K-1

MACKENZIE/DEMPSTER HIGHWAY HYDROLOGY STUDY

INUVIK TO NWT-YUKON BORDER

Conducted for

Government of Canada
Department of Public Works
Western Region
Edmonton, Alberta

by

Northwest Hydraulic Consultants Ltd.
4823 - 99 Street
Edmonton, Alberta

November, 1972

Issue # 8

MACKENZIE/DEMPSTER HIGHWAY HYDROLOGY STUDY

1. INTRODUCTION

As part of a program of road construction in the Arctic, the Dempster Highway is being built from near Dawson in the Yukon to a junction with the Mackenzie Highway near Arctic Red River in the Northwest Territories, passing near Fort McPherson. The Mackenzie Highway is being constructed along the Mackenzie Valley, passing through Inuvik and terminating at Tuktoyaktuk. The general location is shown in Figure 1.

Many drainage structures are required along the routes, but the hydraulic design of these structures is difficult as little is known about the hydrology of the regions through which these roads are being built. In order to have a firmer basis for design, the Department of Public Works, Western Region, retained Northwest Hydraulic Consultants Ltd. to study the streamflow hydrology of the region with the objective of determining design peak runoff values.

2. APPROACH TO THE PROBLEM

As there were no direct streamflow records on which flood flow predictions could be based, it was decided to approach the problem of estimating peak runoff from several independent directions and to base recommendations on an assessment of all estimates so obtained. The approaches were: first, for selected streams, flood flow estimates were made using two methods, runoff analysis based on precipitation data and slope-area analysis based on channel characteristics; second, an indication of rare floods for streams with various drainage areas was obtained from flow records for the Yukon Territory, Alberta, and Alaska; and third, an attempt was made to estimate peak discharges from an empirical relation between meander length and discharge, but the results were not used as the method was deemed unreliable.

As the first step of the process, topographical maps covering the entire route were studied and all significant streams located and their drainage areas delineated. The drainage basins fell into thre general categories: mountainous with good drainage, flat with poor drainage, and some smaller basins with intermediate slopes and drainage characteristics. In each region, about four streams, covering the range of drainage areas, were selected as being typical. These were: unnamed creeks at Miles 283.6, 286, 288.3, 290.3 and 296.8 (mountainous); unnamed creeks at Mile 315.4, 932.2 and 941.5 and Cabins Creek at Mile 954.4 (intermediate); and Frog Creek at Mile 353, the Rengleng River at Mile 913.3, Caribou Creek at Mile 940 and Campbell Creek at M 956.3 (flat). Locations are shown in Figures 2a, b, c and d.

The study was confined to an investigation of these 'study streams' with the objective of developing a design curve relating peak runoff to drainage area for each drainage basin category. The individual study streamsand in many cases their contributing drainage areas were examined in the field. Where possible stream cross-sections were surveyed in the field by the Department of Public Works personnel.

3. METHODS OF ESTIMATING PEAK RUNOFF

3.1 General

A flow with a 50 year return period has been adopted as the design flood for most drainage structures on the highway. However, the available data does not permit a specific frequency to be accurately assigned to a given flow. Most of the precipitation data has been transposed from distant recording stations and as such is approximate at best. The flows calculated from channel characteristics give an indication of rare floods but a given frequency cannot be attached to the estimates. The data from Alberta and Alaska provide some guidance but not direct information. In summary, the recommended curvesgive peak instantaneous flows for design, but the lack of direct data qualifies labelling them as accurately as 1:50 years.

Major drainage structures on the highway may be designed for 1:100 year floods and minor structures 1:25 years. Multiplication factors are recommended for calculating floods values for these frequencies based on the 1:50 year design curves.

Peak flows may occur as a result of snowmelt, rainfall, or a combination thereof. Estimates of rare floods in the mountainous and intermediate terrain are based on the assumption that the cause is a rainfall event. Annual high water or high stage may well be associated with snow melt events or ice affected streamflow, but it is our opinion that rare flow events will be rainstorm floods. In the case of the larger flat basins, the design recommendations are based solely on channel characteristics as the uncertainties in rainfall runoff analysis were too great and there were absolutely no data regarding snowmelt runoff.

3.2 Runoff Analysis using Precipitation Data

Figure 3 shows the derived intensity-duration-frequency curves for the study area. The analysis was based on meteorological records for Yellowknife, Whitehorse, Fort McPherson, Inuvik and Aklavik. Records were available for Yellowknife and Whitehorse for durations of 5, 10, 15, 30 minutes, 1, 2, 6 and 12 hours and for daily precipitation. Only daily precipitation records were available for the other stations. It was assumed that the short duration intensities for the study area were comparable to those for Yellowknife and Whitehorse. This assumption was based on two factors. First, the 24 hour intensity-frequency curves for Fort McPherson, Inuvik and Aklavik matched those for Yellowknife and Whitehorse quite closely, and second, the rainfall intensity-duration-frequency maps for Canada published by The Canada Department of Transport, Meteorological Branch (1)*, indicates that short duration intensities in the study area are similar to those for Yellowknife and Whitehorse, as shown in Table 1. The magnitudes indicated for the study area are about 80% of those for Yellowknife-Whitehorse. The information from the meteorlogical maps is of questionable value considering possible

* Numbers in parenthesis refer to list of references

local variations in precipitation patterns, but there are no other data available.

Duration	Study Area	Yellowknife	Whitehorse
	Rainfall in inches; 25 Year Return Period		
5 min	.13	.15-	.175
10	.17	.2	.25
15	.2	.3-	.3+
30	.35	.4-	.5
60	.4	.4	.5
24 hr	2.-	2.5	2.0

TABLE 1. Comparison of Regional Data From the Atlas of Rainfall Intensity-Duration-Frequency Data of Canada

Also plotted on Figure 3 are data for Alaska (2) and data from the above-mentioned Canadian Meteorological Atlas. The Alaska data show good agreement for 1:50 year storms with longer durations but for short duration intensities the Alaska data indicate magnitudes about two-thirds those of our analysis. The data from the Canada Meteorological Atlas are for a 25-year return period. If this is allowed for, the data from this source are in fairly good agreement with the Alaska data. There should be no contradiction between the information from the Canadian Meteorological Atlas and the curves as shown on Figure 3 as both were derived using data from the same stations. As the latter analysis was based on a longer period of record it is assumed to be more accurate.

In the derivation of the intensity-duration-frequency curves and in their subsequent use, no factor was included for elevation. Rainfall on the windward side of orographic barriers can range up to 30% higher than values for lower elevations (2). On the leeward side, precipitation values can be 5 to 10% lower. It is felt that refinements for elevational effects were not warranted.

Values taken from intensity-duration-frequency curves apply to point precipitation. When applied to larger areas, an area-depth correction factor should be applied. Figure 3A is recommended for use in frequency-duration analysis by the U.S. Weather Bureau, and was adopted for use in the present study.

Peak runoff rates for the smaller watersheds for a 1:50 year storm were derived from the precipitation data using both the rational method and a simplified unit graph method used by the U.S. Soil Conservation Service (USSCS). These methods are outlined in the Appendix.

3.3 Channel Characteristics

3.3a Slope-Area Method

Estimates of the magnitudes of rare floods were calculated using Mannings equation for steady open channel flow. The value of Mannings 'n' was assessed from photographs taken during site visits to the selected streams. Also during the site visits, estimates of flood breadths and depths were made and bank heights and historical high water marks noted. Stream channel slopes were obtained from stream profiles taken from topographic maps. In several cases surveyed stream cross sections were supplied by the Department of Public Works.

3.3b Meander Length

Inglis gives the following formula which, for spilling rivers in India and the United States, relates meander length to 'peak' flow:

$$M_L = C\,Q_p$$

the average value for 'C' for sand-bed rivers is 28, but the band width of calculated values is quite large.

Meander lengths for the streams studied were difficult to ascertain and when values were approximated the results were obviously too low. Also, the applicability of the equation to steep gravel-bed rivers with peaky hydrographs or to rivers with erosion-resistant banks is questionable. Other investigators have reported that the meander length is related to the formative discharge of a river, the magnitude of which is generally thought to be considerably less than the peak flow. It was decided that the results indicated by this method were not reliable, and they were not given further consideration.

3.4 Water Survey of Canada Streamflow Records

Water Survey of Canada records for the Yukon and Alberta were examined and flow values for suitable watersheds noted. There were no directly useful data, but the records for the Porcupine and Peel Rivers provided some indirect information.

3.5 Alaska Flood Frequency Data

Regional flood frequency analyses for Alaska carried out by the United States Geological Survey (3) provide some data that areuseful for our study area. Flood estimates have been made for a 50-year return period for some rivers and for a 25-year return period for several others and peak instantaneous discharges tabulated for many streams. There are long-term records for several small and medium sized watersheds, but it is not known how comparable the regions in which they are located are to the study area.

4 RESULTS

4.1 General

The estimates of peak runoff rates were based on four sources of data: precipitation records, observed or measured stream channel characteristics, streamflow records from Water Survey of Canada and flood frequency data from Alaska. The data on stream channel characteristics are nearly all approximations and the other data were all transposed from considerable distances, thus fairly wide confidence limits must be allowed in the interpretation of the results.

The discharge values obtained using the various methods are shown on Figure 4 and in Table 2. Sample calculations are included in the Appendix.

4.2 Rainstorm Runoff Analysis

4.2.1 General

Two principal sources of error in both the rational method and the USSCS method are the estimates of the time of concentration of the watershed, and the runoff coefficient.

For the two methods of analyses employed, two different ways of estimating the time of concentration were tried. Although both ways are widely used, neither were derived for this type of terrain.

The runoff coefficient is usually determined by assessing the effects of infiltration and storage. The former was assumed to be negligible considering that the study area is in the zone of continuous permafrost. The latter is very difficult to assess as it is a function of surface slopes, vegetation, antecedent conditions, depth of thaw, percent non-contributing area, percent marshes and lakes and surface storage due to micro-relief. It can be seen that any value assigned for the runoff coefficient must be regarded as very approximate.

4.2.2 Mountainous Terrain

It was assumed that the methods used to estimate the times of concentration yielded reasonable results. As for the runoff coefficient, a large percentage of the areas of the watersheds in the mountains is very steep with relatively light vegetal cover. If one assumes pre-saturated conditions, surface storage would be negligible in these portions of the basins. Also, virtually 100% of the drainage areas contribute to runoff. In view of the foregoing, the runoff coefficient was assumed to be 1.0.

The rational method resulted in the highest flow estimate for each of the study streams. This was possibly due to the maximizing assumption regarding runoff, or to the fact that the rational method, due to its intrinsic assumptions, yields results that are generally high, particularly for watersheds larger than about 5 square miles.

The USSCS method indicated somewhat lower discharge values.

4.2.3 Intermediate Terrain

Considering the poorly defined drainage patterns in the upper areas of the watersheds and the fact that the channels of the smaller streams were heavily vegetated, it was obvious that the usual methods would under-estimate the times of concentration, so the times were increased arbitrarily by a factor of about 1.5. The runoff coefficient was set at 0.3. The rational method only was applied to two watersheds and in both instances it indicated relatively high flow values. Because of the assumptions involved, wide confidence limits must be applied to these results.

4.2.4 Flat

It was decided that rainfall runoff analysis would not provide meaningful results for the large flat basins. The areas were too large to apply the rational method to, and there were uncertainties regarding factors involved in the USSCS method.

The above notwithstanding, the USSCS method was applied to the Rengleng basin to obtain an order of magnitude figure. As the channel is long and well-defined, it was assumed that the calculated time of concentration was a reasonable estimate. A runoff coefficient of 0.3 was used. The calculated 1:50 year peak flow was comparable to the estimate based on slope-area.

4.3 Channel Characteristics

Also shown on Figure 4 and in Table 2 are the results of the slope-area method. Considerable scatter is evident in the plot, which is to be expected under these circumstances, but generally the slope-area method indicates lower flows.

The channels of the streams at Miles 315.4, 932.2 and 941.5 were so poorly defined and heavily vegetated that actual slope-area calculations were meaningless. The results listed in Table 2 under Slope-Area for these streams are rough estimates based on approximate cross-sectional areas of flow and estimated average flood velocities.

4.4 Water Survey of Canada

Little data is available for small or medium-sized watersheds in the northern part of Alberta. There is, however, an envelope curve for maximum flows that have been recorded on various-sized drainage areas throughout Alberta. The curve was not derived for the region including the study area, nor is it implied that it is valid for the study-area but it was included in our analysis as it was thought to give some indication of very rare discharge values versus drainage area, at least in the mountainous region. Although precipitation intensities are greater in Alberta, losses, due to infiltration, retention and non-contributing areas, are also greater and these factors tend to cancel.

Water Survey of Canada has gauged the Porcupine River below the Bell River confluence and at Old Crow for about ten years. As the mountainous region of the study area is adjacent to the Porcupine Basin, these records provide an indication of regional runoff characteristics. The maximum mean daily discharges recorded at the two stations are shown on Figure 4. The period of record is not sufficiently long to predict a 1:50 year flood, but the maximums shown give a good indication for the location of the upper end of the design curve. Also shown is the maximum recorded mean daily discharge of the Peel River above Canyon Creek. This point agrees well with the Porcupine River data.

There are no WSC streamflow data available on which an indication of peak flows for the other regions of the study area may be based.

4.5 Alaska Flood Frequency Data

Instantaneous peak flood estimates and recorded instantaneous maximums for four rivers in the general vicinity of Fairbanks, Alaska are also shown on Figure 4. According to Reference (2), the area near Fairbanks is subject to storms with intensities about 3/2 as great as those in the study area (extrapolated estimate). However, if our derived intensity-duration-frequency curves are accepted, then the precipitation rates of Fairbanks and the study area are comparable.

It is not known how the areas compare with regard to infiltration and retention losses. The various Alaska data show reasonable agreement with the Alberta and Yukon Territory data.

4.6 Recommended Design Curves

The design curves were drawn through the various data by eye, giving greater weight generally to the slope-area results, with slopes based on the indications given by the WSC and Alaska data. Only two design curves are given as the results for the intermediate and flat regions plotted in one broad band and it was felt that the accuracy of the estimates did not warrant distinguishing between them.

5. SUMMARY

Regional relationships for estimated 1:50 year peak instantaneous runoff rates versus drainage area have been determined. They were based on flow estimates made for several study streams using runoff analysis and slope-area calculations. As no short duration precipitation records were available for the region, assumptions concerning precipitation were necessary and contradictions are apparent between various sources of data.

Site visits were carried out to all of the study streams to obtain necessary information regarding stream channel characteristics. Streamflow records and analyses, particularly those for the Porcupine River, provided some supporting evidence. It was pointed out that some caution must be exercised in referring to the recommended design curves as 1:50 year curves.

6. RECOMMENDATIONS

1. The drainage structures on the Dempster Highway between the Northwest Territories-Yukon border and Arctic Red River and on the Mackenzie Highway between Arctic Red River and Inuvik should be designed in accordance with the Recommended Design

Curves shown in Figure 4. There is no factor of safety as such included in the Design Curves.

2. Mile 288.3. These crossings should perhaps be treated as a single crossing with a single drainage structure (or twin structures). Taken individually, the stream to the northwest (drainage area of 5.2 sq mi) should be designed for 2500 cfs and the stream to the northeast (area of 13.3 sq mi) 4300 cfs. Taken together (area of 18.5 sq mi) the design discharge would be about 5200 cfs.

3. Miles 294 to 303. The peak runoff rates will start to decrease at about Mile 294 because the slopes become less steep and the percentage of the drainage areas vegetated increases. The mountain region curve should be used, but the design discharges indicated could be reduced about 50%.

4. Mile 329.7. The drainage area of this stream (shown on Figure 2b) was reported to us as about 55 sq mi, but close inspection of both 1:50,000 and 1:250,000 maps raises questions. Some or all of the flow from the drainage area probably reaches the Peel River through another channel located about seven miles to the south. A field inspection should be made to determine the actual drainage area.

   If the road embankment were to be built as a dike, perhaps all of the flow could be diverted through the other channel, thus eliminating a major drainage structure.

5. Mile 353 (Frog Creek). The design discharge value for Frog Creek can be somewhat lower than indicated by the lower design curve. The watershed is very flat, and the many marshes and lakes, particularly Nevejo Lake, have a significant damping effect. A discharge value about 50% of that indicated could be used.

6. Mile 956.3 (Campbell Creek). The design discharge indicated is valid, but the hydraulic design of the structure must allow for large backwater effects from Campbell Lake.

7. High rates of sediment transport, which could cause difficulties at the drainage structure, may be associated with the flow in some of the mountain streams. Careful attention should be paid to this factor in design.

8. Efforts should be made to collect streamflow and precipitation data in the region to facilitate future hydraulic design.

9. It is doubtful if the accuracy of the recommended 1:50 year curves warrants the application of factors for obtaining 1:100 year or 1:25 year estimates. If, however, such factors are to be applied, suggested values are: 1:25 year, .8 and 1:100 yr, 1.2.

LIST OF REFERENCES

1. Bruce, J.P. 1959. "Rainfall intensity-duration-frequency maps for Canada". Canada Dept. of Transport Meteorological Branch, Technical Circular 308.

2. U.S. Department of Commerce. "Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska". Technical Paper No. 47.

3. Childers, Joseph M. 1970. "Flood Frequency in Alaska". United States Department of the Interior, Geological Survey.

		Drainage Basin			Peak Flow Estimates								
					Precipitation				Slope-Area				
		Area	Length	Relief	Rational		USSCS		n	d	b	s	Q
		sq mi	mi	ft	t_c min	Q cfs	t_c min	Q cfs		ft	ft		cfs
Mountainous													
283.6	Unnamed	4.5	4.0	2200	43	2900			.045	3.5	50	.029	2300
286	Unnamed	16.8	7.5	2400	77	6700			.05	2	300	.012	3200
288.3	Unnamed	18.5	6	2100	71	8000	60	5900	.045	3.5	120	.018	3500
290.3	Unnamed	2.8	4.0	1800	42	1800	39	1300	.045	1.5	120	.05	1750
296.8	Unnamed	0.6	1.2	900	15	770							400
Intermediate													
315.4	Unnamed	1.0	2.0	350	50	170							150
932.2	Unnamed	17.0	11.2	300	400	900							700
941.5	Unnamed	8.0	4.8	450									400
954.4	Cabins Cr.	48.0	18	600					.06	8	25	.005	1100
Flat													
353	Frog Cr.	95	23	175					.05	6	35	.0032	1000
913.3	Rengleng R.	450	66	800			1500	6750	.045	9	100	.0042	8600
940	Caribou Cr.	253	23	600					.05	7	70	.005	3700
956.3	Campbell Cr.	136	20	350									

TABLE 2. Basin Characteristics and Flow Estimates for Study Streams

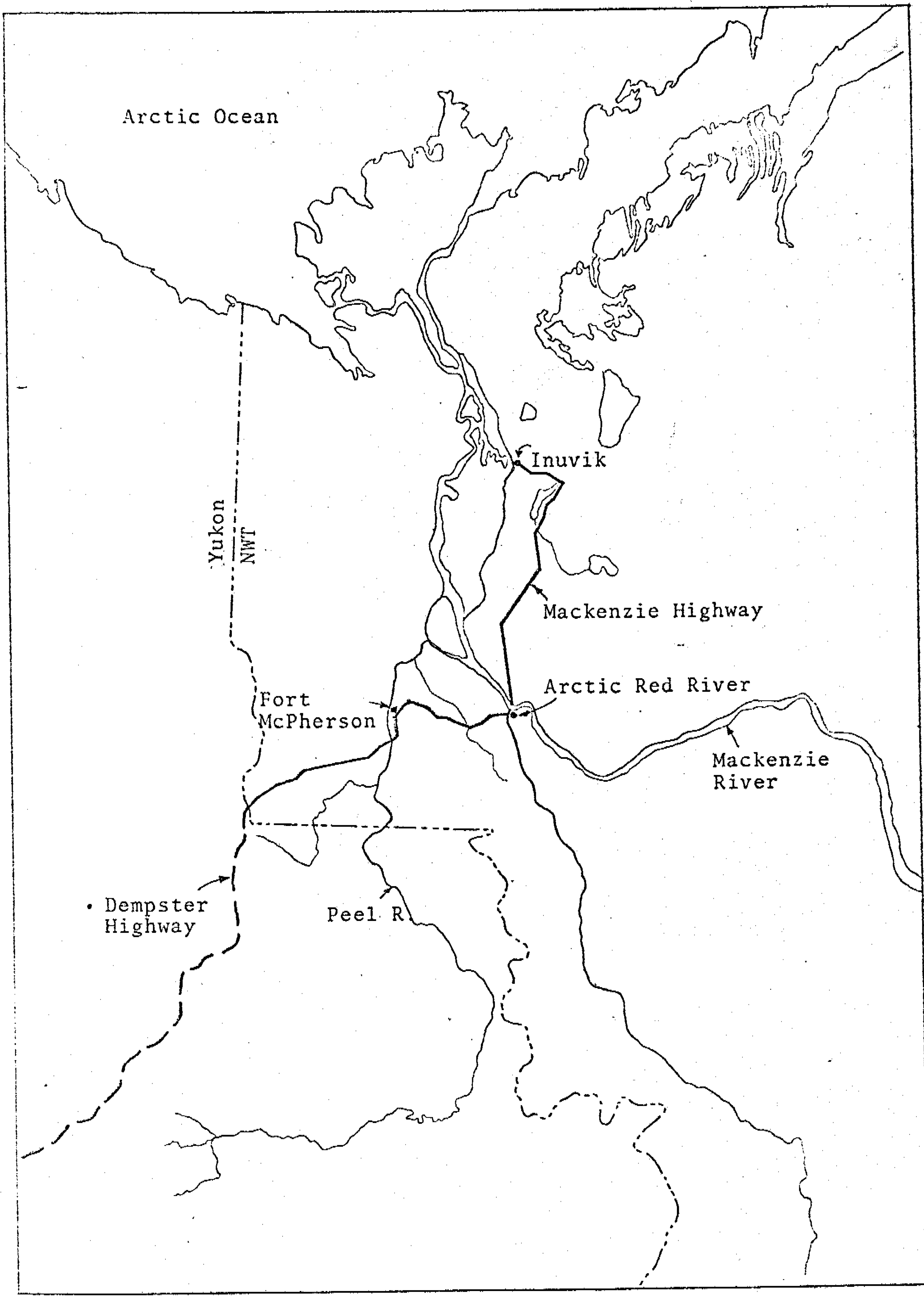

FIGURE 1. General Location

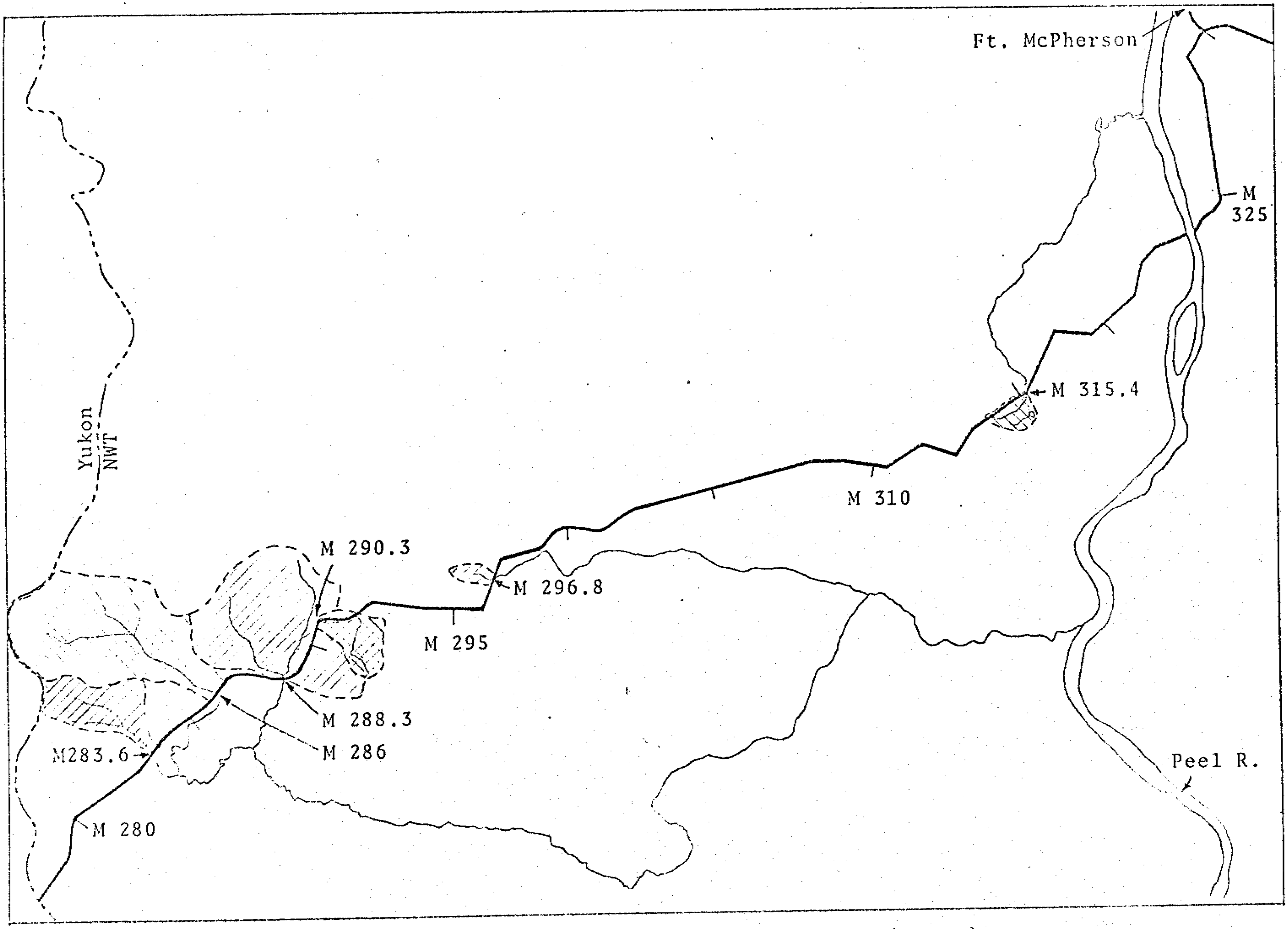

FIGURE 2a. Study Area (Mile 277 to Fort McPherson)

FIGURE 2a

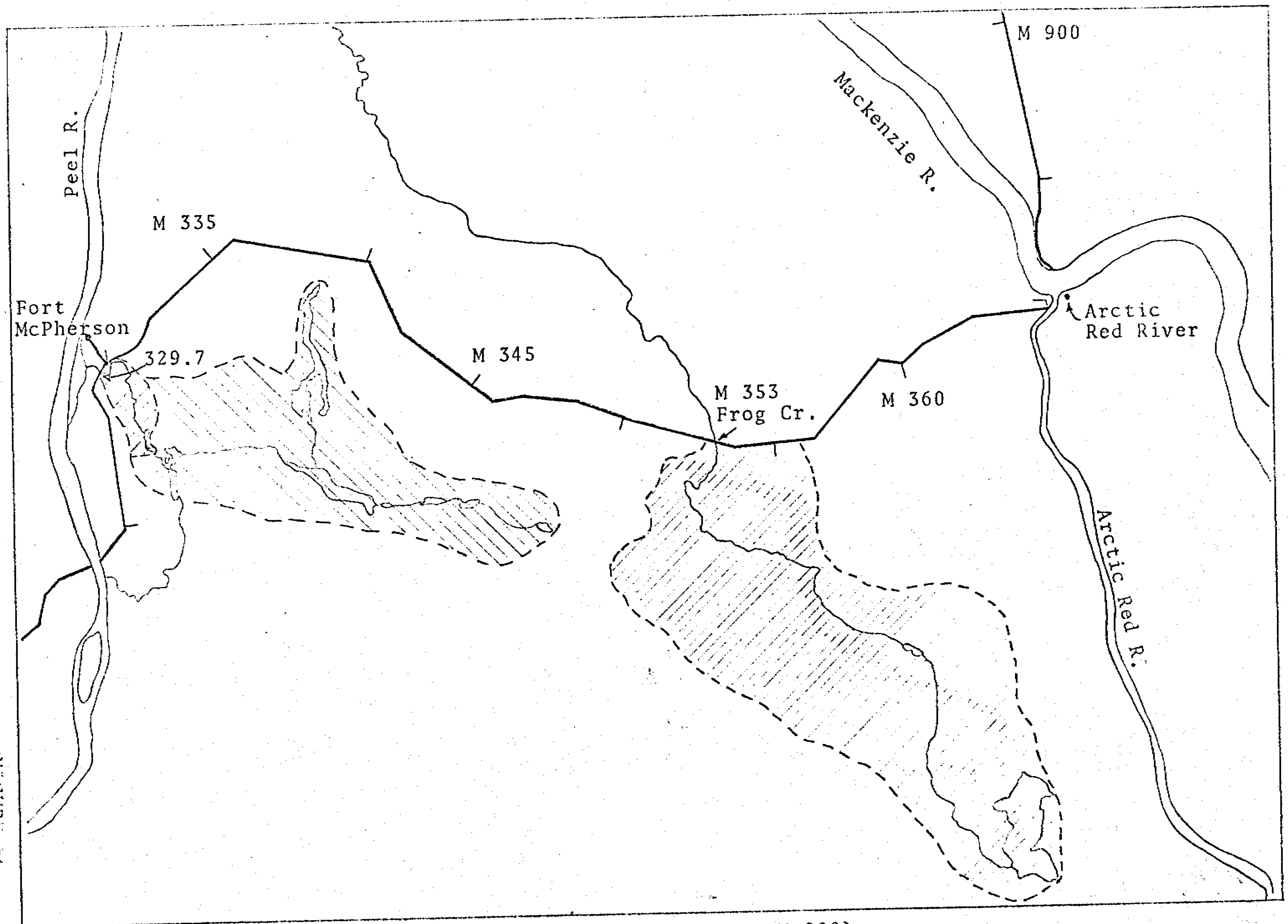

FIGURE 2b. Study Area (Ft. McPherson to M 900)

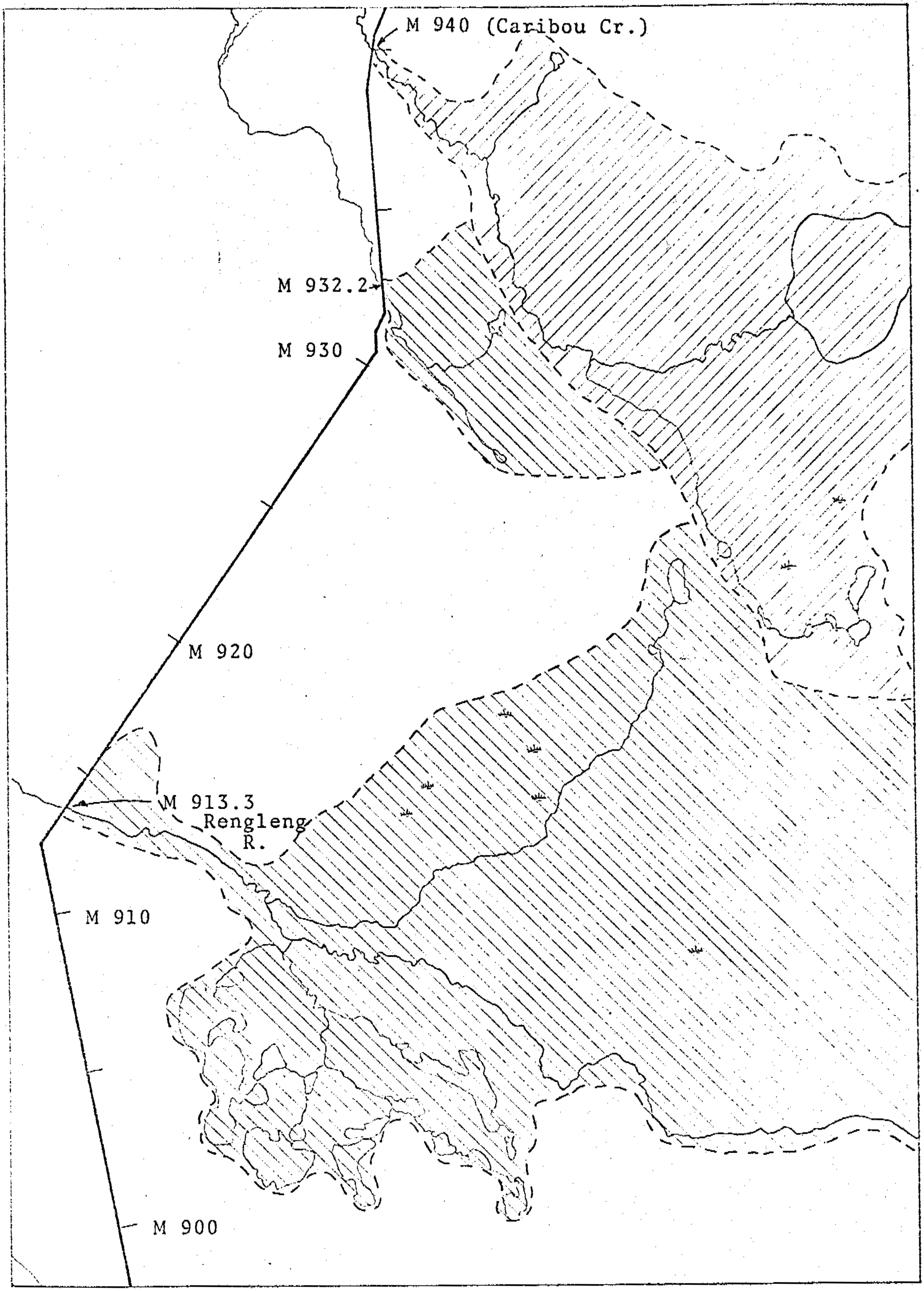

FIGURE 2c. Study Area (M 900 to M 940)

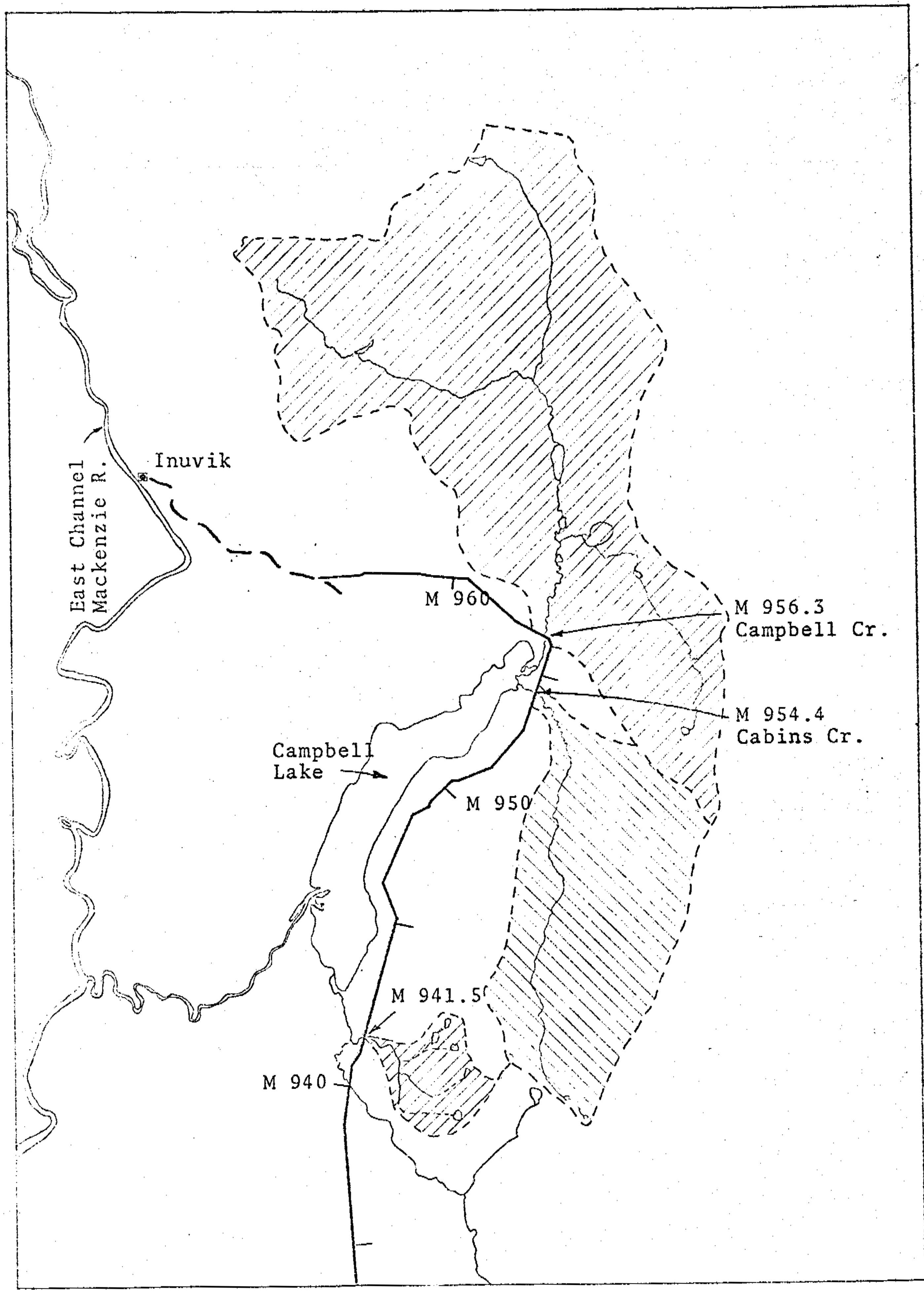

FIGURE 2d. Study Area (Mile 940 to Inuvik)

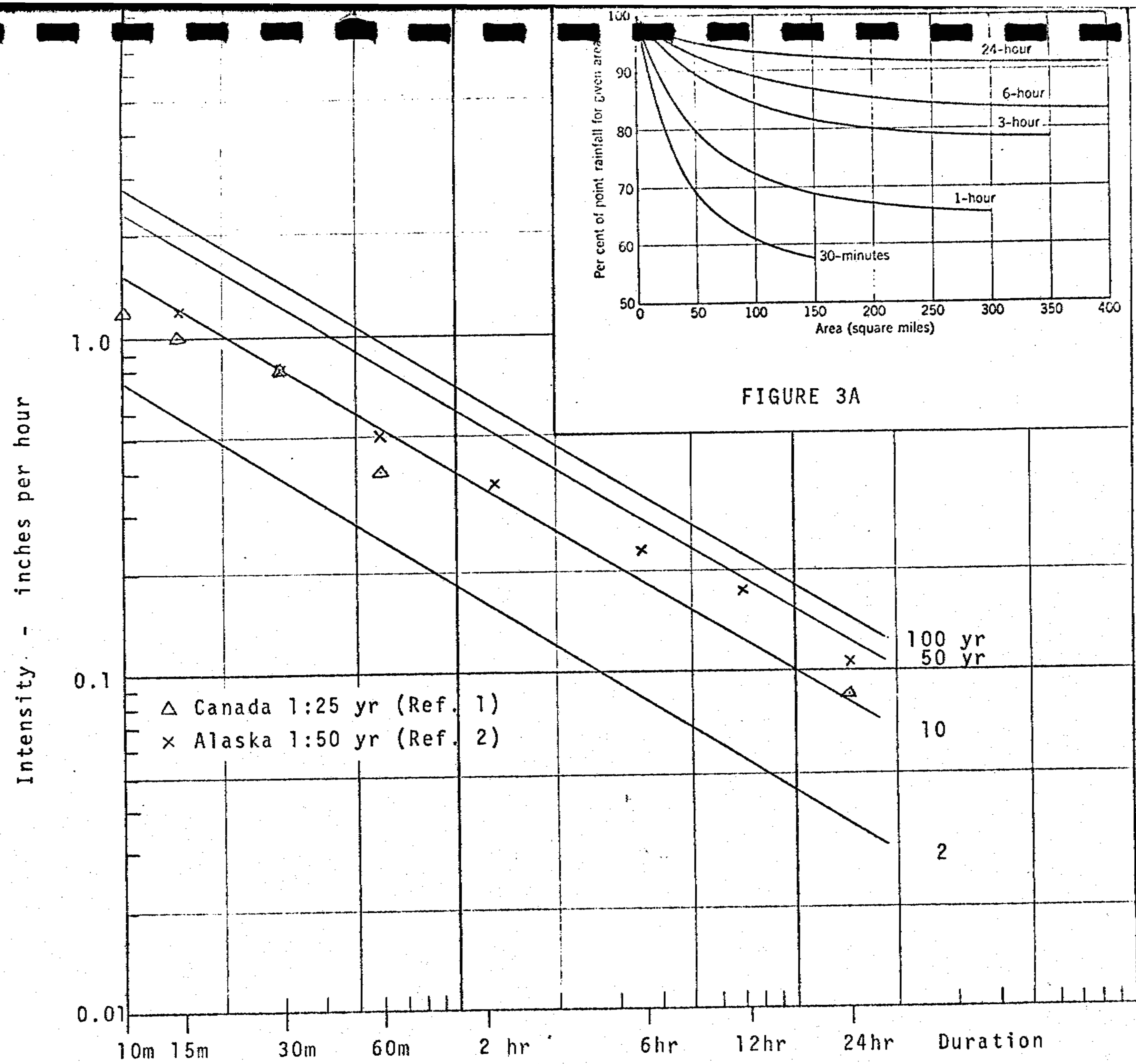

FIGURE 3A

FIGURE 3. Intensity-Duration-Frequency Curves for the Study Area

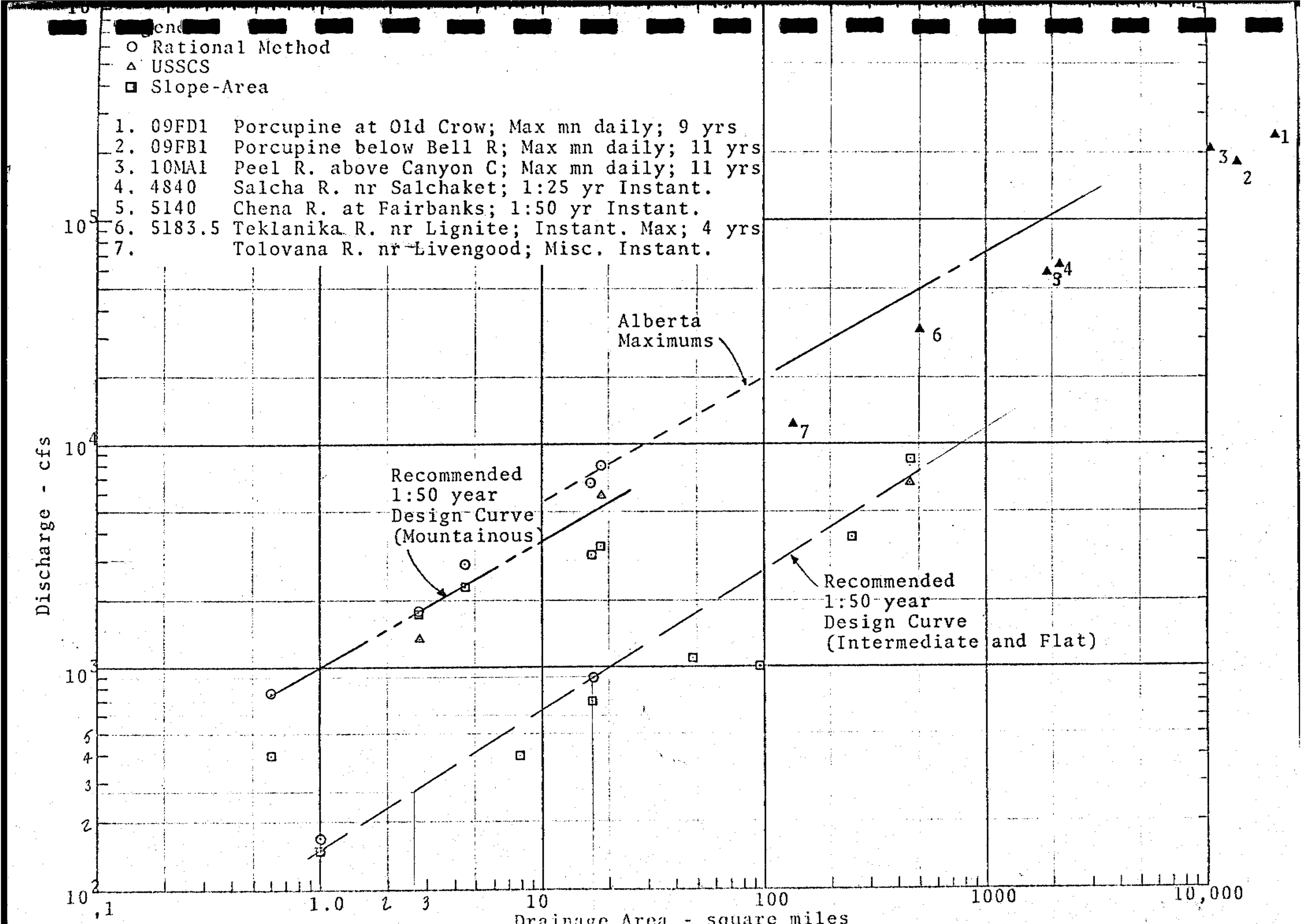

FIGURE 4. Area-Discharge Relationships

APPENDIX

SAMPLE CALCULATIONS FOR UNNAMED CREEK AT MILE 290.3

A1 RAINFALL RUNOFF ANALYSIS

A1.1 Basin Data

Drainage area	=	2.8 sq mi
	=	1800 acres
Length	=	4.0 mi
	=	21,000 ft
Relief	=	1800

A1.2 Rational Method

a) Time of concentration

$$t_c = \frac{.0078\ L^{.77}}{S^{.385}}$$

Where
t_c = time of concentration in minutes
L = basin length in feet
S = basin slope

$$t_c = \frac{.0078\ (21,000)^{.77}}{\left(\frac{1800}{21,000}\right)^{.385}}$$

$$= \frac{.0078\ (2100)}{.39}$$

$$= 42 \text{ minutes}$$

b) Peak runoff rate

$$Q_{50} = C\ i_{50}\ A$$

Where
Q_{50} = flow with 50 year return period
C = runoff coefficient
= 1 (maximizing assumption)

L_{50} = intensity of rainfall for duration = t_c with 50 year return period

A = basin area in acres

= 1800 acres

From Intensity-Duration-Frequency Curves

i_{50} (for D = 42 min) = 1.0 ins/hour

Area-depth correction factor for duration of 42 minutes and drainage area of 2.8 sq mi = 1.0 (i.e. no correction necessary)

$$Q_{50} = (1.0)\ (1.0)\ (1800)$$

$$= 1800 \text{ cfs}$$

A1.3 U.S. Soil Conservation Service Triangular Hydrograph Method

$$Q_{50} = C_1 \frac{484\ A\ R_E}{\frac{D}{2} + 0.6\ t_c}$$

Where Q_{50} = flow with 50 year return period

C_1 = area-depth factor

= near 1.0 (small area)

A = basin area in square miles

= 2.8 sq mi

R_E = total runoff in inches

D = rainfall excess period in hours

t_c = time of concentration

= 0.65 hrs (from a nomograph, an SCS guide, shown as Figure 13 in Design of Small Dams)

$$Q_{50} = \frac{(1.0)\ 484\ (2.8)\ R_E}{\frac{D}{2} + 0.6\ (.65)}$$

$$= \frac{1350\ R_E}{\frac{D}{2} + .39}$$

This must be maximized by trying various values for D:

For $D = .75$ hrs

$i_{50} =$ 0.96 ins/hr (from intensity-duration-frequency curves)

$R_E = (0.96)\ (.45)$

$= 0.72$ (assumes no losses)

$$Q_{50} = \frac{(1350)\ (.72)}{.375 + .39}$$

$= 1270$ cfs

For $D = 0.5$ hrs

$i_{50} = 1.22$ ins/hr

$R_E = 0.61$ ins

$$Q_{50} = \frac{(1350)\ (0.61)}{.25 + .39}$$

$= 1300$ cfs

For $D = .33$ hrs

$i_{50} = 1.57$ ins/hr

$R_E = 0.52$ ins

$$Q_{56} = \frac{(1350)\ (0.52)}{.17 + .39}$$

$= 1250$ cfs

Maximum $Q_{50} = 1300$ cfs

A2 SLOPE-AREA ANALYSIS

$$Q = \frac{1.5}{n}\ bd^{5/3}\ S^{1/2}$$

$n = 0.045$

$d = 1.5$ feet

$b = 120$ feet

$S = 0.05$

$$Q = \frac{1.5}{.045}\ (120)\ (1.5)^{5/3}\ (.05)^{1/2}$$

$= 1750$ cfs

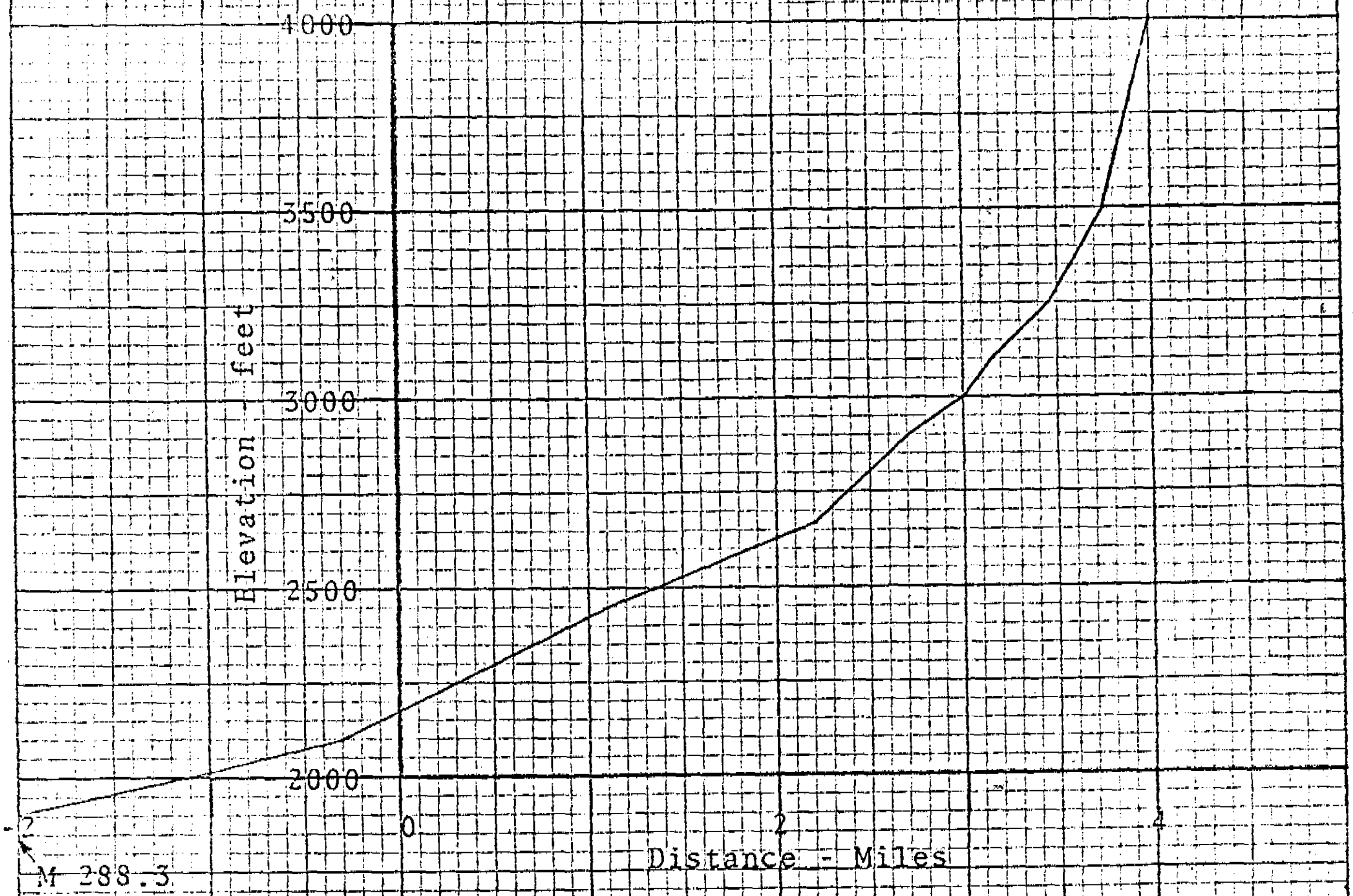

FIGURE 5. Channel Profile of Unnamed Creek at M 290.3. (From 1:50,000 topographic map)

Slope at the crossing: 0.05