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HYDROLOGIC AND HYDRAULIC CHARACTERISTICS OF THE ATHABASCA RIVER FROM FORT MCMURRAY TO EMBARRAS

by

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FOREWORD

The majority of the data contained in this report has been collected by two agencies: Water Survey of Canada and Alberta Research Council. Much of the Water Survey of Canada data utilized in this report is contained in Water Survey of Canada publications; other unpublished Water Survey of Canada data has been kindly provided by M. Spitzer of the Calgary office.

In addition to the data presented herein, the Transportation and Surface Water Engineering Division of Alberta Research Council has on file numerous photographs of the Athabasca River from Fort McMurray to the mouth during open water and spring breakup as well as several surveyed cross-sections between Embarras and the mouth.

The Alberta Research Council data has been collected by a number of Council personnel under Technologists H. Schultz and M. Anderson. R. Gerard supervised collection of much of the data and originated this report as well as suggesting improvements to several drafts. S. Beltaos made many helpful comments during reviews of the report.

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INTRODUCTION

The Athabasca River below Fort McMurray, until recently, has served as a main transportation link to the far north for nearly two centuries. In the early days, trading, trapping, and exploration took place along the river. Fort McMurray, located at the confluence of the Clearwater and Athabasca Rivers, grew into the main trading center for the region. In the first half of this century, the waterway served as the main link for shipment of goods north from Fort McMurray. The airplane and the MacKenzie highway have since reduced the importance of the river as a transportation corridor, although barges still carry freight downriver from Fort McMurray to centers on Lake Athabasca. The commercial importance of the river downstream of Fort McMurray is now associated with the growing Tar Sands oil industry in the area.

This report has two main objectives:

(i) to disseminate the data which has been collected on this reach of the Athabasca by Alberta Research Council (ARC) and other agencies, and

(ii) to provide some insight into the river's behavior in this reach.

Figure 1 shows the reach of the Athabasca covered in this report, and the surrounding area. Headwaters of the Athabasca River are glaciers in the Rocky Mountains, at an elevation above 1500 m. At the Water Survey of Canada (WSC) gauge 6 km downstream of Fort McMurray, the drainage area is 129,600 km^2. The gauge zero at this site is 236.0 m geodetic. The river distance from the source to the WSC gauge below McMurray is about 1160 km (Kellerhals, Neill and Bray, 1972)

For about 140 km upstream of Fort McMurray, the Athabasca River drops through a series of rapids. The last of these is 2 km upstream of Fort McMurray. Downstream of Fort McMurray, the Athabasca flows north through lowlands for 187 km to Embarras. Downstream of Embarras the river flows through its delta into Lake Athabasca. In this reach the water surface profile is nearly flat, falling only 3.5 m from Embarras to the mouth in Lake Athabasca, a river distance of 116 km. Northwest of Fort MacKay is the Birch Mountains upland (see Fig. 1). Left bank tributaries to the Athabasca between the Clearwater River and Embarras have their sources in these uplands. East of Fort MacKay is the Muskeg Mountain upland. The Muskeg and Steepbank rivers have their sources here and the upland is also the source of tributaries to the Clearwater and Firebag Rivers. For about 120 km downstream from Fort McMurray, the river flows through the Athabasca Tar Sands deposits.

The Fort McMurray area has a typical continental climate with warm summers and cold winters. Spring and fall are short since the temperature changes rapidly during the transitional seasons. North from Fort McMurray the mean annual temperature decreases, due mainly to colder winters. Average annual precipitation at Fort McMurray is about 430 mm per year, with more than half of the annual precipitation occurring in June, July and August. Mean annual precipitation decreases north from Fort McMurray.

Few quantitative measurements of channel changes with time have been made on this reach of the Athabasca as discussed later in this report, except at the gauging stations below Fort McMurray and at Embarras. However, there is evidence suggesting that the river is very active downstream of Fort McMurray.

The thalweg shifts within a year in much of the reach from Fort McMurray to Embarras. Some sections migrate weekly[1]. In order to maintain an adequate navigation channel, dredging is required in many places. Occasionally the same location requires dredging two or three times in one season. (Longley, 1970). Comparison of the 1973 edition of the navigation chart compiled by the Canadian Hydrographic Service, with the 1962 edition shows many changes in the location of the navigation channel in this reach. In places, the

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[1]Verbal communication from Jim Doherty, Ministry of Transport.

1973 navigation channel is located in what were shallows in 1962.

Little information on channel sub-bed material within this reach is available except within a few kilometres of Fort MacKay, where the foundations for five possible bridge sites were investigated. A total of forty-five cross-sections were sounded and all of them showed bedrock at the surface on at least one bank. The maximum depth to bedrock ranged from 18 to 55 m. Two reports produced for Alberta Transportation - Thurber Consultants Ltd. (1975) and Huntec (70) Ltd. (1975) - contain the sub-bed information obtained in the vicinity of Fort MacKay.

The hydrologic, geomorphic, hydraulic, and spring ice breakup characteristics of the river in the reach from Fort McMurray to Embarras are discussed in subsequent sections of this report.

HYDROLOGIC CHARACTERISTICS

WSC has compiled a preliminary report containing the hydrologic data collected by that agency through 1976 on the Athabasca and Clearwater Rivers, and tributaries between Fort McMurray and Embarras (Loeppky and Spitzer, 1977). Table 1 is a summary of the streamflow data for the two WSC stations on the Athabasca River for the period of record.

The hydrographs for the gauging stations below McMurray and at Embarras generally show a rapid increase in discharge in April from winter minima of less than 200 m^3/s to a snowmelt peak of between 1100 and 2800 m^3/s. The latter is usually followed by one or more higher peaks during the summer. Only in 1963 was the snowmelt peak discharge higher than the summer peak at the gauge below McMurray. At Embarras in 1976, the peak daily discharge for both the spring and summer peaks was 2150 m^3/s. The higher spring discharges probably result from a combination of rainfall and snowmelt.

Figure 2 shows the frequency curves for the annual peak flows at the WSC gauges below McMurray and at Embarras. Figure 3 compares the frequency curves for the water level at MacEwan bridge just upstream of Fort McMurray for both the spring and summer peaks, and is discussed more fully in the spring ice breakup section.

Figure 4 is a baseflow recession curve at the gauge below McMurray for a period in 1976 which had little, if any, inflow to the basin. The baseflow recession constant (K_r) is equal to 0.998 which compares favorably with baseflow recession constants calculated for other years.

Figure 5 is the flow duration curve for the WSC gauging station below McMurray for the years 1958 through 1976.

Table 2 is a hydrologic data summary for the period of record for the WSC gauging stations on Athabasca River tributaries between Fort McMurray and Embarras with three or more years of continuous record. The Clearwater River is by far the largest of the tributaries (drainage area at Draper gauge is 30,600 km^2). The MacKay and Firebag Rivers are the only other streams draining more than 2500 km^2 in the reach. In addition to the six stations summarized in Table 2, WSC has installed gauges on twelve other tributaries to the Athabasca between Fort McMurray and Embarras since 1974.

Roughly half the annual peaks on all the tributaries, including the Clearwater, are due to snowmelt. Although records for the stations downstream of the Clearwater are very short, it appears that, during spring breakup, the tributaries between Fort McMurray and Embarras often contribute a larger percentage of the flow in the Athabasca than during the rest of the year. This is probably due to rapid snowmelt occurring over most of the tributary basin. The MacKay River, in particular, during its spring peaks in 1974 and 1976, contributed nearly 25 percent of the total flow at Embarras in both years.

During eighteen years of record at the WSC gauge at Draper, the Clearwater has contributed between 13 and 29 percent of the annual flow in the Athabasca at the gauge below McMurray from a drainage area comprising 24 percent of the total basin. Annual peak daily discharges have been as much as 38 percent of the flow at the gauge below McMurray.

Tributaries to the Athabasca between the gauge below McMurray and the gauge at Embarras drain 25,400 km^2 - 16 percent of the drainage area at Embarras. In the upstream half of the reach the larger tributaries with several years of record include the Beaver, Steepbank, MacKay and Muskeg Rivers. These rivers drain a total of 8220 km^2 or five percent of the total drainage area at Embarras. During the peak annual runoff periods in 1974 and 1975, these four rivers contributed three to four percent and four to nine percent of the flow, respectively, in the Athabasca at Embarras. The only major tributory in the downstream half of the reach is the Firebag River which drains 6030 km^2 (3.9 percent of the total drainage area at Embarras). During the 1974 peak runoff period, the Firebag contributed between two and four percent of the total flow at Embarras; during the 1975 peak flow period, it contributed three to four percent of the flow. During the 1976 peak annual runoff period, roughly the same percentage of the total flow at Embarras was contributed by the Beaver, Muskeg, MacKay and Steepbank Rivers in the upper half of the reach and the Firebag River in the lower half of the reach as in 1974 and 1975. These three years of record indicate that during annual summer peak discharges on the Athabasca of less than 2900 m^3/s, tributaries downstream of Fort McMurray contribute approximately the same unit runoff as the entire basin. There are occasions when the peak annual flows on the tributaries contribute a much greater percentage of the flow in the Athabasca. For instance, the 1973 peak discharge on the Firebag River was 12 percent of the total flow at Embarras.

Flood flow attenuation through the reach from Fort McMurray to Embarras varies from flood to flood. Figure 6 shows the hydrographs at WSC gauges below McMurray and at Embarras for the peak annual floods below Fort McMurray for 1971 through 1976. In three of the six years shown, the peak at Embarras has been greater than the peak at the gauge below McMurray. This must be due to inflow from tributaries downstream of Fort McMurray, although 1975 and 1976 flows from tributaries measured were not particularly high and the Firebag River is the only tributary of any size near the downstream end of the reach. Table 3 gives Muskingum flood routing coefficients for the 1971 and 1974 peak flows at the gauge below Fort McMurray using a routing period of one day. It is obvious that these two floods exhibited different characteristics travelling through the reach. The big 1971 flood peak was slow passing through the reach with a lot of channel storage as compared to the smaller 1974 flood. This may be due to increasing overbank flow in the reach near the downstream end once flow exceeds 2600 m^3/s combined with the lesser effect of tributary inflow during higher annual peak floods. Flow Forecasting Branch, Alberta Environment, uses the SSARR model to route flow through this reach. The SSARR model is based on the linear reservoir concept where storage is a function of outflow only. The hydrographs computed by the SSARR model, with the reach divided into ten reservoirs and a time interval of six hours, for the maximum flood events of 1971, 1974 and 1975 compared favorably with the recorded hydrographs at Embarras.[2]

Winter flows in the small tributaries are zero and flows in the larger ones are very low. Minimum winter flows in the Clearwater are generally between 30 and 60 m^3/s, or about one-third of the total flow in the Athabasca at the WSC gauge below Fort McMurray. The Beaver River ceases to flow during winter while the combined flow of the Muskeg, Steepbank, and MacKay Rivers drops to less than one percent of the flow in the Athabasca at Embarras during minimum winter flows. The Firebag contributes between two and five percent of the flow at Embarras during low winter flows.

GEOMORPHIC CHARACTERISTICS

Kellerhals, Neill and Bray (1972) have described the geomorphic characteristics of the Athabasca River in the vicinities of the gauging station below McMurray and the gauging station at Embarras.

The river at the WSC gauge below McMurray has a stable entrenched channel 75 m lower than the tops of the valley walls. The top width of the valley is 3.2 km and the bottom width is 1.3 km. There is very little floodplain in the vicinity. The channel itself is straight with occasional islands and mid-channel bars. Bed material is sand with local gravel over limestone. Banks are 80 percent erodible rock and 20 percent clay and gravel.

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[2]Written communication from Thai Nguyen, Alberta Environment.

At Embarras, the channel is moderately unstable and occasionally confined, with meanders progressing downstream. The irregular meandering channel has islands, point bars, and mid-channel bars with the valley top a maximum of 15 m above the river. The valley top width is 3.4 km and the moderately forested floodplain is 3.2 km wide. Bed material is sand, which probably extends quite deep. The banks are composed of entirely alluvial material; a mixture of sand, silt and clay.

Figure 7 is a longitudinal profile of the river reach from Fort McMurray to Embarras showing the height of the valley bank tops as well. Going downstream from Fort McMurray, the height of the bank tops decreases and the width of the valley bottom increases. Table 4 gives water surface slopes and average channel geometric properties for selected reaches downstream of Fort McMurray. Going downstream, the two trends which are apparent are the decreasing slope (particularly downstream of Embarras) and the increasing mean channel depth. Figure 8 is a plot of channel properties vs. discharge in the vicinity of the McMurray gauge, and in the vicinity of Embarras. The data have been taken from Kellerhals, Neill and Bray (1972), and represent open-water conditions.

Figure 9 shows the location of all cross-sections surveyed by Alberta Research Council, as well as 1976 bed material sample sites. Figure 10 is a plot of four ARC cross-sections in the reach selected to show the channel during low winter flows, approximate mean discharge, and higher discharge. All cross-sections as well as thalweg soundings taken along some sections of the reach at various times are available on request. Other cross-sections have been surveyed during investigations of possible bridge sites in the vicinity of Fort MacKay (Huntec (70) Ltd., 1975; Northwest Hydraulic Consultants Ltd., 1974).

Figure 9 also shows the location of five river valley cross-sections plotted from 1:50,000 topographic maps, and a valley cross-section at km 251.2 surveyed by Alberta Transportation. Figure 11 shows these valley cross-sections, going downstream from the Firebag River (km 174) to Embarras (km 116). Figure 12 is the surveyed valley cross-section at km 251.2, 4.8 km upstream of Fort MacKay.

Grab samples of bed material taken at km 238.4, km 220.6, km 179.3, km 154.2, and km 116.5 in 1976 (see Figure 9) show the bed material to be mostly fine sand with decreasing amounts of clay going downstream. Figure 13 depicts the grain size distribution of each of these bed samples which were taken along the thalweg and except for the two single samples at km 116.0 are a combination of 3 individual samples. Contrary to the general trend found in most rivers, the size of the bed material increases in the downstream direction. This unusual increase in sediment size downstream may reflect the grain size of the local bank material which has been eroded.

HYDRAULIC CHARACTERISTICS

Figure 14 shows the stage-discharge rating curves for the WSC gauging stations below McMurray and at Embarras (Loeppkey and Spitzer, 1977) as well as rating curves developed for the abandoned WSC stage gauges at Fort MacKay (km 243.7) and Shott Island (km 178.6).

Surveys made during stages corresponding approximately to the mean discharge in the vicinity of the WSC gauge below McMurray and the WSC gauge at Embarras indicate Manning's "n" values of 0.018 below Fort McMurray and 0.024 at Embarras (Kellerhals, Neill and Bray, 1972). At higher flows, "n" values have not been verified and because the predominantly sand bed is very mobile, estimation of resistance to flow at higher discharges is not attempted.

Simons and Senturk (1976) indicate that a stream having the slope and mean discharge of the Athabasca River below Fort McMurray should be a meandering stream, according to equations developed by Lane (1957). However, Lane (1957) also indicates that overloading of a stream with sediment can be one of the primary reasons in the formation of a braided stream. Considering the relatively steep slope of the river above Fort McMurray, and the suspended sediment concentrations measured at Fort McMurray and Embarras, this is probably one of the reasons why the Athabasca between Fort McMurray and Embarras is relatively straight with numerous islands rather than meandering. Also bedrock control may be another reason for the channel being straight.

Figure 15 shows suspended sediment rating curves for the WSC gauges below McMurray and at Embarras, using WSC data collected between 1969 and 1973. The curves were fitted by eye as there is a wide variation in suspended sediment concentration for a given discharge depending on whether the stage is rising or falling, antecedent conditions, water temperature, measurement techniques, etc. The suspended sediment rating curves and the dredging data indicate that during high flows there is a certain amount of sediment deposited between Fort McMurray and Embarras, which is then gradually removed at lower flows when the sediment concentration is approximately the same at both Fort McMurray and Embarras but the discharge is greater at Embarras. Although there is only limited sediment data available for the Embarras gauge, it appears that when flows exceed approximately 1000 m^3/s, deposition begins to take place downstream of Fort McMurray and when flows increase above 3000 m^3/s, concentrations near Fort McMurray may exceed those at Embarras by 50 to 100 percent. For example during the record maximum daily discharge in 1971 suspended sediment concentration at the gauge below McMurray was 2400 mg/l while the average of 5 samples taken as the flood peak passed Embarras was 1250 mg/l. On the average about 75 percent of the suspended sediment is finer than 0.062 mm which would probably remain in suspension throughout the reach during higher flows.

Information on bed scour, both long-term and instantaneous, for much of the reach is sparse. At the discharge measuring section for the WSC gauge below McMurray, there have been four rating curves used since 1963 which show that the channel just below the gauge has scoured, filled, and scoured again since 1963. The rating curve presently being used is much the same as the 1963 curve. The rating shifts in discharge have been less than 15 percent at any particular stage. In this vicinity at least, the scour/deposition process appears to be continual but temporary. Figure 16 shows three cross-sections at the WSC measuring section for the gauge below McMurray; one done in 1957, one in 1966, and one in 1975 (Loeppkey and Spitzer, 1977) At the WSC gauge at Embarras, two 1976 cross-sections are shown in Figure 17 (Loeppky and Spitzer, 1977). As much as one metre of deposition occurred on the left bank side of this cross-section, and one metre of scour at mid-stream during a summer of relatively low flow (peak daily discharge between surveys was 2150 m^3/s).

Between the two gauging stations not many cross-sections have been surveyed more than once to determine actual bed scour and bank erosion. At km 251.2 the proposed centerline for a highway bridge was surveyed in February 1974, and again in May, following spring breakup. A NWH Consultants (1974) report indicates that as much as 3.7 m of bed scour had occurred between surveys, although the thalweg did not deepen. This report also shows considerable change in the channel configuration just upstream and downstream of the cross-section. Figure 18 shows the changes in the cross-section at km 251.2 during low flow and high flow. This figure is illustrative of the type of change which the sand bed of the stream can undergo at various flow conditions. Apparently, in many sections in the winter, the flow is mainly within one channel with a relatively deep thalweg. At some sections higher flows during open water result in increased erosion of the bed in general but not necessarily any deepening of the thalweg. When high flows diminish, there is general deposition across the bed but the thalweg elevation appears to remain fairly constant. Doyle (1977) reports that six cross-sections between the WSC gauge below McMurray and the MacEwan bridge, which were surveyed in 1976 and 1977 at nearly the same location and same discharge, showed little change in thalweg position and depth or general configuration of the channel. One of these cross-sections at km 299.3 had been surveyed previously in 1973 and the 1976 survey showed very little change.

SPRING BREAKUP CHARACTERISTICS

Breakup at Fort McMurray has often been marked by a sudden swift rise in water levels, which may be due to failure of an ice jam somewhere in the rapids upstream of Fort McMurray. The running ice will often jam initially a short distance downstream of Fort McMurray, occasionally causing extremely high water levels in the town. Reports by Blench & Associates (1964), NWH Consultants (1974), Gerard (1975), and Doyle (1977), as well as WSC data and unpublished ARC data, document some breakups at Fort McMurray since 1875 and some breakup events downstream of Fort McMurray in the last few years. The frequent ice jams during breakup at or just downstream of Fort McMurray apparently result from a combination of the following three factors:

1. the slope of the Athabasca becomes markedly flatter at Fort McMurray, accompanied by reduced average velocity and depth and a wider channel containing numerous islands and shallows,
2. generally breakup progresses downstream, with the broken ice cover jamming against an intact ice cover, and
3. the channel is choked by a high volume of ice when a jam upstream of Fort McMurray releases.

Figure 3 shows an approximate frequency curve of water levels during spring breakup. This frequency curve was plotted assuming that water levels above elevation 247.0 m would have been noted at any time subsequent to 1875 when the highest water level ever recorded occurred (between elevation 251.5 and 253.0). Comparing the frequency curve for summer flood stages to the frequency curve for breakup flood stages (see Figure 3) it is obvious that it would take a very rare summer flood to even approach elevation 247.0, a level which is reached or exceeded once every 12 years on the average during the spring breakup.

Breakup at Fort McMurray occurs between early April and early May and generally from mid to late April. It progresses downstream past Embarras usually one to two weeks later. Table 5 gives thickness of ice cover in late winter at the WSC gauges below Fort McMurray and at Embarras which were obtained by WSC personnel while making discharge measurements. Actual ice thicknesses were probably ten percent greater than that shown in the table.

Inspection of Table 5 indicates no apparent relationship between ice thickness and the severity of spring ice jams in the vicinity of Fort McMurray. Significant jams have occurred when there was appreciable slush ice and also when the ice cover was relatively thin. The reverse is also true - the running ice has not jammed to any extent both when appreciable slush ice was present and when the ice was relatively thin. However, the fact that such thick accumulations of ice and slush ice do occur (up to 290 cm thick) could help explain how the running volume of ice might grind to a halt in the shallows at Fort McMurray. The slush ice is probably formed in the rapids upstream of Fort McMurray and transported downstream under the ice.

The volume produced and the locations where it builds up underneath the ice no doubt vary from year to year, but it is likely that a large amount of slush ice forms in the rapids and travels under the ice cover downstream of the rapids every year.

Gerard (1975) reports that thicknesses of ice floes in the vicinity of Fort McMurray following the 1974 breakup averaged 80 cm; with a maximum thickness of 90 cm, of which about 40 cm was clear ice and the rest snow ice. Following the 1977 breakup, floes in the vicinity of Fort McMurray were up to 140 cm thick, generally in the 90-110 cm range, and were entirely snow ice. There were a few floes noticeably thinner than the rest, being about 50 cm thick, of which 30 cm was snow ice and 20 cm clear ice.

In February of 1974, ice thicknesses for eight cross-sections in the river reach from km 173.4 (Mildred Lake dock) to km 160.8 ranged from 30 to 90 cm with most thicknesses between 45 and 65 cm. Also in February 1974, NWH Consultants (1974) reports ice thicknesses at km 159.0 were as little as 30 cm. This relatively thin ice may be due to warm water entering the river from the tailings ponds upstream.

Data and observations of breakup downstream of Fort McMurray are limited, but suggest that breakup is sometimes accompanied by formation and release of ice jams - some of them occasionally spectacular. Newspaper accounts described unusual flooding in 1925 due to ice jams downstream of Embarras near the Embarras River. In 1958, an ice jam(s) caused the water to rise 3 metres above bankfull at Embarras. A report by NWH Consultants (1974) indicates that the ice jammed and released at numerous locations at least as far downstream as Morrison Island (91 km downstream of Fort McMurray) as the breakup front moved downstream in 1974. Observations in 1977 following breakup at Fort McMurray reported by Doyle (1977) show jams had occurred at Inglis Island (23 km downstream of Fort McMurray) and at Ells River (73 km downstream of Fort McMurray).

Tributaries downstream of Fort McMurray, including the Clearwater, may discharge their ice before the Athabasca breaks up. In both 1974 and 1976, the MacKay River broke up prior to the Athabasca causing the ice to jam at the mouth against the Athabasca ice cover, which resulted in overbank flooding along the MacKay. This appears likely to happen to other tributaries as well.

SUMMARY

Data collected by ARC, WSC, and other agencies on the characteristics of the Athabasca River between Fort McMurray and Embarras has been presented in this report. The data base will increase greatly in the next few years and provide more conclusive answers to questions about the river's behavior in this reach. The following paragraphs review the major findings of this report.

The Athabasca River below Fort McMurray is laterally stable and deeply entrenched in its valley. Progressing downstream, the river becomes less incised; by Embarras the valley walls no longer exist and the river has started to meander over a wide floodplain. The average channel depth increases downstream from Fort McMurray and the average velocity decreases. Bed material size increases from Fort MacKay to Embarras, contrary to what is generally the case. Dredging data, navigation charts, channel cross-sections which have been surveyed at different flows, and the heavy sediment load carried in the river at high flows indicate that the river bed is very active in much of the reach; however, the channel appears to be stable over long periods of time.

Spring ice jams are a common occurrence, particularly in the vicinity of Fort McMurray. Water levels reached during some of these spring jams far exceed the levels reached during the highest summer floods over the same period of record. Summer floods passing through the reach show considerable difference in their time of travel and attenuation apparently because of overbank flow and the relative volume of tributary inflow. Flood peaks exceeding 3200 m^3/s at the WSC gauge below McMurray are generally reduced at Embarras; flood peaks less than 3200 m^3/s are generally higher at the Embarras gauge due in part to the relatively greater proportion of the flow contributed by the tributaries downstream of Fort McMurray.

Hydrologic record on all the tributaries except the Clearwater River is short but a representative sample of tributary streams in the reach is now being gauged by WSC. About half the annual peak discharges on the tributaries are due to snowmelt and tributary flow in the spring can comprise a large part of the total flow at Embarras.

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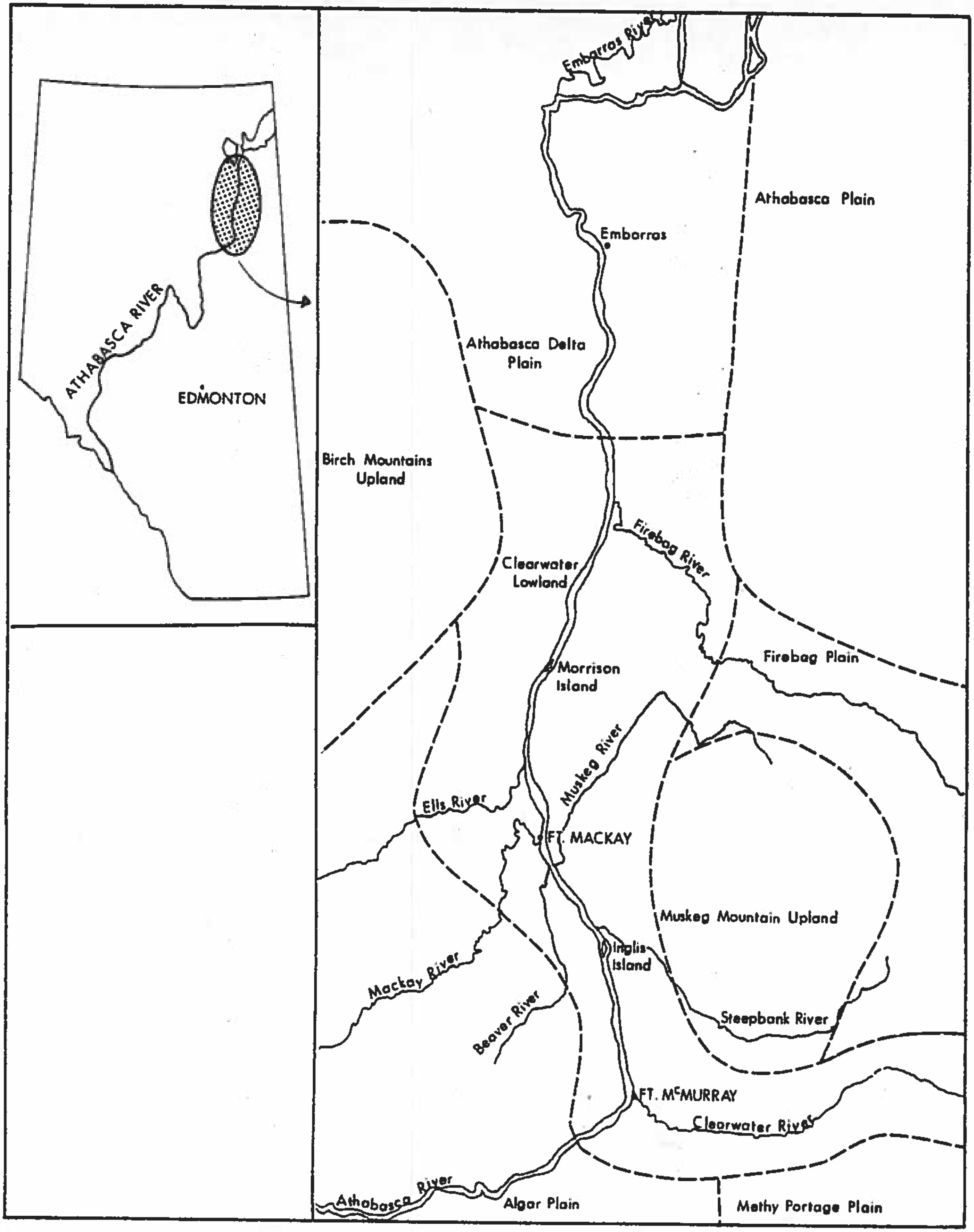

FIGURE 1. Location map and physiographic features.

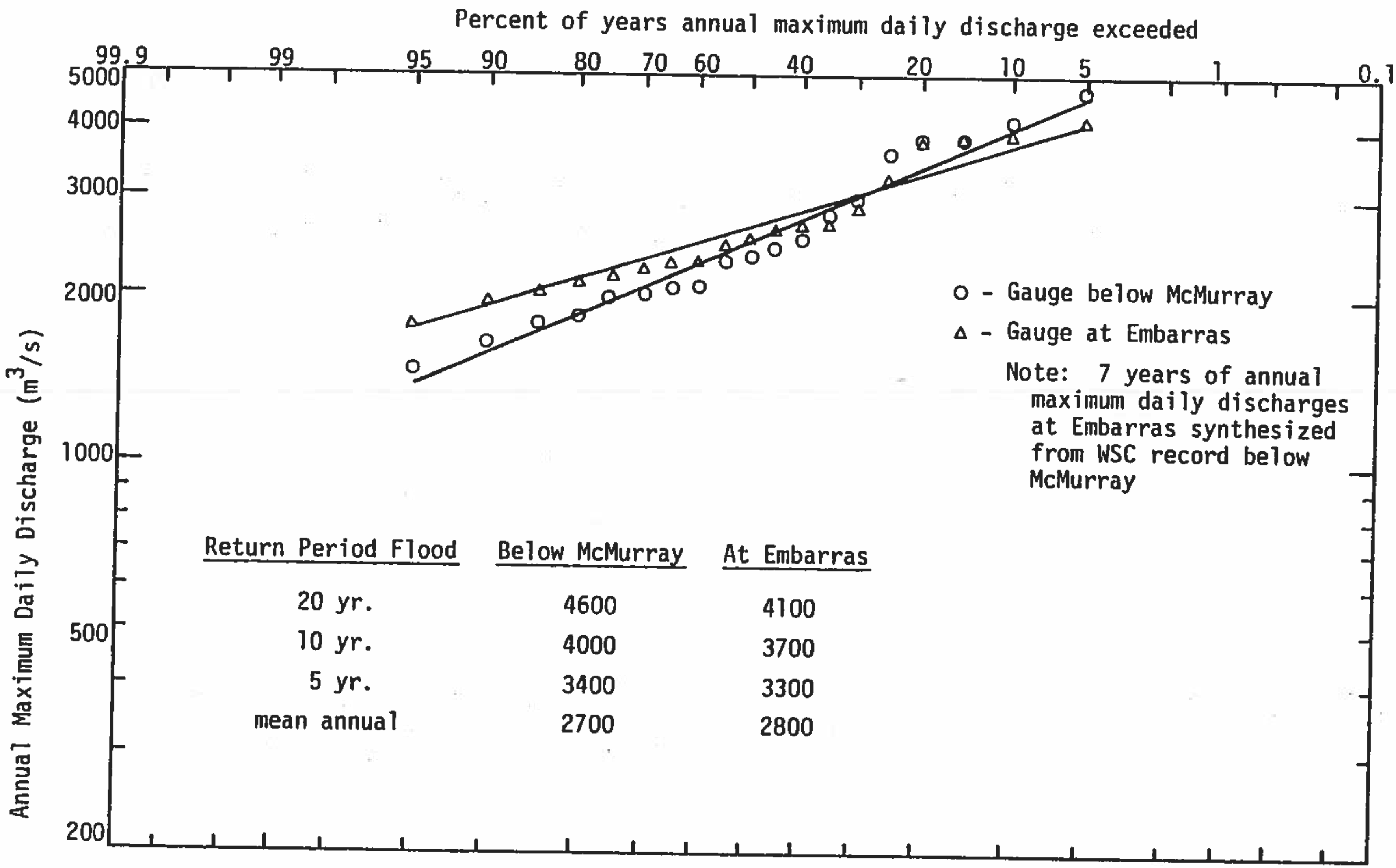

FIGURE 2. Flood frequency curves for Athabasca River at WSC gauges below McMurray and at Embarras

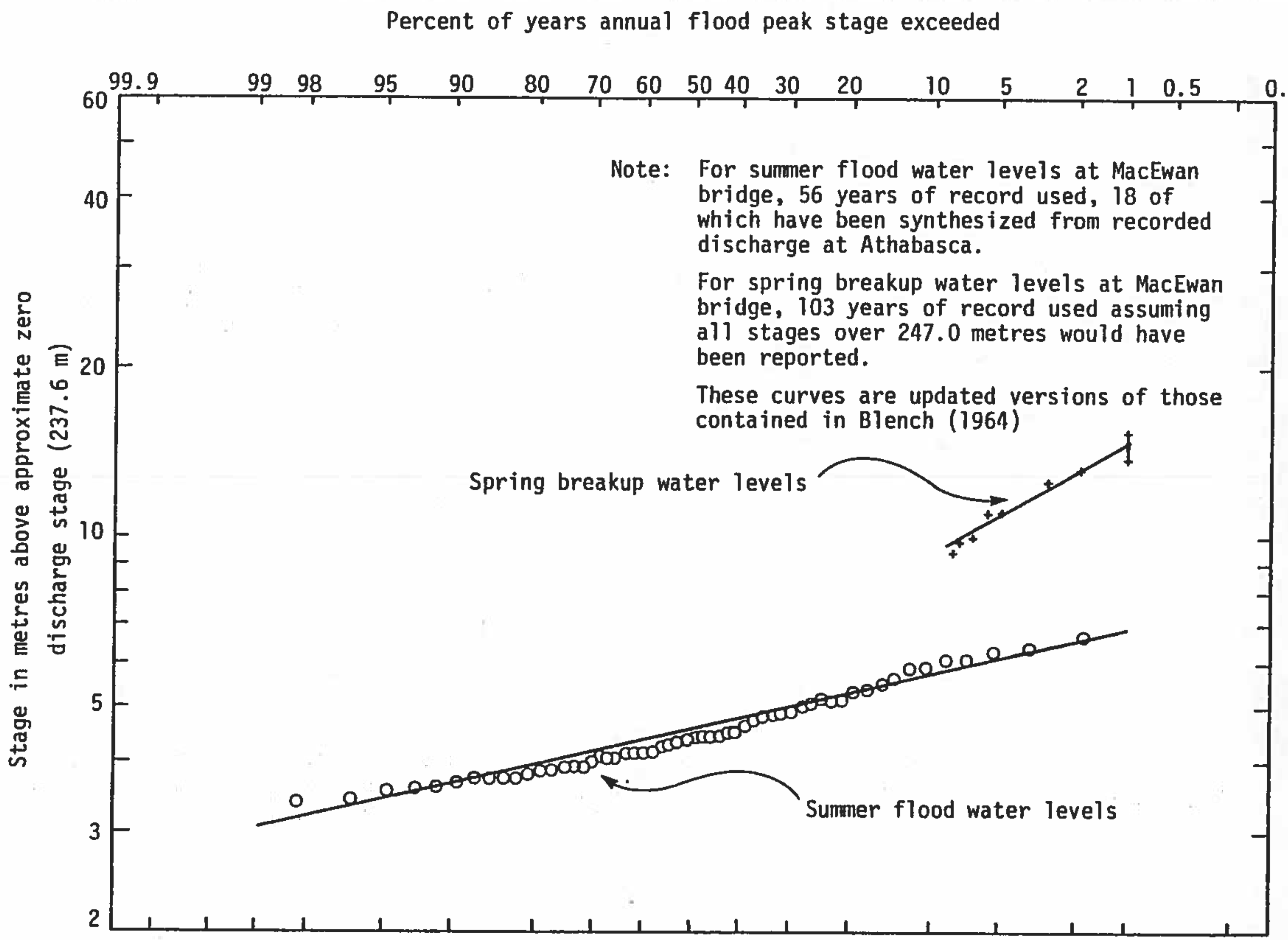

FIGURE 3. Frequency curves for peak annual water level at MacEwan bridge for both spring and summer floods.

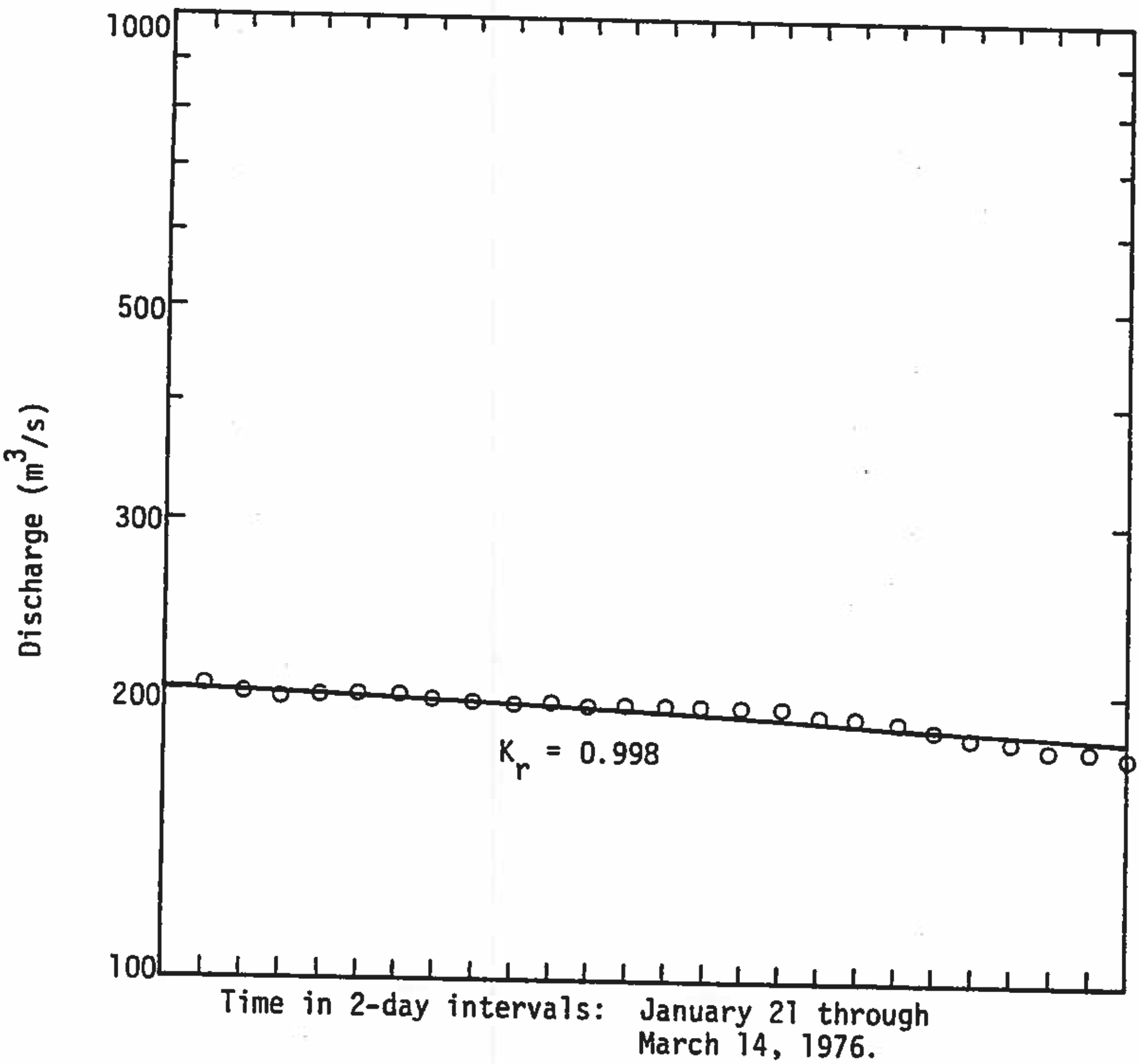

FIGURE 4. Baseflow recession curve for Athabasca River below McMurray

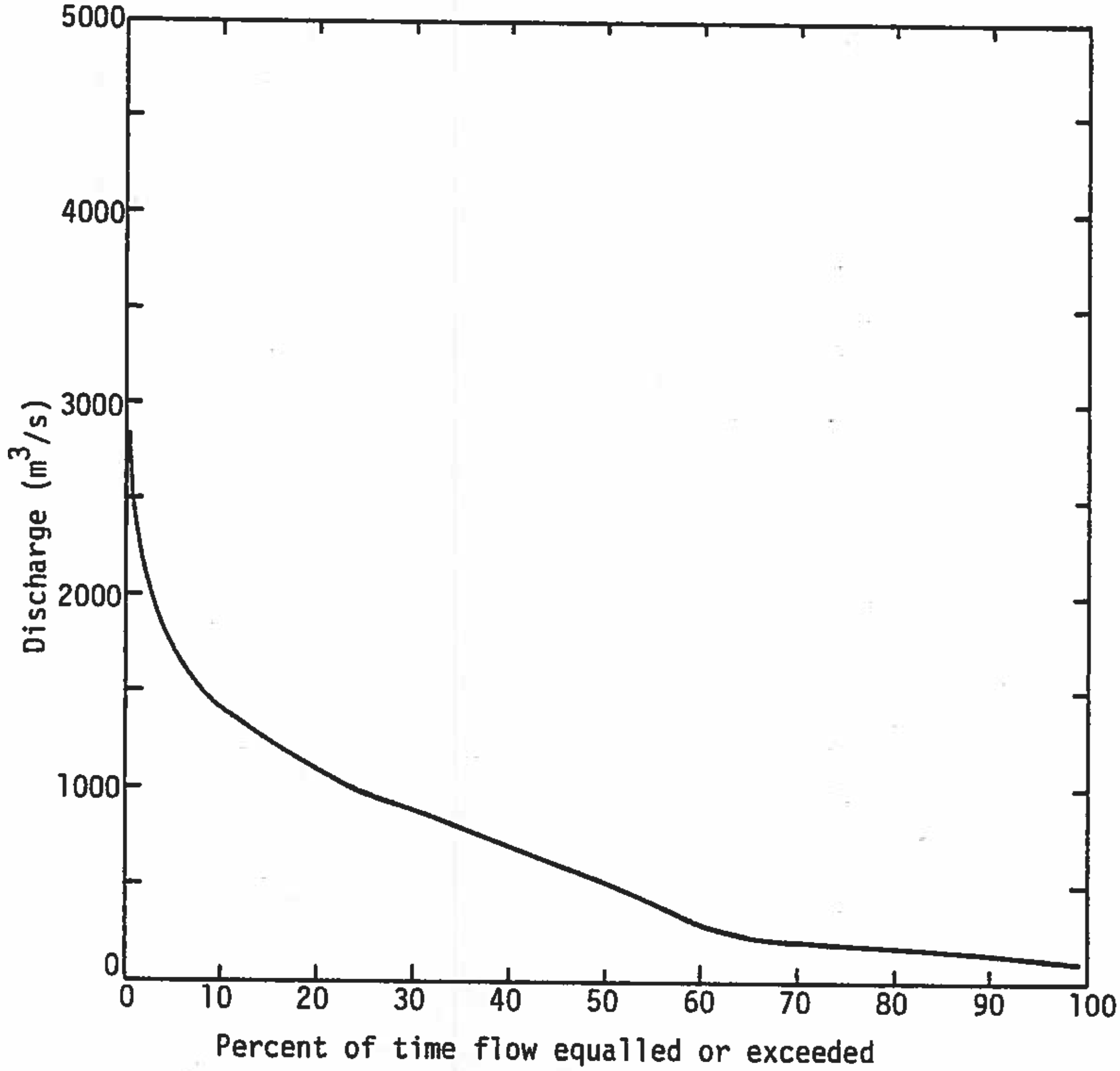

FIGURE 5. Daily flow duration curve at WSC gauge below McMurray 1958-1976

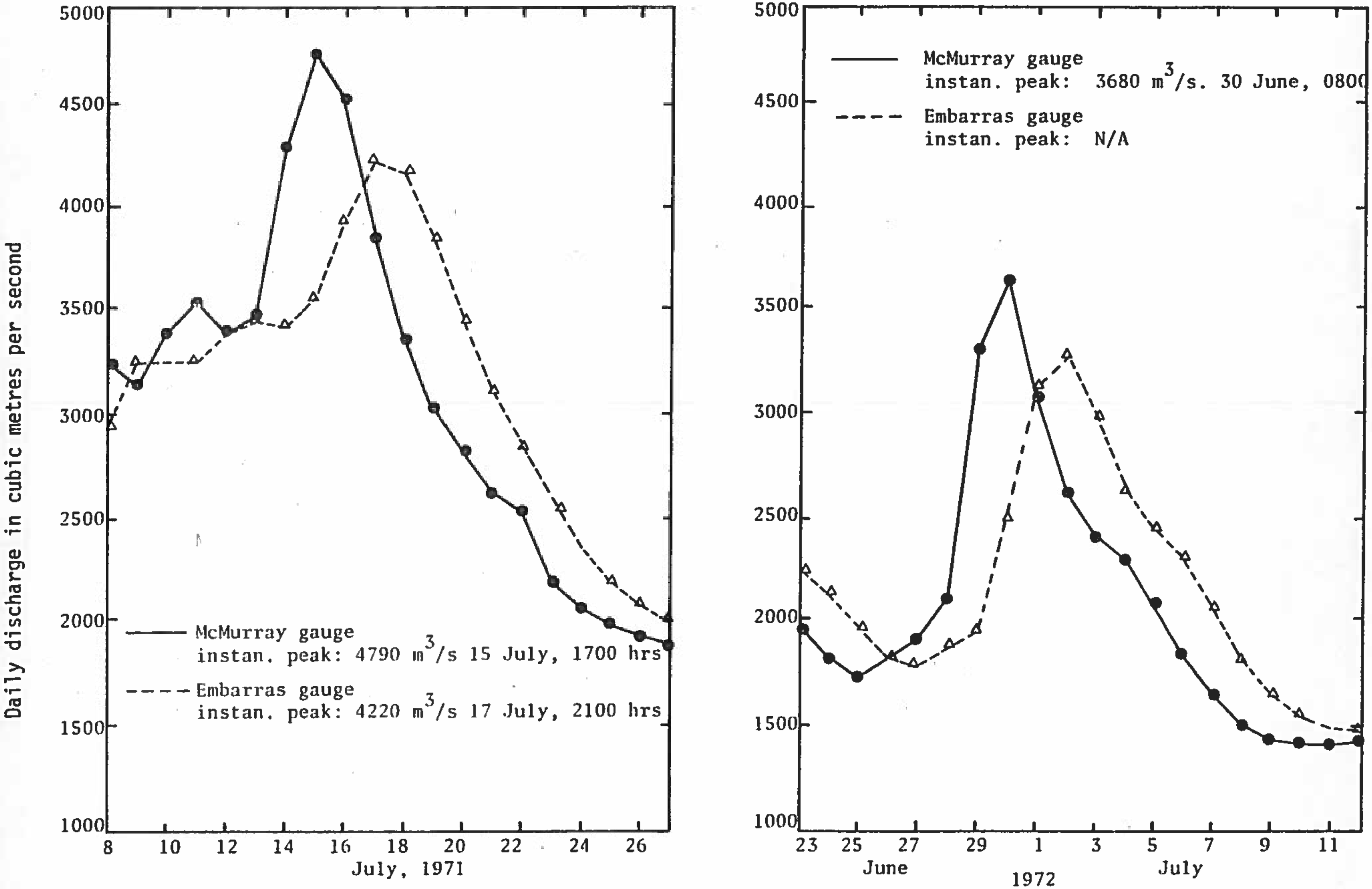

FIGURE 6. Daily discharge hydrographs for annual summer flood peaks for 1971 through 1976 at the WSC gauges below McMurray and at Embarras

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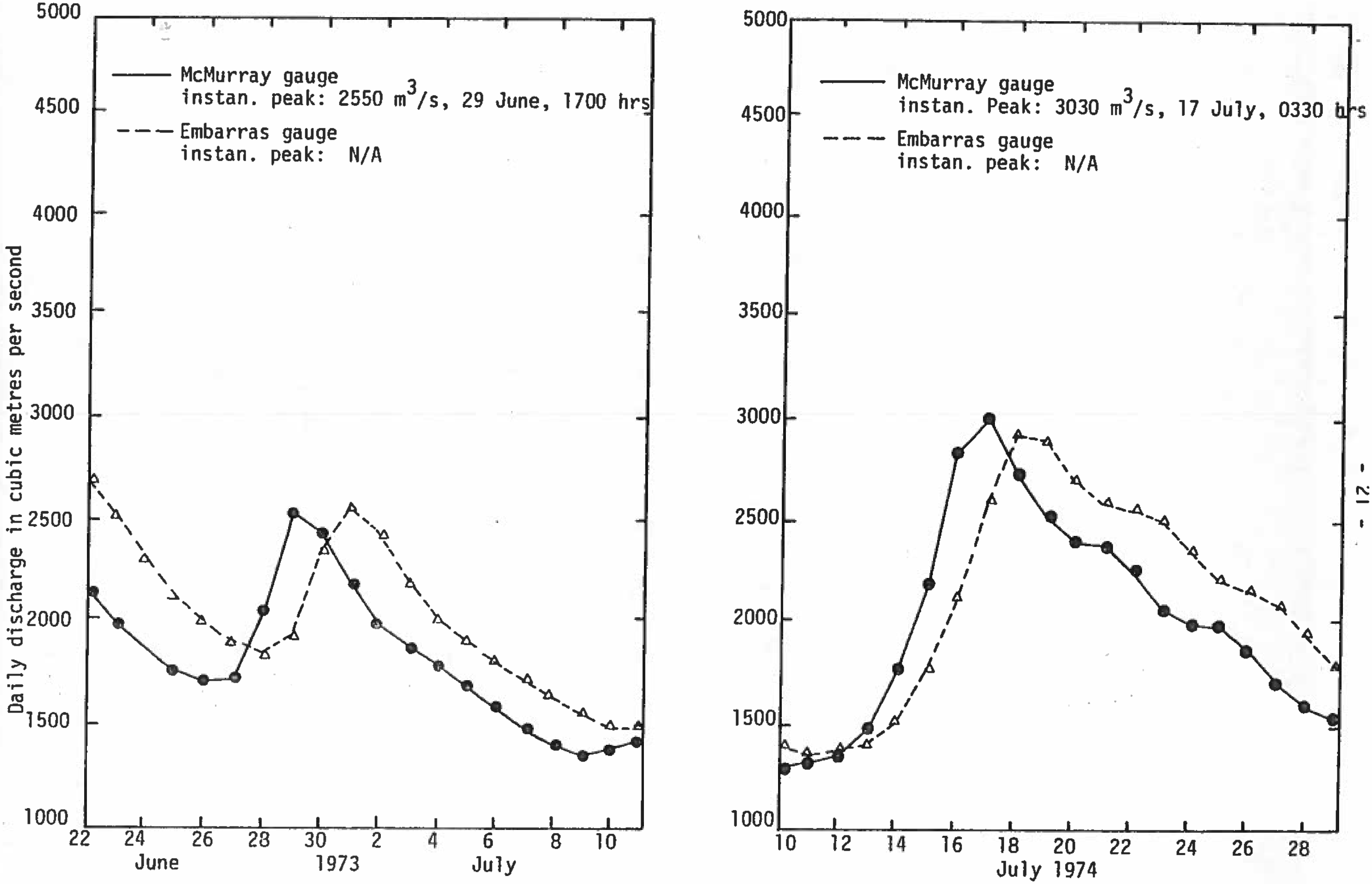

FIGURE 6. Continued

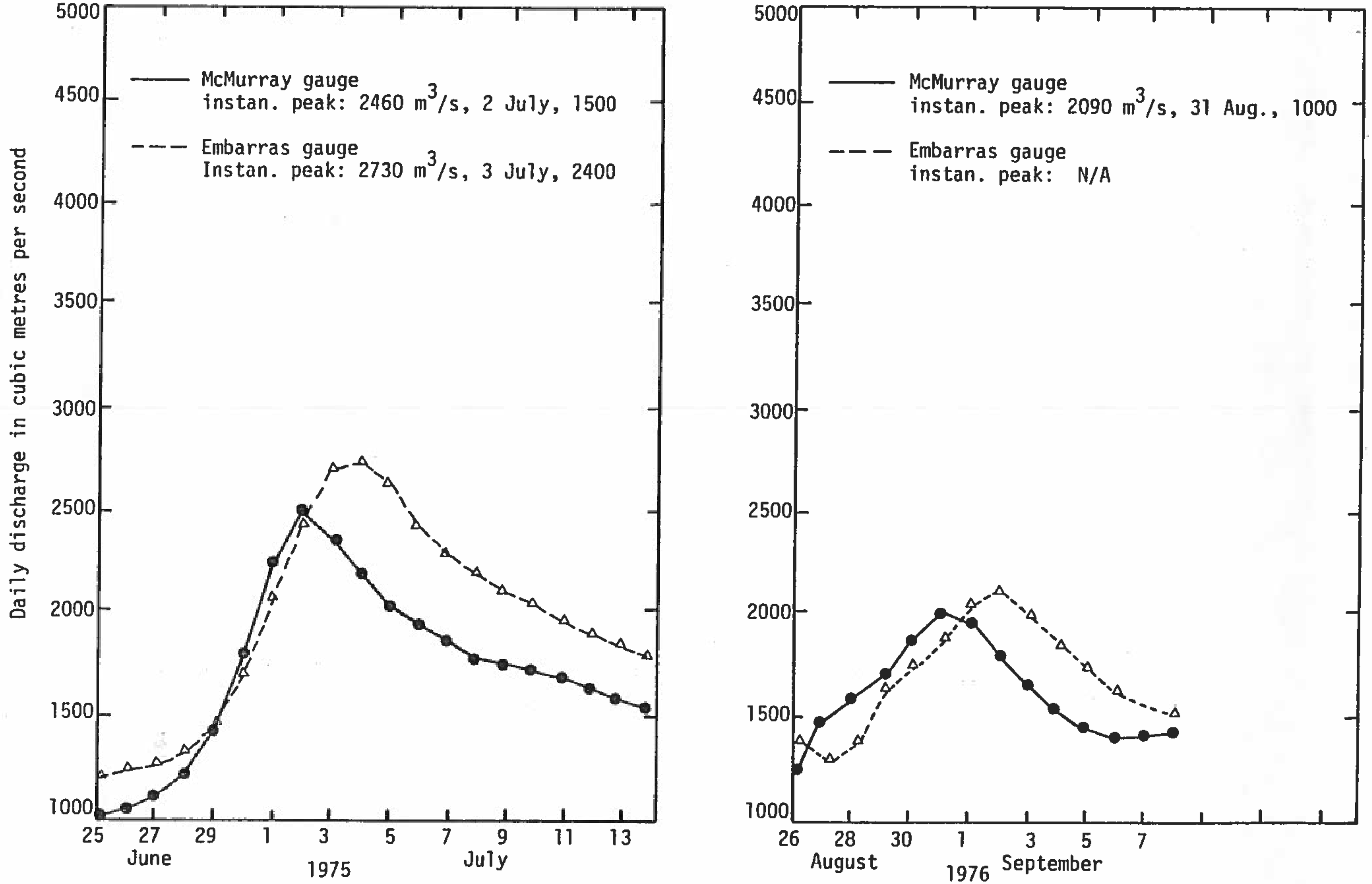

FIGURE 6. Continued

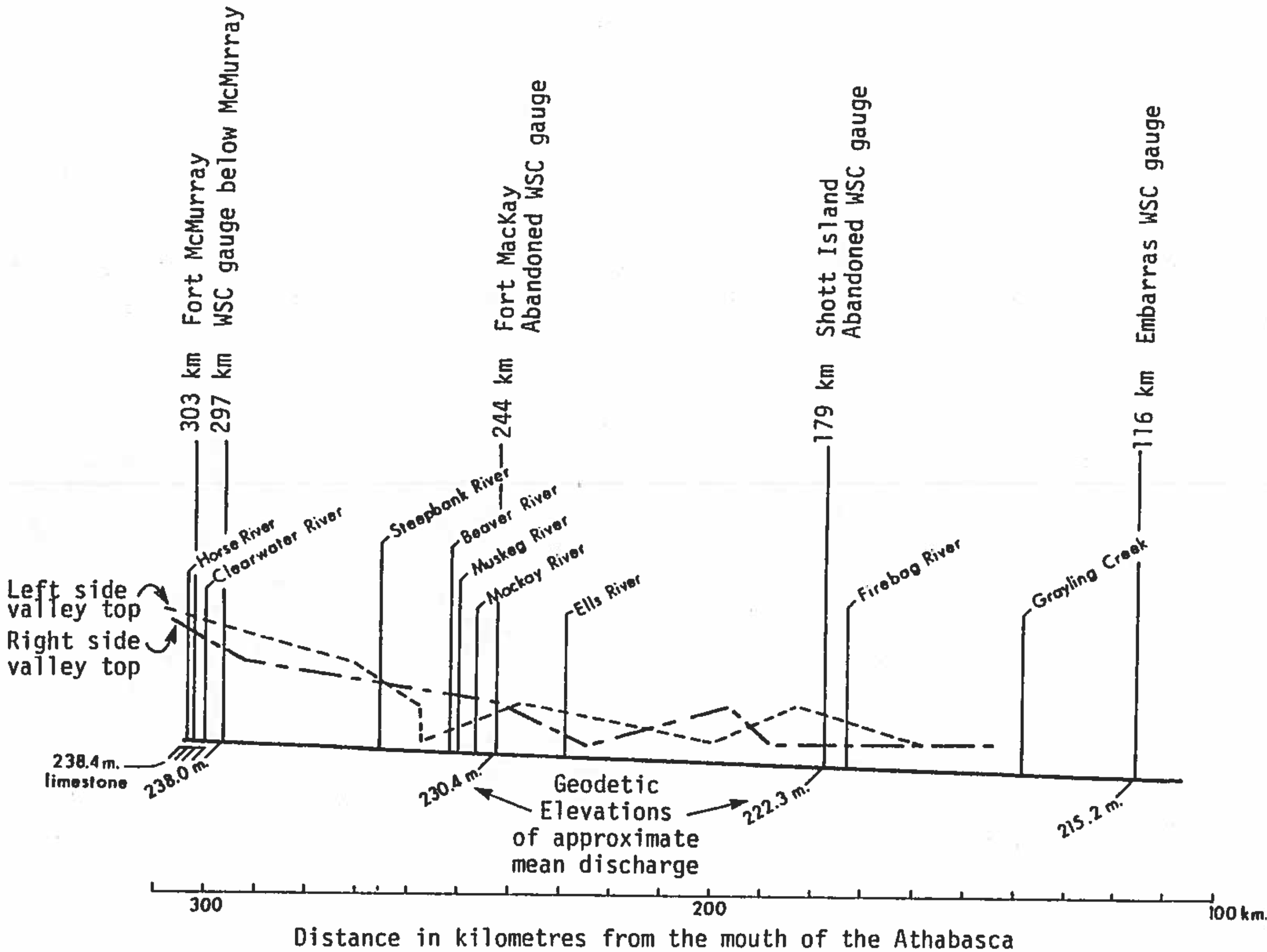

FIGURE 7. Longitudinal profile of Athabasca River and valley bank tops from Fort McMurray to Embarras (after Kellerhals, Neill and Bray).

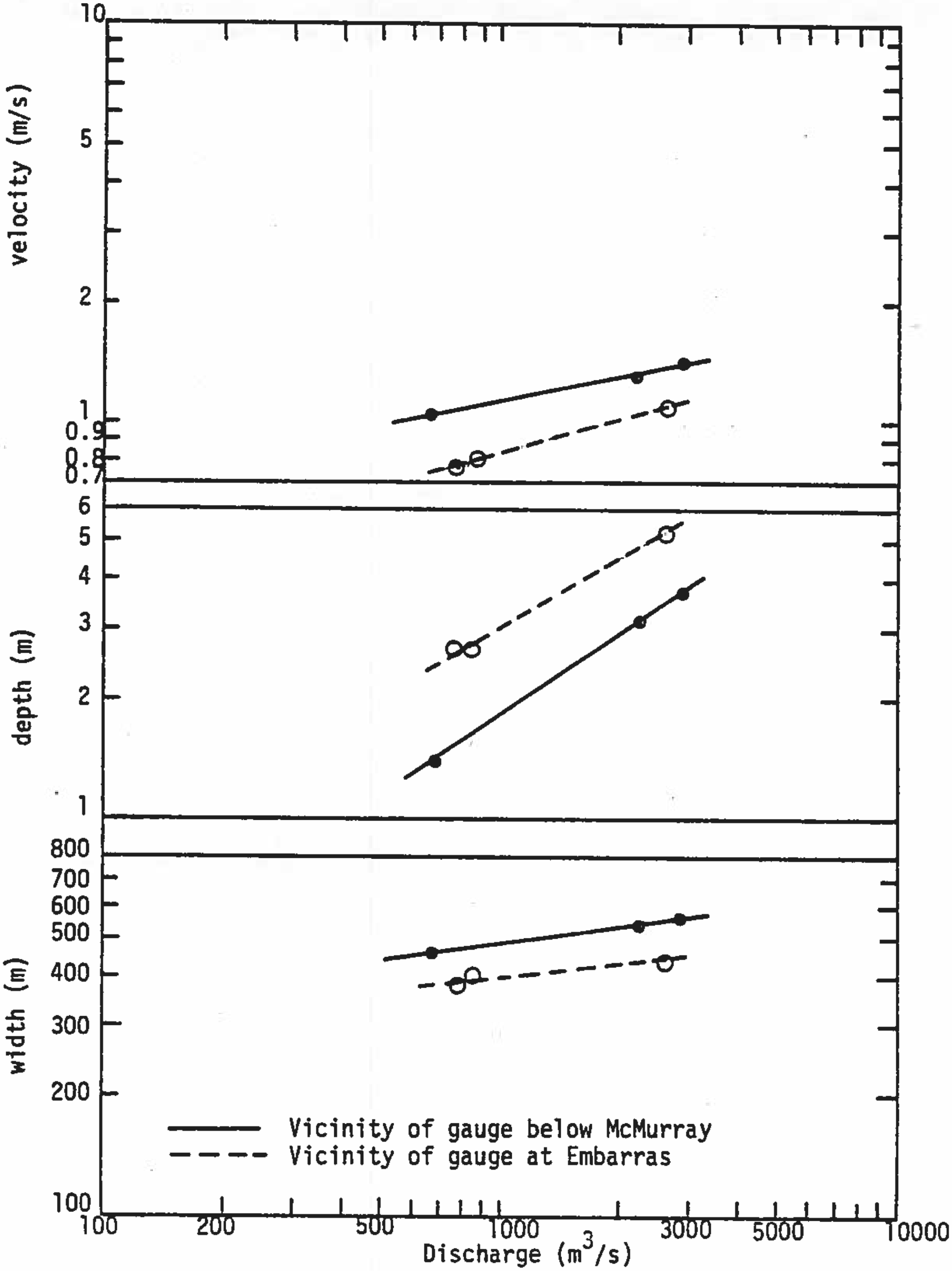

FIGURE 8. Channel width, mean depth, and mean velocity versus discharge for reachs of the Athabasca in the vicinity of the WSC gauge below McMurray and in the vicinity of Embarras

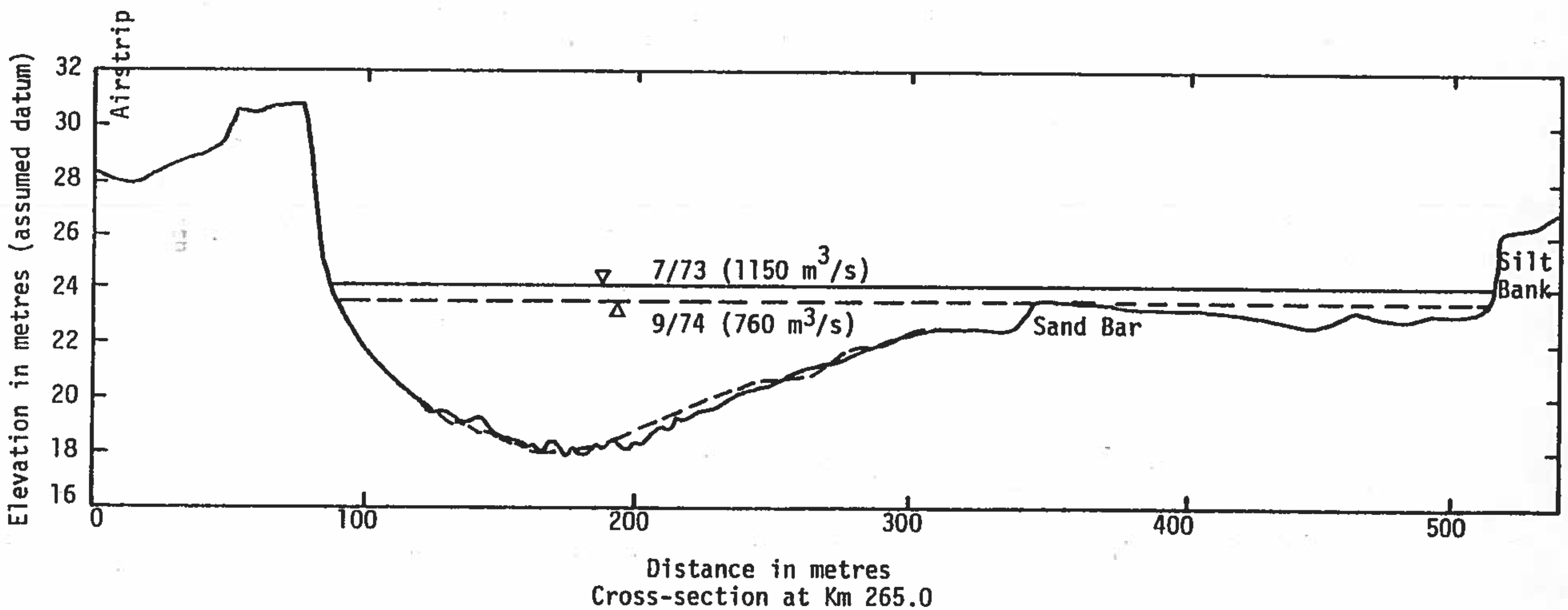

FIGURE 10. Selected cross-sections of the Athabasca River below Fort McMurray

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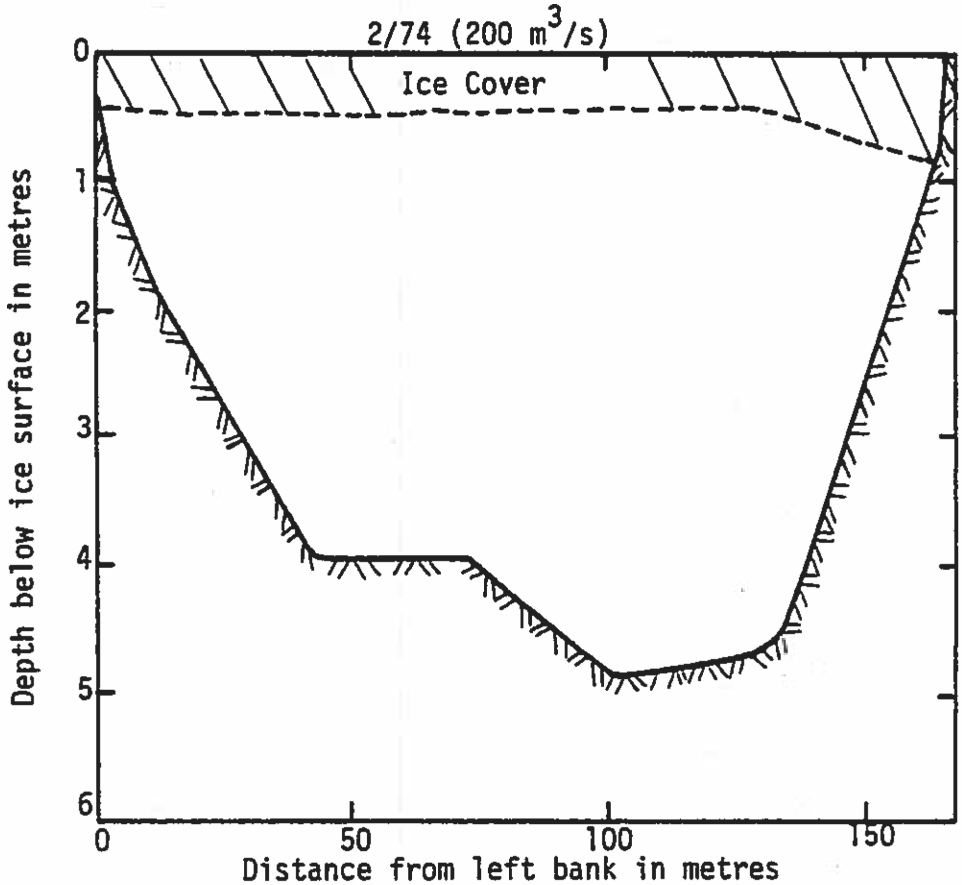
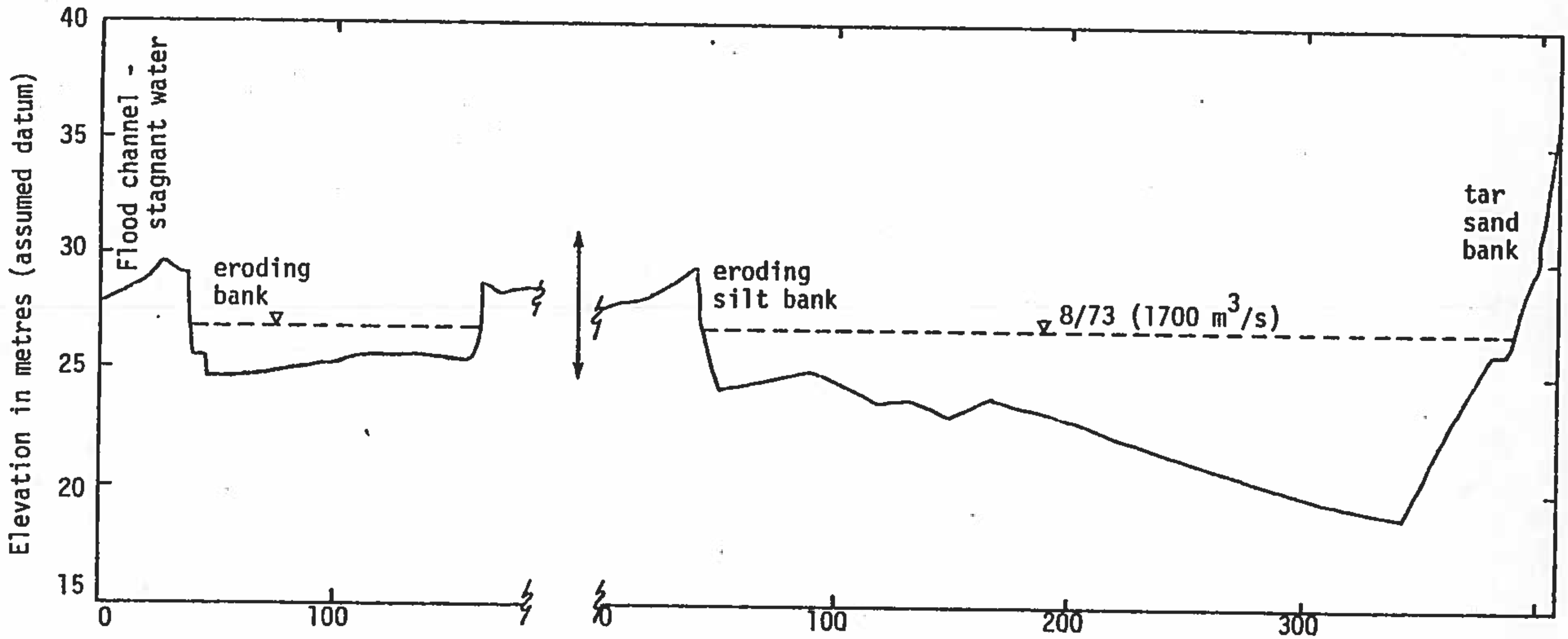


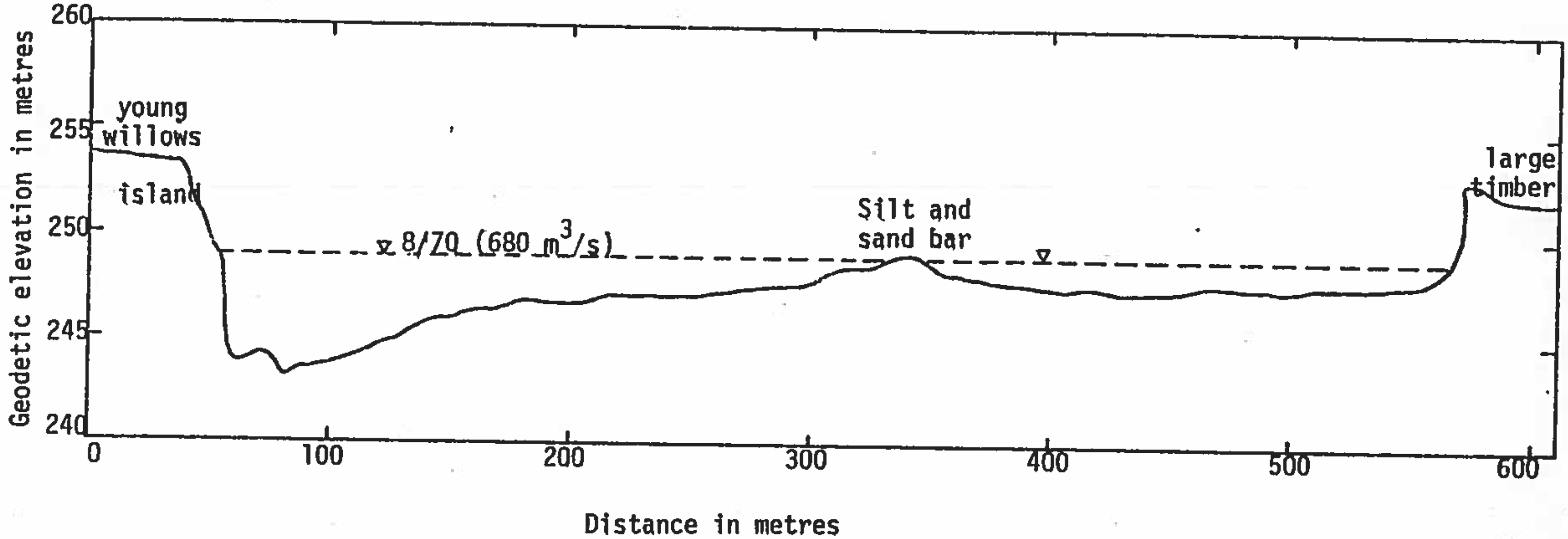
Cross-section at Km 256.0

FIGURE 10. Continued



Cross-section at km 210.3

FIGURE 10. Continued



Cross-section at km 140.1

FIGURE 10. Continued

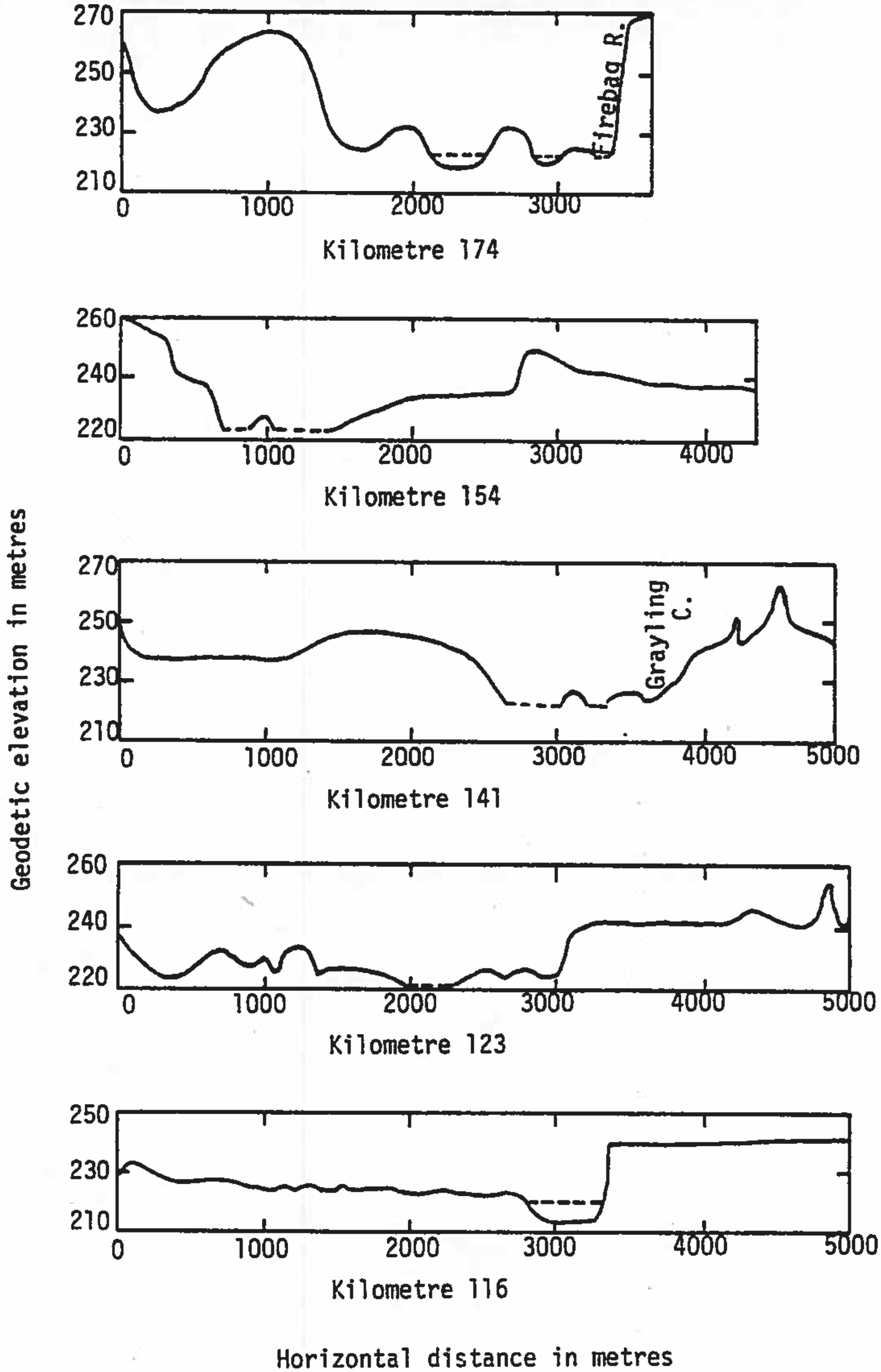


FIGURE 11. Athabasca River valley cross sections from the Firebag River to Embarras plotted from 1:50,000 map sheets

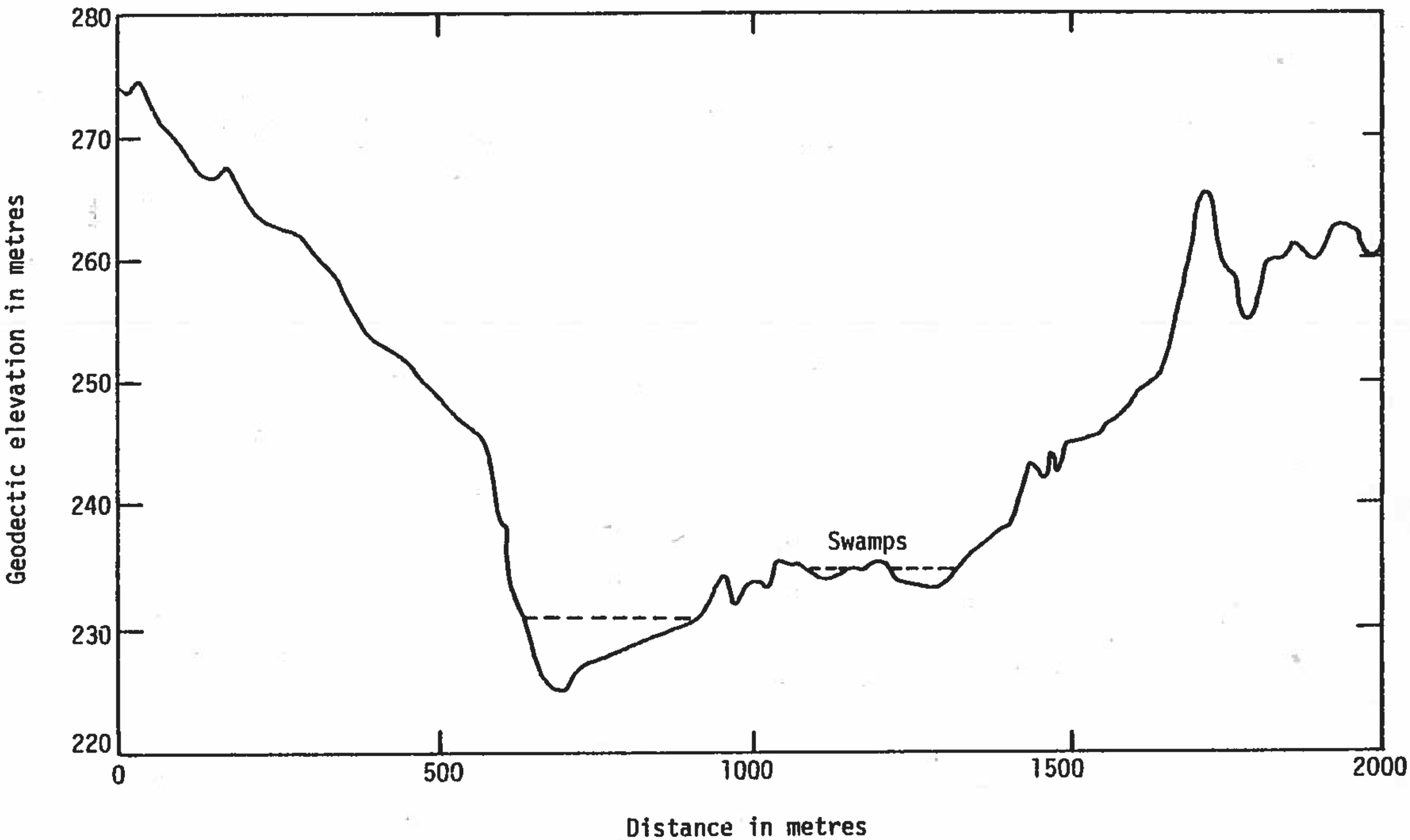


FIGURE 12. Surveyed ground profile for proposed bridge across Athabasca River at km 251.2 immediately downstream of Muskeg River (Profile provided by Alberta Transportation)

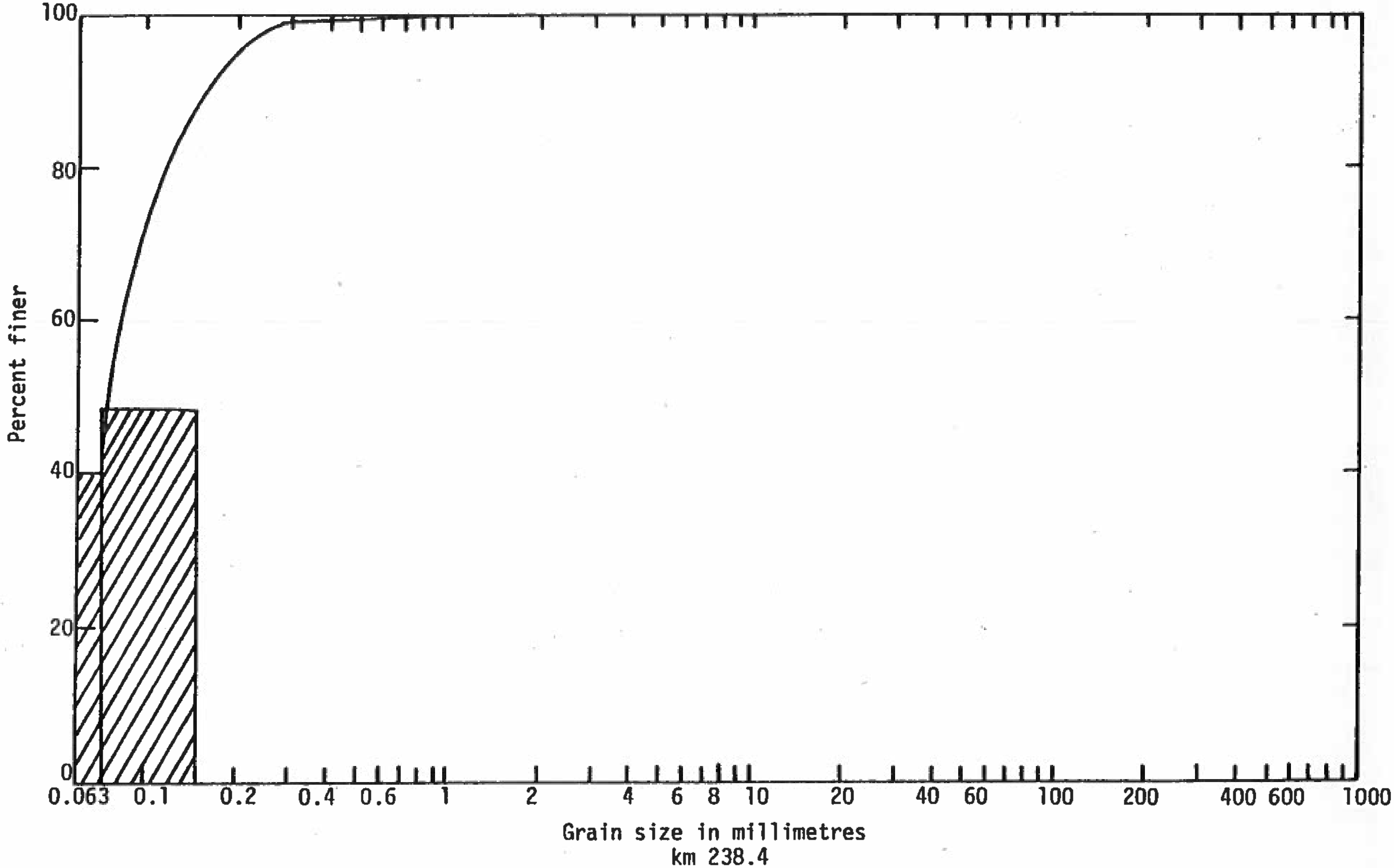


FIGURE 13. Bed material grain size at five locations from the vicinity of Fort MacKay to Embarras

...../(Cont'd.)

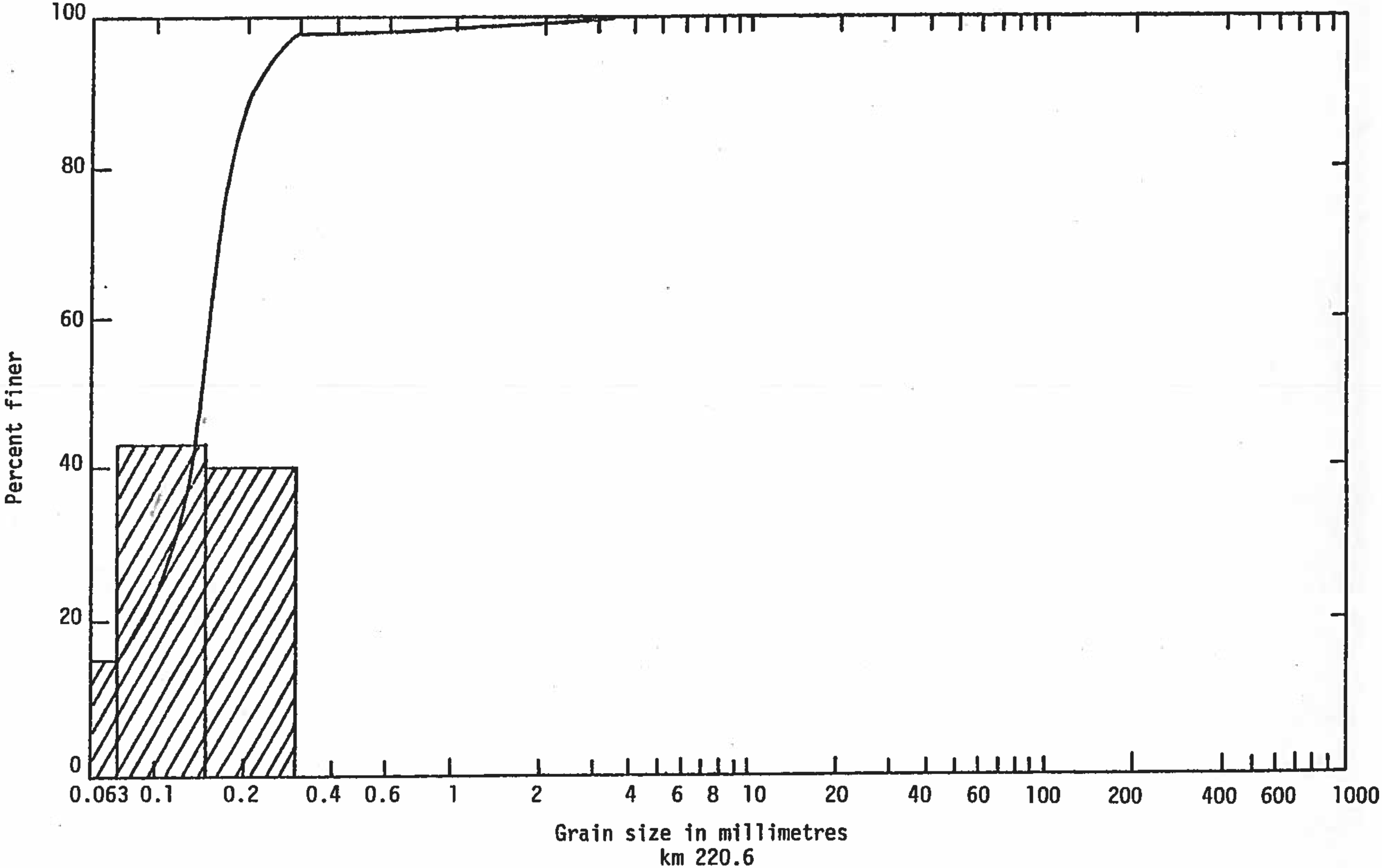


FIGURE 13. Continued

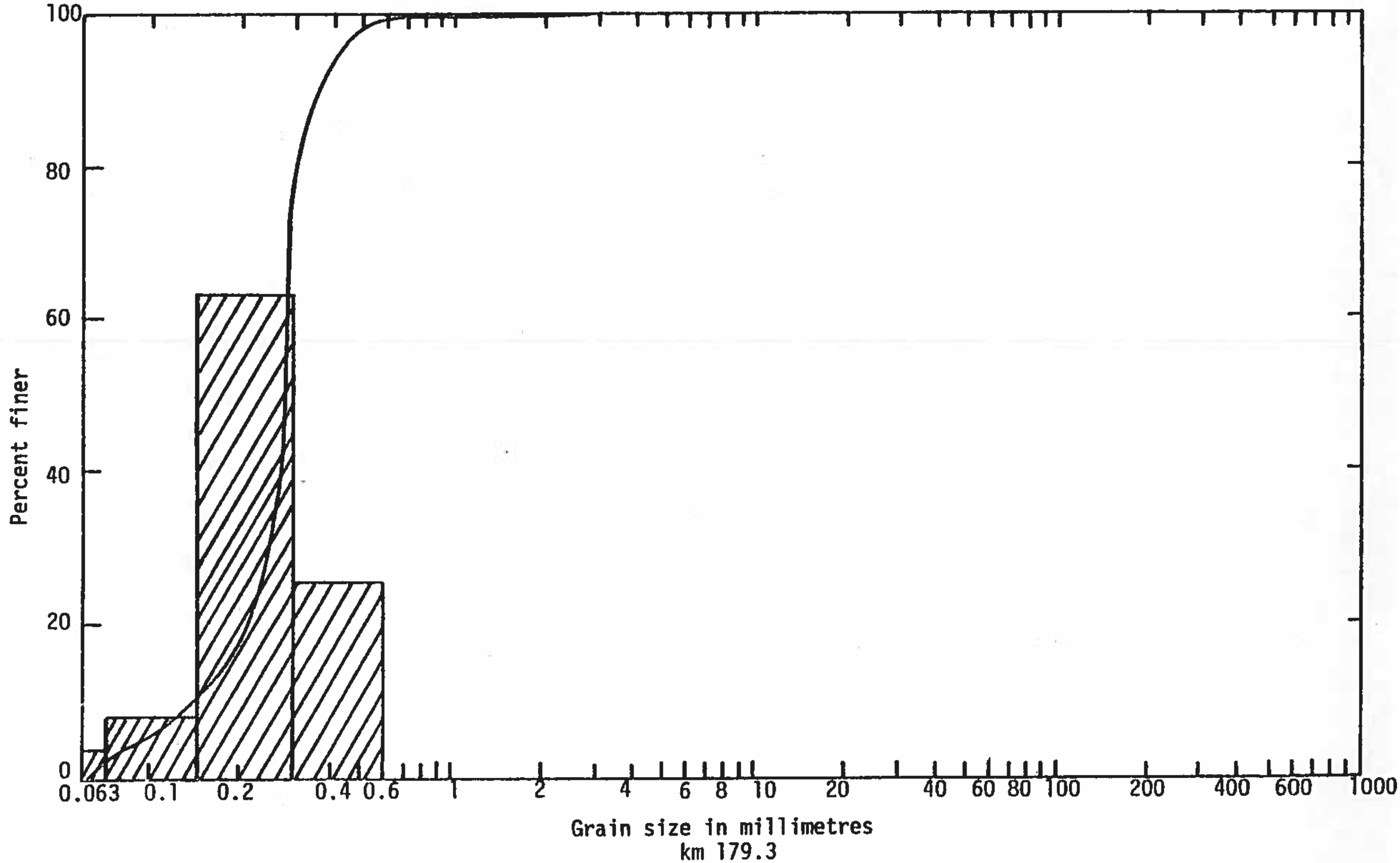


FIGURE 13. Continued

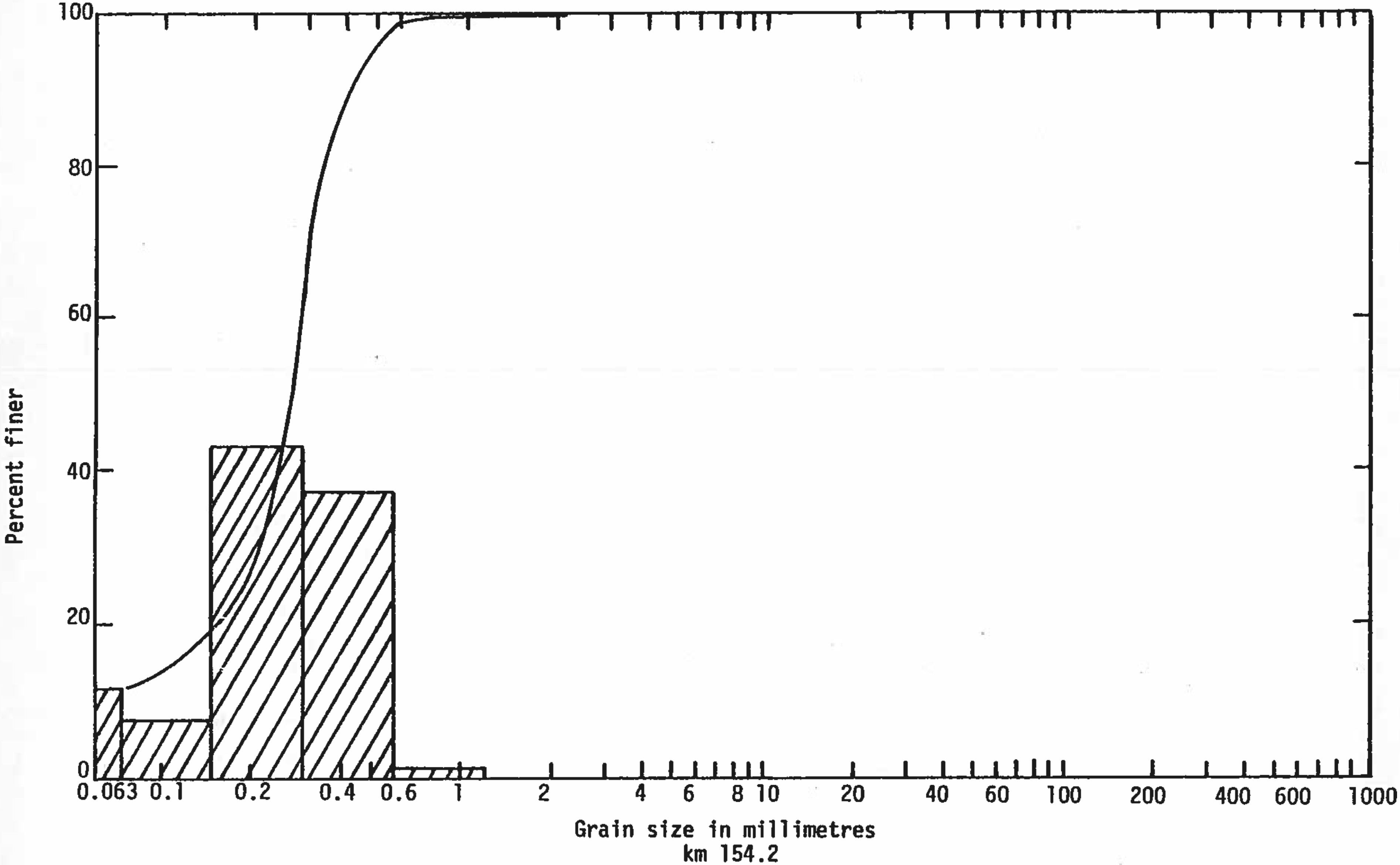


FIGURE 13. Continued

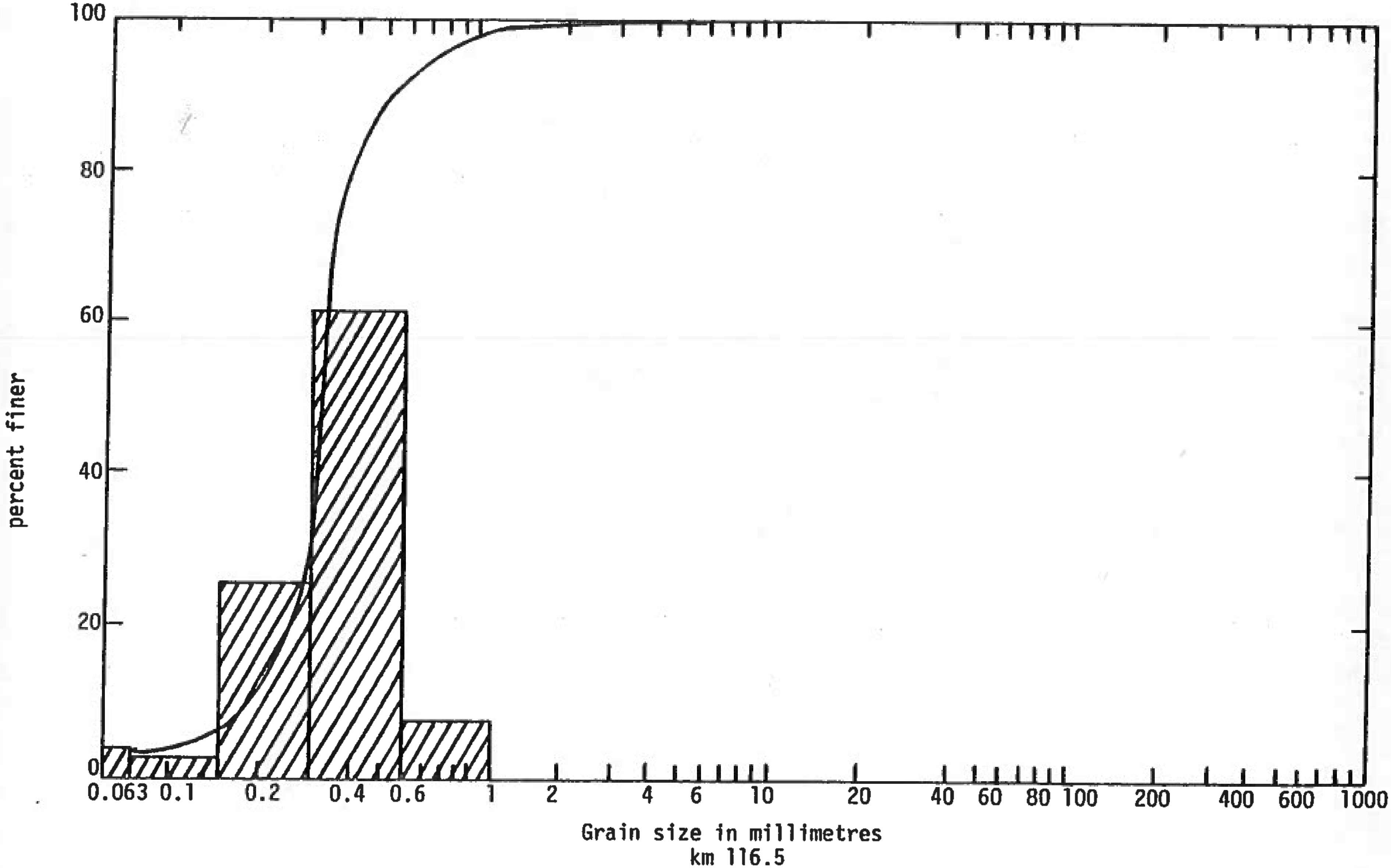


FIGURE 13. Continued

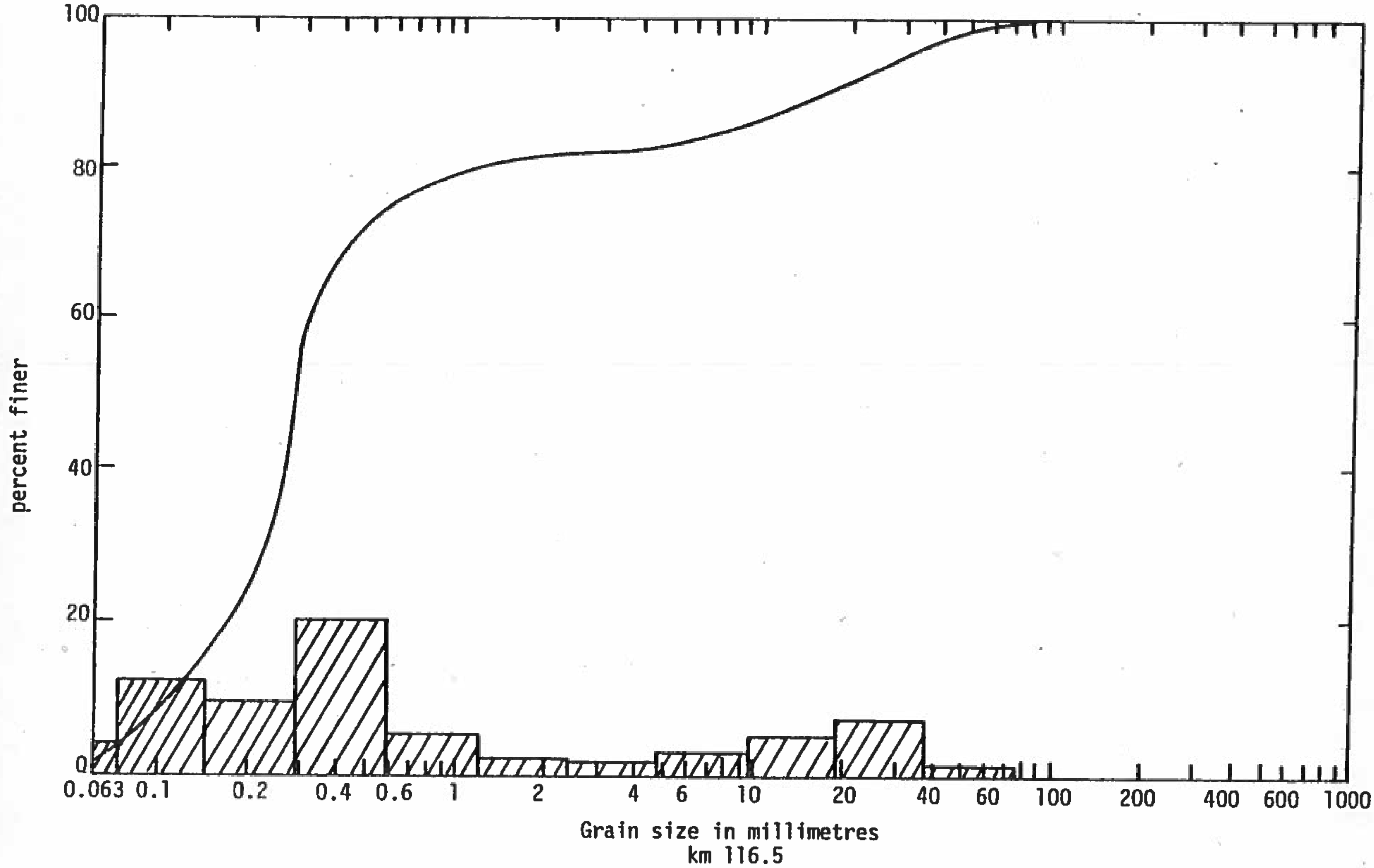
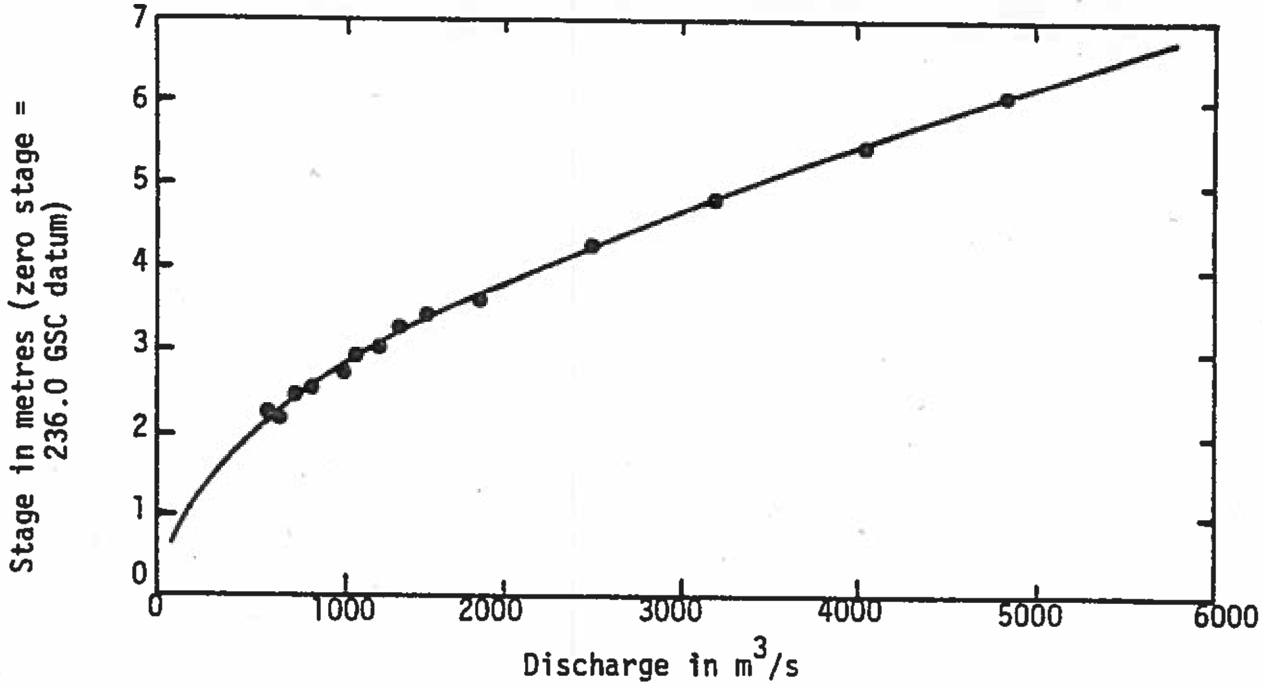
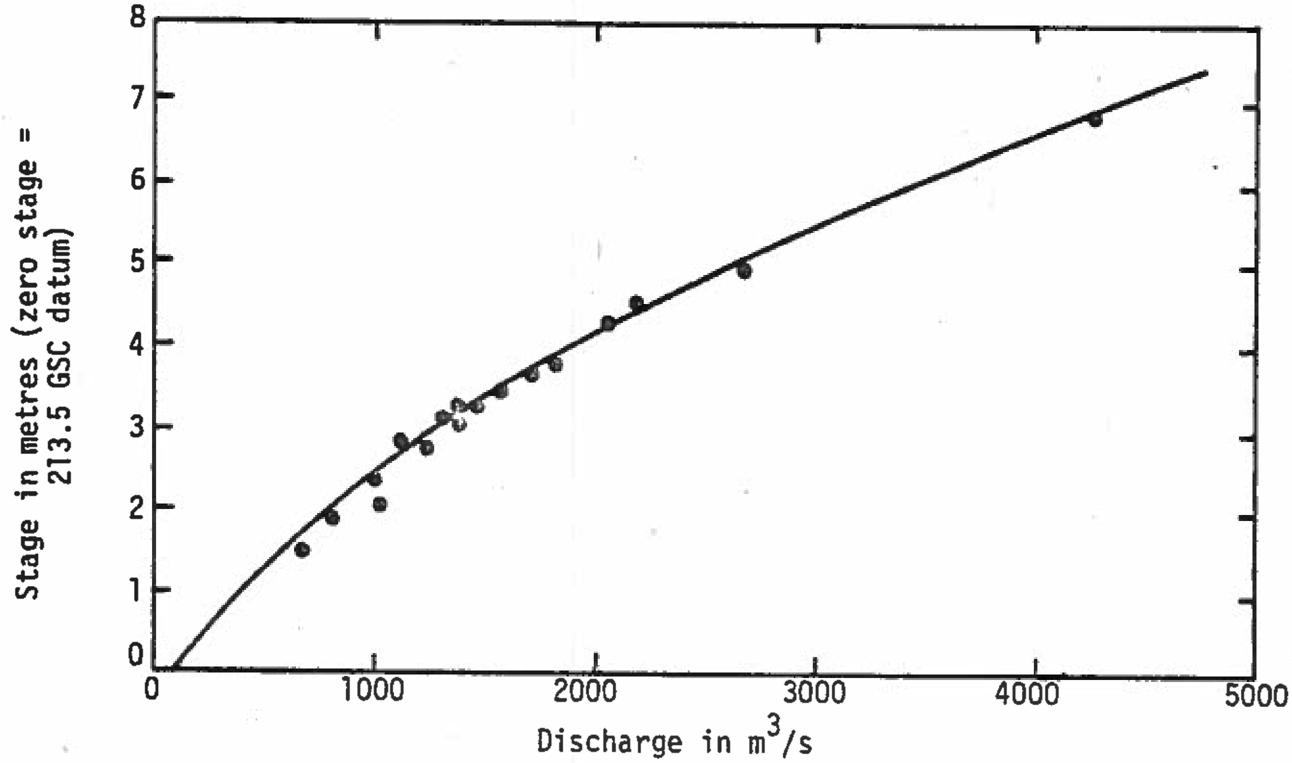


FIGURE 13. Continued



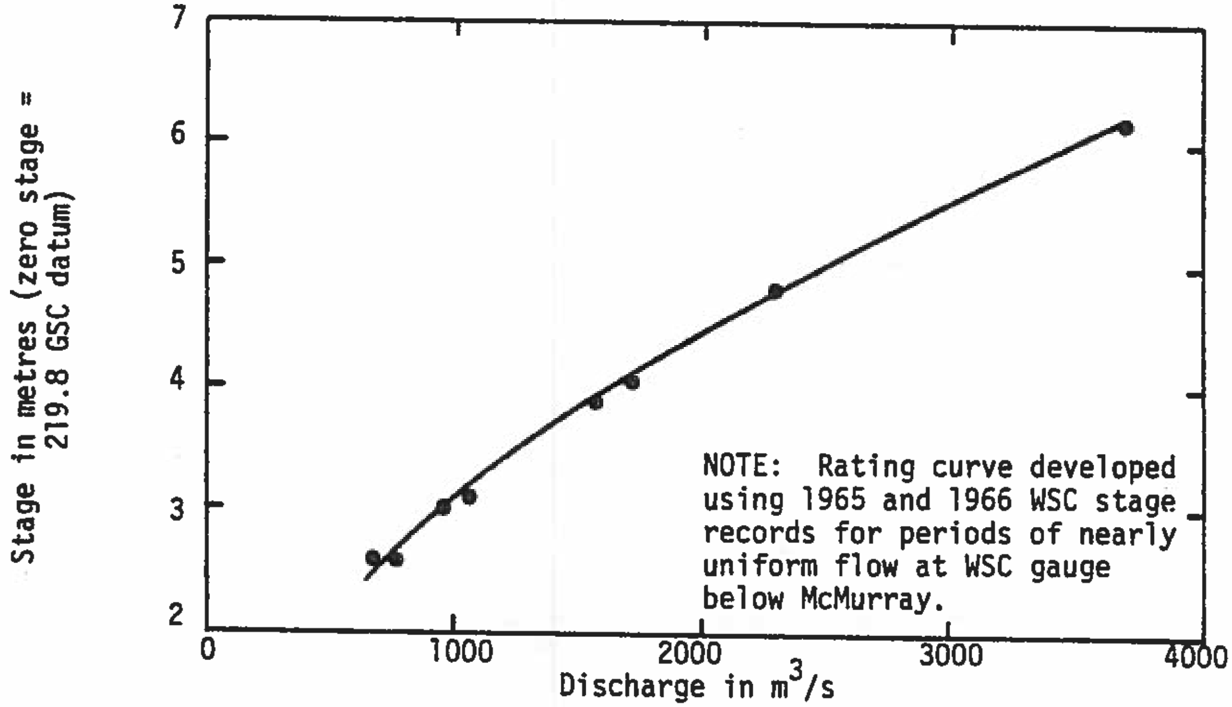
WSC station below McMurray (km 297.6)



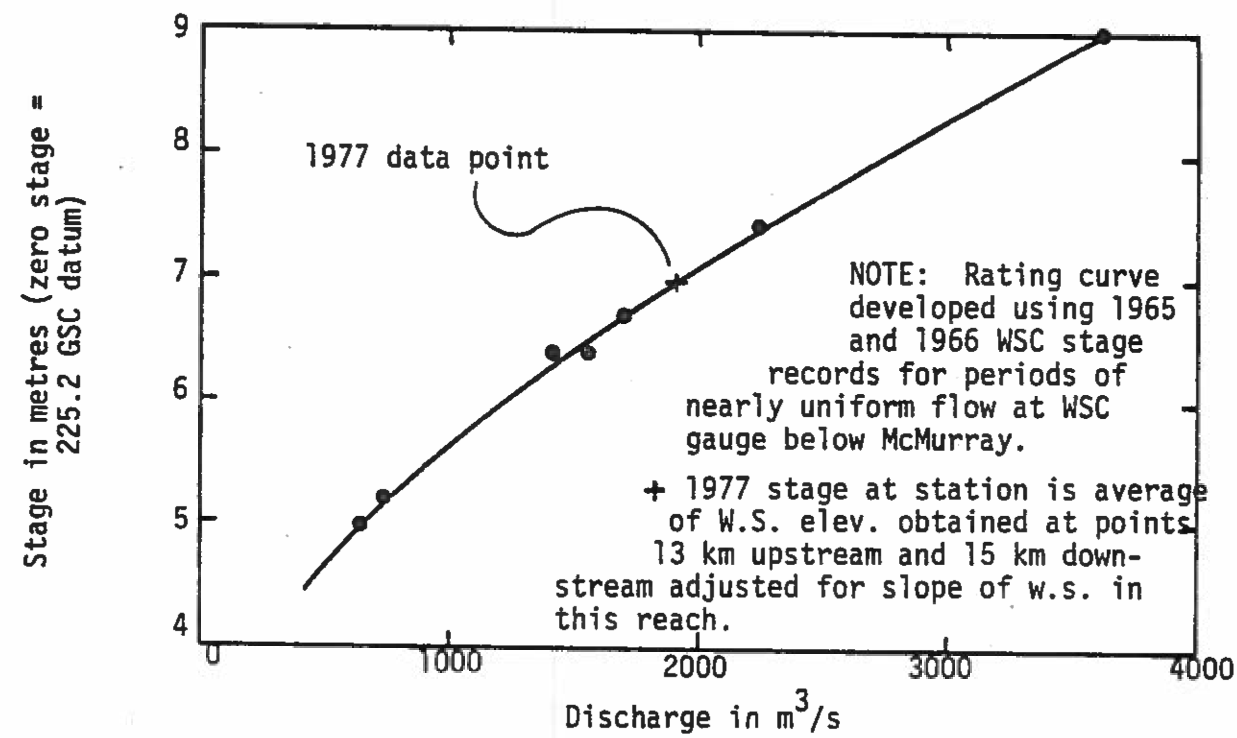
WSC station at Embarras (km 116.0)

FIGURE 14. Stage-discharge rating curves for WSC stations below McMurray (km 297.6) and at Embarras (km 116.0) and at abandoned WSC stations near Fort MacKay (km 243.7) and at Shott Island (km 178.6)

...../(Cont'd.)



Abandoned WSC stage gauge at Shott Island 5 km upstream of Firebag River (km 178.6)



Abandoned WSC stage gauge 2 km downstream of Fort MacKay (km 243.7)

FIGURE 14. Continued

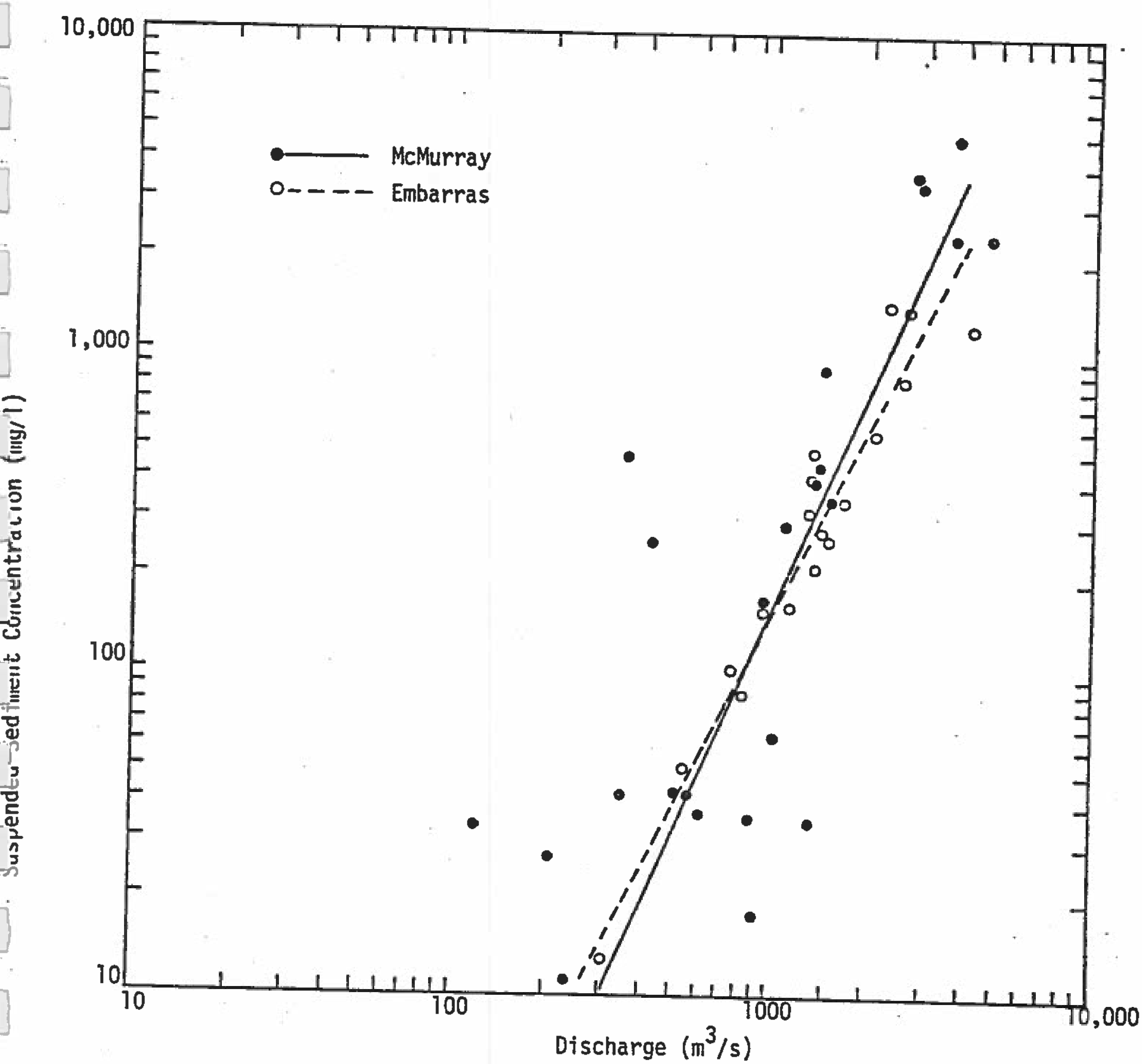


FIGURE 15. Suspended sediment rating curves at the WSC gauges below McMurray and at Embarras

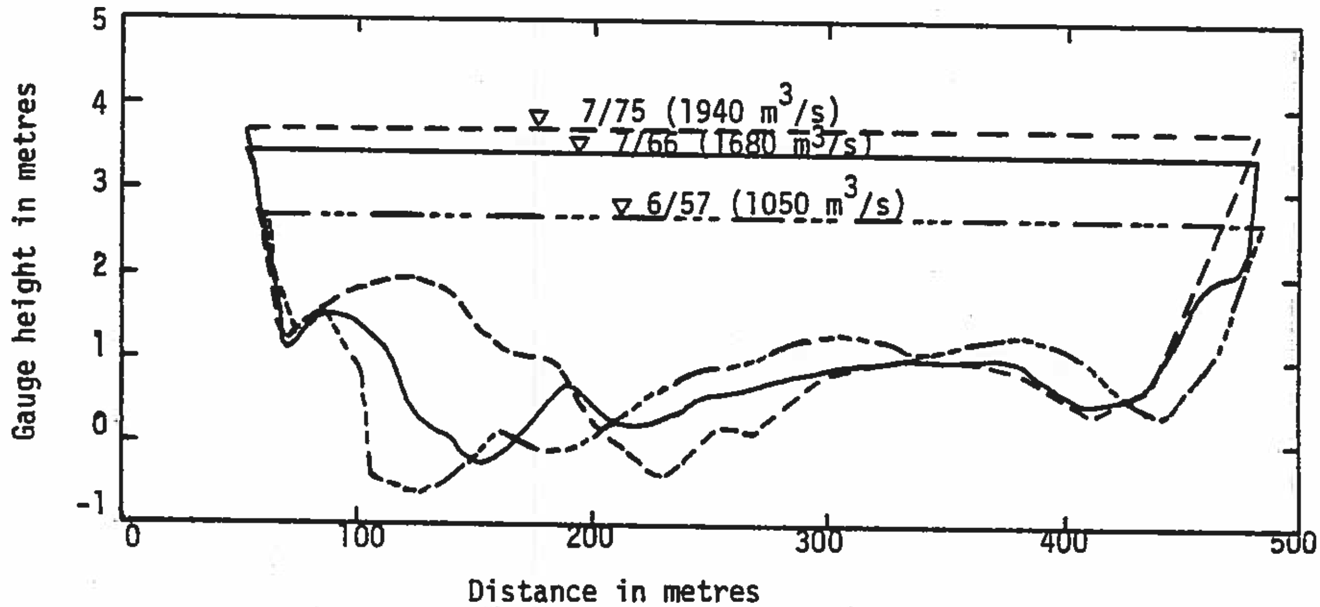


FIGURE 16. Cross-section changes at WSC gauge below McMurray (after Loeppky and Spitzer)

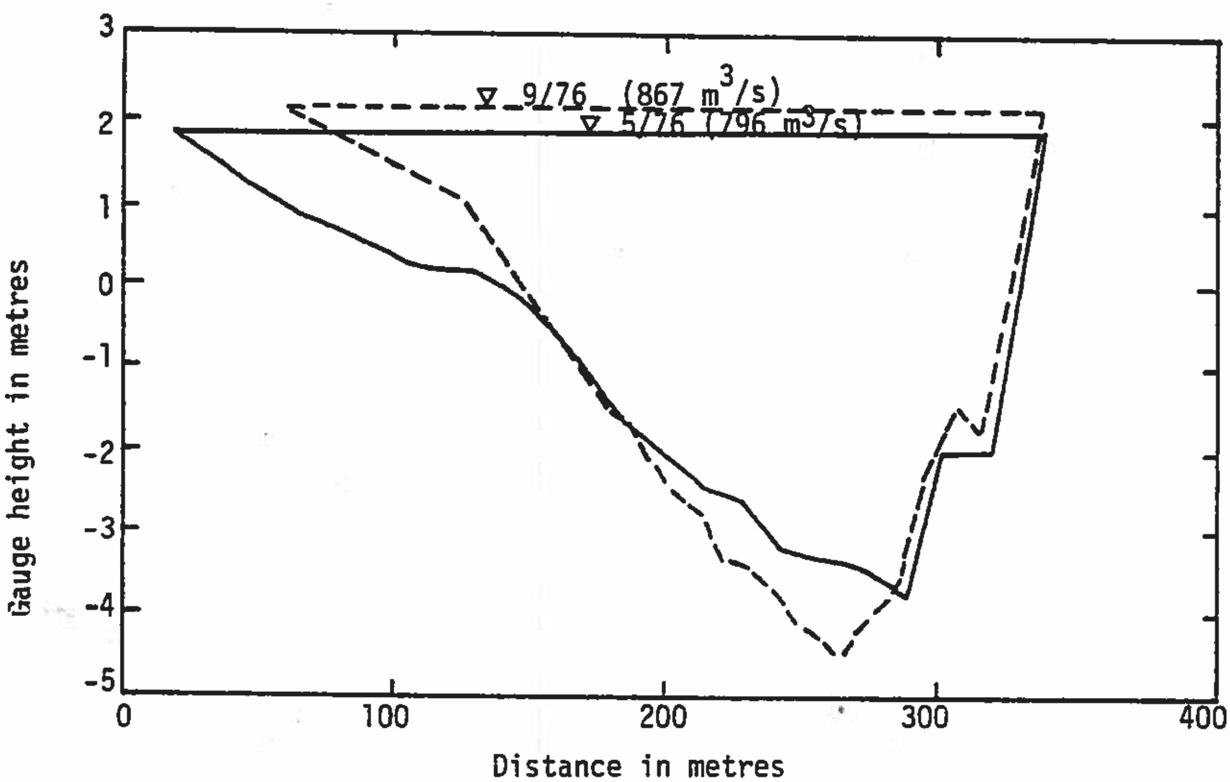


FIGURE 17. Cross-section changes at WSC gauge at Embarras (after Loeppky and Spitzer)

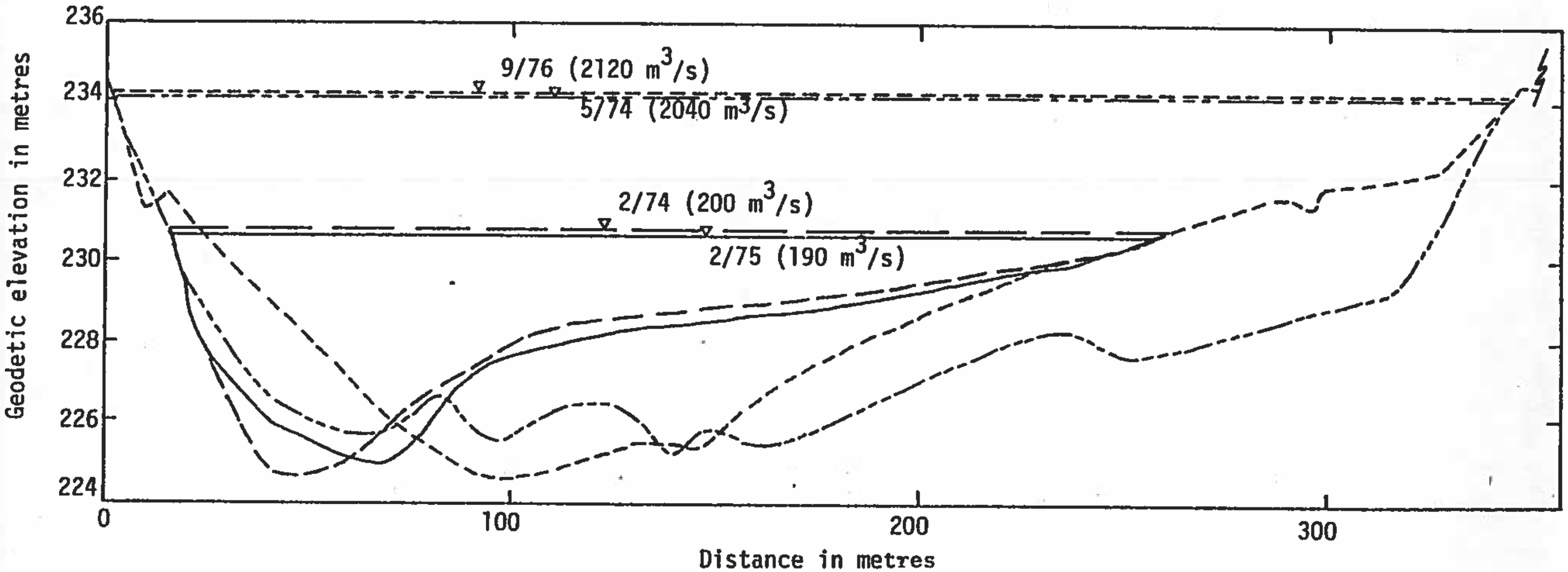


FIGURE 18. Cross-section at km 251.2 at low winter flows and at high flows

	WSC GAUGING STATION BELOW McMURRAY	WSC GAUGING STATION AT EMBARRAS
Drainage area (km^2)	129,600	154,900
Years of record	19	6
Summer rainstorm peak daily discharge (m^3/s)	4,700 July 15, 1971	4,190 July 17, 1971
Corresponding peak instantaneous discharge (m^3/s)	4,790	4,220
Spring snowmelt peak daily discharge (m^3/s)	2,760 April 30, 1971	3,060 May 8, 1972 (probably result of ice jam release) (may have been higher in 1974 - record lost)
Minimum daily discharge (m^3/s)	104 November 26, 1970 (17 yr. of record)	123 February 5, 1972 (4 yr. of record)
Mean discharge (m^3/s)	675 (17 yr. of record)	793 (4 yr. of record)
Range of mean annual discharge (m^3/s)	484 - 884	750 - 824

Table 1. Hydrologic data summary for WSC Athabasca River gauging stations below McMurray and at Embarras.

STATION	DRAINAGE AREA (km^2)	YEARS OF RECORD	MAX. DAILY DISCHARGE (m^3/s)	MAX. INSTANTANEOUS DISCHARGE (m^3/s)	MIN. DAILY DISCHARGE (m^3/s)	MEAN DISCHARGE (m^3/s)
Clearwater R. @ Draper	30,600	19	790 April 30/74	-	30.3 Jan. 15/68	136 (18 yr. record)
Hangingstone R. @ Ft. McMurray (1)	914	12	135 July 2/70	-	0 Mar. 12/65	5.18 (7 yr. record)
MacKay R. nr. Ft. MacKay	5,230	4	303 June 18/73	306	0.02 Mar. 2/73	22.0
Muskeg R. nr. Ft. MacKay	1,460	3	42.2 Apr. 28/74	43.0	0.14 Dec. 17/76	7.24
Poplar Crk. (2) nr. Ft. McMurray	99.2	4	17.3 Aug. 30/76	17.8	0 Jan. 1/76	0.72
Steepbank R. nr. Ft. McMurray	1,370	3	60.8 Apr. 27/74	61.7	0.38 Dec. 26/76	7.33

(1) Clearwater R. tributary.
(2) Beaver R. partially diverted into Poplar Cr. in 1976.

Table 2. Hydrologic data summary for WSC gauging stations on Athabasca tributaries having three or more years of continuous record.

YEAR	PEAK DAILY DISCHARGE BELOW McMURRAY (m^3/s)	MUSKINGUM FLOOD ROUTING COEFFICIENTS				
		$x^{(1)}$	$k^{(2)}$	$C_o^{(3)}$	$C_1^{(3)}$	$C_2^{(3)}$
1971	4700	0.10	3.0	0.06	0.25	0.69
1974	2970	0.40	1.8	-0.14	0.77	0.37

(1) factor defining relative weights given to inflow and outflow in determining channel storage.

(2) ratio between storage and discharge; a measure of time of travel through reach. (days)

(3) coefficients relating outflow in a reach at end of a time period to outflow at beginning of the time period and inflow at beginning and end of the time period: $O_2 = C_o I_2 + C_1 I_1 + C_2 O_1$.

Table 3. Muskingum Flood Routing coefficients for reach of Athabasca River between WSC gauges below McMurray and at Embarras for 1971 and 1974 annual flood peaks at gauge below McMurray.

LOCATION VICINITY	DISTANCE BETWEEN LOCATIONS (km)	AVERAGE SLOPE (m/km)	NUMBER OF CROSS-SECTIONS IN VICINITY	LENGTH OF REACH (km)	AVERAGE CHANNEL PROPERTIES Width (m)	Depth (m)	Velocity (m^3/s)
WSC gauge below McMurray			7	2.68	450	1.4	1.04
	53.9	0.14					
Abandoned WSC gauge near Fort MacKay			5	7.25	410	2.2	0.76
	65.2	0.12					
Abandoned WSC gauge at Shott Island			3	9.50	510	2.3	0.64
	62.6	0.11					
WSC gauge at Embarras			7	10.6	380	2.6	0.78
	116.0	0.03					
Lake Athabasca	-	-	-	-	-	-	-

Table 4. Average slope and geometry of the Athabasca River channel from the WSC gauge below McMurray to Embarras at approximate mean discharge.

	WSC GAUGE BELOW McMURRAY			WSC GAUGE AT EMBARRAS		
	FINAL WINTER MEASUREMENT ICE THICKNESS (1) (cm)		MAX. ICE THICKNESS (1) MEASURED DURING WINTER	FINAL WINTER MEASUREMENT ICE THICKNESS (1) (cm)		MAX. ICE THICKNESS (1) MEASURED DURING WINTER
YEAR	MAX.	MIN.	(cm)	MAX.	MIN.	(cm)
1977 (2)	125	70	128	-	-	-
1976	104	64	107	82	64	128
1975	85	52	122	70	55	104
1974 (2)	82	49	82	85	09	137
1973	229 (3)	110	290 (3)	91	55	91
1972 (2)	146	79	146	85	67	107
1971	104	70	229 (3)	-	-	-
1970	122	52	274 (3)	-	-	-
1969	85	43	88	-	-	-
1968	152 (3)	52	183 (3)	-	-	-
1967	107	52	107	-	-	-
1966	110	52	110	-	-	-
1965	128	85	204 (3)	-	-	-
1964	91	61	104	-	-	-
1963 (2)	195 (3)	58	195 (3)	-	-	-
1962 (2)	177 (3)	85	213 (3)	-	-	-

(1) Thicknesses from measurement field notes. Add 10 percent to thicknesses shown to get actual ice thickness.

(2) Significant ice jam occurred in vicinity of Fort McMurray.

(3) Very likely that slush ice was present.

Table 5. Thickness of Athabasca ice cover at WSC gauges below McMurray and at Embarras (Data provided by WSC).