HYDROLOGIC STUDIES ALONG THE LIARD HIGHWAY SPRING AND SUMMER, 1978.

by

B.J. Grey

Arctic Hydrology Section
Glaciology Division
Inland Waters Directorate
Environment Canada
Ottawa, Ontario
K1A 0E7

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ABSTRACT

In the second year of a hydrologic program along the Liard Highway, streamflow was recorded at four crossings, and precipitation was measured at two sites along the highway and in the headwaters of two basins. Observations were made of icing depths, and suspended sediment samples taken in the period after snowmelt. Analyses of the meteorologic records revealed that precipitation was below normal for both the winter of 1977/78 and the summer of 1977, while temperatures were very close to normal. Also, summer rainfall is very variable over the study region, but it appears that the region is divided into northern and southern zones in terms of this rainfall. Snowmelt runoff was the peak event of the hydrologic season for the four gauged basins. Summer storm events were recorded everywhere, but did not have the impact of the previous year. None of the recorded peak flows exceeded the design curves relevant to this region. The influence of culvert icings to design flow is also discussed.

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INTRODUCTION

This study has been carried out through the funding of the Northern Roads Environmental Working Group of the Department of Indian Affairs and Northern Development. The basic aim is to investigate the effects of the highway on adjacent water resources, including any modifications affecting fish passage (under study by personnel of the Freshwater Institute, Winnipeg), such as increased sediment loads. Thus, the pre-construction data collected and presented in this study will stand as the baseline data against which construction and operational effects of the highway can be judged. Because of the dearth of hydrologic information in this area, any data relevant to streamflow and runoff are also amenable for use in updating the design curves from which stream crossings are constructed. This is especially true in the Liard Valley where no hydrologic program has been undertaken to produce specific design curves, and stream crossings are to be based on theoretical design curves, or generalized ones based on information from eleswhere in the Mackenzie Valley.

This is a report based on the second year of study (spring and summer 1978), and reference should be made to the previous report (Grey and Jasper, 1978) for more general information on the Liard Highway. The streamflow monitoring program continued with water level recorders operating for most of the open water season at Miles 8, 13.8, 59.4 and 115.7. The gauge at Rabbit Creek (Mile 117.6) was operated by Water Survey of Canada who added this basin to their network in the spring of 1978. They also operate a gauge on the Birch River. These basins are shown in Figure 1.

The importance of summer precipitation, and its variability, was shown in the 1977 study, and accordingly, a network of precipitation gauges was operated in conjunction with the streamflow gauges. The network is shown in Figure 1 and it can be seen that an attempt was made to obtain good basin coverage, with gauges in the headwaters and near the mouths of the northern and southern basins. Another gauge was installed along the highway at Mile 59.4, but unfortunately this malfunctioned and produced no record. Precipitation data are also available from the A.E.S. Stations at Forts Simpson, Liard and Nelson.

Other information was collected on a more limited scale. Ice thickness in culverts were noted in April, and these data could prove important in consideration of design flows. Several snow courses were run in April, the sites shown in Figure 1. During the early part of the open-water season suspended sediment samples were taken at the study basins, as well as the associated water temperature.

THE 1977/78 WATER YEAR

Climatic data for Forts Simpson and Nelson for the period October 1, 1977 to September 30, 1978 are given in Tables 1 and 2 respectively. Departure of the monthly data from station normals are also given, indicating the presence and persistence of the weather conditions. Table 3 presents the summary of meteorologic data for Fort Liard, but since this station has a very short operational record, the departures of the 1977/78 data from monthly means of the previous four years are used as an analogy to the

TABLE 1. FORT SIMPSON METEOROLOGIC SUMMARY, WATER YEAR OCTOBER 77-SEPTEMBER 78

	PRECIPITATION						TEMPERATURE (°C)					
MONTH	TOTAL (mm)	Δ	RAIN (mm)	Δ	SNOW (mm)	Δ	MEAN MAX	Δ	MEAN MIN	Δ	MEAN DAILY	Δ
OCT.	29.6	+ 3.4	5.5	- 5.7	23.6	+ 8.6	4.0	+ 1.6	- 5.7	-1.0	- 0.9	+0.3
NOV.	23.2	- 0.2	0.3	+ 0.3	23.6	+ 0.2	-13.4	- 2.5	-19.9	-2.5	-16.7	-2.5
DEC.	8.7	-10.4	0	-	8.7	-10.4	-25.7	- 5.8	-34.2	-6.5	-30.0	-6.2
JAN.	9.7	-11.1	T	-	9.7	-11.1	-19.8	+ 1.8	-28.3	+2.1	-24.1	+1.9
FEB.	5.3	- 9.2	0	-	5.3	- 9.2	- 8.5	+10.0	-21.4	+6.7	-15.0	+8.3
MAR.	16.1	- 2.4	0	-	16.1	- 2.4	- 6.8	+ 2.2	-19.8	+1.3	-13.3	+1.7
APR.	14.2	- 7.4	2.0	- 4.1	12.8	- 2.7	2.9	+ 0.7	- 8.9	+0.9	- 3.0	+0.8
MAY	4.2	-16.6	2.5	-14.0	1.7	- 2.6	14.0	+ 0.1	1.2	-0.4	7.6	-0.2
JUNE	64.1	+20.4	64.1	+20.4	T	-	21.0	+ 0.4	8.2	+0.1	14.6	+0.3
JULY	76.9	+27.1	76.9	+27.1	0	-	21.0	- 2.1	8.8	-1.8	14.9	-1.9
AUG.	18.8	-27.9	18.8	-27.9	0	-	20.2	- 0.3	6.2	-2.4	13.2	-1.4
SEPT.	7.6	-32.8	7.6	-30.2	0	- 2.5	14.7	+ 2.1	2.6	-0.3	8.7	+1.0
ANN.	278.4	-67.1	177.7	-34.1	101.5	-32.1	+ 2.0	+ 0.7	- 9.3	-0.3	- 3.7	+0.1

Δ - Difference from normal

T - Trace event

TABLE 2. FORT NELSON METEOROLOGIC SUMMARY, WATER YEAR OCTOBER 77-SEPTEMBER 78

	PRECIPITATION								TEMPERATURE (°C)					
MONTH	TOTAL (mm)	Δ	RAIN (mm)	Δ	SNOW (cm)	Δ	SNOW WE (mm)	Δ'	MEAN MAX	Δ	MEAN MIN	Δ	MEAN DAILY	Δ
OCT.	24.9	*- 0.8*	5.1	*- 2.3*	12.6	*- 6.5*	19.8	*+ 1.5*	8.9	*+2.8*	- 3.5	*+0.3*	2.7	*+1.5*
NOV.	16.5	*-10.2*	T	*- 0.8*	21.8	*- 7.7*	16.5	*- 9.4*	-10.3	*-2.0*	-18.2	*-1.9*	-14.3	*-2.0*
DEC.	13.4	*-12.5*	0	-	18.4	*-10.3*	13.4	*-12.5*	-21.5	*-4.6*	-28.4	*-3.9*	-25.0	*-4.3*
JAN.	10.3	*-16.1*	1.0	*+ 1.0*	12.5	*-17.7*	9.3	*-17.1*	-16.1	*+2.7*	-24.9	*+2.7*	-20.5	*+2.7*
FEB.	8.7	*-15.7*	T	*- 0.3*	10.3	*-15.9*	8.7	*-15.4*	- 6.6	*+5.1*	-18.9	*+3.5*	-12.8	*+4.3*
MAR.	33.1	*+ 8.2*	0	*- 0.8*	57.1	*+29.7*	33.1	*+ 9.0*	- 1.3	*+1.4*	-15.0	*+0.7*	- 8.2	*+1.0*
APR.	6.1	*-15.5*	1.2	*- 3.9*	7.4	*-11.9*	4.9	*-11.6*	7.9	*+0.6*	- 5.0	-	1.5	*+0.3*
MAY	52.5	*+14.9*	46.9	*+15.1*	10.0	*+ 4.2*	5.6	*- 0.2*	15.5	*-0.6*	2.3	*-0.9*	8.9	*-0.8*
JUNE	33.9	*-30.4*	33.5	*-30.5*	0.4	*+ 0.4*	0.4	*+ 0.1*	22.9	*+2.0*	8.5	*+0.4*	15.7	*+1.2*
JULY	64.6	*-10.1*	64.6	*-10.1*	0	-	0	-	22.1	*-0.9*	9.8	*-0.6*	16.0	*-0.7*
AUG.	94.0	*+38.4*	94.0	*+38.4*	0	-	0	-	19.6	*-1.6*	7.3	*-1.1*	13.5	*-1.3*
SEPT.	73.9	*+35.3*	73.9	*+40.6*	0	*- 5.3*	0	*- 5.3*	14.3	*-0.3*	3.1	*+0.1*	8.7	*-0.1*
ANN.	431.9	*-14.5*	320.2	*46.4*	150.5	*-41.0*	111.7	*-60.9*	4.6	*+0.4*	- 6.9	-	- 1.2	*+0.1*

Δ - Difference from normal

Δ' - Difference from computed normal

T - Trace event

TABLE 3. FORT LIARD METEOROLOGIC SUMMARY, WATER YEAR OCTOBER 77-SEPTEMBER 78

MONTH	PRECIPITATION (mm)						TEMPERATURE (°C)					
	TOTAL	Δ	RAIN	Δ	SNOW	Δ	MEAN MAX	Δ	MEAN MIN	Δ	MEAN DAILY	Δ
OCT.	1.0	*- 23.9*	T	*- 8.4*	1.0	*-15.5*	7.9	*+4.3*	- 3.8	*+0.4*	2.1	*+2.4*
NOV.	32.1	*+ 4.3*	0	-	32.1	*+ 4.3*	-13.6	*-3.9*	-19.2	*-1.5*	-16.4	*-2.7*
DEC.	43.5	*+ 15.8*	0	-	43.5	*+15.8*	-24.2	*-6.7*	-30.1	*-5.1*	-27.2	*-5.9*
JAN.	8.1	*- 17.9*	0	-	8.1	*-17.9*	-17.7	*+1.1*	-25.2	*+2.3*	-21.5	*+1.6*
FEB.	9.2	*- 7.6*	T	-	9.2	*- 7.6*	- 6.7	*+5.4*	-17.1	*+4.8*	-11.9	*+5.8*
MAR.	27.5	*- 0.7*	T	-	27.5	*- 0.7*	- 3.1	*+2.9*	-16.5	*+2.9*	- 9.8	*+2.9*
APR.	7.0	*- 12.7*	1.2	*- 6.0*	5.8	*- 6.7*	6.7	*-2.6*	- 5.5	*-1.0*	0.6	*-1.8*
MAY	51.0	*+ 3.6*	47.1	*+ 3.0*	3.9	*+ 0.6*	15.2	*-0.7*	2.2	*-0.7*	8.7	*-0.7*
JUNE	26.4	*- 50.5*	26.4	*- 50.5*	0	-	23.4	*+2.9*	9.6	*+2.0*	16.5	*+2.4*
JULY	96.8	*+ 11.1*	96.8	*+ 11.1*	0	-	21.3	*-0.8*	10.4	-	15.9	*-0.3*
AUG.	43.7	*- 46.9*	43.7	*- 46.9*	0	-	19.9	*+0.6*	6.9	*-1.5*	13.4	*-0.5*
SEPT.	28.4	*- 4.6*	28.4	*- 2.3*	0	*- 2.3*	15.3	*-0.8*	3.3	*-0.7*	9.3	*-0.8*
ANN.	374.7	*-130.0*	243.6	*-100.0*	131.1	*-30.0*	3.7	*+0.1*	- 7.1	*+0.1*	- 1.7	*+0.2*

Δ - Difference from the average of previous 4 years

T - Trace event

normal, but these deviations are not to be considered as meaningful as the departures from the normal for the other two stations. For Forts Simpson and Liard the snow column provides the value of snow water equivalent through the reduction of snow depth by a factor of 10, while the Fort Nelson snow water equivalent values are actually measured, and the snow water equivalent normal has been calculated from the normals of total precipitation.

During the summer of 1977 (May to September) precipitation had been moderate to high with Fort Simpson receiving 89% of normal, Fort Nelson 158% and Fort Liard 121%. Therefore antecedant moisture was probably high at the start of the following winter period. During the winter period 1977/78 (October to April) all three stations had less than normal precipitation with Fort Simpson receiving 74% of normal, Fort Nelson only 64% and Fort Liard 75%. However, for Forts Simpson and Liard this was more precipitation than received during the previous winter period. The temperature regime was similar for all stations, with November and December being below normal months for all, and October, January, February and March being above normal. April was close to normal for Forts Simpson and Nelson, while it was below at Fort Liard. Generally, the winter of 1977/78 was slightly above normal for temperature, but was colder than the previous winter which had been persistently above normal. The three factors of high antecedant moisture, moderately high winter precipitation (compared to winters in the recent past) and almost normal winter temperatures had a bearing on the type of snowmelt (especially in the Fort Simpson area) and the severity of river channel and culvert icings.

Summer precipitation was less than in 1977 at all three stations. Fort Simpson received 85% of normal, which was closest to the 1977 value (89%) while Fort Nelson's 118% of normal (down from 158%) and Fort Liard's 74% (down from 121%) was reflected in the lack of extreme storm runoff events. At Fort Simpson, June and July were strongly above normal, while May, August and September were much below normal. The pattern was reversed at Fort Nelson which had June and July below normal, and May, August and September enough above normal to allow a summer total that was itself above normal. The shortness of record at Fort Liard is a hindrance to this type of analysis, but May and July were above average, and June, August and September were well below. Summer temperatures were in general slightly below normal.

The annual patterns revealed by these records show that all three stations had almost normal conditions with respect to temperature, the slightly below normal summers balancing the slightly above normal winter. However, in terms of precipitation there was greater variation between stations. Fort Simpson was below normal for both winter and summer precipitation leading to a net water year of 81% of normal. The above normal summer precipitation at Fort Nelson almost compensated for the extreme drought of the winter to produce an annual amount 97% of normal. At Fort Liard the annual amount was 74% of the average which was the same percentage received during winter and summer. Thus for the stations at Fort Simpson and Fort Nelson the water year 1977/78 was closer to normality than the previous year in both precipitation and temperature. This should be held in mind when considering the hydrology section, since it implies that although the less severe summer storm events of 1978 may be more normal than the extremes of 1977, the study basins have not experienced normal snowmelt events during the period of record.

Snowcover and snowmelt will be considered in the next section. During the summer of 1978 four automatic rain gauges were operating in the study area. The records obtained will be used, where relevant, in the hydrology section, as well as forming a major part in a later section on regional variability. Icing severity, partially a function of meteorological attributes, will also be discussed in the next section.

HYDROLOGY OF THE STUDY BASINS

Snow Cover

Winter precipitation in the Liard Valley falls mostly as snow, although rain is likely in October and April. Since the winter precipitation at Forts Simpson and Liard was greater in 1977/78 than in 1976/77, it follows that snowfall, and presumably snow accumulation, was also greater. The records of the A.E.S. stations usually show snow depth at the end of each winter month, and on this basis the maximum depth of 48 cm occurred at Fort Simpson at the end of March, while 55 cm were recorded at Fort Nelson at the end of March. No snow depths were recorded at Fort Liard after December, 1977. Five short snow courses were run within the study area on April 17. The sites are shown in Figure 1, and the information is displayed in Table 4. Also shown in Table 4 are snow depth and water equivalent data obtained from

TABLE 4. SNOW COURSE DATA, LIARD HIGHWAY, 1978

Site	Date	Mean Depth (cm)	Mean Water Equivalent (mm)	No. Sample Points	Site Description
Goose Lake	April 17	44.5	98	10	Headwaters of Mile 8 Basin near SE shore of Lake
Cormack Lake	April 17	56.4	119	10	Headwaters of Birch River, near northern shore
Mile 59.4	April 17	46.0	113	10	Near gauge site at Mile 59.4 of Liard Highway
Mile 117.6	April 17	30.2	86	12	Near gauge site of Rabbit Creek at Liard Highway
Rabbit Creek	April 17	42.0	98	12	Near lake in headwaters of Rabbit Creek
Fort Nelson, B.C.*	March 15	64.4	166	10	Near upper air Met. station Fort Nelson airport
	April 1	54.5	196	10	
	April 15	37.9	110	10	

* Data source: upper air meteorological station, Fort Nelson, B.C.

the Upper Air Meteorologic Station at Fort Nelson. These are the last three snow surveys of 1978, and reveal that the maximum snow depth was measured on March 15, but that the maximum water equivalent was not until April 1. The April 15 value for Fort Nelson is fairly close in time to the other snow courses, and the water equivalent is very similar to the others obtained on April 17. The greatest snow water equivalent value was obtained near Cormack Lake (119 mm) at an elevation of approximately 565 m (1850 ft), and the lowest at Mile 117.6 (86 cm) at an elevation of 215 m (700 ft). All water equivalent values are fairly close and the mean water equivalent for the study area was 103 cm. Unfortunately, no snow courses were run at the Fort Simpson A.E.S. station, but it is felt that snow accumulation by the spring of 1978 was greater than in 1977 due to the heavier snowfall, and the slightly lower temperatures which reduced the possibility of winter melt. At Forts Nelson and Liard all snow had disappeared before the end of April, while only a trace existed at Fort Simpson on April 30.

Runoff

Miscellaneous stream gauging was undertaken at the four study basins in late April, since extensive ice prevented the re-occupation of the stilling wells installed the previous summer. Gradually, the sites became sufficiently ice-free to obtain a water-level record; first at Mile 115.7, then Mile 13.8, and Mile 8, and finally at Mile 59.4 only in the second week of May, due to the extreme thickness of the icing deposit. At the three larger basins the water-level record ran through to August, except at Mile 115.7 where the water-level fell below the stilling well in July. The record for Mile 13.8 ran only until the first week of June. As stated above the gauging program at Rabbit Creek (referred to as Mile 117.6 in the previous report) was carried out by personnel of Water Survey of Canada, who have provided the preliminary data from that gauge.

The hydrometeorologic data records for the study basins are shown in Figures 2 to 5, while the hydrograph of mean daily flow of Rabbit Creek is shown in Figure 6. For all basins the hydrographs have two components; a snowmelt peak in early May (late April for some) and recession into the latter part of the month; various peaks in response to rainfall during June, July and August (except for Mile 13.8 which has a short record). For all the study basins other than Rabbit Creek, the snowmelt peak is the greatest value recorded during the 1978 open water season, and this event is reinforced by the preliminary W.S.C. data for other rivers in this area; the Birch, Trout, Harris, Martin and Jean-Marie rivers all had their peak values between May 3 and May 8 in 1978. There was an indication of a south to north trend in snowmelt with Rabbit Creek and Mile 115.7 peaking on April 29 and 30, respectively and Miles 8 and 13.8 on May 5 and 6, respectively. Although there was some precipitation input to all basins in the period May 3 to 5, this increase in discharge was mainly in response to snowmelt as the mean daily temperature rose above $0^{o}C$ on April 25, and stayed positive for the rest of the open water season.

During the post-snowmelt period, each of the basins with water-level records, displayed several peaks in response to rainfall inputs. The response of the southern basins (59.4, 115.7 and Rabbit Creek) was rapid, while the basin at Mile 8 had a more sluggish response. For Rabbit Creek the first major rainstorm after snowmelt produced the greatest discharge of the season ($4.1\ m^3/s$ in response to 30 mm of rain in two days), while the same storm resulted in a discharge peak almost equal to that of snowmelt at Mile 115.7. It also appears that later storms during the summer did not produce as great a response as those that occurred soon after snowmelt, possibly because the saturation of these southern basins decreased with increasing evapotranspiration.

Various hydrologic attributes of the study basins are shown in Table 5. At those basins which recorded a significant rainfall peak discharge, this value is noted along with the snowmelt peak. The peak unit area discharges from snowmelt for Miles 8 and 13.8 are much higher than recorded for the peak event (rainfall) of 1977, while this snowmelt value is lower for all the other basins in 1978 compared to their response to rainfall in 1977. It appears that the amount of basin storage (as represented by the percentage of lake and muskeg) has less effect on snowmelt than it apparently had on storm discharge in 1977. It is even possible that it increased the basin response to snowmelt in the basins at Miles 8 and 13.8, since such storage areas would be highly saturated (wet summer of 1977) and probably still frozen since snowmelt occurred rapidly after the inception of positive temperatures.

The runoff totals and ratios for the period of snowmelt, open-water season,

TABLE 5. HYDROLOGIC ATTRIBUTES OF STUDY BASINS, LIARD HIGHWAY, 1978

Basin	Area km^2	% Lake and Muskeg	Maximum Instantaneous Discharge (m^3/s)	Date	Peak Unit Area Discharge ($m^3/s/km^2$)
Mile 8	175.5	56	4.12	May 5	0.024
Mile 13.8	20.5	24	1.10	May 6	0.054
Mile 59.4	43.9	47	0.69 (Snowmelt)	May 7	0.016
			0.56 (Rainfall)	July 25	0.013
Mile 115.7	33.3	2	1.15 (Snowmelt)	April 30	0.035
			0.78 (Rainfall)	May 31	0.023
Rabbit Creek*	123.5	4	[†]2.26 (Snowmelt)	April 29	0.018
			4.10 (Rainfall)	May 30	0.033
Birch River*	557	-	[†]19.81	May 3	0.036

* Preliminary data provided by Water Survey of Canada

† Mean daily discharge

and for individual storm events have been calculated and are shown in Table 6. The first period shown for each basin is that of snowmelt, and the end-point of this period varies among basins, a reflection of the variability of the snowmelt recession period. The second period shown for each basin is the full open-water season as recorded. It can be seen that only one period is shown for Mile 13.8. This is the full length of record, but is also that of the snowmelt period. The basins of Rabbit Creek and Mile 115.7 experienced one large storm event, and the May 28 - June 6 period is an analysis of this event.

The runoff ratio is the ratio of the actual measured runoff and the "potential" runoff of the snowpack water equivalent and measured precipitation. Mile 13.8 had the greatest runoff ratio for the snowmelt period, with nearly 70% of the potential runoff passing through the gauging site. Miles 8 and 115.7 had moderate ratios (more than 25% of accumulated water running off), while the other two basins had a low runoff response to snowmelt. The runoff total for Mile 59.4 may be lower than actually occurred because of the late installation of the water-level recorder due to ice conditions. The runoff ratios for the open-water seasons were either lower or the same, and this indicates the importance of the snowmelt period to the annual runoff. The ratios for the rainstorm event in the Rabbit Creek and Mile 115.7 basins are much higher than those of the other periods, and this is an indicator of the low storage capacity, and therefore rapid response to a heavy water input, as was indicated by these basins in 1977, although the precipitation network in 1978 was a great improvement over that existing in the previous year. The great difference between the storm runoff ratio (0.52) and the seasonal ratio

TABLE 6. RUNOFF DATA, LIARD HIGHWAY BASINS, 1978

Basin	Period	Runoff (mm)	Snowpack W.E. (mm)	Precip. (mm)	Runoff Ratio
Mile 8	April 26 - June 5	32	97	31	0.25
	April 26 - Aug. 21	48	97	137	0.21
Mile 13.8	April 26 - June 6	87	97	31	0.68
Mile 59.4	April 26 - May 28	21	116	25	0.15
	April 26 - Aug. 18	38	116	137	0.15
Mile 115.7	April 23 - May 20	32	92	8	0.32
	April 23 - July 10	64	92	110	0.32
	May 28 - June 6	18	-	32	0.55
Rabbit Creek*	April 25 - May 20	19	92	8	0.19
	April 25 - Aug. 18	48	92	171	0.18
	May 28 - June 6	17	-	32	0.52

* Runoff data calculated from Water Survey of Canada preliminary information.

(0.18) for Rabbit Creeek, is also a reflection of the low proportion of the basin area in lakes and muskeg, since the streamflow between discharge peaks declines to very low values without the benefit of water storage, and the low seasonal runoff ratio is more a result of the extended periods of low values than the infrequent storm ratios.

Icings.

An icing occurs where streamflow continues into the winter, and the water freezes in layers to an existing ice sheet. The ice that is formed is very hard, usually extends down to the bed of a small stream or to the base of the culvert. As a result, it forms an obstacle to the passage of the spring flood, and unlike river 'surface' ice which breaks into pieces and can be pushed out by the increasing freshet flow, the icing has to erode from the formation site, mostly by melting, thereby causing an elevation of stage and increasing flood potential. Basins with high lake and muskeg areas have great potential for icings, because these storage areas can allow flow to continue into winter, especially after a wet summer leading to high antecedant moisture.

It has been shown that the northern part of the Liard Highway region had moderately high antecedant moisture, and an almost 'normal' winter in terms of temperature, and the occurrence of icing was more severe than in the spring of 1977. Icing depth is most easily measured at culvert installations, and Table 7 shows the values measured at the culvert outlets of Miles 8 and

TABLE 7 ICE DEPTHS AT STUDY BASINS ALONG LIARD HIGHWAY, 1978

Site	Date	Culvert Dimensions Max Width (m)	Depth (m)	Ice Depth Max (m)	% Culvert Occupied by Ice
Mile 8	April 24	3.7	2.75	0.92	33
Mile 13.8	April 24	2.4	2.4	0.84	26
Mile 59.4	April 29	2.75* 2.75*	2.75* 2.75*	0.99	41*

* As proposed, reported in Unies Ltd., 1974
2 culverts

13.8. The depth at Mile 59.4 was marked against the water-level recorder stilling well, which was almost buried. It should also be noted that at one site along the Fort Simpson airport road, total blockage of a culvert occurred and this resulted in severe upstream ponding, and the formation of more than 2 m depth of icing at the deepest point. At the two Liard Highway culverts the ice was slightly deeper at the culvert inlet and this resulted in a bed slope within the culvert greater than the natural invert, and accordingly, much greater stream velocities, especially at the Mile 13.8 exit which is slightly elevated above the bed.

The final column in Table 7 is based on calculations of culvert cross-sectional area. They are necessarily estimates since they assume that the culverts have retained the shape they had prior to installation. For the circular culvert at Mile 13.8, slightly more than 25% of the flow area was filled by ice. However, although the icing depth was similar at Mile 8, due to the arch-shape (i.e. the maximum width of the culvert is close to the bed) the percentage of the culvert blocked by ice was 33%. At Mile 59.4 it was proposed to install two circular culverts, and therefore with the measured icing depth at that site, it is likely that at least 40% of the flow area would have been blocked if these culverts had been in place before the spring of 1978. This reduction in flow area due to icing will also be discussed in a later section.

Suspended Sediment.

Suspended sediment samples were taken from the streams of the four gauged study basins for the snowmelt period during May. The results are shown in Table 8. In general all the sampled concentrations were low (all but two were less than 40 mg/l). These results are very similar to those obtained during the summer period of 1977. There is a very general relationship between stream discharge and sediment concentration, but the scatter from the small number of samples is too great to justify plotting. These data do confirm that the streams crossed by the Liard Highway transport (and concomitantly produce) very small suspended sediment loads, and therefore, the aquatic environments are vulnerable to any great increases in sediment caused by highway construction. On the other hand, the samples from Miles 8 and 13.8 were taken below the culverts, and are quite low, indicating that no permanent increase in suspended sediment is likely after the construction phase has been completed.

REGIONAL VARIABILITY

In many hydrologic studies, especially in remote areas, precipitation data are used in various models to simulate runoff records for ungauged streams. This is mainly due to the fact that it is cheaper and often easier to set up a precipitation network than one to record streamflow. Consequently, even in areas with limited streamflow records, the precipitation records are usually longer, and are often used in an attempt to extend the streamflow record back in time. However, each precipitation gauge is a point measurement of an extremely variable spatial phenomenon, while the streamflow record is the integrated result of the precipitation variability throughout the space

TABLE 8 LIARD HIGHWAY SUSPENDED SEDIMENT DATA, 1978

Basin	Basin Area km^2	Date	Concentration mg/L	Stream Discharge m^3/s	Water Temp. °C
Mile 8	175.5	May 5	38.9	3.20	0.5
		May 11	25.7	2.47	2.0
		May 15	20.6	1.42	4.0
		May 18	16.1	1.59	8.0
		May 20	16.2	1.43	7.5
		May 24	24.8	1.13	8.5
		May 28	22.8	0.76	9.5
Mile 13.8	20.5	May 5	37.4	1.01	-
		May 11	37.0	0.62	2.0
		May 15	32.8	0.50	3.8
		May 18	25.6	0.51	6.5
		May 20	5.1	0.46	6.0
		May 24	21.9	0.35	7.0
		May 28	7.9	0.26	-
Mile 59.4	43.9	May 2	53.4	0.49	0.5
		May 5	143.3	0.65	1.5
		May 11	39.5	0.59	2.5
		May 17	25.3	0.44	9.0
		May 22	19.8	0.28	-
		May 27	30.1	0.21	11.0
Mile 115.7	33.3	May 2	27.3	0.78	0.9
		May 11	20.2	0.34	2.5
		May 17	17.8	0.18	7.5
		May 27	37.8	0.20	-

represented by that basin. Nonetheless, a greater understanding of regional hydrologic variability is to be gained through an analysis of the precipitation pattern, than through the limited temporal and spatial records of streamflow available within the study region. The problems to be met in precipitation analysis for this region have been well summarised by Burns (1974) in a study of the climate of the Mackenzie Valley:

> "Precipitation analysis is very difficult in this area. The difficulty arises from the paucity of data in both time and space; the unreliability of data because of approximations or error in measurement, and topographically induced variations."

The region around the Liard Highway displays two very distinct precipitation periods. Although the monthly totals of winter precipitation differ among the meteorologic stations in the region, at the end of the winter the snow cover is similar throughout, especially with respect to snow water equivalent, with a trend of slight increase from north to south. However, the pattern of summer precipitation (May to September) is not so easy to elucidate. Most of the summer rainfall is frontal, associated with cyclonic paths down the Liard Valley (Currie, 1953), and under these conditions the rate of fall is moderate and usually long lasting, thereby affecting larger areas. Convectional processes can also produce moderate falls over small areas. A combination of both types can produce heavy falls with long storm paths, but great variability within the storm path. Physiographic effects can complicate the pattern further, since the Liard Range near Fort Liard is a formidable barrier, and the plateau area to the northeast of Fort Liard is higher than the valley. This physical situation might be expected to have a greater influence on rainfall than the essentially level and open terrain around Fort Simpson.

One method of examining rainfall variability is the 'mass curve' in which accumulated rainfall amounts are plotted against time (storm period) for various stations. In Figure 7 daily rainfall totals have been accumulated through the summer of 1977 for the three A.E.S. stations in the study region. Differences in the amount measured are reflected in the vertical positioning on the graph, and similar storm responses are reflected in the parallelism of the lines along the time axis. It can be seen that Fort Simpson had the lowest rainfall total for the summer, and from June onwards had a very different pattern to the other two lines. On the other hand, although Fort Nelson received more rain than Fort Liard, they had similar patterns of accumulation for much of the summer. Figure 8 is a similar plot for the records of 1978, and also shows the records of the two gauges at Mile 8 and a site henceforth called 'Rabbit Lake', located on the shore of a lake in the headwaters of Rabbit Creek. Again Fort Nelson received the most rain, Fort Simpson is dissimilar to the other A.E.S. stations for May and August, but all stations are essentially parallel for most of June and July. Throughout most of the summer the record from Mile 8 resembles most nearly that of Fort Simpson, while the gauge at 'Rabbit Lake' is fairly close to that of Fort Liard until late July.

It has been stated above that the streamflow record is an integration of variable precipitation inputs. Therefore, although the pattern of accumulated daily totals appear similar for much of the summer of 1978, the great distances between gauges can mask very real differences, such that adjacent basins can have different runoff values from apparently the same storm, or vice versa. Figure 9 is a plot of mean daily runoff for three of the gauged basins along the highway route. The pattern for May, essentially snowmelt recession, was quite similar. However, great disparities were seen during the summer rainfall months. A storm in late May produced a great response at Mile 115.7, a small response at Mile 59.4 and does not appear to have reached the basin at Mile 8. This pattern repeated itself throughout the summer. It is this response to daily rainfall amounts that is important to regional hydrologic modelling and it appears that no one station would be capable of predicting expected inputs to all basins along this section of the highway.

The difficulty in predicting daily precipitarion amounts might be expected because of the variation of intensity within cyclonic systems. However, it is even difficult to predict the occurrence of any amount of rainfall. Figure 10 is a plot of the frequency of precipitation on a daily basis. The monthly differences are as expected, peaking in June or July for all stations. The variations among stations for each month are a reflection of the variability of the storm paths, and the possible influence of local convection, and environmental factors. An influence external to the actual meteorologic processes could be observer and/or instrument differences. The automatic gauges used in this study recorded rainfall on a regular 24 hour basis (midnight through to midnight), whilst the A.E.S. stations record on a shift basis (2000 to 0800 hrs and 0800 to 2000 hrs). This could account for some of the variation between the two types of gauges, if rain fell (or did not fall) in the 4 hour period at the beginning and end of the A.E.S. records.

It is probable that any discrepancies between the two types of records would be for light, short duration falls. It can be seen from Table 9 that these occurrences of daily precipitation contribute very little to the monthly total. For most stations, and for most of the summer months, more than 80% of the total monthly rainfall is contributed by falls of more than 2.5 mm, and that almost half occurs in amounts greater than 10 mm, although usually less than 20% of rainy days result in falls this great. The influence of these infrequent heavy falls is strongest in July, when convective processes might be expected to be most prevalent. On the basis of these monthly totals no regional patterns are obvious although station differences are seen for the various months.

The amounts of summer precipitation received on the various sites are shown in Table 10. During May, Fort Simpson received very little precipitation and was dissimilar to Mile 8. On the other hand, the gauges at Mile 115, 'Rabbit Lake', Fort Liard and Fort Nelson, were fairly close in amount. The records for June show a similarity among the first five stations, with Forts Liard and Nelson being dissimilar. Thereafter, the lack of complete records make such comparison impossible. However, even when the monthly totals of two stations are similar, the maximum daily amounts do not seem to be as comparable, even for adjacent gauges. However, the date of maximum daily amount at one station was usually one of high rainfall amount at an adjacent station, but not necessarily the maximum. This can be seen from

TABLE 9 MONTHLY PRECIPITATION BY FALL AMOUNTS, LIARD HIGHWAY, 1978

STATION	MAY				JUNE				JULY				AUGUST				SEASONAL			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Fort Simpson	20	67	0	0	63	90	6	17	31	87	13	58	43	79	0	0	43	87	7	34
Mile 8	44	91	11	54	54	88	15	53	42	88	17	64	*25	*77	*11	*56	*43	*87	*14	*57
Goose Lake	*0	*0	*0	*0	36	81	7	48	25	74	8	52	*14	*54	* 0	* 0	*23	*73	* 5	*44
Mile 115	80	99	20	48	53	95	7	28	*50	*87	*0	*0	-	-	-	-	*58	*95	* 8	*31
'Rabbit Lake'	67	98	17	47	21	74	7	40	35	68	0	0	-	-	-	-	*35	*79	* 5	*29
Fort Liard	50	94	20	74	56	96	11	46	50	89	25	61	50	90	33	71	51	91	22	64
Fort Nelson	50	94	10	45	27	80	0	0	67	91	0	0	53	96	20	72	43	92	7	37

* Incomplete monthly record

N.B. Trace events not included

A - % Rainy Days with Falls > 2.5 mm

B - % Monthly Total Contributed by Falls > 2.5 mm per day

C - % Rainy Days with Falls > 10 mm

D - % Monthly Total Contributed by Falls > 10 mm per day

TABLE 10 SUMMER PRECIPITATION IN AREA OF LIARD HIGHWAY, 1978

STATION	MAY (mm)		JUNE (mm)		JULY (mm)		AUGUST (mm)	
	Total	Max. Daily	Total	Max. Daily	Total	Max. Daily	Total	Max. Daily
Fort Simpson	4.2	(8) 2.8	64.1	(7) 10.6	76.9	(23) 31.2	18.8	(9) 7.4
Mile 8	29.0	(3)15.5	58.7	(30) 18.8	49.0	(16) 20.6	*18.5	(15)10.4
Goose Lake	* 4.5	(29) 1.8	56.1	(26) 26.7	32.5	(16) 16.8	* 6.1	(10) 3.3
Mile 115	49.0	(29)23.4	52.1	(8) 14.7	*20.1	(12) 9.1	-	-
'Rabbit Lake'	41.4	(29)19.3	51.3	(14) 20.6	47.5	(22) 7.9	*28.2	-
Fort Liard	51.0	(28)21.4	26.4	(8) 12.1	96.8	(1) 24.8	43.7	(10)20.2
Fort Nelson	52.5	(21)23.6	33.9	(17) 9.3	64.6	(27) 8.5	94.0	(10)25.5

* Incomplete monthly record.

(22) Date of maximum daily amount.

Table 11 in which the dates of the three highest daily rainfall totals have been shown for each station and month. From this table the two general groupings are apparent for these data; firstly the Fort Simpson, Mile 8 and Goose Lake gauges have the same dates reappear among the rankings; and secondly, the Fort Liard, Mile 115 and 'Rabbit Lake' gauges are similar to each other, but generally different from the first group. The great differences in monthly totals between relatively close gauges indicate the variability of rainfall to the basins and perhaps, explain the discrepancy between runoff in adjacent basins to be largely one of differential input.

In all of the above attempts at precipitation analysis the record of rainfall at the Fort Simpson station has been seen to differ markedly from the other A.E.S. stations. Other analyses were attempted to find if the daily record at Fort Simpson could be used to predict daily amounts at the other gauges sites. The results were inconclusive, but it can be stated that Fort Simpson was generally unreliable as a predictor, and tended to underpredict. This is important since the UNIES (1974) modelling proceedure to simulate basin runoff used the Fort Simpson record as the input information. The only alternate station record available at that time was Fort Nelson, which is not a good predictor of daily rainfall because of the time lag involved, and because of the possibility that the cyclonic storms would diminish in intensity in their passage from the southwest towards Fort Simpson. When the gauge records are reviewed on a daily basis there does appear to be an association between the gauges at 'Rabbit Lake' and Mile 115.7 with the station at Fort Liard; and the gauges at Goose Lake and Mile 8 seem to be associated with the record from Fort Simpson, as seen in Table 11. It is

TABLE 11

MONTHLY RANKINGS OF HIGHEST DAILY RAINFALL
TOTALS BY DATE, LIARD HIGHWAY, 1978

STATION	MAY			JUNE			JULY			AUGUST		
RANKS	1	2	3	1	2	3	1	2	3	1	2	3
Fort Simpson	8	1	3	7	21	17	23	16	24	9	24	15
Mile 8	3	16	8	30	20	17	16	12	22	*15	10	9
Goose Lake	-	-	-	26	30	17	16	11	23	*10	16	9
Mile 115.7	29	28	21	8	24	20	*12	1	5	-	-	-
'Rabbit Lake'	29	28	21	14	8	20	22	13	1	-	-	-
Fort Liard	28	20	27	8	15	17	1	16	12	10	14	4
Fort Nelson	21	22	14	17	9	5	27	25	1	10	18	11

* Incomplete monthly record.

possible that the meteorologic information reviewed above are from abnormal years, but nonetheless, it suggests that the Liard Highway crosses two different rainfall regions, and this, allied with the different basin attributes shown by the southern and northern basins of the study region, might explain the different responses shown to summer rainfall inputs by these two basin groups.

DESIGN FLOWS

The design flow determines the minimum capacity of a culvert required to pass the expected peak discharge for a drainage basin with respect to a selected return period, usually the 50 year flood. The capacity is the cross-sectional area of the culvert at its inlet and exit. The design flow is usually computed by flood frequency analysis from a long record of flood discharges. However, in the remoter areas, such records do not exist, and the design flows have to be computed either by extending a short term flow record through regional cross-correlations, or by using long-term meteorologic records to compute runoff data by various modelling techniques. The design flows currently in use in the Liard Highway project are mainly the extension of short-term records and regional correlation (Water Planning and Management Branch, 1975); while the only modelling attempt for the basins crossed by the highway used meteorologic data transformed into runoff predictions (UNIES, 1974).

In the report on the 1977 study (Grey and Jasper, 1978) various relevant design flow curves were plotted along with measured and estimated values for the peak discharges of the various basins. Figure 11 is a similar plot and incorporates the data from 1977 and 1978. It should be noted, that since the completion of the report of the 1977 work two of the 1977 values have been revised. The peak discharge measure of Rabbit Creek has been reduced as a result of reassessment by personnel of W.S.C. Accordingly, the high water mark estimate for that basin has also been reduced, since it was an extrapolation from the peak discharge measure. The revised plotting position shows that the peak measured discharge measure was below all the design flows predicted for that basin, while the unrevised value had equalled the lowest design flow. However, the revised high water extrapolation plots higher than most of the design flows, and therefore, would have posed a threat to culverts constructed using the exceeded values.

In general, the 1978 peak discharges were lower than attained during the summer storms of 1977. The exceptions were the snowmelt peaks for the basins at Miles 8 and 13.8. This is partly because the storm responsible for the 1977 floods had diminished greatly before reaching these northern basins, and these basins do not have a rapid response to rainfall. On the other hand, these basins do appear to have physical conditions suitable for moderately high snowmelt. In fact, it is expected that the culverts installed at Miles 8 and 13.8 are adequately designed to pass peak flows from summer rain, and also snowmelt, as long as most of the inlet and exit cross-sectional areas of the culverts are capable of passing the flow. The southern basins appear to require design for critical summer storm runoff. The basin at Mile 59.4 may have conditions similar to both groups, but perhaps should be considered closer to the northern set, with snowmelt being the critical flow for design, especially if culvert blockage is severe.

The depths of icings measured at Liard Highway culverts were presented above in Table 7. It was also shown that these ice depths translated into significant reduction of culvert capacity (from 25 to 40%). The situation of total culvert blockage along the Fort Simpson airport road was also noted, as well as the extreme thickness of the icing layers formed behind the blocked culvert. Similar extreme occurrences of culvert blockage were noted in the previous Liard Highway report, and therefore the 1978 situation should not be considered unusual. However, the possibility of such reduction in culvert capacity is not considered in the development of design curves; and while it may be difficult at present to factor in this potential condition because of insufficient site observations, the limited data suggest that it can have a major influence. It should be noted that the winter of 1977/78 had an almost normal series of monthly temperatures, and that the icing problem would be more severe in a winter with below normal temperatures in most winter months - the situation which has occurred during 3 of the 5 months of winter 1978/79 (October to February) at Fort Simpson.

CONCLUSIONS

1. In the four basins gauged for this study, the peak discharge resulted from snowmelt, and at Rabbit Creek the snowmelt peak discharge was only exceeded by one summer rainstorm event.
2. Although most of the basins exhibited discharge peaks from summer rainstorms, the values attained were all less than achieved in the same basins during a summer storm in 1977.
3. Suspended sediment concentrations are very low in all the gauged basins, and this indicates the vulnerability of the downstream aquatic environments to increased sediment loads during highway construction.
4. Although the data are not conclusive, there appears to be two regions of summer rainfall, and concomitantly, two regions of basin hydrologic response to this rainfall. Accordingly, Fort Simpson does not seem to be representative of the southern group of basins with regard to summer rainfall.
5. None of the peak discharge values of 1978 exceeded the design curves presented for Liard Highway streams.
6. Moderately severe icings occurred in the northern Liard Highway region, and these significantly reduced the conveyance capacity of installed culverts.

REFERENCES

Burns, B.M.
1974: The Climate of the Mackenzie Valley-Beaufort Sea. Volume II. Department of Environment, Atmospheric Environment Service, Toronto, Ontario. Climatological Studies No. 24, 239 pp.

Currie, B.W.
1953: Prairie Provinces and N.W.T. precipitation. Unpublished report of Physics Department, University of Saskatchewan, 38 pp.

Grey, B.J. and J.N. Jasper
1978: Hydrologic studies along the Liard Highway, Spring and Summer, 1977. Report to the Hydraulic Design Assessment Committee, Environmental Working Group, Mackenzie Highway, 27 pp.

UNIES Ltd.
1974: Report on Fort Simpson - Fort Liard Highway Stream Crossings. Volume 1 (Mile 0 - 50), Volume 2 (Mile 50 - 130), Volume 3 (Technical Appendix - Hydrology).

Water Planning and Management Branch
1975: Mackenzie Highway Project, Tentative Guidelines for Culvert Design. Engineering Division, Inland Waters Directorate, Environment Canada, 17 pp.

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would not have been possible.

FIGURES

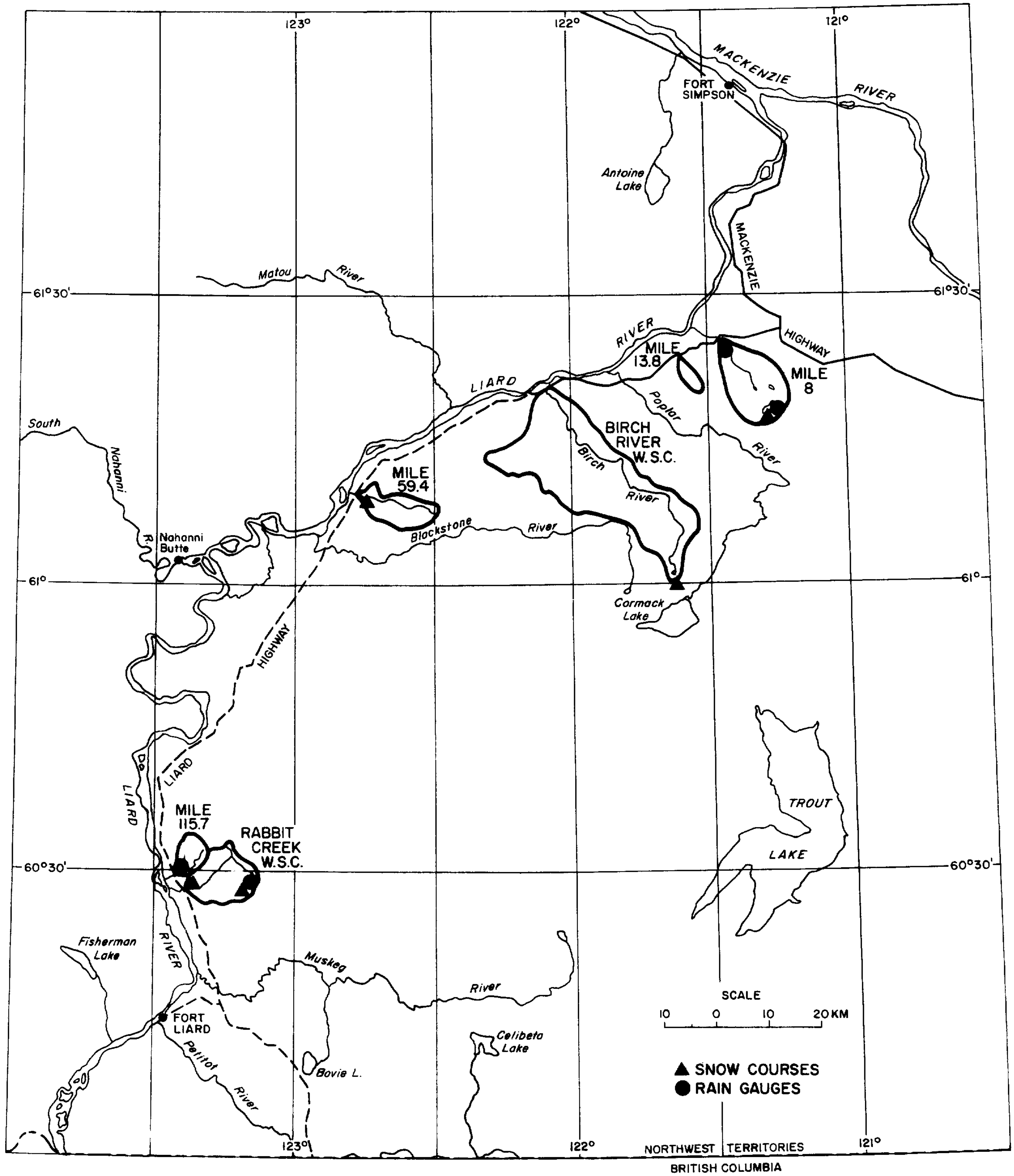

FIGURE 1 Location of study basins along route of Liard Highway

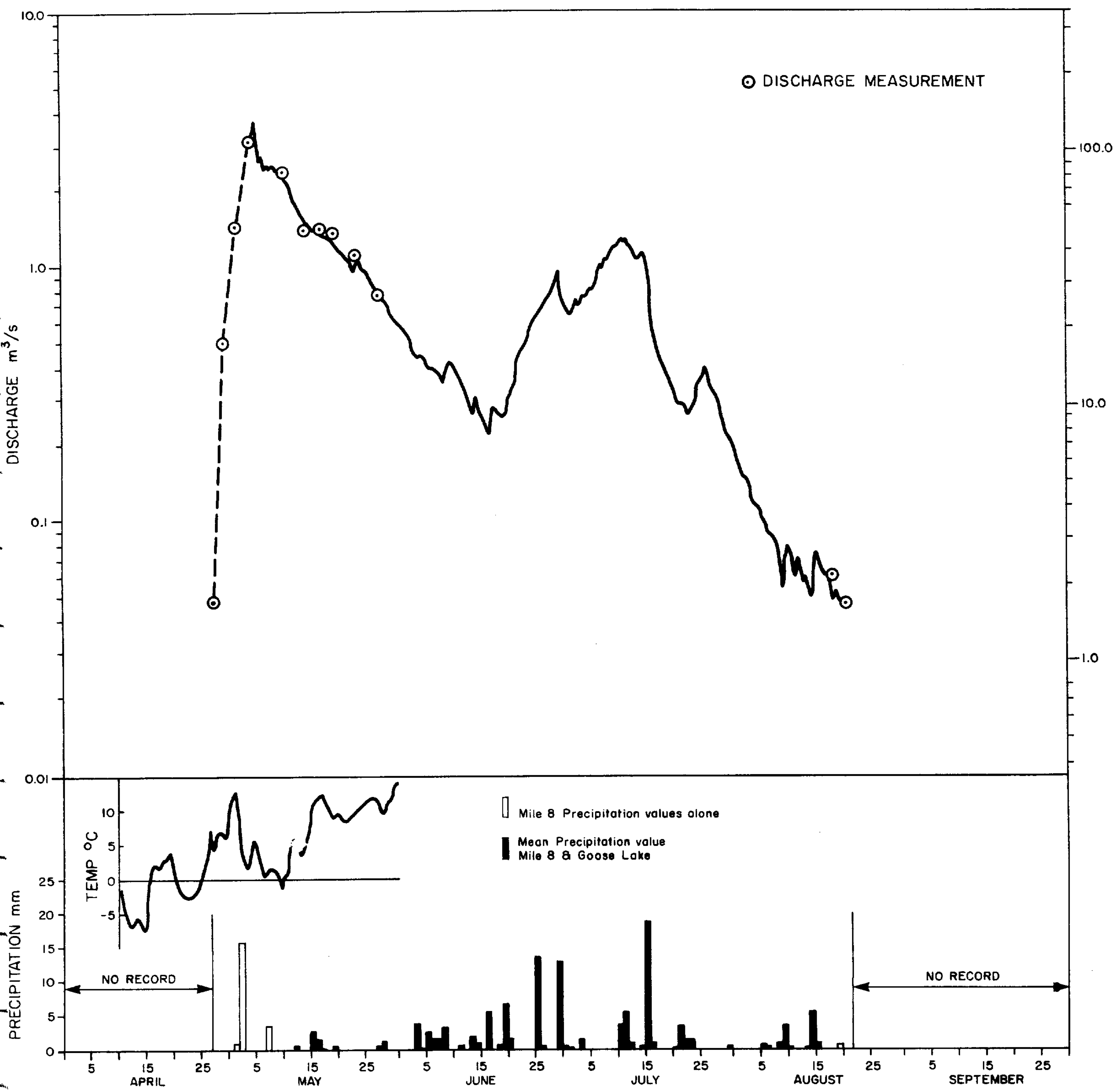

FIGURE 2. 1978 Hydrometeorologic data record for Mile 8 Liard Highway

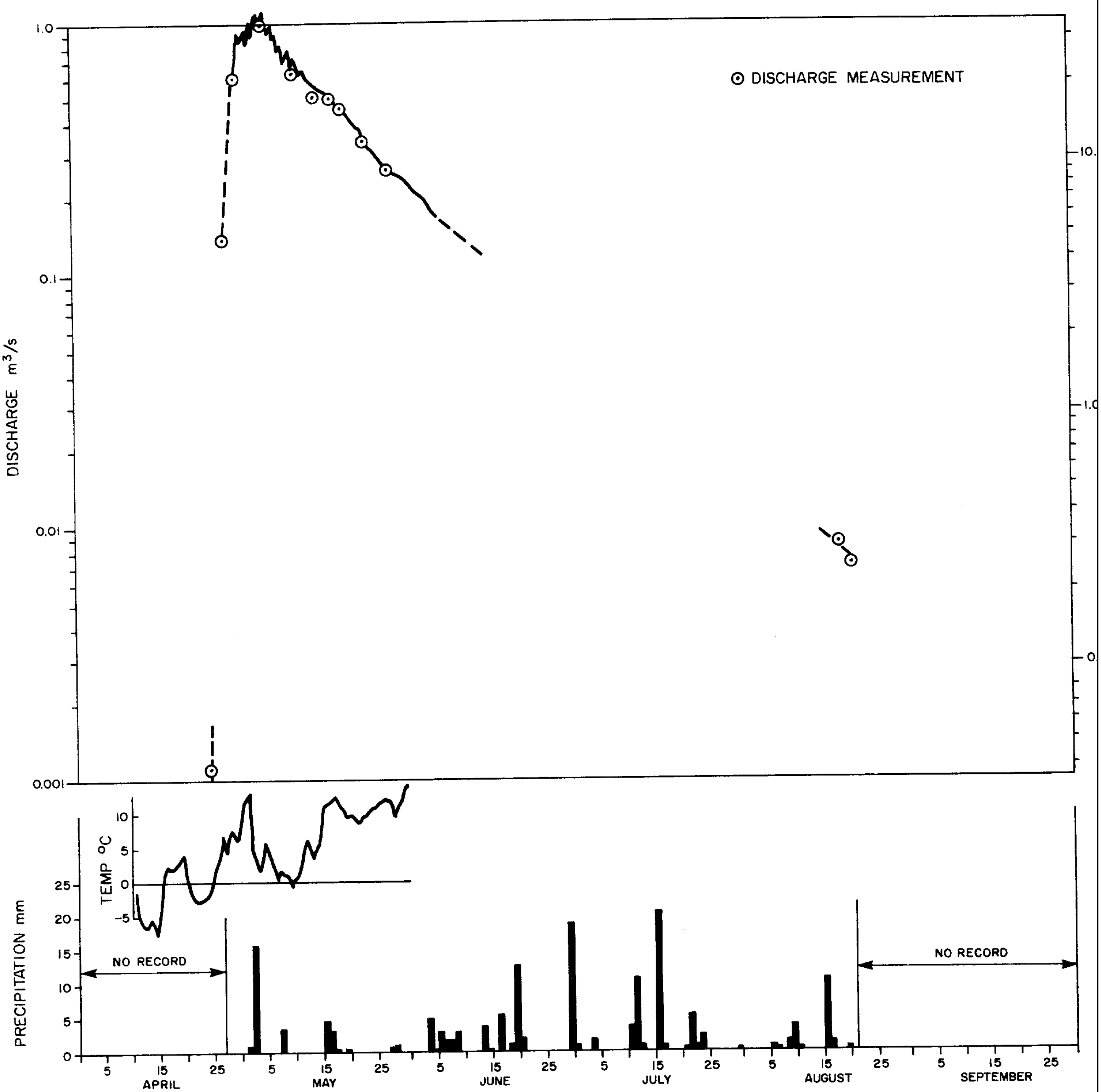

FIGURE 3 1978 Hydrometeorologic data record for Mile 13.8 Liard Highway

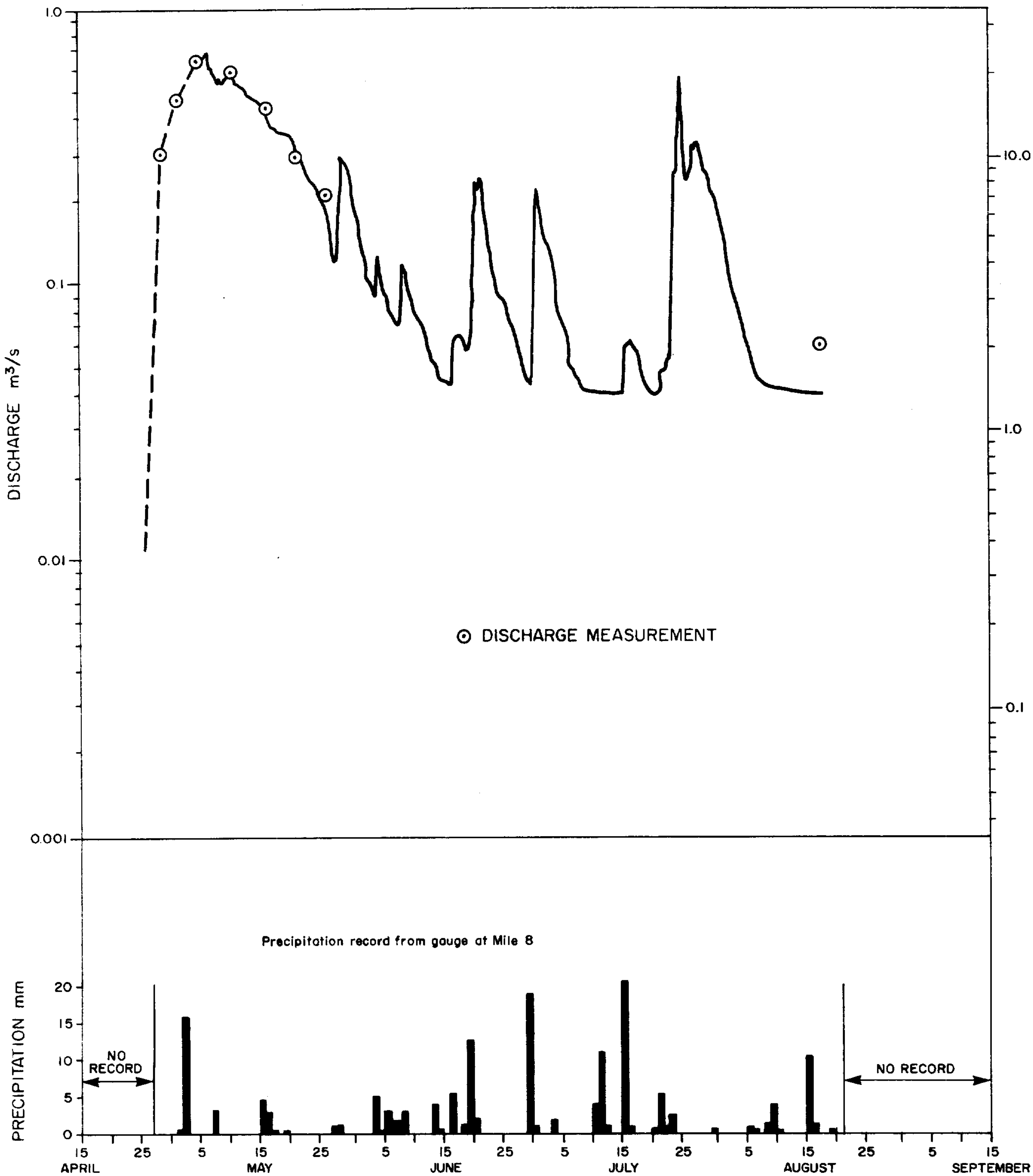

FIGURE 4 1978 Hydrometeorologic data record for Mile 59.4 Liard Highway

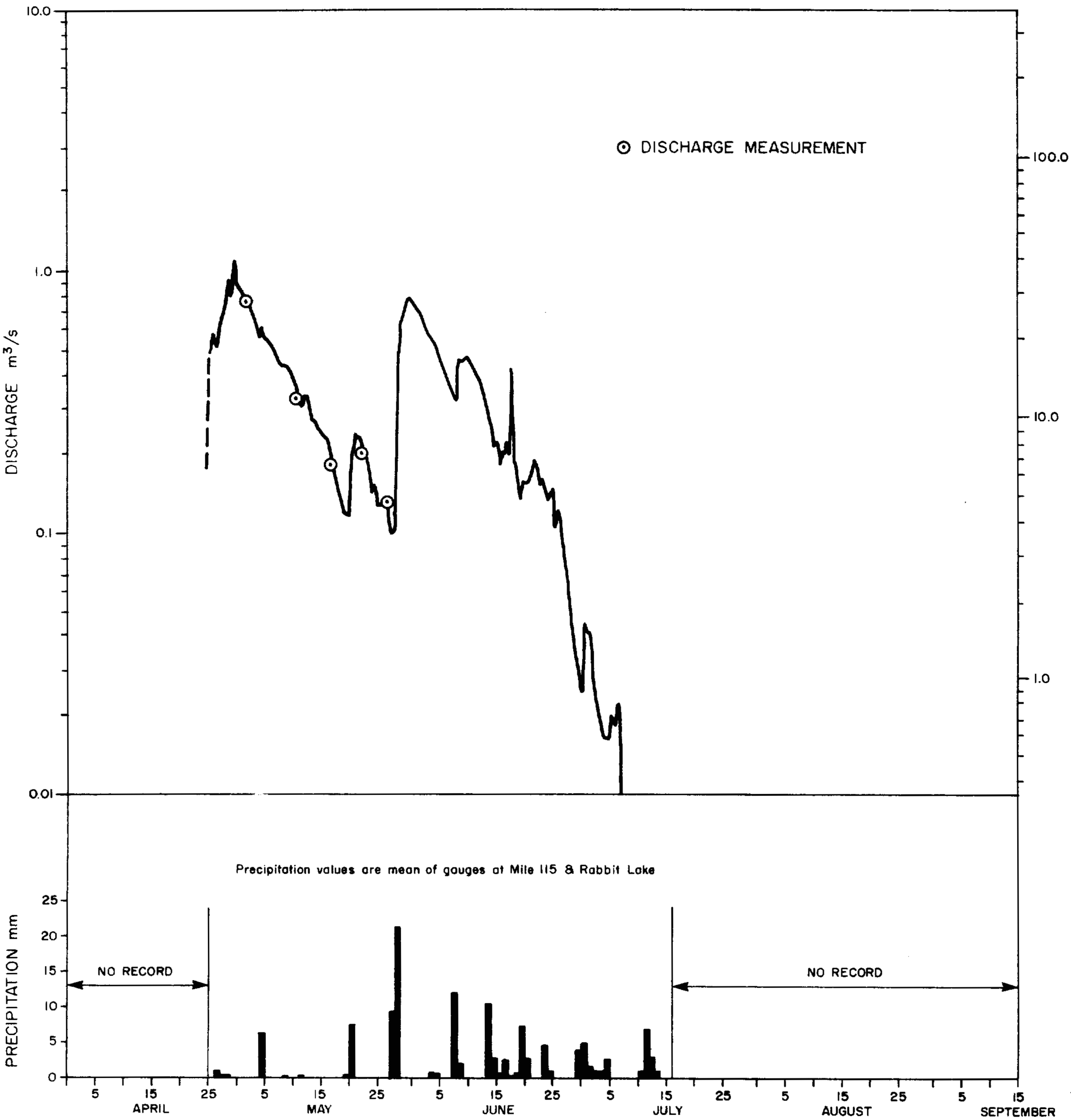

FIGURE 5 1978 Hydrometeorologic data record for Mile 115.7 Liard Highway

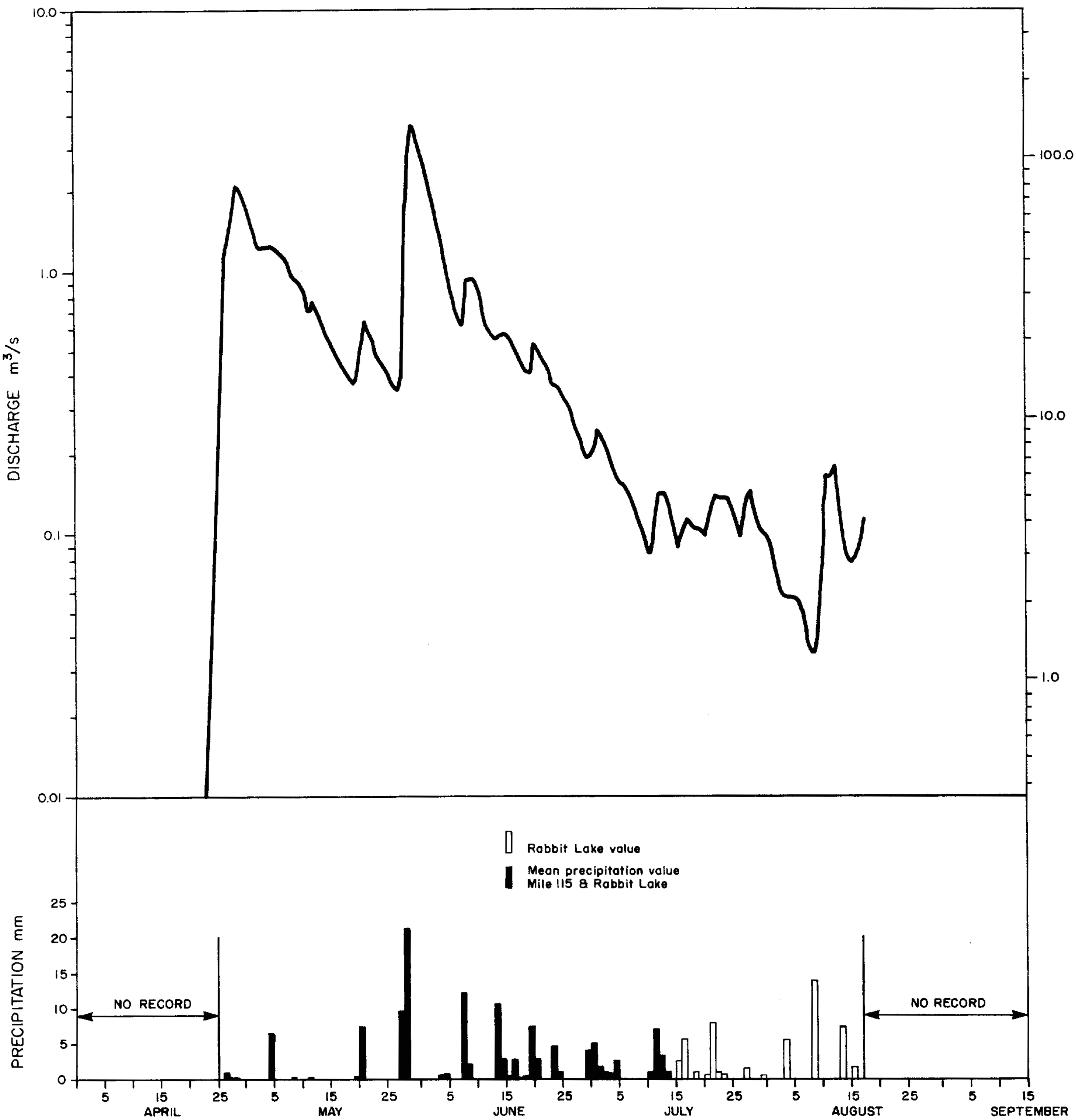

FIGURE 6 1978 Hydrometeorologic data record for Rabbit Creek at Liard Highway
(discharge from W. S. C. preliminary data records)

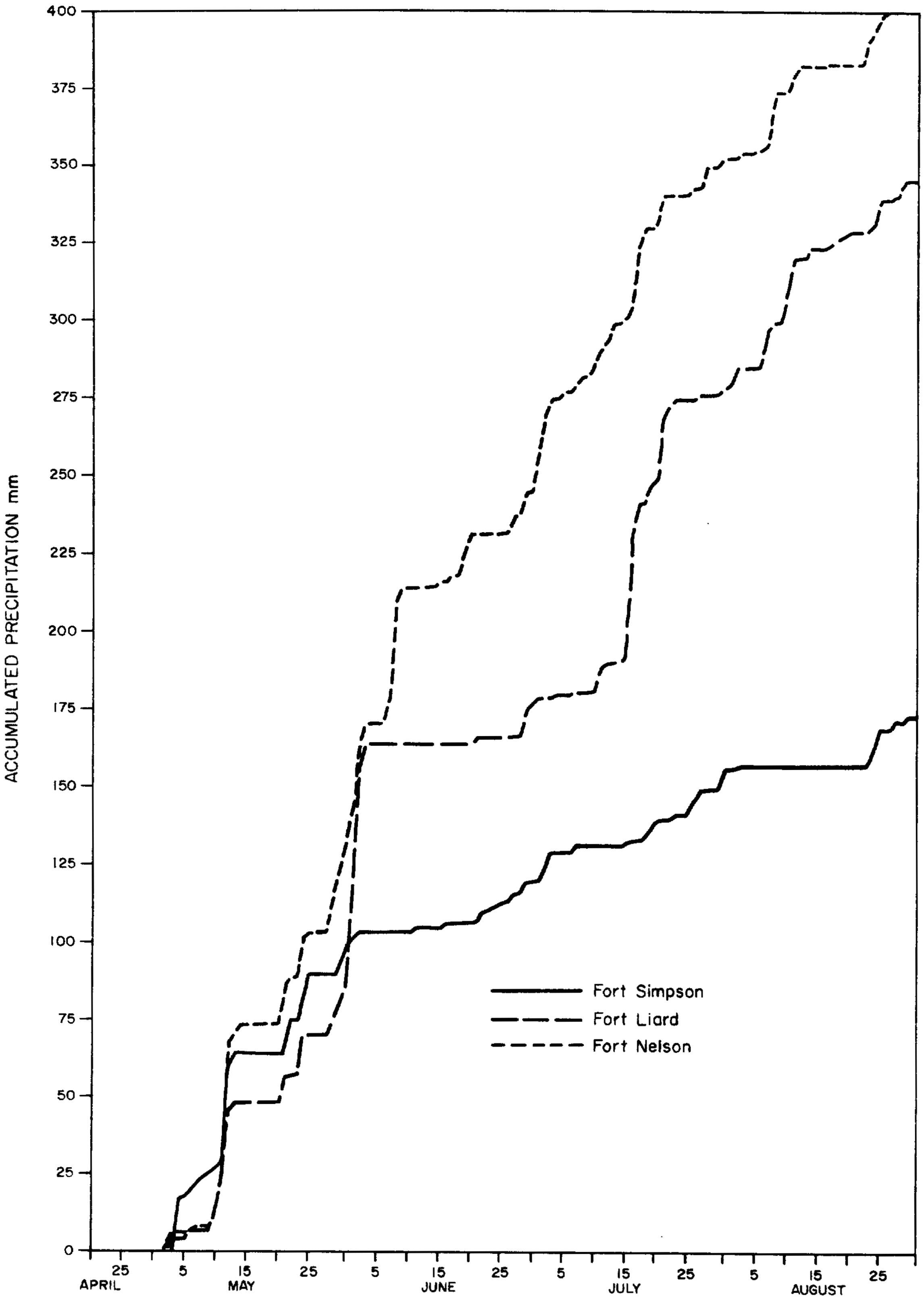

FIGURE 7 Mass curves of precipitation for Liard Valley Met. Stations, 1977

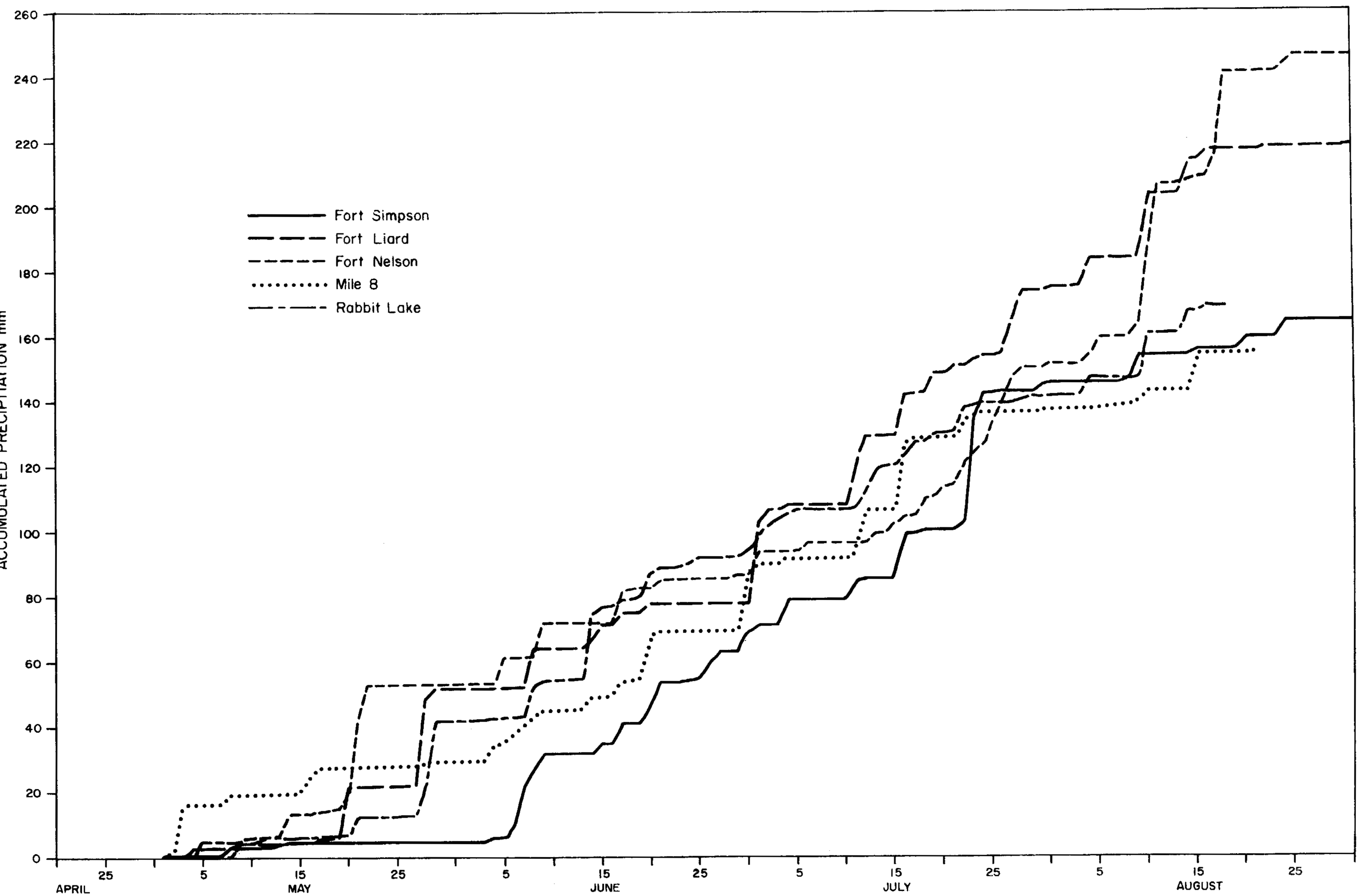

FIGURE 8 Mass curves of precipitation — Liard Highway 1978

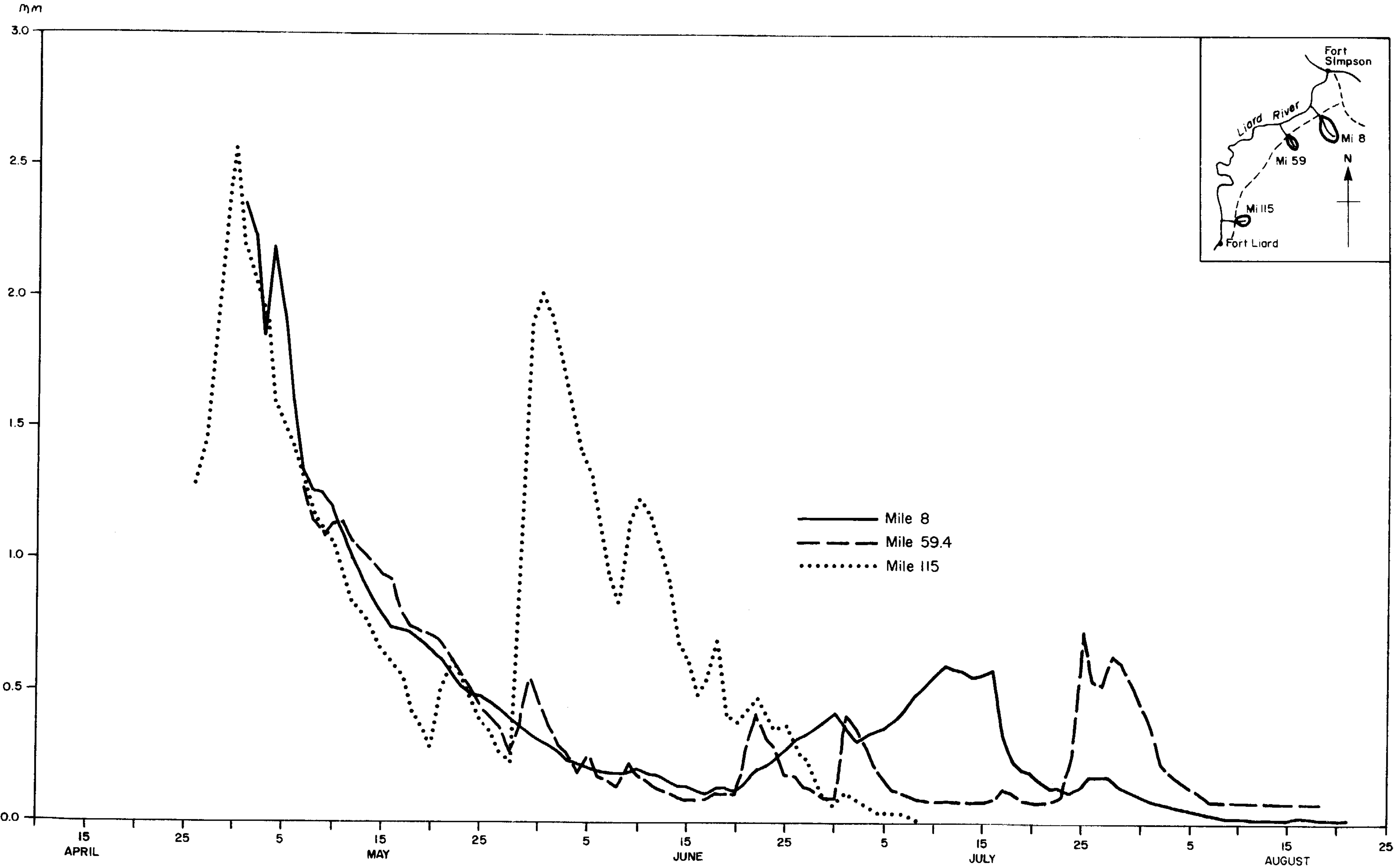

FIGURE 9 Mean daily runoff for three basins along the Liard Highway, 1978

DESIGN CURVES

1 Water Planning & Management (1975) Tentative Design Flow

2 UNIES – Snowmelt predictions converted to instantaneous flows, 50 year return period

3 UNIES – Rainfall predictions converted to instantaneous flows, 50 year return period

4 UNIES – Snowmelt mean daily flows, 50 year return period

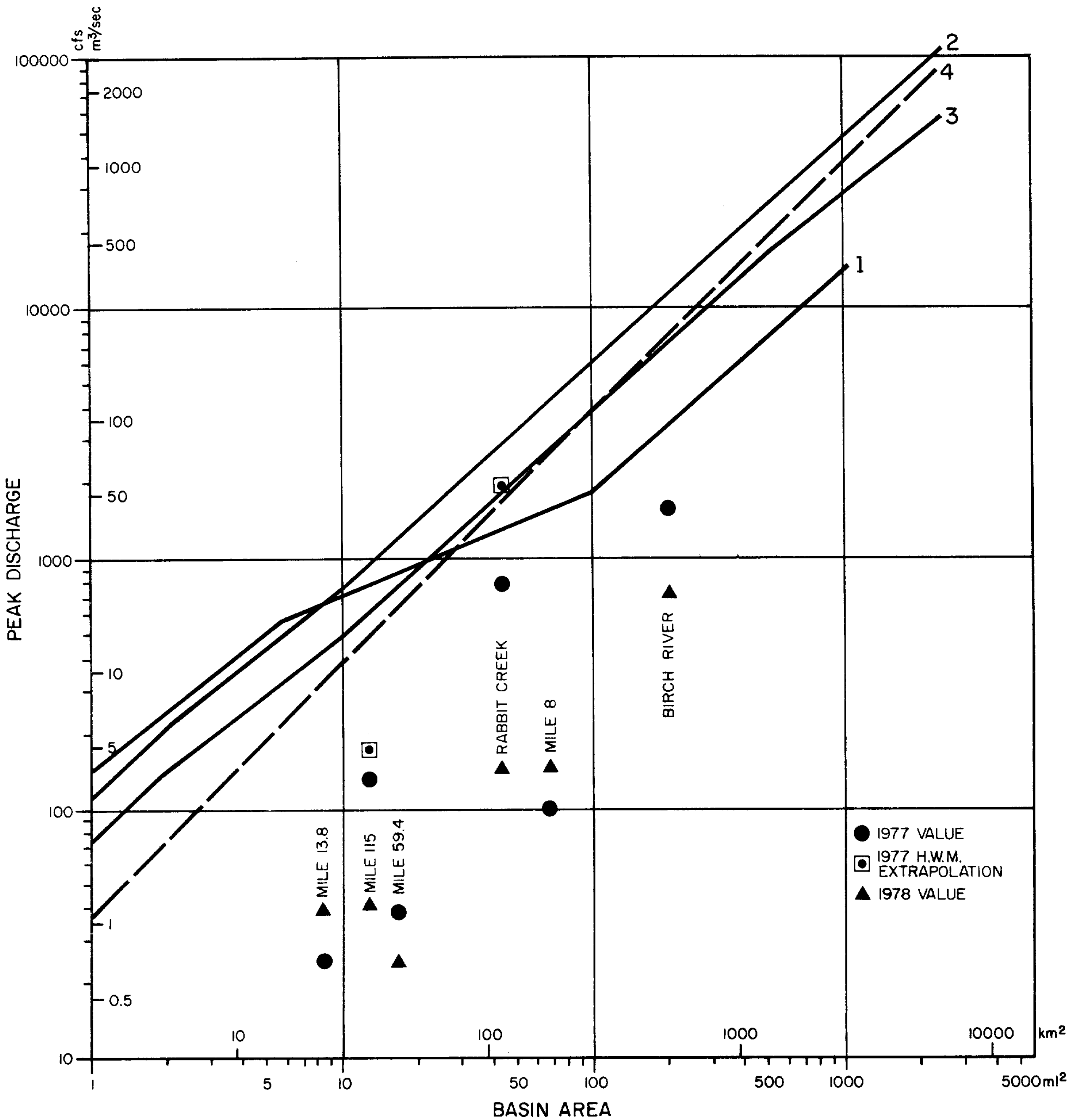

FIGURE 11. Peak discharge against drainage areas with recommended design discharges