The streams were cleared of debris downstream of the gauges to assure reasonably constant stage-discharge rating curves, and foot bridges were installed at all but the Beaver Creek site (near the upstream boundary of the lease) to permit discharge measurements during flood flows. The gauges were read by LGL or Syncrude personnel at somewhat irregular intervals of 1 to 5 days. Before the program was started the gauges were calibrated to give stream discharge (c.f.s.) *vs* gauge reading (feet): the relationships obtained are plotted in Appendix 1. No reliable calibration could be obtained for Bridge Creek because the channel shifted several times during floods. The data from the gauge readings are plotted in Fig. 12.

Some general conclusions may be drawn from the stream gauging program.

1. All streams responded to precipitation in a similar manner, with the exception of Mildred Creek whose basin is the only

*See Glossary

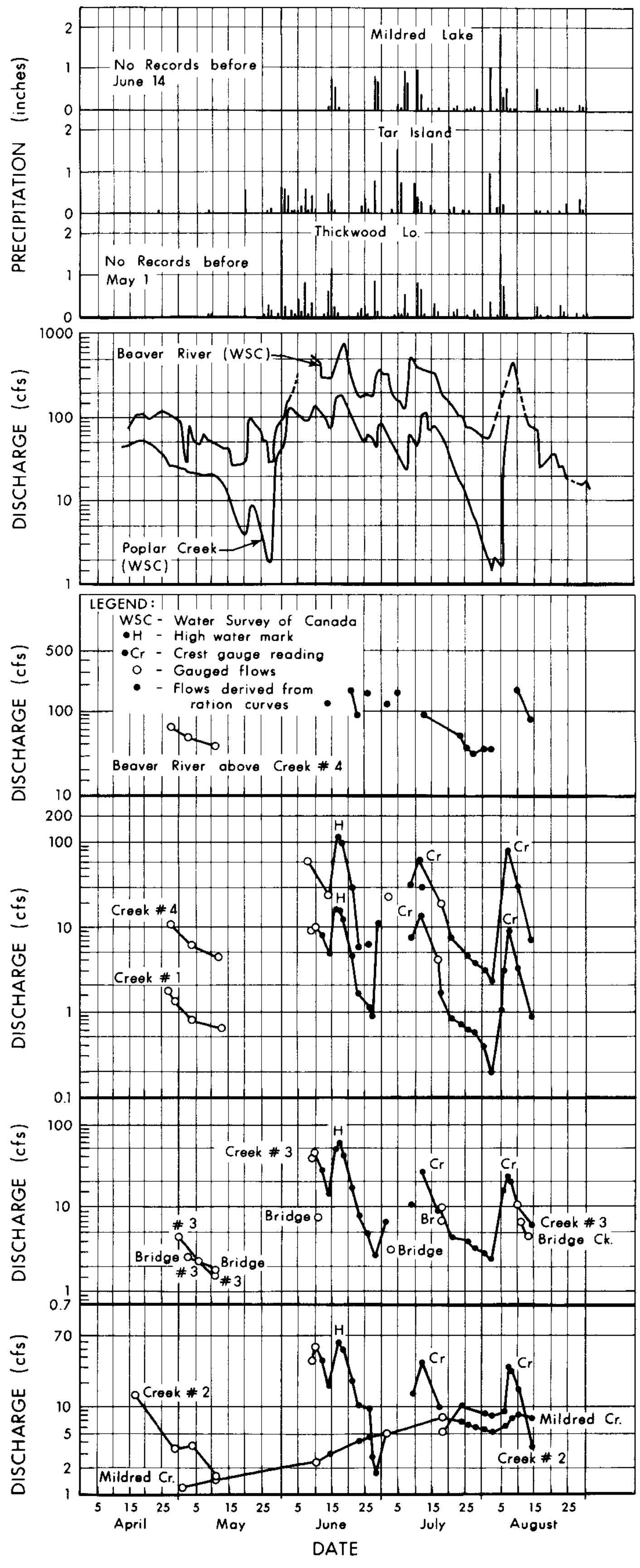

Figure 12 Hydrographs and Hytographs - April to August, 1973

one with a large proportion of lake storage (8.6% of basin area is lake surface).

2. Snowmelt does not appear to have caused a noteworthy flood peak during 1973. Rain-caused runoff during June, July, and August, considerably exceeded the snowmelt of late April.
3. The highest runoff occurred in mid-June as a result of a relatively minor rainstorm falling on wet basins. The heavier storm of August 5 and 6 failed to produce high runoff, due to the basins being much drier.

Conclusion 3 above exposes the difficulty associated with using one year's readings to make general assumptions about surface water behaviour. Drainage basins do not respond in a constant manner according to the precipitation falling upon them: account must be taken of the wetness or dryness of the basins themselves at the time that precipitation is being measured. Therefore, although the stream gauging program of 1973 for the first time provided runoff data for the creeks of the study area, it was necessary to decide how far the collected data were typical.

6.2 Precipitation

Because long-term records of precipitation exist for the Fort McMurray area, they may be used in estimating the typicality of 1973.

6.2.1 Total Precipitation

Precipitation for summer 1973 for selected meteorological stations is reproduced in Table 6. Hydrologically, this period appears to have been unexceptional because heavy summer precipitation was balanced by low spring runoff. Table 6 shows how May to August suffered from abnormally high rainfall, the total precipitation exceeding the corresponding long-term mean by from 4.46 inches (Muskeg Lookout) to 7.34 inches (Fort McMurray Airport). If it is assumed that precipitation for the remainder of the year was more or less normal, the return period of such a wet summer would be between 8 and 40 years according to Fig. 3. To be more precise, based on the data for Thickwood Lookout, Tar Island, and Mildred Lake, a return period of 10 years appears likely.

6.2.2 Rainstorms

The high total precipitation of summer 1973 was the result of frequent rain of relatively low intensity during late May, June, and early July, rather than of heavy individual storms. While there were some heavy storms in the wider McMurray area during the summer of 1973 (e.g. 3.42 inches in 24 hours at Muskeg Lookout), no unusually intense storms appear to have occurred in the particular locality of the Beaver or Poplar basins. Table 6, in conjunction with Fig. 5, indicates that the heaviest values of 24 hour precipitation observed in 1973 at Tar Island, Thickwood Lookout, and Mildred Lake (August 5) have return periods of 3 to 4 years. However, this storm would not be expected to produce high runoff since it was preceded by 20 days, and followed by 2 days, of dry weather, causing the hydrological effect to be modified. From both an ecological and a mining point of view storms are of great interest because they represent moments of crisis for the area. Ill-considered interference with the natural drainage system could expose the mine site and portions of the environment to inundation. Hence, correctly to match the actual flood runoff of 1973 with the general curves of Fig. 10, it is important that allowance be made for any unusual dryness of the basins receiving the precipitation.

Table 6: PRECIPITATION SUMMARY, SUMMER 1973

Station		May		June		July		August		Total	
		Total for month	Max. 24 hours	Total for month	Max. 24 hours	Total for month	Max. 24 hours	Total for month	Max. 24 hours	Total for period	Max. 24 hours
Fort McMurray	A	1.90	0.45	4.24	1.08	5.43	1.69	4.91	1.35	16.48	1.69
		(1.30)[1]	(1.51)	(2.42)	(1.81)	(2.90)	(2.03)	(2.52)	(2.17)	(9.14)	(2.03)
Tar Island		1.36	0.65	4.55	0.70	4.47	1.56	3.52	1.45	13.90	1.56
Anzac		2.99	1.24	4.60	1.06	3.98	0.68	5.36	2.58	16.93	2.58
Thickwood	Lo	2.58	1.88[2]	5.71	1.17	3.35	0.81	3.58	1.53	15.22	1.88
		(1.34)	(1.33)	(2.87)	(1.87)	(3.59)	(2.37)	(2.74)	(2.03)	(10.54)	(2.37)
Muskeg	Lo	1.11	0.53	3.37	0.61	4.65	1.42	5.75	3.42[2]	14.88	3.42[2]
		(1.26)	(1.92)	(2.76)	(1.42)	(3.33)	(2.12)	(3.07)	(2.19)	(10.42)	(2.19)
Ells	Lo	2.67	1.87[2]	6.06	1.10	3.24	0.78	4.14	1.32	16.11	1.87[2]
		(1.18)	(0.91)	(2.39)	(1.43)	(3.10)	(1.67)	(2.66)	(1.41)	(9.33)	(1.67)
Mildred Lake					0.82	3.78	0.97	4.97	1.88		1.88

1. Numbers in brackets denote long-term mean.
2. New records.

Mean 24-hour precipitation rates for the study area were calculated from precipitation data from surrounding rain gauge stations. The data was weighted for area using Thiessen Polygons*. A theoretical maximum 24-hour runoff could be computed from this mean precipitation data. The theoretical maximum assumes that there are no losses and no storage, and that the response time is about 24 hours. Of interest are two storms of summer 1973 -- those of June 15 (mild storm) when the drainage basins were wet, and August 5 (heavier storm) when the basins were dry. Table 7 lists the theoretical maximum runoffs for creeks of the study area as calculated from Thiessen Polygons, together with observed runoff values and runoff coefficients (i.e. the ratio of theoretical to observed runoff). The results are both satisfactory and interesting in that for every stream, the runoff coefficient is from 3 to 6 times higher for the mild June storm than for the heavier storm in August. Furthermore, the variations between basins are in agreement with the findings displayed in Fig. 12.

Calculating maximum theoretical runoff for each basin reveals that simple runoff results for any one year may give a distorted picture of the relationship between rainfall and drainage since the state of the basins greatly affects surface water behaviour. To be safe, one should consider what would happen if the heavier rainstorm of August 5 (3 year return period) had occurred when the basins were as wet as they were in June. Clearly, the return period for runoff on this occasion must be more than 3 years since such a storm falling on drier basins would give a return period of only 3 years. Yet, according to Fig. 10 runoff rates computed from theoretical runoff maxima still give return periods of less than 2 years, which is further evidence that the curves of Fig. 10 are set too high.

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*See Glossary

TABLE 7 - RUNOFF COEFFICIENTS FOR TWO STORMS, 1973

Basin	Drainage Area	Mean 24-Hr. Precip. June 15	RUNOFF Theoretical Maximum	RUNOFF Observed	RUNOFF Runoff Coefficient (Observed/ Theoretical)	Mean 24-Hr. Precip. Aug. 5	RUNOFF Theoretical Maximum	RUNOFF Observed	RUNOFF Runoff Coefficient (Observed/ Theoretical)	Peak flow for Aug. 5 storm assumed to occur June 15	Peak flow for 5-year storm
	(sq.mi.)	(in.)	(cfs)	(cfs)	%	(in.)	(cfs)	(cfs)	%		
Beaver Ck.	177.3	0.79	3,770	715	19	1.7	8,100	475	5.9	1,700	1,900
Poplar Ck.	54.9	0.57	842	194	23	1.5	2,220	106	4.8	560	720
Creek #1	5.8	0.7	109	15	14	1.9	296	9	3.0	41	44
Creek #2	14.0	0.7	263	60	23	1.9	715	30	4.2	165	170
Creek #3	13.3	0.7	250	58	23	1.9	679	24	3.5	156	160
Creek #4	18.8	0.85	430	115	27	1.8	910	82	9.0	260	290
Beaver Ck. above Creek #4	101.2										1,650

6.3 Final Adjustment of the Flood Frequency Curves

As a first approximation to improved flood frequency curves it could be assumed that the wet basins of June 1973 would give a runoff return period at least as high as that of the precipitation falling on them. For ease of plotting, a rainstorm with a return period of 5 years was selected (2 in./24 hr. at Tar Island and Mildred Lake, and 2.4 in./hr. at Thickwood Lookout). The stream discharge for a corresponding runoff return period of 5 years was estimated by extrapolating the hydrographs of Fig. 12. These discharge values were then used to obtain the adjusted flood frequency curves of Fig. 13. Because the 1973 peak flows at once assume reasonable positions, it may be claimed that the adjustment is vindicated, and that the adjusted flood frequency curves give a plausible summary of possible hydrological events in the study area, but at the same time offering a fair margin of safety.

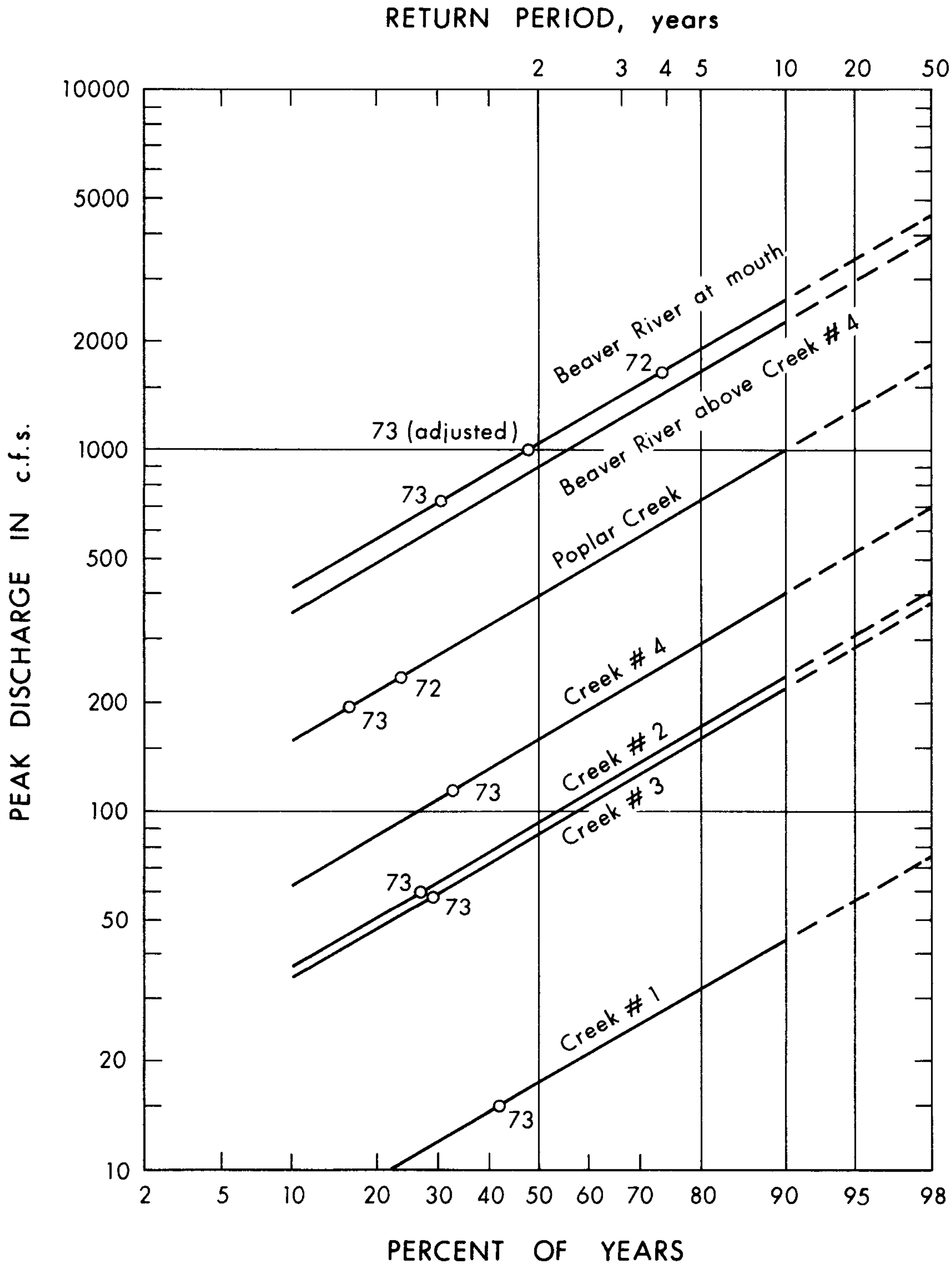


Figure 13 Adjusted Flood Frequency Curves

7. CONCLUSION

The monograph has given preliminary flood frequencies for streams of Lease No. 17 in north-eastern Alberta. These values have had to be derived, directly from 1 year's data for streams on the lease, and indirectly from streams in other areas of northern Alberta. In all cases, the record is too short for rigorous flood frequencies to be calculated, and for this reason the flood frequencies of Figure 13 have been prepared from an "envelope" or worst case runoff to ensure that the diversion scheme for Beaver Creek is designed with adequate capacity for all forseeable floods.

Readers who wish to keep informed of subsequent hydrological studies in the tar sand region may contact the Inland Water Directorate of Environment Canada. The Alberta address is,

700 - 110 - 12 Avenue S.W.
CALGARY, Alberta
T2R 0G7

This organization is funded equally by the Alberta and Canadian Federal Governments and is responsible, amongst other things, for collecting stream runoff data. Because of increased interest in the ecology of the tar sands region 13 new gauging stations were installed in 1975 on tributaries of the Athabasca River, to supplement the 10 stations already operating in the region. The new stations began to produce "raw" data in August, 1975 and this is expected to be available in "processed" form by March, 1976. Assembled runoff data is published by Environment Canada:

a) annually in,
"Surplus Water Data -- Alberta" (as part of the *Water Survey of Canada)*

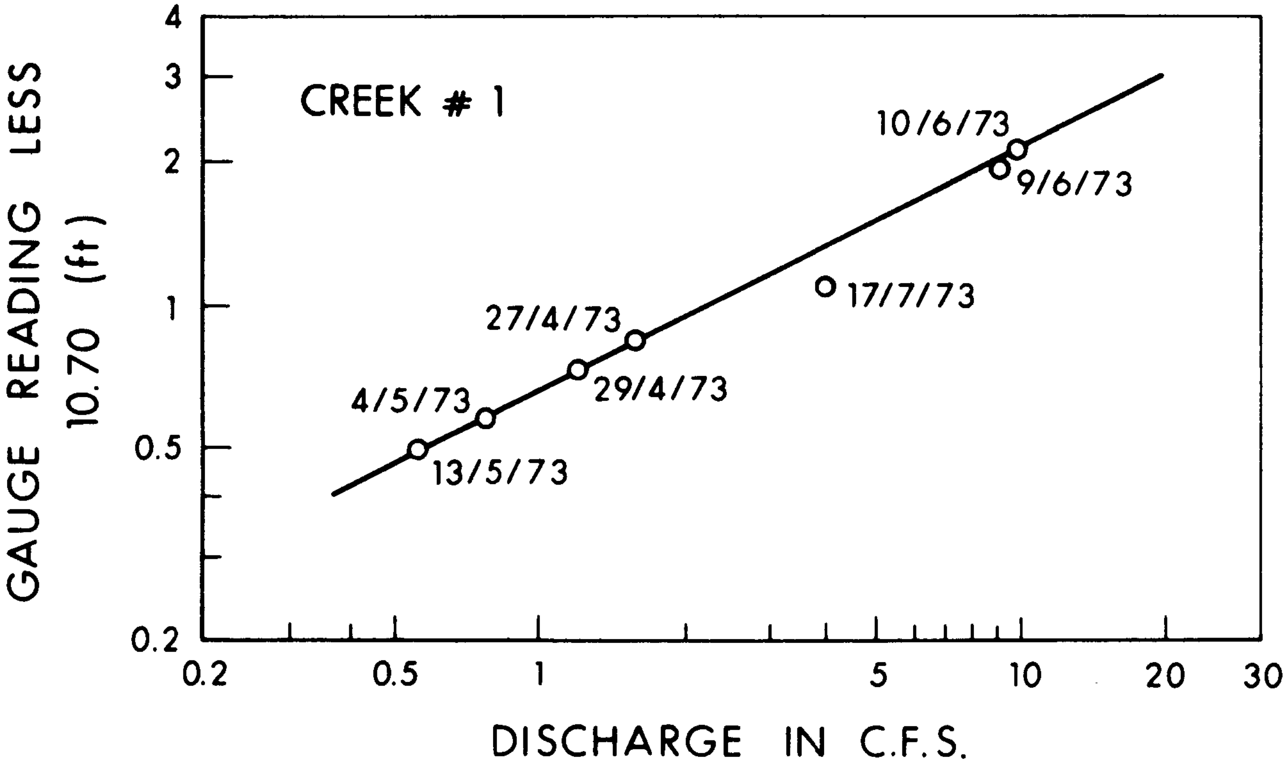
b) approximately every 3 years in, *Surface Water Data Reference Index.* This was last issued in 1974 and the next version will probably appear in 1976. Each issue is a complete historical listing of available data and hence supercedes the previous edition.

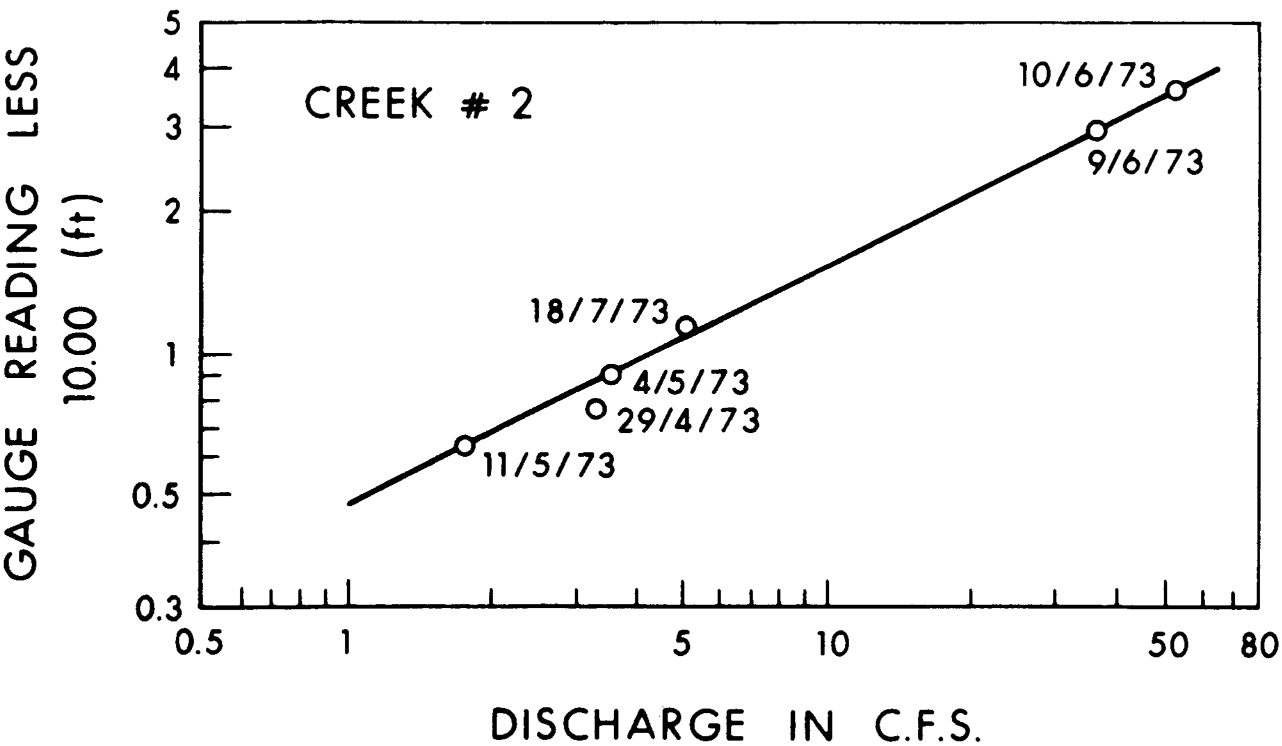
Requests for data on individual streams should be addressed to the Inland Water Directorate.

Syncrude Canada Ltd. continues to monitor the flow of Beaver Creek. The Company is also involved in the "Regional Hydrological Study, McMurray Oil Sands Area, Alberta", as a member of the Oil Sands Environmental Study Group (OSESG). Phase I published on October 1, 1974 was organized under the direction of J.C. Sproule and Associates Ltd., Calgary, Alberta.

With respect to climatology, Syncrude has commissioned an upper atmosphere dispersion climatology study. The principal aim of the study is to assess the dispersion behaviour of effluent gases from the projected manufacturing plant, but it will incidentally provide information about factors affecting precipitation measurements, and the results are issued to the public via the Department of the Environment, and Environment Canada.

RATING CURVES FOR STREAM GAUGES





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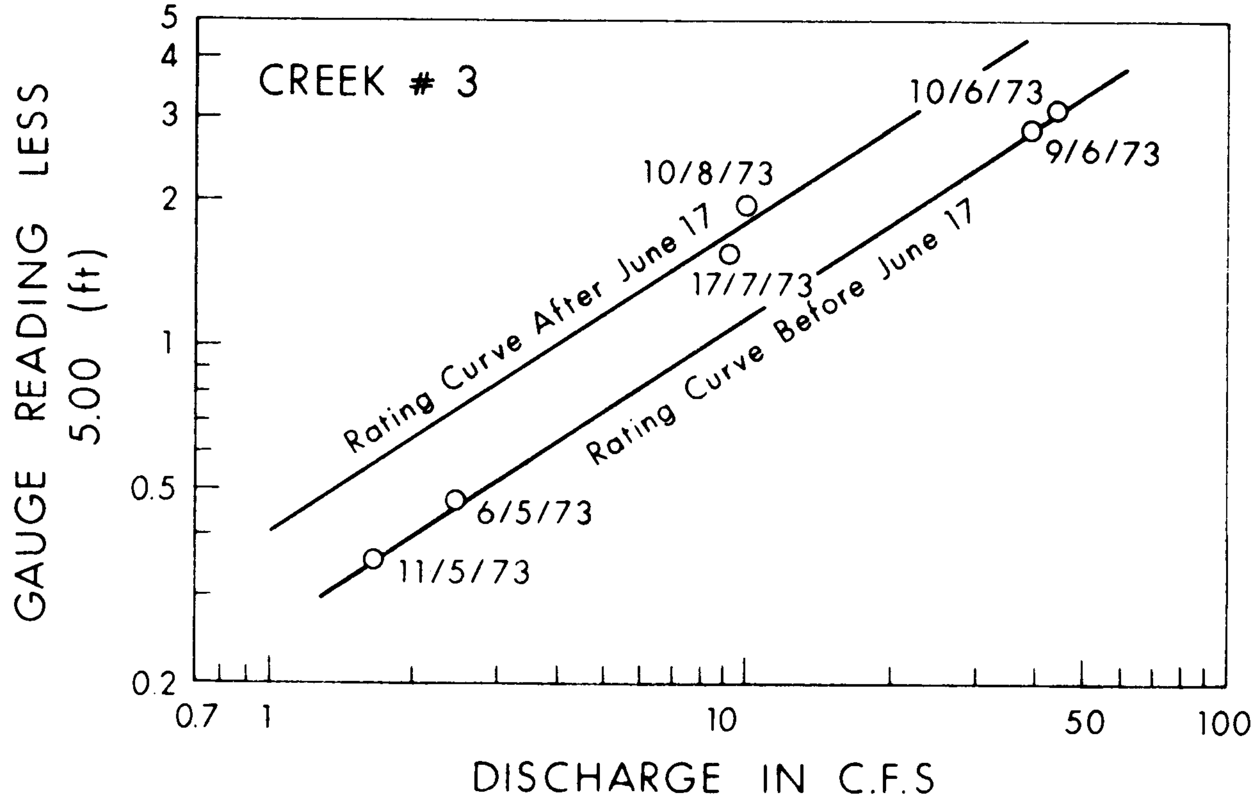

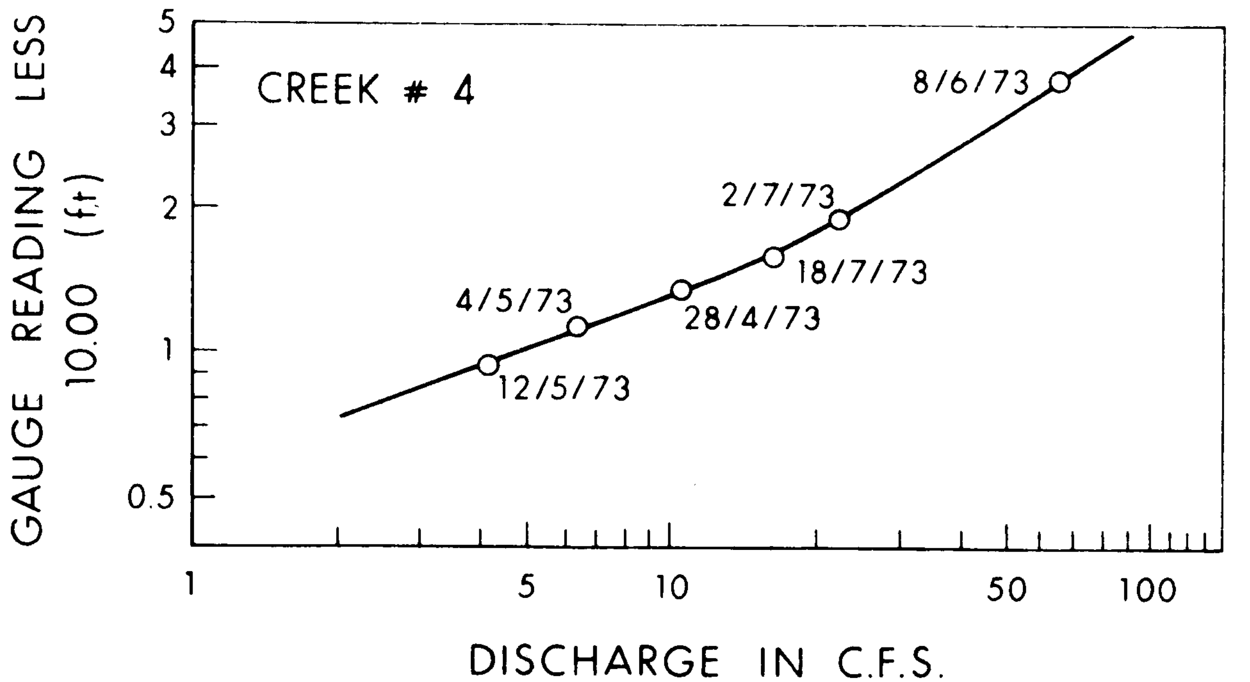

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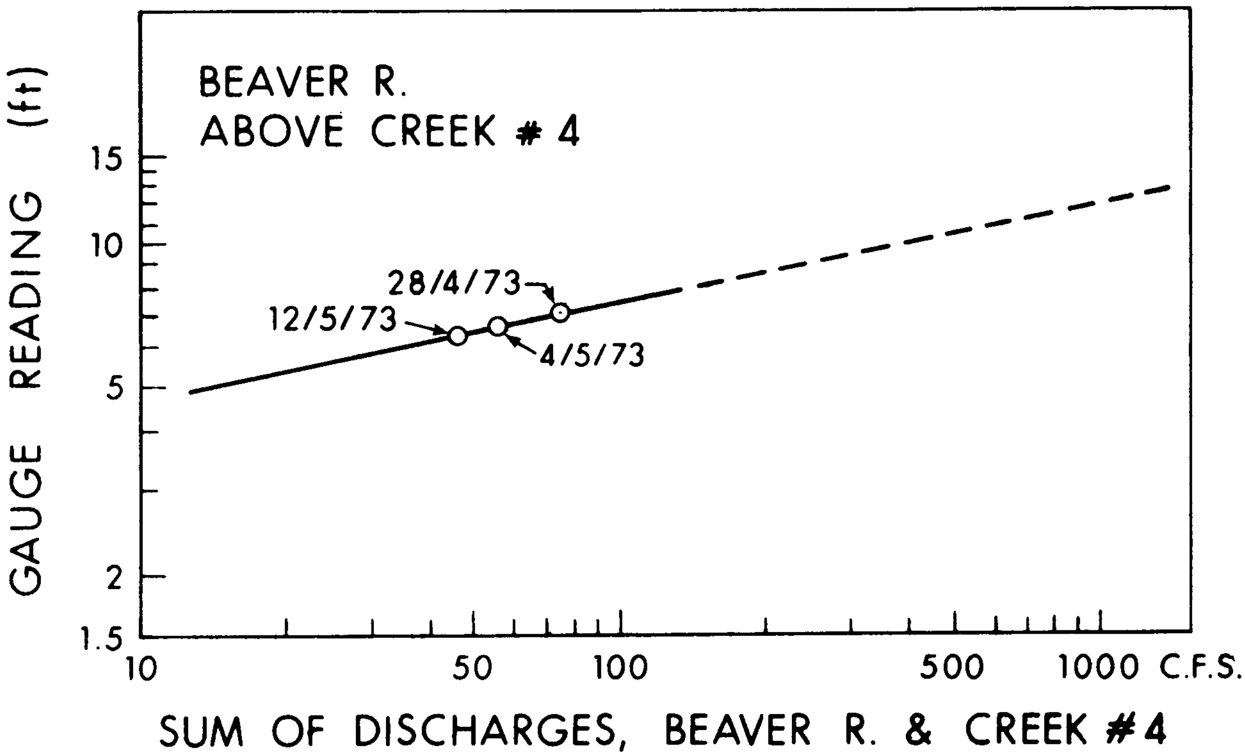

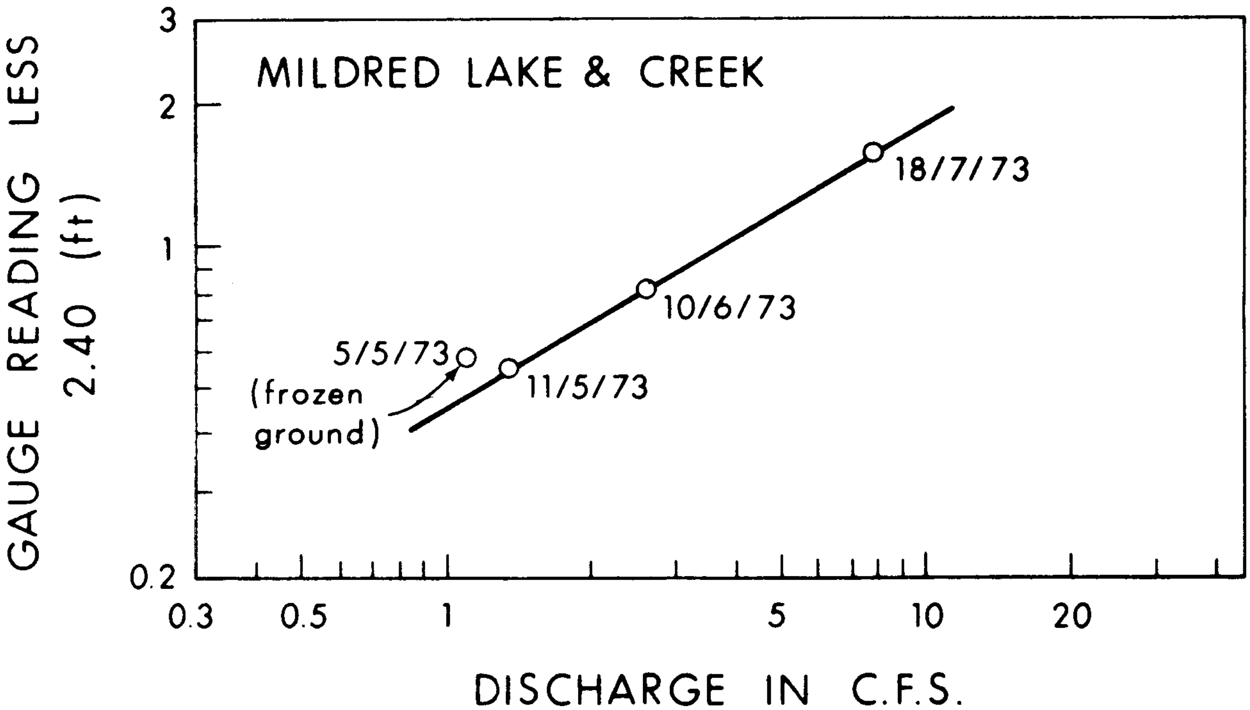

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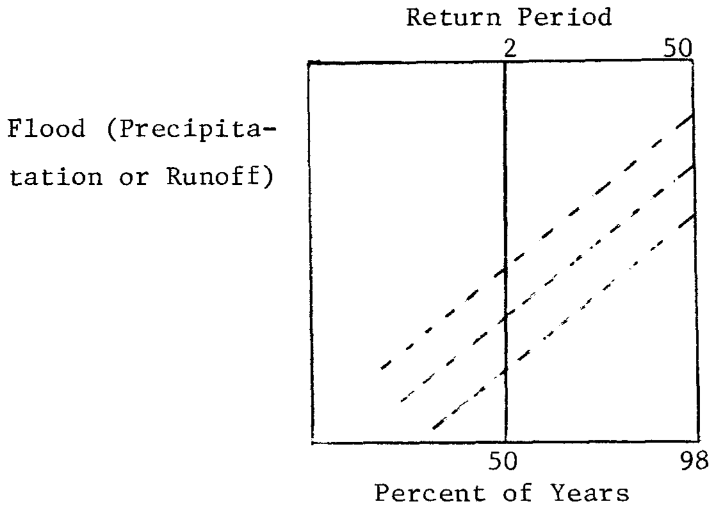
GLOSSARY

Crest Gauge -- a device that records the highest water level occurring at a fixed location on a stream. The staff model is simply a vertical rule set in the stream bed. The gauge is watched by an observer who records the value of the highest crest.

Flood Frequency Curves -- a method of reporting the frequency with which a flood of a certain magnitude is repeated. Such curves may be used to show the frequency of precipitation or ground runoff events. The vertical axis represents precipitation or runoff and the horizontal axis takes two forms -- Return Period, and Percent of Years.



Return Period is the length of time (usually in years) that will elapse before a flood of up to and including a given intensity will be repeated, and Percent of Years expresses the same information but as the number of years per hundred in which such a flood will occur. Data are not usually available for an entire century, but may be averaged over the period for which records exist.

A flood with a return period of 2 years will occur 50 times per hundred years on average (percent of years = 50). A return period as high as 50 years includes all floods up to and including the 50 year value. Since such floods will fail to occur only 2 years out of every 100 on average, a return period of 50 years is equivalent to a percent of years value of 98 percent.

Isohyetal Map -- illustrates the gradient of precipitation within a storm. Rainfall data are collected from several points over which the storm is isolated and "contours" of intensity are drawn by joining points of equal precipitation.

Thiessen Polygons -- because of irregularities in rain gauge spacing, the quantity of rain falling on an area with several gauges must be equalized by reference to the area served by each gauge. The gauging stations are located on a map, connecting lines drawn, and perpendicular bisectors of the connecting lines constructed to form a polygon about each station. Each polygon is considered as the area feeding the gauge that it surrounds.

$$\text{Mean precipitation over an area} = \frac{(\text{Reading}_1 \times \text{Area}) \ \ldots\ldots \ (\text{Reading}_n \times \text{Area}_n)}{\text{Total Area}}$$

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